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RADIO-SONDE TRIALS AT PAYERNE, 1956.

By A. H. HOOPER.

Payerne, a small country town lying away from the main tourist routes of Switzerland, is generally remembered for its white wine and for its "Abbatiale", the clock of which announces the passage of each hour with a double set of chimes. In the field of meteorology it is known, too, as the venue for the two international comparisons of radio-sondes conducted to date. The later of these events took place during May and June of 1956, delegates from 13 countries being present with 14 types of radio-sonde. From the results of this comparison, in the course of which about 370 radio-sondes were launched, it is expected to gain information, up to high levels, of the magnitude of instrumental differences. As nearly all types of the world's radio-sondes were represented, this information will be of considerable significance in the realm of routine upper air analysis and in the aerological programme of the International Geophysical Year.

The comparison, which was conducted by a working group of the World Meteorological Organization Commission for Instruments and Methods of Observation, can be divided into two main sections. In the first, radio-sondes were flown in groups of four, being suspended at standard intervals in a vertical train from a cluster of three balloons. The soundings were carried out by day and by night, the groups of radio-sondes and their positions in the trains following a statistical pattern proposed by Dr. A. Delver of the Netherlands. In the second section larger groups of radio-sondes were flown to obtain sufficient data for the direct comparison of any pair. Over the trials as a whole, ascents reached an average height of 22·1 Km. Although not coming within the main programme, four types of wind-finding equipment were compared in respect of elevation and azimuth measurements. One of them, the 3-cm. equipment by Decca, gives, in addition, a third and important parameter, range, enabling winds to be found without the need for an active balloon-borne transmitter; it also eliminates uncertainties which derive from the use of radio-sonde pressure-temperature data to give height. An attempt was made to overcome the effect of any instrumental damage incurred during launching by comparing each radio-sonde with the values given by a distant-recording meteorograph suspended at a known level from a kite-balloon. To this end the time of transit through the level was obtained from observations made by the Decca radar operated by a very willing team from the company.

For United Kingdom participation a mobile unit (see photographs facing p.48) was prepared, using a vehicle specially fitted as a radio-sonde operations room. Much interest was aroused by this unit, both during the journey and in operation. Despite the poor road surfaces experienced in travelling across Europe the equipment arrived at Payerne in excellent condition, the calibrations of the ground installation were virtually unchanged whilst those of the radio-sondes were altered to an extent smaller than that associated with delivery by rail.

Following the preparatory work of installation and testing, a number of trials were conducted in order to establish a technique for launching the trains of radio-sondes. After two practice launches and much good-humoured controversy, the problems of language and management were overcome and a launching "pattern" agreed for subsequent work.

It was an essential feature of the Delver programme that all radio-sondes in all soundings should yield information at all levels of comparison. In consequence the failure of any one radio-sonde in the course of ascent necessitated repetition by that particular group of radio-sondes. The expense of obtaining complete instrumental reliability is, of course, prohibitive, so that with any type of radio-sonde a small percentage of failures during ascent must be expected. With four radio-sondes in each train the probability of an ascent failure is considerably increased and despite the utmost precautions a number of repetitions were, in fact, necessary.

The second series of ascents began cautiously with a train of eight radio-sondes, later followed by two trains of nine. The photograph in the centre of the magazine shows the final stage of preparation of a train of eight radio-sondes; the last balloon is being tied up in the shelter, the sondes are being assembled down wind and two individuals can be seen running to help in letting up the eight balloons. Then followed the most memorable day of all, June 11, when in calm weather, a train of all 14 types of radio-sonde was assembled and, with some trepidation, attached to a cluster of 15 balloons. With a total lift of 56 Kg. the launch presented several problems. Would the balloon launching team, suitably augmented, be able to let up the balloons successively on their individual cords and retain control until the moment came for release? Would the initial acceleration due to such a great lift so increase the normal launching "snatch" that the earlier sondes of the train would be damaged? Would the 91-m. train of radio-sondes extending in a zigzag right across the launching area and into the neighbouring field so limit manoeuvrability that the later radio-sondes could not be launched clear of adjacent obstacles? In the event the launch was wholly successful. The balloons were restrained by three of the balloon team grasping the junction knot. Then, upon release, the radio-sonde team ran with their instruments first towards the balloon team for the earlier sondes to rise vertically, and then away from them for the later radio-sondes to rise without risk of swinging to the ground. Everyone then retired to their receiving equipment for an hour anxiously awaiting possible failure. With great luck, however, all radio-sondes, in their several ways, gave sounding data to the burst level of 35 mb. This ascent, it is believed, comprising an assembly extending over 200 m. from the uppermost balloon to the lowest radio-sonde, represents a notable achievement in the history of upper air exploration and was, for the fleeting hour of its life a symbol of whole-hearted international collaboration. Encouraged by its success and by the resulting saving in time, further attempts were made in various strengths of wind until, in all, eight such soundings had been completed. Inevitably, the number of radio-sonde failures during this period approached the average, emphasizing thereby the extraordinary luck attending the first attempt. The positions of the radio-sondes in the trains were unchanged over this period, all presenting especial difficulties, ranging from the first with a maximum of "snatch" to the last with a maximum of sprinting.

A small Secretariat was set up whose functions day by day were to duplicate and distribute the voluminous data compiled from each sounding, together with, in several languages, information sheets based upon decisions taken at daily Working Meetings. The commencement of 14-radio-sonde soundings so increased the work of the members of the Secretariat that they were active far into each night. It is to their great credit that the delegations were able to leave Payerne in possession of most of the data. As a result of this very considerable start it is hoped that the extensive tables summarizing the results of the trial will be produced by the Working Group by the Spring of 1957.

To ensure the use of a common time scale for all radio-sonde data a network of slave clocks was installed, a pair at each set of observing equipment, giving time in minutes and seconds. A loudspeaker at each position together with various public-address units gave both additional operational information and, during the stresses of launching, encouraging exhortations. What the neighbouring farmers made of the latter was never ascertained.

In striving for reliability continual attention is given, in radio-sonde work, to the different types of instrumental failure. In nearly all cases the disappearance of a transmission signal is assigned to valve or circuit failure of the radio-sonde. It is possible, however, that a small proportion of such failures can arise from damage by lightning. This occurrence, in routine conditions, cannot readily be proved. It is interesting to record, therefore, that on one occasion during trials the signals from all four of a train of radio-sondes ceased shortly after launching in thundery conditions. The simultaneous cessation of signals from radio-sondes of independent and widely different circuit arrangement is very strong evidence of an "external" cause. Having regard to the conditions prevailing it appears highly probable that the train was struck by lightning and the circuits damaged.

The balloons, upon which the success of the comparison depended, were contributed by several countries and were used in various combinations without noticeable difference in performance. Each balloon in a cluster was provided with a separate cord of unique length leading to a common knot from which hung the train of radio-sondes. Although before release the cords of the upper balloons chafed on the lower balloons it was found that in flight the balloons became widely separated and were at no time in danger of damaging each other. The photograph in the centre of the magazine shows a cluster of 15 balloons in flight. Despite the unusual angle their degree of separation is clear. The parachutes, radar reflector and upper radio-sondes of this particular sounding can just be seen, trailing away to the lower edge of the photograph.

The trials provided an unparalled opportunity of examining the detailed construction of the radio-sondes of the world and of observing them in action.

The main impression was of the great diversity of design and circuits; the fact that they represent 14 solutions to the single problem of measuring upper air conditions is a striking example of the independence of human invention. For pressure measurements all but one use an aneroid, the exception being an experimental radio-sonde of the Netherlands in which a hypsometer is employed. For temperature, bi-metallic strips of various sizes are in general use, but two instruments make use of thermistors. The Japanese sonde includes two mercury-in-glass thermometers to provide checks during ascent of the bi-metal calibration. The sensing materials for humidity are hair, gold-beater's skin and lithium chloride. The weights of complete radio-sondes range from a minimum of 300 gm. to a maximum of 2,200 gm. Naturally the appearances, too, of the radio-sondes vary widely. To one accustomed to handling the British type it was a distinct surprise to learn from a Swiss magazine that our own device was in other eyes, "à forme amusante".

Those of us privileged to participate in the trials will remember many things, the friendships, the amusements arising from diversity of language, the international team-spirit engendered by launchings and, above all, the generous and unfailing help of our Swiss hosts. To them must go the credit for a remarkable achievement of organization, which was so essential to the success of the trials.

ATMOSPHERIC SMOKE CONCENTRATION MEASUREMENTS AT ESKDALEMUIR

By D. H. McINTOSH, M.A., B.Sc.

Introduction.—The measurement of atmospheric smoke concentration has been made continuously at Eskdalemuir Observatory since late 1948 by means of equipment provided by the Director of Fuel Research, Department of

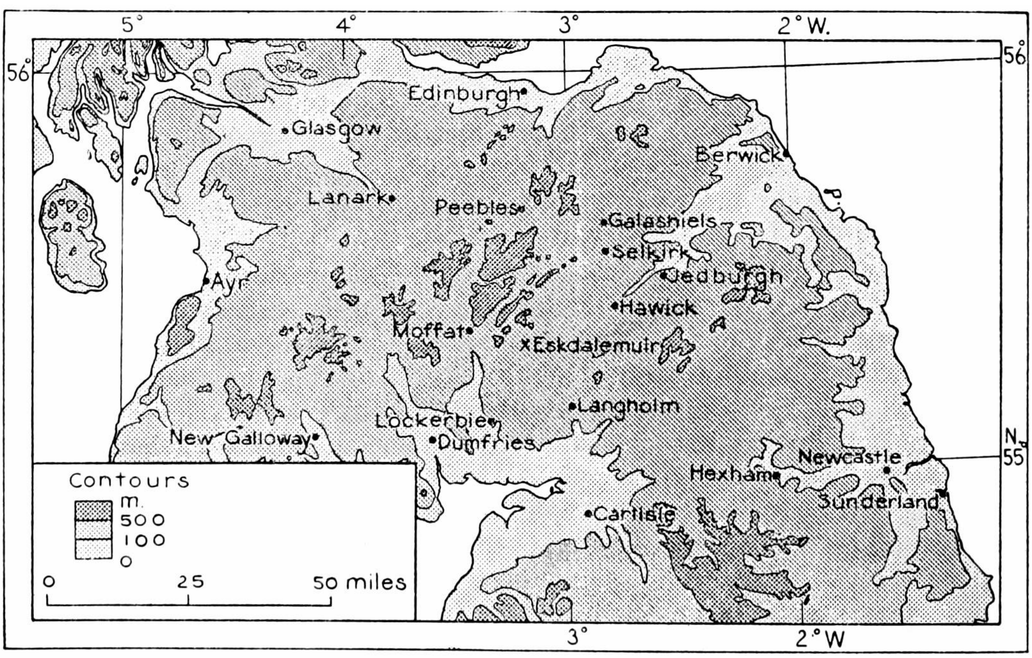


FIG. 1—MAP SHOWING POSITION OF ESKDALEMUIR IN RELATION TO CENTRES OF POPULATION AND INDUSTRY

Scientific and Industrial Research. As would be expected the smoke concentration at Eskdalemuir is relatively very low, but the unusually isolated location of the Observatory—18 miles from the nearest town and nearly three times as far from any major source of smoke (see Fig. 1)—makes for rather special interest in the observations. The possible effects of changes in quite local sources of smoke is a factor which introduces an element of uncertainty into the assessment of most series of smoke measurements: those at Eskdalemuir are unusual in that they may with confidence be regarded as being free from such uncertainty.

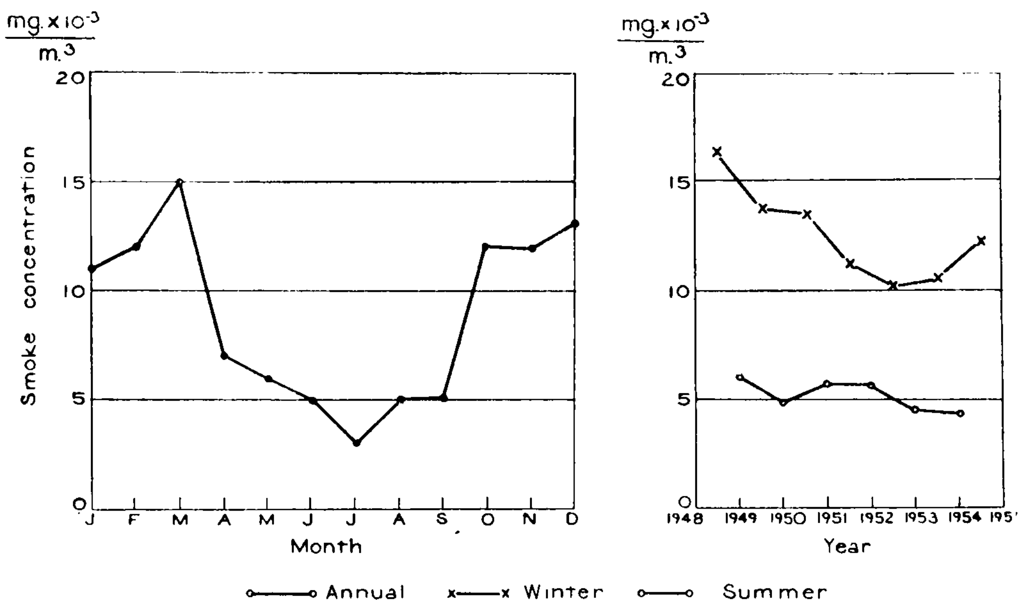
Here the results of nearly seven years' observations are used to investigate systematic weekly, annual and secular variations and the association of daily measured concentration with wind speed and direction.

Method of measurement.—The method of measurement is to draw, by means of an electric pump, a measured volume of air through a white filter paper in such a way that all the solid impurity in the air remains in the filter as a grey stain. The weight of the impurity caught is estimated at the Fuel Research Station by matching the stain with a scale of shades which has previously been calibrated by matching with weighed stains. Before June 1949 the stain values were obtained visually by the scale of shades: subsequently they have been determined by measuring the reflectance of the stains photoelectrically. A fresh stain is obtained at Eskdalemuir for each 24-hr. period beginning in the evening. The daily average smoke concentration was expressed over most of the period in the unit 10^{-3} mg./m.^{3} but recently the Fuel Research authorities have employed the unit 10^{-2} mg./m.^{3} as they no longer consider the accuracy implied in the smaller unit to be justified.

Magnitude of systematic variations.—The departures from monthly mean concentrations had already been evaluated in terms of the smaller unit of measurement when the change to the larger unit was made. It was decided to retain the smaller unit in looking for systematic effects since the additional figure would, at worst, occur as a random element. Subsequent detailed examination of the groupings of the departures, in terms of surface wind speed and direction, for example, strongly suggests that part of the additional implied accuracy is justified during the summer months when the smoke concentration is very low: this does not appear to be the case during the winter months when the average concentration is higher. The operation of the normal law of errors enables systematic, i.e. average, winter effects to be determined with an accuracy of about the discarded unit for individual measurement, while the accuracy in summer is slightly greater.

Weekly variation.—The individual daily smoke concentrations from October 1948 to June 1955 were examined for evidence of a systematic weekly variation: the results for the six "summer" months April to September, and six "winter" months October to March were considered separately. In both cases the minimum daily average concentration occurred on Sunday, the winter value for that day being 5 per cent., and the summer value 20 per cent., below the corresponding weekly average concentration. Examination of the "casual" errors involved shows that only the latter value is statistically significant. Since, however, the average concentrations on Saturday and Monday were in both seasons also below the weekly average, there is little doubt that a week-end decrease of smoke concentration was in both seasons a real feature of the observations. Local conditions provide no explanation for this feature which was therefore presumably caused by the lower week-end smoke output from distant factory chimneys.

Annual variation.—Average monthly smoke concentration over a period of nearly seven years is shown in Fig. 2. The graph shows the expected feature of winter maximum and summer minimum. From results to be discussed later it is probable that the winter maximum is delayed till March mainly because of a higher frequency of easterly winds in that month than in the earlier winter months. Another possible factor in the curve of the annual variation of smoke is the burning of moorland grass which is done in parts of the surrounding countryside in late winter or spring provided there is a suitable dry spell. While this may be an additional factor in the delay of maximum concentration till March it is unlikely to be an important factor because the moor burning is more frequently carried out in April and May, which had in every year appreciably lower average concentrations than March. It should perhaps be emphasized that throughout the series of measurements there was no day or succession of days which showed so large a smoke concentration as to indicate that an important local source of smoke was active.



1400 G.M.T., April 13, 1955 0200 G.M.T., March 16, 1955

FIG. 2—VARIATION OF SMOKE CONCENTRATION AT ESKDALEMUIR, 1948–55

Secular variation.—Fig. 2 also shows the year-to-year change of measured smoke concentration. A decrease over the period of some 30 per cent. in winter and 15–20 per cent. in summer is suggested by the curves, and statistical examination of the individual monthly values shows that the decrease is too large to be accounted for by chance fluctuations. The apparent decrease is however unreliable on two counts:

(*a*) photo-electric as opposed to visual measurement of the stains was introduced in May 1949, and may have caused a discontinuity in the computed smoke concentrations;

(*b*) because of the apparent secular change in the measurements, the gas meter of the ordinary domestic type employed in the measurements was in

September 1955 tested in series with a recently calibrated meter and found to have a positive error of about 7 per cent. Since the meter was accurate at the time of installation, about 7 per cent. of the apparent decrease of smoke concentration can reasonably be attributed to a subsequently developed fault in the meter.

The conclusion drawn from the series of Eskdalemuir measurements is that a decrease in average smoke concentration of some 10–15 per cent. has probably occurred during the period of measurement.

Variation with surface wind.—The smoke concentration on each day of the first three years of observation was expressed as a departure from the appropriate monthly mean, and these values were coupled with the corresponding prevailing surface wind direction and mean speed over the 24-hr. period, obtained from the hourly wind tabulations: on the many occasions on which no "prevailing" wind direction could be decided on, the wind was listed as "variable". The departures were grouped in 13 divisions according to wind direction, 12 each covering a range of 30° (350°–010°, 020°–040° etc.), the other being the "variable" winds: each of these groups was sub-divided five times according to mean wind speed, the lower limits being 0, 2, 4, 7 and 10 m./sec.

A cursory examination was enough to reveal system in the grouping of smoke concentration departures with respect to both surface wind speed and direction, and the period of three years was long enough to provide sufficiently reliable mean departures. The results for the six summer and six winter months were considered separately.

Variation of smoke concentration with surface-wind speed.—Apart from apparently casual influences the progression of the smoke-concentration departures was in all wind-direction groups in the same sense of decrease of smoke concentration with increase in wind speed, this effect being superimposed on another in which, broadly, easterly winds had positive departures and westerly winds negative. The process of condensing the original 13 groups into 5 groups, N.,

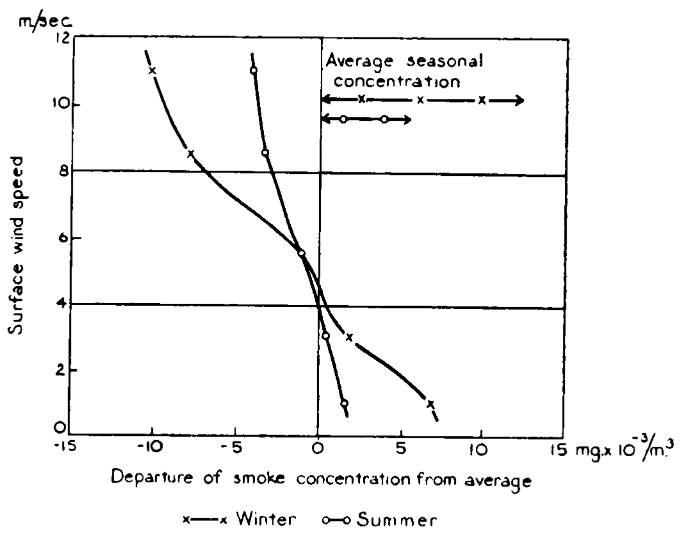
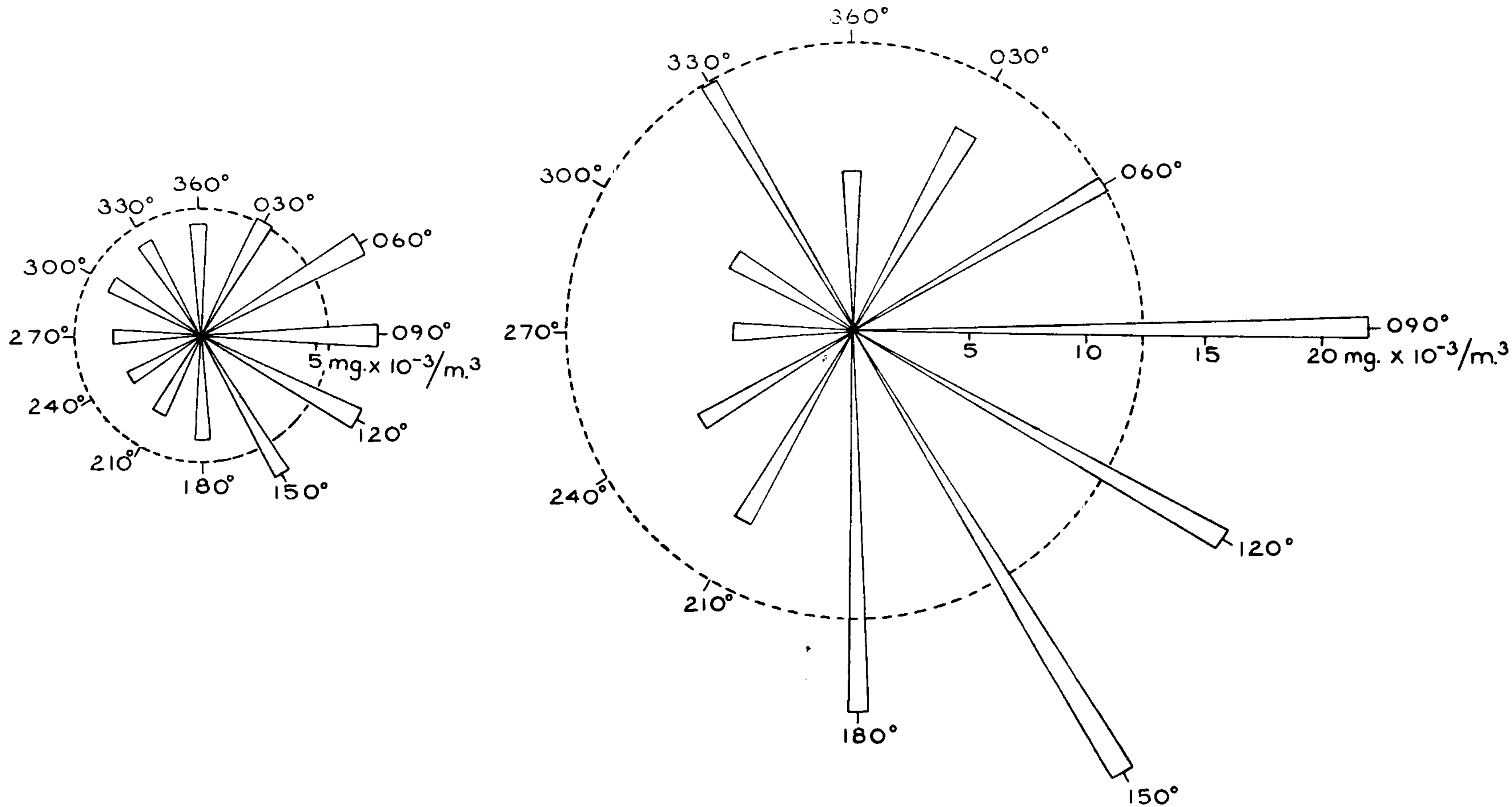


FIG. 3—VARIATION OF SMOKE CONCENTRATION WITH SURFACE WIND SPEED AT ESKDALEMUIR, 1948–51



Summer

Winter

FIG. 4—VARIATION OF SMOKE CONCENTRATION WITH SURFACE WIND DIRECTION AT ESKDALEMUIR, 1948–51

E., S., W. and variable, for better sampling revealed no significant difference in the way in which the smoke concentration varied with wind speed in these bigger groups. The individual mean departures in each wind-speed range of the 13 groups were therefore averaged, appropriate allowance being made for the fact that in some wind directions cases of high wind speed were lacking. The results are shown in Fig. 3 in which the mean departures appropriate to the middle points of the five wind speed-ranges, 11 m./sec. in the highest range, are plotted. These results apply to all wind directions and are freed, as far as possible, by the method adopted from the influence of varying frequency of winds of different direction. The curves cross the line of zero departure at points close to the seasonal mean wind speed, about 4 m./sec.

Variation of smoke concentration with surface-wind direction.—A procedure analogous to that described above was used to determine the variation of smoke concentration with wind direction, the influence of varying wind speed being removed. The results for summer and winter are shown in Fig. 4, the radius of the circle representing the seasonal average concentration of smoke and the lengths of the radii the concentrations corresponding to the wind directions considered. As with the wind-speed variation the effect of the varying frequency of winds in different directions has been removed from the results. The smoke concentration for the group of variable winds was found to differ insignificantly from the seasonal average covering all wind groups.

Precise determination of the standard error of the plotted means is made difficult by the day-to-day coherence of surface wind and of smoke concentration and also by the rather complicated procedure followed in trying to distinguish clearly the separate effects of surface wind speed and direction: approximate calculation shows, however, that all the main features that appear on the graphs are statistically reliable. These features are:

(i) There is in both seasons a decrease of smoke concentration with increase of surface wind speed throughout the range of wind speed observed. The data are not reliable enough to determine the exact nature of the curve in either case.

(ii) The smokiest wind direction at Eskdalemuir is centred on E. in summer and SE. in winter. The Newcastle area appears to be the main source of the smoke, although the relative stability of air masses associated with these surface winds is no doubt also important.

(iii) The relatively high concentration of smoke associated in winter with surface winds in the range 320°–340° appears to be a reliable feature in that season and is probably to be attributed to the Glasgow source in spite of its absence in summer.

Acknowledgment.—The observations were made as part of the co-operative scheme for measuring atmospheric pollution at a large number of places throughout the United Kingdom. The scheme is operated by the Fuel Research Station which also supplies the apparatus.

A STATISTICAL ANALYSIS OF VERTICAL VARIATION OF SUNSHINE OVER GERMANY

By G. A. TUNNELL, B.Sc.

In the course of collecting bright-sunshine data for Europe the vertical variation of the duration of sunshine in Germany (data from Deutsches meteorologisches Jahrbuch 1924–33) was examined as part of the preliminary work for mapping the data. This problem has been examined for numerous areas by continental meteorologists. The most systematic examination has been carried out for 90 stations in Austria by Conrad[1,2] who has expressed the seasonal variation at a number of levels by a Fourier series and has described the variation with height of average values and the amplitudes and phases of the first two terms.

The present analysis is concerned with the mean duration for each place for each month and examines simultaneously both the horizontal and vertical fields. Data for about 40 stations for each month of the year for a uniform

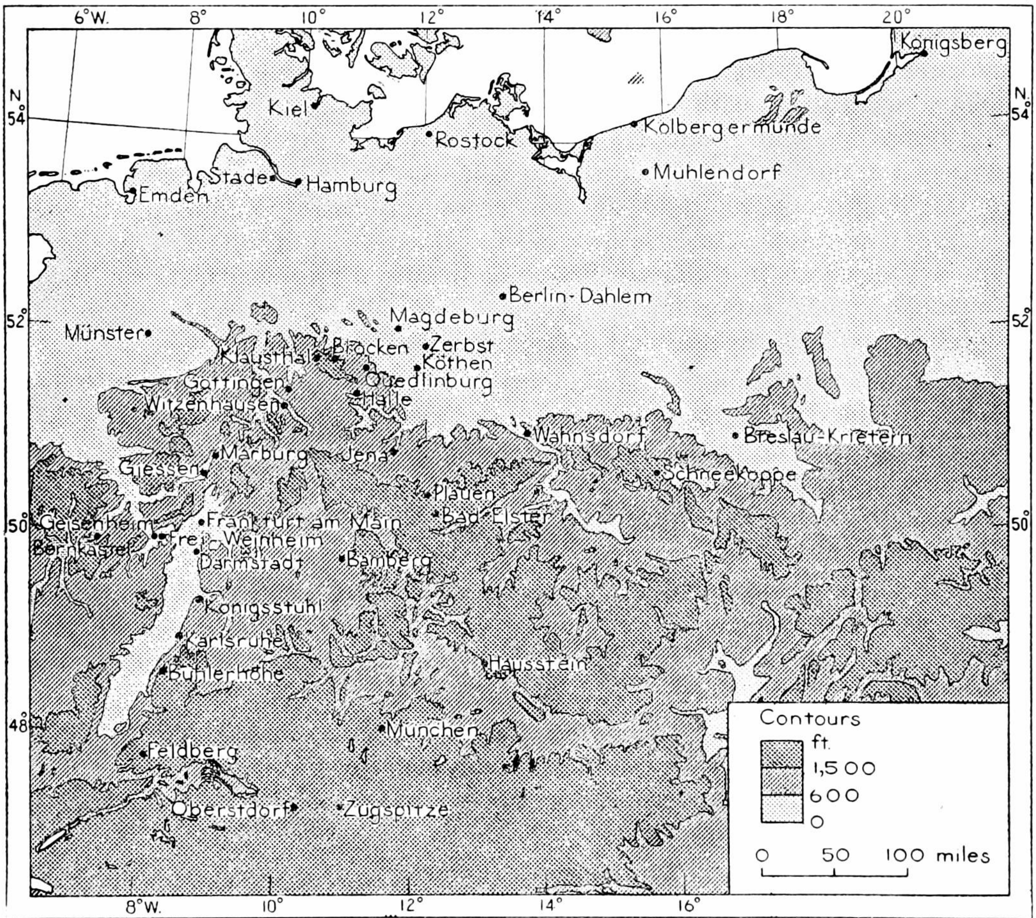


FIG. 1—DISTRIBUTION OF STATIONS IN GERMANY

Station heights in metres

Bad Elster	528	Göttingen	183	Muhlendorf	101
Bamberg	303	Halle	122	München	516
Berlin—Dahlem	58	Hamburg	53	Munster	60
Birnkastel	145	Hausstein	677	Oberstdorf	827
Breslau—Krietern	130	Jena	164	Plauen	401
Brocken	1157	Karlsruhe	136	Quedlingburg	143
Bühlerhöhe	785	Kiel	42	Rostock	45
Darmstadt	166	Klausthal	602	Schneekoppe	1618
Emden	3	Kolbergemünde	17	Stade	41
Feldberg	1471	Königsberg	32	Wahnsdorf	257
Frankfurt am Main	122	Konigstuhl	573	Witzenhausen	152
Frei—Weinheim	97	Köthen	107	Zerbst	73
Geisenheim	112	Magdeburg	88	Zugspitze	2972
Giessen	181	Marburg	251		

period 1924–33 have been analysed. Fig. 1 gives the distribution of stations with their respective heights. The values used are mean daily durations, expressed as a percentage of monthly mean possible sunshine in order to avoid effects due to purely astronomical causes. In the remainder of the paper percentage of possible sunshine is referred to simply as sunshine. The analysis is similar to that used in an earlier paper on the reduction of vapour pressure to sea level[3].

The data have been fitted by the method of least squares to an equation of the form

$$S = Ah + B\lambda + C\phi + D, \qquad \ldots\ldots (1)$$

where

S = Monthly average percentage of possible sunshine
h = Height of the meteorological observing station above sea level in metres
λ = The latitude of the station in degrees north
ϕ = The longitude of the station in degrees east of Greenwich
A, B, C and D are constants for any given month.

A is a constant of particular interest because it is the rate of change of sunshine with height i.e. $\partial S/\partial h$. There are 12 analyses, one for each month and the results have been put in Table I and Fig. 2.

There is a striking seasonal variation of A from a high positive value in December to a high negative value in May; this is the main concern of this paper. The goodness of fit of equation (1), as indicated by the coefficient of multiple correlation (R in Table I) is best when the magnitude of A is greatest. When the magnitude of A is low as in March and September the fit is poor.

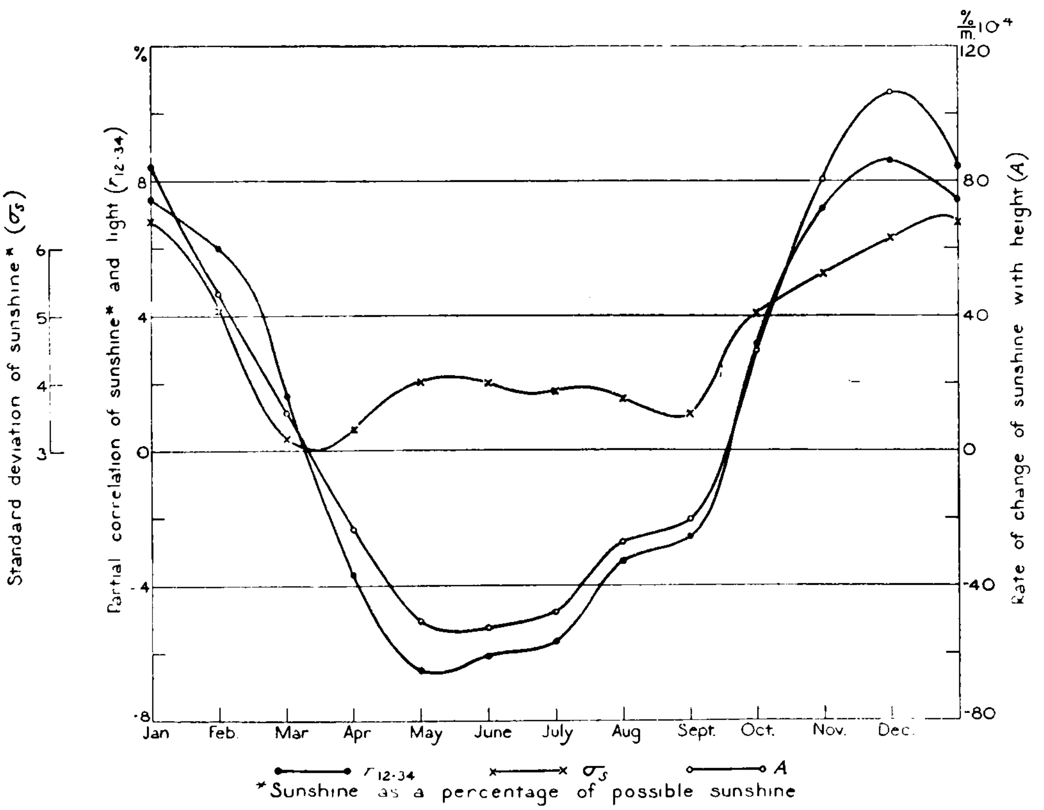


FIG. 2—MONTHLY VARIATION OF SUNSHINE

TABLE I—STATISTICAL ANALYSIS OF SUNSHINE DATA FOR GERMANY, 1924–33

No. of stations = 41

	Values of constants* A	B	C	D	Standard deviation† σ_s	Average value $\overline{S}$	Correlation coefficients r_{sh}	$r_{s\lambda}$	$r_{s\phi}$	$r_{sh \cdot \lambda\phi}$	R
	%.10²/m.	%/°N.	%/°E.	%	%	%					
January	+0·8417	−0·6159	+0·3589	+45·52	6·398	21·20	+0·84	−0·54	+0·09	+0·74	+0·85
February	+0·4600	−1·111	−0·2121	+86·18	5·079	28·83	+0·74	−0·74	−0·28	+0·60	+0·84
March	+0·1110	−0·1626	−0·2099	+48·17	3·181	37·98	+0·25	−0·28	−0·23	+0·16	+0·34
April	−0·2379	−0·1657	+0·5751	+38·79	3·319	35·76	−0·35	+0·32	+0·46	−0·36	+0·58
May	−0·5057	−0·0686	+0·4564	+43·22	4·024	42·83	−0·68	+0·49	+0·31	−0·64	+0·75
June	−0·5236	−0·3348	+0·1716	+61·68	4·001	44·49	−0·64	+0·30	+0·06	−0·61	+0·66
July	−0·4799	−0·8533	+0·5603	+82·65	3·889	43·41	−0·46	+0·13	+0·25	−0·56	+0·60
August	−0·2709	−0·3240	+0·3857	+57·69	3·773	44·37	−0·31	+0·18	+0·23	−0·33	+0·40
September	−0·2018	−0·6855	+0·3329	+71·26	3·531	39·15	−0·11	−0·08	+0·13	−0·26	+0·32
October	+0·2991	−0·9371	+0·6173	+71·04	5·036	31·10	+0·53	−0·40	+0·21	+0·32	+0·63
November	+0·8062	+0·2669	+0·4249	+ 0·1251	5·631	21·49	+0·75	−0·28	+0·25	+0·72	+0·79
December	+1·062	+0·4682	−0·0343	− 8·213	6·147	19·34	+0·88	−0·41	+0·04	+0·86	+0·89

	Sunshine	Value used every month: Height	Latitude	Longitude	Correlation coefficient		Value used for every month
		m.	°	°			
Average	$\overline{S}$	$\bar{h} = 378 \cdot 3$	$\bar{\lambda} = 51 \cdot 08$	$\bar{\phi} = 11 \cdot 01$	Simple	r_{sh}, $r_{s\lambda}$, $r_{s\phi}$	$r_{h\lambda} = -0 \cdot 56$ $r_{h\phi} = -0 \cdot 0019$ $r_{\lambda\phi} = +0 \cdot 38$
Standard deviation	σ_s	$\sigma_h = 558 \cdot 4$	$\sigma_\lambda = 1 \cdot 886$	$\sigma_\phi = 2 \cdot 847$	Partial	$r_{sh \cdot \lambda\phi}$	
					Multiple*	R	

* Associated with equation (1). † Standard deviation of average per cent. of possible sunshine.

It is of interest to note in Table I and Fig. 2 that when A is positive, i.e. in winter, the positional variability as indicated by σ_s is high but $\bar{S}$ the average sunshine is low. When A is negative, i.e. in summer, σ_s is low and $\bar{S}$ is high. A further point of interest is the negative correlation between latitude and height, $r_{\lambda h}$, which for some months causes the correlation between sunshine and latitude, $r_{s\lambda}$, to be of opposite sign to B, i.e. $\partial S/\partial \lambda$. The relationship between height and latitude produces a false correlation between sunshine and latitude.

Fig. 3 gives the values of average sunshine plotted as ordinates, with height above sea level as abscissae, for May, December and March. May is a month of negative partial correlation, December is one of positive, and March the only month when the partial correlation is not statistically significant as determined by the "t" test[4]. The straight lines on the diagrams correspond to equation (1) for the mean position $\bar{\lambda}$, $\bar{\phi}$. The diagrams show that the equation holds over a great thickness of atmosphere when the fit is good. For both May and December almost all the values are near or on the lines, including the high-level values for the Zugspitze. The causes of this annual cycle, illustrated in Fig. 2, are the seasonal changes over Germany which produce the control of sunshine mainly by low cloud in winter and by higher cloud, mainly above 3,000 m., in summer.

In winter Germany is on the edge of the North Atlantic cyclonic circulation and the Eurasian anticyclone and the mean air flow near the surface is fairly strong south-south-west, while the screen temperature falls from west to east

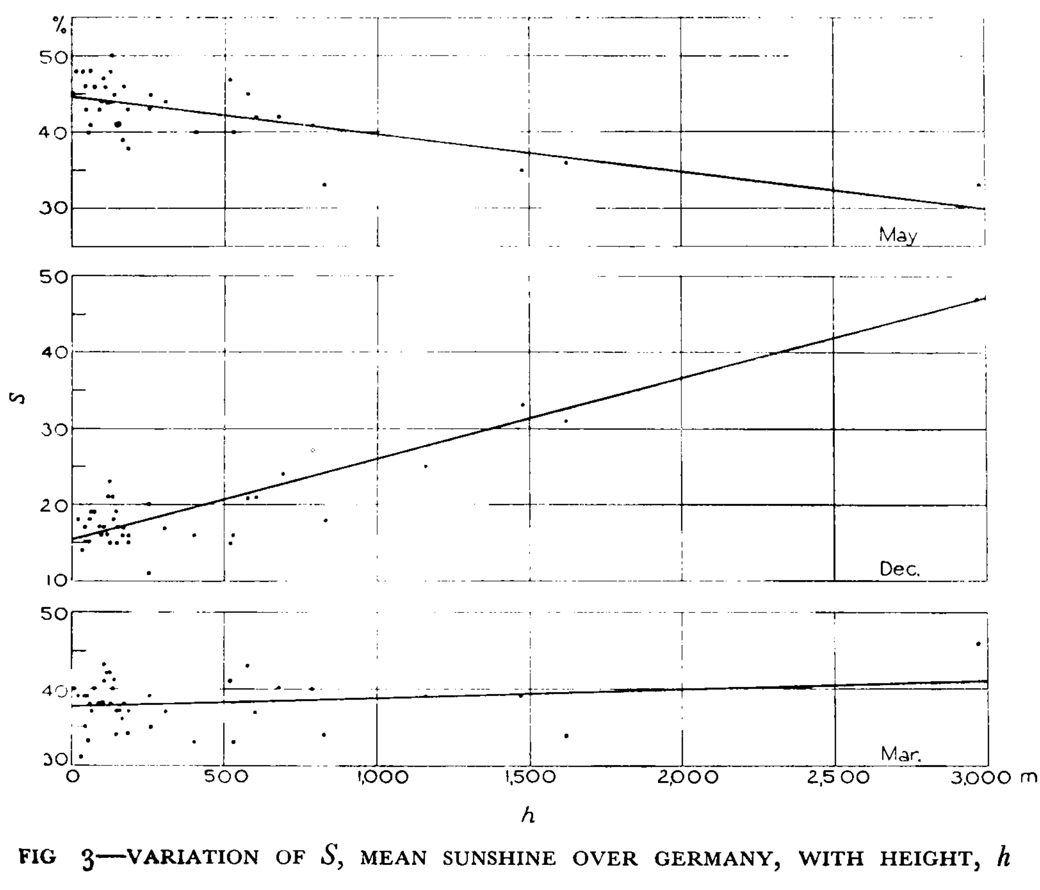


FIG 3—VARIATION OF S, MEAN SUNSHINE OVER GERMANY, WITH HEIGHT, h

and therefore the lower layers are on the average cooling along their trajectories[5,6]. The atmosphere during this time of the year is very stable up to 3,000 m. especially near the surface. Conditions are therefore favourable for the formation of layer cloud below 3,000 m. particularly near the surface. This cloud will vary with the local topography. In summer although Germany is affected by the fringe of the low-pressure region over north-west Europe and Asia, there is on the average a weak ridge with a light north-westerly surface air flow. Surface temperature increases from north to south and the lower layers are therefore warming along their trajectories. The atmosphere is drier but less stable in the lower layers than in winter. Conditions are therefore less favourable for the formation of cloud in these layers. These differences are confirmed by German cloud statistics[7] which show a general rise in cloud base and a decrease in low cloud from winter to summer.

There are two effects of cloud upon the vertical variation of sunshine. Firstly when cloud is above a station, the lower it is the greater the solid angle it subtends at the station. The higher the station above mean sea level the longer the time for which the sun's rays are cut off by cloud at any specific height above mean sea level. This is the cause of negative correlation between sunshine and height. Secondly, the duration of sunshine at a station cannot be influenced by cloud below it and therefore the higher the station the less cloud there is to cut off the sun's radiation. This effect causes positive correlation between sunshine and height. When these two effects cancel each other out there is little correlation and small variation of sunshine with height. This occurs in Germany in March and September. When one or other of these effects strongly predominates there is a large variation with height, a high correlation, and a good fit. In this example the first effect predominates in summer and the second effect in winter. However there is much low cloud in the lower layers in summer and the fit is less good and the variation with height smaller in magnitude than in winter. When there is a large amount of cloud in the lower layers, as in winter, there is associated with the positive partial correlation of sunshine with height a high positional variability, σ_s, because of the variability of topography. When higher cloud predominates there is negative correlation and low positional variability.

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WAVE CLOUDS OVER THE ISLE OF MAN

By W. H. KAVANAGH.

The Isle of Man is about 30 miles long and 10 miles wide at its widest point, tapering sharply at each end. In the southern half the hills form a long narrow

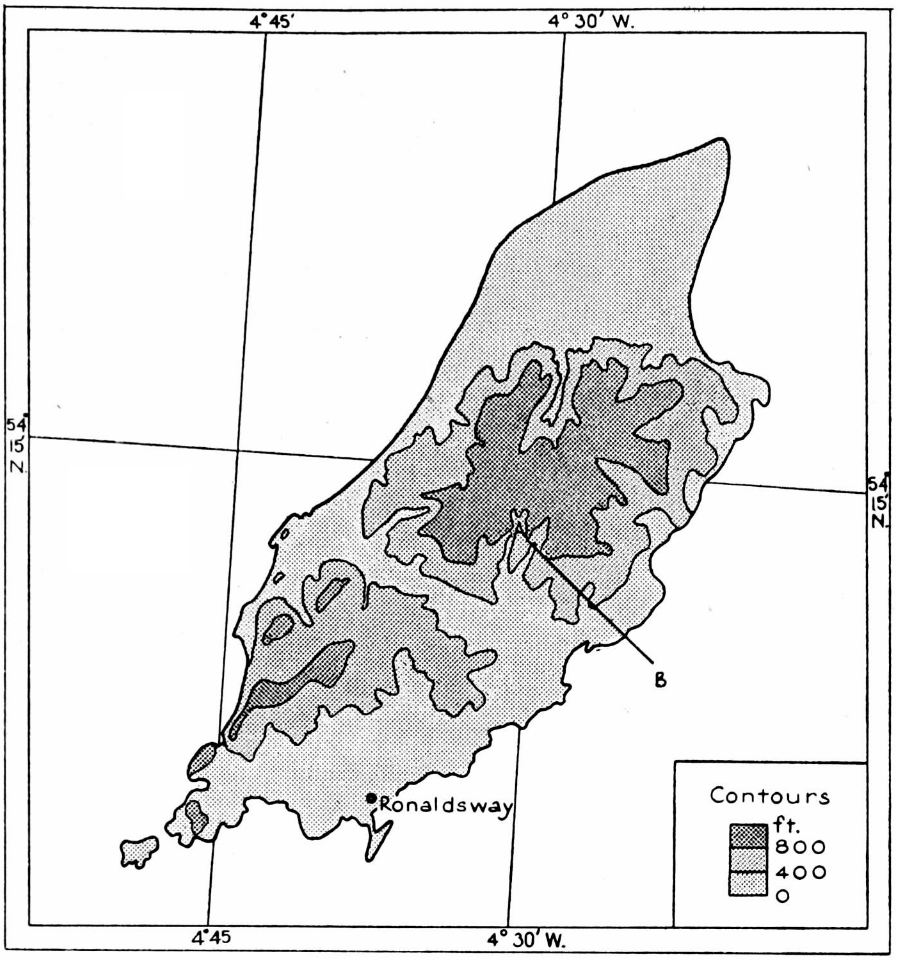


FIG. 1—ISLE OF MAN
A B is the line of cross-section shown in Fig. 4

ridge along the west coast, rising almost sheer from the sea to heights between 700 and 1,400 ft. In the northern part the hills form a rough square extending almost from coast to coast, rising generally to between 900 and 1,500 ft. and split into ridges by narrow steep-sided valleys running back into them. These features are illustrated in Fig. 1. Situated in the middle of the North Irish Sea the island is, in effect, an isolated hill ridge in an otherwise flat area. It is thus favourably placed for the formation and observation of orographic cloud.

During the past year observations have been made of clouds which remain stationary, or nearly so, in relation to the ground. They are believed to be due to the lifting effect over the hills or to orographic lee waves caused by the hills. They are usually lenticular and are often called wave clouds. No detailed analysis of the observations has yet been attempted but experience suggests that the most favourable conditions occur in a north-westerly air stream having a markedly stable layer or inversion in the first few thousand feet of the troposphere and a positive wind shear. Such a conclusion is consistent with the theory of mountain air flow put forward by Scorer[1] and discussed by Corby[2]. By way of example, two cases are briefly described below.

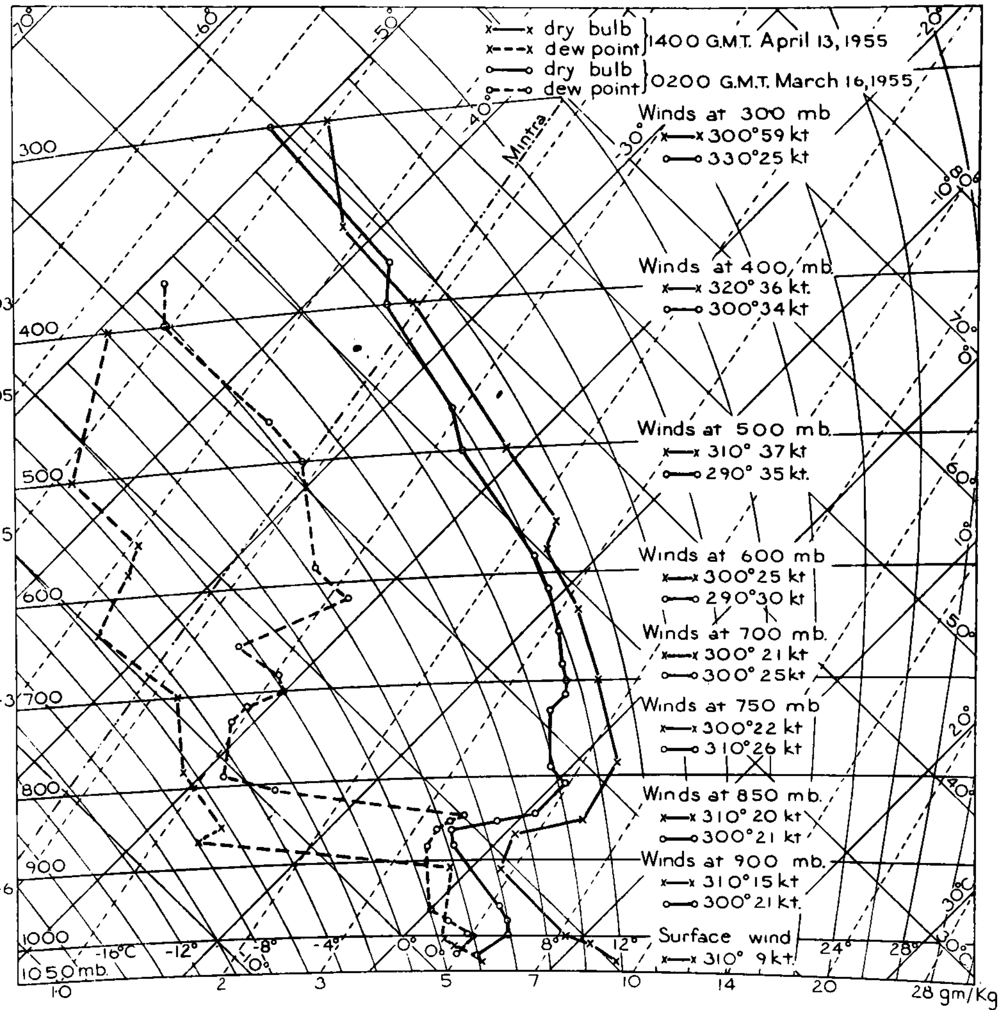
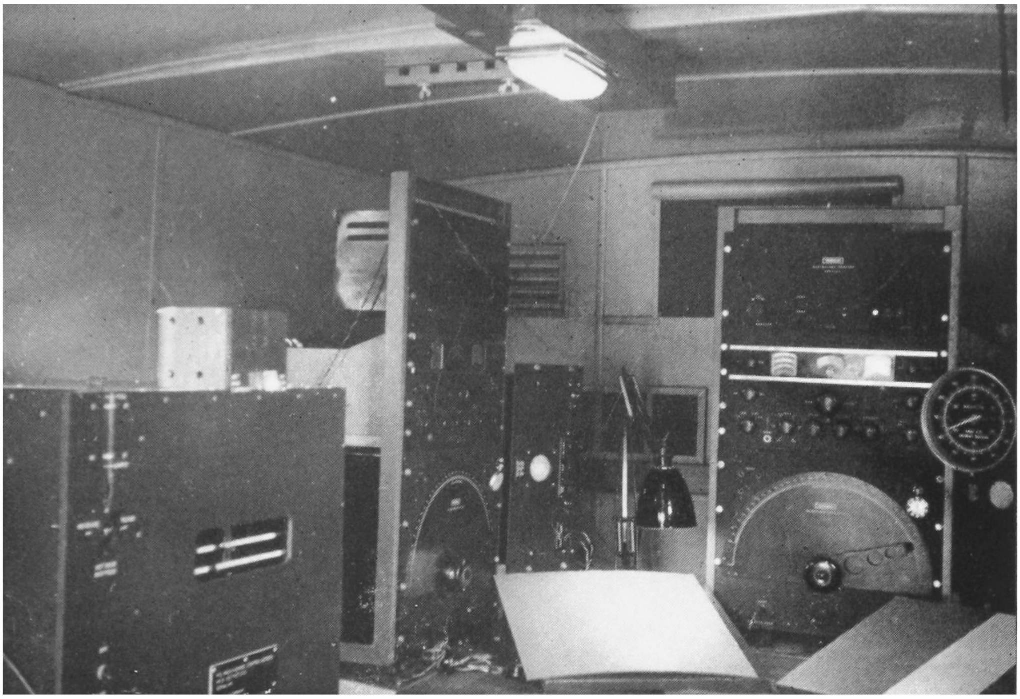


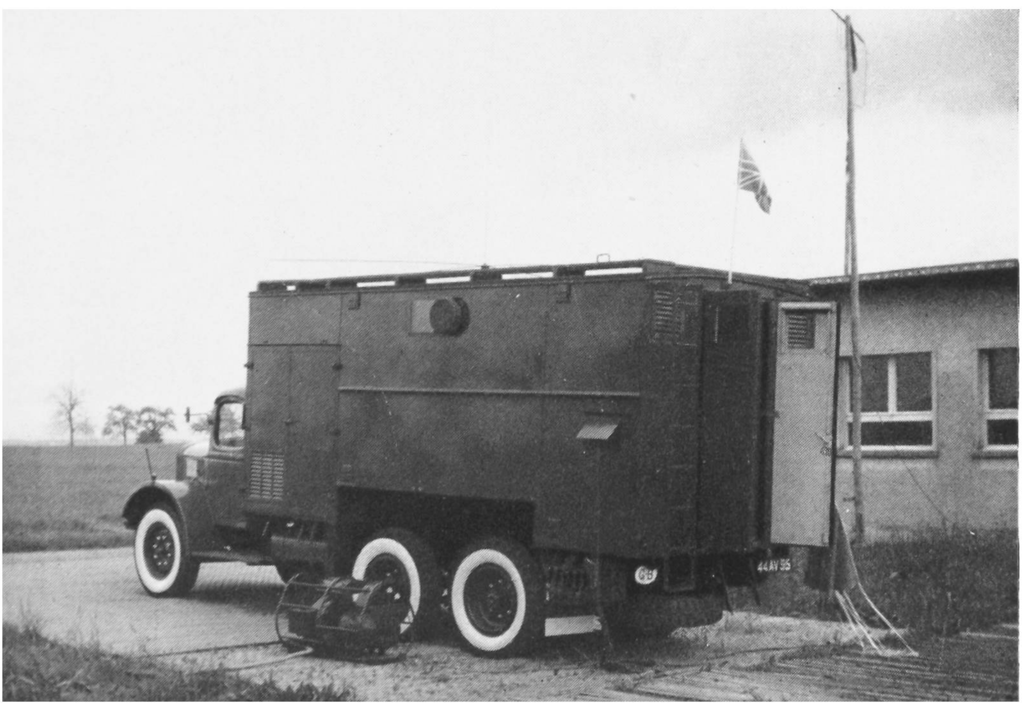
FIG. 2—TEPHIGRAM FOR ALDERGROVE ON MARCH 16 AND APRIL 13, 1955

On April 13, 1955 the air stream across the Isle of Man was north-westerly with little change in direction with height. The wind speed increased steadily from about 10 kt. at the surface to about 60 kt. at 30,000 ft. There was an unstable layer near the surface with marked stability between 900 and 800 mb. and an inversion about 850 mb. These characteristics can be seen in the 1400 G.M.T. Aldergrove sounding illustrated in Fig. 2 and we should expect them to favour the occurrence of lee waves. This is confirmed by the profile of the parameter l^2, which involves the stability and wind structure of the air stream, and has been shown by Scorer to be of fundamental importance in the problem of mountain air flow. The value of l^2 was calculated over 50-mb. layers, using the approximation $l^2 = g\beta/u^2$, and its variation with height is shown in Fig. 3. There is a pronounced maximum in the layer 900–850 mb. and a substantial decrease above that layer. The maximum is due mainly to the existence of the inversion. Scorer's theory thus leads us to expect lee waves.

At 1700 G.M.T. two stationary clouds were observed to the north-east of Ronaldsway Airport, obviously caused by the hills in the north of the island. An hour later there were five lenticular clouds and running through and connecting two of them in a wave pattern was a long grey trail. At 1820 G.M.T.



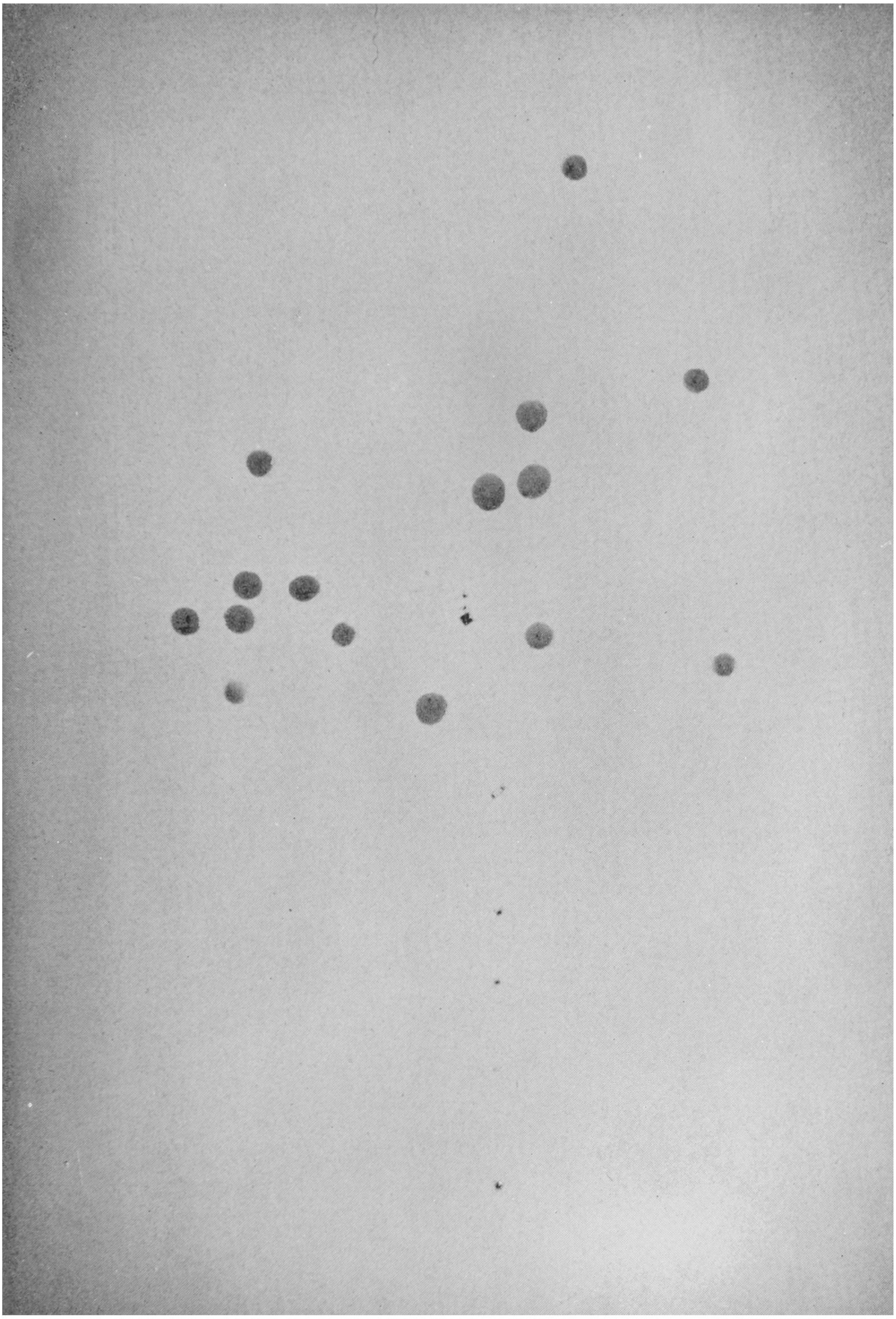
INTERIOR OF BRITISH MOBILE RADIO-SONDE UNIT USED AT PAYERNE



BRITISH MOBILE RADIO-SONDE UNIT USED AT PAYERNE
The generator alongside provides a safeguard against failure of the mains supply
(see p. 34)

PREPARATION FOR LAUNCHING A TRAIN OF EIGHT RADIO-SONDES

(see p. 34)



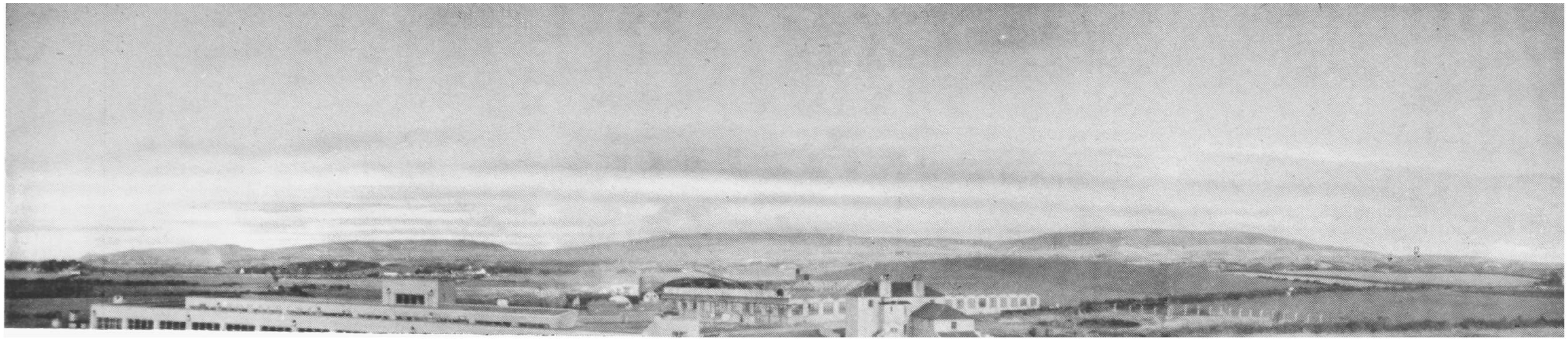
Reproduced by courtesy of W. Preston

GROUP OF FIFTEEN BALLOONS BEARING ALOFT THE FIRST TRAIN OF FOURTEEN RADIO-SONDES

The two parachutes and the target provided for location by Decca radar can be seen, together with the upper five radio-sondes.

(see p. 35)

[To face p. 49



Reproduced by courtesy of J. Connolly

View to the north-west

Reproduced by courtesy of J. Connolly

View to the south-east

WAVE CLOUD SEEN FROM RONALDSWAY MARCH 16, 1955

(see p. 50)

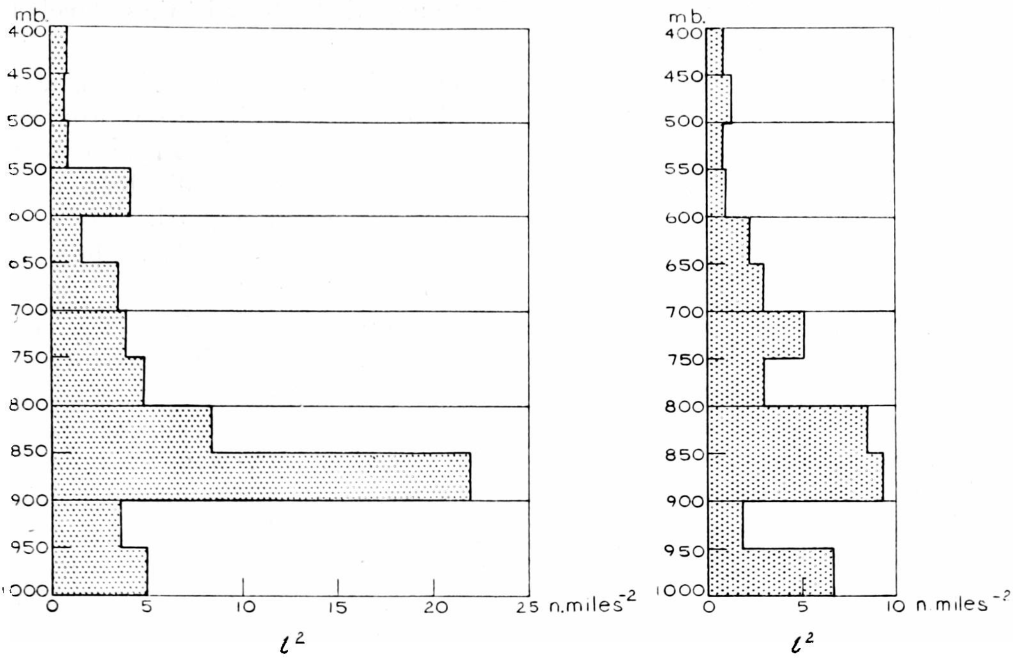


FIG. 3—PROFILE OF SCORER'S PARAMETER, l^2, AT ALDERGROVE

the azimuth and elevation of the crests and troughs of the waves were observed by theodolite. Two members of the meteorological staff, near Douglas at the time, also saw the wave. They took rough bearings and noted which ridge was causing this particular wave. This they were able to do because they could see that the trail joining the clouds was composed of smoke from burning heather on the hills to the north-west of the ridge. From the data thus assembled the positions of the troughs and crests were worked out and the heights calculated. The results are shown in Fig. 4. The cross-section is along the line AB in Fig. 1.

The appearance of the wave clouds during the evening, when they had not been observed earlier in the day, may well be an example of the diurnal variation referred to by Corby. The creation of low-level stability would have

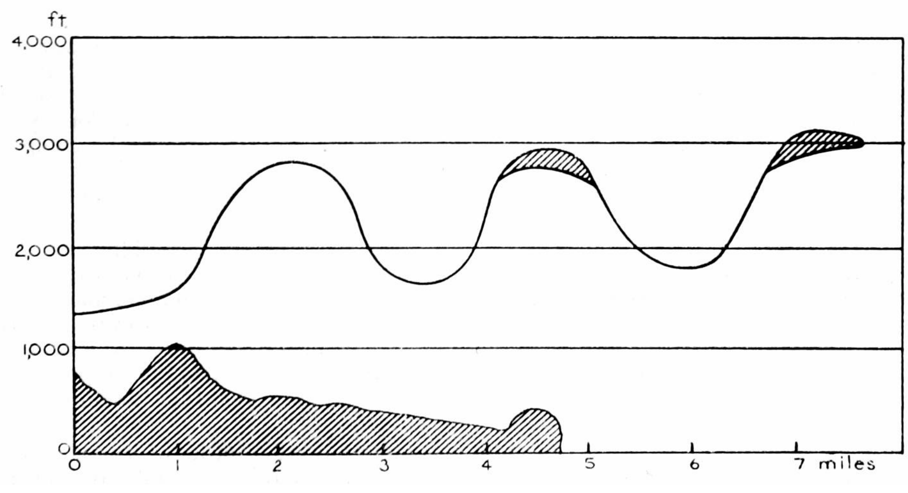


FIG. 4—LEE WAVES OVER THE ISLE OF MAN, APRIL 13, 1955

discouraged separation of the flow and encouraged the flow in these levels to hug the topography.

On the morning of March 16, 1955 an exceptionally good display of wave cloud was observed and photographed. The photographs are reproduced facing p. 49. The cloud was in two main groups which persisted from 0700 to 0930 G.M.T. The first consisted of a line of stratus along the hills, base about 1,200 ft., with a long bar of stratocumulus, base about 2,500 ft., above it. The second group was composed of three lenticular clouds one above the other just off the coast south-east of the airfield, with other lenticular cloud beyond.

The 0200 G.M.T. Aldergrove sounding and winds are shown in Fig. 2. The sounding closely resembles the shape of the 1400 G.M.T. sounding for April 13, 1955, with an inversion at 850 mb., and a stable layer between 860 and 810 mb. The wind was north-westerly increasing with height, though not to such a marked extent as in the previous case. The variation of l^2, using the approximation $l^2 = g\beta/u^2$, shown in Fig. 3, exhibits the same characteristics as that for Aldergrove at 1400 G.M.T., April 13, 1955.

Since the wave motion caused in the air stream in these conditions has at times a turbulent flow in the troughs and crests of the waves, in addition to the vertical currents, pilots often report moderate turbulence on the approaches to the airfield on these occasions. A reversal of surface wind at the airport control tower has also occurred at times, a previous north-westerly wind becoming easterly or varying rapidly. One instance of this has been described by Ward[3].

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METEOROLOGICAL OFFICE DISCUSSION

Some aspects of the microphysics of cloud

The Meteorological Office Discussion held at the Royal Society of Arts on Monday, October 22, 1956, on the physical processes occurring in natural clouds and the methods used by the Meteorological Research Flight to sample atmospheric aerosols was opened by Mr. W. G. Durbin. His statement covered a wide field ranging from an outline of the basic theory of the growth of cloud droplets to the results of recent investigations.

He began by remarking that although for most meteorological purposes the atmosphere was assumed to consist of water (in the vapour, liquid and solid phases) and air only, the cloud physicist had to take account of the nuclei in the atmosphere since without these nuclei clouds would not form at all. Those nuclei which are important in the formation of cloud particles have diameters which are usually between about 1/10 micron and 1 micron. By comparison, the diameters of cloud particles lie between about 1 micron and 100–150 microns. A small drizzle drop, a typical raindrop and a typical hailstone have diameters of about 100 microns, 1mm. and 1 cm. respectively.

Supersaturation leading to condensation occurs when saturated air is rapidly cooled as for example when it is moved rapidly upwards. A typical up-draught in a layered cloud and a strong up-draught in a cumulonimbus cloud have values of about 0·5 m./sec. and 10 m./sec. respectively. Even the latter value would be unlikely to give rise to a supersaturation of greater than 1 per cent. It has been shown theoretically and verified experimentally that a supersaturation of about 400 per cent. is necessary before drops of pure water will form spontaneously from the vapour and it is concluded that in the initial stages of cloud formation direct condensation from the vapour plays little or no part at all.

There must therefore be some agent in the atmosphere capable of allowing the growth of cloud droplets at supersaturations of 1 per cent. or less and this must take the form of a condensation nucleus around which the drop grows. During its growth molecules of water must move from the environment to the drop and for this to happen the vapour pressure at the surface of the drop must be less than that in the environment. Owing to curvature, however, the vapour pressure at the surface of a drop of pure water is higher than that in a saturated atmosphere at the same temperature and can be lower only if the environment is supersaturated. On the other hand the vapour pressure around a drop of solution is less than that around a drop of pure water of equal size and at the same temperature by an amount that depends on the nature and concentration of the dissolved substance. If the vapour pressure resulting from these two effects be less than or greater than that in the environment the drop will tend to grow or evaporate respectively. Moreover, before a droplet can grow to cloud-droplet size it will have to attain a certain critical size which in itself necessitates the existence of a minimum value of the supersaturation in the environment. For sizes of the droplet larger than this critical size the equilibrium value of the supersaturation diminishes so that the droplet can grow more easily the larger it becomes provided the ambient supersaturation is maintained. Theoretically it will continue to grow until it reaches a size which is in equilibrium with a relative humidity of 100 per cent. over a flat surface. In practice, as the drop grows, water vapour is extracted from the ambient air, the degree of supersaturation falls and the growth rate is slowed up.

Since a drop of solution will allow condensation to take place on it more readily than on a drop of pure water of equal size and, since the latter effect will not occur at all without the existence of a much higher degree of supersaturation than occurs naturally in the atmosphere, it appears likely that most cloud droplets originate as drops of solution. There is also the possibility that the nuclei of condensation which promote the formation of cloud droplets may be particles which are either insoluble and unwettable (non-hygroscopic) or insoluble and wettable. Since, however, even the latter type of particle, while being more favourable to condensation than the former, can at best behave only as a drop of pure water of equal size,this is unlikely. It would be possible only if the non-hygroscopic nuclei were appreciably larger than other atmospheric nuclei and there is no reason to believe that this might be so. Drops of solution can arise from particles which at low relative humidities, say less than 50 per cent., are surrounded by a thin film of adsorbed water but which dissolve in this water at higher humidities. Due to their high affinity for water they are said to be hygroscopic. When cloud droplets first form the nuclei activiated, i.e. able to grow larger than the critical size, will be the largest of those which, at the supersaturation available, can allow condensation to occur on them. In growing to cloud-droplet size these largest nuclei will remove water vapour, causing the supersaturation to fall and the smaller or less efficient nuclei will be prevented from becoming activated. This explains why the concentration of cloud droplets may be, and usually is, very much less than the total concentration of condensation nuclei.

The two most popular opinions regarding the nature of those hygroscopic nuclei which are believed to promote the growth of cloud droplets are that they are either salt particles or drops of acid. Salt particles float freely in the atmosphere[1] according to several reports. Their source is probably sea spray and they are carried upwards into the atmosphere by turbulence and convection.

Acids that have been identified in the atmosphere are sulphuric and nitrous acid. The former is a combustion nucleus formed from the combination of sulphur trioxide and water, the sulphur trioxide being formed as a result of the oxidation of sulphur dioxide which itself forms when substances containing sulphur, e.g. coal, are burned. Nitrous acid, on the other hand, forms from the combination of nitrogen, oxygen and water provided sufficient heat is supplied. Nitrogen and oxygen will combine at temperatures greater than 620°C. and it is thought that forest fires and lightning might provide the necessary heat. Nitrous oxide is believed to be a universal constituent of the atmosphere though not enough is known concerning its vertical distribution.

Instruments used to obtain counts of the numbers of nuclei in the atmosphere usually contain a chamber in which the air under test is subjected to sudden expansion. Condensation occurs on the nuclei present and an estimate is made of the concentration of droplets formed. This can be done by allowing the droplets to fall on to a plate and then counting them as in the Aitken instrument, attempting to count them in suspension as was done by Junge[2] or obtaining an estimate of their numbers by a photo-electric device as in the Pollak counter. Mr. Durbin then showed a slide on which was a photograph of the Pollak counter used in the Hastings aircraft of the Meteorological Research Flight. Results of this work are described by Day[3]. After describing the instrument he added that all instruments of this type produced supersaturations so large, from 200 to 300 per cent., that all nuclei down to ionic size acted as centres of condensation. It is not possible with these types of instrument to distinguish between those nuclei which promote the growth of cloud droplets and those which do not. The important nuclei may be salt particles, small drops of acid or it may even be that by far the largest atmospheric nuclei are non-hygroscopic. The real answer is not known.

The growth rate of a cloud droplet depends not only on hygroscopic and surface-tension forces but also on the processes of diffusion and thermal conduction which determine the rate of transfer of water vapour to and from the drop. Other important factors are the concentration and size distribution of the nuclei, the rate of ascent of the air and small-scale turbulence in the cloud.

The relative importance of these physical processes can be estimated theoretically but the crucial test of any theory is the accurate prediction of the drop-size spectrum[4]. Mr. Durbin then said that the most practical method to date of obtaining a cloud-droplet spectrum is the "impaction" method. In this the droplets are captured from an aeroplane on small slides coated with either an oil or a layer of magnesium oxide, photographed and counts made of the numbers of droplets having diameters lying between certain specified limits. Two slides were then shown on the first of which were two photographs giving examples of cloud-droplet samples obtained by both methods. The second slide showed graphically results obtained using the magnesium-oxide technique from the Hastings aircraft of the Meteorological Research Flight on ten flights through cumulus clouds in 1951[5]. The clouds varied in vertical depth from 750 ft. to about 7,000 ft. and each curve represented the mean for the samples taken on any particular flight. Common to all curves was a maximum concentration of droplets at about 8 microns diameter which suggests that having grown beyond the critical size most cloud droplets continue growing until they acquire a diameter of about 8 microns.

Average values of the water content in these clouds were between 0·5 and 1·0 gm./m.^{3} although a value of about 5·0 gm./m.^{3} occurred in one part of a cumulus cloud, 7,000 ft. thick, which was precipitating. Values as high as 10 gm./m.^{3} may occur locally in cumulonimbus clouds but such values have not yet been measured.

Mr. Durbin then discussed the ice phase in the atmosphere. Since snow-flakes and hailstones may originate from ice crystals it is important to consider how ice crystals arise in the atmosphere and to obtain information on their numbers, sizes and crystal habit.

There are two possible ways in which an ice crystal may form from the vapour. Either the water vapour molecules may unite directly to give ice or they may first of all form a drop of water which subsequently freezes. Researches into this problem have been carried out using cloud chambers and it has been found, using purified air in a cloud chamber in which the relative humidity was measured, that ice crystals first formed at relative humidities near to 100 per cent. with respect to water. This represents a considerable supersaturation with respect to ice and the implication is that ice crystals form from the freezing of water droplets rather than directly from the vapour. It has further been shown in these experiments that small water droplets usually change to ice crystals at temperatures between $-32°$ and $-41°$C. Researches into the problem of how far a drop of water can be supercooled before freezing have shown firstly that impure water will freeze at higher temperatures than pure water and secondly that the smaller the drop, the lower the temperature at which it freezes. Data on the results of these various researches have been discussed by Mason[6].

Using unpurified air in cloud chambers the temperatures at which ice crystals appear are appreciably higher than if purified air is used. This, and the fact that ice crystals occur naturally at temperatures appreciably higher than $-32°$C. suggest that in natural or impure air there are particles which promote the freezing of droplets at these higher temperatures. These particles are called "freezing nuclei". It has been suggested that these nuclei may be particles of salt or silicates but their real identity is unknown. From the numbers of crystals appearing at different temperatures in cloud chamber experiments, it appears that these nuclei are activated in minimum concentrations varying from about 1/m.^{3} at $-10°$C. to about 1/cm.^{3} at $-35°$C. but concentrations 100 times as great are sometimes observed.

An interesting hypothesis put forward by Bowen[7] regarding the origin of freezing nuclei is that one important source may be the debris of meteoric showers. An analysis of the rainfall intensity for the months of January and February for the years 1902–1944 revealed peaks of about twice the average value on January 13, 22, and 31. Bowen associated these peaks with meteoric showers which occur annually on December 13–14, 22, and January 3, the lag of 30 days being the time required for the particles to fall from about 100 Km. into the troposphere. Checks on Bowen's hypothesis have been made by flying an aircraft equipped with a cloud chamber throughout the month of January and finding out whether or not significant increases in the numbers of ice crystals appearing at different temperatures occurred on these dates. The evidence obtained does not support Bowen's hypothesis.

Mr. Durbin then briefly reviewed precipitation mechanisms. It is clear that a cloud droplet must grow considerably before it can gain a falling speed which enables it to fall out of the cloud, survive evaporation in the unsaturated air beneath and reach the ground as precipitation. From considerations of the amount of water available and the concentrations of cloud droplets found in natural clouds, of the order of a few hundred per cubic centimetre, it can be shown to be impossible to produce precipitation in the form of water drops, by continued condensation from the vapour, in a reasonable time. Ice crystals, on the other hand, are present in much smaller concentrations than cloud droplets, of the order of 10/cm.^{3}, and in the development of precipitation from ice crystals, continued condensation from the vapour is of great importance, particularly if the water content of the cloud is low.

Bergeron maintained that since within a cloud containing both ice crystals and water droplets the ice crystals are in an ice-supersaturated atmosphere they will grow by diffusion of vapour to their surfaces. The replacement of this vapour, which is necessary to maintain water saturation is effected by evaporation of the droplets so that this process effectively means growth of the ice crystals at the expense of the water drops. Bergeron thought that almost every raindrop originated as a snow-flake but this cannot always be true since a large proportion of the warm-sector rain in this country falls from clouds which contain no ice crystals and in many cases do not reach the freezing level. This type of rain is usually slight and is believed to occur as a result of coalescence between drops of different sizes due to their moving relative to each other with different vertical velocities. In tropical countries heavy rain has been observed to fall from vigorous convective clouds which do not reach the freezing level and a possible mechanism by which this rain can occur has been called by Langmuir[8] a "chain reaction of raindrop multiplication". When a drop grows by coalescence to a diameter of a few millimetres or so it becomes unstable and breaks up. If the up-draught in the cloud is strong enough to support the drop before it breaks up, then, when it does break up, all the drops it breaks into will be carried by the up-draught back into the body of the cloud and the process can repeat itself on each drop. All that is necessary for both this and the simpler coalescence process to occur is that initially there must be drops of different sizes in the cloud so that the process can start. It is worth noting that the possibility exists of the coalescence mechanism forestalling the Bergeron mechanism in clouds where both mechanisms are possible.

Mr. Durbin then described an instrument used at the Meteorological Research Flight for obtaining raindrop spectra in flight. The instrument contains a strip of aluminium foil which, when struck by a moving drop, receives a dent related to the size of the drop and the speed of impact. A typical vertical distribution of raindrop size obtained by this method was then illustrated.

Lastly Mr. Durbin referred to the artificial stimulation of precipitation. Clouds, part or all of which are supercooled yet do not precipitate, can contain very few ice crystals and this is possibly due to a deficit of efficient freezing nuclei. These clouds might be expected to precipitate if this deficiency can be remedied.

Two main methods of increasing the ice crystal content of a supercooled cloud have been tried. The first, which involves seeding a supercooled cloud with pellets of solid carbon dioxide from an aircraft, usually results in dissipation of the cloud. Mr. Durbin then illustrated with slides a seeding experiment of this type in which a large hole was made in a supercooled layer cloud.

The second method involves the generating of silver-iodide smoke on the ground and allowing the smoke to diffuse upwards into the cloud. Silver-iodide particles were found to behave as efficient freezing nuclei in cloud-chamber work. It is difficult to assess the success or failure of this type of experiment because it is not possible to distinguish between the rain which fell subsequent to the release of these particles and the rain that would have fallen if no particles had been released.

Mr. Durbin concluded by saying that evidence existed that the silver-iodide particles produced by ground generators possessed a different crystal structure from those found to act as efficient nuclei. Silver-iodide particles lose their nucleating ability when exposed to ultra-violet light. There is evidence also that these particles are unable to penetrate inversions and so may not be able always to reach those parts of a cloud where they may initiate freezing. Considered together these facts suggest that this method of inducing artificial precipitation is not likely to be very effective.

Dr. Stagg opened the subsequent discussion by remarking that although many problems associated with cloud physics had been solved there was still much to be learned. He wondered why there should be greater numbers of comparatively large cloud droplets near the tops in preference to other regions of the clouds. In reply, Mr. Durbin said that the aluminium foil instrument always showed this to be so and that it was noticeable how wet the wind-shield of an aircraft became on entering the tops of clouds. The droplets at the tops of clouds originate near the bases and probably grow by coalescence with other droplets while being transported vertically through the cloud. On the assumption that this process can happen, Ludlam computed that a 30-micron-radius droplet introduced into the base of a vigorous convective cloud could grow by coalescence to break-up size, a few millimetres diameter, before reaching the freezing level and although this represented an extreme case it illustrated the principle.

Mr. Bushby queried the accuracy of reports of tropical precipitation from cumulus clouds which did not reach the freezing level, pointing out that in his experience the heights of cloud tops in tropical countries were generally underestimated. Mr. Durbin replied that he could not vouch for the accuracy of such reports but that there were many from different sources in the literature. Mr. Bushby then asked for more detail of Bowen's hypothesis on the source of freezing nuclei and this was given.

Dr. Scorer said there was no evidence to suggest that meteoric showers could provide any excess numbers of particles of the right size over the general background of meteoric particles which are always entering the atmosphere. Referring to the peaks in rainfall intensity, found by Bowen, he said rainfall statistics were unreliable. He suggested that by selecting different places for which to analyse the rainfall, peaks would have been obtained on different dates.

Mr. Oddie, after discussing the relevance of the work on nuclei to forecasting, said that no agreement had been reached regarding the parameters that should be measured in the field of nuclei. It was useless to refer to numbers of freezing nuclei without also referring to the temperature at which they acted as freezing nuclei. He doubted the reality of observations that freezing nuclei increase upwards and attributed differences in the numbers found below and above inversions to corresponding differences in water-vapour content. Finally he referred to the seeding of clouds and suggested that a more scientific approach to the problem was needed.

Mr. McNaughton asked if it was possible to carry out cloud-chamber work using supersaturations of the order found in clouds. Mr. Durbin replied that to maintain a given degree of supersaturation was extremely difficult.

Mr. Robins asked what the Pollak counter really measured. Mr. Durbin said that it gave a joint indication of the numbers and sizes of the droplets formed but did not distinguish between them.

Dr. Sutcliffe agreed that the Pollak counter gave only a rough and ready indication of the nuclei content and after enquiring if the instrument had been calibrated against the Aitken counter was told that this had been done.

Mr. Robins asked if the existence of large droplets near the tops of clouds implied heavier icing. Mr. Durbin replied that this was so but added that icing severity depended on the temperature and water content of a cloud as well as the numbers and sizes of droplets.

Dr. Sutcliffe said that prior to the release of precipitation, which would redistribute the water within a cloud, the ordinary theory of convection predicted that the greatest concentration of free water would be found near the top of a cloud.

Mr. Wallington remarked that light icing was often encountered on ascent near the top of supercooled stratocumulus cloud while none occurred below. He wondered if the temperature was higher at the top of a cloud than lower down.

Dr. Robinson said that radiation from the top of a cloud would result in a reduction of temperature at the top.

Dr. Frith asked if this would be true even if the top of the cloud were exposed to direct sunshine. Dr. Robinson replied that it would, explaining that the outgoing radiation is emitted from a shallow cloud layer whereas the incoming radiation is absorbed through a much larger depth of cloud.

Mr. Durbin said that it was not possible to make accurate measurements of temperature in cloud.

Mr. Harper remarked on the effects of ascent and descent of air within a cloud and stressed the necessity of having many observations of large drops at the tops of clouds before making any definite statement about them. Mr. Durbin replied that the slide shown was merely one example of this but other records had been obtained by the Meteorological Research Flight.

Mr. Jones said that the aluminium-foil instrument gave records of only the largest cloud droplets which might be present in only small concentrations. The instrument did not measure the amount of water contained in the cloud in the form of small droplets.

Mr. Rider wondered how the dents made in the aluminium foil had been calibrated against drop size and asked if it was possible to distinguish between dents made by droplets and ice crystals.

Mr. Murgatroyd said that the basic development of this instrument had been carried out by the Mechanical Engineering Department at the Royal Aircraft Establishment, Farnborough. They had mounted it on a whirling arm mechanism passing through a spray of drops and had, at the same time, measured the drop-size spectrum of this spray by means of the Rhodamine-dye method. Thus they obtained a calibration from a comparison of the indentations on the foil and the sizes of the drops on the dyed filter paper. The present Meteorological-Research-Flight instrument has been found to show indentations for droplets having diameters down to 100 microns and rain and snow can readily be identified. Very small crystals and the smallest droplets give rather similar indentations and the interpretation in this case is still being studied.

On the question of drop-size distribution with height it seems that a few hundred droplets form in every cubic centimetre during the initial condensation. Continued condensation then occurs on these droplets and few new droplets form in the up-draught. Since the water content increases with height the sizes of the droplets would be expected to increase with height. Moreover due to coalescence their number will decrease with height. The number of large raindrops however, is likely to be greatest near the base of the cloud because, when the droplets become big enough to be precipitation elements and fall down through the cloud, they grow by coalescence.

Another questioner asked if the answer to measuring small concentrations of nuclei did not lie in simply using a larger chamber. Mr. Durbin replied that chambers as large as a room had been used on the ground but there were serious difficulties in installing a large chamber inside an aircraft.

Asked further if some nuclei were not lost on the walls of a chamber, Mr. Durbin said that they were but in any form of cloud chamber work it was impossible to get away from boundary conditions.

Dr. Scorer remarked that experience with Coastal Command overseas showed that the Bergeron process was not always necessary for producing precipitation. Ice crystals could be produced from the freezing of drops formed by the coalescing of other drops.

Mr. Aanensen asked what laboratory evidence existed to substantiate the coalescence process and over what range of diameters would a drop coalesce with another drop of given size. Mr. Durbin replied that he was not aware of any direct experimental evidence for coalescence of very small droplets but experiments using larger droplets had been made. It had, however, been shown theoretically that for a drop of a given size there was a minimum value of the size of drop with which it would coalesce.

Mr. Sawyer, referring to the cloud-seeding experiments, wondered why, in view of the latent heat of fusion released when droplets change into ice crystals, a supercooled cloud should dissipate rather than reform. He also wondered to what extent the microphysical processes affected rainfall.

Mr. Bushby asked if rain could be stopped or even prevented.

Mr. Oddie replied that very great overseeding was necessary for this.

In reply to another questioner, Mr. Durbin said he thought that a cloud depth of about 6,000 ft. was the minimum necessary to produce rain at the ground. Mr. Bradbury doubted this, saying that in his experience continuous light rain had fallen for hours in East Anglia from stratus cloud only 3,000 ft. thick. Mr. Murgatroyd was inclined to think that only drizzle would fall from clouds 3,000 ft. thick.

Mr. Bannon wondered if he was right in thinking that the forecaster had little to gain from the field of cloud physics and Mr. Durbin replied that this was largely true. Dr. Sutcliffe commented that microphysical studies were more than simply interesting and had application to a number of fields. The extent to which these studies benefit the forecaster is not to be interpreted as a measure of their usefulness.

Dr. Stagg then summed up and thanked the opener for an interesting lecture.

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OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

Five-year summaries of upper air data.

The Meteorological Office publish five-year summaries of radio-sonde observations of temperature and humidity and of radar-wind measurements made at some of its upper air observing stations. These are in the series M.O.555, Upper air data, and so far Parts 1 to 9 have been published for the period 1946–50, Parts 1, 2 and 9 being for Larkhill, Lerwick and Downham Market respectively, other parts being for stations in the Mediterranean and Middle East areas. Recently Part 1, Larkhill, has had to be reprinted as stocks of the original 1952 printing were exhausted. The reprint includes wind roses for each month for the standard levels which were not in the original and some minor errors in the 1952 printing have been corrected.

With the exception of Part 9, Downham Market, the upper air statistics in the M.O.555 series have not been corrected for the effects of lag and radiation on the temperature-element of the radio-sonde[1]. Accordingly a series of Addenda is being prepared giving corrections to be applied to the average temperatures and heights of standard pressure surfaces in each of M.O.555 Parts 1 to 8. The Addendum to Part 1, Larkhill, has already been printed and the Addenda to other Parts will soon follow.

These publications can be obtained from the Meteorological Office, M.O.10, Air Ministry, Kingsway, London, W.C.2. The price per Part of M.O.555 is 4*s*. to 5*s*. depending on the Part, postage 5*d*. extra in the British Isles; each Addendum costs 1*s*., postage 2*d*.

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LETTERS TO THE EDITOR

Record rainfall at Cherrapunji, June 14, 1876

Mr. L. S. Clarkson, Chief Meteorological Officer, Singapore has pointed out that the sentence used in the *Meteorological Magazine* for August 1956, on p. 255 describing the fall of 37·5 in. of rain at Cherrapunji, Assam on June 4, 1956 as a record 24-hr. fall for that place is open to correction. It has been reliably reported that 40·80 in. of rain fell in 24 hr. at Cherrapunji* on June 14, 1876. Our records for this place are incomplete before 1902, when the present station opened. Correspondence with the India Meteorological Department has recently elucidated some changes of site at Cherrapunji in the nineteenth century when measurements were made on the whole nearer the centre of the plateau: the falls obtained at those sites were slightly greater even than the remarkable totals obtained from the present site near the northern edge of the plateau. The early readings are accepted as authentic.

H. H. LAMB.

Tunbridge Wells hailstorm

For the benefit of readers who do not know Tunbridge Wells, the illustration facing p. 304 of the *Meteorological Magazine* for October 1956, shows the opening of the Pantiles looking towards King Charles church. The roadway is A267 carrying traffic for Eastbourne and to some extent for Hastings so the blocking on a Bank Holiday, was, to say the least of it, awkward!

St. James's church, near the top of the ridge carrying the Pembury Road, has a lofty spire which may have been struck. A 50-ft. pollard elm near the summit of the common had a 2-ft. strip of bark near the base removed by lightning and there was slight damage to the roof of the house near-by.

The hailstones froze together and next morning I saw them being removed in chunks quite 6-in. thick from the pavement outside King Charles church. In a shady drive in this road small heaps remained at 9 o'clock on the Wednesday morning.

CICELY M. BOTLEY

2, *Park Road, Tunbridge Wells, November* 2, 1956.

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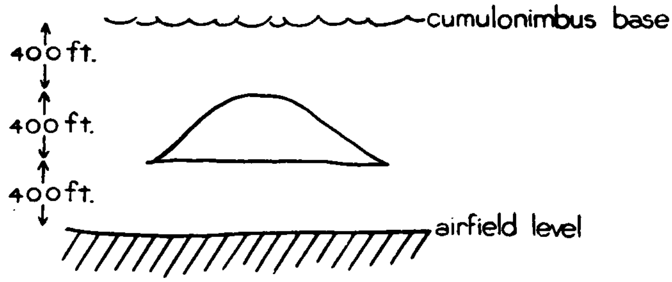
*Jennings, A. H.; World's greatest observed point rainfalls. *Mon. Weath. Rev., Washington*, **78**, 1950, p. 4.

Heavy rainfall and interesting cloud forms at Wunstorf on July 2, 1956

Early on the afternoon of July 2, 1956, thunderstorm and shower activity in warm unstable air over north-west Germany was being intensified by the eastward movement of a cold front[1]. An outbreak of rain started at Wunstorf at 1430 G.M.T., when the front was immediately west of the station. The rain soon increased in intensity, and between 1430 and 1540 G.M.T. 58·2 mm. of rain were recorded: no less than 40 mm. of this total fell during the period 1450–1510 G.M.T., an intensity of 120 mm./hr. This caused a great deal of flooding on the usually well drained tarmac and in the fields and villages round about, but the most interesting phenomenon was the cloud formation.

At 1430 G.M.T. slight rain was reported, with lightning visible to the south of the aerodrome. Visibility was 15 miles and the cloud was 6 oktas cumulonimbus, base 2,500 ft. with 7 oktas altocumulus, base 10,000 ft. Pilots reported the tops of the cumulonimbus at 15,000–16,000 ft. with no higher tops in the immediate vicinity. By 1441 G.M.T. the storm had increased in intensity, and heavy rain had reduced the visibility to 1,200 yd. and brought the cloud base down to 7 oktas cumulonimbus at 1,200 ft. Shortly after this a peculiar cloud formation was observed over the airfield below the main cumulonimbus base.



The cloud, as illustrated, had a well defined base, which was estimated to be 400 ft. above ground level with the top of the dome, when first observed, about 800 ft. above ground level, i.e. 400 ft. below the main cloud base. The top of this dome began to lift visibly until at 1453 G.M.T. it had merged with the main cumulonimbus base. As this happened all cloud was obscured by the onset of rain of tropical intensity, mixed with soft hail. Similar cloud phenomena have been observed and photographed by Coulomb and Sourdillon[2].

It is well known that in the mature stage of development of a thunderstorm, i.e. when precipitation is falling, a dome of cold air is present underneath the thundercloud[1–4]. According to Coulomb and Sourdillon, two possible mechanisms may contribute to the formation of the cloud under the cumulonimbus. First, warm air drawn into the cumulonimbus slides up the slope of the "mountain of cold air" and produces a cloud at the top, similar to the plume which forms regularly over Teneriffe and other peaks. Second, there may be mechanical up-drafts within the cold air itself. There is insufficient evidence to be sure whether both factors were operative in the present case.

R. KING

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Meteorological Magazine: increase in price

It is regretted that because of increases in the cost of printing and publication it has become necessary to raise the price of the *Meteorological Magazine* to 2*s*. 3*d*. an issue with effect from the January 1957 number.

The net annual subscription will become 29*s*. including postage. The increase is due to the necessity to cover a recent increase in postage. Present subscribers will remain on the existing rate until renewal of their subscriptions is due.

REVIEWS

Regional variations in the trend of annual rainfall over the British Isles. By S. Gregory. *Geogr. J., London*, **122**, 1956, p. 346. Royal Geographical Society, London.

The September 1956 number of the *Geographical Journal* contains an article by S. Gregory on Regional variations in the trend of annual rainfall over the British Isles. In this article, using curves of ten-year running means of annual rainfall, totals for the period 1901 to 1930 (1881 to 1950 for some fifty of them) he seeks for areas of the British Isles having the same trend of variation. The trends are independent of location—mountain, valley—in the regions. He finds four areas, Region I roughly over East Anglia and the Thames Valley, Region II over Wales and a central belt from Lancashire over the Pennines to south of the North West Highlands, Region III over the south, south-west and Midlands of England, the Tyne to east of the North West Highlands and Region IV covering the English Lake District and the south-west and north-west of Scotland. Over Ireland the central belt and south coast agree with Region II, most of the south with Region III and the north with Region IV. The Regions IV and I are respectively the areas of maximum and minimum influence of Atlantic depressions.

All regions had relatively low values in the 1885–1895 epoch but subsequent variations differed. Region IV shows a sharp rise in the late 1890's and peaks around 1897–1906 and 1921–30. The variations were most marked in this Region. Region I had a "plateau" from 1909–1918 to 1922–31 followed by a slow decline. Region II rose steadily from the 1890's to 1922–31 followed by a decline. Region III had peaks in 1909–1918 and 1922–31. The range of variation increases with amount and so is greater in mountainous areas. In low areas it is apparently in Regions I and IV about 5 in., in Regions II and III about 10 in. Mr. Gregory points out the importance of the existence of such regions of more or less uniform variation in water supply.

It would be interesting to see confirmation from correlation coefficients as curve "parallels" are a somewhat uncertain basis.

G. A. BULL

Dictionary of meteorological and related terms. Spanish–English. English–Spanish. By D. Brazol, 8½ in. × 5½ in., pp. 557. Librería Hachette S.A. Buenos Aires, 1955. Price £5.

The necessity of a comprehensive book of this nature is stressed in the Foreword which says ". . . English is almost a universal language in meteorological literature, and is still more commonly used for aviation, marine and wireless communications; we must however not forget the importance of the Spanish language spoken by more than 100 million people. . . Spanish . . . one of the official languages of the World Meteorological Organization." This Dictionary is intended for "seamen, flyers, hydrologists, geographers, agriculturists, physicians, radio-operators and meteorologists".

Reviewing a dictionary is rather a formidable task but a scrutiny of this one gives the impression that from the meteorological viewpoint it is very comprehensive and little seems to have been omitted. The contents (English-Spanish and Spanish-English) are arranged into 19 separate sections each section being devoted to some particular aspect of meteorology such as wind; temperature; fog, mist and cloud; precipitation; climatology; aeronautical meteorology; maritime meteorology; hydrology; communications etc. There is also a section devoted to general technical terms and there are two useful Appendices—universal decimal classification for meteorology and conversion tables (metric and English system).

In addition to purely meteorological terms the dictionary contains a considerable variety of other technical phrases which seem to have little or no meteorological connexion. For example, in the maritime section we find such terms as "line of soundings", "quarantine anchorage" and "tow rope". A reduction in the number of such terms might improve a future edition of the book and perhaps reduce its price. On the other hand, the oceanographical and tidal terms etc. which are included seem quite appropriate.

The arrangement into sections may have its advantages but it sometimes makes it difficult to decide in which section to find a certain phrase and it obviously implies a certain amount of duplication. Thus "compass" appears in the "Maritime" section and under "Instruments". Fog and dense fog appear under section 11 "Fog, mist and cloud" and section 16 "Visibility" but "Fog bank" only appears in section 11. One needs to consult the Table of Contents to find which pages the various sections cover. It would perhaps be preferable in a later edition if the whole contents were merely arranged in alphabetical order irrespective of their specialized context.

The book contains a number of instances where lengthy phrases such as "Effect of droughts on surface water and ground water, Humidity elements (indicating the degree of saturation), Marine observations of wind (by visual estimates based on the appearance of the sea surface)" have been picked out direct from some meteorological publication and translated *in toto*. At first glance this procedure might seem a trifle aggravating, but it has the great advantage of enabling the reader to become a little familiar with Spanish as applied to meteorology without any previous knowledge of that language or of its grammar.

One major criticism of this book is that the author does not seem to have a sufficiently expert knowledge of the English language. In the English-Spanish section one finds for example the following: "Land spout = Tornado; Armet = Distance in metres; Soupy weather = Tiempo Suico (dirty weather); Bull's eye = Eye of the storm; Immersion of the ship = Calado del buque (draft of the ship)." Under "Ice terms" the author refers to a "Snow berg = Ice berg covered with snow; A calf = a big piece of floating ice"; and to "Cat ice" and "Highland ice". None of these terms are generally accepted ice terms in the English language. It is true that a berg is said to "calve" when it breaks away from its parent glacier but it is unusual to see a berg referred to as a "calf". Hurricane, whirlwind, and water-spout appear together under the Spanish equivalent of "Manga o manga marine". In Appleton's Spanish Dictionary "Manga (de Viento)" is defined as a whirlwind. A Box sextant which presumably is intended to refer to a Sextant box is defined in Spanish as "Sextant portatil (de bolsillo)" which infers that it is a sextant suitable for the pocket. Arctic sea smoke is referred to as "Niebla densa de los mares articos" (dense fog of the Arctic seas) whereas "frost smoke" is merely termed "humo polar" (polar smoke) or "humo o vaho (vapour) glacial". Surely this seems to be rather misleading. It is a pity that an otherwise good dictionary should be marred by uncertain English; the author might well be advised to seek the assistance of an English speaking meteorologist to assist him in preparing the next edition of this book.

The book contains an unusually varied number of local names for winds including "Candlemass Eve (winds)" which are referred to as "vientos fuertes; Inglaterra" (strong winds in England), and an Afghanistan katabatic wind which rejoices in the name "Bad-i-Sad-Bistros" (*sic*). The uncertainties of forecasting are perhaps emphasized by the inclusion in the English-Spanish section of an item "very doubtful (wind)" = "Viento (determinacion muy dudosa)".

As is pointed out in the Spanish Preface "The preparation of such a book is full of serious difficulties and the possibilities of errors and omissions is fully recognized by the author who will be glad to receive observations and suggestions in order to improve later editions". The criticisms contained in this review are intended to be constructive and they do not in any way detract from the usefulness of this book to anybody engaged in international meteorology.

At a price of £5 it is undoubtedly expensive; and its paper is not particularly good nor is it very well bound. Some drastic pruning of its non-meteorological contents would reduce its size and perhaps its price and some editing of its English text would be an improvement and perhaps increase its sale.

C. E. N. FRANCKOM

Dynamische Meteorologie. By K. T. Logwinow. 9 in. × 6½ in., pp. xii + 154, *Illus.*, Deutscher Verlagder Wissenschaften, Berlin, 1955. Price: *DM* 16.90.

The Russian original of this book is based on lectures to forecasters under training. The text is stated to have been kept as simple as possible with the physical relations placed clearly in the foreground.

The book gives a summary of some parts of dynamical meteorology without much mathematics though ability to use vector analysis and circuit integrals is needed. The mathematical developments have been considerably extended by the translator in footnotes. The mathematical parts, however, seem to have been selected somewhat arbitrarily and some omitted that are no more difficult than those included. The emphasis is on technique such as the use of thermodynamical diagrams (emagram, tephigram, Rossby diagram).

Although much use is known to be made in Russia of the analysis of contours of isobaric surfaces and thickness patterns the account of this subject is disappointingly brief and is little more than a statement of the gradient wind equation on contour charts and a reference to some papers written during the war. Again, V. Bjerknes's circulation-solenoid theory is developed in detail but there is no account of the relation between vorticity and divergence or of Rossby waves, constant-vorticity trajectories, or of air flow over mountains. There is a long account of Kibel's "first approximation" which, as the translator remarks, was effectively given by Exner many years ago. Interesting paragraphs are those on isentropic charts and on Shuleikin's calculation of the transfer of heat across the Arctic shores of the U.S.S.R. In the former it is stated that isentropic charts are drawn daily in Russian forecasting practice with isopleths of height and specific humidity for following the movement of moist and dry air. There is nothing on cloud physics except a comment on the unreality of the classical rain, snow, etc. stages, or on fog or visibility. The book ends with a short reference to a theory of the detailed forecasting of the diurnal variation of temperature published by Schwez in 1943 which it would be interesting to obtain for comparison with the work of Saunders.

Though the book cannot be recommended to English meteorologists for serious study of dynamical meteorology it would be useful to them for practice in German as it is written in a very easy style.

G. A. BULL

British North Greenland Expedition 1952–4: *Scientific results.* By R. A. Hamilton and others. *Geogr. J., London,* **122,** 1956, p. 203. Royal Geographical Society, London.

Mr. R. A. Hamilton, Senior Scientist of the British North Greenland Expedition, 1952–54, describes the use of air-pressure observations in finding heights along a track across the Greenland ice cap. Effectively 700-mb. contour charts were constructed using pressure readings at two stations where heights could be measured by theodolite.

G. A. BULL

Catalogue of books on mathematics, physics, astronomy and meteorology. $8\frac{1}{2} \times 5\frac{1}{2}$ in., pp. 61, H. K. Lewis and Co. Ltd., London, 1956.

H. K. Lewis's catalogue of books on mathematics, physics, astronomy and meteorology for 1956 includes a useful list of over 70 meteorological textbooks now in print with prices and mentions some now in course of preparation.

Several important books on the meteorology of the upper atmosphere are in the list of books on "Astronautics".

G. A. BULL

HONOURS AND AWARDS

The appointment of Mr. C. V. Ockenden, Senior Principal Scientific Officer, Assistant Director (Observations and Communications) of the Meteorological Office, to be an Officer of the Order of the British Empire was announced in the New Year Honours List, 1957.

Air Efficiency Award.—It was announced in Air Ministry Orders dated October 31, 1956 that Flt-Sgt J. Meadows of the Royal Air Force Volunteer Reserve, Meteorological Section, had been granted the Air Efficiency Award. Flt-Sgt Meadows is the Senior Assistant (Scientific) in charge of the meteorological office at Exeter.

OBITUARY

Takematsu Okada, D.Sc.—We regret to report the death of Dr. Okada, the eminent Japanese meteorologist, on September 2, 1956 at the age of 82 years.

Dr. Okada was Director of the Central Meteorological Observatory, Tokyo, the national meteorological service of Japan, from 1922 to July 1941. After graduating in Physics at Tokyo University in 1899 he joined the staff of the Observatory and was head of the forecasting division there from 1904 to 1920. In 1920 he was appointed Director of the Imperial Marine Observatory, Kobe.

He became a Fellow of the Royal Meteorological Society in 1921, was awarded the Symons Medal of the Society for his scientific work in 1924, and was elected an Honorary member in 1925.

His researches covered a wide field from the theory of the formation of glazed frost to the climatology of Japan.

WEATHER OF DECEMBER 1956

Cyclonic activity over the Atlantic was unusually intense but mostly well west and north of the British Isles. Mean pressure for the month was as low as 984 mb. near 60°N. 35°W., an anomaly of −13 mb. and a monthly pressure value which is not often surpassed in the northern hemisphere. Pressures were 8 mb. above normal in parts of central Europe and a mild generally south-westerly air stream was maintained over western and northern Europe, except for a cold break about Christmas associated with a meridional ridge from the west which intensified over Scandinavia. North-eastward displacements from normal position of the main centres of the Pacific, Azores and Siberian anti-cyclones were maintained in December as in November 1956. The displacement of the Atlantic system over western Europe had lasted since October. The highest value of monthly mean pressure over Siberia in December was 1042 mb., rather above normal and representing an anomaly of +12 mb. at the point where it occurred. The depression track in the Pacific appears to have been displaced south of normal and the systems travelled well east over the ocean, leaving an anomaly of +11 mb. in western Alaska.

Intense advection produced generally above normal surface temperatures in the Arctic, culminating with an anomaly of +9°C. from maritime air on the coast of north-east Greenland and +7°C. at Spitsbergen. There was excessive precipitation as in November on the windward aspect in this area (8·6 times the normal at Myggbukta). Temperatures were below normal in a belt between 50° and 70°N. across North America and between 40° and 60°N. across Asia, anomalies reaching −3° to −6°C. South of this cold zone, India and most of the United States were warmer than the December normal; the greatest anomaly was +6°C. at Atlanta, Georgia. The intensified thermal gradient near 50°N. in this sector may be linked with the deep depressions on the Atlantic, where many individual centres attained 950 mb.

The Mediterranean and North Africa were generally 1° to 2°C. colder than normal. Excessive precipitation was noted on the coast of Egypt and between Jugoslavia and the Black Sea, as well as in Iraq, Assam, on the west coast of Africa and in central America.

In the British Isles weather was exceptionally dull in many areas and mostly mild, particularly in the south, but a brief cold spell during Christmas week brought snow to many parts of the country.

During the first week an anticyclone lay to the south of the British Isles: weather in England and Wales was dull, quiet and very mild, especially in the south, with some occasional light rain or drizzle in places, but in Scotland and Northern Ireland conditions were more disturbed with periods of moderate to heavy rain and gales on the coasts. The mild weather continued during the second week but winds progressively freshened and rainfall became more general as pressure fell on the eastern Atlantic. On the 12th gales became widespread over the country and severe in the north-west as a deep depression passed north-eastwards between Scotland and Iceland; there were frequent showers, heavy at times with hail and thunder behind the disturbance. Weather continued very stormy for several days as a series of deep depressions followed on a similar track, but on the 17th the last disturbance of the series moved away north-eastwards and gales rapidly moderated. Fog became widespread on the night of the 18th/19th and persisted, dense in places. especially in the Midlands and northern England until the 23rd when rain, and in many districts snow, spread eastwards into the country. An anticyclone which had formed over Scandinavia increased in intensity and by the 24th a cold continental air stream covered much of the British Isles. On Christmas Day a trough to a depression near Greenland moved eastward across southern England; rainfall was heavy in Wales and south-west England but further east precipitation was in the form of snow which lay on the ground in some places to a depth of several inches. Winds veered to the south-west again on the 28th as another frontal system from the west brought a return of mild weather to all parts of the country. Rainfall was heavy in Wales and south-west England and this, coupled with the melting snow, led to widespread flooding in counties adjacent to the Severn valley and estuary.

Sunshine was below the average everywhere; at some stations it was the lowest ever recorded during December and at Kew it was the dullest December since 1890. Temperature was 9°F. above average in some areas during the first week and was above average for the month as a whole in spite of the brief cold spell around Christmas. Rainfall was above average over the country as a whole but was below average over North Wales, the west Midland counties and most eastern counties of England. Farmers made good progress with outside work during the mild weather of the first two weeks although diseases such as botrytis tended to flourish. The gales mid-month caused structural damage in Yorkshire and severely damaged flowers in Cornwall but, in spite of the bad weather towards the end of the month, autumn and winter work in the countryside is well in hand.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	59	12	+2·3	106	+1	48
Scotland	58	18	+2·5	119	+2	61
Northern Ireland ...	57	23	+2·5	124	0	66

RAINFALL OF DECEMBER 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ...	2·75	115	*Glam.*	Cardiff, Penylan ...	5·15	103
Kent	Dover	2·71	88	*Pemb.*	Tenby	5·02	102
,,	Edenbridge, Falconhurst	4·16	126	*Radnor*	Tyrmynydd	7·34	89
Sussex	Compton, Compton Ho.	6·51	155	*Mont.*	Lake Vyrnwy	6·84	97
,,	Worthing, Beach Ho. Pk.	4·35	145	*Mer.*	Blaenau Festiniog ...	11·47	90
Hants.	St. Catherine's L'thouse	5·37	170	,,	Aberdovey	4·02	85
,,	Southampton (East Pk.)	5·53	151	*Carn.*	Llandudno	2·98	103
,,	South Farnborough ...	3·62	125	*Angl.*	Llanerchymedd ...	4·24	97
Herts.	Harpenden, Rothamsted	3·72	131	*I. Man*	Douglas, Borough Cem.	4·04	82
Bucks.	Slough, Upton	3·11	123	*Wigtown*	Newton Stewart ...	4·54	84
Oxford	Oxford, Radcliffe ...	3·17	129	*Dumf.*	Dumfries, Crichton R.I.	5·01	117
N'hants.	Wellingboro' Swanspool	2·87	122	,,	Eskdalemuir Obsy. ...	8·61	123
Essex	Southend, W. W. ...	1·81	91	*Roxb.*	Crailing...	2·91	108
Suffolk	Felixstowe	1·85	89	*Peebles*	Stobo Castle	5·49	144
,,	Lowestoft Sec. School ...	0·99	42	*Berwick*	Marchmont House ...	2·37	84
,,	Bury St. Ed., Westley H.	2·38	99	*E. Loth.*	North Berwick Gas Wks.	1·69	79
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