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Characteristics of northern hemisphere blocking as determined from a long time series of observational data

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ABSTRACT

30 years of observational 500 mb geopotential height data have been used to assess the characteristics of northern hemisphere blocking situations. A zonal index suitable for identification of blockings is defined and translated into a computer program. Characteristics of blocking situations have been computed and are presented as statistics.

As expected, there are 2 preferred regions for blocking, the Atlantic region and the Pacific region. The results show that the number of days with blocked flow has a maximum over the eastern part of the Atlantic region, while the maximum is found over the western part of the Pacific region. The annual variation shows that there is an extended maximum from February through April in the Atlantic region, while there is a pronounced maximum in January in the Pacific region.

The occurrence of simultaneous blocking in the 2 regions has also been investigated. The results show that there is no preference for a connection.

Investigation of individual blocking situations reveals that the shortest ones are also formed in preferred geographical locations, and are not just random configurations in the changing pattern of waves in the Westerlies. There is a tendency for blocking episodes to seem to be concentrated in certain geographical locations, the longer the duration of the episode. The results also show that long-lasting episodes are notably more frequent in the Atlantic region than in the Pacific.

1. Introduction

Blocking was first noted by Garriott (1904). Numerous synoptic studies of blocking have followed since then. When upper air observations became abundant, several studies of the profound effect of blocking upon the weather and climate appeared in the literature (see, for instance, Namias, 1947; Berggren et al., 1949; Elliot and Smith, 1949; Rex, 1950a, 1950b, 1951). There is as yet no generally accepted theory of the formation, maintenance and decay of blocking. The first theories appeared almost at the same time as the observational studies. Numerous papers on this topic have been published since then. For a review, see, for example, Frederiksen (1982).

The definition of blocking has never been established exactly. The lack of an exact definition is quite natural, as blocking is a complex phenomenon. The most well-known definition of blocking is the criteria established by Rex (1950b). Although Rex's criteria describe the essential features of major blocking situations, many cases of short duration are excluded.

During recent years there has been an increasing interest in the blocking phenomenon. The reason is partly new theories. Parallel to recent theoretical investigations, synoptic studies have been done. White and Clark (1975) studied blockings over the North Pacific. They used monthly mean 700 mb geopotential height and sea level pressure maps to investigate blocking ridge activity over the central North Pacific. Austin (1980) digitized 500 mb geopotential height and sea level pressure synoptic weather maps (at 40 and 60° N at every 10° longitude) to study blocking, and, in particular, the role of planetary waves in the blocking

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phenomenon. Treidl et al. (1981) made a detailed study of blockings during the period 1945–1977. They used more than 23,000 daily hemispheric surface and 500 mb charts for the northern hemisphere and identified all blocks which fulfilled their criteria.

A common feature of all these studies is that synoptic weather maps have been visually inspected in order to identify blockings and to describe their characteristics. Of necessity, the process of identifying blocks using weather maps involves a certain amount of arbitrariness. Rex (1950b) was aware of this problem, and for this reason he introduced his well-known criteria to make the identification procedure as objective as possible. White and Clarke (1975) were not able to determine the growth time of a blocking situation as Rex was able to do. They were able only to determine that it existed for sufficient time to dominate the monthly mean pressure pattern. Treidl et al. (1981) carried out the process of identifying blocks three times; twice independently and the third time on a comparative basis.

Despite the attempts to avoid subjectivity it is clear that none of these investigations was carried in a completely objective manner. Recently Dole (1978) examined whether certain quantitative methods could be useful for analyzing the structure and time evolution of the major features associated with blocking situations. He identified blocking events as persistent departures from the climatological mean height field. Charney et al. (1981) compared barotropic blocking theory with observations. Following Dole (1978) they identified blocking events as large 500 mb geopotential height anomalies lasting for a sufficient length of time.

The aim of the present paper is to assess characteristics of blocking situations in an objective manner on the basis of certain criteria, developed from the kinematic properties of the flow. The criteria are of the same kind as those set down by Rex (1950b). A long time series of daily 500 mb geopotential height data has been used as a data base. Criteria suitable for identification of blockings were translated into a computer program. Characteristics of blocking situations have been computed and are presented as statistics. The intention is not to explain why they exist or how they are formed, but merely to assess their characteristics.

The paper is organized as follows. In Section 2 the data set is described. Section 3 is devoted to a discussion of the criteria we will use to identify blocks. In Section 4 we focus our intention on the frequency of blocks as a function of longitude, i.e., how often the flow is blocked at a specific longitude. Blocks sometimes occur at two different geographical areas simultaneously. The occurrence of simultaneous blocks is discussed in Section 5. Characteristics of blocking episodes, like the number of cases in certain geographical areas, the duration, the spatial extent etc., are discussed in Section 6. Concluding remarks are found in Section 7.

2. Data

The ultimate source of the data used in this study is the U.S. National Meteorological Center (NMC) historical maps. The data are archived at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, U.S.A. (see Jenne, 1975). 30 years of daily 12 GMT 500 mb geopotential height data from January 1, 1950 through December 31, 1979 were used. Data from less than 1% of the days were missing either because they were not in the original set or because they were found to be obviously erroneous. The available data were first interpolated from the NMC octagon to a 5 × 10° latitude–longitude grid from 20° N–85° N. A 16-point interpolation routine available from Roy Jenne at NCAR was used.

These data were then Fourier analyzed along each latitude line and the first 18 wave numbers were retained. For each available day, and at 14 latitudes, zonal means and cosine and sine coefficients of these 18 zonal waves of geopotential height were obtained. The geopotential height at some latitude is thus given by

$$Z(\lambda) = |Z| + \sum_{m=1}^{18} a_m \cos m\lambda + b_m \sin m\lambda, \qquad (1)$$

where λ is the longitude and m the zonal wave number. The square brackets around the first term on the right represent a zonal mean. The data were made available to us in form of the zonal means and the sine and the cosine coefficients.

3. The choice of the criteria

The most well-known definition of blocking is that of Rex (1950b). He used daily synoptic 3000 dynamic-meter (constant level) and 500 mb charts as a data base, and identified blockings as synoptic situations with pressure or contour patterns having the following characteristics:

(a) the basic westerly current must split into two branches;
(b) each branch current must transport an appreciable mass;
(c) the double-jet system must extend over at least 45° of longitude;
(d) a sharp transition in the westerlies from a zonal type flow upstream to a meridional type downstream must be observed across the current split;
(e) the pattern must persist with recognizable continuity for at least 10 days.

The problem with the use of these (or similar) criteria, in an investigation such as ours, is that it is difficult to translate them into a computer program. White and Clark (1975) used essentially the same kind of criteria as Rex did, although they had to alter them somewhat since they used monthly mean maps as a data base. Austin (1980) also used criteria of the same kind as Rex. Treidl et al. (1981) identified blocking highs as highs with closed isopleths present simultaneously in the surface and 500 mb charts, splitting the westerly current aloft into two branches. They also required that the latitude belt where the anticyclone occurred should be northwards of 30° N, and that its minimum duration should be 5 days. Charney et al. (1981) identified blocking events by persistence of an anomaly greater than + 200 gpm for 7 days or more.

For a long time, a measure of the strength of the upper westerlies, a so-called zonal index, has been used to study the irregular quasi-cyclic changes (with periods of 3 to 8 weeks) of the global circulation. These changes are known as the index cycle. Namias and Clapp (1951) used the surface pressure difference between 35° and 55° N as zonal index. A similar index turned out to be the most convenient for our purpose. As blocking occurs at preferred geographical locations, we decided to compute the index for every 10° longitude. There exist several characteristic types of waves at the 500 mb level in connection with blocking. Some of them are shown in Berggren et al. (1949) and Palmén and Newton (1969). Austin (1980) and Treidl et al. (1981) found that in typical northern hemisphere blocking situations, a ridge, or

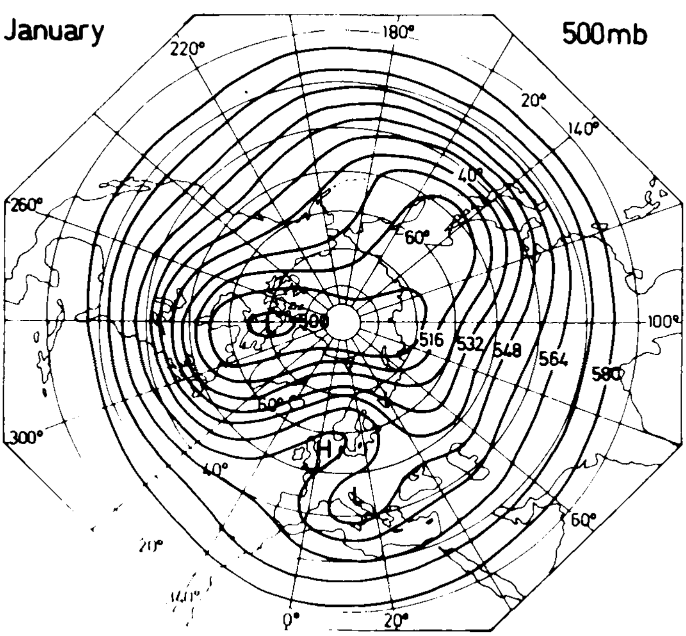

Fig. 1. Composite 500 mb chart made up from all January days during 1950–1979 when $Z_{40°N}-Z_{60°N} < 0$ at 0° longitude.

a high-pressure cell is found near 60° N and a low-pressure cell close to 40° N. Accordingly, we decided to use as index the height difference between 40° and 60° N, that is

$$I(\lambda) = Z_{40^\circ \mathrm{N}}(\lambda) - Z_{60^\circ \mathrm{N}}(\lambda), \quad (2)$$

where $I(\lambda)$ is the index at longitude λ, and Z the 500 mb geopotential height evaluated from (1). $I(\lambda)$ was computed for every 10° longitude. To demonstrate that $I(\lambda)$ is a useful tool for the identification of blocks, we present Fig. 1, which is a composite map made-up from all January days 1950–1979 when $I(0^\circ) < 0$, that is when the index is less than zero at the Greenwich meridian. The flow shows the well-known characteristics of a blocking situation. There is a high-pressure cell to the north of a low-pressure cell, the flow is split into two branches, each of them transporting appreciable mass, and the longitudinal extent is approximately 50°. It should be emphasized that some of these January cases would not have been characterized as blocking situations by most meteorologists, primarily because they did not last long enough. Nevertheless, since we want to rely mostly on objective methods, we decided to compute statistics for the occurrence of a simple blocking criterion. As we shall see in Section 6, most of the cases where $I < 0$ come from the long-lasting blocking episodes. Furthermore, in Section 4 we develop a more discriminating criterion. For the lack of a more precise name we shall refer to the phenomenon described by our statistics as blocks or blockings, being well aware that we differ from most other writers in the definition of these words.

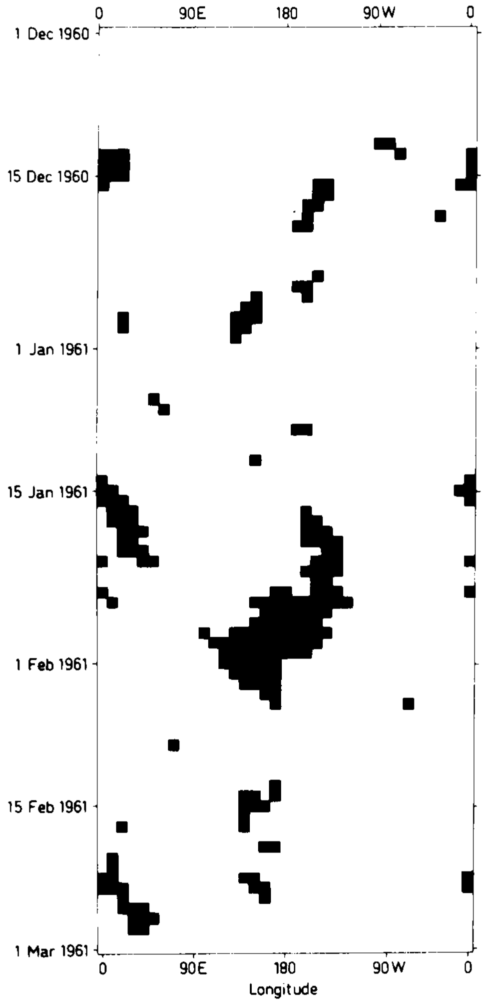

Fig. 2. Hovmöller diagram showing blocking episodes December 1, 1960 through March 1, 1961. A black box indicates a negative index (cf eq. (2)).

4. Frequency of blocking as a function of longitude

In this section we examine the frequency of blocked 500 mb flow as a function of longitude. The index defined in (2) has been computed for the whole period. A convenient way to study the index series is to have it printed in a two-dimensional array, a Hovmöller diagram with longitude running from left to right and the date running downwards. The blocks thereby appear as more-or-less complex areas with negative index values. A similar representation has been used by Dole (1978). Fig. 2 shows a section (from December 1, 1960 through March 1, 1961) of the Hovmöller diagram, where the numbers have been removed while the negative differences are indicated by black boxes. As foreseen in Section 3, there are several occasions when one isolated negative value shows up in the diagram. These single negative values do not represent blocked flow, and therefore they should not be included in the statistics presented in Sections 4 and 5. Accordingly, we decided that if the index values for a specific day and a specific longitude should be included in the statistics, the following conditions should be fulfilled:

$$I(\lambda) < 0, \quad (3a)$$

$$(I(\lambda - 10^\circ) + I(\lambda) + I(\lambda + 10^\circ))/3 < 0. \quad (3b)$$

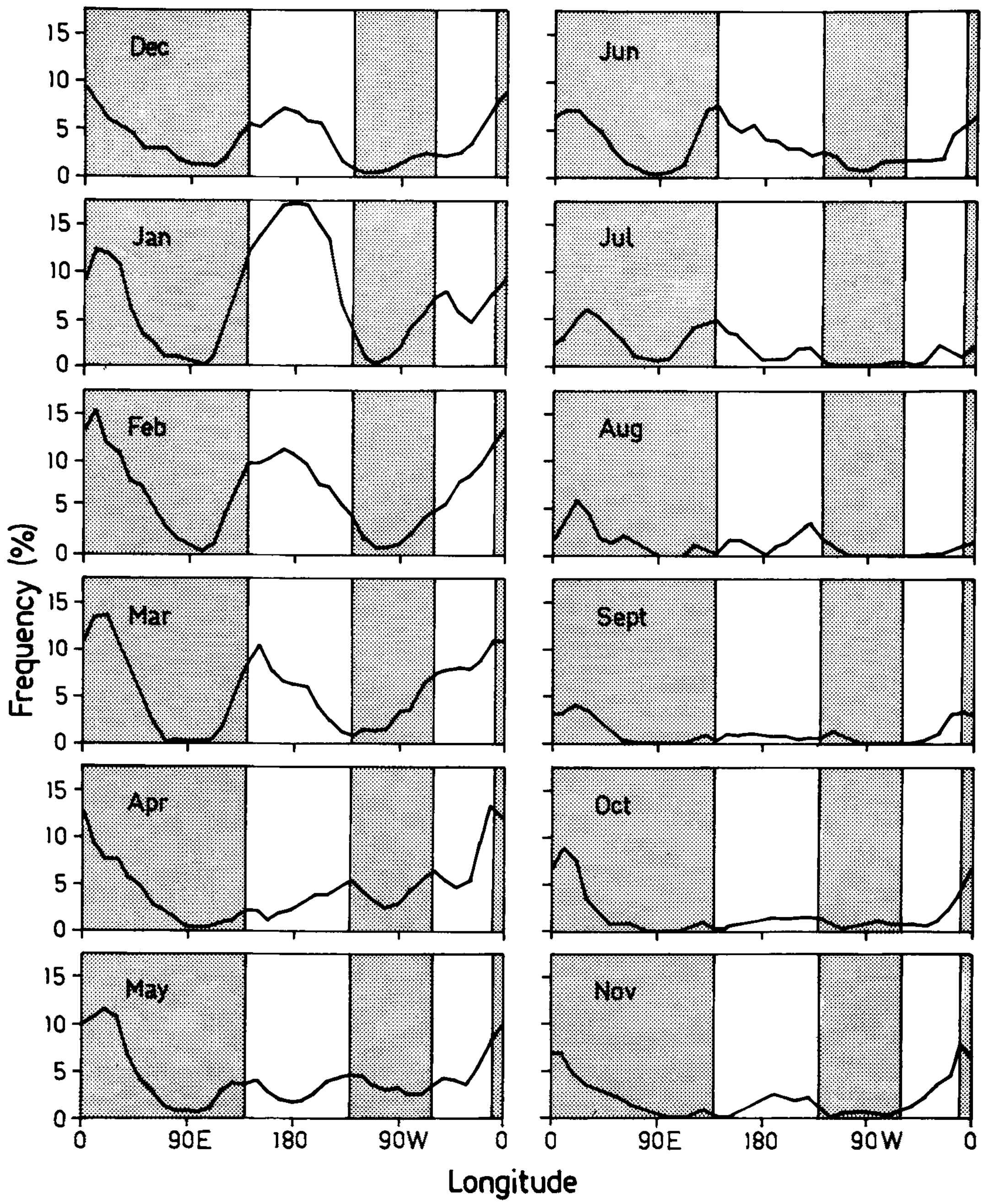

Fig. 3. Longitudinal variation of frequency of blocked 500-mb flow (%). Continents are shaded.

The second condition means that the mean value of the index over 30° longitudes should be less than zero. In this way we make sure that in those cases that are included, blocked flow will prevail over an area having a considerable longitudinal extent. In Section 6 we investigate the longitudinal extent of

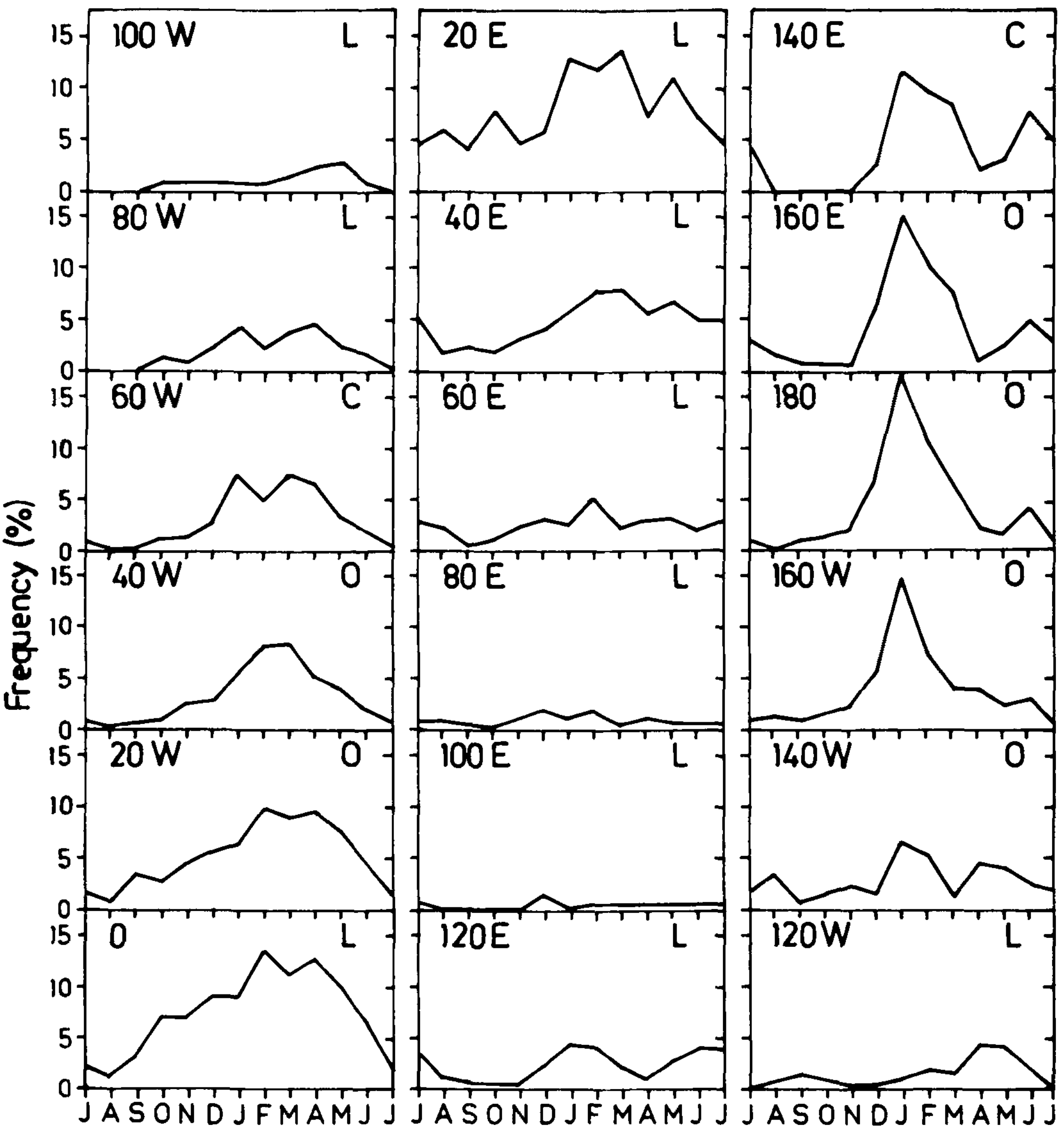

Fig. 4. Annual variation of frequency of blocked 500 mb flow for every 20° longitude. The letter in the upper right corner indicates the nature of the earth's surface L = land, O = ocean, C = coast.

negative index values when they appeared for only 1 day. In 85% of the cases it is only 10°, which means that they are not included in the statistics.

Taking (3) into account we computed the frequency of blocked 500 mb flow as a function of longitude and time. The results are shown in Fig. 3 for each 10° of longitude and each month. They are also plotted in Fig. 4, which shows the annual variation of frequency of blocked flow for every 20° of longitude. The values in Figs. 3 and 4 are 30-year mean values of the frequency (in %), which means that, for instance, the curve for January has been obtained by dividing the total number of days with blocked flow in January at a particular longitude with the total number of observations in January. We notice marked seasonal and longitudinal variations. During the winter there are two preferred regions for blocked flow, namely NE

Atlantic and the Pacific. The maximum values for the Atlantic region are approximately 12%. They are found just east of the Greenwich meridian (Fig. 3) and they occur from February through April. In the Pacific region the number of days with blocked flow varies considerably during the winter, with a peak value of 17% in January. There is a clear tendency for the number of days with blocked flow to have a maximum over the *eastern* part of the Atlantic region, the maximum being found over the *western* part of the Pacific region. To our knowledge this has not been noticed before. Rex computed the geographical distribution of block occurrence for 82 Atlantic and 30 Pacific cases. He found for the Atlantic region that there was a maximum of block initiation between 5° and 15° W. For the Pacific region the maximum was between 145° and 155° W. This does not contradict our results for the Atlantic region as he defined the longitudinal position of a block as the longitude of the westerly current split. In the Pacific region his data base was unreliable as the analysis was uncertain, or missing, over the western Pacific and eastern Asiatic continent. This is, most likely, the reason why Rex found that there are more blocked days over the eastern Pacific than over the western. As our data comprise the 30 years from 1950 through 1979 they should be more reliable over the western Pacific than the data Rex used. White and Clark (1975) found that the blocking ridge over the central North Pacific is usually centered near 170° W in the center of the North Pacific basin and has a typical wave length of 7000 km, which is the width of the North Pacific at 40° N. Treidl et al. (1981) plotted frequencies of block starts and block endings as a function of longitude. For block starts they found frequency peaks at 10° W and 30–40° E (Atlantic region) and 120–160° W (Pacific region). Block endings had frequency peaks at 0–10° E and 30–40° E (Atlantic region) and 170–180° W (Pacific region). They emphasized that for the Pacific region, the frequency peaks were difficult to distinguish from the noise, which means that they are unreliable for the Pacific region. We may thus conclude, that although Rex (1950b), White and Clark (1975) and Treidl et al. (1981) did not derive their frequencies in the same way, their results seem to agree with ours. Charney et al. (1981) used criteria of a different kind (500 mb geopotential height persistent positive anomalies) and data from only 15 winter seasons (1963–1977). Nevertheless, it is of interest to note that they found two major preferred locations for persistent positive anomalies, between 180° and 130° W and 55° and 0° W. The area over the Atlantic is displaced towards the west compared to what Rex (1950b) found in agreement with our results.

The annual variation is also different for the 2 regions. In the Atlantic region there is an extended maximum from February through April. The minimum occurs in late summer. Still blocked flow is found in as many as 5% of the summer days over western and central Europe. Over the Atlantic ocean there are very few days with blocked flow during the summer. In the Pacific most of the days with blocked flow occur during January. During the following months the number of blocked days is reduced considerably. There is, however, a secondary maximum in June. The secondary maximum is most pronounced over the central and western parts of the Pacific. From July through November the frequency of blocked flow over the Pacific region is very low.

The annual mean shown in Fig. 8a (below) reveals that, on the average, there are more days with blocked 500 mb flow over the Atlantic region than over the Pacific. The maximum for the Atlantic region, 8%, is found at 10° E. Over the Pacific there is an extended maximum of almost 5% over the western and middle part of the Pacific.

5. Simultaneous blocking

We have already seen that blocking has a maximum frequency in two distinct locations which we have called the Atlantic and the Pacific region. It has been suggested that there might be a connection between the occurrence of blocking in the 2 regions, on the grounds that a common global source of the blocking phenomenon may tend to produce blocking in both areas simultaneously. Another possibility is that occurrence of blocking in one region would trigger blocking in the other, or inversely that an existing blocking in one region could prevent the creation of blocks in the other.

As we shall see presently, there are a considerable number of days when the 500 mb westerlies are blocked simultaneously in the Atlantic and the Pacific. In Fig. 5 the number of days with blocked 500 mb flow is plotted as a % of the total number of days, separately for the Atlantic and the Pacific regions (continuous lines marked A and P). In this section of the present study, the Atlantic region is defined as the area between 60° W and 50° E and the Pacific region the area between 130° E and 130° W. A comparison with Fig. 3 in the paper by Rex (1950b) shows very good agreement for the Atlantic region. For the Pacific region his smooth curve does not have the 2 maxima we have found (in January and June). However, the monthly values plotted in his figure show a February maximum, followed by a minimum in March and a new maximum in April/May. Therefore there seems to be some support for our 2 maxima even in Rex's results.

The broken line in Fig. 5 is the corresponding

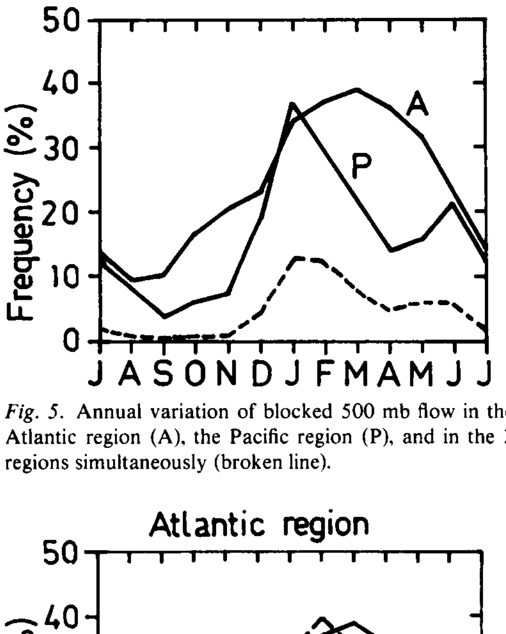

Fig. 5. Annual variation of blocked 500 mb flow in the Atlantic region (A), the Pacific region (P), and in the 2 regions simultaneously (broken line).

frequency of simultaneous blocking, meaning that the criterion (3) is fulfilled in at least one place in the Atlantic and the Pacific region at the same date. The curve shows a January maximum of 13%, but very low frequency of occurrence in the period from July to November. Now the question is: does this reflect a preference for simultaneous blocking, or is it just a consequence of the fact that blocking is frequent in January, but rare in summer and early fall? To answer this question in a fairly simple manner we have in Fig. 6a entered the frequency of blocking in the Atlantic region, together with the *conditional* frequency. By this we mean the number of days with simultaneous blocking divided by the number of days with blocking in the Pacific, reproduced as a % in the diagram. Similarly, Fig. 6b shows the corresponding curves for the Pacific region.

As a *null hypothesis* we postulate that the frequency of simultaneous blocking in part of the data (i.e. Atlantic or Pacific blocking) is the same as in the whole collection. Accordingly, the curves in Figs. 6a, b should coincide, if there is no statistical dependence. Of course, allowances must be made for errors due to the smallness of the samples, leading to differences of a random nature. Therefore, it is not surprising that the curves deviate most where the total frequency of blocking is low, that is from August through November. In the other parts of the curves, the fit is very good, apart from the Spring months in Fig. 6a. Again, this is probably connected with the fact that the frequency of blocking in the Pacific is low during

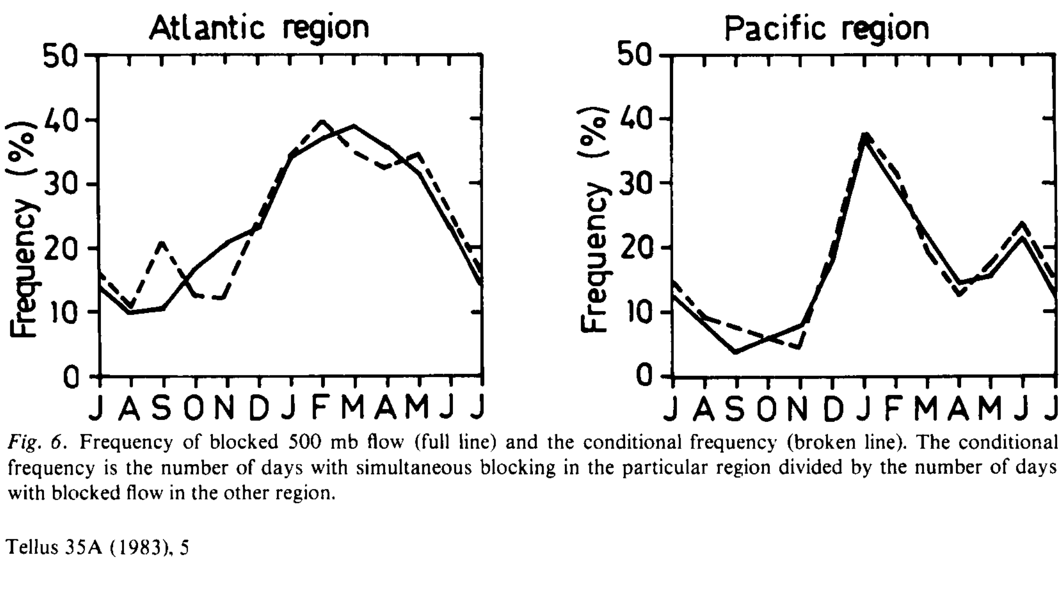

Fig. 6. Frequency of blocked 500 mb flow (full line) and the conditional frequency (broken line). The conditional frequency is the number of days with simultaneous blocking in the particular region divided by the number of days with blocked flow in the other region.

this period. Here we will make no attempt to formulate tests for statistical significance of the observed differences, because of the difficulties in determining the number of degrees of freedom in data which are so highly autocorrelated. However, we feel that the results point to the conclusion that there is no preference for simultaneous blocking in the 2 regions.

There is a possibility, not really covered by the preceding investigation, that blocking in either the Atlantic or the Pacific region could trigger a blocking in the other region, and that this second blocking does not start at the same time as the first, but several days later. To throw some light upon this possibility we have prepared Fig. 7, which shows the frequency of blocking in January for each of the 30 years, and separately for the Atlantic and the Pacific region. A connection between blocking in the 2 regions should show up in the 2 block diagrams as a tendency to parallel variations. This should also be the case if there were a time lag. However, visual inspection of the 2 diagrams reveals no such connection. In fact, the correlation coefficient comes out as low as 0.05.

Another outstanding feature of Fig. 7 is the variability of the frequency of blocking from one year to another. Spectacular in this respect is 1963 when the blocking persisted for almost the whole month of January in the Pacific, while there was no blocking whatsoever the following year. The mean frequency is almost the same for the 2 regions (cf. Fig. 5). Actually, this is the reason why we picked this specific month for the comparison.

6. Blocking episodes

Up to this point we have studied only the statistics of the blocking criterion (3), its monthly and annual variations and its relative frequency at different longitudes. We have paid little attention to the fact that the cases of blocking so defined have a tendency to cluster in space (longitude) and time, so as to form what we shall call blocking episodes. In most previous studies, the main effort has been on the identification of such blocking episodes. Therefore, in order to compare our results with those reported by others, and for other reasons to become clear later, we shall now proceed to derive some statistics for the episodes as well.

The evolution of episodes may be followed on a Hovmöller diagram (Fig. 2). However, in order to derive the statistics effectively, we have written a computer program which recognizes an episode as

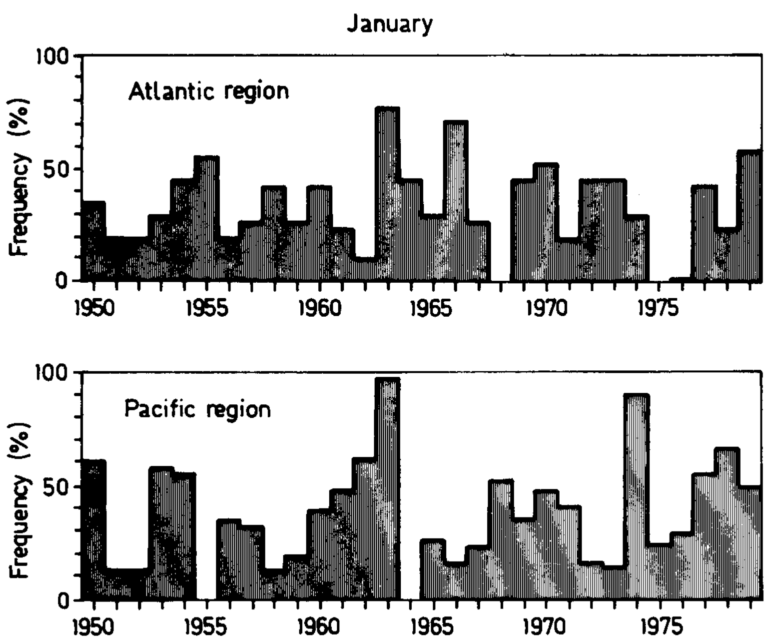

Fig. 7. Annual frequencies of blocked 500 mb flow in January for 1950–1979.

a collection of elements in a 2-dimensional array (λ, t), each satisfying (3a) and having at least one other element in the episode as "neighbour", either in the λ, the t, or the "diagonal" direction. The episode may then be described by the date and longitude of its beginning, its duration in days, and for each day its longitudinal extension. This definition leaves out single isolated elements satisfying (3a). For reasons to become clear later, we also include one day blocking episodes in the statistics of the episodes. Note that only the criterion (3a) is used in this investigation, not (3b).

A total of 3046 blocking episodes were located by the program, 1696 in the Atlantic region and 1350 in the Pacific. In this connection an episode is defined as belonging to the Atlantic region if it starts between 90° E and 90° W, including these 2 longitudes. The 2 boundaries have been chosen somewhat arbitrarily. However, since according to Fig. 3, they are both positioned in areas where the frequency of blocking is low, the statistics are not very sensitive to the precise location.

We shall now discuss the frequency distribution of the episodes with regard to their duration. One third of them (1117) lasted for only 1 day and 85% of these 1-day blocking episodes occurred at only one longitudinal location. The distribution with respect to longitude of these 1-day episodes is shown in Fig. 8b, while Fig. 8a shows the yearly mean of the frequencies pictured in Fig. 3. Note that Fig. 8a is based on both criteria in (3), where (3b) in effect eliminates the 1-day episodes because of their small longitudinal extension. The 1-day episodes seem to be more evenly distributed around the globe than the total mass of blocks. However, some of the features in Fig. 8a are undoubtedly reflected in Fig. 8b. This is notably the case with the maxima over Western Europe and Western Pacific. This seems to indicate that these "incidental" blockings are indeed also formed in preferred geographical locations, and are not just random configurations in the changing pattern of waves in the Westerlies.

More information about this circumstance may be derived from Figs. 8c–d which show frequency diagrams for episodes of 5 to 9 days duration (8c) and 10 days or more (8d). Note that Figs. 8b–d have different scales. Comparison of Figs. 8b–d clearly shows that the longer the duration of the episodes, the more they seem to be concentrated in certain geographical locations.

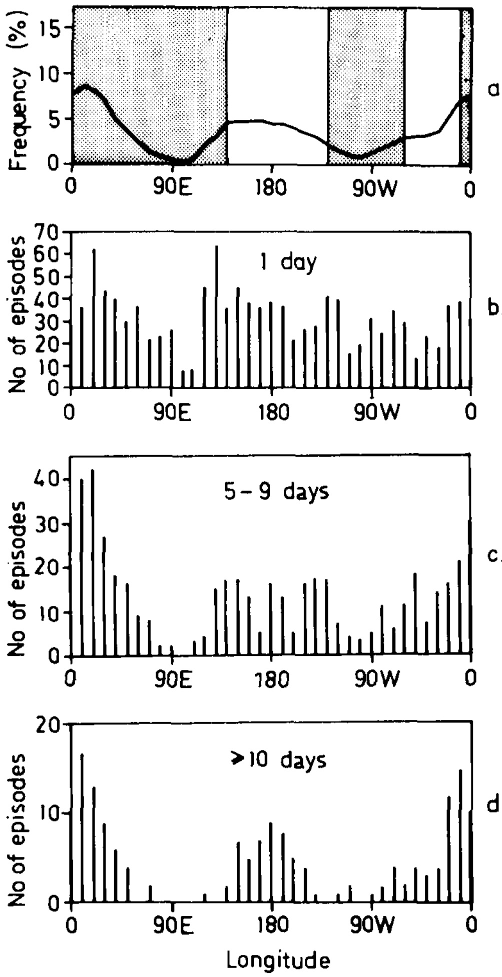

Fig. 8. (a) Longitudinal variation of blocked 500-mb flow averaged over the whole year. Continents are shaded. (b–d) Frequency distribution of blocking episodes as a function of longitude, 1950–1979. Duration 1 day (b), 5–9 days (c) and >10 days (d).

Treidl et al. (1981) considered only episodes lasting for 5 days or more, and show a frequency diagram for these episodes in relation to the duration (their Fig. 8). Based on our investigation, we have prepared similar diagrams, one for the Atlantic and one for the Pacific region (Fig. 9). The most striking difference is that while they found the episodes lasting for 8 days to be the most frequent, we find this to be the case for episodes of 5 days duration (actually, as revealed by Table 1, there is a steady increase in frequency for still shorter episodes). The period used by Treidl et al. is not

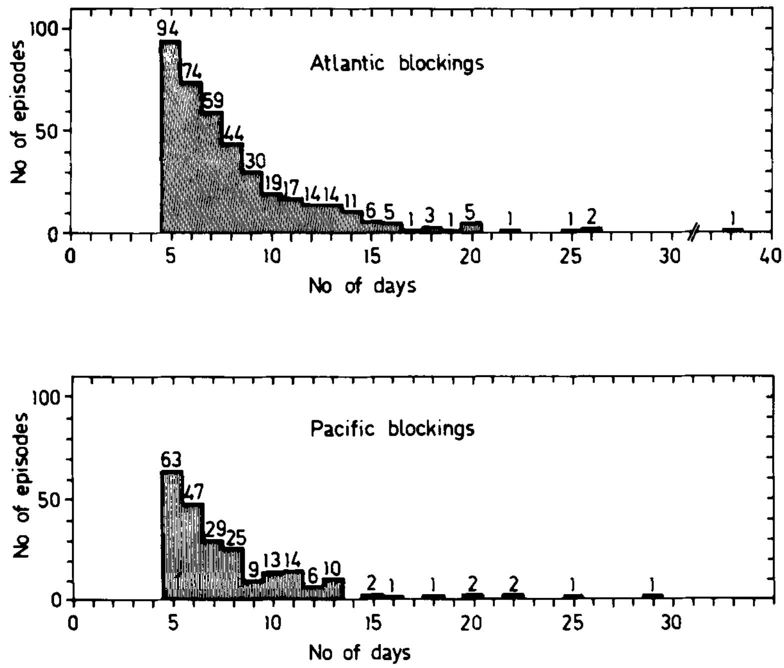

Fig. 9. Frequency distribution of blocking episodes as a function of duration, 1950–1979. Episodes lasting for less than 5 days are excluded.

Table 1 *Frequency distribution for episode duration for the Atlantic (A) and the Pacific (P) regions, together with the ratio of these numbers*

	Duration (days)			
Region	1	2–4	5–7	10
A	576	718	301	101
P	541	583	173	53
P/A	0.94	0.81	0.57	0.52

identical to ours, since they used the 33 years from 1945 to 1977. However, the major reason for the difference is undoubtedly to be found in the method by which blocking is identified. Since their method is partly subjective we are not able to point out the exact cause.

In other respects, the diagrams are quite similar, and also the total number of cases agree quite well (their 664 cases compared to our 628, lasting for 5 days or more).

Visual inspection of Fig. 9 indicates that long-lasting episodes are notably more frequent in the Atlantic region than in the Pacific. To clarify this circumstance we have prepared Table 1, which shows the number of episodes in the Atlantic and in the Pacific for different durations of the episodes. Clearly, the relative frequency in the 2 regions changes significantly as the duration of the episodes increases. Thus it seems that the Atlantic region has a much greater ability to support long-lasting episodes than the Pacific.

For the episodes which lasted for 5 days or more, we have also computed frequency diagrams for the maximum width, that is the largest extension in the longitudinal direction during the evolution of an episode (Fig. 10). Clearly, there is no significant difference between the Atlantic and Pacific regions. The diagrams display a remarkable variability of the width; from 10° to 120°. The most frequent width is 30°. However, 40°, 50° and 60° are also frequent and together contain almost half of the total number of cases.

We have looked into the displacement of the episodes during their evolution. A regression line in (λ, t) space was computed for each episode, and the inclination used to derive a mean displacement velocity. In Table 2 the episodes have been grouped

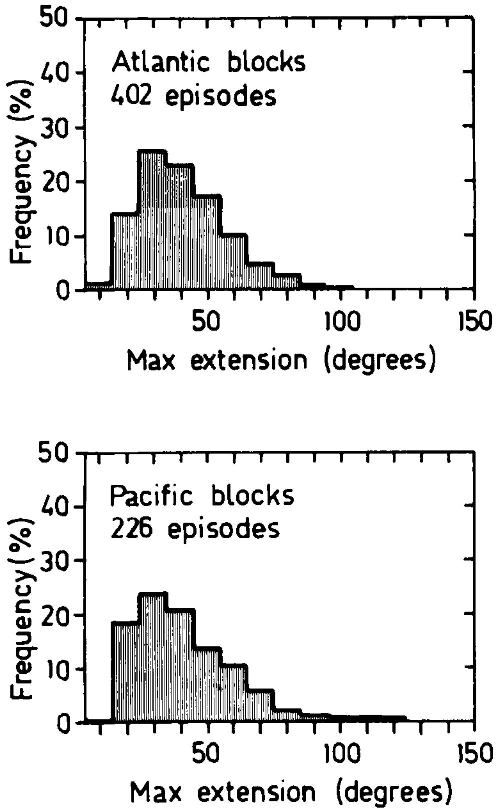

Fig. 10. Frequency distribution of the maximum longitudinal extent of blocking episodes which lasted for 5 days or more.

into 2 categories, those moving towards the west and those moving towards the east. Blocks without a mean velocity are not included. Clearly, episodes of short duration tend to move towards the east, while long-lasting episodes move towards the west. This is in agreement with what Rex (1950b) found. His data showed that Atlantic blocks have a tendency for displacement towards the west during the first 7 days. (Note that he only considered episodes lasting longer than 10 days.) From the 14th day he noted a tendency that the block moved towards the east.

7. Conclusions

Blocking is a unique phenomenon, and has accordingly attracted much attention from meteorologists. However, like many other structures in synoptic meteorology, it is not easy to define rigorously. There is an element of subjectivity in all the definitions presented so far, and the present paper is no exception in this respect. However, in our case the subjectivity is connected with the assessment of the criteria for the occurrence of blocking. Once these criteria have been established, the determination of where and when a blocking occurs, may be carried in an objective manner. We believe that this is the most satisfactory method. However, we have tried to demonstrate that the statistics of the blocking situations recognized by our criteria, are in reasonable agreement with earlier studies.

The frequency of blocked Westerlies as a function of longitude and time of year has been known for some time in its broad features. We think that we have been able to establish these statistics more rigorously and in greater detail. Blocks are most frequent over Western Europe, and over the Central or Western Pacific, depending on the time of the year. There does not seem to be any connection between occurrence of blocked flow

Table 2. *Frequency distribution of the block displacement grouped into 2 categories, those displaced towards the west and those towards the east, and the relative frequency of eastward-moving blocks (as a %)*

	Displacement (no. of episodes)		
Duration (days)	Towards the west N_W	Towards the east N_E	$\frac{N_E}{N_E + N_W}$
2	71	349	0.83
3	80	237	0.75
4	78	183	0.70
5	65	79	0.55
6	47	70	0.60
7	39	49	0.56
8	37	32	0.46
9	23	16	0.41
10	20	12	0.37
11	19	12	0.39
12	12	8	0.40
13	15	9	0.37
14	9	2	0.18
15	7	1	0.13
16	5	1	0.17

in these 2 regions. The European maximum of occurrence extends through the winter and early spring, while 2 maxima show up in the Pacific; one in January, and another, less pronounced, in June.

We have also tried to look upon blocking as a more-or-less continuous phenomenon in space and time, and have thus been led to study what we have called blocking episodes, their duration, longitudinal extension and frequency. Most episodes of short duration move towards the east, and the long-lasting episodes towards the west. Another interesting property of the episodes is that those having the longest duration seem to be more concentrated at certain longitudes, while the shorter episodes have a more scattered appearance. In this connection it is interesting to note that the eigenfunctions in 3-dimensional baroclinic instability problems evidently may take the form of dipoles with lows to the south and highs to the north (Frederiksen, 1982). Furthermore, they occur in certain geographical locations depending on the unperturbated wind and temperature fields. It is tempting to suggest that such phenomena are responsible for the majority of episodes having short duration, the long-lasting episodes being caused by the additional influence of forcings tied to the property of the earth's surface.

Although we have paid attention to existing theories for the blocking phenomenon while working on this investigation, the intention has been basically a statistical study. It is hoped that future theoretical work will benefit from our results.

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