The relationship between Pacific Decadal and Southern Oscillations: Implications for the climate of northwestern Baja California

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Resumen

La relación entre la Oscilación Austral (SO) y la Oscilación Decenal del Pacífico (PDO) es analizada por medio de modelos forzados y de predicción secundaria de la PDO. Estos modelos son construidos con los mismos índices comunmente asociados a diferentes aspectos del clima del noroeste de Baja California, es decir el Índice de Oscilación del Sur (SOI) y el Índice de la Oscilación Decenal del Pacífico (PDOI). El modelo secundario explica alrededor del 40% de la variabilidad anual de la PDO, mientras que el modelo forzado explica alrededor del 60% de la variabilidad anual más la variabilidad decenal de la PDO. Estos resultados verifican que el fenómeno de El Niño-Oscilación del Sur (ENSO) fuerza a la PDO; por lo tanto también sugieren que las variabilidades interanual y decenal del Pacífico, así como sus impactos climatológicos en el noroeste de Baja California, son principalmente generados por el ENSO. Por lo que se espera que en tanto mejoren los pronósticos del ENSO, mejoraran las predicciones climatológicas en esta región así como los pronósticos de la PDO.

Palabras clave: ENSO, PDO, clima, predicción, Baja California.

Abstract

The relationship between the Southern Oscillation (SO) and the Pacific Decadal Oscillation (PDO) is studied by means of forced and secondary forecast models of the PDO. These models are constructed with the same indices frequently associated to different aspects of the climate of northwestern Baja California, namely the Southern Oscillation Index and the Pacific Decadal Oscillation Index (SOI and PDOI). The secondary forecast model explains about 40% of the interannual variability of the PDO while the forced model explains about 60% of PDO interannual plus decadal variability. These results confirm that El Niño-Southern Oscillation (ENSO) forces the PDO. Thus interannual and decadal variabilities in the Pacific Ocean, and related climatological impacts in northwestern Baja California, may be mainly ENSO-generated. As ENSO forecasts improve, PDO forecast and climatological predictions in this region should also improve.

Key words: ENSO, PDO, climate, predictions, Baja California.

Introduction

The El Niño–Southern Oscillation (ENSO) phenomenon dominates tropical Pacific variability (Philander *et al*., 1984). The Pacific Decadal Oscillation (PDO) is the leading mode of sea surface temperature (SST) anomalies in the North Pacific (Mantua *et al*., 1997). Both are believed to play a prominent role in the climate of USA and Mexico (Bove and O'Brien, 2000, Pavia *et al*., 2006). Constructive interference of these two signals may significantly modify precipitation regimes in southwestern California (Gershunov and Barnett, 1998) and in northwestern Baja California (Reyes-Coca and Troncoso-Gaytan, 2004; Pavia *et al*., 2006). Warm phases of both ENSO and PDO seem to favor higher than average wintertime precipitations in this region. However, Newman *et al*. (2003) and Schneider and Cornuelle (2005), extended the stochastic forcing paradigm (Hasselmann, 1976; Frankignoul and Hasselmann, 1977), and suggested that the PDO is dependent on ENSO on both interannual and decadal time scales. This dependence must be taken into account for forecasts of decadal climatic variability in northwestern Baja California (e.g. Reyes-Coca and Troncoso-Gaytan, 2004), where ENSO seems to modulate precipitation (Pavia and Badan, 1998). Similarly it has been suggested that for northwestern Baja California ENSO effects seem to be better represented by an atmospheric index, rather than an oceanic index, at annual and lower-frequency scales (Campos, 1999). Nevertheless previous forced models have been based on oceanic El Niño indices (e.g. Newman *et al*., 2003).

Pacific decadal variability is an "ENSO-like" variability (Zhang *et al*., 1997). It is also related to PDO (Mantua *et al*., 1997); but recently this ENSO-like variability and PDO have been treated as different phenomena (Vimont, 2005). A major problem to identify the physical processes that generate tropical Pacific decadal variability is the lack of long observational records. Progress in understanding this variability has been achieved lately (Timmermann and Jin, 2002; Liu *et al*., 2002; Newman *et al*., 2003; Miller and Schneider, 2000). More recently, some aspects of its spatial structure have been explained by relating the pattern of tropical Pacific decadal variability to patterns associated to interannual ENSO variability (Vimont, 2005; Alexander *et al*., 2002). It has been suggested that ENSO, through an atmospheric bridge and the reemergence of SST anomalies, is an important component of PDO (Newman *et al*., 2003). Furthermore, it has been suggested also that PDO may result from the superposition of SST fluctuations of different dynamical origins (Schneider and Cornuelle, 2005). These contributions suggest that ENSO may generate north Pacific low-frequency variability. And, since our emphasis is on the potential implications for northwestern Baja California climate, we use the same *SOI* and *PDOI* as in Reyes-Coca and Troncoso-Gaytan (2004) and Pavia *et al*. (2006) to construct an ENSO-forced PDO model.

Data and methods

For the tropical Pacific decadal variability we use the *PDOI* data from http://jisao.washington.edu/pdo/PDO.latest, and for ENSO we use the *negative* of the *SOI* available at NOAA's climate prediction center at http://www.cpc.ncep.noaa.gov/data/indices/. We use the data for 1933 to 2008, the longest available record without gaps.

Working indices for PDO and SO are constructed by averaging 12 monthly values from September to August of the next year, centering on the wintertime (Pavia and Badan, 1998). We compute standardized indices as annual values minus the 74-year annual mean divided by the standard deviation. This procedure results in statistical zero-mean and unit standard deviation for two 74-year-long time series (P_n and S_n; n=1, 2, ..., 74).

The forced model (Newman *et al*., 2003), based on Hasselmann (1976), is:

$$P_n = \alpha \text{ x } P_{n-1} + \beta \text{ x } S_n + N_n, \qquad (1)$$

where P_n is the forecast PDO index at year n, P_{n-1} is the PDO index at year $n-1$, similarly S_n is the ENSO index at year n, N_n is white noise at year n, and n is time in years. As in Newman *et al*. (2003) the parameter $\beta = 0.61$ is obtained by the regression of P onto S using a least-squares method; and the parameter $\alpha = 0.76$ is similarly obtained by regressing the residual $\varepsilon = (P_n - \beta \times S_n)$ onto the previous year's PDO index: P_{n-1} (see Fig.1). The first step may be similar to a secondary forecast model (Pavia, 2000) replacing n by $n+1$:

$$P_{n+1} = \beta \text{ x } S_{n+1}, \qquad (2)$$

(see Fig. 2).

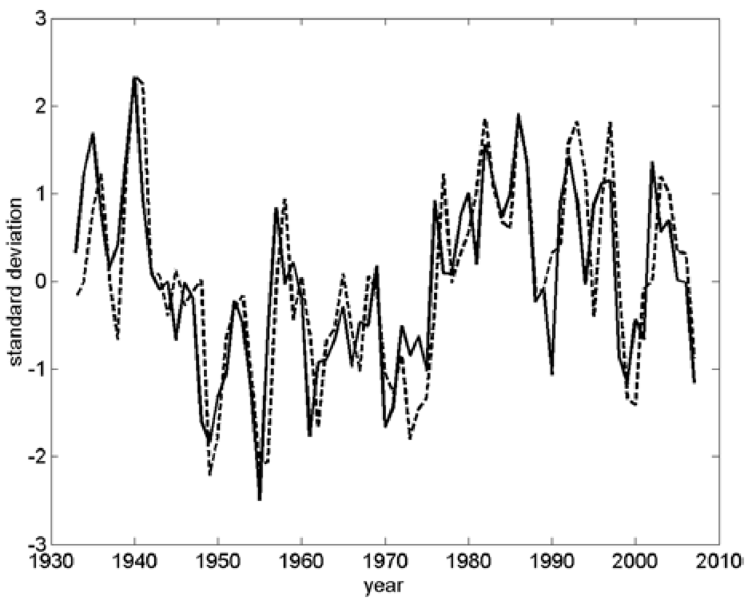

Fig. 1. The observed P_n (solid line) and its S_n-forced model (dashed line), (r=0.76).

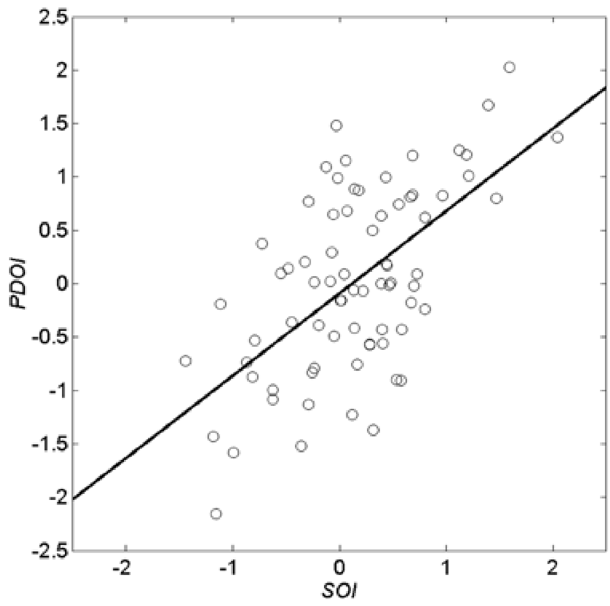

Fig. 2. The SOI (S_n) versus the *PDOI* (P_n) and the linear regression $P_n' = \beta \times S_n'$ (thick line), (r=0.62).

Results

The main results are:

(1) S_n values perform similarly at forcing P_n as in previous models (*e.g*. Newman *et al*., 2003); for example the correlation between "forecast" and observed P_n is $r= 0.76$ (see Fig. 1).

(2) The relatively successful linear model $P_n = 0.61\ S_n$ shows the importance of ENSO as a component of the PDO (see Fig. 2); for example the complementing model $S_n = 0.47\ P_n$ is not nearly as good.

(3) The conspicuous low frequency of the residual ε (see Fig. 3) indicates that S_n is not directly accountable for the variance, $\sigma^2(P_n)$, which corresponds to the decadal variability of the PDO.

(4) The Gaussian character of the selected working indices shows that the non-autoregressive term (β x S_n) of the forced model may even serve as an undemanding secondary forecast for P_n (see Fig. 4).

Discussion and conclusions

We find that the S_n-forced model explains 57% of $\sigma^2(P_n)$ ($r= 0.76$) of which 39% may be explained by the term β x S_n. The remaining 43% of $\sigma^2(P_n)$ must be explained by other mechanisms which may generate the rest of the PDO variability. These may be partially ENSO generated (see, for example, Timmermann and Jin, 2002) or non-ENSO generated (see Liu *et al*., 2002). Or yet combinations of ENSO generated and non-ENSO generated processes, for example direct ENSO forcing, physical re-emergence of SST anomalies, white noise atmospheric forcing (Newman *et al*., 2003); or ENSO, zonal advection in the Kuroshio-Oyashio extension, anomalies of the Aleutian Low (Schneider and Cornuelle, 2005). Our analysis supports a contribution of ENSO to the north Pacific variability. Thus the reddening of S_n is responsible for a large amount of $\sigma^2(P_n)$; the SO forces the PDO and not the opposite, as suggested in northwestern Baja California winter precipitation studies (Reyes-Coca and Troncoso-Gaytan, 2004). Independently of the indices used, while SO may not contribute directly to PDO variability, its stochastic forcing does, by forcing processes generating decadal variability (Fig. 1). Therefore ENSO explains around 60% of PDO variance. The remaining 40% of the total variance may be accounted for by other physical mechanisms. Due to the Gaussian character of the working indices, a secondary forecast model may serve as a simple P_n forecast tool; for example, assuming a perfect primary S_n forecast, a P_n "hindcast" of the last ten years showed a remarkable 9/10 skill (Fig. 4); recall that theoretical and cross-validated skill is just 2/3. Thus better ENSO predictions should improve PDO forecasts and related annual and lower-frequency climate predictions.

In conclusion the expanded null hypothesis for the PDO is corroborated. Variability in the north Pacific on annual to decadal time scales is due to reddening of both white noise and ENSO. This contradicts the idea that PDO may regulate decadal climate variability in northwestern Baja California as well as ENSO.

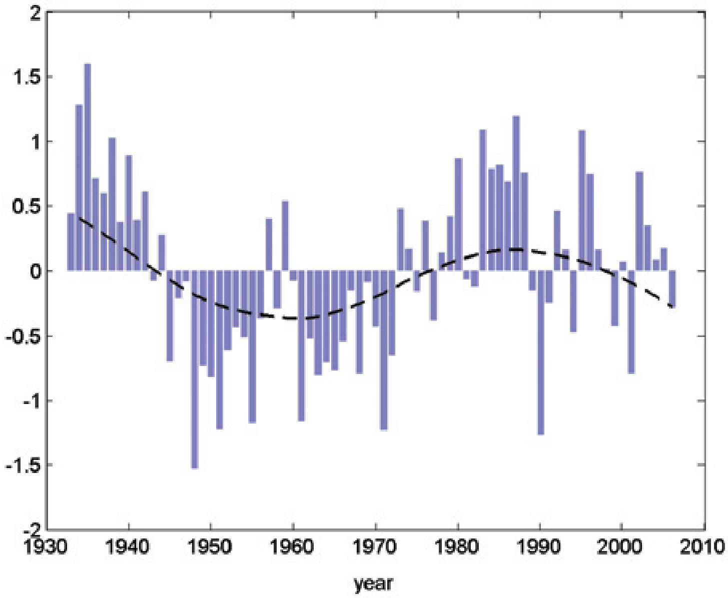

Fig. 3. Bars of the residual error [$P_n - (P_n' = \beta \times S_n')$] and its low-pass filter (dashed line). The amplitude of the chosen filter (*A = 25*) is the maximum allowed by the time series length (*L = 74*) for a zero-phase filter.

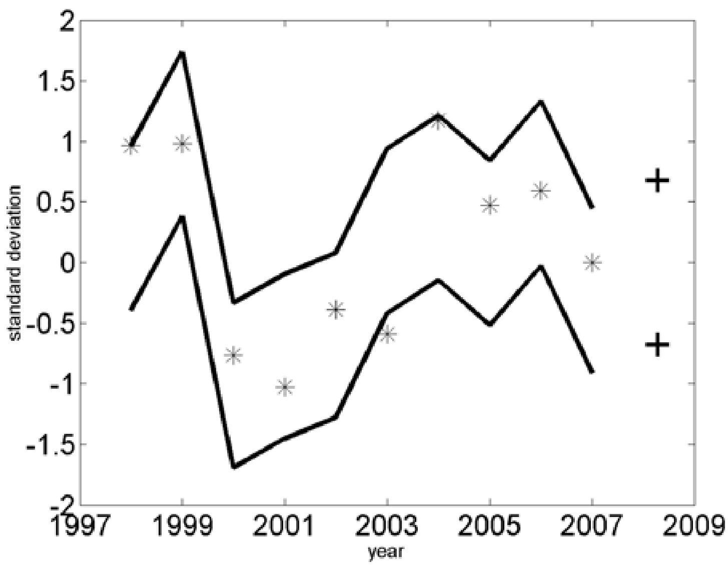

Fig. 4. Ten years (*1998-2007*) of observed (asterisks) and "hindcast" P_n' [that is $P_n' \pm \sigma(P_n')$], plus the P_n'(*2008-2009*) secondary forecast for a likely S_n(*2008-2009*) = $0 \pm \sigma(P_n')$ (+ sign range).

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