NOTE AND CORRESPONDENCE

Southern Hemisphere Planetary-scale Waves and Blocking

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Abstract

The importance of stationary and travelling planetary-scale waves for southern hemisphere blocking has been investigated. The data used are 500-mb geopotential height data from nine winter seasons. The first three zonal harmonics of these data were decomposed in a low-pass filtered quasi-stationary part, and a travelling part being the difference between the unfiltered and filtered values.

The behaviour of the planetary-scale waves during periods with blocked flow is documented. It is found that unlike blocking in the northern hemisphere there is no systematic behaviour of the ultra-long waves during southern hemisphere blocking.

1. Introduction

Theoretical as well as observational studies have documented the importance of planetary-scale waves for northern hemisphere blocking. It has been demonstrated (see, for instance, Austin (1980), Colucci *et al.*, (1981), Hansen and Chen (1982) and Hansen and Sutera (1984)) that stationary and travelling planetary-scale waves are amplified during blocking. Several possible mechanisms have been suggested as the reason for the amplification, like interaction among a triad of waves (Colucci *et al.*, 1981), interaction of forced waves with free waves with or without wave-mean flow interaction (Egger, 1978) and cyclone-scale forcing of the long waves (Metz, 1986).

There are few similar studies of southern hemisphere blocking. Trenberth and Mo (1985), who studied persistent positive anomalies, found some support for a frequent key role of wave-3 during winter blocking events, and that wave-1 and wave-3 appeared to play a role during summer events. Wave-3 is of particular interest in

this connection, because there are three preferred regions for persistent positive anomalies; over Australia-New Zealand, southeast of the southern tip of South America, and southeast of South Africa. Trenberth and Mo (1985) showed this, and found that there are more cases in the Australia-New Zealand region than in the other two. There is a strong correlation between persistent positive anomalies and blocking. However, Lejenäs (1987) demonstrated that the definition of a block is crucial for the statistics. He used data from the Global Weather Experiment, and showed that if blocking is identified as persistent positive anomalies, the three regions mentioned above are the preferred regions. On the other hand, if blocking is identified by means of a criterion focussing on the flow field (the geopotential height at a particular latitude is lower 15 degrees of latitude equatorward of the specified latitude) there is only one preferred region for blocking, viz. the Australian-New Zealand region.

As regards the other two planetary-scale waves, wave-1 has the largest variance in the

low-frequency domain though its role in blockings is less prominent than that of wave-3. Further, the amplitude is almost constant throughout the year (see, for instance, van Loon and Jenne (1972)). Wave-2 is far less pronounced.

The aim of the present paper is to better document the behaviour of stationary and travelling planetary-scale waves during southern hemisphere blocking. The study has been performed in a similar way as an analogous study for the northern hemisphere by Lejenäs and Döös (1987).

A time series of observational 500-mb geopotential height data has been used. The data and the data handling are described in the next section. Characteristics of planetary-scale waves during blocked flow are presented in section 3, and concluding remarks are also found in this section.

2. Data and Data Handling

The data used for this study were extracted from the Australian data set archived at the National Center for Atmospheric Research (NCAR), Boulder, CO, USA. The original data are 500-mb analyses arranged on a 47×47 grid with a horizontal resolution of 507 km at 60°S . The grid covers the southern hemisphere south of 0.9°S . The available data were first interpolated to a $5 \times 10^\circ$ latitude-longitude grid from 20° – 85°S . These data were then Fourier analyzed along each latitude line. For each available day and each latitude zonal means and cosine and sine coefficients were obtained. The data were made available to us in form of these coefficients.

The geopotential height data contain all scales of waves through wavenumber 18. Following Lejenäs and Döös (1987), hereafter referred to as LD, we restricted ourselves to consider only the contribution from the first three wavenumbers, *i.e.* the low-frequency (LF) part of the spectrum. As in LD we use the notation

$$Z(\lambda, t) = z_{LF}(\lambda, t) = \sum_{m=1}^3 z_m(\lambda, t) \quad (1)$$

Stationary and travelling wave components for the first three waves were computed for every

day for the nine winters 1972 to 1980 available in the data set. A winter season was defined as all days from 1 July through 30 September. The wave components were decomposed in a low-pass filtered quasi-stationary part (Z_{ST}), and a travelling part (Z_{TR}), being the difference between the observed and the filtered value. The equations defining Z_{ST} and Z_{TR} are given in LD, and therefore they are not repeated here. LD used a running time average, also called a Bartlett window, to low-pass filter their data, and they averaged over 15 days. Here we use a Parzen window, equivalent to a power window of degree 3 (see for instance Båth, 1974), and 15 consecutive days were used to obtain the stationary wave. The reason we chose 15 days was that this was considered to be a reasonable time for a study of blocking, and that LD used the same number of days. The Parzen window has the advantage that the frequency spectrum has no negative sidelobes. If we disregard those parts of the frequency spectrum where the Bartlett window has negative sidelobes, the amplitude response is almost the same for the two filters. For instance, for $f = 1/25$ days the response is 0.51 for the Bartlett window and 0.49 for the Parzen window. It should also be mentioned that LD found that for the kind of problem studied, the two filters give almost the same result.

In the next section we will present some results for the total contribution from planetary-scale waves, and we use the following notations for the geopotential height field for stationary and travelling waves.

$$Z_{ST}(\lambda, t) = \sum_{m=1}^3 z_{ST, m}(\lambda, t) \quad (2a)$$

$$Z_{TR}(\lambda, t) = \sum_{m=1}^3 z_{TR, m}(\lambda, t) \quad (2b)$$

3. Statistics

Blocked flow was identified in the same manner as was done by Lejenäs (1984), namely when the following expression is negative

$$I(\lambda, t) = Z_{40^\circ\text{S}}(\lambda, t) - Z_{55^\circ\text{S}}(\lambda, t) \quad (3)$$

The index $I(\lambda, t)$ was computed for every five

degree of longitude for all nine winters. These data were plotted in a time-longitude diagram (not shown here) together with the geopotential height field at 55°S for stationary and travelling planetary-scale waves also computed (from (2a) and (2b)) for every five degree of longitude. LD found that blocked flow in the northern hemisphere normally occurs when the geopotential height of the travelling wave at the particular longitude is positive, and when the amplitude of the stationary wave is above its climatological value. Visual inspection of all diagrams did not suggest such a correlation for our data, except that most blockings occur in the Australian region where the stationary wave (Z_{ST}) has a maximum (*cf* Fig. 1).

In order to investigate the features of planetary-scale waves during southern hemisphere blocked flow, we extracted all cases when the criterion for blocked flow (3) was fulfilled. The data were plotted in diagrams with the height of the travelling wave ($Z_{TR}(\lambda, t)$) on the ordinate and the difference between the stationary wave and the mean stationary wave

$$D(\lambda, t) = Z_{ST}(\lambda, t) - \overline{Z_{ST}}(\lambda)$$

on the abscissa. The mean stationary wave $\overline{Z_{ST}}(\lambda)$ was subtracted out since it is a function of longitude. The time mean of the travelling wave was zero, and therefore there was no need for subtracting out a mean value for this wave. All cases were included in the statistics, that is blocked flow all around the hemisphere. All events with negative index $I(\lambda, t)$ are not

Fig. 1. The stationary component of the 500-mb geopotential heightfield at 55°S for the planetary-scale waves 1, 2, and 3 as a function of longitude. The figure shows the climatological mean value for 9 winters (1972-1980).

blockings. For instance, if blocked flow according to our definition occurs one or two days, it is probably not a block. The longer the time period with blocked flow lasts, the more likely it is that it is a block in the classical sense (*cf* for instance Rex, 1950).

The results of LD indicate that the amplitude of the travelling planetary-scale waves increase in time when the block has been established. In view of this we plotted data for the stationary wave minus the mean stationary and the travelling planetary-scale wave at 55°S in six diagrams presented in Fig. 2. In the first one we included all cases with negative index $I(\lambda, t)$. In the second diagram all cases with blocked flow lasting at least 2 days were included, and in the third one those lasting at least 3 days and so

Fig. 2. The 500-mb geopotential height of the stationary minus the mean stationary wave $D(\lambda, t) = Z_{ST}(\lambda, t) - \overline{Z_{ST}}(\lambda)$ and the travelling ($Z_{TR}(\lambda, t)$) planetary-scale wave at 55°S. The six diagrams show events with blocked flow that lasts at least 1, 2, 3, 4, 5, and 6 days respectively.

Table 1. The percentage number of cases with blocked flow as a function of $D(\lambda, t) = Z_{ST}(\lambda, t) - \overline{Z_{ST}}(\lambda)$ and $Z_{TR}(\lambda, t)$. The numbers are given in per cent.

No of days blocked flow at least lasts	$D > 0$ $Z_{TR} > 0$ (%)	$D < 0$ $Z_{TR} > 0$ (%)	$D > 0$ $Z_{TR} < 0$ (%)	$D < 0$ $Z_{TR} < 0$ (%)	total no of cases
1	29.6	21.4	21.4	27.6	416
2	29.9	21.7	21.4	27.0	318
3	30.2	19.8	22.6	27.4	212
4	32.8	19.7	29.5	18.0	122
5	36.7	11.4	30.4	21.5	79
6	35.0	10.0	30.0	25.0	40

forth. LD plotted all northern hemisphere data (blocked flow as well as non-blocked flow) in a diagram like that in Fig. 2 and found that the cases were evenly distributed over the four quadrants. For blocked flow, however, most of them were found in the upper right quadrant, which means that $D(\lambda, t) > 0$ and $Z_{TR}(\lambda, t) > 0$. This is certainly not the case for any of the diagrams in Fig. 2. The crosses are fairly evenly distributed over the four quadrants. If ultra-long waves are amplified during blocked flow, the crosses in the diagram should be found in the upper right quadrant, at least for longlasting blocks. There is, however, no sign at all that this is the case. The percentage distribution of the cases in the four quadrants and the total number of cases are given in Table 1 for all six diagrams. There is a slight increase of the number of cases in the upper right quadrant. The increase is, however, only 5% from the first to the sixth class. A comparative increase is seen in the lower left quadrant. Thus, we conclude that there is no systematic behaviour of stationary and travelling planetary-scale waves in southern hemisphere blocking. There are blocks with above normal amplitude of the stationary ultra-long waves and positive values of the travelling waves, but there are also several cases when this is not the case.

The result is perhaps not surprising in view of the synoptic characteristics of many southern hemisphere blocks. Taljaard (1972) found that frequently the blocking high weakens when a cold front penetrates the blocked area. The high is reestablished in that a new high behind the front replaces the original one that weakens. It is

likely that this course of event is due to cyclone-scale transient eddies, which suggests that this mechanism in contrast to that of the amplified transient planetary-scale waves is more dominant in the southern hemisphere. On the other hand, Trenberth and Mo (1985) found some support for an increased amplitude of wave-3. There is, however, no contradiction between their and our results. We studied the total contribution from the first three waves, while Trenberth and Mo investigated the contribution from individual waves. Further, we also found that the ultra-long waves are amplified in some cases.

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「南半球の超長波とブロッキング」

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