

The Pacific Decadal Oscillation and Climate Forecasting for North America

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Introduction

"Climate" is defined as the statistics of weather, and is often quantified with numbers for things like monthly averaged temperature and precipitation, or the average number of heating degree days in winter, or cooling degree days in summer. As a general rule, important elements of the climate in any region are a moving target, most everyone knows this from their own observations--one year is often warmer than another, or maybe one year sees many more (or less) hurricanes than the next. While the vagaries of climate have often seemed random and unpredictable, recent advances in climate science point to a handful of regularly occurring patterns that impose at least a bit of order in the always variable climate system. The El Niño/Southern Oscillation, for instance, is the best known "natural pattern" of Earth's climate. In addition to El Niño, there are other heavily researched climate patterns that exert important influences on regional climates around the world. For instance, many studies highlight the relative importance of the Pacific Decadal Oscillation and Arctic Oscillation/North Atlantic Oscillation in North American climate. Each of these major patterns--El Niño/Southern Oscillation, Pacific Decadal Oscillation, and Arctic Oscillation/North Atlantic Oscillation--has characteristic signatures in seasonally changing patterns of wind, air temperature, and precipitation; each pattern also has a typical life time for any given "event". Much of the present day skill in the science of climate prediction exploits these signature patterns and typical life times. The remainder of this article is devoted to an overview of the Pacific Decadal Oscillation and how it contributes to skillful climate forecasts over the Pacific and North America.

A PDO definition

The Pacific Decadal Oscillation, or PDO, is often described as a long-lived El Niño-like pattern of Pacific climate variability (Zhang et al. 1997). As seen with the better-known El Niño/Southern Oscillation (ENSO), extremes in the PDO pattern are marked by widespread variations in Pacific Basin and North American climate. In parallel with the ENSO phenomenon, the extreme phases of the PDO have been classified as being either *warm* or *cool*, as defined by ocean temperature anomalies in the northeast and tropical Pacific Ocean.

Two main characteristics distinguish the PDO from ENSO. First, typical PDO "events" have shown remarkable persistence relative to that attributed to ENSO events - in this century, major PDO eras have persisted for 20 to 30 years (Mantua et al. 1997, Minobe 1997). Second, the climatic fingerprints of the PDO are most visible in the North Pacific/North American sector, while secondary signatures exist in the tropics - the opposite is true for ENSO. Several independent studies find evidence for just two full PDO cycles in the past century (e.g. Mantua et al. 1997, Minobe 1997): cool PDO regimes prevailed from 1890-1924 and again from 1947-1976, while warm PDO regimes dominated from 1925-1946 and from 1977 through (at least) the mid-1990's. Recent changes in Pacific climate suggest a possible reversal to cool PDO conditions in 1998, an issue that is discussed in more detail at the end of this article.

Tracking PDO variations

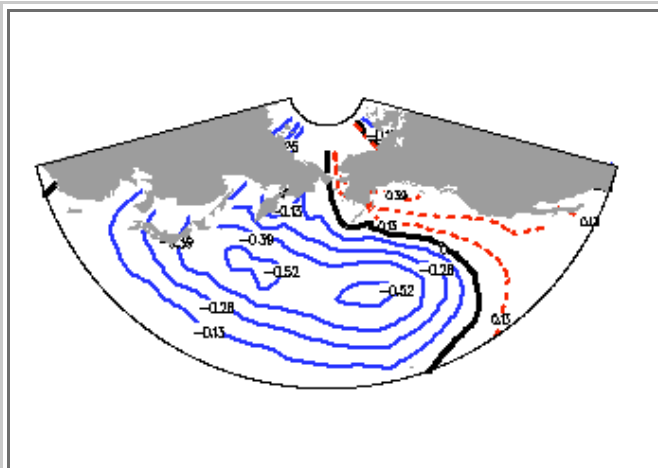


Figure 1: (left panel) Characteristic PDO sea surface temperature anomaly pattern. Solid blue contours depict cooler than average temperatures, while dashed red contours reflect warmer than average temperatures. Contour interval is 0.1 degree C. (right panel) .

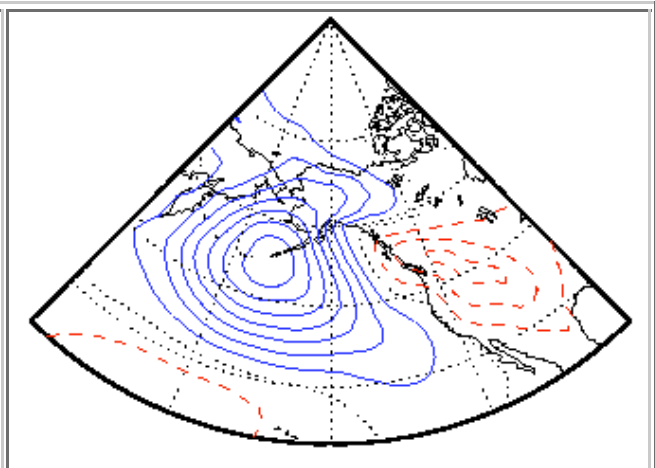


Figure 2: Characteristic PDO (atmospheric) sea level pressure anomaly pattern. Solid blue contours depict lower than average pressures, while dashed red contours reflect higher than average pressures. Contour interval is 0.2 millibars.

As is the case with ENSO, characteristic pressure, wind, temperature, and precipitation patterns have been connected with the PDO (Latif and Barnett 1995, Zhang et al 1997, Mantua et al. 1997). The pattern of North Pacific sea surface temperature (SST) variations noted to capture the oceanic part of the PDO is shown in Figure 1, while the pattern of sea level pressures (SLPs) noted to capture the atmospheric part are shown in Figure 2. The SST pattern highlights the strong tendency for temperatures in the central North Pacific to be anomalously cool when SSTs along the coast of North America are unusually warm, and vice-versa (Graham 1994, Miller et al 1995, Zhang et al 1997, Mantua et al 1997). The contour map of SLP anomalies (Figure 2) identifies a wave-like pattern of surface pressure (and wind) anomalies over the North Pacific. Basin-scale drops in SLP centered over the Aleutian Islands are often described as intensifications of the "Aleutian Low" pressure cell, which generally coincide with periods of anomalously high SLPs over western North America and the subtropical Pacific (Trenberth and Hurrell 1994, Graham 1994).

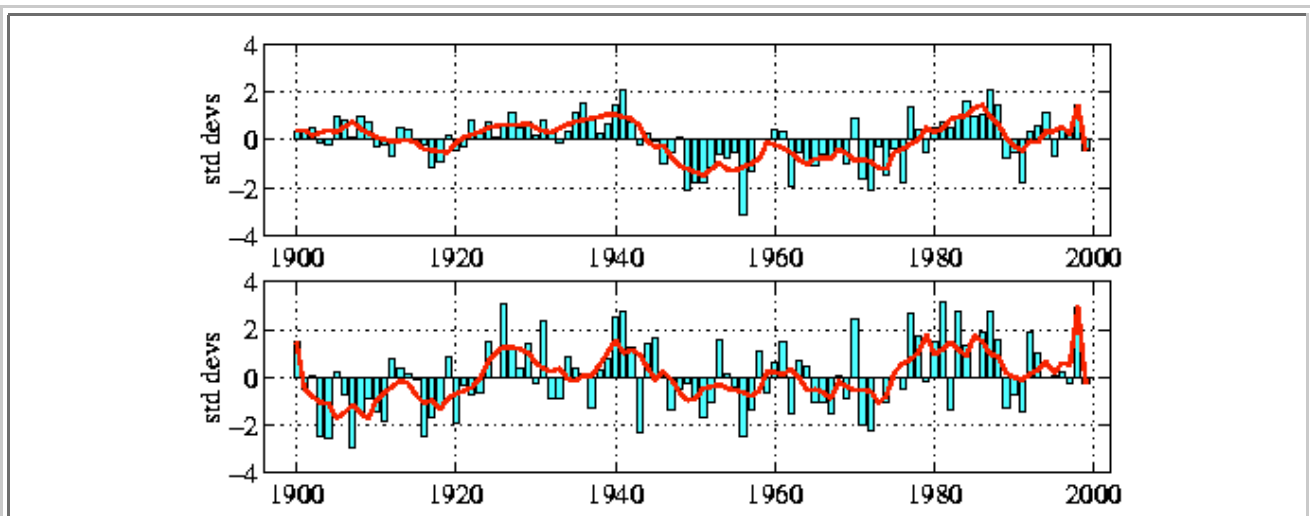


Figure 3: PDO indices based upon projections of observed North Pacific sst and slp patterns onto those shown in Figure 1. Index values are normalized for October to March averages. Solid red lines depict 5-year running average values for each index, respectively.

PDO indices have been constructed by projecting the observed monthly patterns of North Pacific SST and SLP anomalies onto the characteristic SST and SLP patterns shown in Figures 1 and 2, respectively (Trenberth 1990, Trenberth and Hurrell 1994, Zhang et al. 1997, Mantua et al. 1997). When SSTs are anomalously cool in the interior North Pacific and warm along the Pacific Coast, and when SLPs are below average over the North Pacific, the respective indices have positive values. When the climate anomaly patterns are reversed, with warm SST anomalies in the interior and cool SST anomalies along the North American coast, or above average SLPs over the North Pacific, the respective indices have negative values.

Winter/spring (October-March) average values for the PDO indices are shown with the bar graphs in Figure 3 (SST in the top panel, SLP in the bottom panel). Probably the most notable feature of these indices is the year-to-year persistence that characterizes much of their variability in the 20th century; this long-lived persistence is highlighted by the 5-year running averages of the indices. Negative values in both indices correspond to the cool PDO eras, while positive values are indicative of the warm PDO eras. Within the 20-to-30 year regimes there are several short-lived sign reversals in the indices; these include 3 year reversals from 1959-1961 and again from 1989-1991.

PDO influence on North American climate

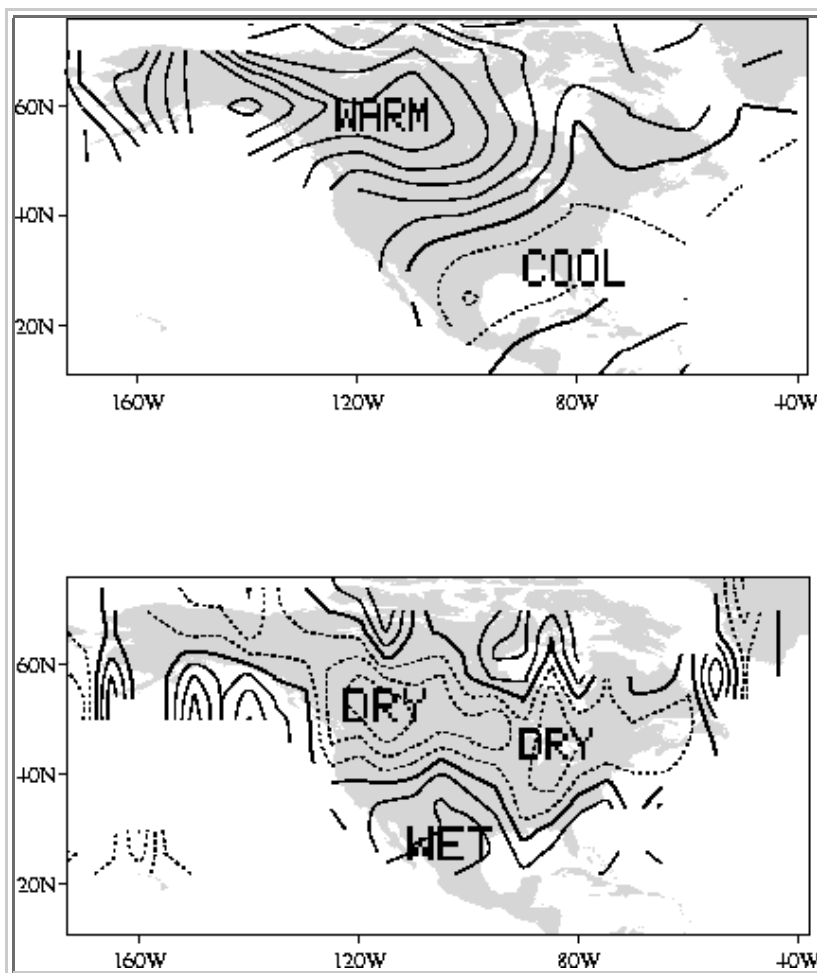


Figure 4: (top) Characteristic warm-phase PDO October-March air temperature anomalies, in degrees C. This field is based on linear regressions between the gridded surface air temperature data and the SST-based PDO index, shown in the top panel of Figure 3, for the period 1900-1993. Contour interval is 0.2 C. (bottom) Contour map of correlation coefficients between gridded North American December-February (DJF) precipitation and the SST-based PDO index, based upon data for the period 1900-93.

The North American climate anomalies associated with PDO warm and cool extremes are broadly similar to those connected with El Niño and La Niña (Latif and Barnett 1995, Latif and Barnett 1996, Zhang et al. 1997, Mantua et al. 1997). Warm phases of the PDO are correlated with North American temperature and precipitation anomalies similar to those correlated with El Niño (Figure 4): above average winter and spring time temperatures in northwestern North America, below average temperatures in the southeastern US, above average winter and spring rainfall in the southern US and northern Mexico, and below average precipitation in the interior Pacific Northwest and Great Lakes regions. Cool phases of the PDO are simply correlated with the reverse climate anomaly patterns over North America (not shown), broadly similar to typical La Niña climate patterns. The PDO-related temperature and precipitation patterns are also strongly expressed in regional snow pack and stream flow anomalies, especially in western North America (see Cayan 1995, Mantua et al. 1997, Bitz and Battisti 1999, Nigam et al. 1999). A summary of major PDO

climate anomalies are listed in Table 1.

Table 1: summary of North American climate anomalies associated with extreme phases of the PDO.		
<u>climate anomalies</u>	<u>Warm Phase PDO</u>	<u>Cool Phase PDO</u>
Ocean surface temperatures in the northeastern and tropical Pacific	Above average	Below average
October-March northwestern North American air temperatures	above average	Below average
October-March Southeastern US air temperatures	below average	Above average
October-March southern US/Northern Mexico precipitation	Above average	Below average
October-March Northwestern North America and Great Lakes precipitation	Below average	Above average
Northwestern North American spring time snow pack	below average	Above average
Winter and spring time flood risk in the Pacific Northwest	Below average	Above average

Implications for climate predictions

Recent studies suggest that ENSO teleconnections with North American climate are strongly dependent on the phase of the PDO, such that the "canonical" El Niño and La Niña patterns are only valid during years in which ENSO and PDO extremes are "in phase" (i.e. with warm PDO+El Niño, and cool PDO+La Niña, but not with other combinations) (Gershunov and Barnett 1999, Gershunov et al. 1999, McCabe and Dettinger 1999). Other studies have identified PDO connections with summer rainfall and drought in the US (Nigam et al. 1999), and the relative risks for winter and spring flood events in the Pacific Northwest (Hamlet and Lettenmeier, in press).

At the time of this writing, causes for (and predictability limits of) the PDO are not known. What is known is that the nature of the mechanisms giving rise to the PDO will determine whether or not it is possible to make decade-long PDO climate predictions. For example, it has been demonstrated that aspects of ENSO variability are predictable at lead times of at least one year. This time frame is related to the time period that equatorial ocean currents and temperatures need to respond and equilibrate to changes in tropical winds. By analogy, if the PDO arises from air-sea interactions that require 10 year ocean adjustment times, then aspects of the phenomenon will be (in theory) predictable at lead times of up to 10 years.

Even in the absence of a theoretical or mechanistic understanding, PDO climate information provides assistance in improving seasonal climate forecasts for North America. This is true because of the PDO's

strong tendency for multi-season and multi-year persistence. NOAA's Climate Prediction Center has exploited this facet of North American climate with their "*Optimal Climate Normals*" (OCN) statistical prediction tool. In the absence of El Niño or La Niña, the PDO provides much of the skill in seasonal climate forecasts for North America. Combining ENSO and PDO information offers improved statistical climate predictions over those based solely upon one of these two important climate patterns (Gershunov and Barnett 1999, Gershunov et al. 1999, McCabe and Dettinger 1999).

The skill in PDO-based forecasts comes from its tendency to persist, thus this skill disappears when there is an unforeseen change in the PDO pattern. Such a change--a flip from warm to cool PDO phases--may have taken place in 1998, coincident with the demise of the 1997/98 El Niño and the beginning of the ongoing La Niña episode. Currently, because no one is certain how the PDO works, it is not possible to say with great confidence that these recent changes in Pacific climate mark the beginning of a 20-to30 year long cool phase of the PDO. Thus, the lack of PDO understanding presents a barrier to both real-time monitoring and forecasting PDO reversals. The research community's ENSO experience showed that improved understanding and predictions came with the synergy of observational, theoretical, and modeling studies (National Academy Press, 1996). Each of these lines of PDO research have been identified as high priorities by the ongoing US CLIVAR program. PDO science is relatively new compared to ENSO science, but insights into the PDO have come at a furious pace in the last decade of the 20th century. More insights into how PDO works, and how to predict PDO variations, are sure to come in the first decade of the 21st century.

References

Bitz, C.C., and D.S. Battisti, 1999: Interannual to decadal variability in climate and the glacier mass balance in Washington, Western Canada, and Alaska. *Journal of Climate*, 12, 3181-3196.

Cayan, D. R., 1996: Interannual climate variability and snowpack in the western United States. *Journal of Climate*, 9, 928-948.

Gershunov and Barnett 1998: Interdecadal modulation of ENSO teleconnections. *Bulletin of the American Meteorological Society*, **79**, 2715-2726.

Gershunov, A., T. Barnett and D. Cayan, 1999: North Pacific interdecadal oscillation seen as factor in ENSO-related north American climate anomalies. *EOS*, 80, 25-30.

Graham, N.E., 1994: Decadal-scale climate variability in the 1970s and 1980s: observations and model results. *Climate Dynamics*, 10, 135-159.

Hamlet, A.F., and D.P. Lettenmeier, 1999: Columbia River Streamflow forecasting based on ENSO and PDO climate signals. *American society of Civil Engineering*, 25, 333-341.

Hare, S.R., and N.J. Mantua, (in press): Empirical indicators for Pacific climate and ecosystem changes, 1965-1997. *Progress in Oceanography*, in review.

Latif, M. and T.P. Barnett, 1994: Causes of decadal climate variability over the north Pacific and North America. *Science* 266, 634-637.

Latif, M. and T.P. Barnett, 1996: Decadal climate variability over the North Pacific and North America: dynamics and predictability. *Journal of Climate*, **9**: 2407-2423.

Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis, 1997: A Pacific decadal climate

oscillation with impacts on salmon. *Bulletin of the American Meteorological Society*, Vol. 78, pp 1069-1079.

McCabe, G.J. and M.D. Dettinger, 1999: Decadal variations in the strength of ENSO teleconnections with precipitation in the western United States. *International Journal of Climatology*. **19**: 1399-1410.

Minobe, S. 1997: A 50-70 year climatic oscillation over the North Pacific and North America. *Geophysical Research Letters*, Vol 24, pp 683-686.

Minobe, S. 1999: Resonance in bidecadal and pentadecadal climate oscillations over the North Pacific: Role in climatic regime shifts. *Geophysical Research Letters*, Vol. 26, pp 855-858.

National Research Council, 1996: Learning to Predict El Niño: Accomplishments and Legacies of the TOGA Program. NationalAcademy Press, 171pp.

Nigam, S., M. Barlow, and E. H. Berbery, 1999: Analysis Links Pacific Decadal Variability to Drought and Streamflow in the United States. EOS, Transactions, American Geophysical Union, Vol 80, No. 51, Dec 21 1999.

Trenberth, K.E., 1990: Recent observed interdecadal climate changes in the northern hemisphere. *Bulletin of the American Meteorological Society*, 71, 988-993.

Trenberth, K.E., and J.W. Hurrell, 1994: Decadal atmosphere-ocean variations in the Pacific. *Climate Dynamics* 9, 303.

Zhang, Y., J.M. Wallace, D.S. Battisti, 1997: ENSO-like interdecadal variability: 1900-93. *J. Climate*, 10, 1004-1020.

http://www.atmos.washington.edu/~mantua/REPORTS/PDO/PDO_cs.htm

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