Decadal Variability of the Aleutian Low

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Abstract. There is considerable decadal variability in the Aleutian low. Thirty-seven percent of the variability of the January-February Aleutian low central pressure from 1900 to 1997 is on time scales greater than 5 years. A change point algorithm suggests sign changes in 1925, 1931, 1939, 1947, 1959, 1968, 1977, and 1989. The 1989 shift in the Aleutian low coincides with pressure falls in the Arctic. This exchange of mass between the Arctic and mid-latitudes is termed the Arctic Oscillation (AO). The variability in the Aleutian low is about equally influenced by large-scale variability in the northeast Pacific, through the Pacific/North American (PNA) pattern, and by variability in the NW Pacific/NE Asia region, through the west Pacific (WP) and Arctic Oscillation patterns.

Introduction

The location and intensity of the Aleutian low pressure center are primary indicators of the climate system of the North Pacific. As a feature, the Aleutian low may be defined as a set of closed contours on a monthly mean or climatological sea level pressure (SLP) chart. The Aleutian low is associated with the large-scale, low frequency mean flow or stationary wave pattern in the general circulation of the Northern Hemisphere. The mean flow becomes unstable and generates transient storm systems that travel downstream along the axis of the westerly jet core (*Lin and Derome* 1997). These propagating synoptic-scale disturbances dominate the weather of the North Pacific throughout the cool season, September through May. The time average of the SLP fields associated with these moving storms and the background stationary wave pattern establishes the climatological Aleutian low.

The Aleutian low is connected to the atmosphere-ice-ocean climate system and to the ecology of the North Pacific. The strength of the Aleutian low provides an index of the surface pressure gradient, which represents the intensity of mechanical forcing of the ocean (*Seckel* 1993). The location of the Aleutian low also identifies regions of low-level warm and cold air advection (*Hurrell* 1996). Storm track climatologies and low with the interannual variability of the ice edge in the Bering Sea and with ocean temperatures both at the surface and at shelf bottom (*Overland and Pease* 1982; *Niebauer and Day* 1989). The local meteorology also correlates with fishery recruitment on the Bering Sea shelf (*Wyllie-Echeverria* 1995; *Ohtani and Azumaya* 1995).

Aleutian low variation

Figure 1 shows the January-February Aleutian low central pressure taken from the 5º lat/long sea level pressure data set beginning in 1899 (*Trenberth and Paolino* 1980); the time series has been smoothed with a 3-year running mean (KZ filter, *Eskridge et al.* 1997). To assess the relative contribution of interannual and long period variability, the time series was smoothed with a 3-year running mean applied twice (*Eskridge et al.* 1997). The ratio of the variance of the twice-filtered time series compared to the variance of the original time series is a rough measure of the variance due to periods longer than 5 years. The time series of central pressure has relatively high low-frequency variability (37%). An objective change point indicator (*Lanzante* 1996) applied to the time series in Figure 1 detected statistically significant shifts in the years 1925, 1931, 1939, 1947, 1959, 1968, 1977, and 1989. While these change points should not be considered "regime shifts," they do suggest sign changes associated with the major decadal variability of the Aleutian low central pressure.

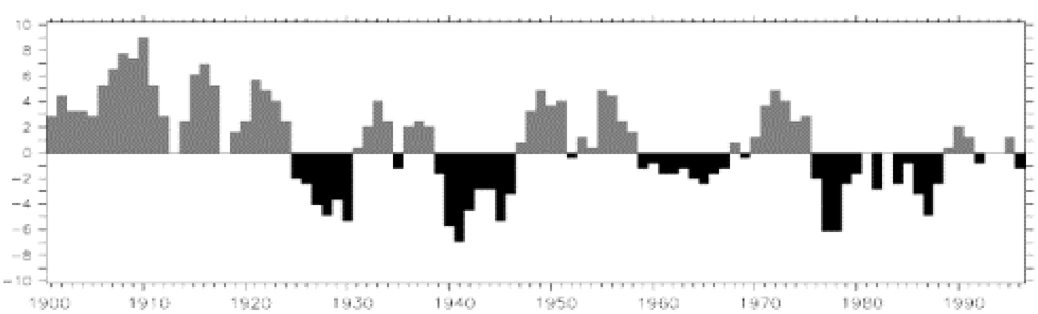
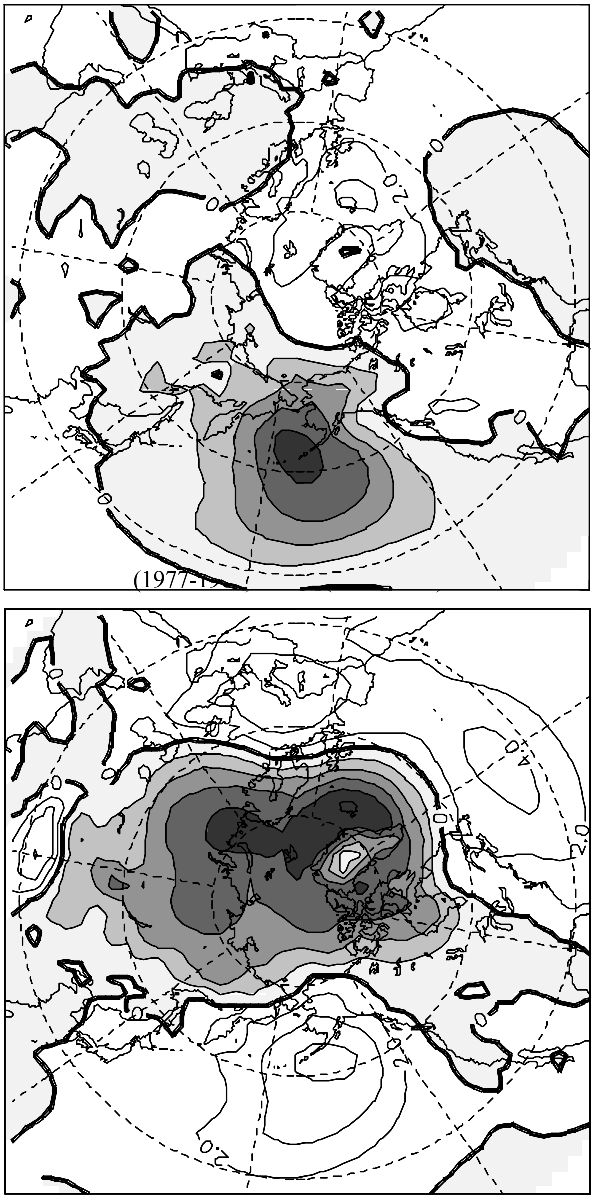


Figure 1. Time series of January-February Aleutian low central pressure, smoothed with a 3-year running mean. An objective change-point algorithm detected shifts in 1925, 1931, 1939, 1947, 1959, 1968, 1977, and 1989.



(1989B1997) minus (1977B1988)

Figure 2. Differences in the January-February mean sea level pressure for the clusters of years surrounding the two most recent climate shifts: 1968-1976, 1977-1978, and 1989-1997. Negative changes are shaded in gray, and the contour interval is 2 mb.

Figure 2 contains Northern hemisphere charts that illustrate the changes in the January-February mean sea, 1977-1988, and 1989-1997. The top panel shows the pressure changes during the shift from a weak Aleutian low in the early 1970s to a level pressure in the North Pacific between the periods 1968-1976deep Aleutian low in the 1980s. The shift to more neutral Aleutian low in the 1990s (bottom panel) corresponds to reduced sea level pressure in the Arctic.

We have investigated the relationship between the Aleutian low and preferred modes of variability of 700 mb heights as analyzed by the Climate Prediction Center (*Bell and Halpert* 1995). These modes are the standardized amplitudes constructed from the rotated principal component analysis (RPCA) for each month. The four dominant winter patterns are the North Atlantic Oscillation (NAO) and three Pacific patterns, the Pacific/North American (PNA), the West Pacific (WP), and the Polar/Eurasian (POL). The POL pattern has an anomaly pole centered in the Sea of Japan/southern Sea of Okhotsk and another near the North Pole. The POL pattern reflects changes in the strength of the circumpolar circulation; it was not identified in the RPCA of *Barnston and Livezey* (1987), yet in more recent years it is the most prominent mode in December and February.

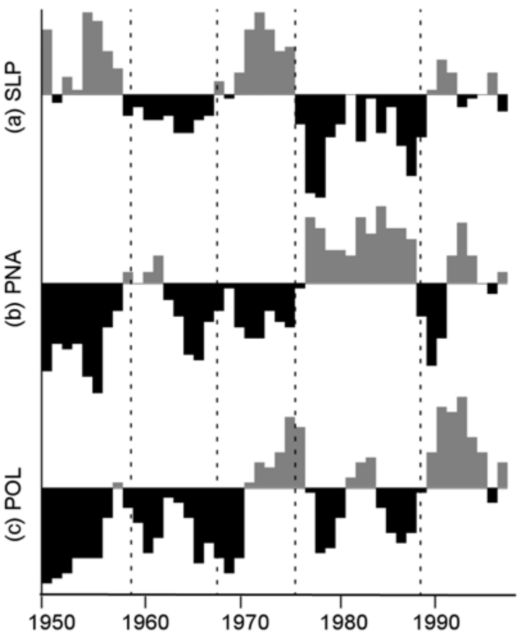


Figure 3. Time series of January-February mean values for (a) the central pressure of the Aleutian Low and (b) the standardized amplitudes for the PNA and (c) the POL. All time series have been smoothed with a 3-year running mean and cover the 45-year period 1951-1996. Vertical dashed lines indicate the shifts in the Aleutian low central pressure anomalies: 1959, 1968, 1977, and 1989.

Figure 3 compares the central pressure of the Aleutian low with the standardized amplitudes of the PNA, and the POL. All time series cover the period 1951-1996 and are smoothed with a 3-year running mean. The time series of the PNA (Figure 3b) exhibits variability over long periods and has been in the positive phase since 1977, except for a short period around 1989. The time series of the POL (Figure 3c) and WP (not shown) exhibit greater variability over shorter periods and are visually well-correlated with the Aleutian low central pressure. The PNA, WP, and POL patterns all contributed to the deepening of the Aleutian low in 1977, while only the POL pattern changed around 1970 and 1989 when the Aleutian low shifted. Regression of the Aleutian low central pressure on the PNA, WP, and

POL results in a correlation of 0.85, with an equal contribution from the Gulf of Alaska (PNA) and the NW Pacific/East Asia regions. Latitudinal shifts which reflect changes in the circumpolar circulation were also seen by *Wallace et al.* (1993). Their leading EOF mode of sea level pressure had a zonally symmetric "see-saw" between polar and temperate latitudes; the second mode was the PNA. At 500 mb the PNA was the leading mode in winter, but the see-saw or "background" pattern was present all year.

There is no doubt that conditions have changed in the Arctic and NE Asia since 1989. There has been a shift to more extreme ice extents in the Sea of Okhotsk (*Tachibana et al.* 1996), near-record minimum ice extents in the East Siberian Sea (*Maslanik et al.* 1996), increased sea ice melting in the central Arctic in summer (McPhee, personal communication), and negative anomalies in the sea level pressure in the central Arctic for every year since 1989 (*Walsh et al.* 1996). Changes associated with the POL pattern appear coupled from the surface to the stratosphere (*Kodera et al.* 1996). *Serreze et al.* (1997) show increased storm activity in the Arctic since 1990. These studies and the existence of see-saw variability patterns in recent analyses suggest that changes in the Arctic since 1989 may have an influence on the sub-Arctic circulation. This coupling is manifest as a strengthening of the circumpolar vortex in the Arctic. Mike Wallace (personal communication) has referred to the generalized POL as the Arctic Oscillation (AO).

The Stochaster, Regimer, and Oscillator

One of the topics of interest at the `Aha Huliko`a was a discussion of the Bayesian versus frequency distribution statistical viewpoint as applied to time series data. There was discussion of the validity of using such notions as statistical significance. A suggested approach was to compare models as applied to a particular time series. To try to understand some of these concepts we review the Aleutian low time series as presented in Figure 1. We first divided the data into 3-year bins and assigned a plus or minus to the interval based on the sign of 2 out of the 3 years. Three models are investigated:

(1) The Stochaster, where the probability of a plus or minus for each interval is considered independent,

$$M_1 : P_r[x_1 = x_{t-1}] = 0.5$$

(2) The Regime Shifter, a first order Markov model, where the transition probability depends only on the previous interval, but the probability of persistence is high,

$$M_2 : P_r[x_1 = x_{t-1}] = 0.7$$

and (3) the Oscillator, where there is a high probability of obtaining an opposite sign on a decadal scale,

$$M_3 : P_r[x_1 = Bx_{t-3}] = 0.7$$

The approach is to determine the probability of obtaining such a time series as Figure 1 for each model and forming ratios of the probabilities. For example, the ratio of the Regimer (R) to the Stochaster (S) is

$$M_2/M_1 = R/S = 38.6$$

and for the Oscillator (O) to the Stochaster is

$$M_3/M_1 = O/S = 3.6$$

Both the Regimer and the Oscillator do better than the Stochaster at fitting the time series and suggest that there is considerable decadal variability in the Aleutian low. That the Regimer does well would support the notion that there may be multiple climate states, with the probability of transition to another state being independent of the length of time within a state.

However, we do have some prior information. There is some indication that the time series before 1925 is contaminated by erroneous high pressure from Dawson City, Canada. If we begin the time series at 1920 we obtain

$$R/S = 5.1 \text{ and } O/S = 27.8$$

suggesting major decadal variability compared to the Stochaster, but now the Oscillator does better than the Regimer.

As a third example, we shifted to the data before 1925 by -3.0 mb, thus the years near 1913 and 1919 change sign. Now the 1900-1997 times series gives

$$R/S = 7.1 \text{ and } O/S = 8.4.$$

We conclude that the model analysis suggests decadal variability, similar to our variance analysis, but we cannot clearly distinguish between the Regimer and the Oscillator.

In summary, we conclude that the Aleutian low has considerable decadal variability and that this variability is influenced nearly equally by a tropical/temperate PNA pattern and a temperate/Arctic NE Asia pattern. Recent climate change in the Arctic suggests that zonal changes in the atmospheric circulation play a major role in understanding decadal variability.

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