NOTES AND CORRESPONDENCE

Relationships between North Pacific Wintertime Blocking, El Niño, and the PNA Pattern

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ABSTRACT

The frequency of persistent high-latitude ridging events (commonly referred to as blocking) over the North Pacific–Alaskan region is investigated using a 44-winter record of daily 500-mb height fields. The winters are stratified in accordance with the phase of the El Niño–Southern Oscillation (ENSO) cycle and according to the sign of the seasonally averaged PNA index. It is found that the occurrence of blocking in the Bering Strait region is sensitive to the averaged polarity of the PNA pattern but is even more sensitive to the phase of the ENSO cycle. Sixty-nine percent more days of blocking are observed during winters occurring during the cool phase of ENSO, compared to those occurring during the warm phase. ENSO-related differences in blocking frequency are found to be associated with changes to both the mean and variance of the circulation over the North Pacific. The variance of geopotential heights on timescales corresponding to the lifetime of blocking events is found to be higher over the Bering Strait region in the cool phase of the ENSO cycle.

1. Introduction

The term ‘‘blocking’’ denotes a breakdown in the prevailing tropospheric westerly flow at midlatitudes, often associated with a split in the zonal jet and with persistent ridging at high latitudes. Preferred Northern Hemisphere locations for blocking are the northeastern boundaries of the Pacific and Atlantic Oceans to the north and east of the Pacific and Atlantic storm tracks, respectively (Rex 1950; Lejenäs and Økland 1983). Blocking has been investigated from a number of perspectives, including the study of the “index cycle” (Willett 1948; Namias 1950; Kidson 1985) and the investigation of possible multiple equilibria in the wintertime circulation (Charney and DeVore 1979; Dole and Gordon 1983; Hansen and Sutera 1986) and, from a forecasting perspective, since blocking remains a difficult medium-range prediction problem (Tibaldi and Molteni 1990; Tracton 1990).

The onset and maintenance of blocking events are thought to involve nonlinear interactions between large-scale, low-frequency planetary waves and high-frequency baroclinic waves. Although a blocking event may last for 15 days or more, its onset and breakdown are usually considerably more rapid, on the order of 2–3 days (Hollingsworth et al. 1987; Dole 1989). The main mechanism appears to be barotropic: the poleward advection of anticyclonic vorticity by high-frequency disturbances maintains a blocking anticyclone against dissipative forces (Shutts 1983; Mullen 1987; Nakamura and Wallace 1990). The development of a blocking anticyclone is associated with enhanced upstream baroclinic wave activity (Dole 1986b; Nakamura and Wallace 1990) and leads to an alteration of the background state of the circulation, encouraging anomalous poleward migration of storms on the upstream side of the block, thereby enhancing the vorticity advection that serves to maintain it (Mullen 1987).

The maintenance of blocking appears to be determined primarily by the internal dynamics of the atmosphere (Dole 1989; Mullen 1989) and may be relatively insensitive to boundary forcings. However, interannual variability in the frequency of occurrence of blocking has been related to variations on interannual timescales. Van Loon and Madden (1981) found a relationship between mean sea level pressures (SLP) and the El Niño–Southern Oscillation (ENSO) cycle, such that during warm phase of the cycle (“low/wet” years) SLP over the North Atlantic tends to be anomalously high, implying that blocking may be enhanced over the North Atlantic in “warm” winters. Over the North Pacific, the correlation is stronger and is in the reverse sense, implying higher mean SLP over the Alaskan region in the cold phase and an enhanced Aleutian low during warm events (their Figs. 2 and 3).

Enhancement of the wintertime Aleutian low during the warm phase of the ENSO cycle is consistent with
the observed association between ENSO and the
Pacific–North American pattern (PNA, Wallace and
Gutzler 1981). During the warm phase of ENSO, the
positive polarity of the PNA pattern (negative height
anomalies over the North Pacific) tends to occur rela-
tively frequently (Horel and Wallace 1981; Simmons
et al. 1983). Data analysis and model simulations by
Horel and Mechoso (1988) show an increase in the
persistence of wintertime circulation anomalies over
the North Pacific during the warm phase of ENSO, of-
ten associated with the positive polarity of the PNA
pattern and with below-normal geopotential heights
in the Gulf of Alaska. Mullen (1989) analyzed GCM sim-
ulations forced with a variety of tropical and midlat-
titude Pacific sea surface temperature (SST) anomalies
and found that such anomalies do not significantly af-
fect the frequency of occurrence of simulated North
Pacific blocking but that they do affect the preferred
locations for block formation. When equatorial Pacific
SSTs are enhanced in the model, as during an El Niño
event, the region of most frequent North Pacific block-
ing moves eastward from the Aleutians toward the
coast of British Columbia. Renwick and Wallace
(1996) report an apparent suppression of wintertime
ridging over Alaska during El Niño conditions based
on a 14-winter record of European Centre for Medium-
Range Weather Forecasts (ECMWF) analyses.

This purpose of this short paper is to further docu-
ment the relationships between the ENSO cycle, the
polarity and amplitude of the PNA pattern, and the
occurrence of blocking, with emphasis on occurrences
over Alaska and the Bering Strait. The datasets and
analysis techniques used are described in section 2. Re-
sults are presented in section 3 and a discussion follows
in section 4.

2. Data and methodology

Most of the results presented here are based on the
record of daily 500-mb height analyses from the U.S.
National Meteorological Center (NMC). Fields were
extracted for 90-day periods covering the months of
December–February (DJF) for the 44 winters 1950/
51 through 1993/94 inclusive. The height data are in-
terpolated from the 1977-point octagonal grid to a 5°
latitude by 15° longitude grid between 25° and 85°N,
as in Renwick and Wallace (1996). Anomalies are de-
ated as departures from a climatology defined by a
parabolic least squares fit in time to the daily mean
height at each grid point. Certain results are taken from
a set of 14 winters of operational model output from
the ECMWF. Each winter, from 1980/81 through
1993/94, is defined as the 100-day period beginning 1
December. Fields are again represented on the 5° × 15°
grid described above, and a daily climatology is simi-
larly defined by a least squares parabolic fit in time.

Although the blocking phenomenon is well known
in the meteorological community, there is no generally
accepted definition of a blocking event (Lejenäs and
Økland 1983). Commonly used definitions include the
occurrence of persistent positive height anomalies at
particular locations (Dole and Gordon 1983; Dole
1986a, 1989) or the occurrence of persistent anomalous
midlatitude easterly flow (Lejenäs and Økland 1983;
Tibaldi and Molteni 1990). In this study, height anom-
aly fields are projected upon a spatial pattern with one
main center of action over the Bering Strait, as shown
in Fig. 1. Strong positive projections onto this pattern

![Fig. 2. Wintertime average time series of the PNA index, Alaskan pattern index, the number of days of Alaskan blocking, and eastern equatorial Pacific mean SST anomaly. The vertical scale is arbitrary. The vertical bars indicate winters occurring during the warm phase of ENSO.](image-url)
Table 1. Means and standard deviations of the listed quantities, stratified in accordance with the phase of the ENSO cycle, for the DJF winter season. "Alaskan index" denotes the index or strength of the Alaskan pattern (Fig. 1). Student’s \( t \) values are all significant at the 95% level, for a two-tailed test. Frequencies in the right-hand column pertain to the Monte Carlo significance testing procedure.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Warm</th>
<th>Cool</th>
<th>( t ) value</th>
<th>Monte Carlo frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNA index</td>
<td>0.34 ± 0.44</td>
<td>−0.14 ± 0.39</td>
<td>+3.5</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Alaskan index</td>
<td>−0.31 ± 0.28</td>
<td>0.12 ± 0.38</td>
<td>−3.6</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Block days</td>
<td>15 ± 8.2</td>
<td>22 ± 12</td>
<td>−2.5</td>
<td>2</td>
</tr>
</tbody>
</table>

The pattern shown in Fig. 1 will be referred to here as the "Alaskan" pattern. It emerged as the height anomaly pattern associated on average with the largest medium-range rms errors in the ECMWF model and was derived through a regression analysis between ECMWF day-10 rms errors and verifying analysis 500-mb height anomalies (see Renwick and Wallace 1996 for a full discussion). The Alaskan pattern “index” referred to here is calculated by the projection of daily height anomaly fields upon the Alaskan pattern. Large positive projections upon the Alaskan pattern coincide with blocking episodes in the Alaskan region and the ensemble mean height anomaly field for days defined as “blocked” is very similar in form to that shown in Fig. 1. The Alaskan pattern is similar in form to the 500-mb height anomaly field associated with the “Pacific” pattern of Hsu and Wallace (1985) and is related to the North Pacific oscillation in the mean sea level pressure field (Walker and Bliss 1932; Rogers 1981). The above definition of blocking is conceptually similar to the definition of Dole (1986a, b) of “persistent positive anomalies” at grid points over Alaska.

The PNA index as defined in Wallace and Gutzler (1981) is also calculated from daily fields. Results are presented in terms of averages over DJF winter seasons. Of the 44 winters used, 13 are considered as having occurred during the warm phase of the ENSO cycle, those including January of 1952, 1954, 1958, 1964, 1966, 1970, 1973, 1977, 1978, 1983, 1987, 1988, and 1992. This list is in agreement with the definitions of Rasmusson and Carpenter (1982) for the years 1950–73 and generally agrees with the definition of low/wet seasons in van Loon (1984), apart from the winter of December 1977–March 1978. It may be argued that warm conditions have continued from 1992 through the winter of 1993/94 and that the last two winters should be included in the warm subset. In either case, test calculations show most results to be insensitive to the designation applied to the last two winters. All remaining winters not listed above are referred to as the “cool” seasons, although strong cold events occurred only in the winters including January 1957, 1965, 1971, 1972, 1974, 1976, and 1989.

3. Results

Figure 2 shows time series of the DJF averages of the daily PNA index and of the daily Alaskan pattern index, together with the total number of days of “blocking” in each season. Also shown is the DJF average of equatorial Pacific SST anomalies calculated from the COADS dataset, averaged over the region 6°N–6°S, 180°–90°W. The vertical lines denote the occurrence of warm conditions in the equatorial Pacific, as listed above.

The PNA index tends to be positive during the warm phase of the ENSO cycle, as expected, and the Alaskan pattern index tends to be negative. These biases in the mean state favor a lower number of days of blocking events during warm winters. The frequency of days of wintertime blocking is approximately 40% lower during the warm phase of ENSO, relative to other winters (Table 1). The mean and standard deviation of each variable in both subsets is listed in Table 1, along with Student’s \( t \) values for the difference in means. Assuming independence between seasons, \( |t| > 2.1 \) indicates significance at the 95% level (for a two-tailed test, since no prior assumption was made about the sign of the difference). A Monte Carlo test was also performed, in which the distribution of mean differences between randomly generated subsets of the data is com-

Table 2. As in Table 1 but stratified in accordance with the sign of the PNA index averaged over the DJF season.

<table>
<thead>
<tr>
<th>Variable</th>
<th>PNA pos</th>
<th>PNA neg</th>
<th>( t ) value</th>
<th>Monte Carlo frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaskan index</td>
<td>−0.16 ± 0.40</td>
<td>0.13 ± 0.36</td>
<td>−2.5</td>
<td>3</td>
</tr>
<tr>
<td>Block days</td>
<td>15 ± 9.2</td>
<td>24 ± 11</td>
<td>−2.8</td>
<td>1</td>
</tr>
</tbody>
</table>
pared to the observed difference. From 500 trials, the percentage of random differences exceeding the observed difference (again a two-tailed test) is shown in Table 1.

Winters were also stratified according to the seasonally averaged sign of the PNA index, as shown in Table 2. The differences between positive- and negative-PNA winters are somewhat less marked than between the warm and cool phases of ENSO, but are still significant. Results are similar if the averaging period is changed to the months of January–March (JFM) or to January–February (JF). The frequency of blocking is most strongly influenced by ENSO during JF, partly because the highest frequency of blocking over Alaska is observed during January (Lejenä and Ökland 1983).

To concentrate upon intraseasonal variability, the NMC fields were bandpass filtered to retain variability on timescales of between 10 and 30 days (see Kushnir and Wallace 1989 for details of the filtering procedure). The difference in wintertime variance between the warm and cool phases of ENSO is shown in Fig. 3a as the ratio of variances, at each grid point, between the two data subsets. Bandpass-filtered anomaly variance is larger in a region from the eastern Siberian coast to Alaska and northwestern Canada during cool winters, with an increase of up to 60% in the region of the Bering Strait. Figure 3b shows the 10–30-day variance ratio between negative- and positive-PNA winters. The differences do not appear to be as large or as systematic as when the data are separated in accordance with the ENSO cycle.

Differences in the variance and in the mean state of the circulation over the North Pacific are summarized in Fig. 4 for the PNA and Alaskan patterns. Normalized values of both pattern indices are shown as a pair of frequency distributions for warm and cool phases of the ENSO cycle. The distributions were fitted using a Gaussian kernel estimator, with densities estimated at 30 equally spaced points, using a “window width” of 0.5 (Silverman 1986). Both polarities of the PNA pattern occur with approximately equal frequency in cool winters. The negative-PNA state occurs much less frequently in warm winters because of the change in the mean of the distribution (the change in the variance, while small, works in the opposite sense). Positive geopotential height anomalies over the Bering Strait are more common on average during the cool phase of the ENSO cycle. Large positive values of the Alaskan pattern index are much more common in cool years from the combined effects of the higher mean and the larger variance of the distribution in those winters.

To assess the sensitivity of the results to the criteria used to define blocking, indices were recalculated using projection patterns having centers of action to the east and west of the center of the Alaskan pattern. Results were quite sensitive to the position of the pattern used. Significant ENSO-related differences in blocking frequency were obtained for patterns centered between 170°E and 165°W. Outside those longitude limits, results were qualitatively similar (a suppression of blocking in the warm phase of ENSO) but were not statistically significant. Similar behavior was observed using the “persistent anomaly” criteria of Dole and Gordon (1983) at a range of longitudes along 60°N. Such results are consistent with Fig. 3a, which indicates a

Fig. 3. Contours of 10–30-day bandpass-filtered 500-mb height variance ratios: (a) the ratio between winters occurring during the cool phase of ENSO to those occurring during the warm phase of ENSO and (b) the ratio of negative-PNA to positive-PNA winter variance. Contours are percentages with a 20% contour interval. Solid contours indicate ratios greater than 100% and dashed contours indicate ratios less than 100%. The 100% contour has been suppressed.
strong response to the phase of the ENSO cycle, but in a limited area centered over the Bering Strait.

4. Discussion

The ENSO cycle affects both the mean and the variance of height fluctuations over the North Pacific, both of which influence the probability of occurrence of Alaskan blocking and the frequency distribution of the PNA index. The warm phase of ENSO is associated on average with 500-mb height anomalies that project positively upon the PNA pattern (Horel and Wallace 1981) and negatively upon the Alaskan pattern (Table 1). Hence, during warm winters there tends to be an increased prevalence of the positive polarity of the PNA pattern and of negative height anomalies over the Alaska/Bering Strait, consistent with the correlation maps and composites of van Loon and Madden (1981), which show warm winters to be associated with below-average SLP over Alaska.

Differences between warm and cool phases of ENSO are not purely linear, however. The variance of the Alaskan pattern index is reduced during the warm phase of ENSO, at which time the variance of the PNA index is slightly increased. The smaller 500-mb height variance over the North Pacific during the warm phase of ENSO (Table 1; Figs. 3, 4) is consistent with the results of Palmer (1988), who found a positive-PNA background state to be relatively barotropically stable to small perturbations. Changes in variance may also be related to fluctuations in wave forcing by high-frequency transients brought about by changes in the location of the Pacific "storm track" (e.g., Dole 1986a).

Changes in height variance over the North Pacific associated with the polarity of the PNA pattern and with the phase of the ENSO cycle may be partly accounted for by fluctuations in the Alaskan pattern index. When the NMC data are stratified on a daily basis in accordance with the sign of the PNA index, the difference in variance over the North Pacific (as seen in Palmer 1988, Fig. 12) is reduced by two-thirds after removal of that part of the variance associated with the Alaskan pattern. When the data are stratified in a similar manner based on the seasonally averaged PNA polarity, or the phase of the ENSO cycle, approximately one-third of the difference in variance over the North Pacific can be attributed to differences in the amplitude of the Alaskan pattern index.

To the extent that the ENSO cycle exhibits predictability on the seasonal to interannual scale, blocking over Alaska may also exhibit some predictability in a statistical sense, even though individual events are not predictable. The suppression of wintertime blocking during El Niño conditions is likely to be associated with the ENSO-related fluctuations in Seattle-area snowfall reported by Ferber et al. (1993).

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REFERENCES


