20th Conference on Weather Analysis and Forecasting / 16th Conference on Numerical Weather Prediction, 11 - 15 January, 2004, Seattle Washington

P1.21 PLANETARY AND SYNOPTIC SCALE INTERACTIONS IN SOUTHEAST PACIFIC BLOCKING USING POTENTIAL VORTICITY DIAGNOSTICS.

Anthony R. Lupo,* John P. Burkhardt, Erin K. Gilliland

Department of Atmospheric Science
389 Mc Reynolds Hall
University of Missouri-Columbia
Columbia, MO 65211

1. INTRODUCTION

Atmospheric blocking episodes have been studied extensively in the Northern Hemisphere (NH) over the past several decades in an attempt to understand the synoptic and dynamic processes that contribute to their existence, strength, and duration (e.g., Shutts 1983; Tracton 1990; Lupo 1997 - *hereafter L97*; Li et al. 1999; Lupo and Bosart 1999 – *hereafter LB99*; Weidenmann et al 2002 – *hereafter WLMT02*). It has been generally accepted, since earlier studies suggested, that blocking occurs as the result of interactions between amplifying synoptic-scale waves and a quasi-stationary planetary-scale wave (e.g., Kalnay and Merkine, 1981; Frederiksen, 1982; Shutts, 1983). Operationally oriented studies have also primarily been performed with the goal of improving medium and long-range forecasts (e.g., Li et al. 1999; Watson and Colucci, 2002; Pelly and Hoskins 2003b). A better understanding of blocking events would be an important element to improving medium and long range forecasting, as present forecast models routinely under-predict their duration and frequency (Watson and Colucci, 2002; Pelly and Hoskins, 2003b).

Climatological studies of blocking in the Southern Hemisphere (SH) demonstrate that blocking events are less common (e.g. Lejenas, 1984; Renwick 1998), and are weaker (e.g. WLMT02) throughout the SH when compared to their NH counterparts. WLMT02 implied that the relative roles in the interaction between planetary-scale and synoptic-scale waves may partially explain the relative paucity of SH blocking. However, the same study demonstrated that blocking events in the South Pacific sector occur with equal frequency and persistence as those in the northern Pacific. Trenberth and Mo (1985) also suggested that the difference in climatological behavior of blocking events between the two hemispheres may be a result of differences in the dynamics that develop and maintain blocking events.

Briefly, blocking events are primarily supported by the influx of anticyclonic vorticity advection into the blocking region by an amplifying synoptic-scale wave, however a few studies (e.g., Tsou and Smith, 1990; Alberta et al., 1991; L97) suggested a role for temperature advections as well. The dynamic forcing mechanisms that contribute to the growth and maintenance of blocking events have also been partitioned into synoptic-scale, planetary-scale, and interaction processes in several studies as well (e.g., Tsou and Smith, 1990; Tracton, 1990; Marques and Rao, 1999; Colucci, 2001). These studies have demonstrated that the importance of synoptic and planetary-scale forcing was different for the growth and maintenance of north Atlantic and North Pacific blocking events (e.g., Nakamura et al., 1997; Colucci, 2001). Nakamura et al. (1997) found that north Atlantic blocking events are primarily dependent on planetary-scale processes while north Pacific events are more dependent on synoptic-scale fluxes of potential vorticity (PV) for growth and maintenance. Lupo and Smith (1995b) (*hereafter LS95b*) and Colucci (2001) found that north Atlantic blocking events were also dependent on interactions between synoptic and planetary-scale processes. L97 also demonstrated the importance of synoptic-scale processes relative to the planetary-scale component in the north Pacific region.

The objective of this research was to examine two blocking events which occurred in the south Pacific during July and August 1986 in order to determine which scales predominated the advection of PV into these two events, and then to compare the results with similar studies of NH blocking events. The hypothesis is that synoptic-scale PVA will be more important for SH blocks than it is for NH blocks, especially in the north Atlantic, as zonal flow in the south Pacific may not be as conducive to block formation. This scenario would be similar to the numerical study of Shutts (1983), in which synoptic-scale disturbances generated by a wavemaker were alone sufficient to generate a blocking event. Then, an examination of the nature of the interactions themselves will be examined in order to determine if these interactions represent the superposition of scales only or are synergistic (non-linear) interactions.

2. METHODS AND ANALYSES

2.1. Analyses

The data set used here was the National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) gridded re-analyses (Kalnay et al., 1996). These data were archived at NCAR and obtained from the mass-store facility in Boulder, CO. These re-analyses were the 2.5^o by 2.5^o latitude-longitude analyses available on 17 mandatory levels from 1000 to 10 hPa at 6-h intervals. These analyses include the standard atmospheric variables geopotential height, temperature, relative humidity, vertical motion, u and v wind components and surface information. The mandatory level data were interpolated quadratically in ln [p] to 50 hPa level-increments, and these more closely resemble raw sounding information (LB99).

**Corresponding author address:* Anthony R. Lupo, Department of Atmospheric Science, 389 McReynolds Hall, University of Missouri-Columbia, Columbia, MO 65211. E-mail: LupoA@missouri.edu.

2.2. Methods

The blocking criterion of Lupo and Smith (1995a) (*hereafter LS95a*) was used here, and this can be summarized as a combination of the Rex (1950) subjective criterion and the Lejenas and Okland (1983) objective criterion, with the exception that a "block" is defined as persisting for five days or more. The Rex (1950) criterion used subjective map analysis, and in his study it was desirable that highly meridional split flow persists for 10 days or more. The Lejenas and Okland (1983) criterion is a zonal index plotted on a time-longitude or Hovmoller diagrams, and persistent weak or negative "non-translating" values can also represent blocking (LS95a). A thorough description of the blocking criterion used here can also be found in WLMT02.

The diagnostic techniques used here are described in LB99. Briefly, PV framework was used as the analysis and map display tool, which included the use of dynamic tropopause (DT) maps (Morgan and Neilsen-Gammon, 1998). PV was calculated on 300 hPa surfaces since these PV fields are similar to those calculated on an isentropic surface (e.g., LB99). This PV calculation, although not strictly conserved, is still an effective diagnostic tool and is given here as:

$$PV = g\left[\hat{k}\cdot\left(\frac{\partial\vec{V}}{\partial p}\times\nabla\theta\right)+\zeta_a\frac{\partial\theta}{\partial p}\right] \quad (1),$$

where ζ_a is the absolute vorticity vector along the vertical axis, θ is potential temperature, g is acceleration due to gravity and V is horizontal wind speed, respectively. The change in block center point PV was calculated assuming that this quantity is conserved (e.g., LB99). The development of a particular blocking event is equivalent to the advection of PV,

$$\frac{\partial PV}{\partial t} = -\vec{V}\cdot\nabla PV \quad (2).$$

In examining these blocking events and assessing the role of the synoptic-scale versus that of the planetary-scale forcing, the methodology of LS95b, or Colucci (2001) (*and references therein*) was used. The filtered analyses were used in partitioned forms of (1) and (2) derived by substituting for each variable X;

$$X = \overline{X} + X' \quad (3),$$

where the first (second) term on the right-hand-side of (3) is the planetary (synoptic)-scale component, respectively. Thus, a scale-partitioned form of (2) is given by;

$$\frac{\partial PV}{\partial t} = \left.\frac{\partial PV}{\partial t}\right|_P + \left.\frac{\partial PV}{\partial t}\right|_S + \left.\frac{\partial PV}{\partial t}\right|_I = P+S+I \quad (4),$$

where P, S and I are the planetary-scale, synoptic-scale, and scale interaction PV advections, respectively. The forcing term in (2), which is a product term, mathematically gives rise to scale interaction terms (I) in (4) via the product rule (e.g., Colluci, 2001).

A second-order, two-dimensional Shapiro (1970) filter was used 1250 times on the variables in the data set in order to separate the planetary-scale wavelengths from the synoptic-scale wavelengths. Applying this filter results in a response function, which retains 2%, 44%, 80% of the signal for waves having a wavelength of 3000, 4500, and 6000 km at 45 degrees N (or S) latitude, respectively. More details regarding the use of the filtering procedure can be found in LS95b.

3. SYNOPTIC AND DYNAMIC ANALYSIS

3.1 climatological comparison and synoptic analysis

The blocking events chosen for study were two southeast (SE) Pacific region events that occurred during a blocking episode that involved three separate events in July and August 1986. The climatological characteristics of the two SE Pacific events are shown in Table 1, and these blocking events Figs. 1,2) were chosen for study since they occurred close together in space and time. The other event occurred over the far southwest Pacific and Australian region during the middle of August. This time of the year represents the SH winter season, which is the part of the season when blocking events occur most frequently and are most persistent and strongest. These blocking events were classified as strong blocking events (e.g., WLMT02) when compared to their SH counterparts, and can be studied as individual events since each event imparted a distinct signature on a Hovmoller plot.

Table 1. The characteristics of the two blocking events chosen for study here (*for BI see* WLMT02).

Event	Dates (Start / Termination)	Days	Block Intensity (BI)
1	23 Jul – 2 Aug	10.5	3.64
2	3 Aug – 16 Aug	13.5	4.06

The development phase of the first blocking event possessed all the characteristics of blocking events studied by LS95b and references cited therein. On 1200 UTC 21 July 1986, an upstream surface cyclone was approximately 25 degrees longitude upstream of the blocking system, which was within one-half wavelength (e.g., LB99). This cyclone event was strengthening and slowly moving poleward. At the same time, the 500 hPa ridge was also intensifying and met the blocking criteria used here by 0000 UTC 23 July 1986. The synergistic strengthening of this cyclone and synoptic-scale wave (as shown by many of the referenced papers), the quasi-stationary downstream ridge, and the jet maxima on the western (and southwestern) flank of the blocking event likely contributed to enhancing the anticyclonic vorticity advection into the blocking region These signatures are key components in the development or intensification of blocking events. A second cyclone of note was just downstream of the developing block. This downstream and moderately equatorward position of the cyclone was also important for contributing to the development of the block due to its close proximity to the subtropical jet stream. The contribution from downstream forcing has also been suggested to play a role in block development (e.g., Tracton, 1990).

Then, two prominent cyclones developed upstream of the block around 0000 UTC 26 July, and the first intensified and moved eastward across the base (equatorward side) of the block. It reached peak intensity of roughly 986 hPa by 1200 UTC 27 July. The eastward movement of this cyclone across the base of the block and intensification of the blocking anticyclone (characterized by rising central heights – Fig. 3) lead to the event becoming a “blocking-dipole” (Fig. 1). Again, this continued interaction with subsequent cyclones was similar to the many studies that demonstrate this interaction in NH events (e.g., Tracton, 1990; LB99).

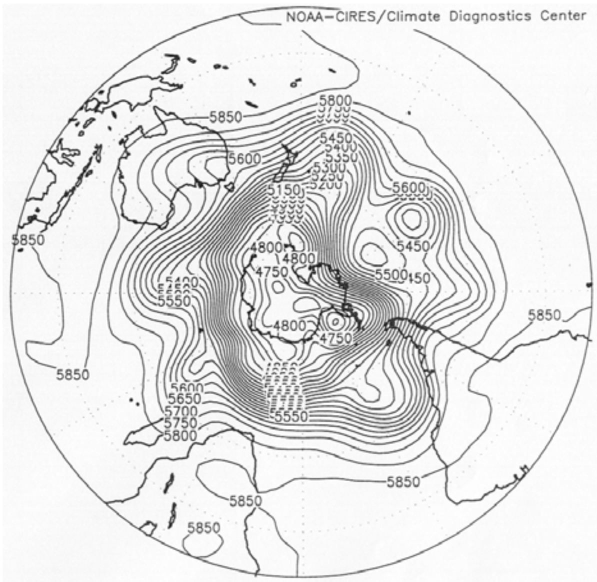

Figure 1. The 0000 UTC 28 July 1986 500 hPa NCEP re-analysis plot for the Southern Hemisphere. The contour interval is 60 dam.

This blocking event decayed during the latter two days of July and into 1 August, a period which was characterized by falling central heights (Fig. 3). The decay period was not associated with upstream cyclones. This blocking event remained quasi-stationary during its lifecycle, being located near 140^o W at onset, and near 100^o W during the decay period. An examination of the 12 hourly 500 hPa and 1000 hPa synoptic maps through this period (not shown) would demonstrate that the emergence of a second event around 150^o W, or upstream of the event. This event became dominant and merged with the remaining downstream ridge That the decaying event was not associated with upstream cyclones, which was likely due to the emergence of the second block, was similar to the decay of the Atlantic case in L97. This type of decay differs from that described by LB99, which described the decay of a blocking anticyclone as the result of an upstream cyclone developing in close proximity to the blocking center.

The second blocking event began developing during the period from 1 to 3 August, and the ridging amplified poleward and expanded in scale eventually filling the region occupied by the decaying downstream ridge. In order to bolster the contention that this second event was a distinct event, it was found that the event spent most of its lifecycle configured as a Rex-type (omega-type) blocking event rather than a blocking dipole. In addition, this event was stronger overall than the first blocking event (Table 1, Fig. 3), which is also implied by the higher central heights for this event’s lifecycle. The central heights are proportional to block intensity (BI – see WLMT02). The dynamic analysis will also demonstrate that this event was a separate blocking event.

This event underwent two intensification periods after onset. The first intensification phase (3 - 5 August) of this block was associated with two upstream cyclones. The 1200 UTC 7 August 1986 time-period corresponds to the time just before the start of the second intensification period. The first cyclone had moved poleward and decayed, while a new cyclone began developing on the upstream side of the block. This new cyclone became the dominant upstream cyclone on 8 August through 12 August. It is interesting to note that the maximum height value of the block was attained when the upstream cyclone reached its lowest central pressure. LS95) found a correlation between block intensity and cyclone deepening in NH blocking, and this occurrence suggests a similar correspondence for SH events.

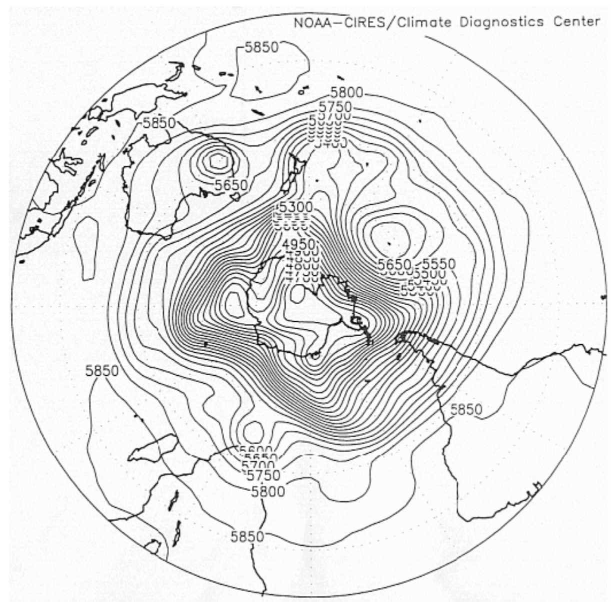

Figure 2. As in Fig. 1, except for 0000 UTC 5 August 1986.

At the start of decay (12 August through 16 August), another new cyclone retrograded due west to a position just equatorward of the block, creating a weak dipole situation. By 0000 UTC 15 August 1986, the cyclone had retrograded to a position approximately 20^o longitude upstream of the blocking center. This configuration is similar to that of LB99, but different from that of the first blocking event.

3.2. dynamic analysis

In order to examine the overall dynamic behavior of this event, a phase diagram is used in order to examine the behavior of the Southern Hemispheric flow. This is a standard technique in dynamic analysis of physical systems (e.g, Lorenz, 1963; Mokhov et al. 2003 and references therein) and is based on the principle that a well-behaved oscillating +system such as a swinging pendulum (without any damping mechanism) would result in a circular set of trajectories on a phase diagram of pendulum position versus the change in position with respect to time. The balance of forces that describes such a simple system results in a Sturm-Liouville equation of the form;

$$\ddot{X} + \omega^2 X = 0 \quad (5)$$

which has a general solution of the form;

$$X(t) = A(t)\sin[\omega(t) + \phi(t)] \quad (6)$$

where X(t) represents a time series of some variable, A(t) the amplitude, and ω(t) the frequency, and ϕ(t) the initial phase in the oscillating system.

Fig. 4 is a plot of the mean 500 hPa planetary-scale height versus the change in the mean 500 hPa planetary-scale height with respect to time. The height fields were averaged over a stationary box within the blocking region that is 30^o latitude by 40^o longitude. The diagram in Fig. 4 looked similar regardless of the size of the box used within the SH mid-latitude flow with only changes in the magnitude of the height tendency being noted (not shown), that is, the height tendencies were larger in general for smaller boxes. The planetary-scale height fields were used in order to eliminate synoptic-scale and sub-synoptic-scale processes.

The period of time covered in Fig. 4 is mid-July through mid-August. The trajectory plotted in Fig. 4 suggests that the large-scale flow field was relatively stable, or in equilibrium, during the first blocking event (near "S" on the diagram), and which likely represents a geostrophically (or quasi-geostrophically) balanced state. As the heights rose toward the end of the lifecycle of blocking event one, the diagram suggests that a new hemisphere-wide balanced state was found (to the right of S), which was not dramatically different from that of a few days previous. During this transition time, the first blocking event decayed, and the second blocking event developed and merged with the remnants of the first event. The event in the southwest Pacific, which was not studied extensively here also emerged after this time. Finally, there was a dramatic change in the hemispheric flow regime late in the period as suggested by a new equilibrium, which is apparently being established near "E" on the diagram. This coincided with the demise of the second blocking event studied here, the blocking event in the southwest Pacific region, and also the abrupt end of the approximately 30 day SH blocking episode.

A brief analysis of the total PV tendencies will be presented here since many of the findings mirror those of previous studies. The total PV tendencies presented in Table 2 and Table 3 are nine point averaged center point PV tendencies calculated using Eq. 2. In order to filter out small scale and computational noise, the center point tendencies were averaged over particular phases of each blocking event following, for example, L97. Each phase of the block lifecycle would correspond to the center-point height tendencies as implied by Fig. 4. Table 2 and 3 demonstrate that, as expected, intensification (decay) periods corresponded to increasing (decreasing) PV values since, in the SH, PV is a negative quantity. Increasing (decreasing) PV in the SH represents the positive (negative) advection of PV in the absence of non-conservative forcing mechanisms (e.g., diabatic heating or friction) or sources and sinks of PV, and higher PV values or anticyclonic (cyclonic) PV advection are associated with block intensification (decay). Positive PV advection during block intensification (not shown) into the block center (in the SH) was associated with block intensification. Also, high θ (low pressure) advection on the dynamic tropopause (DT) were also associated with block intensification. The block center was also located within the equatorward exit region of the poleward jet maximum, and this region would be favored for anticyclogenesis in a SH straight line model jet maximum.

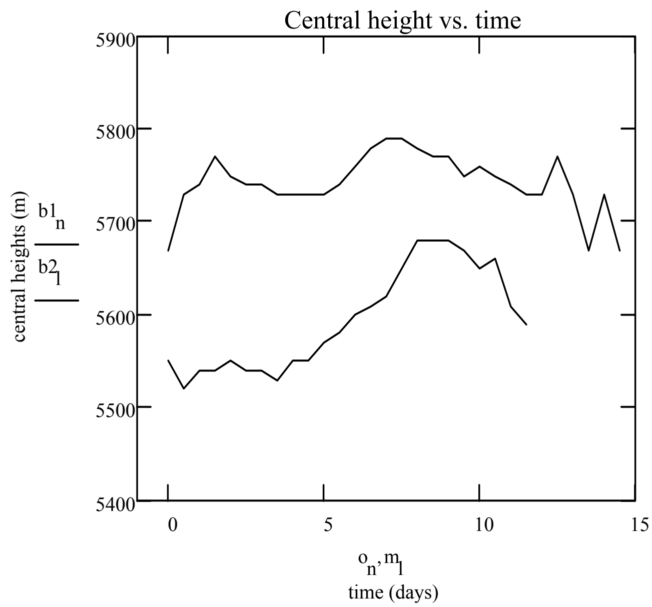

Figure 3. A graph of central height versus time for the first blocking event (solid), and the second blocking event (dashed). Time on the abscissa is days following onset.

When the PV tendencies were partitioned into their planetary, synoptic, and interaction components (Tables 2 and 3), the synoptic scale PV tendencies at the block center point were generally positive contributors throughout the block, while the interaction tendencies were a negative contributor, or countered the block development. The planetary-scale PV tendencies were smaller and generally negative (positive) for the first (second) blocking event. These findings are also similar to those of L97 or LS98, who found that the synoptic-scale tendencies were generally larger than those on the planetary-scale for NH blocking events. These studies suggested that intensification and decay was generally governed by the combined total of the synoptic and interaction tendencies, especially for Pacific region blocking events. They also suggest that, in general, the synoptic-scale and interaction tendencies worked together, especially during the intensification periods. The results implied that the interactions between the planetary-scale and synoptic-scale were synergistic. It is apparent that the synoptic-scale and the interaction tendencies were of opposite sign throughout each block life cycle. Thus, the interactions between the planetary and synoptic scales were not necessarily beneficial to each other in these two SH blocking events.

In order to investigate further the interactions between scales in these two events, the center point PV tendencies for each scale were correlated versus each other and versus the total PV tendency. Only the synoptic-scale and the interactions were highly correlated with each other, especially for the second event, and the correlation was negative (Fig. 5). This correlation was also evident in examining plots of the PV tendencies with time throughout the block lifecycles. The correlations are statistically significant at the 95% confidence level and these were tested using the Z-score test assuming the null-hypothesis, or that no relationship is assumed to exist between the two *a priori*. It is suggested here that, unlike NH events, the interactions in SH blocking events may not be synergistic and this result may explain the paucity and/or the relative feebleness of SH blocking events when comparing to their NH counterparts. These issues will be discussed further below.

Table 2. Average scale partitioned PV (by wavelength) and total PV x 10^{-12} PVU s^{-1} for each blocking phase in blocking event one.

Phase	P	S	I	Total
Pre-block	1.02	0.20	-1.13	-0.1
Onset/Maint.	0.27	-0.21	-0.45	-0.22
Intensification	0.34	-0.11	-0.42	0.20
Decay	0.35	-0.075	-0.30	-0.175
Bock Life	0.34	-0.079	-0.47	-0.039

Table 3. Same as Table 2, except for blocking event two.

Phase	P	S	I	Total
Pre-block	0	0.075	-0.125	0.075
Onset/Maint.	0.371	0.157	-0.23	-0.028
Intensification	-0.70	0.20	0.53	0.40
Decay	0.49	-0.063	-0.036	-0.018
Bock Life	0.174	0.015	-0.162	0.059

4. DISCUSSION

In section 3.1, it was shown that the synoptic evolution of two SH blocking events was similar to that of their NH counterparts in that the upstream forcing associated with the development of surface cyclones, the concurrent amplification of the associated synoptic-scale upper air wave, and phase locking with a quasi-stationary planetary-scale wave contributed to the onset and intensification of blocking. Many of the studies referenced here have suggested that this model which represents block onset is associated with the influx of anticyclonic vorticity or lower potential vorticity air for the NH. Subsequent upstream cyclone development contributes to the further intensification of blocking events well into their life time, and that the same model describes the cycle of intensification and weakening often observed in longer lived blocking events (e.g., Tracton, 1990; L97; LB99). Then, the synoptic evolution of these observed SH events was also similar to the early model results of Kalnay and Merkine (1981), Frederiksen (1982), or Shutts (1983), which demonstrated the importance of the contribution of synoptic transients to block formation and maintenance.

Further, an analysis of the individual upstream cyclone events during the block lifecycle demonstrated that the results of LB99 apply to these two SH events as well. This study suggested that cyclonic development within one-half to one-quarter wavelength upstream of the block center (or ridge axis) contribute to the intensification of the event itself. In a manner similar to the block studied in LB99, synoptic-scale cyclogenesis events further upstream were too far upstream to impact block development while cyclogenesis events too close to the block center were detrimental to the maintenance of the blocking event. Thus, the same key features which can be identified on routinely available maps by operational community for forecasting the onset and intensification of blocking in the NH can also be identified for SH.

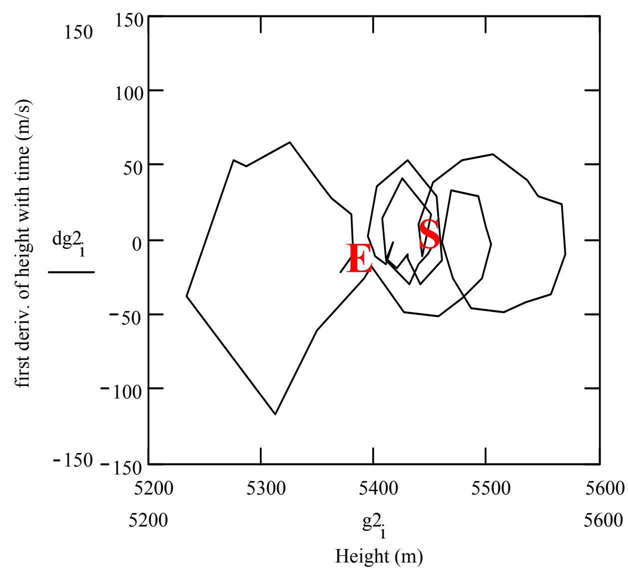

Figure 4. A phase diagram of mean 500 hPa height (m) (abscissa) and the first derivative of mean height with respect to time (m day^{-1}) (ordinate) for a stationary box (130° W to 170° W and 30° S to 60° S) in the mid-latitude Southern Hemisphere flow. The start and end points of the trajectory are marked S and E, respectively.

The synoptic analysis suggested that as long as there was upstream forcing feeding into the blocking region, the events persisted. The phase diagram in Fig. 4 suggests, however, that the blocking episode came to an abrupt end when a new equilibrium was being established in the SH flow in mid-to-late August 1986 near point (E). A re-analysis of the NH events studied by LS95b and L97 suggested a similar recurrence for their events. For the NH events, the wave-amplitude index (e.g., L97) was used in order to identify periods of large-scale flow that were described as "high" or "low" amplitude flow, and which represents "vacillation" in the mid-latitude wave amplitudes as discussed by Lorenz (1963), (more recently) Haines and Holland (1998), and others. These blocking events, generally, did not survive the transition from one quasi-equilibrium state to another, especially if the transition in the planetary-scale flow is large. This may be due to a breakdown in the planetary-scale jet stream as it becomes unstable and transitions from one equilibrium to another. It also suggests that even if the role of planetary-scale PV forcing is small, the planetary-scale provides a key contribution to block maintenance even if this contribution is "preconditioning" or providing a favorable background for block development as posited by several references in this work.

An examination of the partitioned PV processes revealed that the character of the scale-interactions was different when comparing NH blocking to SH events. Previous studies of the wave-wave interactions involved in blocking lifecycles focused on the large-scale. For example, Gottwald and Grimshaw (1999a,b) discuss blocking from the perspective of the interactions between long waves and/or solitary waves ("solitons") when explaining the dynamics of blocking events. Other recent studies have focused on the interactions between planetary and synoptic scale waves, or more specifically, the phase locking of the two scales. The studies referenced above for NH events suggest that the wave-wave interactions between the planetary-scale wave and the amplifying synoptic-scale wave were critical for block onset or further development, and as such represent a non-linear or synergistic amplification. This would occur if amplification or block intensification occurred such that the planetary-scale, synoptic-scale, and interactions all contributed positively to wave development. This is especially true for the north Pacific blocking event studied in L97. This type of mutually beneficial wave-wave interaction between the different wave scales in the intensification of blocking events shares many of the characteristics of resonant Rossby wave triads as described by Lynch (2003), and which is analogous to a swinging spring system. However, that study also concedes that there are potential difficulties in providing an atmospheric analog to their system.

Blocking events also intensified in the NH as long as either the synoptic or planetary-scales along with the positive contribution from the interaction term results in block development (e.g., LS95a; Colucci, 2001). This situation would also represent a non-linear amplification between ridges of two different scales, and the positive contribution from the synoptic-scale and interactions are similar to the observational results of L97 for Euro-Atlantic blocking. Thus, the onset and intensification of NH events are generally associated with non-linear amplification between the two scales reflected by the positive contribution from the interaction term, and not just the superposition of the amplifying synoptic-scale wave and the quasi-stationary planetary-scale wave as they locked into phase. In either case described above, there is a mutually beneficial interaction between the scales.

This contrasts with the result found for the two SH events examined here. As shown in section 3.2, the synoptic and interaction terms were generally of opposite sign throughout the block lifecycles. Thus, there was generally little contribution to ridge or block development that occurred as a result of the interaction between the two scales during onset or intensification periods. In the SH then, blocking would appear to be generally a manifestation of the superposition between the waves of two different scales (constructive interference) as they lock into phase. Since there appears to be little (or less frequent) synergistic link between the synoptic and planetary-scales, this may account for the relative infrequency of blocking in the SH as well as the fact

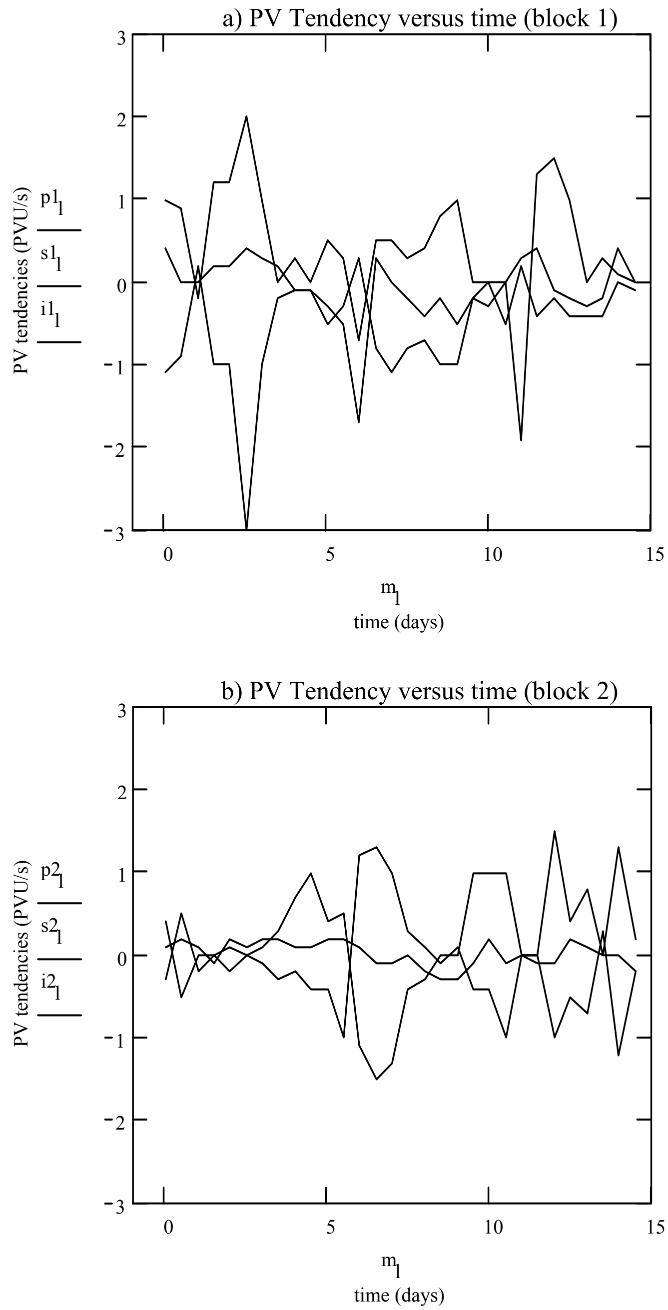

Figure 5. A graph of PV tendencies versus time for the a) first blocking event, and b) the second blocking event, where the solid, dotted, and dashed lines represent the planetary-scale, the synoptic-scale and the interactions, respectively.

they tend to be weaker and less persistent than Northern Hemisphere events as found by the climatological study of WLMT02. Also, they found a correlation between the intensity and duration of NH events, which provides further evidence that the mutual wave-wave interactions in these events were beneficial to the blocking events, whereas no similar correlation found for SH events in that same study would support the conclusion here that these events were the result of the superposition of each scale.

5. SUMMARY AND CONCLUSIONS

The planetary and synoptic scale interactions between two blocking events in the southeast Pacific Ocean region were studied here using the NCAR NCEP re-analyses and the PV system as the diagnostic tool. These two events were stronger and more persistent than typical SH events, and as such provided this study with a clear portrayal of their synoptic and dynamic lifecycle. The forcing contributing to the maintenance of these two blocking events were studied by Marques and Rao (1999), and they found that synoptic-scale transients made important contributions to the maintenance of these two events, and thus, only comment qualitatively on the interactions between these two events.

A synoptic analysis demonstrated that these blocking events followed the same pattern as many observational and model studies of NH events, or that upstream cyclogenesis and the associated synergistically amplifying short wave phase locking with a quasi-stationary planetary-scale wave contributed to the onset and further intensification of these events. Block maintenance or decay occurred when there was no contribution from these upstream events, whether they occur too far upstream of the blocking event or too close to the center point. Thus, those features that can be identified in an operational environment and that contribute to the block lifecycle for NH events can also be identified in the SH.

The dynamic analysis produced a couple of key results. First, it appeared that the SH blocking episode of July and August 1986 came to an abrupt end when the planetary-scale flow transitioned from one equilibrium state to another that was greatly different from the blocked state. A re-analysis of some NH events implied a similar phenomenon could be identified in these previously studied events. This result is consistent with one of the conclusions of Haines and Holland (1998), whose model results lead them to speculate that blocking regimes may persist as long as the large-scale flow remains balanced and does not become unstable and break down or transition to a new state. Then, the importance of the planetary-scale in preconditioning or providing a favorable background is confirmed for the SH, even if the individual scale-partitioned PV tendencies are small.

A second key result is that the synoptic-scale was the largest and most important contributor to block onset and maintenance. This result is similar to that found for studies of north Pacific region blocking events (e.g., L97; or the continental region blocking event studies by LB99), and reinforces the importance of amplifying synoptic-scale transients in the maintenance of blocking events as found by many studies for the NH.

The final key result was that, in spite of the importance of synoptic-scale transients in Pacific region blocking events, the nature of the wave-wave interactions between the planetary and synoptic-scales may be different in each hemisphere. In the NH, the interaction component of the forcing tends to be positive suggesting that the phase locking between the planetary-scale wave and the amplifying synoptic-scale wave takes place in a non-linear or synergistic fashion (active interaction). In these two SH events examined here, the interaction component of the PV tendency correlated negatively with the synoptic-scale component, and were most often opposing block intensification. This indicates that the phase locking between the scales generally resulted in the superposition of the two waves of different scales, but nothing more. In conjunction with the climatological results of WLMT02, this difference in the behavior of planetary-synoptic-scale interactions may account for the tendency of SH blocking events to occur less often, and be less persistent and intense than their NH counterparts.

6. ACKNOWLEDGMENTS

The authors would like to thank Dr. Patrick Market and Dr. Neil Fox, University of Missouri Department of Atmospheric Science, and Dr. Chris Wikle, University of Missouri Department of Statistics for their comments on earlier versions of this work. Also, we would like to give a special thank you to Dr. Wikle for his help in gaining access to the NCAR-NCEP re-analysis data.

7. REFERENCES

Alberta, T.L., S.J. Colucci, and J.C. Davenport, 1991: Rapid 500 mb cyclogenesis and Anticyclongenesis. *Mon. Wea. Rev.*, **119**, 1186 – 1204.

Colucci, S.J., 2001: Planetary-scale preconditioning for the onset of blocking. *J. Atmos. Sci.*, **58,** 933 – 942.

Frederiksen, J.S., 1982: A unified three-dimensional instability theory of the onset of blocking and cyclogenesis. *J. Atmos. Sci*., **39**, 969 – 982.

Gottwald, G., and R. Grimshaw, 1999a: The formation of coherent structures in the context of blocking. *J. Atmos. Sci.*, **56,** 3640 – 3662.

Gottwald, G., and R. Grimshaw, 1999b: The effect of topography on the dynamics of interacting solitary waves in the context of atmospheric blocking. *J. Atmos. Sci.*, **56,** 3663 – 3678.

Haines, K., and A.J. Holland, 1998: Vacillation cycles and blocking in a channel. *Quart. J. Roy. Meteor. Soc.*, **124**, 873 – 897.

Kalnay, E., and L.O. Merkine, 1981: A simple mechanism for blocking. *J. Atmos. Sci.*, **38**, 2077 – 2091.

Kalnay, E., and Co-authors, 1996: The NCEP/NCAR 40-year reanalysis project. *Bull. Amer. Meteor. Soc.*, **77**, 437-471.

Lejenas, H., 1984: Characteristics of Southern Hemisphere blocking as determined from a time series of observational data. *Quart. J. Roy. Meteor. Soc.*, **110**, 967 - 979.

Lejenas, H., and H. Okland, 1983: Characteristics of Northern Hemisphere blocking as determined from a long time series of observational data. *Tellus*, **35A**, 350 – 362.

Li, Z., A. Barcilon, and I.M. Navon, 1999: Study of block onset using sensitivity perturbations in climatological flows. *Mon. Wea. Rev.*, **127**, 879 - 900.

Lorenz, E.N., 1963: Deterministic nonperiodic flow. *J. Atmos. Sci.*, **20**, 130 - 141.

Lupo, A.R., 1997: A diagnosis of two blocking events that occurred simultaneously over the mid-latitude Northern Hemisphere. *Mon. Wea. Rev.*, **125**, 1801 – 1823.

Lupo, A.R., and L.F. Bosart, 1999: An analysis of a relatively rare case of continental blocking. *Quart. J. Roy. Meteor. Soc.,* **125***,* 107 - 138.

Lupo, A.R., and P.J. Smith, 1998: The interactions between a mid-latitude blocking anticyclone and a synoptic-scale cyclone occurring during the summer season. *Mon. Wea. Rev.*, **126**, 503 - 515.

Lupo, A.R., and P.J. Smith, 1995a: Climatological features of blocking anticyclones in the Northern Hemisphere. *Tellus*, **47A**, 439 – 456.

Lupo, A.R., and P.J. Smith, 1995b: Planetary and synoptic-scale interactions during the life cycle of a mid-latitude blocking anticyclone over the North Atlantic. *Tellus*, **47A**: *Tellus Special Issue: The life cycles of extratropical cyclones*, 575 – 596.

Lynch, P., 2003: Resonant Rossby wave triads and the swinging spring. *Bull. Amer. Meteor. Soc.,* **84,** 605 – 616.

Marques, R.F.C., and V.B. Rao, 1999: A diagnosis of a long-lasting blocking event over the Southeast Pacific Ocean. *Mon. Wea. Rev.*, **127,** 1761 - 1776.

Mokhov, I.I., D.V. Khvorostyanov, and A.V. Eliseev, 2003: Decadal and Longer-term Changes in ENSO Characteristics. *I. J. Climatol., in press.*

Morgan, M.C., and J.W. Nielsen - Gammon, 1998: Using tropopause maps to diagnose midlatitude weather systems. *Mon. Wea. Rev.*, **126**, 2555 - 2579.

Nakamura, H., M. Nakamura, and J.L. Anderson, 1997: The role of high and low frequency dynamics and blocking formation. *Mon. Wea. Rev.*, **125**, 2074 - 2093.

Pelly, J.L., and B.J. Hoskins, 2003a: A new perspective on blocking. *J. Atmos. Sci.,* **60**, 734 –755.

Pelly, J.L., and B.J. Hoskins, 2003b: How well does the ECMWF ensemble prediction system predict blocking. *Quart. J. Roy. Meteor. So*c., **129**, 1683 – 1703.

Renwick, J.A, 1998: ENSO-related Variability in the Frequency of South Pacific Blocking. *Mon. Wea. Rev.*, **126,** 3117 – 3123.

*Renwick, J.A., and M.J. Revell, 1999: Blocking over the South Pacific and Rossby Wave Propagation. *Mon. Wea. Rev.*, **127**, 2233 - 2247.

Rex, D.F., 1950: Blocking action in the middle troposphere and its effect on regional climate II: The climatology of blocking action. *Tellus*, **3**, 275 – 301.

Shutts, G.J., 1983: The propagation of eddies in diffluent jet streams: Eddy vorticity forcing of blocking flow fields. *Quart. J. Roy. Met. Soc.*, **109**, 737 – 761.

Shapiro, R., 1970: Smoothing, filtering, and boundary effects. *Rev. Geophys.,* **8,** 737 – 761.

Tibaldi, S., E. Tosi, A. Navarra, and L. Pedulli, 1994: Northern and Southern Hemisphere seasonal variability of blocking frequency and predictability. *Mon. Wea. Rev.*, **122**, 1973 - 2003.

Tracton, M.S., 1990: Predictability and its relationship to scale interaction processes in blocking. *Mon. Wea. Rev.*, **118**, 1666 - 1695.

Trenberth, K.E., and K.C. Mo, 1985: Blocking in the Southern Hemisphere. *Mon. Wea. Rev.*, **113**, 3-21.

Tsou, C.H., and P.J. Smith, 1990: The role of synoptic/ planetary-scale interactions during the development of a blocking anticyclone. *Tellus*, **42A**, 174 – 193.

Watson, J.S. and Colluci, S.J, 2002: Evaluation of ensemble predictions of blocking in the NCEP global spectral model. *Mon. Wea. Rev.*, **130**, 879 - 900

Wiedenmann, J.M., A.R. Lupo, I.I. Mokhov, and E. Tikhonova, 2002: The climatology of blocking anticyclones for the Northern and Southern Hemispheres: Block intensity as a diagnostic. *J. Climate*, **15**, 3459 – 3474.