Seasonal persistence and recurrence of European blocking during 1958–1960

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ABSTRACT

Blocking activity was especially frequent and persistent over Northern Europe during all seasons from late 1958 through 1959 and 1960. Some effects of the blocking on seasonal precipitation are discussed. The initiation and persistent recurrence of the blocking is studied with the help of various mean seasonal charts, particularly those for mid-tropospheric levels.

It is suggested that the physical causes of the blocks lie in complex feed-back phenomena between the atmosphere, the North Atlantic sea surface and the Scandinavian Peninsula (particularly its lack of cold-season snow). The latter two factors appear to serve as conservative links in a feed-back chain, thus providing restorative forcing elements on the general circulation over the area.

Some precursory signs of such long period blocking are suggested by an analysis of the wintertime meridional flow prevailing between southern Greenland and southern Scandinavia.

1. Introduction

In an earlier paper delivered at the UNESCO-WMO Symposium on Climatic Change held in Rome in November 1960 (NAMIAS, 1963*b*) the author briefly described a period of four years during which an apparently regular evolution of blocking took place over Europe. The period was characterized by diminution in annual precipitation at numerous places in Scandinavia and especially on the west coast of Norway, for example at Bergen, where a more or less steady decline in precipitation after 1957 led to 69 % of normal in the year ending November, 1960. This was the second lowest annual total recorded in a series beginning in 1895 (Norway, 1956–1960). This steady decline in annual rainfall is indicated in the central portion of Fig. 1, which for convenience has been reproduced from the earlier cited report.

From Fig. 1 and other material it is also clear that Central and Southern Europe and the British Isles did not partake in this decline in precipitation (e.g., Valentia, Ireland, at the bottom)—a condition well known to be associated with blocking anticyclones to the north which deflect cyclones southward into Europe and the Mediterranean. We shall have more to say about the space and time aspects of the precipitation regimes.

A rough index of the increase in blocking is plotted in the upper portion of Fig. 1. These curves represent differences in departure from normal of 700-mb height between 70° N, 20° E and 50° N, 10° W (roughly between northern Scandinavia and Ireland), and between northern Scandinavia and the area south of Novaya Zemlya (70° N, 20° E minus 60° N, 80° E).

It was also pointed out in this preliminary report that mean annual charts of 700-mb height and their anomalies also indicated a reasonably regular evolution of pattern over the four years 1957–1960, and that extrapolation of this long-period trend would suggest a termination of the northern drought regime (which indeed came about dramatically in the succeeding few years).

Further study of the data for this period of climatic fluctuation has been made in order to determine more about the seasonal development of the blocking pattern, and particularly to ascertain some clues as to why this tenacious and persistently-recurrent pattern of atmospheric circulation came about. Very little is known about these matters, and it is probable that the physics underlying them will remain

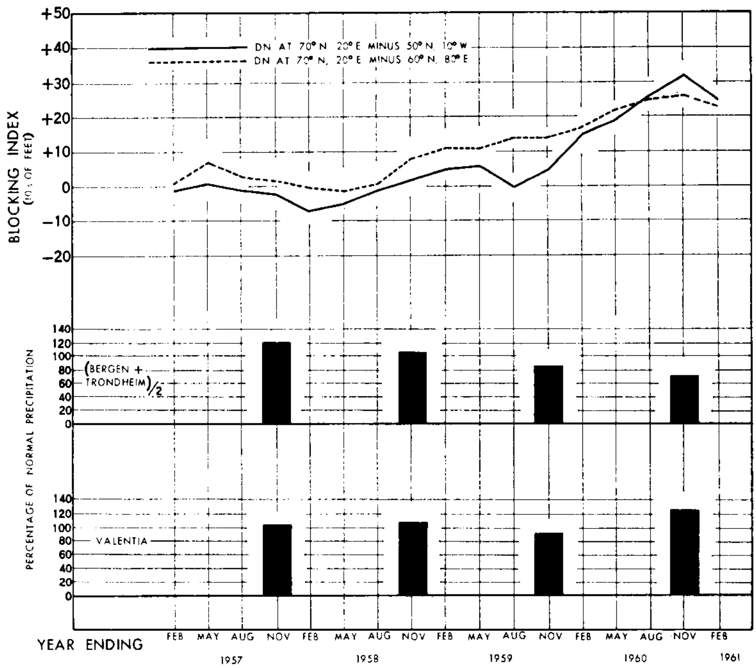

FIG. 1. Central and lower: Percentage of normal precipitation for successive years ending in November for Western Norway and Ireland. Upper: Overlapping 12-month mean blocking index over Northern Europe (see (text).

obscure for many years. In this unsatisfactory stage of a science we must first describe and interrelate phenomena as best we can, and we must also make plausible speculations based on what evidence can be amassed.

Therefore, the purpose of this paper is to describe, to interrelate, and to speculate on factors associated with this climatic fluctuation and its physical causes, with the help not only of data taken in the atmosphere, but also at the surface of the sea and on land (precipitation, both rain and snow). It is believed that these fluctuations are due to feed-back phenomena between the atmosphere and the underlying surface, and without considering the latter, meteorologists cannot hope to solve the problems of climatic abnormalities.

2. Seasonal characteristics of the precipitation along the west coast of Norway

We shall now look into the seasonal changes which made up the annual totals shown in Fig. 1 and relate them to features of the local circulation. These data are plotted in Fig. 2, in which winter is defined as the average of December, January, and February, spring as the average of March, April, and May, and so on. As in Fig. 1, the indices of blocking are displayed at the top, while the percentages of normal precipitation are given in the central and lower parts of the figure. The gradual decline in precipitation at Bergen and Trondheim which appeared in the annual averages of Fig. 1 is evident even in the bar graphs for individual seasons. However, the decrease is by no means regular, and in fact, does not appear in the summer values. Similarly, the sequences of precipitation at Valentia and the blocking index are also irregular, although the latter graph displays the upward trend indicated by the corresponding curves of Fig. 1. In this case, however, the smoothing introduced by overlapping means in Fig. 1 (top) would demand such correspondence.

The most regular seasonal changes for all three graphs occurs during the four fall seasons. In order to highlight this circumstance, a smooth curve has been drawn through the western blocking indices of the fall season and bold F's

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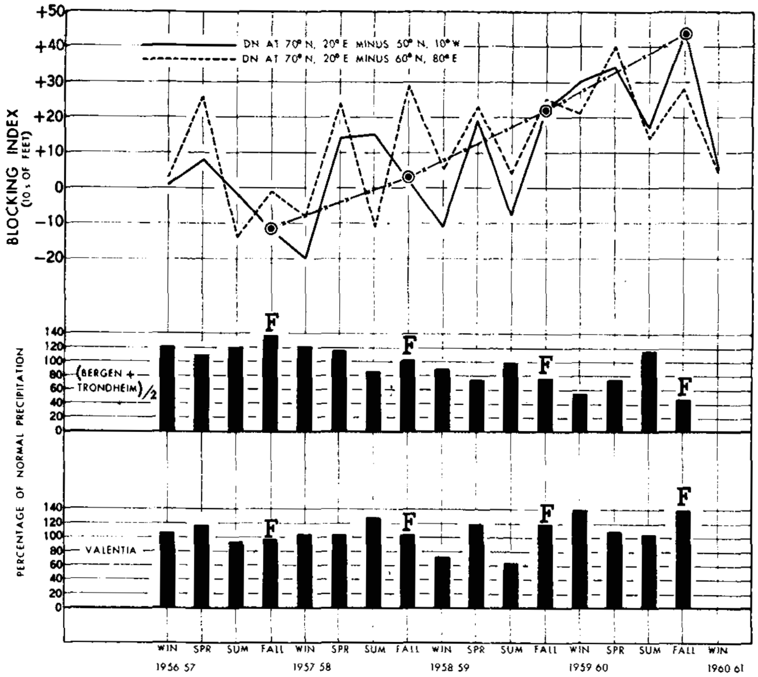


FIG. 2. Central and lower: Percentages of normal precipitation by seasons along the west coast of Norway and at Valentia, Ireland, for indicated four years. Upper: Blocking indices at 700 mb (defined at top) for individual seasons. Lines made with crosses and bold F's indicate long-period trend of fall seasons.

placed above the fall precipitation percentages. In other words, it appears that while a more or less steady decline in precipitation, associated with increased blocking, took place over the four-year interval from winter 1956–57 to fall 1960, it was the autumns which played a major role in this phenomenon. The characteristic fall rains on the west coast of Norway failed to develop in the latter two years, as the westerlies yielded to stronger blocking. Later an attempt will be made to relate this peculiarity to other factors. In passing, it is interesting to note that the fall of 1960 at Bergen had only 44 % of its normal precipitation (88 mm compared to a normal of 199 mm) and was the driest fall in the 66 year Bergen record available to the author (1895 to 1960).

Before leaving the discussion of precipitation we shall describe with the aid of a few charts (Figs. 3*a*, *b*, *c* and *d*) the annual[1] precipitation departures at some other places in Northern

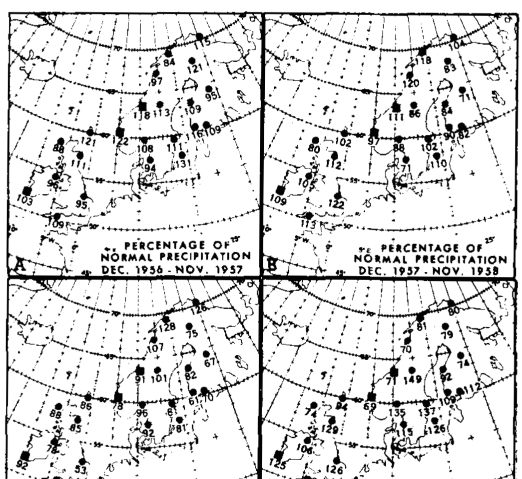


FIG. 3. *a*, *b*, *c*, and *d*, Percentage of normal annual precipitation at numerous stations in Northern Europe. (Bergen, Trondheim and Valentia are indicated by squares.)

[1] Actually, the charts for each year begin with December of the preceding year and end with November. This was done to conform to the mean circulation charts available.

Europe. From these charts of the four years it is clear that the dry regime dominated only two years (1958 and 1959) at most places in Scandinavia and that by 1960 only the west coast of Norway and northern Scotland continued to have substantial deficits in precipitation. Note also that the first evidence of a large-scale decline in Scandinavian precipitation occurred in 1958 after a relatively wet year in 1957.

3. Seasonal mid-tropospheric circulations associated with the blocking

Any attempt to explain or even to describe adequately the situation leading to the events discussed must obviously consider the mean circulation patterns of the atmosphere at one or more levels. For the sake of simplicity we have chosen the 700-mb surface and its departure from normal, largely for the reason that charts of this surface are routinely prepared in connection with an experiment in seasonal prediction, and also that meteorologists have developed a fair degree of experience in interpreting these patterns in terms of cyclone and anticyclone tracks, precipitation, etc. (Namias, 1953). It should be noted that some other level, particularly sea-level, would also be suitable for this work—especially since over maritime areas the correlation between lower-level mean pressure patterns is high. While sea-level charts for this series of seasons are available, they will not be reproduced because of space limitations.

The individual seasonal 700-mb charts for the four years are reproduced in Fig. 4 where solid lines represent mean 700-mb contours and broken lines isopleths of departures from the long-term normal. Examining any row of charts, it is quite apparent that the mean circulations over Northern Europe, as indicated by the mean contours, underwent a change from cyclonic to anticyclonic during the same seasons of successive years. This is more clearly seen in the anomalies which for the most part change from negative to positive. Especially strcng "blocks" with compensating and adjacent negative centers of anomaly appear in winter 1959–60, spring of 1959 and 1960, summer 1959, and particularly the falls of 1958, 1959, and 1960.

The blocking is indeed so characteristic, that its gradual development shows up in a series of annual mean charts (not reproduced). A series of such annual means ending in the Februaries of 1958 through 1961 was shown in Fig. 10 of the previous preliminary article (Namias, 1963*b*). By comparing seasonal charts with one another, and particularly the same season of different years, it appears that there is more regularity in the development than usually seen, and one obtains the impression that in spite of its great complexity we are dealing here with an ordered process.

The negative anomalies correspond to areas where migratory cyclones were frequent and intense, while in the positive areas anticyclones and anticyclogenesis were frequent. Thus the anomalies are also associated with departures from normal in rainfall, so that the dry and wet seasons of western Norway and Valentia shown in Fig. 2 can easily be related to them, as can precipitation departures at other places. Even on an annual basis this is true. During the prevailingly dry year of 1959 (see Fig. 3*c*), the dominance of mean anticyclonic upper-level flow shown in the seasonal charts of Fig. 4 (indicative of subsidence) seems to account for much of the precipitation deficiency.

It is, of course, difficult to indicate precisely the beginning of the dry regime. From the mean circulation charts it appears that the fall of 1958 represented the first strong intrusion of blocking in Europe. Besides, diminution in precipitation over a large area occurred in 1958 relative to 1957 (see Fig. 3).

4. Possible physical reasons for the maintenance of the block

It is well recognized in meteorology that the physical explanation of climatic fluctuations constitutes one of the most difficult problems challenging man. To a large extent this complexity results from the many interdependences between portions of the atmosphere—both in the vertical and horizontal. Thus it is really not possible to isolate a sector of the global atmosphere and be sure that the processes leading to its abnormality are to be found within those confines. For decades it has been known that developments in one area can greatly affect those in other remote places; for example, developments along the east coast of the U.S., can greatly alter the weather situation in the Atlantic and Europe. These "teleconnections" in climatic anomalies have indeed formed the basis for many studies aimed at long-range forecasting.

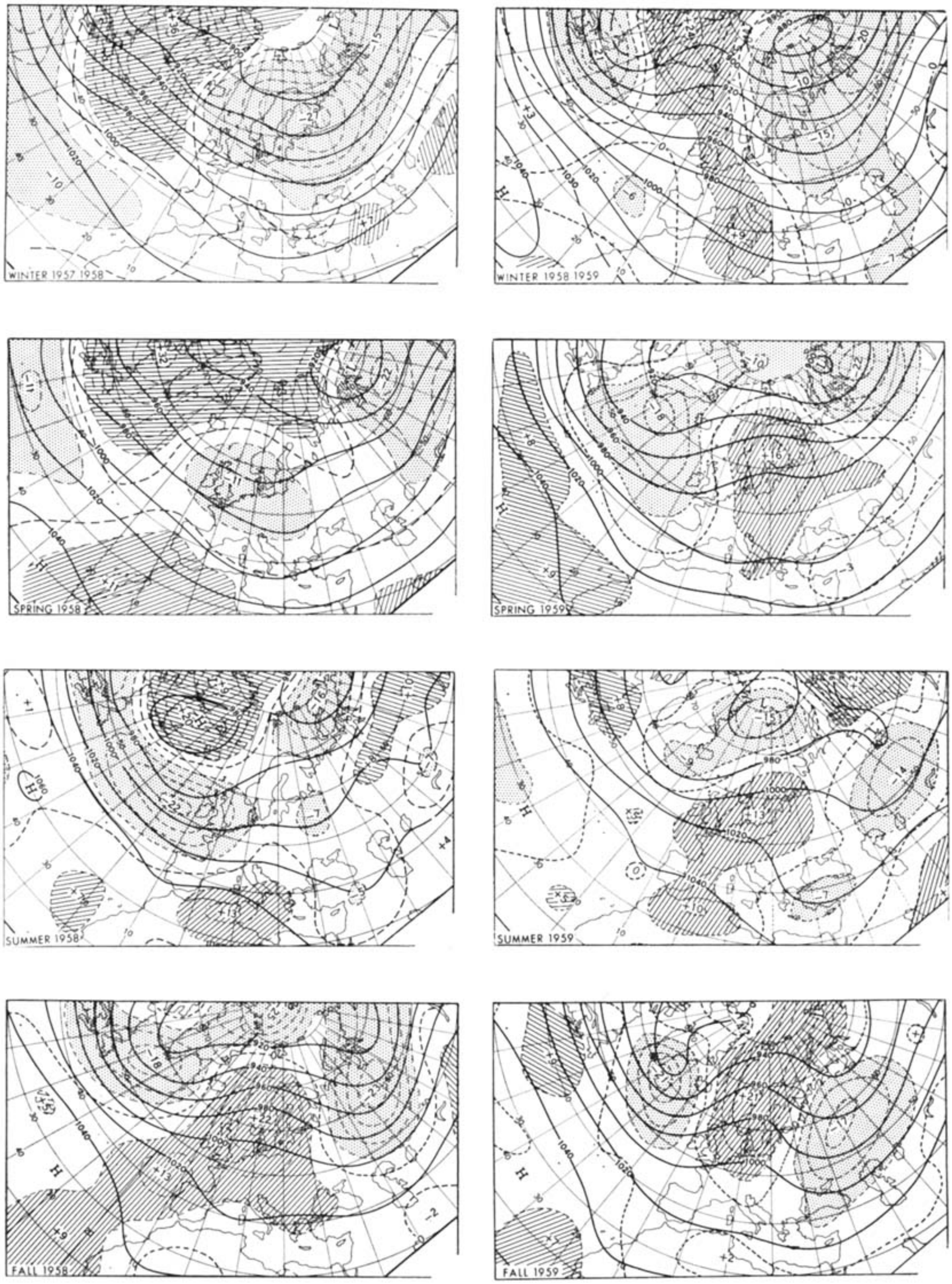
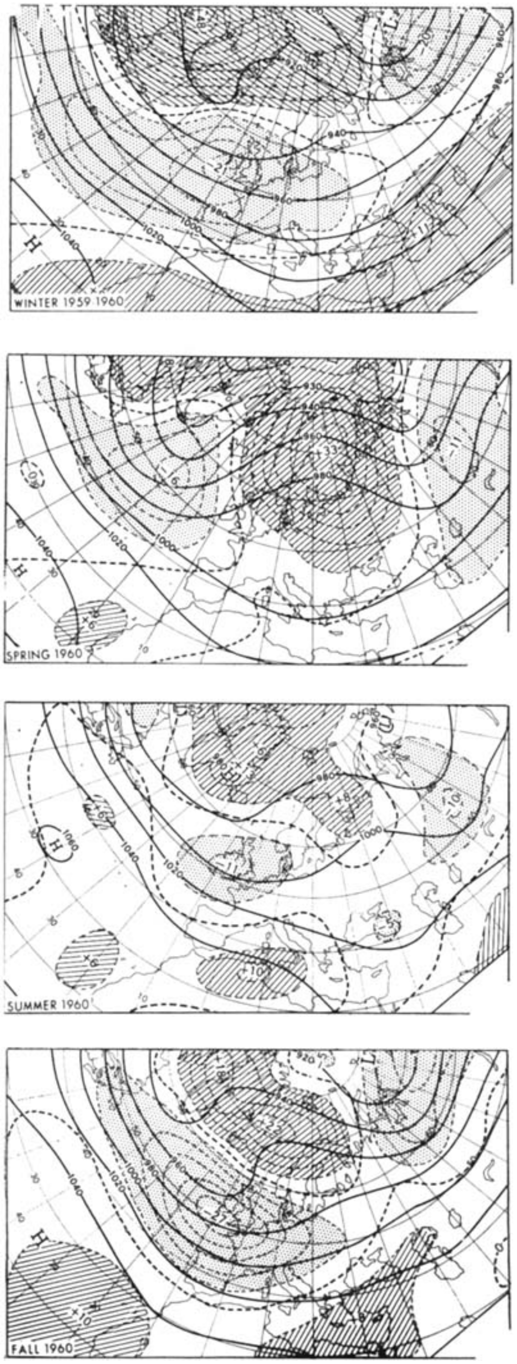


Fig. 4. Seasonal mean 700-mb contours (solid) and isopleths of departure from normal (broken) for winter 1957–58 through fall 1960.



Yet the persistent recurrence of the same circulation pattern over certain geographical areas in seasons or sometimes years implies that some abnormality of the surface may be exerting an effect on the overlying atmosphere. The effect, if present, must vary with the character of the broad-scale air flow, which, in turn, must depend on actions and reactions with remote areas. A consistent effect might be produced in cases when the overlying general flow was frequently developed in a similar fashion, and hence the regional abnormal heating or cooling might operate to distort the general flow in a specific way.

For example, a snow cover laid down in an abnormal area might favor the development of an anomalous component of the thermal wind in the lower layers of the atmosphere. In turn, through direct circulation, this could affect the steering pattern of air flow and thus affect the course and development of cyclones and anticyclones. To the extent that the general large-scale flow repeats, the variations imposed by the underlying surface will be consistently in the same direction and hence the monthly or even seasonal mean patterns may be influenced.

In the case treated here a considerable effort was made to find the character of abnormality at the earth's surface adjacent to the areas of blocking. One of the first considerations was the extent of ice off Greenland, for this has been claimed by some authors (BROOKS, 1928) as significant for European climatic anomalies. Information on ice obtained from the U.S. Navy Hydrographic Office, however, did not indicate great departures from normal off the east coast of Greenland during our period of investigation, with the exception of a greater than average amount of ice at high latitudes (65°–70° N) especially off Cape Brewster. We are unable to say whether this is involved in the production of the abnormal circulation because of our present lack of knowledge and data.

The next part of the investigation of surface abnormality involved surface water temperatures, where data are better and where ocean weather ship reports are available. Recent studies by BJERKNES (1962) PETTERSSEN *et al.* (1962) and the present author (1963*a*) have demonstrated how abnormal sea-surface temperatures over large areas may appreciably affect wind and weather patterns. They affect not only the course and development of cyclones and anticyclones in the area of sea-temperature abnormality but also, through inertial effects, may influence adjacent and remote areas. It is not only the systematic deviation of sea-

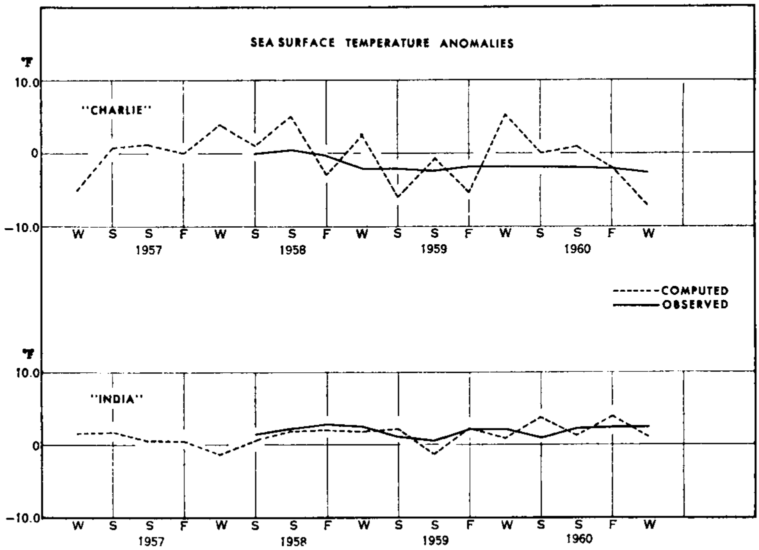


FIG. 5. Solid: observed seasonal sea-surface temperature departures from normal at Ship Charlie (52°45′ N, 35°30′ W) and Ship India (59°00′ N, 19°00′ W). Broken: Seasonal mean sea-surface temperature anomalies computed using Ekman surface drift as described in (Namias, 1959).

surface temperature in one area which induces atmospheric effects, but perhaps more importantly, the gradients of sea-surface temperature. Since more or less heat than normal is provided to the lower atmosphere in different areas, cyclogenesis may be enhanced or suppressed because of the altered baroclinicity. Numerous cases of this kind have been cited by the author (1959). In fact, some fifteen years ago, Dr. Wouter Bleeker of the Netherlands, then a visiting professor at the University of Chicago, investigated some cases of frontogenetic action initiated by sea temperature contrasts.

An index of the striking anomalous sea-surface temperature contrasts over the North Atlantic observed during the blocking period is provided by Ocean Ships Charlie (53° N, 36° W) and India (59° N, 19° W), whose observations of mean seasonal departure from normal of sea-surface temperatures are given by the solid lines in Fig. 5.

The departures from normal obviously depend upon the particular normals used. Those given in Fig. 5 refer to the normals of the U.S. Navy Hydrographic Office Bulletin #225 (1954). If the 1951–60 averages given in the WMO "Clino Normals" are used, the departures are lessened, but the differences between Ship Charlie and Ship India are of the same character.

Whatever the base taken, it is clear that during the blocking period over Northern Europe the seas in the vicinity of Ship Charlie became appreciably colder than normal, while those around Ship India became warmer than normal. These differences, when looked at

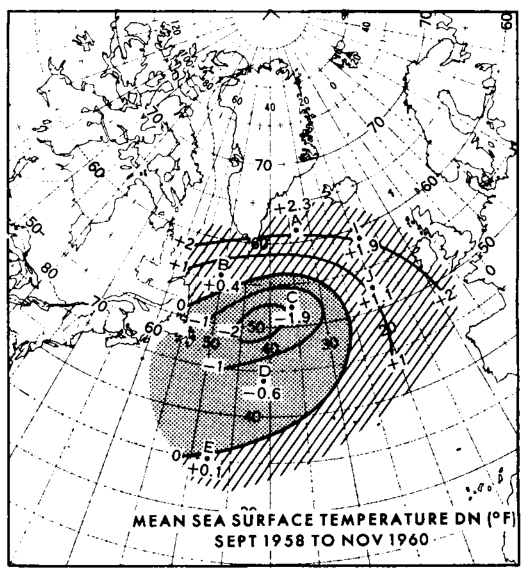


FIG. 6. Mean sea-surface temperature departures from normal for the period September 1958 to November 1960.

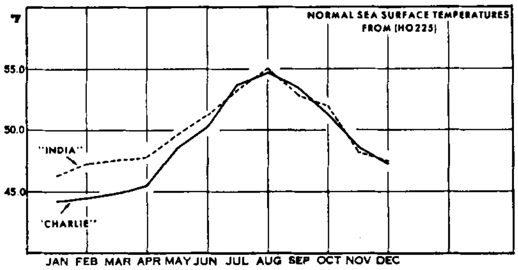


FIG. 7. Normal sea-surface temperatures at Ships Charlie and India (from U.S. Navy Hydrographic Office, 1954).

cumulatively over the last two years of the period, are quite sizeable. Indeed they characterize rather large-scale anomalies as is evident from an analysis of seasonal sea-surface temperature fields constructed from a number of Atlantic weather ship observations. While the charts for individual seasons are not reproduced, the mean of the nine seasons embracing fall 1958 through fall 1960 (the blocking period) is shown in Fig. 6. The gradients on this chart are surprisingly large (e.g., almost 4°F between Charlie and India), especially when the long period of averaging is considered.[1] They represent sea-surface temperature variations due to numerous factors resulting from sea-surface interactions with the abnormal overlying atmosphere, which determine the heat budget of the surface water. It is not the purpose of this report to estimate the various components in the heat budget of this area, but it is qualitatively apparent that the waters around Charlie in 1959 and 1960 were greatly influenced by the anomalously strong Icelandic Low off Southern Greenland (see Fig. 4) while around Ship India an anomalous southerly component prevailed. Thus, qualitatively, it seems that numerous factors such as advection and windiness (and increased or diminished evaporation) helped sustain relative coolness at Ship Charlie but warmth at Ship India. Computations showing the effect of the anomalous advection on the surface water [procedure described in an earlier report (NAMIAS, 1959)] are shown in Fig. 5 as broken lines. The general agreement of computed and observed values, suggesting a relative difference between Charlie and India in the sense of anomalously cooler surface water at Charlie relative to India, indicates an effect of advection, although many other factors obviously enter into the heat budget.

For proper interpretation, the departures cited above must be added to the normals. It is interesting to note that in all seasons the normal sea-surface isotherms in this area run roughly from southwest to northeast in such a way that in every month Ships Charlie and India lie approximately on the same isotherm. The latter fact is demonstrated by Fig. 7, which shows monthly normal sea-surface temperatures at both ships.

The net effect of the anomalous ocean temperatures observed in this area (between Charlie and India) in the late 1950's was therefore to strengthen the southerly component of the thermal wind and thereby the south winds aloft by introducing an enhanced east to west temperature gradient. Of course, this is accomplished through greater than normal flux of sensible heat to the air from the warmer waters at India, and lesser than normal flux from the waters in the vicinity of Charlie. The strengthened east-west gradient would also result in increased frontogenesis, greater development of storms making up the westward displaced Icelandic Low, and particularly, the forcing of high latitude storm paths more *northward* than eastward. The barotropic (inertial) effect of an increased southerly component in the lower troposphere would be to create a stronger ridge than normal some distance to the east. Some of the above reasoning has been incorporated into a schematic illustration (Fig. 8), which shows how the induced water abnormalities, once they persist, may alter the cyclone paths and upper-air flow in such a way as to set up recurrent blocks in Northern Europe. This may have been one of the principal factors operating to establish the tenacious blocks, and there were undoubtedly other areas where sympathetic interactions were proceeding. It should be borne in mind, however, that because of Europe's geographical position and consequent lax meridional temperature gradient, flow patterns are often on the verge of blocking, and that only a small influence may set it off.

To express this barotropic redistribution of energy in more quantitative form, the following experiment was carried out:

[1] If a similar nine season mean is computed using the "Clino Normals", the same pattern results but with slightly reduced gradients. Part of the reduction is undoubtedly due to the fact that 1959 and 1960 were used in the computation of the roughly 10-year "Clino Normals".

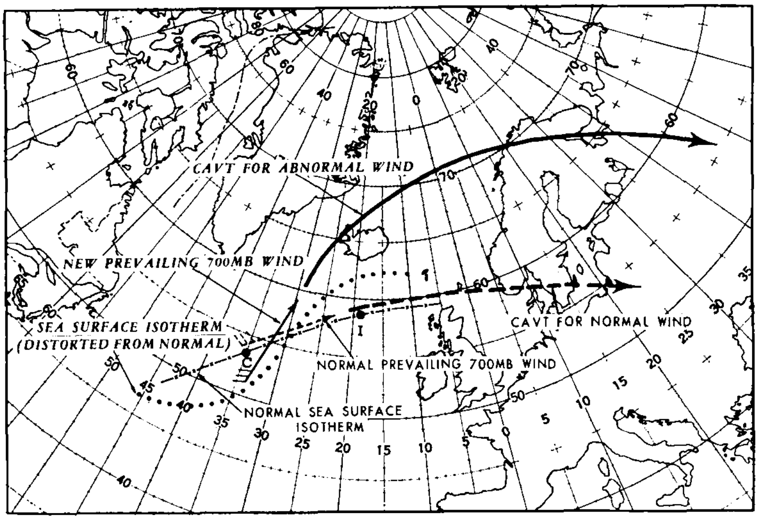


FIG. 8. Schematic illustration of "feed-back" effects introduced by departures from normal of sea-surface temperatures (see text).

The 700-mb height anomalies for fall, 1959 (see Fig. 4), within a pie-shaped area between 10°W and 50°W and extending from the pole to the southern limit of data were added to the hemispheric normal 700-mb height field for fall. The resulting height field was then manually analyzed in such as way a to blend the contours smoothly with the normal height contours in bordering regions. The resulting chart, normal over most of the Northern Hemisphere except in the pie-shaped region, was then used as input to a simple equivalent-barotropic, geostrophic model (Charney, 1949), with a correction for excessive retrogression of long waves (Cressman, 1958). The computations were carried out to 96 hours, holding nearly fixed the anomalies in the pie-shaped region, but allowing heights to vary freely outside that region. Results for the area of interest are shown in Fig. 9 where the emergence of the North European block and the trough to its east are evident.

It should be emphasized that in this experiment geostrophic winds in the selected region are forced to remain invariant, perhaps due to an exchange of heat energy with the sea-surface, as previously suggested. The circulations in other areas, on the other hand, are assumed to respond only to the barotropic (inertial) redistribution of kinetic and potential energy emanating from the disturbed region. Of course, in reality height anomalies over most of the hemisphere are not initially zero as assumed, and in addition these regions are subject to disturbances from other areas as well as to other local sources and sinks of energy. Nevertheless, the closeness with which the anomalies in the "silent" areas may be approximated using such a simple assumption implies the dominant role the Atlantic circulation plays in European blocking phenomena. The choice of time-interval for the computation presupposes that one cannot proceed on the basis of "real" time, for it is physically unrealistic to suppose that a mean circulation pattern can be extrapolated forwards in time for a whole season without introducing sources and sinks of energy. Rather, the assumption previously advanced by the author (Namias, 1957) is made that a thermally-produced disturbance in an otherwise steady-state mean circulation pattern is rapidly dispersed to surrounding areas so that most of the apparent dynamic adjustment is achieved in only a few days. The choice of the exact interval of extrapolation (4 days) is naturally somewhat arbitrary.

It should be recapitulated that the very existence of the blocks and the related westward and southward displacement of the Icelandic Low helps create the described water temperature anomalies which, because of their persistence, are frequently instigators of new blocks.

Finally it should be noted that the general anomalous sea-surface temperature field indicated in Fig. 6 already became established in late spring and summer 1958 immediately preceding the onset of blocking (see Fig. 5; also indicated on seasonal charts of sea-surface temperature not reproduced). This antecedence holds out the hope for more practical utilization of sea temperatures in long range forecasting.

Aside from the sea-surface temperature anomalies, it is probable that the nature of the land surface of Northern Europe exerts an influence on the overlying atmospheric circulation. The most obvious case of this sort results from variable extensive snow fields and the numerous effects exerted by virtue of differences in albedo with or without snow, differences in condensation, in the heat used for melting, and so on. While these effects may appear to be local, they frequently take place over a large area, and what is perhaps more important, introduce variable horizontal temperature gradients which modify the normal flow and may also influence cyclogenesis and anticyclogenesis. Some very large-scale manifestations of important modifications in the overlying air temperature and of cyclogenesis along the southern boundary of an unusually southward displaced snow cover over North America have been detailed by the author (1962).

Scandinavia also has sizeable variations in snow cover from one fall, winter, or spring to another. While the area may appear small in comparison with the United States, it is conceivable that similar local effects occurring in many places can produce large-scale effects. The "a priori" hypothesis was therefore made that some of the warm season blocking discussed earlier might be encouraged by a warmer than normal Scandinavian peninsula during late spring, summer, and fall, because thermal contrasts with the Atlantic and perhaps the Baltic would in this case be strengthened, and thereby enhance the possibility of development of an increased monsoonal effect and upper-level anticyclone. The increased warmth of the peninsula might in the first place be created by complex lag effects following cold seasons when relatively little snow is observed.

With this hypothesis in mind, the number of days with 1 cm or more snow on the ground for the period October through May was tabulated for eight stations[1] which roughly represent the Scandinavian peninsula. Then sums of total number of days with 1 cm of snow on the ground were computed in order to obtain an index which might represent the conservative element being sought. The totals are given below:

TABLE 1. *Number of days with more than 1 cm of snow on the ground at eight Scandinavian stations.*

October 1956–May 1957	953
October 1957–May 1958	1060
October 1958–May 1959	852
October 1959–May 1960	782

It will be noted from Table 1 that a sharp drop in the total number of days with snow on the ground took place in the period from October 1958–May 1959 relative to the preceding year, and that this diminution continued the following year. Part of this reduction may have been due to the deficiency in precipitation, which in turn was associated with the increased anticyclonic curvature aloft (and relative lack of ascending motion). However, inspection of the seasonal percentages of normal over Scandinavia during the period fall 1958 through spring 1959 (not shown) indicates no general deficit of total precipitation relative to normal. Hence, the diminution from 1060 days in the cold season 1957–58 to 852 in the corresponding period 1958–59 was probably due to the frequent occurrence of rain, warmth, and melting snow. Certainly, the circulation patterns of Fig. 4 suggest a colder regime in the cold season 1957–58, a fact also indicated by thickness patterns between 1000 and 700 mb (not shown) as well as in climatological yearbooks. In the period October 1959–May 1960 on the other hand, a number of stations do indicate a decline in total precipitation. Again this is suggested by the form of mean 700-mb contours and isopleths of anomaly shown in Fig. 4.

Precisely how reduced snowfall on the ground may carry over influences to late spring, summer and fall is not known. It is not unreasonable, however, to speculate that when excessive snow has fallen (affecting lakes, streams, glaciers and soil surfaces) not only is more heat required

[1] Tromsö, Karesuando, Stensele, Trondheim, Bergen, Oslo, Falun, and Halmstad (data extracted from Norway 1956–1960 and Sweden, 1956–1960).

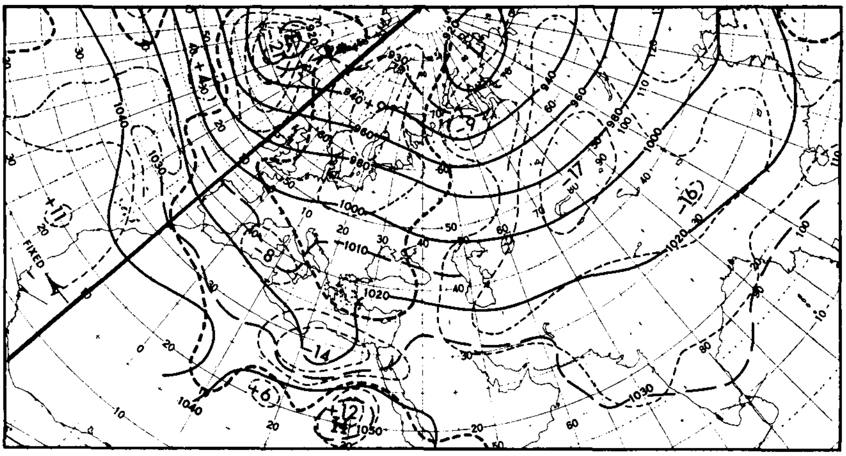


FIG. 9. Barotropically computed 700 mb mean contours and anomalies (area east of 10°W) produced by forced Atlantic perturbation (west of 10°W.) (see text for details).

for melting but also a large fraction of incident radiation is reflected. On the other hand with greatly diminished snow cover, the ground can respond to the rapidly increasing insolation of spring and summer, thereby producing a greater rate of warming. In the former case the delayed spring to summer heating might encourage cyclonic curvature aloft, while in the latter, the more rapid continental heating and the greater contrast with the surrounding waters might help create upper-level ridges. These differences are essentially of a monsoonal nature. Perhaps the suggestions by WALKER (1910) that the timing of the Indian Monsoon is related to the amount of springtime snow in the Himalaysa represents a similar phenomenon.

5. Precursory signs of the long-period blocking regime

The ultimate objective of studies like that described is to develop a method of predicting the onset of abnormal circulations leading to persistently anomalous weather patterns. Needless to say, this *desideratum* is indeed remote. In fact, there are some numerical experiments with model atmospheres done by computer which may suggest that such attempts are futile (LORENZ, 1963). However sophisticated such models, they will not for some time duplicate in detail the real atmosphere—particularly the coupled earth-atmosphere system in which feed-back loops of the type described can operate. Thus, conservative factors such as systematic ocean temperature variations over large areas and large-scale variations in snow cover and soil characteristics could produce *stabilizing* influences on atmospheric developments, rendering true long-range prediction (for months, seasons, and years) easier than anticipated.

Although prognostic indications for seasons and years have been sought in time-averaged records of meteorological elements for many decades, particularly in records of pressure and temperature, no evidence of striking success has been demonstrated in forecasting. In the case of the blocking situation we have discussed, it would be difficult to develop a method to predict the recurrence, even if the ideas put forth contain a germ of truth. Yet the regularity of the synoptic development (Fig. 4) tempts one to try. Although the incipient signs of European blocking were not evident until fall of 1958, it is conceivable that the unusually large anomalies observed during the winter of 1957–58 (see Fig. 4) may have somehow contained the seeds of future evolution.

Therefore a search was made for winters from 1899–1900 to 1959–60 when the flow patterns bore some resemblance to those of winter 1957–58. Of course, upper-air maps for much of this period are not available and consequently sea-level charts had to be used as substitutes. Fortunately, the correlation between sea-level and mid-tropospheric pressure is fairly high over ocean areas, so that a match at sea level provides some assurance of similarity aloft. In order to make the selection of similar cases objective and still capture the primary feature of the anomalous distribution, namely much stronger than normal north to south geostrophic flow between Scandinavia and Greenland, an index of mean meridional flow between 0° longitude and 40° W longitude along 60° N was computed for all winters from 1899–1900 to 1959–60.[1] Those having a north-south mean flow due to a west-east gradient greater than 7.5 mbs (corresponding to about 200 feet of isobaric topography) were then selected as being roughly analogous to the winter of 1957–58. The following 12 winters (mean of December, January, and February) beginning in December of the indicated years fulfill this criterion: 1899, 1901, 1909, 1914, 1930, 1935, 1950, 1952, 1954, 1955, 1957, 1959.

The mean or composite of the first ten of these winters (excluding the years beyond 1957 which we have discussed) is shown in Fig. 10*a*, in terms both of sea-level pressure and departures from the normal computed for the period 1899–1939 (U.S. Weather Bureau, 1952). As would be surmised from the method of selection, a general similarity in the position and extent of anomaly centers exists between the composite and the map for winter 1957–58 (Fig. 4).

If we now compute composites of seasons *subsequent* to the selected winters we can see if there is a tendency for blocks to arise. It turns out that the subsequent fall composite (Fig. 10*b*) does indeed suggest the onset of a Northern European block—not unlike in fall 1958. (It will be remembered that the autumns showed the blocks most consistently and reflected the decline in precipitation most systematically (see Figs. 1 and 2). It also turns out that the mean of winters subsequent to the selected ones (Fig. 10*c*) reinstates the north-south flow over Northern Europe in a similar fashion to winter 1958–59, perhaps suggesting recurrence of blocking for another year.

The question might arise as to whether the departures from normal shown in Figs. 10*b* and 10*c* are significantly larger than the means of 10

[1] This index is representative of the upper-level (700-mb) north-south flow, since the correlation coefficient between corresponding seasonal sea-level and 700-mb gradients in this area was 0.96 for the five years 1956–60 when good data from both levels were available.

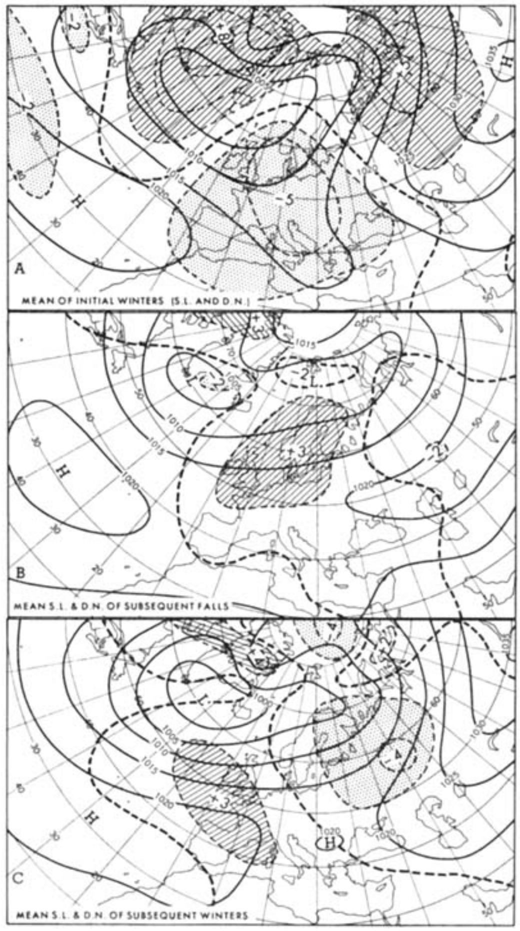


FIG. 10. A. Sea-level means (solid) and isopleths of departure from normal (dashed) for all winters from 1899–1956 when the west-east gradient between 40° W and 0° at 60° N exceeded 7.5 mbs. B. Means and departures of subsequent falls. C. Means and departures of subsequent winters.

arbitrarily chosen maps. Because of the coherence of seasonal mean sea-level pressures in time and space it is impossible to give a conclusive answer to this question, but there is some statistical evidence which lends support to the ideas expressed in the preceding paragraph. Thus for September, October, and November of the years 1899–1960, the standard deviation of monthly mean sea-level pressure over southern Scandinavia is about 5.7 mbs according to maps prepared (but not published) by H. C. Willett. Assuming the coherence between these months reduces the number of independent months to two, the standard deviation of the fall seasons would be about 4 mbs. For a ten-year period (assuming no correlation between years) this would mean a standard deviation of 1.3 mbs, a value which is less than half the 3 mbs observed for the mean of the selected cases. It should further be pointed out that the *pattern* of anomalies for the ten selected years, in which negative areas are found to the east and west of the Scandinavian positive area, is in general agreement with that for the fall of 1958. This should further reduce the possibility of obtaining by chance the ten year anomaly pattern. Similar evidence may be drawn from the pattern of Fig. 9*c* and the winter pattern of 1958–59.

Thus, there is some evidence suggesting that prevailingly strong anomalous north-to-south transport over the North Atlantic and Northern Europe during winter may set in motion a complex chain of events leading to several successive seasons of European blocking. Precisely how this chain operates must be exceedingly complex especially since the anomalous surface water temperature difference between ships Charlie and India were reversed in the winter of 1957–58 relative to that observed in the following spring and summer.

This study may be related to an earlier climatological investigation of cold winters and warm summers at Stockholm in relation to the general circulation (Namias, 1957). Here it was indicated that observed long-period trends in continentality (summer minus winter temperature) are related to the strength of the zonal westerlies at high latitudes in the sense that years of high continentality are associated with prevailingly low index and low continentality with high index. The increased continentality, in turn, is associated with less flow from the Atlantic in winter and summer—both conditions favoring the onset of blocks. In the present study the initial winters (Fig. 10 and also Fig. 4) are primarily of low-index character, favoring increased continentality which to some extent was observed at Stockholm in the average of the 12 years listed above (18.5°C difference between winter and summer as compared to the average of 17.7°C for the remaining 51 of the 63 years 1900–62). Of course, this difference is not statistically significant although it is in the anticipated direction.

Summary

Recurrent and strong blocking activity was observed over northern Europe for several seasons beginning in the latter half of 1958 and continuing through the fall of 1960. This led to a major climatological fluctuation, particularly in pressure and precipitation over much of Scandinavia. Especially noteworthy was the gradual decline in annual precipitation along the west coast of Norway.

The initiation and development of the blocking was studied with the help of mid-tropospheric contour charts and their isopleths of departure from normal. These fields were related to the seasonal precipitation departures.

An attempt was made to explain the physical nature of the blocks and their maintenance. Two possible causes, both acting in concert with the atmospheric circulation, were suggested:

(1) sea-surface temperature anomalies, and
(2) cold-season snow cover over Scandinavia.

The first factor indicated that anomalous sea surface temperature gradients had been established (by the atmospheric circulation) south of Greenland and Iceland in such a way as to encourage differential heating to the overlying air. In this way, direct atmospheric circulations were encouraged (through the thermal wind) favoring enhanced cyclogenesis, stronger than normal southerly wind components and the associated more northward (than normal) motion of cyclones. Inertial effects, operating through barotropic response, then encouraged the development of blocks over Northern Europe. This new pressure distribution again acted to favor the maintenance of the originally produced anomalous sea-surface temperature gradient and also to reduce the cold season snowfall.

The second factor, reduced cold-season snow cover, may have acted in the sense of permitting a strengthened monsoon circulation over Scandinavia during the subsequent warm seasons. This would also favor the development of upper-level anticyclones (blocks).

Finally, some precursory signs of this long period of blocking were sought from the file of sea-level maps since 1899. These data suggested that the process may be initiated by a winter in which much stronger than normal

prevailing north-to-south flow is observed between southern Greenland and southern Scandinavia.

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