The Pacific Decadal Oscillation

By Nathan Mantua, Ph. D.
Joint Institute for the Study of the Atmosphere and Oceans
University of Washington, Seattle, Washington, USA.

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General Summary

Fisheries scientist Steven Hare coined the term "Pacific Decadal Oscillation" (PDO) in 1996 while researching connections between Alaska salmon production cycles and Pacific climate. PDO has since been described as a long-lived El Niño-like pattern of Pacific climate variability because the two climate oscillations have similar spatial climate fingerprints, but very different temporal behavior. Two main characteristics distinguish PDO from El Niño/Southern Oscillation (ENSO): first, 20th century PDO "events" persisted for 20-to-30 years, while typical ENSO events persisted for 6 to 18 months; 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: "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 (Mantua et al. 1997, Minobe 1997). Minobe (1999) has shown that 20th century PDO fluctuations were most energetic in two general periodicities, one from 15-to-25 years, and the other from 50-to-70 years.

Major changes in northeast Pacific marine ecosystems have been correlated with phase changes in the PDO; warm eras have seen enhanced coastal ocean biological productivity in Alaska and inhibited productivity off the west coast of the contiguous United States, while cold PDO eras have seen the opposite north-south pattern of marine ecosystem productivity.

Causes for, and the potential ability to predict, PDO are not currently known. Some climate simulation models produce PDO-like oscillations (e.g. Latif and Barnett 1994, Gu and Philander 1997), although often for different reasons (NRC 1998). The mechanisms giving rise to PDO will determine whether skillful decades-long PDO climate predictions are possible. For example, if PDO arises from air-sea interactions that require 10 year ocean adjustment times, then aspects of the phenomenon will (in theory) be predictable at lead times of up to 10 years. Even in the absence of a theoretical understanding, PDO climate information improves season-to-season and year-to-year climate forecasts for North America because of its strong tendency for multi-season and multi-year persistence. From a societal impacts perspective, recognition of PDO is important because it shows that "normal" climate conditions can vary over time periods comparable to the length of a human's lifetime.

PDO characteristics, impacts, and importance for climate predictions

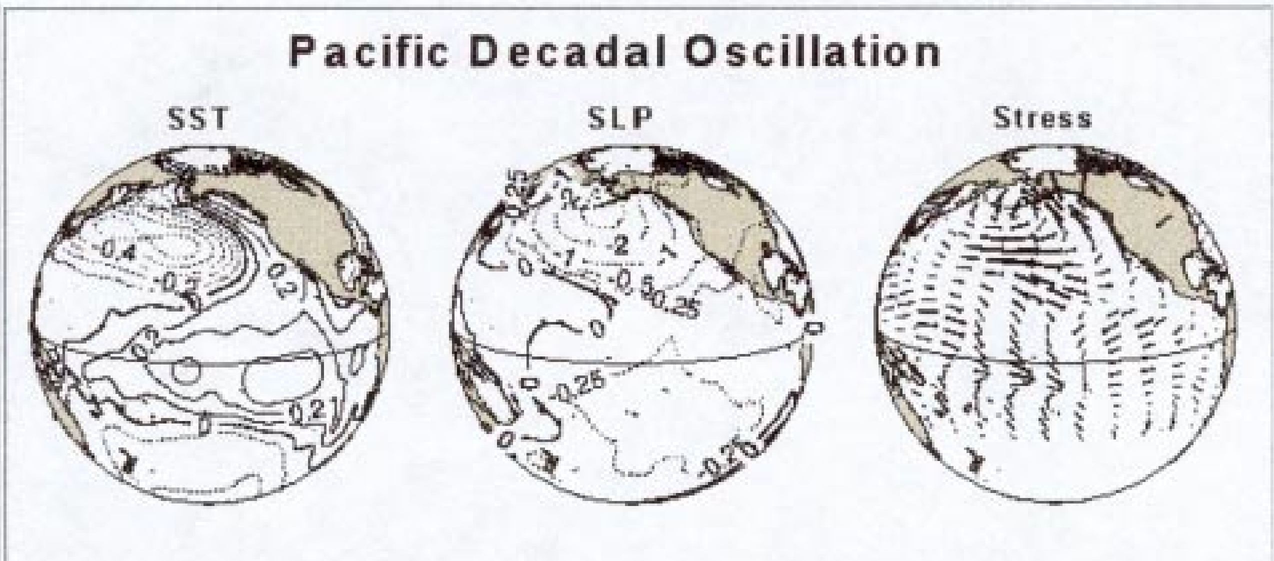

Figure 1: Warm phase PDO surface climate anomalies: (left panel) sea surface temperature anomaly pattern, dashed contours depict cooler than average temperatures, while solid contours reflect warmer than average temperatures, contour interval is 0.1 degree C; (center panel) atmospheric sea level pressure anomaly pattern, dashed contours depict lower than average sea level pressures, while solid contours reflect warmer than average pressures; (right panel) wind stress anomaly vectors, the longest wind vectors represent a (pseudo)stress of 10 m^2/s^2. After Hare et al. 1999.

Typical surface climate anomaly patterns for warm phases of PDO are shown in Figure 1. SSTs tend to be anomalously cool in the central North Pacific coincident with unusually warm sea surface temperatures (SSTs) along the west coast of the Americas. PDO sea level pressure (SLP) anomalies vary in a wave-like pattern, with low pressures over the North Pacific and high SLP over western North America and the subtropical Pacific. These pressure patterns cause enhanced counterclockwise wind stress over the North Pacific. PDO circulation anomalies extend through the depth of the troposphere, well-expressed as persistence in the Pacific North America (PNA) teleconnection pattern described by Wallace and Gutzler (1981) (see also Graham 1994, Trenberth 1994, Latif and Barnett 1994, Zhang et al. 1997, Mantua et al. 1997).

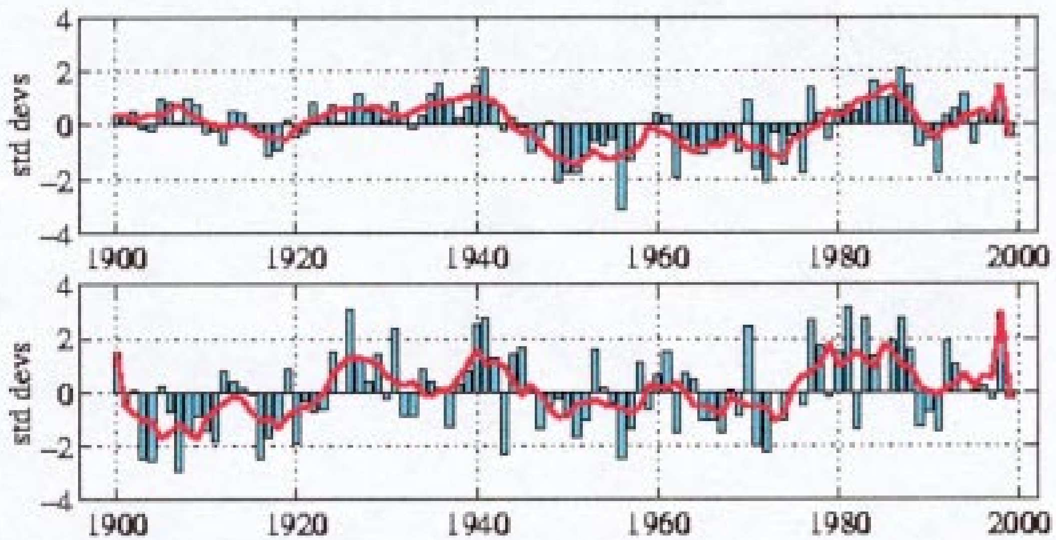

Figure 2: October-to-March averaged PDO indices based upon projections of observed North Pacific SST and SLP patterns onto those shown in Figure 1. Positive values indicate warm phases of PDO, while negative values indicate cool phases of PDO. Index values are normalized for the entire period of record shown. Solid curve shows a 5-year running average for each time series. October-to-March averages are used because year-to-year PDO fluctuations are most energetic during these months.

Tracking PDO variations is typically done with indices constructed from observed Pacific SST and SLP patterns. A representative pair of PDO indices are shown in Figure 2 (see Trenberth 1990, Trenberth and Hurrel 1994, Zhang *et al.* 1997, and 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, these two indices have positive values, indicating warm phase PDO conditions. The most notable feature for these indices is their tendency for year-to-year persistence, with positive/warm or negative/cool index values tending to prevail for 20-to-30 year periods. However, within the 20-to-30 year regimes there are several short-lived sign reversals in the indices, including 3 year reversals from 1959-1961 and again from 1989-1991.

The North American climate anomalies associated with PDO are broadly similar to those connected with El Niño and La Niña, though generally not as extreme (Latif and Barnett 1994, Trenberth and Hurrell 1994, Latif and Barnett 1996, Zhang *et al.* 1997, Mantua *et al.* 1997). Warm phases of PDO are correlated with El Niño-like North American temperature and precipitation anomalies, while cool phases of PDO are correlated with La Niña-like climate patterns. PDO variability is 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, Hamlet and Lettenmeier 1999), and may also influence summer rainfall and drought in the US (Nigam *et al.* 1999). A summary of major climate anomalies associated with PDO are listed in Table 1.

Table I: summary of Pacific and North American climate anomalies associated with extreme phases of the PDO.		
climate anomalies	Warm Phase PDO	Cool Phase PDO
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 and water year (October-September) stream flow	Below average	Above average
Winter and spring time flood risk in the Pacific Northwest	Below average	Above average

Combining PDO and ENSO information may enhance the skill of empirical North American climate forecasts. ENSO influences on North American climate are strongly dependent on the phase of the PDO, such that the "canonical" El Niño and La Niña patterns of North American climate anomalies tend to occur only during years in which ENSO and PDO extremes are "in phase" (*i.e.* with warm PDO coincident with El Niño, and cool PDO coincident with La Niña, but not with other combinations) (Gershunov and Barnett 1999, McCabe and Dettinger 1999).

Important changes in Northeast Pacific marine ecosystems have been correlated with the PDO (Francis *et al.* 1998). For example, warm PDO phases have favored high salmon production in Alaska and low salmon production off the west coast of California, Oregon, and Washington states. Conversely, cool PDO eras have favored low salmon production in Alaska and relatively high salmon production for California, Oregon, and Washington (Hare 1996, Hare *et al.* 1999).

Much controversy now exists over how PDO works, and how it might best be monitored, modeled and predicted. The stakes in PDO science are high, as an improved PDO understanding offers even sharper views of the future than those now provided by ENSO science alone.

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Nathan J. Mantua
Joint Institute for the Study of the Atmosphere and Oceans
Climate Impacts Group
University of Washington
Seattle, WA 98195-4235
USA
Email: mantua@atmos.washington.edu
Ph. (206) 616-5347; Fax: (206) 616-5775