ATMOSPHERIC FORCING AND LARGE-SCALE FLUCTUATIONS IN THE NORTH PACIFIC OCEAN

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TOPEX/POSEIDON sea surface height (SSH) data in the North Pacific Ocean is being examined to identify the dominant dynamics of the North Pacific on seasonal to interannual time scales. SSH fluctuations include the steric response to seasonal heating, transient responses (Rossby and Kelvin waves) to forcing by winds and topography, and large-scale adjustment to winds and thermohaline forcing. The observed SSH is being compared to simulations using an isopycnal model to interpret surface variations in terms of three-dimensional ocean processes.

Introduction

SSH variations have a predominant annual variation in the extratropics, reflecting the oceanic response to atmospheric forcing. On the basis of SSH alone, it is difficult to distinguish between dynamic and thermodynamic responses. In addition, the ubiquitous Rossby waves have a dominant annual period, complicating the problem of characterizing the oceanic processes contributing to SSH variability. We are using a combination of data analysis and numerical model simulations to distinguish these processes from each other, and to give insights into the dynamics of the underlying ocean processes.

Progress

The dominant processes affecting SSH variability vary regionally in the North Pacific. The steric response to surface heating dominates seasonal SSH variability in the subpolar gyre and the eastern subtropical gyre. The steric response was estimated using ECMWF net surface heat flux estimates for 1993-1994 (Figure 1). The skill (fraction of seasonal SSH variance accounted for) exceeds 40% in most locations north of the Kuroshio Extension in the western Pacific, and north of about 25°N in the eastern Pacific. The skill depends sensitively on the method of computing the coefficient of thermal expansion: a coefficient based on vertically integrated temperature and salinity from the Levitus climatology gives the best estimates. Trends in annual mean SSH, after applying the steric correction, occur as expected primarily in the boundary current regions and may be due to advection. Regions of low skill in the subpolar gyre may also be due to the neglect of the freshwater contribution to SSH. Skill in much of the tropical eastern Pacific is negative.

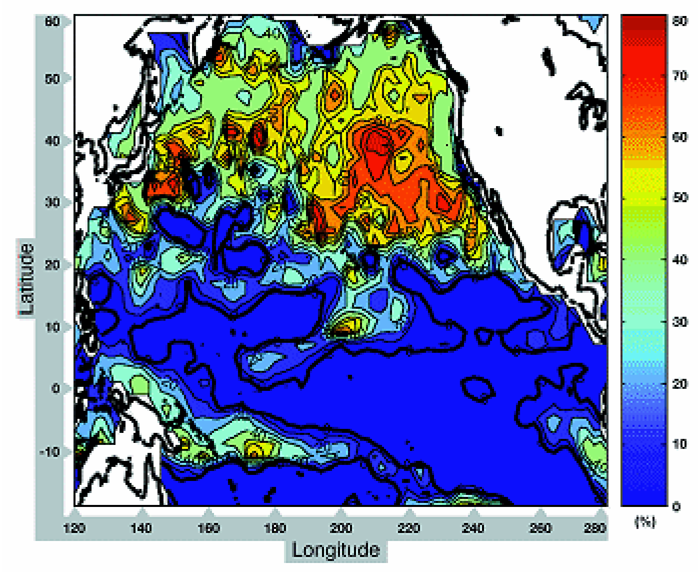

Figure 1
Skill of steric response in accounting for seasonal SSH variations. An estimate of the SSH response to seasonal heating was computed using a coefficient of thermal expansion based on the Levitus climatology and the net surface heat flux estimates from ECMWF. A trend was removed from the difference before computing skill.

South of the Kuroshio Extension and south of 20°N in the eastern Pacific, the dominant contribution to SSH is from near-annual period Rossby waves [Chelton and Schlax, 1996]. A striking feature of these waves is the significantly larger amplitudes in the western Pacific at mid-latitudes than in the eastern Pacific. To characterize these waves, a kinematic model with a Kalman filter/smoother [Gaspar and Wunsch, 1989] was used to extract the westward propagating free waves. Thirty wavenumbers with annual frequency, based on an empirical estimate of the phase speeds, were modeled at each latitude to produce time series of the amplitudes of westward propagating waves. Root-mean-square wave amplitudes were greater than 5 cm in the central and eastern tropical Pacific (Figure 2), and wave amplitudes were significantly larger in the extratropical western North Pacific than in the eastern North Pacific. These waves account for more than 50% of SSH variance between 10°S and 10°N, but only about 20% between 10°N and 30°N. Skill for the kinematic wave model is negative north of 40°N, except for in the California Current, suggesting that westward propagating waves are trapped near the coast. In the mid-latitudes there are late winter maxima in wave amplitude. Wave energy in the tropics does not show this seasonal modulation. An energy maximum in November 1994 was observed simultaneously throughout the North Pacific.

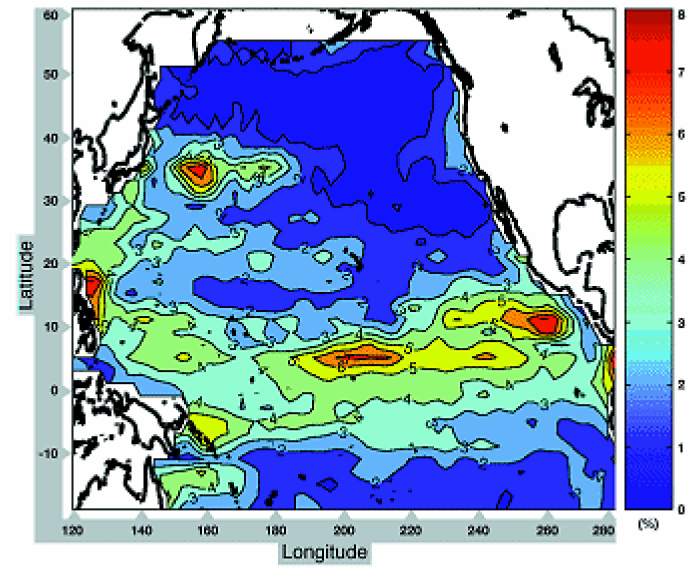

Figure 2
Root-mean-square amplitude of the SSH response due to westward propagating plane waves, based on a kinematic model adapted from Gaspar and Wunsch [1989]. Units are cm. Amplitudes are largest in the tropical Pacific and in the western Pacific at mid-latitudes.

Using an isopycnal coordinate model, with and without bottom topography, we show that the wave characteristics are sensitive to the stratification used, the bottom topography, and the wind forcing. With two layers used to represent the ocean stratification (with only one baroclinic mode), and realistic bottom topography, Rossby waves propagate freely in the eastern Pacific at 20°N (Figure 3b), contrary to what is observed in altimetric SSH (Figure 3a). When three layers are used (and two baroclinic modes), the longitudinal structure more closely matches the observed SSH (Figure 3c). Removing the bottom topography (the Hawaiian Ridge) has little effect on wave propagation (compare Figure 3c and 3d). However, at 30°N (not shown) these results are reversed, and topography has more of an effect on the ocean response and Rossby waves than stratification.

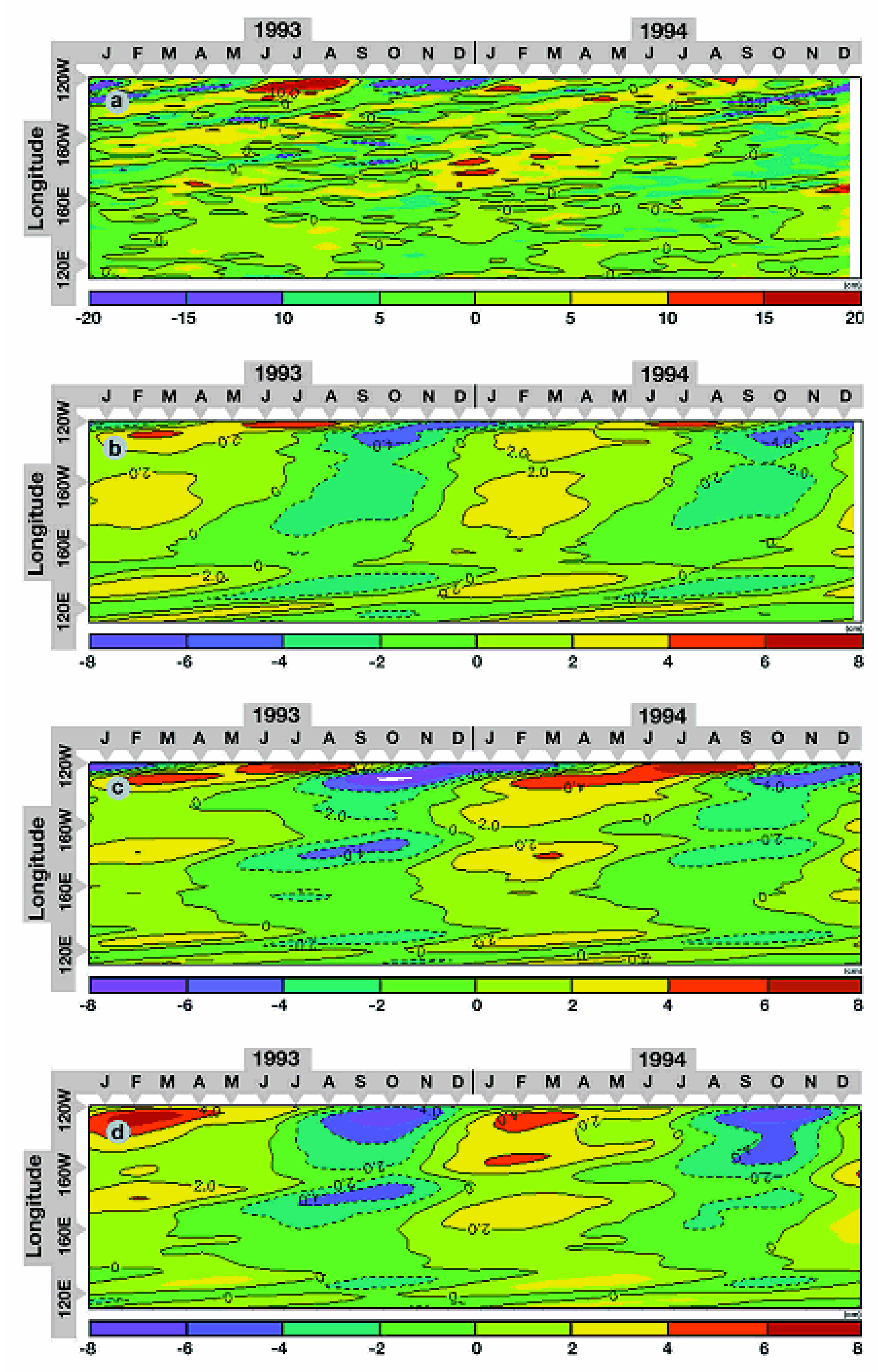

Figure 3

Time-longitude plots of observed and modeled SSH at 20°N. a) SSH from the TOPEX/POSEIDON altimeter; modeled SSH for stratification of b) two layers, and c) three layers; d) as in c), except for flat bottom model ocean.

Future research

SSH variations reflect the combined fluctuations from dynamic and thermodynamic ocean processes, and a careful analysis is required to evaluate the importance of any one process. Based on the preliminary comparisons of modeled and observed SSH, it appears that by combining spatial variations in the characteristics of the Rossby waves and simple models of the wind-forced response we will be able to gain information about the three-dimensional ocean circulation. We will be continuing our model comparisons to determine which vertical modes are dominating SSH variations and the extent to which the bottom topography plays a role in the Rossby wave field. Changes in large-scale circulation (the dynamic SSH response) can be more easily examined after removing the steric SSH response and the propagating waves; significant wind-related fluctuations can be seen, notably an apparent time-varying Sverdrup balance in the subtropical gyre.

References :

- Chelton, D. B., and M. G. Schlax, 1996: Global observations of oceanic Rossby waves, *Science, 272,* 234-238.
- Gaspar, P., and C. Wunsch, 1989: Estimates from altimeter data of barotropic Rossby waves in the northwestern Atlantic Ocean, *J. Phys. Oceanogr., 19,* 1821-1844.