Decadal Variability of the Aleutian Low and Its Relation to High-Latitude Circulation*

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6 July 1998 and 8 October 1998

ABSTRACT

The January–February mean central pressure of the Aleutian low is investigated as an index of North Pacific variability on interannual to decadal timescales. Since the turn of the century, 37% of the winter interannual variance of the Aleutian low is on timescales greater than 5 yr. An objective algorithm detects zero crossings of Aleutian low central pressure anomalies in 1925, 1931, 1939, 1947, 1959, 1968, 1976, and 1989. No single midtropospheric teleconnection pattern is sufficient to capture the variance of the Aleutian low. The Aleutian low covaries primarily with the Pacific–North American (PNA) pattern but also with the Arctic Oscillation (AO). The change to a prominent deep Aleutian low after 1977 is seen in indices of both the PNA and AO; the return to average conditions after 1989 was also associated with a change in the AO. The authors' analysis suggests an increasing covariability of the high- and midlatitude atmosphere after 1970.

1. Introduction

Much attention has recently been devoted to variability in the North Pacific on decadal scales. This variability is manifest in oceanic, atmospheric, and terrestrial variables, such as SST (Latif and Barnett 1996), biological productivity (Polovina et al. 1995), and commercial fish stocks (Francis and Hare 1994; Kodama et al. 1995). Atmospheric changes are evident in the sea level pressure (SLP) field, where differences in 10-yr winter means can be as much as 35% of the climatological seasonal signal. Recent decreases in SLP occurred after 1977 (Trenberth 1990; Hanawa et al. 1996) with some recovery after 1989 (Tachibana et al. 1996); the SLP increase in 1989 was concurrent with a major decrease in SLP in the Arctic (Walsh et al. 1996). Earlier changes in the North Pacific appear to have occurred in the 1920s and 1940s (Mantua et al. 1997; Minobe 1997); these changes and others are suggested by Hollowed and Wooster (1995).

The location and intensity of the Aleutian low pressure center are primary indicators of the climate system of the winter North Pacific. The climatological Aleutian low is established by the time average of the SLP field and is associated with moving storm systems and the background stationary wave pattern. In the present note we investigate the intensity of the central pressure of the Aleutian low in winter and relate it to atmospheric variability patterns on decadal timescales. Several authors have examined the tropical connection to the North Pacific (e.g., Nitta and Yamada 1989; Trenberth and Hurrell 1994; Zhang et al. 1997); we concentrate on the connection with mid- and high latitudes.

2. The winter Aleutian low time series

We use two sources for time series of SLP. First is the Northern Hemisphere Sea Level Pressure (NHSLP) dataset, available through the National Center for Atmospheric Research (NCAR) and described by Trenberth and Paolino (1980). This dataset contains monthly mean pressure values on a 5° lat–long grid beginning in 1899. The second data source is the National Centers for Environmental Prediction (NCEP)–NCAR reanalysis dataset (Kalnay et al. 1996); the NCEP reanalyses of SLP are on a 2.5° lat–long grid and begin in 1958.

A time series of Aleutian low central pressures was created from each data source. For each year in the dataset, we calculated the January–February mean SLP and then located the pressure minimum within the region 40°–60°N, 160°E–160°W. The January–February mean was selected because winter Aleutian low anomalies are

* NOAA/Pacific Marine Environmental Laboratory Contribution Number 1950 and Joint Institute for the Study of Atmosphere and Ocean Contribution Number 488.

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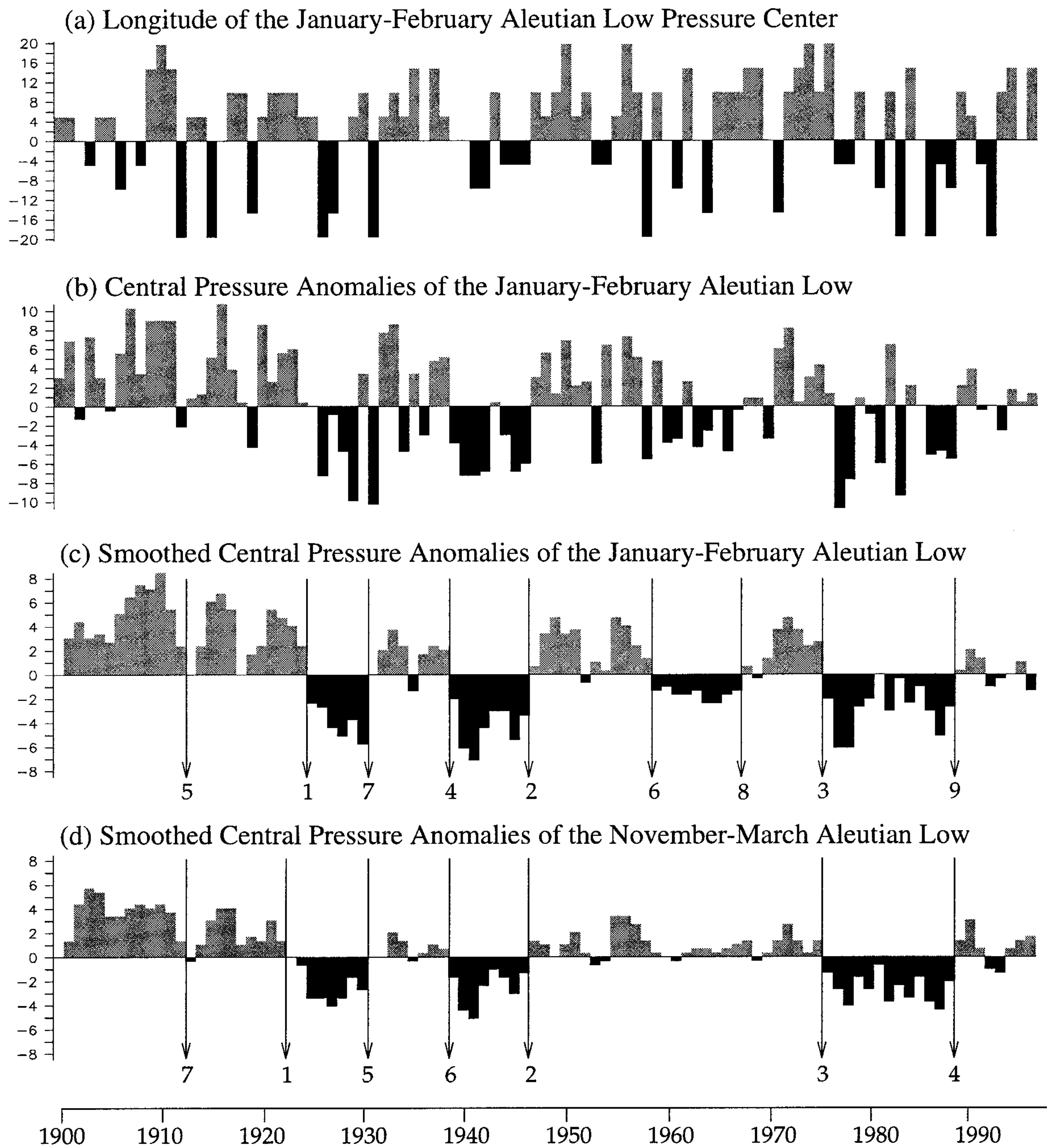

FIG. 1. Characteristics of the Aleutian low for 1900–96. (a) Long of the Jan–Feb Aleutian low pressure center, plotted as degrees west (positive) or east (negative) of 180°; (b) central pressure anomalies of the Jan–Feb Aleutian low, in mb; (c) as in (b) but smoothed with a 3-yr running mean; (d) central pressure anomalies of the Nov–Mar Aleutian low, smoothed with a 3-yr running mean. Numbered arrows in (c) and (d) indicate the objectively determined change points and the order in which they were detected. See text for a discussion on the significance of the change points. Data are from the NHSLP dataset; pressure anomalies are based on a 1946–96 climatology.

largest in these months (Trenberth and Hurrell 1994). We did not include December because it does not appear to have the same Arctic–North Pacific connection as January and February. We also consider a 5-month winter mean. Both central pressure time series were smoothed with a 3-yr running mean (KZ filter; Eskridge et al. 1997) to reduce interannual variability and then correlated for the overlapping period. The correlation was greater than 0.99, with a mean difference of 0.3 mb.

Figure 1 shows the unsmoothed January–February mean values of (a) longitude and (b) central pressure anomalies of the Aleutian low from the NHSLP dataset. Central pressure and west longitude are correlated ($r =$

0.52), with lower central pressures associated with locations farther east. A similar correlation was noted by Rossby (1939).

To assess the relative contribution of interannual and long period variability, the time series of longitudes and central pressures were smoothed with a 3-yr running mean applied twice (KZ filter; Eskridge et al. 1997). The ratio of the variance of the filtered time series compared to the variance of the original time series is a rough measure of the percentage of the total variance with periods longer than 5 yr. The time series of central pressure has more low-frequency variability (37%) than the time series of longitude (22%). Regional average SLP indices (e.g., Hurrell 1996) have similar percentages of low-frequency variance as our central pressure index. In the twentieth century, over one-third of the variance of the winter-average Aleutian low central pressure has been on the decadal scale.

An objective change-point indicator (Lanzante 1996) was applied to the once smoothed time series of January–February Aleutian low central pressure anomalies, shown in Fig. 1c. The algorithm detected eight zero crossings for the period 1900–96 in the years 1925, 1931, 1939, 1947, 1959, 1968, 1977, and 1989. Significance is based on the 95% confidence level for z scores for autocorrelated data. The numbered arrows along the time axis indicate the sequence in which the change points were detected. The first three change points detected in the Aleutian low central pressure time series occurred in the years 1925, 1947, and 1976, with a 20–30-yr timescale. North Pacific climate shifts near these years were also noted by Minobe (1997). Trenberth and Paolino (1980) question the accuracy of the NHSLP dataset before 1925 due to errors in the measurements at Dawson City, in the Canadian Yukon Territory. However, the 1925 sign change was also noted as a shift in the Pacific Decadal Oscillation, the first empirical orthogonal function of North Pacific SST (Mantua et al. 1997). The next four change points indicate decadal reversals embedded within this cycle, on timescales of 8–9 yr. These shifts occurred in 1931, 1939, 1959, and 1968. These higher-frequency shifts fit the analyses of North Pacific circulation noted by Wooster and Hollowed (1995). The final change point, in 1989, indicates a change from a deep Aleutian low to average values. Although the 1989 change has a relatively high z score and is visually evident in the time series plots, Lanzante (1996) cautions about the interpretation of change points near the ends of the time series. Zero crossings at the corresponding years were also detected by the change point algorithm in the time series generated from the NCEP–NCAR reanalyses.

The corresponding time series of Aleutian low central pressure for a 5-month winter mean (November–March) is shown in Fig. 1d. It represents approximately half of the low frequency variance as the January–February mean time series (Fig. 1c). The main difference between Figs. 1c and 1d is lack of major negative anomalies in the 5-month means during the 1960s. The first three change points selected for the 5-month means are the same as for the 2-month means.

3. Connection to variance patterns

a. Spatial variation

The patterns of spatial correlation between the January–February Aleutian low central pressure index for 1959–96 and SLP and 500-mb height fields are shown in Fig. 2. The maximum correlations are less than 1.0 because Fig. 2 is not a point–point correlation plot and we are correlating the January–February gridpoint values for each year with the 3-yr running mean central pressure index (Fig. 1c). Maxima/minima of ± 0.4–0.6 are slightly larger than the 95% threshold for point significance, $r \approx 0.36$, for the once smoothed index using a Monte Carlo technique and assuming decadal independence. Figure 2 is mainly suggestive, as it is difficult to establish rigorous significance. The correlation of the Aleutian low index with the SLP field (Fig. 2a) has a maximum of 0.66 at 50°N, 168°E, near the climatological center for the Aleutian low. Regions of negative correlation are in the Arctic, and over the Tibetan Plateau where adjustment to sea level pressure is ambiguous. At 500 mb (Fig. 2b) the greatest correlation is 0.67 at 48°N, 150°E, with a broad region of positive correlation extending eastward along 55°N. The region of maximum 500-mb correlation in Fig. 2b lies to the west of the dateline and upstream of the SLP correlation maximum, also discussed by Chang (1993). Negative correlation is present in the western Arctic (western longitudes) and a positive correlation is present over northern Europe.

The patterns in the correlation plots in Fig. 2 invite comparison with two atmospheric modes of variability, the Pacific–North America (PNA) pattern and the Arctic Oscillation (AO). The PNA, which is often associated with the Aleutian low, nominally has its 500-mb North Pacific center at 45°N, 165°W. Inspection of Fig. 2b shows positive correlation with the Aleutian low index at 45°N, 165°W, negative correlation across the subtropical North Pacific and over northwest Canada, and positive correlation over the southeastern United States. These collective features are the signature of the PNA and suggest that much but not all of the variation of the Aleutian low is associated with the PNA. The remainder of the correlation pattern resembles the 500-mb height regression map for the AO (Thompson and Wallace 1998, their Fig. 1). The AO is a feature that extends from the surface to the stratosphere and represents a spinup (or spindown) of the polar vortex, with a transfer of mass between high and midlatitudes. The 500-mb height regression map for the AO includes maxima over northeast Asia and Europe and minima over the western Arctic and Greenland. The presence of features of the PNA and AO in the correlation maps in Fig. 2 suggests

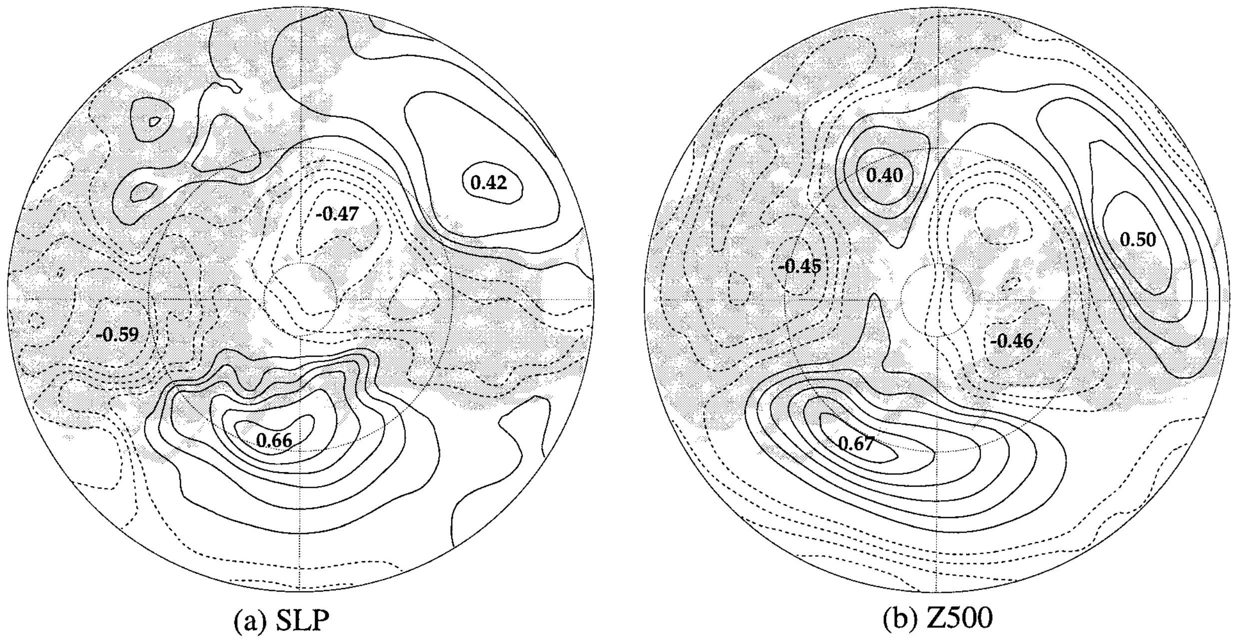

FIG. 2. Correlation maps for the Jan–Feb Aleutian low central pressure index (plotted in Fig. 1c) and (a) Jan–Feb mean sea level pressure, and (b) Jan–Feb mean 500-mb height. The contour interval is 0.1, with negative correlations plotted with dashed lines and positive correlations plotted with solid lines. Printed numbers indicate local maxima and minima. Latitude circles are drawn at 20°, 50°, and 80°N.

a wintertime covariability between the Aleutian low and both of these Northern Hemispheric patterns.

b. Temporal variation

Figure 3 shows the time series of the Aleutian low central pressure index, the AO index—the amplitude of the first principal component of the winter months SLP (Thompson and Wallace 1998), and the classic PNA index given by Wallace and Gutzler (1981), hereafter referred to as WG-PNA:

$$\text{WG-PNA} = 0.25[Z^*(20°\text{N}, 160°\text{W}) - Z^*(45°\text{N}, 165°\text{W}) + Z^*(55°\text{N}, 115°\text{W}) - Z^*(30°\text{N}, 85°\text{W})],$$

where Z^* is the departure of the mean monthly 500-mb height from a (1979–96) climatology, divided by the local standard deviation of that departure. The indices are averaged for January–February of each year. The AO index in Thompson and Wallace (1998) was for a 5-month winter mean and here we show an average of two monthly values, which we obtained from the authors. All time series cover the period from 1958–96 and have been smoothed with a 3-yr running mean to reduce interannual variability.

The WG-PNA exhibits variability over long periods; it was generally in the negative phase from the beginning of the time series until 1977. Since then it has been generally positive, although it does show more variability after 1988. Since the mid-1960s, there is some correspondence between the Aleutian low central pressure anomalies and the AO, for example in the late 1970s and 1990s. Also, the slight weakening of the low in the early 1980s is coincident with a positive anomaly in the AO. Changes in the WG-PNA and the AO coincided with the deepening of the Aleutian low after 1977. The AO changed sign in 1989 when the Aleutian low returned to average conditions. A gradual change in the AO also accompanied the shift from a deep Aleutian low in the 1960s to a weak Aleutian low in the early 1970s.

We have also examined the leading modes of variability of the January and February 700-mb height fields as analyzed by the Climate Prediction Center (CPC) at NCEP (Bell and Halpert 1995). The data are available on the World Wide Web (http://www.nnic.noaa.gov:80/data/cddb/). These modes are the standardized amplitudes constructed from the rotated principal component analysis (RPCA) for each month. The first mode in December and February was termed the Polar–Eurasia pattern (POL) and is similar to the 500-mb height regression map of the AO (Thompson and Wallace 1998), with extremes over northeastern Asia, the western Arctic, and northern Europe. The POL is limited to the three months of December, January, and February. The POL pattern was not identified in the earlier RPCA of Barnston and Livezey (1987), yet it is the most prominent wintertime mode in the more recent analysis, which includes all of the 1980s and most of the 1990s.

The time series of the POL and the CPC version of the PNA (mode 1 in January and mode 2 in February),

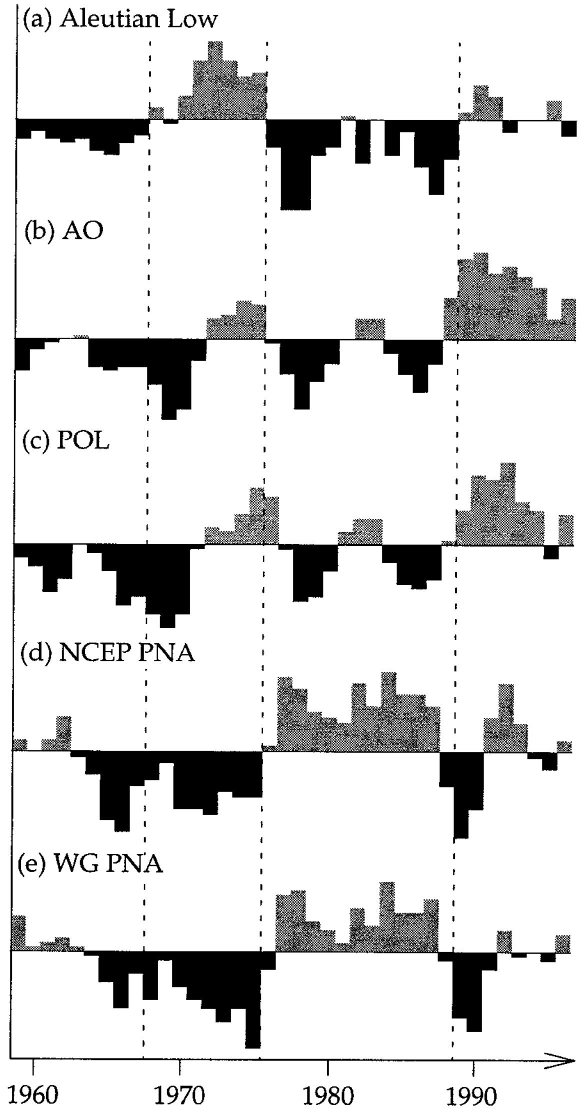

FIG. 3. (a) Central pressure anomalies of the Jan–Feb Aleutian low; (b)–(e) Jan–Feb averages of the amplitudes of the following indices: Arctic Oscillation (AO), the NCEP Polar–Eurasia (POL), the NCEP Pacific–North America (PNA), and the Wallace–Gutzler (WG) PNA. All time series span the period from 1959 to 1996 and have been smoothed with a 3-yr running mean. Dashed lines indicate the zero crossings of the Aleutian low central pressure anomalies in 1967, 1976, and 1989.

hereafter referred to as NCEP-PNA, are also shown in Fig. 3. The correlation between the AO and the POL is $r = 0.88$ and between the WG-PNA and the NCEP-PNA is $r = 0.90$. We show both the WG and NCEP-PNA because their time series are not identical. The NCEP version represents one mode of an orthogonal set, while the WG-PNA has one of its four grid points near the location of the Aleutian low. Likewise, the AO and the NCEP POL are both the main Arctic modes, but there are subtle differences in their spatial patterns. The AO exhibits a center toward Iceland, while the POL is centered more over the high Arctic and has an opposite pole near the Sea of Okhotsk. These correlations of $r \sim 0.9$ represent how similar data are projected onto modal structures with separate mathematical definitions.

TABLE 1. Correlation coefficients for Aleutian low central pressure on combinations of atmospheric modes. Regression variables have been normalized by their variance. WG refers to the Wallace–Gutzler formulation and NCEP refers to the National Centers for Environmental Prediction RPCA analysis.

Mode	R (1959–96)
AO	0.48
NCEP-POL	0.45
WG PNA	−0.77
NCEP PNA	−0.62
NCEP WP	−0.17
WG-PNA + AO[a]	0.80
NCEP PNA + AO[b]	0.73
NCEP PNA + POL + WP[c]	0.85

[a] SLP = 0.23 AO − 0.69 WG-PNA.
[b] SLP = 0.39 AO − 0.56 NCEP-PNA.
[c] SLP = 0.55 POL − 0.39 WP − 0.65 NCEP-PNA.

The covariation of the Aleutian low and the atmospheric modes is determined primarily by visual inspection. There are two to four periods of serial correlation in each of the time series within the 40-yr record. As an aid in interpreting Fig. 3, Table 1 provides the correlation of the Aleutian low central pressure index with the various individual modes as well as the linear multiple regression of the Aleutian low central pressure on the AO and WG-PNA and also on the, NCEP-POL, PNA, and west Pacific (WP) amplitudes. The latter represent a nearly orthogonal basis set for North Pacific variability. All time series were smoothed with a 3-yr running mean before the correlations were calculated. Correlation of the AO and Aleutian low for January–February is $r = 0.48$. Regression of the Aleutian low on the NCEP-PNA, WP, and POL has $r = 0.85$, with a larger combined contribution from the POL and WP than the PNA. The serial correlation of the limited time series makes it impossible to make quantitative estimates about the reliability of this covariability. There is also an upward trend in the AO index. We do not see a trend in the Aleutian low index (Fig. 1c).

The correlation between the AO and Aleutian low index for December was $r = -0.09$, which suggested that December should not be used in the analysis. Including December in the analysis of the spatial fields (Fig. 2) also reduced the correlation. Winter weather is established in the North Pacific by December, but the Arctic connection may not be manifested until the Arctic front is firmly established over Alaska and the Bering Sea (Barry 1967).

Figure 4 shows the change in January–February mean SLP in the Northern Hemisphere between 1977–88 and 1989–97 and illustrates covariability of the Aleutian low with SLP at higher latitudes. This covariability did not exist this strongly in earlier periods. The Aleutian low

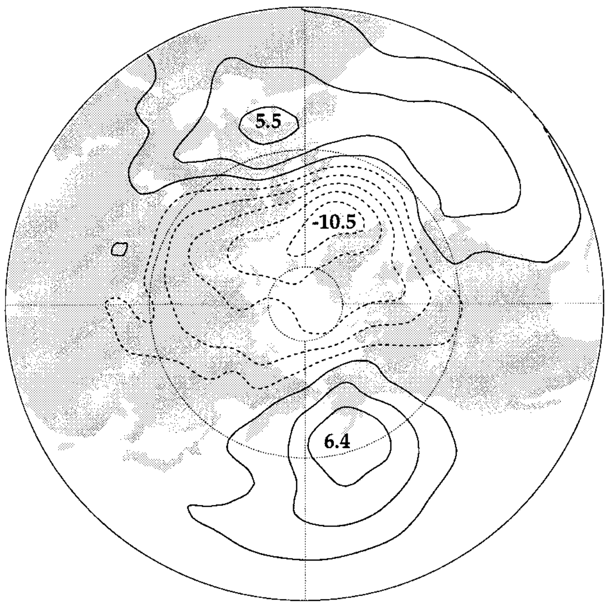

FIG. 4. Hemispheric map showing the changes in the Jan–Feb mean SLP, 1989–97 minus 1977–88. The contour interval is 2 mb, centered on zero, with negative values plotted with dashed lines and positive values plotted with solid lines. Printed numbers indicate local maxima and minima. Monthly mean data are from the NCEP–NCAR reanalysis dataset.

central pressure increases from a low value in the 1980s to neutral conditions in the 1990s, an increase of 4 mb; this is part of a hemispheric transfer of mass from the Arctic to lower latitudes in the Pacific, the Atlantic, and southern Europe. This transfer of mass results in a major decrease in the pressure gradient from the central Arctic to the region of the Aleutian low, approximately 14 mb over 2000 km, which implies a reduction in surface geostrophic easterlies at sub-Arctic latitudes.

4. Summary

Over one-third of the winter interannual variability of the Aleutian low since 1900 is on decadal scales. The January–February variability of the Aleutian low is not associated solely with the PNA; it is also associated with the variability of the Arctic as indicated by the AO. The PNA has been generally negative from the 1950s through the mid-1970s, and mostly positive since 1977. The AO has a higher-frequency variability with recent shifts around 1971, 1977, and 1988. The AO appears to have more covariability with the North Pacific after 1970, as judged by its emergence in the NCEP RPCA analysis (the POL pattern) and its systematic bias (Thompson and Wallace 1998). The cause of the recent trend in the AO and its partial association with the Aleutian low is uncertain, but its influence in the Northern Hemisphere is evident from the surface (Maslanik et al. 1996; Cavalieri et al. 1997) to the stratosphere (Kodera et al. 1996).

Acknowledgments. This research was supported by the NASA Polar Research Program, the ONR Arctic Program, and the NOAA Arctic Research Initiative. Data analysis and figure production were done using FERRET, an interactive data manipulation package developed at PMEL. We appreciate the suggestion of a reviewer for Fig. 2.

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