The State of the Northeast Pacific in 2010

by William Crawford and Marie Robert

El Niño–Southern Oscillation (ENSO) weather patterns have dominated the Northeast Pacific Ocean for the past few years. From 2008 to early 2009, temperature anomalies were typical of La Niña, coinciding with La Niña sea surface temperature (SST) anomalies on the Pacific Equator. Although the Tropical Pacific switched to a full El Niño by mid-2009, it was not until early 2010 that the temperature anomalies in the Northeast Pacific took on the pattern of an El Niño winter, as shown in the SST anomalies in March 2010 (Fig. 1a). By summer 2010, SST in the Tropical Pacific Ocean had reverted to La Niña conditions, characterized by the negative SST anomalies on the Pacific Equator in July–September (Fig. 1b). La Niña strengthened in the Tropical Pacific through the remainder of 2010, ending the year with very negative temperature anomalies on the Equator in December 2010 (Fig 1c).

In typical La Niña winters in the Northeast Pacific Ocean, the SST anomalies along the coast continue to fall more into negative numbers from December to March. The SST anomaly pattern of March 2008, the most recent full La Niña winter, is shown in Figure 1d. Although each ENSO brings somewhat different weather and SST patterns, we might expect the SST anomalies of March 2011 to resemble the pattern of March 2008 (Fig. 1d) if this 2010–2011 La Niña follows tradition.

SST anomalies for March of 2008 and 2010 reveal typical ENSO features on the Equator and also in the Northeast Pacific Ocean, as illustrated in Figure 1:

1. Warm water on the Equator in El Niño (Fig. 1a), cool in La Niña (Fig. 1d). An anomaly of more than 0.5°C for most of a year is a necessary condition for an event to be labelled El Niño, with positive anomalies in El Niño and negative in La Niña.
2. Warm water along the west coast of North America in El Niño winters (Fig. 1a), cool in La Niña (Fig. 1d). Both northward propagating coastal trapped waves and

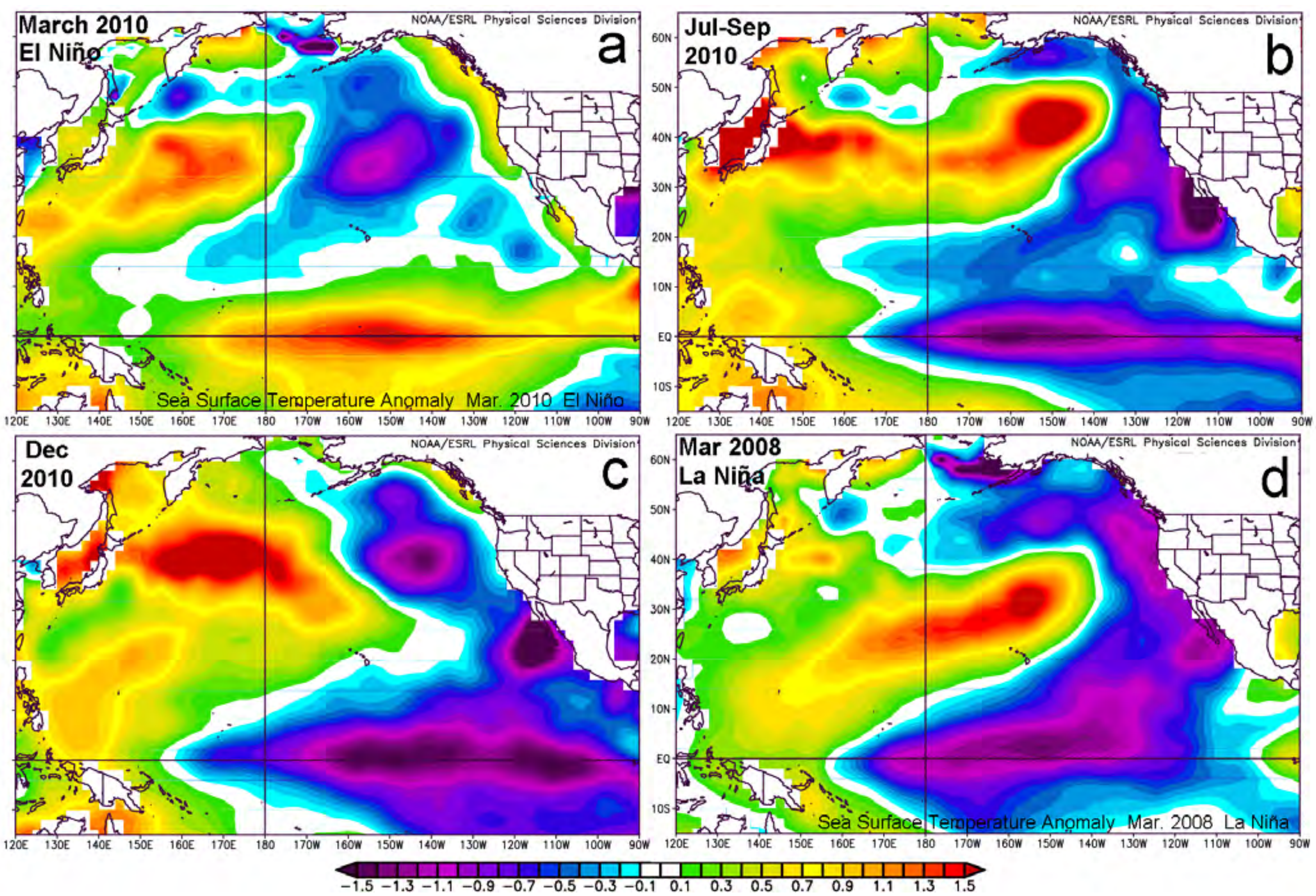

Fig. 1 Average sea surface temperature (SST) anomalies of the Pacific Ocean over the months of March 2010 (a), July–September 2010 (b), December 2010 (c), and March 2008 (d). Colour contours are based on NOAA Extended SST anomalies. Colour scale is in °C, at intervals of 0.1°C, as indicated in the scale bar at bottom. These images were prepared by on-line data display software of NOAA. Readers can create their own contour maps by accessing this Internet site: http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl.

stronger downwelling winds along this coast contribute to the warming during El Niño, with downwelling winds generally dominating north of San Francisco, California. Downwelling winds are much weaker from Oregon to Alaska and upwelling winds can increase off southern California during La Niña. The warm-water band along the west coast of North America in March 2010 was smaller than typical for El Niño winters, perhaps due to the relatively late arrival of southerly winds in this ENSO event.

3. Cool water near 150°W to 170°W and 30°N to 40°N during El Niño (Fig. 1a), generally due to positive wind vorticity in and south of the Aleutian Low. The Aleutian Low increased in strength and expanded to the south in each of the previous six El Niño winters in the Northern Hemisphere. With La Niña (Fig 1d), the Aleutian Low moves northward, and the North Pacific High strengthens and expands, bringing divergent surface currents and relatively cool surface temperatures to this deep-sea region.

The shift from El Niño to La Niña conditions along the continental margin of the Northeast Pacific was captured by water property measurements of the Line P Program. This program measures ocean properties in the Northeast Pacific three times per year along the track shown in Figure 2. Most funding for this program is provided by the Canadian Department of Fisheries and Oceans, with partners at universities in Canada and the United States, and support for ocean moorings from NOAA.

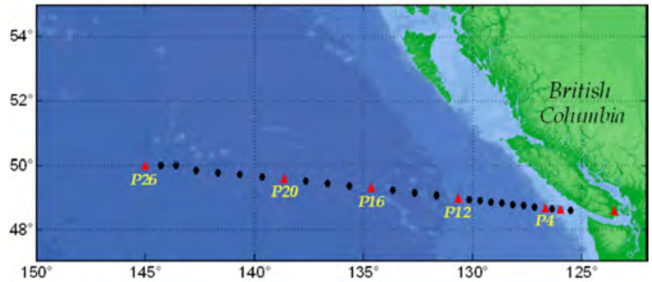

Fig. 2 Stations sampled by the Line P Program in winter, spring and summer every year. Red symbols denote stations with intensive chemical and biological sampling. P26 is also known as Ocean Station Papa.

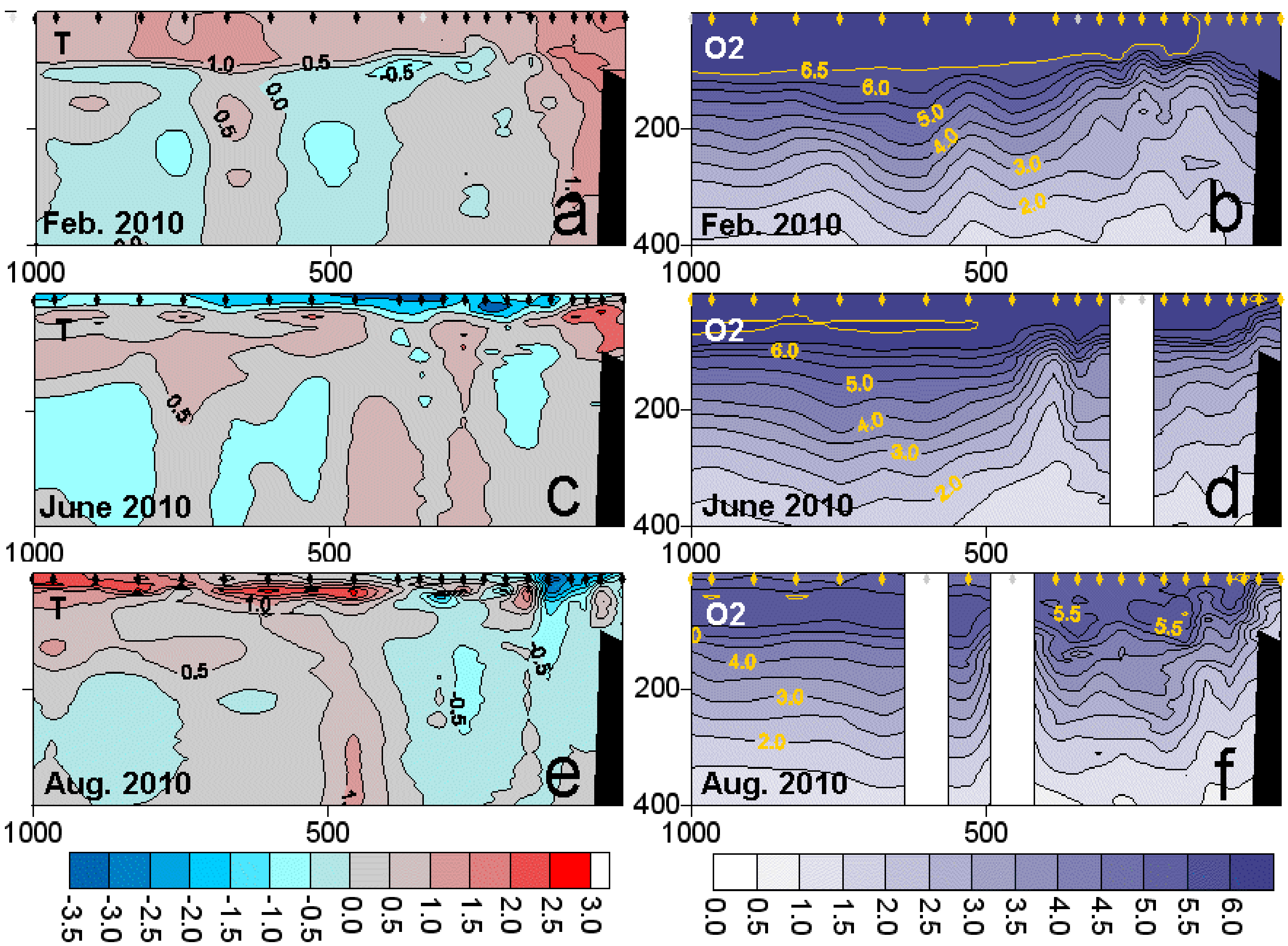

Fig. 3 Contour plots of temperature anomalies (left, °C) and oxygen concentrations (right, ml/L) along the eastern end of Line P in February (a, b), June (c, d) and August (e, f) 2010. The continental shelf of Vancouver Island is at right of each panel.

A characteristic feature of El Niño winters in the Northeast Pacific Ocean is a much more intense Aleutian Low Pressure System, and the 2009–2010 El Niño winter saw exceptionally low pressure and severe storms. The February 2010 Line P cruise encountered too many storms and was unable to reach Ocean Station Papa. These storms were so intense that the average air pressure in January to February 2010 at 46°N, 143°W was 13 millibars below normal, the lowest since the massive El Niño of 1982–1983.

In Figure 3, we present the temperature anomalies and oxygen concentrations of 2010 along the eastern-most 1000 km of Line P to show how shifting wind patterns changed water properties during this year. The Line P stations begin near shore, where stronger southerly winds of the El Niño winter storms brought warmer surface waters in early 2010. Ekman downwelling caused these warm waters to penetrate and mix to the bottom of the continental shelf in March 2010 (Fig. 3a). This coastal warming during El Niño winters normally extends far into the Northeast Pacific, generally west of P26, so the continuous layer of anomalously warm surface water all across Figure 1a was expected.

Although these surface waters were anomalously warm, they carried more oxygen than the deeper waters they displaced on the continental shelf. The oxygen contours in February 2010 sloped downward on the continental margin, as surface waters mixed and downwelled to the bottom (Fig. 3b). Such downwelling was not observed in the previous two winters, and oxygen concentrations in bottom water on the shelf were lower than in March 2010. By June 2010 as upwelling winds arrived, the positive SST anomalies (Fig 3c) and lower oxygen waters (Fig. 3d) advected onto the bottom of the continental shelf. The upwelling winds along Vancouver Island were stronger than normal in July–September 2010, perhaps due to La Niña conditions.

By August 2010, the Line P cruise encountered negative SST anomalies on the continental shelf and out to 400 km from shore, with only a trace of positive temperature anomalies at mid-depth (Fig 3e). This surface cooling might be attributed to stronger upwelling winds here in this summer. The oxygen concentrations (Fig. 3f) declined from those measured in June, as is normal for this region, but did not fall to the very low levels of August 2009, perhaps due to the strong aeration during the previous winter. The oxygen concentration in August 2010 was about 1.0 ml/L near bottom in mid-shelf in 150 m of water, which is typical for summer, but higher than in the late summers of 2006 and 2009. In these two years the near-bottom oxygen concentration dropped to 0.7 ml/L on the southern Vancouver Island shelf, and even lower along Oregon and Washington.

We have associated ENSO cycles with changes in SST and sub-surface oxygen concentrations of the Northeast Pacific from 2008 to 2010. Changes in SST can also be associated with the Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO), and in previous decades these modes of climate variability have been useful, or even needed, to account for the many patterns of SST variability. However, since 1998 the PDO and ENSO patterns have generally aligned in a way to support each other in their impact of SST in the Northeast Pacific, with the result that qualitative predictions of SST anomalies based only on ENSO (and in some regions only on PDO) have been relatively reliable. Given the surprises in climate variability in the past, we do not expect this alignment to continue.


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