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Blocking and persistence

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ABSTRACT

Time series of observational data have been used to study persistence of blocking over the Atlantic (northern hemisphere) and over the Australian-New Zealand region. The data used are 500-mb geopotential height data. It is shown that the probability that a blocking episode, which has prevailed for i days, will exist day $i + 1$ is ca 0.7 for northern hemisphere blocking and ca 0.5 for southern hemisphere blocking. The probability increases somewhat the longer the episode lasts. It is demonstrated that the statistics nevertheless may be modelled as a first order Markov process.

1. Introduction

Blocking is characterized by a specific flow pattern, which tends to persist once established. Actually, persistence is often used as a requirement in the definition of blocking (cf, for instance, Rex, 1950 and Dole and Gordon, 1983). Rex (1950) computed statistics for blocking episodes, and he was one of the first to show that the 500-mb flow has a high persistency in the region where blocking occurs, although the geographical location (the longitude for the blocking) may vary somewhat during the lifetime of an episode. The displacement of blocking episodes was investigated by Lejenäs and Økland (1983), who showed that episodes of short duration tend to move towards the east, while long-lasting episodes move towards the west. Dole and Gordon (1983) counted positive anomalies of the geopotential height field exceeding a certain value and lasting for a certain number of days.

Studies of southern hemisphere blocking have shown that blocking episodes in this hemisphere are less frequent and of shorter duration than in the northern hemisphere (see, for instance, Lejenäs, 1984). It is also a smaller scale phenomenon than its northern hemisphere counterpart.

Although it is widely acknowledged that blocking is a persistent phenomenon, there are, to our knowledge, no quantitative estimates of the probability for blocked flow to prevail. We will compute such a probability. We also compare this conditional probability with the unconditional probability for blocked flow, i.e., the probability for blocked flow at a particular longitude whether this was the case the previous day or not.

2. Data

We used 500-mb geopotential height data for our study. The northern hemisphere data were obtained from daily 12.00 GMT analyses made by the US National Meteorological Center (NMC) archived at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, USA. The NMC data have been interpolated from the NMC octagon to a $5 \times 10°$ latitude-longitude grid. We used 30 years of data from 1 January 1950 to 31 December 1979. The southern hemisphere data were obtained from 23.00 GMT analyses from 24 April 1972 to 31 December 1983 made by the Australian Weather Service. Details about the analysis may be found in Gauntlett et al. (1972). A 47×47 grid with half inch spacing superimposed on a polar stereographic chart of scale 1:40,000,000 at 60°S was used. The data were interpolated to a 5 × 5 degree latitude-longitude grid. Missing data and obviously erroneous data (less than 1% of the total number of days) have been linearly interpolated (in time).

In addition to these two data sets we used statistics for blocking episodes (duration etc.) presented by Lejenäs and Økland (1983) for northern hemisphere Atlantic blockings, and by Lejenäs (1984) for southern hemisphere Australian-New Zealand blockings. The episodes are defined in such a way that a slow displacement in longitudinal direction is permitted.

3. Results

3.1. Persistence of blocked flow

Northern hemisphere blocked flow was identified in the same manner as was done by Lejenäs and Økland (1983). An index defined as

$$I_{NH}(\lambda) = Z_{40^\circ N}(\lambda) - Z_{60^\circ N}(\lambda) \tag{1}$$

is by definition negative when the flow is blocked. In order not to mix data from the Atlantic and the Pacific (the two preferred regions for blocking), statistics for the two regions were computed separately. The results were similar, and therefore we present statistics from one region only (the Atlantic). The index $I_{NH}(\lambda)$ was computed for 40°W $\leqslant \lambda \leqslant$ 30°E, and since the resolution of our northern hemisphere data is 10° longitude we obtained eight time series, each consisting of 10,950 days. Data from eight longitudes were used in order to obtain more accurate statistical results. We shall return to this point later.

Southern hemisphere blocked flow was identified in the same was as in Lejenäs (1984) by means of an index defined as

$$I_{SH}(\lambda) = Z_{35^\circ S} - Z_{55^\circ S}. \tag{2}$$

Data from the Australian-New Zealand region were selected because this area is most preferred for southern hemisphere blocking (Lejenäs, 1984). We computed $I_{SH}(\lambda)$ for 150°E $\leqslant \lambda \leqslant$ 140°W. The resolution for our southern hemisphere data is 5° longitude. and accordingly we obtained 16 time series, each consisting of 4267 days.

The number of consecutive days with blocked flow ($I_{NH}(\lambda) < 0$ resp $I_{SH}(\lambda) < 0$) were counted in each data set. An estimate of the probability that blocked flow lasts at least i days can be computed as

$$S_i = \frac{\sum_{k=i}^{N} n_K}{\sum_{k=i}^{N} n_K} = \frac{\sum_{k=i}^{N} n_K}{N} \tag{3}$$

where N is the total number of cases (3339 for the northern hemisphere and 2029 for the southern hemisphere). The probability S_i is shown in Fig. 1. The full line is for the northern hemisphere and the dashed line for the southern hemisphere. As expected, the probability decreases with increasing number of days with blocked flow, and it decreases faster for the southern hemisphere. The probability that blocked flow,

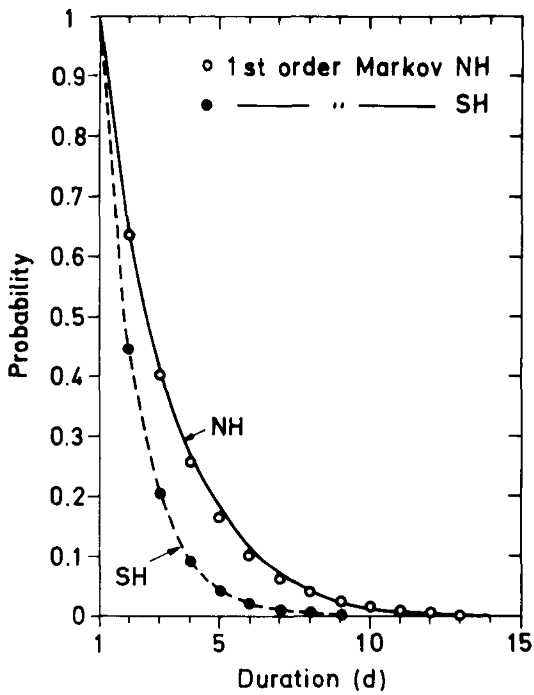

Fig. 1. The probability that blocked flow lasts at least i days. The full line is for the northern hemisphere, and the dashed line for the southern hemisphere. Open circles (northern hemisphere) and full circles (southern hemisphere) indicate expected probabilities if the statistics are modelled as a first order Markov process.

which has prevailed for i days, will exist day $i+1$ is obtained by dividing the probabilities evaluated from (3):

$$p_i = \frac{S_{i+1}}{S_i} = \frac{\sum_{k=i+1}^{N} n_K}{\sum_{k=i}^{N} n_K}. \qquad (4)$$

The result is shown in Fig. 2. For northern hemisphere blocked flow over the Atlantic, the probability is ca 0.6, that, provided we have blocked flow one day, the flow is blocked the next day too. The probability *decreases* somewhat the longer the flow has been blocked. The corresponding number for blocked flow over the Australian-New Zealand region is ca 0.4.

It is interesting to compare these probability values with the unconditional probability for days with blocked flow. Using the same method to identify blocking, Lejenäs and Økland (1983) used 30 years of data to compute an average value of the annual frequency of blocked 500-mb flow as a function of longitude. The maximum value, a frequency of 8%, was found at 10°E. The annual variation is, however, pronounced with a maximum of ca 12% during spring. Corresponding values for blocking in the Australian-New Zealand region were computed by Lejenäs (1984), who obtained a mean value for the whole year of 4%, and a maximum value of 7% (in September).

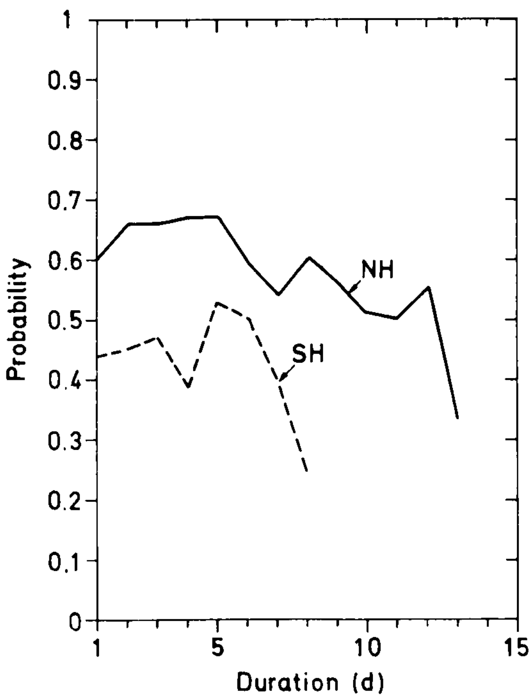

Fig. 2. The probability for blocked flow on a day following a day with blocked flow at the same longitude. The full line is for the northern hemisphere and the dashed line for the southern hemisphere.

3.2. Persistence of blocking episodes

Is it true that the longer a blocking lasts, the more likely it is that it persists for another day? The statistics we presented in Subsection 3.1 are not really material to the question since the flow configuration during a blocking is not quite stationary. The blocking may move slowly from one day to another. In order to find probabilities similar to those in Fig. 2 for blocking episodes, we used statistics for the frequency distribution as a function of episode duration for all episodes appearing in the Atlantic region over the northern hemisphere (see, Lejenäs and Økland, 1983, their Tables 1 and 2). For the Australian-New Zealand region we used statistics presented by Lejenäs (1984) (his Table 1). In this way we obtained 1695 cases for the northern hemisphere and 563 cases for the southern hemisphere. The number of cases are considerably less than those treated in section 3.1, and one might wonder what effect this could have on the statistics. As a simple test we recomputed the curves in Figs. 1 and 2, using a reduced number of data values. Data for the Greenwich meridian were extracted, and it turned out that the resulting curves (not shown) were very similar to those in Figs. 1 and 2. They were, however, somewhat more jiggly.

The result for the blocking episodes is shown in Figs. 3 and 4. Fig. 3 shows the probability that a blocking episode will last for i days, and the probability that a blocking episode, which has prevailed for i days, will exist day $i+1$ is pictured in Fig. 4. Fig. 4 reveals an item of interest. The probability that blocking which has prevailed for i days will exist day $i+1$ is higher in Fig. 4 than in Fig. 2 (~0.7 compared to 0.6 for the northern hemisphere and 0.5 compared to 0.4 for the southern hemisphere), and the probability *increases* slightly as a function of duration.

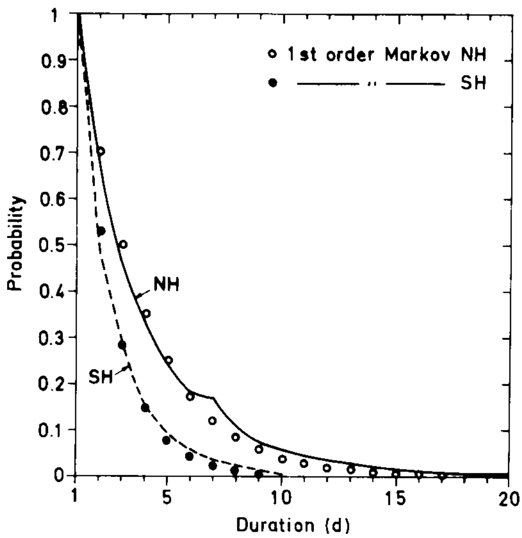

Fig. 3. The same as in Fig. 1 except that the statistics are computed for blocking episodes instead of blocked flow at a specific longitude.

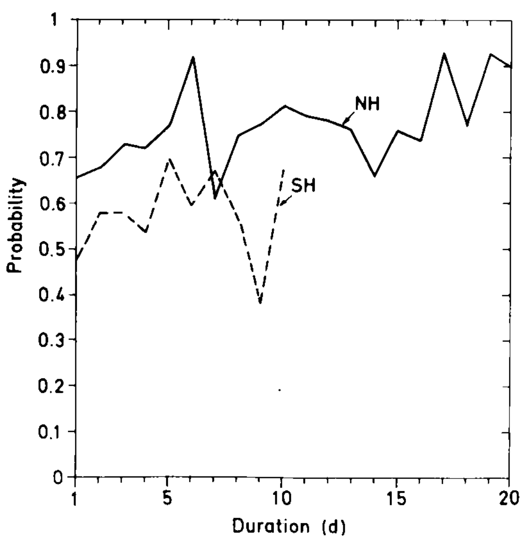

Fig. 4. The same as in Fig. 2 except that the statistics are computed for blocking episodes instead of blocked flow at a specific longitude.

In other words, there seems to be a tendency, although not very strong, that the longer a blocking episode lasts, the more likely it is that it persists for another day. We shall return to this point in the next section. The circumstance that the probabilities in Fig. 2 decrease slightly with increasing duration while those in Fig. 4 increase is presumably due to the fact that the blocking episodes have a tendency to move towards the east (shortlived ones) or the west (longlived ones). This was demonstrated by Lejenäs and Økland (1983) (see their table 2).

3.3. *A simple model*

Fig. 2 suggests that the probability for blocked flow ($I(\lambda) < 0$) on a day following a day with blocked flow at the same longitude, might be approximately independent of the number of previous days in the episode. A similar conclusion may be drawn from Fig. 4. True, all curves are more or less jiggly, a fact which we believe is a consequence of the limited amount of data from which they are derived. We find support for this belief in the circumstance that the curves are more smooth in the left part of Fig. 2 where the number of cases is largest, especially for the northern hemisphere. Also, the curves are generally less smooth in Fig. 4 than in Fig. 2, in agreement with differences in the number of cases treated. It is also in agreement with the test of the impact of the number of data values mentioned in section 3.2. A probability of the kind just mentioned suggests that the statistics described in Figs. 1 and 3 may be modelled as a first-order Markov process, characterized by a constant value, p, of the p_i defined in (4). According to Fjørtoft et al. (1984) an estimate of p may be obtained from the formula:

$$D = \frac{1}{1 - p} \tag{5}$$

where D is the mean duration defined as

$$D = \frac{\sum_{k=1}^{N} k n_k}{\sum_{k=1}^{N} n_K} \tag{6}$$

Then

$$S_i = p^{i-1} \tag{7}$$

In the case of Fig. 1, (5) gives values of p equal to 0.635 and 0.488 for the northern and southern hemisphere respectively. The corresponding values of S derived from (7) are entered in the figures as open and full circles. The blocking episodes, pictured in Fig. 3, give $p = 0.700$ and $p = 0.531$. These numbers reflect the circumstance already mentioned, that long-lasting periods with blocked flow are more common in the northern than in the southern hemisphere. Furthermore, the technique used for identification of the episodes in Fig. 3, catches more long runs than in the case of Fig. 1, probably because the former does not lose the episodes if they move to other longitudes. In general, the agreement between the observed and computed values is quite satisfactory, especially in Fig. 1. However, in Fig. 3 there is a small, but systematic discrepancy between the observed and theoretical values, indicating that a first order Markov model is not really sufficient.

We find no point in constructing more sophisticated statistical models. We mention, however, that the discrepancy between computed and observed frequencies in Fig. 3, not present in Fig. 1, could be attributed to the longitudinal displacement of the episodes, if this displacement is more pronounced in the case of long-lasting blockings. We do not possess data to verify this speculation.

4. Conclusion

One reason for the interest in blocking as a separate phenomenon is of course its persistence. Once established, the characteristic flow pattern has a strong tendency to prevail. In this paper we have tried to derive objective measures for this persistence, based primarily on results published earlier. The number of available cases is limited. We have, however, refrained from using any standard tests of significance. The reason is that the number of degrees of freedom is limited by many kinds of interdependencies among the data. Besides, there is the obvious shortcoming in the somewhat arbitrary definition of blocking, which makes tedious statistical methods somewhat irrelevant. We feel, however, that the method used to identify blocking episodes has one great advantage in connection with a statistical investigation like the one we have undertaken: the fact that we include blocking of all time scales furnishes a much greater data base since the shorter episodes are by far the most common ones. This makes it possible to construct models which with greater reliability may be extended into the domain where the number of cases is small (i.e. long-lasting blocking events). This is one reason why we believe that our conclusions are statistically significant. Besides, we hope that the results may be of interest to modellers of other meteorological events which can be tied to the characteristics of the 500-mb flow.

The persistence of blocked flow seems to be approximately independent of the duration of the episode, apart from some small discrepancies which we have accounted for. This result, which we consider to be quite important, seems to indicate that by and large there is no qualitative difference between episodes that last for a long period of time compared with those of shorter duration.

5. Acknowledgements

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