News of the Northeast Pacific Ocean

by William Crawford, Skip McKinnell and Howard Freeland

Surface temperature of the Northeast Pacific Ocean is still in a cool era that began in 2006 and was interrupted only briefly in 2010. Lower temperatures over the past six years are coincident with mostly La Niña conditions in the tropical Pacific Ocean. Figure 1 shows the anomaly of sea surface temperature for the Pacific Ocean for the months of August and September of 2006 to 2011. This pattern of temperature is a feature of the negative phase of the Pacific Decadal Oscillation (PDO) that dominates North Pacific climate variability (Mantua *et al*., 1997). The main PDO characteristics are: negative anomalies (cool) in the eastern North Pacific that form a crescent around a mid-Pacific pool of positive anomalies (warm) centred between 30°N and 40°N. The dominant La Niña pattern is revealed by negative temperature anomalies along the central Pacific equator. A search of temperature anomalies in August and September of the past two decades indicates a general sequence of positive and negative versions of the patterns of Figure 1. In general, the eastern side of the North Pacific was cool in 1998 to 2001, whereas warmer waters dominated in 1992 to 1998 and in 2001 to 2005. Although the features are not a perfect fit to PDO variability, they do follow it, and the ENSO variability, rather closely.

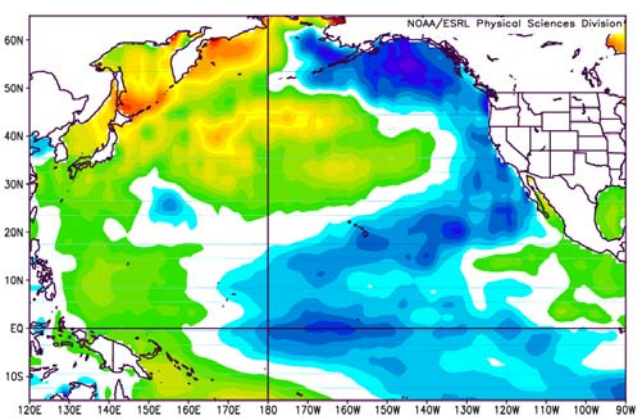


Fig. 1 Anomalies of sea surface temperature for the Pacific Ocean north of 15°S, for the months of August and September of 2006 to 2011. Blue regions reveal negative anomalies; red denotes positive anomalies, with a range of ± 1.5°C. Images provided by NOAA (http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl).

The PDO time series and spatial pattern are calculated as the first mode of an empirical orthogonal function of ocean temperature anomalies of the Pacific Ocean north of 20°N, (Davis, 1976). It is based on time series over the Pacific Ocean at resolution of 2° in latitude and longitude. Since 1982, with better satellite observations, ship-based reporting and Argo floats, the accuracy and spatial resolution has improved. To take advantage of these improved measurements, we have calculated a high-resolution PDO for the years since 1982, with its time series shown in Figure 2. Years of positive PDO and relatively warm ocean waters of the Northeast Pacific dominate the PDO prior to 1998; negative PDO and relatively cool Northeast Pacific Ocean waters dominate after 1998. Although both patterns are briefly interrupted, we do see mostly red at the left and mostly blue at the right. Each phase is attributed to persistent anomalies of winds over the Pacific. This pattern of decadal variability extends back to at least the 1900s, with distinct positive and negative phases each covering periods of more than a decade. Although the PDO spatial stability broke down briefly in the late 1990s and early 2000s when its normally smaller second mode dominated (Bond *et al*., 2003), the PDO mode has generally dominated from 1982 to present, except for a couple of years after the 2002/03 El Niño when North Pacific anomalies shared a common positive sign.

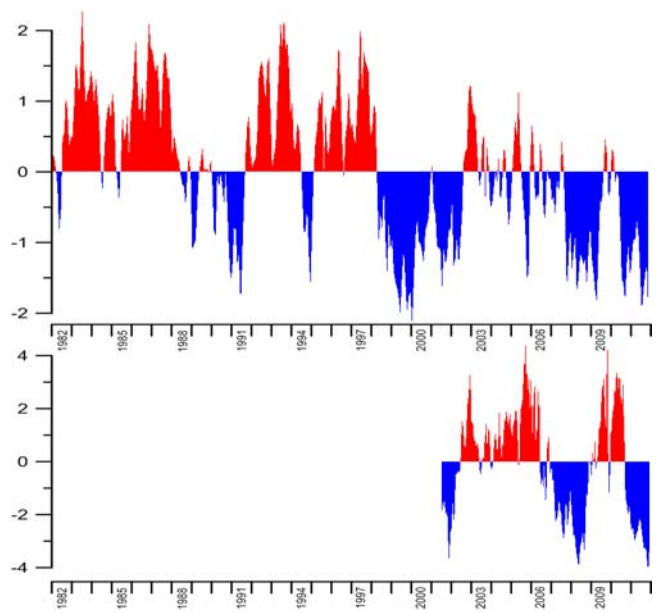


Fig. 2 Upper panel: time series of a high-resolution PDO (standard deviations) computed from monthly time series of Pacific Ocean surface temperature anomalies on a 1° latitude and longitude grid. Lower panel: time series of anomalies of oceanic heat content (10^8 joules/m^2) in the upper 700 m at Ocean Station P (50°N, 145°W), calculated from Argo floats.

The lower panel of Figure 2 reveals anomalies of heat content in the Gulf of Alaska in the upper 700 m, computed from measurements made by Project Argo's profiling floats. There are now more than 3000 active Argo floats scattered across all the oceans, whose measurements have provided high spatial and temporal resolution globally for almost a decade. We note that the time series of heat content at Ocean Station P generally matches the PDO, although their zero crossings on the *y*-axes are offset, likely due to the different periods used to compute long-term average values.

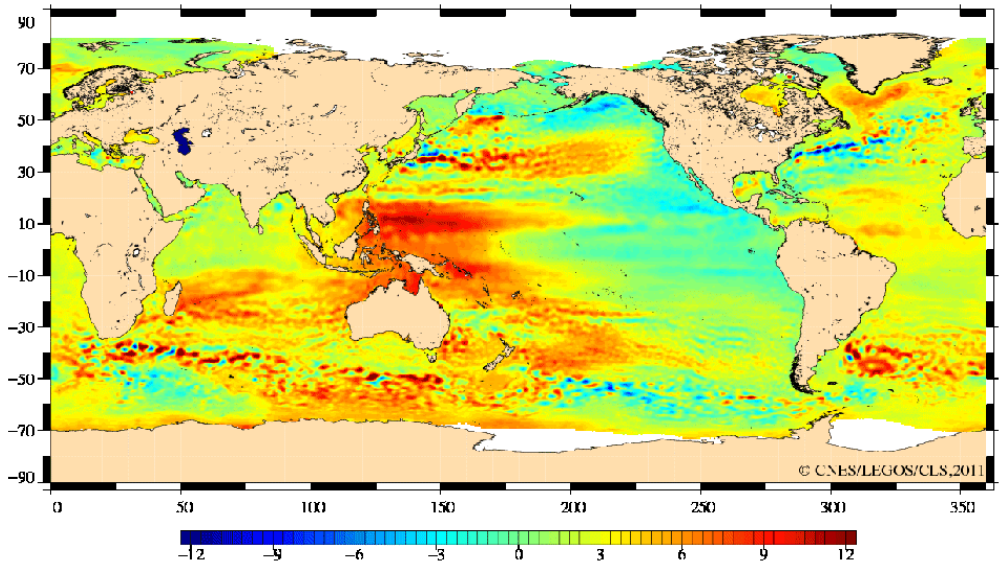
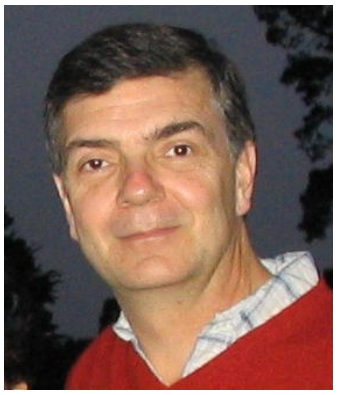


Fig. 3 Sea level rise from October 1992 to December 2010, as measured by satellites. Image provided by AVISO: http://www.aviso.oceanobs.com/en/news/ocean-indicators/mean-sea-level/.

For marine life along the west coast of Canada and the United States, some species have surged and retreated northward along the coast in association with changes between warm and cool waters. For example, sardines returned to west coast Canadian waters in 1992 from more southern regions during a warm period. Through the next decade of mostly warm waters, their numbers increased but since the start of the present cooling in 2006, the biomass of sardine in Canadian waters has declined. The numbers of Pacific hake and Humboldt squid have declined off western Canada in the past few years. Both are warm-water species whose "home" waters are on the continental shelf far to the south.

The shifting PDO phase is itself part of a Pacific-wide signal that extends far into the South Pacific Ocean. Cool phases in the eastern North Pacific are dominated by stronger westerly winds at mid latitudes, and stronger trade winds in the tropics, part of negative PDO and La Niña respectively. Reversals of these winds set up warm phases, associated with positive PDO and El Niño. These persistent anomalies in winds even alter sea levels across the Pacific, which is not too surprising since the temperature anomalies at Ocean Station P extend down to 700 metres, a feature likely common to much of the Pacific. We can observe this Pacific-wide pattern, in Figure 3, of regional sea level rise measured by satellites since 1992.



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The time trend in Figure 3 began with the launch of TOPEX/Poseidon by CNES and NASA in September 1992, and has continued with ERS and ENVISAT satellites of the European Space Agency, and Jason-1 and -2 of the CNES-NASA partnership. The time series of sea level rise since 1992 is calculated by averaging the measurements over all oceans and calibrating sea level measurements among the satellites and with accurate sea level gauges on isolated islands. It indicates a global-average rise of 3 mm/yr over this period. The colours in Figure 3 reveal that this global average has significant variability in the Pacific Ocean. Over much of the Pacific coast of the Americas there has been no sea level rise since 1992. The entire coast north of 20°S is mostly shaded blue, representing sea level fall from 1992 to 2010. On the other hand, the western tropical Pacific has experienced a much greater rise, with some regions surpassing 10 mm/yr.

We attribute this east–west difference to the same wind anomalies that set up the PDO and ENSO patterns since 1992. The 1990s were dominated by El Niño and positive PDO, but since 1998 La Niña and negative PDO have prevailed. To some extent, the figures above reveal that both global warming and its associated sea level rise have been "on hold", or even reversed for the past decade or so in the Northeast Pacific Ocean. Recent winter-averaged sea levels (the season of highest sea level) have not matched the high extreme of the winter of 1997/98. The present era of cooler seawater along Line P (a line of sampling stations between Canada and Ocean Station P) has persisted longer than in any decade back to the early 1970s (DFO, 2011).

Although we do not offer a prediction on when the present cool PDO phase will end, when it does end there could be a relatively rapid rise in sea level along the Central and North American coast and warmer waters, accompanied by poleward movement of warm-water marine species.

References

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