J11.5 NONLINEAR SCALE INTERACTIONS VIA ENERGY EXCHANGES BETWEEN THE PACIFIC DECADAL OSCILLATION AND THE EL NINO-SOUTHERN OSCILLATION

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1. INTRODUCTION

Two main modes of SST and atmospheric variability are found in the Pacific domain – the El Nino-Southern Oscillation (ENSO), whose signature is most pronounced in the tropics, and the lower-frequency Pacific (inter)Decadal Oscillation (PDO), whose signature is most pronounced in the mid-latitudes. The complex interplay between these modes has been the subject of considerable debate in recent years (Barnet et. al. (1999), Cane and Evans (2000)). Is it the tropics – ENSO, or the mid-latitudes – PDO, that govern the relationship?

Using the 1948-2001 data set of NCEP wind reanalysis, we investigate the interaction between the tropics *and the mid-latitudes on ENSO and PDO time scales over the Pacific domain. We address this issue by focusing on the kinetic energy interchange between triplets of frequencies encompassing the tropical oscillations on 24-72 month time scales associated with ENSO and the extra-tropical oscillations on 108+ month time scales associated with decadal oscillations. A co-spectrum formulation is used to calculate the transfer of kinetic energy into/out of the PDO or into/out of the ENSO frequencies resulting from the interaction with two other ENSO or PDO frequencies.

2. SCALES

The 54-years worth of monthly mean winds were subjected to Fourier decomposition in time. Wave numbers 1 through 6, corresponding to waves with periods from 9 to 54 years, were initially designated as PDO. Waves 9 through 27, corresponding to periods of 2 to 6 years, were considered as ENSO. The variance of the 300mb winds at these time scales is shown in Fig. 1.

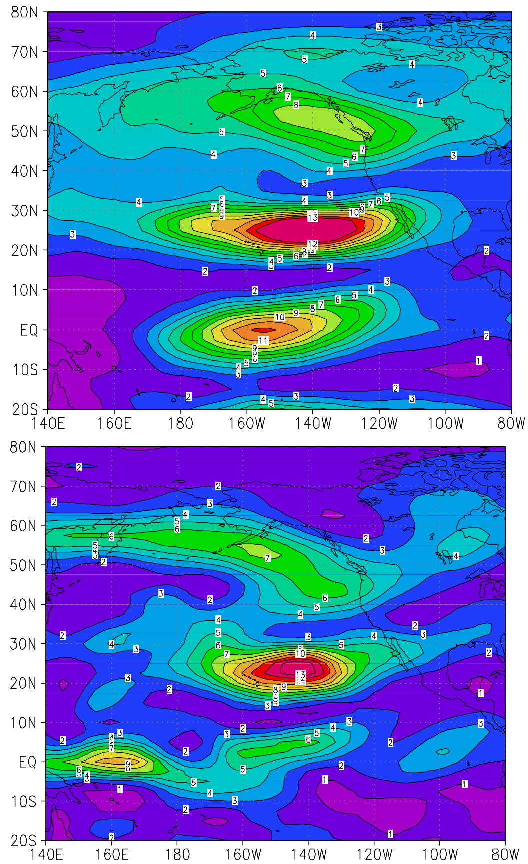

Fig.1: Squared variance of 300mb winds at ENSO (top) and PDO (bottom) time-scales. Contour interval 1 m^2s^{-2}.

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Previous studies (e.g. Mantua et. Al. (1997), Zhang et. al.(1997)) have pointed out that the variance at PDO time scales of the SST, as well as that of the sea level pressure and surface wind stress, exhibits a maximum at higher latitudes, and a secondary peak in the tropics. In our case, the signal is strongest in the tropics, with a secondary peak at higher latitudes, so that the spatial distribution is much like that associated with ENSO. A closer look at the data in the frequency domain suggested that waves with n=1 and n=2 (T=27 to 54 years), hereafter designated as D1, have a rather different spatial distribution of variance from waves with n=3 to n=6 (T=9 to T=18 years), hereafter designated as D2 (Fig. 2).

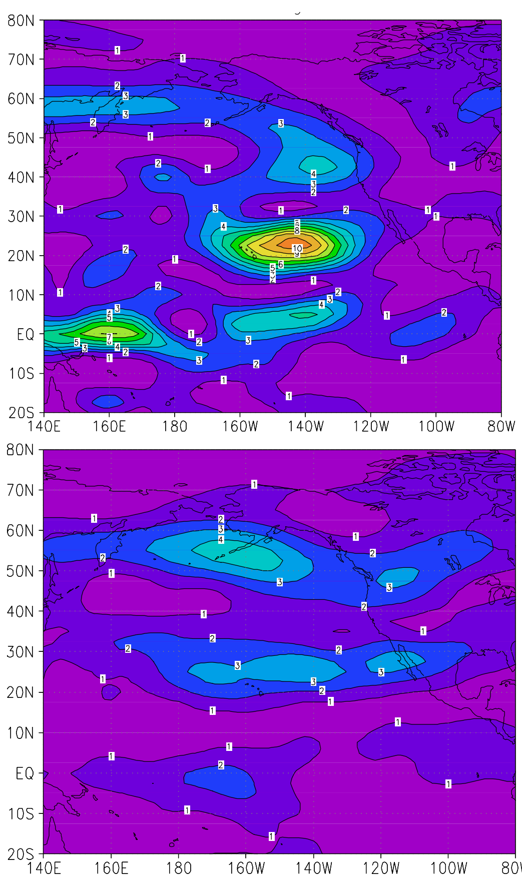

Fig.2: Squared variance of 300mb winds at D1 (top) and D2 (bottom) time-scales. Contour interval 1 m^2s^{-2}

The slower waves, D1, are much more ENSO-like in their spatial distribution of variance. D2 waves behave more like what we had expected of the PDO time-scales.

A separation of the D1 and D2 waves allows us to focus on another fundamental difference in the atmospheric behavior at these two scales. Fig. 3 shows Hofmuller diagrams of D1 and D2 300mb zonal winds from pole to pole over the Pacific domain.

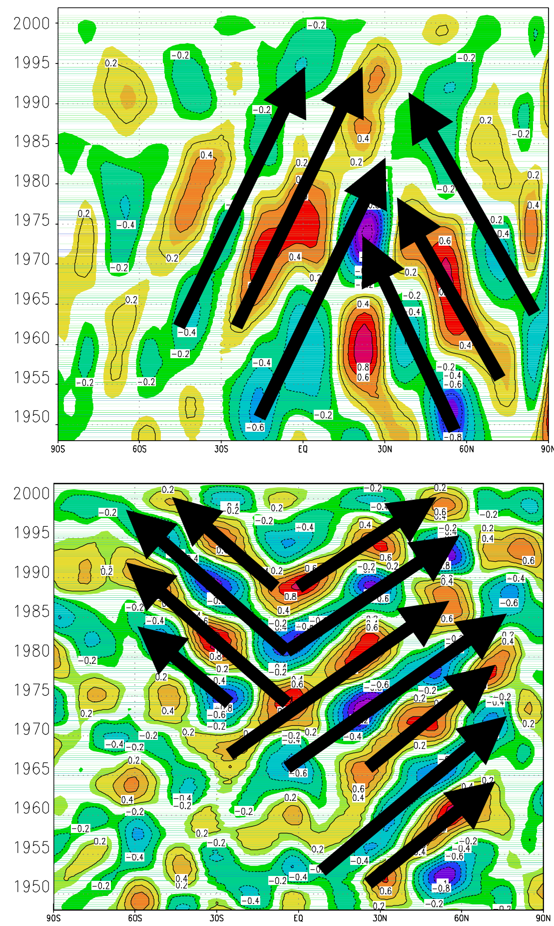

Fig.3: 300mb zonal winds at the D1 (top) and D2 (bottom) time-scales (zonal average between 140E and 80W)).

A most striking feature of these diagrams is the propagation of waves from the high latitudes to the tropics in the case of D1, and the opposite propagation – from the equatorial regions towards the high latitudes – in the case of D2. This suggests that D1 and D2 are different in nature, and hence they should be analyzed separately in the kinetic energy transfer computations.

3. KINETIC ENERGY TRANSFER

The non-linear parts of the equations of motion in spherical coordinate system are given by

$$\frac{\partial u}{\partial t} = -\left[\frac{\partial}{\partial x}uu + \frac{\partial}{\partial y}vu + \frac{\partial}{\partial p}\omega u - \frac{\tan\phi}{a}uv\right]$$

$$\frac{\partial v}{\partial t} = -\left[\frac{\partial}{\partial x}uv + \frac{\partial}{\partial y}vv + \frac{\partial}{\partial p}\omega v + \frac{\tan\phi}{a}uu\right]$$

$$0 = \frac{\partial}{\partial x}u + \frac{\partial}{\partial y}v + \frac{\partial}{\partial p}\omega$$

where *u* and *v* are the zonal and meridional winds, respectively, is the vertical velocity in pressure coordinates, is the latitude, and *a* is the Earth's radius. Following Saltzman (1957), the local rate of change of kinetic energy per unit mass for a given Fourier frequency *n* can be expressed as

$$\begin{aligned}\frac{\partial K(n)}{\partial t} = -\sum_m U(m)[\Psi_{u_x u}(m,n) + \Psi_{v_x v}(m,n) + \\ (\Psi_{vu}(m,n) - \Psi_{uv}(m,n))\frac{\tan\varphi}{a}] + \\ V(m)[\Psi_{u_y u}(m,n) + \Psi_{v_y v}(m,n)] + \\ \Omega(m)[\Psi_{u_p u}(m,n) + \Psi_{v_p v}(m,n)]\end{aligned}$$

where

$$\Psi_{uv}(m,n) = U(n-m)V(-n) + U(-n-m)V(n)$$

and *U(m), V(m)* and *(m)* are the mth complex Fourier coefficients of *u,v* and respectively. The complex coefficients of u, v and are calculated from the 54-year long data set. The decadal oscillations are split into D1 waves with periods larger than 27 years (1•n•2) and D2 waves with periods of 9 to 18 years (3•n•6), while waves with periods of about two to six years (9•n•27) are considered the ENSO signal.

The kinetic energy at a given wave number can grow or decay due to nonlinear interactions of that wave with certain pairs of waves, linear interactions with the time-mean flow, and potential to kinetic energy conversions.

Nonlinear interactions are allowed among triplets of waves whose frequencies are complementary, i.e., the frequencies of two of the waves can be added together to equal the frequency of the third wave.

Fig. 4 shows the local rate of kinetic energy of waves at the ENSO time scales due to such nonlinear interactions with D1 and D2 over the Pacific domain. Both large time scales contribute positively to the ENSO time scales over most of the Pacific domain, with magnitude of D1 contributions being about double that of D2 contributions.

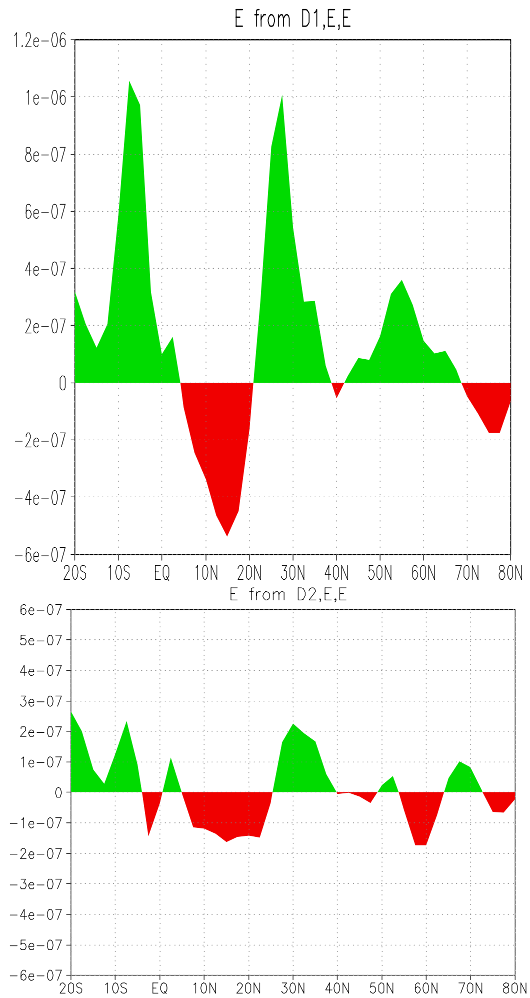

Fig.4: 140E-80W averaged local rate of change of 300mb kinetic energy at ENSO time scales due to non-linear interactions with D1 (top) and D2 (bottom). Units are m^2s^{-3}.

4. CONCLUSIONS

Using a 54-year long data set of monthly mean winds, we have isolated two distinct modes of the PDO. The longest time scales, D1, with periods of 27 to 54 years, are characterized by a maximum of variance over the Tropical Pacific, while the somewhat shorter 9-18 year time scales, D2, exhibit a maximum of variance in the higher latitudes, and a secondary maximum over the Tropics. The behavior of these two PDO scales is radically different in terms of their latitudinal propagation. D1 tend to move from the poles towards the Tropics, while D2 propagate from the Equator polewards. An examination of the kinetic energy exchange via non-linear interactions between the ENSO time scales and D1 and D2 shows that both PDO time scales contribute towards the growth of ENSO-scale kinetic energy, with the effect of D1 almost double that of D2.

5. REFERENCES

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