METEOROLOGICAL GLOSSARY

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Compiled by D. H. McIntosh, M.A., D.Sc.

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PREFACE

In 1916, during the directorship of Sir Napier Shaw, the Meteorological Office published two pocket-size companion volumes, the 'Weather map' to explain how weather maps were prepared and used by the forecasters, and the 'Meteorological glossary' to explain the technical meteorological terms then employed. With the advance of the science and the elaboration of its techniques the publications have been in continuous demand, many times reprinted and on several occasions completely revised. The second edition was in 1930, the third in 1938–39, and soon after World War II it was obvious that radical revision was necessary once again. In 1956 the fourth edition of the 'Weather map' was issued but, for the first time in forty years, it was not found possible to prepare simultaneously a new edition of the 'Meteorological glossary', which had become very much out-of-date and in need of a complete remodelling. For earlier editions the task had been shared amongst the professional staff of the Office and the result was an interesting and up-to-date volume containing much useful information, although the freedom allowed to the many contributors had led to a unique volume of quite uneven character with articles varying from brief dictionary definitions to encyclopaedic essays. For the fourth edition the number of new entries was to be larger than ever before and it was decided that the need was now for a more systematic reference work containing a brief definition of all the terms in ordinary use rather than for a compilation of miscellaneous articles giving information which would more properly be looked for in one of the many modern textbooks. For this purpose a single author, assisted if need be by expert referees, would, it seemed, be advantageous and the Office was fortunate in finding in Dr. D. H. McIntosh of the University of Edinburgh a physicist and meteorologist of wide experience willing to undertake the major task. Before being passed for printing every article has been read critically by more than one member of the scientific staff of the Office and Dr. McIntosh has shown a remarkable readiness to compromise. In this way it is hoped that the excellence of the author's original draft has been fully retained while providing a work which will adequately meet the needs of the official service. It would, however, be too much to hope that no further improvement will be possible and the Office will be pleased to receive from any source criticisms and suggestions calculated to increase the value of the work, not only for the professional meteorologist, but for interested people everywhere.

Meteorological Office,
Bracknell, Berkshire.
1962.

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A

ablation: The disappearance of snow and ice by melting and evaporation. The chief meteorological factor which controls the rate of ablation is air temperature: subsidiary factors are humidity, wind speed, direct solar radiation, rainfall. The rate of ablation of a snow-field is also affected by such non-meteorological factors as size, slope and aspect of snow-field, depth and age of snow, nature of underlying surface.

abroholos: A violent squall on the coast of Brazil, prevalent from May to August.

absolute extremes: See EXTREMES.

absolute humidity: An alternative for VAPOUR CONCENTRATION.

absolute instability: See STABILITY.

absolute instrument: An instrument with which measurements may be made in units of mass, length, and time (or in units of a known and direct relationship to these) and against which other non-absolute instruments may be calibrated. See also STANDARD.

absolute stability: See STABILITY.

absolute temperature: See TEMPERATURE SCALES.

absolute vorticity: See VORTICITY.

absolute zero (of temperature): Temperature of $-273{\cdot}15°$ C, the zero on the Kelvin (absolute) scale. See TEMPERATURE SCALES.

absorption: Removal of radiation from an incident solar or terrestrial beam, with conversion to another form of energy—electrical, chemical or heat.

The absorption of radiation by the gases of the atmosphere is highly selective in terms of wavelength and may depend also on pressure and temperature. Numerical expression is given by the law, variously known as Beer's, Bouguer's, or Lambert's law, applicable to monochromatic radiation:

$$I = I_0 e^{-\alpha m}$$

where I_0 is the intensity of incident radiation, I the intensity after passing through mass m of absorbing substance and α the absorption coefficient. An alternative expression is

$$I = I_0 e^{-\alpha x}$$

where x is the path length through the absorbing substance.

The effectiveness of a gas as an absorber of solar or terrestrial radiation depends on the width and strength (absorption coefficient) of the absorption lines and bands, the concentration of the gas, and the wavelength positions of the bands relative to the maximum of the Planck curve (see RADIATION) at solar or terrestrial temperature, respectively. The relative energies involved in atmospheric absorption processes are represented in Figure 1, in which the Planck curves appropriate to solar and terrestrial radiation temperatures (6000° and 250° K, respectively) are shown with equal areas to represent over-all balance of the two fluxes. Fine structure of the absorption bands is omitted. The main constituents of the atmosphere, N_2 and O_2, are almost completely transparent except in the far ultra-violet: minor constituents

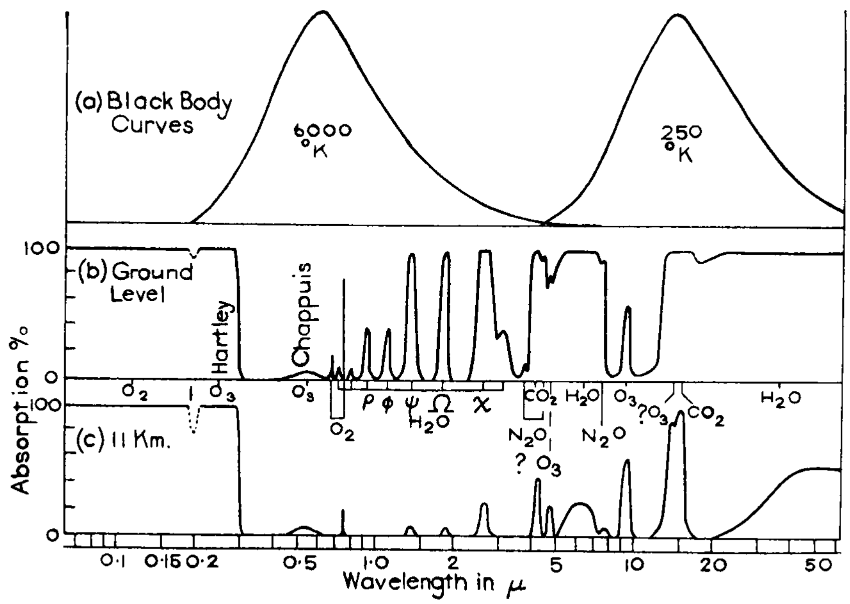

FIGURE 1—Relative importance of various absorptions in the atmosphere
(*a*) Black-body emission for 6000° and 250°K.
(*b*) Atmospheric absorption spectrum for a solar beam reaching ground level.
(*c*) Atmospheric absorption spectrum for a solar beam reaching the temperate tropopause.

ρ, φ, ψ, Ω and χ are the near infra-red bands of water vapour. In (*b*) and (*c*) no fine structure is shown although all the infra-red bands have in fact a very complex structure. Most of the bands shown have a broad doublet structure, but even this is smoothed out. It has been assumed that the atmosphere contains 3 mm of ozone at S.T.P., all above 11 km; that it contains 2 gm/cm² of water vapour above ground level and 10^{-3} gm/cm² above 11 km; that carbon dioxide and nitrous oxide are mixed in equal proportions with the atmosphere at all heights. The small window (dotted) at 0·2μ and the two ozone bands marked (?) have not yet been observed at the two levels concerned.

(GOODY, R. M. and ROBINSON, G. D.; Radiation in the troposphere and lower stratosphere. *Quart. J.R. met. Soc., London,* **77**, 1951, p. 153.)

such as O_3, CO_2, H_2O, N_2O have intense absorption bands, mainly in the infra-red and longer wavelengths. The product of (*a*) and (*c*) in Figure 1 represents the energy absorbed by the stratosphere, and the product of (*a*) and ((*b*)—(*c*)) that absorbed by the troposphere.

Since water has an appreciable absorption coefficient in solar radiation wavelengths greater than about one micron, thick clouds are able to absorb over 20 per cent of incident solar radiation. Towards terrestrial radiation, clouds and fog behave as almost perfect black bodies. The surface of the earth is very variable in its absorption of solar radiation (see ALBEDO) but absorbs nearly all incident terrestrial radiation.

ABTOP: In weather messages, a code word indicating that a report of upper air temperature and wind, in abridged form, follows in figure code. See 'Handbook of weather messages.'*

acceleration: Rate of change of velocity with respect to time. Like velocity, acceleration has both magnitude and direction: thus uniform circular motion, involving change of direction without change of speed, implies acceleration ('centripetal acceleration'). The dimensions are L T^{-2}.

The 'absolute acceleration' of the air ($\dot{V}_a$), i.e. acceleration measured relative to axes fixed in space, is equal to the force acting per unit mass of air (Newton's second law of motion). The important forces per unit mass in air motion are the PRESSURE GRADIENT FORCE $(-\frac{1}{\rho}\nabla p)$, the Newtonian force of GRAVITY directed towards the earth's centre ($\mathbf{g}_a$), and the 'frictional' forces arising from eddy VISCOSITY or molecular viscosity (**F**). Thus we have the 'equation of absolute motion':

$$\dot{\mathbf{V}}_a = -\frac{1}{\rho}\nabla p + \mathbf{g}_a + \mathbf{F}$$

$\dot{\mathbf{V}}_a$ comprises the 'relative acceleration' ($\dot{\mathbf{V}}$), i.e. acceleration measured with respect to the rotating earth, and two other accelerations: (*a*) the 'centripetal acceleration' of the coinciding point of the earth ($\dot{\mathbf{V}}_e$); (*b*) the 'Coriolis acceleration' or 'geostrophic acceleration' ($2\mathbf{\Omega} \wedge \mathbf{V}$ where $\mathbf{\Omega}$ is the earth's angular velocity and $\wedge$ denotes the vector cross product). That is $\dot{\mathbf{V}}_e = \dot{\mathbf{V}} + \dot{\mathbf{V}}_e + 2\mathbf{\Omega} \wedge \mathbf{V}$

Substitution for $\dot{\mathbf{V}}_a$ in the first equation gives

$$\dot{\mathbf{V}} = -\frac{1}{\rho}\nabla p + \mathbf{g}_a - \dot{\mathbf{V}}_e - 2\mathbf{\Omega} \wedge \mathbf{V} + \mathbf{F}$$

Since also the force of gravity along the local vertical (**g**) is given by $\mathbf{g} = \mathbf{g}_a - {}_a\dot{\mathbf{V}}_e$, we have, by substitution, the 'equation of relative motion':

$$\dot{\mathbf{V}} = -\frac{1}{\rho}\nabla p - 2\mathbf{\Omega} \wedge \mathbf{V} + \mathbf{g} + \mathbf{F}.$$

The relative acceleration of the air ($\dot{\mathbf{V}}$) is of fundamental importance in dynamical meteorology because it is directly related to the development of pressure systems. While, in theory, $\dot{\mathbf{V}}$ may be obtained from the equation of relative motion, this is not possible in practice because it is a small residual of much larger and imperfectly known terms.

The equation of relative motion has its most practical application in 'steady' motion ($\mathbf{V} = \mathbf{0}$) in which all the forces acting on the air are balanced. In particular, when the flow is horizontal and frictionless, the forces g and **F** may be neglected and the equation becomes that for GEOSTROPHIC flow.

Common situations in which the air is subject to acceleration, with accompanying AGEOSTROPHIC component of wind, are (*a*) curved flow (see GRADIENT WIND), (*b*) change of pressure gradient in direction of flow (see CONFLUENCE), (*c*) local change of pressure gradient with time (see ISALLOBARIC WIND).

The degree of acceleration experienced in flight is usually expressed in the unit *g*, this being the acceleration produced by gravity at the earth's surface, namely 981 cm/sec^2 (32 ft/sec^2).

acclimatization: The process of adjustment of an animal, normally with implied physiological effects, to a marked change of climatic environment, as to a large change of altitude or a change to extreme conditions of temperature and/or humidity.

accretion: In meteorology, this usually refers to the growth of an ice particle by collision with water drops. The term is also used in the more general sense of growth of water drops, or ice particles, by collision. See PRECIPITATION, ICE ACCRETION.

* London, Meteorological Office; Handbook of weather messages. Parts II and III. London, HMSO, 1959.

accumulated temperature: The integrated excess or deficiency of temperature measured with reference to a fixed datum over an extended period of time. If on a given day the temperature is above the datum value for *n* hours and the mean temperature during that period exceeds the datum line by *m* degrees, the accumulated temperature for the day above the datum is *nm* degree-hours or *nm*/24 degree-days. By summing the daily entries arrived at in this way, the accumulated temperature above or below the datum value may be evaluated for periods such as a week, a month, a season or a year.

In practice, daily values of accumulated temperature are derived not from hourly values but by a method involving the use of daily maximum (*X*) and minimum (*N*) temperatures: empirical formulae relating to *X*, *N* and the datum value (*D*) are used when *D* lies between *X* and *N*. Values of weekly accumulated temperature obtained by summing daily values derived in this way have been included in the *Weekly weather report* since 1928. Prior to that time they were obtained by the use of weekly means of daily maximum and minimum temperatures.*

The datum value used in the *Weekly weather report* is 42° F which is widely used as the critical temperature above which the growth of vegetation in a European climate is initiated and maintained. For the study of heating problems a datum value of 60° F is used by British engineers. Meteorological Office Professional Note No. 125† contains average monthly and yearly values of accumulated temperature with respect to datum values of 42°, 50°, 60° and 70°F at each of 49 stations in the British Isles for the period 1921–50. The data were derived by an empirical method which uses the average value and standard deviation of monthly mean temperature.

accuracy: In physical measurement, the closeness with which an observation of a quantity, or the mean of a series of observations, is considered to approach the unknown true value of the quantity. See also ERROR.

acoustic sounding: Investigation of the properties of the atmosphere by the propagation and reception of sound waves.

actinic rays: Radiation which effects chemical changes, as in photography. The term is also loosely used to signify ULTRA-VIOLET RADIATION.

actinometer: An early name for an instrument which measures solar radiation, as in the Linke–Fuessner and Michelson actinometers (see PYRHELIOMETER). The corresponding term for a recording instrument is 'actinograph'. The name 'actinometer' is also applied to an instrument which measures the intensity of ACTINIC RAYS.

actinon: Gas, of atomic mass 219 and atomic number 86, which is a radioactive isotope of RADON. It occurs in minute concentration in the atmosphere and plays a small part in the IONIZATION of the air at low levels.

adiabatic: An adiabatic process (thermodynamic) is one in which heat does not enter or leave the system. (Greek, *a* not, and *diabaino* pass through).

Because the atmosphere is compressible and pressure varies with height adiabatic processes play a fundamental role in meteorology. Thus, if a parcel of air rises it expands against its lower environmental pressure: the work done by the parcel

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* London, Meteorological Office; Weekly weather report for the period February 26th, 1928, to March 2nd, 1929. London, **45**, 1929, p. 4.

† SHELLARD, H. C.; Averages of accumulated temperature and standard deviation of monthly mean temperature over Britain, 1921–50. *Prof. Notes met. Off., London*, **8**, No. 125, 1959.

in so expanding is at the expense of its internal energy and its temperature falls, despite the fact that no heat leaves the parcel. Conversely, the internal energy of a falling parcel is increased and its temperature raised, as a result of the work done on the air in compressing it.

Observation shows that such processes determine, to a large extent, the vertical temperature distribution within the troposphere. It also supports the view that, to a first approximation, it is justifiable to treat the vertically moving, individual masses of air of indefinite size (termed 'parcels') as CLOSED SYSTEMS which move through the environment without unduly disturbing it or exchanging heat with it. Various non-adiabatic processes such as condensation, evaporation, radiation, and turbulent mixing also operate to produce temperature changes in the free atmosphere but their effects are generally negligible in comparison with those caused by appreciable vertical motion.

Such adiabatic or 'dynamical' temperature changes proceed at a definite rate. For dry (unsaturated) air the change in temperature per unit height change (i.e. the LAPSE rate) is given by the equivalent expressions:

$$\frac{\gamma-1}{\gamma}\frac{g}{R} \text{ or } \frac{g}{c_p}$$

where R is the gas constant for air ($2{\cdot}87\times10^6$ erg/gm °K), g the acceleration of gravity (981 cm/sec^2) and γ the ratio of specific heats of dry air at constant pressure (c_p) and constant volume (c_v) respectively (1·4), from which the 'dry adiabatic lapse rate' (DALR) is about 0·98°C per 100 m or, with sufficient accuracy, 1°C per 100 m (5·4°F per 1000 ft).

For a saturated rising parcel the fall of temperature is checked by the latent heat liberated. The 'saturated adiabatic lapse rate' (SALR) is therefore less than that for unsaturated air by an amount which varies with temperature and pressure: at lower levels in temperate latitudes the SALR is about half that of the DALR. Since widespread vertical motion occurs in the TROPOSPHERE, the average lapse rate in this region lies between the DALR and SALR.

Two extreme types of process involving ascent of saturated air may be visualized: (*a*) a reversible, adiabatic ascent at the SALR, in which all products of condensation—cloud, rain, hail or snow—are retained within the ascending air, partake of the temperature changes of the air, and are available for evaporation at the appropriate stages on subsequent descent of the air, which is also at the SALR; (*b*) an irreversible and, strictly, non-adiabatic process, in which all products of condensation are removed during ascent and in which subsequent descent of the air is at the DALR. The latter process corresponds much more closely to what happens in the atmosphere than does the former and is termed a pseudo-adiabatic process. Because of the loss of the heat content of the precipitated water, cooling on ascent in a pseudo-adiabatic process is at a rate slightly in excess of the SALR, but the difference between the rates is negligible: thus, saturated adiabatics and pseudo-adiabatics (lines on an AEROLOGICAL DIAGRAM representing the respective lapse rates) are, for practical purposes, identical. The important distinction between the pseudo-adiabatic and reversible processes lies in the different rates of temperature change undergone by the air on subsequent descent. See also ENTROPY, ISENTROPIC.

adiabatic diagram: An alternative for AEROLOGICAL DIAGRAM, or THERMODYNAMIC DIAGRAM.

adiabatic region: That region of the atmosphere (the TROPOSPHERE) where the temperature LAPSE rate is determined mainly by vertical ADIABATIC motion of the air: it is also termed the 'convective region'.

adsorption: The penetration of a substance, e.g. gas or thin film of liquid, into the surface layer of a solid with which it is in contact.

advection: The process of transfer (of an air-mass property) by virtue of motion. In particular cases, attention may be confined to either the horizontal or vertical components of the motion. The term is, however, often used to signify horizontal transfer only.

advection fog: Fog formed by the slow passage of relatively warm, moist and stable air over a cool surface. It is associated mainly with cool sea areas, particularly in spring and summer, and may affect adjacent coasts. It may occur also over land in winter, particularly when the surface is frozen or snow-covered—sometimes then, however, in conjunction with RADIATION FOG.

advective change of temperature: That contribution to local temperature change which is caused by either (or both) horizontal or vertical ADVECTION of air. The horizontal component of change, which is generally the more effective in the troposphere, is proportional to the horizontal temperature gradient at the level concerned and to the wind speed in the direction of this gradient; the vertical component of change is proportional to the vertical wind velocity and to the static stability of the air and depends also on whether or not the air is saturated.

AERO: A code word indicating that a meteorological report of surface conditions, intended primarily for aviation purposes, follows in figure code. See 'Handbook of weather messages.'*

aerobiology: The study of the part played by the earth's atmosphere in the movement of living animal and plant organisms.

aerodrome meteorological minima: Specifications of the meteorological conditions, such as the minimum cloud base and visibility and the maximum runway cross-wind component, under which the use of a particular aerodrome is permitted. The specified conditions vary with airline operator and with experience of pilot: they are less stringent for take-off than for landing.

aerodynamic roughness, smoothness: A physical boundary is 'aerodynamically rough' when fluid flow is turbulent down to the boundary itself. Over such a boundary the velocity profile and surface drag are independent of the fluid viscosity (ν) but depend on a ROUGHNESS LENGTH (Z_0) which is related to the height and spacing of the roughness elements of the surface. A surface is 'aerodynamically smooth' if there exists a layer adjacent to it in which the flow is laminar and in which the velocity profile and surface drag are related to the fluid viscosity. A surface which is aerodynamically smooth at low speed of flow may become aerodynamically rough at a higher speed. A surface may thus be described as rough or smooth only in terms of the associated flow: alternatively, the flow itself may be described as aerodynamically rough or smooth.

In meteorology, nearly all surfaces are aerodynamically rough for any significant wind speed.

aerodynamics: The study of the forces and reactions arising from the motion of bodies, more particularly the parts of an aircraft, through the air. It is from such forces or reactions that the lifting power of an aircraft is obtained.

aerogram: An AEROLOGICAL DIAGRAM, due to A. Refsdal, in which the abscissa is log T and the ordinate $T \log p$.

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* London, Meteorological Office; Handbook of weather messages. Parts II and III. London, HMSO, 1959.

aerological diagram: A graphical representation of the observations of pressure, temperature and humidity, made in a vertical sounding of the atmosphere.

The reference lines which facilitate the plotting of a sounding and its assessment after plotting are isobars, isotherms, dry adiabatics, saturated (pseudo-) adiabatics and saturation moisture lines. Each of the diagrams in common use—the tephigram, emagram and Stüve diagram—has its own particular advantage. Each has, exactly or very nearly, the property of being a true thermodynamic ('equivalent') diagram in that equal area represents equal energy at any point of the diagram: possession of this property simplifies energy and height (geopotential) calculations.

The tephigram (T–φ gram)—see Figure 2—has rectangular Cartesian co-ordinates in which the abscissa is temperature (T) and the ordinate ENTROPY (φ), (entropy is now normally designated S, not φ) i.e., log θ, where θ is the dry-bulb potential temperature: the dry adiabatics (θ=constant) are therefore straight lines perpendicular to the isotherms. The basic co-ordinates in the emagram are T and log p (p=pressure): in a 'rectangular' model the T and log p axes are perpendicular to each other; in the 'oblique' emagram these axes meet at an angle of 45°, thus making the dry adiabatics (slightly curved) and isotherms meet at an angle of about 90°. This latter is a decided advantage in assessing the static STABILITY of an ascent curve since the normal range of lapse rate of temperature in the troposphere is between the isothermal and dry adiabatic rates. In the Stüve diagram rectangular co-ordinates of T and $p^{\varkappa}$ ($\varkappa = 0{\cdot}286$) are used: the dry adiabiatics are then straight lines (as are the isobars and isotherms) but the property of strict equivalence of energy and area is sacrificed.

aerology: A word denoting the study of the atmosphere, but generally used in the sense of a study limited to the atmosphere above the surface layers.

aeronomy: A term sometimes used to denote that branch of atmospheric physics which is concerned with those regions, upwards of about 50 km, where DISSOCIATION and IONIZATION are fundamental properties.

aerosol: In meteorology, an aggregation of minute particles (solid or liquid) suspended in the atmosphere. See NUCLEUS.

afterglow: See ALPINE GLOW.

ageostrophic wind: The VECTOR difference between the actual wind and the GEOSTROPHIC WIND (see Figure 3): it is also called the 'geostrophic departure'.

Actual wind = geostrophic wind + ageostrophic wind.

The ageostrophic wind is of fundamental importance in that it is necessarily associated with CONVERGENCE or DIVERGENCE and vertical motion in the atmosphere. Surface friction, pressure gradient change with time (ISALLOBARIC WIND), and air movement on a curved path (GRADIENT WIND), are examples of conditions in which there is an ageostrophic wind.

agro-climatology: The study of those aspects of climate which are relevant to the problems of agriculture. Such study involves types of data, e.g. earth temperature and accumulated temperature, which are often not considered in more general CLIMATOLOGY.

agro-meteorology: Meteorology relevant to problems of agriculture. It is concerned, in particular, with the surface layers of the atmosphere and with the conditions in the top layer of the earth's surface which are associated with variations of the meteorological elements.

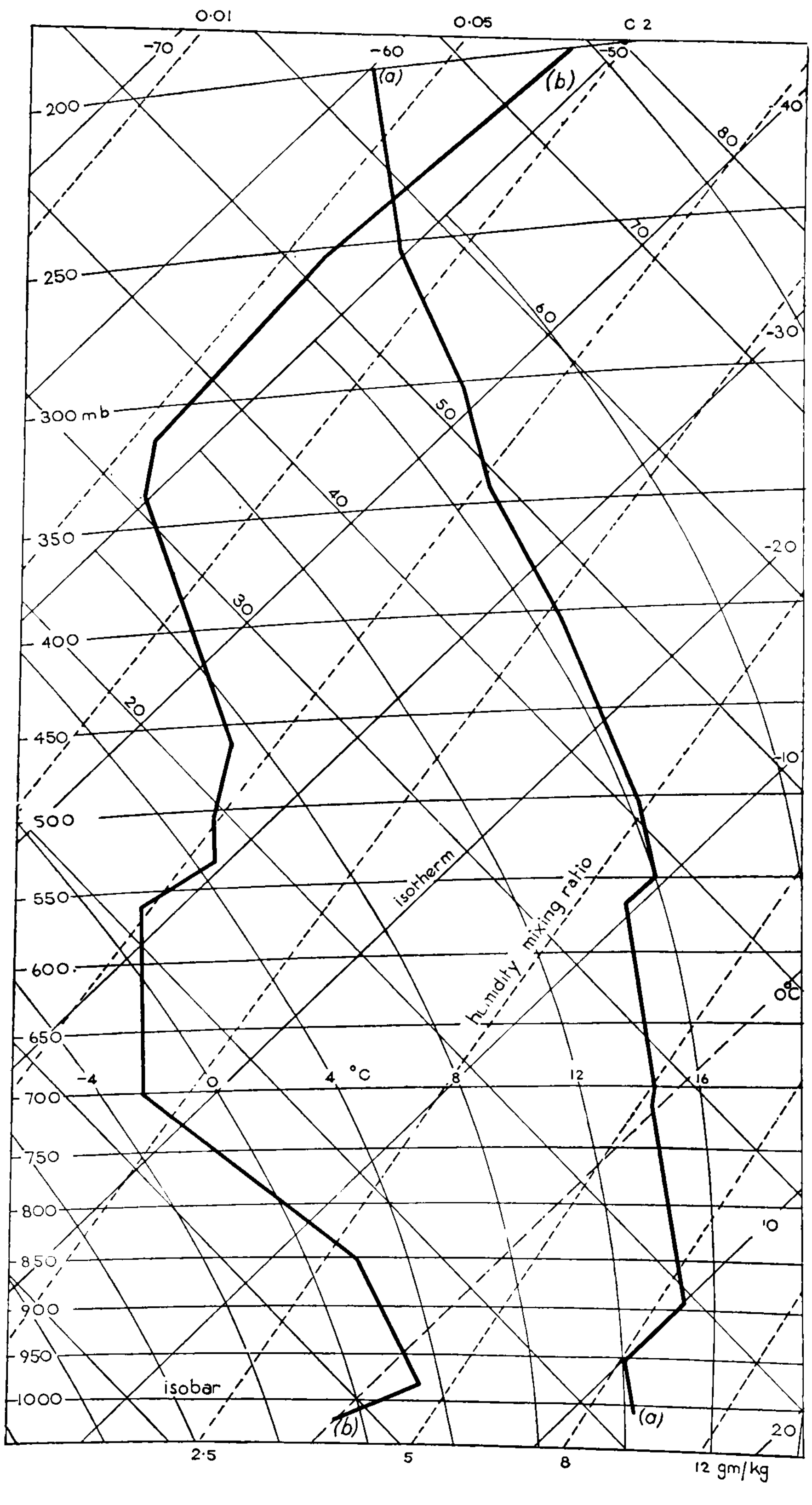

FIGURE 2—Aerological diagram (tephigram) illustrating pressure–temperature plots of two ascents made at Crawley (51° 05′ N, 0° 13′ W).

Curve (*a*): ascent made in maritime tropical air, 2330 GMT, 11 December 1961.

Curve (*b*): ascent made in arctic air, 2330 GMT, 5 December 1961.

air: The mixture of gases which form the earth's ATMOSPHERE. In the absence of dust and water vapour, the composition of the air up to about 20 km is taken to be as shown in Table I: the percentage composition by volume and weight is given, i.e., FRACTIONAL VOLUME ABUNDANCE and MIXING RATIO.

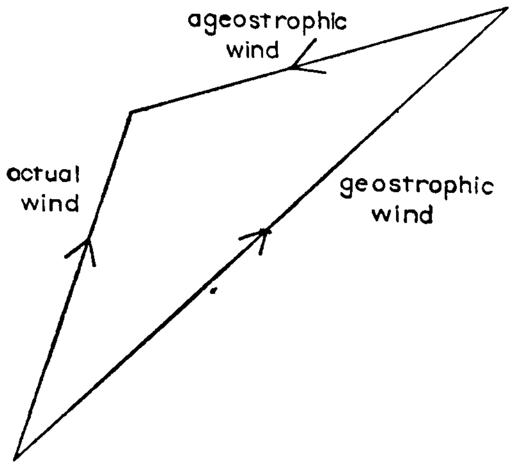

FIGURE 3—Ageostrophic wind.

TABLE I—*Composition of dry air*

	Specific Gravity (O = 16)	Proportional composition By volume %	By weight %
Dry air	14·48	100·0	100·0
Nitrogen	14·01	78·09	75·54
Oxygen	16·00	20·95	23·14
Argon	19·97	0·93	1·27
Carbon dioxide	22·01	0·03	0·05
Neon	10·09	$1{\cdot}8 \times 10^{-3}$	$1{\cdot}2 \times 10^{-3}$
Helium	2·00	$5{\cdot}2 \times 10^{-4}$	$7{\cdot}2 \times 10^{-5}$
Methane	8·00	$2{\cdot}0 \times 10^{-4}$	$1{\cdot}0 \times 10^{-4}$
Krypton	41·85	$1{\cdot}0 \times 10^{-4}$	$3{\cdot}0 \times 10^{-4}$
Hydrogen	1·01	$5{\cdot}0 \times 10^{-5}$	$4{\cdot}0 \times 10^{-6}$
Nitrous oxide	22·01	$5{\cdot}0 \times 10^{-5}$	$7{\cdot}6 \times 10^{-5}$
Xenon	65·65	$8{\cdot}0 \times 10^{-6}$	$3{\cdot}6 \times 10^{-5}$
Ozone	24·00	$1{\cdot}0 \times 10^{-6}$	$1{\cdot}7 \times 10^{-6}$

Of the gases shown in Table I only carbon dioxide and ozone have appreciable local variations of concentration. There are also, mainly in the low atmosphere, minute variable quantities of such gases as radon, actinon, thoron, sulphur dioxide, hydrogen chloride.

Ordinary (moist) air may be regarded as a mixture of dry air and water vapour. The concentration of water vapour in surface air varies from a small fraction of one per cent to over three per cent; in general, the concentration decreases with increasing altitude.

air discharge: A term sometimes used to denote a lightning flash from cloud to air. See LIGHTNING.

AIREP: An indicator word for an air-to-ground report in figure code, containing operational and meteorological information. See 'Handbook of weather messages'.*

* London, Meteorological Office; Handbook of weather messages. Parts II and III London, HMSO, 1959.

airglow: General term for the radiation which is emitted continuously by the upper atmosphere. The day, twilight and night emissions are termed DAYGLOW, TWILIGHT-GLOW and NIGHTGLOW, respectively, the last being the most extensively studied.

airlight: The increase in apparent brightness of a distant object viewed in daylight, owing to scattering of light towards the observer by particles held in suspension in the atmosphere, and by air molecules, between the observer and object. Airlight, and therefore object brightness, increase with object distance owing to increase in the number of scattering agents. A critical point is reached, limiting daylight VISIBILITY, at which the brightness of a suitable object is just indistinguishable from its background. See also KOSCHMIEDER'S LAW, CONTRAST THRESHOLD OF THE EYE.

air mass: A body of air in which horizontal gradients of temperature and humidity are relatively slight and which is separated from an adjacent body of air by a more or less sharply defined transition zone (FRONT) in which these gradients are relatively large.

The horizontal dimensions of air masses are normally hundreds or even thousands of miles. The term is, however, also used in relation to phenomena of much smaller scale, e.g., the sea-breeze.

Homogeneity in a body of air is produced by prolonged contact, in a 'source region', with an underlying surface of uniform temperature and humidity. The main source regions are those in which occur the permanent or semi-permanent anticyclones, with rather indeterminate boundaries, which are a prominent feature of the GENERAL CIRCULATION—the subtropical, polar, and winter continental anticyclones. Slow transformation of the air-mass properties acquired at the source region is effected on subsequent movement of the air from the region, mainly through its contact with a different surface, but to an appreciable extent also by radiation and large-scale vertical motion. The synoptic meteorology of middle latitudes, in particular, is dominated by considerations of the air-mass properties originally acquired and the manner of their recent modification—whether warming or cooling, becoming more or less moist or more or less stable.

Air masses are classified into groups designated as 'polar' (P) or 'tropical' (T), maritime (m) or continental (c), defining the basic temperature and humidity characteristics, respectively: more generally, a twofold classification in terms of both elements, e.g. mT or cP, is used. Further divisions are sometimes made into arctic or antarctic (A) air and into classes of more local significance, e.g. Mediterranean air.

air-mass analysis: Synoptic identification of AIR MASSES and location of boundaries (FRONTS) between adjacent air masses.

The identifying of an air mass implies the finding of its source region and would appear to entail the retrospective tracking of the air back to such a region. In practice, such a procedure is very seldom required because of the continuity provided by a series of synoptic charts. An air mass moving from its source region usually has in early stages a well defined front at its junction with the adjacent air mass. Further identification of the limits of the air masses is largely made in terms of the movement of this front which has a high degree of continuity with time.

The locating of fronts on a surface synoptic chart rests in part on identifying the line or zone of maximum horizontal gradient of air temperature and humidity, and in part on locating the physical and dynamical effects frequently associated with a junction of two air masses—precipitation, and discontinuities of pressure tendency and wind velocity. Cloud type, visibility, and lapse rate of temperature are further parameters in which there is normally a discontinuity at an air-mass boundary.

The locating of fronts on surface synoptic charts is made more difficult by the fact that, at land stations, such elements as temperature and, to a lesser extent, dew-point are not 'conservative', i.e. they are readily changed by such processes as radiational warming and cooling, often to very different degrees at different places. Wind velocity and, more particularly, visibility are other surface elements which at land stations may not be 'representative' of the air mass as a whole. Such lack of representativeness is much less true of observed elements in the upper atmosphere. Temperature and humidity of individual elements of air in the free atmosphere are, however, by no means conservative in vertical motion, and recourse is sometimes made, in identifying air masses, to such derived parameters as POTENTIAL TEMPERATURE and WET-BULB POTENTIAL TEMPERATURE which are conservative, or quasi-conservative, for certain specific processes to which the air may be subjected.

air-mass climatology: Description of climate in terms of the frequencies and properties of the different types of AIR MASS which affect a specified region in a specified period.

air-mass thunderstorm: A THUNDERSTORM which is formed by convection within an air mass, usually by heating of the lower layers. By implication, it is one in whose formation neither a front nor large-scale dynamical lifting of the air mass plays an important part.

air-meter: An instrument for measuring the flow of air. It consists of a light 'windmill' in which inclined vanes are carried on the spokes of a wheel arranged to rotate about a horizontal axis. A system of counters is provided to show the number of rotations of the wheel. Calibration is effected in terms of a speed unit so that the instrument acts as a convenient portable ANEMOMETER. Both 'sensitive' (low-speed) and 'high-speed' air-meters are used.

air pocket: An obsolescent term for a region of descending air in which an aircraft experiences a proportionate decrease of lift.

Air pockets are usually experienced in association with convective-type storms ('downdraughts') and, in strong and squally winds, on the leeward side of hills, buildings and other obstructions. The turbulence produced by an obstacle to wind flow extends to a height which increases with temperature lapse rate up to three or four times that of the obstacle.

Aitken nucleus: See NUCLEUS.

albedo: A measure of the reflecting power of a surface, being that fraction of the incident RADIATION (total or monochromatic) which is reflected by a surface.

Typical values of total albedo (per cent) of various surfaces are: forest 5 to 10; wet earth 10; rock 10 to 15; dry earth 10 to 25; sand 20 to 30; grass 25; old snow 55; fresh snow 80. The albedo of a water surface varies from about 5 per cent at high solar elevation to 70 per cent at low solar elevation. The albedo of clouds is difficult to measure but is known to depend on cloud type and thickness: estimates of an average value in time and space vary from 50 to 65 per cent.

The albedo of the earth–atmosphere system as a whole ('planetary albedo') is estimated to be about 0·4 (i.e. 40 per cent). This signifies that about four-tenths of the incident solar radiation is returned to space, without change of wavelength, by reflexion from clouds and earth's surface and by back scattering from air molecules and dust. A similar value, with real variations up to about 5 per cent, is inferred from photometric comparisons of the earth-lit and sun-lit segments of the moon.

albedometer: An instrument for measuring the ALBEDO of a surface.

Aleutian low: A depression, centred near the Aleutian Islands in the north Pacific, which is a conspicuous feature of the northern hemisphere surface pressure chart in winter. The depression has an average central pressure below 1000 mb in January, and represents the aggregate of the many depressions which affect this region in winter.

alidade: An instrument for measuring the angular elevation of an object, e.g. a cloud feature or a searchlight spot. The object is sighted by the observer along a rod whose angular position (0°–90°) with respect to the horizontal is obtained by reading from an engraved scale of degrees. Both fixed and portable (or 'hand') alidades are used.

alpha (or α) particle: A particle emitted spontaneously from the nuclei of certain radioactive elements. It is identical with a helium nucleus, comprising two neutrons and two protons, and therefore carries a positive charge of two units.

α particles are of such low penetrative power (only a few inches in air) that the particles emitted by radioactive materials in the earth's crust are insignificant in forming IONS. α particles are, however, also emitted from the radioactive gases, mainly RADON, ACTINON and THORON at low atmospheric levels and are responsible for a significant part of the ionization of the air at these levels, over land. See also BETA PARTICLE, GAMMA RADIATION.

alpine glow: A series of phenomena seen in mountainous regions about sunrise and sunset.

Two principal phases are generally recognized:

(i) The true alpine glow.—At sunset this phase begins when the sun is 2° above the horizon; snow-covered mountains in the east are seen to assume a series of tints from yellow to pink, and finally purple. As this phase is due mostly to direct illumination by the sun it terminates when the mountain tops pass into the SHADOW OF THE EARTH. The alpine glow is most striking when there are clouds in the western sky and the illumination of the mountains is intermittent.

(ii) The afterglow.—This begins when the sun is well below the horizon, 3° or 4°. The lighting is faint and diffuse with no sharp boundary and occurs only when the PURPLE LIGHT is manifest in the sky.

altimeter: An instrument for determining the altitude (generally of an aircraft) with respect to a datum level. The two main types are (i) a radio altimeter and (ii) a pressure altimeter.

The pressure altimeter is an ANEROID BAROMETER which is calibrated directly in height units on the basis of the 'altimeter equation':

$$z = \frac{R\bar{T}_v}{g} \log_e \frac{p_0}{p_1} \simeq 221{\cdot}1\ \bar{T}_v \log_{10} \frac{p_0}{p_1} \text{ (feet)}$$

$$\simeq 67{\cdot}4\ \bar{T}_v \log_{10} \frac{p_0}{p_1} \text{ (metres)}$$

where z is height, R is specific gas constant for dry air and $\bar{T}_v$ is mean virtual air temperature in the air column at the bottom and top of which the pressures are p_0 and p_1, respectively.

The assumptions made in the instrument graduation are that p_0 has the value appropriate to MSL pressure of the STANDARD ATMOSPHERE (ICAO or ICAN), and that the variation of mean virtual temperature with height corresponds to that in the standard atmosphere.

Corrections are required to take account of the fact that actual conditions differ from those of the standard atmosphere. The first concerns p_0 and involves an ALTIMETER SETTING: the required correction is the same at all altitudes. Thus an ICAN altimeter, for example, shows the height interval in the ICAN atmosphere between the altimeter-setting pressure and the ambient pressure. The second correction involves a positive (negative) correction when actual $\bar{T}_v$ is higher (lower) than that of the standard atmosphere: this correction is negligible at low altitudes.

altimeter setting: The altimeter setting, designated QNH in the aircraft Q-CODE, is defined as that value of pressure, for a particular aerodrome and time, which, when set on the sub-scale of a standard ALTIMETER (based for example, on the ICAN ATMOSPHERE), will cause the altimeter to read the height of the aerodrome when the aircraft is at rest on the aerodrome. For procedure for obtaining QNH see 'Observer's handbook.'*

altitude: The angular distance of an object above the horizon: synonymous with angle of ELEVATION.

In meteorology, altitude generally signifies height above mean sea level (geometric metres or feet); in dynamical meteorology, however, height is usually expressed in GEOPOTENTIAL metres or feet. In aviation, altitude signifies geometric height of an aircraft above mean sea level.

altocumulus (Ac): One of the CLOUD GENERA (Latin, *altum* height, and *cumulus* heap).

'White or grey, or both white and grey, patch, sheet or layer of cloud, generally with shading, composed of laminae, rounded masses, rolls, etc., which are sometimes partly fibrous or diffuse and which may or may not be merged; most of the regularly arranged small elements usually have an apparent width of between one and five degrees.'† See Plates 8 and 16: see also CLOUD CLASSIFICATION.

altostratus (As): One of the CLOUD GENERA (Latin, *altum* height, and *stratus* spread out).

'Greyish or bluish cloud sheet or layer of striated, fibrous or uniform appearance, totally or partly covering the sky, and having parts thin enough to reveal the sun at least vaguely, as through ground glass. Altostratus does not show halo phenomena.'† See Plate 9: see also CLOUD CLASSIFICATION.

amorphous clouds: A term used in respect of a more-or-less continuous layer of low clouds without regular features and generally associated with rain, as for example NIMBOSTRATUS.

amplitude: The amplitude of a harmonic motion is the maximum swing to either side of the mean position, i.e. half the total range of motion. See HARMONIC ANALYSIS.

anabatic wind: A local wind which blows up a slope heated by sunshine. It is a feature which is much less common than its converse, the KATABATIC WIND.

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* London, Meteorological Office; Observer's handbook. 2nd edn., London, HMSO, 1956, p. 89.

† Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 11.

anafront: As defined by T. Bergeron, a FRONT (warm or cold) along which the warm air is ascending relative to the cold air. Frontal activity is generally well marked with such fronts.

analogue: In synoptic meteorology, a past synoptic situation which resembles the current situation over an appreciable area. Analogues are usually selected from the same time of year as the current situation. The sequence of weather which followed an analogue is sometimes used as the basis of a weather forecast, in both short-range and long-range forecasting. In the former case the analogues refer to the surface (and upper air) synoptic charts which are drawn as a routine. In the latter case they may refer to charts which show, for example, the distribution of the values of monthly temperature anomalies (departures from average) at stations distributed over a large area.

analysis: In synoptic meteorology, the co-ordination by means of isopleths or representative symbols of the elements plotted on a surface or upper air chart ('surface analysis' and 'upper air analysis,' respectively), generally for the purpose of making a weather forecast.

Surface analysis comprises both 'isobaric analysis' (the drawing of isobars) and 'air-mass analysis' (the identification of air masses and drawing of fronts): other types of isopleth, notably ISALLOBARS, may be drawn on the surface chart as aids in analysis. In upper air (isobaric) analysis contours are drawn; sometimes also streamlines, isopleths of temperature and isopleths of wind direction and speed.

anemogram: The record of an ANEMOGRAPH.

anemograph: An instrument for recording the speed, sometimes also the direction, of the wind.

Each of the basic types of ANEMOMETER may be used as an anemograph. For normal purposes, the cup-contact, cup-generator and pressure-tube anemographs are most commonly used. The latter instrument makes use of the difference of pressure set up between two pipes, one of which is kept facing the wind by the action of a WIND VANE, while the other is connected to a system of suction holes on a vertical tube. The difference of pressure so produced is arranged to raise a float carrying a pen, the height of which above the zero position is made proportional to wind speed by suitable design of the float. The instrument takes a certain time to respond to changes of wind speed, but gusts and lulls with periods down to a few seconds are indicated accurately, though they may not be distinguishable on the record. Either 'direct recording' at a point underneath the instrument head, or 'remote recording' at a considerable distance from the instrument, may be arranged.

anemometer: An instrument for determining the speed of the wind. One or other of three properties of the wind is used in such instruments: (i) its kinetic energy, which causes rotation as in cup anemometers and anemometers of the windmill type (AIR-METER); (ii) its pressure, as in the pressure-tube ANEMOGRAPH and pressure-plate anemometer; (iii) its cooling power, as in the hot-wire anemometer.

Cup anemometers consist of three or four cups, conical or hemispherical in shape, mounted symmetrically about a vertical axis. In the cup-contact anemometer, the closing of electrical contacts produces an intermittently audible note the rate of recurrence of which is proportional to the wind speed. In the cup-generator anemometer, the rotating cups are made to generate a voltage which registers on a dial calibrated in knots or miles per hour. In the cup-counter or run-of-wind anemometer, the integrated flow of the air in miles is registered on a counter.

In the pressure-plate anemometer, the deflexion of a flat plate placed in the wind is measured: its use is confined mainly to atmospheric turbulence measurement. In the hot-wire anemometer, the current required to maintain constant the electrical resistance (and so the temperature) of a fine platinum wire which is exposed to the wind may be used as a measure of the wind speed: alternatively, a large resistance may be placed in series with the wire, the current kept constant and the varying potential drop across the wire used as a measure of the wind. This instrument is used when rapidity of response to wind fluctuations is important.

See also EXPOSURE.

aneroid barometer: The aneroid ('without liquid') barometer was invented by Lucien Vidie in about 1843. In its simplest form it consists of a shallow capsule of thin, corrugated metal which is exhausted of air. The faces are kept apart by the stiffness of the metal or by a separate spring. Compensation for temperature is provided by a bimetallic link or (over a limited range of pressure) by a small quantity of residual air in the capsule. In some instruments several capsules are employed. The relative movements of the faces due to changes of atmospheric pressure are conveyed and magnified through a train of levers to a chain which actuates a pointer on a dial.

An aneroid is light, portable and convenient. Since, however, it may be subject to errors introduced by imperfect elasticity of the metal, etc., and to changes of zero (both generally small in modern instruments), it requires occasional checking against a mercury barometer and in the past has normally been used only when the use of a mercury barometer was impracticable. Recently, however, aneroid barometers which show promise of being as accurate and reliable as a mercury barometer have been developed.

angels, radar: Radar reflexions obtained on certain occasions of apparently clear air. One type, comprising clouds of point-target echoes, has been definitely associated with birds. It is probable that other types are associated with abrupt changes of refractive index of the air.

ångström unit: A measure of wavelength, equal to 10^{-8} cm, denoted Å.

angular momentum: The angular momentum (or moment of momentum) per unit mass of a body rotating about a fixed axis is the product of the linear velocity of the

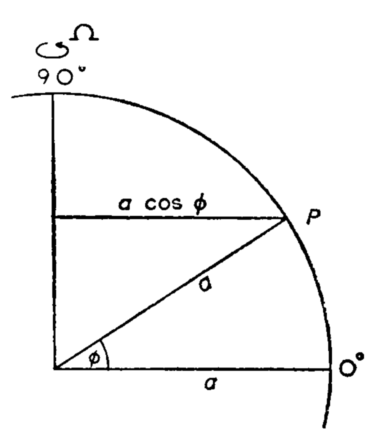

FIGURE 4—Angular momentum.

body and the perpendicular distance of the body from the axis of rotation. The dimensions are L^2T^{-1}.

A point *P* of the earth in latitude φ has a west–east (zonal) velocity of $\Omega a \cos \varphi$ where Ω is the earth's angular velocity and *a* its radius (see Figure 4).

Thus, the absolute angular momentum of air at this latitude, of relative zonal velocity u (and not too far removed from the surface of the earth)

$$= (u + \Omega a \cos \varphi) a \cos \varphi$$
$$= u a \cos \varphi + \Omega a^2 \cos^2 \varphi.$$

The first of these terms is the 'relative angular momentum' of the air, reckoned positive for positive u. The second term is the angular momentum of the coinciding point of the earth.

The transfer of angular momentum effected by the atmosphere and the manner in which the entire earth–atmosphere system conserves absolute angular momentum over a long period of time are of fundamental significance in the explanation of the GENERAL CIRCULATION of the atmosphere.

angular velocity: The angular velocity of a moving line is the time rate of change of the angle between the line and a fixed line in a plane containing two successive positions of the moving line. Angular velocity is represented by a vector normal to this plane. A suitable convention is adopted as to which direction of rotation is considered positive. The angular velocity of a moving point about a fixed point is the angular velocity of the line joining the two points. The angular velocity of a moving point about a fixed axis is the rate of change of the angle between a plane drawn through the axis and the moving point, and a fixed plane passing through the axis. The angular velocity of a solid body about an axis is the angular velocity of any point of the solid body about that axis. The dimensions are T^{-1}.

Angular velocity is a vector quantity which is normally measured either in revolutions per unit time or in radians per unit time. Since there are 2π radians per revolution, ω (radians per second) is related to N (revolutions per minute) by the expression $\omega = \pi N/30$.

angular velocity of the earth: The ANGULAR VELOCITY of the earth (Ω) may be represented by a vector parallel to the axis of the earth and directed northwards. This vector may be resolved into components $\Omega \cos \varphi$ about the line directed

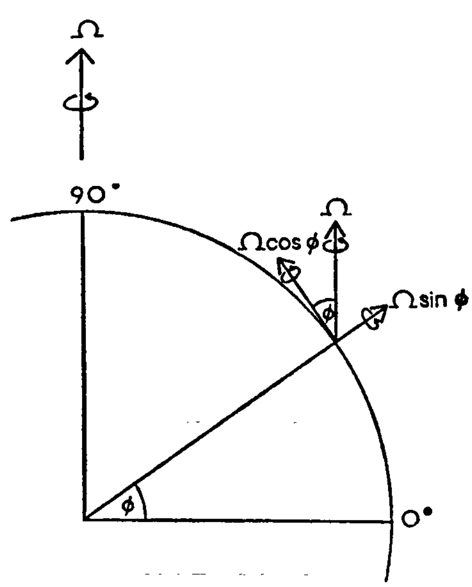

FIGURE 5—Angular velocity of the earth.

towards local north (rotation in a vertical plane) and $\Omega \sin \varphi$ about the local vertical (rotation in a horizontal plane)—see Figure 5. The total vector is of magnitude 2π rad/sidereal day $= 7{\cdot}292 \times 10^{-5}$ rad/sec.

$\Omega \sin \varphi$ is the only component which is significant in large-scale motion, which is almost entirely horizontal. The rotation is anticlockwise in the northern hemisphere, clockwise in the southern hemisphere: it is thus cyclonic in both cases.

anomalous audibility: Audibility of sound waves over a region which is separated from the source of the waves by a 'zone of silence'. See AUDIBILITY.

anomalous radio propagation: Under normal atmospheric conditions, radio waves up to a few metres in length, transmitted in beams (for example, radar) in a direction close to the horizon, attain ranges on the earth's surface which approximate only to the distance of the optical horizon, being limited by the curvature of the earth. In abnormal atmospheric conditions, determined by the abnormal variation with height of the REFRACTIVE INDEX of the low atmosphere, the waves may be subject to 'anomalous propagation' in which they suffer such downward refraction as to extend their normal range by many times, exceptionally from, say, 25 miles to some hundreds of miles.

This effect, also known as 'superrefraction', is associated with the existence of a so-called 'radio duct' in conditions of a large inversion of temperature, or large decrease of humidity with height, or both, extending through an atmospheric layer near the surface of the earth. Such conditions would be expected, for example, in air moving out from a warm, dry land over a cool sea. The depth of the duct required for marked abnormality of propagation increases with wavelength: it is, for example, some 50 feet for a wavelength of 3 cm, and about 600 feet for a wavelength of one metre. The frequency of the phenomenon is, therefore, much greater at the short wavelengths.

anomalous sound propagation: The propagation of sound waves along a path, from source to receiver, other than close to the earth's surface, as the result of which ANOMALOUS AUDIBILITY occurs. See AUDIBILITY.

anomaly: In meteorology, this term usually signifies the departure of an element from its long-period average value for the place concerned. The space distribution of such anomalies at a specified time may be shown as an 'anomaly pattern'.

The term is also used in other senses, for example, a place that is relatively warm for its latitude (as western Norway in winter) is said to have a positive temperature anomaly.

antarctic air: An AIR MASS, originating over the Antarctic continent, which is cold and dry in all seasons. It is sometimes designated continental polar (*cP*) air.

Antarctic Circle: The parallel of latitude 66° 33′ S, south of which lies the 'Antarctic zone', or 'southern polar zone'.

Antarctic front: A FRONT which develops and persists around the Antarctic continent in about latitudes 60°–65°S, and divides ANTARCTIC AIR from the maritime POLAR AIR to the north. At any one time the front is believed to exist round a large part of the hemisphere.

anthelion: A colourless mock sun (PARHELION) appearing at the point of the sky opposite to and at the same altitude as the sun. The phenomenon is rare. Rather more frequently, oblique arcs crossing at that point are reported. The phenomenon is no doubt caused by the reflexion of light from ice crystals, but the exact explanation is in doubt.

anticorona: An alternative for GLORY.

anti-crepuscular rays: See CREPUSCULAR RAYS.

anticyclogenesis: The initiation of anticyclonic circulation, or its strengthening around an existing ANTICYCLONE.

anticyclolysis: The disappearance or weakening of anticyclonic circulation around an existing ANTICYCLONE.

anticyclone: That atmospheric pressure distribution in which there is a high central pressure relative to the surroundings. It is characterized on a synoptic chart by a system of closed isobars, generally approximately circular or oval in form, enclosing the central high pressure (see Figure 6). The term 'anticyclone' was selected (by F. Galton in 1861) as implying the possession of characteristics opposite to those found in the cyclone or depression. Thus, the circulation about the centre of an anticyclone is clockwise in the northern hemisphere (anticlockwise in the southern), and the weather is generally quiet and settled.

Two contrasting types of anticyclone, 'warm' and 'cold', are recognized. The former has a warm troposphere (though sometimes cold in a shallow layer near the earth's surface), high tropopause and cold stratosphere: the anticyclonic circulation is deep and the feature slow-moving. The preferred region is the subtropical belt at 30°–40° latitude, for example the Azores and Bermuda regions, but with frequent extensions across west Europe: typical warm anticyclones also occur in higher latitudes in association with BLOCKING. In contrast, the cold anticyclone has a relatively cold baroclinic troposphere, low tropopause, warm stratosphere and shallow circulation. It often forms in the cold air behind a depression and moves fairly rapidly in a direction between south and east (northern hemisphere), sometimes then slowly transforming to a warm type. Persistent radiational cooling in winter over high-latitude continents produces semi-permanent cold anticyclones, or 'continental anticyclones', as in Siberia and North America.

The dynamical structure of the anticyclone is one of horizontal convergence at high levels, horizontal divergence at low levels and slowly subsiding air throughout a large part of the troposphere. The SUBSIDENCE proceeds at a maximum rate in early stages of formation of the anticyclone and is greatest in mid-troposphere. The subsidence results, through dynamical warming of the air, in a decrease in relative humidity and an increase of static STABILITY of the air, often with the formation of an 'anticyclonic inversion' of temperature. These processes often result in fine, cloudless weather. There are, however, important exceptions: in summer, sea and coastal fog and, in winter, widespread stratocumulus ('ANTICYCLONIC GLOOM'), forming in moist air at the base of the inversion, or radiation fog, forming in conditions of little cloud, are commonly associated with an anticyclone.

anticyclonic gloom: Conditions of poor illumination occurring with an overcast sky of stratus or stratocumulus beneath an inversion in an ANTICYCLONE. It occurs mainly when pollution accumulates in the cloud owing to light winds over industrial areas.

antisolar point: That point, below or above the horizon, towards which the extension of the line from the sun to an observer's eye is directed.

anti-trades: The anti-trades, or countertrades, are upper winds which in some low-latitude areas prevail above the TRADE WINDS and which, more or less opposite in direction to the trade winds, are responsible for poleward transport of air aloft. The transition to anti-trades, marked by a temperature inversion, occurs at some 3000–5000 feet in high trade-wind latitudes in eastern oceanic regions and at increasingly high levels equatorwards and to the west.

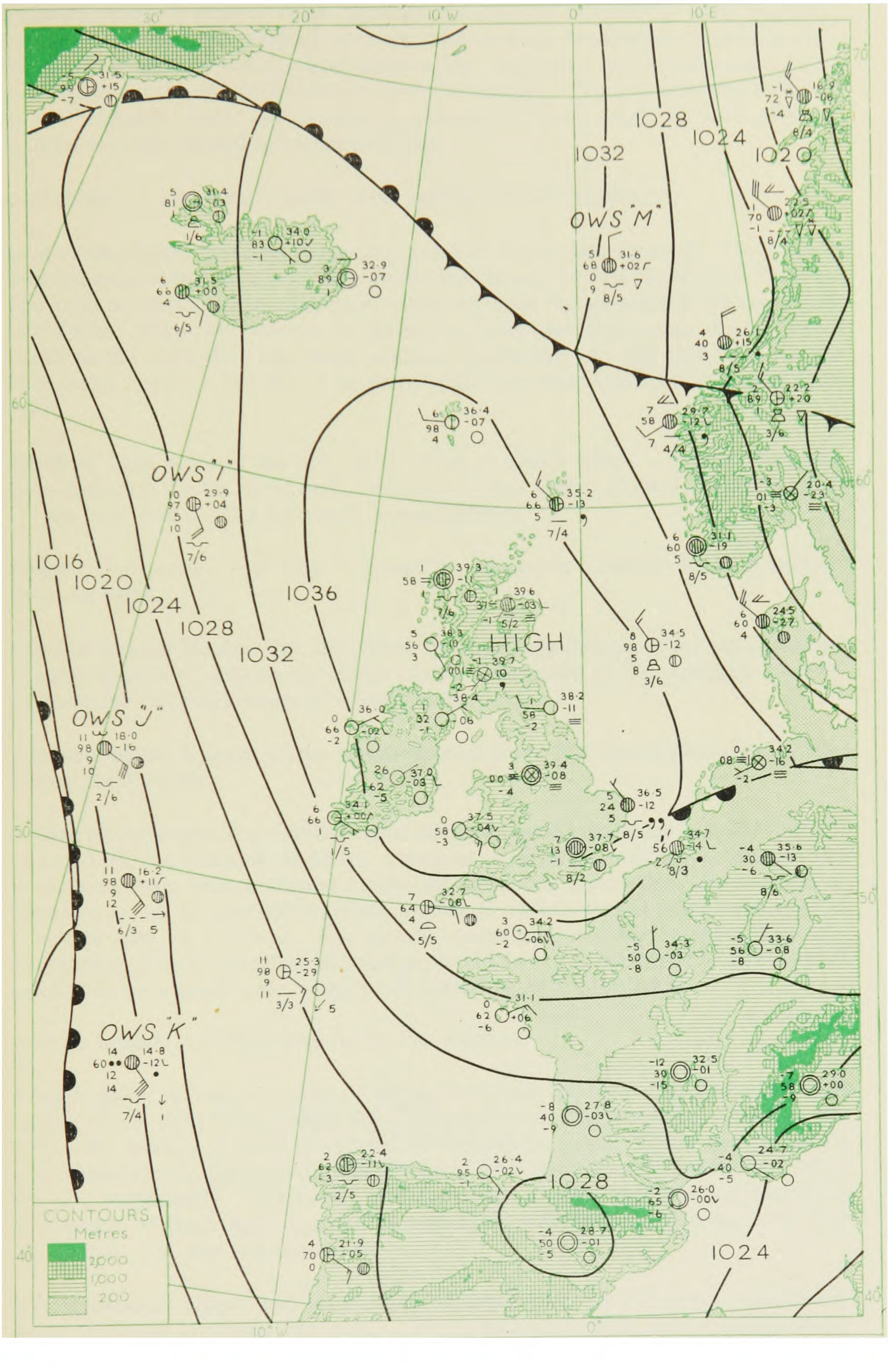

FIGURE 6—Anticyclone over the British Isles, 0600 GMT, 20 December 1961.

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antitriptic wind: A class of winds in which the effect of FRICTION or eddy VISCOSITY predominates over the CORIOLIS ACCELERATION and the CENTRIPETAL ACCELERATION effects. The air movement is from high to low pressure, a quasi-steady state being established by the effect of friction or eddy viscosity. Such winds occur mainly in low latitudes where the Coriolis acceleration is very small, or in small-scale systems (e.g. sea-breeze) in higher latitudes.

antitwilight (or antitwilight arch): Alternatives for COUNTERGLOW.

anvil cloud: Cloud having a projecting point or wedge like an anvil. The form is usually assumed by the tops of fully developed CUMULONIMBUS clouds as in Plate 15. The anvil is considered to indicate in nearly all cases the presence of ice crystals or snowflakes: it quickly assumes a fibrous or nebulous appearance and is often stretched out from the main cloud columns by changes of wind with height. The term 'anvil cirrus' is applied to an anvil which becomes separated from the main cloud.

aphelion: That point of the orbit of a planet or comet which is farthest from the sun. Aphelion for the earth occurs on about 1 July: the sun–earth distance is then 1·5 per cent greater than the yearly mean distance.

apogee: That point of the orbit of a satellite, natural or artificial, which is farthest from the earth.

apparent form of the sky: The somewhat 'flattened' appearance of the sky presented to most observers. Among the effects of this appearance is the tendency to overestimate the elevation angles of objects in the sky.

Appleton layer: A layer of the IONOSPHERE at some 300 km height, now usually termed the F_2-layer.

applied meteorology: The application of meteorological knowledge in a wide variety of activities, for example, industry, transport, hydrology and agriculture, for the purpose of using meteorological conditions to the best advantage. Forecasting, or climatology, or the application of the results of meteorological research in specific problems may be involved. For certain operations, notably in agriculture, the application of meteorological knowledge may include the altering of meteorological conditions on a small scale, as in the construction of shelter-belts.

aqueous vapour: An alternative for WATER VAPOUR.

Arago's point: A 'neutral' point of the sky at which the normally observed polarization of the light from a clear sky disappears: that discovered by Arago in the early 19th century is some 20° above the ANTISOLAR POINT. Other neutral points were subsequently discovered by Babinet and Brewster about 20° above and below the sun, respectively. Day-to-day and systematic diurnal and seasonal variations of position of these points, probably associated with haze variations, have been discovered. See also POLARIZATION.

arcs of contact: Upper and lower 'arcs of contact' to the 22° HALO occasionally form, the lower arc being very rare. At high solar elevations the arcs may appear concave towards the sun. At low solar elevations the higher arc is convex towards the sun. The points of contact may have the appearance of 'mock suns' (PARHELIA) and may display brilliant colour.

arctic air: An AIR MASS originating in the snow and ice-covered Arctic and travelling almost directly south. In the British Isles this air mass is confined mainly to winter and spring and is associated with a northerly wind, snow showers (especially on north-facing coasts and hills), low temperatures, exceptional visibility and steep lapse rate.

Arctic Circle: The parallel of latitude 66° 33′ N, north of which lies the 'Arctic Zone', or 'northern polar zone'.

arctic front: A FRONT which separates ARCTIC AIR to the north from maritime polar air or continental polar air to the south. A section of the arctic front is often found in the area from south Greenland to north of Norway in winter and spring.

arctic sea smoke: If, when cold air moves over warm water, the vapour pressure at the water surface exceeds the saturation vapour pressure at the air temperature, then evaporation from the water surface proceeds at a higher rate than can be accommodated by the air. The excess water vapour over that required to saturate the air condenses and, in the unstable conditions present in the layer near the surface, the condensed water is carried continuously upwards to evaporate into the drier air above. 'Steam' or 'smoke' thus appears to rise off the water surface. If an inversion exists near the water surface, fog may be confined below the inversion and become dense.

The phenomenon occurs, for example, over inlets of the sea in high latitudes; over newly formed openings in pack ice; over lakes and streams on calm, clear nights; over damp ground heated by bright sunshine in cool conditions. Alternative names are 'frost smoke', 'sea smoke', 'steam fog', 'warm-water fog', 'water smoke' and 'the barber'. See Plate 3.

arcus (arc): A supplementary cloud feature. (Latin, *arcus* arch).

'A dense, horizontal roll with more or less tattered edges, situated on the lower front part of certain clouds and having, when extensive, the appearance of a dark menacing arch.

This supplementary feature occurs with CUMULONIMBUS and, less often, with CUMULUS.'* See also CLOUD CLASSIFICATION.

ARDC model atmosphere: See STANDARD ATMOSPHERE.

ARFOR: In weather messages, a code word indicating that a forecast of meteorological conditions over an area follows in figure code. See 'Handbook of weather messages'.†

argon: The most abundant of the INERT GASES, comprising $0{\cdot}93 \times 10^{-2}$ and $1{\cdot}27 \times 10^{-2}$ part per part of dry air by volume and weight, respectively. Its molecular weight is 39·944. Its inertness and relatively high density render it a suitable tracer (in terms, for example, of the argon : nitrogen ratio) of the degree of the GRAVITATIONAL SEPARATION of the atmospheric constituents.

arid: A climate in which the rainfall is insufficient to support vegetation is termed arid. Köppen and Geiger‡ in their 'Klimakarte der Erde' used the following

* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 17.

† London, Meteorological Office; Handbook of weather messages. Parts II and III. London, HMSO, 1959.

‡ KÖPPEN, W. and GEIGER, R.; Klimakarte der Erde. Gotha, Justus Perthes, 1928.

formulae for the limits of rainfall for arid and semi-arid climates:

Rainfall mainly in cold season	$R = 2t$
Rainfall evenly distributed throughout year	$R = 2t + 14$
Rainfall mainly in hot season	$R = 2t + 28$

where t is the mean annual temperature in °C. If the annual rainfall (cm) is less than R and greater than $R/2$ the climate is steppe or semi-arid; if it is less than $R/2$ the climate is desert or arid. See also DESERT, STEPPE.

artificial precipitation: See CLOUD SEEDING.

ascendent: See GRADIENT.

A-scope indicator: See RADAR METEOROLOGY.

ash: The incombustible solid material released when solid fuel is burned: a small proportion escapes to the atmosphere to contribute to ATMOSPHERIC POLLUTION.

The proportion of total ash that emerges into the atmosphere, and also the average size of emerging particles, depend on the velocity of the flue gases and are, in the absence of a grit arrester, much greater for industrial than for domestic chimneys. Emerging particle sizes range from 0·2 cm downwards, all except the smallest particles being deposited near the source. Measurement of such ash and other deposited material is made by the DEPOSIT GAUGE.

aspect: The aspect of sloping ground is the geographic direction in which the line of greatest downslope points. The 'aspect angle' is in the northern hemisphere the angle between this line and geographic south, usually reckoned positive eastwards, negative westwards.

aspirated psychrometer: A PSYCHROMETER in which a high rate of ventilation is provided artificially as in the ASSMANN PSYCHROMETER or WHIRLING PSYCHROMETER.

Assmann psychrometer: A PSYCHROMETER in which a definite rate of ventilation is secured by drawing the air over the thermometer bulbs by means of a fan driven by a motor and in which the thermometers are mounted in a polished metal frame as a protection against solar radiation.

atmosphere: The gaseous envelope which is held to the earth by gravitational attraction and which, in large measure, rotates with it. The internal motions of the atmosphere caused by solar radiational heating comprise, together with their physical effects, the main concern of meteorology. The term is also used of the gaseous envelopes of planets and stars.

The composition of the earth's atmosphere is discussed under AIR. Of special importance in meteorology are the time and space variations of water vapour. A distinction is drawn, in terms of atmospheric composition, between the homosphere, a region extending from the surface to about 80 km in which the permanent gaseous constituents are well mixed, and the heterosphere, the region above 80 km in which the processes of dissociation of oxygen and diffusion effect a change in composition with height.

The atmosphere's outermost fringe has been termed the 'exosphere', at the lower limit of which (about 700 km) the escape to space of neutral particles was calculated to begin. S. Chapman has, however, suggested that since the particles at such levels are mainly ionized and so are controlled not by diffusion but by the earth's magnetic field, the atmosphere may be considered to extend to a height of several or even many earth radii, where the density falls to that of interplanetary gas.

Division of the atmosphere into the regions TROPOSPHERE, STRATOSPHERE, MESOSPHERE, and THERMOSPHERE, according to characteristic temperature lapse rates, is illustrated in Figure 7: the approximate pressure and density variations with height are also shown. The terms OZONOSPHERE, CHEMOSPHERE and IONOSPHERE are also used of certain regions in which specified processes occur.

See also STANDARD ATMOSPHERE.

atmospheric boil: An alternative for SHIMMER.

atmospheric chemistry: A term which is generally taken to comprise the study of the chemical composition of the air (mainly that near the earth's surface), of aerosols, and of rainfall. Less commonly, it is used in a wider sense so as to include the processes of PHOTOCHEMISTRY which are important at levels above about 40 km.

Monthly samples of air and rainfall, collected at a network of stations which was augmented and made world-wide during the International Geophysical Year, are chemically analysed for the presence and concentration of the inorganic substances Na, K, Mg, Ca, NH_3, Cl, S, NO_3 and CO_3. The pH value of the sample (the logarithm, to base 10, of the inverse of the concentration of hydrogen in the solution) has also been determined.

Widely different results, difficult to interpret, have been obtained with the air sampling measurements, which have been concerned mainly with the contained particulate matter. More consistent results, though with unexplained space and time variations, have been obtained with the rainfall sampling measurements. In particular, a deficiency of Cl relative to Na and other ions which occur in sea water has been found.

In addition to the above, surface air has been sampled for carbon dioxide and ozone. Also, various measurements have been made of the nature and amount of the radioactive material from nuclear explosions which is contained in the troposphere and stratosphere, or is deposited as dust on the earth's surface, or is washed out of the atmosphere by precipitation.

atmospheric electricity: The various electrical phenomena which occur naturally in the lower atmosphere: the IONOSPHERE is conventionally excluded, except in so far as it reacts on the electrical properties of the lower atmosphere. While the THUNDERSTORM is the most familiar manifestation of atmospheric electricity, substantial electrical effects exist also in fine-weather regions and have been continuously measured at various places since the latter part of the 19th century. It is now generally held that the two classes of phenomena are closely linked.

The fine-weather electric field recorded in surface POTENTIAL GRADIENT measurements is directed downwards to earth and has a mean value of about 100 volts per metre. Such a field implies a negative charge on the earth's surface of about 1 coulomb per 1000 km^2 (3 e.s.u./m^2) in fine-weather regions.

Balloon measurements show that in such regions the potential gradient decreases with height, rapidly at first, then more slowly: a normal positive SPACE CHARGE is implied in the low atmosphere, with a surplus of positive over negative ions. Integration of the measured electric field with height shows that a positive potential of about 4×10^5 volts exists at a height of about 15 km, relative to the earth's surface, with little further addition to this value with further height increase owing to the high conductivity of the air at such and higher levels.

Various ionizing radiations render the air electrically conducting, though only feebly so near the earth's surface—see ION. A so-called 'conduction current' flows in fine-weather regions under the action of the field which prevails there (positive ions down to negatively charged earth, negative ions up): this is partially offset by a 'convection current' which transfers positive space charge bodily upwards from the low atmosphere. The measured air-earth current averages about 2×10^{-16} amp/cm^2. Its space and time variations are considerably smaller than those of the potential gradient: in particular, decrease of the electric field with increasing height is compensated by increasing conductivity, so maintaining an almost constant current, in accordance with Ohm's law.

Calculation shows that the air-earth current would within a few minutes destroy the electric field which gives rise to it and so would itself die out but for the action of a continuous compensating mechanism. The origin of the required 'supply current', for long a matter of doubt and controversy, is now thought to lie in

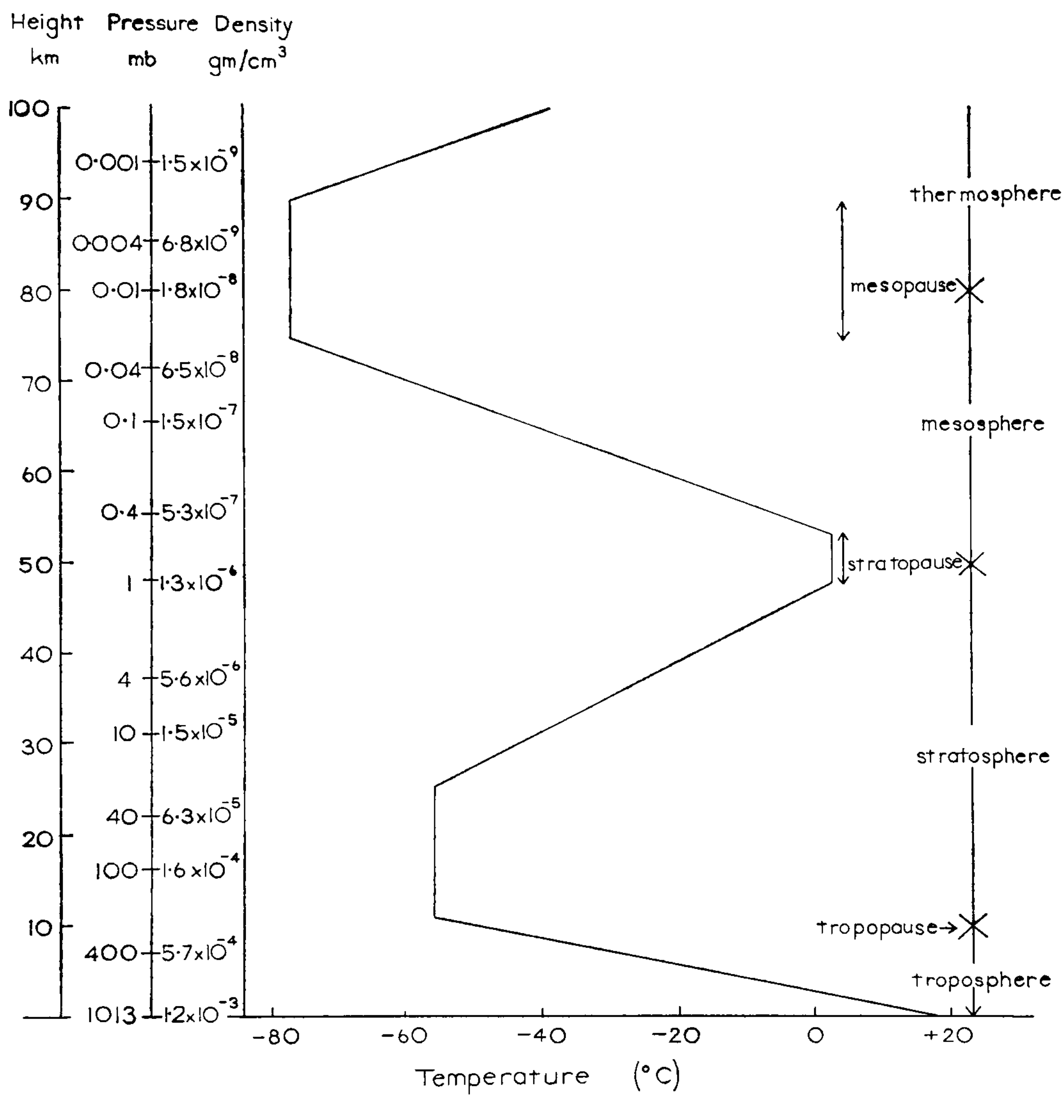

FIGURE 7—Temperature structure of the atmosphere, selected pressure levels and corresponding air densities from 0 to 100 km
0– 20 km: as defined by the ICAO Standard Atmosphere.
20–100 km: temperature structure as defined by the ARDC Model Atmosphere; pressure levels and air densities are mean annual mid-latitude values calculated by R. J. Murgatroyd.

rainstorms and thunderclouds, as was originally suggested by C. T. R. Wilson. Various mechanisms operate in the 'disturbed weather' regions:

(i) Large electrical charges accumulate at the base of thunderclouds: when such clouds are low, the electric field between cloud and ground often exceeds the value required for brush discharge, especially from elevated or pointed conductors. Since thundercloud bases carry a predominant negative charge, positive ions are mainly discharged from earth, leaving there a net negative charge.

(ii) Air-to-ground lightning flashes convey predominantly negative charge to ground.

(iii) Precipitation carries a net positive charge to ground.

(iv) Aircraft measurements above thunderclouds indicate that negative ions flow downwards from the high atmosphere to the positively charged thundercloud tops, leaving a net positive charge on the high atmosphere.

The sum of effects (i) and (ii) exceeds effect (iii), resulting in the conveying of a net negative charge to ground in disturbed regions: this charge and the positive charge conveyed upwards above thunderstorms quickly spread over the conducting earth and high atmosphere, respectively, and give rise to the downward-directed field 'leakage current' observed in fine-weather regions. Over-all (space and time) balance exists between the supply and leakage currents. A major piece of supporting evidence for this mechanism is the existence of a systematic diurnal variation of the fine-weather field in phase with integrated thunderstorm activity over the world (maximum about 1800 GMT, minimum about 0400 GMT), observed in those regions (e.g. oceanic) where complications of diurnal variation of low-level conductivity are absent.

atmospheric optics: The optical phenomena of interest to meteorologists include, among many other examples, the BLUE OF THE SKY, SUNRISE AND SUNSET COLOURS, the production of RAINBOWS, CORONAE, HALOES, MIRAGES, PARHELIA, the fading of daylight, and the twinkling of stars. See for example, Pernter and Exner,* Humphreys,† and Minnaert.‡

atmospheric pollution: Contamination of the atmosphere by gases and solids produced in the burning of natural and artificial fuels, in chemical and some other industrial processes, and in nuclear explosions: the term may be considered also to include contamination produced by such processes as accumulation of cosmic dust, raising by wind of surface dust, eruption of volcanoes, decay of vegetation, evaporation of sea salt spray, natural radioactivity.

Coal burning is the main source of pollution in Great Britain and other industrialized countries, the main pollutants so formed being SULPHUR DIOXIDE, SMOKE, ASH, with smaller quantities of hydrogen chloride, hydrogen fluoride and silicon tetrafluoride. Sulphur dioxide is also produced by burning heavy fuel oils. Petroleum burning, producing mainly hydrocarbons which react with sunlight to form ozone, is an increasing source of pollution. Of increasing importance also, on both a local and world-wide scale, are the radioactive products of nuclear reactions.

Atmospheric pollution measurements have been made in Great Britain since 1914 at an expanding network of stations. Standardization of method has since been achieved by the Department of Industrial and Scientific Research, the measurements being made mainly by local authorities, government departments, nationalized and private industries. The standard measurements are of sulphur dioxide, smoke and deposited pollution (see DEPOSIT GAUGE). Measurement of radioactive pollution is mainly the responsibility of the Atomic Energy Authority.

Systematic variations of smoke and sulphur dioxide concentration are found on several time scales. Typical results for cities in Great Britain are:

(i) a daily variation, with primary minimum in early hours of morning, secondary minimum in mid-afternoon, and total daily range up to about 5 : 1 in winter months;

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* PERNTER, J. M. and EXNER, F. M.; Meteorologische Optik. 2nd edn., Wien und Leipzig, Wilhelm Braumüller, 1922.

† HUMPHREYS, W. J.; Physics of the air. 3rd edn., New York, McGraw-Hill Book Co., 1940.

‡ MINNAERT, M.; Light and colour in the open air. London, G. Bell and Sons Ltd., 1959.

(ii) week-end decrease of some 20 to 40 per cent;
(iii) winter to summer decrease of some 2 : 1 or 3 : 1;
(iv) a SECULAR TREND, irregular but negative at most places.

The smoke and sulphur dioxide output variations at source, combined with the systematic variations of such meteorological factors as temperature lapse rate and turbulence near the ground, wind velocity, and rainfall explain the nature of the daily and annual variations of concentration: the weekly variation and secular trend are explained by output variation alone.

The relatively large particles which comprise most of the ash which reaches the atmosphere soon fall to ground and so are little affected by meteorological conditions. The time variations of suspended or deposited ash are thus controlled almost entirely by output variations.

Superimposed on the systematic variations of smoke and sulphur dioxide concentration are large day-to-day changes, associated essentially with changes in the important meteorological factors: the change from winter minimum to winter SMOG concentration represents, for example, an increase of 1:20 or more.

Mathematical treatment by O. G. Sutton of the distribution of airborne gaseous pollution has shown (i) that maximum concentration is about four times greater, and occurs at a point about five times farther from source, in large-inversion compared with large-lapse conditions, (ii) that great benefit, in terms of maximum concentration at ground level from a given source, is derived in all lapse-rate conditions by increase of chimney height.

Concern for the physiological and financial damage wrought by atmospheric pollution has, since the first half of the 19th century, led to local and national legislation aimed at its mitigation. Among the methods adopted, so far on a limited scale only, are the more efficient use of solid fuel by appropriate design of fire or boiler and by skilled or automatic stoking, the replacement of coal by smokeless fuel, the use of grit arresters, the removal by washing of sulphur dioxide from flue gases, the use of high chimneys, and the control of pollution emission in cases of prolonged unfavourable meteorological conditions.

atmospheric pressure: See PRESSURE.

atmospherics: Electrical impulses of natural origin, mainly originating in LIGHTNING discharges, which cause crashing or grinding noises in a wireless receiver: the phenomenon is also termed 'static'. The impulses which originate within a radius of some thousands of miles reach a particular receiver on a multitude of paths suffering reflexions from the lower ionosphere and the earth's surface, and constitute a varying background noise-level in the receiver. Since the impulses decrease in strength with increasing distance from their place of origin, the noise-level is greatest in low latitudes where thunderstorms are most frequent.

While the phenomenon constitutes a serious difficulty in long-distance wireless transmission, it is used to advantage in geophysics in various ways: first, by suitable arrangement of apparatus, in the locating of thunderstorms; second, by examination of the wave-forms, in the study of the nature of lightning discharges; third, in the determination of diurnal and seasonal variations of thunderstorm activity; fourth, in the detection of sudden enhancements of atmospherics and thus of associated solar flares (see SEA).

The term 'sferics' is the accepted contraction of the word 'atmospherics' for meteorological purposes. See also SFERIC.

atmospheric tides: Effects directly analogous to the simple gravitational tides familiar in the oceans are produced in the atmosphere by the action of the moon, the elements chiefly involved being pressure and wind. The tides are most conveniently identified at the earth's surface from the pressure variations, which are positive or negative with respect to the mean pressure level according as the air is heaped up over, or drawn away from, a locality. Two pressure maxima (one at the longitude corresponding to that 'under' the tide-producing body and the other at the antipodal point) and two pressure minima (at longitudes 90° from the pressure maxima) occur at any given epoch. At any given place the effect is such as to produce a semi-diurnal oscillation. When the pressure data are arranged in lunar time, there emerges a systematic effect of 'correct' phase and very small amplitude (0·09 mb near the equator, decreasing towards either pole).

Despite the fact that the gravitational tidal action of the sun is smaller than that of the moon by the factor 2·4, the amplitude of the atmospheric oscillations which are governed by solar time is much the greater and is clearly visible on low-latitude barograms. This is ascribed to two causes, (i) solar heating of the atmosphere, and (ii) atmospheric RESONANCE. The heating produces a 24-hour component of equatorial amplitude of the order of 1 mb and is also responsible for about half the 12-hour component which is of rather larger total amplitude than the 24-hour component. These thermally produced oscillations are generally considered part of the atmospheric tides or 'tidal oscillations'. The remainder of the 12-hour component comprises a part which is governed by universal time ('stationary wave') and a part governed by local time ('travelling wave'), the latter being predominant in low and middle latitudes and the former in high latitudes. The stationary wave is thought to be due to disturbances introduced into the travelling wave by large-scale topographical features. The travelling wave itself is a gravitationally produced wave whose large magnitude relative to that produced by the moon is considered to be due to the existence of an atmospheric FREE PERIOD very close to 12 solar hours. Support is lent to this 'resonance theory' of the atmospheric oscillations by the fact that the semi-diurnal component of wind velocity has been found to change little in amplitude or phase in the troposphere and lower stratosphere, but is reversed in phase and greatly increased (some 100-fold) in amplitude at levels of 80–100 km, as required by the theory.

atmospheric window: A term applied to that region of the ABSORPTION spectrum of water vapour which extends from about 8·5 to 11 microns. Ground radiation in this range of wavelengths is, in contrast to ground radiation of other wavelengths, little absorbed by water vapour and, in the absence of cloud, escapes to space. See TERRESTRIAL RADIATION, GREENHOUSE EFFECT.

attached thermometer: A thermometer attached with its bulb within the metal tube surrounding a mercury BAROMETER. A reading of this thermometer is required in order that an appropriate 'temperature correction' may be applied to the barometer reading if the thermometer has a reading other than the STANDARD TEMPERATURE of the barometer.

In some marine barometers the attached thermometer is incorporated in the GOLD SLIDE.

attachment: In meteorological literature, often used with particular reference to the disappearance of free ELECTRONS by their attachment to neutral oxygen atoms or molecules, thus forming negative IONS. The rate of the process is expressed by an 'attachment coefficient' with dimensions L^3T^{-1}.

attenuation: In geophysics, the depletion of electromagnetic energy (e.g. solar radiation, or radio waves emitted from the earth's surface) which is effected by the earth's atmosphere and its constituents. The rate of attenuation is represented by the 'attenuation coefficient' σ, which includes the effects both of ABSORPTION and of SCATTERING of the radiation, and is defined for monochromatic radiation by the equation, analogous to Beer's law which applies to absorption only,

$$I = I_0 e^{-\sigma x}$$

where I_0 is the intensity of radiation emitted at the source (or incident on the top of the atmosphere in the case of solar radiation) and I is the intensity after path length x through the absorbing and scattering medium.

The extent to which the above law may be applied over the whole spectrum, or a substantial part of the spectrum, depends on the degree of variation of attenuation coefficient with wavelength.

See also EXTINCTION COEFFICIENT, TURBIDITY.

audibility: The audibility of a sound in the atmosphere may be measured by the distance from its source at which it remains just audible.

The extent to which the loudness of sound decreases with distance from source at a rate other than the 'theoretical' inverse square of distance law is determined by the structure of the atmosphere. The factors mainly involved are the vertical distribution of temperature and wind and probably also the degree of atmospheric

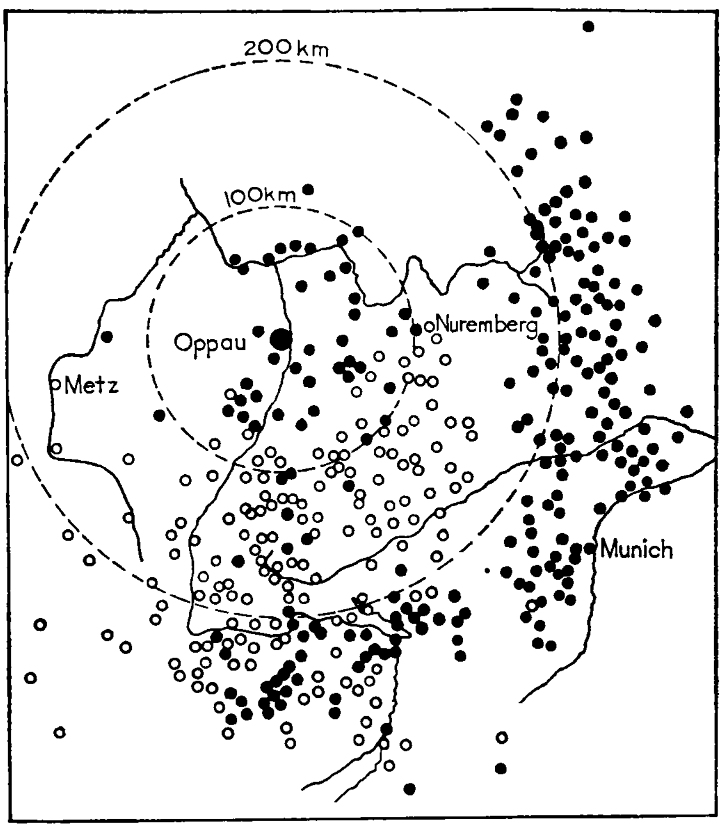

FIGURE 8—Audibility of the explosion on 21 September 1921 at Oppau, Germany. The circles represent observers who did not hear the explosion, while dots represent those who did.
(GOODY, R. M.; The physics of the stratosphere. Cambridge Monographs on Physics, Cambridge University Press, 1954).

turbulence. It is, in turn, possible to infer much about the height variations of temperature and wind in the atmosphere from observations of the space distribution of audibility and time of arrival of sound waves on occasions of natural or artificial explosions.

The REFRACTION of sound waves in a calm atmosphere is governed by the lapse rate of temperature. The waves are bent upwards in conditions of strong lapse, and audibility is correspondingly low: conversely, it is high during a surface inversion because of downward bending of the waves sufficient for them to return to ground. Audibility is greater downwind than upwind, especially when there is a rapid increase of wind with height. A turbulent atmosphere is considered to limit audibility because of the associated mass exchange in the vertical and the accompanying dissipation of the sound energy. Audibility is generally greater, sometimes by a factor of 10 or 20, by night than by day because the conditions required for great audibility are much more characteristic of night than of day. For the same reason great audibility is a prominent feature of polar latitudes.

The 'anomalous audibility' associated with the so-called ANOMALOUS SOUND PROPAGATION is produced not by low-level meteorological conditions but by those at high levels. This feature, observed with large explosions, is characterized by a 'zone of silence' beginning at a distance from the source greater than that reached by the surface-propagated wave, with an outer zone of audibility at still greater distances (see Figure 8). Typical distances from the source are 100 and 200 km, respectively: the zone boundaries may be approximate circles with the source as centre or may depart appreciably from this. The cause of the outer zone is the refraction of sound waves in the high atmosphere to an extent which is sufficient to bend them back to earth. Calculations made from observations of the distribution of audibility and the time of arrival of sound waves on occasions of large explosions show that the major cause of the refraction is a region of high atmospheric temperature at a height of some 50 km, and that the effect of the refraction caused by high-level winds is mainly to make the shapes of the zone boundaries less circular.

aureole: A luminous bluish-white area, of small angular radius, immediately surrounding the sun or moon and bounded by a brownish-red ring: see CORONA.

The term 'aureole' is also used by some authors for the bright area, with no definite boundary, seen round the sun when the latter is not veiled by thin cloud.

aurora: This term (Latin for 'dawn') is applied to the phenomenon in which visible light is emitted by the high atmosphere.

In the 'auroral zones' of maximum frequency, some 20° from the geomagnetic poles, aurora is visible on almost every clear night: the northern auroral zone lies just north of Norway, south of Iceland and Greenland, over northern Canada and north of Siberia. The estimated mean annual frequency of nights of visible aurora, but for the intervention of cloud, twilight and moonlight, is in northern Scotland about 150, in Southern England about 10: the corresponding frequencies of overhead displays are about 10 and 1, respectively. The terms 'aurora borealis' or 'northern lights' and 'aurora australis' or 'southern lights' apply, respectively, to the northern and southern hemispheres.

In Great Britain, aurora is usually seen near the northern horizon as a 'glow', or as a quiet 'arc', a grey-white feature with relatively sharp lower border. In a great display, during which the aurora may extend so far equatorwards as to be visible in the tropics, other auroral forms appear, with much movement and colour, of which the most characteristic are yellow-green and red. Greenish 'rays' may cover most of the sky polewards of the magnetic zenith, ending in an arc which is usually folded and sometimes with red lower border, the display then resembling a moving 'drapery'. If the display passes overhead, the parallel rays moving along the lines of force appear, by perspective, to converge at the magnetic zenith, thus producing a 'corona'. The later stages of a great display are usually marked by 'flaming', in which light surges upwards from the horizon. The display ends with a polewards recession of the auroral forms, the rays often then degenerating into diffuse surfaces of white light. Numerous reports of audible aurora and of aurora reaching almost to the ground in great displays are generally discredited.

The distribution of aurora in time and space has been determined by visual observation and by simultaneous photography from a number of stations. More recently, 'all-sky' automatic cameras and radio-echo equipment have also been used. The observations have shown that aurora is most frequent (in places equatorwards of the auroral zone) towards midnight and near the equinoxes, that auroral

PLATE 1 Auroral corona: Perthshire.

PLATE 2 Auroral rays, Inverness-shire.

[*To face page* 30

PLATE 3 Arctic sea smoke.

PLATE 4 Banner cloud over the Matterhorn.

processes occur also during the day, and that auroral light originates at heights varying between 70 and 1000 km, with a marked peak frequency at about 100 km.

In spectral measurement of auroral light, molecular and atomic nitrogen and oxygen (atmospheric) and atomic hydrogen lines are the chief of those identified: the hydrogen line is subject to Doppler shift (see DOPPLER EFFECT) towards shorter wavelengths, implying the entry of high-speed protons into the atmosphere. The characteristic yellow-green and red colours are atomic oxygen emission lines at 5577 Å and 6300 Å, respectively. The latter is emitted at higher levels; when red coloration appears at low levels, the emission is in a band of molecular nitrogen.

Aurora, like geomagnetic disturbance with which it is very closely associated, is caused by the entry into the high atmosphere of a stream of charged solar particles which are deflected by the earth's permanent magnetic field and precipitate over limited regions of the atmosphere. The various auroral forms arise from the primary and secondary collision processes of the solar particles with atmospheric gases and free electrons, and probably also in part from electric discharge processes which result from the generation of powerful electric fields in the high atmosphere.

See Plates 1 and 2: see also GEOMAGNETISM.

austausch: A German term signifying the mixing and exchange implicit in atmospheric TURBULENCE. The term 'austausch coefficient' is an alternative for EXCHANGE COEFFICIENT.

autobarotropy: The (idealized) atmospheric state in which surfaces of constant pressure and density (or specific volume) remain always in coincidence. See BAROTROPIC.

autoconvective lapse rate: That temperature LAPSE rate which defines a state of constant atmospheric density with height: for lapse rates in excess of this the density increases with height. The lapse rate is given by the expression g/R, where g is the acceleration of gravity and R is the gas constant for air, and has the value 3·42°C/100 m, i.e. about 3½ times that of the dry adiabatic lapse rate. Lapse rates well in excess of the autoconvective lapse rate have been observed near the earth's surface (approximately the lowest 50 feet) during intense INSOLATION.

The implication contained in the term that this lapse rate represents critical conditions for the 'automatic' establishment of convection is erroneous. Because ascending air cools on expansion, the critical condition is not one of increasing density with height, as in an incompressible fluid, but a lapse rate in excess of the adiabatic lapse rate. See ADIABATIC.

autocorrelation: Autocorrelation, also termed 'serial correlation', signifies CORRELATION within a series of observations often spaced at equal intervals of time. The measure of internal correlation—the 'autocorrelation coefficient' or 'serial correlation coefficient'—is often employed as a measure of the degree of PERSISTENCE within geophysical TIME SERIES: such coefficients, evaluated for various interval lags, may also be combined in the CORRELOGRAM as a means of testing for PERIODICITY.

The autocorrelation coefficient for a lag of L intervals of time is given by

$$r_L = \frac{\sum_{i=1}^{i=N-L} (x_i\, x_{i+L})}{(N-L)\sigma_x^2}$$

where x_i, x_{i+L} are departures from the mean of the series of N observations and σ_x is the STANDARD DEVIATION of the series.

The autocorrelation coefficient for successive daily values of pressure and temperature at places in the British Isles is about 0·8.

automatic station: A STATION, situated generally in an isolated location, at which observations of meteorological elements are made, and from which the observations are transmitted, by automatic methods which require no permanent staff for their operation.

autumn: See SEASONS.

avalanche wind: An avalanche often causes, in advance and at the sides of the descending mass of snow or ice, a very high wind capable of causing destruction at some distance from the avalanche itself. It is known as the 'avalanche wind' or 'avalanche blast'.

average: An alternative for arithmetic MEAN.

aviation forecast: A meteorological forecast issued for the purpose of aviation, generally covering conditions over a specific route and at a terminal or terminals.

The main elements included are the clouds (type, base, thickness), visibility, upper level winds, surface winds at terminals, precipitation, freezing-level, icing and turbulence risks.

Avogadro's law: At normal temperature and pressure the weight of any gas in grams which is numerically equal to its MOLECULAR WEIGHT occupies 22·4 litres. The law implies that equal volumes of gases, under the same conditions of temperature and pressure, contain the same number of molecules.

Application of this law allows of ready conversion from mass concentration or density (e.g. mg/m^3) of a particular gas in a mixture of gases to FRACTIONAL VOLUME ABUNDANCE (e.g. parts per million) of the gas, or vice versa. Thus, for CO_2 (molecular weight $12 + 32 = 44$) the relationship is $1 \, mg/m^3 = 0{\cdot}51$ ppm.

Avogadro's number: The number (N) of molecules per MOLE of a gas, equal to $6{\cdot}0247 \times 10^{23}$. See also AVOGADRO'S LAW.

azimuth: The azimuth of an object is the horizontal angle between the observer's MERIDIAN and the line joining observer and object. It is normally measured in degrees (0°–360°) clockwise from true (geographic) north.

Azores anticyclone: Part of the subtropical high-pressure belt of the northern hemisphere. On mean surface-pressure charts the anticyclone in summer has a central pressure of about 1027 mb in about 35° N, with the axis of a ridge extending across northern France and northern Germany: in winter the central pressure is about 1024 mb in about 30° N, with the axis of the ridge then lying across southern Spain.

B

Babinet's point—See ARAGO'S POINT.

Babinet's principle: The DIFFRACTION produced by a drop, for example a drop in a water cloud, is the same as that produced by a small aperture in a screen.

back-bent occlusion: A front which is formed in the rear quadrant of a depression and which is attributed to the air-mass contrast originally developed at the OCCLUSION. As the low-pressure centre moves along the occlusion (usually eastwards) the line of air-mass contrast moves south-eastwards behind the centre as a back-bent occlusion. Secondary cold fronts also appear in the rear quadrant of depressions and do not necessarily arise from back-bent occlusions.

backing: The changing of the wind in an anticlockwise direction, in either hemisphere.

baguio: A local name by which the TROPICAL CYCLONES experienced in the Philippine Islands are known. A number of the cyclones or typhoons of the western Pacific cross the Philippines: in addition, there is a class of cyclone which is especially associated with these islands, occurring from July to November.

ballistics: The science of gunnery. Range tables for ordnance are constructed on the assumption that certain meteorological conditions—those of a hypothetical 'standard ballistic atmosphere' and no wind—are applicable. In actual firings, variations from these conditions will occur and corrections must be applied when laying the gun, or the shell will not hit the desired target. The application of meteorology to gunnery came into great importance during the First World War and a specialized branch of the subject grew out of the requirements of artillery units for upper air data. Methods for computing EQUIVALENT CONSTANT WIND and BALLISTIC TEMPERATURE are now in common use at army meteorological stations.

ballistic temperature: A temperature computed for the purposes of BALLISTICS from a knowledge of the actual temperature distribution in the atmosphere. The temperature is such that if it were a surface temperature and the lapse rate had the value assigned in the 'standard ballistic atmosphere', the effect on the motion of a shell would be the same as that of the observed temperature distribution.

ballistic wind: An average wind computed for the purposes of BALLISTICS. It is that wind, constant in speed and direction, which would produce the same displacement of a shell in flight as would the actual winds, varying with height, met by the shell.

ball lightning: A rare form of LIGHTNING in which a persistent and moving luminous white or coloured sphere is seen: the explanation and even the existence of this form of lightning are yet controversial.

Reports of the sphere dimensions vary from a few centimetres to about a metre but are most commonly from 10 to 20 cm. Duration varies from a few seconds to several minutes. Many reported cases follow a brilliant lightning flash and may be physiological in nature (after-image): other reported cases have, however, occurred without a preceding flash. Sometimes more than one sphere is seen by an observer, or a sphere is reported in the same locality by various observers. The speed of travel is generally about a walking pace. Spheres have been reported to vanish harmlessly, to bounce from the ground or an obstruction, to pass into or out of rooms leaving, in some cases, sign of their passage as, for example, a hole in a window pane.

balloon sounding: Exploration of the earth's atmosphere by means of a balloon inflated with a gas lighter than air (hydrogen or helium). Such a balloon may be uninstrumented and is then followed by theodolite (PILOT BALLOON), or by radar (RADAR WIND); or it may carry automatic instruments (RADIOSONDE). The maximum altitude attained by a balloon depends on its FREE LIFT. Radiosonde balloons generally reach from 18 to 30 km (about 60,000 to 100,000 ft).

Very large balloons carrying considerable equipment loads are used on occasion for geophysical research, e.g. in cosmic rays. Others carry a special device so that they may remain for a considerable period at a predetermined level ('constant-level balloon'). Others are used for launching small rockets—see ROCKOON. Early research balloons were manned, with corresponding limitation in height attained: among the early ascents made for meteorological purposes were those by J. Welsh in 1852 and by J. Glaisher between 1862 and 1866. Captive balloons are sometimes used to obtain meteorological data in the lower atmosphere.

BALTHUM: An indicator word for a special report, in figure code, of wind and temperature observed from a tethered kite-balloon. See 'Handbook of weather messages'.*

banner cloud: A stationary cloud attached to, and extending downwind from, an isolated mountain peak, the cloud appearance being one of an extended flag. The requirements are an isolated sharp peak, strong wind and relatively moist air. Among well known examples of the cloud are those associated with Mount Everest and the Matterhorn.

The physical explanation normally advanced for the cloud formation is the lifting of air in a lee eddy from a lower level than on the windward side. An aerodynamic pressure reduction in the lee of the peak may contribute to the cloud formation in a manner analogous to the formation of aircraft wing-tip CONDENSATION TRAILS. See Plate 4.

bar: The unit of atmospheric pressure, also termed 'hectopieze', equal to the pressure of 29·530 in. or 750·062 mm of mercury under the standard conditions of temperature 0°C (density of mercury 13·5951 gm/cm^3) and acceleration of gravity 980·665 cm/sec^2.

$$1 \text{ bar} = 10^3 \text{ MILLIBARS} = 10^6 \text{ DYNES/cm}^2$$

See STANDARD DENSITY, STANDARD GRAVITY.

barat: A strong, north-westerly squall on the north coast of the island of Celebes, most frequent from December to February.

BARATIC: In weather messages, a code word indicating that the positions of surface pressure and frontal systems and of key isobars—the results of surface chart analysis—follow in figure code. See 'Handbook of weather messages'.†

* London, Meteorological Office; Handbook of weather messages. Part II. London, HMSO, 1959.

† London, Metereological Office; Handbook of weather messages. Part III. London, HMSO, 1959.

barber: A little-used alternative for ARCTIC SEA SMOKE.

baroclinic: A baroclinic atmosphere is one in which surfaces of pressure and density (or specific volume) intersect at some level or levels. The atmosphere is always, to some extent, baroclinic. Strong baroclinicity implies the presence of large horizontal temperature gradients and thus of strong THERMAL WINDS.

baroclinic instability: A type of dynamic instability, associated with a strongly BAROCLINIC region of the atmosphere, which is considered to be responsible for at least part of the development of wave disturbances within the strong westerly wind flow which frequently occurs in middle and high latitudes. Growth of the disturbances is characterized by ascent of the warmer, and descent of the colder, air masses, representing a decrease of potential energy and an associated release of kinetic energy. Theory indicates that the degree of instability of the disturbances depends, among other factors, on their wavelength.

baroclinic wave: A wave depression which forms in a strongly BAROCLINIC region of the atmosphere. BAROCLINIC INSTABILITY is important in the intensification of such waves.

barogram: The record made by a BAROGRAPH.

barograph: A recording BAROMETER. That in common use is essentially an ANEROID BAROMETER which is arranged to give continuous recording. Those used by the Meteorological Office are known as the 'open scale' and the 'small pattern', which differ in the type of aneroid element and lever mechanism used. In ship barographs, use is made of such devices as an increase of lag coefficient and anti-vibration mounting.

Two non-portable types of barograph, used at some observatories, are the 'float barograph', in which the movements of the mercury in a barometer are communicated to a recording pen by means of a float; and the 'photobarograph', in which the position of the mercury meniscus is recorded photographically.

barometer: An instrument for measuring atmospheric pressure. The mercury barometer, for example the FORTIN BAROMETER or the KEW-PATTERN BAROMETER, is the most satisfactory for general use. In this instrument the height of the mercury column in a glass tube, one end closed and uppermost, above the level of mercury in an open vessel (cistern) in which the open end of the tube is immersed, is used as a measure of atmospheric pressure. Barometer 'corrections' must be applied to take account of differences of mercury and scale temperature and of local GRAVITY from the 'standard' values assumed in the calibration of the instrument. See also STANDARD DENSITY, STANDARD GRAVITY, STANDARD TEMPERATURE.

A non-mercury type of barometer in common use is the ANEROID BAROMETER.

barometric characteristic: In synoptic meteorology, an observation of the shape of the BAROGRAPH trace during the three hours prior to the observation. Such observations are plotted on synoptic charts in internationally agreed symbols which simulate the general form of the barograph trace.

barometric tendency: In synoptic meteorology, an observation of the barometric change during a specified period (usually three hours) prior to the observation. Such observations, plotted on synoptic charts, are the basis on which ISALLOBARS are drawn.

barothermograph: An instrument which records temperature and pressure simultaneously, two pens being used to record separate traces of temperature and pressure.

The term has also been loosely used in connexion with the obsolete Dines METEOROGRAPH in which temperature was recorded as a function of pressure: in this instrument the recording pen was made to move in one direction by a change of pressure, and in a direction almost at right angles by a change of temperature.

barotropic: A barotropic atmosphere is that hypothetical atmosphere in which surfaces of pressure and density (or specific volume) coincide at all levels. The concept of barotropy, though idealized, gives a useful first approximation in some types of atmospheric problem. The contrasting atmospheric state is the BAROCLINIC.

barotropic wave: A wave-like disturbance in a BAROTROPIC atmosphere. Since such an atmosphere is likely to be approximately non-divergent, the concept of barotropic waves has been applied at about 600 mb (so-called 'level of non-divergence'). Forecasting of the movement of such waves is based on the conservation of absolute VORTICITY by individual air particles. The same principle is applied in respect of LONG WAVES (or Rossby waves) which are essentially barotropic waves in air flow of relatively uniform speed.

barye: The unit of pressure in the c.g.s. system of units, being equal to 1 dyne/cm^2: it is often termed a microbar.

$$1 \text{ barye} = 10^{-3} \text{ MILLIBAR} = 10^{-6} \text{ BAR}$$

BBBBB: In weather messages, the indicator for a report, in figure code, of a sudden improvement in meteorological conditions observed at the surface. See 'Handbook of weather messages'.*

beaded lightning: An alternative for PEARL-NECKLACE LIGHTNING.

bearing: The true (geographic) bearing of an object is synonymous with its AZIMUTH. Magnetic bearing is the corresponding angle measured clockwise from magnetic north. Approximate bearings may be named as the compass points, N, NE, etc.

Beaufort notation: A code of letters indicating the state of the weather, past or present. The code was originally introduced by Admiral Beaufort for use at sea but is equally convenient for use on land. Additions have been made to the original schedule. A phenomenon of moderate intensity is indicated by the corresponding small letter: if of slight intensity the suffix $_0$ is added, if of great intensity a capital letter is used. Continuity is indicated by repetition of the letter, intermittency by prefixing the letter i, and showers by prefixing the letter p. Thus, for example, ir_0 denotes intermittent slight rain, and pS heavy snow shower. See 'Observer's handbook'.†

Beaufort scale: Wind force is estimated on a numerical scale ranging from 0, calm, to 12, hurricane, first adopted by Admiral Beaufort. The specification of the steps of the scale originally given had reference to a man-of-war of the period 1800–50

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* London, Meteorological Office; Handbook of weather messages. Parts II and III. London, HMSO, 1959.

† London, Meteorological Office; Observer's handbook. 2nd edn., London, HMSO, 1956, p. 58.

and therefore now possesses little more than historic interest. The descriptions of the various scale numbers are: 0, calm; 1, light air; 2 to 6, light, gentle, moderate, fresh, and strong breeze, respectively; 7 to 9, near gale, gale, and strong gale, respectively; 10 and 11, storm and violent storm, respectively; 12, hurricane.

Details of the Beaufort scale are contained in Table II. The velocity equivalents are based on the empirical relationship between estimated number and measured velocity, $V = 1{\cdot}87\sqrt{B^3}$, where V is in miles per hour, and B is the corresponding Beaufort number. The pressure equivalents are derived from the formula $p = 0{\cdot}003 V^2$, where p is in pounds per square foot and V is in miles per hour.

Beer's law: See ABSORPTION.

Bénard cell: When a fluid is carefully heated from below or cooled from above in the laboratory, a cellular pattern of CONVECTION may be established in which the motion in the centres of the cells (upward or downward) is opposed to that on the periphery. Such cells are known as Bénard cells. There is some evidence that such cells develop at times in layered cloud after dusk by radiative cooling at the cloud top.

Bergeron (–Findeisen) theory: That theory which attributes the initiation of precipitation from a cloud to the presence of ice crystals among predominantly supercooled water droplets. See PRECIPITATION.

berg wind: A local name for the offshore FÖHN-type wind in the east of South Africa.

Bermuda anticyclone: That cell of the semi-permanent subtropical high-pressure belt which is frequently centred near Bermuda in the western part of the Northern Atlantic Ocean.

Bernoulli's theorem: In an inviscid fluid in steady motion the sum per unit mass of the kinetic energy ($v^2/2$), the potential energy possessed by virtue of being in a pressure field (p/ρ), and the gravitational potential energy (gz) is constant:

$$v^2/2 + p/\rho + gz = \text{constant.}$$

Here v is fluid velocity, p pressure, ρ density, g acceleration of gravity, and z height above a selected reference level.

beta (or β) particle: A swiftly-moving ELECTRON emitted spontaneously by certain radioactive elements. Beta particles have moderate penetrative power amounting to some yards in air near ground level: their emission by radioactive materials in the ground contributes significantly (about one-fifth) to the total IONIZATION of air at low levels, over land. See also ALPHA PARTICLE, GAMMA RADIATION.

bi-directional vane (or bivane): An instrument comprising two sensitive vanes of similar characteristics, free to turn about vertical and horizontal axes, respectively. The instrument is used, with direct pen or with electrical recording, to indicate simultaneous variations of the horizontal and vertical components of the wind in low-level turbulence measurements. See Geophysical Memoirs No. 65.*

billow clouds: Parallel rolls of cloud, separated by relatively narrow, clear spaces. The phenomenon has been explained in various ways: as waves formed at a surface of discontinuity; as convection cells initiated by shearing motion at an almost horizontal boundary between two airstreams; by cellular motion initiated by the development of static instability in a shallow layer of air.

The term is often loosely applied to clouds of the variety UNDULATUS.

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* BEST, A. C.; Transfer of heat and momentum in the lowest layers of the atmosphere. *Geophys. Mem., London*, 7, No. 65, 1935.

TABLE II—*Specification of the Beaufort scale with equivalents of the numbers of the scale*

Beaufort number	Specification of Beaufort scale for use on land, based on observations made at land stations	Mean pressure (at standard density) on a disk of 1 ft²		Equivalent speed at 33 ft		Limits of speed At 10 m (33 ft) in the open		
		mb	*lb/ft²*	*kt*	*mph*	*kt*	*mph*	*m/sec*
0	Calm; smoke rises vertically	0	0	0	0	<1	<1	0–0·2
1	Direction of wind shown by smoke drift, but not by wind vanes	0·01	0·01	2	2	1–3	1–3	0·3–1·5
2	Wind felt on face; leaves rustle; ordinary vane moved by wind	0·04	0·08	5	5	4–6	4–7	1·6–3·3
3	Leaves and small twigs in constant motion; wind extends light flag	0·13	0·28	9	10	7–10	8–12	3·4–5·4
4	Raises dust and loose paper; small branches are moved	0·32	0·67	13	15	11–16	13–18	5·5–7·9
5	Small trees in leaf begin to sway; crested wavelets form on inland waters	0·62	1·31	19	21	17–21	19–24	8·0–10·7
6	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty	1·1	2·3	24	28	22–27	25–31	10·8–13·8
7	Whole trees in motion; inconvenience felt when walking against wind	1·7	3·6	30	35	28–33	32–38	13·9–17·1
8	Breaks twigs off trees; generally impedes progress	2·6	5·4	37	42	34–40	39–46	17·2–20·7
9	Slight structural damage occurs (chimney pots and slates removed	3·7	7·7	44	50	41–47	47–54	20·8–24·4
10	Seldom experienced inland; trees uprooted; considerable structural damage occurs	5·0	10·5	52	59	48–55	55–63	24·5–28·4
11	Very rarely experienced; accompanied by widespread damage ...	6·7	14·0	60	68	56–63	64–72	28·5–32·6
12	... ...	>8·1	>17·0	68	78	>64	>73	>32·7

* The pressure due to the wind on any object exposed to it arises from the impact of the air on the windward side and suction on the leeward side; the mean pressure depends on the shape and size of the object. The values given are for a disk of 1 ft² in area but they apply with fair approximation for circular or square plates from 1 ft² to 100 ft² in area.

1 mb = 10^3 dyne/cm² = approx. 10 kg/m².

bimetallic thermograph: A THERMOGRAPH in which the sensitive element is a curved strip formed by welding together two metals differing in their coefficients of expansion. The changes of curvature undergone by the strip with changes of temperature are used to actuate a recording pen through a lever mechanism.

bioclimatology: The study of climate in relation to life and health.

biosphere: That part of the earth's envelope, comprising the seas, lower atmosphere and surface layer of the earth's crust, in which living organisms exist in their natural state.

bise: A cold, dry wind which blows in the winter in the mountainous regions of southern France from the north, north-east or north-west. The cold, north-west wind which occurs in Languedoc, near the Mediterranean coast, differs from the MISTRAL in that it is accompanied by heavy clouds and has been given the name '*bise noire*'.

Bishop's ring: A dull reddish-brown ring which is seen round the sun in a clear sky. In the middle of the day the inner radius of the ring is about 10°, the outer 20°: when the sun is low the ring is larger. Bishop's ring was first seen after the great eruption of Krakatoa in 1883 and remained visible till the spring of 1886. It was also seen after the eruptions of Soufrière in St. Vincent and Mt. Pelée in Martinique in 1902, after the north Siberian meteorite in 1908, and at the time of nearest approach to the earth of Halley's comet on 18 and 19 May 1910. The phenomenon is attributed to DIFFRACTION associated with fine dust in the high atmosphere.

black-body radiation: See RADIATION.

black-bulb thermometer: A mercurial maximum thermometer with blackened bulb, mounted in an evacuated outer glass sheath and exposed horizontally to the sun's rays for the purpose of ascertaining the maximum temperature 'in the sun'. On account of the difficulty of obtaining comparable results with different instruments and of interpreting the indications of an individual instrument, black-bulb thermometers are not now recommended as a means of measuring solar radiation. Such measurements are carried out with a PYRHELIOMETER.

black frost: A condition in which the temperature of the ground cools to a sub-freezing temperature but does not reach a value so low as the FROST-POINT of the adjacent air. There is then no deposit of HOAR FROST on the ground or on terrestrial objects which thus remain black in appearance. The phenomenon is associated with relatively dry air.

black ice: A popular alternative for GLAZED FROST, often used with reference to its occurrence on road surfaces. A thin sheet of ice, relatively dark in appearance, may be formed when light rain or drizzle falls on a road surface which is at a temperature below 0°C. It may also be formed on such a surface when supercooled fog droplets are intercepted by, and fall from, bridges or trees.

blizzard: A term originally applied to the intensely cold north-westerly gales accompanied by fine, drifting snow which may set in with the passage of a depression across the United States in winter. The term has come to be applied to any high wind accompanied by great cold and drifting or falling snow.

blocking: The term applied in middle latitude synoptic meteorology to the situation in which there is interruption of the normal eastward movement of depressions, troughs, anticyclones and ridges for at least a few days.

A blocking situation is dominated by an anticyclone whose circulation extends to the high troposphere. The ZONAL CIRCULATION to the west is transformed into MERIDIONAL CIRCULATIONS branching polewards and equatorwards. For Europe and the North Atlantic the longitude most favoured for blocking is about 10° W. Over this region the percentage frequency of days of blocking situation has a maximum in April and minimum in August.

blood-rain: Rain of a red colour which leaves a red stain on the ground. The coloration is due to dust particles contained by the drops: the particles are carried from a sandy region by upper air winds, sometimes for long distances. The phenomenon has been observed frequently in Italy, for example, but has also been known to occur in the British Isles.†

blowing dust or sand: 'Dust or sand, raised by the wind to moderate heights above the ground. The horizontal visibility at eye level is sensibly reduced'.‡

blue moon, sun—A rare phenomenon in which more intense particle SCATTERING of red light than of blue light makes the directly viewed luminary appear blue (or green).

A conspicuous event of this kind occurred in the British Isles on 26 September 1950 and was due to scattering by smoke particles which originated in earlier forest fires in Alberta, Canada. The smoke was shown by aircraft reconnaissance to be between about 30,000 and 40,000 feet. Application of scattering theory to the differential extinction of light measured in different parts of the visible spectrum indicated that the predominant radius of the scattering particles was about 0·5 microns (5×10^{-5} cm).

blue of the sky: The blue of the sky is caused by the SCATTERING of sunlight by the individual molecules of the air—so-called RAYLEIGH SCATTERING. For such small particles, Rayleigh showed that the proportion of scattered light is greater for shorter than for longer wavelengths (inversely proportional to the fourth power of the wavelength). Thus the light which reaches the observer after scattering is rich in the short blue and violet waves (to the latter of which the eye is the less sensitive); while the light reaching the observer directly is deficient in the short waves—hence the yellow or red disk of the sun.

The light scattered by dust particles suspended in the air has no wavelength dependence. Such particles therefore introduce a white tinge to the blue sky to a degree which increases with the dust concentration. Thus, for example, the sky is of a deeper blue in polar than in anticyclonic air, and also as seen from a mountain top compared with from a low level.

boiling-point: That temperature at which, under conditions of equilibrium between a plane surface of a liquid and its overlying vapour, the existing (saturation) VAPOUR PRESSURE is equal to the external pressure. The variation of the boiling-point of water with external pressure is given under HYPSOMETER.

bolide: The name applied to a METEOR so large as to cause an explosion on being destroyed in the atmosphere.

bologram: The record of a BOLOMETER.

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* MILL, H. R.; The Cornish dust-fall of January 1902. *Quart. J.R. met. Soc., London*, **28**, 1902, p. 229.

† MILL, H. R. and LEMPFERT, R. G. K.; The great dust-fall of February 1903, and its origin. *Quart J. R. met. Soc., London*, **30**, 1904, p. 57.

‡ Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 71.

bolometer: An instrument for the determination of the intensity of RADIATION, employing a blackened conductor whose change of resistance with temperature gives a measure of the quantity required. The instrument is often employed in the investigation of the distribution of energy in the spectrum, especially in the infra-red region: it is then called a 'spectrobolometer'.

Boltzmann's constant: The universal constant (k) given by the ratio R^*/N where R^* is the universal GAS CONSTANT and N is AVOGADRO'S NUMBER.

k has the value $1{\cdot}3804 \times 10^{-16}$ erg/° K and appears in equations involving the expression of energy in terms of temperature.

bora: A cold, often very dry, north-easterly wind which blows, sometimes in violent gusts, down from the mountains on the eastern shore of the Adriatic. Strongest and most frequent in winter and on the northern part of the shore, it occurs when pressure is high over central Europe and the Balkans and low over the Mediterranean. If associated with a depression over the Adriatic it is accompanied by heavy cloud and rain or snow. The term is also applied to cold, squally, downslope winds in other parts of the world.

boreal climate: In W. Köppen's classification, a CLIMATE characterized by a snowy winter and warm summer, with a large annual range of temperature, such as obtains over the European, Asian and American continents between about latitudes 60° N and 40° N.

Bouguer's halo: A rare type of HALO, white in colour and centred on the ANTISOLAR POINT with an inner radius of about 35° (also called ULLOA'S CIRCLE).

Bouguer's law: See ABSORPTION.

boundary layer: That layer of a fluid adjacent to a physical boundary in which the fluid motion is much affected by the boundary and has a mean velocity less than the free-stream value. In the 'surface boundary layer' of the atmosphere, of depth up to about 100 metres, the motion is controlled predominantly by the presence of the earth's surface, while within an overlying layer ('planetary boundary layer') with top at about 600 metres, effects on air motion by the boundary remain significant. See also FRICTION LAYER.

Bourdon tube: A curved tube of elliptical cross-section, in which changes of volume cause changes of curvature; these are used to actuate a pointer or recording pen. It may be used as a barometer or pressure gauge, being evacuated and responding to variations of external pressure; or it, for example, may be connected to a steel thermometer bulb, when it responds to variations in the volume of the mercury which fills the bulb, the connecting capillary tubing and the Bourdon tube.

Bowen ratio: The ratio (R) of the amount of sensible heat to that of latent heat (see HEAT) lost by a surface to the atmosphere by the processes of conduction and turbulence.

Even over water surfaces, very variable values of R are found (including negative values, which signify sensible heat transfer from atmosphere to surface). An average value of about $+0{\cdot}1$ is considered to hold for oceans, implying that 90 per cent of the heat energy received by oceans is used in evaporation.

Boyle's law: At constant temperature, the volume of a given mass of gas (or the SPECIFIC VOLUME) is inversely proportional to the pressure on the gas.

Boys's camera: A special type of camera first introduced by Sir Charles Boys for the study of LIGHTNING. Originally, two lenses were rapidly rotated at opposite ends of a diameter of a circle and gave two distorted photographs of a flash of lightning. From these the direction of the discharge and its velocity of travel could be calculated. A later development was to have the lenses fixed and the film mounted on a large and rapidly rotating drum.

brave west winds: A nautical expression denoting the prevailing westerly winds of temperate latitudes. The region of strong westerly winds of the southern hemisphere (latitudes 40° S to 50° S) is termed the ROARING FORTIES.

breakaway depression: A term applied to a WARM-FRONT WAVE or WARM-OCCLUSION DEPRESSION because of the tendency of such secondary depressions to move eastwards away from the parent depression after formation.

breeze: A wind of moderate strength. (See BEAUFORT SCALE.) The word is generally applied to winds, caused by convection, which occur regularly during the day or night: they include LAND- AND SEA-BREEZES, MOUNTAIN BREEZE, VALLEY BREEZE, GLACIER WIND.

Brewster's point: See ARAGO'S POINT.

briefing, meteorological: Oral explanation by a meteorologist of existing and expected meteorological conditions.

bright bands: In meteorological literature, usually refers to quasi-horizontal regions of enhanced reflexion obtained in radar scanning of a precipitation belt in the vertical plane. The most conspicuous of the bright bands is that associated with the melting of snowflakes (see MELTING BAND). Other bright bands which occasionally appear at higher levels are thought to mark regions of appreciable changes of size or shape of solid precipitation elements. They have been ascribed, for example, to 'precipitation streaks', the shapes of which are changed by vertical wind shear as they are moved through the radar beam by the wind. See also RADAR METEOROLOGY.

British Rainfall Organization: This term was first used after the death of G. J. Symons in 1900 to describe the voluntary organization of rainfall observers which he had built up since about 1860. In 1919 the work of the Organization was transferred to the Meteorological Office. The term continued in use on the title-page of *British Rainfall* and elsewhere for several decades but is now (since about 1958) no longer used.

British summer time (BST): The standard of time in common use and that to which all legal and business transactions are referred in the the British Isles during a period in summer which is defined by the Summer Time Act, 1925. British summer time is one hour in advance of Greenwich mean civil time, so that 9h GMT is the same as 10h BST.

Summer time was first introduced in 1916. From 1916 to 1925 the periods during which summer time was in operation were fixed year by year by Orders in Council and are shown in Table III.

From 1926 to 1938 the period of summer time in Great Britain, Northern Ireland, the Channel Isles and the Isle of Man began at 2h GMT on the morning of the day next following the third Saturday in April (or, if that day was Easter

Day, the day next following the second Saturday in April) and ended at 2h GMT (3h BST) on the morning of the day next following the first Saturday in October.

From 1939 the periods during which summer time was in operation were again fixed year by year, and summer time was kept continuously in operation from 25 February 1940 to 7 October 1945. Double summer time was first introduced in 1941 and the periods when the clocks were kept two hours ahead of Greenwich mean time were fixed year by year.

TABLE III—*Periods during which summer time was in operation*, 1916–25

	1916	1917	1918	1919	1920
From ...	21 May	8 Apr.	24 Mar.	30 Mar.	28 Mar.
To ...	1 Oct.	17 Sept.	30 Sept.	29 Sept.	25 Oct.
	1921	**1922**	**1923**	**1924**	**1925**
From ...	3 Apr.	26 Mar.	22 Apr.	13 Apr.	19 Apr.
To ...	3 Oct.	8 Oct.	16 Sept.	21 Sept.	4 Oct.

The times when summer time and double summer time (marked with an asterisk) began and ended are shown in Table IV.

TABLE IV *Periods during which summer time was in operation*, 1939–61

	1939	1940	1941	1942	1943	1944	1945	1946
From	16 Apr.	25 Feb.	4 May*	5 Apr.*	4 Apr.*	2 Apr.*	2 Apr.*	14 Apr.
To ...	19 Nov.	—	10 Aug.*	9 Aug.*	15 Aug.*	17 Sept.*	15 July*	6 Oct.

	1947	1948	1949	1950	1951	1952	1953
From	16 Mar., 13 Apr.*	14 Mar.	3 Apr.	16 Apr.	15 Apr.	20 Apr.	19 Apr.
To ...	10 Aug.*, 2 Nov.	31 Oct.	30 Oct.	22 Oct.	21 Oct.	26 Oct.	4 Oct.

	1954	1955	1956	1957	1958	1959	1960	1961
From	11 Apr.	17 Apr.	22 Apr.	14 Apr.	20 Apr.	19 Apr.	10 Apr.	26 Mar.
To ...	3 Oct.	2 Oct.	27 Oct.	6 Oct.	5 Oct.	4 Oct.	2 Oct.	29 Oct.

* double summer time

In order that the statistics for the diurnal variation of meteorological phenomena may not be affected by the introduction of the disturbing effect of summer time, and to facilitate the international exchange of information, meteorological observations are normally made at fixed hours by GMT throughout the year.

British thermal unit: A unit of energy, defined as the heat required to raise the temperature of one pound of water by 1°F.

1 BThU = 252·1 CALORIES
= 1055 JOULES.

Brocken spectre: When an observer stands on a hill partially enveloped in mist and in such a position that his shadow is thrown on to the mist he may get the illusion that the shadow is a person seen dimly through the mist. The illusion that this person or 'spectre' is at a considerable distance is accompanied by the illusion that he is gigantic. The Brocken is a mountain in Germany. See GLORY.

Brückner cycle: A recurrence in north-western Europe of periods of cold and damp alternating with warm and dry years, the average interval between successive maxima being 34·8 years (as calculated by E. Brückner in 1890), though individual cycles vary from 25 to 50 years. Periodicities of about this length have since been claimed in other meteorological data. The statistical reality of this periodicity is not universally accepted: the amplitude is in any case too small to be useful for weather prediction purposes.

brush discharge: Discharge of electricity from sharp points on a conductor. See ST. ELMO'S FIRE.

Buchan spells: A total of nine periods during the year which were advanced by Alexander Buchan (1867), on the basis of some 50 years' observations, as constituting fairly reliable periods of unseasonal cold (six cases) or warmth (three cases) in south-east Scotland. The periods were: cold, 7–14 February, 11–14 April, 9–14 May, 29 June–4 July, 6–11 August and 6–13 November; warm, 12–15 July, 12–15 August, 3–14 December.

While evidence has since been advanced in support of similar spells in other parts of Europe, the reality of the spells as statistically significant features has also since been disputed. The reliability of the spells is certainly too small to permit of their direct application in long-range weather forecasting.

bumpiness: A condition of the atmosphere characterized by rapid variations, including generally alterations of sign, of the vertical component of velocity experienced by an aircraft in flight.

Bumpiness is associated generally with either (or both) convection currents in an unstable atmosphere or a flow of air across surface irregularities. It is much more common and intense over the land than over the sea. It is generally most marked in the lowest 2000 to 3000 feet (FRICTION LAYER) of the atmosphere but may extend to much higher levels above hilly country. See also AIR POCKETS, CLEAR-AIR TURBULENCE.

buoyancy: The buoyancy of a balloon or airship is the total load, including the envelope and fittings, that can just be supported. This buoyancy arises from the difference between the density of the light gas inside the envelope and that of the heavier air outside. The vessel will just rest in equilibrium when the total weight is the same as that of the air displaced; the buoyancy of the vessel is thus the difference between the weight of the gas in the envelope and that of the volume of air displaced (principle of Archimedes).

Analogous buoyancy forces act on parcels or 'bubbles' of air which are at a different temperature from that of the surrounding air and are fundamental in the process of free CONVECTION. Where T' and T are the temperatures (°K) of the air parcel and environment, respectively, the buoyancy force acting per unit mass is given by $g[(T'/T) - 1]$. The force is reckoned positive upwards ($T' > T$) and negative downwards ($T' < T$).

buran: A strong north-easterly wind which occurs in Russia and central Asia. It is most frequent in winter, when it is very cold and often raises a drift of snow, but strong north-easterly winds in summer are also termed buran. The winter snow-bearing wind is also termed 'purga'.

Buys Ballot's law: A rule in synoptic meteorology, enunciated in 1857 by Buys Ballot, of Utrecht, which states that if, in the northern hemisphere, an observer stands with his back to the wind, pressure is lower on his left hand than on his right, whilst in the southern hemisphere the converse is true. This law implies that, in the northern hemisphere, the winds blow anticlockwise round a depression, and clockwise round an anticyclone: the converse is true in the southern hemisphere. This is a statement of the direction of the GEOSTROPHIC WIND.

C

calendar: For meteorological purposes it is usual to adhere to the civil calendar, and to publish summaries of climatological data for ordinary civil months or weeks. For certain purposes, however, there are advantages in selecting an epoch other than 1 January as the commencement of the year. Thus the 'farmer's year' adopted for the *Weekly weather report* begins on the Sunday nearest to 1 March; a 'grower's year' beginning on 6 November is adopted for the Crop Weather Scheme; and a 'water year' beginning on 1 October is adopted for the summarization of data of surface and underground water by the Inland Water Survey (Ministry of Health).

The existing (Gregorian or 'New Style') civil calendar was introduced in Great Britain in 1752 (earlier in most other parts of Europe), replacing the Julian calendar which was based on a solar year of 365¼ days and which involved an error of one day in 128 years. In the existing calendar, centurial years are ordinary, as opposed to leap years, unless they are divisible exactly by 400, thus reducing the error to one day in 3323 years. The accumulated error of the Julian calendar was eliminated by calling the day, which followed 2 September 1752, 14 September.

See also SEASONS.

calibration: Originally the name given to the process of finding the calibre (area of cross-section) of a tube. When a tube is not of uniform cross-section, marks so spaced that the volume of the tube between consecutive marks is everywhere the same, are calibration marks.

The use of the word has now been extended to include the determination of absolute values appropriate to selected fixed points of an instrument, by comparison with primary or secondary STANDARD instruments.

calm: Absence of appreciable wind. Smoke rises vertically. On the BEAUFORT SCALE of wind force calm is accorded the figure 0 and has a wind speed equivalence of less than one knot.

calorie (or gram-calorie): A unit of heat, being the heat required to raise the temperature of 1 gm of water by 1°C. This quantity of heat depends, however, on the initial temperature of the water. The 15°C calorie (cal_{15}), defined as the heat required to raise the temperature of 1 gm of water from 14·5° to 15·5°C, and the International Steam Table calorie (IT cal) are the calories most commonly used. It was decided at the Ninth General Conference of Weights and Measures (1948) that the JOULE should replace the calorie as the unit of heat, or the joule equivalent be given. The dimensions are ML^2T^{-2}.

$$1\ cal_{15} = 4{\cdot}1855\ \text{joules}$$
$$1\ \text{IT cal} = 4{\cdot}1868\ \text{joules}$$

calvus (cal): A CLOUD SPECIES (Latin, *calvus* bald or stripped).

'CUMULONIMBUS in which at least some protuberances of the upper part are beginning to lose their cumuliform outlines but in which no cirriform parts can be distinguished. Protuberances and sproutings tend to form a whitish mass, with more or less vertical striations.'* See also CLOUD CLASSIFICATION.

* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 14.

canalization: See FUNNELLING.

cap: A name frequently given to the transient patches of cloud which sometimes form on or just above the tops of growing cumulus clouds, and are soon absorbed into them. It is also used for clouds on hill tops. It is technically known as PILEUS.

capillary potential: A concept used in SOIL MOISTURE studies, being the force of attraction exerted by soils on contained water, or the equivalent force required to extract the water from the soil against the capillary forces (SURFACE TENSION) acting in the soil pores. It is generally expressed in the pressure unit of atmospheres or the equivalent height of a specified liquid column (mercury or water).

Since the capillary potential increases very rapidly with increasing dryness of soil, a logarithmic measure pF is often used, defined as the logarithm to base 10 of the capillary potential expressed in centimetres of water. Thus a capillary potential of 1 atmosphere corresponds to pF 3, since a pressure of 1 atmosphere supports a column of water about 1000 cm in length. See also FIELD CAPACITY and WILTING POINT.

capillatus (cap): A CLOUD SPECIES (Latin, *capillatus* having hair).

'CUMULONIMBUS characterized by the presence, mostly in its upper portion, of distinct cirriform parts of clearly fibrous or striated structure, frequently having the form of an anvil, a plume or a vast, more or less disorderly mass of hair. Cumulonimbus capillatus is usually accompanied by a shower or by a thunderstorm, often with squalls and sometimes with hail; it frequently produces very well-defined VIRGA.'* See also CLOUD CLASSIFICATION.

carbon-dating: A technique of estimating the age of carbon-containing fossil materials, based on the measurement of their RADIOACTIVITY per unit mass and comparison with that of materials of known age. The technique is relevant, for example, to problems of past climatic changes. It is based on the fact that assimilation of RADIOACTIVE CARBON (C^{14}) ceases at the time of death of living material, the radioactivity of the material then decreasing at a rate which is determined by the radioactive HALF-LIFE of C^{14}. Thus, for example, a period of 5500 years would be assumed to have elapsed since the death of a fossil sample whose specific radioactivity is one-half that of a living sample. Basic assumptions, inherent in the method, are (i) that a steady state has long existed between the rate of production of C^{14} and its rate of disappearance, and (ii) that the strong latitudinal variation of production of C^{14} by cosmic rays is eliminated in its lifetime by world-wide mixing in the atmosphere and oceans.

A modification of the basic technique has been used in order to estimate a possible secular change of CARBON DIOXIDE concentration in the atmosphere. The method adopted in this case is to measure the specific radioactivity of a recent or living sample and also that of wood, for example, of known greater age since death (say, 100 years). From these measurements the relative proportions of C^{14} and CO_2 in the atmosphere at the two epochs are inferred.

Available data suggest that the basic assumption of a steady state between C^{14} production and disappearance has been recently invalidated, to an extent which is not negligible, by the amount of C^{14} produced in the atmosphere by nuclear weapon testing. For this reason, the use of plant or animal materials which have been alive during the period since about 1950 is best avoided in the application of the techniques.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 14.

carbon dioxide: A gas, of chemical formula CO_2, which comprises 0·03 and 0·05 part per 100 parts of dry air by volume and weight, respectively. It is created by animal life and by the oxidation of carbon compounds (as in fuel burning), and is used by plants: it is also destroyed by photochemical processes in the high atmosphere. Owing to a ready but temperature-dependent solubility of CO_2 in water, the oceans act as a great reservoir of the gas. The measured amount in the atmosphere is generally considered to have increased significantly during this century. Because of the important part played by CO_2 in the radiative equilibrium of the atmosphere, such secular changes of CO_2 amount are advanced as a possible contributory factor in effecting climatic changes. The CO_2 absorption band of chief importance lies between 12·5 and 17·5 microns, with peak absorption at about 15 microns.

carbon monoxide: A poisonous and colourless gas, of chemical formula CO, which is formed by the incomplete combustion of carbon-containing material. Its presence in minute concentration in the atmosphere has been observed spectroscopically.

Cartesian co-ordinates: A system of co-ordinates in which the *x*, *y*, *z* axes are mutually at right-angles (rectangular system). In meteorology, a 'right-handed' system is usually employed in which the *xy* plane is horizontal, positive *x* and *y* to east and north, respectively, and positive *z* vertically upwards.

castellanus (cas): A CLOUD SPECIES, previously termed 'castellatus' (Latin, *castellum* castle).

'Clouds which present, in at least some portion of their upper part, cumuliform protuberances in the form of turrets which generally give the clouds a crenelated appearance. The turrets, some of which are taller than they are wide, are connected by a common base and seem to be arranged in lines. The castellanus character is especially evident when the clouds are seen from the side.

This term applies to CIRRUS, CIRROCUMULUS, ALTOCUMULUS and STRATOCUMULUS.'* See also CLOUD CLASSIFICATION.

catchment area: Defined for administrative purposes as the area within the jurisdiction of a Catchment Board under the Land Drainage Act of 1930. The term is also commonly used with the same meaning as DRAINAGE AREA.

ceiling: The 'ceiling' of a specified mass (e.g. balloon, aircraft, thermal) is the maximum height in the atmosphere which the mass can attain.

The term is also used in the United States of America, and fairly generally in aviation circles, to specify the lowest height above the ground at which all cloud layers at and below that level cover more than half of the sky.

celestial sphere: That imaginary sphere on the inner surface of which the heavenly bodies appear to lie, the observer being situated at the centre of the sphere. See also EQUATOR, POLE.

Celsius scale: A scale of temperature based on one introduced in 1742 by Celsius, a Swedish astronomer and physicist, who divided the interval between the freezing- and boiling-points of water into 100 parts, the lower fixed point being marked 100. The present system, whereby the freezing-point is marked 0 and the boiling-point 100, was introduced by Christin, of Lyons, in 1743. This latter scale is now generally referred to as the Celsius scale: alternative names are the centigrade scale and, less commonly, the centesimal scale. See TEMPERATURE SCALES.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO 1956, p. 12.

centibar: Unit of pressure equal to 10^{-2} BAR, i.e. 10 mb.

centigrade: An alternative, though now less favoured, name for the Celsius scale of temperature.

centre of action: A term, introduced by Teisserenc de Bort in 1881, which generally signifies an area covered by a large-scale low- or high-pressure system, which dominates the circulation, and so has a big influence on weather conditions, over a large area for a considerable period of time.

The term has, however, also been used with other meanings. G. T. Walker, for example, defined a centre of action as an area in which conditions of pressure, temperature, rainfall or ice were strongly correlated with similar conditions in other parts of the world: an 'active' centre was one in which the conditions were highly correlated with conditions which occurred at other, 'passive' centres at a later time.

centrifugal force: A body rotating in a circle round a central point is subject to a 'centrifugal force' acting outwards from the centre, of magnitude ω^2R or V^2/R per unit mass (ω = angular velocity, V = linear velocity, R = radius of curvature of path).

This force arises in meteorology in two main ways:

(i) the observed force of GRAVITY is the vector sum of the force of gravitation directed towards the earth's centre and the centrifugal force acting on the earth and atmosphere due to rotation round the earth's axis;

(ii) air moving on a curved path with respect to the earth's surface is subject to a centrifugal force, and corresponding CENTRIPETAL ACCELERATION, giving rise to the cyclostrophic component of the GRADIENT WIND.

centripetal acceleration: That ACCELERATION of a body moving on a curved path, equal and opposite to the CENTRIFUGAL FORCE per unit mass, which is directed to the instantaneous centre of curvature of path of the body.

ceraunometer: An instrument designed to count and to give warning of the occurrence of LIGHTNING flashes within a specified area.

c.g.s. system: A system of units based on the centimetre, the gram and the second as FUNDAMENTAL UNITS. This is the system in which the various derived units are usually expressed in the sciences, including meteorology; for example, the unit of force is in this system defined as that which, applied to a mass of 1 gm, produces an acceleration of 1 cm/sec^2 and is termed the dyne.

chain lightning: An alternative for PEARL-NECKLACE LIGHTNING.

Chapman layer: An atmospheric layer conforming in properties to a model proposed by S. Chapman, who investigated the distribution in height of the product (electrons, molecules, free radicals, etc.) of a process depending on absorption of solar RADIATION.

The formation of a particular product in the high atmosphere by incident solar radiation is subject to two counteracting influences in that, with increasing depth of penetration, the amount of gas capable of absorbing the radiation increases because of increasing gas density downwards, while the amount of radiation decreases due to absorption at higher levels. There is thus a level, for a particular absorbing gas, at which the rate of formation of the product is a maximum and at which is centred a layer of characteristic 'shape'.

characteristic: See BAROMETRIC CHARACTERISTIC.

Charles's law: At constant pressure, the volume of a given mass of gas (or the SPECIFIC VOLUME) is directly proportional to the absolute temperature.

chemosphere: Term sometimes applied to that region of the ATMOSPHERE, extending mainly over the height range 40 to 80 km, in which PHOTOCHEMISTRY is important.

chinook: A warm and dry west wind, of the FÖHN type, which occurs on the eastern side of the Rocky mountains. Its arrival is usually sudden, with a consequent large temperature rise and rapid melting of snow.

chi-squared test: In statistics, the chi-squared (χ^2) test is a test of closeness of fit between an observed and a hypothetical frequency distribution of a given element. If E_r and F_r denote the 'expected' and actual frequencies, respectively, in the rth of a total of n classes, then the quantity χ^2 is defined by

$$\chi^2 = \Sigma_1^n (F_r - E_r)^2/E_r$$

χ^2 obviously decreases with increase of closeness of fit of the distributions. Values of χ^2, varying with n, appropriate to a fit of the frequency distributions at various probability levels are contained, for example, in the 'Handbook of statistical methods in meteorology'.* The test is unreliable if any E_r is less than about five.

chromosphere: That part of the atmosphere of the SUN above the REVERSING LAYER. Some 10,000 km thick, it consists of faintly luminous gases. Though visible directly only during a solar eclipse it is studied at other times by means of a spectroheliograph and is found to be a region of various types of disturbance including the SOLAR FLARE.

circle of inertia: In horizontal motion of a body on the rotating earth, subject to no force except gravity, the path described by the body, except near the equator, is approximately a circle which is known as the 'circle of inertia'. Inward acceleration (V^2/r) is balanced by the deviating force (fV) due to the earth's rotation and the path is thus of radius r, given by $r = V/f$, where V is the air velocity and f the CORIOLIS PARAMETER. Circular flow (r = constant) is not strictly adhered to because of the variation of f with latitude.

circular frequency distribution: A distribution in a series of vector quantities (e.g. winds) such that, when the individual vectors are drawn on a polar diagram, the lines of equal frequency of the vector end points are circles centred on the end point of the vector mean wind of the series. If the frequency of wind components about the mean is distributed in accordance with the NORMAL FREQUENCY DISTRIBUTION, the distribution is termed 'normal circular'. The frequency distributions of upper winds at most places conform more closely to a normal circular distribution than do those of surface wind.

circulation: The circulation (C) round a closed curve is defined as the line integral round the curve of the velocity vector component along the curve, i.e.

$$C = \oint \mathbf{V} . \mathrm{d}s = \oint V_T \mathrm{d}s$$

where V_T is the component of the velocity vector $\mathbf{V}$ tangential to the curve. Cyclonic circulation is reckoned positive, anticyclonic negative. The dimensions are L^2T^{-1}.

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* BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, HMSO, 1953, p. 382.

circulation, general atmospheric: See GENERAL CIRCULATION.

circulation index: A numerical measure of the strength of the atmospheric circulation as, most commonly, in the ZONAL INDEX.

circumzenithal arc: A HALO phenomenon in the form of a short arc centred on the zenith and convex to the sun, at or near the highest point of the 46° halo (if present). The arc is formed by REFRACTION in suitably orientated ice crystals and may show vivid rainbow colouring.

cirrocumulus (Cc): One of the CLOUD GENERA.

'Thin, white patch, sheet or layer of cloud without shading, composed of very small elements in the form of grains, ripples, etc., merged or separate, and more or less regularly arranged; most of the elements have an apparent width of less than one degree.'* See Plate 6: see also CLOUD CLASSIFICATION.

cirrostratus (Cs): One of the CLOUD GENERA.

'Transparent, whitish cloud veil of fibrous (hair-like) or smooth appearance, totally or partly covering the sky, and generally producing halo phenomena.'* See Plate 7: see also CLOUD CLASSIFICATION.

cirrus (Ci): One of the CLOUD GENERA. (Latin, *cirrus* lock or tuft of hair.)

'Detached clouds in the form of white, delicate filaments or white or mostly white patches or narrow bands. These clouds have a fibrous (hair-like) appearance, or a silky sheen, or both.'* See Plate 5: see also CLOUD CLASSIFICATION.

clear-air turbulence: Air TURBULENCE of a type other than that associated with air flow over rough ground and also that encountered in or near cumulonimbus clouds.

Clear-air turbulence has been observed mainly in the high troposphere and low stratosphere, especially in the vicinity of JET STREAMS. Its chief practical significance lies in the accelerations, varying in intensity up to several times g (acceleration of gravity), which may be imparted to high-speed aircraft. Investigation of the horizontal and vertical anomalies in the flow pattern that constitute the turbulence is made difficult by their small scale. Evidence suggests, however, that favourable conditions for the development of such anomalies include high static stability, and large horizontal and vertical wind shear: orographic effects may also be an important contributory factor.

clear ice: An alternative for GLAZED FROST.

clear sky, day of: In a resolution adopted at the International Meteorological Meeting at Utrecht in 1874, a 'day of clear sky' was defined as one on which the average CLOUDINESS at the hours of observation is less than two-tenths of the sky.

On 1 January 1949 OKTAS were first adopted, and since then a 'day of clear sky' has been defined in Great Britain as one on which the average cloudiness at hours of observation is less than two oktas.

climagram: A climatic diagram comprising a plot of monthly values of two selected meteorological elements (ordinate and abscissa), the plotted points being joined by a line which represents the annual variation of the relationship of the elements.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 10.

CLIMAT: In weather messages, a code word indicating that a message follows, in figure code, which contains information concerning surface pressure, temperature, humidity, rainfall at selected stations for the month preceding the broadcast. A 'CLIMAT SHIP' relates to surface information from the OCEAN WEATHER STATIONS. Similarly 'CLIMAT TEMP' and 'CLIMAT TEMP SHIP' relate to monthly mean upper air temperature and dew-point data from land stations and ocean weather stations, respectively. See 'Handbook of weather messages.'*

climate: The climate of a locality is the synthesis of the day-to-day values of the meteorological elements that affect the locality. Synthesis here implies more than simple averaging. Various methods are used to represent climate, e.g. both average and extreme values, frequencies of values within stated ranges, frequencies of weather types with associated values of elements. The main climatic elements are precipitation, temperature, humidity, sunshine, wind velocity, and such phenomena as fog, frost, thunder, gale: cloudiness, grass minimum temperature, and soil temperature at various depths may also be included. Climatic data are usually expressed in terms of an individual calendar month or season and are determined over a period (usually about 30 years) long enough to ensure that representative values for the month or season are obtained.

The climate of a locality is mainly governed by the factors of (i) latitude (ii) position relative to continents and oceans (iii) position relative to large-scale atmospheric circulation patterns (iv) altitude (v) local geographical features. A broad classification is made into (*a*) 'continental climate', which is found mainly in the interior and eastern parts of continents and is characterized by low rainfall and humidity and large diurnal and seasonal ranges of temperature, (*b*) 'maritime climate', typical of oceanic islands and the western parts of continents and characterized by high rainfall and humidity and relatively uniform temperature, diurnally and seasonally. Among well known classifications of greater refinement (though inevitably imperfect and so subject to criticism) are those of W. Köppen (1923), C. W. Thornthwaite (1931 and 1948)—see, for example, 'An introduction to climate.'†

climatic changes: Geological and botanical evidence of past climates is to the effect that, on the geological time-scale, periods when there was little or no ice anywhere in the world have alternated with much shorter periods when glaciation was widespread—see ICE AGE. The difference between mean world temperatures in these extreme conditions is estimated at about 8°C, the range being greatest in high latitudes.

Since the last GLACIAL PHASE of the Quaternary Ice Age, varying with locality from about 8000 to 40,000 years ago, there have been large fluctuations in climate in what is, technically, yet an 'interglacial' ice-age period. Conspicuous among the fluctuations of European climate, paralleled to a variable extent elsewhere, are the CLIMATIC OPTIMUM of about 5000 to 2000 B.C. and the 'Little Ice Age' of about A.D. 1550 to 1850. Other probable fluctuations are a warm, dry period in the sixth to eighth centuries A.D. and a stormy period in the twelfth to fourteenth centuries A.D. The evidence in the historical period includes, in Europe, fluctuations of Alpine glaciers and in the traffic across Alpine passes; in Asia, variations in the level of the Caspian Sea and other salt lakes; in North America, variations in the rate of growth of the sequoias of California, some of which are over 3000 years old.

It is now generally agreed that in most parts of the world, instrumental observations of the past 100 to 200 years contain SECULAR TREND(S) of statistical significance,

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* London, Meteorological Office; Handbook of weather messages. Parts II and III. London, HMSO, 1959.

† TREWARTHA, G. T.; An introduction to climate. New York, London and Toronto, McGraw-Hill Book Co., 3rd edn., 1954.

implying real climatic change(s) during this period. The most conspicuous feature has been a warming tendency from about 1850 to around 1940 on a scale which is almost world-wide and averages about 1°C. It is supported by other evidence such as the recession of glaciers: in the British Isles, the warming tendency has been confined mainly to the winter months.

Among the suggested causes of climatic variation are changes of solar radiation, astronomical (earth orbit) changes, CONTINENTAL DRIFT, POLAR WANDERING, mountain building, volcanic eruptions, changes of CARBON DIOXIDE content of the atmosphere, changes of heat storage by the oceans. It is yet quite uncertain which of these or other factors is most important in effecting climatic changes.

climatic optimum: That period, lasting from about 5000 to 2000 B.C., when average temperatures are considered to have reached a higher level, probably on a world-wide scale, than in the last million years. During this period European temperatures are thought to have averaged up to about 2°C or 3°C higher than at present.

climatic zones: The word CLIMATE is derived from a Greek word meaning 'to incline' and the original zones of climate were zones in which the inclination of the sun's rays at noon was the same; that is, zones of latitude. The accumulation of meteorological data has shown that winds and rainfall, as well as temperature, have a zonal arrangement, but that the true climatic zones do not run strictly parallel to lines of latitude. Eight principal zones are distinguished: near the equator a zone of tropical rain climate, then two subtropical zones of STEPPE and DESERT climate, then two zones of temperate rain climate, and, in the northern hemisphere only, an incomplete zone of BOREAL CLIMATE with a great annual range of temperature; finally, two polar caps of snow climate. The equatorial zone is divided into the equatorial rain-forest zone, which extends over the Atlantic and Pacific Oceans as the DOLDRUMS, with rain in all seasons, and a belt of SAVANNA climate on either side with a well marked alternation of dry and rainy seasons, the latter occurring in the 'summer' months. The sub-tropical zones include most of the world's great deserts—the Sahara, Arabia, Arizona, Kalahari, and the deserts of South America and Australia; over the oceans they include the TRADE WIND belts and the HORSE LATITUDES. The temperate zones are divided into the Mediterranean climates with mild, rainy winters and hot, dry summers, and the temperate rain belts with rain in all seasons. On the eastern margins of the continents, especially in Asia, the sub-tropical desert zone and the Mediterranean climate are replaced by areas with a MONSOON climate.

climatological station: A STATION at which meteorological observations are made for the purposes of CLIMATOLOGY. Such stations are classified by the World Meteorological Organization as either 'principal' (observations made at least three times daily in addition to hourly tabulations from autographic records) or 'ordinary' (observations made at least once daily, including daily readings of rainfall and of maximum and minimum temperature). Stations may also be classified as 'precipitation stations' (in normal British terminology, 'rainfall stations') where this is the only observed element; or as 'climatological stations for specific purposes' (for example, agriculture).

climatology: The study of CLIMATE.

climatotherapy: The treatment of disease by suitable climatic environment, i.e. applied BIOCLIMATOLOGY.

clinometer: An instrument for measuring the angle of elevation of a surface or of an object seen from the observing point. The angle is read by reference to a spirit level or a small plummet.

closed system: A closed (thermodynamic) system is one in which there is no exchange of matter between the system and its environment though there is, in general, exchange of energy. The atmosphere as a whole may, to a high degree of approximation, be considered a closed system.

cloud: An aggregate of very small water droplets, ice crystals, or a mixture of both, with its base above the earth's surface. The limiting liquid particle diameter is of the order 200 microns, larger drops than this comprising DRIZZLE or RAIN.

With the exception of certain rare types (NACREOUS and NOCTILUCENT) and the occasional occurrence of CIRRUS in the lower stratosphere, clouds are confined to the troposphere. They are formed mainly as the result of vertical motion of air, as in convection, or in forced ascent over high ground, or in the large-scale vertical motion associated with depressions and fronts. Cloud may result, in suitable lapse-rate and moisture conditions, from low-level turbulence and from other minor causes.

At temperatures below 0°C cloud particles frequently consist entirely of supercooled water droplets down to about −10°C in the case of layer clouds and to about −25°C in the case of convective clouds. At temperatures below these very approximate limits and above about −40°C (temperature of HOMOGENEOUS NUCLEATION), many clouds are 'mixed' but with ice crystals predominating in the lower part of the temperature range.

cloud amount: Amount of sky estimated to be covered by a specified cloud type (partial cloud amount), or by all cloud types (total cloud amount). In either case the estimate is made to the nearest OKTA (eighth) and is reported on a scale which is essentially one of the 'nearest eighth', except that figures 0 and 8 on the scale signify a completely clear and cloudy sky, respectively, with consequent adjustment to other figures near either end of the scale. See also CLOUDINESS.

cloud base: That lowest zone in which the type of obscuration perceptibly changes from that corresponding to clear air or haze to that corresponding to water droplets or ice crystals. (Conference of Directors of Members of the International Meteorological Organization, 1947).

Height of cloud base is reported as height above ground level.

cloud-burst: A popular term for a very sudden and very heavy shower, often accompanied by thunder and hail. It is associated with strong upward and downward currents.

cloud chamber: The 'Wilson cloud chamber' is an apparatus in which supersaturation and condensation are produced, for example in moist air, by sudden ADIABATIC cooling of the air contained in a chamber. In its normal use as a tool for studying the tracks of ionizing radiations, use is made of the fact that, in dust-free moist air, condensation occurs more readily on charged IONS than on uncharged molecules. Moist air in the chamber is freed of dust particles (condensation nuclei) by repeated expansion. The dust-free air is then suddenly expanded to a controlled degree, which produces immediate condensation only on ions. A photograph synchronized with the expansion reveals the tracks of ionizing rays passing through the chamber.

cloud classification: Various methods of CLOUD classification are made, as follows:

(i) In the publication 'International cloud atlas',* division is made into

* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 10.

CLOUD GENERA (ten basic characteristic forms); with sub-division as required, into (*a*) CLOUD SPECIES (cloud shape and structure); (*b*) CLOUD VARIETIES (cloud arrangement and transparency); (*c*) Supplementary features and accessory clouds—see INCUS, MAMMA, VIRGA, PRAECIPITATIO, ARCUS, TUBA, PILEUS, VELUM and PANNUS; (*d*) Growth of a new cloud genus from a 'mother-cloud', indicated by the addition of 'genitus' to the new cloud and mother-cloud genera, in that order, if a minor part of the mother-cloud is affected, and of 'mutatus' if much or all of the mother-cloud is affected, e.g. stratocumulus cumulogenitus, or stratus stratocumulomutatus.

(ii) A classification is made in terms of the level (étage)—high, middle, or low—at which the various cloud genera are usually encountered. In temperate regions the approximate limits are: high, 5–13 km (16,500–45,000 ft); middle, 2–7 km (6500–23,000 ft); low, earth's surface–2 km (0–6500 ft). The high clouds are Ci, Cc and Cs (see CLOUD GENERA for significance of abbreviations); the middle clouds are Ac and As (the latter often extending higher), and Ns (usually extending both higher and lower); the low clouds are Sc, St, Cu, and Cb (the last two often also reaching middle and high levels).

For synoptic purposes, a ninefold cloud classification is made in each of these three latter divisions of cloud genera, the corresponding codes being designated C_H, C_M and C_L respectively. The purpose is to report characteristic states of the sky rather than individual cloud types.

(iii) Less formal classifications are made (*a*) in terms of the physical processes of cloud formation, notably into HEAP CLOUDS and LAYER CLOUDS (or 'sheet clouds'); (*b*) in terms of cloud composition, namely ICE-CRYSTAL CLOUDS, WATER-DROPLET CLOUDS and MIXED CLOUDS.

cloud discharge: A lightning flash confined within a thundercloud. See LIGHTNING.

cloud genera: The ten characteristic cloud types, comprising CIRRUS (Ci), CIRROCUMULUS (Cc), CIRROSTRATUS (Cs), ALTOCUMULUS (Ac), ALTOSTRATUS (As), NIMBOSTRATUS (Ns), STRATOCUMULUS (Sc), STRATUS (St), CUMULUS (Cu), and CUMULONIMBUS (Cb). See CLOUD CLASSIFICATION.

cloudiness: Amount of sky covered by cloud, irrespective of type, i.e. total CLOUD AMOUNT.

Charts showing the distribution of mean cloudiness over the earth in each month and the year are given in the 'Manual of meteorology'.*

cloud physics: 'The study of the physical processes which govern the formation, nature, size, size distribution and number (per unit volume) of the individual particles which together constitute CLOUD, FOG or PRECIPITATION.' (A. C. Best, 1957.†)

cloud searchlight: Light projected vertically, by remote control, from a searchlight at distance L (about 1000 feet) from an observer causes a spot of light to be thrown on the lowest cloud overhead. The observer measures the angle of elevation (E) of the light spot by means of an ALIDADE and deduces the cloud base (h) from the relationship $h = L \tan E$. Fixed and portable versions of the instrument are used in the Meteorological Office.

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* SHAW, SIR N.; Manual of meteorology. Vol. IV, Comparative meteorology. Cambridge University Press, 1928, p. 146.

† BEST, A. C.; Physics in meteorology. Applied physics series, London, Sir Isaac Pitman and Sons Ltd., 1957.

PLATE 5 Cirrus.

PLATE 6 Cirrocumulus.

[To face page 54

PLATE 7 Cirrostratus with cumulus humilis below.

PLATE 8 Altocumulus.

PLATE 9 Altostratus.

PLATE 10 Nimbostratus.

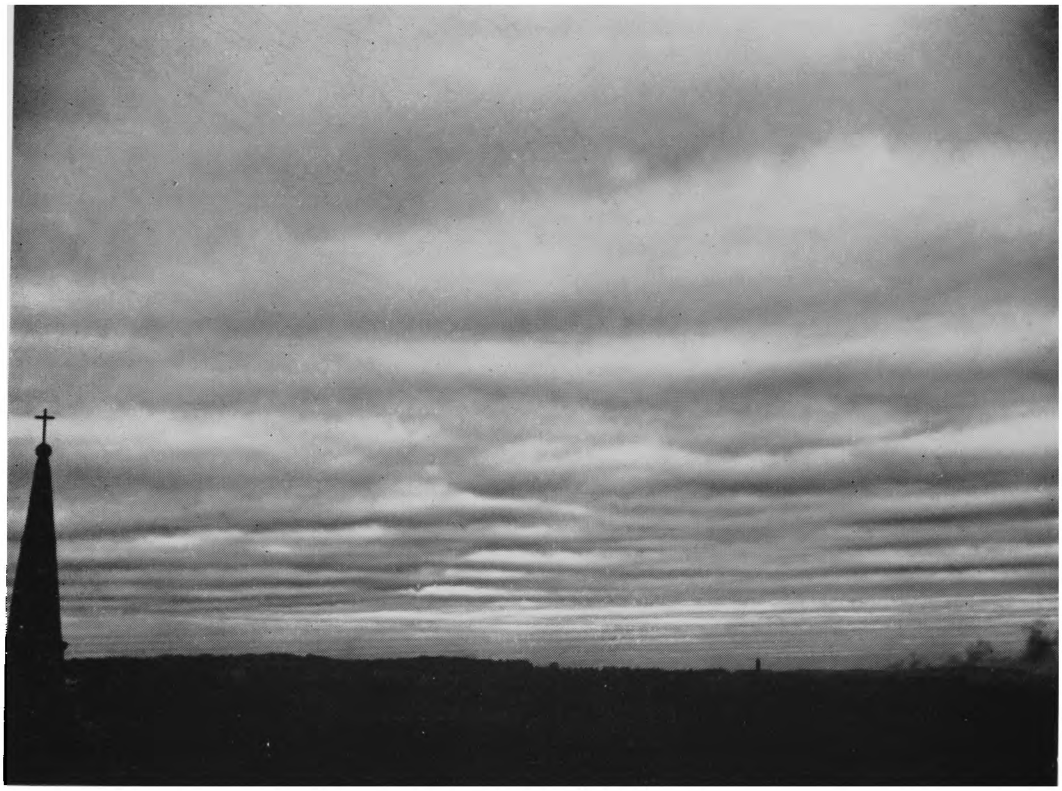

Plate 11 Stratocumulus.

Plate 12 Stratus.

PLATE 13 Cumulus.

PLATE 14 Cumulonimbus with mamma.

PLATE 15 Cumulonimbus with anvil.

PLATE 16 Altocumulus lenticularis.

PLATE 17 Cumulus protruding through stratocumulus.

PLATE 18 Noctilucent cloud: Perthshire.

cloud seeding: The attempted modification of the physical processes occurring within natural clouds, by injecting the clouds with one or other seeding agent: (i) 'dry ice' (solid carbon dioxide) at very low temperature to cause local cooling to below −40°C and spontaneous freezing; (ii) silver iodide to act as ICE NUCLEI; (iii) hygroscopic salt nuclei or a spray of fine water drops to stimulate COALESCENCE.

Injection of the seeding agent into the cloud has been carried out from aircraft, from balloons, and from the ground. In general, the purpose of the cloud seeding has been to stimulate precipitation. Attempts have also been made to clear stratus clouds and to inhibit hail and thunderstorms. Some success has been claimed in at least the first two aims, but the existence of a method of cloud seeding of commercial value has not yet been established.

clouds, particle distribution in: Measurements have shown water droplets in clouds to have a 'median volume diameter' (also termed 'mean effective diameter') of about 15 microns (μ), with a range from about 1 μ to 100 μ: median volume diameter is defined as the drop diameter such that half the total water present is contained in drops of larger diameter. Rather larger median values have been found in convective clouds (15–20 μ) than in layer clouds (10–15 μ). Still larger systematic differences with locality have been reported (larger drops in air free from pollution), probably because of associated differences in concentration of effective condensation nuclei.

Measured water-droplet concentrations are generally in the range 100 to 400/cm^3, but with smaller values in altocumulus clouds.

ICE CRYSTALS occur in clouds in various forms, determined by such conditions as temperature and degree of supersaturation with respect to ice. Clouds composed of ice crystals are very tenuous in comparison with water clouds: a typical range for the concentration of individual particles or clusters of particles is 1×10^5 to 5×10^5/m^3.

cloud species: A sub-division of CLOUD GENERA in terms of cloud shape and structure. The fourteen species comprise FIBRATUS, UNCINUS, SPISSATUS, CASTELLANUS, FLOCCUS, STRATIFORMIS, NEBULOSUS, LENTICULARIS, FRACTUS, HUMILIS, MEDIOCRIS, CONGESTUS, CALVUS and CAPILLATUS.

None, one, or more than one of the cloud species may be allotted to any specific example of cloud genus.

See also CLOUD CLASSIFICATION.

cloud street: An extended line of cumulus cloud parallel to the wind direction, often in an otherwise lightly clouded sky. Various sources of thermals spaced across wind may give rise to parallel cloud streets. It appears that such streets may also be produced in an air mass in which the convection layer has a well marked top and in which the wind direction in the layer is almost constant.

clouds, water content of: The amount of water, in the liquid or solid state, which is contained in unit volume of cloud. It is usually expressed in gm/m^3.

The water content of convective cloud may be computed on the basis of various assumptions. It is normally assumed that the water which is condensed on ADIABATIC expansion is retained within the rising air. The computed values increase with the temperature of the CONDENSATION LEVEL and decrease with the amount of ENTRAINMENT of ambient air which is assumed. In each theoretical model the computed maximum values occur towards the top of the cloud: such a value for mid-latitude summer conditions is, on the assumption that there is no mixing of cloud and environment, about 5 gm/m^3. Measurements have supported the theoretical distribution of water content with height in a convective cloud. While measured values have approached the maximum theoretical values in some instances, most measured values have been much lower. Because of the large dependence of water content on cloud-base temperature and degree of vertical development of cloud, average water-content values of convective clouds are of little significance.

Median values of water content of low-level layer clouds in middle latitudes are of the order 0·2 gm/m³, and of medium level clouds about 0·1 gm/m³. Variability is, however, rather great since values up to about five times the median values have been measured.

cloud varieties: A sub-division of CLOUD GENERA in terms of the arrangement of the cloud elements and the cloud transparency. The nine varieties comprise INTORTUS, VERTEBRATUS, UNDULATUS, RADIATUS, LACUNOSUS, DUPLICATUS, TRANSLUCIDUS, PERLUCIDUS and OPACUS.

None, one, or more than one of the cloud varieties may be allotted to any specific example of cloud genus.

See also CLOUD CLASSIFICATION.

cloudy day: Defined as a day on which the average CLOUDINESS at the hours of observation is more than six OKTAS. (Prior to 1 January 1949 the criterion was based on an average cloudiness greater than eight-tenths of the sky). Such days have sometimes been described in Great Britain as 'overcast days.'

coalescence: In meteorology, usually used to denote the growth of water drops by collision. The term is also often used for the growth of an ice particle by collision with water drops ('accretion'). See PRECIPITATION.

coalescence efficiency: That fraction of the number of collisions between water drops which results in the union of the drops and the formation of larger drops. See also COLLISION EFFICIENCY, COLLECTION EFFICIENCY.

coherence: A term sometimes used in meteorology, synonymously with PERSISTENCE, to signify the normal tendency towards recurrence of relatively high (or low) values of an element in successive intervals of time at a given place. The term is also sometimes used, more appropriately, to signify the normal tendency towards areal grouping of relatively high (or low) values of an element at a given epoch.

col: That atmospheric pressure distribution, saddle-backed in shape, which occurs between two anticyclones and two depressions, arranged alternately (see Figure 9). A col which is markedly elongated along the high-pressure axis is an 'anticyclonic col', along the low-pressure axis a 'cyclonic col': where there is no marked elongation, the col is 'neutral'.

Light, variable winds are a feature of all types of col. The weather of the neutral col is dominated by the characteristics of the particular air mass but is often thundery in summer and dull or foggy in winter. The general characteristics of the anticyclonic and cyclonic cols are those of the anticyclone and depression, respectively.

Since small pressure changes suffice to cause appreciable movement of a col, it is generally not an abiding feature of the synoptic pressure distribution. The cyclonic col occupies a region through which an approaching depression may readily pass.

colatitude: The colatitude at any point is the complementary angle of the LATITUDE (φ), i.e. $90° - \varphi$: it is also termed 'polar distance'.

cold anticyclone: See ANTICYCLONE.

cold dome: A term applied, in upper air analysis, to a closed centre of low pressure on a FRONTAL CONTOUR CHART. Such a region on the chart indicates the isolation

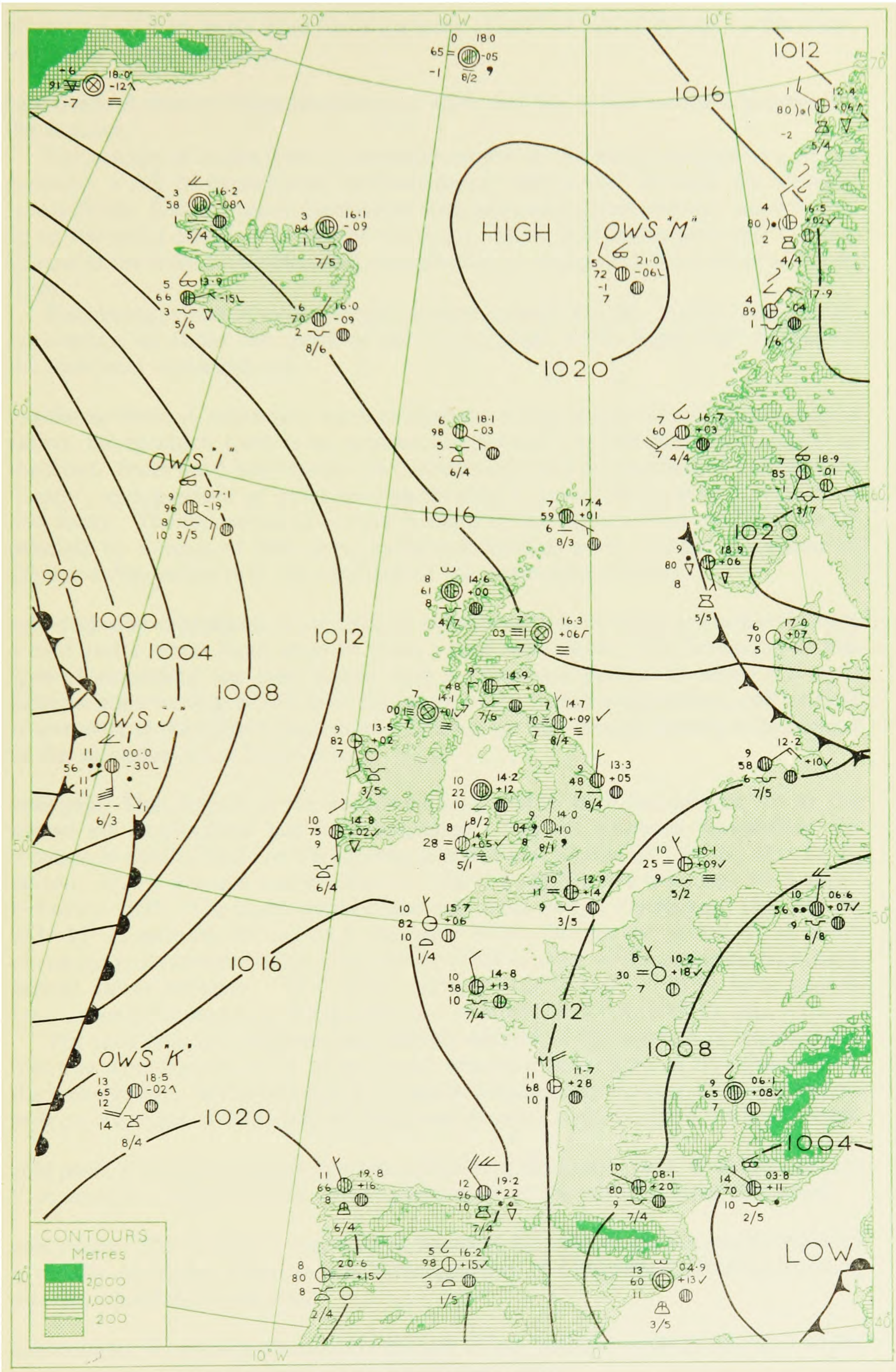

FIGURE 9—Col over the British Isles, 0600 GMT, 29 April 1961.

of cold air at high levels from the main body of cold air which is seen on the chart, usually at higher latitudes.

cold front: A FRONT whose movement is such that the colder air mass is replacing the warmer.

The passage of a cold front is normally marked at the earth's surface by a rise of pressure, a fall of temperature and dew-point, and a veer of wind (in northern hemisphere). Rain occurs in association with most cold fronts and may extend some 50 to 100 miles ahead of or behind the front. Some cold fronts give only a heavy shower at the front. Thunder, and occasionally a LINE-SQUALL, may occur at a cold front.

The average slope of a cold frontal surface is about 1 in 50. A cold front moves, on average, at about the speed of the GEOSTROPHIC WIND component normal to the front and measured at it.

cold-front wave: A secondary wave DEPRESSION which forms on an extended COLD FRONT, along which there is an appreciable thermal wind more-or-less parallel to the front. Such wave depressions are common and may be members of a depression 'family', each member of which may go through a typical life cycle of development and decay. The formation of a wave is aided by the distortion of the front, as for example by a range of hills or by movement towards a COL. Initial movement of the wave depression is in the direction of the warm-sector isobars.

cold-occlusion depression: A SECONDARY DEPRESSION which forms at the point where a cold and a warm front unite to form a cold OCCLUSION. The formation of this type of secondary has been linked with a THICKNESS pattern in which the main features are a weak gradient near the centre of the primary depression, and marked DIFFLUENCE at the point of occlusion. There is no well defined pattern of behaviour of the secondary after formation.

cold pole: That region of the earth's surface, one in each hemisphere, where the lowest air temperature has been measured. For the northern hemisphere the location is usually taken as Verhojansk in north-east Siberia (67° 33′ N, 133° 23′ E, altitude 122m) where a temperature of −68°C (−90°F) was measured on 5 and 7 February 1892. The same temperature was measured at Oymjakon, (63° 16′ N, 143° 15′ E, altitude 800 m) on 6 February 1933. During the period (from 1957) of regular measurement of air temperature in the interior of the Antarctic continent, several values between −85°C and −90°C (−121°F and −130°F) have already been reported at and near the Soviet base Vostok (78° 27′ S, 106° 52′ E).

The cold pole is sometimes alternatively defined as the location of lowest mean monthly temperature, or of lowest mean annual temperature, or of coldest air in the troposphere. In the last case it is usually indicated by the area of lowest THICKNESS on the chart of 1000–500 mb thickness or other representative thickness chart.

cold pool: A closed centre of low THICKNESS on a thickness chart, so called because it represents a region of low mean temperature in the isobaric layer concerned.

cold sector: That part of a DEPRESSION occupied by cold air on the earth's surface: it usually comprises about half to three-quarters of a recently formed depression, and the whole of an old one.

cold trough: A pressure TROUGH (or trough on an isobaric contour chart) in which temperature is generally lower than in adjacent areas.

cold wave: A term which is used in a technical sense by the United States Weather Bureau to signify a fall of temperature at a given place by at least a specified amount in 24 hours, to at least a specified minimum. The specified amount and minimum vary with season and locality.

collection efficiency: That fraction of the total number of water drops (cloud or rain), moving on an initial collision path with other drops, which actually collide and unite with such drops to form larger drops. It is given by the product of the COLLISION EFFICIENCY and COALESCENCE EFFICIENCY.

collision efficiency: That fraction of the total number of water drops (cloud or rain), moving on an initial collision path with other drops, which actually collide. The efficiency is a function mainly of the relative motion and the particle sizes involved. In general, it is less than unity because of the deflexion of the streamlines of the particles on their near approach, in such a way as to avoid collision. In certain cases, for example that of particles of about equal size, the efficiency approaches zero. On the other hand, an efficiency greater than unity occurs in some conditions, due to the sucking of particles into the wakes of others.

The collision efficiency is an important factor in the COALESCENCE process of PRECIPITATION. See also COALESCENCE EFFICIENCY and COLLECTION EFFICIENCY.

collision frequency: The collision frequency (ν) of a particle (e.g. molecule or electron) is the number of collisions it makes per second. Its inverse is the 'collision interval' (τ), which is the interval (in seconds) between collisions. Collision frequency is a function of gas pressure and density and is related to the MEAN FREE PATH (l) and the mean particle speed (v) by the relation $\nu = v/l$.

colour temperature: The colour temperature of a radiating body is that temperature obtained by insertion of the observed wavelength of peak radiation into Wien's formula. See RADIATION.

compass: The magnetic or mariner's compass consists in its simplest form of a graduated card at the centre of which a magnetized steel needle is pivoted so that it may turn freely in a horizontal plane. The card is divided into 32 equal parts of $11\frac{1}{4}°$ each, these being N, N by E, NNE, NE by N, NE and so on (compass 'points'). The compass needle points to magnetic north which does not, in general, coincide with geographical north. See DECLINATION, MAGNETIC and GEOMAGNETISM.

Magnetic compasses have now largely given way to the gyrostatic compass. This compass is one of several devices which utilize the property, possessed by a spinning fly-wheel, of maintaining its axis in space. The gyro is maintained electrically, and has been used in aeroplanes and on board ship, having the advantage of being independent of both magnetic and electrical disturbances.

compensation of instruments: An instrument designed to measure changes in a particular physical quantity (e.g. pressure) may be affected also by some other influence (e.g. temperature). To eliminate or minimize the influence of the disturbing element, a device may be introduced for the purpose of rendering the instrument insensitive to changes in the latter, in which case it is said to be 'compensated'. Thus, chronometers and aneroid barometers are ordinarily compensated for temperature.

component: See VECTOR.

composite forecast chart: A forecast chart so constructed as to depict, for a specified aircraft route, time of departure and air speed, the meteorological conditions which it is expected the aircraft will encounter at each point of the route.

computational instability: A phenomenon which arises in numerical computations employing approximate methods, in which the error of the computation increases exponentially as the computation proceeds. It arises under some circumstances in methods of obtaining NUMERICAL WEATHER FORECASTS. The effect is such that if the selected grid size is less than the distance travelled in the selected time interval by the fastest waves permitted by the equation, small errors of computation and of numerical approximation grow in successive time intervals to such an extent as to swamp the physical solution of the equation.

condensation: The process of formation of a liquid from its vapour: in meteorology, the formation of liquid WATER from WATER VAPOUR.

Since the capacity of air to hold water in the form of vapour decreases with temperature, cooling of air is the normal method by which first SATURATION, then condensation, is produced. Such cooling is effected by three main processes:

(i) adiabatic expansion of ascending air,
(ii) mixing with air at lower temperature,
(iii) contact with earth's surface at lower temperature.

The water vapour condenses as cloud in (i), as fog or cloud in (ii), and as dew or hoar frost in (iii).

Condensation in the atmosphere occurs at or near the temperature appropriate to the saturation VAPOUR PRESSURE, which is defined in terms of equilibrium between the vapour and a plane water surface, because of the presence in all parts of the troposphere of an adequate supply of 'condensation nuclei', which are hygroscopic. In the absence of such nuclei a high degree of supersaturation (several hundred per cent) would be required to produce condensation—so-called 'homogeneous condensation'.

The main factors governing the rate of growth of a cloud droplet formed by direct condensation of water vapour on a condensation NUCLEUS (radius $>$ 0·1 micron, approximately) are the nuclei concentration and sizes, the degree of saturation or supersaturation, the excess saturation vapour pressure over a spherical droplet relative to a plane surface, the reduction of saturation vapour pressure associated with the solution which a hygroscopic salt forms with water, and the warming of the growing cloud droplets by the latent heat of condensation which is released. Calculation shows that the drop grows quickly when small and increasingly slowly with increase of drop size. The process of direct condensation explains well the formation of normal cloud particles (diameter about 15 microns) but proceeds much too slowly to account for the size of drop often associated with PRECIPITATION (diameter about 1000 microns).

condensation level: That level (geometric or pressure) at which CONDENSATION occurs in the atmosphere.

The term is normally used in relation to one or other of the processes of lifting, convection, or vertical mixing. The appropriate condensation level is found by means of an AEROLOGICAL DIAGRAM.

The 'lifting condensation level' is, for an air sample at any height, that (isobaric) level at which the dry ADIABATIC through the temperature intersects the HUMIDITY MIXING RATIO line drawn through the dew-point of the sample.

The 'convective condensation level', applied only to surface air, is the same as the lifting condensation level for surface air if the intersection of the dry adiabatic through the temperature and mixing ratio line through the dew-point lies to the right of the environment curve. If this is not the case, the convective condensation level is the level at which the mixing ratio line through the surface dew-point intersects the environment curve.

The 'mixing condensation level' is the lowest level at which condensation occurs (if at all) as the result of complete vertical mixing throughout a given layer. Such mixing produces constant POTENTIAL TEMPERATURE and mixing ratio throughout the layer: the mixing condensation level is the level of intersection of the dry adiabatic and mixing ratio lines appropriate to these constant values.

condensation nucleus: See NUCLEUS, CONDENSATION.

condensation trail: An initially thin trail of water droplets or ice crystals produced by an aircraft engine exhaust when the humidifying effect of the water vapour exceeds the opposed heating effect of the exhaust air ('exhaust trail'). Such trails generally broaden rapidly and evaporate as mixing with drier air proceeds, but are at times very persistent. Theory indicates that for a given engine there is for a given pressure a critical air temperature above which a trail cannot form. A 'mintra' line corresponding to these critical pressure–temperature conditions is shown on the Meteorological Office TEPHIGRAM form. It is found in practice that the appearance of a trail is delayed until the temperature is several degrees below the corresponding mintra value. The critical temperature is such that over Great Britain trails rarely form below about 28,000 feet in summer and 20,000 feet in winter. In tropical areas the heights are greater but in very cold conditions, such as winter in central Canada, trails can form at ground level.

Non-persistent condensation trails more rarely form, sometimes at low levels, in near-saturated air at aircraft wing tips and propeller tips, because of the aerodynamically produced pressure falls which occur at these points ('aerodynamic trail').

conditional instability: See STABILITY.

conduction (of heat): The process of heat transfer through matter, from regions of high to regions of low temperature, by molecular impact, without transfer of the matter itself. It is the process by which heat passes through solids: its effects in fluids are usually negligible in comparison with those of CONVECTION.

conductivity, thermal: That property of matter whereby thermal CONDUCTION occurs. Two quantities are defined: (i) thermal conductivity (k), by the equation $q = -k\ \partial T/\partial x$ (q, flux of heat per unit area, is proportional to $\partial T/\partial x$, thermal gradient, and acts in the down-gradient direction, k being the constant of proportionality); (ii) thermometric conductivity, or thermal diffusivity (a), by the relation $a = k/c\rho$, where c is the specific heat and ρ the density of the substance.

For most soils the value of a is of the order 10^{-2} to 10^{-3} cm^2/sec, though with appreciable dependence on density and water content. For still air a is about 0·2 cm^2/sec.

In a turbulent atmosphere (its normal state) the vertical heat transfer effected by molecular conduction is swamped by that effected by eddies. See EDDY CONDUCTIVITY.

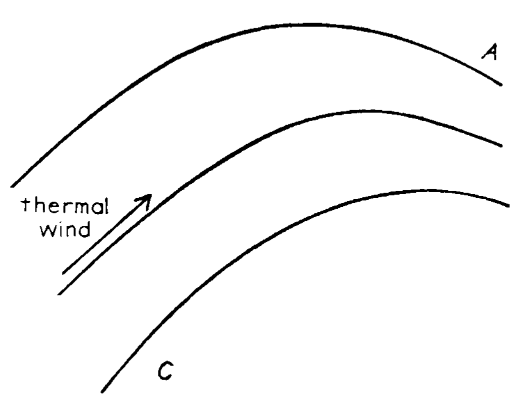

FIGURE 10—Confluent thermal ridge.

confluence: The nearer approach to each other of adjacent STREAMLINES in the direction of flow. See DIVERGENCE.

confluent thermal ridge: A pattern of thickness lines which is concave towards high THICKNESS and in which the thickness lines crowd together in the direction of the THERMAL WIND. According to the theorem of DEVELOPMENT, cyclogenesis (*C*) may be expected to occur behind and to right, anticyclogenesis (*A*) ahead and to left of pattern, as illustrated in Figure 10.

confluent thermal trough: A pattern of thickness lines which is concave towards low THICKNESS and in which the thickness lines crowd together in the direction of

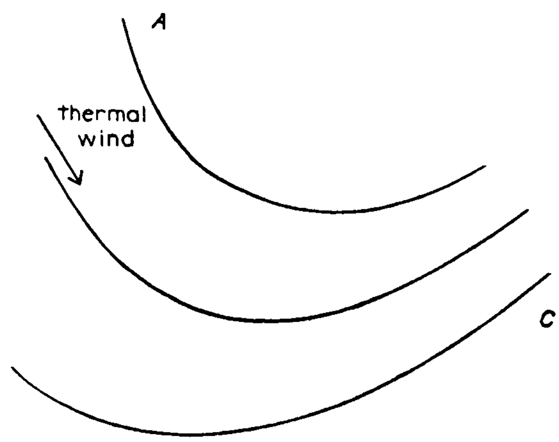

FIGURE 11—**Confluent thermal trough.**

the THERMAL WIND. According to the theorem of DEVELOPMENT, cyclogenesis (*C*) may be expected to occur ahead and to right, anticyclogenesis (*A*) behind and to left of pattern, as illustrated in Figure 11.

congestus (con): A CLOUD SPECIES. (Latin, *congestus* piled up.)

'CUMULUS clouds which are markedly sprouting and are often of great vertical extent; their bulging upper part frequently resembles a cauliflower.'* See also CLOUD CLASSIFICATION.

conjunction, astronomical: A planet or other heavenly body is said to be in conjunction when it is in line with the earth and sun, and on the same side of the earth as the sun.

conservation: In statistics, a term which is sometimes used with the same meaning as PERSISTENCE or (time) COHERENCE.

conservative property: A conservative air-mass property is one that remains unchanged, or almost unchanged (quasi-conservative), in a specified process or processes. Thus, for example, POTENTIAL TEMPERATURE is strictly conservative in a dry-adiabatic process, is quasi-conservative in unsaturated vertical motion in the atmosphere, but is not conservative in a non-adiabatic process such as radiational cooling at constant pressure.
See AIR-MASS ANALYSIS.

* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, 1956, WMO, p. 14.

constancy of winds: Owing to varying wind direction, the magnitude of the VECTOR mean (V_R) of a series of wind observations is less than that of the corresponding SCALAR mean (V_S). The quantity q, defined by $q = 100\ V_R/V_S$, gives a measure of the constancy of wind direction. Values of q range between 0 (winds equally strong and frequent in all directions) and 100 (winds unvarying in direction but not necessarily in speed).

q is controlled in part by synoptic events and in part by the constraints placed on wind direction by local topography. Typical values of q for surface winds over and near the British Isles are within the range 15 to 50. Interpretation of a value of q is, however, unambiguous only on the assumption of a normal and CIRCULAR FREQUENCY DISTRIBUTION of the winds about the vector mean wind.

constant absolute vorticity trajectory (CAVT): The TRAJECTORY of an air parcel, evaluated on the assumption that absolute VORTICITY is conserved during the motion in which there is no shear.

The basis of such trajectories is the POTENTIAL VORTICITY THEOREM which is, in polar co-ordinates,

$$\frac{\dfrac{V}{r} + \dfrac{\partial V}{\partial r} + 2\ \Omega \sin \varphi}{\Delta p} = \text{constant}.$$

Under the restrictive conditions of a broad current of air moving horizontally at constant speed ($V =$ constant) with little lateral WIND SHEAR ($\partial V/\partial r \simeq 0$) and in a thin layer at a level of non-DIVERGENCE ($\Delta p =$ constant), the above equation states that the air will move in such a way that latitudinal (φ) changes of vorticity are compensated by curvature (V/r) changes. A wave-like motion between two parallels of latitude results: the air passes through its mean latitude without curvature of path and acquires maximum anticyclonic curvature in its highest latitude and maximum cyclonic curvature in its lowest latitude. The wavelength and amplitude of the oscillation depend on the wind speed, the mean latitude and the angle at which the trajectory intersects this mean latitude.

Tables for computing CAVT are contained in 'Weather analysis and forecasting.'*

constant-pressure chart: A SYNOPTIC CHART, relating to a surface of specified constant pressure (isobaric surface), on which contours of GEOPOTENTIAL height of the surface are drawn. Other elements, e.g. temperatures and winds observed at the given pressure, are usually entered on the same chart. See also GEOSTROPHIC WIND.

contessa del vento: A type of eddy cloud frequently found to the lee side of isolated mountains. It is often observed over Mount Etna with a westerly wind. In its most characteristic form it consists of a rounded base surmounted by a protuberance directed upwind.

continental climate: A type of CLIMATE, characteristic of the interior of large land masses of middle latitudes: the main distinguishing features are large annual and diurnal ranges of air temperature, with low rainfall a further characteristic feature. The most extreme form of continental climate is found in central Asia where there is an annual range of temperature (July mean minus January mean) of about 60°C. See CONTINENTALITY.

continental drift: A hypothesis, generally linked with the names of F. B. Taylor and A. Wegener, of displacements, on a geological time-scale and by distances of the order of thousands of kilometres, of various parts of the earth's surface relative to other parts. According to this hypothesis continents now separated were once joined

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* PETTERSSEN, S.; Weather analysis and forecasting. Vol. 1, Motion and motion systems. New York, McGraw-Hill Book Co., 1956, p. 414.

together as, for example, South America and Africa, North America and Europe: in general, changes in both latitude and longitude are implied.

Evidence advanced in support of the hypothesis includes similarities of shape and topographical features and of plant and animal life of land masses supposed once to have been joined. The hypothesis has been used to explain, with limited success, climatic changes on a world-wide scale. Recent evidence strongly advanced in support concerns the history of the earth's magnetic field as inferred from rock magnetism (see GEOMAGNETISM).

The hypothesis of continental drift is highly controversial: various geophysicists hold that there is no conceivable mechanism which can give rise to such an effect; in addition, various items of palaeontological and palaeoclimatological evidence are held to be in conflict with, rather than in support of, the theory.

See also POLAR WANDERING.

continentality: In meteorology, a measure of the extent to which the climate at any place is subject to land, as opposed to maritime, influences. Because of the low specific heat of land relative to water and, more especially, the fact that heat exchanges by day and night, summer and winter are confined to a shallow layer of a land surface, the diurnal and seasonal temperature changes of a land mass and its overlying air are great. Various measures of continentality have been suggested, most of them based on the observed annual range of temperature but depending also on latitude (the INSOLATION factor).

At a given latitude continentality increases, in general, with distance from the sea, but maximum continentality occurs at an appreciable distance downwind (relative to the PREVAILING WIND) from the centre of a land mass. A large range of mountains across the prevailing wind produces a marked increase of continentality to leeward of the mountains, mainly due to the clearer skies and consequently greater radiational heating in summer and cooling in winter that prevail there.

See also CONTINENTAL CLIMATE.

continental polar air: See POLAR AIR.

continental tropical air: See TROPICAL AIR.

continuity, equation of: An equation which expresses the law of conservation of mass and states that the mass of air entering an elementary volume is equal to the increase of mass within it.

The equation has various forms, for example

$$\text{div } \mathbf{V} = -\frac{1}{\rho}\frac{d\rho}{dt}$$

$$-\frac{\partial w}{\partial z} = \text{div}_H \mathbf{V} + \frac{1}{\rho}\frac{d\rho}{dt}$$

The latter equation states that if an air parcel contracts vertically it may expand horizontally and increase in density. Since local density change is small in the atmosphere the equation has the approximate form

$$-\frac{\partial w}{\partial z} \simeq \text{div}_H V$$

Assuming that the vertical variation of pressure is governed by the HYDROSTATIC EQUATION, the equation of continuity in PRESSURE CO-ORDINATES has the form

$$\text{div}_p \mathbf{V} = -\frac{\partial}{\partial p}\left(\frac{dp}{dt}\right)$$

See also DIVERGENCE, EULERIAN CHANGE, LAGRANGIAN CHANGE.

contour (contour line): In synoptic meteorology, a line of constant height of an ISOBARIC SURFACE. The terms 'absolute contour' and 'isohypse' are sometimes used.

contrail: A common abbreviation for CONDENSATION TRAIL.

contrast threshold of the eye: A ratio ε, important in measurements of VISIBILITY, defined by the relation

$$\varepsilon = \frac{B-H}{H}$$

where B is the apparent brightness of an object which is just visible against a background of apparent brightness H.

While experiment shows that ε varies considerably with observer and with viewing conditions, it is for normal observers in ordinary daylight illumination about 0·02. The same value is often assumed for purposes of conversion of visibilities gauged from night visibility points to those appropriate to the daylight scale. The World Meteorological Organization suggests the adoption of the more cautious value of $\varepsilon = 0{\cdot}05$.

convection: A mode of heat transfer within a fluid, involving the movement of substantial volumes of the substance concerned. The convection process frequently operates in the atmosphere and is of fundamental importance in effecting vertical exchange of heat and other air-mass properties (water vapour, momentum, etc.) throughout the troposphere.

Two distinct, though not mutually exclusive, types of convection occur in the atmosphere. In 'forced' convection the vertical air motion is produced by mechanical forces, as in the passage of air over rough or high ground, and the vertical transport of properties is effected by 'eddies' (see EDDY). In 'free' or 'natural' convection BUOYANCY forces operate, in the absence of static STABILITY of the air, to effect vertical mixing through the agency of convection cells or 'bubbles'.

convective condensation level: See CONDENSATION LEVEL.

convective rain: Rainfall which is caused by the vertical motion of an ascending mass of air which is warmer than its environment: the horizontal dimension of such an air mass is generally of the order of 10 miles or less and forms a typical CUMULONIMBUS cloud. Convective rain is typically of greater intensity than either of the other two main classes of rainfall (cyclonic and orographic) and is sometimes accompanied by thunder.

The term is more particularly used in those cases in which the precipitation covers a large area as the result of the agglomeration of cumulonimbus masses.

convective region: An alternative for ADIABATIC REGION.

convergence: See DIVERGENCE.

Coriolis acceleration: An acceleration which air possesses by virtue of the earth's rotation, with respect to axes fixed in space. It is sometimes termed 'geostrophic acceleration'.

The Coriolis acceleration is a three-dimensional vector which is given in vector notation by the expression $2\mathbf{\Omega} \wedge \mathbf{V}$, where $\mathbf{\Omega}$ is the earth's angular velocity and $\mathbf{V}$ the wind velocity (see ACCELERATION). It is therefore everywhere at right angles to the earth's axis (in the plane of the equator) and to the air velocity: in the northern (southern) hemisphere it acts to the left (right) looking along the motion. The effect is often expressed in terms of the equal and opposite inertia force termed the 'Coriolis force', or 'deviating force'.

In a Cartesian co-ordinate system in which x and y are in the horizontal plane to east and north, respectively, and z is vertically upwards, the Coriolis acceleration has components

$$\text{C.A.}_x = 2\ \Omega\ (w \cos \varphi - v \sin \varphi)$$
$$\text{C.A.}_y = 2\ \Omega\ u \sin \varphi$$
$$\text{C.A.}_z = -2\ \Omega\ u \cos \varphi$$

where u, v, w are the component wind velocities in the x, y, z directions, respectively, and φ is latitude.

Only the component of the Coriolis acceleration which acts in the horizontal (xy) plane is significant in meteorological dynamics: the vertical component is of comparable magnitude, but is negligible compared with the large forces (gravity and pressure gradient) which act in this direction. For quasi-horizontal air motion ($w = 0$), of velocity V, the horizontal Coriolis acceleration is of magnitude $2\ \Omega\ V \sin \varphi$.

The component of the earth's rotation in the horizontal plane is such that the earth simulates a flat disk rotating anticlockwise in the northern hemisphere and clockwise in the southern hemisphere (see ANGULAR VELOCITY OF THE EARTH). Air moving horizontally outwards from the centre of the disk appears to an observer stationed there to be deflected to the right in the northern hemisphere and to the left in the southern hemisphere, i.e. in a frame of reference fixed in the rotating earth the air has horizontal acceleration in these respective directions. The effect is negligible if the scale of the motion considered (radius of disk) is of the order of only a few miles.

Coriolis force: See CORIOLIS ACCELERATION.

Coriolis parameter: A quantity, denoted f (sometimes l), defined by the equation $f = 2\ \Omega \sin \varphi$, where Ω is the magnitude of the earth's angular velocity and φ the latitude.

corona: A series of coloured rings surrounding the sun or moon. The space next to the luminary is bluish white, while this region is bounded on the outside by a brownish red ring, the two forming the 'aureole'. In most cases the aureole alone appears, but a complete corona has a set of coloured rings surrounding the aureole —violet inside, followed by blue, green, yellow to red on the outside. The series may be repeated more than once, but the colours are usually merely greenish and pinkish tints.

The corona is produced by DIFFRACTION of the light by water drops. Pure colours indicate uniformity of drop size. The radius of the corona is inversely proportional to drop size: thus growth of a corona indicates decrease of drop size.

A corona is distinguished from a HALO (caused by REFRACTION) by its reversal of colour sequence, the red of the halo being inside, that of the corona outside: the dull red, which is the first notable colour in the aureole, ranks as outside the bluish tint near the luminary. An alternative criterion is that the colours of a halo are at the inner edge of a luminous area, while those of a corona are at the outer edge.

For auroral corona see AURORA.

corona, solar: The outer atmosphere of the SUN, extending to great distances and comprising feebly luminous and highly ionized gases at a temperature of the order 10^6°K. Directly visible only during a solar eclipse it is studied at other times by means of the coronograph. Roughly circular in shape at SUNSPOT maximum, it is much extended along the sun's equator at sunspot minimum.

corposant: See ST. ELMO'S FIRE.

correlation: The method of correlation is a mathematical process for determining the degree of relationship between two variable quantities.

Where x and y are the deviations from the respective mean values of their series, the 'correlation coefficient' (r_{xy}) is a numerical measure of the degree of linear relationship between N pairs of associated values of the two series and is given by

$$r_{xy} = \frac{\sum_1^N xy}{\sqrt{\sum_1^N x^2 \sum_1^N y^2}} = \frac{\sum_1^N xy}{N\,\sigma_x\,\sigma_y}$$

where σ_x, σ_y are the respective STANDARD DEVIATIONS of the variables.

The correlation coefficient r ranges from 0 to ± 1 : $r = 0$ signifies no relationship, $r = +1$ a perfect direct linear relationship, $r = -1$ a perfect inverse linear relationship.

Where a correlation coefficient is derived from a large number N of independent sets of variables, the STANDARD ERROR of a computed value of r is given by $(1-r^2)/\sqrt{N}$. If r is evaluated from consecutive values of a TIME SERIES which has strong positive AUTOCORRELATION, the appropriate value of N in this error expression is much smaller than the total number of pairs of values employed in determining the correlation. If N is less than about 20, the probability distribution of an estimate of r differs from the normal law which is assumed in the derivation of the error expression, according to the rule which is operated in STUDENT'S t-TEST.

A value of r which differs significantly from zero is to be regarded as implying a measure of causal relationship only if this view is supported by strong physical reasoning.

correlogram: A correlogram (abbreviation for 'correlation diagram') is a diagrammatic method of testing for hidden PERIODICITIES in a TIME SERIES. The diagram consists of a plot of calculated values of the AUTOCORRELATION coefficient, r_L, as ordinate, against the corresponding values of lag (L), from 1 upwards, as abscissa. The values of L corresponding to peaks in the graph (high values of r_L) represent the most probable periods. Assessment of significance depends on the magnitudes of r_L attained in the peaks and on the interrelationships of the various peaks and troughs of the graph.

cosmic radiation (or rays): Very high energy radiation which originates outside the earth and probably, in large part, outside the solar system.

The cosmic 'primary' radiation consists mainly of positively charged nuclei of hydrogen (protons) and heavier elements, which are deflected by the earth's magnetic field on near approach to the earth and enter the earth's atmosphere in numbers that increase with increasing geomagnetic latitude. Predominance of a positive charge in the primary radiation is inferred from the preponderance of entry of radiation from a westerly direction at all latitudes ('east–west asymmetry').

The primary radiation reacts to an appreciable extent with the nuclei of atmospheric atoms on penetrating to a level some 15–20 km above ground, and so gives rise to a variety of secondary, tertiary, etc., products (especially various types of meson), some very penetrating ('hard'), others less penetrating ('soft'). Continuous recording of the intensity of the radiation which reaches the ground is made in many parts of the world. The intensity and average energy of cosmic radiation increase rapidly with height above mean sea level.

Before the era of nuclear explosions measurement suggested that about one-fourth of the conductivity of the air near the ground was due, on average, to the ionizing power of cosmic radiation: at low levels over the sea, and in all regions at a level greater than about 2 km, nearly all the conductivity of the air was due to cosmic radiation.

Among the time variations of cosmic radiation are a solar-cycle variation more or less in phase with sunspot number; a 27-day recurrence tendency; decreases associated with magnetic storms and increases associated with intense solar flares.

Cosmic radiation intensity measured at the ground is affected by atmospheric conditions in a way which, though not completely understood, proceeds, to a first approximation, as follows. Since atmospheric pressure at any point is a measure of the mass of air vertically above the point, the pressure at which 'frequent' interaction between the primary radiation and the atmosphere occurs, i.e. pressure at the level of production of secondary radiation, will be approximately constant. Since, also, the probability of absorption or radioactive decay of an individual secondary particle increases with depth of layer between height of production and mean sea level, measured intensity of radiation decreases both with high mean temperature in the layer between mean sea level and level of production, and with high mean-sea-level pressure (high thickness between the upper constant-pressure level and mean sea level being implied in either case). While approximate corrections for these meteorological influences are required for the purpose of most analyses, the uncorrected observations may provide valuable information concerning meteorological phenomena. A notable example was the interpretation of an apparent lunar time variation of cosmic radiation intensity as a vertical motion of the mean pressure level of generation of secondary radiation, i.e. as a measure of the amplitude of the lunar tidal motion in the high atmosphere.

counterglow: The narrow coloured band or bands which are seen at TWILIGHT above the blue SHADOW OF THE EARTH thrown by the sun just above the horizon (eastern horizon at sunset, western at sunrise). The light from the bands is scattered back to the observer by dust particles and is predominantly soft red in colour, corresponding to the colour acquired by the incident solar beam as it passes through the atmosphere and suffers preferential scattering of the blue wavelengths by the air molecules. In some cases there are well marked higher bands of orange, yellow and green corresponding to a decrease in redness acquired by the incident light on passage through less dense regions of the atmosphere. The phenomenon is also termed 'countertwilight', or 'ANTITWILIGHT', or 'antitwilight arch'.

The term 'counterglow' is also otherwise used as an alternative for GEGENSCHEIN.

counter sun: An alternative for ANTHELION.

countertwilight: An alternative for COUNTERGLOW.

crachin: Conditions of drizzle combined with low stratus, mist, or fog that occur at times between January and April in south China and in the coastal area between about Cape Cambodia and Shanghai. The conditions are caused by an interaction between the maritime tropical air and the maritime polar air circulating round the eastern side of the Asiatic anticyclone. Orographic and coastal lifting are also significant factors.

crepuscular rays: These include three similar classes of phenomenon:

(i) Sunbeams penetrating through gaps in a layer of low cloud and rendered luminous by water or dust particles in the air (phenomenon termed 'sun drawing water' or 'Jacob's ladder').

(ii) Pale blue or whitish beams diverging upwards from the sun hidden behind cumulus or cumulonimbus clouds. The well defined beams are separated by darker streaks which are the shadows of parts of the irregular cloud. See Plate 19.

(iii) Red or rose-coloured beams, diverging upwards at twilight from the sun below the horizon. The light is scattered to the observer by atmospheric dust: the beams are separated by greenish coloured regions which are the shadows of clouds or hills below the horizon.

In cases (ii) and (iii) the beams and shadows may persist across the sky before converging at the ANTISOLAR POINT (anticrepuscular rays). The apparent divergence and convergence of the rays is an optical illusion produced by perspective.

critical frequency: In radio sounding of the IONOSPHERE, that radio frequency at which the wave just penetrates a specified layer. The square of the critical frequency is directly proportional to the maximum electron concentration in the layer.

critical temperature: That temperature above which a specified gas cannot, and below which it can, be liquefied by pressure alone.

crop weather station: For the study of meteorological factors in the growth and yield of crops, 'crop weather' stations were established in 1924 at various agricultural colleges, research centres and farm institutes. In general, the stations are sited in juxtaposition to growing crops upon which measurements are made, so that the meteorological and plant observations may be closely correlated. In addition, phenological observations are made at certain centres. The scheme is under the control of the Meteorological Office, the Ministry of Agriculture, Fisheries and Food, and the Department of Agriculture for Scotland. It has since been extended to include observations of forest trees, and the Forestry Commission has established stations at certain nurseries.

cross-section: As commonly used in meteorology, this term means the representation in schematic form of conditions prevailing, or expected to prevail, in the atmosphere at a specified epoch in a vertical plane from the surface up to any desired height along a line from one point to another. The information plotted on the cross-section depends upon the purpose for which it is plotted—whether, for example, as an aid in analysis or as a representation of expected conditions along an air route.

cumulonimbus (Cb): One of the CLOUD GENERA. (Latin, *cumulus* heap, *nimbus* rainy cloud.)

'Heavy and dense cloud, with a considerable vertical extent, in the form of a mountain or huge towers. At least part of its upper portion is usually smooth, or fibrous or striated, and nearly always flattened; this part often spreads out in the shape of an anvil or vast plume.

Under the base of this cloud which is often very dark, there are frequently low ragged clouds either merged with it or not, and precipitation sometimes in the form of VIRGA.'* See Plates 14 and 15: see also CLOUD CLASSIFICATION.

cumulus (Cu): One of the CLOUD GENERA. (Latin, *cumulus* heap.)

'Detached clouds, generally dense and with sharp outlines, developing vertically in the form of rising mounds, domes or towers, of which the bulging upper part often resembles a cauliflower. The sunlit parts of these clouds are mostly brilliant white; their base is relatively dark and nearly horizontal.

Sometimes cumulus is ragged.'* See Plates 13 and 17: see also CLOUD CLASSIFICATION.

cup-contact anemometer: See ANEMOMETER, ANEMOGRAPH.

cup-counter anemometer: See ANEMOMETER.

cup-generator anemometer: See ANEMOMETER, ANEMOGRAPH.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol, 1, Geneva, WMO, 1956, p. 11.

PLATE 19 Crepuscular rays.

[*To face page* 68

curie: A measure of the activity of a radioactive substance, defined as that quantity of a radioactive substance which decays at the rate of $3 \cdot 7 \times 10^{10}$ disintegrations per second.

current, ocean: A general movement, of a permanent or semi-permanent nature, of the surface water of the ocean. The term must not be used of tidal streams, which change direction and speed hour by hour. A 'drift current' is a drift of the surface water which is dragged along by a wind blowing over it. A drift current which is deflected by an obstruction, such as a shoal or land, forms a 'stream current'. A stream current may be formed as a counter current to a primary current, replacing the water displaced by the primary current. The 'set' of a current or tidal stream is the direction in which it is going.

Owing to the high specific heat of water, the main ocean currents are of great climatic importance. Ocean currents result from several causes, the most important being wind and differences of density resulting from differences of temperature and salinity.

Among the best known currents are those of the North Atlantic, notably the GULF STREAM, North Atlantic drift, and the Labrador current.

curve fitting: The representation, using an appropriate method, (for example, that of LEAST SQUARES) of experimental data by a curve, the equation of which is then usually determined in terms of arbitrary constants.

If the relationship is represented by a fairly smooth curve, the methods of CORRELATION or of HARMONIC ANALYSIS may be appropriate. Alternatively, the use of logarithmic or semi-logarithmic paper may be helpful: thus if the relationship is of the nature $y = Ax^n$, plotting on logarithmic paper yields the values of A and n; if of the nature $y = Ae^{bx}$, plotting on semi-logarithmic paper yields the values of A and b.

cut-off high: A warm ANTICYCLONE, separated from the subtropical anticyclones, which is usually associated with a marked interruption of the zonal westerlies (BLOCKING). This feature forms initially as a ridge in the upper westerlies, intensifies into a closed circulation, and extends downwards towards the surface.

cut-off low: A DEPRESSION which lies equatorwards of the main mid-latitude belt of westerly winds. The feature starts as a trough in the upper westerlies, deepens into a closed circulation and extends downwards towards the surface.

cyanometer: An instrument for measuring the blueness of the sky.

cyclogenesis: The initiation of cyclonic circulation, or its strengthening around an existing CYCLONE or DEPRESSION.

cyclolysis: The disappearance or weakening of cyclonic circulation around an existing CYCLONE or DEPRESSION.

cyclone: That atmospheric pressure distribution in which there is a low central pressure relative to the surroundings. It is characterized on a synoptic chart by a system of closed isobars, generally approximately circular or oval in form, enclosing a central low pressure (see Figure 12 under DEPRESSION). 'Cyclonic circulation' is anticlockwise round the centre in the northern hemisphere, clockwise in the southern hemisphere: in either case the sense of rotation about the local vertical is the same as that of the earth's rotation.

A cyclone of middle and high latitudes is called a 'depression'. A TROPICAL CYCLONE of moderate intensity is a 'tropical storm': if of great intensity, a tropical cyclone in the Indian Ocean, Arabian Sea or Bay of Bengal is termed a 'cyclone', in the western Pacific a 'typhoon', in Western Australia a 'willy-willy', in most other tropical latitudes a 'hurricane'.

See also DEPRESSION.

cyclonic rain: Rainfall which is caused by the large-scale vertical motion associated with synoptic features such as DEPRESSIONS and FRONTS. It is one of a broad three-fold classification of rainfall, the other classes being 'orographic' and 'convective'.

cyclostrophic wind: A class of winds, of markedly curved flow, in which the CORIOLIS ACCELERATION is negligible in comparison with the CENTRIPETAL ACCELERATION. In such winds the cyclostrophic term is predominant in the expression for the GRADIENT WIND. A tropical cyclone provides an example in which the wind is mainly of this type.

D

daily variation: An alternative for DIURNAL VARIATION.

Dalton's law: See PARTIAL PRESSURE.

dawn: (OE, *dagian* to become day), the time when light appears (*daws*) in the sky in the morning or the interval between the first appearance of light and the rising of the sun. See TWILIGHT.

dawn chorus: A type of radio disturbance which consists of a chorus of overlapping, rising tones, mainly in the middle audio-frequency range, and is most intense at local dawn. The disturbance is rarely heard at geomagnetic latitudes less than about 50°. Since it is correlated with geomagnetic disturbance it is considered to be initiated by extraterrestrial charged particles. It is also, however, sometimes related to the occurrence of SFERICS and WHISTLERS.

day: A 'solar day' is the SYNODIC interval of time between successive occasions on which the sun is in the MERIDIAN of any fixed place (sun 'transits'). A 'sidereal day' is the corresponding interval between successive transits of a distant fixed star. Since the earth moves in an orbit round the sun with the same sense of rotation as that about its own axis, the length of the solar day is slightly greater than that of the sidereal day.

Owing to the eccentricity of the earth's orbit and to the inclination of the equator to the ecliptic, solar days are of slightly unequal lengths at different times of the year. The average length of the solar day is 86,400 seconds. This is called the 'mean solar day' and is taken as the length of the 'civil day', or the 'day' of ordinary parlance. The sidereal day contains 86,164 seconds nearly. The beginning and end of the civil day, as fixed by the civil power, are, in this country in winter, midnight GMT. During the operation of BRITISH SUMMER TIME, the civil day begins and ends at 23 hours GMT.

Other small measured variations of length of day, on various time scales, are of geophysical interest. (i) A secular lengthening (about 10^{-3} sec/100 years) is attributed mainly to tidal friction. (ii) Fluctuations of the order of decades are related to slow changes in the earth's magnetic field and are attributed to transfers of angular momentum between the core and mantle of the earth. (iii) An annual variation (length of day 2×10^{-3} sec greater in February than in August) is mainly attributed to an annual variation of wind velocity on a global scale, involving angular momentum changes of the air opposite to those of the surface of the earth and so maintaining constant the total angular momentum of the earth-atmosphere system.

As used in geophysics, a 'lunar day' is the interval between successive transits of the moon: it varies in length from about 24h 40m to 25h.

dayglow: The day-time AIRGLOW emission, thought to be rather more intense than the NIGHTGLOW but not observable at low levels against the intense background of scattered solar radiation.

daylight: The intensity of daylight illumination on a horizontal surface is recorded at some stations in the British Isles. The method consists of the measurement of the current emitted by a photocell on which radiation from the sun and sky falls after passing through a protective hemispherical dome of clear glass, a horizontal diffusing surface of translucent material, and a filter. The instrument is so designed that its spectral sensitivity is similar to that of the human eye.

débâcle: The breaking up in the spring of the ice in the rivers. The term is chiefly applied to the great rivers of Russia and Siberia and of the North American continent. Débâcle lasts from two to six weeks; during the period the rivers often overflow their banks, inundating the surrounding country. In southern Russia débâcle begins about the middle of March, in latitude 55°–60°N it begins early in April, but in the north it does not begin until May and in the extreme north of Siberia not until June. In Canada the débâcle in Ontario takes place in March and the water is free by April: in the St. Lawrence it is a little later, the river being free of ice in May.

de-briefing, meteorological: Oral description by an aircraft pilot or navigator of the meteorological conditions experienced during a flight.

decibar: Unit of pressure equal to 10^{-1} BAR, i.e. 100 mb.

decibel: Unit of relative measure of two flux densities, increasingly employed in various contexts such as electric power density, sound or light intensity—see, for example, NEBULE.

The decibel is one-tenth of a bel. Two flux densities (I_1, I_2) are said to differ by n bels when

$$\frac{I_1}{I_2} = 10^n \text{ i.e. when } n = \log_{10} \frac{I_1}{I_2}$$

Thus, flux densities differ by N decibels (unit normally employed in preference to bel) when

$$N = 10 \log_{10} \frac{I_1}{I_2}$$

declination: Angular distance of a body north or south of the celestial EQUATOR. In meteorology, seasons are controlled by the sun's declination which varies from about 23° 27′ N at the June solstice, through 0° at the March and September equinoxes, to about 23° 27′ S at the December solstice.

declination, magnetic: The departure (degrees east or west) of a compass needle from true (geographical) north. This angle, termed by mariners 'magnetic variation', varies in space and time. Mean values of westerly declination for 1960, and rates of annual decrease of westerly declination at this epoch were: Lerwick (Shetland Islands) 9° 43·2′ and 4·7′ per year; Eskdalemuir (Dumfriesshire) 10° 26·3′ and 5·8′ per year; Hartland (Devon) 9° 58·8′ and 6·2′ per year.

deepening: In synoptic meteorology, 'deepening' of a depression signifies a decrease of pressure at the centre of the system with time. The converse term is 'filling'.

deformation: In hydrodynamics, the change of shape of a small element of fluid produced by space variations of the fluid velocity. In meteorology, the term is used mainly in respect of the kinematical development of FRONTOGENESIS and FRONTOLYSIS. Thus, flow associated with a COL represents a deformation field of motion. If persistent, such a flow produces a relative crowding of isotherms along the axis of outflow from the neutral point of the col, and a displacement of isotherms away from the axis of inflow.

degree-day: See ACCUMULATED TEMPERATURE.

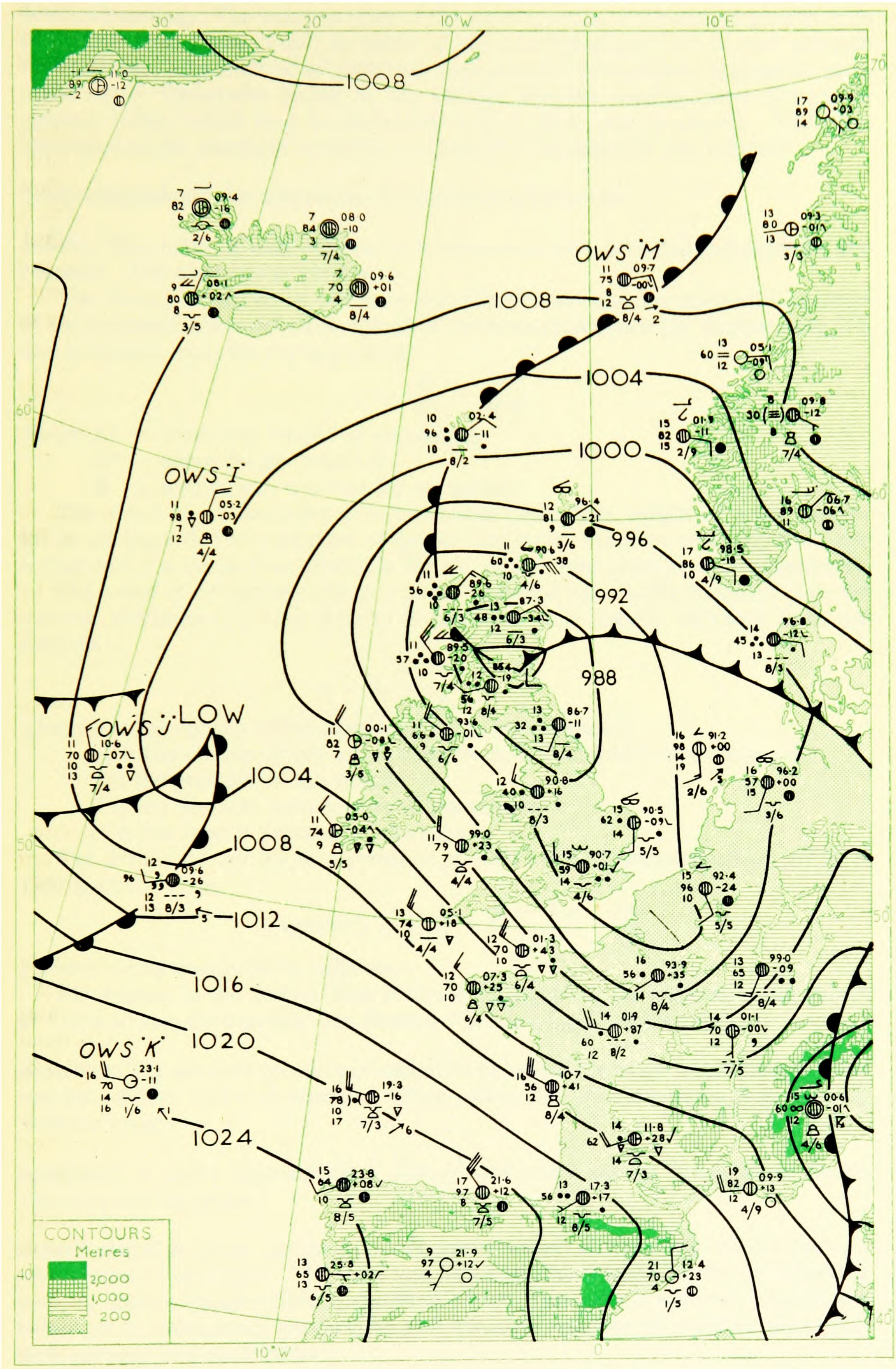

FIGURE 12—Depression over the British Isles, 0600 GMT, 13 July 1961.

dendrochronology: The interpretation of the varying width of the annual growth rings of certain trees ('tree rings') in terms of the corresponding year-to-year climatic fluctuations. This method of inferring past climatic fluctuations appears to have rather strict limitations owing to the various possible combinations of weather element values which may be associated with a given rate of growth. The most important of the elements involved are probably temperature and rainfall.

dendroclimatology: An alternative for DENDROCHRONOLOGY.

density: The mass of unit volume of a substance, at a specified temperature and pressure. The dimensions are ML^{-3}.

The density of the air is not measured directly but may be calculated in terms of the normally observed meteorological elements of pressure (p), temperature (T), and humidity, from the GAS EQUATION:

$$\rho = \frac{p}{RT} = \frac{Mp}{R^*T}$$

where M = molecular weight of air sample
R^* = universal gas constant
R = specific gas constant for air sample.

The value of M decreases with increasing percentage weight of water vapour in the air (regarded as a mixture of dry air and water vapour): relatively moist air is therefore less dense than relatively dry air, at the same pressure and temperature.

The value of M appropriate to a given sample is less readily obtained than the VAPOUR PRESSURE (e'). Air density is therefore more readily obtained from the formula:

$$\rho = \rho_0 \frac{p - \frac{3}{8}e'}{p_0} \cdot \frac{T_0}{T}$$

where ρ is the density of the sample of air to be computed
ρ_0 is the density of dry air at pressure p_0 and absolute temperature T_0
p is the pressure of the sample
T is the absolute temperature of the sample
e' is the vapour pressure of the sample.

The density of dry air at a pressure of 1000 mb and temperature of 290°K is 1201 gm/m³. Thus,

$$\rho\ (\text{gm/m}^3) = 1201 \times \frac{p - \frac{3}{8}e'}{1000} \cdot \frac{290}{T}$$

p and e' being measured in millibars.

Air density in the British Isles is about 1·2 kg/m³ at the surface: mean values at 5 and 10 km, for example, are about 0·7 and 0·4 kg/m³, respectively.

departure: The amount (positive or negative) by which the value of a meteorological element differs from a specified value—generally the corresponding climatic NORMAL value.

depegram: A curve representing a plot of dew-point against temperature on an AEROLOGICAL DIAGRAM.

deposit gauge: A gauge designed for the measurement of the deposited products of ATMOSPHERIC POLLUTION. The solid and liquid products which enter the collecting bowl of such a gauge within a specified period (generally a calendar month) are subjected to volumetric, gravimetric and chemical analyses in order to determine their amount and constitution.

depression: The term commonly applied to CYCLONES, of various intensities, in extratropical latitudes (see Figure 12). It is also used of a weak TROPICAL CYCLONE.

Central pressure of an extratropical depression varies from about 950 to 1020 millibars. It is described as 'shallow' or 'deep' if encircled by few or many isobars, respectively. It is said to 'deepen' or 'fill up' if the central pressure decreases or increases, respectively, with time. Its diameter varies from about 100 to over 2000 miles. The associated weather is unsettled, often with much precipitation and strong winds or gales. It is, in general, a highly mobile feature of the synoptic chart, with speeds ranging up to about 50 knots: large depressions may, however, remain almost stationary for several days. The general direction of movement is eastwards, though any direction of movement may occur. The extratropical depressions

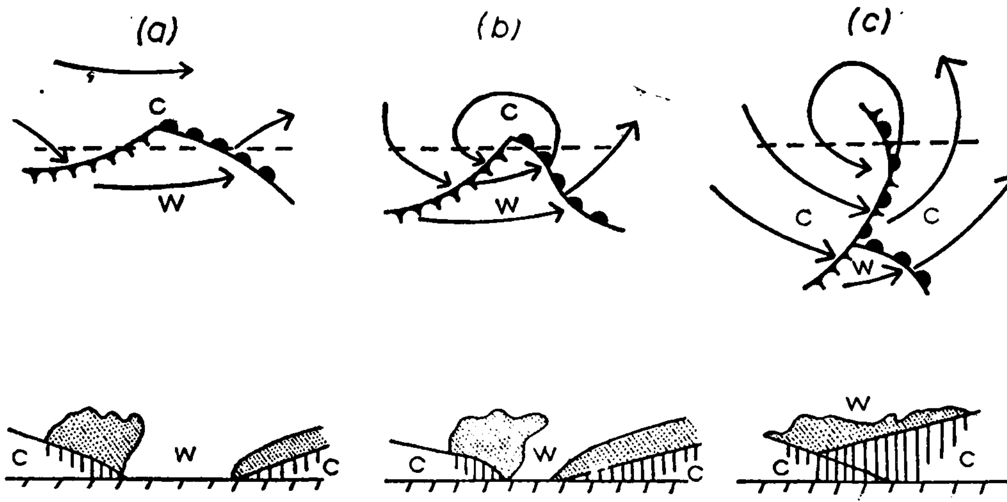

FIGURE 13—Plan views (above) of three stages of development of a frontal depression with (below) corresponding cross-sections along the horizontal dashed line. Letters 'C' and 'W' signify cold and warm air masses, respectively.

In the lower diagrams the vertical lines indicate precipitation and the dotted areas show cloud.

largely control the rainfall distribution of these latitudes and are responsible for much of the interchange of air between high and low latitudes, which is an essential feature of the GENERAL CIRCULATION of the atmosphere.

The typical extratropical depression is associated with FRONTS in the manner illustrated in Figure 13, in which three distinct stages in the 'life cycle'—the 'wave depression', 'warm-sector depression', 'occluded depression'—are shown. Such a cycle usually lasts some three to four days, sometimes appreciably longer. Deepening and rapid movement of the depression are common up to the warm-sector stage, with subsequent filling up and slowing down. The formation of a fresh wave depression on the trailing cold front of a depression which is in a later stage of development is a very common occurrence. Typically there are four or five such members of a 'depression family': the series normally ends with an incursion of cold air to unusually low latitudes.

In the early stages of a depression the troposphere is relatively warm near the centre (except in a shallow layer under the frontal surface) and the cyclonic circulation is shallow: in late stages the air is relatively cold throughout the troposphere and the cyclonic circulation is deep. Horizontal convergence and associated upward motion in the lower troposphere, and horizontal divergence in the upper troposphere, obtain near and in advance of the depression centre. The structure of horizontal divergence and vertical motion is reversed in the rear of the depression.

Important but less common types of extratropical depression which are not associated with fronts are the POLAR AIR DEPRESSION, THERMAL DEPRESSION, LEE DEPRESSION.

Shallow TROPICAL CYCLONES (depressions) are a relatively common feature of low-latitude non-desert regions and accentuate cloudiness and showeriness. They are often associated with horizontal convergence, especially at the INTERTROPICAL CONVERGENCE ZONE. Infrequently, such a depression greatly intensifies and is termed a HURRICANE, TYPHOON, or CYCLONE, depending on locality.

depression, angle of: The angular depression of an object measured by an observer, with reference to the horizontal plane through the observer.

descendent: See GRADIENT.

desert: A region in which rainfall is insufficient, in relation to rate of evaporation, to support vegetation. The main desert regions are in latitudes lower than 50° and are marked by relatively large diurnal and seasonal ranges of temperature. In terms of synoptic meteorology, the main causes of desert conditions are either the presence of a persistent anticyclone, as in northern Africa where the Sahara coincides with the average position of the subtropical belt of high pressure, or a configuration of ground which shuts out the moisture-bearing winds as, for example, Gobi, in central Asia.

For a formula used by W. Köppen and R. Geiger for the limit of rainfall which constitutes a desert climate, see ARID.

desiccation: The permanent disappearance of water from an area due to a change of climate and especially a decrease of rainfall. Large areas in central Asia, Africa and western America have been desiccated since the last GLACIAL PHASE, but there does not appear to have been much progressive desiccation during the past 2000 years. See also EXSICCATION.

detachment: In meteorological literature, usually refers to the process of ejection of ELECTRONS from negative IONS which occurs in the high atmosphere by various types of particle collision and by the action of light photons ('photo-detachment').

development: In synoptic meteorology, the intensification of circulation, cyclonic or anticyclonic.

A strong measure of 'compensation' exists in the atmosphere such that, for example, the surface pressure fall associated with strong surface cyclonic development is a small residual between horizontal convergence at low levels and horizontal DIVERGENCE at high levels (with upward motion through much of the troposphere). The converse situation obtains in strong anticyclonic development. In R. C. Sutcliffe's 'development theorem', which is based on these conceptions, the relative divergence between selected low and high levels, e.g. surface and tropopause, is expressed, on various simplifying assumptions, in terms of the THERMAL WIND and VORTICITY, both of which may be measured from charts.

$$\mathrm{div}_p\,\mathbf{V}_1 - \mathrm{div}_p\,\mathbf{V}_0 = -\frac{1}{f}\left(\mathbf{V}'\frac{\partial f}{\partial s} + \mathbf{V}'\frac{\partial \zeta'}{\partial s} + 2\mathbf{V}'\frac{\partial \zeta_0}{\partial s}\right)$$

where div_p is the divergence in an isobaric surface, $\mathbf{V}_1$ and $\mathbf{V}_0$ are wind vectors at the upper and lower pressure levels, f is the CORIOLIS PARAMETER, $\mathbf{V}'$ the thermal wind vector between the selected levels and ζ' its vorticity, ζ_0 the vorticity at the lower level, and $\partial/\partial s$ denotes differentiation in the direction of the thermal wind. A positive (negative) result implies cyclonic (anticyclonic) development.

Of the three terms on the right-hand side of the above development equation, the first involves the variation of f (i.e. of latitude) in the direction of the thermal wind and is generally small. The second is the so-called 'development term' and is proportional to the strength of the thermal wind and to its variation of vorticity along its own direction. Contributions to the latter vorticity are made by the curvature and shear of the thermal or THICKNESS pattern, as illustrated, for example, in the CONFLUENT THERMAL RIDGE. The third term is the THERMAL STEERING term which is proportional to the thermal wind and to the variation of surface vorticity in the direction of the thermal wind ($\partial\zeta_0/\partial s$). This term predominates when the pattern of surface vorticity is well marked and the thermal wind almost zonal and without horizontal shear, the first two terms then being small.

deviation: In statistics, the difference between a particular value and the arithmetic mean of the series of which the value forms a part. See also MEAN DEVIATION and STANDARD DEVIATION.

The angle between the surface wind and the direction of the isobars is sometimes termed the 'deviation of the wind'. The term 'deviation' is also used to signify the change of direction to which light rays are subject on passing from one medium to another of different refractive index.

dew: Condensation of water vapour on a surface whose temperature is reduced by radiational cooling to below the DEW-POINT of the air in contact with it. Of two recognized processes of dew formation the more common occurs in conditions of calm (wind at two metres less than one knot) when water vapour diffuses from the soil upwards to the exposed cooling surface in contact with it (e.g. grass) and there condenses. The second of the processes is one of 'dewfall' when, in conditions of light wind, downward turbulent transfer of water vapour from the atmosphere to the cooled surface occurs. A night of clear skies, moist air and sufficient but not excessive wind is such as gives maximum dewfall rates (about 3 mg/cm^2 hr in the British Isles). Such nights are relatively uncommon and are estimated by J. L. Monteith* to produce in the British Isles a total of only about 0·1 to 0·2 inch dewfall per year. See also DROSOMETER, GUTTATION.

dewbow: A RAINBOW formed on the ground, usually in the shape of a hyperbola, by the REFRACTION and REFLEXION of the sun's rays in dew-drops.

dew-point: The dew-point (T_d) of a moist air sample is that temperature to which the air must be cooled in order that it shall be saturated with respect to water at its existing pressure and HUMIDITY MIXING RATIO.

T_d is that temperature for which the saturation VAPOUR PRESSURE with respect to water (e'_w) is identical with the existing vapour pressure (e') of the air,

$$e' = e'_w \text{ at } T_d.$$

Dew-point may be measured indirectly from wet- and dry-bulb temperature readings with the aid of humidity tables (see PSYCHROMETER), or directly with a 'dew-point HYGROMETER'.

dew-pond: A pond on high ground on chalk downs, artificially constructed with watertight bottom. It is found that, despite the watering of cattle, such ponds retain water during all but the most prolonged droughts, after ponds at lower levels are dried up.

Observation does not support the theory, which gave rise to the name, that such ponds are replenished to a significant extent by night dewfall. The explanation for their persistence probably lies in the relatively large amounts of precipitation that fall at high levels and in the occurrence of FOG PRECIPITATION.

diabatic: A diabatic thermodynamic process is one in which heat enters or leaves the system. Meteorological examples are evaporation, condensation, turbulent mixing, heat conduction, emission and absorption of radiation.

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* MONTEITH, J. L.; Dew. *Quart. J.R.met. Soc., London*, **83**, 1957, p. 322.

The term 'diabatic' is of recent usage. The established equivalent term 'non-adiabatic' is still generally preferred because it better emphasizes the nature of the process involved. See also ADIABATIC.

diathermancy: The ability of a substance to transmit heat. Oxygen and nitrogen are diathermanous, while water vapour, ozone and carbon dioxide absorb heat radiation of certain wavelengths: the atmosphere is therefore only partially diathermanous.

dielectric constant: The ratio (ε) of the capacity of a condenser with a given substance as dielectric to that of the same condenser with a vacuum as dielectric is the dielectric constant of the substance.

The dielectric constant is a property of a medium which determines the curvature of the path of an electromagnetic wave through it and so is closely related to the REFRACTIVE INDEX (n) of the medium. For a given substance, ε is a function of temperature and frequency. At frequencies and for a substance in which there is

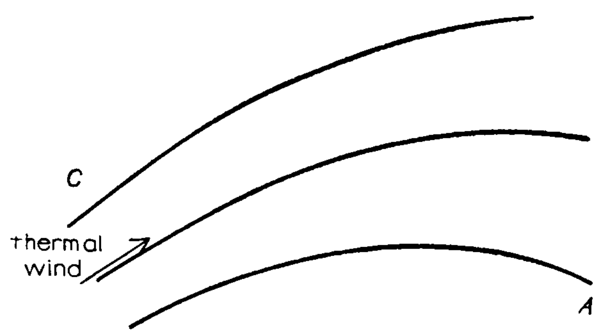

FIGURE 14—Diffluent thermal ridge.

no absorption of the wave energy the relationship between them is $\varepsilon = n^2$. For air, the relatively small departures of ε from unity are determined mainly by the amount of water vapour present.

differential thermal advection: Differential thermal advection signifies a change in the vertical temperature structure, and so in the static STABILITY, of the air at a particular place, brought about by horizontal ADVECTION of air. Thus, the advection of relatively warm air at lower levels, or of cold air at higher levels, or both, is differential thermal advection of the type that leads to a decrease of static stability. In general, in northern hemisphere temperate latitudes veering (backing) of wind with increase of height signifies warm (cold) air advection in the atmospheric layer concerned.

diffluence: The separation of adjacent STREAMLINES in the direction of flow. See DIVERGENCE.

diffluent thermal ridge: A pattern of THICKNESS lines which is concave towards high thickness and in which the thickness lines separate in the direction of the THERMAL WIND. According to the theorem of DEVELOPMENT, cyclogenesis (C) may be expected to occur behind and to the left, anticyclogenesis (A) ahead and to the right, of the pattern, as illustrated in Figure 14.

diffluent thermal trough: A pattern of THICKNESS lines which is concave towards low thickness and in which the thickness lines separate in the direction of the THERMAL WIND. According to the theorem of DEVELOPMENT, cyclogenesis (C) may be expected to occur ahead and to the left, anticyclogenesis (A) behind and to the right, of the pattern, as illustrated in Figure 15.

diffraction: The bending of light rays produced by an obstacle in the path of the radiation, such as to produce an 'interference' pattern within the geometrical shadow region of the obstacle. The amount of the bending varies with the wave-length: resolution into spectral components therefore occurs in the case of visible light. Diffraction is explained by the wave theory of light, but not on the simple assumption that light travels in straight lines.

The phenomenon is responsible for a number of effects in atmospheric optics—see, for example, BISHOP'S RING, CORONA, GLORY. See also BABINET'S PRINCIPLE.

diffuse front: A FRONT at which the changes in air-mass properties (temperature, humidity, wind velocity) from one side of the front to the other are not concentrated in a narrow belt but are spread through a wide 'frontal zone', which may be up to several hundred miles in width.

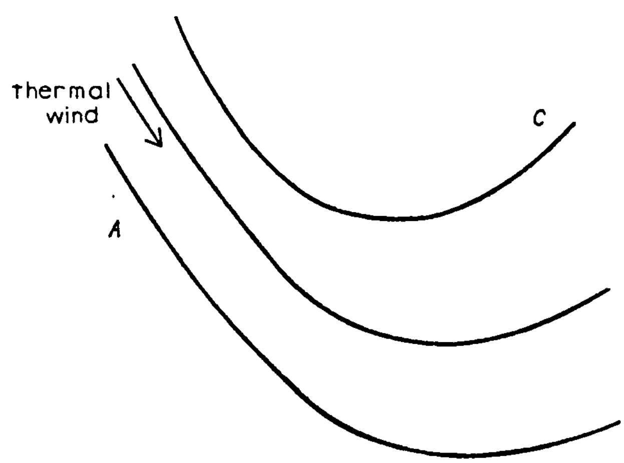

FIGURE 15—Diffluent thermal trough.

diffuse radiation: RADIATION which is received simultaneously from very many directions. In meteorology, it often signifies the solar radiation received (in particular, at the earth's surface) after SCATTERING by atmospheric molecules, cloud, dust etc., as opposed to the parallel radiation received by direct incidence. It is also termed 'sky radiation'.

diffusion: Molecular diffusion is the process by which contiguous fluids mix slowly, despite differences in their density. The process follows laws similar to those of thermal CONDUCTION (heat diffusion). It is, however, so slow a process in the atmosphere as to be negligible in comparison with the mixing effected by turbulent eddies—'eddy diffusion'. See EDDY.

Attention is given in the atmospheric problem to the diffusion of such properties as momentum, heat, water vapour, gaseous or particulate matter, the aim being to relate observed diffusion to the state of the atmosphere, as expressed by the temperature, humidity and wind structure. See also DIFFUSIVITY.

diffusive equilibrium: That state of equilibrium, also termed 'gravitational equilibrium', in which the concentrations of different gases in a mixture of gases change with height according to the molecular weights of the gases involved. Efficient mixing prevents this state from being reached in the atmosphere below a level of about 80 km. See also GRAVITATIONAL SEPARATION.

diffusive separation: See GRAVITATIONAL SEPARATION.

diffusivity: A coefficient (K), of dimensions L^2T^{-1}, which measures the rate of DIFFUSION of a property (E). In the case of simple (Fickian) diffusion, K is defined by the equation

$$\frac{\partial E}{\partial t} = K \nabla^2 E$$

where ∇^2 is the LAPLACIAN OPERATOR.

In meteorology, the term refers to a measure of the rate of diffusion effected by atmospheric eddies, that effected by molecular processes being negligible in comparison. The coefficients involved are termed EXCHANGE COEFFICIENTS. That pertaining to the diffusion of matter is the 'eddy diffusivity', while the exchange coefficients for momentum and heat are the 'eddy viscosity' (see VISCOSITY) and 'EDDY CONDUCTIVITY', respectively. A definition of the coefficients in terms of the Fickian diffusion equation is of limited applicability in meteorology due to wide space and time variability of the exchange coefficients: the appropriate equation which defines K in these circumstances is

$$\frac{\partial E}{\partial t} = \frac{\partial}{\partial l}\left\{K(l)\frac{\partial E}{\partial l}\right\}$$

dimensions (of units): The powers to which the FUNDAMENTAL UNITS of mass (M), length (L), time (T) have to be raised to express fully the units of a physical quantity; e.g. pressure = force/unit area = mass × acceleration/unit area, has the dimensions $MLT^{-2}L^{-2}$, i.e. $M\ L^{-1}T^{-2}$. A pure number is assigned the dimension unity: temperature is allotted the special dimension θ.

dip, magnetic: Angle of inclination of a magnet with respect to the horizontal. This angle, termed also 'inclination', varies in space and time. Mean values for 1960 were: Lerwick (Shetland Islands) 72° 55·0′; Eskdalemuir (Dumfriesshire) 69° 43·2′; Hartland (Devon) 66° 43·9′. At this epoch, magnetic dip in Great Britain was decreasing at the approximate rates of 0·5′ per year in the north and 1·2′ in the south.

In so far as the earth's magnetic field resembles that of a dipole, the angle of dip (I) is related to geomagnetic latitude φ (see GEOMAGNETISM) by the relation

$$\tan I = 2 \tan \varphi.$$

direct circulation: A circulation in which the POTENTIAL ENERGY represented by the juxtaposition of relatively dense and light air masses is converted into KINETIC ENERGY as the lighter air rises and the denser air sinks. Land and sea breezes are examples of such a circulation. In an 'indirect circulation' the converse holds and the potential energy increases as kinetic energy decreases.

discontinuity: As a rule, the fundamental atmospheric variables of wind velocity, temperature and humidity are continuous functions of space and time, while pressure is invariably so. Occasionally, the space rate of change at a fixed time (or time rate of change at a fixed place) of wind velocity, temperature, humidity and also of pressure tendency is so abnormally great that the distribution of these variables may be regarded as discontinuous. Examples occur at well marked FRONTS and surfaces of SUBSIDENCE, more particularly, however, in association with SHOCK WAVES.

dishpan experiment: One of a series of experiments, notably by D. Fultz, in which the motions generated in a rotating liquid have been studied as an aid in the understanding of atmospheric motions. The liquid is contained in a cylindrical vessel ('dishpan') which is rotated about a vertical axis: heat is supplied at the walls of the vessel and removed at the centre, simulating the equatorial heat source and polar heat sink, respectively.

dispersion: In physics, the separation of RADIATION into its component wavelengths, due to wavelength dependence of such processes as REFRACTION, DIFFRACTION, SCATTERING.

In statistics, the 'scatter' of a group of values. The most common measure of dispersion is the STANDARD DEVIATION: other measures are the 'mean deviation' (mean departure from arithmetic mean, independent of sign) and the RANGE of the values.

dissipation trail: An effect, opposite to the CONDENSATION TRAIL, in which the passage of an aircraft through cloud is marked by the appearance of a clear lane. The phenomenon, which is relatively rare, is found under conditions when the effect of the heat of combustion of the fuel released by the aircraft exhaust is sufficient to outweigh that of the released water vapour to the extent of causing tenuous cloud in the wake of the aircraft to evaporate. Occasionally, the effect may be produced by an aircraft flying in relatively dry air, just above a thin cloud layer, due to the dragging down and mixing of the dry air with the cloud in the wake of the aircraft. A similar (spurious) effect is sometimes produced when the shadow of a condensation trail is cast on a thin cloud layer.

dissociation: In geophysics, the breakdown of atmospheric molecules into component atoms by the action of ultra-violet radiation in the high atmosphere. The minimum energy required to effect dissociation of a molecule is its 'dissociation energy'.

Dissociation in the atmosphere becomes increasingly important with increase in height above 80 km, mainly in respect of oxygen (molecular to atomic oxygen).

distrail: A common abbreviation for DISSIPATION TRAIL.

disturbance: Sometimes used instead of DEPRESSION or TROUGH of low pressure, especially in broadcast GENERAL INFERENCES.

diurnal variation: The changes of magnitude, for example of a meteorological element, within the course of a (solar) day, more especially the systematic changes that occur within the average day.

A systematic diurnal variation (or 'daily variation') may be revealed by determining the average values, in a large number of days, of the selected element at 0h, 1h, 2h . . . 24h, and removing the non-cyclic change (if any) which is given by the difference between the average values obtained for 0h and 24h. Irregular fluctuations present on individual days are eliminated by averaging over a sufficient number of days.

The systematic diurnal variation of atmospheric pressure is dominated in most latitudes by a 12-hourly oscillation which proceeds according to LOCAL TIME (maxima at 10h and 22h, minima at 4h and 16h local time) and whose amplitude decreases polewards from the equator: at 0° and 50°, for example, approximate values of the swing either side of the mean are 2·0 and 0·7 mb, respectively. In low latitudes the variation is prominent enough to be easily visible on a barogram, even with the near approach of a tropical storm (see Figure 32 under TROPICAL CYCLONE). In middle latitudes the variation is normally obscured by non-periodic pressure changes, but is easily revealed by averaging. In high latitudes the 12-hourly local time oscillation is very small and the main feature of the diurnal variation is a small 24-hourly UNIVERSAL TIME oscillation.

Temperature and relative humidity have systematic local-time diurnal variations, nearly opposite in phase, and of greater amplitude in summer than in winter.

Minimum temperature, for example, occurs at about sunrise, and maximum temperature some two hours in winter, three hours in summer, after noon.

Systematic diurnal variations within the lunar day—'lunar diurnal variations'—are obtained by averaging the magnitudes of elements arranged according to lunar time. Pressure variations of this type have been determined for many parts of the world, and an associated temperature variation in low latitudes has been discovered.

The *Observatories' Year Book*, a serial publication of the Meteorological Office, contains many data relating to the diurnal variations of geophysical elements.

divergence: The divergence of the flux of a quantity (e.g. radiation or momentum) expresses the time rate of depletion of the quantity per unit volume. Negative divergence is termed 'convergence' and relates to the rate of accumulation.

In meteorology, divergence (or convergence) is mostly used in relation to the velocity vector and so refers to the flux of air particles themselves. The 'divergence of velocity' is a three-dimensional property which expresses the time rate of expansion of the air per unit volume. The following relation holds:

$$\text{div } \mathbf{V} \text{ (or del } \mathbf{V} \text{ or } \nabla \cdot \mathbf{V}) = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}$$

where u, v, w are the components of the velocity vector $\mathbf{V}$ in the Cartesian x, y, z directions, respectively.

In the atmosphere, div $\mathbf{V}$ is small and is of little direct interest. The main concern is with the 'horizontal divergence of velocity' (often referred to as the 'horizontal divergence' or even, misleadingly, the 'divergence') which, denoted $\text{div}_H \mathbf{V}$ or $\text{div}_2 \mathbf{V}$ etc., is identified with the sum $(\partial u/\partial x + \partial v/\partial y)$, and expresses the time rate of horizontal expansion of the air per unit area.

$$\text{Since div } \mathbf{V} \simeq 0,\ \text{div}_H \mathbf{V} \equiv \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = -\frac{\partial w}{\partial z}$$

i.e. horizontal divergence of air is closely associated with vertical contraction (usually termed 'vertical convergence') of an air column centred at the level concerned. Similarly, horizontal convergence is linked with 'vertical divergence' $(\partial w/\partial z)$.

Contributions to $\text{div}_H \mathbf{V}$ may be made by 'diffluence' (separation of streamlines in the direction of flow) and by increase of wind downstream. Since, however, diffluence is generally associated with decrease of wind downstream (and 'confluence' with increase of wind downstream), the respective contributions to $\text{div}_H \mathbf{V}$ are generally of opposite sign. Therefore, $\text{div}_H \mathbf{V}$ is a small remainder which is difficult to determine, even as to sign, in the free atmosphere from the substitution of wind observations in the expression $(\partial u/\partial x + \partial v/\partial y)$. It is more accurately determined from the VORTICITY EQUATION and from the distribution of vertical motion.

The dimensions of div $\mathbf{V}$ are T^{-1}. Values of $\text{div}_H \mathbf{V}$ in large-scale motions in the free atmosphere generally range from zero up to about 10^{-5} sec^{-1}. (It can be considerably greater locally in frontal zones). On average, divergence (or convergence) is least at a level of about 600 mb—the so-called 'level of non-divergence'.

D-layer: That part of the IONOSPHERE, situated between about 65 and 80 km, which is mainly responsible for the absorption of radio energy reflected from higher levels, but from which radio waves of very low frequency may also be reflected. It is sometimes referred to only as the 'D-region' because it has apparently no peak value of electron concentration. The extra ionization caused at this level by SOLAR FLARE radiation gives rise to various types of 'sudden ionospheric disturbance' (see SID).

Dobson spectrophotometer: An instrument used in the routine measurement of atmospheric OZONE. The method consists of isolating, in the solar radiation spectrum, two wavelengths in the region of partial ozone absorption in the near ultraviolet (0·30 to 0·33 μ), allowing them to fall in rapid succession on a photomultiplier connected through an a.c. amplifier and rectifier to a galvanometer, and reducing, by means of a calibrated optical wedge, the intensity of the longer, less absorbed wave until the photomultiplier outputs are equal and the galvanometer records no current. The amount of atmospheric ozone in a vertical column is obtained from the position of the wedge and the solar zenith angle at the time of observation.

Incorporated in the calibration of the instrument is the ratio of the intensities of the selected wavelengths outside the atmosphere. This is obtained, once for all, from a series of instrumental observations at various solar zenith angles and extrapolation to zero path length through the atmosphere. The extrapolation is based on the assumption, supported by photochemical theory, that there is little or no systematic diurnal variation of total ozone.

The standard measurements are those made against direct sunlight. Measurements are also made against the zenith sky, clear or cloudy, and against moonlight, using empirical relations with the direct sunlight observations.

The instrument may be used to obtain the vertical distribution of ozone, using the UMKEHR METHOD.

doctor: See HARMATTAN.

doldrums: The equatorial oceanic regions of light variable (mainly westerly) winds, accompanied by heavy rains, thunderstorms and squalls. These belts, variable in position and extent, have a systematic north and south movement some 5° either side of a mean position, following the sun with a lag of one or two months.

Doppler effect: The observed frequency of a source moving with velocity v towards an observer, and emitting waves (e.g. radio, sound or light) of wavelength λ, is greater than the emitted frequency f by the amount $\delta f = v/\lambda$—the 'Doppler effect'. For a receding source the observed frequency is less than f by the same amount. If, on average, emitting sources approach and recede from an observer in equal numbers, 'Doppler broadening', without shift, is observed. Frequency and spectral measurements may thus be employed to measure the velocity of fast-moving sources.

The Doppler-shift technique may be used to obtain a measure of the vertical velocities of precipitation elements. The frequency shift suffered by a radio wave on reflexion from moving objects ($\delta f = v/\lambda$) gives a measure of the mean 'line of sight' velocity of the elements, while variations of the intensity of the radar echo may be used to infer motions possessed by the various elements relative to one another.

Doppler radar: If a RADAR target is moving towards or away from the radio receiver, the frequency of a reflected signal is, because of the DOPPLER EFFECT, slightly different from the transmitted frequency. Doppler radar is designed to interpret this effect in terms of the radial velocities of targets. It is employed in meteorology to deduce various types of information: for example, horizontal air motion at various heights in a precipitation region, the speeds of fall of precipitation particles and, on certain assumptions, vertical air motion within precipitation regions.

drag coefficient: A non-dimensional coefficient (C_D), also termed the 'skin-friction coefficient', which is defined by the equation $\tau = C_D \rho \bar{U}_S^2$, where τ is the REYNOLDS STRESS (surface shearing stress), ρ the air density, and $\bar{U}_S$ the wind speed observed near the surface.

C_D is a conventional, as opposed to a unique, parameter of surface roughness. Its value depends on the height at which wind speed is observed and also on the stability of the air. Wind speed observed at a height of 1 or 2 m is generally employed.

drainage area: The area whose surface directs water towards a stream above a given point on that stream. See also CATCHMENT AREA and GATHERING GROUND.

drainage gauge: See PERCOLATION.

drainage wind: An alternative for KATABATIC WIND.

drifting dust or sand: 'Dust or sand, raised by the wind to small heights above the ground. The visibility is not sensibly diminished at eye level'.*

drizzle: Liquid precipitation in the form of water drops of very small size (by convention, with diameter between about 200 and 500 microns i.e. 0·2 and 0·5 mm).

Drizzle forms by COALESCENCE of droplets of stratus cloud. It falls from stratus cloud of low base, in which the widespread upcurrents which form the cloud have a velocity smaller than the terminal velocity of the drops concerned. High relative humidity below the cloud base is also required to prevent the drops from evaporating before reaching the earth's surface.

For synoptic purposes, drizzle is classified as 'slight', 'moderate', or 'thick': slight drizzle corresponds to negligible run-off from roofs, thick drizzle to a rate of accumulation greater than 1 mm/hr.

drop, droplet: Terms generally applied in meteorology to the spherical particles of water which comprise liquid PRECIPITATION and CLOUD elements, respectively. The differentiation, while not precise, is essentially one of size, the limiting diameter being of the order 200 microns (0·2 mm).

drosometer: An instrument for measuring the amount of DEW deposit. In the Duvdevani dew-gauge, the size, form and distribution of dew-drops deposited overnight on a rectangular block, carrying a special paint and exposed at a standard height, are compared with standard photographs relating to a dew deposit of known amount. In other gauges, some of them recording, dew deposited (e.g. on a hygroscopic surface) is obtained by weighing. A basic uncertainty in all cases is the relationship between the amount of dew deposited on the gauge and that deposited on natural surfaces.

drought: Dryness due to lack of RAINFALL. Certain definitions have been adopted in order to obtain comparable statistical information on the subject of droughts. Thus an 'absolute drought' is a period of at least 15 consecutive days, to none of which is credited 0·01 in., or 0.2 mm, or more of rainfall. A 'partial drought' is a period of at least 29 consecutive days, the mean daily rainfall of which does not exceed 0·01 in., or 0.2 mm. A 'dry spell' is a period of at least 15 consecutive days to none of which is credited 0·04 in., or 1·0 mm or more of rainfall. During the 62 years 1858–1919, there were 69 absolute droughts and 163 dry spells at Camden Square, London. The definitions of absolute drought and partial drought were introduced in *British Rainfall*† (1887, p. 21) while that of dry spell was first used in *British Rainfall*† (1919, p. 15). A chapter is devoted to the subject in each volume of *British Rainfall.*

dry adiabatic (or dry adiabat): Line on an AEROLOGICAL DIAGRAM representing the dry-adiabatic lapse rate. See ADIABATIC.

dry air: In physical meteorology this term generally signifies air which is completely dry, i.e. which contains no water vapour. In synoptic meteorology and climatology

* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 71.

† London, Meteorological Office; *British Rainfall.* London.

the term usually refers to air of low RELATIVE HUMIDITY. In the BEAUFORT NOTATION the letter 'y' signifies 'dry air', precisely defined as having a relative humidity of less than 60 per cent.

dry- and wet-bulb hygrometer: An alternative for PSYCHROMETER.

dry ice: A common term for the substance solid carbon dioxide, frequently used in CLOUD SEEDING experiments. The substance is generally discharged from an aircraft into supercooled cloud in particles of about half-inch diameter at the rate of a few pounds per mile. The particles vaporize at a temperature of −78·5°C. The local cooling of the ambient air effected by the sublimation process produces myriads of minute ice crystals, which may then act as ice nucleating agents.

dry season: A period of a month or more, recurring every year, which is marked in a given region (generally tropical or subtropical) by the complete or almost complete absence of precipitation. Winter is the dry season in most tropical regions: summer is, however, the dry season in the MEDITERRANEAN-TYPE CLIMATE.

dry spell: Defined as a period of at least 15 consecutive days to none of which is credited 0·04in. or 1·0mm or more of RAINFALL. See also DROUGHT.

duplicatus (du): One of the CLOUD VARIETIES. (Latin, *duplicatus* doubled.)
'Superposed cloud patches, sheets or layers, at slightly different levels, sometimes partly merged. This term applies mainly to CIRRUS, CIRROSTRATUS, ALTOCUMULUS, ALTOSTRATUS and STRATOCUMULUS'.* See also CLOUD CLASSIFICATION.

dust: The atmosphere carries in suspension, often for long distances, solid particles of varying character and size. The chief sources of these particles are volcanic eruptions, meteors, dust and sand raised by winds, and the smoke produced in industrial and domestic combustion processes and in forest fires.

An important meteorological effect of atmospheric dust is its depletion of solar radiation by scattering and, to a smaller degree, by absorption. When present in appreciable quantity it comprises atmospheric HAZE. Most dust particles are of a size sufficiently small to cause differential SCATTERING of sunlight and so produce, for example, highly coloured sunsets—see SUNRISE AND SUNSET COLOURS.

The concentration and size distribution of solid particles suspended in the atmosphere, and their effectiveness as condensation nuclei, are discussed under NUCLEUS.

dust counter: An instrument for counting the dust particles in a known volume of air. In Aitken's dust counter, condensation is made to occur on the nuclei present by ADIABATIC expansion of air, and the number of drops is ascertained. In Owen's dust counter, a jet of damp air is forced through a narrow slit in front of a microscope cover glass. The fall of pressure due to expansion of the air after passing the slit causes the formation of a film of moisture on the glass, to which dust adheres, forming a record which can be studied under a microscope.

duststorm: A storm, occurring mainly in low- and mid-latitude desert regions, in which dust is raised by turbulent winds to great heights and surface visibility is reduced to low limits (less than 1100 yards for the purpose of a synoptic report). The necessary conditions for a duststorm, whose arrival is marked by a 'wall of dust', are a supply of fine dust, the sudden onset of relatively strong winds and a steep lapse rate of temperature. Often associated with desert thunderstorms, they tend to be short-lived if rain reaches the ground before evaporation.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 16.

dust whirl (or devil): A WHIRLWIND, in which dust and sand are carried aloft from the ground by very strong convection from a hot, sandy region. The rotation may be in either direction round the centre, which is itself often free from dust. Heights of several thousand feet have been reported but are generally less than 100 feet. Speeds at which dust whirls move vary from less than 5 knots to over 25 knots. The phenomenon is sometimes termed 'sand pillar'.

D-value: In aeronautics, the difference (metres or feet) radio ALTIMETER reading minus pressure altimeter reading when set to standard ground-level pressure of 1013·2 mb. The D-value is one of the elements reported in the AIREP code.* Plotted D-values may be used, as in the method developed by J. C. Bellamy, in pressure-height synoptic analysis.

dynamical forecast: See NUMERICAL WEATHER FORECAST.

dynamical meteorology: The study of the causes and nature of motion of the atmosphere.

dynamic metre: See GEOPOTENTIAL.

dynamic pressure: In meteorology, the force exerted by the wind on unit area of the windward face of a surface. At points where the air is brought to rest relative to the surface it is given by the quantity $\frac{1}{2}\rho V^2$, where ρ is air density and V the relative wind velocity.

dynamic stability: A term sometimes used, in a restricted sense, as a synonym of INERTIA STABILITY. More generally this term, or the alternative 'hydrodynamic stability', signifies an atmospheric state characterized by there being no tendency for small wave-like perturbations of the flow to grow. Various influences operate in the atmosphere to cause the contrary state of (hydro)dynamic instability, e.g. INERTIA, GRAVITY, SHEAR, or a strongly BAROCLINIC atmosphere. See also STABILITY.

dynamic temperature change: A change associated with the compression (warming) or expansion (cooling) of a gas. See ADIABATIC.

dynamo theory: See GEOMAGNETISM.

dyne: The unit of force in the C.G.S. SYSTEM of units. It is the force that produces an acceleration of 1 cm/sec^2 when applied to a mass of 1 gm. The dimensions are MLT^{-2}.

* London, Meteorological Office; Handbook of weather messages. Part II. London, HMSO, 1959.

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earth: The earth is a spheroid which is somewhat flattened at the poles relative to the equator due to rotation on its axis—the so-called 'equatorial bulge'. It is of mean radius 6371·229 km (about 4000 miles), of angular velocity $7{\cdot}292 \times 10^{-5}$ rad/sec, of mean distance from the sun $1{\cdot}4968 \times 10^{8}$ km, of mass $5{\cdot}975 \times 10^{24}$ kg and of mean density relative to water 5·5.

The earth's interior comprises a thin outer 'crust' of rocks which is part of a solid 'mantle' extending to a depth of about 1800 miles. Below this is probably a metallic fluid 'outer core' of thickness 1400 miles and, near the earth's centre, an 'inner core' of radius 800 miles which is probably solid. The estimated temperature at the earth's centre is in the range 2000 to 10,000°K and the estimated pressure of the order 4×10^{6} atmospheres.

The respective percentages of water and land on the earth's surface are, in the northern hemisphere 60·7 and 39·3; in the southern hemisphere 80·9 and 19·1; for the earth as a whole 70·8 and 29·2.

earth currents: The term 'earth currents' (or 'telluric currents') is generally taken to comprise the world-wide systems of electric currents (with large local differences) which flow in the earth's crust and display both systematic and irregular variations which are closely related to variations of the earth's magnetic field (see GEOMAGNETISM) and to allied phenomena. On some occasions the irregular variations are large enough to interrupt land-line communications. Such small and local currents as are associated with chemical effects in the earth's surface and the large but short-lived current surges associated with lightning flashes are excluded from consideration.

Systematic recording of earth currents is made in terms of the potential gradient between pairs of electrodes which are generally separated by a distance of at least a mile. A typical 'quiet' value is about 0·2 volt/km, and a 'disturbed' value upwards of 1 volt/km. Precise measurements are difficult because of electrode contact potential, and insulation, etc., difficulties. Determination of earth resistivity (found to vary over a wide range with type of soil or rock and to vary greatly also with moisture content) allows, in conjunction with the potential-gradient measurements, the earth-current density to be calculated.

The earth potential gradient undergoes regular solar and lunar diurnal variations, the lunar variations having about one-fifth the range of the solar. The latter show considerable differences in type and amplitude at different stations: two maxima and minima occur, however, at most places. The range of the solar variation is least in winter and greatest near the equinoxes.

Earth-current and magnetic storms accord closely in time and agree well in their general form. The systematic slower diurnal variations of earth currents are also related to magnetic variations, but in a more complex way. The cause of both phenomena lies in electrical effects in the high atmosphere. Complications are introduced, however, by local differences in the conductivity of the earth's crust, by differences in speed of the high atmospheric variations on different occasions, and by reactions of the earth currents themselves on the recorded magnetic variations.

earthlight: See MOON.

earth temperature: If the temperature of the earth's surface were constant, heat would be conducted continually upwards from the earth's very hot interior to the earth's surface and there dissipated, mainly by radiation: a steady state would be reached, with temperature increasing with depth at an almost steady rate. This simple régime is much changed in the top layer of the earth by the fact that the earth's surface is raised, by absorption of solar radiation, to a higher temperature than that appropriate to the above conditions. The diurnal and annual temperature waves observed at the surface proceed downwards by heat conduction, but with rapid reduction of amplitude and progressive increase of time-lag relative to the surface waves. The diurnal wave disappears at a depth of less than 2 feet as a rule, the annual wave at 30 to 40 feet: these values are approximately as the square root of the ratio of the periods (1 and 365 days, respectively), in accordance with the theorv of heat conduction in solids.

earth thermometer: A thermometer for ascertaining the temperature of the soil at a known depth. The commonest form (Symons's) consists of a mercurial thermometer with its bulb embedded in paraffin wax, suspended in a steel tube at a depth of one foot or four feet. For depths of a few inches only, a mercurial thermometer, with its stem bent at right angles for convenience in reading, is employed: this type is termed a 'right-angled thermometer', or 'bent-stem thermometer'. See also LAG.

earthquake: A natural movement of the ground, originating below the surface, due to the build-up and sudden release of strain energy in a small underground region, termed the 'focus' or 'hypocentre' of the earthquake. The point of the earth's surface vertically above the focus is termed the 'epicentre'. The focus of most earthquakes is at a depth of less than 20 km. Earthquakes of much deeper focus (up to 700 km depth) occur in some areas, more especially the Pacific.

About 100 destructive earthquakes occur each year: some damage is done by ten times as many, while many more are felt by human beings and still more are recorded by seismographs.

Major earthquakes are generally followed, over a period, by 'aftershocks' whose foci are in the region of the original focus. No practical method of prediction of earthquakes has yet been devised. See also SEISMOLOGY.

easterly wave: A shallow trough disturbance in the easterly current of the tropics, more in evidence in the upper-level winds than in surface pressure, whose passage westwards is followed by a marked intensification of cloudy, showery weather.

ecliptic: That GREAT CIRCLE on the CELESTIAL SPHERE which the sun appears to describe, with the earth as centre, in the course of a year: the plane in which the apparent orbit of the sun lies is the 'plane of the ecliptic'.

In terms of actual motion, the ecliptic is the path described by the earth round the sun in the course of a year.

The 'obliquity of the ecliptic' is the inclination of the plane of the ecliptic to that of the earth's equator. This value controls the limits of variation of the sun's DECLINATION in the course of the year and gives rise to the meteorological seasons. The obliquity of the ecliptic was close to 23° 26′ 40″ in 1960 and was then decreasing at the rate of about 0·47″ per year. The limits of variation of the value of the obliquity and the period or periods involved are yet uncertain but are very probably significant factors in long-period CLIMATIC CHANGE.

ecoclimatology: That branch of ecology which is concerned with the study of living matter (animal and plant) in relationship to its climatic environment.

eddy: A term in fluid motion for which, like that of the closely associated term 'turbulence', a brief comprehensive definition is impossible. Its essential characteristics are, however, covered by its definition as a mass of fluid which retains its identity for a limited time while moving within the surrounding fluid.

Atmospheric eddies range in size from less than one centimetre (micro-scale turbulence) to some hundreds of kilometres (large depression or anticyclone) or more. The smaller-scale eddies play a vital part in effecting vertical mixing of such atmospheric properties as momentum, heat and water vapour ('eddy flux'), while the large-scale eddies are responsible for much of the meridional transport implicit in the GENERAL CIRCULATION of the atmosphere. See, for example, TURBULENCE, VISCOSITY, DIFFUSIVITY, EDDY SPECTRUM.

eddy conductivity: EXCHANGE COEFFICIENT (K), of dimensions L^2T^{-1}, relating to the transfer of heat effected by eddies. For transfer in the vertical, for example, the coefficient may be regarded as being defined by the equation

$$-\overline{w'T'} = K_z \frac{\partial \bar{T}}{\partial z}$$

where w' and T' are corresponding fluctuations of vertical velocity and temperature from mean values. K varies greatly in space and time.

See, for example, EDDY, DIFFUSIVITY, VISCOSITY, K-THEORY.

eddy diffusion: The mixing of atmospheric matter and properties which is effected by eddies. It is also termed 'turbulent diffusion'. See EDDY, DIFFUSION, DIFFUSIVITY.

eddy flux: The rate of transport of atmospheric properties and matter (heat, momentum, water vapour, etc.) which is effected by atmospheric eddies. Frequently the vertical transport is implied. It is also termed 'turbulent flux'. See EDDY.

eddy shearing stress: An alternative for REYNOLDS STRESS.

eddy spectrum: Specification of the character of turbulence in terms of the frequency distribution of EDDY size, or of the partition of kinetic energy between eddies of various sizes. It is normally obtained by correlogram or Fourier analysis of the time fluctuations of motion, observed at a particular point. It is also termed 'turbulence spectrum'.

effective height of an anemometer: The height over open level terrain in the vicinity of an anemometer which, it is estimated, would have the same mean wind speeds as those actually recorded by the anemometer.

No definite rules are laid down for obtaining the effective height of an anemometer. The nature, extent, height and distance of local obstructions and the height of the anemometer itself must be taken into account. The effective height may be different for different wind directions. See also EXPOSURE.

effective radiation: An alternative for NOCTURNAL RADIATION.

Ekman spiral: An equiangular spiral which is the locus of the end points of the (idealized) wind vectors, starting from a common origin, within the FRICTION LAYER. The centre of the spiral corresponds to the GEOSTROPHIC WIND, while the surface wind is backed 45° from this direction (see Figure 16). Such a spiral, first derived by V. W. Ekman for the ocean currents produced by surface stress is, however, obtained under assumed conditions that are rarely realized in the atmosphere—namely, no variation of eddy viscosity with height and no horizontal temperature gradient, within the friction layer.

E-layer: The lowest regularly observed layer of the IONOSPHERE occurring at a height of about 100 to 120 km, and observable in normal ionospheric sounding mainly during the day. The maximum electron density is of the order 10^5 per cm^3. The structure of the E-region is at times complicated by the appearance of various

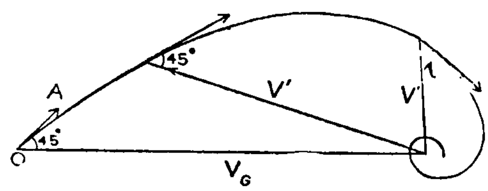

FIGURE 16—Equiangular spiral such that the ageostrophic wind component (V′) makes an angle of 45° with the tangent at all points of the curve.

V′ decreases exponentially to zero with increasing height within the friction layer. V_G represents the geostrophic wind and *OA* the direction of the surface wind.

'ledges' of ionization and of intense 'sporadic E' (E_s) ionization which exists in extensive patches and gives rise to anomalous reception of high-frequency radio waves.

electrical units: The relationship between the practical (m.k.s.), electromagnetic, and electrostatic systems of electrical units is shown in Table V.

TABLE V—*Relationship between electrical units*

	Practical m.k.s.	Electro-magnetic c.g.s.	Electro-static c.g.s.
Quantity of electricity ...	coulomb	10^{-1}	3×10^9
Electric current	ampere		
Potential	volt	10^8	1/300
Resistance	ohm	10^9	$1/(9 \times 10^{11})$
Induction	henry		
Energy	joule	10^7	10^7
Power	watt		
Capacity	farad	10^{-9}	9×10^{11}

electricity: See ATMOSPHERIC ELECTRICITY.

electricity of precipitation: The main features of surface measurements of the electric charge carried by solid and liquid PRECIPITATION are as follows:

(i) Charges of both signs are carried by all kinds of precipitation.
(ii) Rapid fluctuations of sign occur within short intervals of time.
(iii) A net positive charge is, on average, carried to ground by all types of precipitation.
(iv) The charges carried per cm^3 of precipitation and by individual drops are of the general order 1 and 10^3 e.s.u., respectively.
(v) Thunderstorm-type rain and snow carry, on average, larger charges than steady rain.

These observations, together with the results of similar measurements made from aircraft, show that the processes involved are highly complex. As with the generation and separation of charges associated with a THUNDERSTORM, various theories have been advanced to explain the charges carried by precipitation. They include effects associated with a mixture of water in the solid and liquid phases; the separation of charge on the break-up of large rain drops; and the selective capture by precipitation particles of positive ions which stream upwards by BRUSH

DISCHARGE from the ground in the disturbed surface POTENTIAL GRADIENT conditions which obtain in the vicinity of rain clouds. The complexity of the observed effects makes it probable that several processes are important.

electric storm: Little-used alternative for a THUNDERSTORM.

electrojet: The term applied to the narrow belt of intense 'dynamo' electric currents which flow in the low ionosphere near the equator and which produce at the earth's surface in low latitudes a large augmentation of the solar and lunar diurnal variations of the magnetic elements, compared with other latitudes. See GEOMAGNETISM.

electromagnetic radiation: The propagation of energy in which, according to classical 'electromagnetic theory', a transverse wave motion exists in the form of periodic fluctuations of the strengths of electric and magnetic fields which act at right angles to the direction of propagation of the energy. The energy may be propagated through a medium or vacuum: the speed of propagation in the latter, and to a close approximation in air, is about 3×10^{10} cm/sec.

Electromagnetic radiation is divided into various classes which differ only in wavelength. In order of increasing wavelength (decreasing frequency) they comprise GAMMA RADIATION, X-RAYS, ULTRA-VIOLET RADIATION, VISIBLE RADIATION, INFRA-RED RADIATION, and RADIO WAVES. See also RADIATION.

electrometeor: A little-used generic term for a visible or audible manifestation of atmospheric electricity, e.g. thunder, lightning, St. Elmo's fire, aurora.

electrometer: An instrument which measures electric potential difference. Since the operation of an electrometer does not involve the passage of an electric current through the instrument, it can be used for such purposes as the determination of the electric potential at a point in the atmosphere.

electron: The elementary particle that carries the indivisible (unit) negative electric charge of $4{\cdot}803 \times 10^{-10}$ electrostatic units.

electron-volt: The electron-volt (ev) is the unit of energy employed in discussing processes of ION formation: it is the energy acquired by an electron on passing through a potential rise of 1 volt. 1 ev = $1{\cdot}6 \times 10^{-12}$ ERGS; 10^3 ev = 1 kev; 10^6 ev = 1 Mev; 10^9 ev = 1 Gev.

electroscope: An instrument for indicating the presence of electrification, usually by some simple action, such as the mutual repulsion of two strips of foil.

elevation: In meteorology and in aviation, term used to denote the height of the ground above mean sea level.

elevation, angle of: The angular height of an object measured by an observer, with reference to the horizontal plane through the observer.

Elsasser's diagram: See RADIATION CHART.

emagram: A thermodynamic diagram used to depict conditions in the upper atmosphere, the name being a contraction for 'energy-per-unit-mass diagram'. The co-ordinate axes (rectangular or oblique) are T and $\log p$. See AEROLOGICAL DIAGRAM.

energy: A quantity, of dimensions ML^2T^{-2}, defined as the capacity for doing work. The unit of energy in the C.G.S. SYSTEM is the ERG, in the M.K.S. SYSTEM the JOULE.

The various forms of energy include, for example, POTENTIAL ENERGY, KINETIC ENERGY, heat, radiant, electric, magnetic and chemical energy.

energy balance: In meteorology, a concept generally applied in the form of an 'energy balance equation' which relates the net radiation flux at a portion of the earth's surface to the heat lost or gained by conduction to or from below, the heat lost or gained to or from the atmosphere by molecular and eddy processes, and the heat lost or gained at the surface by evaporation or condensation, respectively. See also RADIATION BALANCE.

enthalpy: A thermodynamic quantity (H) which represents the 'total heat' content per unit mass of a substance: the units normally employed are joules/gm or calories/gm.

A change in enthalpy (dH) of a mass of gas is the heat gained or lost by the gas in an isobaric process. It is given by $dH = c_p dT$, where c_p is the specific heat of the gas at constant pressure, and dT is the change in temperature of the gas. The isobaric transport of enthalpy is an important item in the over-all heat balance of the atmosphere.

In recent meteorological literature enthalpy is frequently referred to as 'sensible heat' as opposed to latent ('hidden') heat. See also HEAT.

entrainment: A term applied to the mixing of environment air into the updraught of a cumuliform cloud. The effects of such mixing (and also of the mixing into the cloud of environment air trapped by the rising cloud turrets), on the temperature, moisture and momentum properties of the cloud are progressively spread through the cloud. This general mixing process is a significant factor which is not taken into account in the PARCEL and SLICE METHODS of deducing the kinetic energy available in an atmosphere in which there is static instability.

entropy: If, in a reversible thermodynamic process, a substance absorbs a quantity of heat dQ at absolute temperature T, the ratio dQ/T represents the increase of entropy of the substance. Entropy per unit mass is normally measured in joules (or ergs)/gm °K and has the dimensions $L^2T^{-2}\theta^{-1}$.

Entropy is a function of the pressure, volume, and temperature of the substance but requires for its evaluation the arbitrary choice of a state of zero entropy. Interest in the atmosphere is mainly confined to the changes of entropy to which air is subject in the course of a specified process. Of chief interest is the ADIABATIC process in which no heat is supplied to, or withdrawn from, the air ($dQ = 0$) and in which, therefore, the entropy (S) remains constant: such a process is called 'isentropic' and is characterized by a constant POTENTIAL TEMPERATURE (θ) since S and θ are related by

$$S = c_p \log \theta + \text{constant}$$

where c_p is the specific heat of air at constant pressure.

epicentre: That point of the earth's surface which is vertically above the focal region of an EARTHQUAKE from which the seismic waves originate.

equation of state: See GAS EQUATION.

equation of time: See TIME.

equations of motion: See MOTION, EQUATIONS OF.

equator: The earth's equator is that GREAT CIRCLE whose plane is perpendicular to the earth's axis of rotation (polar axis).

The celestial equator is that great circle whose plane is perpendicular to the line joining the celestial POLES.

equatorial air: A moist and unstable AIR MASS in the equatorial low-latitude circulation, now generally classified as maritime TROPICAL AIR.

equatorial bulge: The slight bulging of the EARTH in low relative to high latitudes. The earth's equatorial diameter is about 43 km greater than its polar diameter. As a result of the bulging the force of GRAVITY varies with latitude.

equatorial front: An alternative for INTERTROPICAL CONVERGENCE ZONE.

equatorial trough: The shallow TROUGH of low pressure, generally situated on or near the equator, marking the convergence zone of air which moves equatorwards from the subtropical anticyclones of either hemisphere. The trough over the oceans lies in the belt of the DOLDRUMS and has a north and south movement which follows the sun with a time-lag of one or two months. The trough is not, however, a permanent feature of the synoptic chart in all longitudes at all times of the year: in particular, it is generally absent over land areas in the northern hemisphere summer.

equatorial westerlies: The north-east or south-east TRADE WINDS are deflected on crossing the equator and acquire a westerly component to become the 'equatorial westerlies' when the INTERTROPICAL CONVERGENCE ZONE is farther than some 5° from the equator.

equinoctial gales: The implication contained in this term, which is in fairly wide popular use, that GALES are either more frequent or more severe near the EQUINOXES than at other times is not supported by observations. In all parts of the British Isles, for example, the peak frequency of moderate or severe gales is near the winter solstice and the minimum frequency near the summer solstice (see Table VIII, p. 107).

equinox: One of two periods of the year, which occur on about 21 March (spring or vernal equinox) and about 22 September (autumnal equinox), when the astronomical day and night are equal, each lasting 12 hours. (The sun is visible by refraction for a little longer than the duration of the astronomical day.)

At an equinox, when the sun is said to be 'on the equator', time of sunrise (or of sunset) is the same all along a MERIDIAN. Apart from the small refraction effect, the sun then rises exactly in the east and sets exactly in the west all over the world.

equiscalar surface: In meteorology, a surface along which a specified scalar quantity, e.g. pressure or temperature, is constant.

equivalent constant wind: An alternative for BALLISTIC WIND.

equivalent head-wind: That uniform wind which, directed at all points along the track of an aircraft, results in the same average ground-speed as that actually attained. A positive head-wind is such as to oppose the flight of an aircraft. A negative head-wind comprises a 'tail-wind', i.e. ground-speed in excess of air-speed.

equivalent potential temperature: See EQUIVALENT TEMPERATURE.

equivalent temperature: The (isobaric) equivalent temperature (T_e) of a moist air sample is the temperature that would be attained on the assumption of condensation at constant pressure of all the water vapour in the sample, all the latent heat released in the condensation being used to raise the temperature of the sample. T_e is given by the equation

$$T_e = T + Lr/c_p$$

where T is the dry-bulb temperature and r the mixing ratio of the sample, L latent heat of condensation, c_p specific heat at constant pressure. Where r is expressed in gm/kg,

$$T_e \simeq T + 2{\cdot}5r$$

The 'equivalent potential temperature' (θ_e) is found on an AEROLOGICAL DIAGRAM by progressing along the dry-adiabatic line from T_e to the 1000 mb level. See also PSEUDO-EQUIVALENT TEMPERATURE.

erg: The unit of work or energy in the C.G.S. SYSTEM of units. It is the work done by a force of 1 DYNE in moving its point of application 1 cm in the direction of the force. The dimensions are ML^2T^{-2}.

1 erg = 10^{-7} JOULE = 10 WATT sec.

error: An error of observation is the departure of a measured quantity from its true value. Such an error is, in general, partly 'systematic', partly 'casual' or 'accidental' in nature. A systematic error, whether instrumental or due to a PERSONAL EQUATION of the observer, can usually be found experimentally and allowed for. A 'casual' error is that part of the total error of an observation which is not systematic and which is also not due to a 'mistake' (e.g. misreading of a scale) which, being usually self-evident from its large value, can be eliminated by disregarding the corresponding measurement.

When an observation of an unchanging quantity is repeated n times, the casual errors present in the individual measurements are reduced in magnitude, in the mean of the n values. This gives rise to the conception of an appropriate significant figure and STANDARD ERROR of a mean value. A systematic error is not reduced in magnitude by the process of averaging.

In meteorology, the problem of errors of measured values, whether individual or mean values, is complicated by the fact that the measured quantities are not themselves constant but are subject to change on various time-scales. Experiment can usually discriminate between casual errors of measurement and short-period fluctuations of the measured quantity. More difficult is the discrimination between influences in the observation which comprise essentially a long-period change of systematic error (e.g. growth of trees in the vicinity of an anemometer site) and a genuine SECULAR TREND of the measured quantity. In some such cases a distinction can be made only by intercomparison of results obtained at various sites.

error function: See NORMAL (FREQUENCY) DISTRIBUTION.

escape velocity: The minimum velocity which a molecular or atomic gas particle must attain in order that it may escape from the gravitational field of a specified planet and so from the planetary atmosphere. Such escape can take place only from the outer fringe (EXOSPHERE) of the atmosphere, where the particle MEAN FREE PATH is large and the probability of its collision with another particle correspondingly small.

The escape velocity (v cm/sec) is given by

$$v = \sqrt{\left(\frac{2GM}{a}\right)}$$

where G = constant of gravitation = $6{\cdot}67 \times 10^{-8}$ c.g.s. units

M = mass of planet (gm)

a = distance of level of escape from centre of planet (cm)

For the earth, $v \simeq 11{\cdot}2$ km/sec; for the moon, $v \simeq 2{\cdot}4$ km/sec.

etesian winds: A Greek term for the winds which blow at times in summer (May to September) from a direction between north-east and north-west in the eastern

Mediterranean, more especially the Aegean Sea. The winds are termed in Turkey 'meltemi'.

Eulerian change: The time rate of change of an element at a fixed point in an Eulerian system of co-ordinates, i.e. the 'local change', designated $\partial/\partial t$. It is to be contrasted with the LAGRANGIAN CHANGE to which it is related by the velocity components and the gradients of the elements in the various component directions.

Eulerian wind: That class of winds, in the classification of H. Jeffreys, in which the earth's rotational term (involving the CORIOLIS FORCE) and the frictional term are unimportant relative to the acceleration term. The EQUATION OF MOTION reduces to

$$\frac{dV}{dt} = -\frac{1}{\rho}\nabla_H p$$

where V is wind velocity, ρ air density, $\nabla_H p$ the horizontal gradient of pressure.

The CYCLOSTROPHIC WIND of the tornado or tropical cyclone is an example of an Eulerian wind.

eustasy, glacial: The release or absorption of water in ice-caps, with consequent rise or fall of mean SEA LEVEL.

evaporation: In meteorology, the change of liquid water or ice to water vapour. In certain usages the term signifies only the liquid to vapour phase change, as distinct from SUBLIMATION which signifies the solid to vapour change. The rate of evaporation is controlled by the water and energy (mainly solar radiation) supplies and by the ability of the air to take up more water.

Since large amounts of energy are required to effect the above changes of state the evaporation that proceeds continuously from the earth's free water surfaces, soil, snow and ice fields, and vegetation, and from ice and liquid water within the atmosphere, is a fundamental item in the energy balance of the earth–atmosphere system. Evaporation also plays a basic role in the earth's HYDROLOGICAL CYCLE and HYDROLOGICAL BALANCE.

Direct measurement of natural evaporation is difficult. Measurements based on the EVAPORIMETER are generally considered to be of doubtful value, even in their application to natural water surfaces. Measurements of the changes in weight of a sample of soil are also used to a very limited extent as a measure of evaporation and conform much better to natural conditions.

Indirect measurements often use the relationship evaporation equals measured RAINFALL minus measured RUN-OFF. In such cases the water storage by the soil is either experimentally held constant or is assumed, by the use of long-period mean values, to be constant. Indirect measurement has also been made using a theoretical formula, due to C. W. Thornthwaite and B. Holzman, which relates the rate of evaporation, regarded as a process of turbulent diffusion, to wind and humidity conditions in a layer near the ground; and also by an 'energy balance' method in which the difference between the measured rates of incoming and outgoing heat to and from the surface boundary, due to the processes of radiation, convection, and conduction, is identified with the heat lost in evaporation. See also EVAPOTRANSPIRATION.

evaporation fog: FOG which is formed by evaporation of relatively warm water into cool air. Examples are ARCTIC SEA SMOKE and FRONTAL FOG.

evaporimeter: An instrument for determining the rate of EVAPORATION of water into the atmosphere. Evaporimeters fall into two classes, (i) those employing a free water surface, (ii) those in which evaporation takes place from a continuously wetted porous surface of blotting-paper, fabric or ceramic material. Class (i) is exemplified by the Symons evaporation tank commonly used in Great Britain. It consists of a galvanized iron tank usually six feet square and two feet deep, nearly filled with water and sunk into the ground with its rim projecting about three inches. The evaporation, expressed as depth in inches, is deduced from daily readings of level made with a micrometer gauge, allowance being made for rainfall. The level of the water is kept at two to three inches below the top of the tank by adding or removing water as required. Evaporimeters of class (ii) have been designed by Piché, Livingston, Owens and others, but they have not come into general use in this country as meteorological instruments.

evapotranspiration: The combined processes of EVAPORATION from the earth's surface and TRANSPIRATION from vegetation. 'Potential evapotranspiration' is the addition of water vapour to the atmosphere which would take place by these processes from a surface covered by green vegetation if there were no lack of available water.

Semi-empirical formulae based on air temperature, duration of sunshine, vapour pressure and wind speed, and on air temperature and length of day, have been suggested by H. L. Penman and by C. W. Thornthwaite, respectively, for application in the regional estimation of potential evapotranspiration over periods of weeks or longer. Penman's formula indicates values ranging from about 14 in. per year in Scotland to about 20 in. in southern England.

exchange coefficient: A general term for the coefficients of VISCOSITY (momentum), CONDUCTIVITY (heat), and DIFFUSIVITY (matter), which are defined, on analogy with molecular exchange processes, in respect of the vertical transfer effected by atmospheric eddies. See also K-THEORY.

exosphere: The outermost 'fringe region' of a planetary atmosphere—in particular, that of the earth—in which the gas density is very small, MEAN FREE PATH large, and COLLISION FREQUENCY so small that particles moving upwards with sufficient velocity may escape from the atmosphere. For the earth, the exosphere is considered to extend upwards from about 700 km. See ESCAPE VELOCITY and ATMOSPHERE.

expansion: An increase in size of a sample of material: such an increase may be due to heat, or to the release of mechanical strain, or the absorption of moisture, or some other physical or chemical change.

The 'size' may be a length, an area, or a volume. Liability of materials to expansion on absorption of heat is expressed by a 'coefficient of (linear, areal, or volume) expansion', being the fractional increase in size per degree rise in temperature at a selected standard temperature. In barometer corrections important coefficients are those of linear expansion of brass (0·0000184 per °C or 0·0000102 per °F) and of volume expansion of mercury (0·000182 per °C or 0·000101 per °F), involving changes in length of brass scale and mercury density, respectively.

Gas expansion may be caused by a reduction of pressure or an increase of temperature. At constant pressure the coefficient of expansion is 0·00366 per °K, referred to 273°K as standard.

explosive warming: An alternative for SUDDEN WARMING.

exponential atmosphere: A hypothetical atmosphere in which pressure decreases exponentially with increasing height. The chief assumption made is that the atmosphere is isothermal, i.e. temperature (T) is constant with increasing height z: minor assumptions are that the acceleration of gravity (g) and the specific gas constant (R) remain constant with height and that the atmosphere is at rest. In such an atmosphere, the pressure (p) at height z above mean sea level is related to mean-sea-level pressure (p_0) by the equation

$$p = p_0 e^{-gz/RT}$$

$$\text{or } z = \frac{RT}{g} (\log_e p_0 - \log_e p)$$

exposure: In meteorology, the method of presentation of an instrument to that element which it is designed to measure or record, or the situation of the station with regard to the phenomena to be observed. If meteorological observations are to be of full value, attention must be paid to the exposure of the instruments. Details are to be found in the 'Observer's handbook'.* Uniformity of exposure is of the greatest importance, and for that reason the pattern of the thermometer screen has been standardized in most countries, while in the British Isles, a standard height of one foot above ground for the rim of the rain-gauge has been fixed. It is important, too, that the sites of the thermometer screen and rain-gauge should not be unduly shut in; on the other hand, a very open exposure, as on a bare moor, is undesirable for a rain-gauge, as is also a position on a slope, a roof, or near a steep bank. In these cases the catch is reduced by the effect of wind eddies due to the obstruction of the gauge itself. An ideal exposure for a SUNSHINE RECORDER requires that there should be no horizon obstruction in the direct line sun to recorder at any time of the year.

The question of the exposure of ANEMOMETERS is one of great difficulty. The effect of the ground on a uniform current of air blowing above it is to reduce the velocity by an amount which increases as the ground is approached, and, at the same time, to introduce into the motion unsteadiness which is manifested by the creation of eddies in the air. The motion is then said to be turbulent (see TURBULENCE). A recording anemometer erected in a turbulent wind shows a large number of gusts and lulls corresponding with various parts of the eddy motion. Hence the extent of the GUSTINESS of the wind as recorded by the anemometer is a fair index of the excellence of the exposure. The ideal exposure for an anemometer is at the top of a pole 30 to 40 feet high, erected on a flat treeless plain. Trees and buildings introduce much turbulence into air motion, and where these occur in the vicinity of an anemometer the head of the instrument is often raised with a view to making the EFFECTIVE HEIGHT equivalent to the standard value of 10 metres (33 feet).

exsiccation: Drying by the draining away or driving away of moisture. The term implies some change, frequently the result of human agency which decreases the quantity of moisture available without any appreciable change in the average rainfall. It is used in contrast with DESICCATION, which implies an actual drying up due to a change of climate. Examples of exsiccation are the washing away of the soil due to the cutting down of forests, with the consequent conversion of a fertile region into the semblance of a desert, the advance of sand dunes across cultivated ground, and the draining of swampy ground.

extinction coefficient: A term synonymous with 'attenuation coefficient' (see ATTENUATION) but often reserved as a measure of the combined effects of ABSORPTION and SCATTERING of wavelengths within the VISIBLE SPECTRUM. The extinction coefficient has the dimensions L^{-1}: its value in the atmosphere varies from about 10 per km in thick fog to 0·01 per km in air of very good visibility.

In relation to VISIBILITY, scattering is much the more important of the two extinction processes.

extrapolation: Extension of a relationship between two variables beyond the limits covered by the observations.

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* London, Meteorological Office; Observer's handbook. 2nd edn., London, HMSO, 1956.

extremes: The highest and lowest values of meteorological elements in a specified period. The following definitions illustrate, with reference to maximum temperature, the nomenclature employed:

(i) Daily maximum temperature: highest temperature reached between two fixed times 24 hours apart.

(ii) Mean daily maximum temperature: mean of the 'daily maximum temperatures' observed during a given calendar month, either in a specified year or over a specified period of years.

(iii) Monthly maximum temperature: highest of the 'daily maximum temperatures' observed in the course of a given calendar month in a specified year.

(iv) Mean monthly maximum temperature: mean of the 'monthly maximum temperatures' observed during a given calendar month over a specified period of years.

(v) Absolute monthly maximum temperature: highest of the 'monthly maximum temperatures' observed during a given calendar month over a specified period of years.

(vi) Annual maximum temperature: highest of the 'daily maximum temperatures' observed during a given calendar year.

(vii) Mean annual maximum temperature: mean of the 'annual maximum temperatures' observed over a specified period of years.

(viii) Absolute maximum temperature: highest temperature observed during the whole period of observation ('absolute extreme').

The absolute extremes of temperature are: United Kingdom: highest 38·1°C (100·5°F) at Tonbridge, Kent, on 22 July 1868; lowest −27·2°C (−17°F) at Braemar, Aberdeenshire, on 11 February 1895. Surface of the globe: highest 57·8°C (136°F) at Azizia, Tripoli, on 13 September 1922; lowest −68°C (−90°F) at Verhojansk (67° 33′ N, 133° 23′ E, altitude 122 m) on 5 and 7 February 1892 and at Oymjakon (63° 16′ N, 143° 15′ E, altitude 800 m) on 6 February 1933. However, temperatures as low as −85°C to −90°C have been reported on several occasions at or near the Soviet Antarctic base Vostok (78° 27′ S, 106° 52′ E).

The extreme mean-sea-level pressures are: United Kingdom: highest 1055 mb at Aberdeen on 31 January 1902; lowest 925 mb at Ochtertyre, Perthshire, on 26 January 1884. World: highest 1079 mb at Barnaul, Siberia, on 23 January 1900; lowest 877 mb in the Pacific Ocean, about 600 miles north-west of Guam, on 24 September 1958. The extreme annual total of rainfall for the United Kingdom is 257 in. at Sprinkling Tarn, Cumberland, in 1954. The heaviest known rainfalls in 24 consecutive hours are: United Kingdom, 11.0 in. at Martinstown, Dorset on 18 July 1955; world, 45·99 in. at Baguio, Luzon, in the Philippines, on 14–15 June 1911.

The extreme gust recorded in the United Kingdom is 101 kt (116 mph) at Tiree, Argyllshire, on 26 February 1961. The highest mean hourly wind speed is 69 kt (80 mph) at St. Ann's Head, Pembrokeshire, on 23 November 1938. These extremes have been exceeded, however, at several hill-top and mountain sites. For example, a mean hourly speed of 74 kt (85 mph) and a gust of 106 kt (122 mph) were recorded at Lowther Hill, Lanarkshire (2412 ft above mean sea level) on 12 February 1962. See also RAINFALL.

eye of storm: The central region of an intense TROPICAL CYCLONE, usually some 10–15 miles in diameter and fairly symmetrical, though subject to time fluctuations. The main features are absence of rain, small horizontal pressure gradient, light winds, high and turbulent sea, and layered clouds, often well broken.

eye of the wind: A nautical expression indicating the direction from which the wind blows.

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facsimile transmission: In meteorology, the direct transmission by radio or telegraph of a synoptic chart: the chart is scanned at a central station and reproduced by electronic means at individual stations.

Fahrenheit scale: A scale of temperature introduced about 1709 by the German physicist Fahrenheit, who was the first to use mercury as the thermometric substance. Primary fixed points were the temperature of a mixture of common salt and ice and the temperature of the human body: with reference to these, the freezing-point of water was marked 32° and the boiling-point of water was marked 212°. See TEMPERATURE SCALES.

fair-weather cumulus: A common alternative for CUMULUS HUMILIS.

fallout: A term applied to both the process of deposition of solid material on the earth's surface and to the deposited material itself. It may be used in such a sense as to signify only 'dry deposition' (mainly the result of gravitational settling): in such a sense it is used in contrast to the term WASHOUT. The term fallout is, however, used mainly in respect of the radioactive debris which is associated with a nuclear explosion. The process of washout is then often important in the manner of deposition of the material, especially when the fallout is other than 'close-in'. See RADIOACTIVE FALLOUT.

fallstreak: A term often used for the supplementary cloud feature VIRGA.

false cirrus: A popular expression for CIRRUS SPISSATUS or anvil cirrus—see ANVIL CLOUD.

fata morgana: A rare and complex form of MIRAGE in which horizontal and vertical distortion, inversion and elevation of objects occur in changing patterns. The phenomenon occurs over a water surface and is produced by the superposition of several layers of air of different REFRACTIVE INDEX.

fetch: The fetch of an airstream is the length of its traverse across a sea or ocean area.

fibratus (fib): A CLOUD SPFCIES. (Latin, *fibratus* fibrous.)

'Detached clouds or a thin cloud veil, consisting of nearly straight or more or less irregularly curved filaments which do not terminate in hooks or tufts.

This term applies mainly to CIRRUS and CIRROSTRATUS.'* See also CLOUD CLASSIFICATION.

FIDO: The term, abbreviated from 'Fog, Investigation Dispersal Operations', signifying the system, developed in Great Britain during the Second World War, of effecting temporary and local clearance of fog by the burning of petrol at intervals alongside an airfield runway.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 12.

fiducial point: A reference point of an instrument or scale, as, for example, the ivory tip of the Fortin barometer to which the mercury in the cistern must be brought before a reading is taken.

fiducial temperature: An alternative for STANDARD TEMPERATURE.

field capacity: The mass of water (per cent of dry soil) retained by a previously saturated soil when free drainage has ceased is known as the soil's field capacity or water-holding capacity. It varies from about 7 per cent in light sand to about 60 per cent in heavy clay and corresponds to a CAPILLARY POTENTIAL of about 500 cm of water (pF = 2·7). See SOIL MOISTURE.

field mill: A type of ELECTROMETER employed, in various forms, more especially in field measurement or recording of atmospheric POTENTIAL GRADIENT. The charge generated in a conductor which is alternately exposed to and sheltered from the atmospheric electric field is conveyed to a meter: d.c. or a.c. amplification is often used.

FIFOR: An indicator word for a flight forecast of meteorological conditions, in figure code. See 'Handbook of weather messages.'*

filling: See DEEPENING.

filtering: In the statistical analysis of a TIME SERIES, the separation of a component of a selected period from all other possible periodic components of the series.

finite-difference method: A method of approximation to space or time derivatives of a mathematical function, widely used in meteorology, in which the derivative is represented as the difference between values of the function at two points in space or time. The appropriate separation between the points depends on the scale of the phenomenon being studied.

The calculus of finite differences is a well developed branch of mathematics dealing with quantities specified for discrete values of the variables and is much used in statistics.

fireball: This term is used to signify BALL LIGHTNING. It is also used of the larger type of METEOR, with the brightness of a first magnitude star or greater.

The rapidly expanding, white-hot ball of gas which is produced on explosion of a nuclear weapon is also termed a 'fireball': the term is applied up to the time at which the volume of gas becomes, through adiabatic and radiational cooling, no longer incandescent.

firn: A German word meaning old snow which is in process of being transformed into GLACIER ice. The word is also used to denote an accumulation area of old snow above a glacier and is synonymous with the French word 'névé'. There is no corresponding word in English.

firn wind: An alternative for GLACIER WIND.

fitness figures: A scale of figures, developed in Great Britain during the Second World War but now obsolescent, used as a measure of the meteorological fitness of a particular airfield for the landing of aircraft. The scale is governed mainly by visibility and observed cloud base in relation to the maximum height of obstructions near the airfield.

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* London, Meteorological Office; Handbook of weather messages. Parts II and III London, HMSO, 1959.

F-layer: A two-part layer of the IONOSPHERE. The lower (F_1) part is best observed in day-time in summer and has a maximum electron concentration, at about 160 km, of the order 3×10^5 per cm^3 with overhead sun. The higher (F_2) part, also called the 'Appleton layer', has a maximum electron concentration at a height which averages about 250 km. The F_2-layer is, in terms of CHAPMAN LAYER theory, highly anomalous and is also the seat of 'ionospheric storm' phenomena.

float barograph: A (seldom used) type of recording SIPHON BAROMETER. See BAROGRAPH.

floccus (flo): A CLOUD SPECIES. (Latin, *floccus* tuft.)
'A species in which each cloud unit is a small tuft with a cumuliform appearance, the lower part of which is more or less ragged and often accompanied by VIRGA.
This term applies to CIRRUS, CIRROCUMULUS and ALTOCUMULUS.'* See also CLOUD CLASSIFICATION.

flux density: The rate of transport (flux) of a specified quantity (e.g. RADIATION) across unit area of a surface.

foehn: An alternative for FÖHN.

fog: Obscurity in the surface layers of the atmosphere, which is caused by a suspension of water droplets or smoke particles or both and which is defined, by international agreement, as being associated with VISIBILITY less than 1 km.

While fogs which are entirely composed of smoke or dust particles do occur, the more persistent and thick fogs of industrial areas contain also water droplets. The term SMOG is sometimes used of such fogs. The frequent occurrence of fog in industrial areas is due in large measure to the plentiful supply of hygroscopic particles which are able to act as condensation NUCLEI when the relative humidity is less than 100 per cent.

Fogs which are composed entirely or mainly of water droplets are generally classified according to the physical process which produces saturation or near-saturation of the air: examples are RADIATION FOG, ADVECTION FOG, UPSLOPE FOG, and EVAPORATION FOG, this last including FRONTAL FOG and ARCTIC SEA SMOKE which is also known as 'steam fog' and has various other synonyms. Natural fogs are frequently the result of the combined action of two or more such physical processes.

Fog data relating to selected stations in the British Isles are shown in Table VI.

fogbow: A white RAINBOW of about 40° radius seen opposite the sun in fog. Its outer margin has a reddish, and its inner a bluish, tinge but the middle of the band is quite white. A supernumerary bow is sometimes seen inside the first and with the colours reversed. The bows are produced in the same way as the ordinary rainbow but owing to the smallness of the drops, the diameter of which is about 0·05mm (50 microns), the colours overlap and the bow appears white.

fog precipitation: Fog precipitation, sometimes also termed 'fog drip', signifies the precipitation of liquid water from non rain-bearing clouds due to the interception of the cloud particles by trees and other vegetation.

The relatively few measurements of this phenomenon suggest that it is common in places which have a high frequency of orographic cloud and suitable vegetation. In measurements over the plateau of Table Mountain, Cape Town, for example, one day in three yielded fog precipitation in the absence of rainfall measured in the normal way, and the total amount of fog precipitation measured in the year was nearly twice that of the measured rainfall.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 12.

TABLE VI—*Average number of days of fog and thick fog at selected times (GMT) and stations in Great Britain*, 1951–60

Station	Latitude	Longitude	Height above MSL	Visibility less than 1100 yd								Visibility less than 220 yd							
				April–September				October–March				April–September				October–March			
				3h	9h	15h	21h	3h	9h	15h	21h	3h	9h	15h	21h	3h	9h	15h	21h
			feet	*number of days*															
Lerwick	60° 08′ N	01° 11′ W	269	21·1	14·2	9·8	14·8	4·2	4·9	4·2	3·8	12·0	9·0	4·4	9·7	1·6	2·5	1·3	2·7
Stornoway	58° 13′ N	06° 20′ W	11	2·5	1·1	0·1	0·7	0·6	0·6	0·7	0·7	0·3	0·0	0·0	0·2	0·2	0·2	0·0	0·1
Aberdeen (Dyce) ...	57° 12′ N	02° 12′ W	190	13·3	2·3	0·8	4·5	4·6	4·5	2·4	4·8	3·9	0·3	0·0	1·7	1·8	1·0	0·4	0·4
Renfrew	55° 52′ N	04° 24′ W	26	1·5	[illegible]·0	0·3	0·6	14·2	28·5	18·0	21·9	0·3	0·0	0·0	0·0	4·1	6·2	3·8	3·0
Acklington ...	55° 18′ N	01° 38′ W	138	11·5	3·4	0·6	6·0	9·5	8·1	4·6	6·9	3·3	0·8	0·1	1·8	2·8	1·9	0·3	1·6
Gorleston	52° 35′ N	01° 43′ E	5	4·5	3·5	2·2	2·5	7·5	13·9	6·5	8·1	1·2	0·8	0·9	0·8	3·8	5·3	2·2	3·1
Mildenhall ...	52° 22′ N	00° 28′ E	15	13·0	2·1	0·3	0·6	23·5	20·2	7·2	13·2	3·6	0·8	0·0	0·2	7·3	7·3	2·6	5·2
Birmingham Airport	52° 27′ N	01° 45′ W	319	6·2	1·8	0·1	1·1	24·3	28·5	11·7	22·7	1·7	0·5	0·0	0·1	10·0	9·5	2·1	5·6
London Airport ...	51° 29′ N	00° 27′ W	82	3·1	2·0	0·0	0·6	21·1	23·6	8·9	23·7	1·6	0·5	0·0	0·0	10·9	9·8	2·4	5·6
Manchester Airport	53° 21′ N	02° 16′ W	248	4·4	0·9	0·2	0·8	15·4	18·5	8·7	18·4	1·0	0·1	0·0	0·0	6·2	6·0	2·2	4·0
Holyhead (Valley)...	53° 15′ N	04° 32′ W	26	4·6	2·5	2·0	3·0	3·5	4·3	1·8	4·0	0·6	0·0	0·0	0·6	0·8	0·9	0·0	0·6
Exeter	50° 44′ N	03° 25′ W	106	13·1	0·8	0·0	1·6	17·7	11·8	1·7	9·4	4·1	0·4	0·0	0·4	8·2	4·9	0·7	4·0
Scilly (St. Mary's)	49° 26′ N	06° 18′ W	158	9·2	7·3	5·2	8·0	6·0	6·3	4·8	5·9	4·7	3·2	1·2	3·7	2·7	2·8	1·8	2·3

föhn: A warm, dry wind which occurs to leeward of a ridge of mountains. The name originated in the Alps, but is now used as a generic name for this type of wind.

When relatively moist air ascends a ridge of mountains, the ADIABATIC cooling of the air proceeds mainly at the saturated-adiabatic lapse rate (about 0·5°C per 100 metres). Provided water is removed by precipitation on the windward side, much of the adiabatic warming of the air on descent to leeward is at the dry-adiabatic lapse rate (1°C per 100 metres) and the air reaches the ground there as a warm, dry wind. It is often accompanied by lenticular clouds.

föhn wall: Associated with the FÖHN effect, a mass of precipitating clouds often forms over the windward slopes of the hills. Cloud continues some way down the lee slope but evaporates in the descending current, terminating along a line parallel to the main ridge of hills.

force: That which alters or tends to alter the state of rest or motion of a body. Force is a vector quantity with both magnitude and direction and has dimensions MLT^{-2}. In meteorology, 'specific force' (force per unit mass), with dimensions LT^{-2}, is used in place of total force. See also ACCELERATION.

forecast: The term, first applied in meteorology by Admiral FitzRoy, which signifies a statement of anticipated (meteorological) conditions for a specified place (or area, route etc.) and period of time.

A three-fold classification of forecasts, in terms of the period covered, is recognized:

(i) 'short-period' forecast for part or whole of a 24-hour period, often with a 'further outlook' for the following 24 hours,

(ii) 'medium-range' forecast for some two to five days,

(iii) 'long-range' forecast for a period longer than about five days ahead, for example a month or season.

The short-period forecast generally contains information concerning wind velocity, weather (state of sky, precipitation, fog, frost, thunder etc.) and temperature (relative to seasonal normal): for special purposes, additional information is given—for example, upper winds for aviation. In medium-range and more especially long-range forecasts the information given is in more general terms and is often confined to precipitation and temperature.

In short-period forecasting, the methods of SYNOPTIC METEOROLOGY are normally used to anticipate changes in surface pressure distribution and positions of fronts, on which, together with an appeal to physical reasoning and to precedent, the forecast is based. Alternatively, the changes in pressure distribution are derived by numerical methods (see NUMERICAL WEATHER FORECAST). Purely statistical methods of short-period forecasting are applied to a small extent. In medium-range forecasting, the synoptic method predominates, with concentration of attention on the dominant circulation features. In long-range forecasting, significant but limited success has been achieved with synoptic methods in which time-averaging of the pressure and circulation patterns is employed, and with a synoptic ANALOGUE method.

forked lightning: LIGHTNING in which many luminous branches from the main discharge channel are visible. Such branching occurs in response to local variations of SPACE CHARGE close to the main channel.

Fortin barometer: A form of mercury BAROMETER, the zero of whose scale is fixed by a pointer inside the cistern, which is made partly of leather. By adjustments of a screw, the level of mercury in the cistern is brought to the scale zero ('fiducial point') before each reading is taken.

Foucault pendulum: A pendulum, designed by J. Foucault in Paris in 1851 to give experimental proof of the earth's rotation. The direction of swing of an oscillating large iron ball, suspended just above a tray of fine sand by a wire over 200 feet in length, was observed to change clockwise (northern hemisphere) at a rate corresponding to 15° per sidereal hour × sin φ (latitude). The observation is consistent with an apparent deviating force arising from the rotation of the earth about a polar axis.

Fourier analysis: An alternative for HARMONIC ANALYSIS.

Fourier series: A representation of any function of an independent variable in terms of sines and cosines of multiples of that variable. Such a series was first developed by J. Fourier in 1822. In symbols:

$$f(x) = A_0 + A_1 \sin x + A_2 \sin 2x + \dots + B_1 \cos x + B_2 \cos 2x + \dots$$

See HARMONIC ANALYSIS.

foyer: The place of origin of a group of ATMOSPHERICS.

f.p.s. system: A system of units, seldom used in meteorology, which is based on the foot, the pound, and the second as FUNDAMENTAL UNITS. In this system the unit of force is the 'poundal', which is the force required to give a mass of 1 pound an acceleration of 1 ft/sec^2. The unit of work, the 'foot-pound', is the work done in raising a mass of 1 pound a distance of 1 foot against the force of gravity.

fractional volume abundance: The relative concentration by volume of a specified gaseous constituent in a mixture of gases, expressed in a suitable unit. For minor constituents it is generally expressed in parts per million (ppm), signifying the number of volume units of the gas (e.g. cubic centimetres) which may be extracted from one million volume units of the mixture, both volumes being measured at the same temperature and pressure. It is identical with MOLE FRACTION. See AIR for tabulated values of fractional volume abundance, expressed as percentages. See also AVOGADRO'S LAW.

fractus (fra): A CLOUD SPECIES. (Latin, *fractus* broken.)

'Clouds in the form of irregular shreds, which have a clearly ragged appearance. This term applies only to STRATUS and CUMULUS.'* See also CLOUD CLASSIFICATION.

Fraunhofer lines: See SUN.

frazil ice: Ice which forms in spicules or small plates in rapidly flowing rivers, and at times in the sea, the movement of the water preventing the ice crystals from forming a solid sheet of ice. The formation has been best observed in the rivers of Canada: the word is from the French-Canadian *frasil,* meaning cinder, the frazil crystals being supposed to resemble forge-cinders.

free atmosphere: The atmosphere above the 'friction layer', i.e. above about 600 metres (2000 feet) above ground, where the influence of surface friction on air motion is assumed negligible.

free lift: The free lift of a balloon is given by the excess load that would be required to make the balloon float at a constant level: it is the excess of the BUOYANCY force over the gross weight.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 13.

free period: That period of vibration of a system, determined by its physical characteristics, which the system adopts when set in motion by the application of an external force which is then removed: the corresponding frequency of vibration is termed its 'natural frequency'. According to the RESONANCE theory of ATMOSPHERIC TIDES the atmosphere has a free period very close to 12 hours, the period being governed by the variation of temperature with height.

freeze, freezing: With reference to the weather, the term 'freezing' is used when the temperature of the air is below the freezing-point of water. Freezing conditions for an appreciable time over a widespread area are in America termed a 'freeze' (in Britain, a 'frost').

freezing drizzle, fog, rain: Supercooled water drops of drizzle (or fog or rain) which freeze on impact with the ground (in aviation, with an aircraft) to form GLAZED FROST or, in the case of the smaller droplets which comprise fog, RIME. See SUPERCOOLING.

freezing level: That lowest height above mean sea level at which, for a given place and time, the air temperature is 0°C: it is now generally termed the height above mean sea level, or if appropriate the PRESSURE ALTITUDE, of the 0°C isotherm.

Over the British Isles the freezing level has average values of about 600 metres in winter and 3000 metres in summer with, however, large day-to-day variations from these values. The term 'melting level' is to be preferred from the physical point of view since water in the atmosphere is not necessarily frozen at temperatures below 0°C—see SUPERCOOLING.

freezing nucleus: See NUCLEUS.

freezing-point: That constant temperature at which the solid and liquid forms of a given pure substance are in equilibrium at STANDARD ATMOSPHERIC PRESSURE. For pure-water substance the temperature is 0°C and is termed the 'ice-point'. In meteorology, the term 'freezing-point' is often used to signify 'ice-point'.

In practice, a cooling liquid may not freeze at the freezing-point due to a pressure variation from standard atmospheric pressure, or the presence of impurities, or the phenomenon of SUPERCOOLING.

frequency: In statistics, the number of times that a specified phenomenon has occurred in a given period. For ease of interpretation 'percentage frequency' is often used in preference to actual frequency. A 'frequency curve' is often used as a graphical representation.

In a wave vibration the frequency is the number of complete vibrations (cycles) per unit time. It is numerically equal to the velocity divided by the wavelength and is usually expressed in cycles per second (c/sec), kilo-cycles (i.e. 10^3 cycles) per second (kc/sec), or megacycles (i.e. 10^6 cycles) per second (Mc/sec). For ELECTROMAGNETIC RADIATION the relationship is frequency (c/sec) $= 3 \times 10^{10}$/wavelength (cm). The unit of frequency (1 c/sec) is termed the 'hertz'.

friction: The mechanical force of resistance which acts when there is relative motion of two bodies in contact, or of a body in contact with a medium, or of adjacent layers of a medium, or of adjacent media. Within a fluid, the friction that arises from molecular collisions is termed VISCOSITY.

In meteorology, the effects of friction are important in the flow of air over the earth's surface ('surface friction') and also when there is WIND SHEAR. Surface friction affects the wind velocity within the FRICTION LAYER and is important in all scales of motion up to and including that implied in the general circulation of the atmosphere, in which it plays a vital part in the over-all momentum balance that is achieved. The effects of surface friction visible on the synoptic scale are a decrease of SURFACE WIND speed relative to that appropriate to the pressure gradient (GEOSTROPHIC WIND or GRADIENT WIND), and a 'frictional outflow' of surface air from higher to lower pressure. The magnitudes of these effects increase with the surface roughness and decrease with increasing height within the friction layer. Typical values for air flow over the ocean at surface wind level are a decrease of speed by about one-third and a 'cross-isobar' wind direction of about 20°.

Direct measurements of the surface friction effect at individual points have been made, employing 'drag plates'. Estimates of the larger-scale effects have also been made, using vertical wind profiles. See also EKMAN SPIRAL.

friction layer: The atmospheric layer, extending from the earth's surface to about 600 metres (2000 feet) above ground, in which the influence of surface FRICTION on air motion is appreciable.

friction velocity: That reference velocity (u_*), employed in the study of fluid flow over a rough surface, which is defined by the equation

$$u_* = \sqrt{(\tau_0/\rho)}$$

where τ_0 is the surface drag per unit area and ρ is the fluid density.

Generally in meteorology, τ_0 is little different from τ, the REYNOLDS STRESS in the fluid, within a shallow layer near the surface.

u_* increases with roughness of surface and with mean wind speed ($\bar{u}$). In meteorology, u_* is of the general order ($\bar{u}/10$).

fringe region: See EXOSPHERE.

front: A term introduced into synoptic meteorology by the Norwegian meteorologists in 1918. A 'frontal surface' is a sloping transition zone separating two air masses of different density and so of different temperature: a surface 'front' is the zone (usually represented on charts as a line) along which a frontal surface intersects the earth's surface.

The equilibrium slope of a surface of discontinuity (tan θ) was derived by M. R. Margules as

$$\tan\theta = \frac{f}{g}\,\frac{(\rho_1 v_1 - \rho_2 v_2)}{\rho_1 - \rho_2} \simeq \frac{fT_m}{g}\,\frac{(v_1 - v_2)}{(T_2 - T_1)}$$

where ρ_1 and ρ_2 are the densities, v_1 and v_2 the geostrophic wind components parallel to the front, T_1 and T_2 the temperatures, in the cold and warm air masses, respectively, T_m the mean of T_1 and T_2, f the Coriolis parameter, g the acceleration of gravity.

Frontal surfaces have very gentle slopes, of the order 1 in 100, which, however, generally differ appreciably from the equilibrium values obtained from Margules's formula because the winds near the front are usually far from geostrophic. Horizontal convergence and associated vertical motion are essential features of a well marked front: the upward motion results, especially within the warmer air mass, in the condensation and precipitation which are associated with a typical active front. Measurements in the free atmosphere show that the horizontal gradients of temperature within the separate air masses are not negligible (though, by definition, smaller than in the frontal zone), and that large local variations of temperature and humidity often occur near the edges of frontal cloud and precipitation.

A front necessarily lies in a trough of low pressure and is marked by discontinuities of wind velocity and, in general, of pressure tendency. The more important and extensive fronts, such as the 'polar front', may be traced from the earth's surface to the tropopause.

frontal contour chart: A synoptic chart of the contours (usually expressed in pressure units) of a selected frontal surface, i.e. a plan view of the intersection of the frontal surface with selected isobaric surfaces.

frontal fog: Fog which forms at and near a FRONT. Such fog forms when raindrops, falling from relatively warm air above a frontal surface, evaporate into cooler air close to the earth's surface and cause it to become saturated.

frontogenesis: The development or marked intensification of a FRONT. This process —the intensification of the horizontal temperature gradient in a restricted zone—is effected mainly by horizontal CONFLUENCE and/or CONVERGENCE in conditions of suitably orientated isotherms.

frontolysis: The disappearance or marked weakening of a FRONT (converse of FRONTOGENESIS). This process is effected mainly by horizontal DIVERGENCE of air from the frontal zone, usually accompanied by SUBSIDENCE.

frost: Frost occurs when the temperature of the air in contact with the ground, or at screen level (about four feet), is below the freezing-point of water ('ground frost' or 'air frost', respectively). The term is also used of the icy deposits which may form on the ground and on objects in such temperature conditions (GLAZED FROST, HOAR FROST).

Since the sensation of cold depends not only on air temperature but on the accompanying wind speed, the fourfold classification of frosts used in forecasts of this condition in the British Isles is varied with wind speed. Thus, frost is classified as 'slight', 'moderate', 'severe', or 'very severe' for screen temperature ranges of −0·1° to −3·5°C, −3·6° to −6·4°C, −6·5° to −11·5°C, or below −11·5°C, respectively, if the accompanying wind speed is less than 10 knots; and for screen temperature ranges of between −0·1° to −0·4°C, −0·5° to −2·4°C, −2·5° to −5·5°C, or below −5·5°C, respectively, if the wind speed exceeds 10 knots. See also GROUND FROST, FROST DAY.

frost day: A day of frost is defined as a period of 24 hours ending at 9h GMT, or at 21h GMT where observations are made at 21h, in which the minimum air temperature in the screen is below 0°C (32°F). See also GROUND FROST.

Table VII gives average numbers of frost days at selected stations in the United Kingdom, based on the period 1946–60.

frost heaving: The uneven lifting and distortion of the ground close to the surface, resulting from the expansion of water on freezing associated with the local formation of ice crystals, accumulating into ice 'lenses', within the soil. The phenomenon has such effects as damage to road surfaces and loosening of root-hold of plants.

frost hollow: A local hollow-shaped region in which, in suitable conditions, cold air accumulates by night due to KATABATIC flow. Such regions are subject to a greater incidence of FROSTS, and to more severe frosts, than are the surrounding areas of non-concave shape.

frost-point: The frost-point (T_f) of a moist air sample is that temperature to which the air must be cooled in order that it shall be saturated with respect to ice at its existing pressure and HUMIDITY MIXING RATIO.

T_f is that temperature for which the saturation VAPOUR PRESSURE with respect to ice (e'_i) is identical with the existing vapour pressure (e') of the air,

$$e' = e'_i \text{ at } T_f$$

Frost-point may be measured indirectly from wet- and dry-bulb temperature readings with the aid of humidity tables (see PSYCHROMETER), or directly with a FROST-POINT HYGROMETER.

frost-point hygrometer: A development by G. M. B. Dobson and A. W. Brewer of the well known dew-point principle, for use in aircraft flying in air at sub-freezing

TABLE VII—*Average number of frost days at selected stations in the United Kingdom*, 1946–60.

Station	Height above MSL	Latitude	Longitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	feet								*number of frost days*							
Lerwick Observatory ...	269	60° 08′ N	01° 11′ W	10·8	11·5	7·9	4·9	1·3	0·1				0·8	2·7	5·9	45·9
Stornoway	11	58° 13′ N	06° 20′ W	9·1	10·0	6·7	3·3	0·6					1·0	3·9	6·1	40·7
Craibstone	300	57° 11′ N	02° 12′ W	15·7	14·7	8·4	5·3	1·4				0·2	1·0	4·5	10·2	61·4
Renfrew	26	55° 52′ N	04° 24′ W	12·8	12·8	8·1	4·0	0·9				0·3	2·8	5·9	9·9	57·5
Eskdalemuir Observatory	794	55° 19′ N	03° 12′ W	19·2	19·0	15·7	13·0	4·9	0·9	0·2	0·1	1·3	4·8	10·4	15·3	104·8
Douglas	284	54° 10′ N	04° 29′ W	6·3	8·7	3·5	0·3						0·1	0·7	2·9	22·5
Cockle Park	326	55° 13′ N	01° 41′ W	17·2	17·5	12·5	7·4	1·8	0·1			0·1	1·5	6·4	12·1	76·6
Gorleston	5	52° 35′ N	01° 43′ E	7·8	9·3	5·0	0·7	0·1					0·3	1·7	5·0	29·9
Cambridge	41	52° 12′ N	00° 08′ E	13·7	14·0	10·2	4·5	0·7				0·1	2·5	6·1	10·5	62·3
Birmingham (Edgbaston)	536	52° 28′ N	01° 56′ W	11·1	12·5	8·3	0·9						0·6	2·5	6·2	42·1
Kew Observatory ...	18	51° 28′ N	00° 19′ W	10·5	10·3	7·2	1·1						1·3	3·5	7·0	40·9
Southampton	65	50° 55′ N	01° 24′ W	12·1	10·8	7·3	1·1						1·1	3·5	7·3	43·2
Stonyhurst	377	53° 51′ N	02° 28′ W	13·7	14·1	9·4	2·3	0·2					1·6	4·5	9·2	55·0
Holyhead (Valley) ...	26	53° 15′ N	04° 32′ W	6·3	7·7	4·7	1·0							0·8	2·4	22·9
Falmouth	167	50° 06′ N	05° 03′ W	4·0	5·7	2·4	1·0							0·2	1·3	14·6
Aldergrove	217	54° 39′ N	06° 13′ W	11·5	12·5	7·6	4·3	1·3	0·2			0·3	1·1	5·1	7·2	51·1

TABLE VIII—*Average number of days with gale*, 1946–60

Station	Latitude	Longitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Lerwick	60° 08′ N	01° 11′ W	11·2	7·5	5·7	4·1	1·8	1·3	0·5	0·7	2·9	5·9	6·6	9·5	57·7
Tiree	56° 30′ N	06° 53′ W	6·1	3·1	2·1	1·5	0·3	0·0	0·2	0·7	1·5	2·5	3·4	7·3	28·7
Holyhead (Valley) ...	53° 15′ N	04° 32′ W	3·2	2·3	0·7	1·5	0·3	0·2	0·1	0·5	1·7	1·3	2·5	4·2	18·5
Scilly (St. Mary's) ...	49° 56′ N	06° 18′ W	3·5	1·9	1·5	0·9	0·5	0·4	0·3	0·7	1·0	0·8	1·7	4·7	17·9
Shoeburyness ...	51° 32′ N	00° 49′ E	0·4	0·4	0·4	0·2	0·2	0·0	0·1	0·4	0·3	0·4	0·3	0·8	3·9
Spurn Head ...	53° 35′ N	00° 07′ E	3·5	2·1	1·4	1·5	0·4	0·7	0·3	0·1	0·8	1·4	2·2	2·9	17·3
Aberdeen (Dyce) ...	57° 12′ N	02° 12′ W	1·9	1·3	0·6	1·1	0·0	0·1	0·0	0·1	0·8	0·5	0·4	0·9	7·7

temperatures. The air is arranged to pass in a jet across the polished surface of an aluminium thimble which is cooled from below at a controlled rate by a flow of liquid air, counteracted by a heating coil surrounding the surface, till a deposit of ice is observed, either visually or photo-electrically, to remain constant: the temperature of the surface, measured by a resistance thermometer, is then the FROST-POINT of the air.

frost, protection against: Various methods are practised of affording protection to crops in orchards, vineyards etc., against damage by frost. Protective measures may be effective only on 'radiation nights', characterized by calm or light wind conditions: no method is effective on occasions of frost in which there is substantial natural air movement.

The methods include direct heating of the air near the ground; the production of a smoke screen over the crop (see SMUDGING); the flooding or sprinkling of crops, thus adding the thermal content of the water and increasing the effective specific heat of the soil; and the use of large fans designed to mix cold air near the surface with warmer air aloft.

frost smoke: An alternative for ARCTIC SEA SMOKE.

Froude number: In fluid flow, a non-dimensional parameter (Fr) defined by the relationship $Fr = \bar{u}/\sqrt{(\delta g)}$, where $\bar{u}$ is the free stream velocity, δ is the thickness of the BOUNDARY LAYER, and g is the acceleration of gravity.

fundamental units: The units of mass (M), length (L), time (T) on which the less fundamental, or 'derived' units are based, e.g. the units of pressure or viscosity.

funnel cloud: The cloud formed at the core of a WATERSPOUT or TORNADO, sometimes extending right down to the earth's surface, attributed to the reduction of pressure at the centre of the vortex. Similar cloud formations are sometimes seen without a waterspout or tornado at the ground (cloud pendants). See also TUBA.

funnelling: The term 'funnelling' (sometimes 'canalization') is applied to the phenomenon in which the surface wind is constrained by topographical features to blow along a valley and is thereby increased in speed. Quantitative data on the phenomenon are lacking, mainly because of the difficulties inherent in expressing natural land features in a numerical form.

further outlook: A statement in brief and general terms appended to a detailed forecast and giving the conditions likely to be experienced in the 24 hours or more following the period covered by the actual forecast.

fusion: An alternative for 'melting'. See MELTING-POINT.

G

gale: A WIND of a speed between 34 and 40 knots (force 8 on the BEAUFORT SCALE of wind force, where it was originally described as 'fresh gale'), at a free exposure 10 metres (33 feet) above ground. In general, a mean speed over a period of ten minutes, as reported in synoptic code, is implied by the term 'gale': where this is not intended, a phrase such as 'gusts to gale force' is used.

While the term 'gale' applies strictly to the speed limits given above, and higher winds are referred to in other terms e.g. strong gale, storm, etc., statistics of gales refer to the attainment of mean speeds of 34 knots or over. See also GALE, DAY OF.

gale, day of: A day on which the wind speed at the standard height of 10 metres attains a mean value of 34 knots or more over any period of ten consecutive minutes during the day. Table VIII (p. 107) gives the average numbers of days with gale at selected coastal anemometer stations in Great Britain and is based on data for the period 1946–60.

gale warning: The Meteorological Office issues notice of the probability of gales (force 8 or more on the BEAUFORT SCALE of wind force in exposed situations or in the open sea) by broadcast warnings and by telegrams to ports and fishing stations recommended by the responsible local authorities.

Receipt of a gale warning notice by a station is made known by the hoisting of a black cone, three feet high and three feet wide at base. Two cones are used, the south cone (point downwards) and the north cone (point upwards). For the detailed significance of these cones reference should be made to the instructions issued to all gale-warning stations or to the 'Admiralty weather manual.'*

gamma (or γ) radiation: ELECTROMAGNETIC RADIATION of wavelength less than that of X-rays and of great penetrative power. Gamma radiation (also called 'gamma rays') is produced during the disintegration of many radioactive elements. Emitted by radioactive material in the ground, it is responsible for part of the total IONIZATION of the air at lower levels over land. It also constitutes the chief hazard in 'close-in' RADIOACTIVE FALLOUT. See also ALPHA PARTICLE, BETA PARTICLE.

gas: A fluid of unlimited capacity for expansion under diminishing pressure. The term is applied to any substance which obeys approximately the 'gas laws' of BOYLE and of CHARLES, and the combination of these two laws in the GAS EQUATION.

gas constant: See GAS EQUATION.

gas equation: The pressure (p), specific volume (α), density (ρ), and temperature (T) of a PERFECT GAS are related by the 'gas equation' ('equation of state'):

$$p\alpha = RT \text{ or } p = R\rho T$$

where R = 'specific gas constant' = R^*/M.

Values quoted in Appendix C of WMO publication 'Technical regulations'† are:

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* London, Admiralty, Hydrographic Department; Admiralty weather manual 1938. London, HMSO, 1938, p. 334.

† Geneva, World Meteorological Organization; Technical regulations. Vol. 1, General. WMO-No. 49.BD.2. 2nd edn., Geneva, WMO, 1959, p. 54.

R^* = ' universal gas constant' (gas constant per gram mole of perfect gas)
= $8{\cdot}3147 \times 10^7$ erg/mol °K
M = MOLECULAR WEIGHT of gas concerned
For dry air up to about 25 km,
M = $28{\cdot}966$
and R = $2{\cdot}8705 \times 10^6$ erg/gm °K = $6{\cdot}856 \times 10^{-2}$IT cal/gm °K
For water vapour,
M = $18{\cdot}016$
and R = $4{\cdot}6152 \times 10^6$ erg/gm °K = $1{\cdot}1023 \times 10^{-1}$ IT cal/gm °K

For moist air the value of M is smaller, and that of R is greater, than the respective values for dry air by amounts which depend on the percentage weight of water vapour in the air—see MOLECULAR WEIGHT.

gathering ground: An area from which water is obtained by way of rainfall, drainage or percolation. See also CATCHMENT AREA and DRAINAGE AREA.

gauss: The unit of magnetic flux density, or magnetic induction, in the C.G.S. SYSTEM of units. In geomagnetism, the unit used is the gamma, equal to 10^{-5} gauss.

Gaussian (frequency) distribution: See NORMAL (FREQUENCY) DISTRIBUTION.

gegenschein: A faintly luminous patch of light on the line of the ZODIACAL BAND at the point of the sky opposite to the sun. It is sometimes termed COUNTERGLOW, which is, however, also used of a different phenomenon.

general circulation: The global atmospheric flow which results from the temperature gradients and associated pressure gradients established in the earth's atmosphere because of the greater amount of solar radiation received per unit area of the earth's surface at the equator relative to the poles.

Calculation shows that the mean atmospheric temperature in low latitudes is lower, and in high latitudes higher, than those appropriate to local radiation balance between incoming solar and outgoing terrestrial RADIATION. The effect of the general circulation is therefore to mix, to a considerable extent, the air of higher and lower latitudes. In the absence of a long-period change of world atmospheric temperature, over-all balance exists between the two fluxes of radiation.

Atmospheric circulation is so complex that recognition of its main features requires the determination of mean flow patterns. The mean flow is derived, and the fluctuations about the mean eliminated, by a process of time averaging of the flow or of the pressure field, which is intimately related to the flow. A systematic annual variation of the circulation is revealed by averaging over individual calendar months or seasons. The number of years' data required for adequate suppression of the fluctuations is small in low and high latitudes but is much greater in middle latitudes, especially in the northern hemisphere, where occurrences of strikingly abnormal mean circulation over large areas for a single month are not uncommon. The large-scale turbulence implied by such irregularities—mainly migrating depressions and anticyclones—has a fundamental role in the general circulation which is not revealed in the mean flow: these features, especially the more numerous and vigorous depressions, are responsible for much of the latitudinal mixing of air and are a dynamical consequence of the establishment of a latitudinal temperature gradient.

An idealized mean surface circulation with associated pressure distribution, appropriate to equinox and a uniform surface of the earth, is considered to be:

(i) A narrow belt of light or variable winds converging in a shallow belt of low pressure on the equator (DOLDRUMS).

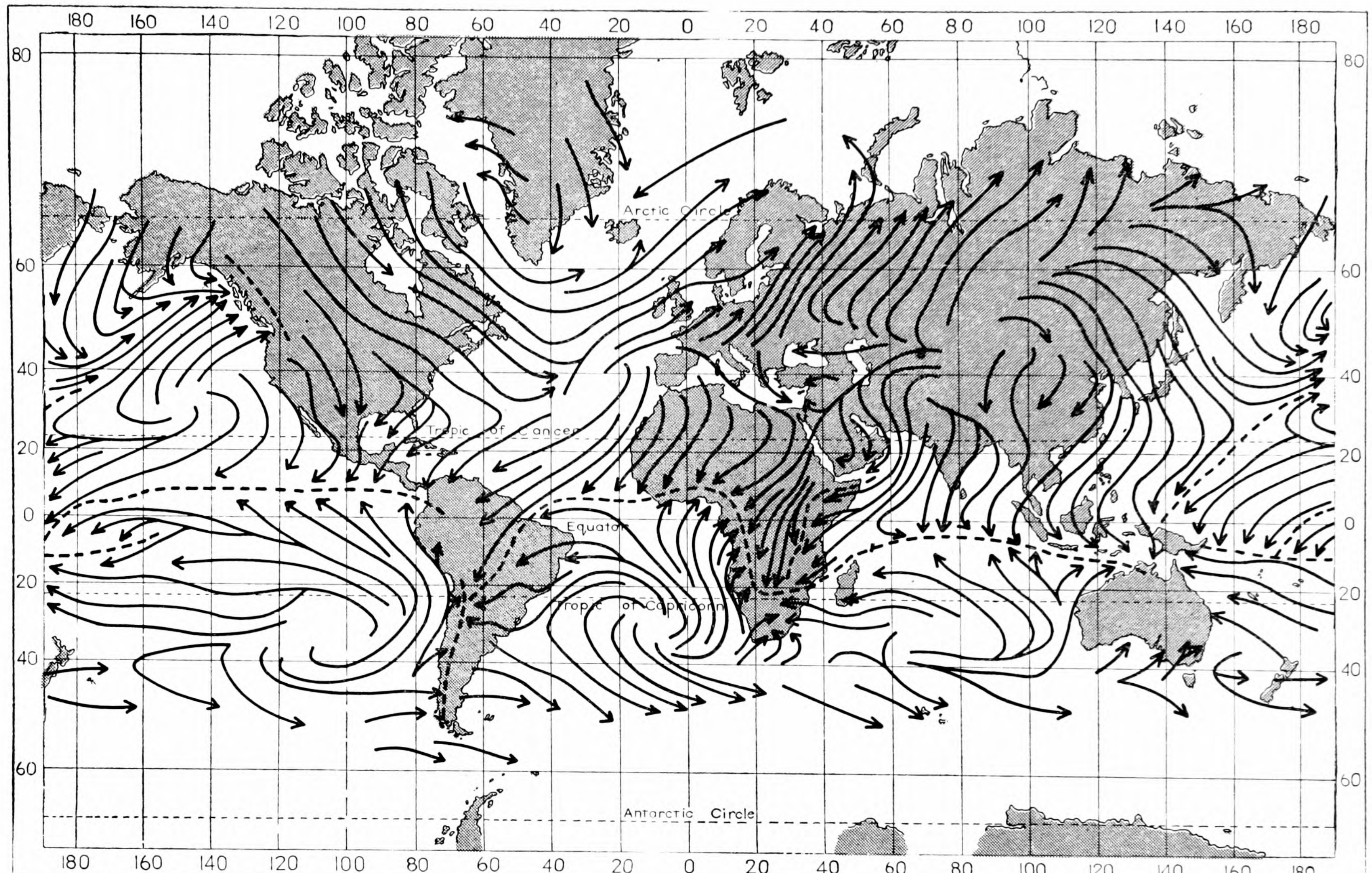

FIGURE 17—Mean surface winds in January.

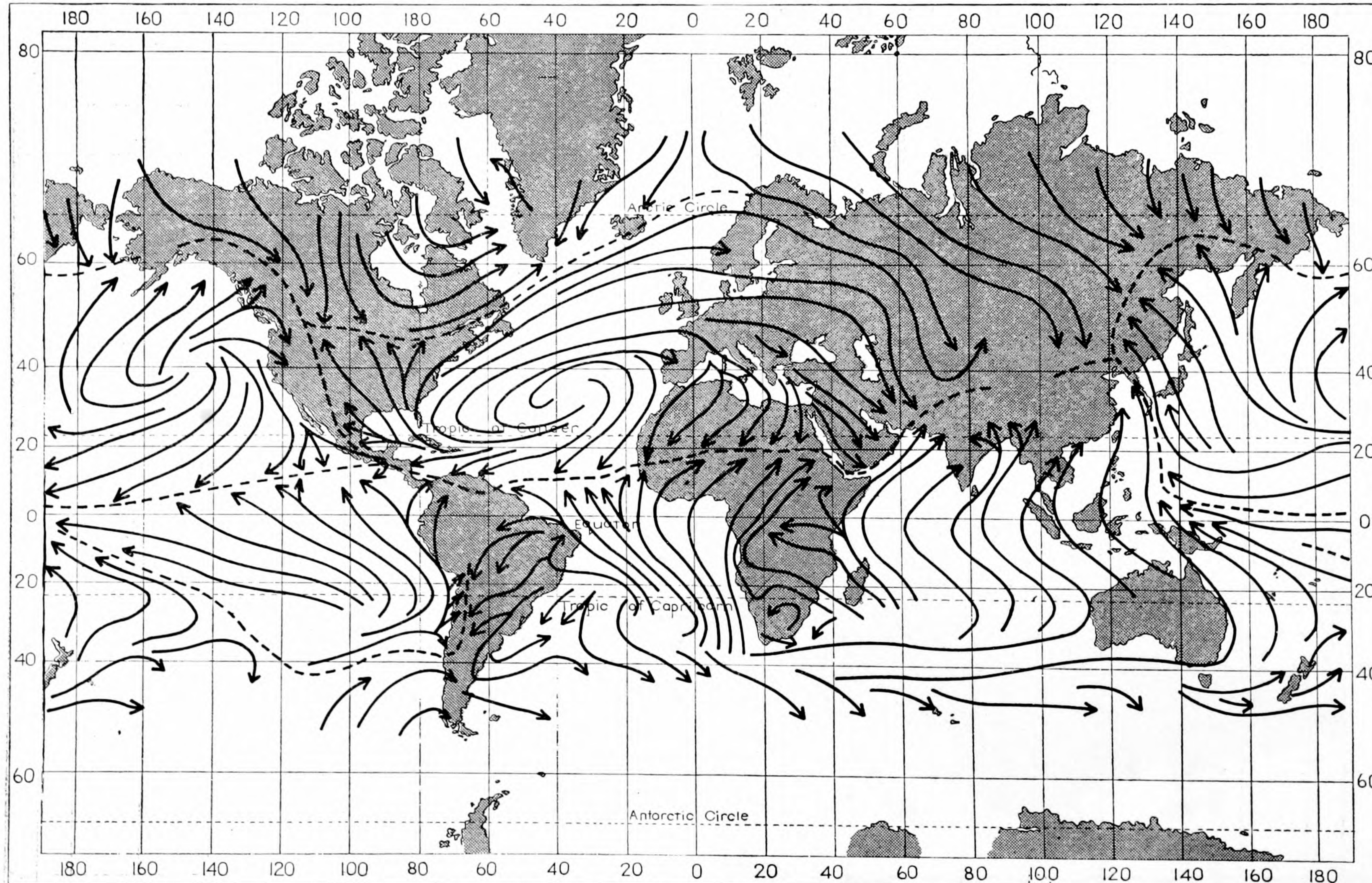

FIGURE 18—Mean surface winds in July.

(ii) TRADE WINDS (or 'tropical easterlies'), north-east in northern hemisphere and south-east in southern hemisphere, between about latitudes 30° N and 30° S and the doldrums.
(iii) Light, variable winds associated with high-pressure belts (subtropical anticyclones) in latitudes 30°–40° N and S.
(iv) Belts of 'westerlies', south-west in northern hemisphere and north-west in southern hemisphere, between about latitudes 40° and 60°.
(v) Variable winds converging in a low-pressure belt at about 60° N and 60° S ('temperate storm belts').
(vi) Regions of outflowing winds with an easterly component, diverging from high pressure near the poles.

The actual mean surface circulations in January and July are shown in Figures 17 and 18. The appreciable departures from the idealized flow, more especially in the northern hemisphere, are due mainly to the non-uniform character of the earth's surface, with associated continental winter anticyclones and summer depressions.

The latitudinal mixing of air implies a three-dimensional mean circulation. At any given latitude continuity demands that average mass transport of air polewards, integrated over all heights, equals that equatorwards: mean meridional flow in the upper air (of the order 1 m/sec) is polewards in low (0°–30°) and high (60°–90°) latitudes and equatorwards in middle (40°–60°) latitudes, balancing the opposite meridional components of the lowest layers. The (very small) mean vertical components of motion which are implied act upwards in the low-pressure belts near the equator and 60° N and S and downwards in the high-pressure belts at 30°–40° N and S and near the poles.

At any given level above the surface the mean flow is more nearly along a parallel of latitude than is the case at the surface. The main feature of the upper air mean circulation is an increase of the westerly wind component with height within the troposphere (increasing THERMAL WIND component) except in equatorial latitudes where easterly winds generally prevail. The strongest mean winds are the westerlies near the tropopause in about latitudes 30°–40° N and S: in winter their mean speed is in excess of 80 knots, in summer some 30–40 knots. Above the tropopause the latitudinal gradient of temperature is reversed and the westerly wind component decreases with height except in high latitudes in winter—the 'polar night JET STREAM'.

general inference: A term used in weather forecasting for a description of the general pressure distribution and the changes of pressure distribution which are in progress, together with a general statement of the type of weather likely to be experienced. It usually precedes a series of more detailed forecasts for individual districts and gives the framework on which these forecasts are based.

genitus: See CLOUD CLASSIFICATION.

geodesy: The science concerned with the size and shape of the earth.

geodynamic metre: See GEOPOTENTIAL.

geomagnetism: The study of the nature and causes of the earth's magnetic field and its variations.

The uniform dipole field which best fits the distribution of the earth's magnetism has 'geomagnetic' (or 'axis') poles at about 79° N, 70° W, and 79° S, 110° E, which define a system of 'geomagnetic co-ordinates' (latitude Φ, east longitude Λ): the 'geomagnetic axis' joining these poles is inclined at 11° to the geographical axis. The two 'magnetic' (or 'dip') poles, where a freely suspended magnet is vertical, are some 500 to 1000 miles distant from the respective geomagnetic poles. Except in higher latitudes, lines of equal geomagnetic latitude are almost parallel to lines of equal angle of DIP (angle of inclination of magnet with respect to horizontal), and angles between geomagnetic and geographic meridians approximate to measured angles of DECLINATION (azimuth setting of magnet with respect to geographic north). The field intensity is about 0·65 gauss (Γ) near the poles and 0·25 Γ near the equator. Decrease of intensity with height above ground proceeds approximately as the cube of distance from earth's centre.

Measurements of the magnetic field vector are made at a world-wide network of some 100 observatories. Continuous photographic recordings of the three independent components, horizontal force (H), angle of declination (D), vertical force (V), are made, and the variations recorded on such MAGNETOGRAMS are reduced to absolute measure by regular calibration. The high standard of accuracy of about 1 gamma (γ) = $10^{-5}\Gamma$ is attained in these measurements.

More than 99 per cent of the earth's magnetic field is of internal origin. Observations since the 17th century have revealed the presence of slow, but cumulatively large, changes of strength and orientation of the field. Their cause is now thought to be large-scale vortices in the conducting molten core of the earth, slowly circulating across the earth's main field and so producing, by dynamo action, slowly changing regional magnetic fields. The origin of the main field itself is not yet satisfactorily explained.

Recent studies in PALEOMAGNETISM indicate some very large changes of field orientation on the geological time-scale. World-wide extension of these studies has yielded evidence of CONTINENTAL DRIFT on this time-scale.

The small part of the earth's field which is of external origin is produced by the entry into the high atmosphere of electromagnetic waves and particles emitted by the sun. Each of these produces characteristic effects on the magnetograms which thus provide a valuable continuous measure of solar activity.

The action of the solar wave-radiation is to ionize the high atmosphere and so make it electrically conducting. The sun and moon cause in the atmosphere tidal movements which, in the presence of the earth's magnetic field, induce by dynamo action electric currents in the conducting region. The magnetic field of these currents is observed at the ground, superposed on the earth's main field. The varying field produced by the thermal and tidal actions of the sun is, in general, clearly visible on the magnetograms as a characteristic local time (S) variation of the magnetic elements. The purely tidal action of the moon on the atmosphere gives rise to a smaller varying field the existence of which is demonstrated by arranging the magnetic element values according to lunar time (L variation). The amplitude of the solar daily variation of the elements, on other than highly 'disturbed' days, is found to be a good relative measure of the sun's ionizing wave radiation. The lower IONOSPHERE, at 60 to 100 km, is the region mainly responsible for these magnetic effects.

The magnetic 'disturbance' produced by solar particles is a highly complex phenomenon which is most frequent in the 'auroral zones', at about 70° geomagnetic latitude, where it is never entirely absent. At higher levels of disturbance, especially beyond the rather arbitrary lower level of a 'magnetic storm', rapid field variations are world-wide and are accompanied by ionospheric disturbances, which produce anomalous radio-reception, and by large earth currents, which adversely affect cable telegraphy. At such times AURORA is visible far equatorwards of its normal position. Field-strength fluctuations during large storms amount to about 3–8 per cent of the undisturbed value, depending on latitude. Field direction changes are in general a few degrees, but are much larger in high latitudes.

Measurement of disturbance intensity is usually made in terms of the range of the magnetic elements. For each Greenwich day, a subjective estimate of the degree of magnetogram disturbance, on the character (C) scale 0, 1, 2, is made for each observatory and averaged for all observatories to give an international character (Ci) figure on the scale 0·0, 0·1, etc. to 2·0. Such daily disturbance character figures are available from 1890, but are now largely replaced in practical use by the 'K index'. This index measures for each observatory, on the scale 0, 1, etc. to 9, the range, in excess of the characteristic wave radiation effect, of the most disturbed of the three magnetic elements in each 3-hour period, 0–3, 3–6, etc. to 21–24 GMT. The K index scale is semi-logarithmic in absolute force units and is fixed for each observatory, once for always, to suit the relative intensity of disturbance at the observatory. A 'planetary' disturbance index K_p for each 3-hour period is derived from the individual K indices of selected observatories. During the period of the INTERNATIONAL GEOPHYSICAL YEAR further disturbance indices Q, relating to each 15-minute period, were prepared at some observatories.

Equatorwards of the auroral zone, the diurnal maximum of disturbance occurs near local midnight (except near the geomagnetic equator) and the seasonal maximum occurs at the equinoxes: polewards of the zone, these maxima occur during the local day and summer, respectively. Although these and other systematic effects in the space and time variations of magnetic disturbance are reasonably well explained, there is yet no unifying theory of the storm phenomenon or of the closely associated aurora. Fundamental difficulties persist concerning the precise nature of the solar stream of charged particles which approaches the earth, and the interaction of this stream with the earth's main magnetic field. Rapidly varying electric currents, concentrated mainly in the auroral zones, together with a 'ring current' in the plane of the equator at a distance of several earth radii, explain qualitatively many of the observed features of disturbance. There is evidence that dynamo action in the high atmosphere is important in the production of the former currents. The existence of the equatorial ring current is not yet definitely confirmed.

The connexion between magnetic disturbance and the physical state of the sun is shown, for example, by a 27-day recurrence tendency (solar rotation period) and an approximate 11-year (solar-cycle) variation of disturbance frequency and intensity. The correlation between individual magnetic disturbances and visual, radio or photographic evidence of solar activity is, however, relatively weak. Dependable prediction of magnetic storms has therefore not yet been achieved.

geophysics: That branch of physics concerned with the earth and its atmosphere. The seven international Associations which at present comprise the International Union of Geodesy and Geophysics (IUGG) are Geodesy, Geomagnetism and Aeronomy, Scientific Hydrology, Meteorology and Atmospheric Physics, Physical Oceanography, Seismology and Physics of the Earth's Interior, Vulcanology: other participating disciplines in the INTERNATIONAL GEOPHYSICAL YEAR project were Cosmic Rays, Ionosphere, Solar Activity.

geopotential: The potential energy per unit mass of a body due to the earth's gravitational field referred to an arbitrary zero. The dimensions are L^2T^{-2}.

Geopotential (Φ) depends on geometric height (z) and GRAVITY (g) in accordance with the equation $\Phi = \int_0^z g dz$, mean sea level being the selected level of zero potential. In general, a geometrically level surface is not one of constant geopotential because of changes of the value of g along it.

The unit of geopotential is the potential energy acquired by unit mass on being raised through unit distance in a field of gravitational force of unit strength. In the C.G.S. SYSTEM it is cm $\times$ cm/sec^2 : the unit 10^5 times greater than this is the 'dynamic metre'.

Geopotential is from the dynamical point of view a better measure of height in the atmosphere than is geometric height: energy is in general lost or gained when air moves along a geometrically level surface but not when it moves along an equigeopotential surface. A 'dynamic height' unit, as defined above, may be used but, by international agreement, a 'geopotential height' unit is preferred because it has the advantage of giving an even better fit, on average over the world, with geometric height, while retaining the dimensions and physical significance of geopotential. The two units are related by the equation: 1 geopotential metre = 0·98 dynamic metre.

The equation which defines the relationship between geopotential height (Z) and geometric height (z) is $Z = \frac{gz}{980}$. Thus, where g has its near average value of 980 cm/sec², heights in geopotential metres and geometric metres are the same: for $g < 980$ cm/sec² the height in geopotential metres is the smaller, for $g > 980$ cm/sec² it is the bigger.

geopotential metre: See GEOPOTENTIAL.

geosphere: That part of the earth which is either solid or is composed of water, i.e. the LITHOSPHERE and HYDROSPHERE combined.

geostrophic approximation: See QUASI-GEOSTROPHIC MOTION.

geostrophic departure: See AGEOSTROPHIC WIND.

geostrophic vorticity: Vorticity evaluated on the assumption of GEOSTROPHIC WIND flow, as from contours on an ISOBARIC SURFACE.

If $\nabla^2 Z$ is the LAPLACIAN of GEOPOTENTIAL on an isobaric surface, then to a close approximation relative geostrophic vorticity $= g\nabla^2 Z/f$ and absolute geostrophic vorticity $= g\nabla^2 Z/f + f$ where f (Coriolis parameter) $= 2\Omega \sin \varphi$ and g is acceleration of gravity. See VORTICITY.

geostrophic wind: That horizontal equilibrium wind (V_G), blowing parallel to the isobars, which represents an exact balance between the horizontal PRESSURE GRADIENT FORCE ($-\frac{1}{\rho}\nabla_H p$) and the horizontal component of the CORIOLIS FORCE ($2\Omega V_G \sin \varphi$). This state of balance implies that V_G is of magnitude $|\nabla_H p|/2\rho\Omega \sin \varphi$. Looking along the wind vector, low pressure is to the left in the northern hemisphere, to the right in the southern hemisphere (see Figure 19).

In terms of the GEOPOTENTIAL height gradient of an isobaric surface ($\nabla_p Z$), the magnitude of V_G is $980|\nabla_p Z|/2\Omega \sin \varphi$. V_G blows parallel to the contours with low values of height to the left in the northern hemisphere, to the right in the southern hemisphere.

Geostrophic wind scales, based on the above relationships, are used and give a good approximation to the actual wind in the free atmosphere. A scale based on the isobaric surface relationship has the advantage of being independent of ρ (air density) and so may be used at any isobaric level.

glacial phase: A period during an ICE AGE (alternating with 'interglacial phases') when there is marked extension of ICE SHEETS equatorwards from polar regions: for the northern hemisphere average extension south of 75° N has been proposed (by G.C. Simpson) as a suitable definition of such a period.

glaciation: A term applied to the sudden transformation, near the top of a developing shower cloud, of supercooled cloud droplets into ice crystals: the transformation is often marked by the formation of ANVIL CLOUD.

glacier: An extensive mass of ice which is formed over land where there is net accumulation of snow. It is considered that growth of glaciers is favoured by snowy winters and cool summers, while recession or disappearance of glaciers is favoured by relatively dry winters and warm summers. Observed changes in thickness and areal extent of glaciers are used as important climatic indicators.

glacier wind: A gravitational (downhill) flow which develops above a GLACIER in day-time, especially in summer, because of the low temperatures then attained close to the glacier, relative to the surroundings. Maximum wind speed occurs some six feet above ground.

glaciology: The study of the distribution and behaviour of snow and ice on the earth's surface. There is appreciable meteorological significance in this study, particularly in relation to climatic changes—see GLACIER. See also EUSTASY.

Glaisher stand: A form of stand devised by James Glaisher for the exposure of thermometers. The stand consists of a vertical portion, partially roofed, on which the thermometers are mounted, with a doubly roofed sloping rear portion designed

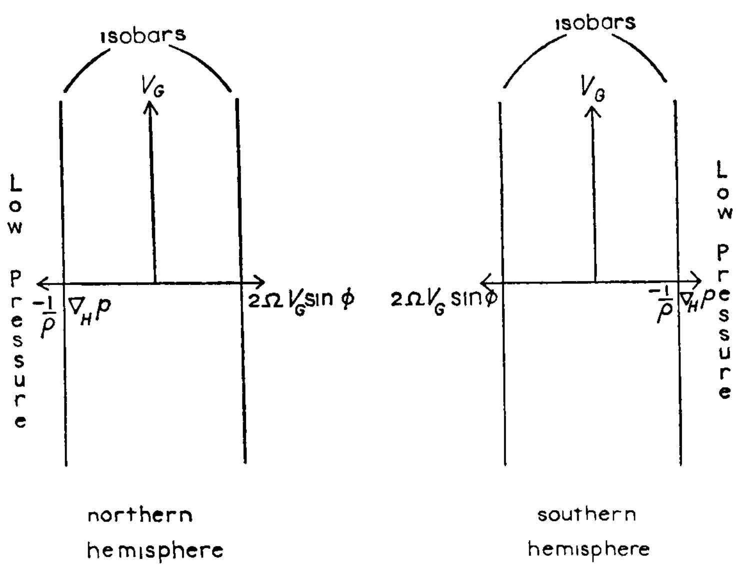

FIGURE 19—Geostrophic wind.

to prevent the front portion becoming heated from the rear. The whole is capable of rotation about a vertical axis so that direct sunshine may be prevented from affecting the thermometers at all times. The stand has been superseded at nearly all important stations by the STEVENSON SCREEN.

glaze: An alternative for GLAZED FROST.

glazed frost: A coat of ice, generally smooth and clear, formed by the falling of rain or drizzle (or sleet) on a surface whose temperature is below freezing-point: alternative terms are 'glaze' and 'clear ice'. It may also be formed, in a sudden onset of a warm, moist air current following severe frost, by the condensation and freezing of water on surfaces at temperatures still below freezing-point. Glazed frost may, on rare occasions, attain sufficient thickness to bring down telegraph wires etc. There was a notable occurrence of glazed frost in late January 1940 over much of south and west England and in Wales: see *Geophysical Memoirs*, No. 98.* See also BLACK ICE.

glory: The system of coloured rings similar to those of a CORONA round sun or moon, surrounding the shadow of an observer's head on a bank of cloud or mist.

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* BROOKS, C. E. P. and DOUGLAS, C. K. M.; Glazed frost of January 1940. *Geophys. Mem., London*, **12**, No. 98, 1956.

The phenomenon is also termed 'anticorona'. A several-fold effect is sometimes observed, while a FOGBOW may be seen to surround a glory.

When light passes through circular holes in an opaque screen, colours are produced by DIFFRACTION. If little mirrors all facing the sun could be substituted for the droplets in a cloud, the light from each mirror would behave as if it came through a hole from the reflexion of the sun and similar diffraction colours would occur. The action of the drops is probably analogous. The mathematical theory developed by B. Ray is on these lines. Earlier writers had supposed that the phenomena were produced by the diffraction, by particles comparatively near the surface, of light reflected from deeper portions of the fog or cloud. See Plate 20.

Gold slide: An attachment, devised by E. Gold, for a marine mercury barometer to allow of the rapid correction and reduction to sea level of such a barometer reading, with sufficient accuracy.

The ATTACHED THERMOMETER is mounted on a brass stock and the corresponding 'barometer correction scale' of millibars (1 mb per 6° K difference from STANDARD TEMPERATURE) is mounted on a vertical slide. The position of the zero of this scale is altered according to the (closely approximate) corrections required for index error, latitude difference from 45°, and height of barometer above sea level: the required correction is then read from that part of the scale, in its adjusted position, opposite the end of the thermometer column.

goodness of fit: In CURVE FITTING, a measure of the closeness with which the selected curve fits the data as a whole.

gradient: The word 'gradient' is used in surveying and in common practice to indicate the slope of a hill, i.e. the change in height per unit distance along the hill. In mathematics, the gradient of a function φ is a vector quantity, written grad φ or $\nabla\varphi$ or del φ, whose direction is that in which φ increases most rapidly and whose magnitude is the rate of increase of φ with distance in this 'up-gradient' or 'ascendant' direction. In meteorology, the PRESSURE GRADIENT FORCE acts from high to low values of pressure, i.e. in the 'down-gradient' or 'descendant' direction. The respective nouns are 'ascendent' and 'descendent'.

For synoptic and other purposes, attention is often confined to gradients in the horizontal plane, as for example the pressure gradient at mean sea level, as defined by mean-sea-level isobars. In common but not universal usage, the term 'temperature gradient' is reserved for temperature change with horizontal distance, change of temperature with height being referred to as 'temperature lapse rate' (or simply 'LAPSE rate'). The same is true of humidity.

gradient wind: That equilibrium horizontal wind (V), blowing parallel to curved isobars of radius of curvature r, whose centripetal acceleration $\left(\frac{V^2}{r}\right)$ represents the net inward horizontal force acting per unit mass of air. The only forces considered to be acting are the horizontal components of the PRESSURE GRADIENT $-(\nabla_H p/\rho)$ and CORIOLIS $(2\Omega V \sin\varphi)$ forces (see Figure 20). The equations, for cyclonic and anticyclonic curvature of isobars, are:

cyclonic (acceleration in direction of pressure gradient force)

$$-(\nabla_H p/\rho) + 2\,\Omega\,V\sin\varphi = -\frac{V^2}{r}$$

anticyclonic (acceleration opposite to pressure gradient force)

$$-(\nabla_H p/\rho) + 2\,\Omega\,V\sin\varphi = +\frac{V^2}{r}$$

PLATE 20 Glory: Tower Ridge, Ben Nevis.

PLATE 21 Halo.

In middle latitudes the gradient wind speed (V) is normally a rather closer approximation to the actual wind speed than is the GEOSTROPHIC WIND speed (V_G). V and V_G are related by the equation

$$V = V_G \pm \frac{V^2}{2\ r\ \Omega \sin \varphi}$$

(+ for anticyclonic, − for cyclonic curvature)

where the term $V^2/2\ r\ \Omega \sin \varphi$ is the so-called 'cyclostrophic component' of the wind. This latter is the AGEOSTROPHIC component of the gradient wind: it is normal to and to the left of the acceleration.

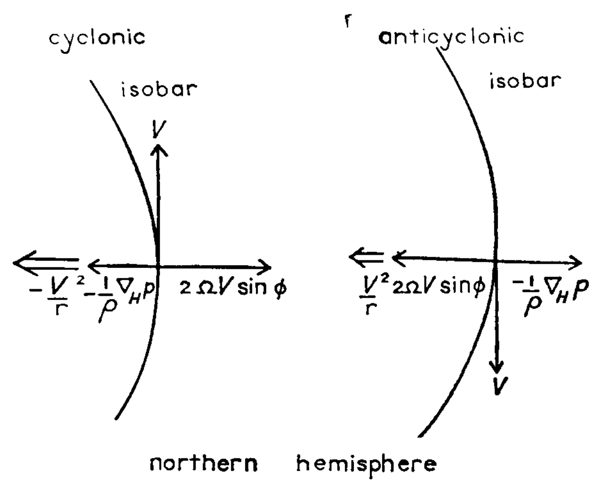

FIGURE 20—Gradient wind.

gram: The unit of mass in the C.G.S. SYSTEM of units. It is one-thousandth part of the standard kilogram which was originally supposed to represent the weight of a cubic decimetre of pure water at 4°C, but subsequent research has shown that the relationship is not exact. One gram = 15·4 grains, or rather more than 1/30 ounce.

gram-calorie: See CALORIE.

Grashof number: In heat transfer by free CONVECTION, a non-dimensional parameter (Gr) defined by the relationship Gr $= gl^3 \Delta T / \nu^2 T$ where l is a characteristic length, g the acceleration of gravity, ν the kinematic VISCOSITY, and ΔT the difference between the temperatures of the surface and the air in contact with it.

grass minimum temperature: The minimum temperature indicated by a thermometer freely exposed in an open situation at night with its bulb in contact with the tips of the grass blades on an area covered with short turf. See also GROUND FROST.

graupel: The German word for 'soft hail'. See HAIL.

gravitational equilibrium: An alternative for DIFFUSIVE EQUILIBRIUM.

gravitational separation: The separation of particles, which are free to fall to earth, by virtue of the different TERMINAL VELOCITIES acquired. For particles of a given substance, for example rain drops, the terminal velocities acquired increase with particle size.

Gravitational separation of the gases which comprise the atmosphere—usually then termed 'diffusive separation'—in accordance with the different weights of their molecules or (at high levels) atoms, is negligible below a level of about 80 km, due to the efficient mixing of the air at the lower levels. See also DIFFUSIVE EQUILIBRIUM.

gravity: The force of attraction between material bodies. The law of universal gravitation is that every mass attracts every other mass with a force which varies directly as the product of the attracting masses and inversely as the square of the distance between their centres of mass. The acceleration of gravity (g), i.e. the acceleration produced in a body which is free to move by the downward pull of the earth, is the force acting per unit mass of the body and is about 981 cm/sec^2 near the earth's surface. It decreases with increasing height in the atmosphere, being about 3 per cent less at a height of 100 km.

Because of the earth's rotation about its axis the observed force of gravity at the earth's surface is the vector resultant of the universal gravitational force and the centrifugal force which arises from the earth's rotation (force $\Omega^2 r$, where Ω is the earth's angular velocity and r the distance from the earth's axis, acting at right angles to the earth's axis). Since the latter force varies with latitude, being zero at the poles ($r = 0$) and a maximum at the equator (but of opposite sense there to the gravitational force), the force of gravity also varies with latitude and has a maximum value at the poles and minimum value at the equator. The direction of the force of gravity defines the direction of the local vertical, being normal to a *level* surface at the corresponding point. Because of the spheroidal shape of the earth (equatorial radius about 21·5 km longer than polar radius)—also the result of the earth's rotation—the force of gravity is not, in general, directed exactly towards the earth's centre. Small local anomalies of gravity occur and are associated with local topographical features and variations of mass distribution.

The formula for the variation of gravity over the earth's surface which is recommended by the World Meteorological Organization for use in applying corrections to barometer readings is:

$$g_{\varphi, \lambda} = 980{\cdot}616(1 - 0{\cdot}0026373 \cos 2\varphi + 0{\cdot}0000059 \cos^2 2\varphi) - 0{\cdot}00009406h$$

where φ is latitude and h is height of station in feet. This formula was adopted by the Meteorological Office with effect from 1 January 1955.* See also STANDARD GRAVITY.

gravity wave: A type of wave, also referred to as a 'gravitational wave', in which the controlling forces are GRAVITY and BUOYANCY. Such waves may be generated at a free surface of a single layer, as at an ocean surface, or at the boundary between adjacent layers or in a stably stratified medium. In the atmosphere additional forces may control the particle movement, as in a SHEAR-GRAVITY WAVE.

great circle: Any plane which passes through the centre of a sphere cuts the surface of the sphere in a 'great circle'.

green flash: On some occasions the last glimpse obtained of the sun at sunset, or the first glimpse at sunrise, is a brilliant green—the 'green segment'—lasting a few seconds. On still rarer occasions a 'green flash' or 'green ray', also lasting a few seconds, shoots above the horizon from the upper limb. The explanation is the greater REFRACTION of the short waves (violet, blue, green) than of the long waves (red) of white sunlight, coupled with the greater degree of RAYLEIGH SCATTERING experienced by the violet and blue rays. In a hazy atmosphere such differential scattering may not be appreciable and the flash may then appear blue or violet. It is probable, though not yet confirmed, that an unusual degree of refraction, such as occurs with a low-level inversion of temperature, is required for the phenomenon.

Differential refraction of white light is also the cause of the analogous very rare phenomenon of the 'red flash' which may occur when the sun's disk appears just below a bank of clouds near the horizon.

The green flash has been observed in association with the moon and planets on rare occasions.

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* FRITH, R., New barometer conventions. *Met. Mag., London*, **84**, 1955, p. 38.

greenhouse effect: The effect, analogous to that which has been supposed to operate in a greenhouse, whereby the earth's surface is maintained at a much higher temperature than the temperature (about 250°K) appropriate to balance conditions with the solar radiation reaching the earth's surface. The atmospheric gases are almost transparent to incoming solar radiation, but water vapour and carbon dioxide in the atmosphere strongly absorb TERRESTRIAL RADIATION emitted from the earth's surface and re-emit the radiation, in part downwards. See ABSORPTION.

gregale: A strong north-east wind occurring chiefly in the cool season in the south central Mediterranean, but used also of a strong north-east wind in other parts of the Mediterranean, for example the south coast of France (grégal) and in the Tyrrhenian Sea (grecale).

grenade sounding: A type of rocket sounding in which a succession of grenades is released between the heights 30 and 100 km, say, during the ascent of the rocket. The grenade flashes made at a known instant are recorded on special cameras and the arrival of the sound waves is recorded on an array of microphones distributed over a wide area. From the basic observational data (time and position of burst, and time of arrival of waves at various places on the ground) it is possible to infer, by a laborious process which is performed electronically, the distribution of wind and temperature throughout the layer concerned.

grey body: A 'grey-body radiator' is defined as one which emits, for every wavelength, the same proportion of the maximum or 'black-body' radiation at a given temperature. Treatment of the atmosphere as a grey-body radiator has been found to give results which are too inaccurate to be useful: consideration of the detailed ABSORPTION spectrum is required. See RADIATION.

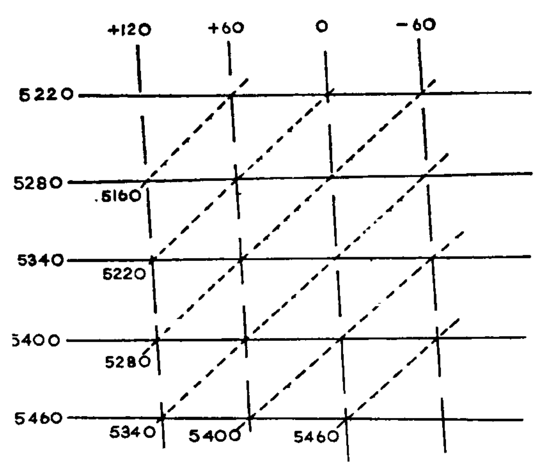

FIGURE 21—Isopleths of heights of 500 mb surface (Z_{500} ——), 1000 mb surface (Z_{1000} — —) and 1000–500 mb thickness (T - - -), each drawn at 60m intervals.

Since $T = Z_{500} - Z_{1000}$, isopleths of Z_{500} may, for example, be obtained by graphical addition of T and Z_{1000}, or isopleths of Z_{1000} by graphical subtraction of T from Z_{500}. It is to be noted that the 1000–500 mb thickness isopleths pass through the intersections of the 1000 mb and 500 mb isopleths.

gridding: In synoptic meteorology, a system of graphical addition or subtraction of two fields represented by isopleths, used for example in upper air work and in obtaining 'anomaly patterns'.

Gridding may be performed on a single chart, as illustrated in Figure 21. Alternatively, two superimposed charts may be used, each with a set of isopleths, the points of intersection of which are made visible by illuminating the charts from below.

Grosswetter: A German term which is used to indicate, with special reference to long-range weather forecasting, the main features of weather over a specified region and period of time. The use of this term involves the concept that certain variable but non-random influences (not yet definable) govern the large-scale pattern of weather development. 'Grosswetterlagen' are the synoptic situations corresponding to the types of Grosswetter.

ground discharge: Lightning flash from cloud to ground. See LIGHTNING.

ground frost: From 1906 to 1960, inclusive, the Meteorological Office practice was to record a 'ground frost' when the grass minimum thermometer reached 30°F or below (30·4°F for thermometers read to tenths) and to base the 'number of days of ground frost' on this criterion. The reason for this choice is rather obscure: it may have been based on the belief that a temperature appreciably below 32°F is required before damage is caused to the tissues of growing plants.

From 1 January 1961, the statistics issued have referred to the 'number of days with grass minimum temperature below 0°C' and no statistics have referred to 'ground frost'. The use of the term 'ground frost' in forecasts signifies a grass minimum temperature below 0°C (32°F).

ground, state of: Observations of the state of ground are made at selected stations in connexion with the operations of aircraft and of agriculture. The code provides for ten different conditions of the ground in the vicinity of a station, namely dry, moist, wet (standing water in pools etc.), frozen, covered with glazed frost without snow, wholly or partly covered with ice, snow, loose dry snow, dust, or sand. An amplified code is used at CROP WEATHER STATIONS. See 'Observer's handbook'* for details of times of observation.

ground water: In HYDROLOGY, the water which is retained at all levels below the WATER TABLE.

growing season: That period of the year during which the growth of vegetation proceeds. For the common vegetation of north-west Europe a mean screen temperature exceeding 42°F is regarded as an approximate critical value: the approximate length of growing season for any locality may therefore be obtained from the corresponding curve of annual variation of mean temperature.

Gulf Stream: Originating in the eastern area of the Gulf of Mexico, the ocean current known as the Gulf Stream flows through the Straits of Florida and up the eastern coast of the United States, following the edge of the continental shelf. Leaving the coast of America in about 40°N, it proceeds as a weaker and broader current across the Atlantic and reaches the British Isles in about 50°N. Its mean speed across the Atlantic is 3–5 miles per day: near the American coast mean speeds of about 30 miles per day are reached in spring and summer. Though one of the strongest and most constant of ocean currents, the Gulf Stream is subject to variability and even to reversals. While the term 'Gulf Stream' is popularly applied to the entire current system described above, more precise technical definition subdivides the system into the Florida Current to about 40°N, the Gulf Stream eastwards to 45°W, the North Atlantic Drift farther eastwards and northwards. It is popularly supposed that the temperate climate of the British Isles is due to the warmth conveyed by the Gulf Stream: a more accurate view is that the temperate, maritime nature of the climate is due to the prevalence of south-west to west winds, which also cause the extension of the Gulf Stream towards the British Isles.

gust: A rapid increase in the strength of the wind relative to the mean strength obtaining at the time. It is a much shorter-lived feature than a SQUALL and is also

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* London, Meteorological Office; Observer's handbook. 2nd edn. London, HMSO, 1956.

different in nature, being due mainly to mechanical interference with the steady flow of air: it is, therefore, a pronounced feature of air flow near the ground, especially where there are large obstructions. Other factors, notably temperature lapse rate and vertical wind shear, are important, however, in determining the existence and magnitude of gusts. Such factors may produce gusts in circumstances where mechanical interference with the flow appears to be insignificant, as in CLEAR-AIR TURBULENCE.

The definition of the gust implies the existence of 'negative gusts' (lulls) of wind. The fluctuations of either sign are involved in the definition of 'gustiness'. The range between gusts and lulls increases with the mean wind strength: there is, however, also a dependence on anemometer exposure and, at most stations, on wind direction. See also GUSTINESS, TURBULENCE.

The strongest gusts recorded in recent years on anemographs of the Meteorological Office are shown in Table IX.

TABLE IX—*Strongest gusts recorded on anemographs of the Meteorological Office in recent years*

Year	Station	Strongest gust *kt*	Strongest gust *mph*
1936	Tiree	90	104
1937	Holyhead	93	107
1938	St. Ann's Head	94	108
1945	St. Ann's Head	>98	>113
1950	Pendennis Castle	90	104
1951	Millport	94	108
1952	Cranwell	96	111
	Stornoway	94	108
1954	Kete	95	109
	Scilly	91	105
1956	Lerwick	90	104
	Stornoway	96	111
1957	Tiree	98	113
	Benbecula	95	109
1961	Kirkwall (Grimsetter)	90	104
	Stornoway	93	107
	Lerwick	95	109
	Tiree	101	116
	Rannoch	92	106
	Ballykelly	92	106
1962*	Lowther Hill	106	122
	Stornoway	98	113
	Rannoch	92	106
	Kirkwall (Grimsetter)	95	109

gustiness: The important characteristics of a fluctuating wind, characterized by GUSTS and lulls about a mean level, are the frequency and strength of the gusts. The former is usually expressed by the number of wind maxima occurring within a specified period of time. The strength is defined in various ways:

(i) In normal surface observations by a 'gustiness factor', i.e. by the percentage ratio of the difference between the maximum and minimum horizontal wind speeds to the mean wind speed recorded in a given period. In a selection of eight British stations, values of the gustiness factor ranging from 25 to 100 per cent were obtained, large dependence of the factor on mean wind direction being found at some of the stations. A gustiness factor in ordinary observations may also be defined in terms of wind direction: the angular width (in radians) is a measure of lateral gustiness which for small values is nearly equivalent to the speed ratio.

* To 31 March.

(ii) In micrometeorology, by 'gustiness components', longitudinal (g_x), lateral (g_y), and vertical (g_z), defined as the ratios of the average magnitudes of the component fluctuations independent of sign $|\bar{u}'|$, $|\bar{v}'|$, $|\bar{w}'|$, to the mean wind velocity ($\bar{V}$), where the x-axis is taken in the direction of $\bar{V}$,

$$\text{i.e. } g_x = \frac{|\bar{u}'|}{\bar{V}}, \; g_y = \frac{|\bar{v}'|}{\bar{V}}, \; g_z = \frac{|\bar{w}'|}{\bar{V}}$$

Alternatively, gustiness may be defined by a standard deviation (root mean square fluctuation); or by the ratio of the standard deviation to the mean velocity (termed the 'intensity of turbulence').

See also TURBULENCE, EDDY, EDDY SPECTRUM.

guttation: The exuding of liquid water from the tips of plants, usually under conditions of a warm, moist soil. The phenomenon is often mistaken for one of DEW formation.

H

haar: A local name in eastern Scotland and parts of eastern England for a wet sea fog which at times invades coastal districts. Haars occur most frequently in summer months. See ADVECTION FOG.

haboob: The name, derived from the Arabian *habb* meaning to blow, applied to a DUSTSTORM in the Sudan north of about 13° N. Such storms occur from about May to September and are most frequent in the afternoon and evening.

Hadley cell: A simple thermal circulation first suggested by George Hadley in the 18th century as part explanation of the TRADE WINDS and still thought to be approximated in the troposphere between latitudes 0° and 30°. Neglecting the effects of the earth's rotation, the circulation comprises a high-level poleward flow from heat source to heat sink in response to a horizontal pressure gradient (at a high level, pressure is greatest above the heat source since pressure decreases less rapidly with height in the warmer air column), and a compensating low-level flow towards the heat source: upward and downward motions at the heat source and sink, respectively, complete the circulation—see Figure 22.

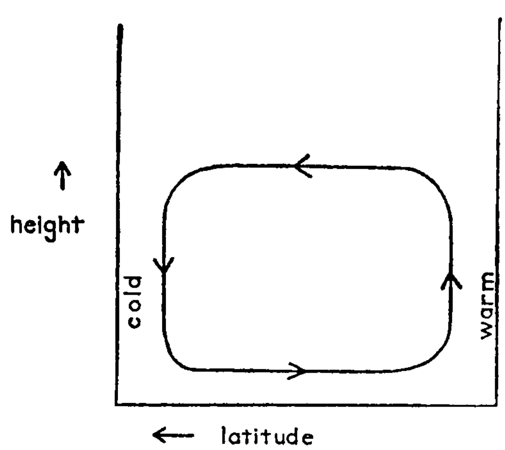

FIGURE 22—Hadley cell.

Haidinger's brush: A faint and transitory figure, in the shape of a yellowish brush with a small blue 'cloud' on either side, which appears when a source of strongly polarized light, such as the blue zenith sky with the sun close to the horizon, is closely observed. Because of physiological differences, the phenomenon is apparently not seen by all observers in quite the same form.

hail: Solid PRECIPITATION in the form of hard pellets of ice which fall from CUMULONIMBUS clouds. The pellets are spherical, conical or irregular in shape and often have a structure of concentric layers of alternately clear and opaque ice. They are variable in size, usually a few millimetres in diameter but sometimes very much bigger: hailstones as big as a grapefruit and weighing over 2 lb have been observed.

Because of the high liquid-water concentration of cumulonimbus clouds, the growth of ice particles, following their initial formation on ice nuclei at temperatures well below freezing and at saturation with respect to water, is mainly by collision and coalescence with supercooled water drops. The particles are supported within the cloud by strong updraughts (of the order 10 m/sec) and so are able to attain an appreciable size.

The opacity of the ice is caused by the trapping of air bubbles within the ice on freezing of supercooled water drops on the ice particles. Since this occurs only at temperatures lower than about −5°C it has been suggested that alternate clear and opaque rings occur when the stone is fluctuating at about this temperature level in the cloud, supported by a (varying) updraught nearly equal to the TERMINAL VELOCITY of the stone. It is, however, also suggested that the clear (opaque) rings reflect slow (rapid) freezing of supercooled water drops on the stone, associated with a high (low) water concentration in the cloud, and that the concentric rings result, therefore, from variations of liquid water content. (The freezing of the drops involves the release of latent heat which must be dispersed before the freezing can be complete.)

Two other varieties of hail are recognized: (i) 'soft hail' (or 'graupel')—crisp, opaque and easily compressible pellets; (ii) 'small hail'—pellets with a soft hail nucleus and outer coating of clear ice. In either case the diameter does not exceed a few millimetres. The density of hail varies between about 0·1 and 0·9 gm/cm^3, depending on structure.

hail, day of: A day on which HAIL, of whatever variety, is observed even though in so small a quantity as to yield no measurable amount in the rain-gauge.

half-life: In RADIOACTIVITY, the time taken for the activity of a given quantity of a radioactive element to decrease to one-half of its original value. The half-lives of radioactive elements range from a small fraction of a second to many thousands of years.

halo phenomena: The term 'halo', which might be applied to any circle of light round a luminous body, is restricted by meteorologists to a circle produced by REFRACTION through ice crystals, in contrast to CORONAE which are produced by DIFFRACTION. All the optical phenomena produced by REFLEXION and refraction of light by ice crystals are sometimes grouped together as halo phenomena.

The most common halo is a luminous ring of 22° radius surrounding the sun or moon, the space within the ring appearing less bright than that just outside. The ring, if faint, is white; if more strongly developed the inner edge is a pure red, outside which yellow may be detected. The halo of 22° is very common. In England it can be seen by an assiduous observer about one day in three. See Plate 21.

The angle of 22° is the angle of MINIMUM DEVIATION for light passing through a prism of ice (refractive index 1·31) with faces inclined at 60°. Thus the occurrence of the halo of 22° radius indicates the presence of ice crystals with faces inclined at 60°. Alternate faces of a hexagonal prism are inclined at this angle, and as hexagonal prisms are frequently found amongst ice crystals the halo is probably due to the refraction of light through such prisms.

A halo of 46° is to be seen occasionally, though seldom complete. This halo requires crystals with faces at right angles.

The halo of 22° is sometimes within a circumscribed nearly elliptical halo, the points of contact being at the highest and lowest points. The complete circumscribed halo is only seen when the elevation of the sun is 40° or more. With lower elevations separate tangent arcs are seen. These phenomena are explained by the presence of prismatic ice crystals floating with their axes horizontal.

Another group of phenomena requires prismatic crystals with their axes vertical. In this group are PARHELIA (mock suns) and the CIRCUMZENITHAL ARC.

In weather lore, haloes are often spoken of as presaging storms. Haloes are, however, too common to be good signs of exceptional weather.

harmattan: A dry wind blowing from a north-east or sometimes easterly direction over north-west Africa. Its average southern limit is about 5° N latitude in January and 18° N in July. Beyond its surface limit it continues southwards as an upper current above the south-west monsoon. Being both dry and relatively cool, it forms a welcome relief from the steady damp heat of the tropics, and from its health-giving powers it is known locally as 'the doctor' in spite of the fact that it carries with it from the desert great quantities of dust. This dust is often carried in sufficient quantity to form a thick haze, which impedes navigation on the rivers.

harmonic analysis: The statistical analysis of a series of data in such a way as to determine the PERIOD, AMPLITUDE and PHASE of the harmonic (wave) components which comprise the series. The method involves the use of FOURIER SERIES and is therefore also termed 'Fourier analysis'. The reverse process, that of determining any particular value of the function by addition of the known harmonic components, is termed 'harmonic synthesis'.

Harmonic analysis has been much used, for example, in the examination of the nature of the systematic diurnal variation of pressure (components of period 24 hours and its sub-multiples) and the systematic annual variation of temperature (components of period 12 months and its sub-multiples). It has also been used, notably in conjunction with PERIODOGRAM analysis, in the search for PERIODICITY in many types of meteorological time series.

See 'Handbook of statistical methods in meteorology'.*

harmonic dial: A representation, on a polar diagram, of the results of HARMONIC ANALYSIS, in which periodic components of a given frequency are compared. The components may, for example, refer to different stations at a given epoch, or to results for different seasons at a given station. Points are plotted on the diagram at positions corresponding to the amplitude, measured on a linear scale from the origin, and to the epoch of maximum of the component. The scale of angular measure employed in the analysis and the corresponding scale of time are generally both shown on such diagrams.

harmonic mean: The harmonic mean (H) of a series of n numbers a, b, c, etc., is the reciprocal of the arithmetic MEAN of the reciprocals of the numbers, i.e.

$$\frac{1}{H} = \frac{1}{n}\left(\frac{1}{a} + \frac{1}{b} + \frac{1}{c} + \text{etc.}\right)$$

haze: A suspension of very small, non-aqueous, solid particles of SMOKE, DUST, etc., which produce a milky appearance of the sky. For synoptic purposes the term is used when the particles are sufficiently numerous to give the air an opalescent appearance. There is no upper or lower limit to the horizontal visibility in the presence of which haze may be reported. When VISIBILITY is reduced to distances exceeding one km by water droplets the phenomenon is termed MIST.

In most cases the particles comprising haze are small enough (less than about 1 micron) to cause differential scattering of sunlight and to contribute, for example, to sunrise and sunset colours.

hazemeter: A term sometimes used synonymously with VISIBILITY METER. The 'loofah hazemeter' is an instrument in which the intensity of the light scattered at a particular angle to the original beam passing through an enclosed air sample is

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* BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, HMSO, 1953.

used as a measure of the SCATTERING coefficient of the air and hence its visibility (neglecting direct ABSORPTION of light).

head-wind: See EQUIVALENT HEAD-WIND.

health-resort station: A CLIMATOLOGICAL STATION which participates in the Meteorological Office health-resort scheme whereby participating stations send daily a coded report or reports relating to observed temperature, rainfall, sunshine, and weather for issue to the press. See 'Observer's handbook'* for details.

heap clouds: CLOUDS of appreciable vertical development (CUMULUS and CUMULONIMBUS), as opposed to 'layer clouds'.

heat: A form of energy, normally measured in CALORIES or JOULES. The dimensions are ML^2T^{-2}.

The transfer of heat to or from a substance is effected by one or more of the processes CONDUCTION, CONVECTION, RADIATION. The common effect of such a transfer is to alter either the temperature or the state of the substance (or both). Thus, a heated body may acquire a higher temperature ('sensible' heat) or may change to a higher state (thus acquiring latent or 'hidden' heat).

The relation between the joule (J) and other heat units is:
1 15°C calorie (cal_{15}) = 4·1855 J
1 International Steam Table calorie (IT cal) = 4·1868 J
1 60°F British thermal unit = 1054·54 J
1 International Steam Table British thermal unit = 1055·06 J
See also SPECIFIC HEAT and LATENT HEAT.

heat capacity: An alternative for THERMAL CAPACITY.

Heaviside layer: A layer of the IONOSPHERE at about 100 km height, now usually termed the E-layer: it has also been termed the 'Kennelly–Heaviside layer'.

hectopieze: Unit of pressure equal to 10^2 PIEZE. The unit is thus 10^6 dyne/cm^2 and is equivalent to the BAR.

heiligenschein: A diffuse, white ring of light surrounding the shadow of the head of an observer which is cast on dewy grass. The phenomenon occurs mainly when the sun's elevation is low and the observer's shadow long.

heliostat: An instrument mounting designed to provide automatic orientation of the instrument towards the sun or automatic direction of the light from the sun on to the instrument. A familiar form is that used, in conjunction with a PYRHELIOMETER, to obtain continuous measurement of direct solar radiation.

helium: So named because of its original discovery in the sun's atmosphere, helium is one of the INERT GASES. It occurs in very low concentration in the atmosphere, $5 \cdot 2 \times 10^{-6}$ and $7 \cdot 2 \times 10^{-7}$ part per part of dry air by volume and weight, respectively. Being very light, with a molecular weight of only 4·003, it escapes continuously from the top of the atmosphere at a rate which is in approximate balance with the rate of production of ALPHA PARTICLES (helium nuclei) near the earth's surface.

helm wind: A strong, cold, north-easterly wind which blows down the western slope of the Crossfell Range in Westmorland and Cumberland. Its greatest frequency is in late winter and spring. When the helm wind blows, a heavy bank of cloud (the

* London, Meteorological Office; Observer's handbook. 2nd edn., London, HMSO, 1956, p. 8.

'helm') rests along or just above the Crossfell Range and a slender, nearly stationary roll of whirling cloud (the 'helm bar'), parallel with the 'helm', appears above a point one to four miles from the foot of the fell. The helm wind is very gusty and often violent as it blows down the steep fell sides but ceases under the helm bar cloud. To the west of this point a light westerly may prevail over a short distance. The helm wind has a marked drying effect.

The term 'helm wind' is applied to a similar wind with associated cloud elsewhere, e.g. in the Lake District, but the full development is confined to the strip of country east of the River Eden, particularly near Crossfell itself.

hertz: The unit of frequency of a periodic function, equal to one cycle per second.

heterosphere: Term proposed for that region of the ATMOSPHERE, upwards of about 80 km, in which the composition of the atmosphere changes, hence also the mean molecular weight of the gases, due mainly to the partial DISSOCIATION of oxygen and to DIFFUSION. It forms a contrast with the underlying HOMOSPHERE.

HIFOR: An international code word which precedes a high-level forecast.

high: A term sometimes used in synoptic meteorology to indicate a high-pressure system, for which the term ANTICYCLONE was coined by Sir Francis Galton.

hill fog: A term generally used of low cloud which envelops high ground. The production of saturation and condensation by forced uplift of the air is not necessarily implied in the use of this term as it is in the case of UPSLOPE FOG.

histogram: A graphical representation of a frequency distribution in which the frequency (abscissa) in each class interval (ordinate) is shown as a horizontal line extending over the class interval.

hoar frost: Thin ice crystals in the form of scales, needles, feathers or fans deposited on surfaces cooled by radiation. The deposit is frequently composed in part of drops of DEW frozen after deposition and in part of ice formed directly from water vapour at a temperature below 0°C. The presence of fog, in so far as it checks the radiational cooling of surfaces, tends to prevent the formation of hoar frost. See also RIME.

hodogram: See HODOGRAPH ANALYSIS.

hodograph analysis: A method of analysis of a wind sounding at a station. By a recent convention which is contrary both to previous practice and to normal mathematical convention, the individual wind vectors at selected levels are plotted on a polar co-ordinate diagram from the origin of the diagram (representing station position) towards the direction from which the wind blows (see figure 23). This new method has the advantages of being easier to apply in practice and of being in accordance with the normal method of representing wind direction at a station. The lengths of the vectors are proportional to the corresponding wind speeds. The sense of each vector is towards the origin.

The lines joining the 'starting points' of air flow at successive levels form a hodograph (or hodogram). Each such line corresponds to the WIND SHEAR vector in the layer concerned. When taken in the appropriate sense (higher to lower level) it represents, on the assumption of geostrophic flow, the corresponding THERMAL WIND.

hollerith system: A mechanical system widely used in the processing of climatological data. The system is one in which observational figures are represented by holes punched in appropriate positions on a card. The punched cards are sorted in groups, and the figures on the cards tabulated and summed, by insertion of the cards into sorting and tabulating machines, respectively, electrical contact being made through the punched holes.

homogeneous atmosphere: A hypothetical atmosphere in which air density is constant with height: the lapse rate is, by definition, the AUTOCONVECTIVE LAPSE RATE. The height (z) of such an atmosphere is from the hydrostatic and gas equations given by

$$z = p_0/g\rho_0 = RT_0/g,$$

where p_0, ρ_0 and T_0 are the surface pressure, density and temperature, R the gas constant for air, and g the acceleration of gravity. Ignoring the small variation of g with height, z is thus proportional to the absolute air temperature at the surface. For $T_0 = 273°K$, z is about 8 km. See also SCALE HEIGHT.

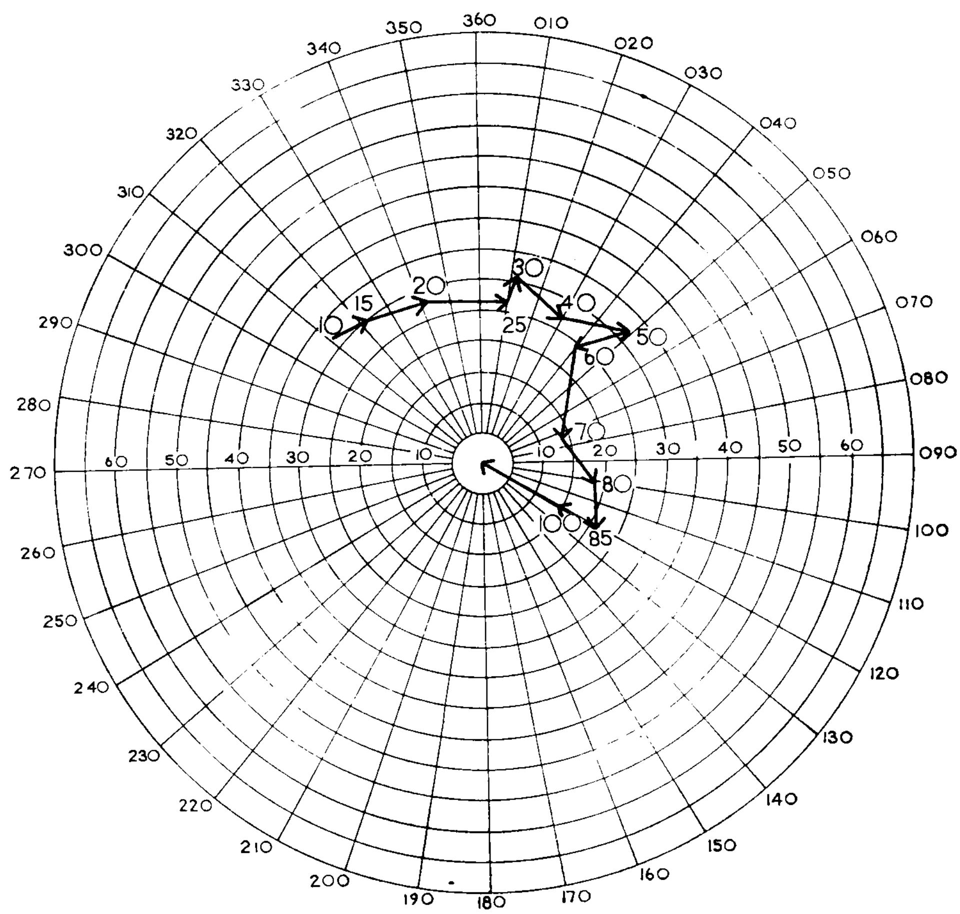

FIGURE 23—Hodograph relating to winds observed at Shanwell (56° 26′ N, 2° 52′ W) at 2230 GMT, 22 December 1961.

Successive arrows represent the vector difference between the wind at the top of a layer (denoted by figures, in tens of mb at arrow tail) and the wind at the bottom of a layer (figures at arrow head). The bottom of the lowest layer is the earth's surface.

homogeneous condensation, freezing: See HOMOGENEOUS NUCLEATION.

homogeneous nucleation: Homogeneous or 'spontaneous' nucleation signifies the initiation of either CONDENSATION or FREEZING in the absence of condensation or freezing nuclei, respectively: the processes are also termed homogeneous or spontaneous condensation, and freezing, respectively.

Aggregates of water molecules continuously form and evaporate in supersaturated air which is free from condensation nuclei. The probability that such aggregates will attain a critical size big enough for them to become more stable than the vapour and so act as centres on which further rapid growth (spontaneous condensation) will occur is small for degrees of SUPERSATURATION less than about 400 per cent: such an order of supersaturation does not occur in the atmosphere.

In air which is deficient in freezing nuclei, lowering temperature below 0°C increases the probability that aggregates of water molecules may take up an ice-like configuration and grow to a size sufficient for them to act as centres on which ice crystals may rapidly form. The variation with temperature of the probability of homogeneous nucleation is such that, in practice, there appears to be a critical temperature below which it occurs and above which it is absent. For water it is about −40°C.

homosphere: That region of the ATMOSPHERE, extending from the earth's surface to about 80km, in which, neglecting water vapour, the composition of the atmosphere is constant (apart from some gases in very small concentration, e.g. carbon dioxide, ozone) and in which, therefore, the mean molecular weight of dry air is effectively constant. It forms a contrast with the overlying HETEROSPHERE.

horizon: In meteorology, this term signifies the line where the earth's surface and the sky apparently join. Neglecting REFRACTION, the distance of the horizon from an observer at height h is $\sqrt{(2ha)}$, where a is the earth's radius. For a height of 100

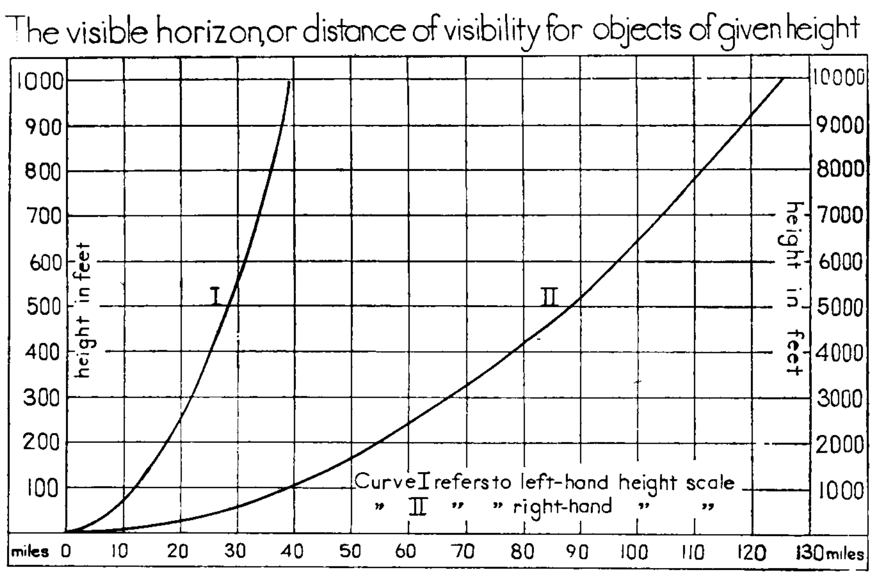

FIGURE 24—Relation between the height of an observing point in feet and the distance of the visible horizon in miles (neglecting refraction), or the height in feet of a cloud or other distant object and the distance in miles at which it is visible on the horizon.

feet the corresponding distance is 12 miles: the actual distance is about two miles greater on account of refraction. A level canopy of clouds 10,000 feet high is visible from a point on the earth's surface for a distance of about 125 miles, or the visible canopy has a width of 250 miles. Distances corresponding to other heights may be obtained from Figure 24.

horse latitudes: The belts of variable, light winds and fine weather associated with the subtropical anticyclones at about 30°–40° latitudes. The belts move slightly north and south after the sun. The name arose from the old practice of throwing overboard horses, which were being transported to America or the West Indies, when the ship's passage was unduly prolonged.

hot-wire anemometer: See ANEMOMETER, ANEMOGRAPH.

hour angle: The hour angle (H) of a heavenly body at any instant is the angle (usually expressed as a time on the scale 24 hours = 360°) between the observer's MERIDIAN and the meridian through the body. The angle is measured westwards from the observer's meridian.

humidiometer: An instrument for measuring atmospheric HUMIDITY. The term is used in particular of the 'Gregory humidiometer' in which the changes of electrical resistance with relative humidity of a strip of cloth or tape impregnated with a hygroscopic salt (lithium chloride) are measured.

humidity: The condition of the atmosphere in respect of its WATER VAPOUR content. The word 'humidity' used alone generally signifies RELATIVE HUMIDITY, but various other measures are employed such as HUMIDITY MIXING RATIO, VAPOUR CONCENTRATION, VAPOUR PRESSURE, SPECIFIC HUMIDITY, DEW-POINT, etc.

humidity mixing ratio: The humidity mixing ratio (r)—or, more generally, simply the 'mixing ratio'—of moist air is the ratio of the mass (m_v) of water vapour to the mass (m_a) of dry air with which the water vapour is associated,

$$r = m_v/m_a$$

If e' is the vapour pressure, p the total pressure and ε the ratio of the densities of water vapour and dry air (ε = 0·62197), then

$$r = \varepsilon e'/(p-e')$$

Since e' is small compared with p, r (gm/gm) is a small quantity of the order 0·01 gm/gm. For convenience, therefore, r is usually expressed in gm/kg.

humidity slide-rule, tables: The slide-rule or tables, based on the psychrometric formula (with an assumed value of the product Ap in this formula appropriate to the conditions of exposure of the instruments), from which the DEW-POINT, VAPOUR PRESSURE, and RELATIVE HUMIDITY of an air sample may be obtained from readings of the DRY- and WET-BULB HYGROMETER. See PSYCHROMETER.

humilis (hum): A CLOUD SPECIES. (Latin, *humilis* low.)

'CUMULUS clouds of only a slight vertical extent; they generally appear flattened'.* See also CLOUD CLASSIFICATION.

hurricane: A name (of Spanish or Portuguese origin) applied to the intense TROPICAL CYCLONES which occur in the West Indies and Gulf of Mexico regions and off the Queensland coast. They are essentially of the same type as the western Pacific 'typhoon' and Bay of Bengal 'cyclone'.

In the BEAUFORT SCALE of wind force the name hurricane is given to a surface wind of force 12, corresponding to a mean speed in the range 64–71 knots. Mean speeds of this magnitude are very rarely attained in the British Isles, but the speed is frequently exceeded in gusts.

hurricane wave: The raising of the level of the sea by some 10–20 feet in a restricted region near the centre of an intense TROPICAL CYCLONE.

hydrodynamic stability: An alternative for DYNAMIC STABILITY.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 13.

hydrogen: A gas, of molecular weight 2·02, which comprises $5{\cdot}0 \times 10^{-7}$ and $4{\cdot}0 \times 10^{-8}$ part per part of dry air by volume and weight, respectively.

Hydrogen is very abundant in the universe but occurs in only minute concentration throughout most of the atmosphere because its extreme lightness causes it to diffuse upwards to high levels. See also ATMOSPHERE.

hydrography: The study of water, more especially in the open seas and oceans, both from the physical standpoint and from that affecting the safety of navigation. In so far as tidal heights in estuaries and rivers are affected by river water, the science overlaps with that of HYDROLOGY.

hydrological balance: The hydrological balance, or hydrological budget, is the relationship between the EVAPORATION (E), PRECIPITATION (P), RUN-OFF (R), and the change in water storage (ΔS), for a specified land area and period of time, and is expressed by the hydrological balance equation

$$P = E + R + \Delta S,$$

in which ΔS may be positive or negative.

hydrological budget: An alternative for HYDROLOGICAL BALANCE.

hydrological cycle: The full cycle of events through which water passes in the earth–atmosphere system, comprising EVAPORATION from land and water surfaces, CONDENSATION to form clouds, PRECIPITATION on to the earth's surface, movement and accumulation in the soil and bodies of water, and finally re-evaporation. 'Short-circuiting' of the complete cycle occurs in the form of evaporation of products of condensation and precipitation within the atmosphere.

hydrology: The study of the incidence and properties of water on and within the ground, including that held in rivers and lakes. It comprises studies of RAINFALL, EVAPORATION, RUN-OFF, GROUND WATER, SOIL MOISTURE, the HYDROLOGICAL BALANCE, snow and ice accumulation, and the chemistry of natural waters.

The practical applications of hydrology are extremely wide and the number of local and government agencies and other bodies concerned with the subject in Great Britain is correspondingly large. The most comprehensive regular publication is the 'Surface water year book' published by the Ministry of Housing and Local Government.

hydrometeor: A generic term for products of CONDENSATION or SUBLIMATION of atmospheric water vapour. Hydrometeors include ensembles of falling particles which may either reach the earth's surface (rain, snow, etc.) or evaporate during their fall (virga); ensembles of particles suspended in the air (cloud, fog, etc.); particles lifted from the earth's surface (drifting or blowing snow, spray); particles deposited on the earth or on exposed objects (dew, hoar frost, etc.).

hydrometer: An instrument for measuring the density of liquids. In marine meteorology, hydrometers are used for determining the density of sea water.

hydrosphere: That part of the EARTH's surface which is covered by water substance.

hydrostatic equation: In an atmosphere at rest with respect to the earth, the variation of pressure (p) with height (z) is given by

$$\frac{\partial p}{\partial z} = -\rho g$$

where g is acceleration due to gravity and ρ is air density.

In terms of GEOPOTENTIAL cm (Z) the equation is

$$\frac{\partial p}{\partial Z} = -980\,\rho,$$

p and g being expressed in c.g.s. units.

The hydrostatic equation is very closely approximated when the air has horizontal motion relative to the earth and is therefore used as the basis for computations of height from vertical soundings.

hydroxyl: Hydroxyl molecules, of chemical formula OH, consist of one oxygen and one hydrogen atom. Hydroxyl has been identified in the spectrum of the AIRGLOW. It is considered to be formed by the DISSOCIATION of water vapour in the high atmosphere to form hydrogen atoms and hydroxyl.

hyetograph: A proprietary pattern of self-recording RAIN-GAUGE in which the recording pen is actuated by a series of stops attached to a vertical float rod.

hygrograph: A recording HYGROMETER. The type most familiar is the 'hair hygrograph' which uses the fact that human hair increases in length with increasing RELATIVE HUMIDITY. The changes in hair length are not linear, being proportionately less at high relative humidity than at low, but the recorded changes are generally made linear by the design of the mechanism. Hair hygrographs are not very precise, being subject in particular to gradual changes, but have the advantage of operating above or below the freezing-point.

hygrometer: An instrument for measuring the humidity of the air. Among the many types of hygrometer are:

(i) the 'dry- and wet-bulb hygrometer' which is used in routine surface observations, (see PSYCHROMETER);

(ii) those hygrometers which use the property of expansion and contraction of certain materials with changing RELATIVE HUMIDITY as, for example, the 'hair HYGROGRAPH' in surface observations and goldbeater's skin in upper air observations;

(iii) 'DEW-POINT hygrometers' of the type designed by Daniell, Regnault and others, in which artificial cooling of a polished surface, whose temperature is measured, is continued until dew is seen to condense on it (see also FROST-POINT HYGROMETER);

(iv) chemical hygrometers in which the quantity of moisture in a given mass of air is determined by direct weighing.

hygrometric formula: An alternative for 'psychrometric formula'. See PSYCHROMETER.

hygroscope: An instrument for showing whether the air is dry or damp, usually by the change in appearance or dimensions of some substance. Hygroscopes are frequently sold in the form of weather predictors, e.g. 'weather houses' in which the appearance of the 'old man' or the 'old woman' is determined by the twisting and untwisting of a piece of catgut in response to changes of humidity.

hygroscopic: A hygroscopic substance is one which tends to absorb moisture by accelerating the condensation of water vapour.

hygrothermograph: A combined HYGROGRAPH and THERMOGRAPH, i.e. an instrument in which variations of atmospheric humidity and temperature are continuously recorded by separate traces on a single sheet. The instrument is sometimes termed a 'thermohygrograph'.

hypsography: The configuration of ISOHYPSES, i.e. lines of constant height of an ISOBARIC SURFACE.

hypsometer: Literally, an instrument for measuring height (Gk. *hypsos*). In meteorology, however, the term is applied exclusively to an instrument in which the boiling-point of water is measured and the corresponding atmospheric pressure deduced from the boiling-point–pressure relationship (see Table X): if, as is normal, the instrument is used on a mountain and the pressure is known at some known (low) level, the pressures deduced at higher levels may be converted to heights by means of the ALTIMETER equation. An accuracy of one-hundredth of a degree (°K) in temperature measurement is required to obtain height to within ten feet.

TABLE X—*Dependence of boiling-point of water on atmospheric pressure*

Boiling-point °*K*	Pressure*	
	mm of mercury	*mb*
374	787·67	1050·12
373	760·00	1013·23
372	733·16	977·45
371	707·13	942·74
370	681·88	909·08
369	657·40	876·44
368	633·66	844·79
367	610·64	814·10
366	588·33	784·36
365	566·71	755·54
364	545·77	727·62

* Pressure values are at 0°C, sea level, latitude 45°.

hythergraph: A CLIMAGRAM in which the selected meteorological elements are temperature and humidity or temperature and rainfall.

I

I.A.C.: An abbreviation for 'International Analysis Code', sections of which are used, for example, in BARATIC and PRONTOUR messages. An abridged form, (I.A.C. Fleet) is adopted for marine use. See 'Handbook of weather messages.'*

ICAN atmosphere: See STANDARD ATMOSPHERE.

ICAO atmosphere: See STANDARD ATMOSPHERE.

ice: Water substance in solid form. It occurs in the atmosphere and/or on the earth's surface in many forms such as ICE CRYSTALS, SNOW, HAIL, HOAR FROST, RIME, GLAZED FROST, GLACIER, etc.

The density of ice is generally about 0·917 gm/cm³. At 0°C the latent heat of fusion (pure ice to water), L_f, is 79·67 IT cal/gm and the latent heat of sublimation (pure ice to vapour), L_s, is 676·93 IT cal/gm: these large values imply that the formation and disappearance of large masses of ice are important items in the heat budget of the earth–atmosphere system. The coefficient of linear expansion of pure ice at −10° to 0°C lies between 0·000050 and 0·000054; its specific heat at 0°C is 0·5. The physical properties of sea ice—in particular the values of latent and specific heats—may be very different from those of pure ice and vary greatly with temperature and SALINITY.

When a natural water surface cools, the water cooled at the surface is continually replaced by warmer water from below until the whole mass has fallen to 4°C (39°F), at which temperature water has its greatest density. The surface water then cools undisturbed until the freezing-point is reached and ice begins to form.

Three kinds of ice are produced in rivers: (i) sheet ice which forms on the surface of the water, first of all near the banks and extending gradually towards the centre, (ii) FRAZIL ICE and (iii) ground ice, both of which form in the rapidly moving stream in the centre of the river in very cold weather. Ground ice (or anchor ice) forms at the bottom, adhering to rocks and other substances in the river bed. It often rises to the surface, dragging with it masses of rock, and may destroy river structures.

When the sea freezes the crystals formed contain no salt, but cannot easily be separated from the brine which is mixed up with them. When, however, the ice forms hummocks under the action of pressure, the brine drains out and leaves pure ice.

See 'The marine observer's handbook'† for the International Ice Nomenclature adopted in 1955 by the World Meteorological Organization.

ice accretion: The formation and building-up of a layer of ice on terrestrial objects or on aircraft in flight which are at sub-freezing temperatures. The ice forms by direct sublimation of water vapour or by the impingement of supercooled drops of precipitation, fog or cloud. See also ICE FORMATION ON AIRCRAFT.

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* London, Meteorological Office; Handbook of weather messages. Parts II and III London, HMSO, 1959.

† London, Meteorological Office; The marine observer's handbook. London, HMSO, 1950, p. 59 (amendment list no. 2, 1956).

ice age: A geological period during which great glaciers and ice sheets extended from the polar regions to as far equatorwards as about latitude 55°. Individual ice ages wax and wane in strength in 'glacial phases' and 'interglacial phases', respectively. Present-day climate is considered to be that appropriate to an interglacial phase of the Quaternary Ice Age which began about one million years ago and in which four main glacial periods are recognized, the last ending some 8000 to 40,000 years ago, depending on locality. At the peak of a glacial phase, land ice is considered to have covered an area about twice as large as at present. The term 'Little Ice Age' is applied to the period from about 1550 to 1850 which was conspicuous for its low mean temperature and equatorward extension of glaciers.

Other great ice ages occurred in the Permo-Carboniferous, some 250 million years ago; in the late Proterozoic and early Cambrian, some 500 million years ago; and more than one in the early Proterozoic, 700 to 1000 million years ago. The Permo-Carboniferous Ice Age is thought to have developed mainly within the present tropics, in South America, Africa, India and Australia. See also CLIMATIC CHANGES.

iceberg: A mass of ice, broken from a glacier ('glacier berg') or an ice-shelf ('barrier berg' or 'tabular berg'), which floats in the sea: the World Meteorological Organization nomenclature specifies a minimum height of five metres above sea level. The former are greenish in colour and irregular in shape and are typical of the Arctic: the latter are whitish in colour, more regular in shape and typical of the Antarctic.

Erosion of icebergs proceeds most rapidly at and below the water line. Favourable winds sometimes carry icebergs to latitudes 40°–50° or even below.

Iceberg ice is as pure as distilled water, containing only four parts of solid per million. Icebergs also contain a considerable quantity of air, ranging in various specimens examined from 7 to 20 or 30 per cent.

iceblink: A typical whitish glare on low clouds above an accumulation of distant ice. See also WATER SKY.

ice-bulb temperature: That temperature (T_i) at which pure ice must be evaporated into a given sample of air, adiabatically and at constant pressure, in order to saturate the air at temperature T_i under steady-state conditions. The temperature recorded by an ice-covered 'wet bulb' of a PSYCHROMETER may not exactly accord with this definition. See also THERMODYNAMIC TEMPERATURES.

ice-crystal cloud: A cloud which is composed (almost) exclusively of ice crystals, as opposed to water droplets. The CLOUD GENERA Ci, Cc and Cs are normally ice-crystal clouds.

ice crystals: Ice crystals form in the atmosphere on ICE NUCLEI at temperatures appreciably below freezing-point and, it is generally thought, at about saturation with respect to water. They exist in simple form, notably needles and hexagonal columns and plates, and in more complex star-shaped and branched forms. They multiply by SPLINTERING and grow, by diffusion of water vapour on to them, into forms and at rates which depend on a variety of conditions, for example the internal and surface structure of the crystals, and the prevailing conditions of temperature and supersaturation. The crystals collide and coalesce with other crystals or supercooled water droplets to form SNOWFLAKES, GRAUPEL or HAIL.

ice-crystal theory: An alternative term for the BERGERON (–FINDEISEN) THEORY of PRECIPITATION.

ice day: An ice day is defined as a period of 24 hours, beginning normally at 9h GMT, on which the maximum temperature is less than 0°C (32°F).

ice formation on aircraft: ICE ACCRETION on aircraft in flight may constitute a danger by affecting the aerodynamic characteristics or engine performance, or in other ways.

The four main types of 'icing' are as follows, types (iii) and (iv) being the most dangerous:

(i) A white semi-crystalline coating of ice (HOAR FROST) which forms in clear air, by sublimation of water vapour, when an aircraft surface is at a temperature below 0°C and is lower than the frost-point of the air with which it is in contact. This may occur when an aircraft moves rapidly (normally by descent) from a level at which the temperature is below 0°C into a layer of warmer and relatively moist air.

(ii) A light, white, opaque deposit which forms in filmy clouds consisting of small, supercooled water drops (RIME).

(iii) A transparent or translucent coating of ice, of glassy surface appearance, which forms within dense clouds consisting of large, supercooled water drops.

(iv) A heavy coating of clear ice which forms when rain falls on an aircraft flying in a layer of air whose temperature is below 0°C (GLAZED FROST).

When a supercooled water drop impinges on an aircraft, part of the drop freezes immediately at the leading edges, part may be lost before freezing ('run-off'), while the remainder freezes subsequently. In the case of a small drop the final freezing occurs quickly, giving opaque ice on and near the leading edge: a light deposit of this kind may, however, be lost by the action of wind ('blow-off'). For a large drop the final freezing is less rapid and the drop has the opportunity to spread over the wing, leading to the more dangerous type of clear ice.

Observations indicate that icing risks are greatest at temperatures not too far below freezing-point, from, say, −12°C to 0°C. No lower temperature limit can, however, be set for possible ice formation: icing has, for example, been reported at a temperature of −60°C. Icing rate tends to increase with liquid water content of clouds and with cloud-particle size (greater for cumuliform clouds than for layer clouds). Glazed frost is associated with the passage of fronts, chiefly warm fronts in winter, and is comparatively rare in the British Isles.

Icelandic low: The 'Icelandic low' has a value of about 994 mb on the January chart of mean surface pressure. This mean depression is centred between Greenland and Iceland and represents the aggregate of many deep depressions. In summer, depressions in this region are less intense.

ice nucleus: A generic term which includes both 'freezing nucleus' and 'sublimation nucleus'. See NUCLEUS.

ice pellets: Solid precipitation, of small size, which is neither HAIL nor SNOW but consists of solid ice particles, generally transparent, which are formed by the freezing of raindrops or refreezing of melted snowflakes. See also SLEET.

Ice Saints: St-Mamertus on 11 May, St-Pancras on 12 May and St-Gervais on 13 May are known on the continent as the 'cold Saints' days'. It is said in France that these three days do not pass without a frost. A Buchan cold spell from 9-14 May covers this period—see BUCHAN SPELLS.

ice sheet: A large area of land ice with a dome-shaped, almost level surface. The largest ice sheets now existing are those of the Antarctic and Greenland.

icing: See ICE ACCRETION and ICE FORMATION ON AIRCRAFT.

IGC: Abbreviation for INTERNATIONAL GEOPHYSICAL CO-OPERATION.

IGY: Abbreviation for INTERNATIONAL GEOPHYSICAL YEAR.

inclination, magnetic: An alternative for DIP, MAGNETIC.

incus (inc): A supplementary cloud feature. (Latin, *incus* anvil.)
'The upper portion of a CUMULONIMBUS spread out in the shape of an anvil with a smooth, fibrous or striated appearance.'* See also CLOUD CLASSIFICATION.

independence: In statistics, independence between values signifies (depending on text) either that the values have been shown or are known to be unrelated to each other, or that the selection of the values from a larger sample has been made strictly at random.

index: The pointer or other feature in an instrument whose position with regard to the scale determines the reading. The term is also sometimes applied to the fixed mark which constitutes the zero: thus the 'index error' of a barometer is the error which is due to faulty positioning of the scale.

index correction: The quantity which (with proper sign) has to be added to an instrumental reading to correct for index error. It is of the same magnitude as the INDEX error, but of the opposite sign.

index error: See INDEX, INDEX CORRECTION.

Indian summer: A warm, calm spell of weather occurring in autumn, especially in October and November. The earliest record of the use of the term is at the end of the eighteenth century, in America, and it was introduced into the British Isles at the beginning of the nineteenth century. There is no statistical evidence to show that such a warm spell tends to recur each year.

indirect circulation: See DIRECT CIRCULATION.

inert gases: The elements HELIUM, NEON, ARGON, KRYPTON, XENON, RADON, THORON, ACTINON, termed 'inert gases' (sometimes also 'noble gases' or 'rare gases') because of their chemical inactivity. Apart from argon (0·93 per cent by volume) these gases occur in the air in only minute quantities.

inertial flow: Flow in the absence of external forces. See CIRCLE OF INERTIA.

inertia stability: A type of DYNAMIC STABILITY, associated with the earth's rotation, in which an air particle, embedded in a wind flow along a circle of latitude, tends to return to this latitude on being subjected to a small displacement from it. Inertia instability arises when such a displacement results in an acceleration of the particle away from its original latitude.

The condition for stability is that the CORIOLIS PARAMETER should exceed the northward increase of the geostrophic west wind component, i.e. $f > \partial u_G / \partial y$. Similarly, instability arises when $f < \partial u_G / \partial y$.

Similar conditions apply to air currents which are not east–west and may be extended to displacements along sloping isentropic surfaces which are most likely to give rise to instability. The criterion for stability in such currents is $f > (\partial v / \partial n)_\theta$ where v is the velocity and differentiation is normal to the flow along the isentropic surface.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 16.

inertia wave: A type of stable atmospheric wave which arises because of the inertia of a mass moving over the earth's surface and the associated CORIOLIS FORCE arising from the earth's rotation.

infra-red radiation: ELECTROMAGNETIC RADIATION in the approximate wavelength range from about 0·7 to 1000 microns (7×10^{-5} to 10^{-1} cm). 52 per cent of the total solar RADIATION intensity is contained within this range of wavelengths, the amount at wavelengths greater than 4 microns being very small.

In meteorology, the term is often used loosely as an alternative for LONG-WAVE RADIATION.

insolation: A term which is used in various senses:

(i) the intensity at a specified time, or the amount in a specified period, of direct solar RADIATION incident on unit area of a horizontal surface on or above the earth's surface;

(ii) the intensity at a specified time, or the amount in a specified period, of total (direct and diffuse) radiation incident on unit area of a specified surface of arbitrary slope and aspect.

Important factors in these definitions are (*a*) SOLAR CONSTANT, (*b*) calendar date, (*c*) latitude (involving variations of length of day and degree of obliquity of sun's rays), (*d*) slope and aspect of surface, (*e*) degree of transparency of atmosphere.

The purely astronomical factors (including variations of length of day but omitting all effects of atmospheric attenuation which depend in part on latitude) are accounted for in the tables and chart contained in the 'Smithsonian meteorological tables'*, on pages 418 and 419. These show the daily solar radiation totals on a horizontal surface at various latitudes and dates, on the assumption of a perfectly transparent atmosphere: seasonal and annual totals are also given. Their main features are a primary daily maximum at the summer pole, a secondary daily maximum at about 45° latitude in the summer hemisphere, a minimum (zero) at and near the winter pole, and an annual total at the equator about 2·4 times that at either pole.

These theoretical results have only partial relevance to what is found in practice. If, for example, account is taken of attenuation of the radiation by the atmosphere, the maximum at the summer pole disappears because of the oblique nature of the radiation received in high latitudes. If, further, account is taken of systematic latitudinal variations of atmospheric attenuation of radiation by clouds, the secondary maximum at latitude 45° moves to the semi-arid climatic zone at about 35°.

instability: See STABILITY.

instability line: In synoptic meteorology, a line or belt generally some hundreds of miles in length, along which slight or moderate instability (convective) phenomena exist but which is not marked by a surface front: such a line may, however, be marked by an UPPER-LEVEL TROUGH. When the instability phenomena are of a violent nature the term SQUALL LINE is generally used.

intensification: In synoptic meteorology, 'intensification' of a pressure system signifies an increase with time of the pressure gradient around the centre of the system. The converse term is 'weakening'.

inter-diurnal variation: Day-to-day change (of a specified element).

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* Washington, Smithsonian Institution; Smithsonian meteorological tables. 6th revised edn. Washington, Smithsonian Institution, 1951, pp. 418, 419.

interglacial phase: A period of an ICE AGE during which (as now) permanent ice at low levels is confined to latitudes polewards of about 75°.

International Geophysical Co-operation (IGC): Period from 1 January–31 December 1959, during which the major part of the observational programme of the INTERNATIONAL GEOPHYSICAL YEAR was, by international agreement, continued.

International Geophysical Year (IGY): An international programme of observation in nearly all branches of GEOPHYSICS, on a world-wide scale, from 1 July 1957–31 December 1958, near sunspot maximum.

International Polar Year: See POLAR YEAR.

interpolation: When a varying quantity has been observed at certain intervals of time, or of some other independent variable, the determination of values of the dependent variable appropriate to intermediate values of the independent variable is called interpolation. Interpolation may be performed graphically or by one or other of a variety of numerical methods.

inter-quartile range: See QUARTILE.

intertropical convergence zone: The intertropical convergence zone (ITC) is a relatively narrow, low-latitude zone in which air masses originating in the two hemispheres converge. Since characteristics distinct from a FRONT of higher latitudes are involved, the term ITC is generally preferred to the alternative 'intertropical front' (ITF). The term 'equatorial front' is sometimes also used.

Over the Atlantic and Pacific Oceans, where it is closely related to the DOLDRUMS, the ITC is the boundary between the north-easterly and south-easterly trade winds. Over the continents it is replaced by the boundary between other wind systems with components directed towards the equator, for example in Africa between the HARMATTAN and the south-west monsoon. The ITC moves northwards in the northern summer and southwards in the southern summer, its mean position being somewhat north of the equator. Over the oceans the range of movement is small, but over the continents it may be very large.

The horizontal convergence associated with the ITC implies generally upward motion in the lower troposphere and cloudy, showery weather. The zone is subject to day-to-day oscillations of position and variations of activity. Shallow low-latitude depressions, which may on occasion greatly intensify, are often associated with the zone.

intertropical front: See INTERTROPICAL CONVERGENCE ZONE.

intortus (in): One of the CLOUD VARIETIES. (Latin, *intortus* twisted.)

'CIRRUS, the filaments of which are very irregularly curved and often seemingly entangled in a capricious manner.'* See also CLOUD CLASSIFICATION.

inversion: An inversion (of temperature) is said to occur at a point, or through a layer, at which or through which temperature increases with increasing height: such a feature is an inversion of the condition of a positive LAPSE of temperature which normally obtains in the atmosphere.

An inversion is marked on a normal temperature-height diagram (height the vertical ordinate) by a line which slopes upwards to the right. It implies great static STABILITY and absence of turbulence at the level concerned, and is often present at the top of a stratified cloud layer or of fog, especially radiation fog.

* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 14.

Inversions are often associated with a RADIATION NIGHT, prolonged SUBSIDENCE, the TROPOPAUSE, sometimes also with FRONTS.

inversion layer: An atmospheric layer in which there is an INVERSION of temperature. Vertical motion of air through such a layer is inhibited by considerations of static STABILITY. If the air under the inversion is relatively moist, the layer itself often lies above a layer of stratified cloud. An inversion layer near the earth's surface ('surface inversion') occurs on a RADIATION NIGHT: examples of inversion layers at higher levels are often associated with anticyclones, sometimes with fronts.

ion: The name (selected by Faraday) for an electrically charged atom or molecule: the presence of ions in a gas or electrolyte renders it an electrically conducting medium.

Ions are formed in the low atmosphere mainly by radiations from radioactive material in the air and by cosmic radiation: on a local scale, the rupture of water drops or the friction of wind-driven snow or sand may be important in producing atmospheric ions. Cosmic rays are an increasingly important ionizing source with increase of height above sea level. Solar ultra-violet radiation and X-rays are mainly responsible for the intense ionization of the atmosphere above about 50 km.

In the process of ion formation, an electron is ejected from a neutral particle (molecule or atom) which thus acquires a positive charge, while the electron attaches itself to another neutral particle which acquires a negative charge: an 'ion pair' is thus formed. These so-called 'small ions' are highly mobile: they may disappear by recombination or, near the earth's surface, by becoming attached to electrically neutral (e.g. pollution) particles, forming 'large ions' of much lower mobility, with a resulting decrease in air conductivity.

ionization: The process of ION formation.

ionization potential: The minimum energy (ELECTRON-VOLTS) required to remove an electron from an atom or molecule. It is also termed 'ionization energy'.

ionogram: In radio echo sounding of the IONOSPHERE an automatic record of corresponding values of wave frequency and VIRTUAL HEIGHT.

ionosphere: That portion of the earth's ATMOSPHERE, extending upwards from about 60 km to an indefinite height, which is characterized by a concentration of IONS and free ELECTRONS high enough to cause reflexion of radio waves.

The IONIZATION, which is caused at these levels mainly by solar ultra-violet and X-ray radiation, reaches peak values, separated by shallow troughs, in rather well defined regions of the atmosphere, giving rise to the ionospheric E-, F_1- and F_2-layers situated at about 110, 160 and 250 km, respectively. There is sometimes no peak value but only a 'ledge' in which the height gradient of electron concentration is small. Radio reflexions are sometimes also obtained from heights of 65–80 km—the so-called D-layer which is not, however, characterized by a maximum ionization concentration.

The E- and F_1-layers are, to a first approximation, 'regular' in that their peak values of ion and electron densities and corresponding heights have systematic latitudinal, diurnal, seasonal and sunspot-cycle variations in reasonable accord with CHAPMAN LAYER theory (electron density highest near the equator, at midday, in summer, and at sunspot maximum, respectively, when the intensity of the ionizing radiation is greatest). The corresponding features of the F_2-layer, on the other hand, show many anomalies due to solar and lunar tidal effects and the influence of the earth's magnetic field. The large, short-period changes of electron height distribution and concentration in this layer are closely correlated with geomagnetic storms and are termed 'ionospheric storms'.

The properties of the ionosphere are regularly investigated at a world-wide network of stations by an automatic radio-echo technique ('ionospheric echo sounding') in which short bursts of radio waves of different frequencies are emitted in rapid succession at vertical incidence and the resulting reflected waves registered on an 'ionogram'. Since the electron concentration required for reflexion of radio waves increases with the frequency of the waves the technique yields a CRITICAL FREQUENCY (f_0) of penetration of the regions of electron peak concentration and the corresponding VIRTUAL HEIGHT. Rockets and satellites are also used to sound the ionosphere and have yielded information, in particular, of the electron concentrations in the troughs separating the various layers and at levels above the F_2-layer.

Observations show that the ionosphere is in a state of constant and complex motion which is in part systematic (including tidal), and in part random, in nature. In the lower ionosphere the charged particles are generally moved bodily with the uncharged particles: at higher levels the motion of the charged particles is mainly independent of that of the uncharged particles and is much affected by the forces exerted by the earth's magnetic field.

iridescence: A word formed from the name of Iris, the rainbow goddess, to indicate rainbow-like colours: an alternative is 'irisation'.

Iridescence in the form of tinted patches of red and green, sometimes of blue and yellow, is occasionally observed on high clouds, generally within about 30° of the sun. The boundaries of the tints are not circles with the sun as centre but tend to follow the outlines of the cloud. Iridescent clouds are considered to be parts of CORONAE, the coloration being caused by DIFFRACTION of sunlight by very small cloud particles.

irisation: An alternative for IRIDESCENCE.

irrotational motion: Motion in which there is no VORTICITY. It is defined by the equation curl $\mathbf{V} = 0$ where $\mathbf{V}$ is the three-dimensional velocity vector which defines the motion.

isallo: A prefix used, in conjunction with another word, to denote lines drawn on a map or chart to display the tendency (time rate of change) of any element, each line being drawn through places at which the element has the same tendency, e.g. ISALLOBAR, isallotherm.

isallobar: A line of constant BAROMETRIC TENDENCY. Such lines are sometimes drawn on synoptic charts, mainly as an aid to forecasting the movement of features of the pressure distribution.

isallobaric wind: That part of the AGEOSTROPHIC WIND which is associated with local time change of the PRESSURE GRADIENT.

One of the conditions for the application of the GEOSTROPHIC WIND equation is that the pressure distribution should be steady. In the treatment by D. Brunt and C. K. M. Douglas of the effect on the wind of a changing horizontal pressure gradient, it was shown that the main term additive to the geostrophic wind corresponds to a wind directed normally to the ISALLOBARS towards isallobaric low and of magnitude $\frac{1}{\rho f^2}\,\mathrm{grad}_H \frac{\partial p}{\partial t}$, where ρ is air density, f the Coriolis parameter $= 2\Omega \sin \varphi$, and $\mathrm{grad}_H \frac{\partial p}{\partial t}$ the horizontal gradient of the isallobars. This, now generally known as the 'isallobaric wind', rarely exceeds 5 m/sec, but is at times important in its effects on horizontal convergence and rainfall.

isanomaly: A line of constant anomaly (i.e. difference from normal) of a meteorological variable. See ISO.

isentropic: Without change of ENTROPY, generally equivalent in meaning to ADIABATIC. Isentropic surfaces in the atmosphere are surfaces of constant POTENTIAL TEMPERATURE.

isentropic analysis: An analysis of the physical and dynamical processes taking place in the free atmosphere on the basis of the location and configuration of the various ISENTROPIC surfaces and distribution of atmospheric properties (e.g. temperature, humidity mixing ratio) and motion on them. 'Isentropic charts' are the main tool of this work.

iso: A prefix meaning 'equal', extensively used in meteorology, in conjunction with another word, to denote lines drawn on a map or chart to display the geographical distribution of any element, each line being drawn through places at which the element has the same value, e.g. ISOBAR, ISOTHERM. The words 'isogram' or 'isopleth' are sometimes used as generic names of this type.

isobar: A line of constant (atmospheric) pressure.

'Surface isobars' are based on pressure readings corrected to a common level (see REDUCTION to sea level). Such isobars, drawn at intervals of one millibar or more (depending on scale of chart), produce characteristic patterns such as are illustrated in the articles on ANTICYCLONE, COL, DEPRESSION, RIDGE, SECONDARY, TROUGH.

isobaric analysis: Analysis along a surface of constant pressure: the analysis usually includes variations of GEOPOTENTIAL, temperature, humidity, wind.

For study of conditions in the upper air there are theoretical and practical advantages in employing isobaric analysis rather than analysis along surfaces of constant geopotential. The GEOSTROPHIC WIND speed is related to contour spacing in a way that is independent of air density and permits the use of the same wind scale at different isobaric levels.

isobaric surface: Surface of constant (atmospheric) pressure.

isoceraunic line: A line of constant percentage frequency of days in a year on which thunder is heard. See ISO.

isochasm: A line of constant frequency of visible AURORA. See ISO.

isochrone: A line drawn on a map in such a way as to join places at which a phenomenon is observed at the same time, e.g. lines indicating the places at which rain commences at a specified time.

isoclinic (or **isoclinal**) **line:** A line of constant magnetic DIP. See ISO.

isodynamic line: A line of constant total magnetic intensity. See ISO.

isogon: A line of constant wind direction. See ISO.

isogonic (or **isogonal**) **line:** A line of constant magnetic DECLINATION. See ISO.

isogram: See ISO.

isohel: A line of constant sunshine duration. See ISO.

isohyet: A line of constant rainfall amount. See ISO.

isohypse: An alternative for CONTOUR.

isomeric line: The distribution of monthly rainfall over an area may be represented by a plot of percentage of average annual rainfall attained in the month at each station (isomeric values). A line of constant percentage on such a chart is an isomeric line or isomer.

isoneph: A line of constant cloud amount. See ISO.

isopleth: See ISO.

isopycnic surface: A surface of constant (atmospheric) density. Such surfaces intersect ISOBARIC SURFACES in a BAROCLINIC, but not in a BAROTROPIC, atmosphere.

isosteric surface: A surface of constant (atmospheric) SPECIFIC VOLUME. Since specific volume is the inverse of density, an isosteric surface is also ISOPYCNIC.

isotach: A line of constant wind speed. See ISO.

isotherm: A line of constant temperature. See ISO.

isothermal: Of equal temperature. The term 'isothermal layer' was originally applied to the region now known as the STRATOSPHERE. The term is, in this restricted sense, now obsolete but is still used to denote any layer with zero LAPSE rate of temperature, revealed by vertical sounding of the atmosphere.

isovel: An alternative for ISOTACH.

J

Jacob's ladder: See CREPUSCULAR RAYS.

jet stream: A strong narrow current of air, generally near the tropopause, characterized by strong vertical and lateral WIND SHEARS and with one or more velocity maxima.

A jet stream is normally some thousands of kilometres in length, and some kilometres in depth. The vertical and horizontal wind shears are, respectively, of the order 10–20 kt/km and 10 kt/km. For certain purposes a jet stream has been arbitrarily defined as having a minimum speed of 60 kt at every point along its axis.

Two main types of jet stream are recognized, (i) subtropical (westerly) and (ii) polar front (westerly). The subtropical jet stream is relatively constant in position in a given season and dominates mean seasonal wind charts: in contrast, the polar front jet stream is highly variable in position from day to day over a wide range of temperate latitudes and is therefore masked on such charts. In addition, a westerly 'polar night jet stream' (high latitudes in winter) occurs at times within the stratosphere above 50 mb.

joule: The unit of work or energy in the M.K.S. SYSTEM of units. This unit was also recommended at the Ninth General Conference of Weights and Measures (1948) for use as the unit of HEAT.

The joule is the work done by a force of one NEWTON in moving its point of application one metre in the direction of the force. The dimensions are ML^2T^{-2}.

1 joule = 1 watt sec = 10^7 ERGS
1 15° CALORIE = 4·1855 joules
1 IT calorie = 4·1868 joules.

K

Kármán's constant: A non-dimensional quantity (k) in the equation which defines the nature of the wind structure in the low atmosphere in adiabatic lapse rate conditions—see LOGARITHMIC VELOCITY PROFILE. k is found experimentally to have a value close to 0·4.

katabatic wind: On a 'radiation night' of clear skies and low pressure gradient, TERRESTRIAL RADIATION from the earth's surface causes a layer of cold air to form near the ground, with an associated INVERSION of temperature. If the ground is sloping, the air close to the ground is colder than air at the same level but at some horizontal distance. Downslope gravitational flow of the colder, denser air beneath the warmer, lighter air results and comprises the 'katabatic wind'. It is known also as the 'drainage wind' or 'mountain breeze'. This downslope wind, and the associated formation of FROST HOLLOWS, have important agricultural effects. On a larger scale it is experienced, for example, as the fjord winds of Norway: on a still larger and more violent scale, it largely comprises the outflowing winds from the Greenland and Antarctic continents.

katafront: As defined by T. Bergeron, a FRONT (warm or cold) along which the warm air is descending relatively to the cold air. Downward motion of the warm air at most levels is generally implied, with frontal activity feeble or absent.

katathermometer: A large-bulb spirit thermometer with graduations at 35°C and 38°C: the bulb is heated to a temperature above 38°C, the time is taken for the spirit to fall from the 38°C mark to that at 35°C, and the wind speed producing the cooling is computed.

In another form of the instrument used in relation to human bioclimatology two bulbs, one wet, the other dry, are employed and the cooling of the bulbs (at about human body temperature) effected by the wind is measured.

Kelvin effect: An effect, relating to the saturation vapour pressure over liquid surfaces, discovered by Lord Kelvin.

The saturation VAPOUR PRESSURE (p) at a curved liquid surface (e.g. spherical water droplet) exceeds that over a similar plane surface (p_∞) by an amount which increases with decreasing radius of curvature (r) of the surface. The relationship between them is given by

$$\log_e \frac{p}{p_\infty} = \frac{2M\sigma}{\rho R^* T r}$$

where M is the molecular weight of the vapour, σ the surface tension of the liquid, ρ the liquid density, R^* the universal gas constant, and T the temperature.

The effect of surface curvature is important for droplets of diameter less than about 1 micron: at 10°C, for example, the ratio p/p_∞ is 1·023 for a water droplet of diameter 0·1 micron, and 1·002 for a diameter of 1 micron. The effect is of fundamental importance in the initiation of CONDENSATION in the atmosphere. See also NUCLEUS.

Kern's arc: A faint and very rare HALO which is centred on a point opposite to, and on the same circle as, a CIRCUMZENITHAL ARC.

Kew-pattern barometer: A portable marine BAROMETER designed by P. Adie in 1854 for the Kew Committee of the British Association. The scale is graduated to take account of changes of the level of the mercury in the steel cistern so that it is only necessary to read the top of the mercury column. The tube is constricted to minimize PUMPING when the barometer is used at sea. Similar barometers, known as 'station' barometers, but without the constriction, were subsequently adopted for use on land and are regularly employed at British meteorological stations.

khamsin: A southerly wind blowing over Egypt in front of depressions passing eastwards along the Mediterranean or North Africa, while pressure is high to the east of the Nile. As this wind blows from the interior of the continent it is hot and dry, and often carries much dust. It is most frequent from April to June.

Gales from the south or south-west in the Red Sea are also known as khamsin.

K-index, geomagnetic: See GEOMAGNETISM.

kinematical analysis: Analysis of the field of atmospheric wind flow.

kinetic energy: The ENERGY possessed by a body by virtue of its motion. It is a scalar quantity of magnitude $\frac{1}{2}mv^2$, where m is the mass and v the velocity of the particle.

D. Brunt estimated that the total kinetic energy of the large-scale motion of the atmosphere is of the order 3×10^{27} ergs (8×10^{13} kilowatt-hours). He also estimated that, in the absence of solar radiant energy, dissipation of the atmosphere's kinetic energy by turbulence, generated mainly at the earth's surface, would be almost complete after six days.

Kirchoff's law: See RADIATION.

kite: In the now out-moded use of kites carrying aloft instruments for sounding the upper atmosphere, heights of over 20,000 feet were attained.

kite balloon: A captive BALLOON, of such a form as to have aerodynamic lift, sometimes used for carrying METEOROGRAPHS and other types of sounding instrument.

knot: A speed of one nautical mile per hour. See MILE.

kona storm: A storm over the Hawaiian Islands, associated with a depression passing north of the islands, and characterized by strong or gale southerly winds and heavy rain.

konimeter: An instrument for counting the dust particles in a known volume of air. See DUST COUNTER.

kosava: A RAVINE WIND which occurs on the Danube, south-east of Belgrade.

Koschmieder's law: A law which states that the apparent brightness, B_s, of a black object at distance d, due entirely to scattered light, is related to the brightness of the horizon at the same azimuth, B_h, by the equation

$$B_s = B_h\,(1 - e^{-\beta d})$$

where β is the SCATTERING coefficient, assumed constant throughout the part of the atmosphere concerned.

See also VISIBILITY, AIR-LIGHT.

krypton: One of the INERT GASES, comprising $1{\cdot}0 \times 10^{-6}$ and $3{\cdot}0 \times 10^{-6}$ part per part of dry air by volume and weight, respectively. Its molecular weight is 83·80.

K-theory: The K-theory, also termed the EXCHANGE COEFFICIENT theory, of turbulent mixing is based on the assumption that the vertical flux of a conservative air-mass property ($\bar{E}$) which is effected by atmospheric eddies may be expressed as the product of an exchange coefficient (K) and the vertical gradient of the property concerned, i.e.

$$\text{flux} = K\,\partial\bar{E}/\partial z$$

The value of the theory is limited by the extent to which K is dependent on height and atmospheric stability and on the atmospheric property concerned (heat, water vapour, momentum etc.). A typical value of K is 10^4 cm^2/sec. See also TURBULENCE, DIFFUSIVITY, EDDY CONDUCTIVITY.

Kuro Shio: Variously translated 'blue salt' or 'black' stream, a warm-water current of a characteristic dark blue colour, the main branch of which flows north-eastwards along the south coast of Japan before merging in the general drift of the North Pacific. This current is analogous to the Gulf Stream of the Atlantic in that it carries warmth to higher latitudes. A branch of the Kuro Shio sets into the Japan Sea.

kurtosis: A property of a frequency distribution which is symmetrical about the mean but which, relative to the NORMAL (FREQUENCY) DISTRIBUTION, has an excess proportion of values close to the mean (platykurtic), or far removed from the mean (leptokurtic).

L

labile: A term sometimes used to denote a condition of static instability or of neutral equilibrium in the atmosphere, i.e. a LAPSE rate equal to or exceeding the ADIABATIC. In German, the word is used to denote instability only.

lacunosus (la): One of the CLOUD VARIETIES. (Latin, *lacunosus* having holes.)
'Cloud patches, sheets or layers, usually rather thin, marked by more or less regularly distributed round holes, many of them with fringed edges. Cloud elements and clear spaces are often arranged in a manner suggesting a net or a honeycomb.
This term applies mainly to CIRROCUMULUS and ALTOCUMULUS; it may also apply, though very rarely, to STRATOCUMULUS.'* See also CLOUD CLASSIFICATION.

lag: A delay between a change in conditions and its indication by an instrument. While instrumental construction is usually designed to minimize lag, it is in some cases deliberately introduced, e.g. in mercurial barometers (by narrowing of tube) to avoid PUMPING, and in Symons's earth thermometers (by immersion of bulb in paraffin wax) to ensure negligible change of indicated temperature on withdrawal of the instrument from the earth for reading.
In statistics, the term 'lag' signifies a specified displacement in time of two correlated TIME SERIES ('lag correlation coefficient'), or within a given time series—see AUTOCORRELATION.

Lagrangian change: The Lagrangian change of an element (e.g. pressure) is the time rate of change of the value of the element possessed by an individual moving fluid parcel ('change following the motion' or 'substantial change' or 'individual change') and is usually written, for example, $\frac{\mathrm{d}p}{\mathrm{d}t}$.

Lagrangian change is related to EULERIAN CHANGE (e.g. $\frac{\partial p}{\partial t}$) by the relationship

$$\frac{\mathrm{d}}{\mathrm{d}t} = \frac{\partial}{\partial t} + u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial z}$$

where u, v, w are the velocity components in the x, y, z directions, respectively.

Lambert's law: See ABSORPTION.

Lambert's projection: See PROJECTION.

laminar boundary layer: A very shallow layer of air, adjacent to a fixed boundary, in which the air velocity increases very rapidly but fairly regularly from the boundary (where it is zero) to the free airstream. The molecular viscous stress in such a layer greatly exceeds the REYNOLDS STRESS.

laminar flow: Fluid flow is described as 'laminar', or 'streamline', if each particle follows the precise path of its predecessors: an essential feature of such flow is that there is no mixing of adjacent layers of the fluid.

* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 15.

land- and sea-breezes: Local winds, caused by the unequal heating and cooling of adjacent land and water surfaces under the influence of solar radiation by day and radiation to the sky at night, which produce a gradient of pressure near the coast. During the day the land is warmer than the sea and a breeze, the sea-breeze, blows onshore; at night and in the early morning the land is cooler than the sea and the land-breeze blows offshore. The breezes are most developed when the general pressure gradient is slight and the skies are clear. In such circumstances the sea-breeze usually sets in during the forenoon and continues until early evening reaching its maximum strength during the afternoon; the land-breeze may set in about midnight or not until the early morning. The land- and sea-breezes are much influenced by topography and vary considerably from one part of the coast to another. In the British Isles the pure sea-breeze rarely exceeds Beaufort force 3, but in lower latitudes it may reach force 4 or 5. The land-breeze is usually less developed than the sea-breeze. The sea-breeze does not usually extend more than 15–20 miles on either side of the coastline, and often its extent is considerably less. Its farthest penetration inland is often marked by a line of horizontal convergence of wind and vigorous convection, sometimes termed a 'sea-breeze front'. The depth of the current is shallow at its commencement, but in favourable circumstances it may exceed 2000 feet at the time of its maximum development.

langley: A unit of energy per unit area, equivalent to 1 CALORIE/cm^2.

Laplacian (or **Laplacian operator**)**:** A mathematical operator, designated ∇^2 and defined in rectangular Cartesian co-ordinates by the equation

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}.$$

lapse: 'Temperature lapse' (or often simply 'lapse') denotes decrease of temperature with increasing height in the atmosphere. 'Temperature lapse rate', or 'lapse rate', signifies decrease of temperature per unit increase of height, taken positive when temperature decreases with height.

The temperature lapse rate, as denoted for example by a 'lapse line' drawn on a temperature–height diagram, is of fundamental significance in atmospheric ADIABATIC vertical motion and static STABILITY. The lapse rate averages about 0·6°C per 100 metres in the TROPOSPHERE, where, however, it is very variable in space and time: over a limited interval of height it may be negative, corresponding to an INVERSION. The lapse rate is very small in the lower STRATOSPHERE.

The term 'lapse' is also used, as in 'humidity lapse rate', to signify the rate of decrease with height of certain meteorological parameters other than temperature.

latent heat: The quantity of heat absorbed or emitted, without change of temperature, during a change of state of unit mass of a material. The unit is CALORIES per gram or JOULES per gram: the dimensions are L^2T^{-2}.

In meteorology, the energy transformations associated with changes of state of water are very important: heat is absorbed in the changes from ice to water to water vapour and is released in changes which are in the opposite sense.

The latent heat of fusion (ice to water, at 0°C is 79·67 IT cal/gm. The latent heat of sublimation (ice to water vapour, at 0°C is 676·93 IT cal/gm, varying with temperature by less than 0·2 per cent in the meteorological range. The latent heat of vaporization (water to water vapour) at 0°C is 597·26 IT cal/gm, at 25°C is 583·22 IT cal/gm, and at 50°C is 568·97 IT cal/gm.

$$1 \text{ IT calorie} = 4{\cdot}1868 \text{ joules} = 4{\cdot}1868 \times 10^7 \text{ ergs}$$

See also HEAT, ENTHALPY.

latent instability: See STABILITY.

latitude: The geographical latitude is defined as the angular elevation of the celestial POLE above the surface tangential to the spheroid which represents the earth. It is also equal to the angle between the normal to this surface and the plane of the equator. The geographical latitude φ at any point differs only slightly from the geocentric latitude φ', the latter being the angle between the radius of the earth passing through the point and the plane of the equator. The relation between φ and φ' is, approximately, $\varphi - \varphi' = 68{\cdot}8'' \sin 2\varphi$. Geocentric latitude is found to be more useful than geographical latitude in seismology as the calculation of distance from place to place is facilitated.

Astronomical latitude is defined as the elevation of the celestial pole above the level of a mercury surface, or in other words the angle between the plumb-line and the plane of the equator.

For an explanation of geomagnetic latitude and magnetic latitude see GEOMAGNETISM.

law of storms: A nautical expression denoting the mariners' rules for avoiding the so-called 'dangerous half' of a TROPICAL CYCLONE (that part of the cyclone which is to the right of the cyclone's path in the northern hemisphere, to the left in the southern hemisphere).

layer clouds: CLOUDS of no marked vertical development, also termed 'sheet clouds', as opposed to 'heap clouds'. The layer cloud types comprise CIRRUS, CIRROCUMULUS, CIRROSTRATUS, ALTOCUMULUS (except Altocumulus castellanus), ALTOSTRATUS, NIMBOSTRATUS, STRATUS, STRATOCUMULUS.

leader stroke: See LIGHTNING.

least squares, law of: A law, based on the theory of errors, which states that the best estimate of any quantity, observations of which are distributed according to the NORMAL LAW OF ERRORS, is that for which the sum of the squares of the residuals of these observations is least. It may be applied to pairs of related values $x_1 \ldots . x_n$ and $y_1 \ldots . y_n$ to obtain the constants of the function $y = f(x)$ which best expresses the relation between x and y, i.e. that for which the sum of the squares of the differences between the observed and computed values of y is a minimum.

lee depression: An alternative for OROGRAPHIC DEPRESSION.

leeward: Leeward of a point signifies the 'downwind' direction from the point, e.g. eastwards in the case of a west wind.

lee waves: A system of stationary air waves ('standing waves') forming, under certain conditions, to the lee of a hill or mountain which presents a mechanical obstruction to the wind. The existence of such waves is sometimes shown by the presence of cloud near the wave crests ('lee wave clouds'). The 'lee wavelength', i.e. the distance between adjacent wave crests, is usually between 2 and 20 miles. The 'lee-wave amplitude', i.e. half the vertical distance from wave trough to crest, is very small at very low and high levels and reaches a maximum at an intermediate level.

Meteorological conditions suitable for lee-wave formation are (i) a stable layer of air between less stable layers at the ground and at a higher level, (ii) a wind of at least 15 knots across the top of the ridge, (iii) constancy of wind direction up to the top of the stable layer. R. S. Scorer expressed the required conditions mathematically as an upward decrease of l^2 where

$$l^2 = \left(\frac{g\beta}{V^2} - \frac{1}{V}\frac{d^2V}{dz^2}\right)$$

where β is the static stability ($\theta^{-1}\frac{\partial\theta}{\partial z}$, where θ is potential temperature and z is height), g is acceleration of gravity, V is wind speed in the direction across the hill. The first of the terms is the more important.

See STANDING WAVE, MOUNTAIN WAVE.

Lenard effect: The separation of electric charges that accompanies the shattering of water drops. In pure water the larger drops are found to carry a positive charge to earth while the very fine droplets carry a negative charge into the surrounding air. Experiments show, however, that the magnitude of the effect and even the charge signs may be altered by various factors, such as the presence of impurities.

The Lenard effect forms the main basis of G. C. Simpson's theory of charge generation and distribution in a thundercloud—see THUNDERSTORM.

lenticularis (len): A CLOUD SPECIES. (Latin derivation from *lens* lentil.)

'Clouds having the shape of lenses or almonds, often very elongated and usually with well defined outlines; they occasionally show irisation. Such clouds appear most often in cloud formations of orographic origin, but may also occur in regions without marked orography.

This term applies mainly to CIRROCUMULUS, ALTOCUMULUS and STRATOCUMULUS'.* See Plate 16: see also CLOUD CLASSIFICATION.

leste: A hot, dry, southerly wind occurring in Madeira and northern Africa in front of an advancing depression.

levanter: An easterly wind in the Straits of Gibraltar. It is most frequent from July to October and in March. At Gibraltar it causes complex and dangerous eddies in the lee of the Rock. With moderate winds a BANNER CLOUD stretches out from the summit of the Rock a mile or more to leeward: when the wind reaches Beaufort force 7 or over the cloud lifts and disappears. Levanter is usually associated with high pressure over western Europe and low pressure to the south-west of Gibraltar over the Atlantic or to the south over Morocco.

leveche: A hot, dry, southerly wind which blows on the south-east coast of Spain in front of an advancing depression. It frequently carries much dust and sand, and its approach is indicated by a strip of brownish cloud on the southern horizon.

level: A surface is 'level' if it is everywhere at right angles to the direction of the force of gravity which is indicated by a plumb-line: along such a surface the GEOPOTENTIAL is constant. In general, a level surface in the atmosphere does not quite coincide with one of equal geometric height above mean sea level.

libeccio: A strong, squally south-westerly wind in the central Mediterranean, most common in winter.

life-cycle: A term used in synoptic meteorology to include the processes of formation, deepening, occluding and filling-up which are typical of a frontal DEPRESSION. The cycle usually occupies some three days but is subject to a wide range of variation of length.

lifting condensation level: See CONDENSATION LEVEL.

lightning: A visible electric discharge ('lightning flash') associated with a THUNDERSTORM. The various types include the 'cloud discharge' occurring within the THUNDERCLOUD, the 'air discharge' between a part of the cloud and the adjacent air, and the 'ground discharge' between cloud and ground. Centres of charge of

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 12.

opposite sign are neutralized by the occurrence of each flash, that in the air being the SPACE CHARGE.

High-speed recording of lightning discharges by BOYS'S CAMERA and also studies of associated electric field charges have shown that the ground discharge comprises at least two 'strokes' or 'streamers' which are generally as follows: first, a 'leader stroke' from cloud to ground in which the luminosity is relatively faint, the time of travel variable but often between 10^{-1} and 10^{-2} second, the progress sometimes in distinct steps ('stepped leader') and the path sometimes tortuous and with many branches of luminosity extending out from the main channel; second, an immediate 'return stroke' from ground to cloud which is very rapid and vivid and which lights up the main channel and any branches. Observations have shown, however, that leader strokes directed upwards from ground to cloud may predominate in the case of very high structures. Sometimes (in the British Isles in a minority of cases) the ground discharge comprises a series of double strokes separated by a time interval of the order of microseconds: any subsequent leader stroke ('dart leader') is much more rapid than the first, since it follows the relatively ionized path to ground made by the first leader.

The typical lightning flash discharges a quantity of about 20 coulombs and involves a potential difference of some 10^8 or 10^9 volts. The sign of the charge carried by discharges to earth is predominantly negative.

See also BALL LIGHTNING, CHAIN LIGHTNING, FORKED LIGHTNING, PEARL-NECKLACE LIGHTNING, RIBBON LIGHTNING, ROCKET LIGHTNING, SHEET LIGHTNING and STREAK LIGHTNING.

light waves: ELECTROMAGNETIC RADIATION contained within the VISIBLE SPECTRUM, i.e. between about 0.4 and 0.7 micron (4×10^{-5} to 7×10^{-5} cm).

line-squall: A phenomenon accompanying the passage, at any particular place, of a SQUALL LINE. The characteristic features of a line-squall are (i) arch or line of low black cloud, (ii) rapid rise of wind speed and veer of wind, (iii) rapid drop in temperature, (iv) rapid rise in pressure, (v) severe thunderstorm, often with hail.

lithometeor: A little-used generic term for non-aqueous solid particles suspended in the air or lifted from the earth's surface, e.g. haze, smoke, dust, drifting sand.

lithosphere: That part of the EARTH which is solid.

local time: Time reckoned from the epoch noon which at any place is the time of transit across the meridian of either the true sun or mean sun (according as local apparent time or local mean time is being used). A local time (LT) variation is one based on the mean sun, while a sunshine recorder or sundial indicates local apparent time. (See TIME).

logarithmic velocity profile: The theoretical variation of mean wind speed near the earth's surface (within the 'surface BOUNDARY LAYER'), derived under various restrictive conditions. For aerodynamically rough flow—the meteorologically significant case—the wind profile is given by the equation

$$\frac{\bar{u}}{u_*} = \frac{1}{k} \ln \left(\frac{z}{z_0}\right)$$

where $\bar{u}$ is the mean wind velocity at height z, u_* the FRICTION VELOCITY, z_0 the ROUGHNESS LENGTH, and k is Kârmân's constant (about 0·4). The equation applies only for $z \geq z_0$. Observations show that the equation applies only in conditions of neutral stability.

longitude: The longitude of any place is the angle between the geographical MERIDIAN through that place and a standard or 'prime meridian', which is taken to be the meridian of Greenwich.

long-range forecast: See FORECAST.

long wave: In synoptic meteorology, a smooth, wave-shaped contour pattern on an isobaric chart with a wavelength of the order of 2000 km, relating more especially to the middle or high troposphere. Some four or five such waves (also termed 'Rossby waves') typically extend across a hemispherical chart.

Assuming a sinusoidal long-wave pattern of wavelength L in a BAROTROPIC atmosphere with no viscosity, and in which absolute vorticity is conserved, Rossby obtained the formula:

$$c = U - \frac{\beta L^2}{4\pi^2}$$

where c is the wave speed (positive, eastward; negative, westward), U the mean zonal wind speed and β is the ROSSBY PARAMETER, i.e. the northward rate of change of the CORIOLIS PARAMETER. The formula accounts for progressive, stationary and retrograde waves ($c > 0$, $c = 0$, $c < 0$, respectively) but not for waves which may progress faster than the zonal current ($c > U$).

long-wave radiation: In its usual meteorological usage, an alternative for TERRESTRIAL RADIATION.

looming: An optical phenomenon, associated with a greater-than-normal rate of decrease of air density with height near the surface, in which objects which are normally below the HORIZON become visible. See MIRAGE.

Loschmidt's number: The number of gas molecules per unit volume at normal temperature and pressure. By AVOGADRO'S LAW this is the same for all gases and equals $2{\cdot}687 \times 10^{19}$ per cm^3.

low: A term commonly used in synoptic meteorology to denote a region of low pressure, or DEPRESSION.

Lowitz, arcs of: On rare occasions arcs slightly concave towards the sun extend obliquely downwards and inwards from the parhelia of the 22° HALO. They are formed by REFRACTION through ice crystals oscillating about the vertical.

luminosity: For a given wavelength, the ratio of the luminous flux to the radiant energy flux. It varies throughout the VISIBLE SPECTRUM from zero at either end of the spectrum to a maximum at wavelength 0·555 micron. The ratio is also termed 'luminous efficiency', or 'visibility ratio'.

luminous efficiency: An alternative for LUMINOSITY.

luminous night clouds: An alternative for NOCTILUCENT CLOUDS.

lunar: Relating to *luna*, the moon: thus a lunar rainbow is a rainbow formed by the rays of the moon.

The 'lunar month' or 'lunation' or 'synodic month' is the period of revolution of the moon round the earth relative to the line joining the centres of the sun and earth and averages about 29·53 days. The 'sidereal month' is the moon's revolution period relative to the fixed stars and averages about 27⅓ days. These periods are to be distinguished from the civil 'calendar month' (January, February etc.). A 'lunar day' signifies, in geophysics, the interval between successive lunar TRANSITS and averages about 24 hr 51 min.

lustrum: A period of five consecutive years, which is sometimes used for grouping meteorological statistics which extend over a long period of years.

lysimeter: An instrument for measuring the rate of PERCOLATION of rain through a soil.

M

Mach angle: See SHOCK WAVE.

Mach lines: See SHOCK WAVE.

Mach number: A pure number, significant in the movement of bodies through the air, defined as the ratio of the air-speed of a body to the speed of sound at the corresponding temperature. Neglecting a very small variation with water-vapour concentration, the speed of sound varies directly with the square root of the temperature (°K) of the air: in the international STANDARD ATMOSPHERE it is 762 m.p.h. at 0 ft. (15°C) and 660 m.p.h. at 37,000 ft. (−56·5°C).

mackerel sky: A sky covered with ALTOCUMULUS clouds arranged in regular waves and showing blue sky in the gaps.

macroclimate: The general CLIMATE of a substantial part of the earth's surface, as for example all or most of a continent.

macroclimatology: The study of MACROCLIMATES.

macrometeorology: The study of large-scale processes in the atmosphere occurring over substantial regions of the earth's surface, up to and including the GENERAL CIRCULATION of the atmosphere itself.

macroviscosity: A quantity denoted N and defined by O. G. Sutton as $N = u_* z_0$ where u_* is the FRICTION VELOCITY and z_0 the ROUGHNESS LENGTH. Aerodynamically rough flow—the meteorologically important case—signifies a value of N greater than about $10^2 \text{cm}^2/\text{sec}$, i.e. a value some 10^3 times greater than the kinematic VISCOSITY (ν). The parameter N plays a part in fully rough flow analogous to that of ν in smooth flow.

maestro: A north-westerly wind in the Adriatic. It is most frequent on the western shore and in summer. North-westerly winds in other parts of the Mediterranean, notably in the Ionian Sea, and on the coasts of Sardinia and Corsica are also known as maestro.

magnetic character: The magnetic character of each day, from the point of view of disturbance, is classified 0, 1, 2 on the local scale and 0·0, 0·1, . . . 2·0 on the international scale—so-called C and Ci figures, respectively. See GEOMAGNETISM.

magnetic crochet: A short-lived disturbance (lasting generally less than one hour) of the earth's magnetic field, observed only in the sunlit hemisphere synchronously with an intense SOLAR FLARE. The disturbance is essentially an augmentation of the normal solar diurnal variation of the magnetic elements and is attributed to a sudden increase in ionospheric conductivity produced by solar flare wave radiation. It is also termed a (magnetic) 'solar flare effect' (sfe). See also GEOMAGNETISM.

magnetic storm: See GEOMAGNETISM.

magnetogram: The record from a MAGNETOGRAPH.

magnetograph: An instrument for obtaining continuous records of the earth's magnetic field. In the usual (La Cour) type, three magnets are suspended with their axes horizontal. One has its axis in the magnetic meridian, the second is perpendicular to the magnetic meridian, and the third can move in the vertical plane, the magnets responding to variations of DECLINATION (*D*), horizontal force (*H*), vertical force (*V*), respectively. To each magnet is attached a mirror which reflects light from a fixed lamp on to photographic paper which covers a rotating cylinder. A system of prism reflexions enables the reflected traces to be contained within a single chart, even in the greatest magnetic storm. Regular time marks are made automatically and 'scale values' determined experimentally. Comparison with absolute (MAGNETOMETER) measurements of each element at known times enables the value of the reference or 'base line' for each element to be calculated and hence the absolute value of each element at any time. A fresh magnetograph record is obtained daily. A 'quick run' record with much expanded time-scale may also be operated.

magnetohydrodynamics: The study of the motion of an electrically conducting fluid in the presence of a magnetic field. Geophysical spheres in which such study is important include those concerned with motions in the earth's core and in the earth's high atmosphere.

magnetometer: An instrument for obtaining absolute measurements of the earth's magnetic field. The fundamental measured elements are generally the angles of DECLINATION (*D*) and DIP (*I*), and the value of the horizontal component (*H*): total force (*F*) and vertical force (*V*) are, however, sometimes measured.

magnetosphere: Term proposed for that composite region of the earth's high atmosphere, including the EXOSPHERE and much of the underlying IONOSPHERE, in which the earth's magnetic field exerts strong control over the motion of ionized particles.

mamma (mam): A supplementary cloud feature, previously termed 'mammatus'. (Latin, *mamma* udder.)

'Hanging protuberances, like udders, on the under surface of a cloud.

This supplementary feature occurs mostly with CIRRUS, CIRROCUMULUS, ALTOCUMULUS, ALTOSTRATUS, STRATOCUMULUS and CUMULONIMBUS'.* See plate 14: see also CLOUD CLASSIFICATION.

manometer: An instrument for measuring differences of pressure. Ordinarily the weight of a column of liquid is balanced against the pressure to be measured. The mercury BAROMETER is, therefore, a form of manometer.

mares' tails: The popular name for tufted CIRRUS clouds.

Margules's formula: See FRONT.

MARID: In weather messages, a code word indicating that reports of sea surface temperatures follow in figure code. See 'Handbook of weather messages'.†

marine climate: An alternative for MARITIME CLIMATE.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 16.

† London, Meteorological Office; Handbook of weather messages. Part III. London, HMSO, 1959.

maritime climate: A type of CLIMATE which is dominated by the near presence of the sea and is characterized by small diurnal and annual ranges of air temperature. Such a climate prevails over islands and windward parts of continents, e.g. the British Isles, more especially the extreme west. See CONTINENTAL CLIMATE.

maritime polar air: See POLAR AIR.

maritime tropical air: See TROPICAL AIR.

Marsden square: Mainly used for identifying the geographical position of meteorological data over the oceans. System devised by Marsden in 1831 who divided a Mercator chart of the world into squares of 10° latitude by 10° longitude. Each square is arbitrarily numbered, and is again subdivided into 100 one-degree squares which are numbered from 00 to 99 so that, given the position of the square, the first figure of the sub-square denotes the latitude and the second figure the longitude.

mass concentration: See SPECIFIC HUMIDITY.

maximum: In meteorology, the highest value reached by a specified element in a given period. See EXTREMES.

maximum thermometer: Usually, a mercury-in-glass THERMOMETER which has a constriction in the bore, close to the bulb. If the thermometer is exposed horizontally the mercury is able, on expansion, to flow from the bulb past the constriction but not, on subsequent contraction, in the opposite direction. The end of the mercury column farther from the bulb indicates the maximum temperature attained since the last 'setting' of the thermometer which is effected by shaking the mercury past the constriction.

mean: The arithmetic mean, often termed simply the mean, of a set of n numbers is the sum of the n numbers divided by n. In some cases there may be an ambiguity unless the context makes it clear as to how the numerical quantities are classified. For example, the mean temperature of the atmosphere extending above a certain place may indicate the arithmetic mean of the temperatures taken at equal intervals of height or at equal intervals of pressure, from the ground upwards.

mean deviation: In a series of n values, the mean deviation (e) is the mean of all the deviations (x) from the arithmetic mean, taken without regard to sign, i.e. $e = \Sigma|x|/n$. In a series with approximately NORMAL DISTRIBUTION, $e \simeq 0{\cdot}8\sigma$, where σ is the STANDARD DEVIATION.

mean effective diameter: See CLOUDS, PARTICLE DISTRIBUTION IN.

mean free path: Mean distance travelled by the molecules or atoms of a gas between consecutive collisions with other molecules or atoms. Mean free path is a function of gas pressure. At low atmospheric levels it is of the order 10^{-7} cm, increasing with height to about 1 cm at 85 km, to 10^4 cm at 180 km, and to still greater values at higher levels.

mean sea level: See SEA LEVEL.

median: When a series of n observations is arranged in order of magnitude, the central value (n odd), or the mean of the two central values (n even), is termed the 'median'. The median may differ appreciably from the MEAN, in which case the frequency distribution is said to be 'skew'.

median volume diameter: See CLOUDS, PARTICLE DISTRIBUTION IN.

mediocris (med): A CLOUD SPECIES. (Latin, *mediocris* medium.)
'CUMULUS clouds of moderate vertical extent, the tops of which show fairly small protuberances'.* See also CLOUD CLASSIFICATION.

Mediterranean-type climate: A distinctive type of subtropical CLIMATE, included in W. Köppen's classification, which is characterized by dry, hot, sunny summers and mild, moderately rainy winters. The type is found in the land regions bordering the Mediterranean, central and coastal southern California, central Chile, extreme south of South Africa, and parts of southern Australia.

medium-range forecast: See FORECAST.

megadyne: One million dynes. A pressure of a megadyne per square centimetre is equal to one BAR or 1000 MILLIBARS. See DYNE.

megathermal climate: A CLIMATE of high temperature: more specifically, in the Köppen classification, one in which no month has a mean temperature below 18°C. Such conditions are found in the more humid of the tropical or subtropical regions.

melting band: The most conspicuous of the BRIGHT BANDS which are observed in vertical cross-section radar displays of precipitating clouds.
On reaching the melting (0°C) level, falling snowflakes begin to melt. Since an ice particle with a wet skin reflects almost as well as if it were an entirely liquid particle, the strength of the echo returned from the region below 0°C is greater than that above. Since, further, (i) the melting particles are spheroidal in shape and have a larger surface area than raindrops, and (ii) the rate of fall of the particles increases and their volume concentration decreases when completely melted, the radar reflectivity of the melting particles exceeds that of the raindrops below. The various effects combine to produce a bright band which has a maximum intensity a few hundred feet below the 0°C level. See also RADAR METEOROLOGY.

melting-point: That temperature, characteristic of a given substance at a given pressure, at which the change of state from solid to liquid occurs. For pure ice at standard atmospheric pressure the melting-point is 0°C.

meniscus: The curved upper surface of liquid in a tube. The meniscus is concave for water, convex for mercury. The curvature effect arises from SURFACE TENSION. Scales and measures are graduated on the assumption that readings are taken at the centre of the meniscus in either case, i.e. lowest point of water meniscus, highest point of mercury meniscus.

Mercator's projection: See PROJECTION.

mercury: Mercury is a metallic element of great value in the construction of meteorological instruments. In the mercury barometer its great density enables the length of the instrument to be made moderate, while the low pressure of its vapour at ordinary temperatures makes possible a nearly perfect vacuum in the space above the top of the barometric column. In the mercury thermometer there is no risk of condensation in the upper end of the stem, as in the case of the spirit thermometer.

Specific gravity	=	13·5951 at 0°C
Specific heat	=	0·0335 at 0°C
Vapour pressure	=	0·00021 mb at 0°C
	=	0·00343 mb at 30°C
Freezing-point	=	234·2°K
Coefficient of expansion ...	=	0·000182 per °C.

* Geneva, World Meteorological Organization; International cloud atlas. Vol. I, Geneva, WMO, 1956, p. 14.

meridian: The (geographical) meridian at any point of the earth's surface is the semi-GREAT CIRCLE which passes through the point and terminates at the geographical POLES. The 'prime meridian' is that which passes through Greenwich.

The meridian of an observer is that semi-great circle of the CELESTIAL SPHERE which passes through the observer's ZENITH and terminates at the celestial poles.

The magnetic meridian at any point of the earth's surface is the direction of the compass at that point. The 'geomagnetic meridian' or 'dipole meridian' at any point is the meridian which passes through the point and terminates at the geomagnetic poles—see GEOMAGNETISM.

meridional circulation: North to south or south to north air flow.

mesoclimate: The CLIMATE of a moderately restricted region of the earth's surface; an urban district, as opposed to a neighbouring rural district, is near the lower end of the scale of areas encompassed by this term.

mesoclimatology: The study of MESOCLIMATES.

mesometeorology: The study of the atmosphere, pursued on a geographical scale between those employed in MICROMETEOROLOGY and SYNOPTIC METEOROLOGY. A several-fold increase in the number of synoptic stations over a restricted region of southern England, say, would meet the observational needs of mesometeorology, the object of which is a study of those substantial local variations of meteorological phenomena which are missed on the normal synoptic network.

mesopause: The top of the MESOSPHERE, at a height of about 80 km, marked by a temperature minimum and hence temperature inversion.

mesosphere: That part of the ATMOSPHERE, between the STRATOPAUSE at about 50 km and the MESOPAUSE at about 80 km, in which temperature generally falls with increasing height. An alternative definition, in which the mesosphere was considered to include also the layer from about 20 to 50 km in which temperature generally increases with height, is not now favoured.

mesothermal climate: A CLIMATE of moderate temperature: more specifically, in the Köppen classification, a climate in which the mean temperature of the coldest month lies between −3°C and +18°C (see MICROTHERMAL CLIMATE and MEGATHERMAL CLIMATE). Such conditions are found mainly between latitudes 30° and 45° but extend up to about 60° on the windward side of continents.

MESRAN: In weather messages, a code word indicating that a collective upper air message follows, in an abridged figure code, for intercontinental exchange. See 'Handbook of weather messages.'*

meteor: As defined in the 'International cloud atlas',† 'a phenomenon, other than a cloud, observed in the atmosphere or on the surface of the earth, which consists of a precipitation, a suspension or a deposit of aqueous or non-aqueous liquid or solid particles, or a phenomenon of the nature of an optical or electrical manifestation'. Meteors so defined are classified into four groups, namely HYDROMETEOR, LITHOMETEOR, PHOTOMETEOR and ELECTROMETEOR: the last three of these terms, in particular, are very little used.

In its more commonly used sense, a meteor, or 'shooting star', is a fragment of solid material (iron or stone) of undetermined origin, which enters the upper regions

* London, Meteorological Office; Handbook of weather messages. Parts II and III. London, HMSO, 1959.

† Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 61.

of the atmosphere and is there made visible by incandescence caused by compression of air in front of the meteor, the meteor itself evaporating in the air. (In another usage, the term 'meteor' is applied only to the visible trail, the particle itself being termed a 'meteoroid'). In clear-sky conditions an individual observer normally sees a few meteors per hour: in large 'meteor showers', however, many more are to be seen. Most meteors are visible for only one or two seconds but a very large meteor may have a luminous trail that persists for half an hour or longer. The size of meteors ranges from about a centimetre downwards, most being very much smaller. Those too small to be detected visually or by the reflexion of radio waves from the ionized trail which they leave in the high atmosphere are termed 'micro-meteors' comprising, at very small particle size, 'meteoric dust'. The occasional bodies large enough to reach the ground are termed 'meteorites'. The large and very bright meteors are known as 'fireballs': those whose destruction in the atmosphere is associated with an air explosion (audible up to a distance of about 50 miles) are termed 'bolides'.

Meteors are grouped into (i) 'meteor showers' which comprise parts of great streams of particles orbiting the sun; they are mostly associated with comets and appear to enter the atmosphere from those points of the heavens and around those calendar dates given in Table XI: (ii) 'sporadic meteors', of random occurrence, which account for the bulk of total meteor activity. Evidence advanced by E. G. Bowen to the effect that meteor-shower occurrence is a significant factor in the time distribution of world-wide rainfall, through the formation of condensation nuclei, is not generally accepted as convincing.

From synchronized meteor observations at a known distance apart (now obtained photographically through wide-angle telescopes) the velocity and brightness and the heights of appearance and disappearance of individual meteors may be measured. Such observations show that most visible meteors appear at about 110 km and disappear at about 80 km, with a secondary maximum frequency of disappearance at about 45 km and minimum frequency at 55 km. Since the rate of burn-out of a meteor is a function of air density, the density and hence the temperature of the air may be calculated from such data. The results indicate a temperature maximum at about 60 km at least as high as that near the ground and a rapid increase of temperature above about 85 km.

The IONIZATION of the air which is produced along the path of a meteor is significant in the sporadic E-LAYER. The radio-echo technique has been used with the ionized trails produced by meteors in order to determine density, temperature and winds at the atmospheric levels concerned.

TABLE XI—*Meteor-shower occurrence*

Shower	Date of maximum	Shower	Date of maximum
Quadrantids	3–4 January	Perseids	5–14 August
Lyrids	21 April	Giacobinids	10 October
η-Aquarids	4–6 May	Orionids	20–23 October
o-Cetids	14–23 May	Taurids	3–10 November
Arietids	29 May–18 June	Leonids	16–17 November
ζ. Perseids	1–16 June	Geminids	12–13 December
β-Taurids	26 June–5 July	Ursids	22 December
δ. Aquarids	28 July		

meteorite: A METEOR, or 'meteoroid', large enough to survive passage through the earth's atmosphere and so reach the earth's surface.

meteorograph: An instrument which gives an automatic record of two or more of the ordinary meteorological elements. The term has been used more especially of an instrument, now obsolete, attached to a kite or balloon to measure the pressure, temperature and humidity of the upper atmosphere.

meteorological office: In aeronautical terminology, an office designated to provide meteorological information for international air navigation. Sub-division is made in this terminology into:

(i) regional, (ii) main, (iii) dependent, (iv) supplementary, (v) watch offices, defined as follows:

(i) Regional meteorological office: headquarters of a meteorological region which directs, controls and inspects the various stations of the region; it is qualified to issue directives, technical instructions, regional forecasts and warnings.
(ii) Main meteorological office: a meteorological office competent to prepare forecasts, supply meteorological information and briefing to aeronautical personnel, supply meteorological information required by an associated dependent or supplementary office.
(iii) Dependent meteorological office: a meteorological office competent to prepare forecasts under the guidance of a main meteorological office, supply meteorological information and briefing to aeronautical personnel, supply meteorological information required by an associated supplementary office.
(iv) Supplementary meteorological office: a meteorological office competent to supply aeronautical personnel with meteorological information received from a main or a dependent office and with meteorological reports otherwise available.
(v) Meteorological watch office: a meteorological office competent to maintain watch over meteorological conditions within a defined area or along designated routes or portions thereof for the purpose of supplying meteorological information, in particular, meteorological warnings. A watch office may be an independent office or may be part of a main or dependent meteorological office.

meteorological optical range (MOR): As recommended by the World Meteorological Organization in 1957, a quantity which is identical for practical purposes with VISIBILITY, and is defined as the length of path in the atmosphere required to reduce the luminous flux in a collimated beam of light to 0·05 of its original value. (The 'light' is defined as that emanating from an incandescent lamp at a colour temperature of 2700°K).

meteorological reconnaissance flight: An aircraft flight made for the specific purpose of obtaining information in a region inadequately served by surface observations (generally over the sea). The results of such flights, which usually include vertical ascents at selected points on the route, are reported in the RECCO code.

meteorology: The science of the atmosphere; from the Greek *meteoros*, lofty or elevated and *logos*, discourse. Meteorology embraces both WEATHER and CLIMATE and is concerned with the physical, dynamical and chemical state of the earth's atmosphere (and those of the planets), and with the interactions between the earth's atmosphere and the underlying surface.

methane: Gas, of chemical formula CH_4, which occurs in minute concentration in the atmosphere (about $2{\cdot}0 \times 10^{-6}$ part by volume—see AIR).

Methane is released to the atmosphere mainly by the decay of biological products and is destroyed mainly by atmospheric ozone. Its mean lifetime in the atmosphere is considered to be not greater than 200 years.

metre: The unit of length in the M.K.S. SYSTEM of units. It was intended to be equal to one forty-millionth of the Paris meridian, but errors entered into the calculation and it must now be considered as an arbitrary length. For many years it was defined as the distance, at the melting-point of ice, between two lines engraved upon a platinum-iridium bar kept in Paris. In October, 1960 it was decided at the International Bureau of Weights and Measures to abandon the ruled metre bar as a standard and to redefine the metre as being 1,650,763·73 wavelengths, in a vacuum, of the radiation corresponding to the transition between two specified energy levels (2 P_{10} and 5 D_5) of the krypton atom of mass 86. This is a measurement whose accuracy can be maintained to one part in 100 million.

An Order in Council in 1898 defined the inch as 25·400 millimetres from which it may be deduced that one metre is 39·370113 inches.

micro: A prefix meaning small, from the Greek *mikros;* for example, microbarograph, microseism. In units it signifies one-millionth, as in 'microfarad'.

microbarograph: An instrument designed for recording small and rapid variations of atmospheric pressure. In the Shaw–Dines microbarograph, differences in pressure between a large and well lagged reservoir of air and the external atmosphere are reflected in movements of a bell-shaped float in a bath of mercury and recorded on a clockwork-driven chart by a pen which is directly linked with the float. The reservoir is provided with a slow leak to atmosphere in the form of fine capillary tubing. In all but rapid changes of atmospheric pressure the leak equalizes the reservoir and atmospheric pressures, and the pen remains at the centre of the chart.

microclimate: The physical state of the atmosphere close to a very small area of the earth's surface, often in relation to living matter such as crops or insects. In contrast to CLIMATE, microclimate generally pertains to a short period of time.

microclimatology: The study of MICROCLIMATES.

micrometeorology: The study of the fine structure of the physical processes occurring in the atmosphere. This branch of meteorology is much concerned with atmospheric conditions close to limited regions of the earth's surface but embraces also the detailed structure of physical processes, more especially TURBULENCE, at higher levels of the atmosphere.

micron: A measure of length, equal to 10^{-4} cm, denoted μ.

microseisms: Term usually restricted, by convention, to a type of quasi-periodic motion of the ground which is unrelated to earthquakes, explosions, or such artificial agencies as industry and traffic.

The periods of microseisms range from a fraction of a second to several minutes. Atmospheric phenomena—notably the effect of wind on the oceans and resultant effect on the ocean bottom—play an important part in their production which is, however, not well understood. Microseisms have long been used as an early indication of tropical storm development over the sea. Tripartite stations, spaced in a triangle at distances a few kilometres apart, have more recently been developed as a useful aid in the tracking of tropical storms across sea areas.

microthermal climate: A CLIMATE of low temperature: more specifically, in the Köppen classification, a climate of long, cold winters and short summers, the mean temperature of the coldest month being less than −3°C and of the warmest month greater than 10°C. Such conditions are found in the interior and eastward parts of continents between about latitudes 40° and 65°.

microwaves: RADIO WAVES of short wavelength (generally in the range from a fraction to some tens of centimetres) employed, for example, in RADAR.

Mie scattering: SCATTERING of ELECTROMAGNETIC RADIATION by spherical particles. The theory of such scattering, developed by G. Mie in 1908, does not depend on the assumption that the scattering particle has a radius small compared with the wavelength of the radiation and thus has wider application than the theory appropriate to RAYLEIGH SCATTERING. Extension of the theory to particles of various types and shapes, together with formulae and numerical data required to apply the theory, are contained in the book 'Light scattering by small particles'.*

mile: The 'statute mile' is defined as 1760 yd or 5280 ft. The 'geographical mile' is defined as the length of one minute of arc of longitude at the equator, *i.e.* 1/21,600 of the earth's equatorial circumference and equals 6087·2 ft. The 'nautical mile' was originally taken, for navigational purposes, as the length of one minute of arc of latitude. Owing to the spheroidal shape of the EARTH this length varies with latitude, being given by $(6076{\cdot}8 - 31{\cdot}1 \cos 2\varphi)$ ft where φ is latitude. The precise length of 6080 feet was adopted by the British Admiralty as the nautical mile. The U.S. nautical mile is 6080·21 ft, while the 'international nautical mile' is exactly 1852 metres (6076·12 ft).

millibar: The thousandth part of a BAR. The millibar (mb), equivalent to 10^3 c.g.s. units of pressure (dynes/cm^2), has replaced the inch or millimetre of mercury as the unit of pressure in the Meteorological Office since 1 May 1914. See also PRESSURE.

$$1 \text{ bar} = 10^3 \text{ millibars} = 10^6 \text{ dynes/cm}^2$$

minimum: In meteorology, the lowest value reached by a specified element in a given period. See EXTREMES.

minimum deviation: In REFRACTION, the minimum change of direction suffered by radiation in passing through a refractive medium, as for example light rays through ice crystals. Since changes of direction of the refracted rays are least near the position of minimum deviation, rays emerging after total refraction at and near this position contribute most to the brightness seen by an observer. Minimum deviation is fundamental in the production of the simple refraction phenomenon of the HALO and in the refraction plus REFLEXION phenomenon of the RAINBOW.

The 'angle of minimum deviation' (D) in a plane normal to the faces of a prism intersecting at angle A is given by the formula:

$$n = \frac{\sin\{(A + D)/2\}}{\sin(A/2)}$$

where n is the REFRACTIVE INDEX of the medium. For the passage of light through hexagonal ice crystals ($A = 60°$, $n = 1{\cdot}31$), D is nearly 22°, corresponding to the radius of the small halo.

minimum temperature: The lowest temperature attained, usually in the Stevenson screen or on the ground ('screen minimum temperature' and 'grass minimum temperature', respectively), during a given period.

Because of their significance in the formation of frost and fog, much attention has been given to the problem of forecasting night minimum temperatures of either type. Various empirical formulae have been derived, using mainly the observed dry-bulb and wet-bulb temperatures and dew-point, and the observed values (or those estimated for the cooling period) of surface wind speed and cloud amount. Owing to variations of topographical influences and length of cooling period, such formulae may be applicable only to a specified location and time of year.

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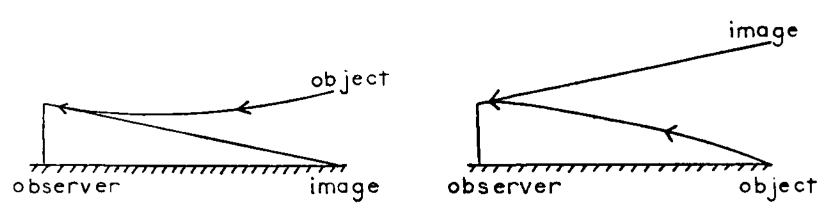
* VAN DE HULST, H. C.; Light scattering by small particles. New York, John Wiley and Sons, 1957.

minimum thermometer: Usually, an alcohol-in-glass THERMOMETER which carries a small index within the bore, below the surface of the liquid. Initial 'setting' of the instrument is effected by raising the bulb of the thermometer higher than the stem: the index then falls till its lower end meets the end of the spirit column, being prevented from further fall by surface tension. Contraction of the spirit on cooling causes the index to be dragged back closer to the bulb by the end of the spirit column, while expansion of the spirit on heating does not affect the position of the index. The position of that end of the index farther from the bulb thus indicates the minimum temperature attained since the last setting of the thermometer. The thermometer is supported in the screen so that the stem has a slight slope downwards towards the bulb. With this arrangement the movement of the index towards the bulb is slightly assisted by gravity.

mintra: That temperature above which, at a given pressure, theory indicates that no CONDENSATION TRAILS will form. The variation of mintra temperature with pressure is shown by a line on the Meteorological Office TEPHIGRAM chart.

mirage: An atmospheric optical phenomenon produced by REFRACTION of light in the layers of air close to the earth's surface due to large temperature gradients in the vertical and associated changes of REFRACTIVE INDEX.

Two main classes of mirage occur, (i) 'inferior' and (ii) 'superior', in which the virtual image is below and above the object, respectively. The inferior mirage is seen over a flat, strongly heated surface (e.g. desert or road) and gives the illusion



(*a*) Inferior mirage (*b*) Superior mirage

FIGURE 25—Mirages.

of an expanse of water: it is caused by the strong upward refraction of light from the clear sky towards the observer. The superior mirage is seen above a flat surface of much lower temperature than the air above it: light from an object is in this case bent downwards towards the observer, as in LOOMING (see Figure 25). In such physical conditions multiple reflexions may give rise to various images, some displaced laterally with respect to the object, as in FATA MORGANA.

mist: A state of atmospheric obscurity produced by suspended microscopic water droplets or wet hygroscopic particles. The term is used for synoptic purposes when there is such obscurity and the associated visibility exceeds one km: the corresponding relative humidity is greater than about 95 per cent. The particles contained in mist have diameters mainly of the order of a few tens of microns. See also HAZE, FOG.

mistral: A north-westerly or northerly wind which blows offshore along the north coast of the Mediterranean from the Ebro to Genoa. In the region of its chief development its characteristics are its frequency, its strength and its dry coldness. It is most intense on the coasts of Languedoc and Provence, especially in and off the Rhône delta. On the coast, speeds are about 40 knots but in the Rhône valley a speed of over 75 knots has been reached.

mixed cloud: A cloud which is composed of both ice crystals and water droplets. The CLOUD GENERA As, Ns and Cb are normally mixed clouds.

mixing condensation level: See CONDENSATION LEVEL.

mixing length: That distance (l) moved by a discrete EDDY in a turbulent fluid, carrying with it the momentum and other properties appropriate to the mean motion at the original point of the fluid, before mixing again with the general flow. This quantity, introduced in eddy diffusion by L. Prandtl (1925) on analogy with the 'mean free path' appropriate to the process of molecular diffusion, appears in expressions for the eddy velocity (u'), REYNOLDS STRESS (τ), and eddy VISCOSITY (K_M), as follows:

$$u' = l\frac{\partial \bar{u}}{\partial z}$$

$$\tau = -\rho\,\overline{u'w'} = \rho l^2 \left(\frac{\partial \bar{u}}{\partial z}\right)\left|\frac{\partial \bar{u}}{\partial z}\right|$$

$$K_M = l^2 \frac{\partial \bar{u}}{\partial z}$$

mixing ratio: The ratio of the mass of a particular gaseous constituent (e.g. ozone) of the atmosphere to the mass of air with which the constituent is associated.

The term is most often used in respect of the admixture of water vapour with dry air in the atmosphere—see HUMIDITY MIXING RATIO.

mizzle: See SCOTCH MIST.

m.k.s. system: The system of units, analogous to the C.G.S. SYSTEM but much less widely used in meteorology, in which the basic units are the metre, the kilogram and the second. See also ELECTRICAL UNITS.

MMMMM: In weather messages, the indicator for a report, in figure code, of a sudden deterioration in meteorological conditions observed at the surface. See 'Handbook of weather messages'.*

mock moon: An alternative for PARASELENE.

mock sun: An alternative for PARHELION.

mock sun ring: An alternative for PARHELIC CIRCLE.

mode: In a series of values, the value of most frequent occurrence. An approximate rule, when there is only one mode, is:

$$\text{mode} = \text{median} - 3\,(\text{mean} - \text{median}).$$

modified refractive index: For convenience in radio meteorological work, in which the curvature of radio waves with respect to the curvature of the earth has to be considered, a 'modified refractive index' (M.R.I.) is employed. The M.R.I. is defined by the equation

$$M' = (n - 1 + h/a) \times 10^6\ M \text{ units}$$

where M' denotes the M.R.I., n is the refractive index of the air, h is height above earth's surface, and a is the earth's radius. See also REFRACTIVE INDEX.

moist air: A term which in physical meteorology usually signifies simply a mixture of DRY AIR and water vapour. In synoptic meteorology and climatology the term is applied to air of high RELATIVE HUMIDITY.

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* London, Meteorological Office; Handbook of weather messages. Parts II and III. London, HMSO, 1959.

moisture content: See SPECIFIC HUMIDITY.

mole (or **mol**): The gram-molecular weight of a substance, i.e. the weight of it in grams which is numerically equal to its MOLECULAR WEIGHT.

molecular weight: The weight of a molecule of an element, defined on a scale in which the molecular weight of oxygen is 32.

The mean molecular weight (M) of moist air, as applied, for example, in the GAS EQUATION, is

$$M = \frac{m_1 + m_2}{m_1/M_1 + m_2/M_2}$$

where m_1, m_2 are relative weights of dry air and water vapour, respectively,
M_1 is mean molecular weight of dry air = 28·966,
and M_2 is molecular weight of water vapour = 18·016.

mole fraction: The mole fraction N_i of the ith component of a mixture of gases is defined by

$$N_i = \frac{m_i/M_i}{\Sigma\,(m_i/M_i)}$$

where m_i is the mass of the ith component in a given volume or mass of the mixture and M_i is its molecular weight, the summation indicated being made over all components. It is identical with FRACTIONAL VOLUME ABUNDANCE. See also AIR.

moment of inertia: The moment of inertia (I) of a body about an axis is the sum of the products of the mass (m) of each element of the body and the square of its perpendicular distance (r) from the axis, taken for all elements of the body, i.e. $I = \Sigma mr^2$.

momentum: The (linear) momentum of a particle is the product of its mass and its velocity. It has dimensions MLT^{-1}.

monochromatic radiation: RADIATION of a single wavelength. 'Monochromatic flux', 'monochromatic intensity', etc. signify the flux, intensity, etc. per unit wavelength interval.

monsoon: Derived from an Arabic word for 'season', the term originally referred to the winds of the Arabian Sea which blow for about six months from the north-east and for six months from the south-west, but is now used also of other markedly seasonal winds. The essential cause is the differential heating of large land and sea areas, altering with season.

Monsoon conditions are best developed in the subtropics, as in east and south-east Asia (north-east and south-west monsoons in winter and summer, respectively). The rainy season associated with the south-west monsoon is the outstanding feature of the climate of these regions and the term 'the monsoon' is there popularly used to denote the rains, without reference to the winds.

Monsoon conditions occur also, but to a lesser degree, in northern Australia, parts of western, southern and eastern Africa, and parts of North America and Chile. The term is also employed, for example, in north-west Germany.

MONT: In weather messages, a code word indicating that a supplementary synoptic report from a mountain station follows, in figure code. See 'Handbook of weather messages'.*

month: See LUNAR, CALENDAR.

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* London, Meteorological Office; Handbook of weather messages. Part II. London, HMSO, 1959.

moon: The earth's only (natural) satellite. Its radius is 1738 km, mass about $7{\cdot}38 \times 10^{22}$ kg, mean density $3\frac{1}{3}$ times that of water, mean distance from the earth 384,400 km. Its SIDEREAL PERIOD of revolution averages about $27\frac{1}{3}$ days, but varies as much as three hours from this value on account of the eccentricity of its orbit and its 'perturbations'. The SYNODIC PERIOD of revolution (i.e. the interval from new moon to new moon) has a mean value of about 29·53 days, but varies by about 13 hours on account of the eccentricities of the orbits of the moon and earth.

The brightness of the moon is caused by its reflexion of direct sunlight falling on it; while the faint illumination of the dark segment is caused by reflected sunlight which has been first reflected to the moon by the earth's surface and atmosphere ('earthlight')—see ALBEDO. The moon's ALBEDO is about 10 per cent: this value and the considered absence of appreciable atmosphere imply a mean temperature of the moon's surface, in radiative equilibrium with absorbed solar radiation, of 267°K. The moon causes a measurable, though very small tidal movement of the earth's atmosphere but has no other substantiated meteorological effect. See also LUNAR.

moon, phases of: The appearance of the moon, by custom restricted to the particular phases of 'new moon' when nothing is visible, 'first quarter' when a semi-circle is visible with the illuminated bow on the west, 'full moon' when a full circle is visible and 'last quarter' when a semi-circle is visible with the bow on the east. The changes of phase are caused by changes in the relative positions of earth, moon and sun. The moon rotates on its axis once in each orbital revolution and so the same face of the moon is always turned towards the earth.

mother-cloud: A cloud from which another cloud develops. See CLOUD CLASSIFICATION.

mother-of-pearl clouds: An alternative term for NACREOUS CLOUDS. The name was given to them by H. Mohn (1893) because of their brilliant IRIDESCENCE, similar to that shown by mother-of-pearl.

motion, equations of: The equations of motion of the atmosphere are obtained by applying Newton's second law of motion, which equates the total force acting per unit mass, to the acceleration produced. For meteorological purposes the equation is required in terms of 'relative motion', i.e. in terms of accelerations and velocities measured on the rotating earth.

In vector notation the equation is:

$$\dot{\mathbf{V}} = -\frac{1}{\rho}\nabla p - 2\boldsymbol{\Omega}\wedge\mathbf{V} + g + \mathbf{F}$$

(see ACCELERATION for explanation of symbols)

In Cartesian co-ordinates in which x and y are in a horizontal plane to east and north, respectively, and z is positive vertically upwards, the equations of relative motion are:

$$\frac{du}{dt} = -\frac{1}{\rho}\frac{\partial p}{\partial x} - 2\,\Omega\,(w\cos\varphi - v\sin\varphi) + F_x$$

$$\frac{dv}{dt} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - 2\,\Omega\,u\sin\varphi + F_y$$

$$\frac{dw}{dt} = -\frac{1}{\rho}\frac{\partial p}{\partial z} + 2\,\Omega\,u\cos\varphi - g + F_z$$

where

u, v, w are the velocities in the positive x, y, z directions respectively; F_x, F_y, F_z are the components of friction in these directions, due to viscosity or, in mean flow on the meteorological scale, to Reynolds stresses; φ is latitude; and $\frac{d}{dt}$ is the change with time of an individual particle of air ('individual change' or 'change following the air motion').

mountain breeze: An alternative for KATABATIC WIND.

mountain wave: An air wave which is stationary, or almost stationary, with respect to the earth's surface. Such a wave sometimes has cloud in the wave crest. It is formed over and/or to leeward of a hill or mountain which obstructs air flow. See STANDING WAVE, LEE WAVES.

moving averages: An alternative for RUNNING MEANS.

M-regions, solar: The hypothetical restricted solar regions which are thought to emit, usually during a few successive months, SOLAR CORPUSCULAR STREAMS. The existence of such M- (magnetically active) regions is inferred from a marked tendency for small and moderate magnetic storms to recur at intervals of about 27 days, which is the solar rotation period. M-regions have not yet been identified with any visible solar feature.

mutatus: See CLOUD CLASSIFICATION.

N

nacreous clouds: A rare type of stratospheric cloud, also termed 'mother-of-pearl clouds'. The reported occurrences of this cloud have been mainly in Norway and Scotland in winter on occasions of strong and deep west/north-west flow (deep depression over northern Scandinavia). The clouds are somewhat lenticular in form, very delicate in structure, and show brilliant IRIDESCENCE at angular distances up to about 40° from the sun's position. The colouring is most brilliant shortly after sunset (or before sunrise) and endures for a considerable time after sunset. The mean of C. Störmer's height measurements of the cloud is 24 km. The clouds show little or no movement: this fact, together with the circumstances of their occurrence strongly suggests that they are in the nature of MOUNTAIN WAVE clouds. The nature of the particles is not known but the associated optical effects suggest diffraction by spherical particles of diameter less than $2{\cdot}5 \times 10^{-4}$ cm.

natural co-ordinates: A system of co-ordinates in which the xy plane is horizontal, positive x being selected in the direction of the wind or isobars, positive y normal to and to the left of the x axis, and positive z vertically upwards.

Navier–Stokes equations: The equations of motion appropriate to a viscous fluid. Where the fluid is incompressible, the component of acceleration, with reference to axes fixed in space, which acts in the x direction of the Cartesian system of co-ordinates is related to the corresponding forces acting per unit mass by the equation:

$$\frac{\mathrm{d}u}{\mathrm{d}t} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + X$$

where ν is the kinematic VISCOSITY and X the component of the external forces per unit mass in the x direction. Analogous expressions obtain in the y and z directions. See also MOTION, EQUATIONS OF.

nebule: A measure of atmospheric opacity, defined by the statement that a screen of 100 nebules transmits the fraction 1/1000 of the incident light. The definition implies that a screen of opacity 1 nebule has a TRANSMISSIVITY of 0·933 and an EXTINCTION COEFFICIENT of 0·069. The number of nebules per km of air varies from about 1 in very good visibility to about 10,000 in thick fog.

Reference to the unit DECIBEL shows that an opacity of 100 nebules corresponds to a difference of flux density of $10 \log_{10} (1000/1) = 30$ decibels.

nebulosus (neb): A CLOUD SPECIES. (Latin, *nebulosus* fog covered.)

'A cloud like a nebulous veil or layer, showing no distinct details.

This term applies mainly to CIRROSTRATUS and STRATUS.'* See also CLOUD CLASSIFICATION.

neon: One of the INERT GASES, comprising $1{\cdot}8 \times 10^{-5}$ and $1{\cdot}2 \times 10^{-5}$ part per part of dry air by volume and weight, respectively. Its molecular weight is 20·183.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 12.

NEPH: In weather messages, a code word indicating that a report of a NEPHOSCOPE observation follows in figure code. See 'Handbook of weather messages.'*

nephoscope: An instrument for determining the direction of motion of a cloud and its angular velocity about a point on the ground directly below it: the product of the angular velocity (radians/hour) and the cloud height, measured or estimated, in miles gives a measure of the cloud speed in miles per hour.

The types of nephoscope most commonly employed are the Fineman reflecting (or mirror) nephoscope and the Besson comb nephoscope: see 'Observer's handbook.'† A camera obscura arranged to project a view of the clouds near the zenith on to a graduated board may be used as a nephoscope.

neutral point: See POLARIZATION.

newton: The M.K.S. unit of force. It is the force that produces an acceleration of 1 m/sec^2 when applied to a mass of 1 kg. The dimensions are MLT^{-2}.

$$1 \text{ newton} = 10^5 \text{ DYNES}$$

nightglow: The night-time AIRGLOW emission, being the feeble light of the night sky emitted continuously by the upper atmosphere. It has also been termed 'night skylight' and 'permanent aurora'.

The light of the nightglow is measured by a photometer or a spectroscope. It is estimated to account, on average, for nearly half the intensity of light which is present on a clear, moonless night.

The 'auroral green line' 5577Å of atomic oxygen, the SODIUM D line (5893Å), and HYDROXYL bands are among the prominent identified emissions in the complex nightglow spectrum. Photometer measurements reveal the presence of systematic solar-cycle and shorter-period time variations of intensity similar to those of electron density in the IONOSPHERE. Measurements indicate that emissions are generally most intense at 80–100 km but occur also at 200–300 km.

Nightglow is caused by the radiation emitted in the night-time chemical reactions of the ionized and dissociated products which are formed during the day by solar ultra-violet radiation in the atmospheric gases of the ionosphere.

night skylight: An obsolescent alternative for NIGHTGLOW.

night-sky lights: The light received near the ground on a clear, moonless night is estimated to be composed, on average, of direct light from stars and nebulae (about 40 per cent), ZODIACAL LIGHT (15 per cent), NIGHTGLOW (40 per cent), and light from all these sources scattered by the earth's atmosphere (5 per cent).

night-sky recorder: A camera with long focus lens which is mounted with its axis directed towards one of the celestial poles. The camera shutter is arranged, by a clockwork mechanism, to be open only when the sun is 10° or more below the horizon. As the earth rotates images of the stars trace arcs of concentric circles on the film. Quantitative assessment may be made of the incidence of clouds (or fog or thick haze) which cause interruptions of the record.

Use of this instrument, which is also termed a 'starshine recorder', is very limited.

nimbostratus (Ns): One of the CLOUD GENERA (Latin, *nimbus* rainy cloud and *stratus* spread out).

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* London, Meteorological Office; Handbook of weather messages. Parts II and III. London, HMSO, 1959.

† London, Meteorological Office; Observer's handbook. 2nd edn. London, HMSO, 1956, pp. 30, 33.

'Grey cloud layer, often dark, the appearance of which is rendered diffuse by more or less continuously falling rain or snow, which in most cases reaches the ground. It is thick enough throughout to blot out the sun.

Low, ragged clouds frequently occur below the layer, with which they may or may not merge.'* See Plate 10: see also CLOUD CLASSIFICATION.

Nipher shield: A form of screen, based on a suggestion by F. E. Nipher in 1897, which is fitted to a rain-gauge (or snow-gauge), for the purpose of eliminating, as far as possible, wind eddies at the mouth of the gauge and so enabling a truer catch of rain to be made. Such screens are not used in the Meteorological Office.

nitric oxide: A gas, of chemical formula NO, which occurs in minute quantities (of the order 10^{-9} by volume ratio) in the low atmosphere where it is of industrial origin. It is produced in the high atmosphere by DISSOCIATION and subsequent chemical reactions.

In various experiments nitric oxide has been injected into the high atmosphere and has been followed either visually (glow produced at night) or by radio.

nitrogen: A chemically inactive gas, of molecular weight 28·016, which comprises 78·09 and 75·54 parts per 100 parts of dry air by volume and weight, respectively.

Nitrogen exists only in the molecular form (formula N_2) in the lower atmosphere, but has been identified in atomic form in the high atmosphere where it suffers DISSOCIATION to a small extent.

nitrogen cycle: A complex circulation of nitrogen involving the soil, plants, animals and atmosphere. In that part of the circulation which involves the atmosphere, nitrogen is released to the atmosphere from the soil (as NITROGEN and NITROUS OXIDE) by the action of nitrogen-fixing bacteria. R. M. Goody and C. D. Walshaw estimate the average magnitude of the earth–atmosphere nitrogen cycle to be not less than 10^{11} molecules/cm^2 sec.

nitrogen dioxide: A gas, of chemical formula NO_2, which occurs in minute quantities (of the order 10^{-9} by volume ratio) in the low atmosphere where it is of industrial origin. It is produced in the high atmosphere by DISSOCIATION and subsequent chemical reactions.

nitrous oxide: A gas, of chemical formula N_2O, which occurs in the approximately uniform volume ratio of about 4×10^{-7} throughout the troposphere and lower stratosphere. N_2O is considered to be supplied to the atmosphere from the soil as part of the NITROGEN CYCLE and to be destroyed by DISSOCIATION in the high atmosphere.

n-method: See SUPERPOSED-EPOCH METHOD.

noble gases: An alternative for INERT GASES.

noctilucent clouds: Tenuous but at times brilliant clouds in the very high atmosphere. These clouds, also termed 'luminous night clouds', have been observed in latitudes higher than about 50° during the midnight hours of the summer months. The clouds are to be seen in appropriate viewing conditions (direct illumination by sunlight against a dark sky and in the absence of lower clouds) more frequently than was previously thought. They resemble cirrostratus in appearance but have a bluish-white to yellow colour. In the British Isles they are usually seen towards the northern horizon, but extend on occasion to high elevations.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 11.

Measurements have shown the clouds to be at a height of 80–85 km and to have a movement from the north-east at speeds between about 100 and 300 knots. Pronounced wave formation is often visible and slower movement of the waves towards the north-east, contrary to that of the cloud material, has been reported. It is yet uncertain whether the clouds are composed of dust or of ice particles. A particle radius of the order 10^{-5} cm is indicated by measurements of the strong POLARIZATION of the light from the clouds. No clear association between the appearance of the clouds and such occurrences as volcanic eruptions or meteor showers has yet been shown. See Plate 18.

nocturnal radiation: The excess RADIATION emitted by the earth's surface at night relative to that received by the earth's surface from the atmosphere (mainly from clouds and from atmospheric water vapour and carbon dioxide). It is also termed 'effective radiation'.

Since the earth radiates as a black body at its own temperature while the atmosphere is transparent over an important range of wavelengths at terrestrial temperatures (see ATMOSPHERIC WINDOW) the excess is nearly always positive and results in a fall in temperature of the earth's surface at night. Nocturnal radiation is greatest when the air is cloudless and relatively dry.

The term is perhaps unfortunate because the same process occurs by day: the energy loss is then, however, generally small compared with the influx of solar radiation.

normal: The name given to the average value over a period of years of any meteorological element such as pressure, temperature, rainfall or duration of sunshine.

Normal meteorological values are subject to 'uncertainty' owing to year-to-year variability of the observations: the computed STANDARD ERROR of the mean, decreasing with increasing length of period over which averages are taken, is a measure of this uncertainty. In the selection of a suitable length of period, a compromise must be struck in that the period must be long enough for the computed standard error of the mean to be small, but must not be so long that there is a risk that the period contains an appreciable SECULAR TREND (change of normal) of the observations. A period of about 30 years has in the past been thought to be a reasonable compromise and is generally used in deriving normals.

Climatological normals for Great Britain and Northern Ireland are contained in a number of Meteorological Office publications (temperature 1921–50*; sunshine, 1921–50†; rainfall, 1916–50‡). For the British Isles, monthly and annual charts of pressure, wind, temperature, rainfall, snow, thunder, sunshine, fog and cloud are given in the 'Climatological atlas of the British Isles'.§ Tables of temperature, relative humidity and precipitation for the world are contained in another Meteorological Office publication.¶

normal (frequency) distribution: The normal (also termed the Gaussian) distribution corresponds to the distribution of random errors about a population mean which is indicated by the NORMAL LAW OF ERRORS. The equation on which the distribution is based is

$$y = \frac{1}{\sigma\sqrt{(2\pi)}} e^{-x^2/2\sigma^2},$$

* London, Meteorological Office; Averages of temperature for Great Britain and Northern Ireland, 1921–50. London, HMSO, 1953 (reprinted 1959).

† London, Meteorological Office; Averages of bright sunshine for Great Britain and Northern Ireland, 1921–50. London, HMSO, 1953 (reprinted 1959).

‡ London, Meteorological Office; Averages of rainfall for Great Britain and Northern Ireland, 1916–50. London, HMSO, 1958.

§ London, Meteorological Office; Climatological atlas of the British Isles. London, HMSO, 1952.

¶ London, Meteorological Office; Tables of temperature, relative humidity and precipitation for the world. Parts I to VI. London, HMSO, 1958, 1959.

where σ is the standard deviation. There is maximum frequency (y) of small errors (x), the frequency decreasing rapidly with increase of error size. The curve is therefore bell-shaped and is symmetrical about the y axis along which the mean, mode and median all coincide.

The normal distribution is widely used in statistics, partly because many observational curves approximate to it and also because PROBABILITY theory is closely linked with it. Tabulated probabilities of occurrence of an error within various specified limits (expressed as a ratio of error to standard deviation, i.e. x/σ) are known as the 'probability integral' or 'error function' (erf) and are contained in books on statistics. Probabilities for a few selected values of x/σ are given under STANDARD DEVIATION.

The distributions of some of the meteorological elements, notably of pressure and temperature, approximate to the normal distribution, while those of other elements, e.g. daily rainfall, depart widely from it.

normalized series: One in which each value of the series is divided by the STANDARD DEVIATION of the series, generally with the purpose of affording a better comparison with another series which is also normalized.

normal law of errors: When an error to which an observation is subject may be regarded as made up of a large number of small independent errors, each as likely to be positive as negative, it can be shown that the probability that any one observation of a series should have an error between x and $x + dx$ is

$$\frac{1}{\sigma\sqrt{(2\pi)}} e^{-x^2/2\sigma^2} dx$$

where σ is the STANDARD DEVIATION of the series. In a large number n of observations, we should therefore expect a number

$$\frac{n}{\sigma\sqrt{(2\pi)}} e^{-x^2/2\sigma^2} dx$$

to lie between the limits x and $x + dx$. The observations are then said to satisfy the 'normal law of errors': the corresponding frequency distribution is termed the NORMAL DISTRIBUTION or 'Gaussian distribution'.

Normand's theorem: Of various propositions enumerated by C. Normand in relation to the thermodynamics of the atmosphere, that generally termed 'Normand's theorem' is to the effect that, on an AEROLOGICAL DIAGRAM, the dry adiabatic through the dry-bulb temperature, the saturated adiabatic through the wet-bulb temperature, and the saturation mixing ratio line through the dew-point temperature of an air sample, all meet in a point.

norte, norther: A strong, cold, northerly wind which blows mainly in winter on the shores of the Gulf of Mexico. Here it is sometimes humid and accompanied by precipitation. The northers reach the Gulf of Tehuantepec as cold, dry winds, where they often set in suddenly and quickly raise a heavy sea.

North Atlantic drift: See GULF STREAM.

nor'wester: A violent, convective type of storm, often accompanied by a LINE SQUALL, which occurs in Bengal and Assam in the months March to May. The storms are so named because of their pronounced tendency to move from the north-west.

N.T.P.: An abbreviation for 'normal temperature and pressure', signifying a temperature of 0°C and a pressure of 760 mm of mercury, these being the selected standard conditions under which volumes of gases are compared. It is also termed S.T.P. (standard temperature and pressure.)

NUBEX: A code word indicating that a report of radar echoes from clouds follows in figure code. See 'Handbook of weather messages'.*

nucleation: In meteorology, the initiation of either of the phase changes from water vapour to liquid water, or from liquid water to ice. The normal process in the atmosphere is one of 'heterogeneous nucleation' in which the phase change is initiated on minute foreign particles—see NUCLEUS. In the absence of nuclei, the phase change is one of HOMOGENEOUS NUCLEATION or 'spontaneous nucleation'.

nucleus: In meteorology, a minute solid particle suspended in the atmosphere.

Classification of nuclei is now generally made into 'Aitken nuclei' of radius less than 0·2 micron (μ) i.e. 2×10^{-5} cm, 'large nuclei' (radius from 0·2 to 1μ) and 'giant nuclei' (radius $> 1\mu$). Nuclei are most numerous in the Aitken range, at about 0.05μ. At the earth's surface, concentrations as low as about 1000/cm^3 are measured in country air and over the oceans but numbers may be up to nearly 1000 times greater than this in industrial areas. The particle mass is generally between 10^{-12} and 10^{-16} gm. The concentration decreases with height, more rapidly in the case of the larger than of the smaller particles. The large and giant nuclei act as nuclei of CONDENSATION, the former being the more effective because they are much the more numerous: condensation nuclei are hygroscopic in nature, i.e. have an affinity for water. The high saturation VAPOUR PRESSURE associated with drops of very small radius (see KELVIN EFFECT) prevents the Aitken nuclei from acting as condensation nuclei.

Nuclei are dispersed into the atmosphere by such processes as dust storms, volcanic eruptions, formation of sea salt spray, and combustion. Chemical analysis shows that the nuclei contain the ions SO_4, NH_4, NO_3, Na, Cl.

A 'freezing nucleus' is one on which an ice crystal forms by the freezing of a water droplet. A 'sublimation nucleus' is one on which direct deposition of ice from water vapour occurs: the extent (if any) to which this sublimation process actually occurs in the atmosphere is doubtful. 'Ice nucleus' is a generic term which includes both freezing and sublimation nuclei. Such nuclei are much less common than condensation nuclei. Their number, or at least their effectiveness, increases as the temperature decreases below 0°C. Measurement indicates that their size distribution is of the order 0·1 to several microns and that they are composed of volcanic dust and clay and other soil particles of crystalline structure similar to that of ice. Ice crystals appear to form on such nuclei at saturation with respect to water and to grow by sublimation. Freezing of water droplets is generally considered to occur spontaneously (without the aid of nuclei) below a temperature of about −40°C—so called 'homogeneous nucleation'.

numerical weather forecast: A type of OBJECTIVE FORECAST, sometimes termed a 'dynamical forecast', in which the future state of the atmosphere, as represented by the height distribution of a selected isobaric surface or surfaces, is determined by the numerical solution of the basic theoretical equations involved. The calculations are so lengthy as to necessitate, in general, the use of an electronic computer.

Initial data are generally based on both surface and upper air observations and comprise the values of the heights of the isobaric surface(s) at 'grid points' over a selected area. Gross approximations, involving the assumption of QUASI-GEOSTROPHIC MOTION and the omission of heating, moisture and friction terms, are commonly made mainly in order to make the equations more tractable. The

* London, Meteorological Office; Handbook of weather messages. Part III. London, HMSO, 1959.

assumption of initial geostrophic motion has, however, the advantage of eliminating the very small components of the motion.

One or other of various atmospheric 'models' is adopted. The simplest and most restrictive is the BAROTROPIC model, in which a single pressure surface, generally 500 mb, is considered. Alternatively, BAROCLINIC models, which allow of vertical air motion and vertical variation of wind velocity and which involve consideration of the height distribution of two or more isobaric surfaces (e.g. 1000 and 500 mb), may be employed. Solution of the VORTICITY EQUATION is involved in nearly all applications of the numerical technique, the required integration being performed by the FINITE-DIFFERENCE METHOD. Suitable selection of grid size and finite time interval is required in order to avoid COMPUTATIONAL INSTABILITY.

The technique described is one which employs essentially the inertia of the dynamical system which is represented by the initial observations and is therefore applicable only in short-period forecasting. The normal end-product is a surface PREBARATIC for a time some 24 hours ahead, which requires separate interpretation for a forecast of meteorological elements other than pressure. Advancement of the technique is mainly sought by means of refinements of atmospheric model, inclusion of some of the many neglected factors, and elimination of restrictive assumptions.

NUREP: A code word indicating that a report of height of cloud top and/or cloud base follows in figure code. See 'Handbook of weather messages'.*

Nusselt number: A non-dimensional number (Nu) which occurs in respect of the transfer of heat by free CONVECTION from a heated surface immersed in a fluid. It is given by

$$\mathrm{Nu} = lq/k\Delta T$$

where l is a length characteristic of the system, q is the rate of heat flow per unit area of the surface, k is the thermal conductivity, and ΔT the characteristic temperature difference between the heated surface and the fluid.

* London, Meteorological Office; Handbook of weather messages. Part III. London, HMSO, 1959.

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objective analysis: In synoptic meteorology, an ANALYSIS of initial observational data by a predetermined numerical (or graphical) method, such that the results obtained from a given set of data are independent of the analyst.

Methods of objective analysis so far developed have been mainly in connexion with NUMERICAL WEATHER FORECASTS made by machine computation, the objects being to eliminate entirely the subjective element and to effect an economy in time, the analysis itself being carried out by machine. The aim of the analysis in such cases is to obtain appropriate values of initial data (mainly contour heights) at fixed grid points. The method consists essentially in achieving a best possible fit (e.g. by the method of LEAST SQUARES) between the observational data and a polynomial function representing the data. Tests show that the accuracy attainable is much the same as that obtained by hand analysis. A requirement of the objective method, as with the hand method, is to eliminate, preferably also by an objective method, any gross errors in the observational data received.

objective forecast: A weather forecast which is entirely based on the application of a single rule or equation, or combination of rules or equations, to selected observed meteorological elements: personal judgement on the part of the forecaster is thus completely eliminated.

A NUMERICAL WEATHER FORECAST is an example of an objective forecast. Simpler examples include forecasts of night minimum temperature or radiation fog by the application of (largely) empirical rules based on observed values of such elements as temperature, dew-point, wind speed, cloud amount.

oblique visibility: Oblique visibility, or 'slant visibility', is the greatest distance at which a given object can be seen and identified with the unaided eye along a line of sight inclined to the horizontal.

Oblique visibility in a downward direction, an important element in aircraft operation, is generally different from the VISIBILITY measured at the earth's surface due (i) to height variations of atmospheric EXTINCTION COEFFICIENT in the layer concerned, (ii) to the fact that objects are then viewed against a terrestrial background.

occlusion: A FRONT which develops during the later stages of the life-cycle of a frontal DEPRESSION. The term arises from the associated occluding (shutting-off) of the warm air from the earth's surface.

As convergence takes place at the fronts and in the WARM SECTOR of the depression, the COLD FRONT closes in on the WARM FRONT. The warm sector is thus reduced to a TROUGH line called the line of occlusion and is subsequently lifted from the surface of the earth. The trough line is marked by a belt of cloud and precipitation and by a wind shift. In those cases where there is a substantial temperature difference between the cold air mass in advance of the warm front and that behind the cold front a 'warm occlusion' (less cold air behind) or 'cold occlusion' (less cold air in advance) forms: the effect is to extend the cloud and precipitation well in advance of the surface occlusion in the former case, and behind the occlusion in the latter case. Occlusions are common in north-western Europe, the warm type being the more common in winter, the cold type in summer.

ocean current: See CURRENT, OCEAN.

oceanity (or **oceanicity**): In meteorology, a measure of the extent to which the climate at any place is subject to maritime, as opposed to land, influences. See CONTINENTALITY.

oceanography: The study of the seas and oceans, including their physical, chemical, and dynamical properties (CURRENTS, TIDES, etc.).

The seas and oceans are by far the main source of atmospheric water vapour and are also a major reservoir of heat. Their interaction with the atmosphere is of great importance in controlling the distribution of climate over the earth as a whole, and also in affecting the day-to-day weather elements in neighbouring land areas.

ocean weather stations: The existing designations and locations of the nine North Atlantic ocean weather stations, as agreed at an international conference in February 1946 are, from west to east: B (Bravo) 56° 30′ N, 51° W; E (Echo) 35° N, 48° W; D (Delta) 44° N, 41° W; C (Coca) 52° 45′ N, 35° 30′ W; A (Alfa) 62° N, 33° W; J (Juliett) 52° 30′ N, 20° W; I (India) 59° N, 19° W; K (Kilo) 45° N, 16° W; M (Metro) 66° N, 2° E.

The four most westerly stations (B, C, D and E) are operated by Canada and the United States, the remainder by European countries on a rotational basis.

ogive: A graph of cumulative frequency (or percentage frequency) versus a selected element, from which the frequency of occurrence above or below any specified value of the element may be read. The term, referring to the inflected shape of the curve, is borrowed from architecture.

okta: Unit, equal to area of one eighth of the sky, used in specifying cloud amount.

opacus (op): One of the CLOUD VARIETIES. (Latin, *opacus* shady.)

'An extensive cloud patch, sheet or layer, the greater part of which is sufficiently opaque to mask completely the sun or moon.

This term applies to ALTOCUMULUS, ALTOSTRATUS, STRATOCUMULUS and STRATUS'.* See also CLOUD CLASSIFICATION.

open system: An open (thermodynamic) system is one in which there is exchange of matter between the system and its environment, e.g. a precipitating cloud.

opposition, astronomical: A planet or other heavenly body is said to be in opposition when it is in line with earth and sun, and in the direction opposite to that of the sun, as viewed from the earth.

optical mass: A term used, in calculations of emission or absorption of radiation, to signify the total mass of a given emitting or absorbing substance which lies in a vertical column of unit cross-sectional area between two specified levels (frequently, the earth's surface and the top of the atmosphere). It is also termed the 'optical thickness' or 'optical depth'.

optical phenomena: See ATMOSPHERIC OPTICS.

orientation: From the Latin, *oriens* the rising of the sun—the east. The direction of an object referred to the points of the compass.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 16.

orographic cloud: Cloud which is formed by forced uplift of air over high ground. The reduction of pressure within the rising air mass produces ADIABATIC cooling and, if the air is sufficiently moist, CONDENSATION. Lenticular wave clouds, including those formed well to leeward of the high ground, are common orographic clouds: stratus, cumulus and cirrus clouds are also sometimes orographic in origin.

orographic depression: A non-frontal DEPRESSION (or TROUGH of low pressure) formed by purely dynamical processes to leeward of a range of mountains which presents a barrier to the air flow. Well broken cloud usually characterizes the central region of such a depression because of the action of the FÖHN effect. It is also termed a 'lee depression'.

orographic rain: Rain which is caused, entirely or in major part, by the forced uplift of moist air over high ground. The formation of OROGRAPHIC CLOUD is followed, in the event of continued uplift of the air, by PRECIPITATION which in the British Isles generally reaches the ground as rain. The warm sector of a vigorous depression is the synoptic situation in which the orographic influence on rainfall is generally seen to best effect.

Even where rainfall is predominantly cyclonic or convectional in nature, the orographic influence is always present to some extent. Its dominant influence in mean RAINFALL distribution is readily seen on mean rainfall charts where, to a first approximation, high ground corresponds to high rainfall amount. In those (normal) cases in which a definite prevailing wind direction may be defined, larger rainfall amounts to windward than to leeward of high ground (over regions of average upward and downward air motion, respectively) are apparent. Empirical relationships, differing with locality, may be derived between mean rainfall amount and height of ground. Such relationships may, in the absence of detailed rainfall information, be usefully employed to obtain an estimate of spot or areal rainfall, provided either that the period is long enough to ensure, or it is otherwise confirmed, that departures of wind velocity from average values for the region were small during the period concerned.

orography: A term used in meteorology to signify the physical land features of a specified area.

oscillation: A periodic movement to and fro, or up and down, or a periodic variation of a quantity above and below its mean value. The simplest dynamical illustration is the simple pendulum.

In meteorology the term is also used in connexion with a wide variety of phenomena which are at best only quasi-periodic in nature, such as the diurnal variation of pressure, annual variation of temperature, gusts and lulls of wind, etc. See also SOUTHERN OSCILLATION.

oscillations, atmospheric: This term generally signifies the tidal movements undergone by the atmosphere. See ATMOSPHERIC TIDES.

overcast day: See CLOUDY DAY.

overlapping means: An alternative for RUNNING MEANS.

overseeding: In CLOUD SEEDING, the hypothetical artifical production of an excessive number of ice crystals. The consequent multiple sharing out of available water among the crystals prevents any of them from growing big enough to fall through the cloud updraught and so inhibits precipitation.

overturning: A rapid exchange of air between different levels effected by BUOYANCY forces. Such an exchange occurs by vigorous CONVECTION in an atmosphere in which there is a super-adiabatic lapse rate.

oxygen: A chemically active gas which in the molecular form (O_2), of molecular weight 32, comprises 20·95 and 23·14 parts per 100 parts of dry air by volume and weight, respectively.

Oxygen also occurs in the atmosphere as atomic oxygen (O) and as OZONE (O_3). The dissociation of O_2 by ultra-violet radiation results in a rapidly increasing proportion of unattached atoms relative to molecules upwards of about 80 km, the atoms predominating above about 100 km. The dissociation process operates to a decreasing extent down to about 20 km, but in the denser air at these levels the atoms are quickly lost by attachment to oxygen molecules.

That part of the absorption spectrum of oxygen of chief meteorological interest is the strong Schumann–Runge region from about 0·13 to 0·17μ, with a peak at 0·146μ. Strong absorption by O_2 and O of wavelengths below 0·1μ is important in the formation of the ionosphere.

ozone: The triatomic form (O_3) of OXYGEN, of molecular weight 48, which is present in the atmosphere in very small amounts ranging from about 0·2 to 0·6 cm equivalent thickness at normal temperature and pressure.

The presence of ozone is due mainly to photochemical processes in the high atmosphere. Downward diffusion brings the gas in very small concentration (generally less than 5×10^{-2} part per million) to the lower atmosphere where it is reduced to oxygen by contact with various organic suostances. Minor and local sources of ozone exist close to the earth's surface due to the oxidation by ultra-violet light of exhaust gases of motor vehicles. Local low-level formation in lightning discharges and in connexion with radioactivity has also been suggested.

Ozone is formed and destroyed in the high atmosphere by the absorption of ultra-violet radiation by oxygen and ozone, respectively, and by subsequent particle collision processes. The main absorption processes concerned are absorption by molecular oxygen of radiation in the Schumann–Runge region (wavelength about 0·13 to 0·17μ) to form atomic oxygen, and by ozone in the Hartley region (about 0·20 to 0·30μ) to form molecular and atomic oxygen. The main collision processes are (i) a triple collision between molecular and atomic oxygen and a third molecule to form ozone, and (ii) collision between ozone molecules and oxygen atoms to form oxygen molecules.

The absorption processes are so intense that the associated temperature rise is largely concentrated near the top of the OZONE LAYER at about 50 km. The ozone which is formed at, or transferred to, levels below about 35 km is, in large measure, protected from destruction. The result is that some 90 per cent of atmospheric ozone is at levels below 35 km, with maximum concentration at about 25 km; and that total ozone or, more precisely, the ozone mixing ratio at various levels, is a useful tracer of horizontal and vertical air motion in the stratosphere.

The standard instrument for surface measurement of total ozone amount is the DOBSON SPECTROPHOTOMETER. The use of this instrument, in conjunction with the UMKEHR method, yields a smoothed picture of the vertical distribution of ozone. Optical and chemical types of instrument, carried aloft by balloon, rocket or aircraft, have been used to obtain the ozone profile in finer detail and have shown, for example, a jump to higher ozone concentration on passage upwards through the tropopause.

The systematic space and time variations of total ozone also do not accord with conditions of photochemical equilibrium but largely reflect the corresponding large-scale vertical and horizontal transport mechanisms which are at work in the atmosphere. The main features are large amounts of ozone in high relative to low latitudes, especially in spring; and, in middle and high latitudes, a spring maximum and autumn minimum. Day-to-day changes which are correlated with surface and upper-air synoptic features also occur.

Ozone is an important gas in the radiation balance of the stratosphere. The main features of its absorption spectrum are: the intense Hartley region (0·20 to 0·30μ, with a maximum at 0·25μ) and the weak Huggins bands (0·30 to 0·35μ) in the ultra-violet; the weak Chappuis bands (0·45 to 0·65μ) in the visible; and bands centred at 4·7, 9·6 and 13·0μ in the infra-red.

ozone layer: That layer of the atmosphere, also termed the 'ozonosphere', in which the concentration of OZONE is greatest. The term is used in two ways: (i) to signify the layer from about 10 to 50 km in which the ozone concentration is appreciable; (ii) to signify the much narrower layer from about 20 to 25 km in which the concentration generally reaches a maximum.

ozonosphere: An alternative for OZONE LAYER.

P

pack ice: Sea ice which has drifted from its original position. It is termed 'close pack' if the floes are mainly in contact and 'open pack' if the floes for the most part do not touch.

paleoclimatology: The study of the nature of and reasons for the types of climate that are inferred, from a variety of evidence, to have obtained over the earth in the course of geological time. See CLIMATIC CHANGES.

paleomagnetism: The study of the nature of and reasons for the changes (more especially directional changes) in the earth's magnetic field that are inferred, from studies of remanent rock magnetism, to have occurred in the course of geological time. Deductions of possible significance in the theory of CLIMATIC CHANGES have been made from such studies. See GEOMAGNETISM.

pallium: An obsolete term for NIMBOSTRATUS.

pampero: A name given in the Argentine and Uruguay to a severe storm of wind, sometimes accompanied by rain, thunder and lighting. It is a LINE-SQUALL, with the typical arched cloud along its front. It heralds a cool south-westerly wind in the rear of a depression; there is a great drop of temperature as the storm passes.

pannus (pan): An accessory cloud. (Latin, *pannus* shred.)

'Ragged shreds sometimes constituting a continuous layer, situated below another cloud and sometimes attached to it.

This accessory cloud occurs mostly with ALTOSTRATUS, NIMBOSTRATUS, CUMULUS and CUMULONIMBUS.'* See also CLOUD CLASSIFICATION.

parallax: An apparent change in the position of an object caused by a change in the position of the observer. In connexion with the reading of meteorological instruments, an error of parallax may arise whenever the indicator of the instrument (e.g. end of column of mercury or water, pointer, etc.), and the scale against which the indicator is to be read are at a distance from one another which is comparable with the length of the smallest readable scale division; for in such a case a movement of the observer's head may cause his line of vision to the indicator to intersect the scale at different points and so give rise to different readings. The error is eliminated by ensuring that the line of vision to the indicator is at right angles to the scale when the reading is made.

parameter: A quantity related to one or more variables in such a way that it remains constant for any specified set of values of the variable or variables.

paranthelion: A PARHELION ('mock sun') at the same elevation as the sun and in azimuth greater than 90° from the sun may be called a paranthelion. White paranthelia at 120° from the sun are fairly common. Paranthelia at about 140° from the sun have been recorded on rare occasions.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 18.

paraselene (plural, paraselenae): An image of the moon, also termed 'mock moon', produced in a way analogous to the PARHELION: because of the weak intensity of the moon's light relative to that of the sun the paraselene is more weakly coloured and less frequently observed than the parhelion.

parcel method: The estimation of vertical STABILITY in the atmosphere by a method based on the assumption that individual 'parcels' of air move upwards without disturbing their environment. See also ADIABATIC, SLICE METHOD.

parhelic circle: A bright but colourless circle passing through the sun parallel to the horizon. The phenomenon is explained by the REFLEXION of sunlight from hexagonal ice crystals whose axes are vertical. REFRACTION of light through such crystals produces PARHELIA with which, therefore, the parhelic circle is often associated.

parhelion (plural, parhelia): An image of the sun, coloured or white: it is also termed 'mock sun'.

The parhelia seen most frequently are at the same elevation as and on both sides of the sun and are coloured with red nearest the sun. When the sun is near the horizon the distance is equal to the radius of the ordinary HALO, i.e. 22°. When the sun is higher the distance is greater so that if halo and parhelion are both seen the parhelion is outside the halo: for a solar elevation of 55° the angular difference is about 14°. Parhelia are occasionally seen at points on the PARHELIC CIRCLE other than near 22°, notably at 120° ('paranthelion'), less frequently at 46°, 90° and 140°.

Parhelia are caused by the REFRACTION of sunlight within hexagonal ice crystals whose axes are vertical. Oblique rays (sun above the horizon) do not lie in a plane perpendicular to the axes of such crystals and emerge at an angle greater than that corresponding to MINIMUM DEVIATION.

Parry arcs: Rare small arcs observed above and below the small HALO at angular distances varying with solar elevation. They are ascribed to REFRACTION of light through hexagonal ice crystals floating with principal axis and a pair of opposite sides horizontal.

partial pressure: In a mixture of gases, that part of the total gas pressure which is exerted by a specified constituent gas: it is the pressure that each would exert if it alone were present and occupied the same volume as the whole mixture.

According to Dalton's law, the total pressure of a mixture of gases is the sum of the partial pressures, as defined above.

pastagram: An AEROLOGICAL DIAGRAM, designed by J. C. Bellamy, in which the ordinate is a combined linear scale of height (Z_p) and corresponding pressure (p) in the STANDARD ATMOSPHERE, and the abscissa is the temperature anomaly $(T - T_p)/T_p$ where T is the actual temperature at pressure p and T_p the temperature at pressure p in the standard atmosphere.

path method: A term applied in synoptic meteorology to signify the method of extrapolation, for forecasting purposes, of the path of a pressure system or other set of contours (e.g. isallobars) drawn on a synoptic chart.

pearl-necklace lightning: A rare form of LIGHTNING, also termed 'chain lightning' or 'beaded lightning', in which variations of brightness along the discharge path give rise to a momentary appearance similar to pearls on a string.

pentad: A period of five consecutive days. Five-day means are often used in meteorological work, as five days form an exact sub-division (1/73) of the ordinary year, an advantage not possessed by the week.

percentile: The 'upper one percentile' of a series of values is that value which is exceeded by one per cent of the values: similarly, the 'lower one percentile' is that value below which one per cent of the series lies. The term is also used at other levels, e.g. 'five percentile'. Compare QUARTILE.

percolation: The downward passage of surface water through the soil. Part of the rain which falls on the land surface re-evaporates, part runs off into streams and rivers to the sea, while part percolates through the soil. Measurements of the amount of rain water which percolates through certain depths of soil have been published in the annual volumes of *British Rainfall.* Usually the gauge consists of a cubic yard of natural earth inserted in a metal container and sunk in the hole formed by removing this earth. The rain water which percolates through is drained off and measured daily at 9h, access to the receiver being obtained by means of a trap door at the side of the gauge. Such or very similar types of gauge are sometimes referred to as a 'drainage gauge' or 'seepage gauge'. The results are usually published as a depth in hundredths or thousandths of an inch. See EVAPORATION.

perfect gas: A hypothetical gas which obeys the gas laws of Boyle and Charles perfectly. For practical purposes the gases which comprise unsaturated air may be considered perfect gases.

perigee: That point of the orbit of a satellite, natural or artificial, which is nearest the earth.

perihelion: That point of the orbit of a planet or comet which is nearest the sun. Perihelion for the earth occurs on about 1 January: the sun-earth distance is then 1·5 per cent less than the yearly mean distance.

period: A function which varies with time and which repeats itself exactly after a constant time interval (say, T) is said to be 'periodic', and T, the time of a complete oscillation, is termed the 'period' of the function.

periodicity: A time variation of a function comprising a single fixed PERIOD, or combination of fixed periods.

The standard methods of identifying periodicity in a variable quantity are HARMONIC ANALYSIS, PERIODOGRAM analysis, CORRELOGRAM analysis and FILTERING. A (simple) periodicity requires for its complete determination the length of the period, the amplitude (i.e. half the total range) of the variation, and the time of occurrence of the maximum ('phase').

While periodicity uncomplicated by other factors is not found in any meteorological element, the process of averaging over a large number of periods tends to remove non-periodic factors and to allow certain periodic phenomena to emerge. Examples are the average diurnal variation of surface pressure and the average annual variation of surface temperature, both of which average variations are almost entirely explained by a combination of the first two harmonic components of periods 24 and 12 hours, and 12 and 6 months, respectively.

An exhaustive search for periodicity, other than diurnal or annual, in meteorological elements has been almost entirely unsuccessful. More probable than true periodicity in these phenomena is 'quasi-periodicity' of the type shown by annual sunspot numbers (i.e. rather variable period and amplitude but apparently little or no change in phase); and a RECURRENCE TENDENCY as shown, for example, by certain types of ionospheric and magnetic storm (little change in period but abrupt changes in phase). While some effects, more especially of the latter type, have been found, none is yet so striking as to be of much significance in the problem of long-range weather forecasting.

periodogram: A diagram used in a method devised by Schuster for the investigation of possible hidden PERIODICITIES in a series of observations. The amplitudes (R) corresponding to different trial periods (T) are first obtained by the standard methods employed in HARMONIC ANALYSIS. The periodogram consists of a plot of the various values of R^2 (or R) as ordinate against the corresponding values of T as abscissa. The values of T corresponding to any conspicuous peaks in the graph (high values of R) are the most likely periods. If the original n observations formed a random distribution, with standard deviation σ, the expectation (or mean value) of R^2 would be $4\sigma^2/(n - 1)$. Schuster showed that the probability that any particular value of R^2 should exceed k times $4\sigma^2/(n - 1)$ is e^{-k}. This expression may be used to test the reality of any period suggested by the periodogram. Where, as in most geophysical data, the observations comprise a TIME SERIES, the value of n used in the test should be the 'effective number of independent observations' which, because of PERSISTENCE, may be several times smaller than the total number of observations in the series.

perlucidus (pe): One of the CLOUD VARIETIES. (Latin, *perlucidus* allowing light to pass through).

'An extensive cloud patch, sheet or layer, with distinct but sometimes very small spaces between the elements. The spaces allow the sun, the moon, the blue of the sky or over-lying clouds to be seen.

This term applies to ALTOCUMULUS and STRATOCUMULUS'.* See also CLOUD CLASSIFICATION.

permafrost: Soil which remains permanently frozen, summer heating being insufficient to raise above freezing-point the lower part of a frozen layer formed during the winter. The limit of permafrost is considered to accord very approximately with an annual mean air temperature of −5°C.

permanent aurora: An obsolete alternative for NIGHTGLOW.

permanent gas: A gas which is at a temperature above its 'critical temperature', i.e. at a temperature at which it cannot be liquefied by pressure alone. The gases in the air other than water vapour, sulphur dioxide, carbon dioxide are permanent gases.

persistence: In meteorology, a term used of a synoptic feature or meteorological condition that is unusually long-lasting.

In meteorological and other geophysical TIME SERIES, persistence (sometimes termed 'coherence' or 'conservation') signifies a greater-than-random tendency for relatively high (or low) values to occur in succession. The degree of persistence varies with meteorological element and generally decreases with increase of time interval between successive members of the series.

The persistence which is inherent in most time series is fundamentally important in questions of statistical SIGNIFICANCE. Thus, for example, the estimate of average seasonal pressure at a specified place which is provided by a mean of, say, 20 successive daily pressure values is much less reliable than that provided by a mean of 20 such values selected at random in the season: in the former case the average may be biased by the dominance of a particular synoptic pattern during the period concerned.

In statistical investigations of time series, unnecessary labour may be saved by confining attention to statistically independent data, i.e. to data spaced at intervals greater than the 'persistence interval', which may be defined as that interval beyond

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva. WMO, 1956, p. 16.

which AUTOCORRELATION becomes negligibly small. When this is not done allowance must be made, in assessing significance, for the fact that the total number of observations employed may be far in excess of the number of statistically independent data. The 'equivalent number of repetitions' ($\varepsilon(n)$) in a series of n values may be obtained from the formula

$$\varepsilon(n) = 1 + 2/[n \{(n-1)r_1 + (n-2)r_2 + \ldots + r_{n-1}\}]$$

where r_1, r_2, r_3 etc. are the correlation coefficients between successive terms, terms two apart, terms three apart, etc. An approximate expression for $\varepsilon(n)$ is

$$\varepsilon(n) \simeq 1 + 2/n\{(n-1)r_1 + (n-2)r_1^2 + (n-3)r_1^3 + \text{etc.}\}$$

The 'effective number of independent observations' in the series of n values is given by $n/\varepsilon(n)$.

The tendency for the persistence of wet or fine weather at Greenwich was shown by E. V. Newnham* to increase with increase of length of period through which similar conditions have already persisted.

persistence forecast: A type of FORECAST, often used as a basis of comparison in the assessment of the success attained in forecasts made by conventional methods, in which the assumption is made that meteorological conditions during the forecast period will remain unchanged from those obtaining at the beginning of the forecast period.

personal equation: An expression used to denote the error of an observer's readings of an instrument which is due to an unconscious tendency on his part to read too high or too low. The tendency is usually nearly constant for any given observer reading a given instrument. PARALLAX is a common source of personal equation.

perturbation method: A method, widely applied in meteorology, by which a formal solution to the fundamental, non-linear equations of motion is obtained by the superposition of small disturbances on basic steady fluid flow. Such solutions have the form of waves, the stability and speed of which are found to depend on the wavelength and on the characteristics of the undisturbed flow. Though strictly applicable only to waves of very small amplitude, the solutions are often found to apply, with minor modifications, to disturbances of appreciable amplitude.

phase: The phase of a periodic function is its arrangement of maximum and minimum point or points with regard to a specified initial or starting point. It is measured by a 'phase angle' in which a complete revolution (360°) is equated to a complete PERIOD. Two periodic functions are said to display 'phase reversal' with respect to each other if a maximum value of one function corresponds to a minimum value of the other.

The term 'phase' is also used synonymously with 'state' of matter—solid, liquid, or gaseous.

phenology: The study of the sequence of seasonal changes in nature. All natural phenomena are included, seed-time, harvest, flowering, ripening, migration, and so on, but the observations are often limited to the time at which certain trees and flowering plants come into leaf and flower each year, and to the dates of the first and last appearances of birds and insects.

The phenology of plant flowering in the British Isles is contained in *The Phenological Reports* (1877–1948) of the Royal Meteorological Society. Long-term means are contained in a paper by E. P. Jeffree.†

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* NEWNHAM, E. V.; The persistence of wet and dry weather. *Quart. J. R. met. Soc., London*, **42**, 1916, p. 153.

† JEFFREE, E. P.; Some long-term means from The Phenological Reports (1891–1948) of The Royal Meteorological Society. *Quart. J. R. met. Soc., London*, **86**, 1960, p. 95.

phenomenon: Word used in meteorology to denote either (i) an unusual intensity of some occurrence, e.g. 'ugly' sky, high rainfall, low temperature, high pressure, gale, or (ii) occurrences which are only occasionally noted, e.g. thunder, halo, fog, glazed frost.

photochemistry: The study of chemical reactions involved in the absorption or emission of RADIATION. In meteorology, such reactions are mainly confined to high atmospheric levels as, for example, in the absorption of radiation by oxygen to form ozone. Reactions also occur locally near the earth's surface in connexion with certain products of atmospheric pollution.

photodissociation: The splitting of a molecule into atoms or into smaller molecules by the absorption of RADIATION.

photoelectron: An ELECTRON ejected from an atom or molecule which is exposed to RADIATION of a frequency higher than a critical value. The process of 'photoionization', important for example in the formation of the IONOSPHERE, is involved in such release of electrons.

photoionization: See PHOTOELECTRON.

photometeor: A little used generic term for the luminous phenomena produced by the reflexion, refraction, diffraction and interference of light from the sun or the moon. Photometeors are observed in clear air (mirage, green flash, etc.), on or inside clouds (corona, halo, etc.), and on or inside certain HYDROMETEORS and LITHOMETEORS (rainbow, glory, etc.).

photosphere: The bright disk of the SUN from which continuous emission of solar radiation takes place.

physical meteorology: Because of overlapping at many points with other 'branches' of meteorology this term cannot be defined precisely but is often used to signify all those directly physical aspects of meteorology which are not normally dealt with in DYNAMICAL METEOROLOGY.

pieze: Unit of pressure of 1 STHENE/m². It is equivalent to 10^4 dyne/cm².

piezotropy: In a change of the state of the pressure and density of an individual element of the atmosphere the condition that there exists a relationship

$$B = \frac{d\rho}{dp},$$

where $\frac{d\rho}{dp}$ is the change of density with pressure of the individual element and B is the 'coefficient of piezotropy'.

B is a function of the thermodynamic variables and so depends on the initial state of a selected particle and varies for different particles. The condition of piezotropy is implicitly assumed in drawing an adiabatic 'path curve' of a selected particle on an AEROLOGICAL DIAGRAM. In this important special case of piezotropy, the coefficient B has the value $1/\gamma RT$ where γ is the ratio (c_p/c_v) of the specific heats of air at constant pressure and constant volume, R is the specific gas constant, and T is the absolute temperature.

pileus (pil): (Latin, *pileus* cap).

'An accessory cloud of small horizontal extent, in the form of a cap or hood above the top or attached to the upper part of a cumuliform cloud which often penetrates it. Several pileus may fairly often be observed in superposition.

Pileus occurs principally with CUMULUS and CUMULONIMBUS.'* See also CLOUD CLASSIFICATION and CAP.

PILOT: In weather mesages, a code word indicating that a report follows, in figure code, relating to pilot-balloon or radar observations of upper winds made from land stations. See 'Handbook of weather messages.'†

pilot balloon: This term is generally applied to the smaller meteorological balloons. Their main use is the determination of upper winds, although the smallest balloon, one weighing about 10 gm, is most commonly used for the measurement of cloud-base height by timing the duration of flight below cloud base and assuming a constant rate of ascent. For this reason, 10 gm balloons are sometimes known as 'ceiling balloons'. The theoretical rate of ascent V of a balloon filled with hydrogen (as are most balloons) is approximately

$$V = qL^{\frac{1}{2}}/(L + W)^{\frac{1}{3}}$$

where L is the FREE LIFT in gm, and W is the total weight (gm) of the balloon and any attachments. q is a constant and has a value of 275 if V is expressed in ft/min (1·40 if V is in m/sec)—see 'Handbook of meteorological instruments'.‡

Larger balloons, such as the 30 gm balloon, are used for wind finding. In the 'single theodolite' method, the height of the balloon is estimated by timing as for cloud-base determination. The 'tail' method employs one (or two) piece(s) of paper attached to the balloon by a known length of string. The height of the balloon at any instant can then be deduced from the angle subtended by the tail (assumed vertical) at the theodolite; this angle is measured on a divided scale (graticule) fitted to the eyepiece of the theodolite. The 'double theodolite' method employs simultaneous observations of the balloon's position by two theodolites at known relative positions: greater accuracy is possible by this method since not only wind direction and speed but also height are determined.

The calculation of wind velocity from the theodolite readings is normally performed by a special slide-rule, although graphical methods can also be used.

When absence of cloud permits optical wind finding at greater heights, balloons as large as 100 gm may be used up to about 16 km.

pitot tube: An instrument for determining the velocity of a stream of fluid by measuring the increase of pressure, above the 'static' or undisturbed pressure, in an open tube facing the stream. The velocity is computed from the relationship $p = \frac{1}{2}\rho v^2$ (where p is pressure, ρ density and v velocity). Suitably mounted, a pitot tube may be used as an ANEMOMETER.

Planck's law: See RADIATION.

planetary albedo: See ALBEDO.

planetary temperature: See RADIATION.

pluvial period: A geological period of large amounts of rainfall relative to earlier and later periods. Evidence of such periods, which are generally thought to have coincided in time with the glacial periods of ICE AGES, is found in those land regions which lay equatorwards of the ice-covered regions during the glacial periods.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 18.

† London, Meteorological Office; Handbook of weather messages. Parts II and III. London, HMSO, 1959.

‡ London, Meteorological Office; Handbook of meteorological instruments. Part II. London, HMSO, 1961, p. 139.

poise: The unit of VISCOSITY in the C.G.S. SYSTEM of units, being the tangential stress in dynes/cm^2 when the velocity gradient is 1 cm/sec cm. The dimensions are $ML^{-1}T^{-1}$.

polar air: Air originating in high latitudes, normally subdivided in synoptic meteorology into 'maritime polar' (*mP*) air and 'continental polar' (*cP*) air, according to the nature of the surface over which the AIR MASS originates. Air which moves almost directly equatorwards from the ice-bound areas of the Arctic is now usually termed ARCTIC AIR.

During the motion of *mP* air away from its source region, heat and moisture may be convected into the air mass from a warmer underlying sea surface. In the British Isles *mP* is the most common of all air masses and is associated generally with a west or north-west wind, steep lapse rate, low freezing-level, good visibility, instability showers (sometimes with thunder), and surface temperature below seasonal normal.

Easterly winds are often associated in the British Isles with the less common *cP* air mass. In winter, typical conditions are very cold but dry apart from light snow showers near the east coast: in summer, conditions are dry and rather warm except on the east coast where coastal fog ('haar') is often widespread. (The *cP* air is warmed in winter, cooled in summer, by its passage over the North Sea.)

Maritime polar air which travels far to south and then returns to the British Isles from the south-west is termed 'returning maritime polar air': typical conditions associated with this air mass are much cloud but few showers, and temperatures close to seasonal average.

polar air depression: A SECONDARY DEPRESSION of a non-frontal character which forms, more especially in winter, within an apparently homogeneous polar air mass: near the British Isles the development is usually within a northerly or north-westerly airstream. The chief characteristics of this type of depression, which seldom becomes intense, are a movement in accordance with the direction of the general current in which the depression forms and the development of a belt of precipitation near the depression centre and along a trough line which often forms on the side farther from the parent depression where also the pressure gradient (and surface winds) are increased.

polar climate: A type of CLIMATE which obtains, in general, within the polar regions (polewards of 66° 33′ N and S). In W. Köppen's classification, the polar climate is subdvided into TUNDRA climate (mean temperature of warmest month between 0° and 10°C), and 'perpetual frost' climate (mean temperature of warmest month below 0°C).

polar co-ordinates: A system of co-ordinates in which the position of a point is specified by its distance (r) from the origin ('pole') and by the angle (θ) made by the line joining point and origin with a reference line ('polar axis').

polar distance: An alternative for COLATITUDE.

polar front: A FRONT which divides 'polar' and 'tropical' air masses and on which most of the travelling disturbances of middle latitudes form. In the North Atlantic, for example, this front, which can often be traced as a continuous line over thousands of miles, extends in winter, on average, in a north-easterly direction from a position off the east coast of the United States of America (at about 30°N). In summer the front is less well marked and has little tendency for a preferred position.

polarization: A state of ELECTROMAGNETIC RADIATION in which the transverse vibrations which comprise the wave motion occur wholly or in part ('partial polarization') in a specified manner—for example in a plane, circle or ellipse—that is, they do not occur in all the possible planes which contain the direction of propagation of the radiation. The plane of polarization is defined as that in which the wave motion is a minimum, or, in terms of electromagnetic theory, that in which the electric vector is a minimum.

Polarization of emitted radiation may be effected by a suitable aerial array. Since SCATTERING causes polarization of initially unpolarized radiation, the phenomenon is observed naturally in the atmosphere in the DIFFUSE RADIATION which reaches the earth's surface, such radiation being polarized in the plane which contains the sun, the observer and the observed point of the sky. In accordance with the theory of RAYLEIGH SCATTERING the polarization is strongest in the solar zenith (i.e. in the light scattered from a point 90° from the sun) and in the antisolar point. Because of multiple and non-molecular scattering, the polarization disappears at the 'neutral points' discovered by Arago, Babinet and Brewster—see ARAGO'S POINT.

polarization, electric: The separation of positive and negative charges within a particle in response to an electric field acting on the particle.

The occurrence of this effect within falling water and ice particles, due to the presence of the atmospheric electric field, was advanced by C. T. R. Wilson as leading to selective ion capture and hence the separation of charge in a thunderstorm.

polar wandering: Hypothetical movement of the earth's axis of rotation relative to the earth's surface, in the course of geological time. Such movement has been advanced as a possible cause of climatic changes on this time-scale. Among the evidence advanced in support of the hypothesis is that of remanent rock magnetism (see GEOMAGNETISM), on the assumption that the earth's magnetic axis has always been close to the axis of rotation. (Further evidence of the same kind is to the effect that CONTINENTAL DRIFT has also been involved.)

Some geophysicists consider that physical reasoning is not in favour of polar wandering. The arguments are, however, admitted to be less strong than those advanced against the hypothesis of continental drift.

polar year: In the First International Polar Year (F.P.Y.), from 1 August 1882 to 1 September 1883, and the Second (S.P.Y.), from 1 August 1932 to 31 August 1933, near times of sunspot maximum and minimum, respectively, stations were manned by co-operating nations in the Arctic, and to a much smaller extent the Antarctic regions. Observational programmes covered mainly meteorology, geomagnetism and aurora.

pole: The earth's geographical poles are the points of intersection of the earth's axis of rotation (polar axis) with the earth's surface.

For an observer situated at the centre of the CELESTIAL SPHERE, the 'celestial poles' are points on the celestial sphere in the direction parallel to the earth's axis of rotation. In the northern hemisphere the pole star is about 1° away from the north celestial pole. The altitude of an observer's celestial pole is equal to his latitude.

See GEOMAGNETISM for an explanation of magnetic and geomagnetic poles.

pollution: See ATMOSPHERIC POLLUTION.

ponente: A westerly wind which blows in the Mediterranean.

potato blight warning: A screen temperature of at least 10°C (50°F), associated for at least 46 out of 48 consecutive hours with a relative humidity of at least 75 per cent, constitute the conditions under which selected representative Meteorological Office stations issue a warning of possible potato blight. It has been found that this potato fungus disease tends to follow humid conditions, defined in this way, after an interval of one to three weeks.

potential energy: The ENERGY possessed by a body by virtue of its position. It is measured by the amount of work required to bring the body from a standard position, where its potential energy is zero, to its present position. A common example is that of 'gravitational potential energy', mean sea level being then the normal selected standard level.

potential evapotranspiration: See EVAPOTRANSPIRATION.

potential gradient: Atmospheric potential gradient is defined as the difference of electric potential between two points vertically disposed with respect to each other and separated by unit distance: it is expressed in volts/metre (v/m) and is, by convention, reckoned positive if directed downwards.

Surface potential gradient—the potential difference between a conductor at a height of one metre and the level ground—is the most regularly measured element of ATMOSPHERIC ELECTRICITY.

potential instability: See STABILITY.

potential temperature: That temperature (θ), readily obtained from an AEROLOGICAL DIAGRAM, which a given sample of air would attain if transferred at the dry ADIABATIC lapse rate to the standard pressure, 1000 mb. If the pressure (mb) and absolute temperature of the air are p and T, respectively, and γ is the ratio of the specific heat of air at constant pressure to that at constant volume, then

$$\theta = T\left(\frac{1000}{p}\right)^{(\gamma-1)/\gamma} = T\left(\frac{1000}{p}\right)^{0\cdot 29}$$

θ is related to ENTROPY (S) by the equation

$$S = c_p \log \theta + \text{constant}$$

where c_p is the specific heat of air at constant pressure.

The 'partial potential temperature' (θ_d) of an air sample, as defined by C. G. Rossby and used in the ROSSBY DIAGRAM, is the potential temperature appropriate to the temperature and partial pressure (p_d) exerted by the dry air of the sample ($p_d = p - e'$, where e' = vapour pressure):

$$\theta_d = T\left(\frac{1000}{p_d}\right)^{0\cdot 29}$$

potential transpiration: See TRANSPIRATION.

potential vorticity: In ADIABATIC motion of a column of air the quotient of the absolute VORTICITY of the air column ($\zeta + f$) to the pressure difference between the top and bottom of the column (Δp) is constant (potential vorticity theorem) i.e.

$$\frac{\zeta + f}{\Delta p} = \text{constant}$$

where ζ is the relative vorticity of the column and f is the CORIOLIS PARAMETER.

The value of the absolute vorticity of a column which corresponds to a standard value of Δp (say, 50 mb) is termed the potential (absolute) vorticity. This is a value which, on analogy with the definition of the POTENTIAL TEMPERATURE of an air element, is conserved in adiabatic motion of an air column.

PPI: Abbreviation for 'plan position indicator'. See RADAR METEOROLOGY.

praecipitatio (pra): (Latin, *praecipitatio* fall.)

'A supplementary cloud feature, appearing as an extension of certain clouds, comprising precipitation (rain, drizzle, snow, ice pellets, hail, etc.) falling from a cloud and reaching the earth's surface.

This supplementary feature is mostly encountered with ALTOSTRATUS, NIMBOSTRATUS, STRATOCUMULUS, STRATUS, CUMULUS and CUMULONIMBUS.'* See also CLOUD CLASSIFICATION.

Prandtl number: The non-dimensional ratio (σ) defined by the relationship

$$\sigma = \nu/a$$

where ν is the kinematic VISCOSITY and a the thermometric CONDUCTIVITY of a fluid. σ has the approximate value 0·7 in air near the earth's surface.

Prebaratic: British terminology for a forecast chart of isobars and frontal positions.

precipitable water: The precipitable water of a column of air is the depth of water (alternatively expressed as the total mass of water) that would be obtained if all the water vapour in the column, of unit area cross-section were condensed on to a horizontal plane of unit area. 'Precipitable water' is a useful measure of the water vapour content of an air column. The term is not, however, to be regarded as implying that the amount of water may, in fact, be precipitated by an actual physical process.

In the c.g.s. system of units the two expressions for precipitable water, cm and gm, are numerically equal and are given by the approximate expression:

$$\text{Precipitable water (cm or gm)} = \frac{1}{g}\int_{p_2}^{p_1} r \, dp$$

where p_1 and p_2 are the pressures (mb) at the bottom and top of the column, respectively, r is the mixing ratio (gm/kg) and g is acceleration of gravity (980 cm/sec^2).

A typical value for temperate latitude summer conditions is 2 to 3 cm.

precipitation: Used in meteorology to denote any aqueous deposit, in liquid or solid form, derived from the atmosphere.

The main problem in the 'precipitation process' is the explanation of the manner of growth of drops from the size commonly associated with non-precipitating clouds (diameter about 15 microns) to that found in most forms of precipitation: growth by direct CONDENSATION on to a NUCLEUS is too slow to account for the transformation. Two mechanisms are considered to operate.

(i) Ice crystal (Bergeron) process. In a cloud of predominantly supercooled water droplets ice crystals form, in increasing numbers with decrease of temperature below 0°C, because of the presence of natural ICE NUCLEI. The formation of the ice crystals occurs at saturation with respect to water. Since the saturation VAPOUR PRESSURE over ice is less than that over water at the same temperature (maximum deficit of 0·27 mb at −12°C), the ice crystals increase rapidly in size due to diffusion of water vapour from neighbouring water droplets to the ice crystals. (Growth is subsequently accelerated by 'coalescence' of the relatively heavy ice crystals with other ice crystals or with water drops.)

(ii) Coalescence (accretion) process. If, within a cloud, there are some liquid drops appreciably larger than the great majority of drops, the slower rate of rise of such large drops in a cloud updraught leads to collisions and, in some cases, coalescence with the smaller liquid drops. Factors which promote this process are appreciable cloud depth and updraught speed which permit of collision growth to a size sufficient to ensure that the drop will not evaporate at the top of the cloud but will fall back through the

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 17.

cloud, growing further by collision and reaching the ground as rain. The cause of the initial differences in drop size which are essential to the coalescence mechanism—whether, for example, the differences are due to the presence of rare giant nuclei or are associated with variations of updraught velocity and nuclei concentration near the condensation level—is yet uncertain.

For many years it was considered that the ice crystal process was much the more important of the two mechanisms. It is now clear that both play an important part. Attempts have been made, by appropriate CLOUD SEEDING, to promote precipitation by either mechanism.

pressure: Pressure is the force per unit area exerted on a surface by the liquid or gas in contact with it. Pressure at any point in a fluid is exerted equally in all directions. The dimensions are $ML^{-1}T^{-2}$.

The pressure of the atmosphere at any point is the weight of the air which lies vertically above unit area centred at the point: on average, the weight above each square inch of the earth's surface near sea level is about 14½ lb. Pressure may be expressed in 'inches' or 'millimetres', being the equivalent height of a column of mercury of STANDARD DENSITY (13·5951 gm/cm^3) under conditions of STANDARD GRAVITY (980·665 cm/sec^2) required to balance atmospheric pressure. In meteorology the MILLIBAR (mb), equivalent to 10^3 c.g.s. units of pressure, has almost entirely supplanted the inch or millimetre as the unit of pressure.

The pressure exerted by the wind is relatively small: a wind of force 6 on the BEAUFORT SCALE, for example, exerts only about one thousandth part of the pressure of the atmosphere.

Conversion formulae for pressure units are:

$$\text{millibars} = \text{inches} \times 2{\cdot}54 \times 13{\cdot}5951 \times 980{\cdot}665 \times 10^{-3}$$
$$\text{millibars} = \text{millimetres} \times 13{\cdot}5951 \times 980{\cdot}665 \times 10^{-4}$$

pressure altitude: The height of a given level in the STANDARD ATMOSPHERE above the level corresponding to a pressure of 1013·2 mb.

pressure co-ordinates: A system of co-ordinates in which the independent variables are x, y and p. x and y are horizontal rectangular co-ordinates while position in the vertical is defined by the hydrostatic pressure (p). This system has advantages over the closely similar CARTESIAN CO-ORDINATE system where, as is normal in dynamical meteorology, isobaric analysis is preferred to constant-level analysis.

pressure gradient force: That force which acts on air by virtue of the variation of pressure in space. It is a three-dimensional vector, denoted $-\nabla p$ or $-$ grad p, and equals $-\left(\frac{\partial p}{\partial x}\mathbf{i} + \frac{\partial p}{\partial y}\mathbf{j} + \frac{\partial p}{\partial z}\mathbf{k}\right)$, where **i, j, k,** are unit vectors in the x, y, z directions. The force is normal to surfaces of constant pressure: the sign is negative because the force acts from high to low values of pressure.

The horizontal pressure gradient force is a horizontal vector which is perpendicular to horizontal isobars. It is denoted, for example, $-\nabla_H p$ or $-\nabla p$ and equals $-\left(\frac{\partial p}{\partial x}\mathbf{i} + \frac{\partial p}{\partial y}\mathbf{j}\right)$.

In meteorological dynamics, the pressure gradient force acting per unit mass of air is the significant force and is generally referred to simply as the 'pressure gradient force'. This force is $-\frac{1}{\rho}\nabla p$ or $-\frac{1}{\rho}\nabla_H p$ in three or two dimensions, respectively, where ρ is air density.

pressure jump: A sudden and short-lived rise of pressure, of the order mb/min, which often accompanies the arrival of a LINE-SQUALL or similar phenomenon.

pressure-pattern flying: The planning of a flight route in such a way as to complete the flight, for a given aircraft and load, in the shortest possible time. The normal synoptic aids in such planning are isobaric charts on which contours are drawn.

pressure-plate anemometer: See ANEMOMETER, ANEMOGRAPH.

pressure-tube anemometer: See ANEMOMETER, ANEMOGRAPH.

prevailing wind: That direction of wind which, at a given place, occurs more frequently than any other during a specified period.

Over all parts of the British Isles statistics show the prevailing wind to be, on an eight-point compass, south, south-west or west. There is, however, an appreciable annual variation, e.g. in some places the prevailing wind in spring and early summer has an easterly component.

probability: In statistics, the fractional likelihood, ranging between the limits 0 (no likelihood) and 1 (certainty), that a specified event will occur. Probability is often expressed in the form of 'odds on' or 'odds against', e.g. a probability of an event of 1/10 signifies odds of 9 to 1 against the event.

Probability is, in practice, generally estimated from past frequency of occurrence, e.g. if, in a large number N of trials, an event occurs n times and fails to occur $(N-n)$ times, the probability of occurrence is n/N.

The 'expected' total of events of probability p in N trials is Np. If, as is general the actual total of events in N trials of probability p is different from this expected total by an amount D (say), possible abnormality of the sample may be judged by comparing D with the PROBABLE ERROR (r) of the total, given by

$$r = 0{\cdot}6745\sqrt{Np(1-p)}.$$

probability integral: See NORMAL (FREQUENCY) DISTRIBUTION.

probable error: A quantity which gives a measure of the scatter of individual values of a series about their mean value and which is equal to $0{\cdot}6745\sigma$, where σ is the STANDARD DEVIATION of the individual values of the series. For mean values, the probable error of a mean is $0{\cdot}6745\ \sigma_m$, where σ_m is the STANDARD ERROR of the mean. Standard deviation and standard error are now generally preferred to probable error as measures of dispersion.

The term 'probable error' is derived from the fact that in a series with NORMAL DISTRIBUTION, a value selected at random has a precisely even chance of having a departure from the mean greater than the probable error. In such a distribution the probabilities of occurrence of a departure from the mean greater than that specified in terms of probable error (r) are as follows: r, 0·500; $2r$, 0·177; $3r$, 0·043; $4r$, 0·007; $5r$, 0·001; $6r$, 0·00005. The standard error is now generally preferred to the probable error in the application of tests of statistical significance.

prognostic: An alternative adjective for FORECAST, as in 'prognostic chart'.

projection: This term is used in connexion with maps in a sense wider than that of geometrical perspective. It denotes any relationship establishing a correspondence between a domain of the earth's surface and a domain of a plane surface, the map, such that to each point of one corresponds one and only one point of the other. The projection is completely represented by constructing, on the plane surface, a graticule formed by two intersecting systems of lines, corresponding respectively to parallels of latitude and meridians of longitude on the earth. The position on the map of any features on the earth's surface is then determined by reference to this graticule.

The scale of the map is the ratio of the distance between two neighbouring points on the map to the corresponding distance on the earth. A perfect map in which the scale is uniform throughout is not possible. A class of projections termed 'orthomorphic' or 'conformal' has the property that, at any point, the scale in all directions is the same, though varying from point to point. This is equivalent to the property that the angle of intersection of any two lines on the earth (such as an isobar and a meridian) is preserved unchanged on the map, or the shape of any small area is preserved. Orthomorphic projections are not much used generally, but owing to the above properties, they enter into meteorological practice as base maps for the representation of meteorological elements.

Three orthomorphic projections are recommended for the purposes of synoptic meteorology:

(i) the stereographic projection for the polar regions on a plane cutting the sphere at 60°;

(ii) the Lambert orthomorphic conic projection for middle latitudes, the cone cutting the sphere at 30° and 60°;

(iii) Mercator's projection for the equatorial regions with true scale at 22½°.

The projection recommended in (i) is a special case of conical orthomorphic projection in which the meridians converge at their true angle and in which the scale is correct on any one chosen parallel. It is particularly suitable for the polar regions.

The projection recommended in (ii) is very suitable, especially for middle latitudes, and is used for the majority of the working charts of the Meteorological Office. The meridians are straight lines converging to the pole and the parallels of latitude are circles centred at the pole. The scale is correct at all points along two chosen parallels and any two meridians converge at an angle which is a fraction of the angle between them on the earth, the fraction depending solely on the choice of standard parallels. The spacing of the other parallels is then uniquely determinate to secure the orthomorphic property. The scale is somewhat too low between the standard parallels and increases rather rapidly outside them.

The projection recommended in (iii) is another special type of orthomorphic projection in which the angle between the meridians is zero. The meridians are equally spaced parallel straight lines and the parallels of latitude are straight lines at right angles to the meridians and spaced so as to secure the orthomorphic property. This projection is most suitable for the equatorial zone.

Conical and zenithal projections can be made with other than orthomorphic properties by suitably altering the spacing of the parallels. Preservation of areas, or a compromise between the equal area and orthomorphic properties, may be secured. The latter is the case in Clarke's zenithal projection used in the *Daily Weather Report* (British Section) of the Meteorological Office.

There are, in addition, many other projections, each to serve a special purpose. Of these Mollweide's 'equal-area projection' is often useful when a world map is required. The whole globe is represented within an ellipse whose major axis is twice the minor axis.

For further information see 'Map projections'* and 'Principles of meteorological analysis'.† The mathematical properties of orthomorphic projections are to be found under 'conformal representation' in books on the theory of functions of a complex variable.

prontour: British terminology for a forecast chart of the contours of an isobaric surface.

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* HINKS, A. R.; Map projections. 2nd edn. Cambridge, University Press, 1921.

† SAUCIER, W. J.; Principles of meteorological analysis. Chicago, University Press, 1955.

proton: A constituent particle of all atomic nuclei, itself comprising the hydrogen nucleus, which carries unit positive charge (equal but opposite to that of the ELECTRON) and has a mass about 1850 times that of the electron.

pseudo-adiabatic (or **pseudo-adiabat**)**:** Line on an AEROLOGICAL DIAGRAM representing the pseudo-adiabatic lapse rate.
See ADIABATIC.

pseudo-equivalent temperature: The pseudo-equivalent temperature (T_{se}) of a sample of air at any level is found from an AEROLOGICAL DIAGRAM by dry adiabatic expansion to the lifting CONDENSATION LEVEL of the sample, followed by ascent along the saturated adiabatic till all the water vapour is condensed, and finally dry adiabatic descent to the initial pressure level.

The 'pseudo-equivalent potential temperature' (θ_{se}) is found by progressing along the dry adiabatic line from T_{se} to the 1000 mb level.

T_{se} for an air sample exceeds the (isobaric) EQUIVALENT TEMPERATURE (T_e), and θ_{se} exceeds the equivalent potential temperature (θ_e), by an amount which is not negligible.
See also ADIABATIC.

pseudo wet-bulb temperature: A temperature (T_{sw}) obtained most readily from an AEROLOGICAL DIAGRAM by ascent of the sample at the dry-adiabatic lapse rate until saturation is reached (at the 'lifting condensation level'), followed by descent at the saturated-adiabatic lapse rate till the original pressure is reached. The temperature so attained is T_{sw}.

The 'pseudo wet-bulb potential temperature' (θ_{sw}) is found by progressing along the saturated adiabatic from T_{sw} to the 1000 mb level.

T_{sw} for an air sample is smaller than the WET-BULB TEMPERATURE (T_w), and θ_{sw} is smaller than the WET-BULB POTENTIAL TEMPERATURE (θ_w), to a degree which is in practice negligible (usually less than 0·5°C).
See also ADIABATIC.

psychrograph: A recording PSYCHROMETER.

psychrometer: A type of HYGROMETER (also termed the 'dry-and-wet-bulb hygrometer' or 'Mason's hygrometer') in which two similar thermometers are used: one, the 'dry-bulb', gives the air temperature (T), while the other, the 'wet-bulb', whose bulb is covered with muslin wetted with pure water, gives a reading (T_w). In unsaturated air T_w is lower than T by an amount (the 'wet-bulb depression') which, at a specified temperature, depends mainly on the relative humidity of the air but also, to a small extent, on the degree of ventilation of the wet bulb. The lower temperature is explained by the fact that the latent heat required to evaporate water from the muslin is supplied by the air which is in contact with the wet bulb.

At air pressure p, the vapour pressure (e') of an air sample is related to the saturation vapour pressure at the wet-bulb temperature (e'_w) and to the wet-bulb depression ($T-T_w$) by the semi-empirical 'psychrometric formula'

$$e' = e'_w - Ap\,(T-T_w)$$

where A is a 'constant'.

The 'Hygrometric tables'* and humidity slide-rule issued by the Meteorological Office for the purpose of obtaining values of vapour pressure, dew-point and relative humidity from readings of T and T_w observed in a STEVENSON SCREEN ('light air' conditions of ventilation) are based on a value of the product Ap of 0·799 for $T \geq 0$°C and of 0·720 for $T < 0$°C for readings in °C (0·444 for $T \geq 32$°F

* London, Meteorological Office: Hygrometric tables. Parts I and II. London, HMSO. 1961.

and 0·400 for $T < 32°F$ for readings in °F); in this product p is assigned the value 1000mb. The saturation vapour pressure with respect to water is used as the standard at all temperatures.

In the ASSMANN PSYCHROMETER and WHIRLING PSYCHROMETER (or 'sling psychrometer') the rate of ventilation of the bulbs is controlled and values of A are used in the reduction tables and slide-rule other than those appropriate to Stevenson screen readings.

psychrometric formula: See PSYCHROMETER.

pumping: Unsteadiness of the mercury in the barometer caused by fluctuations of the air pressure produced by a gusty wind, or due to the oscillation of a ship.

purga: See BURAN.

purple light: Shortly after the sun has set below the western horizon a brighter patch appears on the darkening sky about 25° directly above the position where the sun has disappeared. This patch appears brighter as the sky darkens and takes on a purple tone. The patch expands into a disk and when the sun is about 4° below the horizon it reaches its maximum brilliancy, when it may be so bright that white buildings in the east which are lit up by it glow with a purple colour which corresponds to the AFTERGLOW seen on the peaks of snow-covered mountains. The disk of purple light sinks downwards at twice the rate at which the sun sinks while at the same time its radius expands and its light becomes less intense. It finally sets behind the bright segment of the TWILIGHT ARCH. Occasionally when the first purple light has passed below the horizon, the phenomenon repeats itself with less intensity. The second patch of light appears at a slightly lesser altitude than the first but otherwise follows the same course.

pyranometer: A term applied both to the type of instrument used in measuring the DIFFUSE RADIATION (direct sun excluded) on a horizontal surface and to that which measures the total radiation ('sun plus sky') received on a horizontal surface: the latter type of apparatus is also termed 'solarimeter'.

The instrument generally consists of a THERMOPILE which is under a protective hemispherical glass cover and is connected to a recorder.

pyrgeometer: An instrument for measuring the NOCTURNAL RADIATION. That designed by Ångström uses the fact that the radiation from a gilded strip of manganin is less than that from a blackened strip.

pyrheliometer: An instrument for measuring the direct solar RADIATION (DIFFUSE RADIATION excluded) at normal incidence.

Three main types are used. In Ångström's form, the rate of absorption of heat by a thin strip of blackened platinum, normal to the sun's rays, is found by measuring the electric current necessary to heat a similar strip to the same temperature. In Abbot's silver-disk pyrheliometer, the rise of temperature in a silvered disk exposed normal to the sun's rays is measured directly and the intensity of radiation determined by reference to calibration data of the instrument. In a third type, a THERMOPILE, covered by a flat glass plate and fitted in a HELIOSTAT, is used: direct and continuous recording is employed with this instrument.

Q

Q-code: A letter code used by aircraft in requests for information: it is also used in the supply of information to aircraft. Certain items in the code relate to meteorological information, e.g. QFE refers to station-level pressure, QFF to mean-sea-level pressure, QNH to ALTIMETER SETTING. See 'Handbook of weather messages'.*

quartile: When a series of values is arranged in order of magnitude, the 'upper quartile' is that value above which 25 per cent of the observations lie, the 'lower quartile' that value below which 25 per cent of the observations lie. The difference between these values is termed the 'interquartile range' and is sometimes used as a measure of DISPERSION. Compare PERCENTILE.

quasi-geostrophic motion: Air motion which is known, or more frequently assumed, to be closely approximate to the GEOSTROPHIC WIND. Such an assumption is generally valid in those cases where large-scale atmospheric motion is considered. In preparing NUMERICAL WEATHER FORECASTS this assumption—often termed the 'geostrophic approximation'—is usually made: the purposes are (i) to simplify the mechanics of performing the forecast (for example, by using the contours of a pressure surface as a measure of wind velocity); (ii) to simplify the mathematics; and (iii) to make the solution more meaningful in synoptic terms by eliminating all waves of short wavelength, small amplitude and very high velocity. In this last connexion the assumption is usually termed a 'filtering' device.

In describing the motion as 'quasi-geostrophic' rather than 'geostrophic', it is usually implied that derived quantities such as the horizontal divergence which depend on small horizontal gradients of wind speed or direction cannot be taken from the gradients of the geostrophic wind, but must be determined in other ways.

quasi-stationary front: A FRONT whose position is (almost) unchanged on successive synoptic charts. There is a strong tendency in such cases for wave-like disturbances of the front to form.

* London, Meteorological Office; Handbook of weather messages. Parts II and III. London, HMSO, 1959.

R

radar: A system of detection and location of 'targets' which are capable of reflecting high-frequency radio waves (microwaves), generally in the wavelength range from a fraction of a centimetre to some tens of centimetres.

The system consists of sending from a transmitter a narrow beam of radio waves and obtaining any reflected signal ('echo') in an adjacent receiver which generally uses the same aerial system as the transmitter. The distance of the target is obtained from the time interval between transmission and reception, and its direction from that of the aerial system employed. The information is presented visually on a cathode ray tube. Detection of the echo requires a very sensitive receiver and portrayal requires great amplification since much of the emitted radio energy is lost by atmospheric absorption and sideways scattering. See also RADAR METEOROLOGY.

radar meteorology: The main applications of RADAR in meteorology are in the measurement of RADAR WINDS and in the detection of cloud and precipitation elements. The latter is used as a direct forecasting aid and in detailed studies of the structure of precipitation regions.

Various types of radar display are used in the surface investigation of precipitating clouds. They include a 'plan position indicator' (PPI), which employs a horizontally-scanning aerial system and gives a picture of the distribution of precipitation regions in all directions round the observing point to a distance dependent on the characteristics of the set and the intensity of precipitation—for moderate precipitation this distance may be of the order of 100 miles; a 'range-height indicator' (RHI), in which the scanning is in the vertical plane; and an 'A-scope indicator', which shows the variation of amplitude of reflected signal with range of target. See Plates 24 and 25.

Since the amount of back-scattered energy and the degree of atmospheric attenuation of the waves which travel to and from the target both increase with decrease of wavelength, a compromise choice of wavelength is required. For detection of precipitation a choice is made in the approximate range 3 to 20 cm, while detection of the larger cloud particles even at very short range requires a wavelength in the millimetre range.

For a given wavelength, the strength of the echo increases with the concentration, and very rapidly with the size (proportional to the sixth power of the diameter), of cloud or precipitation particles. The echo strength is, therefore, almost entirely due to the energy back-scattered by any precipitation particles, as opposed to the much smaller cloud particles, which may be present. Empirical relations have been obtained between precipitation rate and corresponding echo intensity.

The vertical and horizontal extent, development and movement of a precipitation region may be indicated by radar. Various complicating factors greatly reduce, however, the amount of quantitative work possible and make very difficult even qualitative assessment as to the precise nature of the reflecting particles. These factors include particle size distribution relative to radio wavelength in use (determining whether RAYLEIGH SCATTERING or MIE SCATTERING obtains); particle shape (affecting 'radar cross-sections'); and particle phase (whether, for example, ice or water, or dry or wet hailstones). See also DOPPLER RADAR, BRIGHT BANDS, MELTING BAND, RAYLEIGH SCATTERING.

radar storm detection: The detection of precipitation regions in the atmosphere by means of ground-based or airborne RADAR. See RADAR METEOROLOGY.

radar wind: A wind in the upper atmosphere determined by means of radar reflexions from a 'radar target' carried aloft by a free balloon, the observed elements being the range, elevation, and azimuth of the target.

radian: A unit of angular measure, being the angle subtended at the centre of a circle by an arc equal in length to the radius of the circle. Thus, π radians = 180°.

radiation: The transmission of energy by electromagnetic waves. See ELECTROMAGNETIC RADIATION. (The term is also used to signify the emission of particles by a source, as in 'cosmic radiation', 'solar particle radiation').

Radiation flux across a surface is the energy which crosses unit area of the surface in unit time. The following relations hold for the various units of flux used in meteorology:

$$1 \text{ cal/cm}^2 \text{ min} = 4{\cdot}185 \times 10^7 \text{ erg/cm}^2 \text{ min}$$
$$= 6{\cdot}976 \times 10^{-2} \text{ abs. watt/cm}^2$$

A valuable concept in radiation is that of the 'black body'. A perfect black body is one which absorbs all the radiation falling on it and which emits, at any temperature, the maximum amount of radiant energy. The term arises from a correlation between darkness of colour and proportion of visible light absorbed. A body which appears white because it scatters the visible light falling on it may, however, act nearly as a black body to radiation of different wavelength. Snow is an example, being effectively a black body for wavelengths greater than 1·5 microns (μ).

The properties of a black-body radiator are expressed in a number of laws:

(i) Planck's law. The distribution of energy with temperature (T) and wavelength (λ) for a perfect radiator was represented by Planck as:

$$E_\lambda = c_1\lambda^{-5}/(e^{c_2/\lambda T} - 1)$$

where E_λ is the energy emitted in unit time from unit area within unit range of wavelength centred on λ, and c_1 and c_2 are constants. The corresponding energy distribution curve is illustrated in Figure 26 for four radiation temperatures: it shows, for example, that the solar radiation spectrum barely overlaps that of ground radiation. The area bounded by the curve, the wavelength axis and any pair of selected wavelengths gives a relative measure of the energy contained in the corresponding part of the spectrum.

(ii) Wien's (displacement) law. The variation of wavelength of maximum energy emittance (λ_{max}) with temperature of radiator is given by

$$\lambda_{max}\, T = 0{\cdot}2897 \text{ cm°K}$$

(iii) Stefan–Boltzmann law. The amount of energy emitted in unit time from unit area of a black body is proportional to the fourth power of absolute temperature, i.e.

$$E = \sigma T^4 \text{ where } \sigma \text{ (Stefan's constant)}$$
$$= 5{\cdot}673 \times 10^{-5} \text{ erg/cm}^2 \text{ deg }^4\text{C sec}$$
$$= 8{\cdot}132 \times 10^{-11} \text{ cal/cm}^2 \text{ deg }^4\text{C min}$$

(iv) Kirchoff's law. The ratio of emissive to absorptive power, for a particular wavelength and temperature, is the same for all types of body and is numerically equal to the emissive power of a black body (whose absorptive power is, by definition, unity). Thus, if a body at a given temperature strongly absorbs radiation of a certain wavelength, it also radiates strongly this wavelength, provided it is present in the radiation spectrum for the temperature. The wavelength dependence is here crucial, e.g. fresh snow absorbs very little direct (short-wave) solar radiation but acts very nearly as a black body to long-wave radiation from the atmosphere.

The spectrum of solar radiation outside the earth's atmosphere, inferred from ground observations or measured directly by rockets and satellites, extends from the X-ray region through the ultra-violet, visible (0·4 to 0·7 μ) and infra-red to the radio-wave region. About half the total solar energy is in the form of visible light. The spectrum observed at the ground is sharply cut off in the near ultra-violet at about 0.29μ, owing to the complete ABSORPTION of shorter wavelengths, containing about 5 per cent of the total energy, by gases in the high atmosphere: there is also selective absorption of higher wavelengths by atmospheric constituents.

Application of the inverse square and Stefan–Boltzmann laws, with the assumption of a SOLAR CONSTANT of 2·00 cal/cm² min, shows that the sun has a black body radiation temperature of about 5800°K; while a sun 'colour' temperature of about 6100°K is obtained by insertion of the value $\lambda_{max} = 0{\cdot}474\mu$ into Wien's formula.

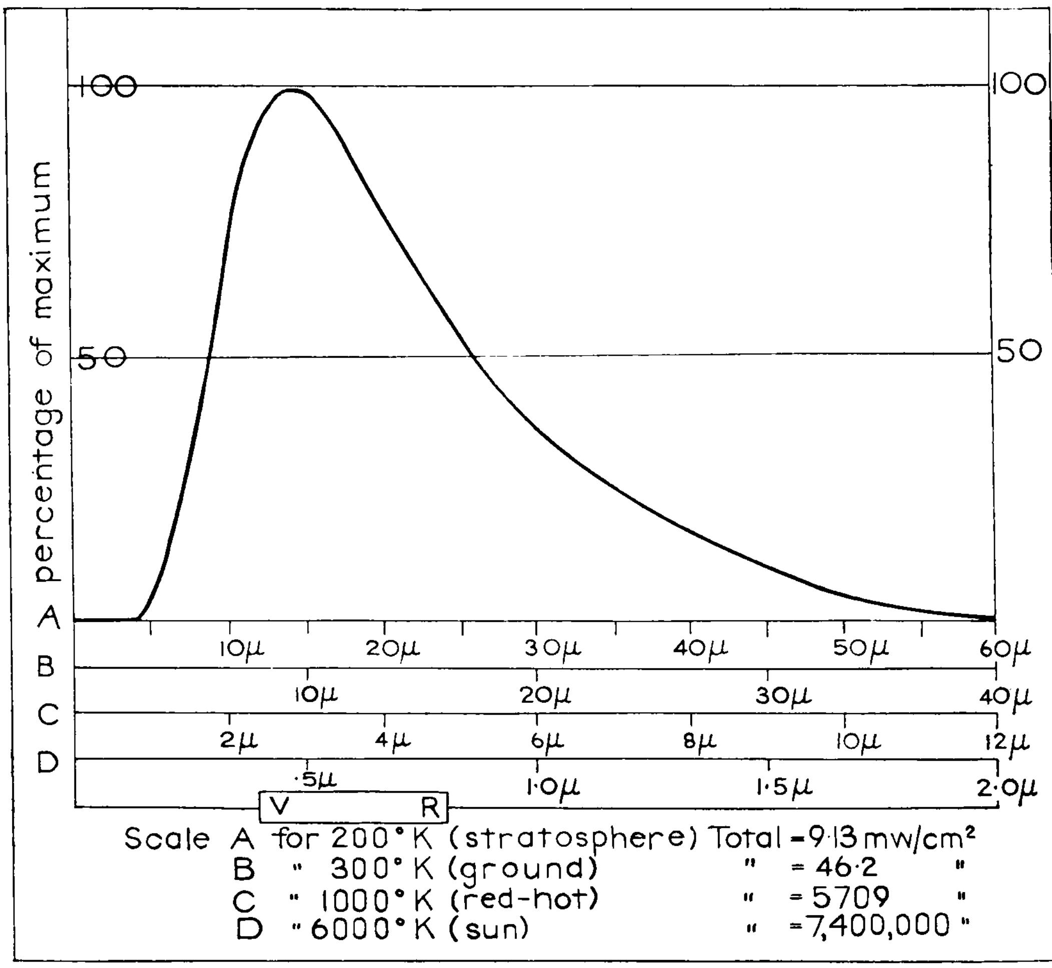

FIGURE 26—Distribution of energy in black-body spectrum.

Detailed examination of the extraterrestrial solar spectrum in terms of Planck's law reveals, however, that there is no close fit at all points of the spectrum with a perfect radiator of any given temperature, probably because the radiation originates at different levels in the sun's atmosphere and therefore at different temperatures.

The radiant energy delivered by the sun to the fringe of the earth's atmosphere, about 7 per cent greater at PERIHELION (early January) than at APHELION (early July) is 2·00 cal/cm² min at the earth's mean distance ('SOLAR CONSTANT'). The mean flux perpendicular to the earth's surface is about 0·5 cal/cm² min. About 40 per cent of this incident radiation is diffusely reflected to space without change of wavelength (ALBEDO of earth–atmosphere system), about 15 per cent heats the atmosphere by direct absorption by constituents, and the remaining 45 per cent is absorbed at the earth's surface as both direct ('sun') and diffuse ('sky') radiation.

The ratio of sky to sun radiation increases with cloudiness and latitude and is greater in winter than in summer; in middle latitudes it averages 30–40 per cent.

Most of the solar energy absorbed at the earth's surface is transferred as heat to the atmosphere initially by conduction, then by turbulence and convection and by evaporation: radiation in the wave band appropriate to the temperature of the surface is smaller but also important. The total amount of long-wave radiation emitted to space by the atmospheric gases and direct from the earth's surface (terrestrial radiation) equals, on balance, the 60 per cent of solar radiation which is effective in heating the earth and atmosphere: the black-body radiation 'planetary' temperature appropriate to this radiation balance is about 250°K. Study of the conditions of balance within the earth–atmosphere system shows that, except in higher latitudes in winter, the earth's surface radiates less heat than it absorbs (heat source) and the troposphere everywhere radiates more heat than it absorbs (heat sink): in the stratosphere local radiative equilibrium more nearly obtains.

Direct absorption of solar radiation has been found by estimation and measurement to cause a daily heating of about 0·1°C in the low stratosphere and of 0·1° to 0·6°C (depending on season and water-vapour content) in the lower troposphere in middle latitudes. In the high stratosphere solar heating effects are much greater —notably at about 50 km, associated with absorption by oxygen and ozone. The daily net cooling rates, associated with the divergence of terrestrial radiation, is about 1° to 2°C throughout a cloudless troposphere and low stratosphere: cooling is much reduced below a cloud layer but is increased at the top of such a layer.

See also TERRESTRIAL RADIATION.

radiation balance: The difference between the amounts of RADIATION which are absorbed and emitted, for example by the earth's surface or by the atmosphere at a specified level. In general, the balance at the earth's surface is positive (absorption greater than emission) by day and negative by night. When there is complete balance between the incoming and outgoing radiation fluxes, a state of 'radiative equilibrium' is said to exist. See also ENERGY BALANCE.

radiation chart: A chart (for example, that of W. M. Elsasser) which, by providing a graphical method of numerical integration of the equations of radiative transfer in the atmosphere, permits of the calculation of the upward and the downward fluxes of radiation at any level, the vertical distribution of temperature and humidity being known.

radiation fog: A common type of FOG which forms overland on nights characterized by light wind, clear sky, and moist air in the lower levels of the atmosphere. The first two conditions lead to the formation of a RADIATION INVERSION. Since, however, loss of water from air in contact with cold ground proceeds rather more quickly than loss of heat, some turbulent interchange of air (with associated adiabatic cooling), together with a downward-directed gradient of humidity mixing ratio (to maintain the moisture supply), are required to produce condensation in an appreciable layer. The presence of hygroscopic nuclei, as in industrial areas, facilitates fog formation by allowing condensation to occur in unsaturated air. In the British Isles fog is often caused in part by radiation and in part by advection processes—see ADVECTION FOG.

radiation inversion: An INVERSION of temperature through an atmospheric layer extending upwards from the earth's surface, such a condition developing in the course of a RADIATION NIGHT over a land surface due to radiational cooling of the surface. The depth of the inversion layer increases in the course of the night due to downward conduction of heat from the atmosphere.

radiation night: A night, characterized by absence of cloud and wind, on which there is marked radiational cooling of the ground and, by conduction of heat from air to ground, of the surface layers of air. Absence of cloud ensures that there is relatively little compensating radiation directed downward to ground (see ATMOSPHERIC WINDOW). Absence of wind confines cooling to a shallow layer near the ground and produces a low minimum surface temperature. The occurrence on some occasions of minimum air temperature at a few centimetres above the ground rather than at the ground itself is well substantiated but has as yet no accepted explanation.

Other factors which favour a low temperature minimum on a radiation night are relatively dry air, low heat conductivity of the ground, and long hours of darkness.

radiation pressure: The pressure exerted on a body by the electromagnetic RADIATION incident on it. That exerted by solar radiation which is absorbed near the earth's surface is minute relative to atmospheric pressure. In solar physics, radiation pressure is considered to play an essential part in the emission of atoms from the sun.

radiative equilibrium: State of balance between the absorption and emission of RADIATION.

Turbulent transfer, evaporation and condensation are the processes which chiefly inhibit the occurrence of the state of radiative equilibrium. The state is therefore of little or no significance at the earth's surface and in the troposphere. At higher levels, evaporation and condensation are unimportant and the effect of turbulent transfer on the temperature distribution is, in general, secondary to that of radiation processes. Thus, for example, approximate radiative equilibrium obtains in the upper part of the ozone layer where ultra-violet radiant energy is strongly absorbed by oxygen and ozone in certain lines and bands and is shared by collision with other atmospheric gases. The air temperature is thus raised to a level at which the terrestrial radiation emitted by the gas mixture (mainly by the constituents ozone, carbon dioxide and water vapour) is in balance with the incoming radiation. See also RADIATION BALANCE.

radiatus (ra): One of the CLOUD VARIETIES. (Latin, *radiatus* having rays.)

'Clouds showing broad parallel bands or arranged in parallel bands, which, owing to the effect of perspective, seem to converge towards a point on the horizon or, when the bands cross the whole sky, towards two opposite points on the horizon, called 'radiation point(s)'.

'This term applies mainly to CIRRUS, ALTOCUMULUS, ALTOSTRATUS, STRATOCUMULUS and CUMULUS'.* See also CLOUD CLASSIFICATION.

radioactive carbon (radiocarbon): The radioactive isotope of chief importance in geophysics is carbon-14 (C^{14}). Bombardment of the atmosphere by cosmic rays produces neutrons which react with nitrogen (N^{14}) to form C^{14} at a rate which is greatest at 30,000–40,000 feet. Measurements indicate that about 2·4 C^{14} atoms are produced in this way per second per square centimetre of the earth's surface. C^{14} has a radioactive HALF-LIFE of about 5500 years and reverts to N^{14} by emission of a beta particle.

Radiocarbon is distributed, like the vastly more plentiful non-radioactive carbon, throughout the earth–atmosphere system. Only 1 or 2 per cent of C^{14} is stored (as radioactive carbon dioxide) in the atmosphere. About 90 per cent is

* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 15.

contained in the carbonaceous materials of the oceans which are in exchange equilibrium with carbon dioxide. The remaining 8 or 9 per cent which is retained by plant and animal life gives rise to the technique of CARBON DATING.

Local artificial injections of C^{14} into the atmosphere have been caused by nuclear explosions. The C^{14} introduced in this way has been used as a tracer element of atmospheric motion, by the measurement of the C^{14} content of air samples collected at various levels and of vegetation.

radioactive fallout: The descent to the earth's surface of radioactive material produced in a nuclear explosion.

A distinction is made between two classes of fallout: (i) 'close-in fallout', (or 'local fallout') i.e. material that descends close to 'ground zero' (point on earth's surface at or above which the device is exploded); (ii) 'delayed fallout', (or 'world-wide fallout') i.e. material that reaches the earth's surface after a long delay and generally far from 'ground zero'. Meteorological processes are important in both types of fallout.

(i) *Close-in fallout.*

If a nuclear explosion occurs at a level sufficiently low for the associated FIREBALL to intersect the earth's surface (technically, a 'ground-burst'), fused ground material is sucked into the rising cloud and made radioactive. The average size of cloud particle is, in these circumstances, relatively large and the average TERMINAL VELOCITY correspondingly great. The largest (fastest falling) particles reach the earth's surface about 20 minutes after the explosion, the smaller particles proportionately later and farther downwind. Since the particles start their descent from a range of levels within the cloud, they are subject to horizontal movement by mean vector winds extending through various layers (all terminating at the surface) as well as to horizontal diffusion and so give rise to a fallout pattern on the ground, the edges of which are likely to be irregular if there are strong vertical currents or precipitation in the region. The pattern is long and narrow if the upper winds are strong and have little vertical shear, much more elliptical or near-circular if the upper winds are light and have pronounced shear. For a large thermonuclear ground-burst device (5–10 megatons), the height reached by the top of the cloud is of the order 80,000–100,000 feet.

The radioactive dust which settles on the ground emits GAMMA RADIATION which is relatively intense downwind from ground zero along that line which corresponds to the direction of the mean vector wind in the layer from the surface to the most active part of the cloud (the so-called 'hot line') and which is relatively weak towards either edge of the plume. After fallout is complete at any place within the plume, the intensity of emitted radiation decreases at an approximately exponential rate, reckoned from the time of burst. The limits of close-in fallout are arbitrarily selected on the basis of a minimum measured dose-rate of radiation at a fixed time interval after the explosion: the selected limits are such that it is only particles of diameter greater than about 50 microns, falling in the period up to some 36 hours after the explosion, which are involved. Close-in fallout comprises more than half the total radiochemical energy of a ground-burst weapon.

(ii) *Delayed fallout.*

If a nuclear explosion occurs at such a level that the fireball does not intersect the surface of the earth (an 'air-burst'), the size of the particles is very small and terminal velocities are low. There is then negligible close-in fallout (except, perhaps, in the event of rain at the time of the explosion), but a delayed fallout, partly by deposition of radioactive dust and mainly by WASHOUT with rain. If the original cloud is confined to the troposphere, most of the delayed fallout occurs within a period of weeks. If, however, the material reaches the stratosphere, most of the fallout is delayed for months or years (depending on the height, season and latitude of injection). The term 'residence half-time' or 'storage half-time', signifying the time required for one half of the material to be deposited, is used with respect to delayed fallout.

During the period when the material is stored in the atmosphere, it acts as a 'tracer element' in respect of air movement. Other meteorological factors, however, —notably the distribution and intensity of rainfall—play an important part in determining the eventual pattern of deposition of the material on the earth's surface.

radioactivity: The property of spontaneous disintegration of unstable, into more stable, elements, accompanied by the emission of ALPHA PARTICLES, BETA PARTICLES, or GAMMA RAYS. It is a property possessed by some of the naturally-occurring elements: those in the earth's crust play a significant part in the IONIZATION of air at low levels over land areas.

radio direction-finder: An instrument, also termed 'radiogoniometer', for determining the azimuth from which radio waves are received. The term is sometimes used when elevation also is determined, being then a RADIO-THEODOLITE.

radio direction-finding (RDF): Measurement of the direction of arrival of radio waves. It is also termed 'radiogoniometry'. See RADIO DIRECTION-FINDER.

radio duct: See ANOMALOUS RADIO PROPAGATION.

radiogoniometer: An alternative for RADIO DIRECTION-FINDER.

radiogoniometry: An alternative for RADIO DIRECTION-FINDING.

radiosonde: A small radio transmitter, by means of which observations, usually of pressure, temperature and humidity, may be obtained from the upper atmosphere.

In the current Meteorological Office Mark 2B radiosonde there are sensitive elements consisting of an aneroid capsule for pressure, bimetallic strip for temperature and gold-beater's skin for relative humidity, and these control the armatures of variable inductors. As the balloon ascends, a small windmill-driven switch causes each inductor to be connected in turn to a valve oscillator. The completed circuit generates a note whose frequency (pitch), determined by the variable gap between the inductance and armature, modulates the carrier frequency generated in the instrument circuit. The transmitted note is picked up by a radio receiver on the ground; the frequency or period is measured, and these readings are converted into pressure, temperature or humidity by means of calibration curves or tables.

In practice, wind velocities may also be obtained in the course of a radiosonde ascent, either by tracking the balloon by means of a RADIO-THEODOLITE or by radar reflexions from a 'radar target' carried by the balloon: the latter method is used in the Meteorological Office.

The height attained by the sonde is of the order 18 km (60,000 ft): a large balloon used in favourable circumstances may give observations up to about 30 km (100,000 ft). Strong winds during an ascent reduce the height from which wind information is obtained because of limited range of the radar equipment.

radio-theodolite: An apparatus for determining the direction (angles of elevation and azimuth) from which radio waves reach a receiver. It consists essentially of a receiver coupled to an aerial which can be rotated about horizontal and vertical axes. Used with a RADIOSONDE, it gives upper-level winds with a lower degree of accuracy than is obtained by the radar method ('radar wind') in which slant range is measured.

radio-waves: ELECTROMAGNETIC RADIATION of wavelengths greater than about 1000 microns (10^{-1}cm), i.e. beyond the rather indefinite upper limit of INFRA-RED RADIATION.

The radio band of waves is subdivided according to frequency and ranges from 'extremely high' to 'very low' frequency bands. Those of lowest wavelength (highest frequency) are termed 'microwaves' and are used, for example, in RADAR. Very long waves (of length about 30 km) are used in the locating of SFERICS.

radio wind: A wind in the upper atmosphere determined by radio means (see RADIO-THEODOLITE).

radon: One of the INERT GASES, radon is emitted by radioactive materials in the earth's crust and comprises a minute constituent of air at low levels. Its atomic mass is 222 and atomic number 86. The ALPHA PARTICLES which are emitted by the decay of radon, (together with those emitted by its isotopes THORON and ACTINON), are responsible for part of the IONIZATION of the air at low levels over land.

rain: Liquid PRECIPITATION in the form of DROPS of appreciable size (by convention, of diameter greater than about 500 microns, that is 0·5 mm, which is the limiting size of DRIZZLE drops).

For synoptic purposes, rain (other than in showers) is classified as 'slight', 'moderate', or 'heavy', for rates of accumulation less than 0·5 mm/hour, 0·5 to 4 mm/hour, and greater than 4 mm/hour, respectively. See also RAINDROPS.

rainbow: A rainbow is seen when the sun shines upon raindrops. The drops may be at any distance from the observer from a few yards to several miles. When sunlight falls upon a drop of water the light is refracted on entering the drop, is reflected from the far side and emerges with further refraction, from the near side. The light which is reflected in this way does not come out in all directions but only in directions lying within about 42° from the direction of the sun. The reflected light is most intense near the limit. Accordingly an observer looking towards the raindrops receives a certain amount of light from all directions within 42° from the shadow of his head but most light along rays which make about 42° with the central line. The limiting angle depends on the colour of the light and insomuch as white light is compounded of light of different spectral colours the observer sees a number of concentric arches of different colours, generally with violet to the inside and red to the outside. See Plate 22.

Some of the light falling on a drop does not emerge until after it has been reflected twice. None of the twice reflected light which reaches an observer makes an angle of less than 50° with the line to the centre of his shadow. The colours of the outer bow formed in this way are in the reverse order to those of the inner bow. The space between the inner and outer ('primary' and 'secondary') bows appears darker than the space inside the primary bow or beyond the secondary bow. Several 'supernumerary'-bows may also appear within the primary bow.

The coloration of a rainbow depends on the size of the drops. Drops larger than 1 mm in diameter yield brilliant bows about 2° in width, in which the limiting colour is distinctly red. With drops about 0·3 mm in diameter the limiting colour is orange and inside the violet there are bands in which pink predominates. With smaller drops 'supernumerary' bows appear to be separate from the primary bow. With still smaller drops about 0·05 mm in diameter the rainbow degenerates into a white fogbow with faint traces of colour at the edges. The variations of colour with drop size, and also the appearance of supernumerary bows, are due to DIFFRACTION.

Rainbows are not infrequently observed by moonlight but as the human eye cannot distinguish colour with faint lights the lunar rainbow appears to be white.

rain day: Defined for statistical purposes as a period of 24 hours, commencing normally at 9h GMT, on which 0·01in. or 0·2 mm or more of RAINFALL is recorded.

See also WET DAY.

PLATE 22 Rainbow: Inverness-shire.

Primary and secondary bows, with opposite sequences of colour, are seen. A faint and rare 'reflexion rainbow', produced by light which has been reflected from Loch Morlich (behind the observer) is visible in the relatively dark segment of sky between the primary and secondary bows.

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raindrops: Liquid water drops of diameter greater than about 0·5 mm. The term is sometimes used to include also *drizzle* drops, extending then to a lower limit of about 0·2 mm.

Surface tension forces act on small raindrops to minimize the surface to volume ratio and so make them spherical. The lower surface of larger drops is, however, appreciably flattened by aerodynamic forces. Raindrops of greater (equivalent) diameter than about six or seven mm break up into smaller drops.

Both 'median volume diameter' (defined as the drop diameter such that half the total water is contained in larger drops) and drop concentration (drops/m^3) tend to increase with rate of rainfall. There is, however, considerable variability and dependence, in particular, on type of rainfall. A. C. Best quotes the following as typical values: at a rate of rainfall of 0·5 mm/hour there are about 250 drops/m^3 and drops of about 1 mm diameter contribute most of the water (the average drop size being smaller); while at a rainfall rate of 25 mm/hour there are about 1200 drops/m^3 and drops of about 2 mm diameter contribute most of the water.

rainfall: The total liquid product of PRECIPITATION or CONDENSATION from the atmosphere, as received and measured in a RAIN-GAUGE. Snow, sleet and hail, in addition to RAIN, make up much the greater part of the total 'rainfall', as defined above. There are also small additions due to the deposition of dew, hoar frost and rime on to the collecting surface of the raingauge. One inch of rainfall is equivalent to about 100 tons of water per acre.

Three general classifications are made into OROGRAPHIC, CYCLONIC, and CONVECTIONAL types of rainfall. These types, discussed under their individual headings, are by no means mutually exclusive. Other terms, such as 'frontal rainfall', are sometimes also employed.

The average monthly and annual rainfall during the current standard period, 1916–50, for the larger divisions of the United Kingdom are given in Table XII.

TABLE XII—*Average rainfall* 1916–50

	England	Wales	England and Wales	Scotland	Northern Ireland	Great Britain
	in.	in.	in.	in.	in.	in.
January ...	3·35	5·83	3·69	5·66	4·23	4·36
February ...	2·44	4·08	2·67	3·93	2·93	3·10
March ...	2·13	3·34	2·30	3·30	2·56	2·64
April	2·30	3·18	2·42	3·30	2·60	2·72
May	2·44	3·34	2·56	3·20	2·76	2·78
June	2·10	3·07	2·23	3·19	2·76	2·56
July	3·05	4·13	3·20	4·19	3·73	3·54
August ...	3·04	4·56	3·25	4·50	3·94	3·67
September ...	2·84	4·45	3·06	4·71	3·73	3·62
October ...	3·38	5·78	3·71	5·81	4·32	4·43
November ...	3·55	5·67	3·84	5·29	4·02	4·33
December ...	3·21	5·56	3·53	5·29	4·32	4·13
Year ...	33·83	52·99	36·46	52·37	41·90	41·88
Area (square miles) ...	50,307	8001	58,308	30,137	5454	88,445

Table XIII shows the rainfall over England and Wales, Scotland and Northern Ireland for the 60 years 1901–60 as a percentage of the average for 1916–50, the average for each district being taken as 100.

In England and Wales the wettest year of the period 1901–60 was 1960, with 47·5 in.: in the longer series available from 1727 there were two wetter years, 1872

TABLE XIII—*Annual rainfall for each year,* 1901–60, *expressed as a percentage of the average of the* 35 *years* 1916–50

Year	England and Wales	Scotland	Northern Ireland	Year	England and Wales	Scotland	Northern Ireland
1901	85	91	96	1931	105	100	103
1902	81	83	91	1932	100	104	92
1903	124	124	114	1933	78	77	73
1904	86	90	92	1934	92	106	100
1905	83	93	84	1935	109	104	94
1906	98	106	95	1936	105	90	104
1907	96	99	97	1937	106	87	95
1908	88	95	97	1938	96	118	111
1909	101	97	92	1939	109	91	97
1910	109	101	100	1940	98	94	107
1911	91	95	83	1941	93	84	90
1912	121	104	109	1942	91	96	107
1913	95	89	96	1943	90	102	98
1914	104	99	99	1944	97	101	105
1915	106	93	90	1945	90	97	93
1116	110	113	103	1946	114	95	103
1917	95	93	103	1947	89	93	100
1918	103	102	104	1948	103	118	107
1919	101	90	90	1949	85	104	94
1920	105	101	110	1950	110	109	114
1921	68	95	88	1951	120	105	96
1922	102	91	92	1952	97	90	86
1923	109	115	115	1953	82	93	80
1924	116	101	113	1954	117	122	118
1925	102	96	98	1955	85	78	88
1926	98	107	100	1956	94	98	93
1927	119	110	96	1957	97	102	102
1928	111	118	122	1958	114	96	106
1929	97	97	99	1959	88	96	87
1930	114	104	101	1960	130	97	108

(50·7 in.) and 1852 (49·8 in.). The driest years were 1731 (22·9 in.), 1788 (23·0 in.), 1741 (23·9 in.), and 1921 (24·7 in.). In Scotland the wettest years (in a series of observations from 1869) were 1872 (67·5 in.), 1877 (65·7 in.) and 1903 (65·1 in.); the driest year was 1933 (40·3 in.). Data for Northern Ireland are available only from 1900: the wettest year was 1928 (51·2 in.) and the driest year was 1933 (30·3 in.). Over Great Britain the wettest and driest years were 1872 and 1887, respectively. Extreme annual values at individual stations are a maximum of about 257 in. (at Sprinkling Tarn, Cumberland in 1954) and a minimum of 9·29 in. at one station in Margate in 1921.

The wettest months were: Great Britain, October 1903 (8·7 in.); England and Wales, October 1903 (8·3 in.); Scotland, December 1867 (10·4 in.); Northern Ireland, December 1929 (7·6 in.). The driest months were: England and Wales, March 1742, February 1891, and June 1925 (each 0·1 in.); Scotland, August 1947 (0·2 in.); Northern Ireland, February 1932 (0·2 in.). The largest individual monthly value was Snowdon (Llyn Llydaw) in Caernarvonshire in October 1909 (56·54 in.). No rain was recorded at a number of stations in sixteen months since 1901: they include, since 1940, June 1942, August 1946, February and August 1947, March 1953, July 1955 and April 1957. The largest area over which there was no measurable rain in a calendar month was 6410 square miles in June 1925. The longest periods on record, with no rainfall, were in 1893, when some twenty stations in south-east England recorded no rain for a period of fifty days or more; locally there was a two months' drought from 17 March to 16 May.

The geographical distribution of extreme annual values is much influenced by topography, the largest values occurring in the mountainous regions and the smallest in the plains. For short periods, on the other hand, the largest values have occurred mainly in central, southern and eastern England where instability rainfall is most frequent. The largest fall on record for one day (9 h to 9 h) is 11.00 in. on 18 July 1955 at Martinstown (the Chantry), Dorset. The most widespread, heavy rain occurred in East Anglia on 25 and 26 August 1912, when 1939 square miles of country had more than 4 in., a volume of water equal to 154,133 million gallons.

The following list of maximum recorded falls in specified short periods refers to the period 1860 to 1960: (i) 1·25 in. in 5 minutes at Preston, Lancashire, on 10 August 1893; (ii) 3·15 in. in 30 minutes at Eskdalemuir, Dumfriesshire, on 26 July 1953; (iii) 3·63 in. in an hour at Maidenhead, Berkshire, on 2 July, 1913; (iv) 6·09 in. in 2 hours at Hewenden Reservoir, Bradford, Yorkshire, on 11 July 1956.

The local and seasonal distributions of rainfall over the British Isles are illustrated in the 'Climatological Atlas of the British Isles'.* 'Averages of rainfall for Great Britain and Northern Ireland 1916–50'† contains monthly and annual averages for 719 stations. The annual publication 'British Rainfall'‡ contains detailed information of rainfall amounts and duration and of the incidence of RAIN SPELLS, WET SPELLS, DRY SPELLS, DROUGHTS, etc. during each year. Heavy falls are classified, in ascending order of intensity, as 'noteworthy', 'remarkable', or 'very rare'. The classification concerned is described in 'British Rainfall', 1935. Checks with more recent data have not suggested that there is a need for a revision of the criteria.

rainfall station: A STATION at which the only regular measurements made are those of the amount of precipitation collected as rainfall. The large majority of the total of about 5500 stations in Great Britain and Northern Ireland which make returns of measured rainfall to the Meteorological Office are of this category.

rain-gauge: An instrument for measuring rainfall. In the 'Snowdon', 'Meteorological Office' and allied patterns, a funnel, usually 5 in. (or 8 in.) in diameter, is used to collect the rain. A brass tube, made of fairly narrow bore in order to minimize evaporation, conducts the collected water into the collecting vessel which may be a bottle or a copper can. The funnel is supported by means of an outer can, preferably of sheet copper. The rim is of stout brass with a sharp bevelled edge and the funnel is deep, with vertical sides to minimize errors due to splashing and to retain snow. The gauge is mounted in an open situation with its rim horizontal and 12 in. above ground level.

In self-recording gauges, such as the HYETOGRAPH and the 'tilting-siphon rain-gauge', the collected rainfall is usually made to raise a float to which is attached a pen which records on a chart wound on a clock-driven drum. In the latter instrument the float chamber is so arranged as to overbalance when full of water and to siphon out, thus returning the pen to the zero of the chart: a counterweight returns the empty chamber to its normal working position. See also EXPOSURE.

rain shadow: An area with a relatively small average rainfall due to sheltering by a range of hills from the prevailing rain-bearing winds. The phenomenon is noticeable in rainfall maps for months in which unusually strong westerly winds have predominated, e.g. to the east of Wales.

rain spell: Defined as a period of at least 15 consecutive days to each of which is credited 0·01in. or 0·2mm or more of RAINFALL. The definition is analogous to

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* London, Meteorological Office; Climatological atlas of the British Isles, London, HMSO, 1952.

† London, Meteorological Office; Averages of rainfall for Great Britain and Northern Ireland, London, HMSO, 1961.

‡ London, Meteorological Office; British Rainfall, London.

that of the term 'absolute DROUGHT'. During the 62 years, 1858–1919, there were seven rain spells at Camden Square (London). See also WET SPELL.

rainy season: A period of a month or more, recurring every year, which is characterized in a given region (generally tropical or subtropical) by relatively large amounts of precipitation for the region. Thus, for example, the period of the south-west MONSOON is the rainy season (or 'wet season') in most parts of south-east Asia, while winter is the rainy season in regions with a MEDITERRANEAN-TYPE CLIMATE.

random forecast: A type of FORECAST, sometimes used as a basis of comparison in the assessment of the success attained in forecasts made by conventional methods, which is based on chance selection of values of the meteorological elements concerned.

randomization: In a statistical experiment, the random selection of material under conditions calculated to avoid the possibility of bias in the selected material and in the conclusions drawn from the experiment.

random sampling: The chance selection of one or more items from a much larger group or 'population'. The object of such sampling is generally to determine, within defined limits, the average characteristics of the entire population.

range: The range of a group of numbers or of a continuous function is the difference between the highest and lowest values. The range of a harmonic motion is the sum of the maximum swings either side of the mean position, i.e. twice the 'amplitude' of the motion.

rare gases: An alternative for INERT GASES.

ravine wind: A wind which blows through a ravine or narrow valley penetrating a mountain barrier due to the existence of a pressure gradient directed from one side of the barrier to the other. Such winds may attain great strength because of FUNNELLING. An example is the ravine wind at Genoa, caused by a pressure difference between the Po valley and the Gulf of Genoa.

Rayleigh number: A non-dimensional parameter (Ra) which is critical in the static stability of fluids. It is defined by the equation

$$Ra = g\Delta T\alpha h^3/\nu a$$

where g is the acceleration of gravity, ΔT the initial temperature difference between the bottom of the fluid and the fluid at height h, α the coefficient of expansion, ν the kinematic VISCOSITY, and a the thermometric CONDUCTIVITY of the fluid. If the fluid state is such that Ra is less than a critical value, which depends to some extent on the nature of the fluid boundary conditions (free or rigid), any tendency for convection is damped out by viscosity and conductivity.

Rayleigh scattering: SCATTERING of ELECTROMAGNETIC RADIATION effected by spherical particles of radius less than about one-tenth the wavelength of the incident radiation. Two important cases arise in meteorology: (i) scattering of incident solar radiation by air molecules in a manner which explains the BLUE OF THE SKY; (ii) scattering of radar waves by raindrops in the atmosphere. Solid particles of appropriately limited radius also conform to this type of scattering.

According to Lord Rayleigh's theory of molecular scattering, the scattering coefficient (β) is given by:

$$\beta = \frac{32\pi^3(n-1)^2}{3N\lambda^4}$$

where n is the refractive index of the gas, N its number of molecules per unit volume, and λ the wavelength. The wavelength dependence of n is so slight that to a close approximation molecular scattering varies inversely as the fourth power of λ. Thus, molecular scattering of white sunlight is such that the scattering of blue light is about five times greater than that of the red light contained in the incident beam.

Rayleigh's theory of molecular scattering includes also the angular distribution of intensity of scattered light (symmetrical about a plane normal to the incident beam with maxima in the 'forward' and 'backward' directions) and of its state of POLARIZATION.

The radar reflectivity of raindrops of a size which satisfies the condition for Rayleigh scattering is given by

$$\frac{\pi^5}{\lambda^4}\left(\frac{n^2-1}{n^2+2}\right)^2 \Sigma N d^6$$

where λ is the radar wavelength, n the refractive index of the particle, N the number of particles per unit volume, and d their diameter.

RDF: Abbreviation for RADIO DIRECTION-FINDING.

Réaumur scale: A scale of temperature, now almost obsolete, introduced in 1731 by the French physicist Réaumur. On it the freezing-point of water is 0°, and the boiling-point 80°.

RECCO: A code word indicating that a report from a meteorological reconnaissance aircraft follows in figure code. See 'Handbook of weather messages.'*

recombination: The various processes by which positive and negative IONS, or positive ions and ELECTRONS, recombine to form neutral particles. The rate of recombination is expressed by a 'recombination coefficient' with dimensions L^3T^{-1}.

recurrence tendency: A recurrence tendency in a TIME SERIES is a feature which, though not strictly periodic, implies a greater-than-random frequency of separation of relatively high (or low) values in the series by a specific 'recurrence interval' of time.

A well known example in geophysics is the 27-day recurrence tendency in geomagnetic disturbance. This feature would not be revealed by PERIODOGRAM analysis of a geomagnetic disturbance time series, since it is associated with a solar cause which, after persisting for a few solar rotation periods of about 27 days, dies out before reappearing, after a variable time interval, very probably out of phase with the solar cause previously in operation. A SINGULARITY in meteorology is an example of a type of recurrence tendency which, though yet only quasi-periodic in nature, is not subject to such changes of phase.

recurvature (of tropical storm): See TROPICAL CYCLONE.

red flash: See GREEN FLASH.

reduction: In meteorology, the substitution of computed values for those directly observed, the purpose being to eliminate the effect of some particular factor or factors.

The reduction process is most commonly used to eliminate the effects of varying height on observed surface values of air temperature and pressure and is termed 'reduction to sea level'. Isobars drawn on surface synoptic charts, often also isotherms drawn on climatological charts, refer to values reduced in this way.

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* London, Meteorological Office; Handbook of weather messages. Parts II and III. London, HMSO, 1959.

Mean temperature values are sometimes reduced to sea level by addition to observed values at the rate of 1°C per 165 metres or 1°F per 300 feet of station elevation. Observed pressures are reduced to sea level by application of the ALTIMETER equation: the normal assumption in the latter case is that the mean temperature of the 'missing' air column is the same as the screen temperature, and involves negligible errors except for stations at heights greater than about 1000 feet above sea level.

reflexion: The return to the original medium of the RADIATION incident on a boundary between two media: 'total reflexion' is said to occur when all the incident radiation is returned. Reflexion is said to be 'specular' (or 'regular') if the reflecting boundary has irregularities which are small relative to the wavelength of the radiation, 'diffuse' if they are large relative to the wavelength. The two laws of reflexion—(i) incident ray, reflected ray and normal to the reflecting surface at the point of incidence lie in the same plane, and (ii) angle of incidence (that is, angle between incident ray and normal) equals angle of reflexion (angle between reflected ray and normal)—apply to specular reflexion. Radiation which is diffusely reflected, on the other hand, emerges in many different directions which are unrelated to the angle of incidence.

In meteorology, the reflecting power (ALBEDO) of surfaces is of fundamental importance in the heat balance that is achieved, either locally or in the earth-atmosphere system as a whole. The albedo has some important dependence on wavelength and on the angle of incidence of radiation.

Reflexion of light waves plays an important (in some cases the sole) part in some atmospheric optical phenomena: the reflexion of radio waves (radar) has a number of meteorological applications. *Also* 'reflection'.

refraction: The change of direction to which energy waves (light, sound or radio waves) are subject on passing through a medium of varying density (gradual bending) or through a boundary separating media of different densities (sudden bending).

The two laws of refraction state that (i) the incident and refracted rays and the normal to the surface of separation of two media at the point of incidence lie in the same plane, (ii) (Snell's law) the ratio of the sine of the angle of incidence (angle between incident ray and normal) to the sine of the angle of refraction (angle between refracted ray and normal) is a constant for any two media. (See also REFRACTIVE INDEX).

Among the many atmospheric optical phenomena in which refraction plays at least the major part are the delay of apparent SUNSET relative to the sunset time indicated by geometry, the apparent flattening of the sun or moon close to the horizon, the HALO, RAINBOW, MIRAGE. The associated colouring is due to the fact that the amount of bending suffered by light waves is wavelength dependent.

ANOMALOUS AUDIBILITY and ANOMALOUS RADIO PROPAGATION are examples of the refraction of sound and radio waves, respectively.

refractive index: The refractive index (n) of a medium is a non-dimensional measure of the degree of the REFRACTION of energy waves passing through the medium. It is given by the ratio of the velocity (c) of an electromagnetic wave in a vacuum to its velocity (v) in the medium, that is

$$n = c/v$$

Changes (continuous and discontinuous) of refractive index of the air with height are associated with lapse rates of temperature and humidity and cause various atmospheric optical effects and anomalous propagation of radar waves. Wavelength dependence of n causes dispersion of visible light and coloration of various of the optical phenomena.

The variation of n for dry air with air density (ρ) is represented by

$$(n^2 - 1)/(n^2 + 2)\rho = \text{constant}$$

Since $n \simeq 1$ the simple relation $(n - 1)/\rho = \text{constant}$ is normally assumed. The equation implies that n generally decreases with height and that rays which pass through the atmosphere, in a direction other than a normal, acquire curvature towards the denser part of the medium. For a ray travelling nearly horizontally in a horizontally stratified atmosphere the ray curvature is proportional to dn/dh (height gradient of refractive index).

n for dry air is for practical purposes given by the same formula for light and radio waves:

$$n - 1 = 79 \left(\frac{p}{T}\right) \times 10^{-6}$$

where p is in mb and T in °K.

For moist air at optical wavelengths n is given by:

$$(n-1)\,(Tp_0/T_0p) = 0.0002918 - 0{\cdot}000035r/(1 + r)$$

where T and p are air temperature and total pressure, T_0 and p_0 are the 'standard' values 273°K and 1013 mb, respectively, and r is humidity mixing ratio.

At radio wavelengths, n for moist air is given by:

$$n - 1 = \frac{79}{T}\left(p - \frac{e}{7} + \frac{4800e}{T}\right) \times 10^{-6}$$

where p and e are total pressure and vapour pressure (mb) and T is absolute temperature.

In the atmosphere $(n - 1)$ is of the order 300×10^{-6}: for convenience this is normally expressed as 300 M units, signifying 300 millionths.

For the standard conditions $T = 273$°K and $p = 1013$ mb and for wavelength $= 0.5893$ micron (sodium D line) the following are the values of n: dry air, 1·0002918; water vapour 1·000257. At 15°C and for the sodium D line relative to air, n for liquid water $= 1{\cdot}333$ and n for ice $= 1{\cdot}31$.

See also DIELECTRIC CONSTANT, MODIFIED REFRACTIVE INDEX.

refractometer: In meteorology, an instrument which employs a microwave radio technique for measuring the REFRACTIVE INDEX of the atmosphere. The instrument, carried in an aircraft, gives continuous recording of the resonant frequency of a cavity exposed to the ambient air, corresponding to changes of the quantity N, defined by $(n - 1) \times 10^6$ where n is the refractive index of the air.

regelation: Ice at a temperature near its MELTING-POINT may be melted by the application of excess pressure, owing to the reduction of the melting-point effected by such pressure. The re-solidification of the ice which accompanies the removal of the excess pressure (as in the making of snowballs) is known as 'regelation'.

Regional Association: The Regional Associations of the WORLD METEOROLOGICAL ORGANIZATION each comprise those members of the organization the networks of which lie in or extend into one of the six meteorological Regions of the world. The Regions comprise Africa, Asia, South America, North and Central America, south-west Pacific, Europe. Each Association meets as often as is necessary to comply with the policies of the WMO.

regression equation: An approximate relation, generally linear, connecting two or more quantities, derived from the CORRELATION coefficient.

relative contour: An alternative for THICKNESS line.

relative humidity: The relative humidity U (per cent) of moist air is defined by:

$$U = 100 \frac{e'}{e_w'}$$

where e' is the VAPOUR PRESSURE of the air and e_w' the saturation vapour pressure with respect to water at the same pressure and temperature. To a close approximation the corresponding ratios of the MIXING RATIO or of SPECIFIC HUMIDITY may be used. The actual relationship in terms of mixing ratio, for example, is

$$U = 100 \frac{r}{r_w} \cdot \frac{0{\cdot}62197 + r_w}{0{\cdot}62197 + r}$$

where r and r_w are mixing ratio and saturation mixing ratio, respectively.

Relative humidity may be measured indirectly from wet- and dry-bulb temperature readings, with the aid of humidity tables, or directly, as with a hair hygrometer. At temperatures below 0°C, relative humidity is evaluated with respect to supercooled water and not with respect to ice.

Relative humidity has a marked systematic diurnal variation opposite in phase to that of temperature, that is, it has a daily maximum around dawn and minimum in the afternoon. It has a less well marked annual variation, more especially in afternoon hours, also of opposite phase to that of temperature.

relative isohypse: An alternative for THICKNESS line.

relative vorticity: See VORTICITY.

report, meteorological: See WEATHER REPORT.

representativeness: A representative air-mass property is one that is typical of the air mass as a whole and so may be useful in AIR-MASS ANALYSIS. Some of the surface meteorological elements, in contrast to the same elements measured in the upper atmosphere, are readily changed by purely local influences and so are not representative: surface temperature is an example of such an element.

Réseau Mondial: An annual publication, now discontinued, of the Meteorological Office. It contained climatological data for all parts of the world on the basis of two stations per ten-degree square of latitude and longitude. The last volume published (in 1957) was that for 1934.

reshabar or **rrashaba:** A name meaning 'black wind' given to a strong, very gusty, north-easterly wind which blows down certain mountain ranges in southern Kurdistan. It is dry, comparatively hot in summer and cold in winter.

residence half-time: See RADIOACTIVE FALLOUT.

residual: The difference between an individual observation and the mean of a series, or the difference between an individual observation and the value derived from the adopted values of the constants which have been obtained by a discussion of the observations.

Thus an observed quantity may be known to be a function of variables x, y, z, and constants a, b, c, of the form of $ax + by + cz = l$. If a number n of observed values of l are given for known values of x, y and z, there will be n equations to determine the three constants a, b and c. The equation will not in general be accurately satisfied for any one observation, and the value of $l - (ax + by + cz)$ is the residual.

resonance: If a periodic force is applied to a system, resonance is said to occur when the period of the force comes into close accord with a FREE PERIOD of the system, resulting in an increase in the amplitude of vibration of the system. Resonance is advanced as an explanation of the large magnitude of the semi-diurnal atmospheric pressure wave. See ATMOSPHERIC TIDES.

resultant: The sum of a number of directed quantities or vectors. See VECTOR.

RETOP: In weather messages, a code word indicating that a report of upper air temperature and wind information, interchanged within the European region, follows in figure code. See 'Handbook of weather messages.'*

retrograde system: In synoptic meteorology, a pressure system which reverses its direction of movement.

An atmospheric wave is said to be retrograde if it moves in a direction opposite to that of the flow in which it lies.

return stroke: See LIGHTNING.

reversing layer: The lower part of the atmosphere of the SUN, comprising a layer of relatively cool gas extending about 1000 km outwards from the PHOTOSPHERE.

revolving storm: A term synonymous with an intense TROPICAL CYCLONE.

Reynolds number: An important parameter in the flow pattern of fluids, designated *Re* and defined by the non-dimensional quantity $\bar{u}d/\nu$, where $\bar{u}$ is a characteristic fluid velocity, d a characteristic length, and ν the kinematic viscosity of the fluid.

Reynolds (1883) showed experimentally that turbulent, as opposed to laminar, flow is not sustained for a value of *Re* less than about 2000. A critical value of *Re* similarly exists for the onset of TURBULENCE as the speed of fluid flow past a smooth body increases.

Reynolds stresses: Fundamental stresses (τ), also termed 'eddy shearing stresses', which operate within a turbulent fluid to transport momentum. τ has the DIMENSIONS $ML^{-1}T^{-2}$.

If u', v', w' are turbulent components of velocity (instantaneous departures from average) in rectangular co-ordinate directions x, y, z, respectively, and ρ is the fluid density at a point, then the additional shearing stresses in the x, y plane are $-\overline{\rho u'w'}$, $-\overline{\rho v'w'}$ in the x and y directions, respectively: corresponding shearing stresses act in the other two planes. (Bars represent time averages).

Non-zero values of τ depend on the existence of correlation between the component eddy velocities in the above products as, for example, a general association of gusts (u' positive) with descending air (w' negative). τ is generally assumed constant within about the lowest 25 metres of the atmosphere.

RHI: Abbreviation for range-height indicator. See RADAR METEOROLOGY.

ribbon lightning: A name applied to a markedly tortuous LIGHTNING discharge from cloud to ground.

Richardsom number: An important parameter in atmospheric TURBULENCE, designated *Ri* and defined by the non-dimensional quantity—

$$Ri = \frac{g}{T}\frac{(\partial T/\partial z)+\Gamma}{(\partial u/\partial z)^2} = \frac{g}{\theta}\frac{\partial\theta/\partial z}{(\partial u/\partial z)^2}$$

where g is the acceleration of gravity, Γ the dry adiabatic lapse rate, and $\partial T/\partial z$, $\partial\theta/\partial z$, $\partial u/\partial z$ the vertical height gradients of air temperature, potential temperature, wind velocity, respectively.

An equivalent 'flux form' of the parameter is

$$Ri = -\frac{gH}{c_pT\,\tau(\partial u/\partial z)}$$

* London, Meteorological Office; Handbook of weather messages. Parts II and III, London, HMSO, 1959.

where H is the flux of sensible heat, c_p is the specific heat of air at constant pressure, and τ is the REYNOLDS STRESS.

Richardson (1925)* investigated the rate of consumption of energy which is implied in vertical motion of fluid elements in relation to the rate of energy production associated with vertical wind shear. On certain assumptions he derived the criterion that turbulence will persist in a fluid if $Ri < 1$ and will subside if $Ri > 1$. While subsequent measurements have not yet verified as critical the value $Ri = 1$, or any other single value, Ri is employed as a fundamental stability parameter in the study of atmospheric turbulence and dynamical meteorology.

ridge: A ridge (of high pressure), also termed a 'wedge', is an extension of an ANTICYCLONE or high-pressure area shown on a weather chart, corresponding with a ridge running out from the side of a mountain (see Figure 27). It is the converse of a TROUGH of low pressure and is generally associated with fair, anticyclonic-type weather.

Maximum curvature of isobars occurs along the 'axis' of a ridge. One in which such maximum curvature is relatively small is termed a 'flat' ridge and tends to be a faster-moving isobaric feature than one in which the curvature is great.

rime: Deposit of white, rough ice crystals which forms when supercooled water droplets of fog come into contact with a solid object at a temperature below 0°C. The deposit grows out on the windward side of the object. The phenomenon seldom occurs at low levels in the British Isles because supercooled fogs are uncommon at these levels. It occurs, however, much more frequently on mountain tops. It is often popularly confused with HOAR FROST.

Ringelmann shades: A scale of shades, varying in degree of blackness, which is used by an observer to form a subjective comparison with the blackness of SMOKE emitted by a chimney and so afford an estimate of the concentration of solid material which is being emitted.

A numerical measure of the average smoke content of air over a period of time is obtained by measuring photoelectrically the reflectance of a stain made on white filter-paper by the passage of a measured quantity of air and comparing with the measured reflectance of the various Ringelmann shades.

roaring forties: A nautical expression used to denote the prevailing westerly winds of temperate latitudes (below 40°S) in the oceans of the southern hemisphere.

rocket lightning: A very rare and unexplained form of LIGHTNING in which the speed of propagation of the lightning stroke is slow enough to be perceptible to the eye.

rocket sounding: Exploration of the earth's atmosphere up to heights of several hundred kilometres by means of instruments carried by a rocket. Among the geophysical measurements obtained from such soundings are those of atmospheric pressure, air temperature, density and composition, winds, solar radiation, electrical properties, and the earth's magnetic field. The data are obtained mainly by radio telemetering, or by recovery of photographic record, etc., after descent by parachute.

rockoon sounding: Exploration of the earth's atmosphere by a small instrumented rocket which is carried aloft by a large balloon to a pre-determined height where it floats till fired by means of a radio relay operated from the ground at the moment when some particular event, e.g. a SOLAR FLARE or AURORA, is seen to occur.

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* RICHARDSON, L. F.; Turbulence and vertical temperature difference near trees. *Phil. Mag., London,* **49**, 1925, p. 81.

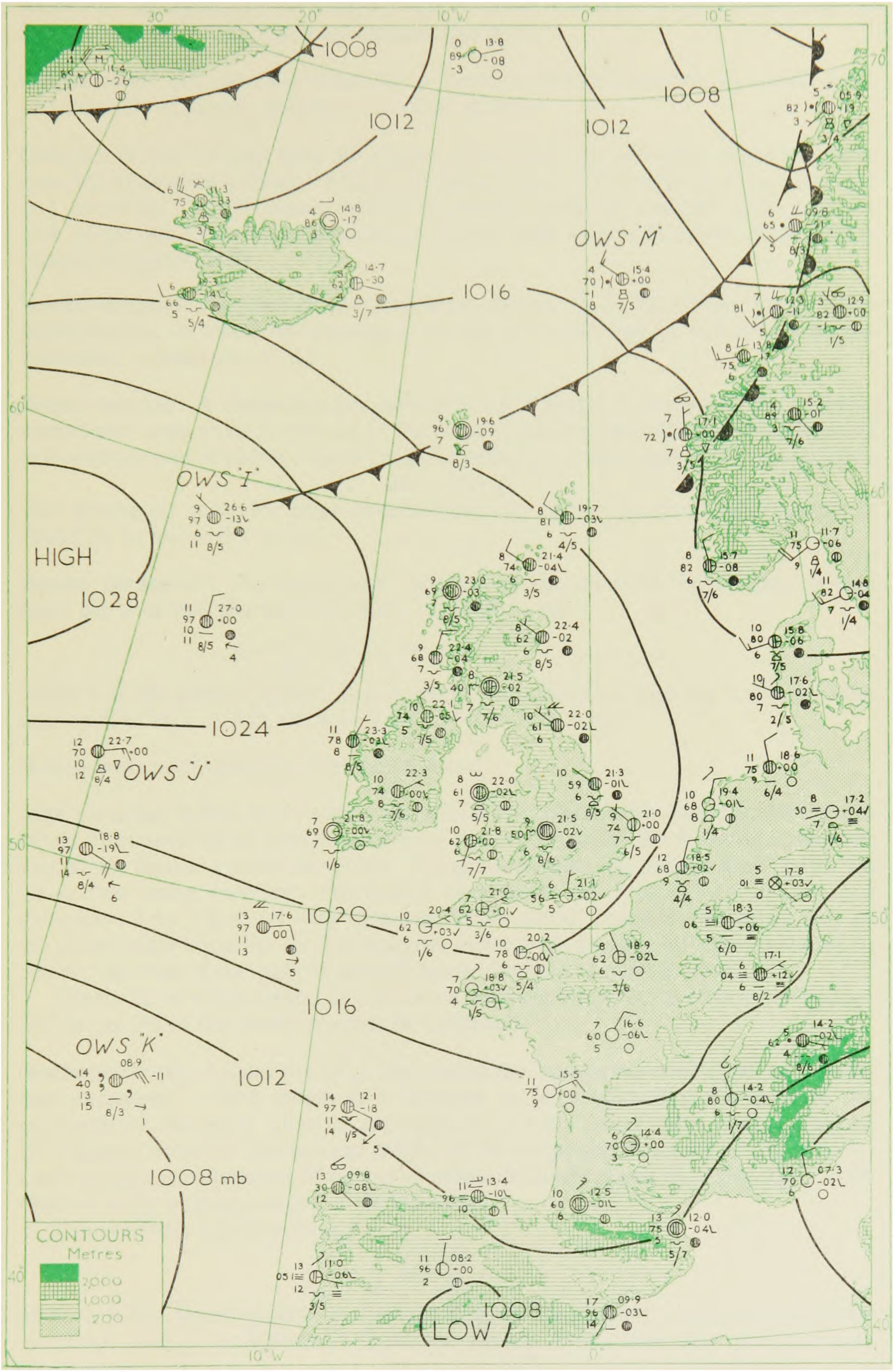

FIGURE 27—Ridge extending over the British Isles from the west, 0600 GMT, 22 May 1961.

ROFOR: An indicator word for a route forecast of meteorological conditions, in figure code. See 'Handbook of weather messages.'*

roll cumulus: An obsolete term for a form of STRATOCUMULUS in which long, parallel rolls of cloud alternate with clear spaces.

röntgen: A unit of intensity of GAMMA RADIATION (or X-RAYS), defined as that quantity of gamma radiation which will form $1{\cdot}61 \times 10^{12}$ ION pairs when absorbed in 1 gm of air. The biological hazard of gamma radiation is closely related to this unit of dosage since harmful chemical effects follow the ionization of molecules present in animal cells.

Rossby diagram: An AEROLOGICAL DIAGRAM, devised by C. G. Rossby for air-mass identification, in which the abscissa is MIXING RATIO (r) and the ordinate is partial POTENTIAL TEMPERATURE (θ_d).

Rossby number: A dimensionless parameter (Ro) found in studies of the DISHPAN EXPERIMENT type to be important in the form of relative fluid motion (U) generated in a rotating pan of radius r and of angular velocity Ω: Ro is defined by the equation

$$Ro = U/r\Omega$$

The analogous ratio for large-scale relative air motion on the rotating earth is found to be about 0·1 to 0·2.

Rossby parameter: The northward variation of the CORIOLIS PARAMETER, arising from the spherical shape of the earth. It is given by

$$\beta = \frac{d}{dy}(2\Omega \sin \varphi) = \frac{2 \quad \cos \varphi}{a}$$

where a is the earth's radius. It is sometimes assumed to have the constant value appropriate to $\varphi = 45°$, i.e. $\beta = 1{\cdot}619 \times 10^{-13}\ \text{cm}^{-1}\ \text{sec}^{-1}$.

Rossby wave: An alternative for LONG WAVE.

rotor: A large, closed EDDY with a horizontal axis which is produced in the lee of a range of mountains or hills crossed by a stable airstream. Such closed eddies are sometimes formed under LEE WAVES of large amplitude, the surface wind under the wave crest being reversed. Horizontal dimensions are 3 to 10 km and vertical dimension 1 to 3 km. A very turbulent 'rotor cloud' forms in the upper part of the closed eddy when the air is sufficiently moist, with an apparent motion round its centre: the axis of the eddy is usually below the base of such a cloud.

Examples of rotors occur in connexion with the HELM WIND ('helm bar' cloud) and in the lee of the Sierra Nevada in California.

roughness length: A quantity (Z_0), also called the 'roughness coefficient' or 'roughness parameter', which enters as a constant of integration into the form of the LOGARITHMIC VELOCITY PROFILE appropriate to 'fully rough' flow near a surface. Z_0 is proportional to the average height of the roughness elements of the surface: wind tunnel measurements of flow over grains of sand suggest the value $Z_0 = \varepsilon/30$, where ε is the average height of the obstacles.

The equation which defines Z_0 is

$$\frac{u}{u_*} = \frac{1}{k} \log_e \frac{Z}{Z_0}$$

where u is the mean velocity at distance Z from the boundary, u_* is the FRICTION VELOCITY, and k is Kármán's constant (about 0·4). See also AERODYNAMIC ROUGHNESS.

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* London, Meteorological Office; Handbook of weather messages. Parts I, II and III. London, HMSO, 1959.

running means: In a series of numbers a_1, a_2, a_3 etc., the '3-term running means' (sometimes termed 'overlapping means' or 'moving averages') are $(a_1 + a_2 + a_3)/3$, $(a_2 + a_3 + a_4)/3$ etc. Similarly, n-term running means may be formed, where n is any integer less than the total of numbers in the series: the greater n is, the greater the 'smoothing' of the original data. Occasionally, weighted means may be calculated, chief weight being given to the more central term or terms.

Where, in geophysics, the original numbers form a TIME SERIES, running means may be used either (i) to eliminate from the original series a variation of known periodicity (e.g. by the formation of 12-term running means from a series of successive mean monthly temperatures), or (ii) to smooth out short-period fluctuations and so reveal to better effect any long-period fluctuation present in the original series. Theory and experiment show, however, that spurious PERIODICITY may be introduced by the use of data which have been smoothed by the formation of running means.

run-off: That portion of the rainfall over a DRAINAGE AREA which is discharged from the area in the form of a stream or streams.

run-of-wind anemometer: See ANEMOMETER.

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St. Elmo's fire: 'A more or less continuous, luminous electrical discharge of weak or moderate intensity in the atmosphere, emanating from elevated objects at the earth's surface (lightning conductors, wind vanes, masts of ships) or from aircraft in flight (wing tips, propellers, etc.).'*

This phenomenon is usually bluish or greenish in colour, sometimes white or violet. It is accompanied by a crackling sound and occurs when the electrical field in the neighbourhood of the object becomes very strong, as when a CUMULONIMBUS cloud is overhead. The phenomenon is also termed 'corposant', i.e. ghost-like, because of its once-supposed supernatural nature.

St. Luke's summer: A period of fine weather which is popularly supposed to occur about the time of St. Luke's day, 18 October.

St. Martin's summer: A period of fine weather which is popularly supposed to occur about the time of St. Martin's day, 11 November.

St. Swithin's day: A well known example of British weather lore is to the effect that if rain falls on St. Swithin's day (15 July) then, in the same locality, each of the next forty days will also have some rain. Rainfall records lend no support to this tradition.

salinity: The salinity of a natural water surface, such as sea water, is usually expressed in parts per thousand by weight. Thus a salinity of 35 per mille (written 35°/₀₀) indicates that there are 35 lb of salt in 1000 lb of sea water. Since the total dissolved solids are difficult to determine directly with accuracy, salinity is derived in practice by applying factors to the specific gravity or to the halide content, which can be exactly measured (dissolved solids are present in constant ratios).

The salinity value of 35 per mille is a rough average for surface ocean water. Salinity varies systematically by a few per cent with latitude and is subject also to small casual and systematic time variations.

Depression of the freezing-point temperature and of the temperature of maximum density increase with increase of salinity: for a salinity of 35 per mille the freezing-point temperature is −1·9°C and the temperature of maximum density is −3·5°C (compared with 0°C and 4°C, respectively, for pure water).

sand pillar: A rarely used alternative for DUST WHIRL.

sandstorm: A storm in which relatively coarse sand is raised by strong winds to a height which seldom exceeds 50–100 feet and surface visibility is reduced to low limits (less than 1100 yards for the purpose of a synoptic report).

sastruga (also zastruga): (From the Russian.) An irregularity or wave formation caused by persistent winds on a snow surface. The size varies according to the force and duration of the wind, and the state of the snow surface in which it is formed.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 76.

satellite sounding: Satellites launched from the earth have since October 1957 yielded much important geophysical information both directly (by means of automatic instruments) and indirectly (by inferences drawn from the precise path of the satellite).

A satellite of mass m, in a circular orbit at distance R from the earth's centre, has a critical velocity (v) such that the CENTRIFUGAL FORCE is exactly balanced by the force of GRAVITY acting on it. Where r is the earth's radius and g the force of gravity at the earth's surface, the balance equation is $mv^2/R = mg(r/R)^2$, whence $v^2 = gr^2/R$. For $(R - r) = 300$ miles, v is about 17,000 m.p.h. and the corresponding period of revolution ($2\pi R/v$) is about 103 minutes. Since the achievement of a circular orbit requires great precision of the final velocity imparted to the satellite, the orbit is, in practice, more or less elliptical: from the geophysical viewpoint this has the advantage that a range of heights is covered by the satellite. The frictional drag exerted on the satellite by the earth's very high atmosphere causes its orbital radius gradually to decrease till it is eventually burnt up in the denser lower atmosphere.

Among the direct meteorological measurements made by satellites are those of solar and terrestrial radiation, earth albedo, and cloud distribution. Air density at great heights and the shape and size of the earth have been calculated from accurate tracking of the orbit. Other geophysical measurements have included those of the earth's magnetic field, cosmic rays, meteor impact, and properties of the ionosphere.

saturated soil: A saturated soil, or waterlogged soil, is one in which all the soil pores, including those which in a healthy soil contain air, are filled with water.

saturation: A moist air sample is said to be saturated, with respect to water or to ice, if its composition is such that it can coexist in neutral equilibrium with a plane surface of pure condensed phase, water or ice, at the same temperature and pressure as the sample.

To a high degree of approximation the capacity of air to hold water in the form of vapour depends only on temperature: at temperatures below 0°C, however, an important factor in the equilibrium conditions is the phase (liquid or solid) of the water substance (see VAPOUR PRESSURE). A sample of air is said to be 'supersaturated' if it contains more than enough water vapour to saturate it at its existing temperature. Owing to the presence of condensation nuclei, an appreciable degree of supersaturation with respect to water is rarely observed in the atmosphere.

saturation (or saturated) adiabatic (or adiabat): Line on an AEROLOGICAL DIAGRAM representing the saturation adiabatic lapse rate. See ADIABATIC.

saturation deficit: The difference between the actual VAPOUR PRESSURE of a moist air sample at a given temperature and the saturation vapour pressure corresponding to that temperature.

savanna: The term applied to a type of tropical CLIMATE, with a wet and a dry season, in which the most common form of vegetation is the tall tropical grass 'savanna'.

SCA: An abbreviation for 'sudden cosmic (noise) anomaly'. When a SOLAR FLARE occurs, ionospheric absorption of the cosmic radio waves entering the earth's atmosphere suddenly increases in the sunlit hemisphere and there is an associated decrease of the radio noise level (SCA) recorded at the earth's surface. See also SID.

scalar: A scalar quantity is one that is completely specified by its magnitude, expressed in a given system of units (as opposed to a directed or VECTOR quantity such as wind velocity). Meteorological examples of a scalar quantity are pressure, temperature, divergence of wind velocity.

scale height: The equivalent height (H) of a hypothetical atmosphere in which air density is constant (see HOMOGENEOUS ATMOSPHERE). It is defined by the equation:

$$\frac{dp}{p} = -\frac{1}{H}dh$$

where $H = kT/mg$ (k = Boltzmann's constant = $1{\cdot}3804 \times 10^{-16}$ c.g.s. units, m = mean molecular mass, T = absolute temperature at base of atmosphere and g = acceleration of gravity).

The height variations of atmospheric scale height (termed then 'local scale height') provide a measure of the proportional variations of pressure with height, and mainly reflect corresponding height variations of temperature and composition (to a minor extent of gravity). Local scale height is a concept mainly used in studies of the high atmosphere and is a quantity which may be inferred from the vertical sounding of the ionosphere.

scatter diagram: A graphical point plot of corresponding pairs of associated values of two variables (ordinate and abscissa). A diagram on which, for example, the points are closely grouped round a line inclined to both axes indicates a near-linear relationship between the two variables. A diagram on which the points are randomly distributed indicates no relationship between the variables.

scattering: The process by which some of the electromagnetic RADIATION incident on particles, of molecular size upwards, which are suspended in a medium, is dispersed in all directions. The scattering process is one which gives rise to a diminution of the intensity of an incident beam of radiation: the measure of this effect—the 'scattering coefficient '(β)—is defined by the equation (analogous to the case of ABSORPTION)

$$I = I_0 e^{-\beta x}$$

where I_0 is the intensity of incident radiation and I the intensity after a path of length x through the scattering (non-absorbing) medium. The 'scattering cross-section' of a scattering particle is the area normal to a beam of radiation which would intercept the same amount of radiation as that actually scattered by the particle.

In meteorology, radiation which has been subject to scattering is generally termed DIFFUSE RADIATION. Such radiation may have been scattered once or more than once—so-called single or multiple scattering, respectively: the terms primary, secondary, tertiary scattering are also used, as appropriate, while in some usages secondary scattering signifies multiple scattering.

Scattering is a complex phenomenon which depends mainly on the ratio of the size of scattering particle to the wavelength of the incident radiation but depends also on the refractive index, shape and composition of the scattering particle. Atmospheric scattering is usually classified as either molecular scattering or that effected by haze particles or water droplets. See RAYLEIGH SCATTERING, MIE SCATTERING, POLARIZATION.

scintillation (of stars): Rapid variations of apparent brightness ('twinkling') of stars, much more marked in stars near the horizon than in those near the zenith. Variations of colour may also occur at altitudes less than about 50°. The phenomenon is caused by small variations of REFRACTIVE INDEX of air associated with atmospheric inhomogeneities, mainly in the low atmosphere. A similar effect is visible at times in terrestrial objects, for example the shimmering of objects near the earth's surface on a hot day.

scirocco: A warm, southerly wind in the Mediterranean region. Near the north coast of Africa the wind is hot and dry and often carries much dust. After crossing the Mediterranean, the scirocco reaches the European coast as a moist wind and is often associated with low stratus.

Scotch mist: A combination of thick mist and drizzle, so called because it is most commonly experienced in the hillier districts of much of Scotland: it also affects at times low-lying districts of the west and north. In its most typical form it is associated with a moist stream of maritime tropical air.

In the uplands of the Devon–Cornwall peninsula the same phenomenon, which is there very frequent, is known as 'mizzle'.

scud: A mainly nautical term for ragged fragments of low cloud, often moving rapidly in a strong wind below rain clouds. The meteorological term is stratus fractus.

SEA: An abbreviation for 'sudden enhancement of atmospherics'. When a SOLAR FLARE occurs, the extra ionization of the D-layer in the sunlit hemisphere makes it a more efficient reflector of the radio waves emitted at times of lightning flashes: there is, therefore, an associated sudden increase in the recorded level of distant atmospherics (SEA). See also SID.

sea-breeze: See LAND- AND SEA-BREEZES.

sea disturbance: The degree of sea disturbance is reported in a 'state of sea' code in which the scale number increases from 0 to 9 according to the average wave height. The specifications are: 0, glassy; 1, rippled; 2, smooth; 3, slight; 4, moderate; 5, rough; 6, very rough; 7, high; 8, very high; 9, phenomenal. Scale number 5, for example, corresponds to waves of average height 2·5 to 4 metres, and scale number 9 to an average height of over 14 metres.

sea level: Owing to waves, swell, tides and varying atmospheric static pressure, the actual LEVEL of the sea is constantly changing. A 'mean sea level' at any place may be determined, such that short period fluctuations of level are eliminated, by averaging coastal observations of tide level over a period of years. The length of period required to obtain a suitable mean value varies considerably from place to place because of local variation of the amplitude of fluctuation about the mean position.

The present datum mean sea level—often referred to simply as 'sea level'—used in Great Britain, with reference to which contour levels on ordnance survey maps of Britain are shown, is based on observations at Newlyn in Cornwall, on the edge of the Atlantic. This datum is 0·13 feet below the Liverpool datum previously used. The permanent land survey datum is not the mean-sea-level datum itself but is referred to permanent bench marks in the neighbourhood of the tidal gauge. Land survey datums of other countries do not all depend on mean sea level. That used in Ireland, for example, refers to a particular low-water datum in Dublin bay and is estimated to be about 8 feet lower than that of Newlyn.

World sea level, as given by the average of observations in many places, varies in response to (i) changes of average temperature of the oceans in depth, with accompanying expansion or contraction, and (ii) melting or accretion of ice-caps and glaciers. There is evidence that a world-wide ('eustatic') rise of almost 100 m occurred between 15,000 and 5000 years ago because of the melting of the ice sheets of the last glaciation, and that subsequent changes have been relatively slight, the present level being lower than that 5000 years ago by a few metres. On a shorter time-scale, it is considered that a eustatic fall between about 1680 and 1850 was followed (up to at least 1930) by a more rapid rise to about the 1680 level: in the early years of the present century the rise was at the rate of about 10 mm/decade.

Mean world changes of sea level may be locally masked because of local ('isostatic') changes in response to movements of the land and in the ocean floor and by modification of coastline. Thus, for example, sea level in the Thames Estuary is apparently some 8–10 feet (3 metres) higher than in Roman times. This is a local effect produced mainly by down-warping of the land—possibly a form of compensatory movement as Scotland and Scandinavia continue to rise by isostatic recovery from the depression caused by the former load of ice.

sea smoke: An alternative for ARCTIC SEA SMOKE.

seasons: In meteorology, the manner of the division of the year into seasons for climatological purposes varies with latitude. In middle latitudes the normal division corresponds to that of the 'farmer's year': in the northern hemisphere the divisions made are autumn—September, October, November; winter—December, January, February; spring—March, April, May; summer—June, July, August.

In the tropics, the terms 'winter' and 'summer' lose their higher-latitude significance and a division into seasons is usually made in terms of rainfall amount or, in places, the associated wind direction—thus, 'dry season' and 'rainy season' or 'north-east monsoon' and 'south-west monsoon' in India. In the continental subtropical regions the natural seasons are usually defined in terms of temperature (cold and hot), or rainfall (dry and rainy), or both.

In a country of temperate climate such as the British Isles, the seasonal temperature changes progress much more gradually than in continental regions of the same latitude. In polar regions, the transition from winter to summer and vice versa is so sudden that spring and autumn largely disappear.

sea temperature: The normal methods of measuring sea temperature are: (i) to draw water in a specially designed bucket from the ship's side, forward of all ejection pipes, and to read the temperature of the sample with a specially designed thermometer ('bucket method'); or (ii) to read the temperature of the engine-room intake water ('condenser intake method'). The water temperatures so measured are, respectively, a mean value in the surface layer of depth about one foot, and a value at a depth of several feet. Either is referred to as a 'sea surface temperature' to which they are thought to approximate except when the sea is calm. No simple method of measuring the temperature of the actual surface of the water has yet been devised.

The mean annual sea surface temperature exceeds 27°C (80°F) over a broad belt of the equatorial region, and is somewhat less than −1°C (30°F) in the polar regions. The run of the isotherms varies in the two hemispheres and in the different oceans. The seasonal range of temperature is of the order of 6°C (10°F) in both polar and equatorial regions, and is greater in middle latitudes, where for the most part it lies between 6°C and 16°C (10°F and 30°F). The greatest range, some 30°C (50°F or more), is found in small areas, extending to the coast of the western North Atlantic and western North Pacific Oceans. The diurnal variation of sea surface temperature is very small, 1°F or less.

secondary cold front: The development of a TROUGH or troughs of low pressure within the cold AIR MASS lying in the rear of a deep depression is relatively common. On those occasions on which a trough appears to mark the line of advance of colder air (due to rather different recent histories of the air masses on either side of the trough) the trough line is termed a 'secondary cold front'.

secondary depression: A secondary depression is one which, forming within the region of circulation of another depression, is, at least on initial formation, of higher central pressure than the other ('primary') depression. The formation of the closed circulation which defines the 'secondary' is preceded by a widening of the isobars in the region concerned.

Most secondaries of middle latitudes form at fronts—see COLD-FRONT WAVE, WARM-FRONT WAVE, COLD-OCCLUSION DEPRESSION, WARM-OCCLUSION DEPRESSION—but non-frontal secondaries also form, more especially in an unstable air mass, as, for example, the POLAR AIR DEPRESSION. In general, a secondary deepens at the expense of the primary depression: on some occasions, mainly with the cold-front wave, the secondary deepens to such an extent as to absorb the original primary depression. (See Figure 28.)

secular trend: In statistics, a persistent tendency for a variate to increase or decrease with the passage of time, apart from irregular variations of shorter period. A secular trend is generally revealed more clearly by smoothing the data sufficiently by the formation of RUNNING MEANS.

A secular trend of a meteorological element cannot continue indefinitely, though it may do so over an entire period for which statistics are available. In the available statistics of mean January temperature for central England there is, however, at least one apparent reversal of a secular trend: this trend was negative throughout most of the 18th century and positive in the 19th and early 20th centuries.

seepage gauge: See PERCOLATION.

seiche: A tidal oscillation of the waters of inland lakes, very variable in period and amplitude. Among probable causes of the phenomenon are winds, earth tremors, and atmospheric oscillations of the type revealed by a microbarograph. Temperature seiches—abrupt changes of temperature below a lake surface, with associated wave motion in the layer of transition—have also been observed.

seismogram: The record of a SEISMOGRAPH.

seismograph: An instrument which records ground tremors, in particular, EARTHQUAKES. It consists essentially of a damped pendulum, the axis of which is rigidly fixed to the ground and which oscillates in response to a specific component of ground movement. At a seismological observatory three instruments are used to measure the independent components in the north-south, east-west, vertical directions, respectively. Recording is made on a very open time-scale.

seismology: The science concerned with the measurement and analysis of earth tremors and, indirectly, with the nature of the earth's interior revealed by such analysis.

Observational data on earth tremors are provided by the SEISMOGRAPH recordings operated at some 600 observatories distributed over the world. Such data are found to accord with the mathematical theory which relates to the propagation of disturbances in a deformable, perfectly elastic medium. This theory postulates that the shock waves or 'seismic waves', which transport energy from the focal regions of an earthquake, are of two main types: (i) waves which travel over the earth's surface; and (ii) 'body' waves which travel downwards and which subdivide into the primary or 'push' (*P*) longitudinal waves, and the secondary or 'shake' (*S*) transverse waves. *P* waves move faster than *S* waves by some 50 per cent, while *S* waves move faster than surface waves. Thus, when the epicentre of an earthquake is at a distance of one quarter of the earth's circumference, the times of passage of the *P*, *S* and surface waves are, respectively, about 13 min 16 sec, 24 min 14 sec, and 43 min 30 sec. The *P* and *S* waves usually constitute 'preliminary tremors' to the surface waves which are of much larger amplitude: in the more unusual case of a deep focus earthquake, the surface waves are relatively small.

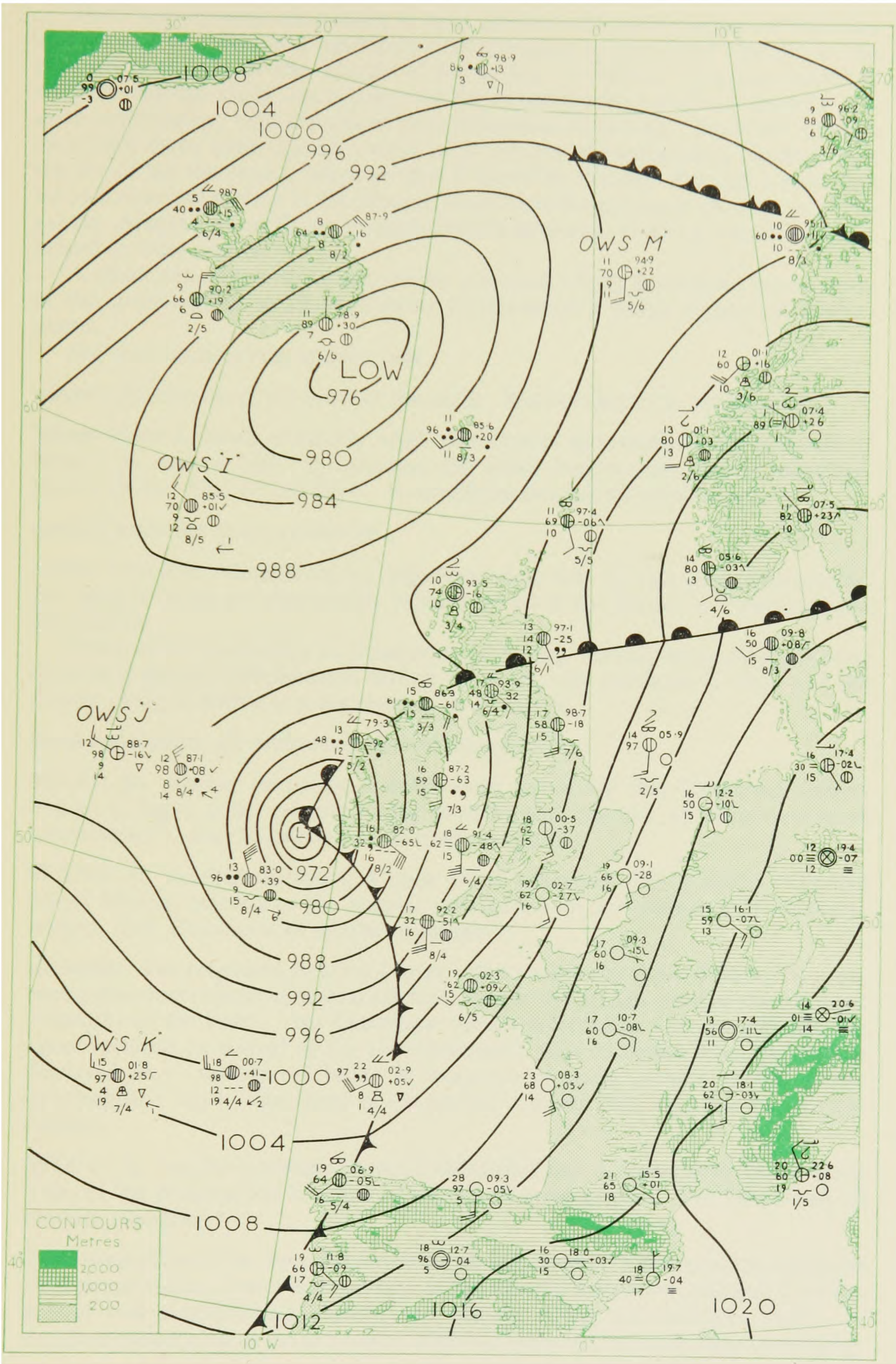

FIGURE 28—Secondary depression centred off Irish coast, 0600 GMT, 16 September 1961.

The *P* and *S* waves are subject to both gradual and rapid changes of direction and speed (refraction and reflexion), corresponding to associated changes in the physical properties of the interior of the earth. A complex situation results in which waves frequently take a large number of paths from a single earthquake to a given observatory, with associated time differences of arrival. The study of such data from many observatories over a large number of earthquakes, together with the use of the theoretical inference that *S* waves do not pass through a fluid, has led to a coherent picture of the physical nature and properties of the interior of the EARTH. Analysis of artificially produced earth tremors, as by large explosions, has helped in these studies.

A direct link with both oceanography and meteorology is provided by the study of the quasi-regular small oscillations ('microseisms') which appear on seismograms.

See also EARTHQUAKE, MICROSEISMS.

seisms: Oscillations of the crust of the earth. See EARTHQUAKES, MICROSEISMS.

seistan wind: A strong northerly wind which blows in summer in the province of Seistan, in eastern Iran. It continues for about four months and is, therefore, known as the 'wind of 120 days'. It sometimes reaches hurricane force.

sensible heat: See HEAT, ENTHALPY.

serein: Fine rain falling from an apparently clear sky. In this rare phenomenon, the cloud droplets are presumably evaporated when the larger precipitation drops are formed.

Much more commonly, in conditions of strong vertical wind shear between cloud and ground, precipitation arrives when the sky overhead is clear and the shower cloud is visible at a lower angle of elevation.

serial correlation: An alternative for AUTOCORRELATION.

SFAZI: In weather messages, a code word indicating that individual reports follow, in figure code, relating to the position and intensity of storm centres of ATMOSPHERICS. See 'Handbook of weather messages'.*

SFAZU: In weather messages, a code word indicating that a coded collective report follows, relating to the angular distribution of ATMOSPHERICS at recording centres. See 'Handbook of weather messages'.*

sferics fix: The estimated location ('foyer') of a LIGHTNING flash, deduced by combining the observations at several stations (four in the British Isles) of the direction (azimuth) of the flash. Two directional aerials are used at each station and the signal received on arrival of the electromagnetic wave radiation from the flash is displayed on a cathode ray tube. A frequency of about 10 kc/s (30,000 metres wavelength) is used. The range of the system is about 2000 km. See also ATMOSPHERICS.

SFLOC: In weather messages, a word indicating that a report follows, in figure code, of the geographical location of sources of atmospherics. See 'Handbook of weather messages'.*

shade temperature: The temperature of the air indicated by a thermometer sheltered from precipitation, from the direct rays of the sun and from heat radiation from the ground and neighbouring objects, and around which air circulates freely. A standard shelter such as the STEVENSON SCREEN is intended to satisfy these conditions.

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* London, Meteorological Office; Handbook of weather messages. Part II. London, HMSO, 1959.

shadow of the earth: A steely-blue segment darker than the rest of the sky rises from the eastern horizon just after sunset, encroaching on and soon obliterating the COUNTERGLOW. This is the shadow thrown by the solid earth on the atmosphere: all light received by an observer from that part of the atmosphere within the earth's shadow has been scattered more than once. The edge of the shadow weakens as TWILIGHT progresses and, except in a very clean atmosphere, is indistinguishable well before its passage through the zenith. A similar shadow, descending to the western horizon, occurs just before sunrise.

shamal: A north-westerly wind which blows in summer over Iraq and the Persian Gulf. It is often strong during the day-time but decreases at night.

shear: See WIND SHEAR.

shear-gravity wave: A wave disturbance which forms at the boundary between two atmospheric layers of different densities and moving with different speeds. Theory based on an incompressible atmosphere, specifies a critical wavelength (of the order 10 km for typical atmospheric values of density and wind discontinuities) below which such waves are unstable and above which they are stable. Wind shear is therefore inadequate by itself to account for the development of frontal wave depressions.

shear hodograph: See HODOGRAPH.

shearing instability: That type of dynamical instability which arises at the boundary between two atmospheric layers moving with different speeds or in a layer containing WIND SHEAR.

shearing stress: An alternative for REYNOLDS STRESS.

shear wave: An unstable type of wave which forms at the boundary between two atmospheric layers moving with different speeds.

sheet clouds: See LAYER CLOUDS.

sheet lightning: The popular name applied to a 'cloud discharge' form of LIGHTNING in which the emitted light appears diffuse and there is an apparent absence of a main channel because of the obscuring effect of the cloud.

shelter-belt: A term which is sometimes used synonymously with WIND-BREAK, but which is more usually now employed in those cases where protection against wind is provided by a belt of trees. Where the protection is afforded by shrubs or hedge, such a term as 'shelter-hedge' is often employed. See WIND-BREAK.

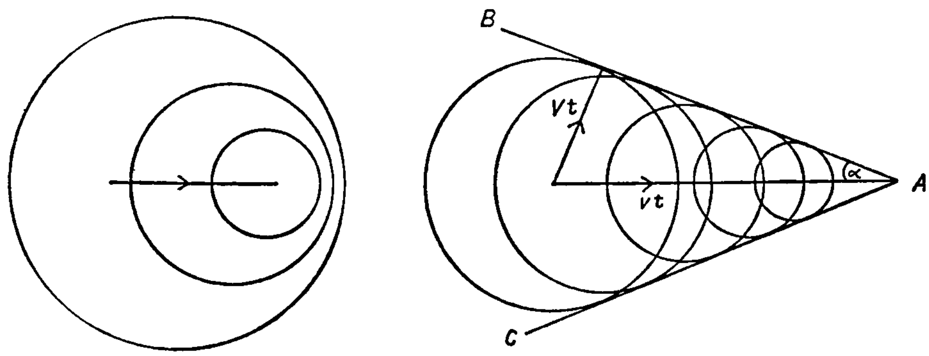
shimmer: The apparent distortion of terrestrial objects due to atmospheric inhomogeneities at low levels. It is also referred to as 'atmospheric boil'.

shock wave: A thin layer of a medium (in particular, the atmosphere) in which the temperature, pressure, density, and velocity suddenly jump to new values. Such an effect is produced, for example, by the sudden outward movement of air particles from the site of an explosion, or by the passage of an object through air at a supersonic speed. In the former case, the passage of the shock wave is marked by a jump to high values of air pressure and temperature. This is quickly followed (at places beyond a critical distance from the explosion) by a rather longer-lived period in which the pressure and temperature fall to values lower than those which prevailed before the arrival of the wave. These phases are termed the 'compression' and 'suction' phases, respectively.

In atmospheric flight at subsonic speeds, i.e. v (speed of flight) $< V$ (speed of sound), pressure disturbances are propagated outwards through the atmosphere in all directions from the moving object as a series of non-overlapping spherical waves —see Figure 29(*a*). In contrast, the spherical disturbance waves emitted at successive time intervals by an object moving at a supersonic speed ($v > V$) intersect and are contained within a solid cone behind the object, the air in advance of the object being unaffected by the motion—see Figure 29(*b*). The semi-angle (α) of the cone ('Mach angle') is given by

$$\sin \alpha = \frac{Vt}{vt} = \frac{V}{v} = \frac{1}{M}$$

where M is the MACH NUMBER. Lines AB and AC in Figure 29(*b*) are the two-dimensional representation of so-called 'Mach lines' within which the cone is contained. The position of the lines remains unchanged with respect to the moving



(*a*) Subsonic speeds (*b*) Supersonic speeds

FIGURE 29—Shock waves.

body. Density of intersection of successive waves and, therefore, pressure disturbance are greatest along these lines. The waves propagated by the body advance in a direction normal to the surface of the cone with the speed of sound and are heard as a sharp report, coinciding with the arrival of the 'shock wave'.

short-wave radiation: In its common meteorological usage, is solar radiation received near the earth's surface, of maximum intensity at about 0·5 micron (μ) and confined within the approximate limits 0·29 and 4μ. The term is used in contrast to the LONG-WAVE RADIATION emitted at terrestrial temperatures.

shower: In weather reports, solid or liquid precipitation from a CONVECTION cloud is designated a shower and is distinguished in such reports from the precipitation, intermittent or continuous, from layer clouds. Showers are often characterized by short duration and rapid fluctuations of intensity. Hail invariably implies a shower, while drizzle very seldom does.

For synoptic purposes, rain showers are classified as 'slight', 'moderate', 'heavy' or 'violent' for the rates of accumulation 0–2, 2–10, 10–50, or greater than 50 mm/hr, respectively.

shred cloud: A term sometimes applied to the cloud species FLOCCUS.

Siberian anticyclone: A cold ANTICYCLONE which is a feature of the winter sea-level mean pressure distribution. In a January mean pressure chart, for example, it is represented by a centre over east central Eurasia, with central pressure over 1036 mb.

SID: An abbreviation for 'sudden ionospheric disturbance', which is a collective name for the effects of SCA, SEA, SPA, SWF and MAGNETIC CROCHET. These effects are due to the extra ionization produced suddenly in the low ionosphere at the time of a SOLAR FLARE. They are confined to the sunlit hemisphere, seldom last longer than an hour, and vary in intensity and duration approximately in relation to the associated flare intensity.

sidereal period: The sidereal period of a planet or the moon is the time required for the body to make a complete circuit of its orbit, with respect to the stars. See also DAY.

significance: In statistics, the degree to which support is lent to a particular hypothesis, by the results of a series of observations, is normally assessed by testing the 'null hypothesis' that that aspect of the observations apparently supporting the hypothesis was, in fact, produced by chance fluctuations ('sampling error'). Thus, if a hypothesis is stated to be supported, by a series of data, at the one per cent level of significance, it is implied that in not more than 1 trial in 100 would chance fluctuations combine to lend support to the hypothesis to the degree observed in the data. A necessary condition for such 'probably significant' support to be held demonstrated is that selection of the series of data for test be made at random.

Most problems of statistical significance in meteorology are basically concerned with such questions as whether or not a given sample is drawn from a specified population, or whether an observed frequency distribution does or does not accord with a specified distribution. The 'significance tests' normally applied in these respective cases are 'STUDENT'S *t*-TEST' (or the probability integral of the NORMAL DISTRIBUTION if the sample concerned is large), and the 'CHI-SQUARED TEST': tables of corresponding values of significance level and parameters employed in these tests are contained, for example, in 'Handbook of statistical methods in meteorology'.*

silver iodide: A substance used, in the form of a fine smoke which is scattered from the ground or from the air, as an ice-nucleating agent in CLOUD SEEDING experiments.

silver thaw: An expression of American origin. After a spell of severe frost, the sudden setting in of a warm, damp wind may lead to the formation of ice on objects which, being still at a low temperature, cause the moisture to freeze upon them and give rise to a 'silver thaw'. See GLAZED FROST.

simoom: A hot, dry, suffocating wind or whirlwind which occurs in the deserts of Africa and Arabia. Most frequent in summer, it usually carries much sand and is short-lived (less than about 20 minutes).

single observer forecasting: Local weather forecasting which is based purely on observation of the weather elements for the same locality. The application of experience in synoptic meteorology, combined with physical reasoning, is capable of producing reasonably reliable local forecasts for a few hours ahead: in some situations reliability is possible for an appreciable time ahead. The observations chiefly used in such forecasting are those of pressure and pressure tendency, wind velocity at surface and higher levels, cloud, temperature.

singularity: An annual RECURRENCE TENDENCY in a meteorological element during a group of successive calendar dates. An example is a period of unseasonal warmth or cold, such as a BUCHAN SPELL.

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* BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, HMSO, 1953.

The precise definition of singularities and their verification as reliable features of climate are often difficult and controversial. Their application in long-range weather forecasting appears to have some, though very limited, usefulness.

sink: See SOURCE.

sinusoidal pattern (of thickness): That synoptic pattern, approximating to a sine curve, which is formed by alternate thermal TROUGHS and thermal RIDGES of about equal amplitude (see Figure 30). The theory of thermal DEVELOPMENT implies the tendency for cyclogenesis (*C*) and anticyclogenesis (*A*) in the regions indicated.

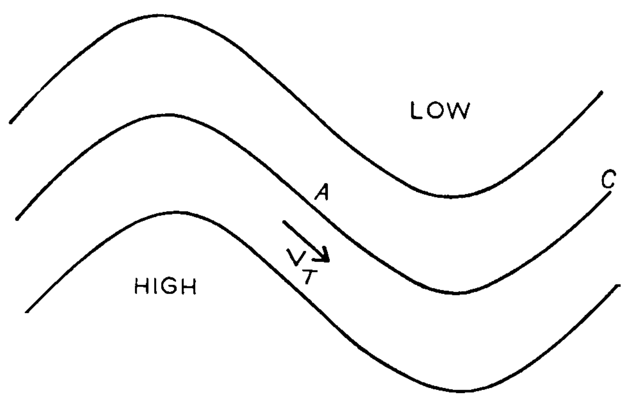

FIGURE 30—**Sinusoidal pattern.**

When the 'wave' amplitude is small, THERMAL STEERING predominates and surface depressions move through the pattern without much deepening. With marked deepening and subsequent occluding of an associated depression, the pattern becomes distorted beyond recognition.

siphon barometer: A U-shaped mercury BAROMETER in which the areas of the upper and lower mercury surfaces are nearly equal. The instrument is adapted, as in the float barograph (see BAROGRAPH) to give a continuous record of pressure variation.

sirocco: See SCIROCCO.

site: In order to secure observations comparable with those at other stations, the site of a meteorological STATION has to be carefully selected in accordance with certain rules which are set out in the 'Observer's handbook'.* A rain-gauge requires a certain amount of protection from the wind, but for other outdoor instruments the more open the site, the better. A compromise is usually effected. The latitude, longitude and height of the ground on which the rain-gauge stands are used to define the position of a station. See also EXPOSURE.

Six's thermometer: A U-shaped thermometer, designed by J. Six, in which the positions of two iron indexes, subsequently reset by means of a magnet, indicate the maximum and minimum temperatures attained since the previous setting.

skewness: Asymmetry of a frequency distribution, reckoned positive if the MODE lies to the left of the MEAN (as, in general, in the case of rainfall), negative if the mode lies to the right of the mean.

skin-friction coefficient: An alternative for DRAG COEFFICIENT.

* London, Meteorological Office; Observer's handbook. 2nd edn. London, HMSO, 1956, p. 141.

skip distance: The distance, measured along the earth's surface, between the point at which the ground signal from a radio-wave transmitting source is just undetectable by a receiver of normal sensitivity and that at which reception of the transmitted waves is first possible after reflexion by the IONOSPHERE. This distance corresponds to a minimum angle of incidence of the waves on the ionosphere: if this angle is not attained, the energy passes on to outer space.

The 'zone of silence' corresponds to the skip distance in the case of sound waves —see AUDIBILITY.

sky light: An alternative for DIFFUSE RADIATION.

sky radiation: An alternative for DIFFUSE RADIATION.

sky, state of the: Fraction of the sky obscured by cloud on a scale of 0 (cloudless) to 8 (an entirely overcast sky in which no patches of blue sky are visible). In the BEAUFORT NOTATION letters, b, blue sky whether with clear or hazy atmosphere; c, cloudy, i.e. detached opening clouds; o, sky overcast with one impervious cloud; and u, ugly, threatening sky, are also used in addition or alone to indicate the general appearance of the sky. (See 'Observer's handbook'.*)

slant visibility: An alternative for OBLIQUE VISIBILITY.

slantwise convection: A type of motion, considered significant in the GENERAL CIRCULATION of the atmosphere, in which exchange of air between different levels is effected despite the absence of a super-adiabatic lapse rate.

In a normal atmospheric state isentropic (equal potential temperature) surfaces slope upwards from lower to higher latitudes. While, therefore, an air parcel may be prevented from rising vertically because of a sub-adiabatic lapse rate, poleward travel brings it to an environment more dense than itself, thus enabling it to rise. Air at higher levels and higher latitudes may similarly descend by equatorward movement. The effective slope along which the movement occurs is less than that of the original isentropic surfaces.

sleet: Precipitation of snow and rain together, or of snow melting as it falls.

In American terminology, sleet is often used to signify ICE PELLETS.

slice method: The estimation of vertical STABILITY in the atmosphere by a method which takes some account of the compensating downward motion induced in the environment by upward rising parcels of air. Since the environment is assumed to warm at the dry-ADIABATIC lapse rate during its descent, greater stability is in general deduced by this method, as compared with the PARCEL METHOD.

sling psychrometer: An alternative for WHIRLING PSYCHROMETER.

sling thermometer: A thermometer mounted on a frame pivoted about a handle so that it can be whirled in the hand, thus providing 'ventilation'. If the bulb is shielded from direct solar radiation, satisfactory readings of air temperature can thus be obtained in a simple and inexpensive manner. A pair of thermometers, dry- and wet-bulb, similarly used, constitute a 'sling' or 'whirling' psychrometer. See also PSYCHROMETER.

small circle: Any plane which does not pass through the centre of a sphere cuts the surface of the sphere in a 'small circle'.

London, Meteorological Office; Observer's handbook. 2nd edn. London, HMSO, 1956, p. 59.

smog: A term, being a contraction for 'smoke fog', which signifies a FOG in which smoke, or other form of atmospheric pollutant, besides playing an important part in causing the fog to form and to thicken (for example, by acting as condensation nuclei) has unpleasant or dangerous physiological effects. A noteworthy smog occurred in the London area in early December 1952.

smoke: The visible product of incomplete combustion: in Great Britain the main source is coal burning. Coal smoke comprises mainly carbon and hydrocarbon particles of very small size (about 0·1 micron) which remain in the air, on average, for 1 to 2 days.

Atmospheric smoke concentration is measured by a 'smoke filter' method in which the weight of smoke deposited on a white filter paper by a known volume of air is inferred from the measured reflectance of the smoke stain. Typical annual mean values in Great Britain are, for country air 5×10^{-2}, and for city air 3×10^{-1}, mg/m^3. See ATMOSPHERIC POLLUTION, RINGELMANN SHADES.

smoothing: A process of performing space or time averaging of data with the object of suppressing local or short-period variations, respectively, and thus permitting the larger-scale or longer-period effects to emerge more clearly. When smoothing is applied to a TIME SERIES, allowance must be made for the fact that the increased AUTOCORRELATION thereby introduced into the series increases the probability of the appearance of spurious PERIODICITY in the series.

smudging: A method of FROST PROTECTION consisting of the production, by combustion or by chemical means, of a smoke pall over a confined area, e.g. vineyard. The resulting reduction in outgoing terrestrial radiation results, in suitably calm conditions, in a decrease in the rate of fall of temperature of the ground in the locality.

Snell's law: See REFRACTION.

snow: Solid PRECIPITATION which occurs in a variety of minute ICE CRYSTALS at temperatures well below 0°C but as larger SNOWFLAKES at temperatures near 0°C. 'Granular snow' consists of opaque grains, rather flattened in shape and generally less than 1 mm in diameter.

For synoptic purposes, snow (or a snow shower) is classed as 'slight', 'moderate', or 'heavy' for a rate of accumulation of snow (in the absence of drifting or melting) less than 0·5 cm/hr, 0·5 to 4 cm/hr, or greater than 4 cm/hr, respectively.

See also SNOWFALL.

snow, day of: In British climatology, any period of 24 hours ending at midnight GMT upon which snow is observed to fall is regarded statistically as a 'day of snow'.

See also SNOWFALL.

snowdrift: When a strong wind blows, there is a strong tendency for falling snow, or fallen snow on the ground, to accumulate not in open places but in any sheltered place, as in the lee of natural or artificial obstacles, there forming 'drifts'.

The symbols $\underset{\downarrow}{\rightarrow}$ and $\overset{\uparrow}{\rightarrow}$ are employed, in synoptic chart plotting, to distinguish drifting snow at 'generally low' and 'generally high' levels, respectively.

snowfall: The depth of fresh snowfall is normally measured with a graduated ruler. Its measurement as RAINFALL (i.e. its water content) may be made in a suitable SNOW-GAUGE, or by melting the snow caught in a normal rain-gauge, or by collecting and melting samples of fresh snow which has fallen in the open. One foot of freshly fallen snow has about the same water content as one inch of rainfall.

The amounts of snow which fall over the British Isles are measured as rain: separate statistics of snowfall amount are therefore not available. Separate records are, however, kept of the numbers of days of snowfall and of snow lying, and also of snow depth.

The average annual number of days with snow falling on low ground up to about 200 feet above mean sea level increases with increasing latitude and from west to east, and ranges from less than five days in southern Cornwall to over 35 days in north-east Scotland. At places above 200 feet the average number of days increases by approximately one day for every 50 feet of elevation; above 1000 feet the increase is greater than this, the corrections being about +20, +52, +90 and +140 days at 1000, 2000, 3000 and 4000 feet, respectively.

The average annual number of days with SNOW LYING is one of the most variable of meteorological elements over the British Isles. Factors which influence it include monthly mean temperature, frequency of snowfall, quantity of snowfall and the character of the station and its surroundings, such as its height, aspect and distance from hills. Values range from less than five days per year in southern and western coastal districts to over 100 days per year in the Grampians. In some winter months, such as February 1942 and February 1947, snow lying has been reported on every day of the month over large areas of Britain, whereas in February 1943 the majority of stations reported no single day of snow lying.

Falls of undrifted snow of depth exceeding six inches on level ground at low altitudes occur somewhere in England in one-third to one-half of winters: the average number of days in ten years with snow lying at such depths ranges from less than one day in south-west coastal districts to between 30 and 40 days in eastern England.

snowflakes: Aggregates of ICE CRYSTALS which occur in an infinite variety of shape and form. At very low temperatures the flakes are small and their structure simple. At temperatures which are close to freezing-point, the individual flakes may be composed of a very large number of ice crystals (predominantly star-shaped) and the flake may then have a diameter up to several inches.

snow-gauge: A device for the retention and measurement of SNOW. In the Hellmann–Fuess snow-gauge the snow is caught in a receiver supported on a balance, the displacement of which is continuously recorded, so that an autographic record of snowfall (and of the fall of rain and hail also) is obtained. Most snow-gauges are, however, merely rain-gauges fitted with jackets or other devices to make them suitable for collecting solid precipitation, and for melting it before taking the reading.

snow-line: The lower limit in altitude of the region of perpetual snow. In high polar latitudes the snow-line is at sea level; in northern Scandinavia it is at about 4000 feet, in the Alps at about 8500 feet, in the Himalayas at about 15,000 feet. These figures are only approximate, as the height of the snow-line varies on the north and south sides of a mountain and from one mountain to another in the same latitude or region. It has no direct relation to the mean annual temperature, depending more on the summer temperature, but many other factors exert an influence, such as amount of snow in winter, prevailing winds, exposure and steepness of the slopes, etc.

snow lying: This expression (international symbol ⧆) is used for occasions when one-half or more than one-half of the ground representative of the station is covered with snow. The ground representative of the station is defined as 'the flat land easily visible from the station and not differing from it in altitude by more than

100 feet.' British statistics of snow lying refer only to occasions when this state of affairs exists at the hour of morning observation.

See also SNOWFALL.

snow rollers: Cylinders of snow, formed and rolled along by the wind.

snow survey of Great Britain: A survey started in 1937–38 by the British Glaciological Society, with an annual report covering each snow season published in the *Journal of Glaciology*. The survey lapsed during the Second World War but was restarted with the report for 1946–47 and continued by the Society until 1952–53. With the report for 1953–54 the work was taken over by the Meteorological Office, with publication at first in the *Meteorological Magazine* and later in *British Rainfall*. The report for 1956–57 was the first to appear in the latter, in the volume for 1957.

sodium: A very minor constituent of the atmosphere, estimated to total about one ton in weight. The sodium D line (5893 ångströms) is observed in the NIGHTGLOW emission spectrum and is conspicuous in the TWILIGHTGLOW. The sodium is thought to have maximum concentration at about 85 km.

Exeriments have been made in which a few pounds of sodium are injected by rocket into the high atmosphere to produce an artificial glow which, observed from the ground, is used as a measure of the high atmospheric winds.

soil moisture: The moisture content of soils is generally expressed as the percentage ratio of the mass of water to that of dry soil, but may be expressed also in terms of inches of water per given depth of soil. Soil moisture is of obvious importance in regard to the growing of plants and is of direct meteorological interest in affecting the thermal conductivity of soil and so the rate at which heat is conducted upwards to or downwards from the atmosphere, and also in affecting, in certain circumstances, the rate of EVAPORATION from the soil and of TRANSPIRATION from vegetation. Conversely, the rates of evaporation and transpiration are much affected by the meteorological parameters temperature, sunshine, humidity and wind.

Among the measures of soil moisture which are employed are SATURATED SOIL, FIELD CAPACITY, and WILTING POINT. The varying force with which soil retains contained water is termed the CAPILLARY POTENTIAL.

soil moisture deficit: The amount of rainfall or irrigation required to restore soil to its FIELD CAPACITY.

soil temperature: See EARTH TEMPERATURE.

soil thermometer: See EARTH THERMOMETER.

solano: An easterly wind which brings rain to the south-east coast of Spain and in the Straits of Gibraltar.

solar activity: See SUN.

solar constant: The solar radiation flux at a surface normal to the sun's beam outside the earth's atmosphere at the earth's mean distance from the sun.

Measurement of the solar constant has been made at high-level observatories since 1902, mainly by the Smithsonian Institution. Direct solar radiation intensity is continuously measured and is related to an absolute standard: atmospheric attenuation is allowed for by measurement, at various solar zenith angles, of relative flux over a wide band of selected wavelengths and extrapolation to 'zero path length'. The generally accepted value of the solar constant is 0·1395 abs. watt/cm^2: this is equivalent to 2·00 cal/cm^2 min.

There has been much controversy as to whether measured day-to-day variations and longer time-average variations of the solar constant are real or spurious. As measuring technique has developed the values have more nearly approached a constant value (for a given absolute standard). It is generally held that no significant variation of the solar constant has yet been experimentally shown and that the upper limit of such variation is about 0·1 per cent. This is in marked contrast to the large percentage solar-cycle variations known from geophysical evidence to occur in the far ends of the solar spectrum where, however, the amount of energy involved is very small.

solar corpuscular streams: Streams of charged corpuscles (particles) which are emitted at high speed from disturbed regions of the sun are affected by the earth's magnetic field in the event of their crossing the earth's path and, in turn, affect this field, causing geomagnetic and ionospheric storms. It is generally held that these particles do not penetrate the earth's atmosphere below about 70 km (above which height their interaction with the atmosphere gives rise to visible AURORA) and that no relation between the incidence of particle streams and lower atmosphere meteorological phenomena has yet been shown. See also GEOMAGNETISM.

solar cycle: The relative sunspot number varies in a quasi-periodic manner, with successive maxima separated by an average interval of about 11 years—the so-called 'solar cycle'. If reversal of sunspot magnetic-field polarity in a given hemisphere in successive 11-year periods is taken into account, the complete solar cycle may be considered to average some 22 years. See SUNSPOT.

solar day: See DAY.

solar flare: A solar explosion, unpredictable in nature and up to a few hours in duration, from a restricted region of the CHROMOSPHERE above certain types of SUNSPOT. Flares are classified on an ascending scale from 1 to 3+, on the visual basis of intensity of emitted light and solar area covered. In the sunlit hemisphere, short-lived 'sudden ionospheric disturbances' (SID) start almost simultaneously with the visual appearance of a great flare, attributed to the arrival in the high atmosphere of a flood of ionizing radiation released by the flare: the extra ionization is thought to occur mainly in the D-layer at about 70–90 km height.

An intense and world-wide magnetic storm follows a great flare, which is near the centre of the sun's disk, with a frequency which is much in excess of chance expectation. It is thus inferred that a SOLAR CORPUSCULAR STREAM is ejected almost radially from the flare region, the delay of about 20 hours corresponding to the slower speed of travel of the solar particles compared with that of the wave radiation.

solarimeter: An instrument for measuring the total solar radiation received on a horizontal surface. See PYRANOMETER.

solar radiation: See RADIATION.

solar-radiation thermometer: An alternative for BLACK-BULB THERMOMETER.

solar spectrum: See RADIATION and ELECTROMAGNETIC RADIATION.

solar–terrestrial relationships: The relationships between the (variable) physical state of the SUN ('solar activity') and the (variable) particle and wave radiations emitted by the sun on the one hand, and the resulting physical effects produced in the earth's atmosphere on the other. Meteorological events observed in the troposphere and stratosphere appear to depend very little, if at all, on observed solar variability. The latter is, however, very important in certain types of COSMIC RAY event, and in studies of the AURORA, GEOMAGNETISM and the IONOSPHERE.

solar wind: Term proposed for the motion of interplanetary gas outwards from the sun towards the earth near which it interacts with the earth's magnetic field. It is generally assumed that the strength of this 'wind' increases with increasing solar activity. See SUN.

solenoids: The intersection in a BAROCLINIC atmosphere of surfaces of constant pressure with surfaces of constant specific volume (isobaric and isosteric surfaces, respectively) forms three-dimensional 'isobaric–isosteric solenoids': since isosteric (constant specific volume) surfaces are also isopycnic (constant density) the intersections may also be said to form 'isobaric–isopycnic solenoids'. 'Unit solenoids' are formed by the intersection of surfaces separated by one unit of pressure and specific volume, or of pressure and density.

The existence of such solenoids in the atmosphere tends to produce a so-called 'direct circulation': in the absence of CORIOLIS FORCES the rate of production of circulation is proportional to the concentration of unit solenoids and is so directed as to cause the lighter air to rise and the denser air to subside.

solstice: The time of maximum or minimum DECLINATION of the sun when, for a few days, the altitude of the sun at noon shows no appreciable change from day to day. The summer solstice for the northern hemisphere (winter solstice for southern hemisphere) occurs on about 22 June, when the sun is farthest north of the equator: the winter solstice for the northern hemisphere (summer solstice for southern hemisphere) occurs on about 22 December, when the sun is farthest south of the equator.

sounding: In meteorology, investigation of atmospheric properties by means of a device which ascends into the atmosphere, e.g. a balloon, rocket, or satellite. See also BALLOON SOUNDING.

sound waves: Sound passes through a medium by means of longitudinal waves whose velocity of propagation depends on the temperature and nature of the medium. The passage of sound waves at a point in the atmosphere is associated with air pressure fluctuations about a mean value. Where these fluctuations are small relative to the mean pressure, the velocity of the waves is given by

$$V = \sqrt{(\gamma RT)}$$

where γ is the ratio (c_p/c_v) of the specific heats of air, R is the specific gas constant for air, and T is absolute temperature.

V in air at 0°C is about 332 m/sec or 760 m.p.h. See also WAVE MOTION, MACH NUMBER.

source: In hydrodynamics, a 'source' is a point within a fluid at which fluid is continuously created and from which it moves equally in all directions: the source 'strength' is measured by the rate of production of fluid. The converse is a hydrodynamic 'sink' to which fluid converges and at which it disappears.

In an analogous way a 'heat source' in a thermodynamic system is that part of the system in which heat is continuously generated and from which it is transferred to be continuously dissipated at a 'heat sink'. The large-scale atmospheric heat source is at low levels in low latitudes, the heat sinks are at low levels in high latitudes and at high levels in all latitudes.

source region (air mass): See AIR MASS.

southerly buster: A name given in south and south-east Australia to a sudden change of wind, usually from a north-westerly direction to a southerly direction, which is accompanied by a sudden fall in temperature. This change of direction occurs behind a cold front, and if the rise of pressure is considerable the southerly wind is violent. The arrival of the southerly wind is usually marked by a long crescent-shaped roll of cloud. The temperature sometimes falls as much as 20°C (30°F or 40°F) in half an hour. These storms are sometimes accompanied by thunder and lightning. They are similar to the PAMPEROS of South America and the LINE-SQUALLS of middle latitudes. They are most prevalent from October to March.

southern oscillation: The best known of three indices, derived empirically by G. T. Walker and associated by him with a suggested period of 2·33 years. The index was based on the observed seasonal distribution of pressure, and to a lesser extent temperature and rainfall, over a large and predominantly oceanic region of lower latitudes.

A 'North Atlantic oscillation' and a 'North Pacific oscillation', derived in a similar manner for these regions, were also employed by Walker.

SPA: An abbreviation for 'sudden phase anomaly'. When a SOLAR FLARE occurs, the extra ionization of the D-layer in the sunlit hemisphere causes the layer to lower as a reflecting medium with respect to long waves reaching it from the earth's surface: an associated sudden change of phase (SPA) is observed between the direct ground wave and reflected sky wave, by a receiver at some distance from a long-wave transmitter. See also SID.

space charge: In ATMOSPHERIC ELECTRICITY an excess, within any specified portion of the atmosphere, of positive over negative IONS, or vice versa—positive or negative space charge, respectively.

The downward movement of positive electric charge, and upward movement of negative charge, in response to the existing POTENTIAL GRADIENT, implies a positive space charge in fair-weather regions where the field is directed downwards. This space charge is greatest at low levels where the field is greatest. Large space charges of either sign are, however, measured in association with precipitation elements.

specific heat: The specific heat of a substance is the heat required to raise the temperature of unit mass of it by one degree: it is normally expressed in the unit calories/gm °K. The dimensions are $L^2T^{-2}\theta^{-1}$.

The specific heat of a substance is to some extent dependent on the temperature (see CALORIE). The specific heat of water is, within one per cent, 1·00 IT cal/gm °K; the specific heat of ice is 0·346 at −90°C, 0·450 at −30°C, 0·503 IT cal/gm °K at 0°C.

The specific heat of dry air at constant pressure (c_p) is 0·240 IT cal/gm °K, and at constant volume (c_v) 0·171 IT cal/gm °K. The ratio γ of the specific heats (i.e. c_p/c_v) is 1·40. The specific heats of water vapour at constant pressure (c_{pv}) and at constant volume (c_{vv}) are, respectively, 0·441 and 0·331 IT cal/gm °K. Admixture of water vapour increases the specific heat of air, to a degree negligible for most purposes, as follows:

$$c_{pm} \text{ (moist air)} \simeq c_p\,(1 + 0{\cdot}9r)$$
$$c_{vm} \text{ (moist air)} \simeq c_v\,(1 + 1{\cdot}0r)$$

where r (HUMIDITY MIXING RATIO) is expressed in gm/gm.

1 IT calorie = 4·1868 JOULES = 4·1868 × 10^7 ERGS.

specific humidity: The specific humidity (q)—also termed the 'mass concentration' or 'moisture content'—of moist air is the ratio of the mass (m_v) of water vapour to the mass ($m_v + m_a$) of most air in which m_v is contained, m_a being the mass of dry air:

$$q = \frac{m_v}{m_v + m_a}$$

Since m_v is much smaller than m_a, specific humidity for a given sample is almost identical with HUMIDITY MIXING RATIO, which is now generally preferred.

specific volume: The volume occupied by unit mass of a substance, at a specified temperature and pressure. It is the inverse of DENSITY.

spectrobolometer: See BOLOMETER.

spectrophotometer: An instrument which measures the intensity of radiation of a given wavelength. In meteorology, such an instrument is used mainly in the measurement of ozone—see DOBSON SPECTROPHOTOMETER.

spissatus (spi): A CLOUD SPECIES. (Latin, *spissatus* thickened.)
'CIRRUS of sufficient optical thickness to appear greyish when viewed towards the sun.'* See also CLOUD CLASSIFICATION.

splintering: The splintering or fragmentation of ICE CRYSTALS, more especially of the delicate branched form of crystal, is considered to be an important source of the multiplication of ice crystals within a cloud. The electric charge separation associated with splintering has been proposed as a factor in the rapid rate of charge separation which occurs within a THUNDERSTORM cloud.

spontaneous nucleation: An alternative for HOMOGENEOUS NUCLEATION.

spring: See SEASONS.

squall: A strong wind that rises suddenly, generally lasts for some minutes, and dies comparatively suddenly away. It is distinguished from a GUST by its longer duration.

The term is often used in such a sense as to include the precipitation, thunderstorm, etc., which are a common accompaniment of the sudden increase of wind. The following definition of 'squall' was adopted in April 1962 by the Third Session of the Commission for Synoptic Meteorology of the WMO:

'A sudden increase of wind speed by at least 8 m/sec (16 knots), the speed rising to 11 m/sec (22 knots) or more and lasting for at least one minute. Note: When Beaufort scale is used for estimating wind speed, the following criteria should be used for the reporting of squalls: a sudden increase of wind speed by at least 3 stages of the Beaufort scale, the speed rising to Force 6 or more and lasting for at least one minute.'

squall line: The name originally given to what is now known as a COLD FRONT.

The use of the term is now generally confined to violent convective phenomena extending along a line or belt which is non-frontal in nature—see INSTABILITY LINE.

stability: A system which is subjected to a small disturbing impulse is said to be in stable, neutral (or indifferent), or unstable equilibrium, according to whether it returns to its original position, remains in its disturbed position, or moves farther from its original position, respectively, when the disturbing impulse is removed.

Investigation of the 'static stability' of the atmosphere is made most simply by the 'parcel method', in which an assessment is made of changes of kinetic energy of a test parcel of air, displaced vertically and adiabatically with respect to its environment as represented by an ascent curve on an AEROLOGICAL DIAGRAM: the

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 12.

environment is termed stable, neutral, or unstable (at defined points or in defined layers) according as the kinetic energy of the parcel decreases, remains constant, or increases, respectively.

The following rules apply to the most general case of a moist but unsaturated test parcel which is subject to a smaller or larger vertical ascent through a moist but unsaturated environment:

(i) 'absolute stability' exists if the existing LAPSE of temperature (γ) is less than the saturated-ADIABATIC lapse rate (Γ_s) i.e. if $\gamma < \Gamma_s$.

(ii) 'absolute instability' exists if $\gamma > \Gamma_d$ (dry-adiabatic lapse rate).

(iii) 'conditional instability' exists if $\Gamma_d > \gamma > \Gamma_s$.

Case (iii) is subdivided into two classes defined by the vertical distribution of humidity in the environment curve, as follows:

(*a*) The case is one of stability if none of the pseudo wet-bulb potential temperature (θ_{sw}) lines (with sufficient accuracy, the WET-BULB POTENTIAL TEMPERATURE (θ_w) lines) corresponding to possible test parcels intersects the environment curve—(see PSEUDO WET-BULB TEMPERATURE).

(*b*) The case is one of 'latent instability' if one or more θ_w lines intersects the environment curve. The latent instability is termed 'real latent' if the 'negative area' (that lying between the ascent curve of the test parcel and the environment curve, and to left of environment curve) is less than the 'positive area' (to right of environment curve); the latent instability is termed 'pseudo-latent' if the converse is true.

The term 'convective instability', or 'potential instability', is applied to the case in which a layer of air will become unstable on being lifted bodily (as over high ground) till it is saturated: the criterion for this case is that θ_{sw} (with sufficient accuracy θ_w) decreases with increasing height through the layer.

Estimation of the static stability by means of the parcel method and, in particular, calculations by this method of available kinetic energy in conditions of instability with associated convection, cloud formation and precipitation, are liable to serious error by the neglect of such factors as the mixing of rising parcels with the environment, the compensating downward motion induced in the environment, and the additional energy released by the cooling of the environment by the evaporation of precipitation into it. The method is, nevertheless, capable of producing useful results. See also DYNAMIC STABILITY.

standard: A prescribed measure or scale of any kind, such as a unit or scale of reference. The legal magnitude of a unit of measure or weight.

A 'primary standard' instrument (ABSOLUTE INSTRUMENT) is often used in the CALIBRATION of some 'sub-standard' or 'secondary standard' instruments which, in turn, may be used to calibrate many instruments for field use.

standard atmosphere: Hypothetical atmosphere, corresponding approximately to the average state of the real atmosphere, in which the pressure and temperature are defined at all heights. Such an atmosphere is adopted internationally as the basis for the calibration of altimeters, evaluation of aircraft performance, etc.

The ICAO (International Civil Aviation Organization) Atmosphere is now generally in use. Its chief specifications are: mean-sea-level (MSL) pressure 1013·25 mb; MSL temperature 15°C; temperature lapse rate 6·5°C/km up to 11 km, (where $T = -56{\cdot}5$°C) and with an isothermal lower stratosphere above (to at least 20 km). The specified temperatures are, strictly, appropriate to dry air (i.e. they are virtual temperatures), while the height units are expressed not in a geometric height unit but in a GEOPOTENTIAL unit based on an assumed constant value of g (acceleration of gravity) of 980·665 cm/sec^2. Differences between the ICAO Atmosphere and the ICAN (International Commission for Air Navigation)

Atmosphere which was previously adopted by many countries are generally negligibly small: they arise from the assumed values in the ICAN Atmosphere of MSL pressure 1013·2 mb and of g, constant with height, 980·62 cm/sec².

The main features of an ARDC (Air Research and Development Command) Model Atmosphere (1956), which is a provisional extension of the ICAO Atmosphere to higher levels, are: zero lapse rate 11 km to 25 km ($T = -56{\cdot}5$°C); then negative lapse rate of 3·0°C/km to $T = +9{\cdot}5$°C at 47 km; then isothermal to 53 km ($T = +9{\cdot}5$°C); then positive lapse rate 3·9°C/km to $T = -76{\cdot}3$°C at 75 km; then isothermal to 90 km ($T = -76{\cdot}3$°C). Above 90 km negative lapse rates prevail, 3·5°C/km to 126 km ($T = 49{\cdot}7$°C), 10°C/km to 175 km ($T = 539{\cdot}7$°C), 5·8°C/km to 500 km ($T = 2424{\cdot}7$°C).

standard atmospheric pressure: A concept used in some physical definitions. It is the pressure exerted by a column of mercury 760 mm high, of density 13·5951 gm/cm³, subject to gravitational acceleration 980·665 cm/sec², and equals 1,013,250 dynes/cm². See STANDARD DENSITY, STANDARD GRAVITY.

standard ballistic atmosphere: See BALLISTICS.

standard density: A conventional value of the density of mercury, adopted for the sake of uniformity in the conversion of pressure readings from units of pressure to units of height (mm or in.), or vice versa. The value adopted by the World Meteorological Organization is the density at 0°C, equal to 13·5951 gm/cm³. See also STANDARD GRAVITY, BAR.

standard deviation: The standard deviation (σ) of a group of n observations $x_1, x_2, \ldots x_n$ is a measure of the dispersion of the observations about their arithmetic mean $\bar{x}$ and is defined by

$$n\sigma^2 = (x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots + (x_n - \bar{x})^2$$

σ^2 is called the 'variance' of the observations.

If n is small, the mean ($\bar{x}$) of the sample may differ significantly from the mean of the population from which the sample is drawn. Since the definition of $\bar{x}$ implies that the sum of the squares of the departures from $\bar{x}$, i.e. $(x_1 - \bar{x})^2 + \ldots$ etc., is smaller than the sum of the squares of the departures from any other value (including the population mean), the standard deviation defined above is an underestimate of the population standard deviation, for which a better estimate (sometimes called the 'standard error' of the observations) is

$$(n - 1)\sigma^2 = (x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots + (x_n - \bar{x})^2$$

For large n, the difference between the two estimates of σ is negligible.

In a NORMAL DISTRIBUTION the probabilities of occurrence of a departure from the mean, of unspecified sign, greater than a given multiple of σ are: σ, 0·318; 2σ, 0·046; 3σ, 0·003; 4σ, 0·00006. If the sign of the departure is specified the probabilities are half those quoted.

standard error: The mean values of samples, each of size n, drawn at random from a given population of STANDARD DEVIATION σ, have a normal or near-NORMAL DISTRIBUTION about the population mean and a standard deviation of $\sigma/\sqrt{n}$. This quantity may be regarded as a measure of the dependability of an individual sample mean and is termed the 'standard error of the mean' (σ_m). For small n, a better estimate of σ_m is $\sigma/\sqrt{(n-1)}$.

The standard error (σ_s) of the sum of n independent values drawn from different populations of standard deviation σ_1, σ_s, etc. is $\sigma_s = \sqrt{(\sigma_1^2 + \sigma_2^2 + \ldots + \sigma_n^2)}$: when drawn from the same population of standard deviation σ, this reduces to $\sqrt{(n)}\sigma$.

The standard error (σ_d) of the difference of two independent values, or means, of standard deviation σ_1 and σ_2 is $\sigma_d = \sqrt{(\sigma_1^2 + \sigma_2^2)}$, reducing to $\sqrt{(2)}\sigma$ when the means are drawn from the same population of standard deviation σ.

The provision concerning randomness of selection, implying independence of selected values, is very important in geophysical statistics owing to the time persistence and geographical coherence of many geophysical quantities. See PERSISTENCE.

standard gravity: A conventional value of the acceleration of gravity, adopted for the sake of uniformity. The value adopted by the World Meteorological Organization is 980·665 cm/sec². It is to this value, not to the value of 980·616 cm/sec² which is the best determined value of gravity at sea level in 45° latitude, that pressure data in height units (mm or in.) refer. (The value 980·665 cm/sec² is a previous best-determined value.)

See also GRAVITY, BAR, STANDARD DENSITY.

standard temperature (of barometer): That temperature at which, under STANDARD GRAVITY, the indicated reading of a mercury barometer is correct. At any temperature of an ATTACHED THERMOMETER other than the standard temperature, a 'temperature correction' must be applied to the barometer reading to take account of differences between the density of the mercury and dimensions of the metal scale of the barometer and those values assumed in the CALIBRATION of the instrument.

WMO has resolved that, with effect from 1 January, 1955, the standard temperature for all mercury barometers should be 0°C.

standard time: Time referred to the mean time of a specified meridian. The meridian of Greenwich is the standard for western Europe. The standard meridian for other countries is generally so chosen as to differ from Greenwich by an exact number of hours or half-hours. See also ZONE TIME.

standard vector deviation: The standard vector deviation of a group of vectors is a measure of the scatter of the vector end points about the point which represents the end of the vector mean, all the vectors emanating from a common origin. The standard vector deviation (σ) is defined as the root mean square vector deviation: it is most readily calculated from the equation

$$\sigma^2 = \Sigma|\mathbf{V}_i|^2/n - |\mathbf{V}_m|^2$$

where $|\mathbf{V}_i|$ is the module (magnitude) of the individual vectors and $|\mathbf{V}_m|$ the module of the vector mean.

σ for the wind vector is found to increase with height in the troposphere in accordance with the approximate relation $\sigma\rho$ = constant, where ρ is air density. The average value of σ at a pressure level of 500 mb over the British Isles is about 30 knots in summer, 40–45 knots in winter.

Some 50 per cent of vector observations are contained within a circle centred on the end point of the mean vector and of radius 0·83σ, 95 per cent within radius 1·73σ, 99 per cent within 2·15σ.

See also CONSTANCY OF WINDS.

standing wave: In meteorology, an air wave which is (almost) stationary with respect to the earth's surface. Such wave or waves are commonly associated with air flow over mountains. See MOUNTAIN WAVE, LEE WAVES.

starshine recorder: An alternative for NIGHT-SKY RECORDER.

state, equation of: An alternative for GAS EQUATION.

state of ground: See GROUND, STATE OF.

static: See ATMOSPHERICS.

static stability: See STABILITY.

static stability, equation of: An alternative for HYDROSTATIC EQUATION.

station: In meteorology, a location at which regular weather observations are made. Among the classes of station are the SYNOPTIC STATION, CLIMATOLOGICAL STATION, CROP WEATHER STATION, HEALTH RESORT STATION, RAINFALL STATION and OCEAN WEATHER STATION.

station index number: A group of three figures used in synoptic messages to signify the particular station, within a given block area the boundaries of which coincide in most cases with national frontiers, at which the observation was made.

statistics: Accumulation of numerical facts. The science of statistics is concerned with methods of dealing with numerical data (generally in large quantities), the representation of their essential features by a small number of parameters, and the determination of relationships between two or more variables. See, for example, STANDARD DEVIATION, NORMAL LAW OF ERRORS, CORRELATION, PROBABILITY, FREQUENCY.

steam fog: An alternative for ARCTIC SEA SMOKE.

steering: In synoptic meteorology, controlling factor(s) in the direction and speed of movement of pressure systems, sometimes also of precipitation belts, thunderstorms, etc.

The forecasting problem relating to the movement of pressure systems is one of DEVELOPMENT combined with steering. The principle of THERMAL STEERING operates well when development is not very pronounced. Attempts to find by more empirical means an appropriate 'steering current', that is wind velocity at a particular 'steering level' or mean wind velocity in a particular 'steering layer', have had only limited success.

The movement of thundery precipitation belts is often found to accord well with the wind velocity at a level of 700 mb.

Stefan–Boltzmann law: The law, discovered empirically by Stefan and later shown theoretically by Boltzmann, that the total radiation in all directions from an element of a perfect radiator is proportional to the fourth power of its absolute temperature. See RADIATION.

steppe: A name given to the grassy, treeless plains in Russia and Siberia. The word is sometimes extended to mean similar plains and regions of semi-ARID climate elsewhere.

steradian: The unit of solid angle, being the solid angle subtended at the centre of a sphere of unit radius by a cap of unit area on the spherical surface. The whole sphere subtends a solid angle of 4π steradians at the centre of the sphere.

stereographic projection: See PROJECTION.

Stevenson screen: The standard housing for meteorological thermometers designed by Thomas Stevenson, civil engineer (father of Robert Louis Stevenson). It consists of a wooden cupboard, with hinged door, mounted on a steel or timber stand, so that its base is about 3 ft 6 in. above the ground, the whole painted white. Indirect ventilation is provided through the bottom, double roof and louvered sides, and thermometers placed within it give a close approximation to the true air temperature, undisturbed by the effects of direct solar or terrestrial radiation. The 'ordinary' pattern accommodates the wet- and dry-bulb, maximum and minimum thermometers. In the 'large' pattern additional accommodation is provided for a thermograph and hygrograph.

sthene: That force which produces an acceleration of 1 m/sec^2 when applied to a mass of 1 TONNE. It is equal to 10^8 DYNES.

Stokes's law: A sphere of radius *r* cm, moving with velocity *v* cm/sec through a fluid of viscosity η poise, experiences a viscous drag of *F* dynes, tending to oppose its motion, given by

$$F = 6\pi\eta r v \text{ dynes}$$

This formula holds only for a small sphere moving with low velocity in conditions of laminar flow in a wide expanse of fluid. See also TERMINAL VELOCITY.

storage half-time: See RADIOACTIVE FALLOUT.

storm: The term 'storm' is commonly used for any violent atmospheric phenomenon, such as a gale, thunderstorm, line-squall, rainstorm, duststorm, snowstorm. In synoptic meteorology, the term is applied to an active centre of low pressure with which are associated gales, precipitation, etc.

storm cone: See GALE WARNING.

storm, eye of: See EYE OF STORM.

storm surge: A deviation, positive or negative, of the observed tide from the computed astronomical tide at the corresponding time and place. The storm surge is an essentially dynamical phenomenon: wind velocity is the main cause, with static pressure a minor contributory factor. A notable storm surge occurred in the North Sea on 31 January and 1 February, 1953 and caused widespread flooding in adjacent land areas.

S.T.P.: An alternative for N.T.P.

stratiformis (str): A CLOUD SPECIES. (Latin, *stratus* flattened and *forma* appearance.)

'Clouds spread out in an extensive horizontal sheet or layer. This term applies to ALTOCUMULUS, STRATOCUMULUS and, occasionally, to CIRROCUMULUS.'* See also CLOUD CLASSIFICATION.

stratocumulus (sc): One of the CLOUD GENERA. (Latin, *stratus* flattened and *cumulus* heap).

'Grey or whitish, or both grey and whitish, patch, sheet or layer of cloud which almost always has dark parts, composed of tessellations, rounded masses, rolls, etc., which are non-fibrous (except for virga) and which may or may not be merged; most of the regularly arranged small elements have an apparent width of more than five degrees.'† See Plates 11 and 17: see also CLOUD CLASSIFICATION.

stratopause: The atmospheric boundary between the stratosphere and MESOSPHERE. See STRATOSPHERE.

stratosphere: That region of the ATMOSPHERE, lying above the TROPOSPHERE and below the MESOSPHERE, in which, in contrast to these regions, temperature does not decrease with increasing height. The stratosphere therefore extends from the TROPOPAUSE to a height of about 50 km, where the temperature reaches a maximum. Sub-division of the region is sometimes made into the 'lower', 'middle' and 'upper'

* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 12.

† Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 11.

stratosphere, with approximate limits from tropopause to 20 km, 20 to 30 km, and 30 to 50 km, respectively.

An alternative definition of the stratosphere as that region from the tropopause to about 20 km in which temperature changes little with height, is not now favoured.

The stratosphere is a region which is characterized by relatively large amounts of ozone but by amounts of water vapour which are lower (mixing ratio of the order 10^{-2} gm/kg or less) than in the high troposphere. These constituent gases, together with carbon dioxide, largely determine the radiation balance which, in general, controls the vertical temperature distribution of this region. Despite the absence of convective motion, the (lower) stratospheric region has vigorous circulations which are often clearly related to low-level pressure systems.

stratus (st): One of the CLOUD GENERA. (Latin, *stratus* flattened.)

'Generally grey cloud layer with a fairly uniform base, which may give drizzle, ice prisms or snow grains. When the sun is visible through the cloud, its outline is clearly discernible. Stratus does not produce halo phenomena except, possibly, at very low temperatures.

Sometimes stratus appear in the form of ragged patches.'* See plate 12: see also CLOUD CLASSIFICATION.

streak lightning: LIGHTNING discharge which has a distinct main channel, often tortuous and branching: the discharge may be from cloud to ground or from cloud to air.

stream function: At a level of non-DIVERGENCE in a horizontal air current a stream function (ψ) may be defined such that

$$\mathbf{V} = \mathbf{k} \wedge \nabla\psi$$

where **V** is the wind velocity vector

k is the vertical unit vector

$\nabla\psi$ is the GRADIENT of the stream function.

The wind velocity vector is normal to, and to the left of, ψ, that is the wind blows along the isopleths of ψ (and with low values to the left). The isopleths of ψ are therefore streamlines, hence the term 'stream function'. ψ is a scalar quantity with dimensions L^2T^{-1}.

streamline: A curve which is parallel to the instantaneous direction of the wind vector at all points along it. Isobars are streamlines only in strict geostrophic flow.

Student's *t*-test: In statistics, 'Student's *t*-test' is used in such SIGNIFICANCE problems as whether a given sample (small or large) is derived from a given population, or whether two specified samples are derived from the same population.

Values of the function t (defined by the equation t = deviate/standard error), varying with size of sample, which are appropriate to significance at specified probability levels are contained in 'Handbook of statistical methods in meteorology'.† For large samples the probability levels approximate to those derived from the NORMAL DISTRIBUTION curve.

Stüve diagram: An AEROLOGICAL DIAGRAM with rectangular co-ordinates of T (temperature) and $p^{\varkappa}$ (p = pressure, $\varkappa = (c_p - c_v)/c_p$ = constant (c_p and c_v are specific heats of dry air at constant pressure and volume, respectively).

subcooling: A seldom-used alternative for SUPERCOOLING.

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 12.

† BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, HMSO, 1953.

subjective forecast: A FORECAST in which, in contrast to an OBJECTIVE FORECAST, the personal judgement of the forecaster plays a significant part. A forecast in SYNOPTIC METEOROLOGY, though based on physical and dynamical principles, is in some degree subjective.

sublimation: In chemistry, the conversion of a solid to a vapour, without melting. In meteorology, the term is applied with respect to water both in the above sense (direct evaporation from an ice surface) and in the converse sense (direct deposition of ice from water vapour).

sublimation nucleus: A type of NUCLEUS, the existence of which has not been definitely confirmed in the atmosphere, on which direct SUBLIMATION of water vapour to ice crystals may occur.

subsidence: The word used to denote the slow downward motion of the air over a large area which accompanies DIVERGENCE in the horizontal motion of the lower layers of the atmosphere. The greatest divergence is from regions of rapidly rising pressure and the subsidence is probably of the order of 100 to 200 ft per hour in many cases. In stationary unchanging anticyclones the subsidence is due to the outward air flow at the earth's surface only, and is then very much slower. The subsiding air is warmed dynamically (see ADIABATIC) and its relative humidity therefore becomes low, occasionally falling below 10 per cent at about 4000 to 6000 ft after prolonged subsidence. The downward movement and consequent warming increase with height, up to 10,000 ft or perhaps more, so that the LAPSE rate of temperature is decreased, and INVERSIONS are often developed. The vertical velocity is zero at the horizontal ground, but turbulence often mixes up the lower layers and brings some of the warm dry air to the ground. Subsidence normally results in fine dry weather, but fog, stratus or stratocumulus clouds may occur in certain conditions.

substantial change: An alternative for LAGRANGIAN CHANGE.

subtropical high: One of the cells of high atmospheric pressure (ANTICYCLONES) which comprise the quasi-permanent belt of high pressure of the 'subtropics' (i.e. that part of the earth's surface between the TROPICS and the 'temperate regions' whose equatorial boundaries are about 40°N and S). See GENERAL CIRCULATION.

sudden change report: In weather messages, a special report of sudden 'improvement' (BBBBB) or 'deterioration' (MMMMM), relating to a specified weather element or elements. See 'Handbook of weather messages'.*

sudden ionospheric disturbance: See SID.

sudden warming: A term applied to a relatively sudden temperature rise which occurs on some occasions in the stratosphere at higher latitudes, generally in late winter. The main warming, typically of the order of 50°C in one or two weeks but sometimes much more rapid, occurs at levels of 25 km or above: modified effects occur, however, at lower levels. The warming is thought to be associated with downward motion of air at the levels concerned since, with the lapse rate which prevails in the stratosphere, relatively slow subsidence is able to produce appreciable warming. The phenomenon is also termed 'explosive warming'.

sulphur dioxide: Gas, of chemical formula SO_2, which occurs in minute and variable concentration in the atmosphere and is of industrial and volcanic origin. In populated regions sulphur dioxide is formed by oxidation of much of the sulphur content of coal or coke or of heavy fuel oils, on combustion. The gas is estimated to amount

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* London, Meteorological Office; Handbook of weather messages. Parts II and III. London, HMSO, 1959.

PLATE 23 Sun pillar: Jersey.
Part of the upper tangent arc to the 22° halo (not itself visible) is also seen and has, at this low solar elevation, a marked V-shape.

to about 3 per cent by weight of fuel burned. It dissolves readily in water to form sulphurous acid, and oxidizes photochemically in sunlight to sulphur trioxide which similarly becomes sulphuric acid. These acids cause damage by corrosion.

Sulphur dioxide concentration of air is measured either by finding the acidity of a sulphuric acid solution formed by the reaction between known volumes of air and hydrogen peroxide, or by exposing a prepared surface of lead peroxide to the air for a considerable time (usually a month) and measuring the yield of lead sulphate; in either case the sulphur dioxide concentration of the air may be inferred. Typical annual mean values in Great Britain are, for country air 0·01, and for city air 0·08, part per million parts by volume. See ATMOSPHERIC POLLUTION.

sultriness: In meteorology, a combination of high atmospheric temperature and humidity.

sumatra: A SQUALL which occurs in the Malacca Strait, blowing from between south-west and north-west. There is a sudden change of wind from a southerly direction and a rise in speed is accompanied by a characteristic cloud formation—a heavy bank of cumulonimbus which rises to a great height. These squalls usually occur at night, and are most frequent between April and November. They are generally accompanied by thunder and lightning and torrential rain. There is a sudden fall of temperature at the moment the squall arrives.

summer: See SEASONS.

sun: A luminous gaseous sphere round which the earth moves in a slightly elliptical orbit at an average distance of $1{\cdot}4953 \times 10^8$ km. The sun's diameter is $1{\cdot}3914 \times 10^6$ km, its apparent diameter at the earth's mean distance 0·533 degree, its mass $1{\cdot}9866 \times 10^{33}$ gm, its mean density 1·41 gm/cm^3. The RADIATION emitted from the sun's luminous disk (photosphere) corresponds to a black-body radiation temperature of about 5800°K, the internal gases being at a temperature of many millions of degrees. The gaseous regions above the photosphere, visible during solar eclipses, comprise the REVERSING LAYER, the CHROMOSPHERE, and finally the solar CORONA which extends outwards to a distance of several solar diameters. The Fraunhofer spectral lines due to absorption by gases in these regions show the presence of terrestrial elements. The SYNODIC PERIOD of rotation of the sun, as judged by sunspot movement is 26·9 days in latitude 0° and 28·3 days in latitudes $\pm 30°$.

The energy output of the sun, both particles and waves, varies with time. This so-called 'solar activity' is associated with disturbances which are observed in the photosphere and solar atmosphere and which are in large measure interrelated. Chief among the solar disturbances are SUNSPOTS and SOLAR FLARES but they include, for example, also faculae, flocculi, prominences and outbursts of solar 'radio noise'. The sun is described as 'quiet' or 'disturbed' if the disturbances are relatively few and weak or numerous and active, respectively. The relationships between solar activity and various geophysical phenomena to which they give rise are termed SOLAR–TERRESTRIAL RELATIONSHIPS.

sun dog: A popular alternative for mock sun or PARHELION.

sun drawing water: See CREPUSCULAR RAYS.

sun pillar: A vertical column of light above (and sometimes below) the sun, most often observed at sunrise or sunset. The colour may be white, pale yellow, orange or pink. The phenomenon, which is due to the reflexion of sunlight from ice crystals, may be seen over a wide area. See Plate 23.

sunrise and sunset colours: The general explanation of the variety of colours that are to be seen in the sky about the time of sunrise or sunset is as follows. White light such as that from the sun may be regarded as composite, the constituents being light of all the colours of the spectrum. When the light waves meet obstacles in their course, such obstacles as the molecules of the atmospheric gases or larger obstacles such as particles of dust, the waves are broken and secondary waves proceed in all directions from the obstacles. The direct light is therefore reduced in strength and the farther the light goes through an atmosphere of such obstacles the more the strength is reduced, the energy being used up in producing scattered light. This effect is more pronounced with blue light, for which the wavelength is longer. Accordingly a beam of white light passing through air loses the constituents of shorter wavelength and becomes yellow, then orange, and finally red.

This accounts for the changing colour of the sun as it nears the horizon. The SCATTERING by air alone merely makes the setting sun yellow, but if there is dust in the air or even the nuclei on which water vapour is condensed then the sun becomes orange or red before it sets.

Clouds which are illuminated by the light from the setting sun are also red, whilst other clouds which are illuminated by scattered light in which the blue constituents are present are white or grey; higher clouds illuminated by light which has only passed through less dense and cleaner air may also appear white.

The colours of the sky itself are to be explained in the same way. When sunlight has already travelled a great distance through the lower atmosphere it has lost the constituents of short wavelength, and in the light which remains to be scattered the longer wavelengths predominate. Farther in the passage of scattered light to the eye of the observer the longer wavelengths have the preference.

When we look at the sky in a particular direction we receive light which has been scattered by the atmosphere at all heights. Blue may predominate, whilst that coming from the lower levels may be red. The combination of light from both ends of the spectrum gives us purple. On the other hand in other parts of the sky the middle wavelengths may predominate and the resulting colours are green or yellow.

sunrise, sunset: The times at which the sun appears to rise and set, in consequence of the rotation of the earth on its axis. Owing to the effect of atmospheric REFRACTION, which increases the apparent angular altitude of the sun when near the horizon by about 34′, sunrise is earlier and sunset later than geometrical theory indicates. There is a further uncertainty caused by the fact that the sun has an appreciable diameter (32′) so that time elapses between the first and last contacts with the horizon. ~~For meteorological purposes, allowance is made for refraction and it is assumed that sunrise and sunset occur when the centre of the sun's disk is on the horizon.~~

The times of sunrise and sunset vary with latitude and with the declination of the sun. Diagrams illustrating the variations, so far as the British Isles are concerned, are given in the 'Observer's handbook'.*

sunshine: Direct, as opposed to diffuse, solar RADIATION.

The routine measurements of the duration of sunshine which are made for climatological purposes refer in the British Isles, as in most other countries, to so-called 'bright' sunshine. Since different instruments differ in their response characteristics to the radiation, this term lacks precise definition. Climatological means for places in the British Isles for the period 1921–50 are contained in 'Averages of bright sunshine for Great Britain and Northern Ireland, 1921–50'.†

sunshine recorder: An instrument for recording the duration of bright SUNSHINE. Such instruments depend either on the heating action of the sun or on the chemical

* London, Meteorological Office; Observer's handbook. 2nd edn., London, HMSO, 1956, p. 153.

† London, Meteorological Office; Averages of bright sunshine for Great Britain and Northern Ireland, 1921–50. London, HMSO, 1953.

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† London, Meteorological Office; Averages of bright sunshine for Great Britain and Northern Ireland, 1921–50. London, HMSO, 1953.

action produced by the sun's rays. The Campbell-Stokes recorder, an instrument of the former class, is in general use in the British Isles. A spherical glass lens focuses the solar image on a graduated card held in a frame of special design. The duration of sunshine is indicated by the length of the burnt track of the image. See 'Observer's handbook'.* See also EXPOSURE.

sunspot: A relatively dark region on the disk of the SUN, with an inner 'umbra' of effective radiation temperature about 4500°K and an outer 'penumbra' of somewhat higher temperature.

Sunspot duration varies from a few hours to many solar rotation periods. Their frequency is quasi-periodic, with an average 'period' of about 11 years. In the typical sunspot 'cycle' there are at first few spots in about solar latitude ±30°, maximum spots in about ±15° after some $4\frac{1}{2}$ years, and again few spots in about ±8° after a further $6\frac{1}{2}$ years, these last spots overlapping in time the first high latitude spots of the following cycle. There are, however, some large departures from these average figures. The mean time taken for a spot in solar latitude 0° to return to the central meridian, as seen from the earth, is 26·9 days: in latitude ±30° the time taken is 28·3 days.

Sunspots are vortex-like disturbances with large associated magnetic fields. There is yet no accepted theory of their formation or quasi-periodic nature. There are well established relationships of a general nature between sunspottedness and effects measured in the ionosphere, geomagnetism etc., but not as yet in meteorology.

Sunspottedness is represented by the 'relative sunspot number' (R), introduced by R. Wolf of Zürich Observatory and expressed by the formula

$$R = k(10g + f)$$

in which g is the number of groups of spots plus single spots, f is the total number of spots counted in the groups and spots combined, and k is a factor whose value

TABLE XIV—*Sunspot numbers* 1750–1961

	0	1	2	3	4	5	6	7	8	9
1750	83	48	48	31	12	10	10	32	48	54
1760	63	86	61	45	36	21	11	38	70	106
1770	101	82	66	35	31	7	20	92	154	126
1780	85	68	38	23	10	24	83	132	131	118
1790	90	67	60	47	41	21	16	6	4	7
1800	14	34	45	43	48	42	28	10	8	2
1810	0	1	5	12	14	35	46	41	30	24
1820	16	7	4	2	8	17	36	50	64	67
1830	71	48	28	8	13	57	122	138	103	86
1840	63	37	24	11	15	40	62	98	124	96
1850	66	64	54	39	21	7	4	23	55	94
1860	96	77	59	44	47	30	16	7	37	74
1870	139	111	102	66	45	17	11	12	3	6
1880	32	54	60	64	64	52	25	13	7	6
1890	7	36	73	85	78	64	42	26	27	12
1900	10	3	5	24	42	64	54	62	48	44
1910	19	6	4	1	10	47	57	104	81	64
1920	38	26	14	6	17	44	64	69	78	65
1930	36	21	11	6	9	36	80	114	110	89
1940	68	48	31	16	10	33	93	152	136	135
1950	84	69	31	14	4	38	142	190	185	159
1960	112	54								

* London, Meteorological Office; Observer's handbook. 2nd edn., London, HMSO, 1956, p. 122.

depends on the viewing instrument. The value of R for each day is compiled at Zürich from the results obtained at many observatories. Investigation has shown that the sunspot numbers derived in this arbitrary way are a reasonable index of 'spotted area' of the sun. $R = 100$ corresponds to about 1/500 of the sun's visible disk covered by spots.

The list of mean annual relative sunspot numbers since 1750 is contained in Table XIV.

superadiabatic lapse rate: A 'lapse rate' (rate of fall of temperature with height) greater than the dry ADIABATIC lapse rate of 1°C/100 m. Such a LAPSE rate does not occur within the free atmosphere, but the dry-adiabatic rate is often exceeded by a factor of several times near a land surface which is strongly heated by solar radiation.

supercooling: Supercooling of a liquid (sometimes termed 'subcooling' or 'undercooling') signifies the existence of a substance in the liquid state at a temperature below the normal freezing-point.

Although the supercooled state is regarded as unstable in the sense that its achievement in the laboratory requires very careful cooling of the liquid, supercooling of cloud droplets is common in the atmosphere. All clouds which extend above the 0°C isotherm contain supercooled droplets at some stage in their history: altocumulus is predominantly a water droplet cloud though generally at a temperature well below 0°C and it is necessary to attain cirrus level to find clouds almost invariably in the form of ice crystals. The larger raindrops do not undergo a marked degree of supercooling.

Supercooling is fundamental in the ice crystal process of PRECIPITATION.

superior air: A term sometimes used, in synoptic meteorology, in respect of air at higher levels which has been made very dry by the process of SUBSIDENCE.

superposed-epoch method: A method of statistical analysis (also called the 'n-method') which is used, for example, to investigate the possibility of a RECURRENCE TENDENCY in a given TIME SERIES, or the relationship between two synchronous time series.

Where a single series is involved, average values are calculated of the n terms $(+1, +2, \ldots + n)$ of the series which follow various '0' terms selected on the basis of an objective criterion, for example, the peak value in successive equal blocks of terms: statistical SIGNIFICANCE may be looked for in the departures of the computed average values from the over-all mean of the series, taking into account the standard deviation of the series.

Where the relationship between two series is involved, average values of terms $+1, +2, \ldots + n$ are computed in each series, the epoch of the '0' term being selected on the basis of a criterion applied to one of the series: the significance of the distribution of the means may be assessed by the CHI-SQUARED TEST, for example. Corroboration of a suggested relationship between the series may be sought by defining the '0' epoch on the basis of a criterion applied to the second series and repeating the calculations on the data arranged on this basis.

superrefraction: See ANOMALOUS RADIO PROPAGATION.

supersaturation: See SATURATION.

surface chart: In synoptic meteorology, an alternative for WEATHER MAP.

surface free energy: An alternative for SURFACE TENSION.

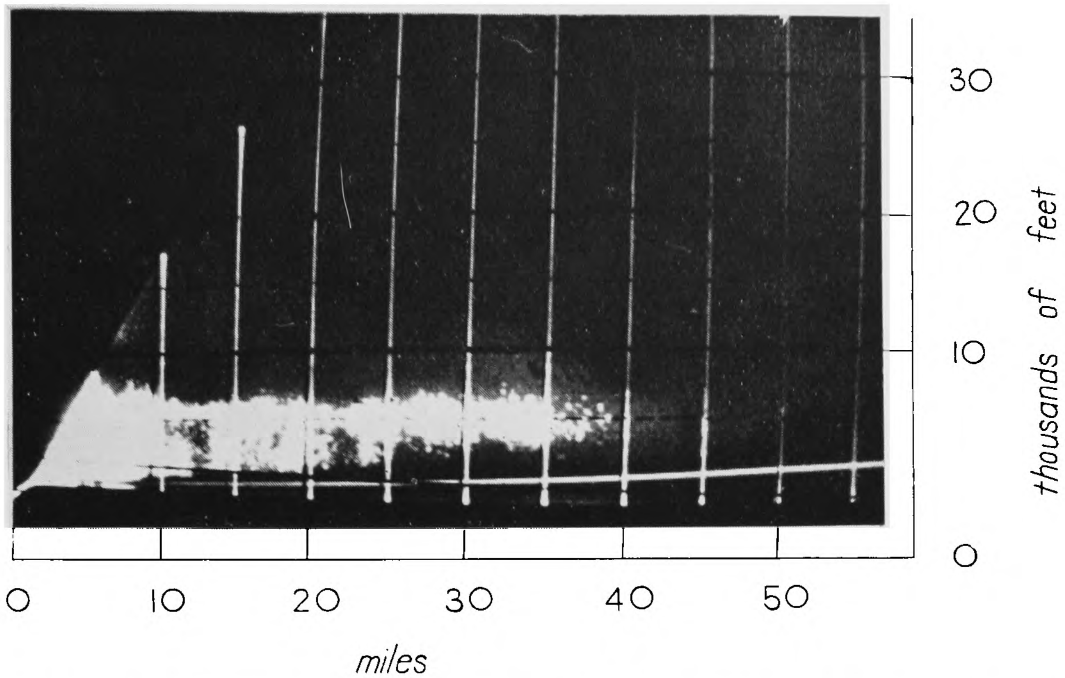

PLATE 24 RHI pattern in warm-front rain at 1750 GMT on 5 February 1957, (East Hill near Dunstable). Range markers are at 5-mile intervals and height lines at 5000-foot intervals.

In this photograph, taken with reduced receiver sensitivity, the strong echo from the melting level at 5000 ft (see MELTING BAND) is clearly revealed. (In a photograph taken immediately prior to this, with the receiver on full sensitivity, echoes from snow were obtained up to a height of 20,000 ft at short ranges; the melting band was then correspondingly reduced in relative intensity).

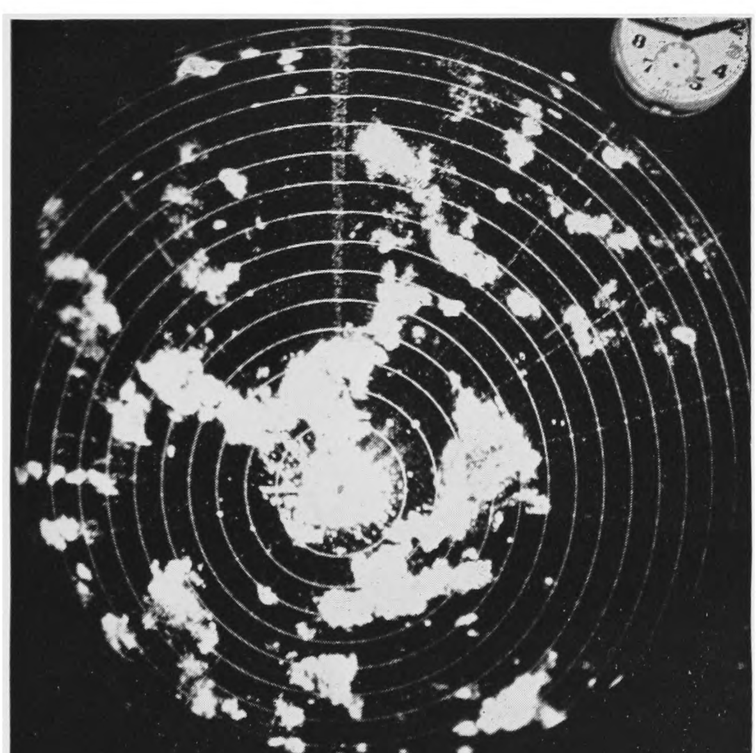

PLATE 25 PPI pattern of widespread showers and thunderstorms at 1345 GMT on 12 August 1958, (East Hill, near Dunstable). Range circles are at 5-mile intervals (maximum 80 miles) and azimuth lines at 20° intervals with magnetic north accentuated. The display has been slightly off-centred.

The well defined edges of the shower echoes are a notable feature of the pattern.

PLATE 26 Swell proceeding ahead of a tropical storm (actually approaching Nassau, Bahamas from West Indian hurricane). Note that the swell waves are long, low and long-crested. The wind is blowing almost at right angles to the direction of motion of the swell (i.e. parallel to the crests), as is made clear by the breaking of sea waves in the foreground.

surface inversion: An INVERSION of temperature through an atmospheric layer extending upwards from the earth's surface. This is frequently a RADIATION INVERSION, but it may form also as the result of a slow drift of air over a surface colder than itself.

surface temperature: Unless otherwise specified, the air temperature measured in the shade at a height of between 1·25 and 2 metres, as in the STEVENSON SCREEN.

surface tension: Any surface of a liquid is subject to a tension, expressed in dynes/cm in the c.g.s. system of units, due to forces of attraction between the liquid molecules which act in such a way as to distort the shape of the surface.

The phenomenon, which is also termed 'surface free energy' (ergs/cm^2), is important, for example, in NUCLEATION processes and in SOIL MOISTURE. The surface tension of pure water increases with decrease of temperature: values at +20°C, 0°C and −20°C are, for example, 72·7, 75·7 and 79·1 dynes/cm, respectively.

surface wind: Generally, the WIND velocity at a height of 10 metres in an unobstructed area.

surge: A term in synoptic meteorology which is sometimes used (first by Abercromby) to denote a substantial and general rise of atmospheric pressure over an area, the rise being greater than that attributable to the movement of depressions or anticyclones in the vicinity.

In tropical meteorology the term is used to signify a marked and sudden increase of strength of a monsoon or trade wind current.

The term is also used of water disturbances—see STORM SURGE.

swell: Swell is wave motion in the ocean caused by a disturbance which may be at some distance away; the swell may persist after the originating cause of the wave motion has ceased or passed away. It often so continues for a considerable time with unchanged direction, as long as the waves travel in deep water. The height of the waves rapidly diminishes but the length and velocity remain the same, so that the long low regular undulations, characteristic of swell, are formed. Swell is often observed to have a wavelength greatly in excess of that of waves seen during a storm: the probable explanation is that the longer waves are then masked by the shorter and steeper storm waves. Swell observations are useful in denoting the direction in which sea disturbance due to tropical cyclones or other storms has taken place. See Plate 26.

SWF: An abbreviation for 'short-wave (radio) fadeout'. When a SOLAR FLARE occurs, short radio-waves, which are normally received after reflexion by the F-layer, suffer extra absorption in the sunlit hemisphere D-layer, with an associated sudden fadeout (SWF) of reception of the waves. See also SID.

symbols, international meteorological: See WEATHER MAP.

symmetry point: In a graph of successive daily values of a meteorological element (particularly pressure) against time, a point about which the pattern displays a high degree of reflexion over a period lasting perhaps several weeks: the reflexion may be direct or reversed.

It has been suggested that, if such a symmetry point were recognized soon after its occurrence, the implied foreknowledge of subsequent variations of the element would be useful in long-range weather forecasting. Apart from the obvious difficulty of recognizing a symmetry point at a sufficiently early stage, the physical significance of the phenomenon appears very doubtful in the light of the statistical finding that, when the day-to-day PERSISTENCE of the element is taken into account, symmetrical patterns are no more remarkable or frequent than may be accounted for by chance.

synodic period: The synodic period of a planet or the moon is the interval of time between successive CONJUNCTIONS of the body and the sun, as viewed from the earth. See also DAY.

SYNOP: In weather messages, a code word indicating that surface meteorological reports from land stations follow in figure code. See 'Handbook of weather messages'.*

synoptic chart: A chart or map on which is represented the distribution of selected meteorological elements over a large area at a specified instant of time. 'Surface synoptic chart' is an alternative for WEATHER MAP.

synoptic meteorology: That branch of meteorology which is concerned with a description of current weather as represented on geographical charts and applied especially to the prediction of its future development.

The starting point for this branch of meteorology is the 'synoptic report' or 'synoptic message' containing a coded summary of the current weather at each of a large number of 'synoptic stations'. Many such reports, transmitted by land-line or wireless, are on receipt at selected centres plotted symbolically on a 'synoptic chart' which thus provides a representation of the weather at a particular time, and generally over a large geographical area, in a synoptic (summary or condensed) form which is suitable for the purposes of synoptic meteorology, as defined above.

synoptic station: A STATION at which meteorological observations are made for the purposes of SYNOPTIC METEOROLOGY. The observations are made at the 'major synoptic hours' 00, 06, 12, 18 GMT and normally also at the 'minor synoptic hours' 03, 09, 15, 21 GMT, the observed elements being plotted symbolically on the WEATHER MAP.

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* London, Meteorological Office; Handbook of weather messages, Parts II and III. London, HMSO, 1959.

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tablecloth: The term applied to the orographic stratus cloud which often occurs on the windward side of Table Mountain at Capteown, South Africa.

TAF: A code word for an aerodrome forecast, issued in an abbreviated TAFOR code.

TAFOR: A code word indicating that an aerodrome forecast follows in figure code. See 'Handbook of weather messages'.*

tail-wind: See EQUIVALENT HEAD-WIND.

Technical Commission: The Technical Commissions of the WORLD METEOROLOGICAL ORGANIZATION are each composed of experts in the various meteorological fields Aerology, Aeronautical Meteorology, Agricultural Meteorology, Climatology, Hydrological Meteorology, Instruments and Methods of Observation, Maritime Meteorology, and Synoptic Meteorology. Meetings of the Commissions take place at least once every four years.

telluric currents: An alternative for EARTH CURRENTS.

TEMP: In weather messages, a code word indicating that reports from land stations of upper air observations of pressure, temperature and dew-point, with or without wind information, follow in figure code. 'TEMP SHIP' is the indicator for similar reports from ships. See 'Handbook of weather messages'.*

temperature: The condition which determines the flow of heat from one substance to another. Temperature has no recognized DIMENSIONS, the normal convention being to allot to it the special dimension θ.

temperature scales: The scales in common use are the Celsius (or centigrade), the Fahrenheit and the Kelvin (or absolute) scales.

On the Celsius (centigrade) scale the freezing- and boiling-points of water at standard pressure are respectively 0°C and 100°C; on the Fahrenheit scale these points are 32°F and 212°F, the zero on this scale being the temperature of a mixture of common salt and ice. Alternative conversion formulae °C to °F and vice versa are:

$$(1)\qquad {}^{\circ}C = ({}^{\circ}F - 32) \times \frac{5}{9} \text{ and } {}^{\circ}F = ({}^{\circ}C \times \frac{9}{5}) + 32,$$

$$(2)\qquad {}^{\circ}C = ({}^{\circ}F + 40) \times \frac{9}{5} - 40 \text{ and } {}^{\circ}F = ({}^{\circ}C + 40) \times \frac{5}{9} - 40.$$

* London, Meteorological Office; Handbook of weather messages. Parts II and III. London, HMSO, 1959.

The use of the gas thermometer is based on the gas equation, combining BOYLE'S and CHARLES'S LAWS in the form:

$$\frac{p_1 v_1}{p_2 v_2} = \frac{1+\alpha t_1}{1+\alpha t_2}$$

where α is the volume coefficient of expansion of the gas. α is found experimentally to be nearly the same for all pure gases and to be identical on extrapolation to zero pressure, the state of 'perfect gas', with the value 0·0036609 per °C. The equation shows that zero pressure occurs at the temperature $t = -1/\alpha$ i.e., $1/\alpha = 273{\cdot}15$ centigrade degrees below the ice point (0°C) and defined as the 'absolute zero'. Kelvin showed from thermodynamic reasoning that the perfect gas scale, measured from absolute zero in centigrade units, is 'absolute' in the sense that it is independent of the thermometric substance. The symbol °K is now recommended in preference to °A for temperatures measured on this Kelvin (absolute) scale. It is the appropriate scale to use in basic physical equations which involve temperature. Its use has also the practical advantage of avoiding negative values. In meteorological practice °K = 273+°C with sufficient accuracy.

tendency: A term used in synoptic meteorology to signify local time rate of change of an element, for example of surface pressure or of GEOPOTENTIAL (height) at a fixed pressure level. See BAROMETRIC TENDENCY.

tendency equation: The equation relating the change of pressure with time at a point at height h in the atmosphere (pressure TENDENCY) to the change in the weight of the air above is:

$$\left(\frac{\partial p}{\partial t}\right)_h = -g\int_h^\infty \rho\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)\mathrm{d}z - g\int_h^\infty\left(u\frac{\partial \rho}{\partial x}+v\frac{\partial \rho}{\partial y}\right)\mathrm{d}z + (g\rho w)_h$$

where g is the acceleration of gravity (assumed here constant with height), ρ air density, and u, v, w the components of the wind velocity in the x, y, z directions, respectively (z the vertical co-ordinate).

The equation shows that the local pressure tendency at height h has contributions from three processes (the three terms, taken in order):

(i) horizontal DIVERGENCE at heights greater than h,
(ii) horizontal ADVECTION of air of different density at heights greater than h,
(iii) vertical motion of air at height h.

The third process does not normally operate in the surface pressure tendency $(\partial p/\partial t)_0$ because of the boundary condition $w = 0$ at the earth's (level) surface.

tenuity factor: In BALLISTICS, the ratio of the density of the air having the observed pressure at the surface, and temperature equal to the BALLISTIC TEMPERATURE, to the density of air at pressure 30 in. of mercury and temperature 60°F.

tephigram: An AEROLOGICAL DIAGRAM with Cartesian co-ordinates T (temperature) and log θ (potential temperature). See Figure 2.

tercentesimal scale: The name for the approximate absolute scale, sufficiently accurate for meteorological purposes, obtained by adding 273° to the Celsius temperature. See TEMPERATURE SCALES.

terminal velocity: The velocity of a body, falling through a viscous fluid, increases to a 'terminal' value when the weight of the body is balanced by the combined up-thrust and viscous drag.

For a small sphere of radius r cm and of material density σ gm/cm³, falling through a fluid of density ρ gm/cm³ and viscosity η poise, under conditions where STOKES'S LAW is obeyed, the terminal velocity v is given by:

$$v = \frac{2}{9} g \frac{r^2(\sigma - \rho)}{\eta} \text{ cm/sec}$$

where g is acceleration of gravity (cm/sec^2).

From the formula, v for water drops of radius 10 microns (μ), i.e. 0·01 mm, is 1·3 cm/sec in still air at N.T.P. and varies directly as the square of the drop radius. Owing to turbulence and departure of drops from spherical form, however, the formula does not hold for drops of radius greater than about 25μ. For drops that are larger but of radius less than 500μ, the approximate empirical formula $v = 0{\cdot}8r$ cm/sec (r, radius, in microns) has been suggested: for still larger drops the approximate formula $v = 650\sqrt{r}$ cm/sec applies (r now in mm), with a limiting value of about 900 cm/sec for the largest raindrops (radius about 3 mm). Terminal velocities at 3 and 6 km exceed those at N.T.P. by about 10 and 30 per cent, respectively.

The terminal velocity of a single ice crystal is about 70 cm/sec, of a small snowflake about 100 cm/sec, and of a large snowflake about 200 cm/sec. For hailstones, of diameter d mm, the following approximate formulae have been suggested. The formulae are not generally agreed: some workers assume a smaller factor by up to about 50 per cent for soft hail, and a larger factor by up to about 50 per cent for other hailstones.

$v = 2\sqrt{d}$ m/sec, for soft hail

and $v = 2{\cdot}8\sqrt{d}$ m/sec, for other hailstones ($10 \leq d \leq 100$ mm).

terrestrial magnetism: See GEOMAGNETISM.

terrestrial radiation: RADIATION, (also termed 'long-wave radiation' or, loosely, 'infra-red radiation'), which is emitted by the earth and atmosphere in the approximate temperature range 200°–300° K. The radiation is confined within the wavelengths of about 3 and 100 microns and has maximum intensity at about 10 microns. Since the earth is nearly a perfect radiator, the radiation from its surface varies in close accord with the Stefan–Boltzmann law, i.e. directly as the fourth power of the absolute temperature of the surface.

thaw: The transition by melting from snow or ice to water. The term is especially used to indicate the end of a spell of FROST, which in the British Isles in winter is generally associated with the displacement of a stagnant or continental air mass by one of maritime origin.

theodolite, pilot-balloon: An instrument consisting of a telescope mounted to permit of rotation in elevation and azimuth, and fitted with a right-angled prism so that the observer continues to look horizontally into the eyepiece no matter what the elevation of the balloon.

thermal: A volume of air which possesses BUOYANCY on account of low density relative to its environment and so rises through the environment.

Thermals are produced in conditions of intense solar heating over land, with a resulting SUPERADIABATIC LAPSE RATE at low levels. Strong thermals tend to occur over regions where the earth's surface is warmer than the surrounding area: sun-facing slopes and towns are among the good thermal sources recognized by glider pilots. Cumulus clouds show the presence of thermals which, however, often exist without such evidence.

Observations have shown that the typical pattern of air motion within a thermal is one in which maximum vertical velocity occurs within the central core, with circulatory motions ('vortex rings') towards either edge of the thermal. A thermal grows in size by mixing with surrounding air at its upward moving head and by the mixing of air into its wake. The temperature excess and buoyancy of the thermal relative to its environment are thus progressively reduced.

thermal capacity: The thermal capacity, also called heat capacity, of a body is the product of its mass and its SPECIFIC HEAT.

thermal conductivity: see CONDUCTIVITY, THERMAL.

thermal depression: A surface depression whose formation is the direct result of differential solar heating of neighbouring land and sea areas: in summer, for example, air density and therefore also surface pressure over land tend to be reduced relative to the values over sea, because of the higher surface temperatures reached.

A thermal depression may form over the British Isles during afternoon and evening in summer if the general pressure gradient is very slight: such a depression is weak, is of low vertical extent and has no pronounced associated weather characteristics. An example of the opposite kind is the tendency for formation of shallow depressions in winter over the relatively warm Mediterranean. The Asiatic 'monsoon low' is an example of a thermal depression on a much larger scale.

thermal diffusivity: see CONDUCTIVITY, THERMAL.

thermal equator: The latitude of highest mean air temperature. Because of the non-uniform distribution of land and sea, this does not coincide, over a year, with the geographic equator. In northern summer the thermal equator is at about 20°N, in northern winter at about 0°, averaging about 10°N for the year as a whole.

thermal high (low): A closed centre of high (low) values of THICKNESS on a thickness chart. The centre is so called because it represents, to a close approximation, a centre of high (low) mean temperature in the isobaric layer concerned.

thermal steering: The principle of thermal steering states that surface patterns of the vertical component of vorticity (corresponding closely to surface depressions

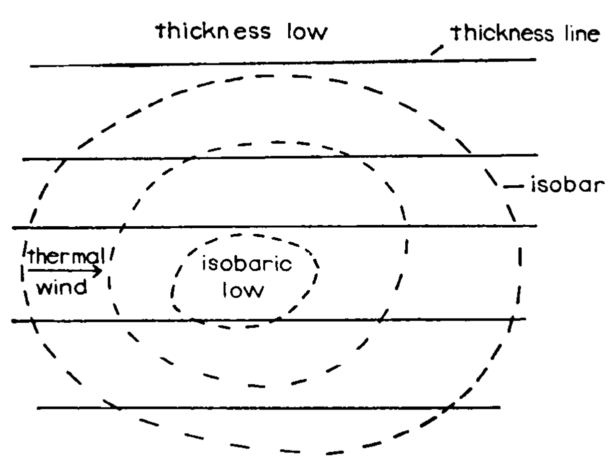

FIGURE 31—Thermal steering.

and anticyclones) are 'steered' in the direction of the THERMAL WIND in the troposphere, with a speed proportional to that of the thermal wind. The process is one of forward development, rather than translation, of the vorticity patterns.

Thermal steering is always present but is often masked by other processes of development. Application of the steering principle is most successful in the type of situation illustrated in Figure 31, i.e. one in which almost straight thickness lines intersect a well marked pattern of surface vorticity. See DEVELOPMENT.

thermal wind: The thermal wind ($\mathbf{V}_T$) in a specified atmospheric layer, at a given time and place, is the vertical geostrophic WIND SHEAR in the layer concerned. Where $\mathbf{V}_1$ and $\mathbf{V}_o$ are the geostrophic winds at the top and bottom of the layer, respectively, $\mathbf{V}_T$ is defined by the relationship

$$\mathbf{V}_T = \mathbf{V}_1 - \mathbf{V}_o$$

The term 'thermal wind' was adopted because the wind shear concerned is determined by the distribution of mean temperature in the layer. Where, as in normal practice, the layer is defined by two isobaric surfaces, $\mathbf{V}_T$(m/sec) is of magnitude

$$\left| \frac{9{\cdot}8}{f} \frac{\partial Z'}{\partial n} \right|$$

where f is the CORIOLIS PARAMETER, Z' is the THICKNESS of the layer, and n is a co-ordinate normal to the thickness lines. The thermal blows parallel to the thickness lines (mean isotherms) in such a sense as to keep low thickness (low mean temperature) on the left in the northern hemisphere and on the right in the southern hemisphere. If, as was at one time the practice, the layer thickness is expressed in geometric (z') units, $\mathbf{V}_T$ is of magnitude

$$\left| \frac{g}{f} \frac{\partial z'}{\partial n} \right|$$

where g is the acceleration of gravity.

See also VECTOR.

thermocouple: An instrument for measuring temperature. It consists basically of two wires of different metals joined at each end. One junction is kept at a fixed (known) temperature, the other put at the point where the temperature is to be measured. A thermoelectric e.m.f. is generated, of magnitude proportional to the temperature difference (for two given metals): this e.m.f., or the resulting electric current in the circuit, may be used as a measure of the temperature difference between the junctions.

thermodynamic diagram: A diagram on which may be represented graphically the states of air samples (or the varying state of a single air sample) in terms of pressure, temperature, and humidity or of other functions related to these. It is also termed an 'adiabatic diagram' or, in meteorology, an AEROLOGICAL DIAGRAM, many forms of which exist.

The term 'thermodynamic diagram' is restricted by many authors to those types of adiabatic diagram in which the area enclosed on the diagram by a curve which represents a cyclic thermodynamic process is proportional in all parts of the diagram to the amount of work performed in the process.

thermodynamics: That part of the science of heat which deals with the transformation of heat into other forms of energy, and vice versa.

thermodynamic temperatures: Definitions of thermodynamic dew-point, frost-point, ice-bulb, and wet-bulb temperatures are identical with those of DEW-POINT, FROST-POINT, ICE-BULB TEMPERATURE, and WET-BULB TEMPERATURE. The distinction in nomenclature is made in recognition of the fact that the measured values of these elements may differ slightly from the defined values because of instrumental limitations or procedure.

thermogram: The continuous record of temperature yielded by a THERMOGRAPH.

thermograph: A recording THERMOMETER. Many patterns are in use, the sensitive member being, for example, a bimetallic spiral, a Bourdon tube, a resistance element, or a steel bulb filled with mercury.

thermohygrograph: An alternative for HYGROTHERMOGRAPH.

thermometer: An instrument for measuring temperature, from one or other of the physical changes produced in matter by heat, e.g. expansion of solids, liquids or gases, changes in electrical resistance, production of electromotive force at the junction of two different metals etc.

In normal meteorological practice mercury-in-glass thermometers are used. At temperatures below −38·9°C (freezing-point of mercury), and also in measuring minimum temperatures, alcohol (freezing-point −114·4°C) is used.

See BOURDON TUBE, EARTH THERMOMETER, MAXIMUM THERMOMETER, MINIMUM THERMOMETER.

thermopile: An instrument for measuring RADIATION. It consists essentially of a number of THERMOCOUPLES, either connected in series (if e.m.f. is measured) or in parallel (if electric current is measured), as a means of increasing the sensitivity beyond that possible with a single thermocouple.

thermosphere: That part of the ATMOSPHERE, extending from the top of the MESOSPHERE at about 80 km to the atmosphere's outermost fringe, in which the temperature increases with increasing height.

thickness: The GEOPOTENTIAL height difference at a given place between specified pressure levels. Thickness values relating to selected standard pressure levels are obtained from radio-sonde observations and are plotted on geographical 'thickness charts'. Contours are drawn, at an appropriate thickness interval, joining places of equal thickness and are termed 'thickness lines'. The analysis of such charts is termed 'thickness analysis' and has an important role in synoptic meteorology—see, for example, DEVELOPMENT.

thoron: Gas, of atomic mass 220 and atomic number 86, which is a radioactive isotope of RADON. It occurs in minute concentration in the atmosphere and plays a small part in the IONIZATION of the air at low levels.

thunder: The noise which follows a flash of LIGHTNING, caused by a sudden heating and expansion of air along the path of the lightning. The distance of a lightning flash may be roughly estimated from the interval between seeing the flash and hearing the thunder, counting one mile for every five seconds. The long duration of thunder compared with the associated lightning flash is explained by the different distances travelled by the sound from different parts of the flash and by echoing from mountain sides. Echoing causes intensity variations which, however, also arise from the multiple and tortuous nature of many lightning strokes.

Thunder is seldom heard at distances greater than 10 miles, though distances up to about 40 miles have been reported on occasion. Owing to refraction of sound waves in the lower atmosphere, thunder is sometimes inaudible at distances much less than 10 miles, especially when the initiating lightning flash is not to ground.

thunderbolt: Popular term for a LIGHTNING discharge from cloud to ground.

thundercloud: Popular expression for CUMULONIMBUS, the cloud associated with thunderstorms.

thunderstorm: 'One or more sudden electrical discharges, manifested by a flash of light (lightning) and a sharp or rumbling sound (thunder.'*)

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* Geneva, World Meteorological Organization; International cloud atlas. Vol. 1, Geneva, WMO, 1956, p. 76.

Necessary conditions for a thunderstorm are generally stated to be a CUMULONIMBUS cloud base lower than the 0°C isotherm, such vertical depth of cloud as to ensure a cloud top of temperature less than about −20°C (probably implying glaciation of the cloud top), and the occurrence of precipitation. There are, however, well substantiated observations, mainly in low latitudes, of the occurrence of lightning in clouds no parts of which were at a temperature below 0°C. The mature thundercloud often has a cellular structure and there are both updraught and downdraught regions: in earlier stages of development only updraught occurs, in later stages of dissipation only downdraught. Vertical updraught averages about 6 m/sec and may reach 30 m/sec: downdraught velocities are about half those of updraught.

Charge separation in thunderclouds is such as to produce a positive charge in the upper part of the cloud and negative charge in the lower part: small regions of positive charge near the base have also been observed. Initial charge separation has been attributed by various workers to mechanisms such as the selective capture of ions by water drops or ice particles, the frictional rupture of large raindrops, and surface and volume interactions of water, in its various phases, contained in the cloud. Experimental support has been obtained for most of the theories but the relative importance of the various mechanisms is yet uncertain.

Rainfall in a thunderstorm at a particular place typically reaches peak intensity more quickly than it dies away; behaviour is, however, sometimes complicated by the effects of two or more cells. Other well marked surface effects are attributable to the arrival of the downdraught air which, cooled by evaporation of water drops, is accelerated earthwards. Surface wind suddenly becomes strong and gusty; temperature falls sharply, sometimes by 10°C or more; relative humidity rises unsteadily to nearly 100 per cent; and pressure rises sharply, reversing a previous fall. Thunderstorms are fairly frequently accompanied by hail: in Great Britain, snow in thunderstorms is mainly confined to exposed west and north coasts.

An adequate supply of moisture and a lapse rate of temperature in excess of the saturated adiabatic through a range of height not less than 3000 metres above cloud base are required for the development of a thunderstorm: high surface temperature is a common but not an essential condition. An initial 'trigger' action is often provided by orographic uplift or, especially, by horizontal convergence of surface air. This latter most frequently exists in a shallow depression, trough of low pressure (as at a cold front), or col: the line of convergence which often marks the farthest inland penetration of the sea-breeze may provide the necessary impulse.

In Great Britain thunder is a very variable element, the highest and lowest annual totals at many individual stations ranging from less than five in a quiet year to twenty or more in an active one. One consequence of this is that published maps showing the average frequency of days of thunder differ considerably in detail according to the period of records used. They agree, however, in showing that the average annual frequency is less than 5 days in western coastal districts and over most of central and northern Scotland and 15–20 days over the east Midlands and parts of south-east England. There is relatively little seasonal variation on the western seaboard but elsewhere summer is the most thundery season.

The most thundery part of the earth is the island of Java where the annual frequency of thunderstorms is about 220. C. E. P. Brooks has estimated that the earth has a total of about 44,000 thunderstorms per day and a total of about 100 lightning discharges each second.

thunderstorm day: A local calendar day on which THUNDER is heard.

tidal wave: A popular term for a destructive type of wave motion in seas and oceans, associated either with strong winds or with under-water earthquakes. In technical terms they are classified as STORM SURGE and TSUNAMI, respectively.

tide: The periodic rise and fall of the earth's oceans due to combined gravitational forces applied by the moon and sun. Similar, though more complex, effects occur in the earth's atmosphere—see ATMOSPHERIC TIDES.

time: When the centre of the sun is due south of an observer, the time is called 12h or noon, local apparent time (LAT). The sun is said to 'transit' at this time. The interval between two consecutive transits of the sun is divided into 24 equal parts, and the times where the lines of division fall are numbered 13h, 14h . . . 23h, 24h (or midnight), 1h, 2h . . . 12h. Local apparent time is recorded by sunshine recorders and sundials.

The interval of time between successive transits of the sun is not quite constant, but goes through a cycle of changes during the year. This is due to the two facts that the orbit of the earth is elliptical, and that the earth's axis is not at right angles to its orbit. As it would be very inconvenient in daily life if the length of the day varied in this way, astronomers have invented a 'mean sun' whose apparent motion round the earth is uniform throughout the year. The apparent positions of the real and mean suns are always very close, and coincide on the average of a year. The moment of transit of the mean sun is 12h (or noon) local mean time (LMT). The interval between successive transits is called a DAY and each day is divided into 24 equal parts. All hours, and all days, are equal in duration. Local mean time is obtained from local apparent time by adding (or subtracting, if sign is minus) the 'equation of time' which is given very accurately in 'The Astronomical Ephemeris'* and elsewhere, and sufficiently accurately for meteorological purposes in the 'Observer's Handbook'.† The equation of time varies from about $+14\frac{1}{2}$ minutes in mid-February to about $-16\frac{1}{2}$ minutes in early November.

Local mean time at Greenwich is called Greenwich mean time (GMT). Differences in local mean time between different places are determined solely by longitude differences on the scale 1 hour per 15° of longitude. Thus, LMT for any place is derived from GMT by adding to GMT, or subtracting from GMT, a correction on this scale (4 minutes of time per degree of longitude), according as the place is to the east or west of the Greenwich meridian.

The inconvenient use of a clock time which varies continuously with longitude is avoided by the use of ZONE TIME. In the British Isles, GMT is used for normal civil purposes, except in summer when the clocks are advanced by one hour (BRITISH SUMMER TIME): GMT is, however, adhered to throughout the year for meteorological observation purposes, other than evening reports for the Press from selected stations, which are based on clock time.

time series: In statistics, a series of values which are arranged in order of occurrence and which refer, in general, to equally spaced time intervals. Such series are common in geophysics. The values may be those which obtain at discrete intervals of time or which are averaged over successive periods of time.

Some degree of persistence normally exists between successive values in a time series, provided the time interval of separation is not too long. The presence of persistence implies that the number of statistically independent values in the series may be much smaller than the total number of values, with important implications in questions of statistical SIGNIFICANCE. See PERSISTENCE.

tonne: Metric ton, equal to 10^6 gm (0·9842 ton).

topography: A term used to signify the configuration of contours of a surface. It is used both of natural contours which delineate higher and lower levels of the earth's surface, and, in synoptic meteorology, of contours of an isobaric surface.

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* London, Her Majesty's Nautical Almanac Office; The Astronomical Ephemeris, London.

† London, Meteorological Office; Observer's handbook, London, HMSO, 1956, p. 209.

tornado: A violent whirl, generally cyclonic in sense, averaging a few hundred feet in diameter and with an intense vertical current at the centre capable of lifting heavy objects into the air. Uprooting of trees and the explosive destruction of buildings, due to local pressure differences that occur in the intense horizontal pressure gradient near the tornado centre, mark the paths of tornadoes. The paths vary in length from a few hundred yards to some hundreds of miles: associated winds in extreme cases are estimated to attain speeds of the order of 200 knots. Heavy rain, and generally thunder and lightning, occur with the tornado.

While the conditions required for the formation of a tornado are similar to those required for a severe THUNDERSTORM, namely great instability, high humidity, and horizontal convergence of winds at low levels, the precise conditions which cause tornadoes (rather than merely thunderstorms) are not yet known. Tornadoes are most frequent and intense in the United States, east of the Rocky Mountains, especially in the central plains of the Mississippi region where they form in unstable air of tropical origin and move towards north or north-east.

Destructive tornadoes have been reported in the British Isles (mainly south and central) with a frequency somewhat greater than once in two years: because of their very local nature, however, some may be unrecorded and their actual frequency of occurrence is probably appreciably greater than this.

The term 'tornado' has also been used for thunderstorm squalls in West Africa.

torr: Unit of pressure equal to 1 mm mercury under conditions of STANDARD DENSITY and STANDARD GRAVITY.

Torricelli, Evangelista: The inventor of the barometer, born at Piancaldoli in 1608. In 1641 he became amanuensis to Galileo for three months until Galileo's death. Subsequently he was professor to the Florentine Academy until his death in 1647. Torricelli deduced from the fact that water would rise only about 32 ft in a suction pipe, that the air had weight, and could, therefore, exert a definite pressure equivalent to a height of 32 ft of water or 2½ ft of mercury. This conclusion was confirmed by the well known Torricellian experiment.

torrid zone: The torrid (or equatorial) zone is the region of the earth which lies between the Tropics of Cancer and Capricorn at about 23·5°N and 23·5°S, respectively.

tower of the winds: An octagonal tower, built in Athens in about the second century B.C. The tower carries on its sides the names of the winds associated with the eight compass points and also symbolic figures which represent the character of the winds. A description of the figures is given by Theophrastus in his treatise 'On winds and on weather signs' and is quoted by Sir Napier Shaw in 'Manual of Meteorology', Volume 1,* together with an estimate of the corresponding weather.

trace of rain: In rainfall measurement, a 'trace' is recorded if either, (i) the measured fall is less than 0·05mm (0·005in.) and the observer knows that the water in the gauge is not the result of water draining from the sides of the can after the previous measurement; or (ii) the gauge contains no water but the observer knows from his own observation that some rain or other precipitation has fallen since the previous observation.

trade winds: The trade winds (or 'tropical easterlies') are the winds which diverge from the subtropical high-pressure belts, centred at 30°–40° N and S, towards the equator, from north-east in the northern hemisphere and south-east in the southern hemisphere.

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* SHAW, SIR NAPIER; Manual of Meteorology, Cambridge, 1942, Vol. 1, p. 80.

The characteristics of the trade wind belt vary considerably with both latitude and longitude. Marked steadiness of the winds is a feature only in latitude belts some 10°–15° wide, centred on about 15° N and S (but varying somewhat with season), mainly in the eastern half of the tropical oceans. Fine weather prevails in the poleward and eastern sections of the belts, due to the marked anticyclonic subsidence undergone by the trade wind air. Towards the equator and the western oceanic regions of the belt, the stability of the air is decreased by added moisture: more cloudy, showery weather prevails in these regions, accentuated at times by horizontal convergence of air and the development of cyclones.

The name originated in the nautical phrase 'to blow trade', meaning to blow in a regular course or constantly in the same direction, afterwards shortened to 'trade'. The word is allied to the words 'track' and 'tread': its use in the sense of commerce was a later development.

See also ANTITRADES.

trajectory: A curve drawn to represent the actual path of an air particle over a finite time interval. Such a path is in general three-dimensional: normally, only the horizontal projection of the path is drawn because of insufficient knowledge of the relatively small vertical component of motion.

tramontana: A local name in the Mediterranean for a northerly wind. It is usually dry and cold.

transit: Transit of a heavenly body is said to occur when the body is on the MERIDIAN of the observer. The body is at its maximum elevation at the moment of transit.

translucidus (tr): One of the CLOUD VARIETIES. (Latin, *translucidus* transparent.)

'Clouds in an extensive patch, sheet or layer, the greater part of which is sufficiently translucent to reveal the position of the sun or moon.

The term applies to ALTOCUMULUS, ALTOSTRATUS, STRATOCUMULUS and STRATUS.'* See also CLOUD CLASSIFICATION.

transmission coefficient: A quantity τ, also called the 'transmissivity', which is the fraction of the radiation intensity incident on a medium which remains in the beam after passing through unit thickness of the medium. It is related to the ATTENUATION coefficient α by the relation

$$\tau = e^{-\alpha}$$

transmissivity: An alternative for TRANSMISSION COEFFICIENT.

transmittancy: The transmittancy T of a medium of thickness r is the pure number defined by

$$T = \tau^r$$

where τ is the TRANSMISSION COEFFICIENT of the medium.

transparency: The capacity of a medium for allowing RADIATION to pass. Of fundamental importance in meteorology are the different transparencies of the various atmospheric constituents in respect of radiation of a given wavelength, and of individual constituents in respect of radiation of different wavelengths. See also ABSORPTION.

transpiration: The process by which the liquid water contained in soil is extracted by plant roots, passed upwards through the plant and discharged as water vapour to the atmosphere. The process is one necessary for the health and growth of the

* Geneva, World Meteorological Organization; International cloud atlas, Vol. 1, Geneva, WMO, 1956, p. 16.

plant. The rate of transpiration during the day is about the same as that from an open water surface in the same meteorological conditions but is almost zero during night hours.

If the root system of a plant is never short of water the process corresponds to so-called 'potential transpiration'. The actual rate of transpiration falls significantly below the potential value only in a long spell of dry weather, a difference between the rates appearing sooner with the shallower-rooted plants. See also EVAPOTRANSPIRATION.

tree line: A term used to signify, on the hemispherical scale, the latitudinal limit of tree growth; on the regional scale, the higher altitude limit of tree growth within a region.

In the northern hemisphere the tree line divides the TUNDRA regions from those of BOREAL CLIMATE. Within the British Isles the tree line is generally at a height of 1500 to 2000 feet above sea level. The tree line depends mainly on summer temperature, an approximate criterion for growth being a mean temperature in excess of 10°C (50°F) in at least two months. Such physical factors as exposure and drainage are also important.

tree ring: See DENDROCHRONOLOGY.

triple point: That point on a pressure–temperature diagram which is the common meeting point of the liquid–vapour, solid–liquid, and solid–vapour lines for a given substance. These lines sharply define the conditions of pressure and temperature at which the changes of state from liquid to vapour, etc. occur. The triple point thus represents the pressure–temperature conditions, unique for a given substance, at which the substance may be solid, liquid or gas. The triple point of water substance has the co-ordinates $p = 4{\cdot}58$ mm, $T = +0{\cdot}0075$°C.

The term triple point is also used in low-latitude synoptic meteorology to indicate the meeting place of three distinct air masses at which CYCLOGENESIS may occur. Opinion is, however, divided as to whether such a junction of air masses really exists.

tropical air: An AIR MASS originating in low latitudes, normally in the SUBTROPICAL HIGHS at around 30°–35° N and S.

Tropical air which reaches the British Isles generally originates in the Atlantic ('maritime tropical air'). It is characterized on and near the south and west coasts by stability at low levels, low stratus clouds, hill fog, poor visibility, and frequent drizzle. Inland and in the east the weather is often modified, especially in summer, to become fair but close. Occasionally, tropical air reaching the British Isles is of continental (African) origin ('continental tropical air') and is then generally associated with fine, mild (in summer, very warm) weather.

tropical climate: A type of CLIMATE which obtains in most equatorial and tropical parts of the earth and is characterized by high temperatures and high humidity throughout the year and frequent rain throughout most of the year.

tropical cyclone: A CYCLONE of tropical latitudes. Nomenclature is not completely standardized but, in general, a distinction is made between a 'tropical depression' (winds of Beaufort force less than 6), a 'tropical storm' (force 6 to 11), and, depending on locality, a 'cyclone', 'hurricane' or 'typhoon' (force 12 or greater).

The more intense tropical cyclones are confined to fairly specific regions and seasons which, broadly, are the western sides of the great tropical oceans, beyond 5° from the equator, towards the end of the hot season or seasons. More specifically, the main oceanic regions and times are: North Atlantic (West Indies), North Pacific (off west coast of Mexico), and North Pacific, westwards of 170°E (China

Seas), July to October; South Indian (Madagascar to 90°E and near north-west Australia) and South Pacific (150°E eastwards to 140°W), December to March; Bay of Bengal and Arabian Sea, April to June and September to December.

The mean annual cyclone frequencies for the North Atlantic (1887–1948) are 7·3 (all intensities) and 3·5 (hurricanes): the respective mean monthly frequencies for the month of maximum frequency (September) are 2·4 and 1·3. Months of maximum frequency of cyclones of hurricane intensity are not always, though usually, those of maximum frequency of cyclones of all intensities, for example, depressions are most common in the Bay of Bengal in July but development to hurricane intensity does not occur then.

Central pressure of the more intense tropical cyclones is often about 960 mb and pressure at the periphery about 1020 mb. These values are comparable with those of a mid-latitude depression but the tropical storm diameter is much smaller

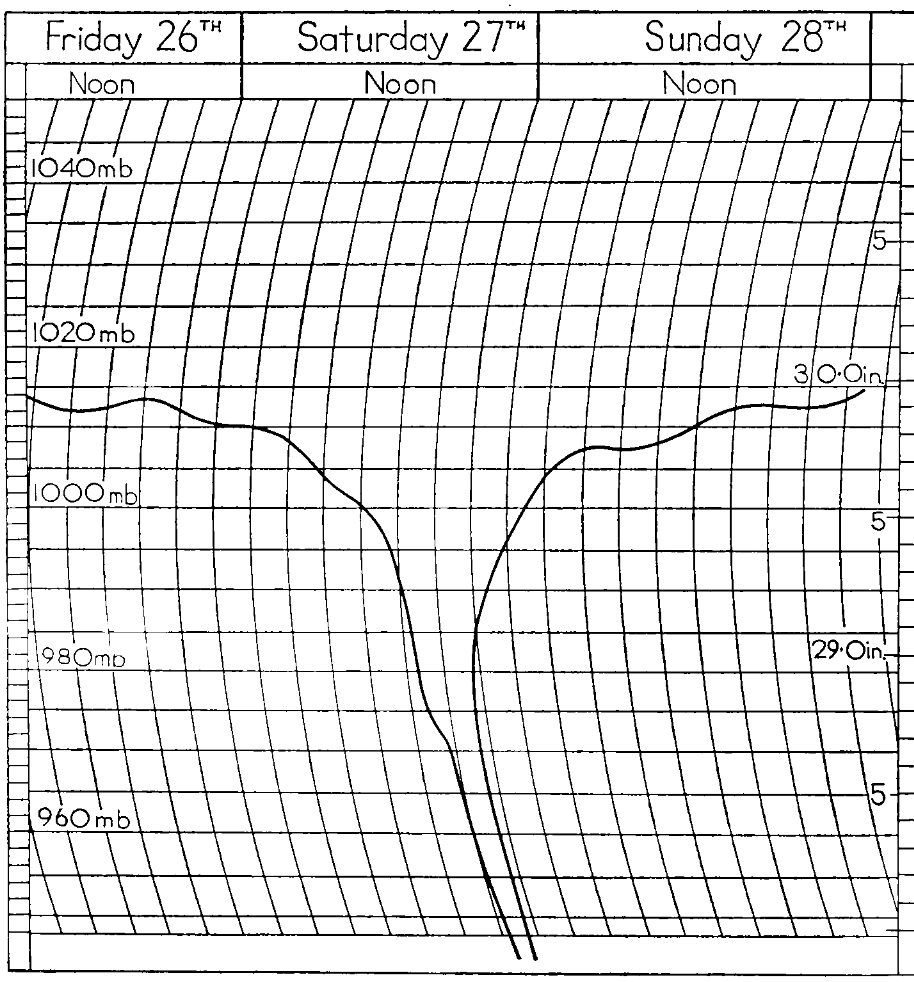

FIGURE 32—Barogram for Cocos Island, November 1909.

(some 500 miles compared with 1500 miles) and pressure gradients and winds are correspondingly greater. Very low surface pressures are sometimes attained: the lowest known value reduced to mean sea level is about 877 mb, recorded about 600 miles east of Guam on 24 September 1958. Pressure tendencies are very large near the centre of an intense tropical cyclone: Figure 32 is a reproduction of a barogram during the passage of such a cyclone.

A tropical cyclone generally moves initially towards west or north-west in the northern hemisphere and towards west or south-west in the southern hemisphere: the speed is generally about 10 knots. 'Recurvature' of the cyclone, that is change of path direction towards north-east in the northern hemisphere and towards south-east in the southern hemisphere, sometimes occurs at about latitudes 20°–30°. Much more complex tracks, however, are not uncommon. After recurvature, the cyclone tends to assume the characteristics of a mid-latitude depression.

Apart from a central EYE region, some 10 miles in diameter, heavy and continuous rain and multi-layer cloud occupy the central regions of the cyclone, with more showery precipitation towards the edges. Decay of a cyclone is usually rapid after passage inland.

A sufficient supply of both real and latent heat (sea surface temperature at least 27°C or 80°F) at a distance from the equator (at least some 5°) sufficient for the CORIOLIS FORCE to be active are necessary conditions for the formation of a tropical storm. The precise mechanisms which cause shallow tropical cyclones to form, or having formed, to intensify to a tropical storm or hurricane are yet uncertain. An essentially dynamical explanation, rather than a frontal or convective explanation, is now favoured.

tropics: That region of the earth's surface lying between the Tropics of Cancer and Capricorn at about 23° 27′ N and S, respectively.

tropopause: The atmospheric boundary between the TROPOSPHERE and the STRATOSPHERE.

(i) The 'first tropopause' is the lowest level at which the lapse rate decreases to 2°C/km or less, provided also that the average lapse rate between this level and all higher levels within 2 km does not exceed 2°C/km.

(ii) When, above the first tropopause, the average lapse rate between any level and all higher levels within 1 km exceeds 3°C/km, then a 'second tropopause' can occur and is defined by the criteria of para. (i) above. This tropopause can either be above or within the 1 km layer.

(iii) Further tropopauses may be defined similarly.

Day-to-day changes of tropopause height occur and there are also appreciable systematic seasonal changes (height greater in summer than in winter).

Detailed synoptic studies have revealed a complex, sometimes discontinuous, tropopause structure, usually in association with deep depressions, jet streams and fronts. Terms used to describe such complexities include 'tropopause funnel' (a bowl-shaped lowering of the tropopause to an unusually low level), 'folded' tropopause and 'multiple' tropopause (also termed 'laminated' or 'foliated' tropopause).

Synoptic studies by J. S. Sawyer* led him to the conclusions that the tropopause generally moves as a material surface embedded in the air stream and that short-period height changes are due in approximately equal measure to horizontal advection and vertical motion.

troposphere: The lower layers of the atmosphere, extending to about 16 km near the equator, 11 km in latitude 50°, 9 km near the poles, and with upper limit the TROPOPAUSE.

The troposphere is characterized in general by a positive LAPSE rate of temperature and is the region to which precipitation and clouds (apart from certain rather rare types) are confined. (Greek, *tropos* turn).

trough: A trough (of low pressure) is a pressure feature of the SYNOPTIC CHART: it is characterized by a system of isobars which are concave towards a DEPRESSION and have maximum curvature along the axis of the trough, or 'trough line' (see Figure 33). The trough is said to be 'deep', or 'shallow', according as the maximum curvature of the isobars along the trough line is great, or small, respectively: the

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* SAWYER, J. S.: Day-to-day variations in the tropopause. *Geophys. Mem., London*, XI, No. 92, 1954.

former corresponds to the V shape referred to in the obsolete term 'V-SHAPED DEPRESSION'. If the isobars of a depression are circular the trough line is generally taken to be the line through the centre perpendicular to the line of advance of the centre.

A FRONT is necessarily marked by a trough but the converse is not true. Those troughs which are not frontal in character are, however, also generally marked by cloudy, showery weather.

The term 'trough' is also used in meteorology to signify an elongated region of low values of any specified element, e.g. 'thickness trough', 'temperature trough'.

trowal: A term used, mainly in Canada, to signify the projection on the earth's surface of a tongue of warm air aloft, such as may be formed during the OCCLUSION process of a depression. This feature is often found to mark a line of discontinuity of surface weather, cloud type and pressure tendency.

tsunami: A 'tidal wave' generated by an under-water upheaval of the earth's crust. Such a wave moves out in all directions from the point of origin and is capable of causing great destruction on arrival at a coast.

***t*-test:** See STUDENT'S *t*-TEST.

tuba (tub): A supplementary cloud feature: (Latin, *tuba* trumpet.)

'Cloud column or inverted cloud cone, protruding from a cloud base; it constitutes the cloudy manifestation of a more or less intense vortex.

This supplementary feature occurs with CUMULONIMBUS and, less often, with CUMULUS.'* It is commonly known as a 'funnel cloud'. See also CLOUD CLASSIFICATION.

tundra: Treeless lands of northern Canada and Eurasia which lie mainly just inside or just outside the Arctic Circle. In these regions mean monthly temperature rises above freezing-point in some 2 or 3 months in summer but remains below freezing-point throughout the year at a depth of about 1 foot.

turbidity: That property of a cloudless atmosphere which produces ATTENUATION of solar RADIATION. Measurements of atmospheric turbidity (turbidity factor) are generally concerned with the attenuation which is additional to that associated with molecular SCATTERING, the particles responsible being DUST, SMOKE, etc.

turbulence: Turbulent motion is defined by O. G. Sutton as one which contains random oscillations of finite size, leading to irregularities in the path of a particle of scale comparable with lengths which determine the kinematics of the mean motion, such as the shape of the boundary. While there is no precise mathematical definition of turbulence, it is generally taken to comprise the complex spectrum of fluctuating motion which is superimposed on a 'mean flow'. The theory of atmospheric turbulence has been mainly developed in relation to processes which are very restricted in both space and time. The phenomenon is, however, of fundamental importance in meteorological processes of even the largest space and time dimensions.

Small-scale atmospheric turbulence is evident in the fluctuations of wind speed and direction recorded by an anemograph. Such fluctuations are greatest within the 'atmospheric BOUNDARY LAYER' and are much influenced by the nature of the surface over which the air flows and by other factors such as the degree of static stability of the air.

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* Geneva, World Meteorological Organization, International cloud atlas, Vol. 1, Geneva, WMO, 1956, p. 18.

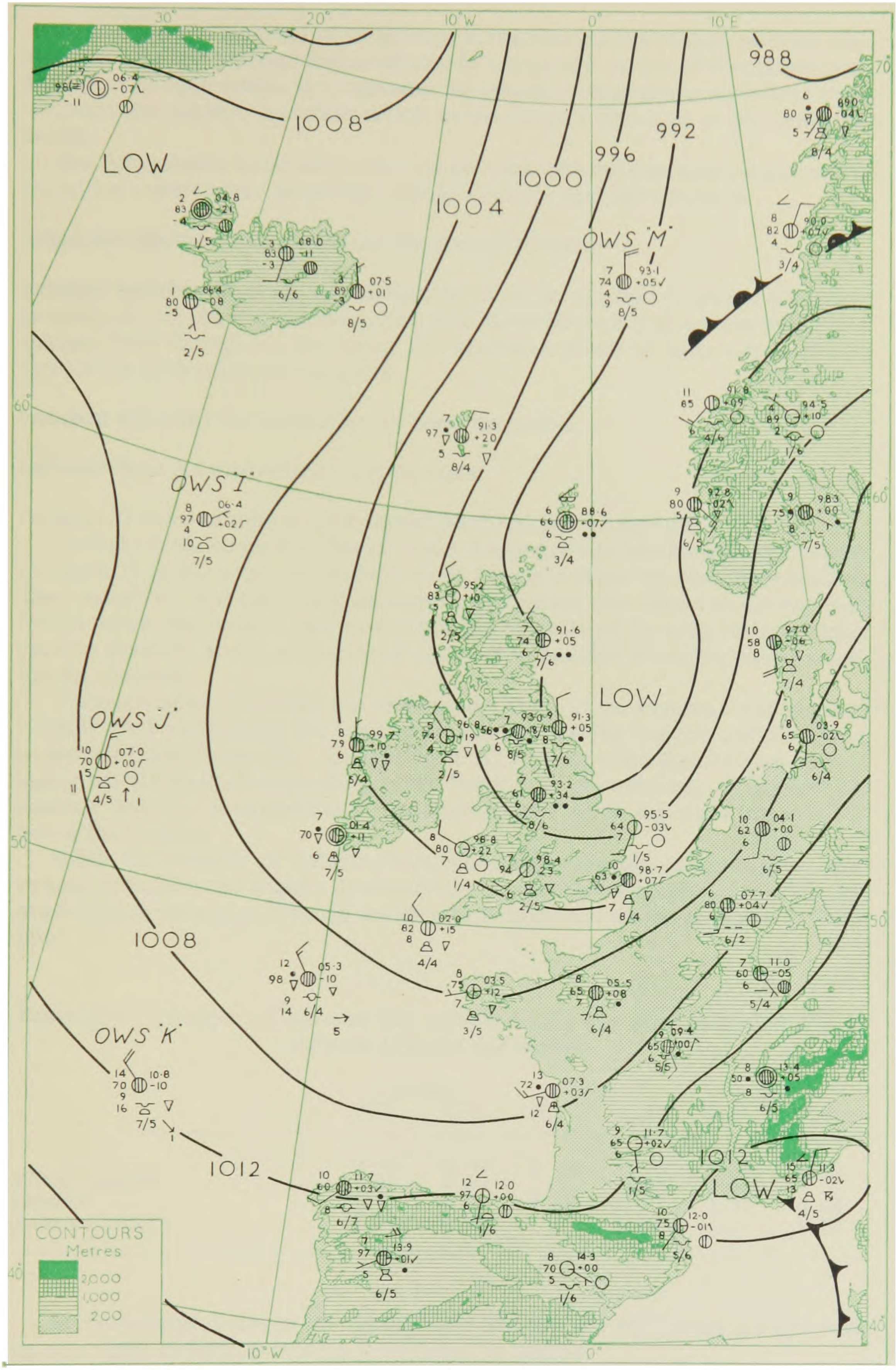

FIGURE 33—Non-frontal trough extending over the southern British Isles from the north-east, 0600 GMT, 28 October 1961.

A fundamental property of turbulence is the vertical interchange of mass, momentum, heat and vapour which is effected by eddies of a variety of shapes and sizes. The effect of such eddies is to increase the effective atmospheric DIFFUSIVITY and VISCOSITY far beyond the values which would be appropriate to purely molecular action.

See, for example, LAMINAR FLOW; AERODYNAMIC ROUGHNESS, SMOOTHNESS; EDDY; EXCHANGE COEFFICIENT; K-THEORY; MIXING LENGTH; REYNOLDS NUMBER.

turbulence spectrum: An alternative for EDDY SPECTRUM.

turbulent boundary layer: A very shallow layer of air, adjacent to a fixed boundary, in which the air velocity increases from zero at the boundary to a value which then changes little throughout the layer. The REYNOLDS STRESS in such a layer greatly exceeds the molecular viscous stress.

turbulent diffusion: An alternative for EDDY DIFFUSION.

turbulent flux: An alternative for EDDY FLUX.

twilight: The pre-SUNRISE or post-sunset period of partial daylight.

Twilight is caused by the reflexion and scattering of sunlight towards an observer on the earth by the upper atmosphere, when the sun is below the observer's horizon. The amount of light received progressively diminishes after sunset as the sun sinks farther below the horizon and as the sunlight is scattered by progressively higher and less dense air and is subject more and more to multiple scattering before reaching the observer.

Various stages of twilight are recognized. Thus, in the evening, 'astronomical twilight' (A.T.) ends when the sun's centre is 18° below the horizon, corresponding to the last trace of daylight. 'Civil twilight' (C.T.) ends when the sun's centre is 6° below the horizon, corresponding to the lower limit of sufficiency of daylight for outdoor activity. Intermediate is 'nautical twilight' when the sun's centre is 12° below the horizon.

While the intensity of indirect illumination from sunlight (assuming no cloud or haze) is fixed by the angular depression of the sun below the horizon, the duration of twilight (morning or evening) varies with latitude and season as shown in Table XV.

TABLE XV—*Duration of astronomical twilight (A.T.) and civil twilight (C.T.) in different latitudes and seasons.*

	Equator		50°		60°	
	A.T.	C.T.	A.T.	C.T.	A.T.	C.T.
	h m.	h. m.	h. m.	h. m.	h. m.	h. m.
Winter solstice	1 15	0 26	2 1	0 45	2 48	1 9
Equinox	1 10	0 24	1 52	0 37	2 31	0 48
Summer solstice	1 15	0 26	—	0 51	—	1 59

At midsummer, between the Arctic Circle and latitude 48½°, there is a belt with no true night, twilight extending from sunset to sunrise.

The following figures are quoted from Kimball and Thiessen for the intensity of illumination (foot-candles) of a horizontal surface in cloudless conditions: sun in zenith, 9600; sun on horizon, 33; sun 6° below horizon, 0·4; sun 18° below horizon, 0·0001; full moon in zenith, 0·02.

twilight arch: The 'primary twilight arch' appears after the sun has set, as a bright, but not very sharply defined segment of reddish or yellowish light resting on the western horizon. The 'secondary twilight arch' is the slightly luminous segment near the western horizon in the last stages of TWILIGHT.

twilight flash: An alternative for TWILIGHT GLOW.

twilight glow: A marked intensification (also termed 'twilight flash') of the brightness of certain lines, notably the SODIUM D line at 5893 ångströms, in the AIRGLOW emission spectrum near the times of sunrise and sunset. Observation of the variation of intensity of the emission with solar zenith angle near these times has enabled the height distribution of sodium in the high atmosphere to be inferred.

twinkling (of stars): See SCINTILLATION.

type: Different distributions of atmospheric pressure are characterized by more or less definite kinds of weather. Accordingly, when a certain form of pressure distribution is seen on a chart the weather is described as being of a given type. The types are therefore defined by the shape or general trend of the isobars: thus an 'anticyclone' or a 'cyclonic' type denotes that an ANTICYCLONE or a DEPRESSION is the main feature of the pressure distribution; on the other hand a 'westerly' type indicates that the isobars run in more or less parallel lines over a considerable distance from west to east, having the lowest pressure to the north; a 'northerly' type will have isobars running north and south with the low pressure to the east, etc.

The weather associated with each type varies with season but members of the same type have nearly always something in common; thus, an anticyclonic type has usually rainless weather, the cyclonic, wet weather; the southerly type in the northern hemisphere will in general be relatively warm and the northerly type cold. The westerly type is very persistent and often gives rise to long periods of rather unsettled weather. The easterly type gives in winter suitable conditions for severe frosts, while in summer, in at least the southern part of the British Isles, the weather is usually very warm.

typhoon: A name of Chinese origin (meaning 'great wind') applied to the intense TROPICAL CYCLONES which occur in the western Pacific Ocean. They are of essentially the same type as the Atlantic 'hurricane' and Bay of Bengal 'cyclone'.

U

UCONAL: In British weather messages, a code word indicating that the positions of key contours and thickness isopleths for selected standard pressure levels, obtained by upper air chart analysis, follow in figure code. See 'Handbook of weather messages'.*

Ulloa's circle (or ring): A white rainbow or fogbow. See RAINBOW and BOUGUER'S HALO.

ultra-violet radiation: ELECTROMAGNETIC RADIATION in the approximate wavelength range from 10 to 4000 ångströms (10^{-7} to 4×10^{-5} cm), i.e. in the wavelength region below visible radiation. See VISIBLE SPECTRUM.

The relatively small fraction of the total energy contained in solar RADIATION in the 'far ultra-violet' is strongly absorbed in the high atmosphere, resulting in various photo-chemical reactions including that of OZONE formation and a sharp cut-off, at about 2900 Å, of the solar spectrum observed at the earth's surface. The latter is, therefore, in large measure protected from the strongly actinic and biological effects which are produced by ultra-violet radiation.

Umkehr effect: An effect which is used to infer the vertical distribution of OZONE from surface measurements.

A series of measurements of the relative intensities (I), in light scattered from the zenith sky, of two selected wavelengths, one (A) strongly absorbed by ozone, the other (B) less strongly absorbed, is made when the sun is near the horizon. The ratio I_A/I_B decreases with increasing zenith angle (Z) of the sun, due to increasing path length through the ozone, up to the point at which the 'effective' scattering height for both wavelengths (increasing with increase of Z) lies below or within the OZONE LAYER. A critical point is reached (e.g. $Z > 85°$) when most of wavelength A, but not of B, reaches the observer after being scattered from above the ozone layer: during a further increase of Z by a few degrees, the ratio I_A/I_B increases, constituting a reversal (German '*Umkehr*') of the previous trend. The vertical distribution of ozone may on certain assumptions be inferred from the precise variation of I_A/I_B with Z.

uncinus (unc): A CLOUD SPECIES. (Latin, *uncinus* hooked.)

'CIRRUS often shaped like a comma, terminating at the top in a hook, or in a tuft the upper part of which is not in the form of a rounded protuberance.'† See also CLOUD CLASSIFICATION.

undercooling: A seldom-used alternative for SUPERCOOLING.

undersun: A HALO phenomenon produced by reflexion of sunlight on ice crystals in clouds. 'It appears vertically below the sun in the form of a brilliant white spot, similar to the image of the sun on a calm water surface. It is necessary to look

* London, Meteorological Office; Handbook of weather messages. Part III, London, HMSO, 1959.

† Geneva, World Meteorological Organization; International cloud atlas, Vol. 1, Geneva, WMO, 1956, p. 12.

downward to see the undersun; the phenomenon is therefore only observed from aircraft or from mountains.'*

undulatus (un): One of the CLOUD VARIETIES. (Latin, *undulatus* waved.)
'Clouds in patches, sheets or layers, showing undulations. These undulations may be observed in fairly uniform cloud layers or in clouds composed of elements, separate or merged. Sometimes a double system of undulations is in evidence.'† See also CLOUD CLASSIFICATION.

universal decimal classification (U.D.C.): A method of classifying bibliographies and publications intended for international dissemination, in which Meteorology is allotted the number 551·5. The main divisions of the subject made so far, with corresponding numbers, are: 551·50 Practical Meteorology (methods, data, instruments, forecasts and other applications); 551·51 Structure, Mechanics and Thermodynamics of the atmosphere in general; 551·52 Radiation and Temperature; 551·54 Atmospheric Pressure; 551·55 Wind; 551·57 Aqueous Vapour and Hydrometeors; 551·58 Climatology; 551·59 Various Phenomena and Influences.

universal time: TIME determined by the average rate of the apparent diurnal motion of the sun relative to the MERIDIAN of Greenwich. In geophysics, the term signifies a common reference time of day (GMT) in all longitudes. While systematic diurnal effects of most phenomena progress entirely according to local solar time (LT), a systematic UT effect is found in certain cases, for example, potential gradient measurements in ATMOSPHERIC ELECTRICITY.

upbank thaw: The precedence of a THAW in a valley situation, sometimes by many hours, by a thaw or marked rise of temperature at mountain level in the same vicinity. The phenomenon is usually caused by the arrival at higher levels of the warm air in advance of a surface warm front: it may also be caused by the subsidence and dynamical heating of air at the higher level.
The associated inversion of the normal temperature lapse rate is a contributory cause of GLAZED FROST.

upper-level trough: In synoptic meteorology, a line along which there exists in the upper air a TROUGH of low pressure (or the analogous contour trough on an isobaric chart), with an associated change of wind direction.
By implication, such a feature is not associated with a trough or front on the surface chart. It may, however, especially in summer, be associated with a line of convective phenomena—see INSTABILITY LINE.

upslope fog: FOG which is formed on the windward slopes of high ground by the forced uplift of stable, moist air till saturation is reached by adiabatic expansion.

upwelling: The term applied to the movement of cold water from moderate depths up to the surface, as near a coast on occasions when the warmer surface water is driven from the coast by the wind.

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* Geneva, World Meteorological Organization, International cloud atlas, Vol. 1, Geneva, WMO, 1956, p. 72.
† Geneva, World Meteorological Organization; International cloud atlas, Vol. 1. Geneva, WMO, 1956, p. 14.

V

valley breeze: The upslope (ANABATIC) wind which blows during the day, more especially in quiet, summer conditions. The air is driven by the local pressure gradient which develops because of the high temperature attained near the inclined slope, relative to that of the air at the same level over the centre of the valley.

Van Allen radiation belts: Two regions above the earth, more particularly in and near the equatorial plane, in which the flux of penetrating radiation due to particles of high energy reaches a maximum. The regions were discovered in satellite measurements made in 1958, under the leadership of J. A. Van Allen.

The inner belt is confined to lower latitudes and is at a height of about 2000 miles. The outer belt, markedly horn-shaped, is at about 10,000 miles near the equator but is narrower and at much lower levels in high (magnetic) latitudes. The charged particles concerned, protons and electrons, perform a spiral motion along magnetic lines of force across the equatorial plane to high latitudes where their motion is reversed. While thus essentially trapped by the magnetic field the particles suffer some continuous loss by collisions with atmospheric particles at lower levels and are also continuously replenished—it is thought by cosmic rays and streams of solar particles in the lower and higher belts, respectively.

vane: See WIND VANE.

vapour: A gas which is at a temperature below its 'critical temperature', i.e. at a temperature at which it can be liquefied by pressure alone. Water vapour is the main example of such a gas in the earth's atmosphere. Carbon dioxide and sulphur dioxide are also technically vapours at atmospheric temperatures, but in their low concentrations are not liquefied in the ranges of pressure and temperature that exist in the atmosphere.

vapour concentration: The density of water vapour (d_v) in a mixture of water vapour and dry air, being defined as the ratio of the mass of water vapour (m_v) to the volume (V) occupied by the mixture,

$$d_v = m_v/V$$

This quantity is of the order 10^{-5} gm/cm^3 and it is usually expressed in gm/m^3. The alternative terms 'absolute humidity' and 'vapour density' applied to this quantity are not now favoured.

vapour density: An alternative for VAPOUR CONCENTRATION.

vapour pressure: In meteorology, that part of the total atmospheric pressure which is exerted by WATER VAPOUR. The vapour pressure e' of water vapour in moist air at total pressure p and with MIXING RATIO r is defined by:

$$e' = \frac{r}{0{\cdot}62197 + r}p$$

Vapour pressure is measured indirectly from dry- and wet-bulb temperature readings, with the aid of humidity slide-rule or tables (see PSYCHROMETER).

If r_w, r_i denote SATURATION mixing ratio of moist air with respect to a plane surface of pure water and ice, respectively, then the 'saturation vapour pressure' with respect to water (e_w') and that with respect to ice (e_i'), of moist air at pressure p and temperature T are, respectively, defined by:

$$e_w' = \frac{r_w}{0{\cdot}62197 + r_w} p$$

$$e_i' = \frac{r_i}{0{\cdot}62197 + r_i} p$$

The implied pressure dependence of e_w' and e_i' is in practice negligible: to a close approximation the saturation vapour pressure of moist air depends only on temperature, as is strictly true of pure water vapour in equilibrium with a plane (or ice) surface, in accordance with the values shown in Table XVI.

In the table the values of e_w' at temperatures 0°C and below are those which obtain with respect to supercooled water. At such temperatures, the excess of e_w' over e_i' (which has a maximum of 0·27 mb at about −12°C) is important in the formation of PRECIPITATION.

For equilibrium conditions other than those at a plane surface of pure water or ice, the values of saturation vapour pressure are changed, relative to those in the table, to a degree which is significant in the CONDENSATION process:

(i) Kelvin showed that at a given absolute temperature (T) the equilibrium vapour pressure (e_r') over a drop of pure water of radius r is greater than the corresponding value (e_w') appropriate to a plane surface:

$$\rho RT \log_e \frac{e_r'}{e_w'} = \frac{2\sigma}{r}$$

where ρ is the water density, R the gas constant for water vapour, and σ is the surface tension of the water drop.

(ii) Reduction of the saturation vapour pressure (Δe) occurs over a hygroscopic electrolyte in accordance with Raoult's law:

$$\frac{\Delta e}{e_w'} = -\frac{in'}{n + in'}$$

where n and n' are the numbers of moles of water and electrolyte, respectively, and i is a factor which varies with the concentration of the solution.

TABLE XVI—*Variation of e_i' and e_w' with temperature*

T°C	−40	−30	−20	−10	0	+10	+20	+30
e_i' mb ...	0·13	0·38	1·03	2·60	6·11	—	—	—
e_w' mb ...	0·19	0·51	1·25	2·86	6·11	12·27	23·37	42·43

vardarac (or **vardar**): A cold northerly wind which blows through the Morava-Vardar gap in the rear of a depression and affects the Thessaloniki region: it is a type of RAVINE WIND.

variance: See STANDARD DEVIATION.

vector: A physical quantity which requires both direction and magnitude for its complete specification. Meteorological examples are wind velocity, vorticity, pressure gradient, as opposed to such SCALAR quantities as temperature and pressure. The scalar part of a vector is termed the 'modulus' of the vector.

A vector quantity may be represented by a straight line drawn in a specific direction and of specific length. Graphical addition of two (or more) forces not acting in the same straight line or, alternatively, resolution of a single force into two (or more) 'components' is done by using the parallelogram (or polygon) law relating to vector quantities. Thus, for example, in Figure 34 $\overrightarrow{AC}$ is the vector sum or 'resultant' of $\overrightarrow{AB}$ and $\overrightarrow{BC}$, which are thus components of $\overrightarrow{AC}$. A meteorological illustration relating to this diagram is that the GEOSTROPHIC WIND at an upper isobaric level ($\overrightarrow{AC}$) may be regarded as the vector sum of the geostrophic wind at a lower isobaric level ($\overrightarrow{AB}$) and the THERMAL WIND in the isobaric layer concerned ($\overrightarrow{BC}$).

Vector mean is the vector sum divided by the number of observations. The vector sum may be obtained by graphical addition, or may be computed by resolution of each vector into north and east components, algebraic addition of the respective components, and recombination of the two sums into a single vector.

veering: The changing of the wind in the direction of the motion of the hands of a watch, in either hemisphere. The opposite to BACKING.

velocity: A VECTOR quantity signifying rate of change of position with time in a specified direction.

In meteorology, this term is often loosely used, e.g. in relation to motion of air or pressure systems, as being synonymous with speed, which is a SCALAR quantity.

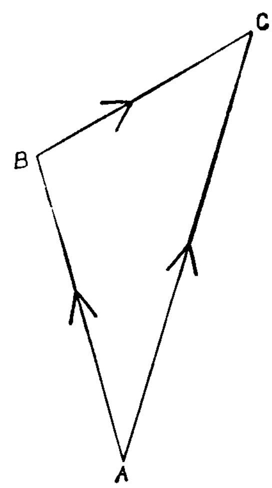

FIGURE 34—Vector addition.

velocity potential: A scalar function (φ) which always exists in irrotational fluid motion and is defined by the equation:

$$\mathbf{V} = -\nabla\varphi$$

where V is the velocity vector. The equation implies that V is normal to the equipotential lines and is directed from high to low potential. See GRADIENT.

velum: (vel): (Latin, *velum* sail of ship.)

'An accessory cloud veil of great horizontal extent, close above or attached to the upper part of one or several cumuliform clouds which often pierce it.

Velum occurs principally with CUMULUS and CUMULONIMBUS.'* See also CLOUD CLASSIFICATION.

vendavales: Strong, squally south-west winds in the Straits of Gibraltar and off the east coast of Spain. Associated with depressions mainly between September and March, they bring stormy weather and heavy rain.

* Geneva, World Meteorological Organization: International cloud atlas, Vol. 1, Geneva, WMO, 1956, p. 18.

venturi tube: A tube used in the measurement of fluid velocity, as in wind tunnel experiments. The fluid velocity (V) is related to the measured pressure difference (Δp) at the tube entrance, relative to that at a constriction in the tube through which the fluid passes, by the equation

$$V = \sqrt{\frac{2\Delta p}{\rho(r^2-1)}}$$

where ρ is the fluid density and r the ratio of the tube cross-sections at entrance and constriction.

veranillo: The two or three weeks of fine weather which break the rainy season near midsummer in tropical America.

verano: The long, dry season near midwinter in tropical America.

verification of forecasts: The process of obtaining a measure of the success of FORECASTS by relating predicted weather to actual weather. While simple comparison may serve to reveal certain features, for example a systematic bias towards optimism or pessimism, the verification process generally consists of deriving an index by one or other of a variety of methods which depend on the nature of the forecast. Such an index may then be compared with various standard indices based, for example, on a RANDOM FORECAST, a PERSISTENCE FORECAST, or a forecast based on climatic normals.

Among the many purposes of forecast verification are the evaluation of forecasting techniques, the nature of forecasting errors, the short- or longer-period variation of accuracy of forecasts, the economic value of forecasts, and the skill of individual forecasters.

vernier: A contrivance for estimating fractions of a scale division when the reading to the nearest whole division is not sufficiently accurate. The vernier is a uniformly divided scale which is arranged to slide alongside the main scale of an instrument. An example of a vernier (on a barometer) and the method of reading are given in the 'Observer's handbook'.*

vertebratus (ve): One of the CLOUD VARIETIES.

'Clouds, the elements of which are arranged in a manner suggestive of vertebrae, ribs, or a fish skeleton.

This term applies mainly to CIRRUS.'† See also CLOUD CLASSIFICATION.

vertical visibility: The greatest distance at which a given object can be seen and identified in the vertical plane of the observer. This element, required in synoptic observations on occasions when the sky is obscured by fog, etc., may be measured by pilot balloon and theodolite, the vertical visibility being taken as h cosec E where h is the height of the balloon and E its angular elevation at the moment of its disappearance from view.

virga (vir): A supplementary cloud feature. (Latin, *virga* rod.)

'Vertical or inclined trails of precipitation (fallstreaks) attached to the under surface of a cloud, which do not reach the earth's surface.

This supplementary feature occurs mostly with CIRROCUMULUS, ALTOCUMULUS, ALTOSTRATUS, NIMBOSTRATUS, STRATOCUMULUS, CUMULUS and CUMULONIMBUS.'‡ See also CLOUD CLASSIFICATION.

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* London, Meteorological Office; Observer's handbook, London, 1956, pp. 82, 84.
† Geneva, World Meteorological Organization; International cloud atlas, Vol. 1, Geneva, WMO, 1956, p. 14.
‡ Geneva, World Meteorological Organization; International cloud atlas, Vol. 1, Geneva, WMO, 1956, p. 17.

virtual height: In radio echo sounding of the IONOSPHERE, the equivalent height of reflexion of the radio waves obtained from the time delay between emission and reception of the wave on the assumption that the wave travels with the speed of light.

virtual temperature: The virtual temperature of a sample of moist air is that temperature at which completely dry air of the same total pressure would have the same density as the given sample.

The following closely approximate relations hold between absolute virtual temperature (T_v) and absolute air temperature (T):

$$T_v \simeq T/(1 - \frac{3}{8}\frac{e'}{p})$$

'Virtual temperature increment' $\equiv T_v - T \simeq 0{\cdot}61qT \simeq 0{\cdot}61rT$ where e' is vapour pressure, p is total pressure, q is SPECIFIC HUMIDITY (gm/gm), r is MIXING RATIO (gm/gm).

As a further, but generally sufficient, approximation:

$$T_v - T \simeq q/6 \simeq r/6$$

where q and r are expressed in gm/kg.

viscosity: That property of a fluid whereby it resists deformation. In a fluid in which different layers move with different velocities, molecular viscous forces operate so as to tend to make the velocities more uniform: for two layers a short distance apart, both parallel to the direction of flow, the viscous stress per unit area (τ) is proportional to the velocity gradient, the constant of proportionality being the coefficient of (dynamic) viscosity (μ), i.e. $\tau = \mu \partial u/\partial z$. The ratio of the dynamic viscosity to the density (ρ) of the fluid is termed the kinematic viscosity (ν). Air near the earth's surface has the approximate values $\mu = 1{\cdot}8 \times 10^{-4}$ gm/cm sec and $\nu = 0{\cdot}15$ cm^2/sec.

In the atmosphere, turbulent eddies are very much more important in effecting mixing of momentum than is the molecular viscosity. On analogy with the definition of ν, the vertical 'eddy viscosity' (K_M), for example, is defined by the equation

$$\tau/\rho = K_M \, \partial\bar{u}/\partial z$$

where τ is the corresponding REYNOLDS STRESS. K_M varies with height and is generally of the order 10^4 cm^2/sec, i.e. some 10^5 times greater than ν. See also DIFFUSIVITY.

visibility: Visibility is defined as the greatest distance at which an object of specified characteristics can be seen and identified with the unaided eye in any particular circumstances, or, in the case of night observations, could be seen and identified if the general illumination were raised to the normal daylight level. Lower visibilities are expressed in metres or yards, higher visibilities in kilometres or miles. Reports generally refer to a visibility based on all directions: where there is marked variation with direction, the lowest visibility is recorded for synoptic purposes, with an appropriate entry in a 'special phenomena' group.

'Visibility objects' by day are ideally confined to black or nearly black objects which appear against the horizon sky. Night visibility objects comprise mainly unfocused lights of moderate and known intensity at known distances. Conversion of such night observations to daylight scales involves an assumption of the different values of CONTRAST THRESHOLD appropriate to the visibility objects by day and night. Various types of VISIBILITY METER are also used for observation by night.

Visibility, though to some extent dependent in its measurement on extraneous physiological and physical factors, is an element which is governed mainly by the atmospheric EXTINCTION COEFFICIENT associated with solid and liquid particles held in suspension in the atmosphere: the extinction is primarily caused by scattering, rather than by absorption, of the light. While visibility is an element which is characteristic, in a general way, of an air mass—it is, for example, broadly much better within air masses which originate in high latitudes and move equatorward than in those which originate in low latitudes and move poleward—local variations of visibility associated with precipitation, atmospheric pollution and other factors prevent its use as a reliable air-mass indicator. See also METEOROLOGICAL OPTICAL RANGE, CONTRAST THRESHOLD OF THE EYE, KOSCHMIEDER'S LAW, OBLIQUE VISIBILITY, VERTICAL VISIBILITY.

visibility meter: A class of instruments designed to measure VISIBILITY by the determination of either the EXTINCTION (e.g. the Gold visibility meter) or SCATTERING of light by the atmosphere. In an instrument measuring the latter of these properties the assumption is made that the reduction of visibility due to direct ABSORPTION is negligible.

Visibility meters are not ABSOLUTE INSTRUMENTS and require calibration in terms of the daylight visibility scale. Their use in practice tends to be limited to night observations in places where suitable night visibility points are not available.

visibility ratio: An alternative for LUMINOSITY.

visible spectrum: That part of the ELECTROMAGNETIC RADIATION spectrum, between about 0·4 and 0·7 micron (4×10^{-5} to 7×10^{-5} cm), to which the human eye is sensitive. Within the visible spectrum the wavelength increases through the range of colours violet, indigo, blue, green, yellow, orange and red. 41 per cent of the total solar RADIATION intensity is contained within this part of the electromagnetic spectrum. See also LUMINOSITY.

volcanic dust: Volcanic dust is known to have spread in the stratosphere as a veil covering more than half the surface area of the globe in some instances and to have persisted in observable quantities for up to three years. The latitude zones which are sooner or later affected probably depend greatly on the latitude of injection. Such dust veils are associated with certain atmospheric optical effects (see, for example, BISHOP'S RING). It is also probable that significant effects on atmospheric circulation and world weather are caused by the scattering of solar radiation by widespread and persistent veils.

According to H. H. Lamb's estimate of the magnitude of eruptions dating later than 1600 (estimate based on evidence of dust veils and/or of quantities of solid material ejected), meteorological effects were probably significant in at least the following cases, listed in approximate order of magnitude. 1783, Skaftárjökull or Laki (Iceland), Eldeyjar (Iceland) and Asama (Japan), effects lasting until 1785; 1815, Tambora (8°S 118°E); 1883, Krakatoa (6°S 105°E), effects lasting until 1885–86; 1680, Krakatoa and Tonkoko (1°N 125 E); 1831, group of major eruptions including Pichincha (0°S 79°W), Mediterranean submarine eruption (37°N 12–13°E), Babuyan (19°N 122°E), Etna and Vesuvius; 1821–24, group of major eruptions including Kluchevskaya Sopka (55°N 161°E) in 1821, Eyafjallajökull (Iceland) from 1821, Vesuvius in 1822, Galunggung (7°S 108°E) in 1822, and Lanzarote (Canary Islands) in 1824; 1902–04 group of major eruptions including St. Vincent (West Indies) from 1902 to 1903, Mont Pelée (15°N 61°W) in 1902, Santa Maria (Guatemala) from 1902 onwards, and Colima (Mexico) in 1903; 1835, Coseguina (Nicaragua) and several in Chile (mainly between 33°S and 44°S); 1755–56, Katla (Iceland).

In addition to the above cases, thick volcanic ash layers in various parts of the world supply evidence of former volcanic activity of a magnitude likely to have had significant climatic effects. In some cases they can be approximately dated. It appears that volcanic activity was particularly frequent from A.D. 1500 to 1900, around 500–0 B.C., around 3000 B.C., and around 7500 B.C. Both hemispheres were apparently affected by the three earlier waves of activity, but the A.D. 1500–1900 period seems to have affected mainly the northern hemisphere and the equatorial zone.

See also DUST.

VOLMET: The code word for an hourly ground-to-air broadcast of meteorological reports and forecasts. See 'Handbook of weather messages'.*

vortex: A fluid flow which possesses VORTICITY. A 'vortex line' is one drawn from point to point of a fluid such that it coincides at all points with the instantaneous direction of the axis of rotation of the fluid. A 'vortex tube' is the surface which contains all the vortex lines which intersect a closed small curve within the fluid. A 'vortex filament' is the fluid contained within a vortex tube. A 'vortex sheet' is a surface of discontinuity of velocity which separates two adjacent streams of a fluid and on which the vorticity is infinite.

vorticity: The vorticity at a point in a fluid is a vector which is twice the local rate of rotation of a fluid element. The component of the vorticity in any direction is the CIRCULATION per unit area of the fluid in a plane normal to that direction. The dimensions are T^{-1}.

Vorticity is a three-dimensional property of the field of motion of a fluid. In large-scale motion in the atmosphere the vorticity component of chief significance is that which occurs in the horizontal plane (i.e. rotation about the vertical axis): the other components are, however, significant in some dynamical problems.

In vector notation the vorticity of a velocity vector **V** is written as curl **V** or rot **V** or $\nabla \wedge \mathbf{V}$. In Cartesian co-ordinates the vertical (z) component of 'relative vorticity' (i.e. rotation in a horizontal plane, evaluated from winds measured relative to the rotating earth) is

$$\text{vorticity}_z = \zeta = \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)$$

Similarly, $$\text{vorticity}_x = \xi = \left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\right)$$

and $$\text{vorticity}_y = \eta = \left(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\right)$$

The expression for the vertical component of vorticity in terms of velocity V, radius of curvature of the streamlines r, and differentiation along the normal to the streamlines $\partial V/\partial n$, namely

$$\zeta = \frac{V}{r} + \frac{\partial V}{\partial n}$$

shows that the vertical component of vorticity may be regarded as the sum of components due to curvature (V/r) of horizontal flow and to horizontal wind shear ($\partial V/\partial n$). Thus, for example, the contribution to vorticity about the vertical axis made by the horizontal wind shear associated with a westerly jet stream in the northern hemisphere is strongly cyclonic poleward of the jet axis and anticyclonic equatorward of the axis.

In 'solid rotation' of angular velocity ω the vorticity is 2ω. In latitude φ, where the ANGULAR VELOCITY OF THE EARTH about the vertical axis is $\Omega \sin \varphi$, the earth has a vorticity about this axis of $2\Omega \sin \varphi$, and is cyclonic in sense. Air partakes of the vorticity of the earth appropriate to its latitude, in addition to any relative vorticity it may possess. Thus, in latitude φ, 'absolute vorticity$_z$'

$$(\zeta_a) = \zeta + 2\Omega \sin \varphi.$$

Relative vorticity in a cyclonic sense is reckoned positive, in an anticyclonic sense negative.

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* London, Meteorological Office, Handbook of weather messages, Parts II and III, London, HMSO, 1959.

vorticity equation: The vorticity equation as used in meteorology relates the rate of change of the vertical component of VORTICITY to the horizontal DIVERGENCE. It is derived by eliminating geopotential (or pressure) from the equations of motion. In PRESSURE CO-ORDINATES the vorticity equation can be written

$$\frac{\mathrm{d}}{\mathrm{d}t}(\zeta + f) = -(\zeta + f)\,\mathrm{div}_p\, V + \left(\frac{\partial \omega}{\partial y}\frac{\partial u}{\partial p} - \frac{\partial \omega}{\partial x}\frac{\partial v}{\partial p}\right)$$

$$\qquad\qquad(a)\qquad\qquad\qquad(b)$$

In CARTESIAN CO-ORDINATES it is

$$\frac{\mathrm{d}}{\mathrm{d}t}(\zeta + f) = -(\zeta + f)\,\mathrm{div}_H\, V + \left(\frac{\partial w}{\partial y}\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\frac{\partial v}{\partial z}\right) + \left(\frac{\partial p}{\partial x}\frac{\partial \alpha}{\partial y} - \frac{\partial p}{\partial y}\frac{\partial \alpha}{\partial x}\right)$$

$$\qquad\qquad(a)\qquad\qquad\qquad(b)\qquad\qquad\qquad(c)$$

Here ζ = vertical component of vorticity $= \dfrac{\partial v}{\partial x} - \dfrac{\partial u}{\partial y}$

f = Coriolis parameter
ω = $\mathrm{d}p/\mathrm{d}t$ (equivalent of vertical velocity in pressure co-ordinates)
w = vertical velocity
α = specific volume
p = pressure

The first term (*a*) on the right-hand side of the equation is the dominant one in large-scale atmospheric motion. The second term (*b*) is sometimes known as the 'twisting term' and represents the transformation of vorticity from the horizontal to the vertical component. It is believed to be important within smaller-scale motions as in fronts. The third term (*c*) in the second form represents the direct generation of vorticity by horizontal density and pressure gradients and is usually unimportant.

vorticity theorem: The vorticity theorem is derived from the circulation theorem of V. Bjerknes. It relates the local generation of VORTICITY to the local BAROCLINITY of the atmosphere and may be written

$$\mathrm{curl}\,(\rho\dot{\mathbf{V}} - \rho\mathbf{C}) = \nabla\rho \wedge \nabla(-\Phi)$$

where ρ = density
$\dot{\mathbf{V}}$ = acceleration of the air
$\mathbf{C}$ = vector representing apparent deviating force per unit volume due to earth's rotation
Φ = geopotential

Direct application of the vorticity theorem to large-scale motions is limited because the term arising from the deviating force is usually in approximate balance with the term arising from the density gradients.

V-shaped depression: An obsolete term for a sharply defined TROUGH of low pressure, with the isobars in the form of a V.

W

warm anticyclone: See ANTICYCLONE.

warm front: A FRONT whose movement is such that the warmer AIR MASS is replacing the colder.

Temperature and dew-point rise, and pressure tendency becomes increasingly negative within the cold air mass with nearer approach of the front. Precipitation usually occurs within a wide belt (some 200 miles) in advance of the front. Passage of the front is usually marked by a steadying of the barometer, a rise of temperature and dew-point, a veer of wind (in northern hemisphere), and by a cessation or near cessation of precipitation. Substantial lanes of clear air separating cloud layers are found in all except a small minority of warm fronts.

The average slope of a warm-frontal surface is about 1 in 150. A warm front moves, on average, at a speed some two-thirds of the component of the geostrophic wind normal to the front and measured at it.

warm-front wave: A secondary WAVE DEPRESSION which forms on an extended WARM FRONT at a point which is usually a considerable distance (some 1000 miles) from the parent depression and which, after formation, moves quickly east or south-east away from the parent depression. This type of depression, which is not common, seldom becomes deep but is responsible for a considerable spread and intensification of the warm-front precipitation. Formation may be aided by a frontal distortion produced by a range of hills or by movement towards a col.

warm-occlusion depression: A SECONDARY DEPRESSION which forms at the point where a cold and warm front unite to form a warm OCCLUSION. Such a secondary generally moves quickly away from the primary depression and deepens, though seldom to a marked extent, at the expense of the primary.

warm pocket: A term applied in upper air analysis to a closed centre of high pressure on a FRONTAL CONTOUR CHART. Such a region on the chart indicates the isolation of warm air at low levels from the main body of warm air which is seen on the chart, usually at lower latitudes.

warm rain: The term 'warm rain' is sometimes applied to rain which falls from clouds whose tops do not reach the freezing-level. Such rain is initiated by the coalescence process—see PRECIPITATION.

warm ridge: A pressure RIDGE (or ridge on an isobaric contour chart) in which temperature is generally higher than in adjacent areas.

warm sector: In the early stages of the life history of at least the majority of the DEPRESSIONS of temperate latitudes, and of the more important SECONDARIES, there is a surface sector of warm air, which disappears as the system deepens and the cold front catches up the warm front (see OCCLUSION). The warm sector is usually composed of tropical air, sometimes of maritime polar air.

washout: The removal of solid material from the air, and its deposition on the earth's surface, due to capture by falling PRECIPITATION elements. See also FALLOUT.

water: The oxide of hydrogen of chemical formula H_2O. Its maximum density (0·99997 gm/cm³) occurs at 4°C. Its thermal conductivity at 0°C and 20°C is, respectively, 0·00132 and 0·00143 cal/cm sec °C. Its physical properties are slightly modified by the small but variable amounts of impurities, due mainly to dissolved salts, which occur in natural water. It comprises, as liquid or ice, 70·8 per cent of the earth's total surface—see EARTH.

Water plays a fundamental part in the energy balance of the earth–atmosphere system, notably because of the LATENT HEAT exchanges involved in its widespread changes of state. See also ICE, WATER VAPOUR, SALINITY.

water (-droplet) cloud: A cloud which is composed entirely of water droplets, either in the supercooled state or at temperatures above 0°C, as opposed to ice crystals. The CLOUD GENERA Ac, St, and Cu are normally water clouds.

watershed: In physical geography, the line separating the head streams which are tributaries to different river systems or basins, i.e. the line enclosing a CATCHMENT AREA.

water sky: Term applied, mainly in polar regions, to the dark appearance presented by the underside of a cloud layer which lies above a water-covered region relative, in particular, to that of a cloud layer above a snow- or ice-covered region (see ICEBLINK). Such an appearance is often useful in indicating the presence of open water which is not itself then visible.

water smoke: An alternative for ARCTIC SEA SMOKE.

waterspout: A funnel-shaped TORNADO cloud which extends from the surface of a sea or inland water to the base of a cumulonimbus cloud.

A cone-like point of cloud descends from the cumulonimbus base to the agitated sea below and assumes the appearance of a column of water, the diameter of which may vary between a few tens and a few hundreds of feet. The duration of a waterspout ranges up to about half an hour, during which time the column may be appreciably bent by vertical wind shear. A circular and violent circulation of air is caused near the waterspout with an associated confused sea. The phenomenon is more common in the tropics than in higher latitudes. See Plates 27 and 28.

water table: The depth at which the soil is persistently saturated with water. Such depth generally varies appreciably with the wetness of the season.

water vapour: Water substance in the vapour form is, meteorologically, the most important constituent of the atmosphere and is also the most variable in space and time.

Supplied to the atmosphere by EVAPORATION and SUBLIMATION at the earth's surface, water vapour has a concentration which decreases fairly steadily with height from a mass ratio to dry air of about 1×10^{-2} near the ground to about 2×10^{-6} in the lower stratosphere. There are some recent indications of an increase of concentration with increase of height between about 20 and 35 km. Partial dissociation of water vapour by ultra-violet radiation into HYDROGEN (H) atoms and HYDROXYL (OH) molecules is effective above about 60 km.

The meteorological importance of water vapour derives from the part it plays in forming cloud and precipitation elements, in controlling the long-wave radiation balance of the atmosphere, in determining atmospheric stability, and in affecting the heat balance conditions of the earth-atmosphere system by the powerful absorption of heat in the course of evaporation and sublimation from liquid water and ice, and by the eventual release of the stored latent, or 'hidden', heat which is involved in the reverse processes.

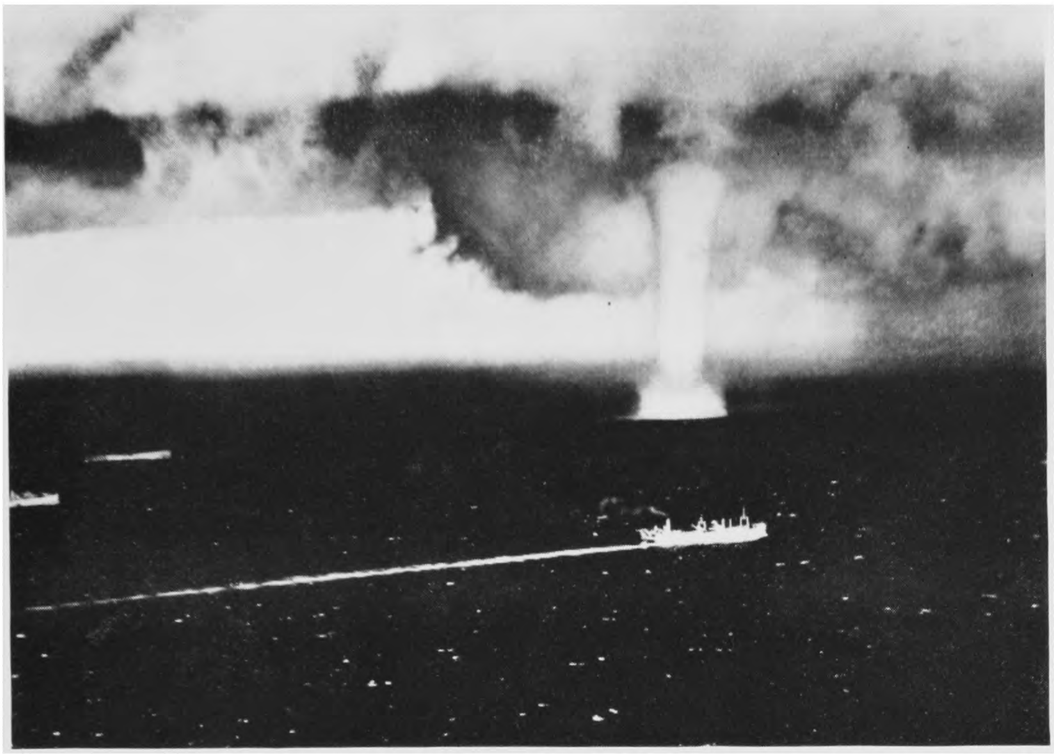


PLATE 27 Waterspout in the eastern Mediterranean, October 27, 1943, 0910 GMT
View from aircraft at 100 feet, waterspout $\frac{1}{4}$-$\frac{1}{2}$ mile distant.

PLATE 28 Waterspout seen from Malta, October 14, 1920, 1645 GMT.

The amount of water vapour held in the atmosphere is specified by various 'humidity elements' which include VAPOUR PRESSURE, HUMIDITY MIXING RATIO, RELATIVE HUMIDITY, VAPOUR CONCENTRATION, DEW-POINT, FROST-POINT and WET-BULB TEMPERATURE. Different types of HYGROMETER are commonly used to measure the humidity at different atmospheric levels.

Water vapour is by far the most strongly absorbing constituent of the atmosphere and has a wide range of absorption bands over a range of wavelengths extending from the near infra-red upwards—See Figure 1, p. 4. A conspicuous feature of the absorption spectrum, of particular importance at terrestrial radiation temperatures, is the region between about 5·5 and 7 microns in which water vapour is almost opaque—see also ATMOSPHERIC WINDOW.

See also SPECIFIC HEAT and LATENT HEAT for values referring to water vapour.

watt: The unit of power associated with the practical system of ELECTRICAL UNITS. It is the rate at which energy is transformed into heat in a lamp using 1 ampere at 1 volt.

1 watt = 1 ampere–volt = 1 JOULE per second.
= 10^7 ERGS per second.
1000 watts = 1 kilowatt = $1\frac{1}{3}$ horse-power.

Units derived from the watt are used by meteorologists for the measurement of the intensity of radiation.

1 milliwatt/cm^2 = 1 kilowatt/square decametre
= 0·01435 gram CALORIES/cm^2 min.

wave clouds: Clouds which form in the crests of MOUNTAIN WAVES.

wave depression: A DEPRESSION which forms at the tip of a wave-like distortion of a FRONT. Most of the depressions of middle and high latitudes are of this type.

wave motion: An oscillatory movement of the particles of a medium as the result of which 'waves' are propagated through the medium. If the particle movement is perpendicular to the direction of wave propagation, the waves are 'transverse'; if the particle movement is a rhythmic advance and retreat along the direction of wave propagation, the waves are 'longitudinal'. Energy but not, in general, matter is propagated with the waves. In ELECTROMAGNETIC RADIATION, periodic disturbances of electric and magnetic fields, and not movement of particles, are, from the viewpoint of electromagnetic theory, involved; such waves can be propagated through space or through a medium.

The simplest type of wave is the 'simple harmonic wave', as represented by a sine curve. The main characteristics of waves are the amplitude, a, (half the distance between the extremes of the oscillations); the wavelength, λ, (distance between successive maxima); the period, τ, (time interval between successive crests passing the same point); and the frequency, f, (number of complete oscillations per second). In a TIME SERIES the wavelength and period are identical. The speed of propagation, v, of the wave pattern (termed the PHASE velocity) is related to τ, λ and f by $v = \lambda/\tau$ and $v = f\lambda$. The wave number, k, is alternatively defined as $k = 1/\lambda$ or $k = 2\pi/\lambda$ (i.e. number of waves per unit distance or 2π times this quantity).

A large variety of types of wave motion, or of quasi-wave motion, occurs in the atmosphere. See, for example, SOUND WAVES, SHOCK WAVES, ATMOSPHERIC TIDES, GRAVITY WAVE, SHEAR WAVE, INERTIA WAVE, LONG WAVE, BAROTROPIC WAVE, BAROCLINIC WAVE, LEE WAVES and WAVE DEPRESSION.

weakening: See INTENSIFICATION.

weather: The changing atmospheric conditions, more especially as they affect man, which, in synthesis, constitute the CLIMATE of a region.

Weather in its wider sense comprises the study pursued in SYNOPTIC METEOROLOGY. In this branch of meteorology, however, the term itself is used in a more limited sense to denote the state of the sky and the occurrence of precipitation or of mist or fog. Codes of 'present weather' and of 'past weather' are two of the codes used in synoptic meteorology.

A concise system of notation of weather introduced by Admiral Beaufort is described under BEAUFORT NOTATION. A concise, international method of recording weather and optical phenomena by means of symbols is given in the following tables and text taken from the 'International cloud atlas'.*

Symbols of meteors

In order to facilitate the representation and entry of meteors in meteorological documents, symbols have been assigned to most of them.

The following table summarizes the classification of meteors and shows the basic symbols.

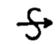
TABLE OF METEORS AND THEIR SYMBOLS

Hydrometeors

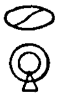
Designation of meteor	*Symbol*	*Designation of meteor*	*Symbol*
Rain	•	Drifting or blowing snow	+→
Freezing rain	•∼	Drifting snow	+→
Drizzle	,		
Freezing drizzle ...	,∼	Blowing snow	+→
Snow	*	Spray	⅄
Snow pellets	*	Dew	⌓
Snow grains	–▵–		
Ice pellets	▲	White dew	
Hail	▲	Hoar-frost ...	⊔
Ice prisms	↔	Rime	V
Fog	≡		
Ice fog	≡	Glaze	∼
Mist	=	Spout	)(

* Geneva, World Meteorological Organization; International cloud atlas, Vol. 1, Geneva, WMO, 1956, pp. 63–65.

Lithometeors

Designation of meteor	*Symbol*	*Designation of meteor*	*Symbol*
Haze		Dust storm or sandstorm	
Dust haze		Wall of dust or sand ...	
Smoke		Dust whirl or sand whirl (dust devil)	
Drifting or blowing dust or sand			
Drifting dust or sand ...			
Blowing dust or sand ...			

Photometeors

Designation of meteor	*Symbol*	*Designation of meteor*	*Symbol*
Halo phenomena: solar ...		Bishop's ring	
lunar ...		Mirage	
Corona: solar		Shimmer	No symbols established
lunar		Scintillation	No symbols established
Irisation on clouds ...		Green flash	No symbols established
Glory		Twilight colours	No symbols established
Rainbow		Crepuscular rays ...	No symbols established
Fog bow			

Electrometeors

Designation of meteor	*Symbol*	*Designation of meteor*	*Symbol*
Thunderstorm		Saint Elmo's fire ...	
Lightning		Polar aurora	
Thunder			

It is possible to provide information concerning the character (intermittent or continuous) and intensity (slight, moderate or heavy) of precipitation by certain arrangements of the basic symbols. The following table, established for rain, illustrates various arrangements which may be used for this purpose.

CHARACTER / INTENSITY	INTERMITTENT	CONTINUOUS
slight	•	• •
moderate	• •	• • •
heavy (dense)	• • •	• • • •

Combinations of two basic symbols of meteors may be used to indicate the occurrence of mixed precipitation or the occurrence of a thunderstorm accompanied by precipitation or dust storm or sandstorm. For example, the symbol $\overset{\bullet}{*}$ or $\overset{*}{\underset{*}{\bullet}}$ denotes a mixture of falling raindrops and snowflakes; the symbol $\dot{[}\!\zeta$ indicates thunderstorm with rain at the place of observation.

In addition to the basic symbols, several auxiliary symbols have been established to provide information concerning the showery character of precipitation and also the variation with time of various meteors and their location with respect to the station. These symbols are the following:

▽	shower, slight
$\overline{\triangledown}$	shower, moderate or heavy
|X	has increased (or formed) during the preceding hour
X|	has decreased during the preceding hour
X]	during the preceding hour, but not at the moment of observation
(X)	not at the station, but within sight [estimated distance less than 5 km (3 miles)]
)X(	within sight and at an estimated distance of more than 5 km (3 miles)

Useful supplementary information about meteors can thus be given by combining the above auxiliary symbols with one, or sometimes two, basic symbols. For example, the symbol ≡| denotes fog which has become thinner during the preceding hour; the symbol $\dot{\triangledown}$] indicates shower(s) of rain during the preceding hour, but not at the time of observation.

weather lore: Empirical weather forecasting rules, world-wide in origin, many of which are expressed in rhyme. They include rules based on the influence of the moon and tides, the appearance of plants and trees, the behaviour of animals, the weather prevailing on specified key dates and the colour and appearance of the sky. Comparison of the various rules reveals many contradictions, while tests of statistical significance lend no support except to certain of the short-period forecasting rules based on local observation of sky and wind etc. See 'Weather Lore' compiled by R. Inwards.*

weather map: A chart of a geographical area on which selected meteorological elements observed at a particular time at various points over the area are plotted in symbolic code and the positions of mean-sea-level isobars and surface fronts (also, on occasion, of other features, for example isallobars) are subsequently drawn.

* INWARDS, R.; Weather Lore, London (Rider and Company), 4th edn. 1950.

The elements usually plotted on the weather map, which is also termed 'synoptic chart' or 'surface chart', are: atmospheric pressure, reduced to mean sea level; barometric characteristic and tendency; wind direction and force; air temperature; dew-point; visibility; 'present weather'; 'past weather'; type, amount and height of clouds. In the case of ship observations, sea temperature and the direction and speed of movement of the ship are also plotted. See SYNOPTIC METEOROLOGY.

weather maxim: See WEATHER LORE.

weather proverb: See WEATHER LORE.

weather report: Statement of the values of meteorological elements observed at a specified place and time. The elements included depend upon the purpose for which the report is required.

It is a record of an observation, not a FORECAST.

wedge: In synoptic meteorology, an alternative for RIDGE (of high pressure); the term is mainly applied to a relatively fast-moving ridge on a surface synoptic chart.

weighting: In statistics, varying the share which different figures contribute to some final result in accordance with their reliability or for some other reason. A mean calculated in this way is a 'weighted mean'.

wet adiabatic: An alternative for 'saturated adiabatic'. See ADIABATIC.

wet air: A term used to define the condition when objects become wet even when rain is not falling. It occurs when a warm, saturated or practically saturated air mass replaces a cold dry air mass and is denoted by the letter 'e' in the BEAUFORT NOTATION.

wet bulb: A thermometer whose bulb is covered with muslin wetted with pure water substance. It is used, in conjunction with a 'dry-bulb' thermometer, in the PSYCHROMETER. The reading of the wet bulb also has some independent value at temperatures much above the freezing-point, since the discomfort accompanying a given high temperature of the air varies greatly with the humidity, and is more nearly defined by the wet-bulb reading than by the temperature of the air. Reliable wet-bulb readings have been known to exceed 32°C (90°F) in the Red Sea, Sierra Leone and Bahrein regions. During recent years values up to 26°C (78°F) have been observed occasionally in the British Isles.

wet-bulb depression: In a wet- and dry-bulb PSYCHROMETER, the amount by which the wet-bulb reading is below that of the dry bulb.

wet-bulb potential temperature: The wet-bulb potential temperature (θ_w) at any level is obtained on an AEROLOGICAL DIAGRAM as that temperature at which the saturated ADIABATIC through the WET-BULB TEMPERATURE at the level concerned intersects the 1000 mb isobar.

θ_w is for practical purposes conservative for such processes as evaporation or condensation and both dry-adiabatic and saturated-adiabatic temperature changes: it is therefore a useful property in AIR-MASS ANALYSIS.

wet-bulb temperature: That temperature (T_w) at which pure water must be evaporated into a given sample of air, adiabatically and at constant pressure, in order to saturate the air at temperature T_w under steady-state conditions. The temperature recorded by the WET BULB of a psychrometer may not exactly accord with this definition. See also THERMODYNAMIC TEMPERATURES.

wet day: Defined for statistical purposes as a period of 24 hours, commencing normally at 9h GMT, on which 0·04 in. or 1·0 mm or more of rainfall is recorded. See also RAIN DAY.

wet season: An alternative for RAINY SEASON.

wet spell: Defined as a period of at least 15 consecutive days to each of which is credited 0·04 in. or 1·0 mm or more of RAINFALL.

whirling psychrometer: A PSYCHROMETER in which the thermometers are mounted on a frame which is rapidly rotated by hand in order to provide the required ventilation of the bulbs. It is also termed a 'sling psychrometer'.

whirlwind: A small revolving storm of wind in which the air whirls round a core of low pressure. Whirlwinds sometimes extend upwards to a height of many hundred feet, and cause DUST WHIRLS when formed over a desert.

whistlers: A type of disturbance heard on a suitable radio receiver. It comprises a succession of whistles which progressively become fainter and take longer to fall through the audio range of frequencies.

The disturbance, strongest at about 55° geomagnetic latitude, originates in a burst of electromagnetic waves in the audio frequency range, emitted by a lightning discharge or produced artificially. The interval between successive whistles corresponds to the time taken by the waves to travel along the lines of force to the geomagnetically conjugate point in the opposite hemisphere, and, on being reflected there, to return along the same path to the radio receiver. The arrival of the waves produces a whistle because the higher frequencies travel faster through the IONOSPHERE than do the lower. The initiating discharge is close either to the receiver or to the conjugate point.

Detailed study of the dispersion of frequencies in whistlers has led to inferences concerning the geomagnetic field and state of ionization above the ionosphere. See also DAWN CHORUS, SFERICS.

white-out: A term applied to that condition in which the contours and natural landmarks in a snow-covered region become indistinguishable. The associated meteorological conditions appear to be a uniform layer of relatively low cloud: under such conditions the light which reaches the surface arrives in nearly equal measure from all directions, with a resulting absence of shadows.

Wien's (displacement) law: See RADIATION.

willy-willy: The name given in Western Australia to a severe TROPICAL CYCLONE.

wilting point: The mass of water (per cent of dry soil) at which the soil is unable to supply water at a rate sufficient to prevent permanent wilting of plants. It varies with the type and structure of the soil, being of the order of 3 per cent for light sand and 20 per cent for heavy clay, and corresponds to a CAPILLARY POTENTIAL of about 15,000 centimetres of water (pF = 4·2). See SOIL MOISTURE.

wind: The (horizontal) movement of air relative to the rotating surface of the earth: the vertical component of air movement, generally much the smaller, is identified as such, where appropriate.

In meteorology, the specified wind direction is that, relative to true (geographic) north, from which the wind blows. The converse practice has, however, been used with certain high-level winds, e.g. those inferred from radio measurement of METEOR trails; more commonly, doubt is now removed in such cases by reference, for example, to a 'westward' wind, i.e. an east wind in the normal meteorological sense. The wind direction is generally specified as a bearing in degrees clockwise from true north: the compass point direction (8, 16 or 32 points according to the accuracy required) is also used. By international agreement (1956) the KNOT is the meteorological unit of wind speed. The specifications of the Beaufort forces are given under BEAUFORT SCALE, together with the forces exerted on unit surface. The relationships between the knot and alternative speed units are:

1 km/hr = 0·278 m/sec = 0·621 mph = 0·540 kt = 0·911 ft/sec.

Surface wind velocity is normally measured by some form of ANEMOMETER or ANEMOGRAPH, and WIND VANE. Appropriate EXPOSURE of the instrument to ensure reasonable comparability of observations at different stations is especially difficult in wind measurement: 'surface wind' in synoptic reports refers to an 'equivalent' height of 10 metres (33 feet). Upper-level winds are normally measured by the PILOT BALLOON, or RAWIN techniques. They may be inferred from measurements of the angular velocity of clouds, excluding certain (wave) types of cloud through which the air moves.

Wind velocity is intimately related to the pressure distribution. In large-scale motion the relationship gives rise to BUYS BALLOT'S LAW, the GEOSTROPHIC WIND and the GRADIENT WIND while for example changing pressure distribution in space or time is related to the AGEOSTROPHIC WIND. Height changes of wind velocity are generally considered in terms of the THERMAL WIND. On the more local scale the pressure–wind relationship gives rise to such winds as LAND- AND SEA-BREEZES, the KATABATIC WIND and the ANABATIC WIND.

Diurnal variation of atmospheric TURBULENCE is associated with variations of surface wind velocity due to stronger vertical mixing of air at lower levels by day than by night (appreciable increase of speed and very slight veer by day). Associated with the systematic diurnal variation of pressure is a variation of wind velocity of an amplitude which is too small at the surface to be revealed except by averaging over a long period but which increases with height to such an extent as to be a prominent feature of winds at very high levels—see ATMOSPHERIC TIDES.

wind-break: A term sometimes used in such a sense as to include both natural and artificial barriers to wind flow which provide shelter to animals, crops, etc. More usually the term is now restricted to artificial barriers (palings, etc.). See also SHELTER-BELT.

The degree of shelter from wind provided by a barrier depends, among other factors, on the height, lateral extent and permeability of the barrier and on the angle of incidence of wind to the barrier. Thus, for example, a dense barrier (over 80 per cent blockage) of height h provides almost complete shelter in its immediate lee but no shelter beyond a distance of about $20h$ downwind, while a barrier of medium density (about 60 per cent blockage) reduces the speed of a wind blowing at right angles to it to a minimum value of about 20 per cent of the undisturbed wind speed at a downwind distance of about $4h$ and produces a measurable reduction out to about $40h$. Strongly eddying motion is a marked feature of the air flow up to a distance of about $15h$ downwind from a dense barrier.

Other physical effects of wind-breaks include alterations of air temperature and humidity, soil temperature and moisture, and evaporation rate over the region affected by the presence of the barrier.

wind rose: One of a class of diagrams showing, for a specified locality and usually for an extended period, the frequencies of winds blowing from each of the 8 or 16 leading points of the compass within (in most cases) specified speed ranges. The compass directions emanate from a circle within which the frequency of calms is shown (see Figure 35).

A wind rose may be adapted to demonstrate the relationship between surface winds and other meteorological elements, or to represent the distribution of wind velocities at selected levels in the upper atmosphere.

wind shear: The local change of wind velocity in a specified direction normal to the wind direction. The differentials $\partial v/\partial s$ (v wind velocity, s horizontal distance) and $\partial v/\partial z$ (z vertical distance) are the horizontal (wind) shear and vertical shear, respectively. Large shear of both types occurs near the axis of a JET STREAM.

Shear is an important hydrodynamical property of the wind velocity field. Thus, for example, the shear that exists at a well marked frontal surface may produce so-called SHEARING INSTABILITY; while horizontal shear is closely associated with the vertical component of VORTICITY. Large vertical shear in the free atmosphere implies a strong THERMAL WIND: it is, in fact, identical with the thermal wind if geostrophic motion is assumed.

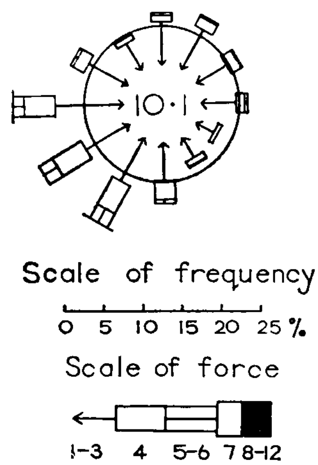


FIGURE 35—Wind rose for London Airport, 1949–58, showing annual frequency of wind direction and velocity.

wind vane: A device for indicating the direction from which the wind is blowing. In the Meteorological Office pattern a horizontal arm pivoted on a steel spindle is provided with a pointer at one end and an aerofoil of streamline section at the other. Below the vane is a fixed framework showing the four cardinal points. If well exposed and accurately balanced, almost any type of vane will show the correct direction in moderate or strong winds but ornamental vanes are rarely sensitive enough for meteorological purposes in light winds.

windward: Windward of a point signifies the 'upwind' direction from the point, e.g. westward in the case of a west wind.

winter: See SEASONS.

WMO: Abbreviation for WORLD METEOROLOGICAL ORGANIZATION.

World Meteorological Organization: The World Meteorological Organization (WMO) is a specialized agency of the United Nations encompassing the field of meteorology. It replaced the IMO (International Meteorological Organization) in 1951. The WMO comprises over 100 States and Territories and has a permanent Secretariat in Geneva.

The purposes of the WMO are, *inter alia*, to facilitate world-wide co-operation in the establishment of networks of meteorological observation stations and to promote the development of centres charged with the provision of meteorological services; to promote the rapid exchange of weather information and the standardization of meteorological observations and their publication; to further the application of meteorology to human activities and to encourage research and training in meteorology.

X, Y, Z

xenon: One of the INERT GASES, comprising $8 \cdot 0 \times 10^{-8}$ and $3 \cdot 6 \times 10^{-7}$ part per part of dry air by volume and weight, respectively. Its molecular weight is 131·3.

x-rays: ELECTROMAGNETIC RADIATION in the approximate band of wavelengths from 0·1 to 10 ångströms (10^{-9} to 10^{-7} cm). The X-rays which are contained in the solar radiation incident on the high atmosphere are responsible for an appreciable part of the IONIZATION of the region.

year: The time taken by the earth to revolve once in its orbit round the sun. See CALENDAR.

zenith: The point of the sky in the vertical produced upwards from the observer. The word is now commonly used to denote a more-or-less extensive stretch of sky immediately overhead.

zenith distance: The zenith distance of a body is the angle between the body and the ZENITH, as observed at a particular point of observation.

zenith, magnetic: The direction indicated by the upper end of a suspended magnetic needle. In the north of the British Isles it is some 17°, and in the south some 23°, south-south-east of the geographical zenith. See DIP, magnetic.

zephyr: A westerly breeze with pleasant warm weather supposed to prevail at the summer solstice.

zero: The point of origin in the graduation of an instrument: for example, the freezing-point of water on the CELSIUS SCALE of temperature is assigned the value of '0'. An error in the positioning of the entire scale of an instrument may be regarded as an incorrect location of the zero, and the term 'zero error' is commonly applied to it.

zodiac: The series of constellations in which the sun is apparently placed in succession, on account of the revolution of the earth round the sun, are called the Signs of the Zodiac, and in older writings give their names and symbols to the months, thus:

Month	*Symbol*	*Month*	*Symbol*
March	Aries, the Ram	September	Libra, the Scales
April	Taurus, the Bull	October	Scorpio, the Scorpion
May	Gemini, the Heavenly Twins	November	Sagittarius, the Archer
June	Cancer, the Crab	December	Capricornus, the Goat
July	Leo, the Lion	January	Aquarius, the Watercarrier
August	Virgo, the Virgin	February	Pisces, the Fishes

Owing to precession, the position of the equator relative to the zodiacal constellations has altered a good deal since classical times. The sun now enters Aries late in April and reaches the other zodiacal constellations with the same retardation but in textbooks of astronomy the point at which the sun crosses the equator at the spring equinox, 21 March, is still called the first point of Aries.

zodiacal band: A very faintly luminous band, a few degrees wide, joining the apices of the morning and evening ZODIACAL LIGHTS.

zodiacal light: A cone of faint white light in the night sky, extending along the ZODIAC from the western horizon after evening TWILIGHT and from the eastern horizon before morning twilight.

The phenomenon is caused by the scattering of sunlight from a cloud of particles lying in the ecliptic. The composition and origin of these particles—whether of dust or molecules or electrons, solar or terrestrial—is not yet certain. Molecular emission may also play a part.

zonal circulation: West to east air flow. East to west air flow is generally reckoned a negative zonal circulation.

zonal index: A measure of the strength of the ZONAL CIRCULATION, either at the surface or in the upper air, for a specified (large) area and period of time. Thus, for example, the mean surface pressure difference between the circles of latitude 35° and 55° is a convenient zonal index of surface air flow for mid-latitudes of the northern hemisphere.

zone of silence: See AUDIBILITY.

zone time: A system of local TIME classification, differing from GMT in steps of 1 hour per 15° of longitude. The individual zones are distinguished by the letters A, B, C etc. (omitting J) for areas centred on 15°E, 30°E, 45°E etc., respectively; and by the letters N, O, P etc. for areas centred on 15°W, 30°W, 45°W etc., respectively. GMT is in this system designated Z time.

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