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SOME ASPECTS OF SATELLITE METEOROLOGY

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Introduction.—The use of artificial satellites to observe the atmosphere and the earth's surface from above may be fundamental to the solution of many problems in forecasting and research, provided that the full potential of the observations is recognized, evaluated and used. Cloud photographs and infra-red measurements have been made from the American satellites of the Television and Infra-red Observation Satellite (TIROS) series and the observations, which are still continuing in this experimental phase, have been shown to be of great value, both as direct forecast aids and as research data. This paper gives a brief description of the American satellite programme as a whole and of the capabilities of the satellites. The data from experimental and operational satellites are also discussed in relation to forecasting services and to research.

The satellite programme.—The experimental phase of satellite meteorology began with the launching by the United States of TIROS I in April 1960. Several TIROS satellites have since been launched and have carried different combinations of wide-angle and medium-angle television cameras and infra-red scanning systems. All the TIROS satellites have carried an advanced vidicon camera subsystem capable of producing and storing television pictures which have a resolution of about a mile. (A vidicon is a small television-type tube.) The experimental phase is now being concluded with the TIROS VII, VIII and IX satellites, which are still in orbit and from which television pictures are being received at ground stations in the United States (see Plate I). Within a few hours of being received the pictures are analysed and distributed internationally as nephanalyses, i.e. coded or facsimile analyses of the organization of clouds. The reduction and use of data obtained from the TIROS meteorological satellites are described in World Meteorological Organization Technical Note No. 49.[1]

In September 1964, additional experimental data were also obtained for a few weeks from a more advanced meteorological satellite—NIMBUS A. The next step, however, will be to launch a series of satellites to give regular world-wide coverage. The series will be known as the TIROS Operational Satellite system (TOS) and the first launching is expected in late 1965. It will be based on the proven TIROS meteorological satellite travelling in a polar orbit designed to give a northward crossing of the equator about every 113 minutes at local noon. In 12 hours every part of the earth will come within the field of view of the cameras so that photographs of a series of overlapping strips of the earth will be obtained during successive orbits.

TIROS VIII and NIMBUS A also carried an automatic picture transmission system (APT) giving broadcasts of television pictures every 3½ minutes. Relatively simple equipment on the ground could receive the pictures during the time the satellite was above the horizon at the receiving station (see Plate II). The APT system was in experimental use for only a few weeks on TIROS VIII and NIMBUS A but some remarkable results were obtained and the operational value of directly-received satellite pictures was demonstrated.

Infra-red scanning equipment has also been carried on some of the TIROS satellites and on NIMBUS A. The infra-red observations have been used extensively in research projects concerned with the heat balance of the earth and atmosphere. Furthermore night-time cloud photographs were obtained from NIMBUS A using high-resolution infra-red equipment (see Plate III).

The United States and the United Kingdom co-operated in the ARIEL satellite project. The ARIEL II satellite carried British equipment designed to obtain the vertical distribution of ozone in the atmosphere at each satellite sunrise and sunset.

The observational capabilities of satellites.—The composite nephanalyses produced by the United States Weather Bureau from the space-stabilized (or spin-stabilized) TIROS satellites have been based on up to 32 separate satellite pictures. A resolution down to about one mile is possible at the centre of a picture taken vertically downwards. The resolution is much poorer when the satellite, maintaining the direction of its axis of spin in space, takes a slant view of the earth. The coverage for one picture taken vertically is about 1200 kilometres square.

Since the experimental TIROS satellites were spin stabilized with the spin axis in the plane of the orbit, there were long periods of each orbit during which the cameras were not pointing towards the earth; this limits the usefulness of the nephanalyses.

The satellites in the operational satellite system (TOS) will also be spin stabilized but now with the spin axis normal to the plane of the orbit so that the satellite will behave like a 'rolling wheel' (see Plate IV). The cameras mounted on the 'rim' of the 'wheel' will be activated only when they are pointing towards the earth, thus giving maximum resolution for each picture and facilitating the addition of a grid to give latitude and longitude. The planned polar orbit will allow regular daily surveillance of the whole of the earth's surface. The main limitations of the operational system will be the reduction of ground illumination towards the winter pole and the delay in compiling composite nephanalyses.

The time factor in satellite data.—Pictures are generally not available in 'real time' i.e. at the time they are taken, because the data obtained are stored and later 'read out' at a time when the satellite can be commanded by one of the ground control stations in the United States. The process of compiling nephanalyses is a complex one which takes time. A composite picture is compiled from separate photographs and a grid is included to give latitude and longitude. The composite is then translated into a nephanalysis suitable for transmission by facsimile or teleprinter. The total delay in receiving a nephanalysis in the U.K. usually varies from about five to eight hours, occasionally much longer and rarely shorter.

Satellite data should be available within about three hours of observation in order to be of maximum use to a forecaster or in a computer programme. The satellite data can then be processed together with other data available at the most recent main synoptic hour.

The automatic picture transmission (APT).—The APT facility avoids some of the delay associated with nephanalyses. The forecaster has the advantage of receiving current or 'real time' data for a large surrounding area.

The coverage for each APT transmission, taking place every $3\frac{1}{2}$ minutes, will be about the same as for the individual pictures used in the composite nephanalyses and the resolution will similarly be about one mile. Any one ground station should be able to receive about three pictures during each orbit, and to follow three consecutive orbits. For a station in the British Isles this should, under the best conditions, give coverage roughly from the Denmark Strait to the eastern Mediterranean and from the Azores to the Barents Sea. The installation of APT receiving equipment on weather ships would considerably extend the observed area over the Atlantic if the satellite signal could be relayed to land receiving stations equipped with the appropriate facsimile recorders.

The basis of improvement in forecasting.—The improvement of forecasting services depends upon four interrelated factors:

(i) an increase in the range, quantity and quality of observations;
(ii) the reduction of the interval between the time of an observation and its availability to the forecaster or computer;
(iii) the development of specialized services to meet increasing requirements; and
(iv) advances in meteorological knowledge leading to improvements in forecasting techniques.

These four factors may be used as a basis for assessing the effect of satellite data on forecasting techniques and services.

The uses of meteorological satellites in forecasting.—

APT pictures.—The most useful direct contribution of an operational satellite system to forecasting in the immediate future is likely to be provided by APT pictures which have the considerable advantage of providing, within an analysis centre, current observations over a wide surrounding area. On most occasions APT pictures should provide valuable information to supplement existing forecasting services for aviation, particularly if accumulated experience and research allows the forecaster to extract 'hidden' data related to such factors as turbulence or icing. These advantages are, however, offset to some extent by the limitation of APT coverage to two or three consecutive orbits near noon from one satellite and by the difficulty of interpreting satellite pictures.

Regional forecasting.—Some improvement in short-range forecasting accuracy should follow the routine use of APT data. For example, in regional forecasting for the British Isles it would be very useful, in an easterly situation, to have some idea of the distribution of cloud over the North Sea, or in a westerly to know how cloud is organized over the Irish Sea, the English Channel and the western and north-western approaches, and what effect high ground is having under particular circumstances. With increased experience and research into the interpretation of APT pictures it may prove possible to establish some relation between the intensity of rainfall and cloud patterns or cloud-top reflectivities, provided that the APT receiving equipment is capable of reproducing the tonal range of the original satellite signal.

Area forecasts.—For forecasting over much wider areas, the nephanalyses produced by the United States Weather Bureau in Washington, and given international distribution, will take on a greater importance with an operational satellite system than they have had in the experimental phase because global data will be available on a routine basis. The present form of nephanalysis, as received by facsimile, is probably the best method of giving the data a wide distribution, although the National Weather Satellite Center of the U.S. Weather Bureau welcomes suggestions for improvements from users. Each nephanalysis contains a wealth of data, identifying cirriform, cumuliform and stratiform cloud, jet cores (by the shadow of the cirrus edge on lower cloud), and the character and organization of cloud systems on every scale from the frontal cloud of major depressions down to the cloud streets of the sub-tropical Trades or polar outbreaks.

Analyses.—Experience in relating nephanalyses, or APT pictures, to conventional analyses has already shown that the distribution of cloud is occasionally different from that suggested by analyses based on the coarse grid of observations on surface and upper air charts. This implies that the full potential of satellite observations cannot be realized in existing forecasting techniques. Even so, any analyst to whom satellite data are available should give the information full consideration even if the data arrive late and can only be used to revise analyses on which forecasts have already been issued. Over ocean areas the extrapolation of cloud systems observed by the satellite may be important to future forecast issues, and should help to make widely-separated ship observations more meaningful.

Air survey.—A direct application of APT in the improvement of services to aviation is in air survey in remote areas. Aircraft, crews and ground equipment may be inactive for long periods waiting until clear skies permit the completion of an air survey. If the area is remote the available observations may be few and far between and forecasting clear skies can be extremely difficult, particularly in or near the intertropical convergence zone where the terrain is usually such that air survey is the only practical form of mapping or prospecting. The capital cost of APT receiving equipment is likely to be more than recovered under these circumstances.

Snow cover.—Some remarkable satellite pictures of snow and ice cover have already been obtained and it might be expected that an operational satellite system, giving regular snow cover observations within the limits set by cloudiness, would provide some means of assessing river flood levels, hydroelectric resources and reservoir inflow.

Ice limits.—The boundary between sea ice and open water is likely to be a region of increased cloudiness but there should be a sufficient number of occasions of clear skies in such areas for routine satellite observations to provide information on ice-limit changes which might be of importance for climatology and long-range forecasting. Ice-limit observations would, in any case, be of direct use in navigation at sea.

Satellite data and the development of forecasting techniques.—Satellite pictures of cloud systems have shown many unusual features such as clear areas where dry air has penetrated right through the frontal zones in occluding depressions, apparent vortices in the distribution of convective cloud in polar air which are closely related to the thermal wind field, and cloud systems only loosely associated with conventionally positioned fronts (Sawyer[2]). The significance of an operational satellite system is that conventional surface and upper air observations will be reinforced by satellite observations with a resolution down to about a mile over land and sea alike. Satellite observations of cloud and its organization will go a long way to completing a full description of the actual behaviour of the atmosphere when added to the observations of widely-spaced radiosonde ascents and the limited information which can be conveyed in the coded versions of surface observations. Perhaps the real importance of satellite data to the development of forecasting techniques lies in the observations of cloud organization.

To use satellite data to confirm or amend conventional analyses is of limited short-term use but one which should serve to convince the synoptic meteorologist that the observations provided by operational satellite systems are likely to lead to new concepts of behaviour of the atmosphere and these, carried forward on computer techniques, may eventually lead to major advances in the accuracy and applications of forecasting services.

Meteorological research using TIROS data.—The data obtained from a TIROS satellite are basically of two types. The photographs are obtained by the projection of the whole of the field of view of the optical system on to a sensitive surface whilst the radiation measurements are made by scanning the field in small sections. Research using the data has, in general, continued to follow such a division determined more by the availability and quality of the measurements rather than by the instrumentation or wavelength.

Although less than five years has elapsed since the launch of TIROS I the quantity of research publications concerned with satellite data is enormous as indeed is the diversity of topics involved. Consequently only a selection of this research can be presented here. For a fuller description of some of these topics we refer you to other writers, for example Hanson.[3]

Photographs.—Even on the first photographs received in April 1960 it was obvious that in the cloud patterns there were significant features which were not evident from conventional surface observations. Investigations relating to the interpretation of cloud patterns have been reported by Erickson and Hubert[4] and Conover.[5] Both of these papers attempt to identify clouds observed in satellite photographs in terms of classifications based on ground observations. They show that provided the clouds are large enough to be resolved by the optical system and dense enough to reflect sufficient light into the field of view of the camera it is indeed possible to identify cumulus, stratocumulus and so on; for cloud patterns however, only a few crude classifications are possible from conventional surface observations. In this respect satellite photographs have been quite an eye-opener showing cloud organization on scales from 10 miles—the dimensions of maritime convection cells (see for example Krueger and Fritz[6])—up to 1000 miles—the dimensions of a middle latitude depression (see for example Boucher and Newcomb[7]).

The orbital inclination of the earlier TIROS satellites was only 48° so that relatively few photographs were obtained in the middle and high-latitude regions. The coverage at the equator however was excellent and a considerable amount of research was concerned with the cloud types and structures associated with meteorological phenomena found in these regions. In particular, photographs have shown that there have been facets of the structure of the hurricane (Fett[8]) which were not suspected from conventional surface observations. For example, there seem to be intense squall lines which completely ring the hurricane and are separated from it by a well-defined clear area. Furthermore the origin of such storms has—certainly in two instances—been shown to be considerably further east than had been previously suspected. Fritz[9] in analysing the origins of hurricanes ANNA and DEBBIE found that they could be traced to disturbances of the easterly flow over central Africa.

Most research using TIROS photographs has been concerned with case studies of individual phenomena, for example a sharp-edged bright cloud which produced a severe storm over central U.S.A. (Whitney[10]) or a developing depression (Timchalk and Hubert[11]). Researches such as these have tended to show the distance over which the particular meteorological disturbance exerts an influence. For example the bright clouds described by Whitney which were associated with distinctly separate areas of thundery activity were of the order of 100 miles across, whilst developing depressions exerted an influence over an area with linear dimensions of more than 1000 miles. This sort of research with limited objectives has been very profitable if only to show that the organization of clouds in association with meteorological phenomena does not usually conform with theories based entirely on surface observations.

The operational value of satellite cloud photographs will be increased if they can provide quantitative data for use in numerical weather prediction. Unfortunately there does not seem to be a one to one correlation between cloudy areas and any of the parameters at present used numerically (even the positioning of the centres of cloudiness may differ by 100 or 200 miles from the position of the surface depression, see for example Boucher and Newcomb[7]). Investigations relating to this problem have therefore been confined to subjective trial and error techniques. Broderick[12] obtained the expected correlation between extensive cloudiness as observed from the TIROS photographs and the advection of cyclonic vorticity at 500 mb. The correlation was too weak to be of practical use and although it could be improved when it included only those cases where the advection term was greater than a certain value it was still not good enough to be of use objectively. However he concluded that the correlation was usable if the analysis also included other features of the synoptic situation determining the structure of the cloud sheet. To our knowledge the only published attempt to introduce cloud analyses from TIROS photographs into numerical forecasting has been that of Ruzecki.[13] In this report an example was selected of a contour analysis over the Pacific from which the computed vertical motions at 500 mb (proportional to the vorticity advection at this level) did not seem to agree with the cloud distributions as shown by a TIROS photograph of the same areaf Ruzecki assumed that thick middle-level clouds would be found in the areas o. strong, positive vorticity advection and used an iterative technique to adjust the stream function and the field of vorticity advection to agree with both the TIROS photograph and the conventional upper air observations. The redefined initial data field was then fed to the computer and a routine numerical forecast obtained. There is little doubt that an improvement was made to the forecast 500 mb contour field. This is only one example, but it is understood that more cases are being re-analysed in a similar fashion by a group at the Satellite Laboratory of the U.S. Weather Bureau. This is but a small beginning to a project which may be vital to the future of meteorological information from satellites—and perhaps for numerical forecasting too.

Radiation data.—The satellites TIROS II, III, IV and VII each carried a five-channel radiometer capable of measuring radiances in five different spectral intervals. A full description of the instrument is given elsewhere, for example Hanel and Wark.[14] Briefly, each channel of the radiometer consists of a thermal detector which receives radiation through a filter determining the spectral interval, and reception is arranged alternately from two directions 180° apart. The output of the detector is thus an alternating voltage whose amplitude is proportional to the difference in radiance from the two directions. When one of these is directed towards the earth the other points towards space where the radiance is effectively zero, so that the output depends on the amount of incoming radiation from the earth and the atmosphere.

During the four years that have elapsed since the launch of TIROS II, the first satellite to carry a radiometer, an ever-increasing volume of literature has appeared dealing with the accuracy of the observations and the application to meteorological investigations. No attempt will be made at a summary here; rather we will select various aspects of these researches which appear to us to have produced or to be likely to produce significant meteorological information. First, however, a word should be said about the performance of the instrument itself. There is little doubt that the instrument on each occasion deteriorated rapidly after being launched. It is not known for certain what causes this degradation—possibly a change of reflectivity of the mirrors—but since it exists and can be calibrated only empirically we must treat with some suspicion any deductions made from the absolute values of the radiances observed. This should be borne in mind in the discussion which follows.

Channel II of the radiometer measures radiances in the spectral interval 8 to 12 microns. This is loosely termed the atmospheric 'window', by which we mean that at these wavelengths there is no absorption by atmospheric constituents. Thus in cloud-free areas the radiation in this interval measured at the satellite comes entirely from the ground and could give an estimate of the surface temperature. For an extensive cloud sheet the radiation would rise from the cloud itself enabling an estimate of cloud-top temperature. Unfortunately the 'window' is not perfect, there being absorption by ozone and slight absorption by water vapour too, so that any temperatures deduced directly would be in error. A correction therefore has to be applied for the distribution of these gases and also for the length of path between the earth and the satellite. This correction has been determined empirically by Wark, Yamamoto and Lienesch[15] and reduces the measured radiances to surface temperatures. Naturally to obtain accurate estimates of surface or cloud temperatures one should know the distribution of ozone and water vapour in the path. Although the former may be obtained with sufficient accuracy from published data of ozone measurements the variability of water vapour in the troposphere could lead to errors of more than 5°C in surface temperatures.

One of the earliest uses of the Channel II data was described by Fritz and Winston[16] who plotted the radiances, reduced to effective black-body temperatures, on a synoptic chart which also showed frontal boundaries and cloud cover. As we might expect, the high and low temperatures corresponded to clear and cloudy areas respectively, with the lower temperatures agreeing with the denser and higher cloud sheets. Furthermore, using representative temperature soundings it was possible to put heights to the cloud tops. This technique was applied to other examples by Rao and Winston[17] who also pointed out ambiguities which might arise if one assumed that all low temperatures occurred with high cloud. In their examples snow-covered areas had lower temperatures than cloudy regions nearby. They also observed that the decrease in radiance apparently caused by particulate matter near the tropopause gave erroneously low values for surface temperature. Their paper clearly emphasizes the fact that the radiation data of Channel II possess anomalies only partially explained by the presence of ozone and water vapour. However even this data can be used to locate cloudiness, to show variations in the cloud-top heights and to portray variations of surface temperature. It should be noted here that an optical system using a narrow band within the window region was used on NIMBUS A to observe cloud cover at night.

Channel IV of the satellite radiometer measures radiances within the spectral interval 8 to 30 microns and was included because this measurement represents a substantial fraction of the total intensity of terrestrial radiation. To obtain the outgoing flux, that is the radiation leaving unit area of the atmosphere, it is necessary to integrate the intensity over a hemisphere. This requires a knowledge of the angular variation of the intensity which in turn depends on the distribution of absorbing gases within the beam. Wark, Yamamoto and Lienesch[15] used more than 100 model atmospheres with various temperature and humidity combinations to determine this angular variation for various types of atmosphere, and have presented some examples of outgoing flux from a series of TIROS II observations.

One of the first analyses of Channel IV data has been reported by Winston and Rao[18] using TIROS II data for about 25 days in the winter of 1960. They constructed a composite map of outgoing long-wave radiation for the northern hemisphere. They showed that the average latitudinal distribution so obtained agreed tolerably well with the computations of other workers and that small-scale fluctuations about this average could in some cases be associated with changes in the zonal flow. But perhaps their most important conclusion was that there was a correlation between temporal variations of long-wave radiation and corresponding variations of available potential energy, a parameter which is closely linked with the general circulation of the atmosphere.

Before concluding this section special mention must be made of the radiometer on TIROS VII. The radiometers on earlier satellites suffered considerably from rapid degradation preventing any long-term radiation studies. That carried on TIROS VII had also experienced degradation but at a much lower rate and more than a year's radiation data have been obtained from it. Bandeen, Halev and Strange[19] using a year's data from this satellite have derived a radiation climatology for the earth between latitude 63°N and 63°S. They calculated the latitudinal variation of (i) the annual (June 1963 to May 1964) long-wave heat loss derived from the 8 to 12 micron channel and (ii) the planetary albedo from the 0.55 to 0.75 micron channel. Further, the seasonal variation of these quantities could be indicated. Perhaps the most interesting aspect of the analyses however is the interpretation of the 14.8 to 15.5 micron channel. Within these wavelengths carbon dioxide, which is uniformly distributed in the atmosphere, absorbs strongly all the radiation coming from the earth and then re-radiates an amount determined by its own temperature. The distribution of the gas in the stratosphere is such that only a small amount of energy originating in the troposphere reaches the satellite so that the measured radiance is indicative of the temperature of the stratosphere. Bandeen and his co-authors show the distribution of the stratospheric temperatures obtained during four weekly periods from June 1963 to March 1964. A surprising feature of these charts is the persistence of a warm stratosphere over the North Pacific region from the 15 to the 22 January 1964, displacing the cold, stratospheric vortex which might be expected around the Pole. The satellite measurements also indicated that in the second half of January 1964 there had been a stratospheric warming of more than 15°C with its centre near Asia Minor. These observations have been amply supported by STRATWARM alerts issued by Professor Scherhag at Berlin and to a lesser extent by observations from the Meteorological Office Skua rocket fired from South Uist at about the same time (Almond, Farmer and Frith[20]).

Conclusions.—In the preceding sections we have reviewed the implications of meteorological satellites for research and for forecasting services. Television pictures and infra-red observations from the experimental TIROS and NIMBUS satellites have provided data for many promising and active lines of research and practical experience in incorporating satellite data into conventional analyses. Some uses of satellite data will be of immediate value to forecasting services but already there are indications that new approaches to many hitherto intractable problems in meteorology may be possible through satellite observations, and advances in fundamental research over a wide range of problems should be possible when routine satellite data are available. For operational use the satellite observations must ultimately be able to provide data suitable for input to a computer and already a promising start has been made in this direction.

Among practising forecasters the availability of meteorological information from satellites has probably evoked more defensive pessimism than enthusiastic optimism. The actual organization of cloud systems is far more complex than the rough approximations and simplifications of existing analytical and forecasting techniques have led us to expect; there are still problems in getting the information to the forecaster in time for it to be used, and observations are not the sole arbiter in forecasting accuracy. Accumulation of satellite data should challenge our existing concepts and techniques and methods of presentation of forecast data.

Progress in meteorology, both in research and its applications to forecasting, is likely to accelerate rapidly in the next decade and data from meteorological satellites operating as part of World Weather Watch will provide much of the observational support for the advance. The use of data from the operational meteorological satellite system will play an increasingly important part in the international development of meteorological services.

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THE DIURNAL MARCH AND INTERDIURNAL VARIABILITY OF THE DURATION OF SUNSHINE AT ATHENS

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Summary.—Hourly values of the Athens sunshine data for the period 1959–63 are analysed. The sunshine at Athens does not show a remarkable diurnal variation for all months and seasons or the year as a whole. However, because of the diurnal variation of cloudiness, a preference is revealed for a maximum in the morning hours in spring and summer and in the noon hours in the corresponding months in winter and autumn.

The interdiurnal variability of sunshine, that is the difference between the duration of sunshine on one day and that on the next, shows a regular annual course—maximum in winter and minimum in summer. This occurs for interdiurnal rises and falls and also for variability irrespective of sign and is due to the interdiurnal cloud variation.

Introduction.—It is well known that the duration of sunshine constitutes one of the most important elements of climatology and is often used as a substitute to gauge the solar climate of a place. The sunshine is usually expressed as the number of hours per month or per year and also as a percentage of the possible sunshine for a particular place.

With regard to the Athens area, such a tabulation exists dating back to 1896. For the period 1959–63, hourly values expressed as a percentage of the possible sunshine are also available. These values are for hours when sunshine could occur for the whole hour (60 minutes) and so, for example, 30 minutes of sunshine in an hour represents 50 per cent of the possible. It seemed worthwhile analysing the data for 1959–63 in order to study the diurnal march and inter-diurnal variability of the duration of sunshine. For convenience only the hours from 0800 to 1700 (Local Apparent Time, LAT) are discussed, these being the times between which the sun is above the horizon in all months of the year.

The records discussed were made with a Campbell-Stokes sunshine recorder on the hill of the National Observatory of Athens (37°58′N, 23°43′E, and 107 metres above sea level).

Diurnal march of sunshine.—The diurnal march of sunshine is obviously governed by the cloudiness and also by the occurrence of fog and dust. However, because of the effects of the different kinds of clouds, an accurate relationship cannot exist between recorded sunshine and cloudiness. The sun may shine even if the sky is cloudy or it may be obscured even if the sky is not completely overcast.

Table I presents, within the hours 0800 to 1700 LAT, the average hourly values of sunshine at Athens expressed as a percentage of the possible for each hour during each month and season and for the year as a whole.

TABLE I—AVERAGE DIURNAL MARCH OF SUNSHINE AT ATHENS, (1959–63)

	Local Apparent Time								
	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17
	percentage of possible								
January	47	55	57	54	57	57	53	48	23
February	51	57	62	66	64	61	61	55	36
March	54	60	62	61	60	60	57	57	42
April	77	78	75	74	76	74	69	69	64
May	85	86	85	82	78	75	75	77	74
June	95	94	93	87	85	89	85	83	83
July	97	96	96	97	94	93	94	95	95
August	99	99	98	98	98	98	97	96	95
September	89	92	90	90	88	88	88	89	81
October	66	72	71	72	73	69	67	61	44
November	57	66	72	77	76	73	66	56	25
December	42	54	55	56	53	51	44	36	12
Winter	47	55	58	59	58	56	53	46	24
Spring	73	75	74	72	71	70	67	68	60
Summer	97	96	96	94	92	93	92	91	91
Autumn	71	77	78	80	79	77	74	69	50
Year	72	76	76	76	75	74	71	68	56

As it appears from this table, the sunshine at Athens does not show a regular diurnal course for all months studied. Nevertheless a tendency is revealed towards a maximum in the morning hours of the spring and summer months, while for the winter and autumn months the same applies for the noon hours. This tendency is clearer if the seasons are considered.

The cause of this behaviour of the diurnal march of sunshine must be sought mainly in the diurnal march of cloudiness. Indeed, especially in winter, the maximum of cloudiness occurs during the early morning hours when stratiform clouds are most frequent.[1] In summer, on the other hand, convection increases the cloudiness during the early afternoon hours. If the year as a whole is considered, the diurnal course of sunshine at Athens presents the maximum values (76 per cent) in the three forenoon hours.

Concerning the minimum values of sunshine and therefore its diurnal range, it must be noted that the Campbell-Stokes recorder is not a perfect instrument. As a result the minimum values are rather doubtful.

In general, although the fluctuation of the diurnal march of Athens sunshine is not remarkable, Table I gives a useful picture of the sunshine duration for each hour (LAT) at Athens.

Interdiurnal variability of the duration of sunshine.—As is well known,[2,3] among the irregular fluctuations of climatic elements are the changes from one day to another, which indicate the variability of the weather. These variations from one day to the next are known as interdiurnal variability and besides the variability irrespective of sign, the rises and falls of the element under consideration can be studied separately (see Table II).

TABLE II—INTERDIURNAL VARIABILITY OF SUNSHINE HOURS AT ATHENS, 1959–63

	Average change irrespective of sign	Average rises (*R*)	Average falls (*F*)	Ratio *R*/*F*	Rises	Falls	No change	Absolute maximum values Rises	Falls
	hours	*hours*	*hours*		*percentage frequencies*			*hours*	*hours*
Jan.	3.1	3.2	3.2	1.00	49	48	3	8.7	8.9
Feb.	3.3	3.2	3.7	0.86	50	47	3	9.5	9.1
Mar.	3.2	3.5	3.3	1.06	47	46	7	10.1	8.6
Apr.	2.7	2.7	2.6	1.04	47	53	0	11.8	8.0
May	2.6	2.8	2.7	1.04	48	48	4	10.8	10.9
June	1.9	1.9	2.3	0.83	53	42	5	8.2	10.5
July	0.9	0.9	0.9	1.00	47	46	7	5.8	5.9
Aug.	0.7	0.7	0.8	0.88	40	50	10	6.0	6.9
Sept.	1.4	1.7	1.3	1.31	39	56	5	9.1	10.0
Oct.	2.6	2.6	2.8	0.93	50	48	2	8.8	9.2
Nov.	2.6	2.7	2.6	1.04	47	52	1	9.0	7.9
Dec.	3.1	3.3	3.3	1.00	48	46	6	8.7	8.8
Winter	3.2	3.2	3.4	0.94	49	47	4	9.5	9.1
Spring	2.8	3.0	2.9	1.03	47	49	4	11.8	10.9
Summer	1.2	1.2	1.3	0.92	47	46	7	8.2	10.5
Autumn	2.2	2.3	2.2	1.05	45	52	3	9.1	10.0
Year	2.3	2.4	2.4	1.00	47	49	4	11.8	10.9

Under the control of the day-length alone, each day should obviously have a greater duration of sunshine than the preceding day during the interval between minimum and maximum day-length, and a smaller one between maximum and minimum day-length (December and June solstice respectively). However, besides the day-length, the cloudiness and also fog and dust in the air produce irregular interdiurnal changes.

The first column of Table II shows that there exists a strongly-marked regular annual course of the interdiurnal variability irrespective of sign. The maximum (3.3 hours) appears in February and there is a marked minimum (0.7 hours) in August. Hence the annual range is 2.6 hours.

Almost the same picture appears in the annual course of the rises and falls (second and third columns of Table II) with high values in winter and the first month of spring and low values in summerand the first month of autumn. The annual ranges amount to 2.8 and 2.9 hours for rises and falls respectively and the average monthly values of rises and falls are very closely correlated, the correlation coefficient being $+0.97$ with a probable error of ± 0.01.

The behaviour of the annual course of the interdiurnal variability of sunshine hours must be attributed to the cloud variation which is small in summer and great in winter. Especially during the cold period there are in the Athens area frequent alternations of cyclonic and anticyclonic conditions which create dense cloudiness and clear weather respectively.

The ratios of monthly rises and falls are also given in Table II. These ratios have rather small variations in the course of the year and are $\geqslant 1.00$ in the majority of cases.

Attention may be directed also to the last five columns of Table II which give the percentage frequencies of rises, falls and occasions of no change (i.e. a difference of 0.0 hours), and also absolute maximum values of rises and falls. From this picture it appears that the greatest contrasts between the frequencies of rises and falls occur in the first month of both summer and autumn (53 as against 42 in June and 39 as against 56 in September). The steady conditions, on the other hand, present a minimum value (0 per cent) in April and a maximum (10 per cent) in August. Concerning the absolute maximum values of rises (11.8 hours in April) and falls (10.9 hours in May) it is to be noted that both occur in the spring.

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551.511.3:551.521.1:551.524.32

THE DISTRIBUTION AND ANNUAL CYCLE OF LOCAL HEATING RATE THROUGHOUT THE TROPOSPHERE IN THE NORTHERN HEMISPHERE

By G. B. TUCKER

Introduction.—During the past few years several attempts to represent the spatial distribution of sources and sinks of heat over the northern hemisphere have been published.[1,2] The order of magnitude of this heating and cooling is 10^{-3} g cal cm^{-2} sec^{-1}, but the observed local rate of change of total heat content of the atmosphere is only of the order of 10^{-4} g cal cm^{-2} sec^{-1} This is because the local temperature change is the result of a small residue between the heat sources (and sinks) and the redistributive effects of horizontal and vertical motion in the atmosphere. This relation can be represented by the formula

$$\bar{R} + \bar{L} + \bar{H} = -\frac{c_p}{g}\int_{\bar{p}_s}^{0} \frac{\partial \bar{T}}{\partial t}\,\mathrm{d}p - \frac{c_p}{g}\int_{\bar{p}_s}^{0}\left(\overline{\mathbf{V}.\nabla T} + \frac{\bar{T}}{\bar{\theta}}\overline{\omega\frac{\partial\theta}{\partial p}}\right)\mathrm{d}p. \quad \ldots (1)$$

The three terms on the left-hand side represent the rate of heating in a vertical column of atmosphere of unit cross-section due to net radiation (R), liberation of latent heat (L), and the rate of gain of sensible heat by exchange with the earth's surface (H). The first term on the right-hand side represents the heat storage or local rate of change of total heat content of the column; c_p is the specific heat of air at constant pressure; g, acceleration of gravity; T temperature; t time; p pressure; p_s representing the pressure at the earth's surface. The remaining terms on the right-hand side represent the redistributive effects of horizontal motion and of vertical motion; $\mathbf{V}$ is the vector representing horizontal velocity; $\omega \equiv \mathrm{d}p/\mathrm{d}t$ vertical motion; θ potential temperature. Horizontal bars represent mean values in time—in this case one month.

Clapp[1] has discussed the difficulties of independently estimating both sides of this equation for a normal winter. Shaw[3] has dealt in detail with the difficulties involved in estimating the redistributive terms on a monthly basis. The object of this paper is to represent the distribution of the heat storage term over the northern hemisphere throughout the year, i.e. to represent the geographical distribution of the annual variation of the rate of change of total heat content of the troposphere.

Method.—The average total heat content from the surface to 200 mb was estimated for each month for five years at 78 stations distributed over the northern hemisphere (Figure 1). The years chosen were 1955 to 1959 inclusive, and CLIMAT temperature data at the surface, 850, 700, 500, 300 and 200 mb levels were used. Five-year average values for each month of the year were

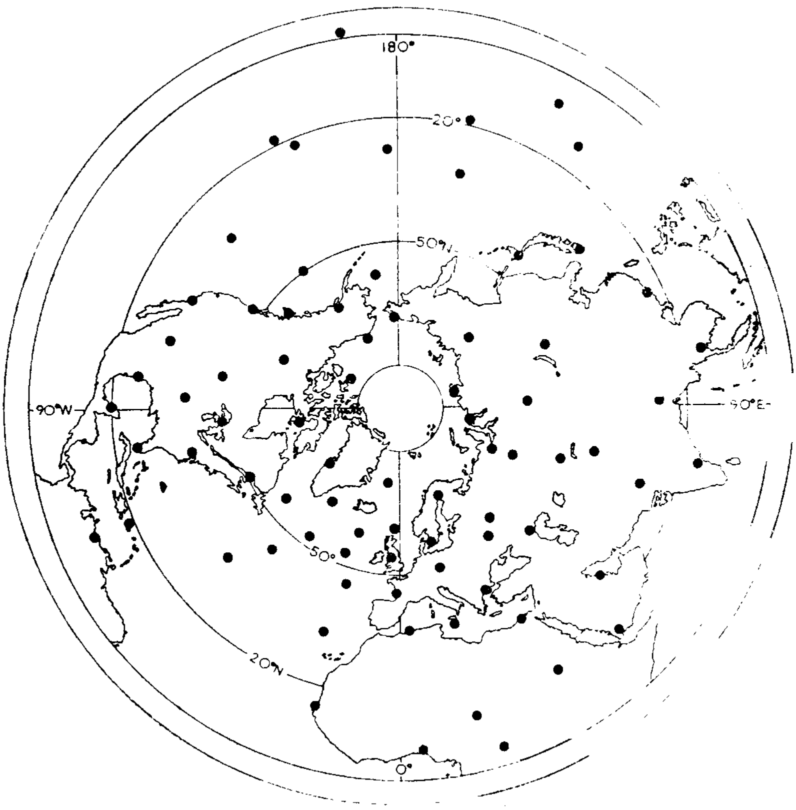


FIGURE 1—KEY MAP OF STATIONS USED

next obtained. The local rate of change of total heat content between successive months was then estimated using the following expression

$$-\frac{c_p}{g}\int_{\bar{p}_s}^{200}\frac{\partial\bar{T}}{\partial t}\,dp = -\left[\frac{c_p}{g\Delta t}\int_{\bar{p}_s}^{200}\bar{T}\,dp\right]_{m+1} + \left[\frac{c_p}{g\Delta t}\int_{\bar{p}_s}^{200}\bar{T}\,dp\right]_{m}$$

where the subscripts m, $m+1$ refer to consecutive months and Δt is the time interval between the middle of one month and the next.

The root mean square deviation of individual monthly values of total heat content about the 5-year mean obviously varies with place and time of year; for the 78 × 12 station-months examined the average value was approximately 400 g cal cm^{-2}. Corresponding to this value a reasonable estimate of the standard error of the charts of local rate of change of total heat content can be shown to be approximately 0.9 × 10^{-4} g cal cm^{-2}sec^{-1}.

Results.—Charts of the normal local rate of change of total heat between successive months throughout the year are given in Figures 2–13.

Before discussing individual charts it should be noted that values south of 20°N generally have a magnitude of less than 0.5×10^{-4} g cal cm^{-2} sec^{-1} and are thus comparable with the standard error. Also the distribution of stations in these low latitudes is very sparse. Discussion will therefore be confined mainly to middle and upper latitudes. In the remainder of this article the terms 'warming' or 'cooling' will refer to increasing or decreasing total heat content in the troposphere, i.e. to areas of rising temperature or falling temperature, and not to the rate at which heat is supplied or abstracted locally.

At the commencement of the year (Figure 2) some warming is already beginning to take place in high latitudes in the form of a three-lobe pattern with centres over Alaska, south of Iceland and to a lesser extent over Siberia. Between about 20°N and 50°N is a broad area of cooling with high values over the central North Atlantic and over Japan. The juxtaposition of positive and negative centres in the North Atlantic region at this time of year is consistent with the strongest thickness gradients and maximum intensity zonal winds occurring in this region in late January and early February (Willett[4]). A general warming appears to occur in very low latitudes. The high-latitude warming persists in late winter (Figure 3), but there has been a shift in the position of the three centres. The main change from the previous chart is the absence of any well-defined zone of cooling in middle latitudes.

The beginning of spring (Figure 4) is marked by an extension of the warming areas with a maximum centred over north-central Canada. The earlier three-lobe pattern of warming (Figure 2) is somewhat compensated by slight cooling in these areas at this time. Figures 5 and 6 show the 'spring warming' well under way, an increase in total heat content being experienced by nearly the whole hemisphere.

Figure 7 shows the 'spring warming' continuing well into June with the maximum centred near the pole. A feature of early summer (Figure 8) is that the local heating area is a maximum in a zone whose average latitude is about 50°N while a zone of cooling has extended northwards to an average latitude of 25°N. Towards the end of summer (Figure 9) cooling appears over much of the chart particularly in the western hemisphere. Maximum cooling at this time is centred close to the pole.

At the beginning of autumn (Figure 10) a three-lobe pattern of cooling is a feature of high latitudes, the centres of cooling occurring approximately mid-way between the centres of warming in winter (Figure 2). In late autumn (Figure 11) cooling continues over most of the middle and upper latitudes with the centre of maximum cooling near the pole.

Pronounced asymmetry in the pattern of cooling occurs in early winter (Figure 12) with a region of intense cooling centred over western Canada and to a lesser degree over Japan, and slight warming occurring over Scandinavia (this latter region has values of the same size as the standard error and thus the warming may be a feature merely of the five years chosen). In midwinter (Figure 13) cooling over Japan continues while a pronounced area of cooling is situated over the north-east Atlantic.

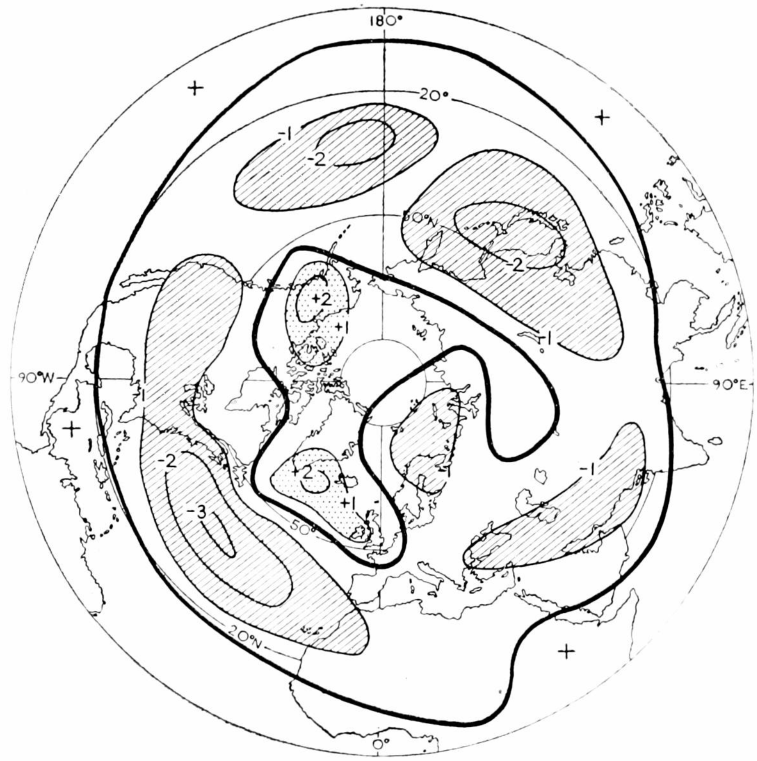


FIGURE 2—LOCAL RATE OF CHANGE OF THE TOTAL HEAT CONTENT OF THE TROPOSPHERE IN THE NORTHERN HEMISPHERE, DECEMBER/JANUARY

Unit: 10^{-4}g cal $cm^{-2}s^{-1}$

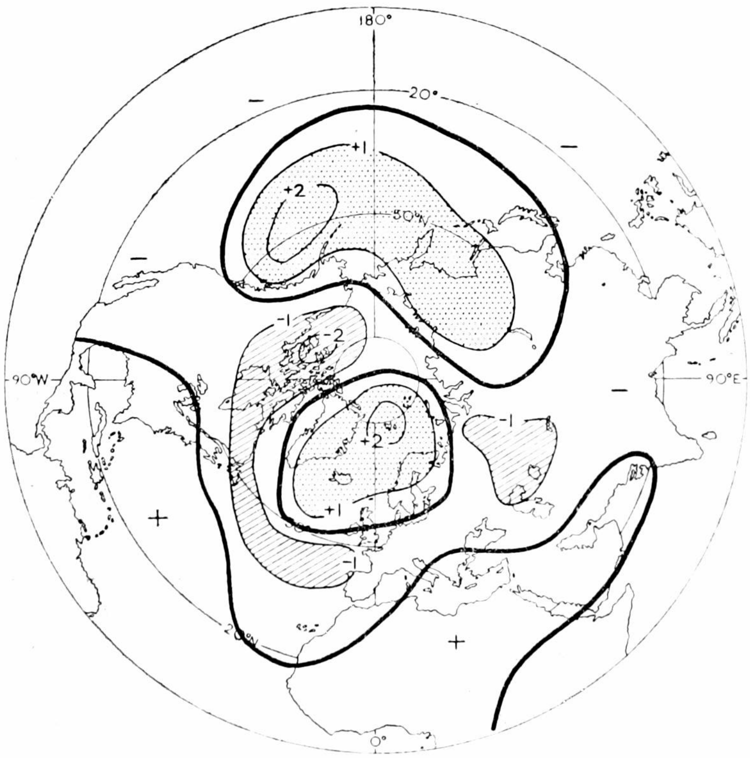
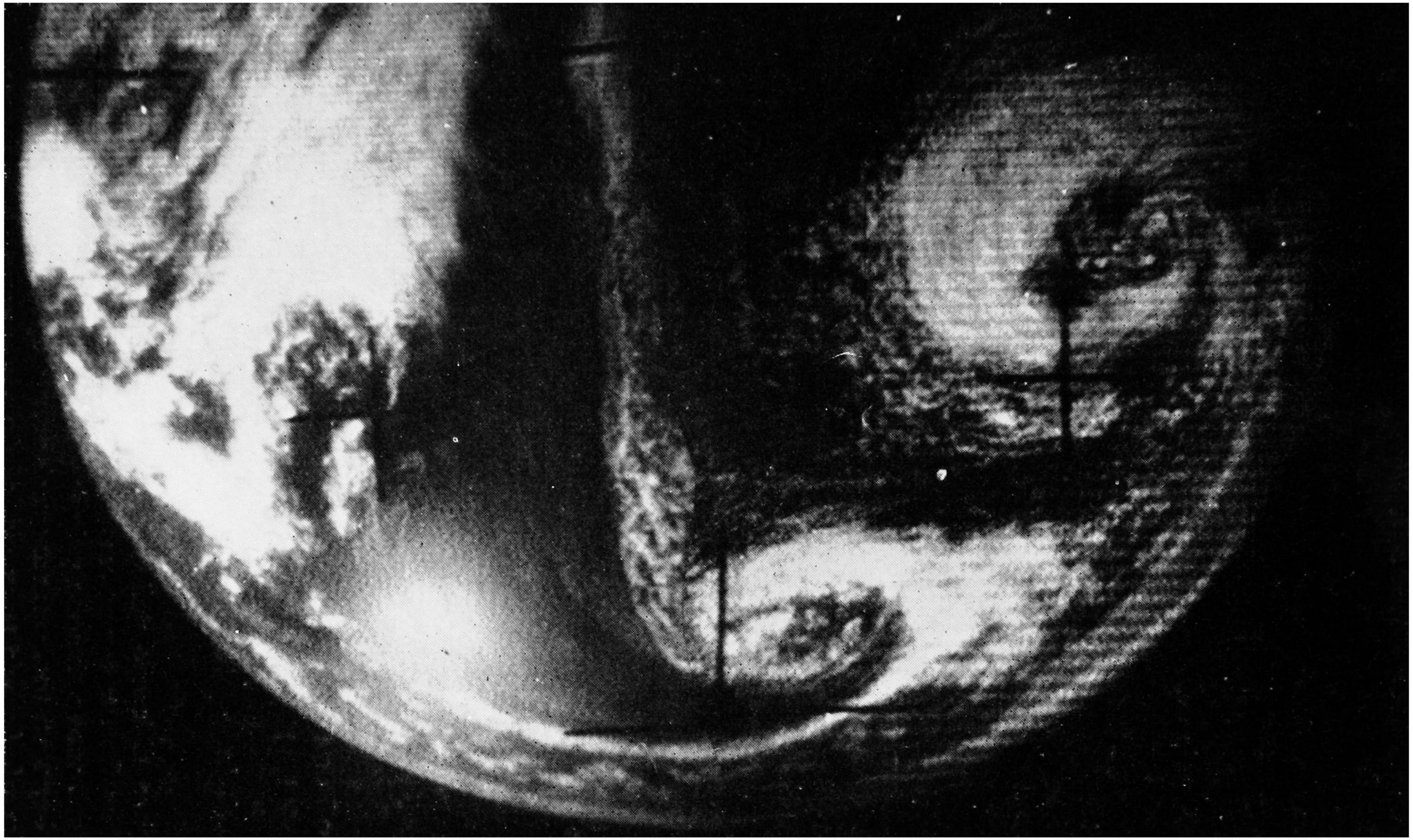


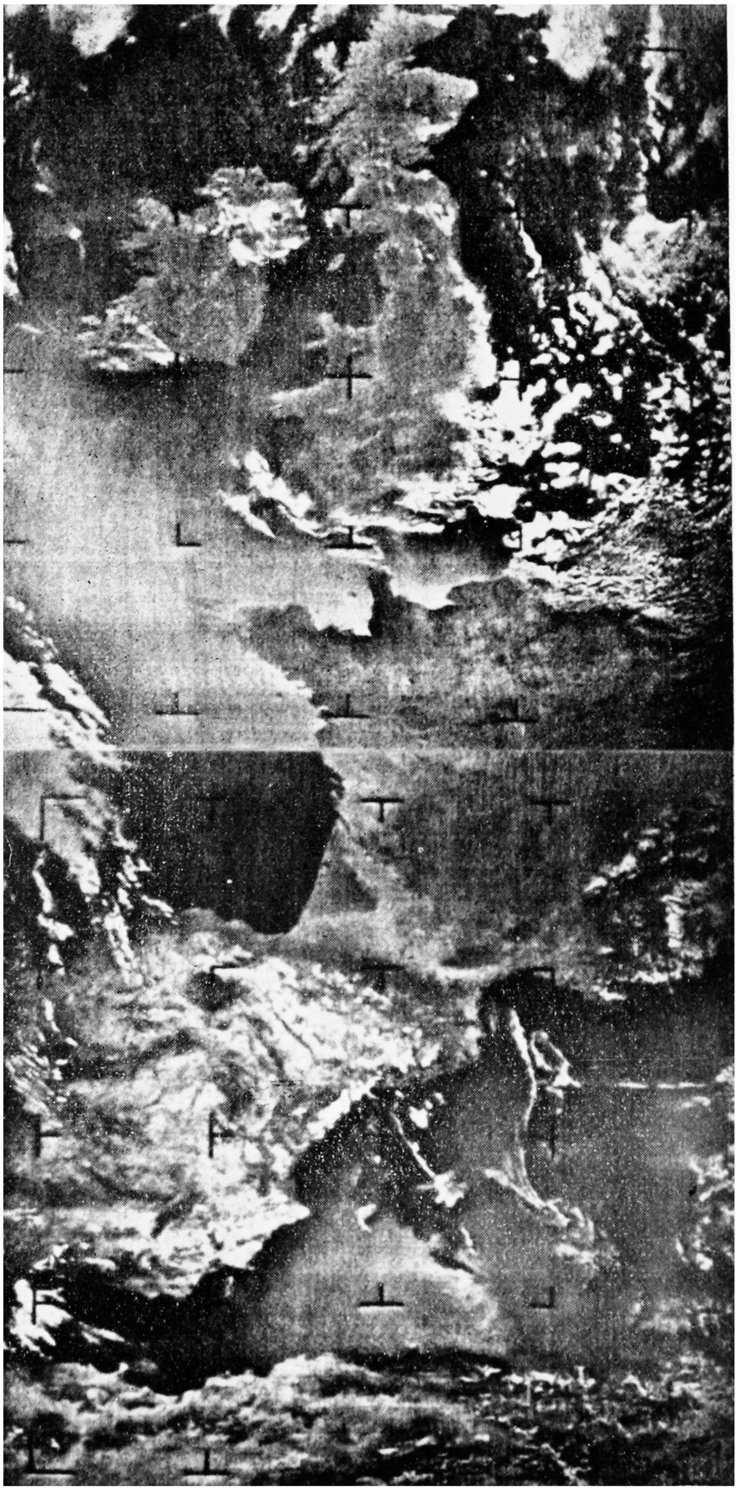
FIGURE 3—JANUARY/FEBRUARY



By courtesy of NASA

PLATE I—DOUBLE VORTEX OVER NORTH ATLANTIC OCEAN

Photograph by TIROS IX, orbit 0101 on 30 January 1965 (see page 193).



By courtesy of U.S. Weather Bureau

PLATE II—AUTOMATIC PICTURE TRANSMISSION RECEIVED AT LANNION, FRANCE

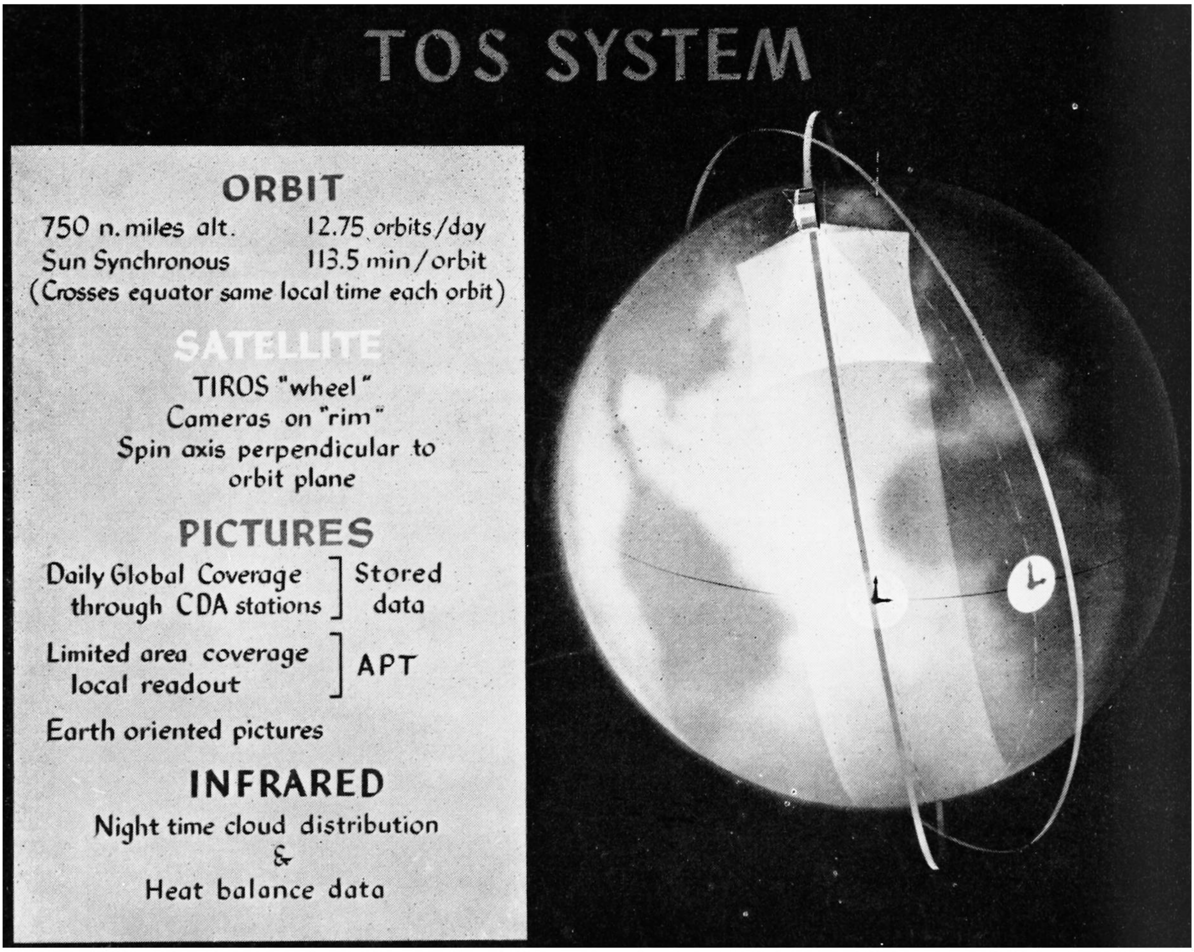
Photograph by NIMBUS A on ~~2 September~~ 1964 (see page 194).

31 AUGUST

By courtesy of NASA

PLATE III—HIGH RESOLUTION INFRA-RED PHOTOGRAPH OF HURRICANE ETHEL

Photograph by NIMBUS A on 10 September 1964 (see page 194).



By courtesy of U.S. Weather Bureau

PLATE IV—TIROS OPERATIONAL SATELLITE SYSTEM

See page 194.

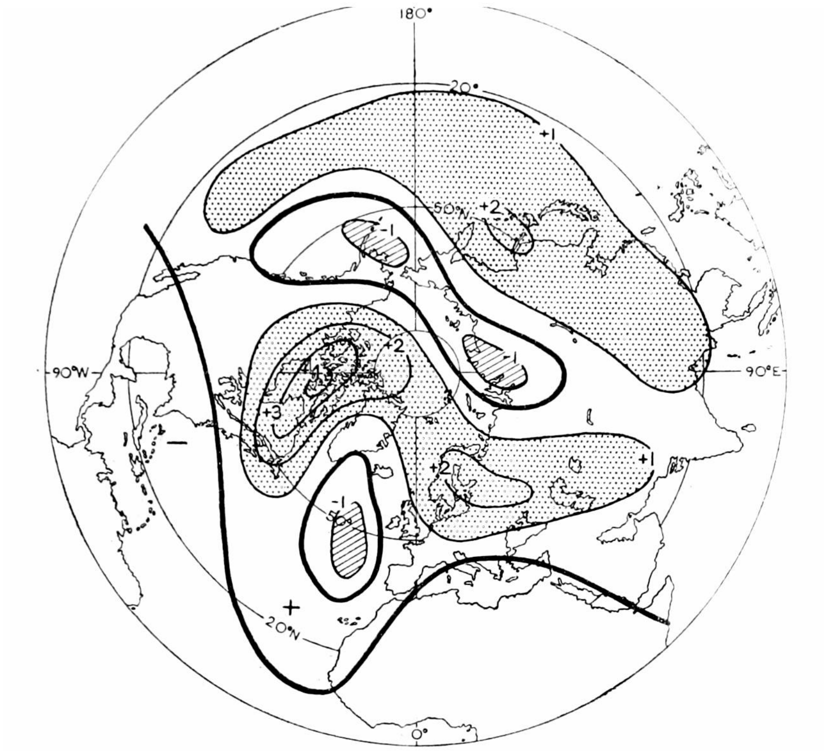


FIGURE 4—FEBRUARY/MARCH

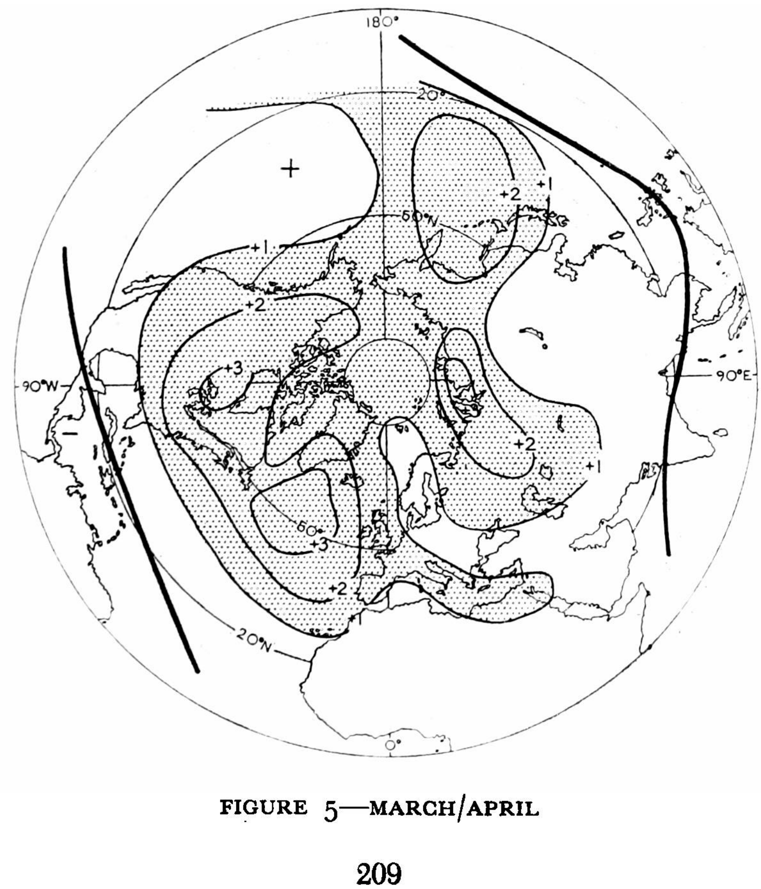


FIGURE 5—MARCH/APRIL

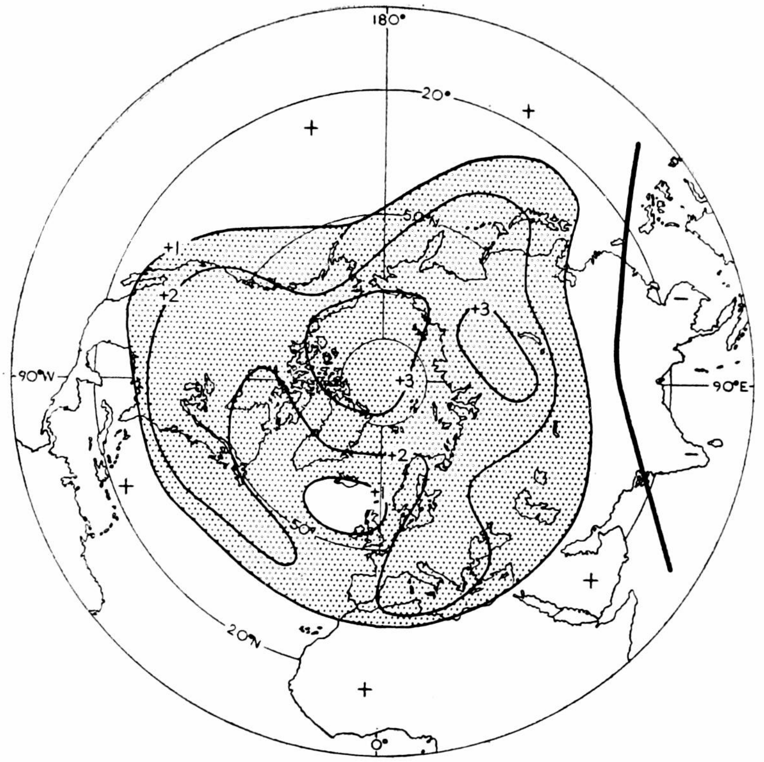


FIGURE 6—LOCAL RATE OF CHANGE OF THE TOTAL HEAT CONTENT OF THE TROPOSPHERE IN THE NORTHERN HEMISPHERE, APRIL/MAY

Unit: 10^{-4}g cal $cm^{-2}s^{-1}$

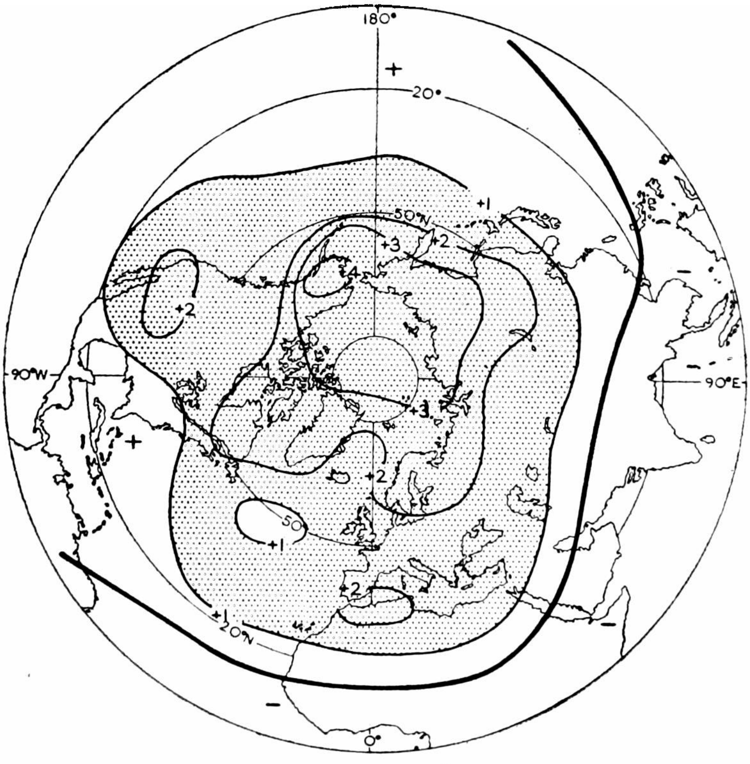


FIGURE 7—MAY/JUNE

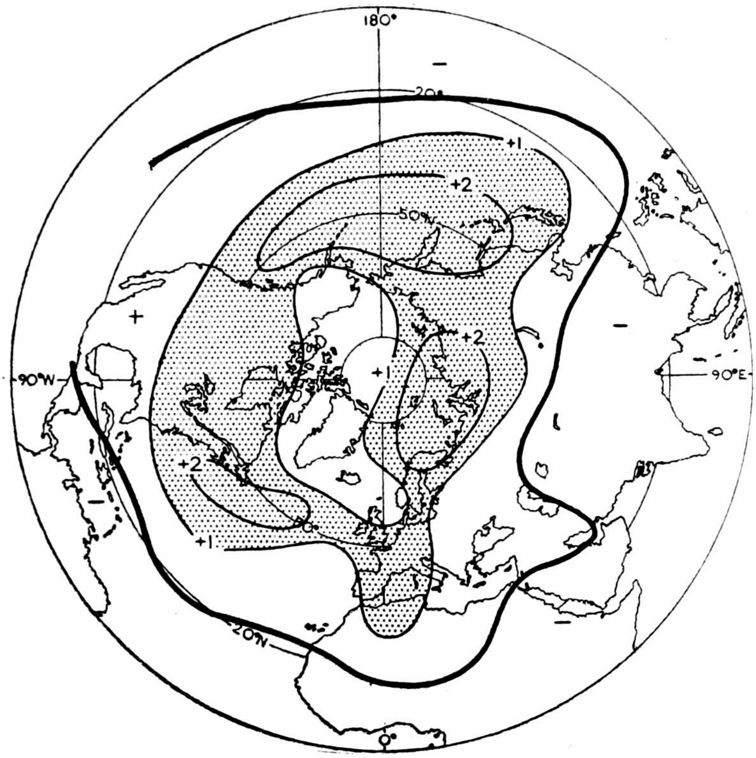


FIGURE 8—JUNE/JULY

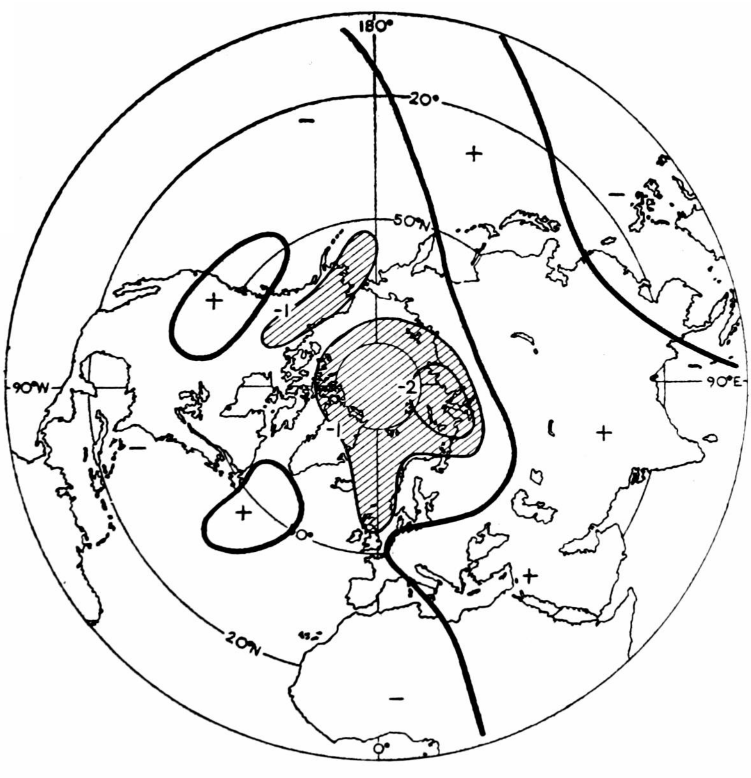


FIGURE 9—JULY/AUGUST

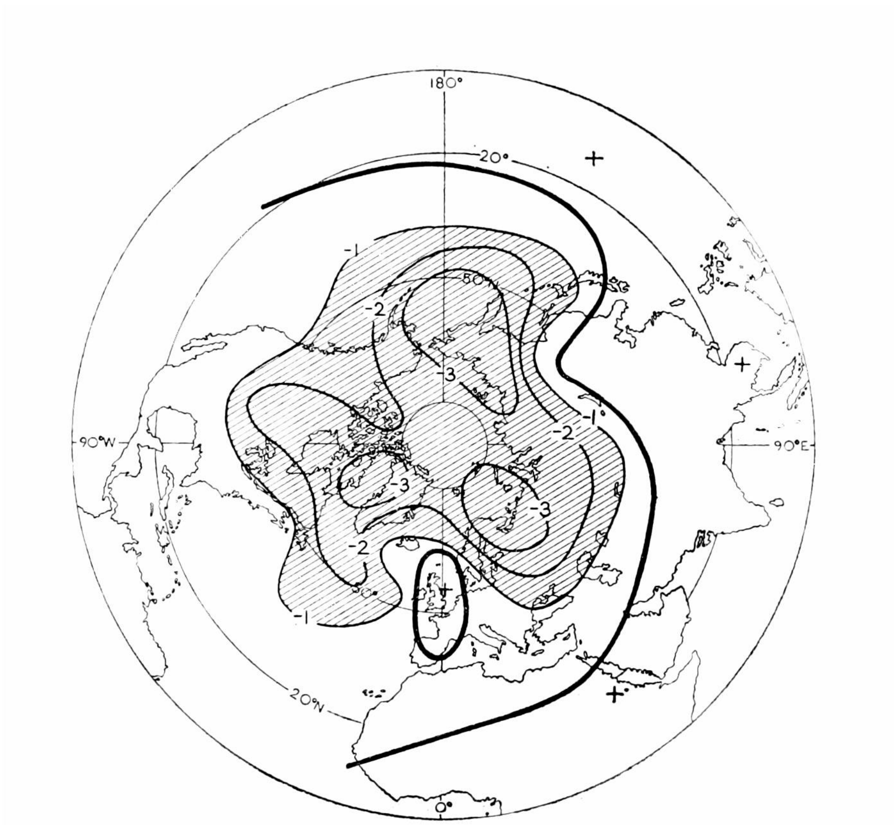


FIGURE 10—LOCAL RATE OF CHANGE OF THE TOTAL HEAT CONTENT OF THE TROPOSPHERE IN THE NORTHERN HEMISPHERE, AUGUST/SEPTEMBER

Unit: 10^{-4}g cal cm^{-2}s^{-1}

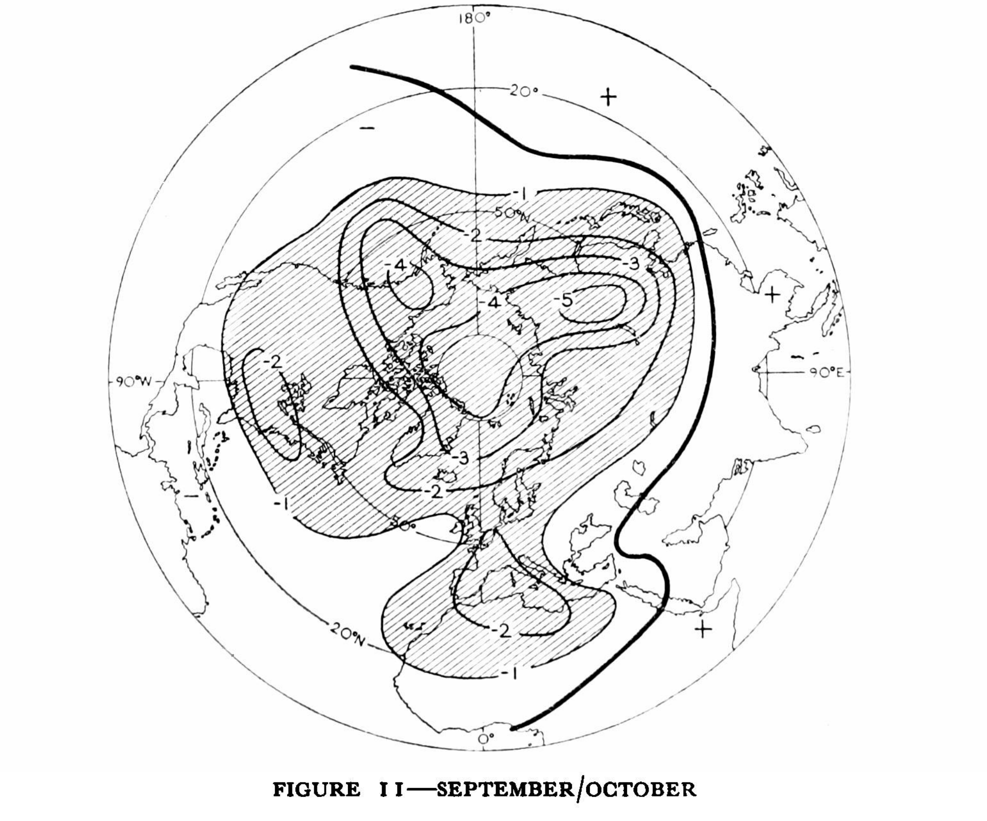


FIGURE 11—SEPTEMBER/OCTOBER

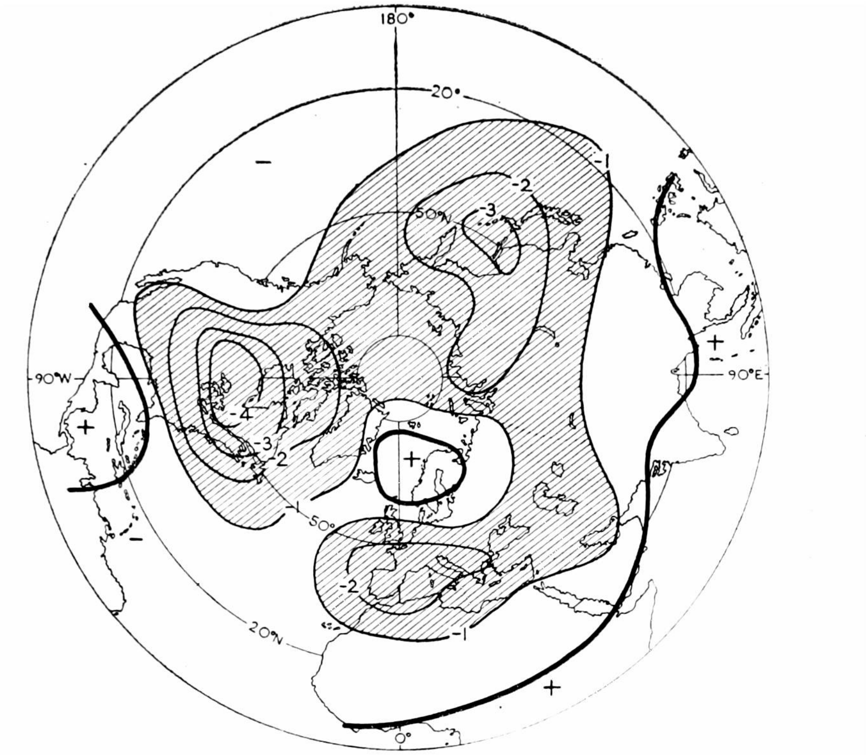


FIGURE 12—OCTOBER/NOVEMBER

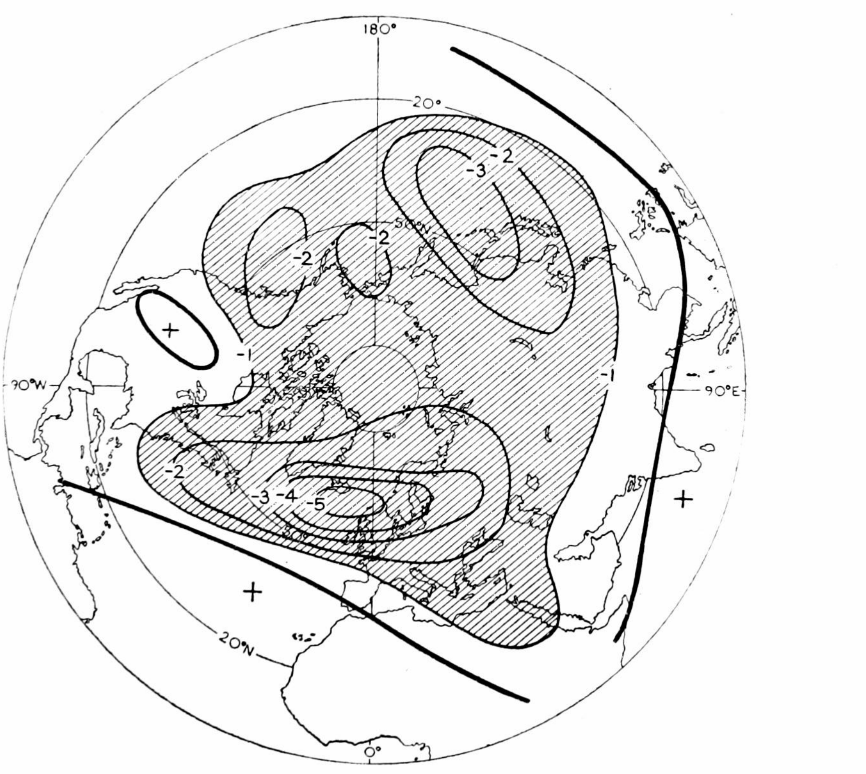


FIGURE 13—NOVEMBER/DECEMBER

Conclusion.—Although the charts given here simply depict the seasonal march of temperature in the northern hemisphere troposphere, several interesting aspects of the geographical distribution are revealed. On a global scale, cooling commences in an area near the pole in late summer and strengthens and spreads in a more or less axially symmetrical way until late autumn and early winter when asymmetry becomes most pronounced. The most intense cooling of over 5×10^{-4} g cal cm^{-2}s^{-1} occurs in the north-west Atlantic in early winter. The reverse is true of warming when in late winter and early spring there is pronounced asymmetry in the pattern; in late spring and early summer the pattern is more uniform and centred on the pole. Longitudinal variations are therefore features of several charts but there is no obvious relation between these variations and the pattern of land/sea distribution.

The winter patterns of local heating and cooling (Figures 2 and 3) bear little resemblance to the charts of heat sources and sinks for a normal winter, given for example, by Clapp[1], and have values an order of magnitude lower. This strongly suggests that any attempt to use equation (1) to estimate the pattern of local heating (e.g. Adem[5]) is unlikely to be successful unless the effects of redistribution of heat by atmospheric motions are adequately represented. Shaw[3] presents strong evidence to suggest that this cannot be done simply by relating these effects to the mean temperature field using a form of large-scale 'austausch' coefficient.

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551.501.5:551.571.7

A USEFUL SYNOPTIC REPRESENTATION OF MOISTURE

By T. H. KIRK

Most synoptic meteorologists would agree that, in present practice, inadequate attention is paid to variations of humidity. Although it is true that individual radiosonde ascents are studied in detail, the systematic charting of humidity has not yet been regarded with much favour and, hitherto, little advantage has been derived from this approach.

At the British Central Forecasting Office (CFO), Bracknell, charts are drawn depicting the dew-point depression at the 700 mb level. The practice is to mark areas where the dew-point depression is less than 5°C (i.e. moist) and areas where the dew-point depression is greater than 20°C (i.e. dry). Although easy to construct, these charts are of limited use chiefly because of the large fluctuations in the positions of the critical lines. These fluctuations may be real as, for example, in situations where the humidity decreases rapidly at a level near the 700 mb surface, or fictitious because of the limitations of humidity measurement. Perhaps the main difficulty, however, is that a value applicable to a particular level cannot be regarded as representative of a layer.

For many purposes it would appear reasonable and profitable to treat humidity on a 'layer' basis, much as temperature has been treated in terms of 'thickness'; for example the mean dew-point depression taken over the layer 1000 mb to 700 mb might confidently be expected to be more representative than a spot value and the humidity patterns drawn in terms of mean values should show greater continuity and conservation. To work out mean values using observations from several levels would be tedious and, where the dew-point fluctuates erratically, the final result would depend on the particular points chosen unless these were numerous.

This procedure may be avoided by the concept of 'dew-point thickness' which may be defined as the thickness of the layer, say 1000–700 mb, on the assumption that the dew-point curve is treated as a temperature curve. In other words, the dry-bulb temperature curve defines the true thickness whereas the dew-point temperature curve, treated as a temperature, defines the 'dew-point thickness'. The same procedure, graphical or numerical, for determining the thicknesses may be used for both.

If T (°A) be the dry-bulb temperature and T' (°A) the dew-point, then $T - T'$ is the dew-point depression. To get an average value over a layer the dew-point depression must be integrated with respect to the vertical co-ordinate. Therefore, using the logarithm of the pressure as the vertical co-ordinate,

$$\int (T - T')\, d(\log p) = \int T\, d(\log p) - \int T'\, d(\log p)$$

and therefore $$-\frac{R}{g}\int (T - T')\, d(\log p) = -\frac{R}{g}\int T\, d(\log p) + \frac{R}{g}\int T'\, d(\log p),$$

where R and g have their usual significance.

But $(-R/g)\int T\, d(\log p) = h$, where h is the thickness of the layer between the two chosen standard pressure levels, while $(-R/g)\int T'\, d(\log p)$ is the corresponding 'dew-point thickness'.

It is therefore possible to write

$$-\frac{R}{g}\int (T - T')\, d(\log p) = h - h',$$

and this gives the result that the difference between the thickness and the 'dew-point thickness' of a layer is a measure of the average dew-point depression. Just as h may be regarded as representative of the average temperature of a layer, so h' may be regarded as representative of the average dew-point. The technique therefore permits the easy evaluation, for any layer, of the average dew-point and the average dew-point depression.

This method has been used, with limited data, for the 1000–700 mb and 1000–500 mb layers and charts have been drawn depicting these quantities Experience shows that the 'dew-point thickness' is, in general, related to the frontal analysis as would be expected on conventional air-mass considerations. The detail, showing variations from one chart to the next, can be of assistance in the interpretation of frontal structure and activity. The 'dew-point thickness depression' measures the departure from saturation of the layer and is naturally inversely correlated with areas of cloudiness and precipitation.

Figures 1–4 show the distribution of 'dew-point thickness' and 'dew-point thickness depression' for the 1000–700 mb layer for 1200 GMT on 9 December and 0000 GMT on 10 December 1964. The isopleths, in units of 5 decametres,

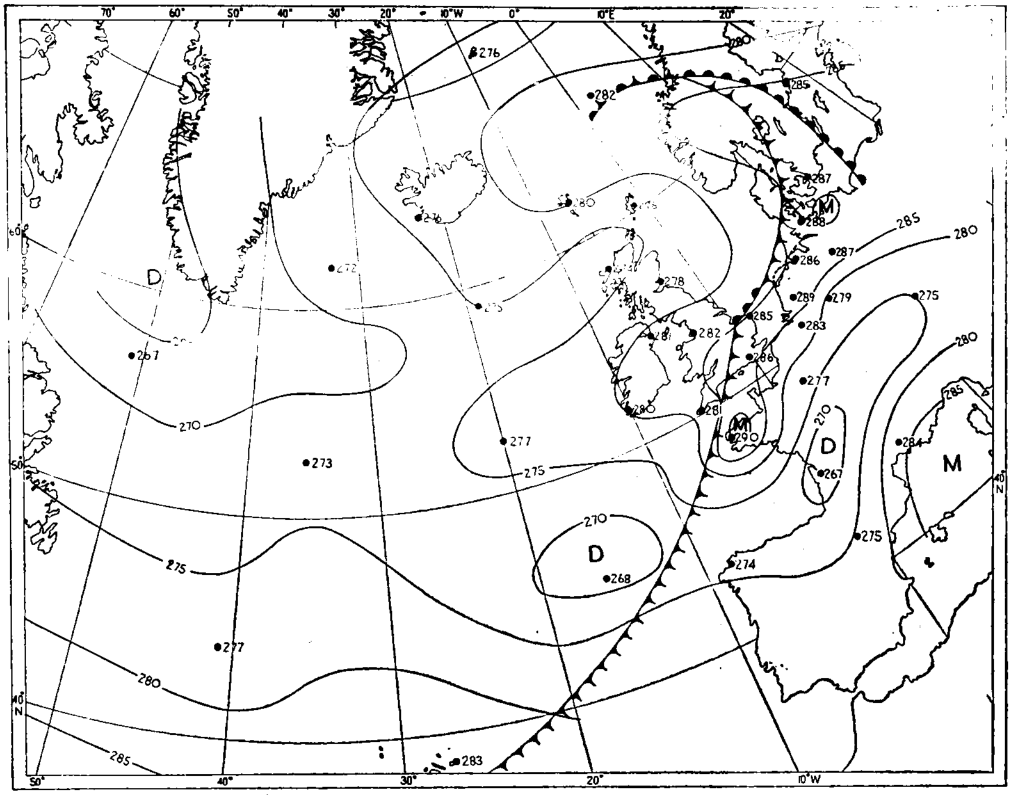

FIGURE 1—'DEW-POINT THICKNESS', 1000–700 MB, 1200 GMT 9 DECEMBER 1964

Thickness values and isopleths are in decametres; the former values are plotted on the right of the station position.

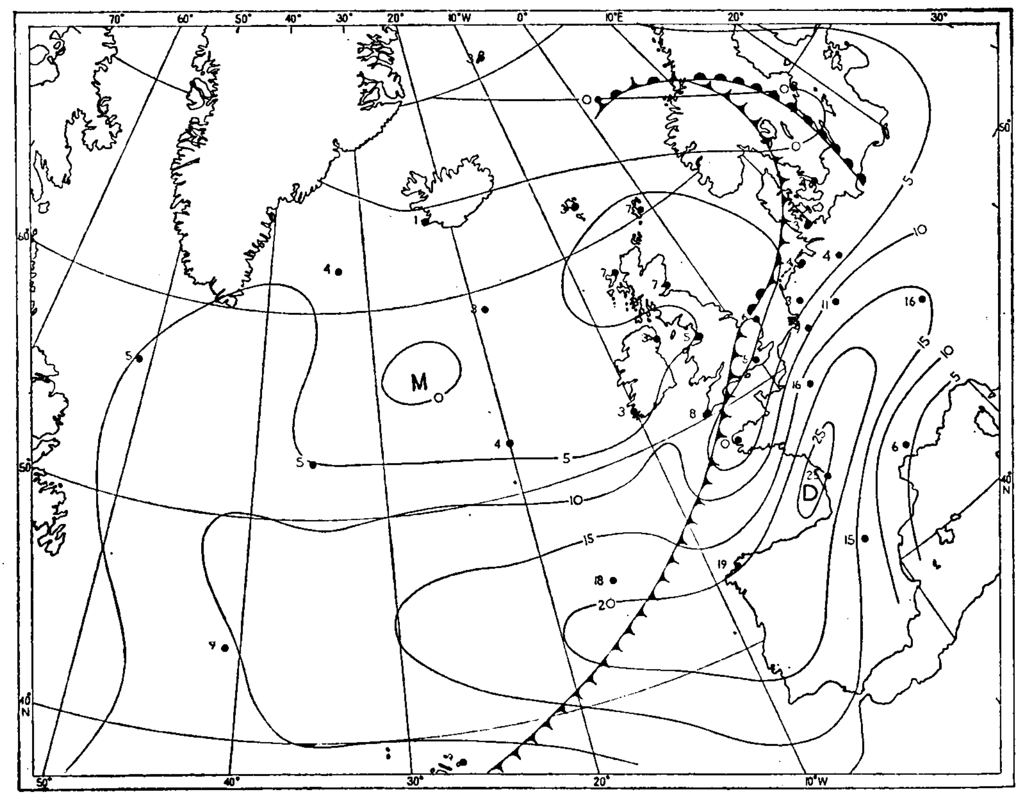

FIGURE 2—'DEW-POINT THICKNESS DEPRESSION', 1000–700 MB, AT 1200 GMT ON 9 DECEMBER 1964

The 'dew-point thickness depression' is plotted on the left of the station position in decametres.

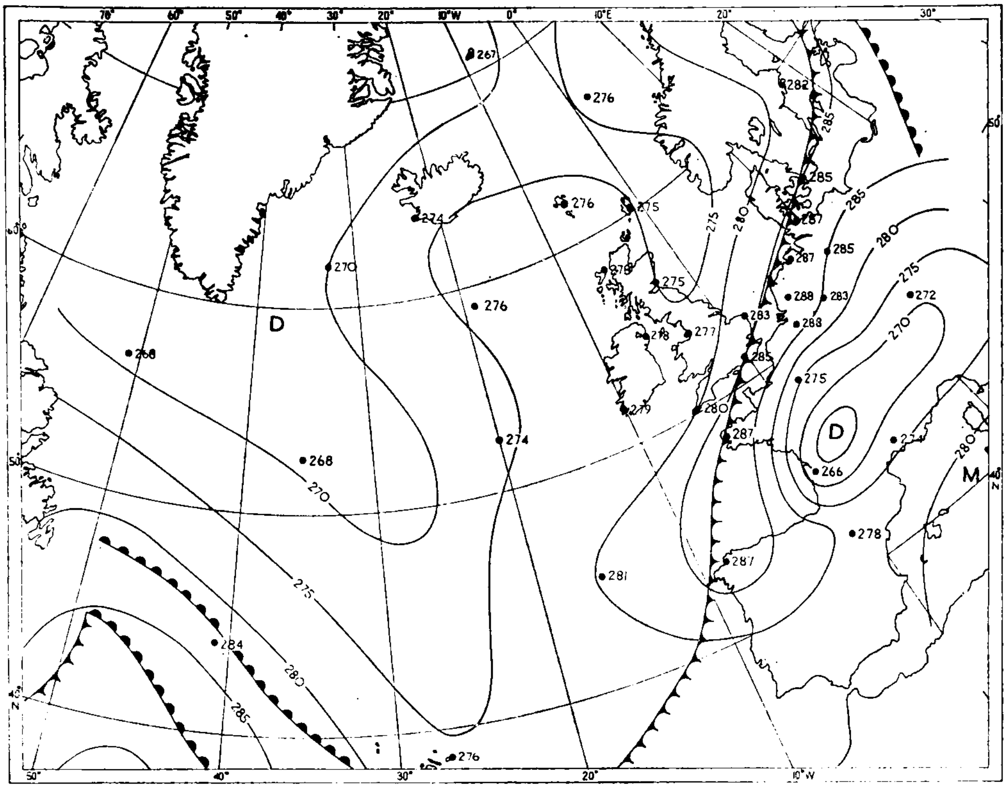

FIGURE 3—'DEW-POINT THICKNESS', 1000–700 MB, 0000 GMT 10 DECEMBER 1964
Thickness values and isopleths are in decametres; the former values are plotted on the right of the station position.

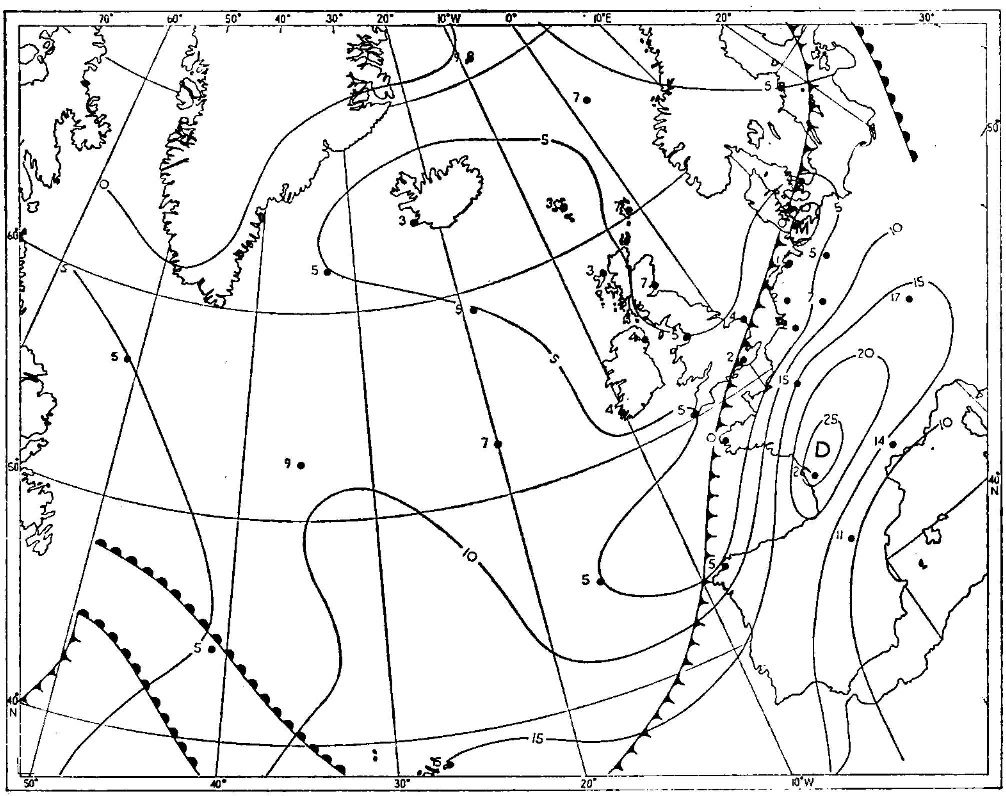

FIGURE 4—'DEW-POINT THICKNESS DEPRESSION', 1000–700 MB, AT 0000 GMT ON 10 DECEMBER 1964
The 'dew-point thickness depression' is plotted on the left of the station position in decametres

were drawn independently using the values shown at each station and the fronts were taken from the CFO facsimile charts and superimposed without amendment.

It is outside the scope of this note to discuss these charts in detail; they are presented solely as an illustration of the potential value of the method. There is, of course, no restriction to the particular layers chosen; charts may be drawn for any layer for which humidity observations are available. Temperature parameters other than dew-point could also be used in a similar way.

It is noted that Swayne[1] makes a somewhat analogous use of thickness in which precipitable water is related to 'saturation thickness'. This is defined as the thickness between the specified constant-pressure surfaces of a saturated pseudoadiabatic column having the same precipitable water value as the observed column.

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551.509.3:551.515.8:681.14

A NOTE ON THE OBJECTIVE LOCATION OF FRONTAL ZONES

By P. E. CARLSON, J. L. GALLOWAY and P. C. HAERING

A relatively short paper by R. J. Renard, U.S. Naval Postgraduate School and L. C. Clarke, U.S. Navy Fleet Numerical Weather Facility, Monterey, California, slipped unobtrusively into the General Session I of the 45th Annual Meeting of the American Meteorological Society in New York on 27 January 1965, marks another step forward in the development of objective frontal analysis.

Although meteorologists welcomed the Bjerknes model of the extratropical frontal depression nearly 50 years ago there has never been any international agreement on how and where in any particular case the fronts should be drawn. The United Nations Educational Scientific and Cultural Organization/World Meteorological Organization seminar on Mediterranean synoptic meteorology in 1958[1] probably came as near as anything to some kind of unanimity in this field. The placing of fronts has been the work of individuals and even within services a common form of training has not produced an overall entirely objective form of analysis. It is true that the Russians have a two-front model but there can be no doubt that the first attempt in the west to systematize frontal analysis throughout the troposphere was the work of Canadian meteorologists in the years succeeding World War II. The work was publicized by the Royal Meteorological Society and the American Meteorological Society and was the subject of an address by Professor B. W. Boville to the Meteorological Office in 1955[2] but it has not yet caught on. Mr. J. S. Sawyer in his Presidential Address to the Royal Meteorological Society in 1964 remarked "it is probably an attempt to force nature into an over-rigid model which has limited the interest in frontal contour analysis."

What the Canadians did was to locate baroclinic zones at the 500, 700 and 850 mb levels by means of thickness and isotherm gradients, insert fronts and extrapolate them upwards to the jet streams and downwards to the surface. In this way a reasonably objective self-consistent frontal analysis was obtained on a routine basis by subjective means.

Montreal meteorologists had a recent opportunity of hearing Professor Renard, who lectured in the Central Analysis Office (CAO) of the Canadian Meteorological Branch on 29 January, and who has made an extensive study of Canadian methods.

In Professor Renard's view an adequate amount of data containing frontal information is now being fed into computers to enable these machines, when properly programmed, to furnish an objective frontal analysis. He and Mr. Clarke have defined a frontal parameter which is used to locate objectively the frontal-zone boundaries as well as the maximum baroclinicity within the zone. The parameter, actually a form of the second derivative of a variable, is versatile to the extent that any conservative air-mass quantity may reasonably be used as the variable. Some amount of experimental work has been done with potential and equivalent potential temperature at the 1000 and 850 mb levels, as well as at the surface. A full report on the status of the frontal-analysis project has been submitted for publication in the *Monthly Weather Review* and is to be entitled 'Experiments in Numerical Objective Frontal Analysis,' by R. J. Renard and L. C. Clarke.

Northern hemisphere charts for 1 January 1965 were presented to illustrate results of the technique and reference to the CAO hand analyses for that day showed excellent agreement with the machine-computed fronts. The polar front was not being carried by the CAO as being too far south, over Central America, but the Maritime and Arctic fronts on the North American land mass came out of the comparison well, as did the Maritime front in the north-eastern Pacific. The numerical analyses picked out the cold-valued Arctic front (between tcA and cA) in the Canadian north-west.

One of the advantages of a systematic frontal contour analysis is the easy association of a front with a statistically determined range of temperatures. By mention of the name of the front one gets an immediate picture of the temperature field, tropopause height and so on. It is not too much to expect that in the near future meteorological satellites will be able to measure tropospheric temperatures and hence indicate the extent of each air mass—and the name of the front in any location.

It appears that synoptic frontal analysis is entering the machine and space age.

REFERENCES

1. BLEEKER, W.; The UNESCO/WMO seminar on Mediterranean synoptic meteorology. *Met. Abh., Berlin*, **9**, Part 1, 1960.
2. London, Meteorological Office. Meteorological Office Discussion. *Met. Mag., London*, **85**, 1956, p. 83.

METEOROLOGICAL OFFICE DISCUSSION

Hydrological forecasting

The last Monday discussion of the 1964–65 session was held at the Royal Society of Arts on 15 March. The opener, Mr. A. Bleasdale, briefly covered the range of topics which appear under the heading of hydrological forecasting in international literature. Some of these are not of great practical importance in the United Kingdom but are of obvious significance within other climatic régimes and hydrological environments, so that they form major sub-divisions of a large and growing subject. Such items include the forecasting of seasonal and annual run-off, notably where melting snow contributes a large proportion, with a regular seasonal incidence, of the total annual flow; the prediction of the formation and break-up of ice on navigable rivers; and the forecasting, for lakes and other land-locked waters, of seiches or storm surges which, as on Lakes Manitoba and Erie, may have amplitudes up to 12 feet.

In the United Kingdom hydrological forecasting is, in practice, restricted almost entirely to the operation of flood-warning schemes, but with considerable interest from time to time in the eventual possibilities of developing techniques which would be useful in the field of water supply and the management of water resources. Flood-warning systems have been developed mainly by the engineers of river authorities (formerly river boards) in England and Wales, and the Meteorological Office has helped in the work in two main ways. In some cases, usually through outstations or Weather Centres, the Office is well equipped to provide information about the coming of rainfall which might cause flooding, or alternatively to advise on and help with the organization of prompt rainfall reports from voluntary observers. Secondly, for some years now the Climatological Services Branch has issued from Bracknell a series of maps showing estimated soil moisture deficits over the whole country. Though the maps are very generalized and on a very small scale, they provide a useful indication, much appreciated by the river authority engineers for whom they are primarily intended, of the development of susceptibility to flooding as soil moisture deficits decrease.

The opener touched on the possibility of using radar to make areal assessments of rainfall for use in flood-warning schemes, but it was left to Dr. Caton in a major contribution to the general discussion to enlarge on this theme. Most of the remaining discussion was concerned with radar techniques of rainfall measurement, or with experience at outstations and Weather Centres in collaborating in flood-warning work. It was particularly stimulating to hear in this way of the contacts which have been established, and in closing the discussion the Chairman, Dr. A. C. Best, commented on the interesting contributions which had been made.

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THIRD ASSEMBLY OF THE SPECIAL COMMITTEE FOR THE INTERNATIONAL YEARS OF THE QUIET SUN, MADRID, 1965

The Third Assembly of the ICSU (International Council of Scientific Unions) Special Committee for the International Years of the Quiet Sun (IQSY) was held in Madrid between 28 March and 3 April, 1965. Some 150 scientists, from 35 countries and many disciplines, attended.

The main purpose of the assembly was to have prepared, and accepted, reports of the many Working Groups. Most of these reports contained a recommendation urging the continuance of programmes initiated or intensified during the IQSY. Reluctance to see programmes close down, or to see them reduced, is, I suppose, natural. Yet the whole concept of periods such as the IGY and the IQSY is to concentrate effort into *limited intervals*. This urge to keep them all going may not, in the long run, be in the best interests of science.

The Meteorological Working Group also recommended the continuation of the World Day Programmes and of STRATWARM alerts. The group recommended, too, that the World Meteorological Organization should arrange for the central collection and publication of meteorological rocket data and of noctilucent cloud data on the lines of the existing collection and publication of ozone and radiation data.

In addition to Working Group activities there were a number of review papers. From Mrs. Dodson-Prince, of the solar activity discipline, came a report on how 'quiet' the sun in fact is during this Quiet Sun period. Solar activity is never the same from one cycle to the next and the present 'minimum' has, it seems, been exceptionally different. The actual minimum seems to have occurred in June last year, in the sense that solar activity of the new cycle then began to appear (sunspots can be identified as belonging to the old, or to the new, cycle by their 'polarity'). However, there has still been little decrease in old cycle activity, so that the minimum was not very marked. It was suggested, indeed, that when the old cycle does die there may be a secondary minimum as did occur once last century. The new cycle is itself anomalous in that, of the large number of sunspots so far recorded, all save one have been in the 'northern' hemisphere. Usually they are more or less equally distributed between the hemispheres. A similar uneven distribution was recorded long ago but, I gathered, this had until now been regarded with suspicion.

From the meteorology discipline Dr. Godson reported further on his investigations into quasi-biennial oscillations. If I understood him correctly, he finds that, whereas in tropical latitudes the oscillations show a well-defined 'period' of just short of 26 months, with no discernible variation of period or phase with longitude, at higher latitudes not only are the oscillations weaker, as is well known, but the phase of the oscillations varies with longitude, and the 'period' becomes less well defined. To some members of the audience the curves which he presented for these higher latitudes were hard to distinguish from curves of 'noise' but Godson, emphasizing similarities between curves prepared from what he recorded as independent sets of data (sets relating to different geographical areas—there are not yet sufficient data to study different epochs separately) expressed some conviction that there really is not just a single quasi-biennial oscillation with period close to 26 months, but a whole collection of oscillations with periods ranging between 18 and 30 months. No mechanism for the maintenance of even one, let alone a family, of such oscillations being known, Godson, likening the atmosphere to a clock with no perceptible pendulum or balance wheel, remarked that it was truly a 'cuckoo' clock and perhaps a somewhat 'alarming' one too.

From the ionospheric discipline Mr. Shapley described an investigation into a correlation between the absorption of radio waves in the ionosphere at round about 90 km, and the temperature in the lower stratosphere. He had taken 16 cases where a stratospheric warming, lasting for a few days, occurred over Berlin, the 30 km temperature curve showing a marked peak, and he demonstrated that there was a strong tendency for a similar peak to occur in the ionospheric absorption curve at precisely the same time. Did the atmosphere at 90 km, he asked, know what was happening at 30 km?

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REVIEW

Atmospheric radiation; Volume I. *Theoretical basis* by R. M. Goody. 9¼ in × 6 in, pp. xi + 436, *illus.*, Clarendon Press, Oxford University Press, Oxford, 1964. Price: 75*s*.

This is the second of the Oxford Monographs on Meteorology (editor P. A. Sheppard) which are intended to deal thoroughly with the basic theory of the subject and provide standard references and textbooks at university post-graduate level. In it Professor Goody has provided a comprehensive presentation of the problems of atmospheric radiation based on the fundamental laws of physics and applicable to planetary atmospheres in general. The treatment is erudite and, before he can hope to appreciate its contents, the student will have to know his basic physics and mathematics well. A useful list of references to source books and original papers is given at the end of each chapter together with advice on further reading. Extensive appendices are also provided on such subjects as spectroscopic units, model atmospheres, the physical state of the sun, optical properties of water and ice, the principal functions used in radiation calculations, etc. In general the subject matter is restricted to basic theory, spectroscopy, computation methods, etc. and their application to theoretical problems. It is hoped that a companion volume will ultimately be produced to deal with practical aspects such as instrumentation, radiation climatology, etc.

In his introductory chapter the author first outlines the nature of the problem. As the source of virtually all the earth's energy is solar electromagnetic radiation, the absorption of parts of the solar spectrum at different levels in the atmosphere, the earth's albedo, and absorption at the surface are first considered. The emission of low-temperature thermal radiation must closely balance in the mean the absorption of the solar radiation and this establishes the mean atmospheric temperature, whereas unbalance between latitudes leads to the general circulation. The solar radiation is virtually confined to wavelengths below about 4μ while the terrestrial radiation is mainly above 4μ, so that they can be treated separately. Since N_2, O_2, and A are almost transparent to radiation of the longer wavelengths, it is the minor polyatomic constituents which are important in terrestrial radiation and their effects are therefore to be studied in detail. Further sections in this chapter outline the thermal structure of the atmosphere and its chemical composition at different levels in some detail.

The author then gives in Chapter 2 a thorough treatment of the theory of radiative transfer in the atmosphere dealing first with extinction and heating. Emission is discussed in terms of the basic concepts of thermodynamic equilibrium and the interaction of matter and radiation. Finally the integral transfer equations are derived and the mathematical problems of obtaining the radiative fluxes and heating from them by numerical and also approximate methods, are discussed. These equations involve the complex absorption spectra of the radiatively important atmospheric constituents and Chapter 3 is therefore devoted to the theory of gaseous absorption and the physical processes determining these spectra. This includes much of the basis of spectroscopy including the behaviour of the various energy modes of the molecules (translational and the quantized rotational, vibrational and electronic modes) and the emissions or absorptions linked with transitions between the various energy levels. This leads to the theoretical prediction of the spectra from the molecular structure and also, since the processes are not strictly monochromatic, the derivation of the Lorentz shape of the spectral lines and broadening due to Doppler and collision effects. Since the spectra are complex and have very fine structure it is necessary for both interpreting measurements and limiting computational effort to develop averaging techniques. Chapter 4 is therefore devoted to band models—infinite arrays of absorption lines with uniform statistical properties—which will simulate the true spectra. The discussion starts with single line models, which are chiefly of interest when the lines do not overlap but are necessary to introduce fundamental ideas such as the weak and strong line approximations. The chapter then discusses well-known regular models due to Elsasser and others and the random models first studied by the author himself. Questions of generalizing to models which are neither regular nor random and restrictions on model theory are considered in some detail. Chapter 5 is a detailed review of absorption data for N_2, O_2 H_2O, CO_2, O_3, N_2O, CH_4 and NO. Many figures and tables are given and 10 pages of references so that this is probably one of the most useful and up-to-date sources of data which are now readily available. Using these data and the theoretical ideas of the previous chapters, a discussion on the computation of fluxes and heating rates is given in Chapter 6. This involves the estimation of radiation transfer in the real inhomogeneous atmosphere and both theoretical and practical aspects are fully considered. These include such subjects as scaling approximations (of which that due to Curtis and Godson is probably the most successful), the treatment of diffuse radiation, calculations of direct heating by the solar beam, all the well-known radiation charts (e.g. Mügge-Möller, Yamamoto, Elsasser, Kew etc.), the previously unpublished Curtis two-parameter method of calculation and several other recent developments. There are many points of interest including an example of intercomparison of results using different radiation charts, and the reader will be disappointed to learn that there can be a spread of the order of 50 per cent in both fluxes and heating rates computed in this way. On the other hand, considerably greater accuracy is likely by using modern machine methods and its may soon be worthwhile to incorporate radiation data in numerical weather or general circulation prediction schemes (provided of course that other factors such as cloud formation can be properly specified).

The subject of extinction by molecules and droplets including scattering by large and small particles, geometric optics and Mie theory is dealt with in the next chapter. The basic problem of radiative equilibrium which bears on the general thermal structure of the atmosphere and the necessity for atmospheric motions is considered in Chapter 8. The outline of the underlying theory is followed by a longer discussion on the lower stratosphere, whose characteristic features are basically determined by radiation considerations, and the requirement for a convective troposphere below. This problem is of course a classical one associated with names such as Emden, Gold, Humphreys, Milne and more recently Simpson, Dobson, Goody himself and Manabe and Möller and the development of modern ideas is fully and clearly presented. Finally in the last chapter the interrelation of radiative transfer and fluid motions is discussed. The former affects the heating rate through the divergence of the radiation flux and the latter through that of the advective and turbulent fluxes. Practical applications include lower-troposphere problems such as the diurnal temperature wave, night cooling, the onset of cellular convection (which follows the treatment of the author's previous papers on this subject) and the modification by radiation considerations of the Richardson criterion for the onset of turbulence.

In summary, this is clearly a very important book and is unique in its coverage of the present-day state of the subject so that it is a 'must' for meteorological libraries, research workers and advanced students. The production is excellent and the price very reasonable for a book of this standard.

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OBITUARY

Mr. H. T. Smith.—It is with very deep regret that we have heard of the death of Mr. H. T. Smith on 5 April 1965. An appreciation of his many years of service in the Office appeared in the March, 1958 issue (page 94) of this magazine. Our deepest sympathy is extended to his widow and family in their sad loss.

D.J.W.