An oceanic heat budget for interannual variability in the northeast Pacific Ocean derived from satellite observations and a 1-d model

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Background

The Pacific Decadal Oscillation (PDO) index (Fig. 1) is usually defined (e.g. Mantua 1997) as the leading principal component of monthly SST anomalies in the North Pacific Ocean. If attention is focused on the NE Pacific, an alternative definition of the PDO index can be based on the sea surface height (Lagerloef 1995).

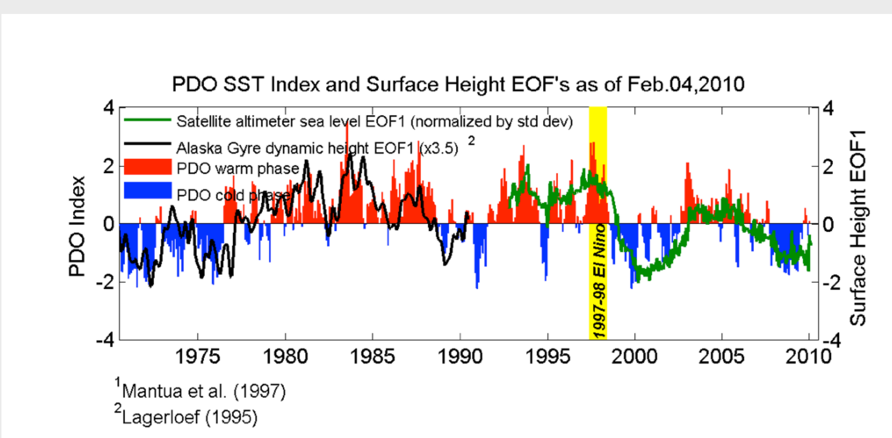


Figure 1: Leading PC of SST in north Pacific (color bars) and leading PC of SSH in the northeast Pacific (solid lines). Prior to 1990, SSH estimates are based on dynamic height from XBTs, and later are based on satellite altimetry.

Objective

This study focuses on interannual variability in the northeast Pacific Ocean during the period 1993-2003, which spans a change in sign of the PDO index, however defined. We use a one-dimensional model of the upper ocean to examine the corresponding changes in SST and SSH observed by satellites.

Observed interannual variability

Interannual variability is characterized by the first EOF of SSH. Variability at periods of a year and less were removed prior to analysis. The time domain is limited to the period from 1993-2007 and the spatial domain is shown in Fig. 2. The co-varying (with no lag assumed) changes in SST and surface currents (shown in Figs. 3 and 4, respectively) were determined by a least squares fit to the first principal component at each point.

Figure 2: Interannual SSH variability from AVISO satellite altimetry

(www.aviso.oceanobs.com)

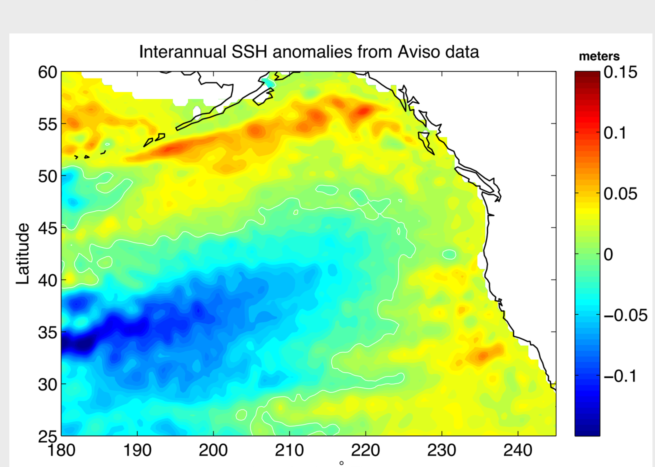


Figure 3: Interannual SST variability from Reynolds analysis.

(www.nhc.noaa.gov/aboutsst.shtml)

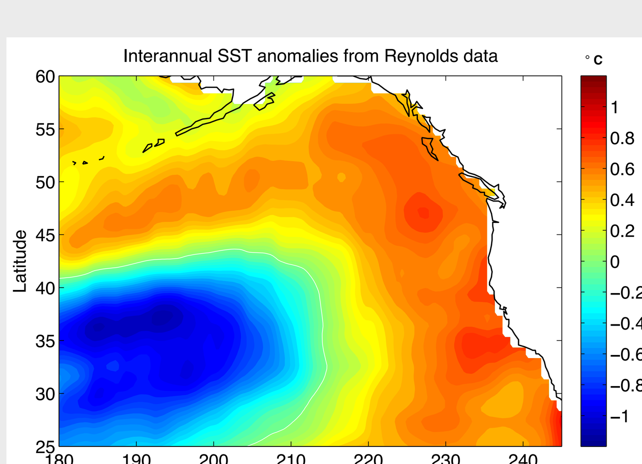


Figure 4: Interannual surface current variability from OSCAR analysis. Geostrophic currents are calculated from gradients in AVISO altimetry and Ekman currents are calculated from QuikSCAT winds

www.esr.org/oscar_index.html)

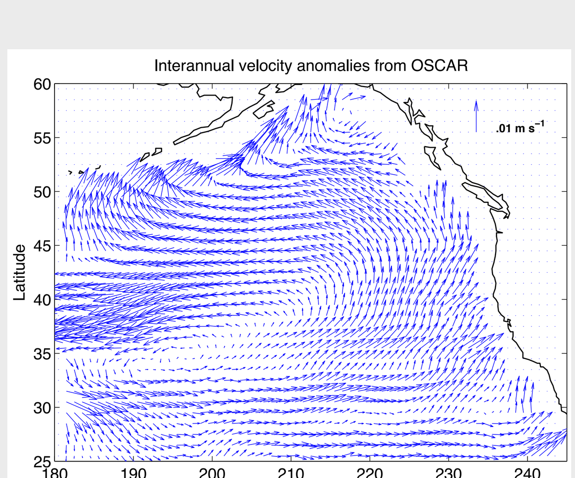
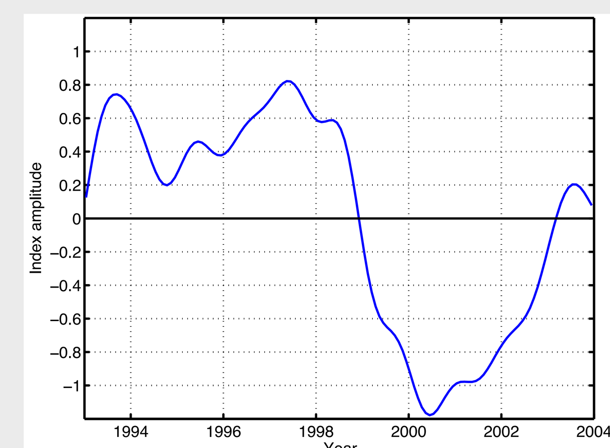


Figure 5: Rescaled principal component used to define interannual variability in this study. The sign change in 1999 is an analogue for changes in phase of the PDO



Model

The General Ocean Turbulence Model (GOTM) solves for the vertical structure of the upper ocean using any of several turbulence parameterizations. Atmospheric fluxes are calculated using a bulk formulation. (Details at www.gotm.net).

This one-dimensional model was implemented at 2 m vertical resolution to 250 m depth at each point on a 1 degree grid in a domain representing the northeast Pacific, initialized with climatological temperature and salinity profiles, and integrated (dt = 1hour) for the period 1993-2003. Atmospheric forcing (wind, air temperature, etc.) was specified from the NCEP-2 reanalysis. In addition, a time-varying horizontal pressure gradient was specified from AVISO satellite altimetry. This gives a diagnostic estimate of geostrophic velocities.

Note that this network of one-dimensional models **does not represent**

- horizontal mass convergence (no Ekman pumping)
- advective heat (or salt) transport

Lacking these dynamics, the model ocean can be viewed as little more than a heat reservoir for the atmosphere.

Model simulated interannual variability

The interannual component of model output was analyzed in the same manner as the observations in Figures 2-4.

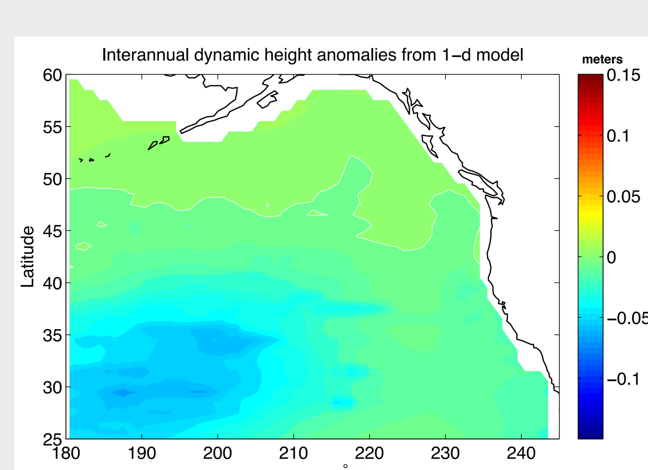


Figure 6: Simulated interannual steric height variability from model. These changes are due solely to thermal expansion.

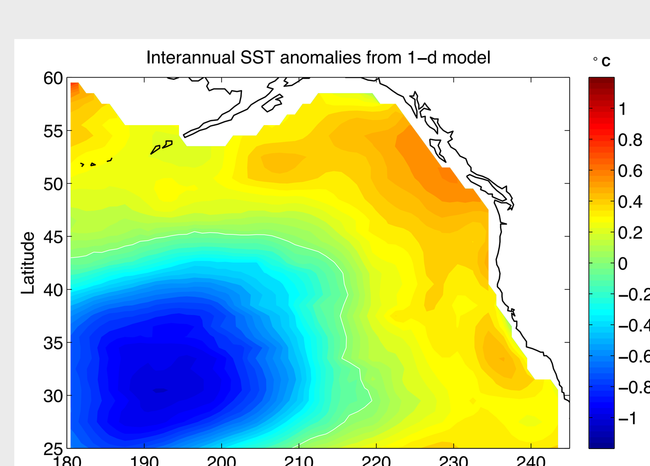


Figure 7: Simulated interannual SST variability. The large-scale pattern is reproduced, but variability is weaker than observed in eastern Pacific.

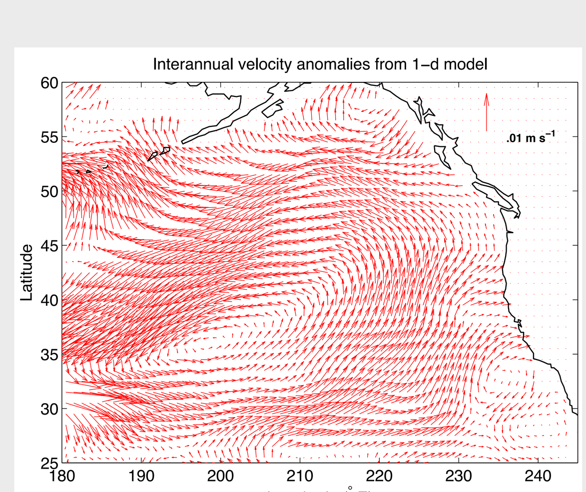


Figure 8: Simulated interannual surface current variability. The differences from OSCAR are due almost entirely to the use of different wind forcing.

Upper ocean heat balance

The heat balance from the surface to depth z is given by

$$\int_z^0 \frac{\partial T}{\partial t}dz + \int_z^0 \nabla_H \cdot (u_H T)dz - (wT)|_z = \frac{Q_{net}}{\rho C_p} - \left(\kappa \frac{\partial T}{\partial z}\right)_z$$

where the subscript H denotes horizontal components. The terms in black are represented in the one-dimensional model.

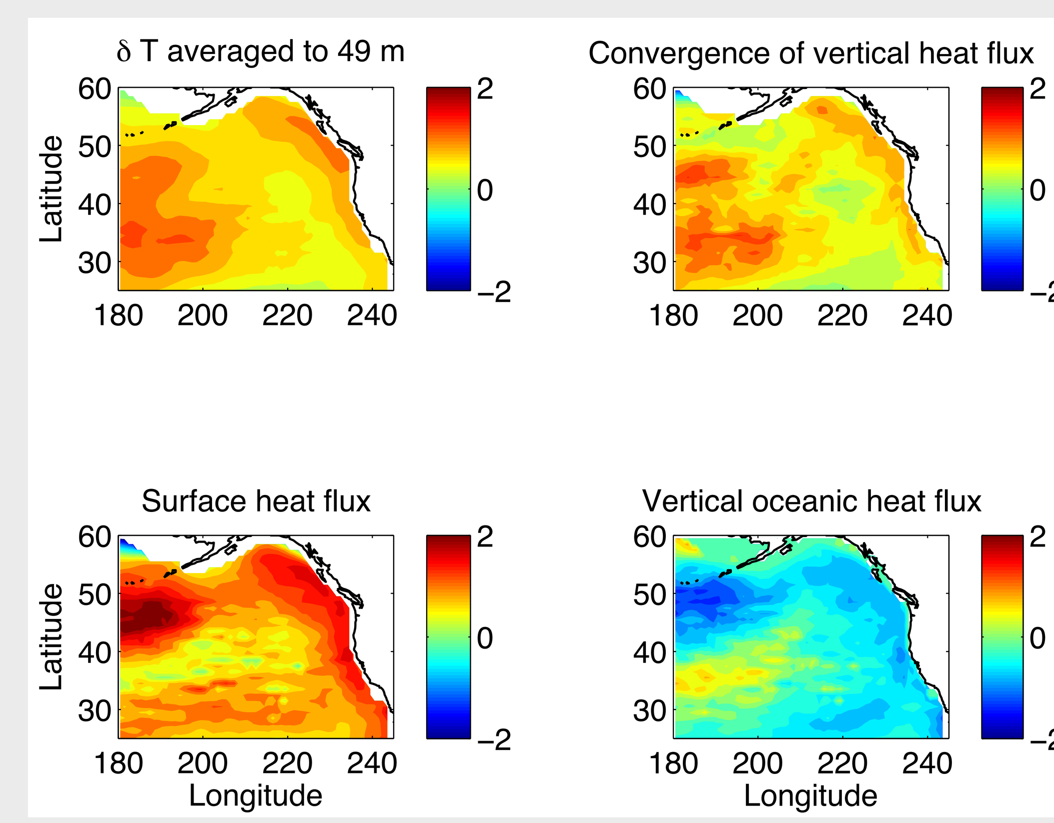


Figure 9: Simulated interannual vertical heat balance (in watts/m²). The top two figures represent the terms in black on the left and right side of the equation.

Although the model heat balance does not include the terms in red, we can use the model output to calculate the remaining terms diagnostically. Here we show just component of horizontal heat advection, the anomalous transport of the mean temperature gradient.

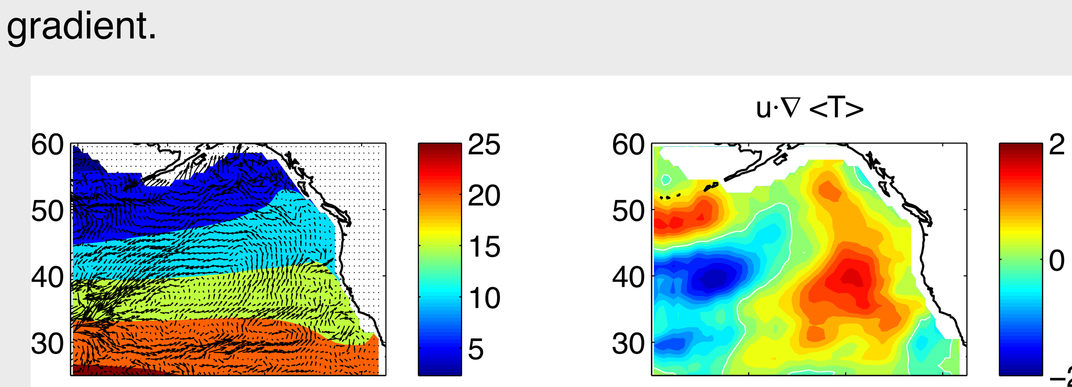


Figure 10: Advection of the mean temperature gradient by the anomalous velocity calculated diagnostically from the model.

This advective component is as large as the other terms in the heat balance. An assessment of the overall importance of oceanic heat transport awaits calculation of the other terms.

Conclusions

- A horizontal grid of one-dimensional upper ocean models reproduces important aspects of interannual variability in the northeast Pacific Ocean.
- Some of the interannual SSH variability in the central tropical Pacific arises from diabatic changes, which are represented in the model (but not most general circulation models, which make the Boussinesq approximation, and thus conserve volume.) However, most of the changes in SSH are likely related to adiabatic process, which are not represented in the model.
- Interannual variability of upper ocean velocities is comparable to that seen in OSCAR.
- The large-scale pattern and amplitude of SST interannual variability is represented well, except in the far eastern Pacific.
- The interannual heat budget in the upper 50 m is primarily between heat storage and surface heat flux. Subsurface heat flux modulates the surface heat flux.
- Diagnostic calculations of horizontal heat advection shows that it is likely to be at least as important as vertical heat fluxes.

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