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

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SUMMARY

A time series of 500 mb geopotential heights has been used to assess characteristics of southern hemisphere
blocking. A zonal index similar to the index used in an analogous study of northern hemisphere blocking has
been used. Characteristics of blocking situations have been computed with a simple algorithm, which has been
programmed, and are presented as statistics.

We found one preferred region for blocking action: the Australian–New Zealand region. Two other
regions where blocks occur are the Atlantic east of South America, and the Indian Ocean south-east of South
Africa. The number of days with blocked flow is considerably less over the Atlantic and the Indian Ocean than
in the Australian–New Zealand region. The annual variation shows two maxima: one peak value of 19% in
April and one extended maximum of c. 20% during June–August in the Australian–New Zealand region.
There is no clear indication of a seasonal variation in the Atlantic and the Indian Ocean region.

Investigation of individual blocking episodes reveals that the majority of the blocks have a mean eastward
velocity, although the longer they last the more of them are westward-moving. Longlasting episodes are almost
exclusively found in the Australian region.

1. INTRODUCTION

Northern hemisphere blocking is a well-documented phenomenon and has been
studied extensively. Several studies used methods similar to those of Rex (1950); that
is, characteristics of blocking situations were assessed by identifying blocks as synoptic
situations with pressure or contour patterns fulfilling certain criteria focusing on the
kinematic properties of the flow. A common feature of most of these studies is that
synoptic weather maps have been inspected visually to identify blockings and to describe
their characteristics. The work by Lejenäs and Økland (1983), which belongs to this
category, is partly an exception. They used criteria of the kind set down by Rex, but the
determination of where and when a blocking occurs was made in an objective way by
translating the criteria into a computer program.

Several recent studies of blocking have used the method suggested by Dole (1978,
1982). He identified blocking episodes as persistent positive anomalies from the
climatological 500 mb geopotential height field, lasting for a sufficient length of time.

The first important study of southern hemisphere blocking was made by van Loon
(1956). He used five years of synoptic charts, from 1 July 1950 through 30 June 1955.
The investigation did not include the region between 85° and 150°W, because no data
were available for that region. Taljaard (1972) reviewed the synoptic characteristics of
southern hemisphere blocking anticyclones. A detailed study of blocking in the Australian
region was made by Wright (1974). Wright used six years of mean sea level and 500 mb
analyses for the period 1966 to 1971 as a data base. Recently, Coughlan (1983) reviewed
and examined statistics for blocking action in both hemispheres.

The above studies made use of criteria focusing on the kinematic properties of the
flow, that is, criteria similar to those of Rex (1950). Mo (1983) and Trenberth and
Swanson (1983), using eight years of data from May 1972 through November 1980,
described some aspects of blockings and persistent anomalies in the southern hemisphere
using the method introduced by Dole (1982).

The aim of the present paper is to assess characteristics of southern hemisphere
blocking situations in an objective manner using the same kind of criteria, developed
from the kinematic properties of the flow, as Lejenäs and Økland (1983). That paper

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will hereafter be referred to as LO. The intention is also to compare characteristics of northern and southern hemisphere blocking situations. A time series of daily 500 mb geopotential heights has been used as a data base. Characteristics of southern hemisphere blocking situations have been computed with a computer program and are presented as statistics. By using the same computer program as in LO, we are able to compare characteristics of blockings in the two hemispheres in a consistent manner. Finally it should be emphasized that we will not try to explain why blockings exist or how they are formed.

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 study how often the flow is blocked at a specific longitude. Characteristics of blocking episodes, like the number of cases in certain geographical areas, the duration, the displacement etc., are discussed in section 5. Concluding remarks are found in section 6.

2. Data

The source of the data used in this study is the Australian data set archived at the National Center for Atmospheric Research (NCAR). Eight years of 23 GMT 500 mb geopotential height analyses from 24 April 1972 through 30 November 1980 were used. Data from less than 1% of the days were missing in the original set. The original Australian analyses are arranged on a $47 \times 47$ grid with a horizontal resolution of 507 km at 60°S. The grid covers the southern hemisphere south of 0-9°S. The analysis procedure includes a model-generated first guess, which is updated objectively based on available observations. Some subjective, or manual, intervention, motivated primarily by satellite information, was also used. A description of the analysis method can be found in Gauntlett et al. (1972).

The available data were first interpolated to a $5 \times 10^°$ latitude–longitude grid from 20°S to 85°S. These data were then Fourier analysed along each latitude line and the first 18 wavenumbers 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

$$z(\lambda) = [z] + \sum_{m=1}^{18} a_m \cos m\lambda + b_m \sin m\lambda$$

(1)

where $\lambda$ is the longitude and $m$ the zonal wavenumber. Square brackets represent a zonal mean. Data for missing days were obtained by a linear interpolation in time of the geopotential heights given by (1). The data were made available to us as zonal means and the sine and cosine coefficients.

3. The criteria for identifying blocks

As stated in the introduction, our intention is to use the same kind of criteria for identifying blocks as in LO. They used criteria of the same kind as those of Rex (1950), but to avoid the arbitrariness that by necessity is involved in the process of identifying blocks using weather maps, they used a simple algorithm, which was programmed, and defined an index suitable for the identification of blocks. They used as index the 500 mb geopotential height difference between 40° and 60°N. The index was computed for every 10° of longitude. When blocking occurs in a specific region, the index is negative in that region. The use of this kind of index implies that the latitudes for the ridge, or the high pressure cell, and the accompanying low pressure cell (if any) have to be specified.
Much attention has been devoted to blockings in the Australian region, because southern hemisphere blocking is most frequent there. Taljaard (1972) plotted the daily positions of blocking highs at sea level, and simultaneous 500mb cut-off lows in the western Pacific during July to September, 1957 and 1958. He found that southern hemisphere blocks on the average are located in lower middle latitudes, in contrast to the higher middle latitude blocks of the northern hemisphere. Most of the sea level blocking anticyclones were centred between 42° and 48°S, but some were found between 50° and 60°S. The 500mb lows were found mainly between 30° and 40°S. Langford (1960), using maps for nine years, found the greatest concentrations of sea level blocking anticyclones in July between 47° and 51°S at 160°E. Wright (1974) tabulated the distribution of average cyclonicity and anticyclonicity per blocking occurrence over the Australian region. His results can also be found in Coughlan (1983), who reviewed existing statistics of blocking action in both hemispheres. The results were similar to those of Taljaard (1972) and Langford (1960). Over Australia, the Tasman Sea and the Western Pacific most cut-off cyclones were found between 30° and 40°S, and most blocking anticyclones between 40° and 50°S. Over the eastern Indian Ocean, however, Wright found that the distribution of average surface anticyclonicity per blocking occurrence had a maximum between 35° and 40°S. The latitudes for the surface cyclonicity per blocking occurrence were about the same as for the other regions. Summarizing the data of Wright, Coughlan concluded that the mean latitude of the blocking high is in the vicinity of 45°S, being slightly polewards of this latitude for the Australasian region, and slightly equatorwards in the eastern Indian Ocean.

Blocking anticyclones and cut-off lows occur also outside the Australian region. Van Loon (1956) showed that they are also present over the Scotia Sea, east of the southern tip of South America, and in the vicinity of Marion and Crozet Islands, south-east of South Africa. Over South America the latitude of cut-off systems is usually between 25° and 35°S (Taljaard 1972). No statistics are available on the preferred latitudes for blocking highs east of South America and east of South Africa. Coughlan (1983), from casual inspection of a number of blocking situations in these regions, concluded that the favoured latitudes of blocking highs are further equatorwards than in the northern hemisphere. The sequence of anomaly maps at 1000 mb for a prolonged blocking episode during winter (June–July) 1973 in Trenberth and Swanson (1983) indicates that sea level blocking anticyclones are found between 45° and 55°S for blockings east of South America and south-east of South Africa.

In view of the available statistics of the preferred latitude for blocking anticyclones and cut-off lows, we decided to use as index the geopotential height difference between 35° and 50°S, that is

$$I(\lambda) = z_{35S}(\lambda) - z_{50S}(\lambda)$$  \hspace{1cm} (2)

where $I(\lambda)$ is the index at longitude $\lambda$, and $z$ the 500mb geopotential height evaluated from (1). $I(\lambda)$ was computed for every 10° longitude. It might be argued that the preferred latitude for blocking anticyclones over the Indian Ocean and/or the Atlantic should have been chosen to be further equatorwards than 50°S. We think, however, that the available statistics for these two regions does not conflict with our choice of latitudes. Nevertheless in the next section we will comment upon how the statistics we present would have been modified if we had chosen latitudes other than 35° and 50°S.

To demonstrate that $I(\lambda)$ is a useful tool for the identification of southern hemisphere blocks, we present in Fig. 1 a composite map from all August days 1972–1980 when $I(180°) < 0$, that is, the index less than zero at 180°. The flow shows the characteristics of a block; a split of the westerlies into two branches, each transporting appreciable
mass, an anticyclone polewards of a cyclone, and a longitudinal extent of about 50°. A comparison with a corresponding map in LO (their Fig. 1) indicates that southern hemisphere blocks do not have the same latitudinal extent as their northern hemisphere counterparts; the jetstream over the eastern Pacific polewards of 60°S and equatorwards of 20°S is hardly influenced by the block. This is in accord with the conclusion of Baines (1983), who extracted salient features from Wright’s (1974) data. Baines found that compared with the northern hemisphere, blocking in the Australian region is a smaller-scale phenomenon spanning 40° longitude, with a correspondingly smaller sphere of influence. Among all August cases used to compute Fig. 1, the duration of blocked flow ranges from one to more than ten days. The next two sections will be about characteristics of blocked flow as a function of longitude and time, as well as characteristics of all individual blocking episodes, including those which would not have been characterized by meteorologists as blocking situations because of their short duration.

4. FREQUENCY OF BLOCKED SOUTHERN HEMISPHERE FLOW AS A FUNCTION OF LONGITUDE

The index defined in (2) was computed for the whole period. The negative index values were plotted in a Hovmöller diagram, with longitude running from left to right and the date running downwards, in the same way as in LO. The blocks thereby appear as areas with negative index values. In this section we examine the frequency of blocked 500 mb flow. There are several occasions when one isolated negative value shows up in the diagram (see LO); as these single negative values do not represent blocked flow,
they are not included in the statistics presented in this section: only index values for a specific day and a specific longitude fulfilling the following conditions are included:

\[ I(\lambda) < 0 \]  
\[ \frac{\{I(\lambda - 10^\circ) + I(\lambda) + I(\lambda + 10^\circ)\}}{3} < 0. \]

This means that in addition to a negative index, the mean value over 30° longitude should be less than zero. By using both (3a) and (3b) we make sure that we include only those cases when the blocked flow prevails over an area having a considerable longitudinal extent, and we eliminate all single negative elements.

Using (3) we computed the frequency of blocked 500mb flow as a function of longitude and time. The resulting longitudinal variation is presented in Fig. 2 for each

![Figure 2](image-url)

Figure 2. Longitudinal variation of frequency of blocked 500 mb flow.
Figure 3. Annual variation of frequency of blocked 500 mb flow for every 20° longitude.

The values have also been plotted in Fig. 3, which shows the annual variation of frequency of blocked flow for every 20° of longitude. The values in Figs. 2 and 3 are mean values of the frequency (in per cent) for the period under consideration, that is 9-year mean values for the months May to November and 8-year mean values for the other months. There are marked longitudinal and seasonal variations. As expected, the most preferred region for blocked flow is in the Australian–New Zealand region, that is, in the area between the east coast of Australia and c. 120°W. The maximum values in this region are approximately 7% and they occur during late winter–spring (August–September). It is interesting to compare this value with corresponding values for the two preferred regions for blocked northern hemisphere flow. LO found that they are 17% for the Pacific region (in January) and 12% for the Atlantic region (February–April). In the Australian region there are two maxima during the winter (May–July). The minimum occurs close to 180°. The tendency for two maxima over the eastern part of the Pacific was also found by Mo (1983) and Trenberth and Swanson (1983). It should be noted that these authors used the same data set. Mo counted the number of events persisting for six days or more exceeding the threshold of +150 gpm,
while Trenberth and Swanson counted the number of cases persisting for five days or more exceeding the threshold of $\pm 100$ gpm at 500 mb during the winter. Trenberth and Swanson also found two separate maxima when they counted the number of cases persisting for 10 days or more exceeding the threshold of $\pm 50$ gpm. It should be noted that Trenberth and Swanson counted positive and negative anomalies. During blocking events the anomalies are positive. The mean of the data is, however, zero, and if the distribution of the variables is Gaussian, then the number exceeding a positive threshold should correspond to those exceeding the corresponding negative threshold. Trenberth and Swanson found that this was true as a first approximation, although there were some differences between the numbers of positive and negative cases. From Fig. 3 it is clear that it is mainly over New Zealand ($180^\circ$ and $160^\circ$W) that the winter minimum occurs. Over this area there are two maxima, one in late winter–early spring, and another in the autumn. Over the Australian continent there is, however, only one maximum and it occurs during June.

Van Loon (1956), Mo (1983) and Trenberth and Swanson (1983) noted that blocking also occurs over the Atlantic east of South America and over the Indian Ocean east of South Africa, although to a lesser extent. We too found blocked 500 mb flow over the Atlantic ($70^\circ$W–$0^\circ$). The maximum values, c. 1.5% of the total number of days, were found at $50^\circ$W in March and at $20^\circ$W in October. These maximum frequencies reveal that the number of cases in the Atlantic are so few that the variations with longitude and seasons displayed in Figs. 2 and 3 are not likely to be significant (for this region). We also found blocked flow over the Indian Ocean ($40^\circ$–$100^\circ$E) most of the year, with a maximum value about the same as over the Atlantic. Also here the cases are so few that the variations with longitude and seasons are not significant.

To be better able to compare our results with those of van Loon, Mo, and Trenberth and Swanson we have also computed the number of days with blocked 500 mb flow in different regions. Following van Loon we will call these the Pacific region, the Atlantic region and the Indian Ocean region, defined as follows: Pacific region: $110^\circ$E–$80^\circ$W; Atlantic region: $70^\circ$W–$0^\circ$; Indian Ocean region: $10^\circ$E–$100^\circ$E.

In Fig. 4 the number of days with blocked 500 mb flow somewhere in the particular region is plotted as a percentage of the total number of days. A comparison with Fig. 2 in van Loon shows that there is fairly good agreement for the Pacific region. Van Loon found two maxima, one with a value of 15% in late winter–early spring and another of 30% in the autumn. We, also, found two maxima: one peak value of 19% in April, and one extended maximum of c. 20% during June–August. For the other two regions there is a marked difference. The number of days with blocked flow is considerably less than found by van Loon. We notice a tendency for two maxima, one in fall–early winter and another in spring. There is, however, no clear sign of a seasonal cycle in these regions. There are probably several reasons why our results and those of van Loon differ. The data sets are different; he used five years of sea level pressure charts (1950–1955), while we used eight (or nine) years of 500 mb analyses. Another important fact is that different criteria have been used for the identification of blocks.

Trenberth and Swanson, who used Dole’s (1982) method to count persistent anomalies, found that the largest values occur near New Zealand. They also found large values, about $\frac{1}{3}$ of those in the Pacific, in a fairly limited region south-east of South America. A third region was weakly evident in the Indian Ocean. In addition, they found a maximum over the Antarctic peninsula. The results of Mo are very much the same. The agreement between our results and those of Mo and of Trenberth and Swanson is good for the Indian Ocean. For the Atlantic we found a lower frequency than they did. It should be noted that Dole’s method of counting the number of positive anomalies
greater in amplitude than some prescribed threshold value persisting for a given time differs from our method. Using Dole's method all blocking anticyclones, and probably also some anticyclones which perhaps should not be characterized as blocking, will be counted, while our statistics emphasize dipole (split-flow) blocks only. Unlike the results of van Loon (1956) we therefore conclude that the number of days with blocked flow is considerably lower in the Atlantic and the Indian Ocean regions than in the Pacific region.

Before we discuss the annual mean values of blocked 500mb flow, we investigate how our results are affected if we compute the index choosing latitudes closer to the equator than in (2). In the way described above, we computed another two index series, one defined by

\[ I_1(\lambda) = z_{258}(\lambda) - z_{408}(\lambda) \]  

and another one defined by

\[ I_2(\lambda) = z_{308}(\lambda) - z_{458}(\lambda). \]  

We used the criteria (3) and computed the number of days with blocked flow in the three regions (Pacific, Atlantic and Indian Ocean regions), that is the analogue to Fig. 4. There is a problem with the use of criteria such as ours to identify blocks because of the subtropical anticyclones. During the summer these anticyclones are well developed and they are closer to the poles than during the winter. Therefore, statistics for the summer computed from (4) and (5) should show high frequencies. These frequencies do
not, however, represent blocked westerlies. This was the case for the Pacific and the Indian Ocean regions. For the Atlantic region, however, the values were hardly affected by the poleward displacement of the South Atlantic anticyclone during the summer. The reason is presumably that this anticyclone in a climatological mean map of the 500mb geopotential height for January is found closer to the equator than the subtropical anticyclones over the Indian Ocean and over Australia (see e.g. Taljaard et al. 1969).

In Fig. 5 the number of days, computed from (4) and (5) also using (3), with blocked

500mb flow somewhere in the Atlantic region is plotted as a percentage of the total number of days. A comparison with the corresponding curve in Fig. 4 (marked ATL) supports our conclusion that the number of days with blocked 500mb flow is considerably lower over the Atlantic than over the Pacific region. We find the same for the Indian Ocean region if we disregard data for the summer months.

The annual mean of the frequency values in Fig. 2 is presented in Fig. 6(a). We notice that the mean maximum value for blocked southern hemisphere 500mb flow is 4% and that the preferred longitude is 170°E, over New Zealand. It is interesting to note that there is a climatological split in the southern hemisphere westerlies in this area.

5. BLOCKING EPISODES

Most studies of blocking have focused on the identification of blocking episodes. The main effort has been on the identification and the assessment of characteristics of individual blocking cases. In this section we derive some statistics for the episodes, and we compare our results with those reported by others. The results have been obtained by using a computer program which recognizes an episode as a collection of elements in a two-dimensional array \((\lambda, t)\), each satisfying (3a). The episode may then be described by the date, the longitude of its beginning and its duration in days. Note that only criterion (3a) is used, not (3b).

A total of 709 episodes were located by the program. A little more than half (395) lasted for only one day and 80% of these 1-day episodes occurred at only one longitude. Clearly, these should not be called blocking episodes. For comparison we have included
them in the statistics that follow. Note, however, that they do not have any influence on the statistics for blocking episodes (frequency, duration, etc.). The longitudinal distribution of the 1-day episodes is shown in Fig. 6(b), while Fig. 6(a) shows the yearly mean of the frequencies pictured in Fig. 2, that is, the longitudinal distribution of blocked 500 mb flow. Note that Fig. 6(a) is based on both criteria in (3), where (3b) in effect eliminates the 1-day episodes because of their small longitudinal extent. We notice the same thing as found in LO for the northern hemisphere. Although the 1-day episodes are more evenly distributed around the hemisphere than the total mass of blocks, some of the features in Fig. 6(a) are reflected in 6(b). The maximum occurs over the Australian region, and there is a secondary maximum over the Atlantic. A third maximum is weakly

Figure 6. (a) Longitudinal variation of blocked 500 mb flow averaged over the whole year. (b)–(d) Frequency distribution of blocking episodes as a function of longitude, 1972–1980. Duration 1 day (b), 2–4 days (c) and ≥5 days (d).
evident over the Indian Ocean. This supports the hypothesis in LO that these 1-day episodes are formed in preferred geographical locations, and are not just random configurations in the westerlies. Frederiksen (1982) presented a 3-dimensional instability theory of the onset of blocking and he showed that the eigenfunctions may take the form of dipoles with lows to the south and highs to the north, and that they occur in certain locations depending on the unperturbed wind and temperature fields. We speculate that such perturbations are responsible for the majority of the episodes, while additional influence of forcing controls the duration.

In Fig. 6(c) we have plotted the frequency distribution of episodes having a duration of 2–4 days, and in Fig. 6(d) those lasting for 5 days or more. The tendency is the same as in the northern hemisphere: the longer the duration, the more they are concentrated in certain locations. Long-lasting blocks are almost exclusively found in the Australian region.

To throw more light on the frequency distributions as a function of location, we have prepared Table 1, showing the number of episodes in the three regions as a function of duration. It is clear that the longer the duration, the greater percentage of all episodes of a certain duration are found in the Pacific region.

The displacement of the episodes during their life-time has also been computed. A regression line in ($\lambda, t$) space was computed for each episode, and the inclination was used to derive a mean displacement velocity for every episode. We counted the number of blocks having a mean velocity towards the east as well as those having a mean velocity towards the west (Table 2). Episodes without a mean velocity are not included. We notice the same tendency as in LO: the longer the duration of an episode, the more of them move towards the west. We also notice that the majority of the episodes move towards the east no matter how long they last. As a matter of fact, our results indicate that all episodes in the Atlantic and the Indian Ocean regions, except those without a mean velocity, have a mean velocity towards the east. The fact that many southern hemisphere blocks tend to move towards the east has been noticed in several studies (see e.g. van Loon 1956; Wright 1974).

<table>
<thead>
<tr>
<th>Duration (days)</th>
<th>No. of episodes</th>
<th>% of all episodes</th>
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<tr>
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<td>Total</td>
<td>PAC</td>
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<tr>
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<tr>
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PAC = Pacific; ATL = Atlantic; IND = Indian Ocean.
TABLE 2. FREQUENCY DISTRIBUTION OF THE MEAN VELOCITY OF THE BLOCKS

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<th>Duration (days)</th>
<th>No. of episodes</th>
<th>Relative frequency</th>
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<td>Eastward-moving</td>
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6. CONCLUDING DISCUSSION

Our results indicate that southern hemisphere blocking is a smaller-scale phenomenon that its northern hemisphere counterpart. This has also been noticed in other studies. Blocked 500 mb flow does not occur as often in the southern hemisphere as in the northern hemisphere, the peak values in the southern hemisphere being about 50% of those in the northern hemisphere. There is one preferred region for southern hemisphere blocks: the Pacific, east of Australia. We also found another two regions where blocks occur: the Atlantic Ocean east of South America and the Indian Ocean southeast of South Africa. The number of days with blocked flow is, however, considerably less in these regions than over the Pacific. This does not agree with van Loon’s (1956) results. He found a difference, but not as pronounced as we found. The results of Mo (1983) and Trenberth and Swanson (1983) support our conclusion. There are probably several reasons for the differences. The use of different data sets is presumably one reason, the different criteria for identifying blocks is probably another. Our statistics are valid for dipole blocks, which means that those blocking situations which are associated with a 500 mb ridge (without a dipole structure) are not included. It might be argued that our data for the Atlantic and the Indian Ocean are not as accurate as in the Pacific region because of few observations, and that this could explain part of the differences between the three regions. This may indeed be true, but the same thing should also be the case for the data sets used by van Loon, Mo, and Trenberth and Swanson. The Australian data set, which we used, is probably the best data set for an extended time period that at present is available. We also computed statistics for individual blocking cases, which we call blocking episodes. We related the duration of an episode to the frequency and the mean velocity. The majority of the episodes move towards the east. There is, however, a clear indication that the longer the duration, the more of them move towards the west. Those having the longest duration are concentrated in certain regions (the Pacific is the preferred region), while the shorter episodes are more scattered. The shortest episodes tend to appear most frequently in the three preferred regions for blocked flow.
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