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SOME IDEAS ON WINTER ATMOSPHERIC PROCESSES OVER SOUTH-WEST ASIA

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Summary.—This paper discusses the weather and climate of south-west Asia in relation to the subtropical jet stream and polar front jet streams over the region.

It is found that the mean position of the axis of, and the circulations associated with, the subtropical jet stream are consistent with the observed precipitation and trade cumulus distributions.

A case study has suggested that cumulonimbus clouds were released by orographic lifting of potentially unstable south-westerly airflows along the coasts of Persia and Pakistan and at the foot-hills of the Himalayas, and that the cumulonimbus clouds were accompanied by jet streams near the 300 mb level. The jet streams over Pakistan and India contained air which had ascended undiluted from the trade-wind layer over the Arabian Sea whilst the jet over the Persian coast probably also contained trade-wind air which had however been modified by rather deep small-scale convection over southern Arabia.

The subtropical jet stream over the Middle East.—During the northern winter the subtropical jet stream (STJ) lies in a continuous belt around the hemisphere, just below the 200 mb surface, and displays a pattern of three long waves, with wind-speed maxima occurring over Florida, Japan and the Middle East, all three areas lying within the latitude band 30° to 35°N. The level of maximum wind (LMW) of the STJ is found, on average, to be about 500–1000 m below the 200 mb level; an LMW situated much lower than 200 mb signifies interaction with a polar front jet stream (PFJ) whose LMW lies near the 300 mb level (Reiter[1]; Abandah[2]).

Studies of the Middle East STJ have confirmed that it is a steady, powerful current throughout the winter and only comparatively small latitudinal variations of the core occur. Abandah found that, in general, the jet axis curves across North Africa, from the west coast (17°N 15°W), over southern Libya to northern Jordan and western Iraq, where the median position of the wind-speed maximum is located, and thence pursues a curving track roughly parallel to, and immediately to the south of, the mountains of Persia and Pakistan, crossing the west coast of India around 22°N. The region from Iraq to India is referred to in this work as the exit from the area of maximum wind, i.e. the diffluence region ; in the exit region the core speed of the jet decreases gradually from a monthly mean value of about 65 m/s to about 40 m/s. Interannual comparisons of the intensity and of zonal and meridional

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locations of the monthly mean STJ axis show that the jet is a vigorous, remarkably steady wind system, to be considered as a seasonal feature of the area ; daily upper-air charts show the presence of a strong wind in the Middle East on nearly every winter day. In the late spring and summer the location of the wind-speed maximum is shifted northwards to central Turkey, and the speed decreases to about 40 m/s.

Precipitation near the axis of the subtropical jet stream.—The relation between weather and the jet stream may be observed simply from the precipitation distribution, which should be studied with reference to the orientation and configuration of the core axis, and to the locations of the confluence and diffluence regions. Precipitation distributions have been studied by many authors and their work is summarized by Reiter.[1] The distributions are consistent with the circulations to be anticipated kinematically ; for instance, in the exit region, where deceleration occurs, an indirect circulation takes place, kinetic energy being converted to potential energy, and there is subsidence in the warm air and ascent in the cool air. Proceeding upwards, it appears that the vertical motion on both sides of the axis first becomes appreciable in the middle troposphere, and extends to somewhat above the core axis. The lateral extent of the area over which there is appreciable vertical motion can be shown to be about 800 to 1000 km on either side of the Middle East STJ axis. Hence, in winter, over south-west Asia*, in the upper and middle troposphere sinking warm air is prevalent over Arabia and the Arabian Sea and rising relatively cool air is prevalent over the countries between Iraq and northern India.

Figure 1 shows the mean monthly precipitation over south-west Asia in January in relation to the mean position of the STJ axis.

The mountain chain which stretches from Turkey to China presents a formidable barrier to air masses, and modifications to the anticipated precipitation distributions occur as a consequence. At first sight, the relative dryness of central Persia, compared with the abundant winter rainfall of southern Persia, seems to be inconsistent with widespread upward motion on the northern flank of the diffluence region of the STJ. However, the intensification and southward movement of the STJ between autumn and winter are known to be accompanied by an increase of rainfall over southern Persia from almost none in September to over 100 mm, in some parts, in December, implying that the two events may be connected.

There is an abrupt decrease of precipitation at the STJ axis and almost no rainfall to the immediate south of the axis, over Arabia, a feature valid even in the seasonal mean and consistent with widespread subsidence south of the diffluence region of the STJ. The subsidence, in the middle and upper troposphere, causes a general suppression of convection and a reduction of rainfall, but occasionally a shower, or even a travelling disturbance, builds up sufficiently to give several millimetres of rain. In contrast, over the Sudan, the air in the lower troposphere is so dry that it must have subsided, eliminating cloudy convection, as there is virtually no water available from ground evaporation, and the mean January rainfall over the Sudan is zero.

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*South-west Asia is defined as that area between 10° and 35°N and between 35° and 80°E.

Koteswaram[3] noted that the winter precipitation along the STJ over Pakistan and India is confined to the region north of the axis and that subsidence occurs to the south. Figure 1 shows that, over India, the heaviest precipitation falls on the south-facing slopes of the mountains of northern India and Kashmir. Notice that Tibet is very dry ; it lies on the lee side of the Himalayas in relation to southerly winds accompanying disturbances over northern India.

According to Rao (private communication, 1966) a preliminary analysis of satellite observations shows that scattered cumulus is the predominant cloud-form in the north-east trades over the Arabian Sea, whilst aloft, on flights between Basra (Iraq), Karachi and Bombay[4], little cloud is encountered and visibility is good. It is, therefore, fair to assume that the usual characteristics of the trades are present over the Arabian Sea, i.e. steady north-easterlies, accompanied by small cumulus whose growth is limited by widespread subsidence, as anticipated.

Atmospheric convection over south-west Asia.—

(i) *Introduction.*—Ludlam[5] recognized two predominant kinds of atmospheric convection, small-scale and large-scale.

Small-scale, nearly upright, convection provides the lower troposphere with energy, partly as sensible heat and partly as the latent heat of evaporated water, and often manifests itself in the form of cumulus clouds, e.g. in the tropical trade cumulus.

In equatorial regions, the cumulonimbus is the principal means by which heat is distributed through the troposphere. In contrast, a large-scale slope-convection conveys heat both vertically and from low to high latitudes in

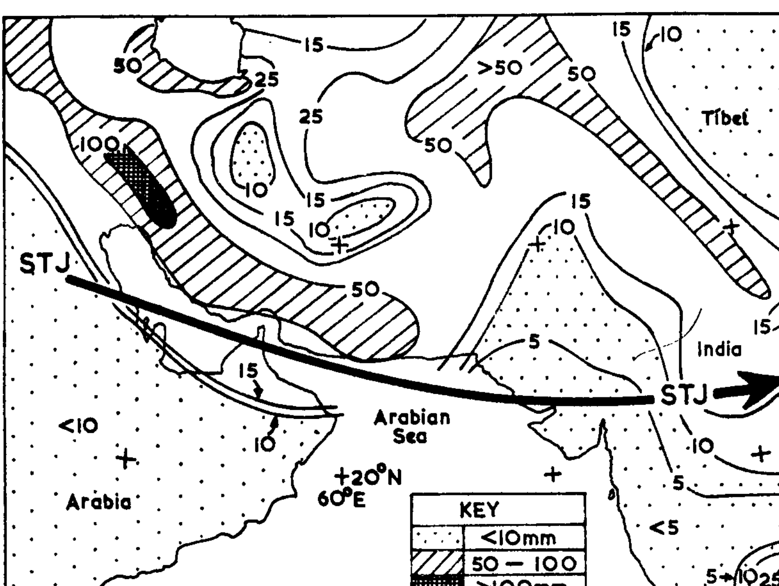

FIGURE 1—MEAN MONTHLY PRECIPITATION OVER SOUTH-WEST ASIA IN JANUARY IN RELATION TO THE MEAN POSITION OF THE STJ AXIS

the trough-ridge systems of middle latitudes ; in this kind of convection the air motion is nearly horizontal and, unlike the small-scale convection, is subject to the effect of the rotation of the earth.

Green, Ludlam and McIlveen[6] have described how small-scale and large-scale slope-convection collaborate in extra-tropical trough-ridge systems ; Figure 2 is a schematic three-dimensional representation of tropospheric slope-convection. They have shown that in the layer of small-scale convection (containing the tropical trade cumulus of low latitudes) subsiding dry air has its wet-bulb potential temperature raised, becomes potentially unstable, and is prepared for ascent ; air from this layer enters large-scale circulations and rises on the east flanks of travelling troughs into the vicinity of the jet streams near the 300 mb level farther north. Furthermore, according to these authors, the air which arrives near the jet stream possesses the highest wet-bulb potential temperature (θ_w) involved in the trough-ridge system, having risen from the trade-wind layer ; they propose that θ_w in the trade-wind air is determined mainly by the sea surface temperature, being typically about 4 degC less at ship's deck level, probably 5 degC less at cloud-base level (about 600 m) and 8 degC less at the 850 mb level.

(ii) *Polar front jet streams.*—Monthly mean charts show that, in winter, winds in excess of 50 m/s near the 300 mb level frequently occur between the Persian Gulf and northern India, a region associated with travelling precipitating disturbances (Kendrew[7]; Banerji[8]; Pisharoty and Desai[9]) usually shown on surface analyses as cold fronts. The occurrence of polar front jet streams as far south as the Persian Gulf (26°N) suggests the possibility

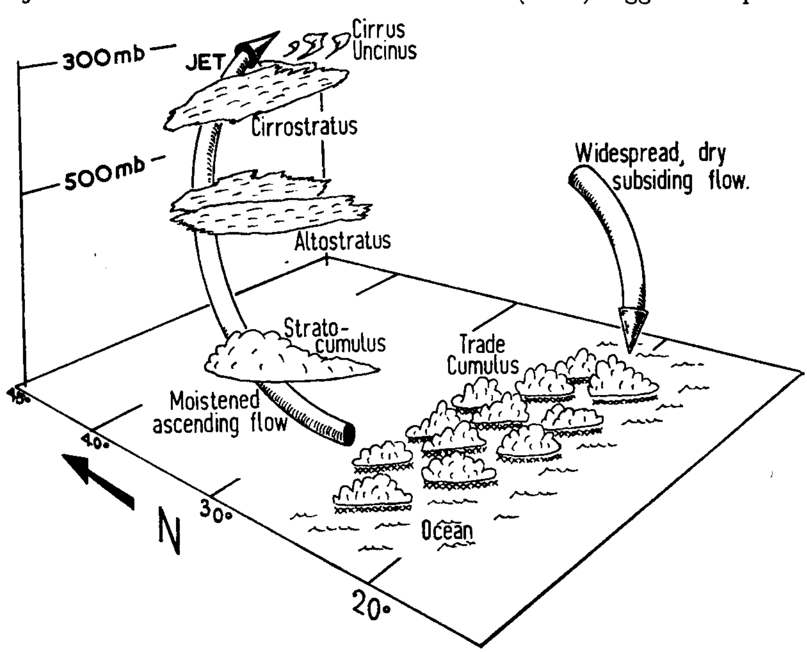

FIGURE 2—SCHEMATIC MODEL OF FLOW IN LARGE-SCALE CONVECTION
In the trade-cumulus subsiding air has its potential temperature raised. Thence, air ascends into the upper troposphere to arrive in, or to the right of the axis of, a jet stream. Ascent is revealed by sheets of low, medium and high clouds. The boundary of the cirrus uncinus (decaying cirrus) and the cirrostratus probably marks the limit of ascent

of rather rapid ascent along, and small radii of curvature for, trajectories leading from the trade winds into the jets. Accordingly, a case study, based on radiosonde and pilot balloon ascents and surface, land and ship observations on a date during a World Meteorological Interval in the International Geophysical Year, 1957–8, was made of a disturbance (front) which travelled from the Persian Gulf to northern India. Thunderstorms developed along the coasts and also near the hills of north-west India, whereas elsewhere the precipitation was reported to be of a more continuous nature. Very strong winds, from about 240°, near the 300 mb level, and south-westerly winds through most of the troposphere below 300 mb, accompanied the disturbance.

The detailed arguments and synoptic evidence are presented in a thesis by the author[10] and only the principal conclusions are presented in this paper.

It appears that when the potentially unstable south-westerly airflow encountered the steep mountain barriers of Persia and Pakistan orographic lifting and condensation took place. Marine observations indicated that, at deck level, in the eastern Persian Gulf $\theta_w \simeq 17$°C and in the extra-tropical Arabian Sea $\theta_w \simeq 20$°C, both figures higher than the corresponding values of θ_w in the upper troposphere (14°C over the Persian Gulf and 19°C over the Pakistan coast). Hence, along the coast, conditions were favourable for the development of cumulonimbus, but inland, in the absence of such an inflow of warm moist air at the surface, it is supposed that precipitation resulted from the release of medium-level instability, i.e. from altocumulus castellanus, and was, consequently, less intense. If cumulonimbus convection is induced on a scale of hundreds of kilometres, as it appears to have been in this case (as distinct from restriction to individual sites), then large-scale slope ascent does not occur ; potential energy is released and perhaps mostly locally dissipated in cumulonimbus, but a high troposphere jet stream may be generated in and downwind of the cumulonimbus tops, instead of forming farther north. This mechanism is proposed to account for jet streams near 300 mb occurring as far south as the Persia and Pakistan coasts.

When the front reached India the strongest 300 mb winds and the region affected by thunderstorms were located farther north, between 29° and 31°N, and the largest precipitation amounts occurred near the foot-hills of the Himalayas in southern Kashmir. Again, it appears that orographic lifting was a very significant process in the formation of cumulonimbus. Near the Himalayan foot-hills deep convection was probably released by the orographic lifting of potentially unstable air (plumes of warm air, in which $\theta_w \simeq 19$°C, created by insolation on the uplands east of Bombay) to its condensation level, whilst on the front, i.e. the interface between the air streams of relatively high θ_w and relatively low θ_w, thunderstorms, once formed, were probably well-organized and self-maintaining, in the manner proposed by Ludlam.[5]

(iii) *Trajectories leading into the polar front jet streams.*—From observations of sea-surface temperatures, $\theta_w \simeq 23$°C at ship's deck level was adopted as a basis for estimates of θ_w in all trajectories leading from the trade-wind layer. If, as Green, Ludlam and McIlveen imply, θ_w is approximately conserved along a trajectory leading from the trade-wind layer, over a front and into the vicinity of a jet stream, then it is reasonable to expect θ_w to be about 19°C in, or close to, the strong winds found near the 300 mb level between Iraq and north-west India. Over Pakistan and India the saturated wet-bulb potential temperature, θ_s, (used rather than θ_w because humidity observations are not available at this level, and at the low temperatures of high levels $\theta_s \simeq \theta_w$) was indeed about 19°C, but, as mentioned earlier, over the Persian Gulf θ_s was only 14°C. It is apparent that trade-wind air probably ascended directly into the jets near the 300 mb level over the Pakistan coast and north-west India ; the air in the PFJ over the Persian Gulf was probably also trade-wind air which appears to have been strongly modified over the south coast of Arabia by rather deep small-scale convection, leading to a reduction in the mean θ_w and the intensity of the associated jet stream.

Over the south coast of Arabia, sea breezes, which can be shown to occur almost daily at Riyan and Salalah, and strong solar heating on the arid slopes of the coastal mountains favour the formation of large cumulus clouds, which probably grow to about the 500 mb level, thus mixing moisture into a layer which is deeper than that of the trade-wind convective layer which flows towards Arabia. The moisture is derived mainly from the rather shallow moist layer over the Arabian Sea, because virtually no water is added by ground evaporation along this parched coast, so approximately the same amount of water is diffused in the lowest 500 mb over the coast as is contained below about the 800 mb level in the trade-wind layer. Hence, in a trajectory in a potentially warm flow which has crossed this coast, a θ_w several degrees lower than in the unmodified trajectories leading directly from the trade-wind layer must be anticipated.

Conclusion.—It is believed that the findings of the case study, summarized in Figure 3, are broadly typical of the main winter conditions over south-west Asia. Trade-wind air from the Arabian Sea appears to ascend directly, undiluted, into polar front jet streams over the Pakistan coast and over north-west India ; the air in polar front jets over the Persian Gulf is probably also

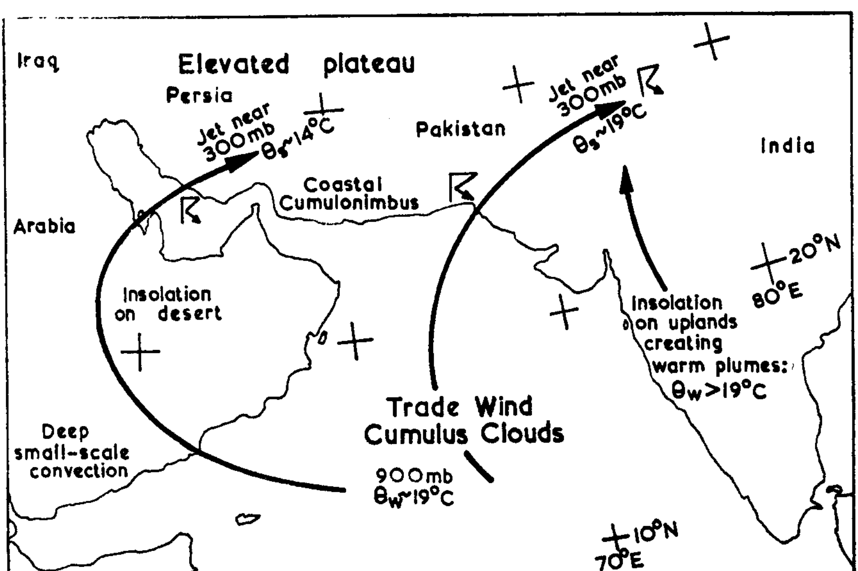

FIGURE 3—SUMMARY OF THE FINDINGS OF THE CASE STUDY

trade-wind air which has been strongly modified by rather deep small-scale convection over southern Arabia. Deep convection along the coasts of Persia and Pakistan is probably initiated by the orographic lifting of plumes of potentially unstable air, assisted by a supply of warm, moist air at low levels from the Persian Gulf and Arabian Sea. In north-west India potential instability is probably released by orographic lifting at the foot-hills of the Himalayas. Plumes of potentially unstable air appear to be created by insolation on the upland parts of western India and on the arid parts of Arabia. Precipitation falls mainly on south-facing (windward) slopes, as is shown by Figure 1. The mean position of the STJ axis is consistent with the observed precipitation and trade cumulus distributions.

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THE ASSOCIATION BETWEEN AUTUMN AND WINTER CIRCULATIONS NEAR BRITAIN

By R. F. M. HAY, M.A.

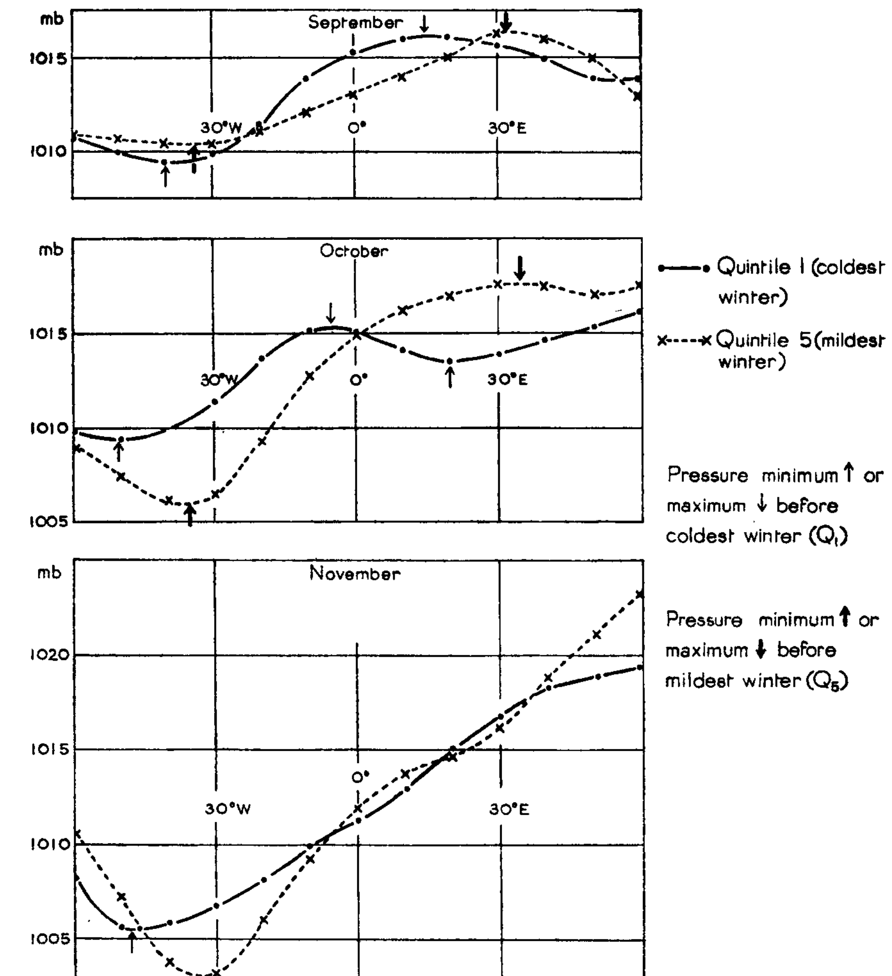
Summary.—Pressure in October to the north-west of Britain during blocked periods within 1873–1963, when the frequency of westerly winds over Britain was much reduced, shows a statistically significant association with the temperatures of the winters following in central England. Tentative forecasting rules are presented.

Circulation types for autumns and winters for blocked and for westerly periods within 1873–1963 related to winter temperatures are examined by means of indices of progression, meridionality and cyclonicity. From tables giving these results it is seen that enhanced frequencies of northerly (together with westerly) types in autumn have tended to persist through the winter following, at least during the past 90 years.

The geographical distribution of monthly mean pressure centres for October in the blocked periods, grouped in relation to the winter temperatures following in central England is found to be synoptically coherent. Strong zonal flow on the North Atlantic with the monthly low-pressure centre near Iceland usually precedes mild winters; whereas northerly or north-westerly flow over Britain, with the main monthly low centre located over the Norwegian Sea or the Kara Sea, is associated with Octobers which precede winters in the colder quintiles in central England.

Introduction.—The monthly mean circulation patterns over the North Atlantic, Europe and western Asia for Octobers preceding mild winters over central England are strikingly different from those which preceded cold winters over a period extending from the autumn of 1873 to the winter of

1962/63. In agreement with recent ideas this period was divided into a 'blocked period' consisting of the periods autumn 1873 – winter 1894/95 and autumn 1940 – winter 1962/63 and a 'westerly period' covering the period autumn 1895 – winter 1938/39* in order to take some account of circulation changes. Although data for years beyond 1963 were not used here, the years since then are considered to belong to the blocked period, and hence conclusions relating to the blocked period described here are relevant at the present time. Winters (December – February) were ranked in order of their mean temperatures in central England and classified into five equal groups—very mild, mild, average, cold and very cold corresponding to quintiles Q_5,



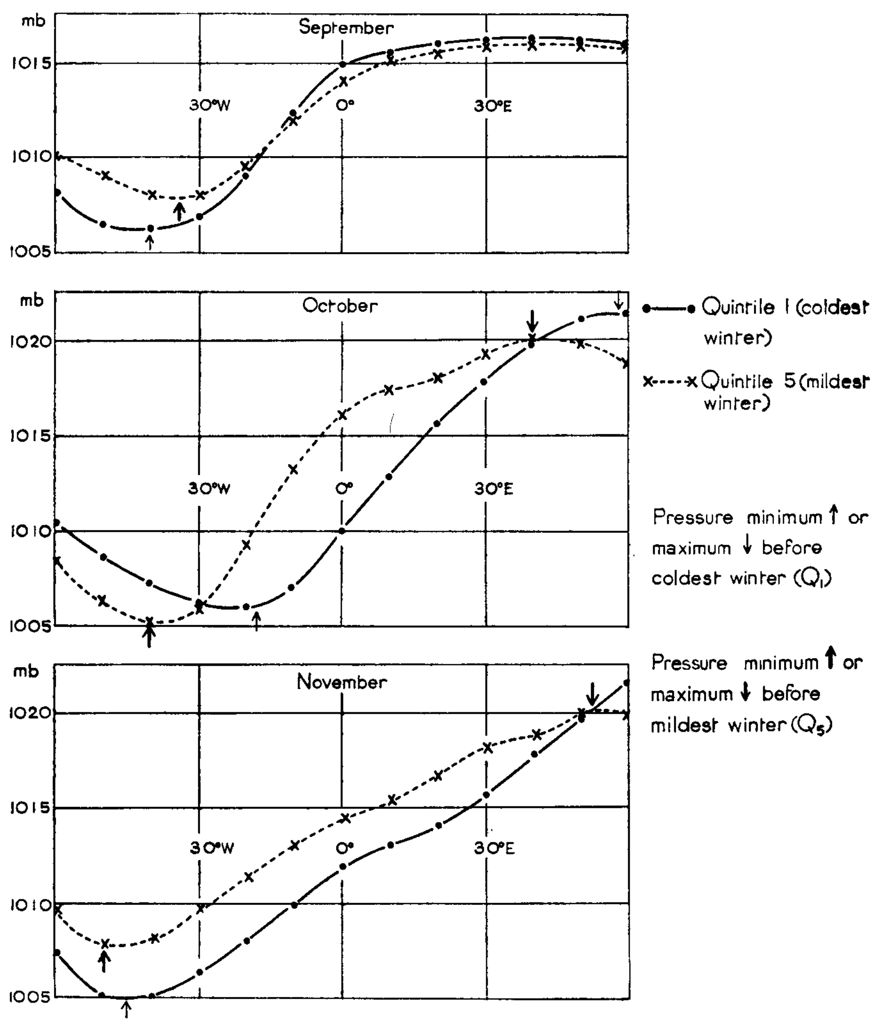
(*a*) Blocked years (autumn 1873–winter 1894/95 and autumn 1940–winter 1962/63). Each profile is the mean of 9 years.

FIGURE 1—MONTHLY MEAN PRESSURE ALONG 55°N IN AUTUMN MONTHS BEFORE THE MILDEST AND COLDEST WINTERS

*The year 1940 had to be omitted on account of missing data.

Q_4, Q_3, Q_2 and Q_1 respectively. The blocked period included 45 years with 9 years in each quintile, but the westerly period of 44 years included one quintile (Q_3) with only 8 years.

Differences between monthly pressure profiles at 55°N during autumns preceding anomalous winters in central England.—Profiles of monthly mean pressures along 55°N during the blocked period were constructed from the mean pressures at grid points at 10-degree intervals from 55°N 60°W to 55°N 60°E meaned for each group of nine Septembers, Octobers and Novembers which preceded the mildest (Q_5) winters and also for those preceding the coldest (Q_1) winters, Figure 1(*a*). Similar procedures were carried out for the westerly periods, Figure 1(*b*).



(*b*) Westerly years (autumn 1895–winter 1938/39). Each profile is the mean of 9 years

The most interesting result relates to the blocked period. In the three months the profile minimum in the western Atlantic is from 10 to 20 degrees further west before the coldest winters than before the mildest, and pressures are generally higher before the coldest winters. This latter effect is most pronounced in October (Figure 1(*a*)) when the pressure difference (Q_1–Q_5) at 55°N 30°W amounts to as much as 5 mb.† In a similar manner, relatively high pressure found near 30°E prior to the mildest winters is displaced westwards before the coldest winters. While this result shows strongly in October, it is less strong in September and is absent in November.

On a chart showing average sea-level pressure for October (1900–39) the lowest mean pressures along 55°N are found between 30°W and 40°W to south-east of Cape Farewell. Hence Figures 1(*a*) and (*b*) suggest that, on the whole, mild winters in both periods are preceded by Atlantic pressure minima in nearly the same longitudes as those of the average pressure minimum, at least in the month of October, while the coldest winters are the ones which are preceded by abnormal pressure distributions.

Differences between monthly pressures in October to the south-west of Iceland preceding anomalous winters.—Since the normal position of the monthly low-pressure centre for October lies slightly to the south-west of Iceland (between 20°W and 30°W) this implies that this largest pressure difference found along 55°N at 30°W should be associated with variations in the Iceland low itself, and hence that similar differences might be even larger nearer the actual low centre. Fortunately a separate set of similar mean monthly pressure values for October was also available for the position 63°N 20°W. A detailed analysis of these results is shown in Figure 2.

Significance test.—In order to test the significance of the apparent association between mean monthly pressure values in October at 63°N 20°W and temperature anomalies in subsequent winters in central England, a chi-square test was carried out on the data in Table I. The test showed that the association was significant at the 1 per cent level. (It is usually assumed that the chi-square test is not valid if the expectation in each box is less than 5 but recent work by Craddock[1] for a 3×3 table and subsequent work by him for a 5×3 table (not yet published) shows that this rule is unnecessarily restrictive, expectations of about 3 per box being still satisfactory.)

TABLE I—MONTHLY MEAN PRESSURE IN OCTOBER AT 63°N 20°W AND THE SUBSEQUENT WINTER TEMPERATURE IN CENTRAL ENGLAND (BLOCKED PERIODS OCTOBER 1873–WINTER 1894/95, OCTOBER 1940–WINTER 1962/63)

Monthly mean pressure in October (terciles)	Winter temperature (quintiles) 1	2	3	4	5	Totals
Upper tercile	8	3	1	2	2	16
Middle tercile	1	2	2	4	5	14
Lower tercile	0	4	6	3	2	15
Totals	9	9	9	9	9	45

Notes : Upper tercile includes 1008.0 mb and above
Lower tercile includes 1000·5 mb and below

†The monthly standard deviation (σ) for October (1900–39) has the same value of 5 mb at 55°N 30°W.

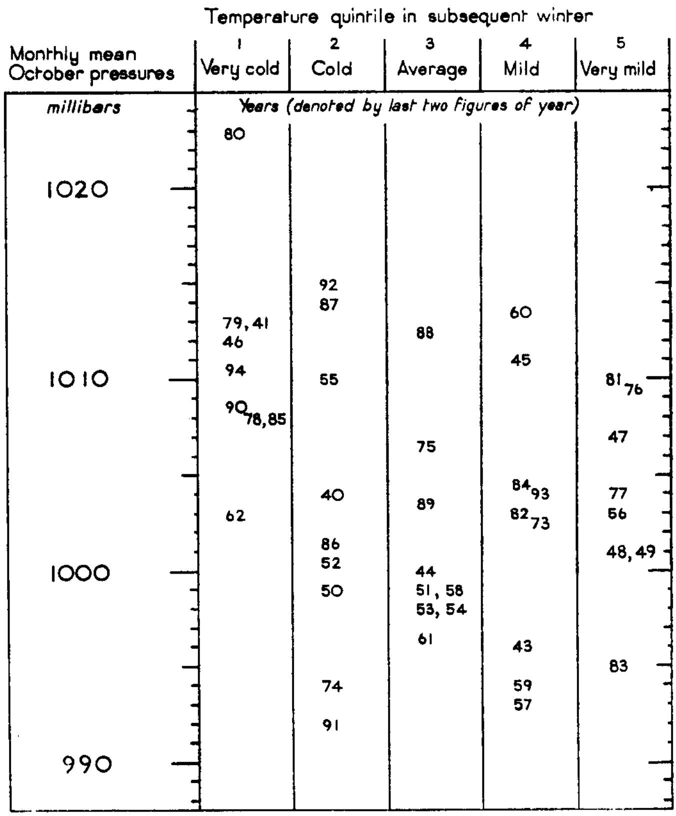


FIGURE 2—MONTHLY MEAN PRESSURES IN OCTOBER AT 63°N 20°W FOR EACH YEAR OF THE BLOCKED PERIOD RELATED TO THE SUBSEQUENT WINTER TEMPERATURES IN CENTRAL ENGLAND (OCTOBER 1873–OCTOBER 1894 AND OCTOBER 1940–OCTOBER 1962)

The last two figures of the year are entered against the mean October pressure of the year and under the temperature quintile of the subsequent winter (December–February).

Example : 73 signifies a monthly mean pressure of 1002·5 mb in October 1873 preceding a temperature quintile 4 in central England in the winter 1873/74.

Tentative rules for forecasting.—Figure 2 and Table I suggest some tentative forecasting rules as follows :

(i) When the October mean pressure at 63°N 20°W is equal to or exceeds 1012 mb the winter following in central England is likely to be cold or very cold.

This condition was fulfilled in 8 cases.

In 6 cases this forecast would have been successful, while in 2 cases it would have failed. In 4 of the successful cases a very cold winter followed while in one of the failures a mild winter followed.

(ii) As for rule (i) but with October pressure $\geqslant$ 1014 mb.

This condition was fulfilled in 3 cases.

In all 3 cases this forecast would have been successful.

(iii) When the October mean pressure at 63°N 20°W is equal to or less than 998 mb the following winter temperature in central England is likely to be average, mild or very mild (i.e. it will not be cold or very cold).

This condition was fulfilled in 9 cases.

In 7 cases this forecast would have been successful, while in 2 cases it would have failed. In 4 of the successful cases the following winter temperatures were above average (Q_4) or much above average (Q_5). In 2 failures the following winter was cold (Q_2).

(iv) As for rule (iii) but with October pressure $\leqslant$996 mb, the following winter will be mild or very mild.

This condition was fulfilled in 6 cases.

In 4 cases the forecast would have been successful, and it would have failed in 2 cases, when cold winters (Q_2) followed. In one of the 4 successful cases a very mild winter followed.

The conditions in which the tentative rules (i) and (iii) can be applied will each occur on about 20 per cent of the total occasions, and the rules could then be used for forecasting with a good chance of success.

Synoptic types in the blocked period.—The Murray and Lewis[2] indices of progression (*P*), meridionality (*S* and *M*) and cyclonicity (*C*) recently derived for each month of the period 1873–1963 afford a convenient method of comparing relative frequencies of synoptic types over the British Isles during calendar months and seasons. Each index is derived from the series of daily synoptic types for each day of the month included in the Lamb catalogue[3] for 1873–1963. Broadly the *P*-index (for progression) is a measure of the frequency of days of westerly synoptic type during the month over the British Isles, corresponding roughly to the region bounded by 50°–60°N, 0°–10°W. Negative values of *P* similarly imply a predominance of days with an easterly synoptic type. The *S*-index is similarly a measure of the frequency of days having meridional pressure gradients (positive for southerly, negative for northerly), while the *C*-index yields a comparable measure of the frequency of days in the month when the inner closed isobar of a depression covered at least a part of the same region around the British Isles. Positive values denote a preponderance of cyclonicity, while negative values similarly refer to anticyclonicity. Finally the *M*-index gives the frequency of all days with meridional pressure gradients, obtained by adding together all days with northerly and southerly synoptic types.

Winters.—Table II(*a*) which gives the mean values of *P*, *S*, *C* and *M* for the nine winters in each quintile, shows these interesting features for the blocked period :

(i) The mildest winters show the highest frequency of progressive (westerly) days.

(ii) Compared with those in the other four quintiles the coldest winters are the most blocked (*P* negative), the most anticyclonic (*C* negative) and mostly south-easterly (*P* negative and *S* positive).

(iii) Cold winters (in Q_2) are the most northerly (smallest positive value of *S*), also they are relatively progressive (frequency of westerly types is intermediate between those for Q_3 and Q_4).

(iv) In average winters (Q_3) meridionality irrespective of sign (*M*) is at a maximum.

The indices for the winters during the westerly years also show some of the features just described, although the differences between winters in the various quintiles are less evident than during the blocked years (Table II(*b*)).

TABLE II—*PSCM* INDICES IN WINTER — MEAN VALUES FOR EACH TEMPERATURE QUINTILE DURING BLOCKED AND WESTERLY PERIODS IN WINTER

Winter temperature quintile (central England)	Index *P*	*S*	*C*	*M*
(*a*) Blocked period (1873–95 and 1941–63)				
5	15·4	7·1	−1·5	15·3
4	11·9	5·4	−0·3	15·0
3	5·5	2·1	−5·1	16·7
2	7·6	0·3	−2·5	15·2
1	−6·4	4·1	−7·7	14·3
Average index	6·8	3·8	−3·4	15·3
(*b*) Westerly period (1896–1939)				
5	29·1	4·7	2·1	9·0
4	17·6	5·9	−0·4	11·3
3	17·9	3·8	−1·2	9·7
2	20·2	2·9	−1·1	10·8
1	6·0	4·6	−3·0	12·1
Average index	18·2	4·4	−0·7	10·6
(*c*) Overall means (1873–1964)*	10·7	4·3	−2·7	13·7

*From Murray and Lewis.[2]

The result in (iii) confirms a result found from investigating the incidence of meridional pressure gradients along 55°N but not published here, namely that the coldness of winters in Q_2 is brought about by a higher than normal frequency of northerly synoptic types over Britain.

Autumns.—Table III gives means of *P*, *S*, *C* and *M* for the nine autumns in each group which respectively preceded the winters in the same quintiles used in Table II.

In the blocked period the coldest winters (Q_1) were preceded by autumns which were more blocked and more anticyclonic than those in any other quintile. Again this was not true during the westerly period. By contrast

TABLE III—*PSCM* INDICES IN AUTUMN — MEAN VALUES ASSOCIATED WITH TEMPERATURE QUINTILES OF SUBSEQUENT WINTERS DURING BLOCKED AND WESTERLY PERIODS

Winter temperature quintile (central England)	Index *P*	*S*	*C*	*M*
(*a*) Blocked period (1873–95 and 1941–63)				
5	7·9	4·5	−4·1	15·5
4	5·7	1·6	−2·6	14·8
3	9·2	5·5	−0·2	13·3
2	9·0	0·6	−0·8	16·1
1	−1·4	1·6	−8·2	14·9
Average index	6·1	2·8	−3·2	14·9
(*b*) Westerly period (1896–1939)				
5	6·2	4·6	−4·7	13·0
4	4·9	3·2	−3·6	13·5
3	11·2	0·5	−3·6	10·6
2	22·0	0·0	0·0	8·0
1	14·3	5·9	−0·8	12·6
Average index	11·7	2·8	−2·5	11·5
(*c*) Overall means (1873–1964)*	7·7	3·0	−2·7	13·0

*From Murray and Lewis.[2]

the autumns preceding cold winters (those in Q_2) were more progressive and more northerly (in fact less southerly) than the others in both periods. Thus, during the last 90 years at least, whenever an enhanced frequency of northerly (together with westerly) types over Britain has occurred in the autumn, it has tended to persist through to the winter following.

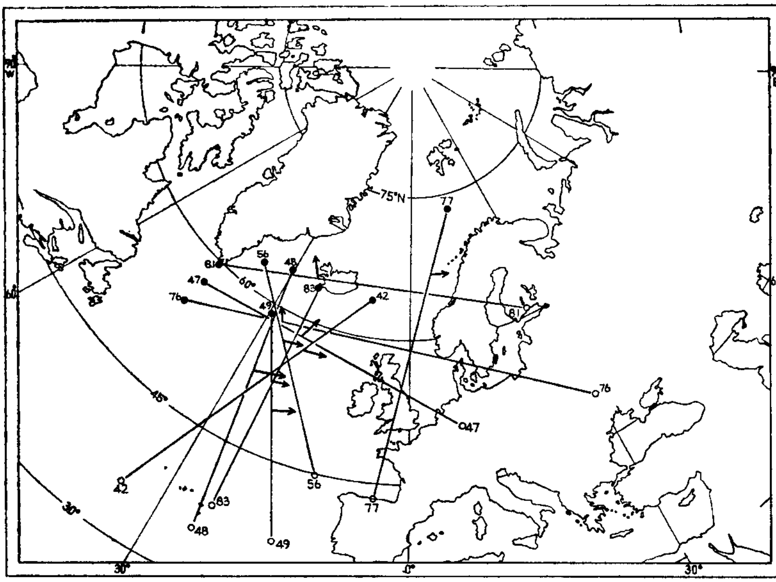
Locations of monthly mean pressure centres in Octobers before anomalous winters in central England.—The October monthly mean pressures at a single point (63°N 20°W) on the North Atlantic for each year of the blocked period were classified according to the temperature quintile of the winter following in central England (see Figure 2). This figure conveys limited information but when attention is directed instead to the geographical distribution of the monthly high-pressure and low-pressure centres, several informative synoptic features are readily identified.

A chart was prepared for each of the five winter temperature classes in the blocked period, and the positions of the most intense and extensive monthly mean low-pressure and high-pressure centres for Octobers prior to the specified category of winter were inscribed on each chart. (Centres were defined thus in relation to an area which included much of the Atlantic, Europe and western Asia, while other centres of lesser significance in this context were omitted from the charts.) High-pressure and low-pressure centres — as just defined — for each year were joined and the position where the pressure gradient was steepest was shown by an arrow tangential to the monthly mean isobar, which thus gave a reasonably accurate indication of the monthly mean vector geostrophic wind at this point for each month in question.

The charts showed the following main features of interest (Figures 3–7).

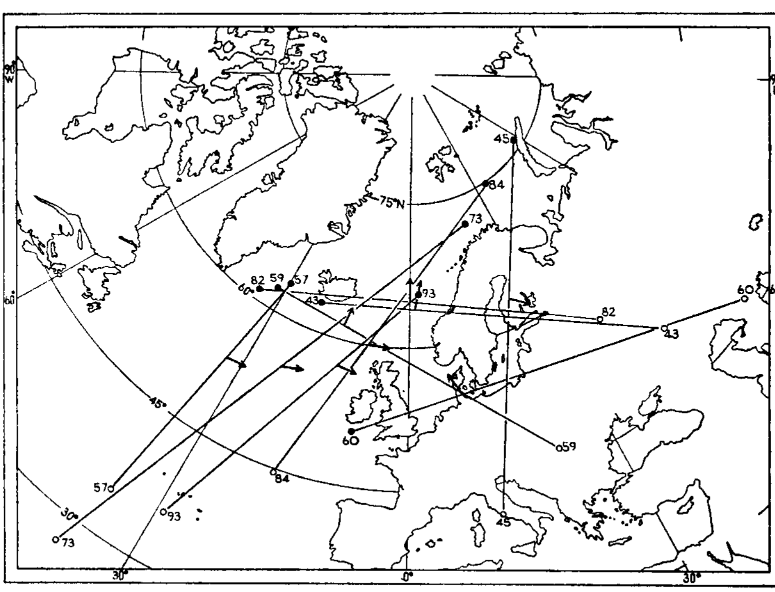
(i) The monthly circulation over the North Atlantic and Europe changes from a mainly zonal pattern in Octobers before very mild and mild winters (Figures 3 and 4) to a much more blocked pattern before cold and very cold winters (Figures 6 and 7). In Figures 3 and 4 the strongest pressure gradients lie to the west or occasionally to the north of Britain in most of the years, and the monthly mean vector geostrophic wind is westerly or southerly. In Figures 6 and 7 these same strong pressure gradients are found mostly to the north-east of Britain, as far away as the Kara Sea (about 75°N 65°E), and the 'wind direction' (as just defined) is north-west or north in a high proportion of the years. Exceptions occur mostly before cold winters (Q_2) and involve south-east or south 'wind directions' (Figure 6). In the Octobers before these cold winters it is clear that both northerly and southerly blocked types were about equally frequent near Britain, while westerly types were decidedly uncommon.

(ii) The disposition of low-pressure centres before the different types of winters shows a striking synoptic coherence. Before the mildest winters, centres are grouped near Iceland, or occasionally in the Norwegian Sea; the story is the same before mild winters with a little more bias towards the Norwegian Sea. An interesting situation arises before average winters (Figure 5) when nearly all the low-pressure centres are again grouped near Iceland, but in this instance they are associated with blocking highs over Scandinavia or Russia, in contrast with the zonal types prevalent before mild and very



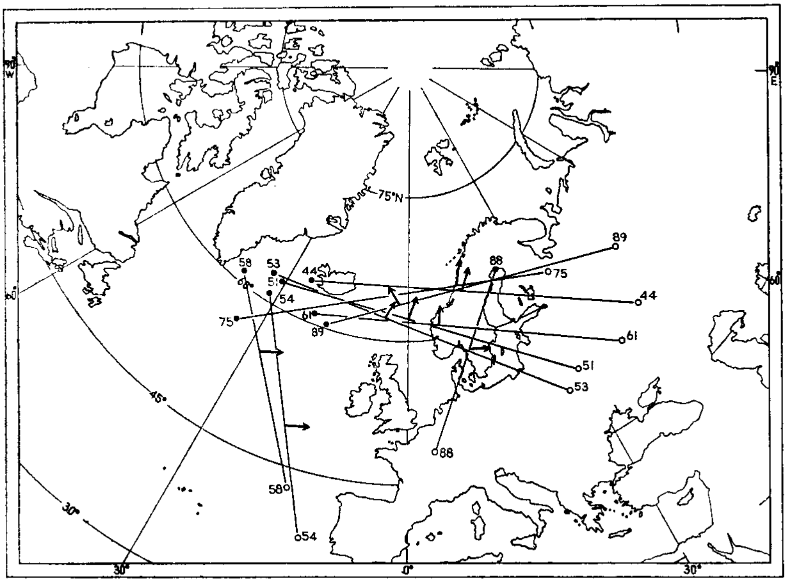
●76 Low centre in 1876   ○76 High centre in 1876   → Direction of monthly mean vector geostrophic wind at the location of steepest monthly mean pressure gradient

FIGURE 3—POSITIONS OF MONTHLY MEAN LOW-PRESSURE AND HIGH-PRESSURE CENTRES IN OCTOBER DURING THE BLOCKED YEARS BEFORE THE MILDEST WINTERS (Q_5) IN CENTRAL ENGLAND



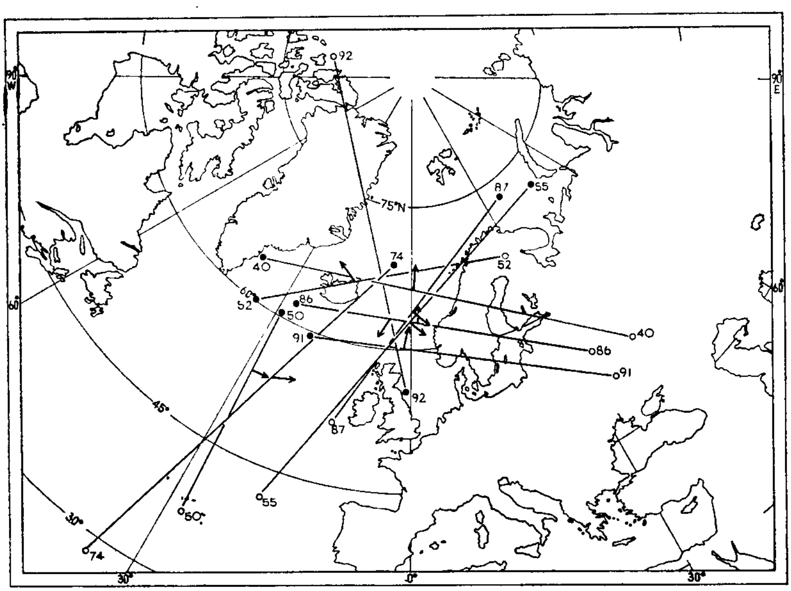
●76 Low centre in 1876   ○76 High centre in 1876   → Direction of monthly mean vector geostrophic wind at the location of steepest monthly mean pressure gradient

FIGURE 4—POSITIONS OF MONTHLY MEAN LOW-PRESSURE AND HIGH-PRESSURE CENTRES IN OCTOBER DURING THE BLOCKED YEARS BEFORE MILD WINTERS (Q_4) IN CENTRAL ENGLAND



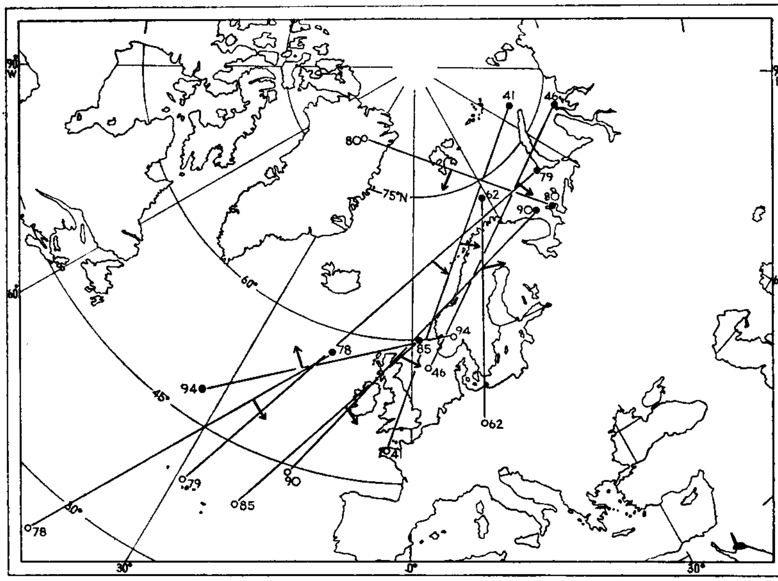
•76 Low centre in 1876 o76 High centre in 1876 → Direction of monthly mean vector geostrophic wind at the location of steepest monthly mean pressure gradient

FIGURE 5—POSITIONS OF MONTHLY MEAN LOW-PRESSURE AND HIGH-PRESSURE CENTRES IN OCTOBER DURING THE BLOCKED YEARS BEFORE AVERAGE WINTERS (Q_3) IN CENTRAL ENGLAND



•76 Low centre in 1876 o76 High centre in 1876 → Direction of monthly mean vector geostrophic wind at the location of steepest monthly mean pressure gradient

FIGURE 6—POSITIONS OF MONTHLY MEAN LOW-PRESSURE AND HIGH-PRESSURE CENTRES IN OCTOBER DURING THE BLOCKED YEARS BEFORE COLD WINTERS (Q_2) IN CENTRAL ENGLAND



•76 Low centre in 1876 ○76 High centre in 1876 → Direction of monthly mean vector geostrophic wind at the location of steepest monthly mean pressure gradient

FIGURE 7—POSITIONS OF MONTHLY MEAN LOW-PRESSURE AND HIGH-PRESSURE CENTRES IN OCTOBER DURING THE BLOCKED YEARS BEFORE THE COLDEST WINTERS (Q_1) IN CENTRAL ENGLAND

mild winters. As an illustration of the coherence within these circulation types, the same effect — lows near Iceland with highs over Russia or Scandinavia — is also found for some of the cases preceding cold winters (those in the second quintile). The remaining cases found before winters in the second quintile consist of lows lying to north of Scandinavia paired with highs lying near the Azores and thus giving mainly north-westerly flow in the vicinity of Britain, similar in fact to the type which predominates in Octobers before the coldest (Q_1) winters. Further, there is evidently an important difference between October circulations before very mild or very cold winters, which is shown up by the positions favoured by the Iceland low in the two situations. Before the mildest winters it is found mostly near the normal October position, as shown by a mean chart for a long series of years, whereas in the cases when a very cold winter followed, the Iceland low is displaced far to the north-east towards the Kara Sea or occasionally well to the south-east towards Britain or the Azores.

(iii) High-pressure centres before very mild and mild winters are found in an area extending from the Azores to south-west Europe. Before average and before cold winters in rather more than half the cases high-pressure centres are found over Russia and western Siberia (north of 50°N and east of 25°E). Before the coldest winters, although the positions of the high-pressure centres are little different from those found before the mildest winters, they are usually paired with low-pressure centres displaced towards or lying near the Kara Sea as described earlier.

Conclusions.—

(i) During the recent periods of relatively blocked circulation (1873–95 and 1941–63), monthly pressure minima along 55°N in the western North Atlantic have been displaced up to 20° of longitude westwards in autumn months before the coldest winters in Britain, compared with their positions before the mildest winters. Pressures are also generally higher in the western North Atlantic before the coldest winters and this effect is most pronounced in October when the pressure difference (Q_1–Q_5) at 55°N 30°W amounts to as much as 5 mb (equal to the monthly standard deviation for October pressure (1900–39) for that point).

(ii) At a location 63°N 20°W, near the mean position of the Iceland low on the chart showing average pressure for October, an association between monthly mean pressure in October and temperature anomaly of the subsequent winter in central England is significant at the 1 per cent level during the same periods of relatively blocked circulation.

(iii) An examination of the October monthly mean pressures at 63°N 20°W reveals that :

(*a*) When pressure equals or is greater than 1012 mb the winter following in central England is likely to be cold or very cold.

(*b*) When pressure equals or is less than 998 mb the following winter in central England is likely to be average, mild or very mild.

(iv) For the blocked periods the geographical distributions of the most intense monthly mean low-pressure and high-pressure centres in the Octobers of the same years, grouped in relation to the temperature classification of the winter following in central England, were found to be synoptically coherent. Before the mildest winters low-pressure centres occur mostly near Iceland. However, prior to the coldest winters they are found mostly over the Kara Sea (to the north-west of Siberia) and they appear to avoid the vicinity of Iceland.

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THE SUMMERS OF NORTH-WEST EUROPE

By N. E. DAVIS, M.A.

In 1962 Poulter[1] classified the summers 1880–1961 at Kew by means of an index I_{sk}. Sutton[2] and Selfe[3] pointed out differences between summers in odd years and summers in even years. More recently in 1966, Booth[4], Sutton[5] and Poulter[6] have made further comments and it would seem appropriate to examine the index in greater detail.

Poulter defined his index for Kew (51° 28′N, 00° 19′W, elevation 18 feet) as

$$I_{sk} = 10T + S/6 - R/5$$

where T = mean temperature in °F for June, July and August
S = total sunshine in hours
and R = total rainfall in millimetres.

He gave the value of the index for all summers from 1880 to 1961.

The values for 1962–65 given by Booth[4] and Sutton[5] are 670, 673, 689 and 660 respectively (the value for 1966 is 669 but it is not included in the calculation as it was not available at the time the other values were done). The average of the 43 even summers is 671 and the average of the 43 odd summers is 691 giving a difference of 20 points. This is equivalent to 2 degF in mean temperature, or 100 mm (approximately 4 in) of rain, or 120 hours of sunshine. These are quite large amounts and although temperature, rainfall and sunshine are highly correlated in summer, nevertheless the 20-point difference would be climatologically a very significant amount, provided it could be shown statistically that the difference was real.

Student's *t* test is normally used to compare two means. Applying it to this difference of 20 points between the means of the odd and even summers, we find the value of *t* to be 2·65 which with 84 degrees of freedom arises by chance only with the probability of 1 in 100, i.e. the difference is significant at the 1 per cent level.

The validity of the *t* test however depends on the distribution of the Poulter index being normal. Whilst this does appear to be the case, the difficulty can be avoided by considering only the change in the value of the index from one year to the next. A year is marked + if its index is higher than that of the previous year and – if it is lower. Then, if the odd summers are better than the even summers, there should be a higher frequency of + in odd years than in even years. The actual frequencies are :

	+	–	Total
Odd years	28	14	42
Even years	14	28	42
Total	42	42	84

The difference from Poulter's totals is accounted for by the year 1880 being excluded and by 1919 having the same value as 1918.

One would expect 21 + and – in both odd and even years if the odd summers were no better than the even ones. Using the chi-square test to compare the actual frequencies with the expected values, we find the value of χ^2 (taking into account Yates's correction) to be $(6{\cdot}5)^2 \times (4/21) = 8{\cdot}05$. The 1 per cent point of the χ^2 distribution with 1 degree of freedom is 6·63 so that the value found is highly significant.

These two tests show that since 1880 (at least) the odd summers at Kew have been better than the even summers, averaging some 20 points better on the Poulter scale. From the point of view of agriculture, water engineering, tourist industry, etc., this would be of considerable economic importance if it were to continue in the future.

An attempt to forecast whether the phenomenon will continue in the future requires knowledge of whether the phenomenon is observed at other places and how far back in the past it has occurred. The scale of the effect can be deduced from the area covered by these places and this, combined with the relative significance at these places, may give some insight into the factors controlling it.

Sunshine records had just begun about 1880 and it is not possible to calculate a Poulter type index for any station prior to this time. However, temperature, sunshine and rainfall are correlated in summer so that much sunshine means an absence of cloud and therefore low rainfall. The higher insolation associated with more sunshine also means high temperatures. Hence we would expect to find a correlation between the mean temperature and the Poulter index. Over the 86 years at Kew, the correlation coefficient is 0·88. However, the clear skies associated with much sunshine as well as implying higher day temperatures would also imply lower night temperatures so that it would be expected that the mean daily maximum temperature should show a higher correlation with the Poulter index. At Kew it is 0·93.

These correlations imply that the mean temperature at Kew and even more so the mean (daily) maximum temperature should show a biennial variation. The mean temperature and mean maximum temperature at Kew for the odd and even years are as follows :

	Mean temperature	Mean daily maximum temperature
	degrees Fahrenheit	
43 odd years	62·1	70·2
43 even years	61·2	69·0

giving a difference of 0·9 degF in mean temperature and 1·2 degF in mean daily maximum temperature. (Incidentally this shows that the temperature contributes 9 points to the 20 point difference between the average Poulter index for odd and even summers, i.e. nearly one half.) The *t* test applied to these differences gives values of *t* equal to 2·68 and 2·81, giving the same level of significance as for the Poulter index. We can also apply the χ^2 test in the same manner as in the case of the Poulter index and the values of χ^2 are 5·77 and 6·36 respectively. Not quite as significant as for the index but still highly significant.

As the Poulter index is highly correlated with the mean daily maximum temperature, and mean daily maximum temperatures are available at many places in the British Isles over a long period, the records for the following places were examined for a biennial effect.

	Latitude N	Longitude W	Elevation *feet*	Period
Edinburgh	55° 55′	3° 11′	441	1896–1964
Stonyhurst	53° 51′	2° 28′	377	1884–1964
Oxford	51° 46′	1° 16′	208	1884–1965
Scilly	49° 56′	6° 18′	163	1884–1965
Armagh	54° 21′	6° 39′	204	1884–1964
Valentia	51° 56′	10° 15′	30	1884–1959

Table I gives the difference between the mean daily maximum temperature for odd and even years for the summer months June – August for these stations and periods and also the value of *t* and χ^2 (the value of χ^2 being calculated in a manner similar to that used for the Poulter index at Kew).

TABLE I—DIFFERENCES BETWEEN ODD AND EVEN YEARS FOR STATIONS IN THE BRITISH ISLES

		Difference (odd minus even)	*t*	χ^2
Kew	Poulter index	20	2·65	8·05
	Mean temperature	0·9°F	2·68	5·77
	Mean daily maximum temperature	1·2°F	2·81	6·36
Edinburgh	Mean daily maximum temperature	0·9°F	2·16	3·78
Stonyhurst		1·4°F	3·51	17·39
Oxford		1·3°F	2·61	2·82
Scilly		1·0°F	2·80	2·46
Armagh		1·1°F	3·29	12·87
Valentia		1·0°F	2·82	1·19

All temperatures are for the summer months June–August.

The difference between the odd and even summer maximum temperature is greatest at Stonyhurst and least at Edinburgh. The significance is also greatest at Stonyhurst and least at Edinburgh, according to the *t* test but least at Valentia according to the χ^2 test.

Now, as higher summer temperatures are correlated with more sunshine and less cloud and rain, this means that depressions are less frequent and anticyclones more frequent in odd years. This implies a greater frequency of easterly winds and a lesser frequency of westerly winds in odd years. Unfortunately the wind speeds of some second order stations in the British Isles from 1908 to about 1930 were given on a reduced scale and winds such as NW 0 were frequently reported leading to considerable confusion as to whether this was a light wind from the north-west or a calm. Furthermore, at many stations topography so influences local wind that some directions are much preferred to others. However, the reports from Scilly do not suffer from either of these defects and Table II gives the totals of winds reported from the 8 cardinal points at the morning observations 0700, 0800 or 0900 GMT during the summer months June–August for the odd and even years separately from 1884–1965.

TABLE II—FREQUENCY OF WINDS AT SCILLY FOR ODD AND EVEN YEARS (MORNING OBSERVATIONS JUNE–AUGUST, 1884–1965)

	Calm	N	NE	E	SE	S	SW	W	NW
Odd years	167	476	351	364	197	332	512	719	654
Even years	149	427	280	271	181	367	599	809	689
Difference	18	49	71	93	16	35	87	90	35

Table II shows that easterly winds (from north to south-east) are more frequent in odd years and westerly winds (from south to north-west) more frequent in even years, the difference amounting to some 247 occasions between the 41 odd and 41 even years, equalling 6 occasions (days) per season. Consider the change from one year to the next and mark + if a year has more easterly winds than its predecessor and – if it has less. Then, as the odd years (summer) have a greater frequency of easterly winds than the even years (summer), there should be a greater number of + in odd years than in even years. The actual values for easterly winds are :

	+	–	Total
Odd years	26	12	38
Even years	14	26	40
Total	40	38	78

The difference in total (78 instead of 82 as in Table II) is accounted for by the year 1884 being excluded and some years having the same number of easterly winds as their predecessors. The value obtained by comparing this contingency table with expected values is $\chi^2 = 7{\cdot}41$.

Precisely the same can be done for westerly winds giving the following contingency table and a value of χ^2 of 6·72.

	+	–	Total
Odd years	13	27	40
Even years	25	14	39
Total	38	41	79

The differences between the two contingency tables are caused by differences in the number of calms. These two contingency tables show that there is a significant difference between the frequency of easterly and westerly winds in odd and even summers.

If the topographical location of the stations in Table I is taken into account, it can be seen how the variation in wind frequencies (assuming they apply equally to all places in the British Isles) produces the variations in the significance levels of the *t* test and χ^2 test applied to the temperature differences at those stations.

Edinburgh is on the south side of the Firth of Forth (an arm of the North Sea), Stonyhurst is on the west side of the Pennines, Oxford is near the centre of England, protected from the west by the Welsh Mountains and the Cotswolds but exposed to the north-east, the reporting station Scilly is on an island 25 miles off Lands End (the south-west tip of England), Armagh is in Northern Ireland, sheltered on most sides, and Valentia is on an island close to the mountainous south-west corner of Ireland. Stonyhurst would be expected to show the greatest contrast in temperatures between odd and even summers because the associated easterly winds of odd summers are down-slope and would tend to be associated with clearing skies, more insolation and higher mean daily maximum temperatures; whereas at Edinburgh easterly winds come immediately off the North Sea but westerly winds have to cross southern Scotland and the differences between the temperatures in the odd and even summers would thereby be minimized. Valentia and Scilly being islands have their temperature more closely controlled by the sea temperature (and it is possible that rainfall differences would be of greater significance at these places).

We can conclude that, after making due allowance for topography, over the British Isles generally the summers of odd years are significantly warmer than the summers of even years, the difference amounting to more than 1 degF in the mean daily maximum temperatures and that this difference may be caused by a greater frequency of easterly winds in the odd summers or a greater frequency of anticyclones and a lesser frequency of depressions. Furthermore, from the correlations implied by the Poulter index we may conclude that sunshine and rainfall are similarly affected.

Even in summer, depressions and anticyclones generally cover an area greater than the British Isles and affect the nearby European continent as well. The records of European countries have therefore been examined and mean daily maximum temperatures for the three months June, July and August have been extracted for a large number of places with long records. However, the locations of most of the stations have changed over the period with a consequent (possible) change in the overall level of temperature. Because of the uncertainty, the data have been examined using the χ^2 test (as in Table I) considering only the change from one year to the next in the mean daily maximum temperature for the three summer months June, July and August taken together. A change in site would therefore affect, at the most, one year only.

Table III gives the approximate location, elevation, number of years and χ^2 value for many places in west Europe listed by countries from north-west to south-east.

The 1 per cent value of χ^2 is 6·63, the 5 per cent value is 3·84 and the 10 per cent value is 2·72. The area where the difference between the odd and even summers is highly significant covers the British Isles, southern

TABLE III—VALUES OF χ^2 FOR DIFFERENCES IN THE MEAN DAILY MAXIMUM TEMPERATURE BETWEEN ODD AND EVEN YEARS FOR A SELECTION OF CONTINENTAL STATIONS

		Latitude	Longitude	Height *feet*	Number of years	χ^2
Iceland	Reykjavik	64°08′N	21°56′W	46	44	0·36*
	Akureyri	65°41′N	18°05′W	13	36	2·78
Norway	Isfjord Radio (Spitzbergen)	78°04′N	13°38′E	20	43	0·23*
	Bjørnøya	74°31′N	19°01′E	49	32	1·18
	Jan Mayen	70°57′N	08°40′W	39	38	0·11*
	Tromsø	69°39′N	18°57′E	335	89	0·55*
	Trondheim	63°25′N	10°27′E	417	76	2·58
	Oslo	59°56′N	10°44′E	308	90	7·60
Sweden	Karesuando	68°27′N	22°30′E	1073	79	1·00
	Stensele	65°04′N	17°10′E	1083	74	0·60
	Östersund	63°11′N	14°30′E	1181	87	0·29
	Stockholm	59°21′N	17°57′E	46	86	7·77
Finland	Helsinki	60°19′N	24°58′E	171	69	0·13
Denmark	Thorshavn (Faeroes)	62°03′N	06°45′W	79	84	4·76
	Copenhagen	55°41′N	12°33′E	30	85	6·28
Holland	De Bilt	52°06′N	05°11′E	7	65	2·59
France	Paris	48°49′N	02°20′E	246	67	7·90
	Lyons	45°43′N	04°57′E	656	69	5·35
	Marseilles	43°27′N	05°13′E	66	70	18·58
Germany	Berlin	52°28′N	13°18′E	167	79	2·10
	Aachen	50°47′N	06°06′E	663	79	4·57
	Frankfurt	50°03′N	08°35′E	367	79	5·38
	Marburg	50°49′N	08°46′E	937	82	8·29
	Munich	48°08′N	11°42′E	1732	80	7·21
Russia	Kaliningrad	54°42′N	20°37′E	89	65	0·02
Austria	Vienna	48°15′N	16°22′E	666	87	11·05
	Sonnblick	47°03′N	12°57′E	10,190	77	0·64
Hungary	Budapest	47°31′N	19°02′E	387	82	1·76
Spain	Corunna	43°22′N	08°25′W	190	31	0·04
	Barcelona	41°24′N	02°09′E	305	31	0·04
	Madrid	40°28′N	03°34′W	1985	31	0·04
	Seville	37°22′N	06°00′W	26	30	0·00
Italy	Milan	45°26′N	09°17′E	351	62	3·16

*At these stations in the contingency table (from which the value of χ^2 is calculated) the odd years have more – cases than + cases and the even years have more + than –, i.e. the opposite to all other stations.

Norway, southern Sweden, Denmark, Western Germany, Austria and France, whilst the area of less significance includes central Norway and appears to extend as far west as Iceland (see Figure 1). Over the whole of western Europe, the odd summers have more + cases than – cases, i.e. the odd summers are more frequently warmer (the mean daily maximum temperature being higher) than the previous even summer and the even summers are more frequently cooler than the previous odd summer except in the extreme north-west (Reykjavik, Isfjord Radio, Jan Mayen and Tromsø) where the reverse occurs. The area at maximum covers about 35° of longitude, whilst the area of greatest significance covers about 25° of longitude and about 15° of latitude.

At Marburg, the site has apparently been unchanged throughout and the record is uninterrupted. Over the 83 years available the even summers give an average daily maximum of 21·3°C and the odd summers 22·0°C, i.e. a difference of 0·7 degC or 1·3 degF (compare with values for the British Isles). The t test applied to this difference gives the highly significant value of 3·03.

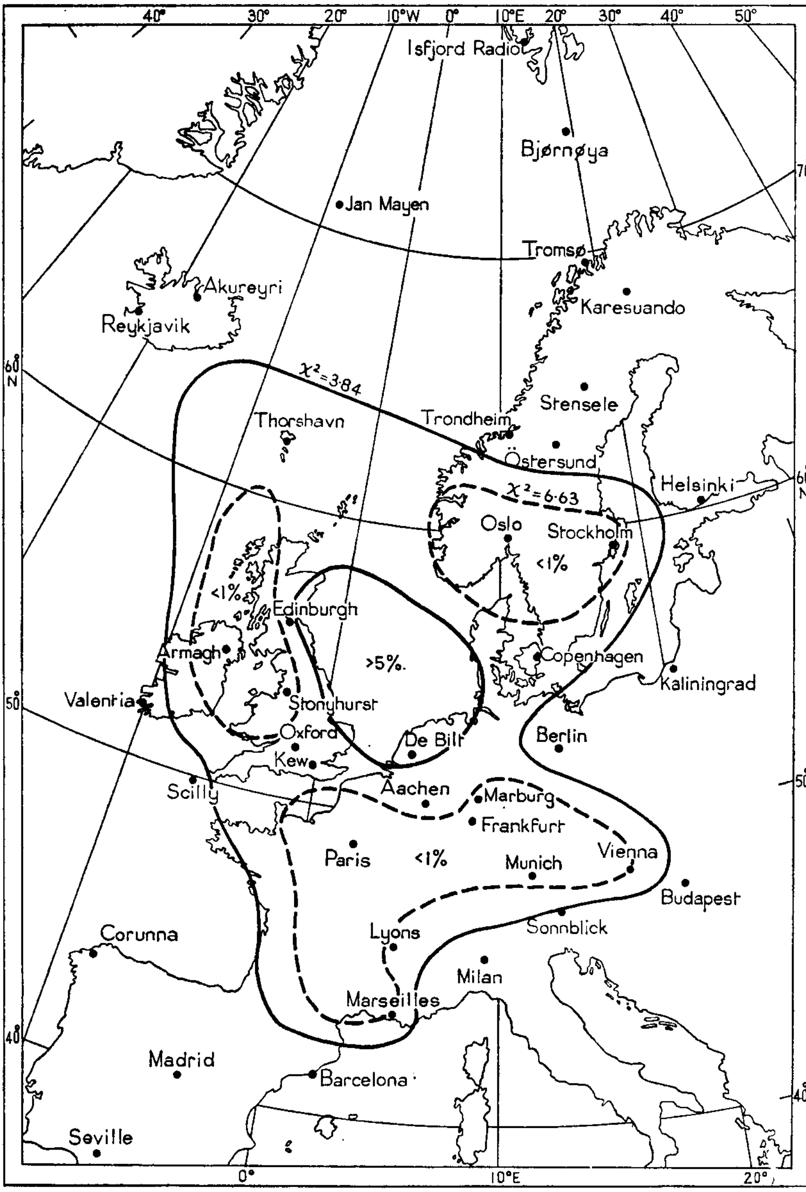

FIGURE 1—APPROXIMATE ISOPLETHS OF 1 PER CENT AND 5 PER CENT LEVELS OF SIGNIFICANCE OF χ^2

$\chi^2 = 6{\cdot}63$ at 1 per cent level

$\chi^2 = 3{\cdot}84$ at 5 per cent level

The correlation coefficients between the mean daily maximum (for the summer months June, July and August together) at Marburg and Armagh are as follows :

All summers	1884–1962	0·64
Odd summers	1885–1961	0·72
Even summers	1884–1962	0·45

Whatever causes the difference between the odd and even summers, these correlation coefficients show that it does not affect all parts of the significant area equally at the same time. The fact that the correlation coefficient is greater in the odd summers bears out the supposition that the phenomenon is associated with the greater frequency of anticyclones over north-west Europe in odd summers.

Anticyclones however tend to be associated with blocking action. Blocking (according to the Meteorological Glossary[7]) is a term applied in middle latitude synoptic meteorology to the situation in which there is interruption of the normal eastward movement of depressions for at least a few days. A blocking situation is dominated by an anticyclone whose circulation extends to the high troposphere. Blocking according to Rex[8] and Sumner[9] occurs most frequently in the sector 19°W – 20°E and according to Sumner the latitude of blocks is between 55°N and 60°N. The area of greatest frequency of blocking is also the area of greatest significance as regards differences between odd years and even years. Blocking however is at a minimum during the summer months June – August; nevertheless, it seems worthwhile examining the records to see if summer-time blocking occurs more frequently in the odd years.

Blocking is generally defined by reference to the state of the zonal flow in the middle troposphere, i.e. blocking occurs in an area where there is a diminution of zonal flow within the latitudinal band occupied elsewhere and previously by the main concentration of westerlies. However, charts of the middle troposphere are only available for the last 20 of the 80 odd years considered here and so the data given by Hess and Brezowsky[10] have been used. Brezowsky[11] combined the types into two anticyclonic groups : (1) with the anticyclonic axis over the north-east Atlantic 20°W–10°E and (2) with the anticyclonic axis over that part of northern Europe 10°–50°E. Days when the classification showed either (1) or (2) were totalled for each year for the summer period June–August. The change in these totals from one year to the next was considered and a year marked + if it had a larger total than its predecessor and – if it had less. Table IV gives the frequencies of + and – for the odd and even years separately.

TABLE IV—DIFFERENCES IN BLOCKING SITUATIONS NEAR EUROPE IN ODD AND EVEN YEARS (1881–1950)

	+	–	Total
Odd	20	12	32
Even	10	22	32
Total	30	34	64

The discrepancy in the totals is due to no data being available for 1945 and some years having the same totals as their predecessors. The χ^2 test applied to the contingency table gives a value of 5·08 (approximately the 2 per cent level of significance).

Brezowsky[11] however, did not include in either (1) or (2) the cases where a high was centred over central Europe. These cases can be added to the total of (1) and (2) to obtain Table V.

TABLE V—DIFFERENCES IN OCCASIONS OF ANTICYCLONES OVER CENTRAL EUROPE OR BLOCKING SITUATIONS NEAR EUROPE IN ODD AND EVEN YEARS (1881–1950)

	+	–	Total
Odd	23	10	33
Even	12	22	34
Total	35	32	67

The χ^2 test gives a value of 6·61 which is significant at the 1 per cent level. Table V shows that anticyclones are more frequent in the odd summers than in the even ones and Table IV shows that this is mainly a consequence of blocking and that blocking in itself has a biennial summer-time variation.

Labitzke[12] reported that winter-time stratospheric warmings (at the level of 10 mb) have a biennial variation in that in the even years 1958–64 the warmings began in the region of the Caspian Sea and moved westward and in the odd years 1957–63 they began in the vicinity of Bermuda and moved eastward. The winter-time warmings in the even years were all followed within about 10 days by a persistent blocking pattern.

Veryard and Ebdon[13] also show a near-biennial oscillation in the stratospheric winds of the tropics and Angell and Korshover[14] considered the extension of this oscillation into higher latitudes. Landsberg[15] has made a band-pass filter analysis of surface temperature along two meridians, 70–90°W and 10–50°E, and finds an approximately biennial peak with a significance level between 1 and 5 per cent.

It is evident that the two-year cycle in summer-time temperatures in north-west Europe is related to a biennial oscillation in the atmosphere affecting both the troposphere and stratosphere over the globe as a whole. What keeps the oscillation going is not yet known — more information is required about conditions in the high atmosphere.

Whatever the causes may be, the two-year cycle in summers in north-west Europe should be accepted as a fact and, over north-west Europe, taken into account in any long-term planning in which the weather over a long period has a considerable effect.

From the point of view of the ordinary man in the street, it would seem that if, over a lifetime, one took one's summer holiday only in alternate years — taking a month every odd year instead of a fortnight every year — on balance one would enjoy several hundred hours more sunshine, be drenched by many inches less rain and have the advantage of all the best summers.

A closer look at the values of Poulter's index[1] reveals, as he suggested, that the best summers occur at intervals of 10 or 12 years. The two previous very good summers occurred in 1955 and 1959. Therefore it would seem that the chances are very high that one of the next three odd summers will be exceptionally good.

Acknowledgement.—The author would like to thank Mr J. M. Craddock for his invaluable suggestion regarding the use of the χ^2 test.

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NOCTILUCENT CLOUDS OVER WESTERN EUROPE DURING 1966

By J. PATON

Table I contains an account of displays of noctilucent clouds compiled from reports that were received during 1966 from observers in Norway, Denmark, Holland, the British Isles and Greenland and from crews of aircraft.

Available data did not permit determination of the latitude of the southern boundary of more than one of the reported displays, but in the last column are given the maximum elevation above the northern horizon and limiting azimuths of the cloud field recorded at selected stations at stated times during the display. The latitude and longitude of each station are given to the nearest half degree.

The frequency of occurrence of the clouds was slightly greater than during 1965[1] and some of the displays, notably those of 27–28 June and 30 June–1 July, were spectacular. As many as 34 observers sent observations for the night of 27–28 June and 17 for each of the nights of 28–29 June and 30 June–1 July.

During each of the last three years over the period of sunspot minimum, the clouds have been seen in Britain on over 20 nights. By contrast, during the summers of 1957 and 1958 at the time of sunspot maximum when careful watch of the sky was being kept by International Geophysical Year observers, the clouds were seen on only 2 occasions. Since the clouds are now generally believed to consist of ice crystals that have formed on a nucleus of cosmic origin, the pronounced maximum in their occurrence at sunspot minimum suggests that the temperature at the mesopause (80 km) where they are situated is then at a minimum, so providing the physical conditions leading to the formation of ice crystals.

The brilliant display seen in the Shetland Islands during the early hours of 15 August was just discernible close to the northern horizon in southern Scotland. This is the first occasion on which noctilucent clouds have been reported after 3 August in Scotland.

It will be noted that, as in previous years, the clouds receded northwards in August at the end of the observing season.

TABLE I—DISPLAYS OF NOCTILUCENT CLOUDS OVER WESTERN EUROPE DURING 1966

Date—night of	Times UT	Notes	Station	Time UT	Max. elev.	Limiting azimuths
27–28 May	2245–2330	Hazy blue veil seen in central Scotland.	56°N 4.5°W	2300	10°	360°
16–17 June	0025–0200	Bands, whirls and veil.	53.5°N 9°W	0200	22°	315°–045°
			56°N 4.5°W	0025	12°	330°–030°
18–19 June	0050–0054	Small patches of noctilucent cloud (NLC) seen to 10° elevation at 57°N and on horizon at 53°N 2.5°W.	57°N 1°W	0050	10°	312°

Date—night of	Times UT	Notes	Station	Time UT	Max. elev.	Limiting azimuths
19–20 June	2245–0040	Two bands at 2245 becoming faint after 2345 UT.	55°N 3°W	2245 2345	20° 10°	022° 340°–010°
24–25 June	0001	BEA aircraft in position 54°45′ N 3°25′W reports NLC to elevation 15° above northern horizon.	55°N 3.5°W	0001	15°	360°
27–28 June	2130–0300	Clear skies and excellent visibility over England and southern Scotland permitted this bright display to be widely observed between latitudes 50.5 and 56.5°N. All NLC forms—veil, bands, billows and whirls were present (see photographs in *Met. Mag.* October 1966). The clouds were first observed in the lowest latitudes extending up to an elevation of 30°, which slowly diminished until the clouds disappeared around 2300 to reappear rather less bright from 0100 until they vanished about 0300 UT in the approaching dawn. North of latitude 53°, the clouds were visible continuously without interruption.	51°N 2°W 53.5°N 0°W 55°N 3°W	2150 0245 2200 0150 0010 0028	30° 20° 14° 15° 5° 7°	320°–010° 010°–050° 256°–285° 320°–040° 355°–020° 360°–035°
28–29 June	2140–0210	Began as a very bright patch of blue-green bands and veil which was apparently moving southwards since there was no apparent recession towards the horizon as midnight approached. Brightness diminished steadily after midnight. Visible only between latitudes 54° and 58°N.	54°N 1.5°W 55°N 3°W 56°N 4.5°W 57.5°N 7°W 58°N 6.5°W	0145 2230 0030 0130 2300 2335 2320 2355	8° 7° 5° 7° 10° 13° 9° 10°	340°–030° 340°–350° 340°–020° 010°–050° 350°–030° 350°–025° 024°–044° 030°
29–30 June	2215–0115	Faint veil with striations.	56.5°N 3°W	2325 0015 0035	5° 6° 6°	015°–050° 340°–025° 350°–030°
30 June–1 July	2120–0225	Brilliant display of veil, bands and billows at its most spectacular around 2230, visible in and north of latitude 52°N. Concealed by low cloud north of 56.5°N. Whirls developed around 0100 UT. Thereafter cloud became faint and diffuse.	52°N 5°E 54.5°N 1.5°W 54.5°N 12.5°E 55°N 3°W 55.5°N–2°W 56.5°N 3°W	2120 2255 2350 0056 0152 2210 2230 0050 2225 2245 2300 0045	15° 16° 8° 8° 10° 20° 20° 12° 24° 54° 37° 15°	315° 310°–030° 340°–030° 360°–050° 030°–060° 315°–360° 300°–050° 330°–060° 345°–040° 340°–070° 350°–050° 010°–070°
2–3 July	2130–0135	Veil, bands and billows visible to 35° elevation in latitude 60°N, 15° in 57° and close to the horizon in 55°. BOAC pilot reports NLC to north and north-west while in flight near dawn south of Newfoundland.	60°N 1°W 57°N 2.5°W	0055 0110 0030	35° 35° 15°	360°–050° 330°–060° 340°–085°
3–4 July	2200–0001	NLC visible in Denmark through low cloud. Overcast over British Isles.	56°N 10°E	2200 2245	15° 25°	315°–045°
4–5 July	2330–2340	Faint NLC seen through broken low cloud at 56°N 3°W.				
6–7 July	2330–0145	Faint veil, bands and billows seen through breaks in low cloud close to northern horizon between latitudes 52.5° and 55°N.				
12–13 July	2145	Low cloud widespread but temporary break in cloud at one station revealed whirls.	51°N 2°W	2145	70°	270°–320°
13–14 July	0115–0229	Bright display of bands, billows and whirls seen through gaps in low cloud between latitudes 52° and 55°N.	52°N 0°W	0155 0210 0229	9° 11° 19°	350°–050° 340°–050°
15–16 July	2240–0220	Bands and billows seen through gaps in low cloud in Scotland and Denmark between latitudes 56° and 57.5°N.	56°N 10°E 56.5°N 7°W 57.5°N 3.5°W	2250 0130 0220 0002	15° 13° 21° 10°	 360°–055° 350°–040°

Date—night of	Times UT	Notes	Station	Time UT	Max. elev.	Limiting azimuths
17–18 July	2130–0030	Faint NLC seen near northern horizon at 55°N 4.5°W.				
18–19 July	2145–0135	Veil and bands 'bright enough for the reflected glow to show up cirrus directly overhead' seen at 57.5°N 3.5°W. Seen earlier as faint features close to northern horizon at 55°N 4.5°W	57.5°N 3.5°W	0020 0105	8° 11°	350°–040° 330°–040°
19–20 July	2200–0100	Veil, bands and billows seen in bright display in Norway. Veil and bands seen in Scotland in latitude 56.5°, visible as weak features close to northern horizon in latitude 55°N.	59.5°N 11°E 56.5°N 2°W	0001 0100	25° 20°	315°–045° 335°
21–22 July	2230–2330	Faint NLC along horizon at 55°N 4.5°W.				
24–25 July	2340–0330	Bands and billows seen in latitudes north of 55°N. Observed nearly overhead at Lerwick. Reported by pilot of aircraft flying west of Goose Bay, Labrador. The southern boundary of the display was in, or south of 60°N.	55°N 52°W 55°N 3°W 56.5°N 7°W 57.5°N 7°W 57.5°N 3.5°W 58°N 6.5°W 60°N 1°W	0330 2210 2340 0210 0115 0145 0055 0050 0137	5° 4° 25° 9° 5.5° 15° 15° 30° 80°	360° 350°–002° 350°–360° 030° 330°–360° 330°–030° 360°–020° 360°–050° 360°–050°
25–26 July	2300–0150	Fibrous veil visible in Scotland north of latitude 57.5°N. NLC reported also by O.W.S. *Weather Reporter* and *Weather Monitor*.	52.5°N 20°W 60°N 1°W	0200 2300	30° 12°	330°–020° 360°–040°
26–27 July	0300	NLC reported by O.W.S. *Weather Monitor*.	56.5°N 7°W	2350	10°	350°
31 July–1 Aug.	2230–0115	A limited area of bands seen between latitudes 55° and 56.5°N.		0030 0115	12° 12°	360°–030° 040°
14–15 Aug.	0150–0230	Very bright display of veil and bands seen in Shetland. Single fine band just visible along northern horizon in south Scotland.	60°N 1°W	0150	10°	360°–050°
16–17 Aug.	0500–0600	Bright display of bands, billows and whirls seen at Prins Christian Sund, Greenland.	60°N 43°W	0500–0600	40°	350°–025°
17–18 Aug.	0355–0425	NLC reported seen at Holsteinborg, Greenland.	67°N 54°W	0355	9°	010°

Noctilucent clouds in the form of a fibrous veil up to an elevation of 5° above the southern horizon were observed at Port Stanley, Falkland Islands (52°S 58°W) between 2255 and 2400 UT on 3 January and at Deception Base (63°S 60·5°W) of the British Antarctic Survey up to an elevation of 20° above the southern horizon on 4 January between 0300 and 0600 UT.

The Auroral Laboratory is much indebted to the many observers who have made this analysis possible. These synoptic studies will continue and the following notes are provided for use by observers who may wish to assist in this work.

Observers should record (*a*) the night of occurrence specified by two dates, e.g. 27–28 June, and the latitude and longitude of the observing station to the nearest half degree: (*b*) the period(s) of time GMT during which the clouds were observed: (*c*) the horizontal and vertical extent, expressed in degrees of azimuth and elevation at specified times, say every quarter hour, half hour or hour. This information is best conveyed by drawing a rough sketch showing the configuration of the cloud elements and the co-ordinates, elevation above the northern horizon and azimuth, of the visible boundaries of the cloud, i.e. the maximum elevation in different azimuths and the limiting azimuths, east and west of north: (*d*) general notes on the nature and behaviour of the clouds. The clouds are classified into four types according to their structure.

I. Veils, resembling cirrostratus and often present as a background to other forms.

II. Bands. Persistent long streaks, diffuse or sharply defined, often arranged in groups nearly parallel to each other.

III. Billows. Groups of closely arranged short streaks, often showing a rippled structure and sometimes changing form within minutes.

IV. Whirls of varying curvature may sometimes be seen in the veil, bands or billows.

It is important to attempt to determine the position of the southern boundary of the clouds.[2] Most displays are situated to the north of the British Isles so that the maximum elevation of the cloud field is generally never greater than 20° above the northern horizon. There are occasions, however, when the cloud may cover a large part of the sky, sometimes the entire sky, though it is visible in the south only when the clouds first appear after sunset (usually before observers are aware of the presence of NLC) and again before sunrise. If the southern sky is reasonably clear of low cloud, observers should, when possible, keep continuous watch of the southern sky on nights when the clouds are present, during the period from about an hour and a half to an hour before sunrise. It is then that the cloud, if it extends sufficiently far south, will become visible first in the south-east and later in the south-west, just when the clouds are about to vanish in the brightening sky as the sun ascends to 6° below the horizon.

Observations sent to the Balfour Stewart Auroral Laboratory, The University, Drummond Street, Edinburgh 8, will be gratefully acknowledged.

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REVIEW

Allgemeine Klimageographie, by J. Blüthgen. Second edition, 9¾ in × 7 in, pp. xxiii + 720, *illus.*, Walter de Gruyter & Co., Genthiner Strasse 13, Berlin 30, 1966. Price : DM 65.

This is the second edition of a work which first appeared in 1964. Changes in general layout are minor, involving merely the renumbering of two chapters, but a good deal of new material, drawn mainly from recent papers, has been incorporated. In the longest section, that dealing with climatic elements, the extra material includes, for example, maps of average water vapour pressure for the whole world in January and July, a schematic explanation of mountain and valley winds, and vertical sections showing air temperature in the northern hemisphere. The sections dealing with meteorology and atmospheric circulation include a classification of the various types of circulation in the west wind drift at the 500 mb level. The expansion of content has led to an increase in length compared with the first edition of over one hundred pages, and it includes new illustrative material such as Troll's map of world climates as characterized by seasonal rhythms, a classification derived from vegetation studies. The increase in the size of the work has been accompanied by a marked increase in price, from DM 48 to DM 65.

A noteworthy feature of this work is the extremely valuable bibliography containing well over three thousand references, drawn mainly from periodicals written in German, French and English.

E. M. YATES

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LETTER TO THE EDITOR

Severe low-level turbulence

Mr Pedgley's letter, which appeared in the *Meteorological Magazine* for March 1967 concerning cases of clear air turbulence over Cyprus as reported by Mr G. J. Jefferson in the *Meteorological Magazine* for September 1966, caused me to examine the upper air data presented by Mr Jefferson.

The 1800 GMT Paphos winds for 14 April 1966 give a mean shear in the layer one thousand to three thousand feet of 29·6 ft/s per 1000 ft which coupled with the instability in this layer shown by the 1200 GMT Nicosia temperature sounding would have given an *Ri* of zero and consequently severe turbulence. Again the Nicosia winds give a mean shear in the layer three thousand to five thousand ft of 26·7 ft/s per 1000 ft which gives a mean *Ri* in this layer of 0·093. This very low value of *Ri* coupled with the large shear of 26·7 ft/s per 1000 ft would be expected to result in severe clear air turbulence.

At 8500 feet, from the 0000 GMT sounding for Nicosia for 15 April (not quoted by Jefferson but the one most appropriate for the discussion of turbulence at 8500 feet), *Ri* was zero (the lapse rate was dry adiabatic) with a mean shear in the layer 800 – 700 mb of about 8 ft/s per 1000 ft resulting in some turbulence. It follows that the severe turbulence in layers from the surface to at least five thousand feet would have been expected from the well-known theory of L. F. Richardson (*Ri* less than ½) but the severity of the turbulence at 8500 feet as encountered by the Canberra is not easily explained. Possibly the vertical shear at about 8500 feet was (*a*) enhanced by the slowing down of the warm front which occurred between 1800 GMT 14 April 1966 and 0600 GMT 15 April 1966; (*b*) very large in the frontal zone at about 8500 feet but not revealed due to the coarseness of the wind sounding; (*c*) increased by local cooling due to evaporation of rain as suggested by Mr Pedgley but it is not certain that rain occurred at the time or near the time of the turbulence incident.

A case of severe low-level turbulence in clear air occurred while the writer was in Habbaniya (1953–55). There was a marked veer of wind from one thousand feet to three thousand feet giving a large wind shear which, in spite of an isothermal temperature distribution, yielded an *Ri* of about 0·3. A Hastings aircraft coming in to land dropped from three thousand feet to nine hundred feet in one bump.

Meteorological Office, Bracknell. A. E. PARKER

NOTES AND NEWS

Retirement of Mr C. W. G. Daking

Mr C. W. G. Daking retired from the Meteorological Office on 22 May 1967 after 39 years' service. For the past 10 years, as an Assistant Director, his responsibilities were mainly focused on the international organization of meteorology and he played a part in most of the far-reaching developments that have occurred in this subject in recent years.

After graduating in physics, Mr Daking joined the Office in 1928 and, after a year at Calshot, the old flying boat base, was transferred to Cardington as a member of the research group concerned with the meteorology of airships, work which came to an end after the accident to the ill-fated R 101 towards the end of 1930. He then spent nearly 10 years as a forecaster, mostly at civil aviation offices, in North America as Liaison Officer, first with the Canadian Meteorological Service and then with the United States Weather Bureau. After the war there were tours as Chief Meteorological Officer with various RAF Commands in Germany and in the United Kingdom.

In 1955 Mr Daking, as a Group Captain in the RAFVR, took up a two-year assignment as Chief Meteorological Officer to the Supreme Headquarters of the Allied Powers in Europe.

On his return to this country in 1957 he was promoted to Assistant Director and was given wide planning and advisory responsibilities in the international field, including related defence aspects. During the past 10 years, therefore, Mr Daking has been the principal adviser to the Director-General on international matters and has regularly accompanied him to the major WMO meetings in Geneva.

In spite of a full and diverse career, Mr Daking found time to support the corporate life of the staff and for many years he was the Chairman of the Office Social and Sports Committee. In 1965 he was made a Companion of the Imperial Service Order in recognition of his distinguished service. His many friends at home and abroad will have lasting memories of Mr Daking as a 'character' in all the best senses of the word. We wish him and Mrs Daking many years of happy retirement.

P. J. MEADE

HONOURS

The following awards have recently been announced :

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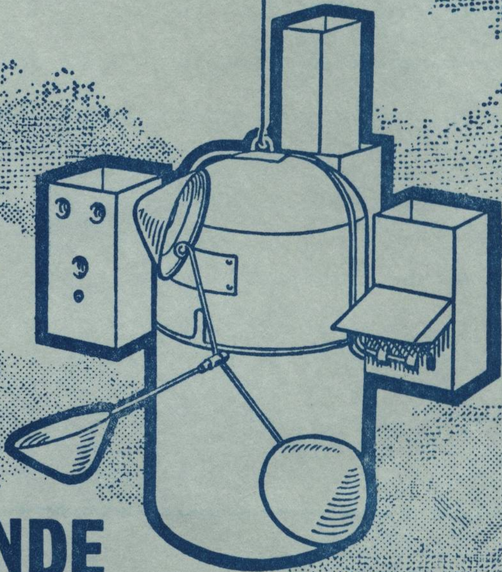

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