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SIMPLE MEASURES OF THE RAININESS OF A MONTH

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Introduction.—It has been recognized for a long time that the 'wetness' or 'raininess' of a month is not always well represented by the total rainfall of the month. Some other rainfall parameter might be a more meaningful indicator, but there would be little point in devising such a parameter unless it were more closely related to the synoptic character of the month than monthly rainfall and also readily understandable by recipients of long-range forecasts. Certain parameters, such as the sum of the cube roots of the daily rainfalls, might be useful for statistical purposes but would hardly satisfy either of the above provisos.

It is natural to consider another simple statistic, namely number of rain-days, especially since climatological data for this parameter are fairly plentiful. However, rain-days are officially defined as days with at least 0.2 mm of rain, and it may be contended that rainfall amounts of less than about 1 mm are too small for the purpose of representing the wetness of a day and for monthly forecasting purposes. It was therefore decided to examine the monthly rainfall at Kew in May in relation to rain-days defined as days with (1) at least 0.2 mm, (2) at least 1 mm, (3) at least 2 mm and (4) at least 3 mm of rainfall. In addition the association of the various rainfall parameters with circulation types as indicated by the monthly mean pressure maps was investigated. Kew rainfall was used simply because daily rainfall data were available. The period studied was the 78 years from 1873 to 1950.

Relationship between monthly rainfall and rain-days.—A correlation exists between monthly rainfall and the number of rain-days in the month, whatever threshold is taken to define a rain-day, as can readily be seen by plotting the two rainfall statistics on a scatter diagram.

Since the present practice is to attempt to predict monthly rainfall in terciles, it is useful to show the association between terciles of monthly rain and terciles of rain-days, by means of contingency tables. From frequency tables of monthly rainfall R and number of rain-days N (lower limit 0.2 mm), N_1 (lower limit 1 mm), N_2 (lower limit 2 mm) and N_3 (lower limit 3 mm) approximate tercile boundaries were readily obtained and contingency Tables I (*a*)–(*d*) were prepared.

TABLE I—KEW RAINFALL IN MAY RELATED (IN TERCILES) TO RAIN-DAYS

(*a*) Type N (where rainfall is 0.2 mm or more per day)

Rain-days of type N	Monthly rainfall R Lowest tercile $\leqslant$ 33 mm	Middle tercile 34–47 mm	Highest tercile $\geqslant$ 48 mm	Total
	number of occasions			
Lowest tercile $\leqslant$ 9 rain-days	18	4	2	24
Middle tercile 10–13 rain-days	7	16	5	28
Highest tercile $\geqslant$ 14 rain-days	1	6	19	26
Total	26	26	26	78

(*b*) Type N_1 (where rainfall is 1 mm or more per day)

Rain-days of type N_1	Monthly rainfall R Lowest tercile $\leqslant$ 33 mm	Middle tercile 34–47 mm	Highest tercile $\geqslant$ 48 mm	Total
	number of occasions			
Lowest tercile $\leqslant$ 6 rain-days	18	3	1	22
Middle tercile 7–9 rain-days	8	17	4	29
Highest tercile $\geqslant$ 10 rain-days	0	6	21	27
Total	26	26	26	78

(*c*) Type N_2 (where rainfall is 2 mm or more per day)

Rain-days of type N_2	Monthly rainfall R Lowest tercile $\leqslant$ 33 mm	Middle tercile 34–47 mm	Highest tercile $\geqslant$ 48 mm	Total
	number of occasions			
Lowest tercile $\leqslant$ 4 rain-days	19	5	1	25
Middle tercile 5–7 rain-days	7	16	5	28
Highest tercile $\geqslant$ 8 rain-days	0	5	20	25
Total	26	26	26	78

(*d*) Type N_3 (where rainfall is 3 mm or more per day)

Rain-days of type N_3	Monthly rainfall R Lowest tercile $\leqslant$ 33 mm	Middle tercile 34–47 mm	Highest tercile $\geqslant$ 48 mm	Total
	number of occasions			
Lowest tercile $\leqslant$ 3 rain-days	19	8	0	27
Middle tercile 4–5 rain-days	7	10	6	23
Highest tercile $\geqslant$ 6 rain-days	0	8	20	28
Total	26	26	26	78

It will be noted that the numbers in each tercile are equal for monthly rainfall but only approximately so for rain-days owing to the limitations of the sample. It must be borne in mind when comparing the tables that the estimated terciles of rain-days suffer from this defect.

Broadly speaking there is a fairly close association between rainfall terciles and rain-days in all categories. It appears that in going from the lowest threshold of daily rainfall for defining a rain-day to the highest threshold the number of most anomalous cases (i.e. a highest tercile related to a lowest tercile and vice versa) is reduced from 3 in Table I(*a*) to 0 in Table I(*d*), but the cases in closest relationship (i.e. where terciles are related to terciles of the same type) are reduced from 53 in Table I(*a*) to 49 in (*d*). Actually Tables I(*b*) and (*c*) suggest a slightly better relationship between the monthly rainfall and number of rain-days than do Tables I(*a*) and (*d*), but the differences between the tables are marginal.

Relationship between rainfall parameters and monthly mean pressure anomaly at Kew.—Were it possible to predict monthly mean pressure anomaly either quantitatively or qualitatively by virtue of forecasting the circulation character of the month, it would be desirable to know the relationship between such anomalies and the various rainfall parameters in terciles. There is a fairly good relationship between pressure anomaly (Δp) and each of the various rainfall parameters. The present sample suggests that N (i.e. ⩾ 0.2 mm) is slightly more closely associated with Δp than are either N_3 (i.e. ⩾ 3 mm) or R. Tables II and III show the relationship between the pressure anomaly and N and R respectively.

TABLE II—KEW RAIN-DAYS IN MAY RELATED (IN TERCILES) TO MONTHLY MEAN PRESSURE ANOMALY

Monthly mean pressure anomaly Δp	Rain-days of type N: Lowest tercile ⩽ 9	Middle tercile 10–13	Highest tercile ⩾ 14	Total
	number of occasions			
⩽ −2 mb	1	4	15	20
−1 to +1 mb	8	14	8	30
⩾ +2 mb	15	10	3	28
Total	24	28	26	78

Rain-days of type N have 0.2 mm or more of rainfall per day.

TABLE III—KEW RAINFALL IN MAY RELATED (IN TERCILES) TO MONTHLY MEAN PRESSURE ANOMALY

Monthly mean pressure anomaly Δp	Monthly rainfall R: Lowest tercile ⩽ 33 mm	Middle tercile 34–47 mm	Highest tercile ⩾ 48 mm	Total
	number of occasions			
⩽ −2 mb	0	8	12	20
−1 to +1 mb	10	10	10	30
⩾ +2 mb	16	8	4	28
Total	26	26	26	78

Relationship between rainfall parameters and monthly circulation type.—The mean surface pressure maps for each May were classified subjectively according to circulation type over the British Isles. The curvature and direction of the mean isobars and the general pressure level were used as a guide in making the classifications. There were three broad types, namely (i) cyclonic, (ii) anticyclonic and (iii) others, with sub-divisions such as cyclonic westerly, anticyclonic north-westerly and so on.

(i) *Cyclonic types.*—Table IV (*a*)–(*d*) shows the association between R and each of N, N_1, N_2 and N_3 when the monthly mean surface-pressure maps are classified as cyclonic over the British Isles.

Table IV speaks for itself. Monthly rainfall is closely related to rain-days in each case in cyclonic circulation types. There is a suggestion, however, that the

TABLE IV—KEW RAINFALL IN MAY RELATED (IN TERCILES) TO RAIN-DAYS IN CYCLONIC CIRCULATIONS

(*a*) Type N (where rainfall is 0.2 mm or more per day)

Rain-days of type N	Monthly rainfall R: Lowest tercile ≤ 33 mm	Middle tercile 34–47 mm	Highest tercile ≥ 48 mm	Total
	number of occasions			
Lowest tercile ≤ 9 rain-days	0	0	0	0
Middle tercile 10–13 rain-days	0	2	0	2
Highest tercile ≥ 14 rain-days	0	3	15	18
Total	0	5	15	20

(*b*) Type N_1 (where rainfall is 1 mm or more per day)

Rain-days of type N_1	Monthly rainfall R: Lowest tercile ≤ 33 mm	Middle tercile 34–47 mm	Highest tercile ≥ 48 mm	Total
	number of occasions			
Lowest tercile ≤ 6 rain-days	0	0	0	0
Middle tercile 7–9 rain-days	0	3	1	4
Highest tercile ≥ 10 rain-days	0	2	14	16
Total	0	5	15	20

(*c*) Type N_2 (where rainfall is 2 mm or more per day)

Rain-days of type N_2	Monthly rainfall R: Lowest tercile ≤ 33 mm	Middle tercile 34–47 mm	Highest tercile ≥ 48 mm	Total
	number of occasions			
Lowest tercile ≤ 4 rain-days	0	2	0	2
Middle tercile 5–7 rain-days	0	1	2	3
Highest tercile ≥ 8 rain-days	0	2	13	15
Total	0	5	15	20

(*d*) Type N_3 (where rainfall is 3 mm or more per day)

Rain-days of type N_3	Monthly rainfall R: Lowest tercile ≤ 33 mm	Middle tercile 34–47 mm	Highest tercile ≥ 48 mm	Total
	number of occasions			
Lowest tercile ≤ 3 rain-days	0	1	0	1
Middle tercile 4–5 rain-days	0	2	2	4
Highest tercile ≥ 6 rain-days	0	2	13	15
Total	0	5	15	20

best association is between N and R and the least good is between N_3 and R. It is noteworthy, though possibly not surprising, that the lowest terciles of monthly rain apparently never occur in association with the lowest terciles of rain-days in cyclonic types. Nor are the lowest terciles of monthly rain associated with the highest terciles of rain-days, or vice versa.

(ii) *Anticyclonic types.*—The relationships between R and the parameters N, N_1, N_2 and N_3 for anticyclonic types are given in Table V(*a*)–(*d*).

The association between monthly rainfall and rain-days for anticyclonic types is fairly good for each category of rain-day but not so strikingly close as

TABLE V—KEW RAINFALL IN MAY RELATED (IN TERCILES) TO RAIN-DAYS IN ANTICYCLONIC CIRCULATIONS

(*a*) Type N (where rainfall is 0.2 mm or more per day)

Rain-days of type N	Monthly rainfall R Lowest tercile ≤ 33 mm	Middle tercile 34–47 mm	Highest tercile ≥ 48 mm	Total
		number of occasions		
Lowest tercile ≤ 9 rain-days	16	1	1	18
Middle tercile 10–13 raindays	2	5	3	10
Highest tercile ≥ 14 rain-days	0	1	1	2
Total	18	7	5	30

(*b*) Type N_1 (where rainfall is 1 mm or more per day)

Rain-days of type N_1	Monthly rainfall R Lowest tercile ≤ 33 mm	Middle tercile 34–47 mm	Highest tercile ≥ 48 mm	Total
		number of occasions		
Lowest tercile ≤ 6 rain-days	15	1	1	17
Middle tercile 7–9 rain-days	3	5	1	9
Highest tercile ≥ 10 rain-days	0	1	3	4
Total	18	7	5	30

(*c*) Type N_2 (where rainfall is 2 mm or more per day)

Rain-days of type N_2	Monthly rainfall R Lowest tercile ≤ 33 mm	Middle tercile 34–47 mm	Highest tercile ≥ 48 mm	Total
		number of occasions		
Lowest tercile ≤ 4 rain-days	16	2	1	19
Middle tercile 5–7 rain-days	2	5	1	8
Highest tercile ≥ 8 rain-days	0	0	3	3
Total	18	7	5	30

(*d*) Type N_3 (where rainfall is 3 mm or more per day)

Rain-days of type N_3	Monthly rainfall R Lowest tercile ≤ 33 mm	Middle tercile 34–47 mm	Highest tercile ≥ 48 mm	Total
		number of occasions		
Lowest tercile ≤ 3 rain-days	14	3	0	17
Middle tercile 4–5 rain-days	4	2	3	9
Highest tercile ≥ 6 rain-days	0	2	2	4
Total	18	7	5	30

for the cyclonic circulations. The cyclonic circulation type has most cases in the top terciles whereas the anticyclonic type has most cases in the lowest terciles with an important minority of cases in the highest terciles. It is of interest to observe that the raininess parameter N gives the lowest number of cases in its top tercile (2 in Table V(*a*)) while R gives 5 in its top tercile in all tables.

(iii) *Other types* (*neither cyclonic nor anticyclonic*).—Examples of this miscellaneous group are easterly, north-westerly, weak westerly, col types and so on. The association between rainfall and rain-days for these types is illustrated in Table VI(*a*) and (*b*).

TABLE VI—KEW RAINFALL IN MAY RELATED (IN TERCILES) TO RAIN-DAYS IN NON-CYCLONIC AND NON-ANTICYCLONIC TYPES

(*a*) Type N (where rainfall is 0.2 mm or more per day)

Rain-days of type N	Monthly rainfall R: Lowest tercile $\leq$ 33 mm	Middle tercile 34–47 mm	Highest tercile $\geq$ 48 mm	Total
	number of occasions			
Lowest tercile $\leq$ 9 rain-days	2	3	1	6
Middle tercile 10–13 rain-days	5	9	2	16
Highest tercile $\geq$ 14 rain-days	1	2	3	6
Total	8	14	6	28

(*b*) Type N_3 (where rainfall is 3 mm or more per day)

Rain-days of type N_3	Monthly rainfall R: Lowest tercile $\leq$ 33 mm	Middle tercile 34–47 mm	Highest tercile $\geq$ 48 mm	Total
	number of occasions			
Lowest tercile $\leq$ 3 rain-days	5	4	0	9
Middle tercile 4–5 rain-days	3	6	1	10
Highest tercile $\geq$ 6 rain-days	0	4	5	9
Total	8	14	6	28

In each case the middle tercile of R, N, N_1, N_2 and N_3 is the most frequent one and the most common association is between the middle tercile of monthly rain and the middle tercile of rain-days. However, each tercile of N_3 is nearly equally likely.

Anomalous relationships between total rainfall and rain-days.—For this purpose anomalous cases were taken as those in which there was at least one tercile difference between the terciles of monthly rain R and rain-days N, N_1, N_2 and N_3. The anomalous behaviour of monthly rainfall relative to rain-days is thus either (i) too much rain relative to the rain-days or (ii) too little rain relative to the rain-days.

(i) *Terciles of R higher than terciles of N, N_1, N_2 or N_3*.—There were 11 of N, 8 of N_1, 11 of N_2 and 14 of N_3. In no case did the same May occur in all the categories of rain-days. In other words in going from threshold 0.2 mm to threshold 3 mm in defining a rain-day anomalous cases were made normal at the expense of bringing in new anomalous months. A variety of circulation types was associated with the anomalous relationships but some rough groupings can be discerned.

For thresholds 0.2 mm (N) and 1 mm (N_1) there is a notable scarcity of cyclonic types (0 for N and 1 for N_1) and a predominance of types involving easterly flow (i.e. south-east, east and north-east) with Δp at Kew rarely positive. Several other cases are associated with rather weak gradients over the British Isles.

For thresholds 2 mm and 3 mm cyclonic types are nearly as frequent as types involving easterly flow and these two make up at least half of the total cases. Others are mainly those associated with rather weak gradients over the British Isles.

(ii) *Terciles of R lower than terciles of N, N_1, N_2 and N_3.*—There were 14 of N, 14 of N_1, 12 of N_2 and 15 of N_3. In this case five Mays persisted as anomalous in changing from thresholds 0.2 mm to 3 mm for the definition of a rain-day.

For thresholds 0.2 mm and 1 mm the circulation types are mixed, including cyclonic and anticyclonic types. However there is a scarcity of types involving easterly flow (contrast this with anomalous cases (i)) and the most common type involves north-westerly or northerly flow.

For thresholds 2 mm and 3 mm the circulation types are again mixed but the difference between the frequency of easterly and north-westerly or northerly types has disappeared. Threshold 3 mm brings in the highest number of anti-cyclonic types.

Concluding remarks.—This analysis covers a limited field. Nevertheless it does not seem that there is any strong evidence for replacing monthly rainfall by rain-days whichever threshold is used to define the latter. There is certainly nothing to suggest that the defining threshold for a rain-day should be raised to 2 mm or 3 mm, and little evidence that it would be worthwhile to use 1 mm rather than 0.2 mm especially since much of the available data about rain-days is based on the lowest threshold.

The analysis does, however, suggest that there is a broad relationship between monthly rainfall or rain-days and the circulation types. In cases where the monthly circulation over the British Isles can be classified as cyclonic, the monthly rainfall and rain-days are closely related to each other and are mostly in the top terciles. For anticyclonic circulations, monthly rainfall and rain-days are mostly in the lower terciles and the association between them is only slightly less good. For the miscellaneous circulation types (i.e. non-cyclonic and non-anticyclonic) the association is least satisfactory.

The anomalous cases, that is the cases with too much or too little rain relative to rain-days, are not clear-cut, but some rough classification according to circulation types can be made.

It is thought that provided the broad circulation type can be predicted the factual information in this note should assist the forecaster in assessing whether the terciles of rainfall are adequate by themselves in describing the rainfall character of the whole month or need some qualification by referring to terciles of rain-days.

No doubt other months will show anomalous rainfall relationships of various kinds according to the circulation pattern, but these would need to be investigated.

OROGRAPHIC EFFECTS AT ACKLINGTON

By A. GRAY and W. J. STEWART

Introduction.—In situations of westerly winds the flow to the east of the Pennines and the Cheviot Hills, on the border of Scotland and England, may contain lee waves such as are described by Förchtgott[1] and Corby,[2] and orographic effects may give rise to lenticular cloud and low-level turbulence including marked variability of surface winds. Several cases have been observed at Acklington, Northumberland (55°18′N 01°38′W, 138 feet above M.S.L.), and this note discusses an occasion when the surface wind showed rapid variations and when low-level turbulence was reported from aircraft. The main areas of high ground around Acklington can be seen in Figure 1.

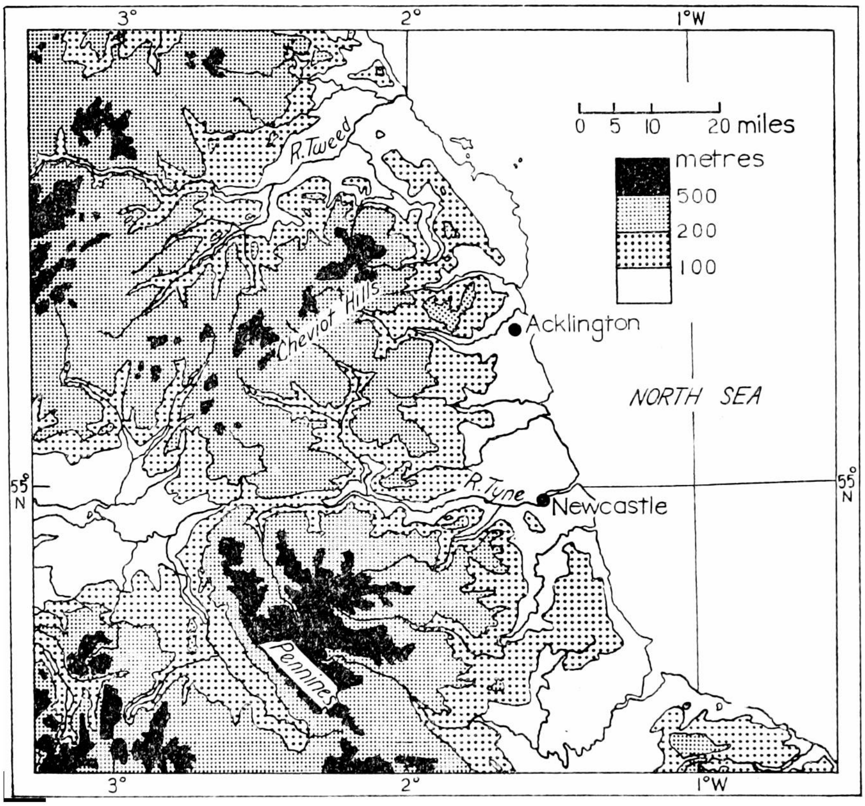

FIGURE 1—RELIEF MAP OF THE ACKLINGTON AREA

Orographic effects on 31 January 1962.—On this occasion there were warm-sector conditions with a strong south-westerly flow over the area. The synoptic situation is shown in Figure 2. Cloud, surface wind and aircraft observations have been summarized as follows:

(i) *Cloud observations.*—Between 0900 and 1030 GMT altocumulus and altostratus were reported in two definite layers—3/8 altocumulus with base 10,000 feet and 7/8 altostratus with base 15,000 feet. The altocumulus had no marked lenticular pattern at this time but later in the day (1400 to 1700 GMT) two small patches, one north and one south of the airfield, were observed with base about 8000 feet and tops about 10,000 feet. These small patches amounted

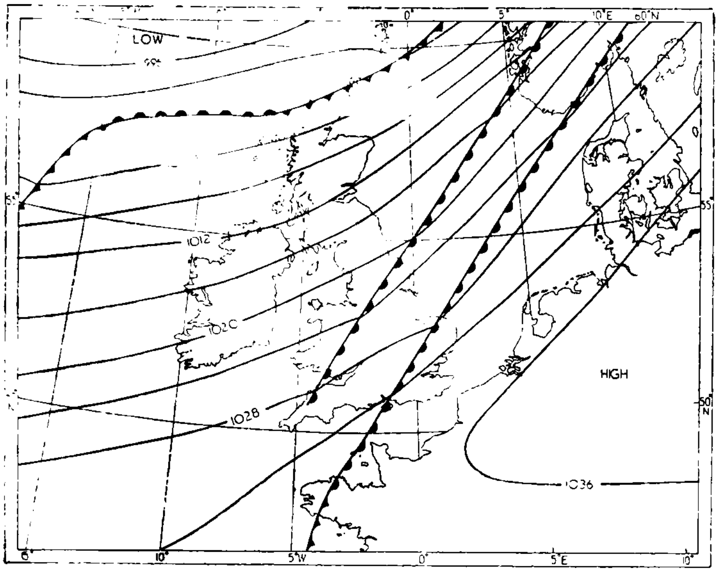

FIGURE 2—SYNOPTIC SITUATION AT 0600 GMT ON 31 JANUARY 1962

to about 1/20 of the total cloud cover. Stratus and stratocumulus were also present during this time (amount 3/8 and base 1400 feet), mainly between Acklington and the coast, some three miles further east. This cloud was too distant to determine whether or not it was a rotor type of cloud.

(ii) *Surface wind observations.*—The surface wind measurement at Acklington is made by a cup-generator and remote-reading direction-indicator. Both units produce instantaneous readings but no permanent record. The surface winds observed between 0900 and 1030 GMT are shown in Table I. The rapid variations were probably caused by orographic effects.

TABLE I—VARIATION OF SURFACE WINDS ON 31 JANUARY 1962

Time	Wind		Time	Wind	
GMT	*degrees*	*knots*	GMT	*degrees*	*knots*
0900	200	7	1000	rapid veer in seconds to	
0940	150	8		220	6
0950	150	10	1010	230	18
0952	150	10	1025	240	25 gusts to 40
0955	050	6			

(iii) *Aircraft observations.*—During the morning experienced pilots were engaged in local flying around Acklington in light aircraft. These pilots reported extreme turbulence in the height band 440 to 1640 feet above M.S.L. (300 to 1500 feet above ground). One pilot stated that he had no effective control over the aircraft. It is significant that this coincided with the period when the surface wind direction was far removed from what would be predicted, and when the speed was light.

Discussion.—The general temperature and wind structures were similar to those required for rotor streaming of the type described by Förchtgott and Corby. The vertical temperature structures at Aldergrove and Aughton are shown in Figures 3 (*a*) and (*b*) as well as the wind speed resolved along the wind direction at 900 metres (about 920 mb), i.e. roughly perpendicular to a nearby ridge of hills. In each case the wind profile shows a layer of strong

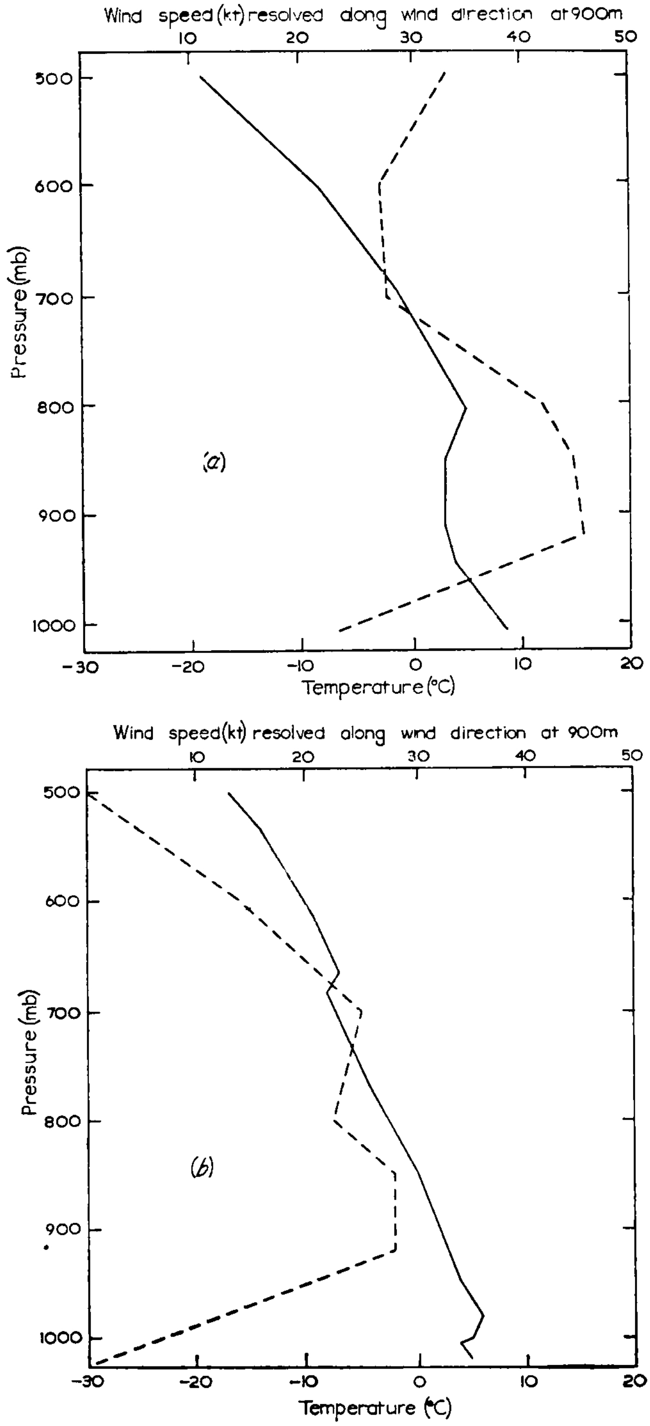

FIGURE 3—VERTICAL TEMPERATURE STRUCTURE AND WIND SPEED RESOLVED ALONG THE WIND DIRECTION AT 900 METRES AT 0000 GMT ON 31 JANUARY 1962

——— Temperature in °C, – – – wind speed in knots resolved along the wind direction at 900 metres.

(*a*) Aldergrove (*b*) Aughton

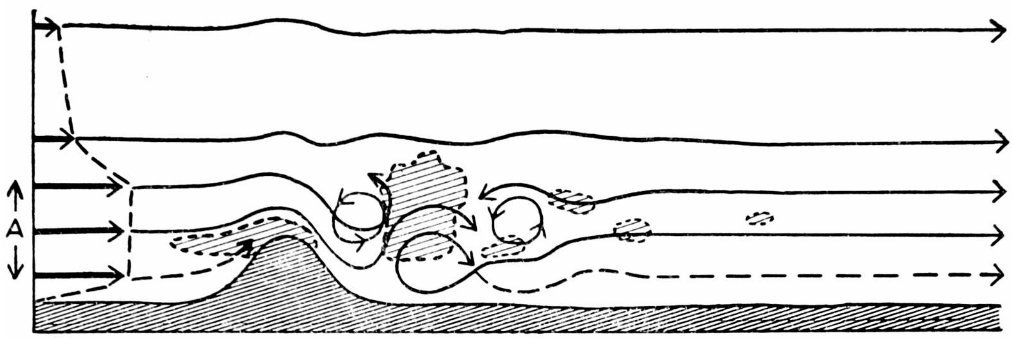

FIGURE 4—ROTOR STREAMING (AFTER FÖRCHTGOTT[1])
'A' indicates streaming layer and bold arrows on the left show the wind profile.

winds with lighter flow above and below similar to that shown in Figure 4. The Aldergrove example also shows a very stable temperature structure in the strong wind flow.

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ASSOCIATION OF CLEAR-AIR TURBULENCE WITH 300 MB CONTOUR PATTERNS

By A. A. BINDING

Introduction.—Clear-air turbulence (CAT) usually in association with jet streams has been forecast at London (Heathrow) Airport for several years using wind shear criteria and actual reports from aircraft as the basis for the prognosis. Some forecasting failures have occurred because in the event reports have been received from areas not indicated as favourable and other apparent failures have occurred because in the event reports have been lacking from quite large areas which were indicated as favourable.

Experience at London Airport had indicated a possible connexion between curvature of the flow and turbulence, and this investigation was made to determine to what extent 300 mb contour patterns might be associated with CAT and whether such associations could be of use in forecasting. Several cases of CAT were found to be in positions remote from any jet-stream core, confirming that it was not possible to forecast all CAT on jet-stream considerations alone. These non jet-stream cases were associated with identifiable 300 mb contour patterns, and it was found possible in the year under review to associate jet-stream cases as well with 300 mb contour patterns, thus indicating the possibility of forecasting CAT primarily by examining data visible on one prontour chart alone.

Subsequent to this investigation a report[1] on CAT over America has been published containing the following statement "Of the 5623 reports of moderate or greater turbulence during the year 36 per cent were within 150 miles to the left or the cold side of the jet, 28 per cent were within 150 miles to the right of the jet and 36 per cent were more than 150 miles from any jet (non-jet cases). In any study or forecast of turbulence limited to 150 miles to the left or cold side of the jet 64 per cent of all the occurrences would have been neglected."

The data.—From a record maintained at London Airport of reports of CAT from eastbound and westbound aircraft on transatlantic routes, all reports of CAT of moderate or greater severity were extracted for the year August 1962 to July 1963 for areas over the sea (topographical influence thereby being largely eliminated) and plotted on the appropriate 300 mb chart for either 0000 GMT or 1200 GMT, since these are the only charts fully analysed. In a few cases where doubts arose some detailed redrawing of the 300 mb contours was done by making use of winds reported from aircraft. Such winds were used in the belief that if a large number of similar winds were reported, a wind-field of the kind indicated was probable. The total area inspected was bounded by latitudes 40°N and 65°N and longitudes 5°W and 65°W.

A report which gave a distance over which CAT was experienced was arbitrarily counted as two reports for arithmetical purposes, one at each end of the line quoted.

All of the reports were from transport aircraft, mostly civil, and turbulence was reported in subjective terms such as slight (or feeble), moderate and severe or combinations of them. It was considered that only severity moderate or greater would be of much interest as feeble or slight intensity would usually refer to 'cobblestone' turbulence which has no operational significance.

Approximately 100,000 in-flight reports were received from transatlantic flights during the year, i.e. about 130 reports per day, and these are necessarily within 6 hours of either 0000 or 1200 GMT. In-flight reports are normally made at intervals of 10° longitude and mention of turbulence is required only if it occurred within the 10 minutes preceding the report, although some crews provide reports in excess of these requirements. Thus there are usually 5 or more reports from each flight.

It is noteworthy that there were only 27 reported cases of severe CAT and 230 of severity moderate or greater in a total of 430 cases for all kinds of CAT, representing 0.4 per cent of the total number of in-flight reports. In comparing these figures with those in earlier reports it is important to remember that, for the period under discussion, there were about 20 flights above 30,000 feet for every flight below, whereas most earlier reports have examined observations with a distinct bias towards low-level flights. Clodman, Morgan and Ball[2] quote turbulence data for 849 Pan American and Trans World jet-engined flights over the North Atlantic for a 3-month period in 1960, when turbulence was reported on only 21 flights. Assuming that there were no more than 21 turbulence reports and that each flight made 5 in-flight reports, the frequency of turbulence was 0.5 per cent of the total number of reports.

Associations of CAT with 300 mb contour patterns and instability areas.—The 230 reports of CAT of severity moderate or greater plotted for the year under consideration could be classified under three headings according to the 300 mb contour pattern and the occurrence of instability areas.

(i) *Ridge type.*—As many as 140 reports were in regions where the contours were anticyclonically curved, and where wind speeds and curvatures were about the theoretical limiting values. These were determined using a scale designed by Jefferson[3] to show the expected limitation of anticyclonic curvature of streamlines on an upper air chart. Additionally, wind shear was anticyclonic except possibly in a few cases of very sharp ridging where shear was apparently small, and difficult to assess.

(ii) *Sharp trough type.*—Another 62 cases occurred in sharp troughs, defined arbitrarily as troughs which would, on passage, produce a wind shift of at least 90°. Turbulence in this situation is already well documented, for example by Briggs.[4]

(iii) *Instability area type.*—Only 28 cases occurred in areas with marked cyclonic curvature of the contours and cyclonic shear. Although reports of great cumulonimbus activity were not always available from these areas, in 9 cases they were and in all 28 cases the thickness pattern indicated that thunderstorms would probably have been forecast. It is suggested that at least in the troposphere turbulence is likely above cumulonimbus tops, while in the stratosphere damping could lead to turbulent wave motions.

Persistence of turbulent situations.—It was found convenient in the study of persistence to define an occasion as a period in which CAT was reported but which was preceded and followed by at least 12 hours without a report of moderate or severe CAT in any part of the corresponding 300 mb pattern. Out of 116 such periods there were, in the year, 102 occasions of less than 12 hours duration, 11 which lasted for more than 12 hours but less than 24 hours and the remaining 3 occasions lasted for more than 24 hours but less than 36 hours. No persistence longer than 36 hours was recorded. The generally low incidence of turbulence may partly account for this apparent lack of persistence but, whatever the reason, it is clear that too much dependence upon actual reports is to be avoided in the preparation of a forecast for more than 12 hours ahead.

Classification of occurrences of CAT.—Table I was prepared by including all reports of CAT of moderate or greater severity associated with:

anticyclonic curvature of the wind,
sharp troughs,
and thermal instability areas.

In each category the reports were also classified according to altitude. The weight of reports around 35,000 feet largely reflects an operational altitude preference, about 20 flights being made above 30,000 feet for each flight below.

TABLE I—CLASSIFICATION OF OCCURRENCES OF CAT

Altitude *feet*	Ridge	Sharp trough	Instability area
20,000–25,000	1	3	11
26,000–30,000	5	4	0
31,000–35,000	82	44	14
36,000–40,000	52	11	3
All altitudes	140 (61%)	62 (27%)	28 (12%)

The table shows that at the lower levels CAT occurred mostly in cyclonic patterns whereas at higher levels there were about twice as many occurrences in ridge conditions as in cyclonic conditions.

The ridge type.—This is a situation not generally recognized as being associated with clear-air turbulence, yet it accounts for 61 per cent of the reports received, and if the year's observations are at all typical it is clearly a situation that merits further consideration.

Theoretical work indicates[5,6] that the vertical component of absolute vorticity must be positive if the flow is to remain stable, i.e. for inertial stability:

$$\frac{V}{r} - \frac{\partial V}{\partial n} + f > 0$$

where V = wind velocity
r = radius of curvature of the streamlines
$\partial V/\partial n$ = horizontal wind shear along the normal to the streamline, the positive direction of the normal being taken to the left of the flow
f = Coriolis parameter.

In the anticyclonic case r is negative, and $\partial V/\partial n$ is positive. The term $V/r - \partial V/\partial n$ is then a negative quantity and when it is numerically equal to f the stability becomes critical. An increase in either V/r or $\partial V/\partial n$ after this critical stage has been reached will lead to inertial instability.

A developing depression frequently causes rapid formation or strengthening of the associated warm-front jet stream with simultaneous rapid lateral movement. In these circumstances if the curvature remains sensibly constant in the upper ridge ahead of the deepening low, increasing V will lead to increased instability especially where the anticyclonic wind shear increases. An increase in anticyclonic curvature can also cause increased instability and this condition sometimes arises well to the right of the jet-stream core.

Illustrations.—Some examples of the types of 300 mb contour patterns associated with CAT are reproduced at Figures 1 to 12.

Turbulence observations are located by an X or two X's joined with a pecked line X- - -X. The degree of turbulence is abbreviated—MOD = moderate, SEV = severe, MOD/SEV = moderate to severe, OCC MOD =occasionally moderate—with the altitude in hundreds of feet to the right in brackets and the time GMT below when the report refers to a position X. When the information refers to a line X- - -X the details are written along the line.

Maximum theoretical curves for appropriate geostrophic wind speeds are drawn as necessary by a dotted line with the maximum speed in knots noted alongside.

Figure 1 illustrates the typical sharpening ridge situation.

Figures 2, 3 and 4 comprise a consecutive series of ridge type occurrences.

Figures 5 and 6 show two occurrences during the advance of a ridge.

Figure 7 shows a case of turbulence in a light anticyclonic gradient.

Figures 8 to 10 show well-known sharp trough situations, the first two being a sequence. Around 50°N in Figure 10 the trough was at about 42°W at 0600 GMT and 38°W at 1800 GMT.

Figure 11 shows a situation which could be classified sharp trough or instability, and Figure 12 instability. In these two cases estimated values of the altitude of the tropopause in hundreds of feet are shown at the locations of each turbulence report.

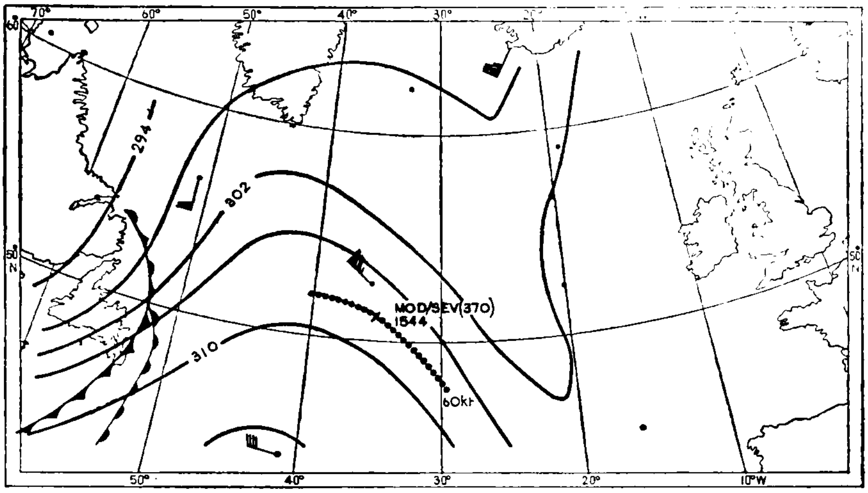


FIGURE 1—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT 1200 GMT, 19 SEPTEMBER 1962

Contours are in hundreds of feet.

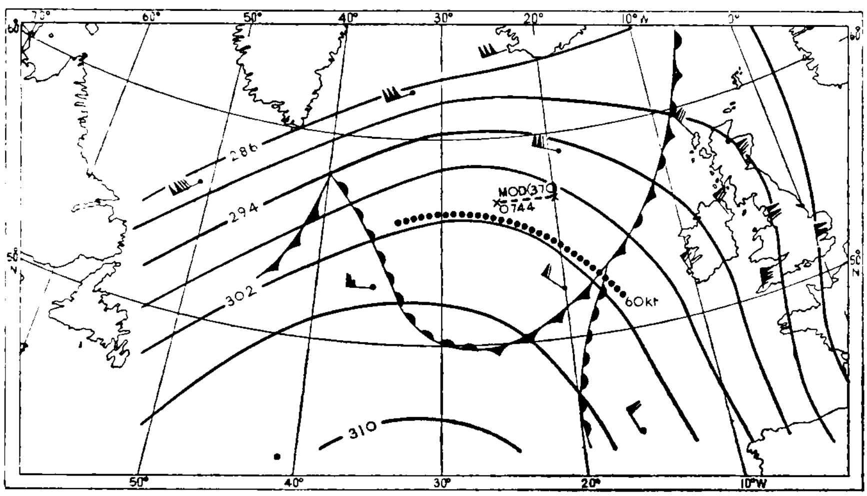


FIGURE 2—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT 1200 GMT, 13 DECEMBER 1962

Contours are in hundreds of feet.

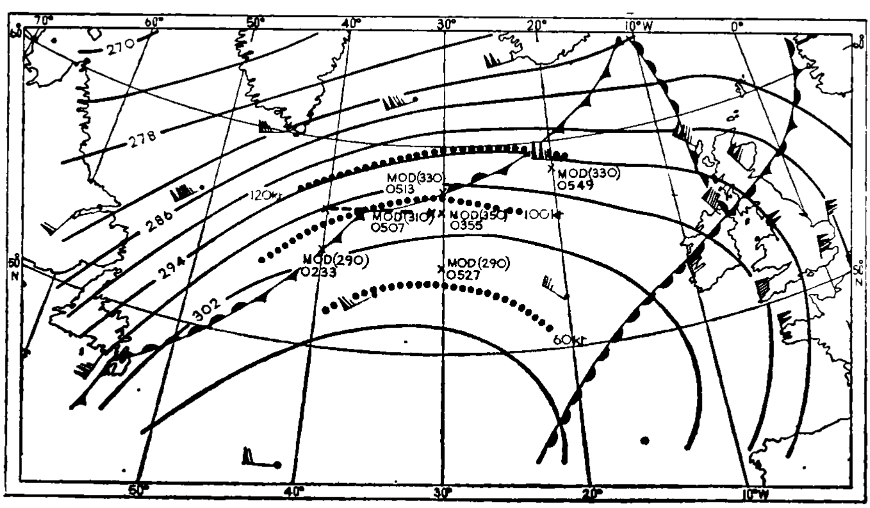


FIGURE 3—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT 0000 GMT, 14 DECEMBER 1962

Contours are in hundreds of feet.

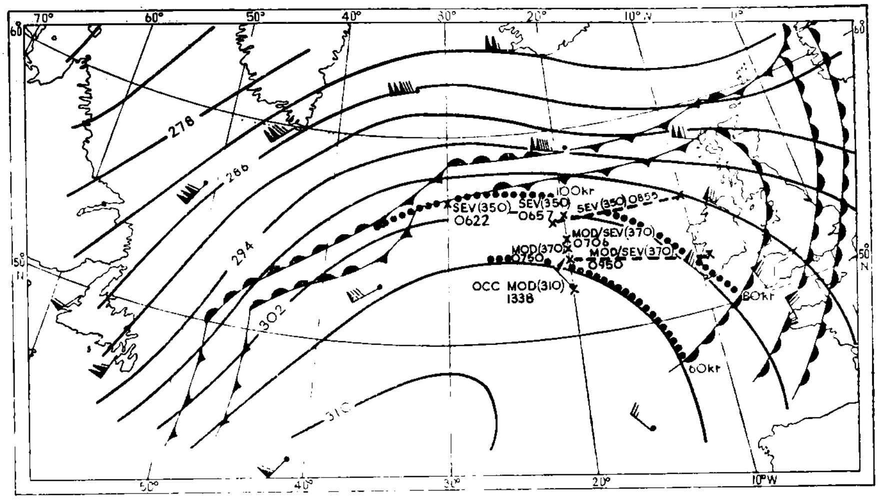


FIGURE 4—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT 1200 GMT, 14 DECEMBER 1962

Contours are in hundreds of feet.

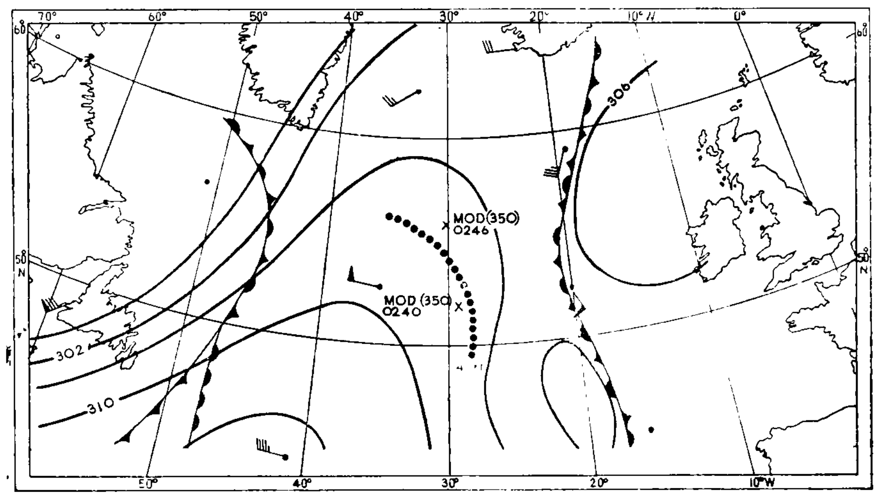


FIGURE 5—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT 0000 GMT, 20 SEPTEMBER 1962

Contours are in hundreds of feet.

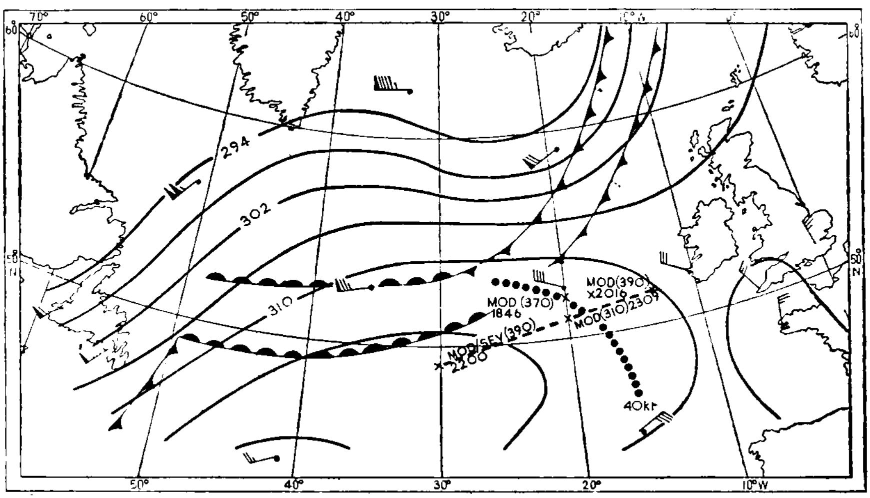


FIGURE 6—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT 0000 GMT, 22 SEPTEMBER 1962

Contours are in hundreds of feet.

Photograph by G. J. Jefferson

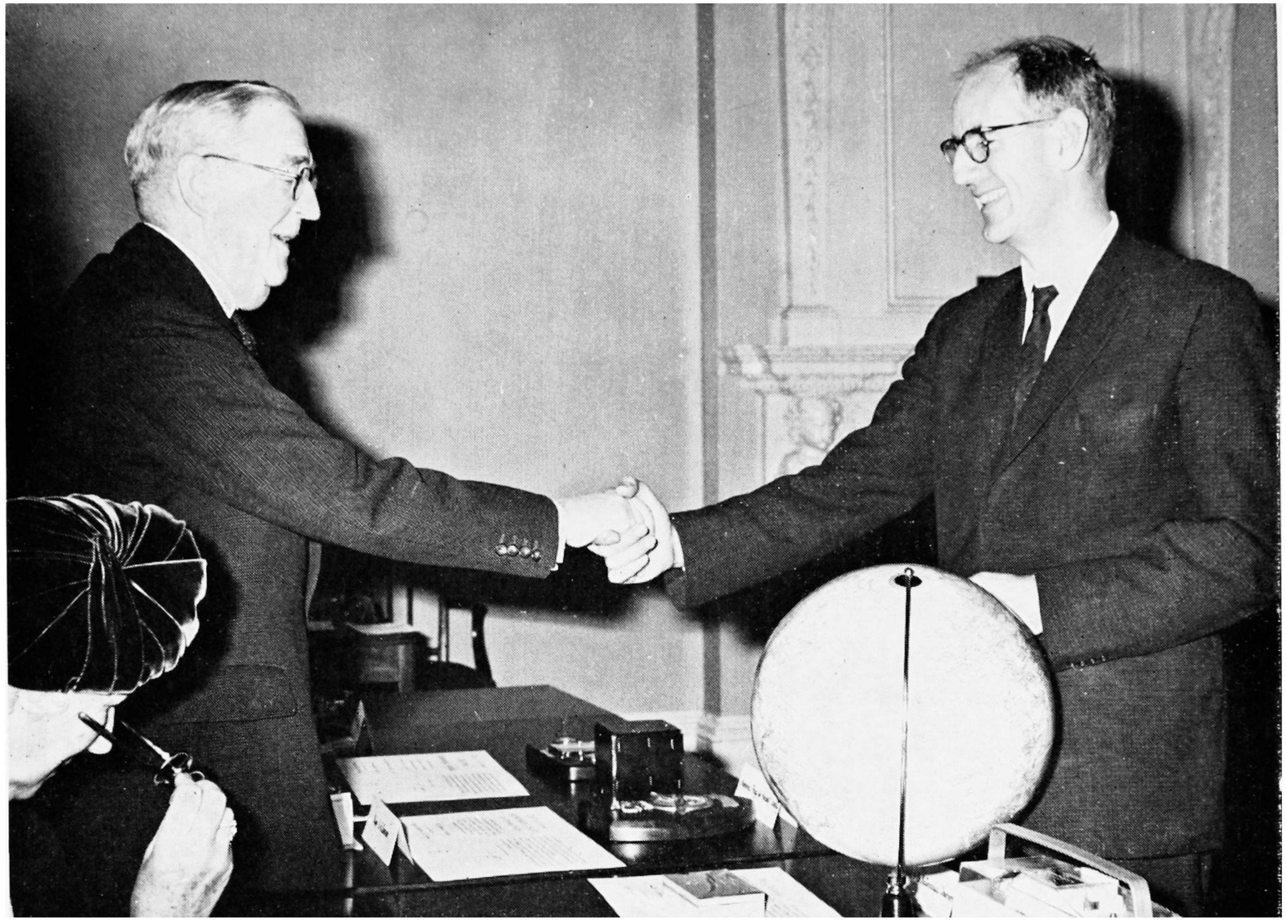
PLATE I—CUMULUS HEADS SHOWING 'ANVIL PUFFS' AT NICOSIA AT 1530 GMT, 7 JUNE 1964

See page 23.

Crown copyright

PLATE II—PRESENTATION OF THE L. G. GROVES MEMORIAL PRIZES AND AWARDS ON 6 NOVEMBER 1964

Left to right: Air Marshal Sir Christopher Hartley, Flight Lieutenant D. C. Evers, Dr. K. H. Stewart, Major K. J. Groves, Mrs. Groves, ex-Flight Sergeant G. F. Earnshaw and Master Pilot R. E. Purdue (see page 30).



Crown copyright

PLATE III—MAJOR K. J. GROVES PRESENTING THE MEMORIAL PRIZE FOR METEOROLOGY TO DR. K. H. STEWART

See page 30.

Photograph by W. G. Pendleton

PLATE IV—HEAVY SNOWFALL AT BRACKNELL ON THE NIGHT OF 15-16 MARCH 1964

The snow as shown in the photograph was about 6 to 8 inches deep on the trees. Many of the branches had been bent to the ground by the heavy weight of snow and some had even been broken.

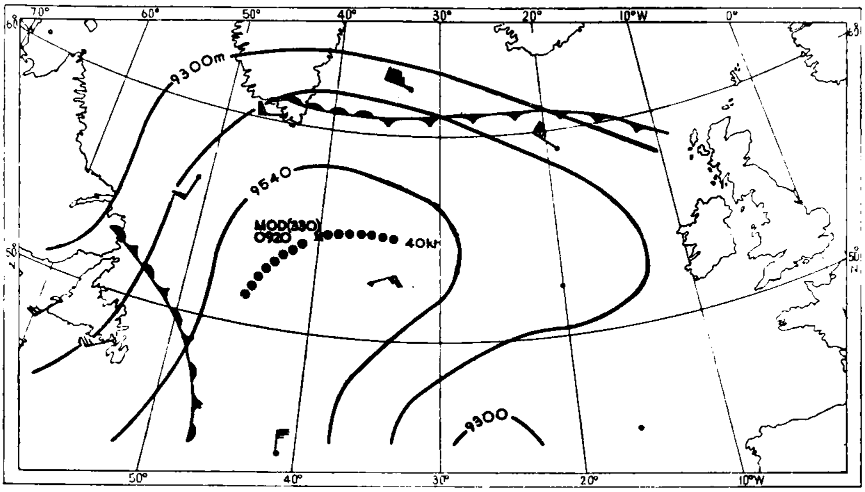


FIGURE 7—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT 1200 GMT, 8 JULY 1963

Contours are in metres.

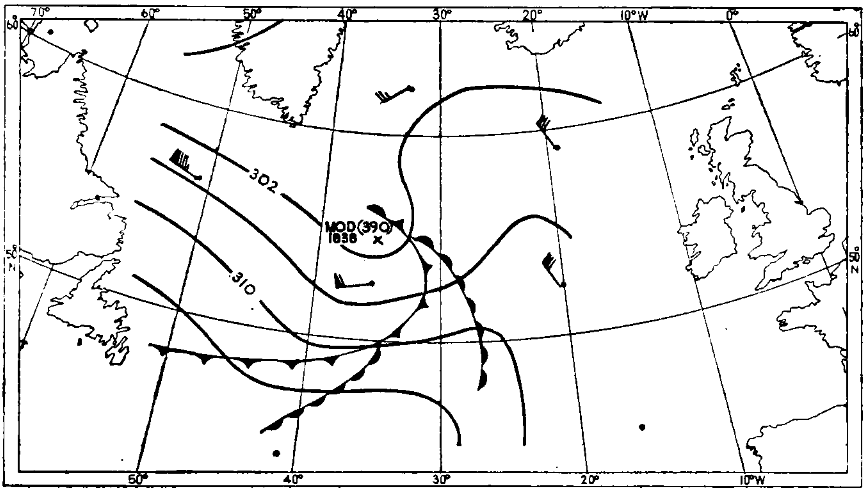


FIGURE 8—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT 1200 GMT, 13 AUGUST 1962

Contours are in hundreds of feet.

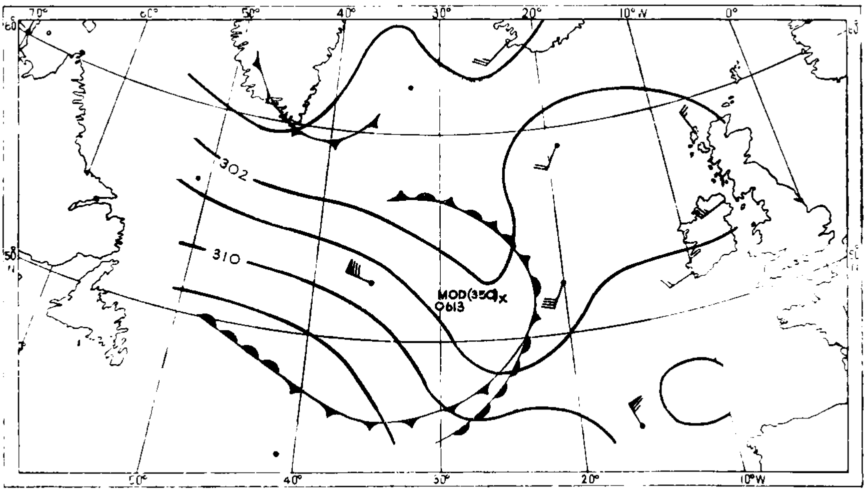


FIGURE 9—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT 0000 GMT, 14 AUGUST 1962

Contours are in hundreds of feet.

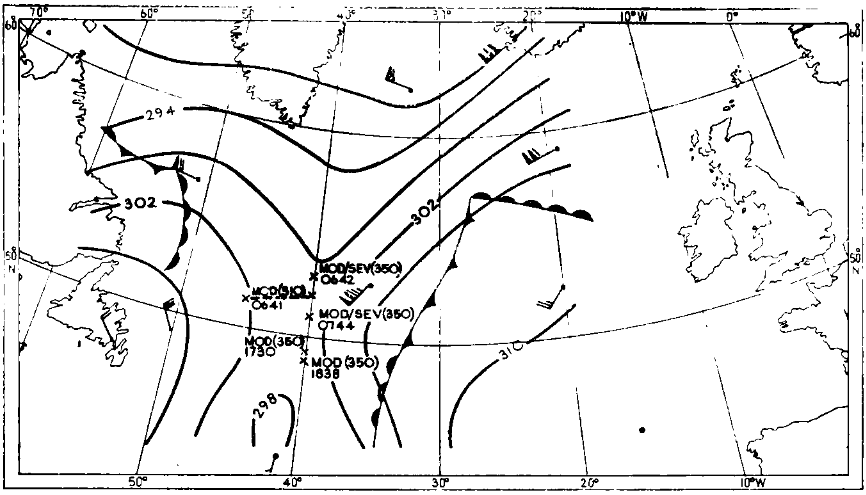


FIGURE 10—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT 1200 GMT, 17 OCTOBER 1962

Contours are in hundreds of feet.

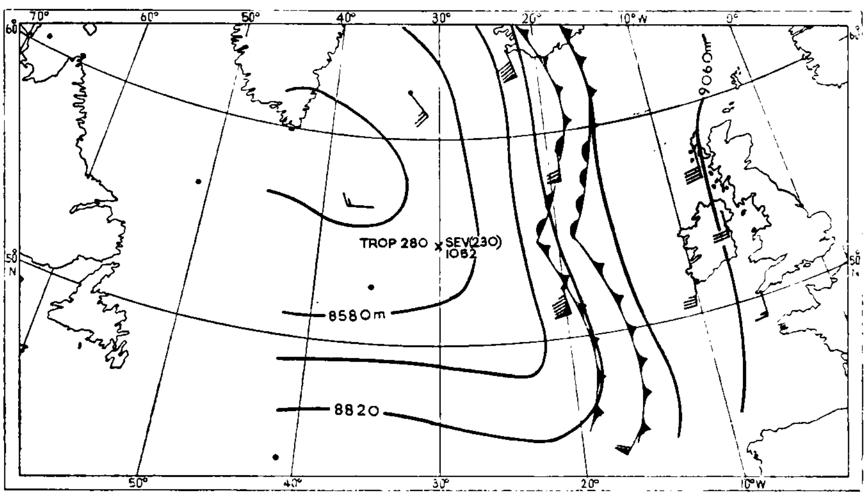


FIGURE 11—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT 1200 GMT, 3 MARCH 1963

Contours are in metres. The height of the tropopause (TROP) is given in hundreds of feet.

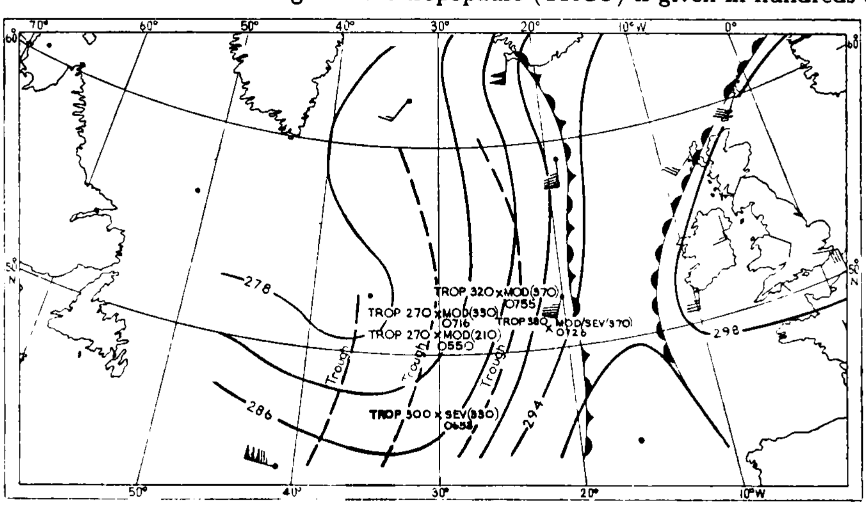


FIGURE 12—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AND TROUGHS AT 1200 GMT, 27 FEBRUARY 1963

Contours are in hundreds of feet.

The height of the tropopause (TROP) is given in hundreds of feet.

Conclusion.—During the year under consideration, using the 300 mb ridge and trough patterns and instability areas, and asuming accurate forecasts of patterns, about 900 separate areas of possible moderate or severe CAT would have been forecast on the 730 charts involved. Of these areas only 12 per cent contained in the event reports of CAT of severity moderate or greater, but all such occurrences were forecast. Forecasting CAT to occur only near jet-stream cores, with a preference for the cold side would probably have required about the same number of forecast areas, but most of the ridge type occurrences would in the event have been missed.

The fact that all reports of CAT of severity moderate or greater over the North Atlantic during the year could be associated with three types of 300 mb contour pattern, whether or not the turbulence was due to jet-stream influences, suggests a simple forecasting guide which could be used to supplement existing methods.

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551.510.534:551.521.17

THE HIGH ATMOSPHERE

By R. FRITH

Impinging on the earth's atmosphere, and responsible in one way or another for the whole of meteorology, is a stream of solar radiation. The earth's atmosphere is almost completely transparent to most of this radiation, but some of it is absorbed, principally at high levels and the absorbed radiation supplies energy for meteorological processes at these levels. Absorption of radiation by a gas is a very selective affair, and each constituent of the atmosphere absorbs radiation only in certain wavebands. These absorption bands are different from gas to gas, but bands for different gases may overlap. The amount of radiation absorbed at any level depends upon the amount of that gas at that level, upon the absorption coefficient of that gas for radiation of that particular wavelength, and also upon the strength of the radiation—and that depends upon how much of the absorbing gas the radiation has already passed through. If the absorption coefficient is small some radiation of this wavelength may reach the ground; but over a wide range of wavelengths including all wavelengths shorter than about 2900 Ångstroms (Å) (visible radiation extends from 4000 to 8000 Å), solar radiation is completely absorbed by the atmosphere.

The ozone layer.—When radiation is absorbed by a gas there is, of course, a rise in temperature; but something else may happen. If the radiation is of sufficiently short wavelength some of the molecules of the gas may be broken up into simpler molecules, or even into atoms. This is known as photodissociation. Thus a molecule of water vapour may be split up into a molecule of hydroxyl, HO, and an atom of hydrogen; a molecule of ozone, O_3, may be split up into a molecule of oxygen, O_2, and an atom of oxygen, and so on. While this is happening the results of the dissociation may recombine chemically, either into a molecule of the original gas (in which case there could be a steady state in which the rate of recombination is equal to the rate of dissociation), or perhaps into molecules of a type which would not otherwise be present. The gas ozone is formed in the high atmosphere in just this way; molecular oxygen is dissociated by solar ultra-violet radiation into atomic oxygen, and ozone is then formed chemically from O_2 and atomic oxygen. Ozone itself is dissociated by solar radiation of rather longer wavelength but still in the ultra-violet range. So there are three processes involved: the first results in the formation of atomic oxygen; the second in the formation of ozone; and the third in the destruction of ozone. The quantity of ozone present at any place at any time will depend, among other things, on the relative intensities of these three processes. At levels above 80 km the ozone destruction process is overwhelming and there is no ozone. At levels below 10 km no atomic oxygen is formed (the radiation capable of dissociating molecular oxygen being all absorbed at higher levels) so ozone cannot be formed. Ozone is, however, formed at intermediate levels and so forms a shell over the whole globe. This ozone shell plays a very important part in the affairs of the high atmosphere.

The heat balance.—In order to avoid unnecessary complexity it will be assumed in what follows that ozone is the only atmospheric gas with radiative properties. This, of course, is not so. Ozone is perhaps the most important but in any quantitative analysis other gases would have to be taken into account.

Ozone absorbs solar radiation in a wavelength band extending from 2000 to 3500 Å. Ozone also emits long-wave radiation. The emission of long-wave radiation is continuous, day and night; but the absorption of short-wave radiation occurs only in the day-time. So a diurnal variation of temperature in the ozone layer is to be expected, just as there is a diurnal variation of temperature at the ground. But the temperature variation in the ozone layer is not expected to be large, since in one night the amount of heat lost is sufficient to reduce the temperature only by a few degrees. Rocket soundings are now providing observational evidence of a diurnal variation of about the expected amount.

In high latitudes during the winter the ozone layer is in continual darkness for many months. During this time it is emitting long-wave radiation and, if the temperature were governed only by radiative processes, there would be a continuous fall of temperature in the ozone layer throughout this period. The temperature does, in fact, fall by about 100 degrees K; but even this is far less than suggested by radiative considerations. It must be concluded that heat is transported into the region to balance, in part, the heat lost by radiation. During the summer months the ozone layer in high latitudes is in continuous sunshine, receiving practically twice as much solar radiation as is being received in low latitudes. It would be expected that the temperature would be, in consequence, much higher. The temperature in high latitudes is indeed higher but not nearly as high as radiative processes would suggest. So in summer there must be meridional transport of heat away from the region to balance, in part, the heat gained by radiation.

Meridional transport of heat also occurs in the troposphere, of course. The mechanism for the transport in the troposphere is complex but a good deal is known about it. Very little is known about the mechanism for heat transport in the high atmosphere, largely because there are so few observations.

The use of ozone as a tracer.—Something may be discovered about circulation systems in the high atmosphere by direct measurement of air movement, but the pressure patterns and the associated wind systems are complex and variable, just as they are at lower levels. It would need large numbers of soundings, from a close network of stations, to sort out just what is happening. However, any air movement which transports heat is likely to change the distribution of such things as water vapour and ozone. Therefore at levels where these gases are stable, i.e. at levels where they are neither created nor destroyed to any appreciable extent, it may be possible to use them as tracers for tracking large-scale air movements. Water vapour concentrations are extremely difficult to measure at high levels, but ozone can be measured. It has been known, from measurements made using ground-based instruments (the Dobson ozone spectrophotometer), that there are features of the 'total ozone' distribution which suggest the existence of some sort of meridional airflow in the ozone region. Firstly, it is found that the measured total ozone is greater in high latitudes than in low (photochemical processes would give the opposite distribution); secondly, it is found that there is an increase in the total ozone in high latitudes in winter. Both these features suggest a polewards movement of air at some level in the ozone region, with subsequent descent and return at some lower level. Measurements of the vertical distribution of ozone would obviously give vastly more information about this circulation, if it exists, than measurement of total ozone, and a good deal of effort is now being put into this in several countries. Ozonesondes have been developed which can be flown on radiosonde balloons and which measure the vertical distribution of ozone at levels up to 30 km or so. Measurements of the vertical distribution can also be made from satellites. Measurements from satellites have the great advantage that they provide world-wide coverage, for long periods, and this is just what is needed for this kind of study.

Techniques of measurement of ozone.—It is not the purpose of this article to say much about techniques of measurement, but it is perhaps appropriate to mention that routine ozonesonde soundings will soon be started at a chain of Meteorological Office stations stretching from Lerwick in the north to Gan on the equator. Also, the satellite ARIEL 2 carries Meteorological Office equipment designed to measure the vertical distribution of ozone. Readers might like to be reminded how, from a satellite orbiting at a height of several hundred kilometres, measurements of ozone concentrations at levels below 80 km can be made. There are a number of possible techniques. The simplest, which is the one used on ARIEL 2, makes the measurements twice per orbit. There is on the satellite a radiation sensor, measuring the intensity of radiation in the wavelength region 2500 to 3500 Å, where ozone has a fairly high absorption coefficient. For most of the orbit the output from this sensor is either zero, when the satellite is in the earth's shadow, or is constant at the 'full sun' value. However twice per orbit, once at sunrise and once at sunset, as the satellite passes into or out of the earth's shadow, the sun is 'seen' through the earth's atmosphere and the radiation will be reduced by ozone absorption (there will be some reduction for other reasons but this can be allowed for). The more ozone there is in the way the greater will be the reduction by ozone absorption.

It takes about 30 seconds for the satellite–sun line to move from just skirting the earth to a position skirting the earth at a distance of 80 km. If the output from the sensor is measured, say every second during the 30-second period, then the vertical distribution of ozone can be computed.

Water vapour.—In the troposphere the mean water vapour mixing ratio decreases more or less steadily with height. There is no obvious change at the tropopause but at a height of about 15 km the mixing ratio seems to become constant. What happens above this? Since there is no obvious source of water vapour in the high atmosphere one would expect the mixing ratio to remain constant with height, up to the level where water vapour is destroyed by photodissociation. However there are American balloon measurements which suggest that the mixing ratio may increase slightly. (Some earlier measurements indicated a large increase of mixing ratio but these measurements are now discounted.) There is some support for this conclusion from measurements made in this country, from aircraft, using radiation techniques.

It used to be thought that the presence of noctilucent clouds, which are observed at high latitudes at heights of 80–85 km, also indicated a high mixing ratio. The cloud particles have now been sampled, by rocket flights from Sweden, and it seems to be confirmed that the particles are coated with ice (and are not simply 'dust' particles as some had suspected). If this is so then the air at that level must be saturated. However the temperature at this level in summer is known to be low; the one measurement so far made when noctilucent clouds were present gave a temperature of about 130°K. At this temperature air would be saturated with a mixing ratio no greater than is found at 15 km. More measurements are needed, of course, but clearly the noctilucent cloud argument must be used with caution. Nevertheless it is interesting to note that the supposition that there is no source of water vapour in the high atmosphere may be incorrect. Water vapour may be created by photochemical processes, just as ozone is created. It has been pointed out that methane, which is given off by decaying vegetable matter and by cows and other ruminants, diffuses upwards and is dissociated by ultra-violet light in the high atmosphere. It is possible that quite large amounts of water vapour may be formed as a result of this dissociation. If it can be confirmed that there is a general, even though slight, increase of the mixing ratio with height above 15 km, then the proposition that water vapour is being created in the high atmosphere will be hard to resist.

The mesopause and above.—Whatever the humidity may be at 80 km the fact that there is a temperature minimum there is well established. Below 80 km, between this temperature minimum and the temperature maximum in the middle of the ozone layer, is a region which is known as the mesosphere, and the temperature minimum itself is called the mesopause. It is not difficult to 'explain' the existence of the mesopause in a general way: below 80 km there is a rise of temperature because of the absorption of radiation by ozone while above 80 km there is a rise of temperature because of the absorption of radiation by molecular oxygen but what is hard to explain is why the temperature of the mesopause in high latitudes is so much lower in summer than in winter: the difference between summer and winter temperature amounting to as much as 100°K. The high temperature in winter is almost certainly associated with subsiding air while the low summer temperature may be associated with ascending air; but that is about all that can be said at present.

Above the mesopause there is believed to be a region of steadily increasing temperature—but in this extremely tenuous atmosphere temperature measurements are difficult to make. At 100 km, for example, the air density is less than the density at the ground by a factor of more than 10^6. At these levels electrical processes, which cannot occur in the denser air at lower levels, become possible. These processes give rise to the ionosphere, to airglow and to aurora—but that is another story.

551.558:551.576.11

UNUSUAL CONVECTION CLOUD

By G. J. JEFFERSON, M.Sc.

The accompanying photograph (see Plate I) was taken at Nicosia, Cyprus at 1530 GMT (1730 local zone time), on 7 June 1964, looking south-eastwards towards the Troodos Mountains. The day had been largely fine but with some cumulus and cumulonimbus development especially over the mountains in the south-west of the island.

At the time of the photograph much of the cloud had flattened out but isolated cumulus heads burst upward from the top of the layer. Their rate of ascent was considerable and, while some of them merely dispersed, a few retained enough of their entity to reach the higher troposphere and form small anvils. The photograph shows one of these, which might be termed 'anvil puffs' with enough cloud retained below to indicate the path along which ascent had taken place. Another cumulus head had just started to ascend but its further development was not so striking as the preceding one.

An examination of the ascent for Nicosia radiosonde station for 1200 GMT, 7 June 1964 (Figure 1) shows that the environment air probably had characteristics consistent with development of this kind. The most significant feature is the very high inversion at 660 mb. The layer cloud probably occurred just below this inversion where the air was rather moist.

Temperatures and dew-points at Nicosia for the period 1200–1800 GMT on 7 June 1964 are given in Table I.

TABLE I—TEMPERATURES AND DEW-POINTS AT NICOSIA ON 7 JUNE 1964

Time (GMT)	1200	1300	1400	1500	1600	1700	1800
Dry-bulb temperature °C	31.1	29.8	28.9	26.7	26.6	24.4	23.3
Dew-point temperature °C	12.3	15.8	15.5	16.9	18.0	16.9	15.3

The most interesting feature shown in this table is the steady rise of dew-point between 1200 and 1600 GMT. The 1200 GMT temperature and dew-point would give rise to convection cloud, but probably only up to the inversion at 660 mb. With a rise of dew-point to 16.9°C at 1500 GMT and to 18.0°C at 1600 GMT the possibility of convection breaking through the inversion is quite evident

In fact the 1500 GMT temperature of 26.7°C and dew-point of 16.9°C suggest that ascending air would be able to break through the inversion. Temperatures at places at the same altitude as Nicosia but in the hilly areas, may not have been as high as at Nicosia itself, which is on the open plain at about 720 feet.

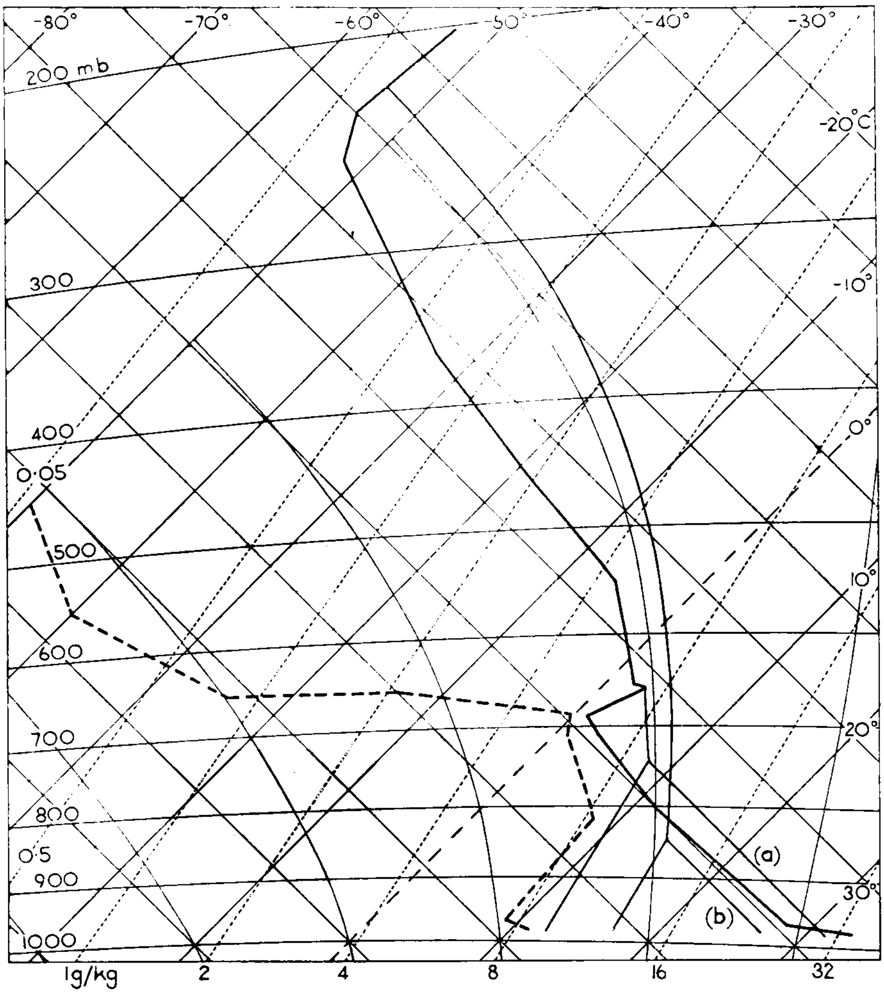

FIGURE 1—NICOSIA ASCENT FOR 1200 GMT, 7 JUNE 1964

——— Dry-bulb temperatures; — — — dew-point temperatures.
Convection paths are shown for (*a*) 1200 GMT and (*b*) 1500 GMT.

However, ascent over the high ground would give an additional impetus to convection. It was clear at the time that the convection was taking place somewhat nearer than the high ground.

The hills which can be seen just to the right of the cloud in Plate I are about 20 miles distant and about 5000 feet high. If we assume the cloud to be 15 miles distant, measurements from the photographic negative allow the heights of the cumulus top and the top of the 'anvil puff' to be calculated. On the photograph these are 12 mm and 32 mm respectively. The focal length of the camera lens was 75 mm. Thus:

Height of cumulus top $= 12 \times 15 \times 5280/75 = 12{,}700$ feet.
Height of anvil top $= 32 \times 15 \times 5280/75 = 33{,}800$ feet.

Both heights would appear to be consistent with the ascent shown in Figure 1 and suggest that the estimated distance of 15 miles was approximately correct.

The large positive energy area above the inversion in Figure 1 can explain the rapid rate of ascent but no explanation can be offered as to how the rising cloudy air was able to reach such a height without the cloud being dispersed by entrainment of the very dry environment air through which ascent was taking place.

No actual measurements were possible of the time taken for the cumulus head above the inversion (similar to the cumulus head seen in the photograph) to reach the stage of the 'anvil puff' but it is thought that it was between 5 and 10 minutes. If it is assumed to be 10 minutes, then the rate of ascent would be of the order of 2000 feet per minute.

REVIEWS

Rayonnement solaire et échanges radiatifs naturels by Ch. Perrin de Brichambaut. 9½ in × 6¼ in, pp. vi + 304, *illus.*, Gauthier-Villars et Cie, Quai des Grands-Augustins, 55, Paris VI^e, 1963. Price: 46F.

There has been increasing interest in recent years in the measurement of solar and terrestrial radiation. This has been partly as a means to the understanding of the transformation of energy within the system earth–atmosphere and of its variation in time and space, and partly to meet certain needs connected with biological, medical, industrial—including building,—agricultural and hydrological activities. As weather satellites increasingly provide a synoptic picture of radiative flux above the atmosphere, the need becomes more apparent for more observations at the surface. There is no doubt that such radiation observations will eventually be required on a synoptic basis for inclusion in numerical forecasting schemes.

The International Geophysical Year (IGY) instruction manual on Instruments and Measurements of Radiation (1957) gave an account of what was required, but with no diagrams, and during the IGY there were some 400 stations, scattered over the world, measuring global radiation on a horizontal surface, and some 30 stations measuring radiative flux at the surface: most of these stations have continued, but this network is a very open one over land and—apart from the British Ocean Weather Ships and later a Canadian Ocean Weather Ship and isolated observations by research ships—non-existent at sea.

Thus with the recognized need all over the world for an increase in the number of stations measuring solar and terrestrial radiation, it is timely that the present textbook has been issued. Previously much of the information on the subject has been scattered among the original papers, although there is a useful section in the *Handbook of meteorological instruments, Part I.*[1] The book is the fourth volume in a series of monographs of meteorology published under the general editorship of A. Viaut, Director of the Météorologie Nationale. The author is well known in radiation circles; he is a member of the Radiation Commission of the International Association for Meteorology and Atmospheric Physics (IAMAP), and is also a member of the Working Group on Radiation for Regional Association VI (Europe) of the World Meteorological Organization (WMO). His aim, as stated in the introduction, is to produce a practical guide for all those interested in solar radiation in the field of natural energy exchanges. The book has 19 chapters followed by several technical annexes. The first 3 chapters are concerned with the fundamental physical laws of radiation. Chapter 4 deals with the relevant elements of astronomy, e.g. the declination of the sun at different periods of the year and the meaning of local apparent time. By chapter 5 the account is turning to the different kinds of instruments used, e.g. pyrheliometer for normal incidence, pyranometer (commonly called solarimeter) for radiation received from a hemisphere, normally on a horizontal surface, and to discussion of errors likely in the measurements. Chapter 6 then deals with the recording of the readings from these instruments, including the use of integrating potentiometers. Chapter 7, concerned with the methods of measuring direct solar radiation, is followed by an account, in the next chapter, of the general characteristics of this radiation and of the practical application of the data; the same plan is followed in the successive chapters 9 and 10 which deal with the measurement and interpretation of global and diffuse radiation. After chapters concerned with terrestrial radiation, radiation from natural bodies, radiation from the atmosphere and the general radiation balance, and a chapter describing the usual instruments for the measurement of the duration of sunshine, the last 3 chapters are more general. They discuss the results obtained from the various types of radiation measurements in a climatological manner and biological and psychological effects are mentioned; the last chapter is concerned with the energy utilization of solar radiation, including, under appropriate conditions, the use of solar furnaces, the heating of houses, refrigeration and the conversion of solar energy into electricity, as adopted for power supplies in satellites; mention is made of the architectural applications of the knowledge of solar radiation. The technical annexes are varied, being entitled, atmospheric transparence and visibility, photography, thermo-electric effects, electric circuits for actinometry and data concerning the sun.

Many tables, diagrams and graphs are included, but the diagrams of instruments are not, in general, as detailed as in the *Handbook of meteorological instruments*, *Part I*; as an attachment at the end of the book there is a series of photographs, albeit rather small, of the various instruments.

A useful account of the subject is thus presented for students generally, and for those coming new to the subject who wish to measure the various elements of solar radiation. Besides the description of instruments, the general background knowledge necessary is mentioned and there are accounts, for example, of the various radiation diagrams, such as Elsasser and Robinson, used for computing radiative flux in the atmosphere, and various aspects of atmospheric scattering (Mie and Rayleigh).

As the author makes it clear, the book is up to date to 1961; thus a relatively new subject like the introduction of modern data logging equipment[2,3] to eliminate the laborious hand-scaling of charts is not included; there is also no mention of measurements at sea.[4] It would have been useful, in view of the variety of types of radiation instruments used in different parts of the world, to have mentioned that the Commission for Instruments and Methods of Observations (CIMO) of WMO has organized international comparisons of radiation standards (the first such comparison of solarimeters was at Davos, Switzerland, in 1959) and is continuing to arrange for further such comparisons in future.

It is a pity that the references to literature at the end of the book, stated by the author to be "easily accessible", are so scanty that it would be very difficult for the reader to trace the volumes concerned. For example a reference to

"Robinson—Notes on the Measurement of Atm. Radiation 1947" would eventually lead to a paper in the *Quarterly Journal of the Royal Meteorological Society* for that year with the full title "Notes on the measurement and estimation of atmospheric radiation", but the full reference would have saved the search. The "*Solar Radiation*" by N. Robinson, 1961, must refer to the book, in English, which Professor N. Robinson of Israel hoped to publish about that date, but which is now not due to appear till late 1964. The useful *Handbook of meteorological instruments, Part I* is not mentioned.

The present reviewer joins in the plea of the previous two *Meteorological Magazine* reviewers of volumes[5,6] in the present series, that an index should be supplied for each volume. This is particularly applicable to the present volume where many instruments, laws and theories, new to the reader, are given the names of those responsible, and, once having read the book, it is difficult to trace a particular name again. Perhaps the general editor of the series would be able to arrange for the missing indexes to be included in a later volume of this most interesting and useful series of books.

L. JACOBS

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3. HOLMES, R. M.; A micrometeorological data logging instrument. *Bull. Amer. met. Soc., Lancaster, Pa.,* **44,** 1963, p. 91.
4. MATEER, C. L.; On the relationship between global radiation and cloudiness on ocean statiuo P. *Arch. Met. Geophys. Bioklim., Vienna,* B, **3–4,** 1963, p. 482.
5. SCRASE, F. J.; *review of* Mesures en Météorologie. *Met. Mag., London,* **91,** 1962, p. 204.
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Oceanic observations of the Pacific: 1951. 11 in × 8½ in, pp. xxxviii + 598, *illus.*: *Oceanic observations of the Pacific*: 1956. 11 in × 8½ in, pp. xliv + 458, *illus.*, Scripps Institute of Oceanography of the University of California. Berkeley and Los Angeles, University of California Press and Cambridge University Press, Bentley House, 200, Euston Road, London N.W.1, 1963. Price: 68*s.* and 60*s.* respectively.

These two well-bound volumes of oceanographic data for the Pacific for the years 1951 and 1956 have recently been received. *Oceanic observations of the Pacific* is a medium for publication of oceanographic data collected in the Pacific Ocean and its adjacent seas by co-operating agencies of the United States and Canada.

The publications give maps showing the locations of the observations, the distributions of serial soundings in the Pacific, and the available bathythermograph observations from 1941 onward in the Pacific, Antarctic, and Indian Ocean. It is evident that in spite of this great volume of 'very high quality' information there are vast areas of unobserved seas in the Pacific.

The purpose of the volume is to tabulate results of serial oceanographical soundings to frequently very great depths (at times exceeding 3000 metres). Actual observations are given with interpolated values for every 10 metres to

50 metres, for every 25 metres to 100 metres, for every 50 metres to 300 metres and then every 100, 200 or 500 metres after respectively 300 metres, 800 metres, and 1500 metres. Depths are given in whole metres; sea temperatures are given to two decimal places of °C and salinities are given in parts per 100,000. Oxygen and phosphate contents are also included in the tables. The weather, sea state, the deviation of the sounding wire from the vertical and the slide numbers of any associated bathythermograph 'dips' are included with the tabulations. In some of the soundings interpolated values of temperature and salinity have been used to compute standard parameters. These parameters are functions of water density, specific volume and pressure and they enable water mass and isobaric analysis to be carried out directly on the data without any further processing.

The data tabulated in these volumes are standard and in no way exceptional. Necessary details of the times of the voyages and the ships' names with an outline of non-standard observations are given, but the full story of any specific voyage would need a reference to other books. The publications however provide a full bibliography for such a purpose.

These volumes which are two of a series provide oceanographical data in a very convenient form, typical of those available in an oceanographic data centre.

Meteorologists in the United Kingdom who need this type of information for such problems as the interaction between sea and atmosphere over either a limited sea area or on a world-wide scale should of course apply to the British Oceanographic Centre at present being organized by the British Hydrographic Department, Ministry of Defence (Navy Department). This new centre which is in its infancy and is co-operating with continental and world centres of America and Europe hopes to have the type of information included in these two excellent volumes available on punched cards or tape so that computers can be used with a minimum of preliminary work.

G. A. TUNNELL

Descriptive physical oceanography, by G. L. Pickard, M.A., D.Phil. $5\frac{1}{4}$ in × $7\frac{3}{4}$ in, pp. viii + 199, *illus.*, Pergamon Press Ltd., Headington Hill Hall, Oxford, 1964. Price: 25*s*.

This is a valuable introduction to descriptive oceanography and gives the background of that part of the subject which corresponds in meteorology to air-mass analysis.

It gives the reader the tools for water-mass analysis which is quite as fundamental to oceanography as the concept of air mass is to meteorology. Convective exchanges in the oceans have to take place from the surface downwards and as water is so much more viscous than the atmosphere some of the deep water masses can exist undisturbed for centuries. There are therefore considerable differences on the time scales of fluctuation and exchange in the oceans from those in the atmosphere. Dr. Pickard in this small book has given a very simple account of the methods and materials of analysis, condensed from a huge mass of basic literature. The book is very easy to read and one could get much enjoyment from it on a long journey.

The introductory chapter gives brief notes on the history of oceanography. This includes a discussion of the terms 'synoptic' or 'descriptive' oceanography.

These terms apparently correspond with the 'climatological' sub-division of meteorology. One wonders what the oceanographers will call a truly synoptic oceanographical chart or map.

Chapter 2 gives the physical dimensions and the geological structure of the ocean bottom, which allows the reader to get the oceans into true 'perspective.' The magnitude of the great deeps and the extent of continental shelves are all described. For example the great 11,000 metres of the Marianas Trench is compared with the 8840 metres of Mount Everest. It is stated that the slope of continental shelves is on the average 1 in 500 for an average distance of 65 kilometres increasing to 1 in 20 as they pass to the ocean deeps.

The magnitude of physical and chemical parameters measured instrumentally is given in chapter 3. The magnitudes of density, temperature and salinity are given with some indication of their importance in the analysis of the oceanic circulation. The complex nature of what the oceanographer understands as salinity, its relationship to chlorinity and electrical conductivity are explained with the limitations of the latter in the rapid and accurate measurement of salinity, These techniques require an accuracy of measurement quite beyond that used by meteorologists. It is also pointed out how valuable are other characteristics of the sea like the oxygen content, the colour, and the diffraction of sound waves in investigating the oceanic current circulation at all depths.

Chapter 4 summarizes the results of thousands of observations giving the world-wide distribution of the characteristics of the oceans and their variation with time. For example it is shown diagrammatically that there is on average a maximum of temperature and a minimum of density and salinity at the equator, and salinity maxima in the two tropical zones of the oceans. It is also shown that there is a uniquely rapid increase of density with depth at the equator but a great constancy and uniformity of density below 2000 metres almost everywhere. It is shown that the surface temperatures and salinities are influenced by the weather, ocean currents and the vertical exchanges within the oceans. The oxygen content of the sea is an important tracer element for detecting the age of a water mass but minimum values in the upper 1000 metres in the equatorial Atlantic and eastern Pacific are not yet fully understood.

Chapter 5 shows how conservation principles may be applied to the sea. For example the conservation of salt can be used to analyse the flow in estuaries. Conservation of heat energy can also be applied to the oceans. The greater part of the chapter contains heat budget equations with parameters and measurements familar to meteorologists. Instruments, physical and chemical measurements and oceanic diagrams are described in chapter 6. The descriptions of instruments are efficient and brief but more diagrams and photographs with some of the associated techniques would have been helpful. The techniques associated with oceanographical diagrams for the study of oceanic circulations are more fully discussed.

Chapter 7 augmented by chapters 8 and 9 is the heart of the book. It is difficult to do justice to them in a review; so much is covered, including the results of much recent work, analysis and thinking that one has to read the chapters with the greatest care to absorb all the details. The very significant role of Arctic water masses and their convergences are explained with the three-dimensional exchanges within the oceans. Included also are brief accounts of sea ice and the oceanic jet stream—the Cromwell current.

The cover of the book is not very durable and started to disintegrate while the book was being read by the reviewer. It would help the reader if references to figures were given with the appropriate page number. A fuller bibliography would be helpful particularly if references to classical works were put at the end of each chapter.

I can recommend this book to mariners and scientists requiring a concise account of modern oceanography, as a preparation for more advanced studies.

G. A. TUNNELL

AWARDS

L. G. Groves Memorial Prizes and Awards

The presentation of the L. G. Groves Memorial Prizes and Awards for 1964 was made by Major K. J. Groves in the Historic Room at the Ministry of Defence, Whitehall, on 6 November 1964. The presentation was presided over by Air Marshal Sir Christopher Hartley and attended by the Director-General of the Meteorological Office, Sir Graham Sutton (See Plate II).

The Memorial Prize for Aircraft Safety was awarded to Flight Lieutenant D. C. Evers, of No. 114 Squadron, RAF Benson, who designed a simple emergency release mechanism for the extractor parachute in transport aircraft which would operate should the extractor or platform mechanism fail during the dropping of heavy supplies. Flight Lieutenant Evers' development should obviate the present procedure whereby a crew member has to sever the parachute cable with bolt croppers in the event of trouble.

The Memorial Prize for Meteorology was presented to Dr. K. H. Stewart, Principal Scientific Officer, of the Meteorological Office, Bracknell, for the most important contribution to the science of meteorology or its application to aviation. Dr. Stewart was in charge of the British team which developed special instruments for the measurement of ozone in the atmosphere, carried in the Anglo-American satellite ARIEL 2, and it is largely due to his imaginative approach to design and his exceptional care and persistence during constant testing and installation in the satellite, that this unique equipment has functioned successfully (see Plate III).

The Air Meteorological Observer's Award went to ex-Flight Sergeant G. F. Earnshaw, formerly with No. 202 Squadron, RAF Aldergrove. He flew 185 sorties in Hastings aircraft during his four and a half years with the Squadron, logging 1900 hours, and his prize was awarded for meritorious work and devotion to duty by a member of aircrew employed on air meteorological observer or other duties relating to meteorology. Flight Sergeant Earnshaw became a Meteorological Observer Leader; he raised the training standards of new 'Met' observers, and was instrumental in improving the efficiency of his section and in perfecting techniques of meteorological survey.

Master Pilot R. E. Purdue received the Second Memorial Award for meritorious work in any field covered by the other prizes. The award is for suggested modifications in the design of aircraft rudder bar and toe brake-assemblies which are likely to eliminate accidents caused by inadvertent braking on landing. Such accidents, though infrequent, have been suffered by both experienced and inexperienced pilots. Master Pilot Purdue is now on air traffic control duties at RAF Honington.

HONOUR

The Director-General is pleased to announce the award of the Imperial Service Medal to Mr. A. L. Henson, who recently retired after having spent over 40 years in the service of the Crown. He served in the armed forces from the latter part of World War I to 1927, and again throughout World War II. During his Civil Service career, which was devoted entirely to radio communication work, many years were spent on radio direction-finding duties providing navigational and safety services for aviation. For the past few years he has been a Radio Supervisor in the Communications Branch of the Office, working first at Dunstable and later at Bracknell.

OBITUARY

Mr. W. R. Galloway, M.Sc.—The news of the sudden death of Mr. W. R. Galloway, Principal Scientific Officer, at his home in Pinner, Middlesex, on 16 November 1964, at the age of 50, came as a profound shock to his many friends inside and outside the Meteorological Office. Having made a wonderful recovery from a serious heart attack in 1956, he seemed to be enjoying ever-improving health.

Mr. Galloway joined the Meteorological Office in 1937, having been with Dunlop Limited for a short time after leaving University. After attending the Training School, then at Croydon, he served successively at Boscombe Down, St. Athan and Manston before going out to Canada in 1940 as a member of the team of meteorological instructors to R.A.F. pilots and navigators under training in the Dominion. Returning in 1943, he spent only a short time in this country before proceeding to India and he stayed until the end of the war in that theatre.

From 1946 to 1958, Mr. Galloway was wholly employed on civil aviation work, first at Headquarters, then at London Airport and lastly with the Ministry of Aviation Examining Unit. In 1958 he took up an appointment as Chief Meteorological Officer of R.A.F. Flying Training Command, moving on to take charge of the Meteorological Office Training School in 1962. He attended the School on the day of his death.

Wesley Galloway ('Bill' to the many who thought the 'W' stood for 'William') was a proud family man, a loyal and highly respected colleague, and the truest of friends. Of great spiritual strength and integrity, he was incapable of unkind thought, and his charity was boundless. He experienced many personal tragedies, but each seemed only to strengthen his wonderfully philosophic outlook on life.

Wesley Galloway will be sorely missed by a very wide circle of friends. We extend our deepest sympathy to his widow and family.

W.E.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:

SCIENTIFIC PAPERS

No. 19—*Some further observations from aircraft of temperatures and humidities near stratocumulus cloud*, by J. G. Moore, B.Sc.

This analysis of observations made by the Meteorological Research Flight during flights through anticyclonic stratocumulus cloud broadly confirms similar earlier work done by James.

Both sets of results show sharp temperature inversions and hydrolapses above the cloud top with considerable turbulence in the cloud and within the first 300 feet above. The heat balance suggests that heat must be transferred downwards through the cloud top by turbulent diffusion to maintain the heat budget of the cloud and air below. The absence of solar radiation by night requires a greater degree of turbulence by night than by day. It seems probable that in the absence of subsidence near the cloud top, water vapour transferred upwards by turbulent diffusion will remain in the lower part of the inversion layer leading to a gradual upward extension of cloud.

No. 20—*The interannual variability of monthly mean air temperatures over the northern hemisphere*, by J. M. Craddock, M. A.

Charts are presented based on most of the information readily available, covering most of the northern hemisphere, and showing, for each month of the year, measures of the variability of the mean temperature between one year and another.