The Effect of Atlantic Blocking Action upon European Climate

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Abstract

The results of the individual analysis of six cases of Atlantic blocking action are presented in the form of mean surface and upper-level pressure distributions and of mean regional precipitation and surface-temperature isanomal patterns for winter and for summer blocked periods over the European area. A "mean" blocked sea-level pressure distribution, together with its associated isanomal pattern, are compared with similar charts constructed for a case of strong European zonal flow. A summary of the weather regime associated with European blocking is given, and variable blocking activity is discussed as a factor in the recent climatic change which has been observed over the North Atlantic-European area.

Introduction

In a previous paper (REX 1950 b) an analysis of the mean surface-temperature and precipitation anomalies, as well as of the mean surface and upper-level (500 mb) pressure distributions, associated with two cases of European (Atlantic) blocking action was presented. The cases analyzed occurred in January 1947 (winter) and in June—July 1949 (summer). Because of the demonstrated position-stability of Atlantic blocks and in view of the moderate success achieved in correlating the blocking "index" with corresponding European temperature and precipitation trends (see REX 1950 b, figs. 13 and 14), it was assumed that these two case analyses were representative of the climatic effects of blocking action quite generally. Nevertheless it appears desirable to further test the validity of this assumption through the analysis of additional blocked periods. This was thought to be particularly pertinent since the effect of changes in the internal geometry of the blocked circulation pattern or of minor changes in the block's position might be supposed to produce relatively large distortions in the associated climatic isanomal patterns produced.

Accordingly four additional blocked periods over Europe (two winter and two summer) have been analyzed and the results combined with those previously reported in order to determine mean seasonal blocked climatic patterns for the European area. The purpose of this paper is to describe the mean winter and mean summer climatic patterns obtained and to discuss in some detail the weather regime over the North Atlantic-European area associated with Atlantic blocking action.

In Table I the six periods used in computing the mean blocked patterns are listed. The new periods selected were taken from the *Blocking Case Catalog* (REX 1950 b, Table I) and represent in each case examples of clearly defined blocking action. The 1948 and 1950 winter cases were chosen in particular since mean pressure pattern analyses were already available for these periods as a result of previous work (see REX 1950 a). The 1947 summer case is of special interest in view of the almost cataclysmic ablation observed on Scandinavian glaciation during this summer season; the 1935 summer case represents an example of strong blocking from the 1930—39 decade.

As shown in Table I the average longitude of initiation for the winter cases is 20° W

Table I. Blocked periods

Year	Period (inclusive)	Initial Long.	Duration	$\bar{N}_T$ and $\bar{N}_R$	α	Remarks
Winter:						
1950	18/1—2/2	25° W	16 days	January	2.0	New case
1948	16/2—29/2	25° W	14 days	February	2.0	New case
1947	16/1—31/1	10° W	16 days	January	2.0	REX (1950 b)
		20° W	46 days			
Summer:						
1949	16/6—7/7	17° W	22 days	$^2/_3$ June + $^1/_3$ July	1.4	REX (1950 b)
1947	8/8—7/9	15° W	31 days	$^3/_4$ Aug. + $^1/_4$ Sept.	1.0	New case
1935	1/5—31/5	20° W	31 days	May	1.0	New case
		17° W	84 days			

(17° W for the summer cases) which agrees rather well with the corresponding mean longitudes of block initiation for the months concerned, 19° W and 12° W longitude respectively (see REX 1950 b, fig. 2). The average durations of the three winter and three summer cases are 15 and 28 days respectively in comparison with a most probable duration for Atlantic blocking action of 14 days (see REX 1950 b, fig. 4). The slight westerly displacement (5° in longitude) and the abnormally long duration (twice "normal") of the summer cases should not appreciably affect the mean summer pattern computed from these cases. We may therefore expect the computed pressure and anomaly patterns to be representative of Atlantic blocking situations in general, i. e. within the limitations of the semi-statistical results previously reported (REX 1950 b).

It will be noted that the 1935, 1947 (winter) and 1950 periods as indicated in Table I do not exactly agree with the corresponding periods as given in the *Blocking Case Catalog*, referred to previously. Periods as indicated in the table define the intervals over which the mean pressure and isanomal patterns have been computed; in the cases just mentioned the computation has been carried over an interval slightly shorter than the actual blocked period in order to simplify the computation of the climatic anomalies.

Method of Analysis

Mean surface and upper-level charts for each of the six cases were computed by taking arithmetic means of the daily values of pressure and contour height at points located 5° of latitude apart (from 30° N to 80° N latitude) and lying along each tenth principal meridian from 50° W to 70° E longitude. Sea-level 0600 GMT (1300 GMT May 1935 only), 3000 dynamic meter 0900 GMT, and 500 mb 0300 GMT (0500 GMT 1947 cases only) analyses were used for this purpose; the chart series used in each case are listed under *Data Sources* and are given at the conclusion of this paper.

Isanomal charts of mean surface-temperature and precipitation for each of the six cases were constructed using anomaly values computed for approximately 200 stations in the area, with respect to the fifty-year period, 1881—1930. Monthly normal values of both temperature and precipitation were taken in most instances from published data given by KÖPPEN and GEIGER (1932 a and b, 1935 and 1939), CLAYTON (1927 and 1934), HANN (1911), U. S. WEATHER BUREAU (1938), BRITISH METEOROLOGICAL OFFICE (1919), and KENDREW (1922), although occasional use of normal values, as published in the various monthly and yearly meteorological and climatological bulletins and yearbooks, was made. In many instances 1881—1930 normal values were not available and in such cases the most suitable substitute values were used. The isanomal patterns obtained reflect in general variations from the 1881—1930 normal.

Whenever available, daily-mean surface-temperatures were taken directly from data published by the various national meteorological services, and mean station values, taken

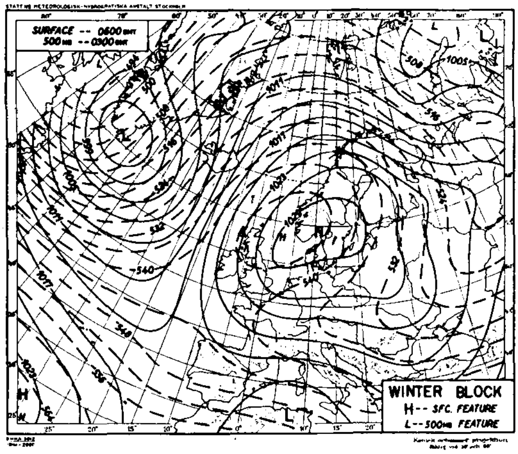

Fig. 1. The European WINTER Block. Absolute topography of the 500 mb surface shown by the thin dashed lines; contour heights given in dynamic decameters. Sea-level pressure distribution shown by the thin solid lines; pressures given in millibars.

over the particular periods in question, were computed as follows;

$$\overline{A} = \frac{1}{n} \sum_{1}^{n} (\overline{T}_1 + \overline{T}_2 + \ldots \ldots \overline{T}_n), \qquad (1)$$

where n is the number of days in the period and $\overline{T}_1$, $\overline{T}_2$, etc. are the several daily-mean values. The arithmetic mean, $\overline{A}$, of the daily mean surface-temperatures, taken over a given period, will define, for the purposes of the following discussion, the *mean surface-temperature* for the period. In other instances *mean surface-temperatures* were computed from tabulated values of the daily maximum and minimum temperature in accordance with the following;

$$\overline{A} \approx \frac{1}{2n} \sum_{1}^{n} (T_1^{\circ} + T_2^{\circ} + \ldots T_n^{\circ}) + $$
$$+ \frac{1}{2n} \sum_{1}^{n} (T_1' + T_2' + \ldots T_n'), \qquad (2)$$

where n is defined as in equation (1) and T_1°, T_2°, etc. and T_1', T_2', etc. are the several daily maximum and minimum values respectively. For a small number of stations, principally located in the Russian and Mediterranean areas, *mean surface-temperatures* were approximated from equation (2) by substituting observed 0600 and 1800 GMT temperatures for the daily maximum and minimum values, or as follows;

$$\overline{A} \approx \frac{1}{n} \sum_{1}^{n} (T_1'' + T_2'' + \ldots T_n'') + \frac{1}{2} (\overline{\Delta D}), \qquad (3)$$

where n is defined as in equation (1); T_1'', T_2'', etc. are the several daily 0600 GMT temperature values; and $\overline{\Delta D}$ is the mean diurnal surface-temperature range for the area (station) and season in question. Mean monthly values for the diurnal surface-temperature range at various stations were taken from SHAW (1936, II, pp. 60—85). Values for the daily-mean, 0600 and 1800 GMT, and maximum & minimum surface temperatures (as well as monthly mean values) were taken from the bulletins, yearbooks and summaries published by the several national meteorological services within the area in question; these sources are listed under *Data Sources* and are given at the conclusion of this paper. Finally, normal temperature values, $\overline{N_T}$, for each of the some 200 stations used and for each blocked period were computed from the monthly normal values as indicated in Table I, column 5 and the corresponding *mean surface-temperature* anomalies in °C, P, obtained as follows;

$$P = \overline{A} - \overline{N_T}, \qquad (4)$$

where $\overline{A}$ is defined as previously and given in °C, and $\overline{N_T}$ is the corresponding 1881—1930 normal station temperature in °C for the particular period in question. Although the use of several techniques for computing, or approximately calculating, the *mean surface-temperature* will no doubt introduce small discrepancies into the analysis, the continuity observed in the resulting field of temperature anomalies suggests that these errors are of minor significance.

Similarly, precipitation anomalies, in percent of normal, R, for each station used and for each blocked period were computed in accordance with the following;

$$R = 100\,\alpha \left(\frac{\Sigma S}{\overline{N_R}}\right), \qquad (5)$$

where ΣS is the total fall recorded during the period in question; $\bar{N}_R$ is the 1881—1930 normal 30-day station precipitation (measured in the same units as those used for ΣS and computed as indicated in Table I, column 5); and α is a dimensionless factor needed to express R in percent of the normal *for the period-length in question.* Approximate values for the factor α are given in Table I, column 6. Daily (and monthly) precipitation values were taken from the various publications mentioned in the preceeding paragraph; these sources are listed under *Data Sources* and are given at the conclusion of this paper.

From the mean surface and upper-level charts and from the *mean surface-temperature* and precipitation isanomal analyses completed for the six individual blocked periods, the corresponding WINTER and SUMMER charts and analyses were constructed. The designations WINTER and SUMMER will be used in the following discussion to indicate averages taken over the three winter and over the three summer periods (given in Table I) respectively. In the case of the surface and 500 mb analyses, the mean seasonal charts were obtained by taking arithmetic means of the values of pressure and contour-height at the fixed grid points described in an earlier paragraph for the three winter and three summer cases. The mean upper-level analysis for the May 1935 case is a 3000 dynamic meter, constant-level chart in view of the fact that no 500 mb analyses were available for this period. In order to permit the inclusion of this case in the SUMMER 500 mb chart, the pressure values given at the 3000 dynamic meter level were extrapolated to the 500 mb level and the corresponding contour-heights used in the averaging process.

In order to obtain mean seasonal isanomal charts of temperature and precipitation over the area in question a grid extending from 25° W to 45° E longitude and from 31° N to 75° N latitude was drawn on each of the isanomal charts for the six blocked periods. The dimensions of the unit grid "square" used were 2° of longitude by 2° of latitude except over Russia, Finland and ocean areas where the unit "square" measured 4° of longitude by 2° of latitude; no grid points were taken between the 31st and 36th or between the 70th and 75th parallels of latitude. The mean seasonal isanomal charts were obtained by taking arithmetic means of the values of *mean surface-temperature* and precipitation anomaly at the grid points just described for the three winter and three summer cases. A grid system was employed for determining the WINTER and SUMMER isanomal patterns because of the limited number of stations for which data was available for each of the blocked periods analyzed. Mean seasonal anomalies were calculated directly for selected stations, located within areas of maximum precipitation and temperature anomaly, in order not to lose extreme values in the averaging process.

The Surface and Upper-Level Pressure Distributions

In figure 1 the WINTER 500 mb contour pattern (thin dashed lines) is shown superimposed over the corresponding surface pressure pattern. A well developed blocking high is centered at the surface over the southern Scandinavian peninsula with anticyclonic flow dominating almost the entire Eurasian area. The anticyclonic center aloft is shifted somewhat toward the west over the North Sea area, indicative of a strong west-east temperature gradient in the lower troposphere. A strong trough aloft extends from the White Sea area across Russia and central Europe almost to the French Atlantic coast.

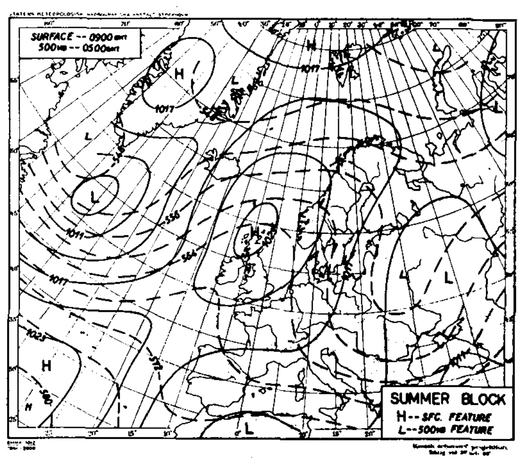

Fig. 2. The European SUMMER Block. Absolute topography of the 500 mb surface shown by the thin dashed lines; contour heights given in dynamic decameters. Sea-level pressure distribution shown by the thin solid lines; pressures given in millibars.

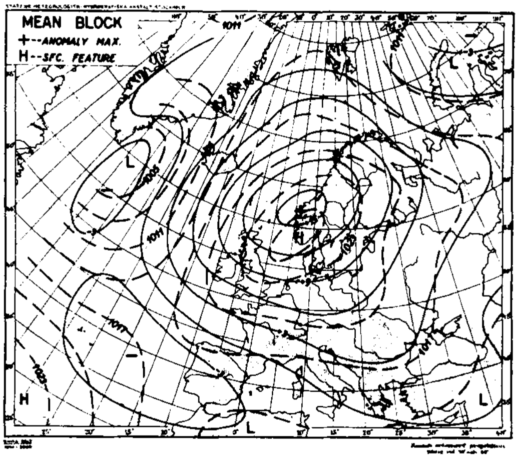

Fig. 3. The European "Mean" Block. Sea-level pressure distribution, not associated with any particular season, shown by the thin dashed lines; pressures given in millibars. Isanomal pattern, constructed for the "mean" block, shown by the thin solid lines; pressure anomalies given in millibars.

The absence of any appreciable variation in pattern geometry between the three winter cases analyzed is most striking. For example, a comparison between figure 1 and the corresponding figure for the January 1947 case (see REX 1950 b, fig. 7) shows remarkable agreement in the location and relative orientation of the various features of the block. Pressure gradients are however somewhat weaker in the January 1947 case, and the downstream trough over western Russia is more strongly developed both at the surface and aloft.

In figure 2 the SUMMER 500 mb contour pattern (thin dashed lines) is shown superimposed over the corresponding surface pressure pattern. A blocking high, centered at the surface over northern Scotland and located immediately beneath the upper ridge-line, is again observed. As would be expected in the SUMMER pattern the low-pressure area centered over Russia at the surface is relatively stronger and the surface blocking anticyclone itself, relatively weaker as compared with the WINTER pattern. Both the upper ridge and downstream trough shown in figure 2 are relatively weaker as a result of the much less intense circulation observed during the summer season (compare figures 1 and 2). The essential geometry of the block however is retained without major modification in both the WINTER and SUMMER patterns.

Again the absence of variation between the three summer cases analyzed is noteworthy. A comparison between figure 2 and the corresponding figure for the June-July 1949 case (see REX 1950 b, fig. 10) shows a striking similarity between these two patterns. The principal difference, as in the winter case, is a stronger development during the June-July 1949 period of the downstream trough over western Russia both at the surface and aloft.

In order to obtain a "mean" surface blocked pattern, not associated with any particular season, arithmetic means were taken of the pressure values given by the two seasonal sea-level analyses (figures 1 and 2), using the grid system described in the first paragraph of the foregoing section. The resulting "mean" surface chart is shown by the thin dashed lines in figure 3. The use of this chart, as being *generally* representative of the sea-level pressure distribution associated with periods of Atlantic blocking, is thought to be permissible in view of the strong similarity between the individual WINTER and SUMMER surface pressure patterns. Also shown in figure 3 is the sea-level pressure isanomal pattern (thin solid lines) corresponding to the overlying "mean" sea-level pressure pattern. In constructing this isanomal pattern, "mean" sea-level pressure anomalies, with respect to normal sea-level pressure values given for the twenty-year period 1920—1939 by U. S. WEATHER BUREAU (1946), were computed at the points of intersection of every fifth principal meridian and latitude circle within the area extending from 50° W to 70° E longitude and from 30° N to 75° N latitude; only intersections of odd numbered meridians with odd numbered latitude circles and of even numbered meridians with even numbered latitude circles being taken. The pressure isanomal pattern obtained shows a large area of abnormally high pressure, centered over southern Norway, with maximum positive anomalies of 15 mb at the center. Two areas of abnormally low pressure, although of much lesser intensity, are centered off the southern tip of Greenland and over the east-central Atlantic and Mediterranean areas, with maximum negative anomalies in each case of 4—5 mb at their centers. It is interesting to compare the isanomal pattern of figure 3 (which may be taken as representative of winter blocks) with the pattern of wintertime mean sea-level pressure-change from the period 1900—1919 to the period 1920—1939 which is given by PETTERSSEN (1949, fig. 2). The general agreement observed between these patterns suggests increased wintertime blocking activity as a possible causative factor of importance in producing the changes in wintertime mean sea-level pressure distribution which have occurred between the two periods 1900—1919 and 1920—1939.

In order to emphasize the essential differences between a blocked-type circulation and a strong zonal type over the European area, a chart of the mean surface pressure distribution was constructed from daily 0600 GMT sea-level charts for the month of January 1949 and is shown in figure 4 by the thin dashed lines. The month of January 1949 provides an excellent example of strong European zonal flow of the type described by REX (1950 b, pp. 293—294). As shown in figure 4 the period was characterized by the development at the surface of a continuous belt of low pressure, extending from southern Greenland, over Iceland and the North Cape region, to the Novaya Zemlya area. In the same figure a continuous high-pressure belt is shown extending across the central Atlantic, over southern Europe, to the Black Sea area. Between these two zones a strong, and essentially zonal, westerly current is maintained. A comparison between the thin dashed-line patterns shown in figures 3 and 4 will clearly demonstrate the marked differences which exist between these two circulation types.

Also shown in figure 4 is the surface pressure isanomal pattern (thin solid lines), corresponding to the overlying mean January 1949 sea-level pressure distribution (thin dashed lines). The isanomal pattern was constructed in the same way as that described in the preceeding paragraph and shows two principal areas of abnormal pressure, one located over Novaya Zemlya with maximum negative anomalies of 18 mb at the center and the other located over the North Atlantic, south of Greenland, with maximum positive anomalies of 13 mb at the center. From a comparison of the isanomal patterns of figures 3 and 4 we see that strong zonal-type circulation may be considered to be an almost exact opposite to the blocked type.

The Mean Surface-Temperature Anomaly

The WINTER isanomal pattern of *mean surface-temperature* is shown in figure 5. The corresponding WINTER sea-level pressure distribution and 500 mb topography have been given in figure 1. As may be seen, strong positive anomalies (> + 2° C) dominate the entire north- and polar-Atlantic and extend across Scandinavia as far east as the Urals in Russia. These abnormally high temperatures result from a strong flow, both at the surface and aloft, of maritime air from the central-Atlantic around the blocking ridge into northwestern Russia; maximum positive anomalies reach 5° C over northern Scandinavia and 8° C over Spitzbergen, Iceland and the coast of East Greenland. Strong negative anomalies (> — 2° C) dominate continental Europe and southwestern Russia with maximum negative values of 8—9° C over the Balkans and central Europe. These low temperatures result from the movement of cold polar or arctic air from the White Sea—Novaya Zemlya area across western Russia and into central Europe under the influence of the anticyclonic flow around the eastern side of the blocking anticyclone. The zero isanomal line, orientated approximately east-west except over the Atlantic, crosses the area at about 58° N latitude. It is interesting to compare the isanomal pattern of figure 5 with the pattern of 20-year winter

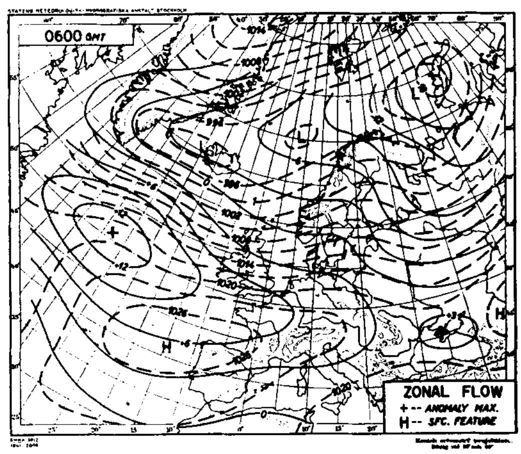

Fig. 4. A Case of Strong European Zonal Flow (January 1949). Mean sea-level pressure distribution shown by the thin dashed lines; pressures given in millibars. Isanomal pattern, constructed for the mean January 1949 sea-level chart, shown by the thin solid lines; pressure anomalies given in millibars.

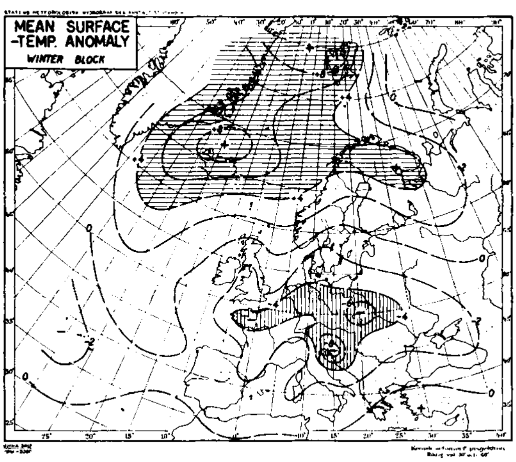

Fig. 5. The European WINTER Temperature Isanomal Pattern. Isanomal lines are given for each 2° C above and below normal and are shown by the thin dashed lines. Areas recording mean temperatures more than 4° C above normal are indicated by the horizontal hatching; areas recording mean temperatures more than 4° C below normal are indicated by the vertical hatching.

temperature-change (1921—1940) given by WILLETT (1950, fig. 5). As may be seen, within the North Atlantic-European area, the geometry of the two patterns is essentially similar, again suggesting the action of increasing winter blocking activity during the 1921—1940 period.

In figure 6 the SUMMER isanomal pattern of *mean surface-temperature* is illustrated; the corresponding SUMMER surface and 500 mb charts being given in figure 2. The basic pattern shown closely resembles that given for the winter season, with positive temperature anomalies dominating the more northerly latitudes and negative anomalies observed over southern and central Europe and western Russia (compare figures 5 and 6). The SUMMER pattern is displaced somewhat southward and rotated anticlockwise with respect to the former case; the line of zero anomaly now running approximately along the northwestern coastline of the European mainland (except over France where it is displaced far inland). Maximum positive anomalies of 4° C over the Atlantic, south of Iceland, and of 3° C over southern Norway and northwestern Russia are observed; negative anomalies reach extreme values of 5° C over southwestern Russia and 3° C over Spain. As would be expected summertime temperature anomalies do not reach the extreme values observed during winter in view of the less intense summertime circulation.

A comparison of figures 5 and 6 with the corresponding figures for the January 1947 and June-July 1949 cases (see REX 1950 b, figs. 9 and 12) shows a striking similarity between the two summer and the two winter isanomal patterns. A lack of appreciable variation between the individual cases of the two seasons is again quite evident. This similarity not only relates to pattern geometry but also to the magnitudes of the extreme anomalies observed in each case.

The Precipitation Anomaly

In figures 7 and 8 are shown the WINTER and SUMMER precipitation isanomal patterns for the European area. The corresponding mean sea-level and 500 mb charts are given in figures 1 and 2. In *general* both patterns show a marked reduction in precipitation over the entire Eurasian area with normal or greater than normal values observed principally over the North Atlantic and northwestern Norway and over the east-central Atlantic and western Mediterranean coasts, in association with the two major cyclone tracks characteristic of blocked periods (see REX 1950 b, pp. 285—286). Areas of normal or greater than normal precipitation over the Continent are confined to isolated coastal and upland areas.

A comparison of figures 7 and 8 shows rather good general agreement in the relative geometry of the two patterns. The more important differences are discussed in the following (refer to figures 1 and 2):

a. *Swedish East Coast:* — The more intense summertime development of the surface low-pressure area over western Russia produces an increased onshore wind-component along the coastline in question. As a result increased precipitation is recorded in this area for the SUMMER case.
b. *British Isles:* —Light northerly surface winds over the British Isles characterize the SUMMER case, and an extremely scanty rainfall results. In the WINTER case east to south-easterly surface winds produce moderate precipitation amounts along the southern and eastern (windward) coasts and over upland areas.
c. *Balkan Area:* — Here we observe a shift in the mean surface air flow from northerly in

the SUMMER case to easterly in the WINTER case accompanied by a displacement of the area of maximum precipitation anomaly from the north slopes of the Carpathians to the western slopes of the Austrian Alps.

d. *Central Russia:* — The more intense summertime development of the cyclonic center over western Russia, which has been mentioned above, produces a strengthened mean northward flow of warm moist air from the Black Sea region out over central Russia. Precipitation amounts accordingly exceed normal in this area for the SUMMER case.

e. *East-Central Atlantic (Spanish Mainland):* — A shift toward the northwest and an intensification of the blocking ridge at the surface for the SUMMER case is indicative of a decrease in the number of storm centers moving into the Mediterranean area along the southerly storm track. SUMMER case anomalies in the area are accordingly lower.

Although the seasonal pattern differences just discussed are greater than those observed in the case of the corresponding temperature isanomal patterns, they do not mask the basic features of the blocked pattern; i. e. subnormal precipitation values for Eurasia generally with a tendency toward supranormal amounts over

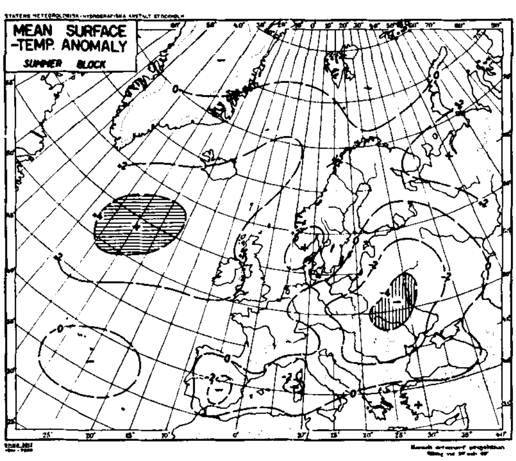

Fig. 6. The European SUMMER Temperature Isanomal Pattern. Isanomal lines are given for each 2° C above and below normal and are shown by the thin dashed lines. Areas recording mean temperatures more than 4° C above normal are indicated by the horizontal hatching; areas recording mean temperatures more than 4° C below normal are indicated by the vertical hatching.

the North Atlantci and in the east-central Atlantic and western Mediterranean areas.

In order to demonstrate the stability of the mean seasonal precipitation patterns, we compare figures 7 and 8 with the corresponding figures for the January 1947 and June-July 1949 cases (see REX 1950 b, figs. 8 and 11). Again the two sets of patterns will be seen to closely resemble one another, although the variability in this case in somewhat greater than that found for the mean seasonal patterns of pressure and temperature. It should be noted that the subsequent inclusion of precipitation stations in the North Atlantic area for the January 1947 case (see REX 1950 b, fig. 8) has indicated the presence of an area of above normal precipitation over Iceland and East Greenland. Accordingly the 10 % isanomal, shown along the Norwegian coast, should turn sharply west and then south at about 65° N latitude joining the 10 % isanomal, shown just north of Scotland, near Thorshavn.

The Blocked Weather Regime in Europe

In view of the statistical results previously reported (REX 1950 b) and since variation between the three winter and the three summer blocked periods has been shown to be quite small, we may summarize the results obtained with some assurance as to their generality. The European weather regime associated with periods of Atlantic blocking activity may be described as follows:

1. During winter the greater part of continental Europe and the British Isles is dominated by a strong surface anticyclone, centered over southern Scandinavia; accordingly, storm centers are displaced far to the north (or south), and storminess, as associated with the passage of intense cyclonic systems, is more or less absent over the entire Continental area. Summer cases are characterized by a much less intense blocking-anticyclone development and the appearance of weak cyclonic systems, moving from the Black Sea area along a southwest-northeast track into south-central Russia. Moderate surface winds, in the northeast quadrant, prevail over the Continent generally with strong northwesterly surface winds observed over northern Scandinavia.

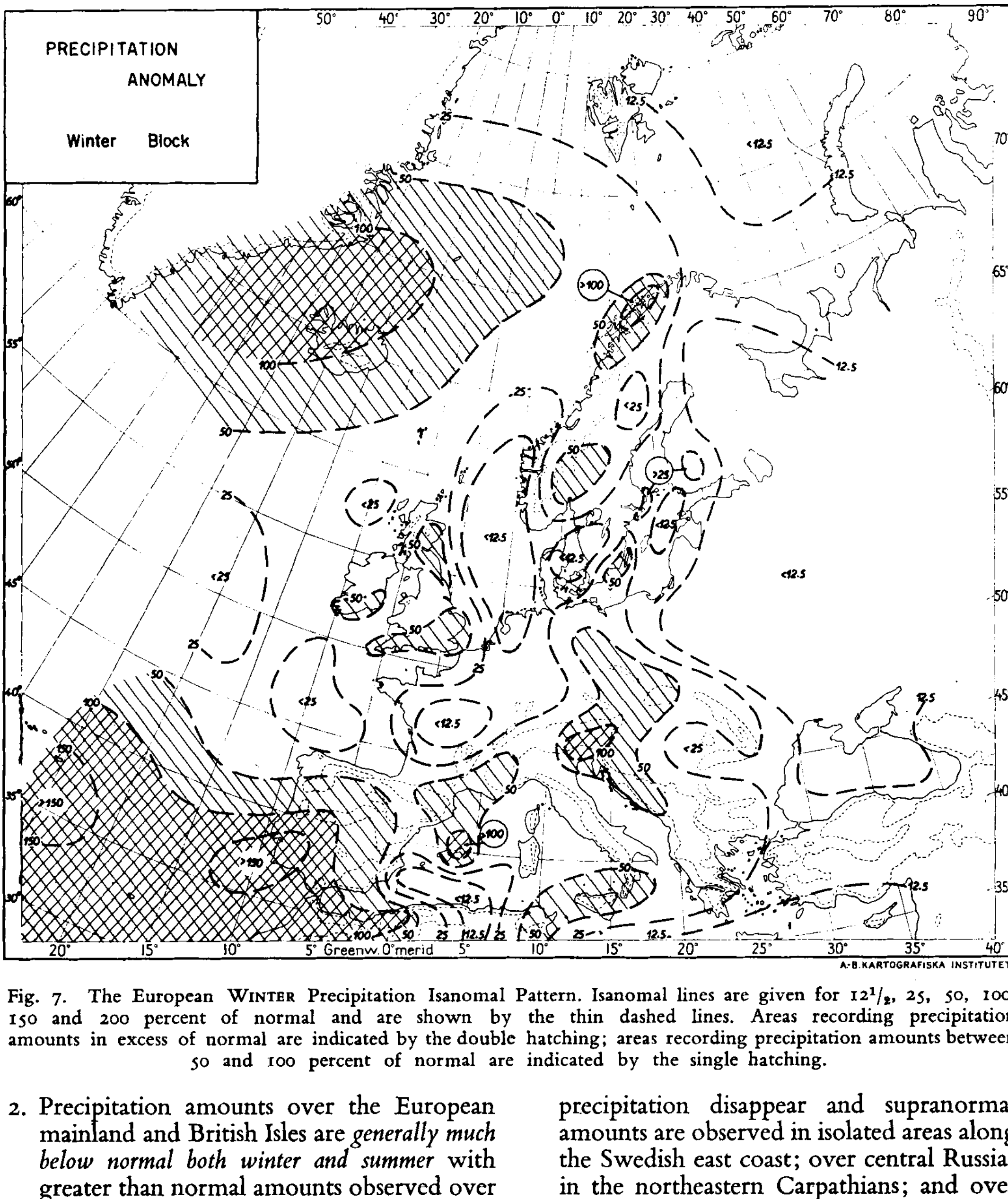

Fig. 7. The European WINTER Precipitation Isanomal Pattern. Isanomal lines are given for $12^{1}/_{2}$, 25, 50, 100, 150 and 200 percent of normal and are shown by the thin dashed lines. Areas recording precipitation amounts in excess of normal are indicated by the double hatching; areas recording precipitation amounts between 50 and 100 percent of normal are indicated by the single hatching.

2. Precipitation amounts over the European mainland and British Isles are *generally much below normal both winter and summer* with greater than normal amounts observed over East Greenland, the North Atlantic and northwestern Norway. In winter additional isolated areas along the southern and eastern coasts of the British Isles; in the Austrian Alps; and over the east-central Atlantic, south-western Spanish mainland and north-west African coast, receive normal or greater than normal amounts. In summer the above-mentioned areas of greater than normal precipitation disappear and supranormal amounts are observed in isolated areas along the Swedish east coast; over central Russia; in the northeastern Carpathians; and over coastal areas adjacent to the western Mediterranean.
3. Wintertime blocking produces above-normal temperatures over the entire North Atlantic area, most of Scandinavia and northwest Russia, with maximum positive anomalies of 8° C in Spitzbergen, Iceland and the coastal areas of East Greenland and 5° C in northern Scandinavia; simulta-

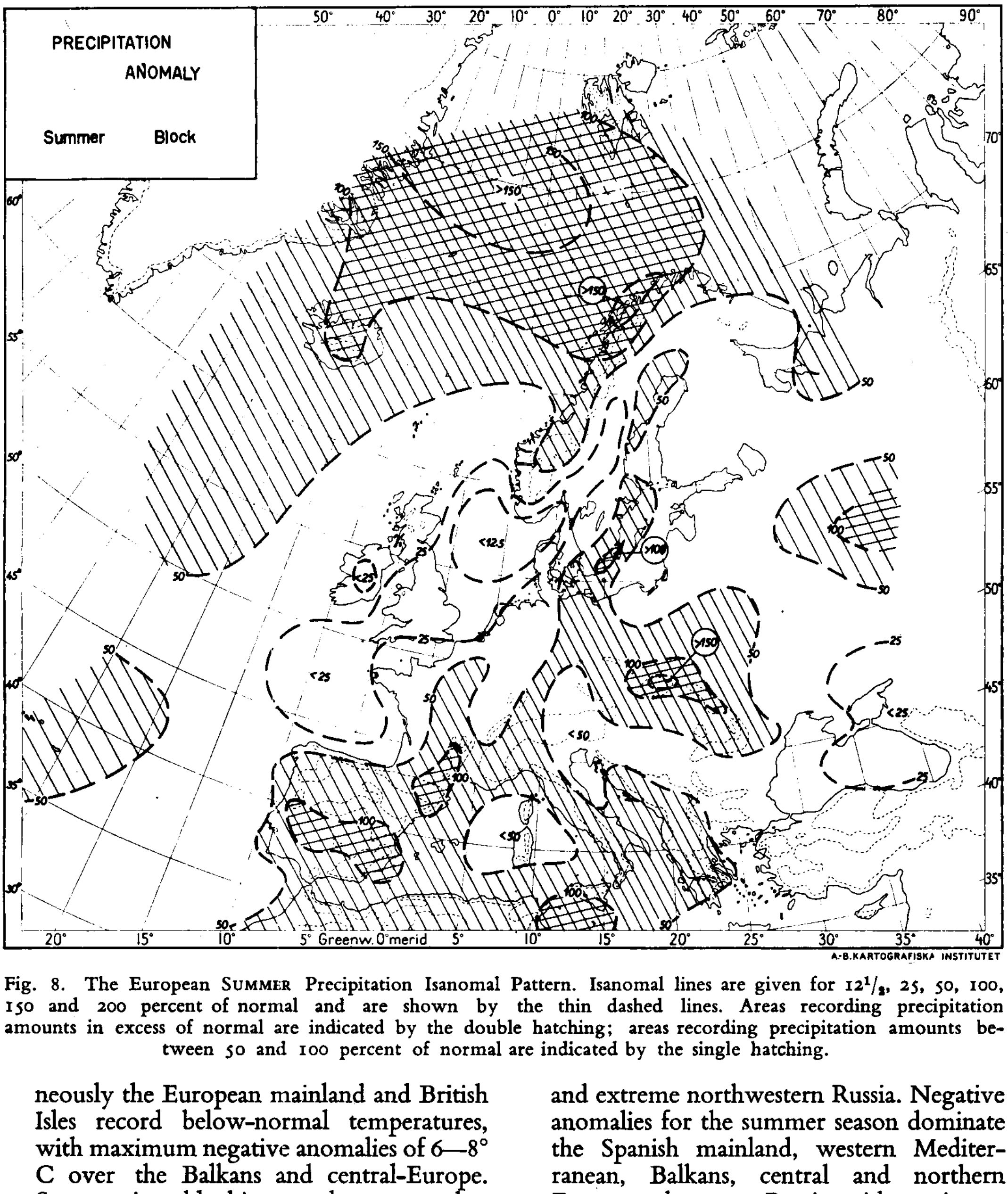

Fig. 8. The European SUMMER Precipitation Isanomal Pattern. Isanomal lines are given for $12^1/_2$, 25, 50, 100, 150 and 200 percent of normal and are shown by the thin dashed lines. Areas recording precipitation amounts in excess of normal are indicated by the double hatching; areas recording precipitation amounts between 50 and 100 percent of normal are indicated by the single hatching.

neously the European mainland and British Isles record below-normal temperatures, with maximum negative anomalies of 6—8° C over the Balkans and central-Europe. Summertime blocking produces a weaker temperature anomaly pattern which is shifted somewhat toward the south, giving above-normal temperatures over the north-central and North Atlantic, British Isles, France, the Low Countries, all of Scandinavia and northwestern Russia, with maximum positive anomalies of 3—4° C in the north-central Atlantic, southern Norway and extreme northwestern Russia. Negative anomalies for the summer season dominate the Spanish mainland, western Mediterranean, Balkans, central and northern Europe and western Russia, with maximum negative values of 5° C in extreme western Russia.

Conclusion

The results obtained from the analysis of the six blocked periods given in Table I indicate that the pattern of European climatic anomalies, associated with Atlantic blocking action, is remarkably stable, both from season to season and, more especially, from case to case within one season. Accordingly, we may interpret the conclusions previously stated by REX (1950 b), in so far as they relate to the isanomal analysis of the January 1947 and June-July 1949 cases, in a somewhat more general light.

In a previous paper (REX 1950 b, figs. 13 and 14) an attempt was made to demonstrate directly a relationship between the year to year variations in Atlantic blocking activity and corresponding year to year variations in mean-temperature and precipitation at various European stations (both winter and summer). Some success was achieved although from a statistical point of view the argument is largely inconclusive because of the short time-period over which a blocking index is available. If however one accepts the existence of such a relationship, it follows that long-term trends in the blocking index should be reflected in the observed long-term trends of European climate. Evidence exists showing a differential pattern of climatic change in the North Atlantic-European area which fits the form of the blocked pattern rather well. Confining our attention to the winter season, a continuous increase is indicated in the level of winter blocking activity from the early 1910's until the early or middle 1930's, followed by a gradual decrease through the middle and late 1930's and a gradual rise through the 1940's to the present time. The portions of this trend from 1933—1940 and from 1945—1949 have been computed in a previous paper (REX 1950 b).

The picture presented is certainly not without gaps and contradictions but, by and large, shows for the winter season a large relative increase in the sea-level pressure over northern Europe and Scandinavia, a general decrease in Continental temperatures and precipitation (or at least a decrease in the rate of rise of these elements), and an increase in the rate of rise of North Atlantic and Scandinavian temperatures and precipitation, beginning in each case in the early 1910's and extending some 20—25 years into the future. The 20-year mean winter pressure- and temperature-change patterns obtained by PETTERSSEN (1949, fig. 2) and WILLETT (1950, figs. 3 and 5) have already been mentioned in a preceeding paragraph. Additional evidence is the overlapping 30-year normals of pressure-difference, precipitation and temperature (January) given by LYSGAARD (1949, figs. 6, 7, 8, 9, 42, 43, 73, 74 and 75) and the mean winter temperature and precipitation trends for Iceland and Greenland given by EYTHORSSON (1950, figs. 5 and 7) and HOVMÖLLER (1947, fig. 26). Certainly variations in the level of Atlantic (and Pacific) blocking activity can not explain the total climatic change which has been observed over the North Atlantic-European area (and Northern Hemisphere) during the past century. It is proposed however that *variable blocking activity has been one factor of importance in conditioning the form of the change observed in certain areas.*

The physical factors responsible for the initiation and development of blocking action remain undisclosed. Accordingly it should be noted that, even if one accepts the concept of variable blocking activity as an important climatic conditioning factor, the two questions "why" and "when" remain unanswered. Perhaps the first clue in this connection has been given by WILLETT (1949, figs. 4, 5 and 6) in the form of mean winter pressure-, temperature- and precipitation-change charts for the period from a sunspot minimum to the following minor sunspot maximum. The marked similarity between figures 3, 5 and 7 and the change-patterns found by Willett invite a more detailed examination and may provide a means of identifying the physical mechanisms responsible for the initiation and development of atmospheric blocks.

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