The precautionary approach to the PDO

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Dr. Skip M^{c}Kinnell is Deputy Executive Secretary of PICES. During one of his former lives, he studied the relationship between various forms of macronekton and the sea. The abundance and diversity of scientific topics crossing his desk still manages to trigger some curiosity about what we think we know about any number of topics and how and why we came to think it. The topic of this article was inspired by some rather stimulating discussions with Jim Overland (PMEL, Seattle), and Steven Bograd (PFEL, Pacific Grove) at the PICES North Pacific Ecosystem Status Working Group meeting in Victoria in August 2003 and the recent paper by Bond et al. (2003).

Our collective approach to the complexity of nature has been to simplify its variability with indices of what we think are the dominant processes. Some typical examples in common use include:

- the difference between surface air pressure at Darwin and Papeete as a measure of the intensity of El Niño events (SOI – Southern Oscillation Index),
- the weighted sea level pressure over the North Pacific Ocean as an indication of average storm activity (North Pacific Index),
- the difference between the air pressure in Iceland and the Azores (NAO index), and
- the temporal pattern of the leading EOF of sea surface temperatures in the North Pacific Ocean, north of 20°N. (PDO index).

The first three of these share a common characteristic; they are continuous, interval-scale variables that represent varying levels of a statistic of some relatively well understood physical process. The fourth does not share this characteristic but it is often used as though it does. A recent and important paper by Bond *et al*. (*Geophys. Res. Lett*, 2003, 30, 2183) gives plenty of reason to be cautious when invoking the PDO index to explain significant fractions of the variability in nature.

During the late 1990s, "we" became fascinated with the idea that ocean/climate variability in the North Pacific was not caused by random perturbations of some steady state. Certainly the ocean appeared autocorrelated, switching at rather infrequent intervals between some apparently limited number of states. The ultimate cause has not yet been discovered, but a paper by Mantua *et al*. (*Bull. Am. Meteor. Soc.*, 1997, 78, 1069) created its own regime shift in scientific activity directed at the idea. They defined the PDO index (PDOI) as the temporal realization (from 1900) of the leading EOF derived from a 5° by 5° latitude/longitude gridded monthly SST anomaly series in the North Pacific, north of 20°N latitude. During its maximum positive phase, the spatial pattern of the PDO is characterized by a zonally oriented region of cold SSTs in the central and western North Pacific accompanied by a warm merdionally oriented region along the North American coast, and the inverse during periods of maximum negative values (Fig. 1). This pattern is now one of the most widely recognized images of earth and ocean sciences.

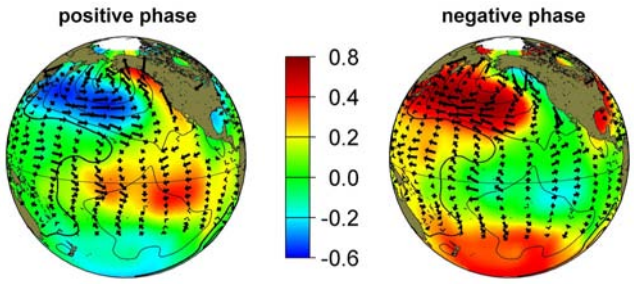

Fig. 1 Extremes of PDO pattern (Mantua et al. 1997)

The PDO pattern receives special attention for a few reasons: (1) it represents the greatest expanse of interannually co-varying surface water in the North Pacific, north of 20°N during the last century; (2) on decadal scales, there is significant autocorrelation as warm/cold phases tend to persist; (3) some aspects of both the atmospheric and biological components of the North Pacific are correlated with these phase changes; and (4) while the patterns are apparent, how it all works is still quite mysterious (to me, at least).

While the PDO may be the dominant pattern over the past century, it represents only ~25% of the SST co-variability. For my own edification, I computed the leading EOFs using a finer grid (1° × 1°) Reynold's Optimally Interpolated SST (Version 2) monthly mean data from 1982 to 2003 (Sept.); each month was analysed independently using the latitudinal range from 20°N to 60°N. Correlations among 4563 timeseries at lat/long grid points were computed and the dominant EOFs extracted using the IMSL routine PRINC. As this is only to illustrate a point, I did not make the extra effort to correct for the correlation bias that will arise at northern latitudes due to converging meridians, but my suspicion is that the bias is not so great.

Restricting the analysis to the most recent 22 year period eliminates the strong "regime-like" changes that occurred earlier in the 20th century but the data have the characteristic of greater consistency in spatial coverage and sampling methodology over this shorter time interval than is possible with the longer reconstructed SST history. The main difference between my result and Mantua *et al*. was that the PDO pattern (Fig. 2b) was the second mode rather than the first. The spatial pattern of the dominant mode from 1982-2003 is characterized in winter (Fig. 2a) by an elliptical region of highest correlation centred in the subtropics near 31°N 175°W and extending southwestward. The region of greatest correlation of opposing sign appears along an well-defined arc stretching from west of the Baja California peninsula through the western Gulf of Alaska just to the west of Station Papa (51°, 155°W) to the western Bering Sea (56°N 168°E).

This result emphasizes the point made by Bond *et al*. that since 1989, the North Pacific has been dominated by variability on their second EOF rather than the PDO. The reorganization of ocean/climate and marine ecosystems in 1989 had been recognized as different from, and clearly not a reversal of the PDO (Hare & Mantua, *Prog. Oceanogr*., 2000, 47, 103; Minobe, *Prog. Oceanogr.*, 2000, 47, 381) but Bond *et al*. (2003) show us why. What was not recognized earlier was that the change in 1989 was a 'mode shift' (change in spatial pattern), rather than a phase shift (change in sign), and this confusion was probably responsible for McFarlane *et al*. (*Prog. Oceanogr.*, 2000, 47, 147) wondering why the change in 1989 was apparent to them in the fish, but not apparent to others looking elsewhere. What is now clear is that there are (at least) two kinds of major pan-Pacific change and we should define them as such in the future.

The practical consequences of distinguishing a mode shift from a phase shift are important. The PDOI has often been correlated with other temporally indexed variables of interest, in the hope of demonstrating some correspondence between the two. Yet these practitioners have not realized that this potentially makes no sense. There is not an interval scale mapping of the range values of the PDOI onto known geographical SST patterns. The PDO spatial pattern does not exist at PDOI=0, a not infrequent occurrence during the last century, especially the first half. In fact, over the entire record, the winter PDOI distribution is normal with a mean not significantly different from 0, hence the central tendency of SSTs in the North Pacific on a centennial scale is not the PDO. This may explain why reconstructions of the PDOI from correlations with various proxies are not that consistent.

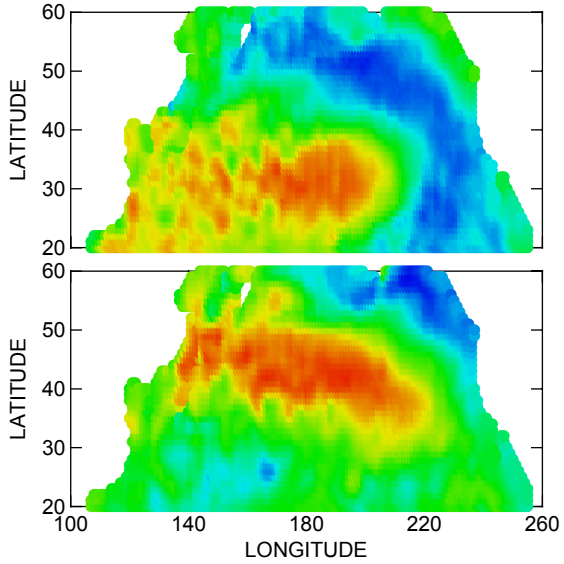

Fig. 2 Victoria spatial pattern (EOF 1 - above) and PDO pattern (EOF 2 - below) calculated from January SSTs from 1982-2003.

Closing thoughts:

- *Regime shift* has been a catch-all phrase for all manner of rapid shifts in the state of nature.
- It is now clear that *mode shifts* (changes in pattern) must be distinguished from *phase shifts* (sign reversals of a particular pattern) as they are different species of the genus *regime shift*.
- 1989 was a mode shift, not a phase shift (of the PDO).
- As these ideas germinated at a PICES meeting last August in Victoria, B.C., I propose that the EOF 2 pattern (my EOF 1) be known as the *Victoria Pattern* and the temporal realization as the *Victoria Oscillation Index*, or perhaps just the *Victoria Index* until we see if it reverses.
- 1999 was a phase shift between the negative and positive phases of the Victoria Index.
- Dramatic changes have occurred in the California Current system since ~1989, including the demise of many Pacific salmon populations during the 1990s. Their equally dramatic reappearance since the 1999 phase shift suggests that their abundance in this region corresponds more closely to the phases of the Victoria pattern than to that of the PDO.
- Future work might consider ecosystem response in each of the 4 dominant states (PDO +/- and Victoria +/-); AND December 2003 resembles neither pattern!