A Comparison of Atmospheric Blockings over the Southeast and Southwest Pacific Ocean

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Abstract

Several earlier studies showed that the southwest Pacific near New Zealand is a region of blocking in the Southern Hemisphere. In this paper a second region of frequent blocking over the southeast Pacific is confirmed using 25 years of daily data. A comparison between the characteristics of blockings over the southwest and southeast Pacific revealed several interesting differences. Although the highest frequency of blocks occurs in the austral winter in both the regions, the frequency of blocks is greater over the southwest Pacific. However, these blocks are short lived and no block is found that lasts beyond 11 days duration. While over the southeast Pacific blocks are longer lasting with several blocks lasting for more than 11 days duration.

Local energetics of two blocks, one with a 21 day duration over the southeast Pacific and another with a 10 day duration over the southwest Pacific are analysed using Mak's formulation. The contributions from various temporal scale interactions (seasonal, intraseasonal and high frequency components) to the episodal average local energetics of these two blocks are evaluated. It is found that blocking disturbances in both the cases extract barotropically, kinetic energy from the seasonal diffusive jet at almost the same rate. But the redistribution of kinetic energy within the block region is wider for the southeast Pacific block than for the southwest Pacific blocks. This seems to maintain the longer duration of the southeast Pacific block. The synoptic eddy straining mechanism proposed by Shutts is manifested in three energetic terms, of which one (\(V_1 \cdot \nabla_2\)) is found to be particularly large for both blocks. The pressure work process and the baroclinic conversion are also important, for both the blocks and the magnitudes are higher for the southeast Pacific block.

1. Introduction

There have been several observational studies of blocking in the Northern Hemisphere (NH) (e.g., Rex 1950a, 1950b; Truitt et al. 1981; Lejenäis and Okland 1983; Dole 1989; among others). Similar studies over the Southern Hemisphere (SH) are found to be smaller in number. One of the early studies was by van Loon (1956) who used five years of synoptic charts to study blocking in the SH. Taljaard (1972) described synoptic characteristics of blocking anticyclones in the SH. Blocking in the Australasian region was documented by Wright (1974) and Baines (1983). Coughlan (1983) compared the characteristics of blockings in both hemispheres. Lejenäis (1984) used 8 years of 500 hPa geopotential height analysis and discussed blocking in the SH. Trenberth and Mo (1985) also used about 8 years of data to discuss blocking in the SH. These studies revealed that the principal region of blocking in the SH is the New Zealand sector. Recently a new region of blocking in the southeast (SE) Pacific has been found by Rutilant and Fuenzalida (1991), Sinclair (1996), Marques (1996) and Renwick (1998). Rutilant and Fuenzalida (1991) used 8 years of
data and found a distinct region of blocking in the SE Pacific. Sinclair (1996) used 10 years of European Center for Medium-Range Weather Forecasts (ECMWF) data and obtained a climatology of blocking in the SH. Blocking episodes were identified as persistent highs having central pressure exceeding the time averaged, mean sea level pressure (MSLP) by more than 20 hPa. Sinclair (1996) found that quasi-stationary intense blocks occur in two regions of the south Pacific: the east of New Zealand and southwest of South America. The latter region of blocking was not found in the earlier studies probably because of poor data coverage. Marques (1996) analysed fourteen years (1980–1993) of ECMWF data to study blocking in the SH. She also found this second region of frequent blocking in the southeast Pacific. Renwick (1998) used sixteen years (1980–1995) of ECMWF data and examined the connection between blocking and ENSO (El Niño-Southern Oscillation). He found that the number of days of blocking tends to increase on the average during the warm phase of the ENSO cycle particularly over the southeast Pacific during austral spring and summer. In a recent study Renwick and Revell (1999) investigated blocking events over the south Pacific using 39 years of NCEP–NCAR reanalysis data and confirmed that the occurrence of blocking over the southeast Pacific is strongly modulated by the ENSO cycle during austral spring and summer. Marques and Rao (1999) analysed the nature of a long-lasting blocking event of 17 days (29 July through 14 August 1986) in the southeast Pacific. They found that this blocking event affected the mean flow and eddy characteristics. The local Eliassen-Palm flux diagnostics indicated that transient eddies act to decelerate the westerlies in the region of the split jet. The deceleration in the region of the blocking high (which forms in the location of the split jet) acts to counter the tendency of the block to move downstream under the influence of mean flow advection.

The purpose of the present article is to study basic characteristics of blocking such as frequency of occurrence and duration in the southeast and southwest Pacific. Another objective of this study is to analyse the local energetics of the long-lasting blocking event found by Marques and Rao (1999) and compare the energetics of this blocking event with the energetics of a blocking in the New Zealand region. Such a study might give clues to improve understanding of the nature of blocking in these two principal regions of blocking in the SH.

To study the energetics of blocks in the two regions, we use Mak’s (1991) formulation. Since atmospheric blocking is essentially a local phenomenon, local energetic analysis would be more relevant. Mak (1991) developed such a methodology to calculate local energetics. Although the duration of a blocking episode is long compared to the time scale of the individual synoptic-scale transient disturbances, it is short compared to the seasonal component of the flow. Thus, Mak (1991) separated the total flow into a high-frequency component, an intraseasonal component and a seasonal component and studied the energetics of a block over North Atlantic that lasted for three weeks. He showed that the principal mechanism during the blocking episode is primarily barotropic, although baroclinic processes are locally important within the block.

2. Data source and methodology

We extended the previous study of Marques (1996), using 25 years (1973–1997) of National Center for Environmental Prediction (NCEP)/NCAR (National Center for Atmospheric Research) reanalysis (Kalnay et al. 1996). The methodology of identifying blocks has been modified to include the occurrence of blocks at latitudes higher than 50°S. As in Lejenäis and Madden (1992) and Marques (1996), first the data were subjected to a Fourier analysis along each latitude and the first 18 zonal harmonics only were retained. This helps to filter short waves of wavelength less than 20° longitude. We used a blocking index, which is a modified version of that suggested by Lejenäis (1984). To include the occurrence of blocking at latitudes higher than 50°S, the Lejenäis index is used for three different latitude belts.

\[ I_1(\lambda) = Z_{35}(\lambda) - Z_{50}(\lambda), \]
\[ I_2(\lambda) = Z_{35}(\lambda) - Z_{55}(\lambda), \]
\[ I_3(\lambda) = Z_{40}(\lambda) - Z_{60}(\lambda), \]

where \( Z \) is 500 hPa geopotential height and \( \lambda \) is the longitude.

The blocking situation should satisfy that mean in 30° longitudes \([I(\lambda - 10) + I(\lambda) + I(\lambda + 10)]/3\) should be less than zero at one of three cases of (1). These criteria are sufficient to define a local (space) blocking pattern. However, a true synoptic blocking requires a certain time persistence of the event. Thus a further time requirement has
to be added to the blocking definition, which is as follow: When two successive days are considered blocked by the index in a sector and are followed by a non-blocked day and then by two more successive blocked days, the entire event is considered as a five day block (implicitly assuming that the failure was due to an index failure). A similar criterion is applied in the case of a single non-blocked day preceded (followed) by three blocked days and followed (preceded) by a single blocked day. In addition all the blocked episodes less than 4 consecutive days duration are excluded in the subsequent analysis. These criteria are similar to those used by D’Andrea et al. (1998) for the Northern Hemisphere blocking identified in 15 atmospheric General Circulation Models.

When we used the modified Lejæns index (Eq. (1)) we noted that the blocking event of August 1986 over the southeast Pacific extended by four more days, that is, it lasted for 21 days (24 July through 13 August, 1986). This is probably because of the inclusion of higher latitudes in the modified index, where the block extended for a longer time. This is the only blocking event which lasted for 21 days in the 25 years (1973–1997) climatology of blocking in the SH obtained with daily data. Although blocking events of 21 days are rare, our results (discussed in the next section) show that the southeast Pacific is the seat of long-lasting blocking events. To compare energetics of this blocking event with energetics of a blocking over the southwest Pacific near New Zealand, we selected the blocking event of June, 1986 (20 June though 29 June, 1986). To calculate the energetics of these two chosen blocking events we used ECMWF daily data at 12:00 UTC at 500 hPa level. We used geopotential height \( Z \), the horizontal velocity \( u, v \) fields, the P-vertical velocity \( \omega \) field and temperature field \( T \). Although the southeast Pacific is sparse of conventional observations, use of remotely-sensed data and drifting buoys improves the analysis. Further a large block is probably hard to miss by any analysis.

To analyse the local energetics of the blocking situation we use the methodology developed by Mak (1991) and his notation. Here we shall briefly illustrate the method. For details the reader is referred to Mak’s paper. Each meteorological variable, \( \xi = Z, u, v, \omega \) or \( T \) at each grid point is partitioned into three parts, a seasonal component \( (0) \), an intraseasonal component \( (1) \) and a high frequency component \( (2) \).

\[
\xi = \xi_0 + \xi_1 + \xi_2. \tag{2}
\]

The three operators in time that would achieve partitioning into three components are given by

\[
L_n\{\xi\} = \xi_n \quad (n = 0, 1, 2). \tag{3}
\]

These components are obtained by two filters. The first filter (zero component) is a 61 day running-mean (denoted by \( - \)). The second filter is a 7 day running-mean (denoted by \( \cdot \)). The difference between the two gives the intraseasonal \( (1) \) component and the difference between the original series and the 7 day running-mean gives the high frequency \( (2) \) component.

\[
L_0\{\xi\} = \bar{\xi} = \xi_0,
L_1\{\xi\} = \dot{\xi} - \bar{\xi} = \xi_1,
L_2\{\xi\} = \ddot{\xi} - \dot{\xi} = \xi_2. \tag{4}
\]

Applying the \( L_1 \) operation to the horizontal momentum equation (neglecting vertical advection of momentum) gives

\[
\frac{\partial}{\partial t} \vec{V}_1 = \vec{A}_{0,0} + \vec{A}_{0,1} + \vec{A}_{0,2} + \vec{A}_{1,1} + \vec{A}_{2,2} + \vec{A}_{1,2} - \nabla \Phi - \vec{k} \times \vec{V}_1 + \vec{F}_1. \tag{5}
\]

\[
\vec{A}_{0,0} = -L_1\{(\vec{V}_0 \cdot \nabla)\vec{V}_0\}, \\
\vec{A}_{0,1} = -L_1\{(\vec{V}_0 \cdot \nabla)\vec{V}_1 + (\vec{V}_1 \cdot \nabla)\vec{V}_0\}, \\
\vec{A}_{0,2} = -L_1\{(\vec{V}_0 \cdot \nabla)\vec{V}_2 + (\vec{V}_2 \cdot \nabla)\vec{V}_0\}, \\
\vec{A}_{1,1} = -L_1\{(\vec{V}_1 \cdot \nabla)\vec{V}_1\}, \\
\vec{A}_{2,2} = -L_1\{(\vec{V}_2 \cdot \nabla)\vec{V}_2\}, \\
\vec{A}_{1,2} = -L_1\{(\vec{V}_1 \cdot \nabla)\vec{V}_2 + (\vec{V}_2 \cdot \nabla)\vec{V}_1\}. \tag{6}
\]

In this analysis, \( \vec{A}_{0,0} \) and \( \vec{A}_{0,2} \) are identically zero by definition, since \( \vec{V}_0 \) is approximated by a seasonal (60 days) mean. Thus \( (5) \) reduces to

\[
\frac{\partial}{\partial t} \vec{V}_1 = \vec{A}_{0,1} + \vec{A}_{1,1} + \vec{A}_{2,2} + \vec{A}_{1,2} - \nabla \Phi - \vec{k} \times \vec{V}_1 + \vec{F}_1. \tag{7}
\]

By taking the scalar product of \( (7) \) with \( \vec{V}_1 \) and taking the average of each resulting term over the duration of the blocks (24 July–13 August, 1986 and 20–29 June, 1986) we get the equation that governs the kinetic energy of the blocking circulation.
\[
\frac{\partial}{\partial t} K_1^b = \bar{V}_1 \cdot \bar{A}_{0,1} + \bar{V}_1 \cdot \bar{A}_{1,1} + \bar{V}_1 \cdot \bar{A}_{2,2} + \bar{V}_1 \cdot \bar{A}_{1,2} - \bar{V}_1 \cdot \nabla \Phi_1 + \bar{V}_1 \cdot \bar{F}_1. \tag{8}
\]

A bar with a “b” subscript represents the average over the blocking period. The fifth term on the right hand side of (8) represents the contribution by the pressure-gradient force. This term can be thought as consisting barotropic and baroclinic parts. The latter is totally associated with divergent (ageostrophic) part of the flow. This baroclinic part may be written as a combination of two terms, a conversion between kinetic and potential energy \(\omega \frac{\partial \Phi}{\partial p}\) and a vertical convergence of energy flux \(\frac{\partial \omega \Phi}{\partial p}\) by the divergent part of the flow (Cai and Mak, 1990). The last term on the right hand side of (8) is a measure of frictional dissipation and is evaluated here as a residual by assuming the time tendency term in (8) is zero.

The equation for the time change of available potential energy is obtained from the thermodynamic energy equation by applying the \(L_1\) operator multiplying the resulting equation by \(\theta_1 R/(\partial \Theta/\partial p)\) and taking an episodic average of the final expression. The resulting equation is given by

\[
\frac{\partial}{\partial t} P_1^b = \theta_1 B_{0,1} + \theta_1 B_{1,1} + \theta_1 B_{2,2} + \theta_1 B_{1,2} + \frac{R}{\partial \Theta/\partial p} \frac{\partial \omega}{\partial p} Q_1. \tag{9}
\]

Where \(P_1 = R \theta_1^2 / (2(\partial \Theta/\partial p))\) is the available potential energy of 1 component associated with the block. In (9) \(\theta\) is the potential temperature, \(\Theta\) is the domain-averaged potential temperature, \(Q\) is the diabatic heating rate in degrees per unit time, and \(\omega\) is the \(p\)-vertical velocity. The explicit forms of the first four terms on the right hand side are

\[
\begin{align*}
\theta_1 B_{0,1} &= \left( \frac{R \theta_1}{\partial \Theta/\partial p} \right) L_1 \{(\bar{V}_0, \nabla) \theta_1 + (\bar{V}_1, \nabla) \theta_0 \}, \\
\theta_1 B_{1,1} &= \left( \frac{R \theta_1}{\partial \Theta/\partial p} \right) L_1 \{(\bar{V}_1, \nabla) \theta_1 \}, \\
\theta_1 B_{2,2} &= \left( \frac{R \theta_1}{\partial \Theta/\partial p} \right) L_1 \{(\bar{V}_2, \nabla) \theta_2 \}, \\
\theta_1 B_{1,2} &= \left( \frac{R \theta_1}{\partial \Theta/\partial p} \right) L_1 \{(\bar{V}_1, \nabla) \theta_2 + (\bar{V}_2, \nabla) \theta_1 \}.
\end{align*}
\tag{10}
\]

The first five terms on the right side of (9) can be evaluated from the temperature, horizontal velocity and \(\omega\) data at 500 hPa. The last term can be estimated as a residual.

3. Results

3.1 General Characteristics

Before starting to discuss the energetics of the two blocking events we examine the duration of blocking events in different seasons over the southwest Pacific (120°E–120°W), southeast Pacific (120°W–70°W), south Atlantic (70°W–10°E) and Indian (10°E–120°E) Oceans regions. Table 1 shows the frequency of blocks in the SH obtained with 25 years (1973–1997) of NCEP reanalysis data.

Fig. 1. Distribution of mean geopotential height (in gpm) in the 30°S–90°S latitude and 175°E–60°W longitude for the period 24 July through 13 August, 1986 at (a) 1000 hPa: contour interval, CI = 50 gpm and (b) 500 hPa: CI = 100 gpm.
Table 1. Number of blockings in the Southern Hemisphere for different durations over the Southwest Pacific, Southeast Pacific, Atlantic and Indian Oceans.

<table>
<thead>
<tr>
<th>Block</th>
<th>WEST PACIFIC</th>
<th>EAST PACIFIC</th>
<th>ATLANTIC</th>
<th>INDIAN</th>
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<tr>
<td>Total</td>
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<td>21</td>
<td>41</td>
<td>18</td>
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</tbody>
</table>

Table 1 shows several interesting features of blocking in the SH. Highest frequency (41) occurred in the austral winter season over the west Pacific. This is followed by the east Pacific again in winter (20 blocks). Blocks over Atlantic and Indian Oceans are rare. Thus the present study confirms the second region of frequent blocking in the east Pacific noted earlier by Rutllant and Fuenzalida (1991), Sinclair (1996), Marques (1996) and Rewick (1998). Another interesting feature revealed in Table 1 is that, over the west Pacific most of the blocks in winter are around 7 days or less duration and no block lasted for more than 11 days. While over the east Pacific there are blocks in autumn and winter which lasted for more than 11 days with at least one which lasted for 21 days. Thus relatively long-lasting blocks are favored over the east Pacific. It is interesting to know which aspect of the atmosphere is responsible for this difference over these two principal regions of blocking. One enlightening way of studying the atmospheric phenomenon is through energetics (Lorenz 1960). Thus the question that arises now is: what are the energy exchange processes for a long-lasting block over the east Pacific and how do they compare with a block of less duration over the west Pacific near New Zealand? To study the energetics, two blocks in the same year (1986) are selected to avoid possible interannual differences in the general circulation of the SH.

Figures 1a and 1b show the distribution of geopotential height at 1000 and 500 hPa respectively for the block of 24 July through 13 August, 1986 (hereafter referred to as block 1). Figures 2a and
Fig. 2. Distribution of mean geopotential height (in gpm) in the 30°S–90°S latitude and 130°E–105°W longitude for the period 20 June through 29 June, 1986 at (a) 1000 hPa: Cl = 50 gpm and (b) 500 hPa: Cl = 100 gpm.

Fig. 3. Distribution of mean zonal wind (in m s\(^{-1}\)) at 500 hPa in the 30°S–90°S latitude and for the period (a) 24 July through 13 August, 1986 (175°E–60°W) and (b) 20 June through 29 June, 1986 (190°E–150°W): areas exceeding 20 m s\(^{-1}\) are shaded. Cl = 5 m s\(^{-1}\).

2b show the distribution of geopotential height at 1000 and 500 hPa respectively for the block of 20 June through 29 June 1986 (hereafter referred to as block 2). These figures clearly show the blocking high at 1000 hPa level and its signature at 500 hPa level over the east Pacific and the west Pacific. There is an interesting difference. In the case of block 1 the configuration is similar to a Ω type blocking while for block 2 it is like a dipole (see Fig. 1.66 of Bluestein 1993). Thus these two blocks, apart from forming in different regions, have different configurations and different durations.

We shall examine the zonal wind distribution (Fig. 3) at 500 hPa for the two cases. This figure shows the occurrence of easterlies in the region slightly to the north of the blocking high confirming the methodology of Lejenäs (1984) for detecting blocking situations. Another interesting feature of Fig. 3 is that the easterlies are weaker in the case of block 1 than in block 2. A careful examination of Fig. 3 shows that in the case of block 2 the subtropical jet and the subpolar jet are located poleward relative to the position of these jets in the case of block 1. In the climatological mean this also happens (Marques 1996). In a recent study Chen and van den Dool (1997) noted that a poleward location of the jet is favorable for a higher incidence of blocking. This explains, at least partially, the higher frequency of blocking over the west Pacific. But the feature relevant for relative difference in the duration of blocks 1 and 2 is the stronger easterlies in the middle and upper troposphere in block 2. In fact the maximum strength of easterlies in block 2 is twice (12 m s\(^{-1}\)) that which occurred in
block 1 (6 ms⁻¹). Thus the stronger easterlies seem to support stronger zonal advection and a shorter duration for block 2 compared to block 1. In order to show that zonal advection for block 2 is in fact stronger, Fig. 4 is prepared. This figure shows the meridional and vertical cross section of a zonal strip wider than the blocks. It can be seen in Fig. 4 that the mean easterlies for block 2 are almost 3 times stronger compared to those of block 1.

3.2 Energetics

Figures 5a, 5b, 5c and 5d show the first four advection terms on the right hand side of Eq.(8) for block 1. It is seen that the values of interaction between the block component and the sea-
Fig. 5. Spatial distribution of the four individual advective terms on the right-hand side of kinetic energy equation (3) in the 30°S–90°S latitude and 175°E–60°W longitude for the period 24 July through 13 August, 1986: (a) $V_1 \cdot A_{0,1}$, (b) $V_1 \cdot A_{1,1}$, (c) $V_1 \cdot A_{2,2}$, (d) $V_1 \cdot A_{1,2}$: Cl = 0.4 x $10^{-3}$ m² s⁻³ and (e) $-V_1 \cdot \nabla \Phi_1$: Cl = 3 x $10^{-3}$ m² s⁻³. Zero contours are suppressed.

Seasonal flow ($V_1 \cdot A_{0,1}$) are largest and thus this interaction is important. Two regions of positive values are seen in Fig. 5a to the southeast and southwest of the blocking high in Fig. 1a. The maximum value in the upstream side of block 1 is more than $0.8 \times 10^{-3}$ m² s⁻³. This is a region of high deformation. We show that the term ($V_1 \cdot A_{0,1}$) contains a deformation term (see equation (11)). Indeed the deformation term also shows positive values in this region (Fig. 7a). Also the term ($V_1 \cdot A_{2,2}$) (Fig. 5c) (self interaction of the high frequency component) is seen to oppose the term ($V_1 \cdot A_{0,1}$). Fig. 5e shows the values of the pressure work term ($-V_1 \cdot \nabla \Phi_1$). The values of this term are in general negative (highest $-3 \times 10^{-3}$ m² s⁻³) to the upstream of the blocking high. South of South America on the downstream the values are positive (highest $3 \times 10^{-3}$ m² s⁻³). This term partly includes the baroclinic processes with conversion between potential and kinetic energies. The maximum negative value indicates that the term redistributes KE downstream.

Figures 6a, 6b, 6c and 6d show the first four advection terms on the right hand side Eq. (8) for block 2. It is seen that the values of interaction between the intraseasonal and the seasonal flow ($V_1 \cdot A_{0,1}$) are positive and large near the block to
the southeast of New Zealand. The values are around $1.2 \times 10^{-3}$ m$^2$s$^{-3}$ over most of the area. This again is associated with deformation as can be inferred from Fig. 7b. In this case also the term $(\overrightarrow{V}_1 \cdot \overrightarrow{A}_{2,2})$ (Fig. 6c) shows positive values to the southeast of New Zealand to the west of the High-Low configuration seen in Fig. 2b and the maximum value is around $1.6 \times 10^{-3}$ m$^2$s$^{-3}$ for block 2. While in the case of block 1 positive and negative values are seen (Fig. 5c) and the values are smaller compared to those of block 2. This probably shows that high frequency components are important for block 2. The term of self interaction of block component $(\overrightarrow{V}_1 \cdot \overrightarrow{A}_{1,1})$, in the case of block 2 (Fig. 6b) shows positive and negative values somewhat akin to a high low configuration noted in Figs. 2a and 2b. Figure 6e shows the values of the pressure work term $(-\overrightarrow{V}_1 \cdot \nabla \Phi_1)$. This shows the redistribution of kinetic energy downstream into the blocking region. A part of it is also associated with the baroclinic process that converts between potential and kinetic energy.

A comparison of the magnitudes of $(\overrightarrow{V}_1 \cdot \overrightarrow{A}_{0,1})$ for blocks 1 and 2 with those of Mak (1991) shows that the values for the SH blockings are lower (about 1/4) compared to those of the North Atlantic block. But the self-interaction term $(\overrightarrow{V}_1 \cdot \overrightarrow{A}_{2,2})$ seems to be comparable. Thus the term which represents the interaction between the block component and the seasonal flow $(\overrightarrow{V}_1 \cdot \overrightarrow{A}_{0,1})$ is very important for the local energetics of the two cases as pointed out by Mak (1991). Using the notation of Mak (1991) this term may be written as follows

$$
\overrightarrow{V}_1 \cdot \overrightarrow{A}_{0,1} = -(\overrightarrow{V}_0 \cdot \nabla) \overrightarrow{K}_1 + \overrightarrow{E}_1 \cdot \overrightarrow{D}_0,
$$

where

$$
\overrightarrow{E}_1 = ((\overrightarrow{V}_1 - \overrightarrow{u}_1 \overrightarrow{v}_1)^2/2, -\overrightarrow{u}_1 \overrightarrow{v}_1),
$$

$$
\overrightarrow{D}_0 = \left[ \begin{array}{c} \frac{1}{a \cos \phi} \frac{\partial u_0}{\partial \lambda} - \frac{1}{a} \frac{\partial v_0}{\partial \phi} - \frac{u_0}{a} \tan \phi \\
\frac{1}{a \cos \phi} \frac{\partial v_0}{\partial \lambda} + \frac{1}{a} \frac{\partial u_0}{\partial \phi} + \frac{u_0}{a} \tan \phi
\end{array} \right].
$$

(11)
Fig. 8. Spatial distribution of the first advective term on the right-hand side of the available potential energy equation (4) \((\bar{v}_1, \bar{a}_{0,1})\) in the 30°S–90°S latitude and for the period (a) 24 July through 13 August, 1986 (175°E–60°W) and (b) 20 June through 29 June, 1986 (130°E–105°W). CI = 0.4 × 10^{-3} \text{ m}^2\text{s}^{-3}. Zero contours are suppressed.

Fig. 9. Spatial distribution of conversion rate from kinetic energy to potential energy \((\bar{w}_1, \theta_1)\) in the 30°S–90°S latitude and for the period (a) 24 July through 13 August, 1986 (175°E–60°W) and (b) 20 June through 29 June, 1986 (130°E–105°W). CI = 0.4 × 10^{-3} \text{ m}^2\text{s}^{-3}. Zero contours are suppressed.

Thus the term \(\bar{v}_1, \bar{a}_{0,1}\) is a combination of two processes 1) a redistribution of the KE of the 1-component due to the advection by the seasonal component and 2) a generation of KE by a barotropic processes given by the term \(\bar{E}_1, \bar{D}_0\). The \(\bar{E}_1\) vector is a measure of the local shape and orientation of the block component of the flow and the \(\bar{D}_0\) vector is a measure of the deformation field of the seasonal flow component. As discussed by Mak and Cai (1989) and Mak (1991), the term \(\bar{E}_1, \bar{D}_0\) can produce a net increase of 1 component of KE in the domain at the expense of the seasonal flow.

Figure 7 shows the values of \(\bar{E}_1, \bar{D}_0\) for block 1 (Fig. 7a) and for block 2 (Fig. 7b). It can be noted that the block disturbance extracts kinetic energy (positive values) from the seasonal diffluent jets (Figs. 5a and 6a) in both cases of blocks 1 and 2. Positive values are seen in Figs. 7a and 7b to the east and west of the blocks. In the case of block 2 higher values are found to the south of New Zealand, which is probably due to higher deformation. The distribution of the advection of 1-component energy by the seasonal average flow is the difference between Figs. 5a and 7a for block 1 and the difference between Figs. 6a and 7b for block 2. This shows that redistribution of kinetic energy of the block component is higher for block 1 than block 2.
Values of $\vec{E}_1, \vec{D}_0$ for blocks in the SH are comparable to those of Mak (1991) for the North Atlantic block. Since values of $\vec{V}_1, \vec{A}_{0,1}$ for the North Atlantic case are more, it can be inferred that advection by seasonal flow is more for the North Atlantic case. Figures 8a and 8b show the advective term $\theta_1 B_{0,1}$ for blocks 1 and 2 respectively. Positive values (around $2.4 \times 10^{-3}$ m$^2$s$^{-3}$) are seen on the upstream side of block 1 and the south of New Zealand (maximum $1.6 \times 10^{-3}$ m$^2$s$^{-3}$) in block 2. These positive values indicate that this blocking disturbance gains potential energy from the seasonal mean baroclinic field. It can also be seen that the areal average in Fig. 8a is positive since the negative values are smaller and occupy less area. The other advection terms (not shown) are generally small. Figures 9a and 9b show the conversion rate between KE and PE of the 1-component $\vec{K} \cdot \vec{V}_1$. Mostly negative values, indicating conversion from $P_1$ to $K_1$ are seen on the upstream side of the blocks 1 and 2. In the case of block 1 negative values are of the order $-0.8 \times 10^{-3}$ m$^2$s$^{-3}$, which is comparable to other values (major processes). In the case of block 2 the values are around $-0.4 \times 10^{-3}$ m$^2$s$^{-3}$. This shows that for these two blocks baroclinic processes are also important. Thus in the case of blocks 1 and 2 both barotropic processes (as indicated by the term $\vec{V}_1, \vec{A}_{0,1}$) and baroclinic processes (as indicated by the term $\vec{K} \cdot \vec{V}_1$) seem to be important. In the case of the North Atlantic block examined by Mak (1991), he noted that baroclinic processes are of minor importance compared to barotropic processes. Further, the conversion from $P_1$ to $K_1$ is higher in block 1 than in block 2 and the duration of block 1 is longer.

4. Summary and conclusions

Recently a new region of blocking in the southeast Pacific has been noted by some authors (Rutllant and Fuenzalida 1991; Sinclair 1996; Marques 1996 and Renwick 1998). The results of the present study confirmed that there are two principal regions of blockings in the SH, namely the southeast and southwest Pacific. A comparison of blockings in these two regions showed several interesting characteristics. Austral winter (June, July and August) is the season of highest blocking in both these regions but blockings of shorter duration (11 days or less) occur more frequently over the southwest Pacific, whereas long-lasting blockings (of more than 11 days duration) occur only over the southeast Pacific.

Two blocks in the southeast and southwest Pacific are analysed in detail to find out the possible causes for the differences in their characteristics, particularly to examine why blocks in the southeast Pacific last longer. It is found that the easterlies in the split jet region are stronger for the west Pacific block of shorter duration. This seems to be responsible for stronger zonal advection and shorter duration, at least for this block. It remains to be seen whether similar features occur for other blocks of the southwest Pacific. Also it is noted that there is a general southward shift of the configuration of the subtropical and subpolar jets in the case of the southwest Pacific block, which seem to favor a higher frequency of blocking (Chen and van den Dool 1997).

Analysis of local energetics of the two blocks showed that the generation of kinetic energy by barotropic processes on the intraseasonal time scale $\vec{E}_1, \vec{D}_0$ is higher for the southwest Pacific block than for the southeast Pacific block. The block disturbances in both the cases extract barotropically kinetic energy from the seasonal diffusive jet at almost the same rate. This shows that the redistribution of kinetic energy within the block region is more for the southeast Pacific block than for the southwest block. The pressure work process and the baroclinic conversions are also important for both the blocks. However, the potential energy to kinetic energy conversion on the intraseasonal scale ($P_1$ to $K_1$) is more for the southeast Pacific block. The high-frequency eddies play an important role in the maintenance of blocks.

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