THE DYNAMICS OF LOW-FREQUENCY VARIABILITY OF THE LARGE-SCALE OCEAN CIRCULATION

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The objectives of this research are to develop more complete descriptions and dynamical understandings of phenomena observed in the TOPEX/POSEIDON (T/P) data. This will be achieved from combined analyses of T/P data, historical hydrographic data, surface wind data, and development of analytical and numerical models. Idealized analytical models will be used to explore first-order dynamical explanations for the observed features. This will provide guidance in the construction of more realistic numerical experiments. Initially, the emphasis will be on the investigation of Rossby waves, as summarized in this brief article.

Seasonal Rossby Waves

Rossby waves are the mechanism for transient adjustment of the ocean to atmospheric forcing. They are therefore of fundamental importance to ocean circulation on a wide range of time scales. On seasonal time scales (periods longer than 100 days), Rossby waves have been found to be present throughout much of the world oceans [Chelton and Schlax, 1996]. The behavior of these waves is qualitatively but not quantitatively consistent with the classical theory for baroclinic Rossby waves. The westward phase speeds outside of the tropics are systematically higher than predicted (upper and middle panels of Figure 1). This disparity has survived a rigorous attempt to remove systematic biases found in previously used methods of computing Rossby-wave phase speeds by the classical theory from eigenanalysis of historical hydrographic data [Chelton et al, 1998].

From analytical modeling for the case of a continuously stratified ocean, we have shown [Killworth et al, 1997] that the effects of vertical shear and advection in the mean circulation (estimated from historical hydrographic data) can account for much of the baroclinic Rossby wave speedup observed in the T/P data (see Figure 1c). A simple 3-layer model [deSzoeke and Chelton, 1998] suggests that the key features in the mean circulation that are responsible for the speedup are the well-known mid-depth layers of homogeneous internal potential vorticity.

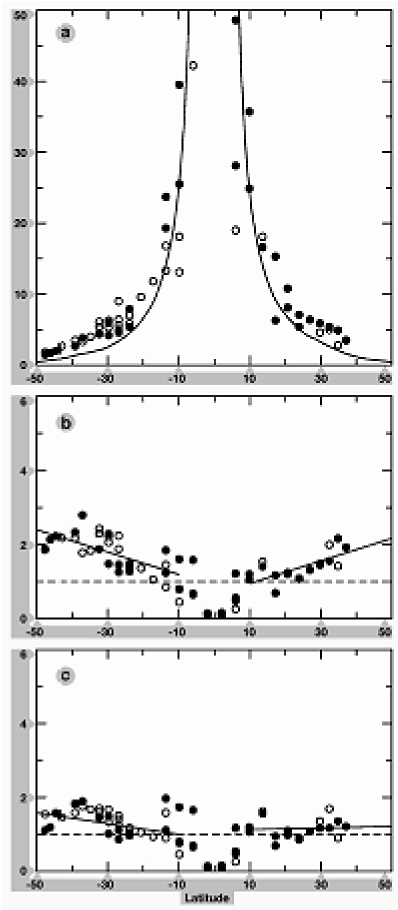

Figure 1

(a) Latitudinal variation of the phase speeds of nondispersive Rossby wave obtained from historical hydrographic data based on the classical theory (solid line) and from T/P observations in the Pacific (solid circles) and the Atlantic and Indian oceans (open circles).

(b) The ratios of the T/P estimates to the classical theory.

(c) The ratios of the T/P estimates to the extended theory of Killworth et al [1997].

Future research will investigate other intriguing features of seasonal Rossby waves. In particular, the amplitudes of seasonal Rossby waves vary geographically. In the Pacific Ocean, for example, amplitudes are distinctly larger in the western basins than in the east (see Figure 3a; see also Figure 2). The small amplitudes in the eastern North Pacfic are surprising in view of the energetic seasonal sea level variations evident in Figure 2 near the eastern boundary. Sea level signals appear to propagate less than 1000 km westward from the eastern boundaries. The fate of these boundary-generated Rossby waves, as well as the generation mechanism for the interior ocean Rossby waves, have not yet been identified.

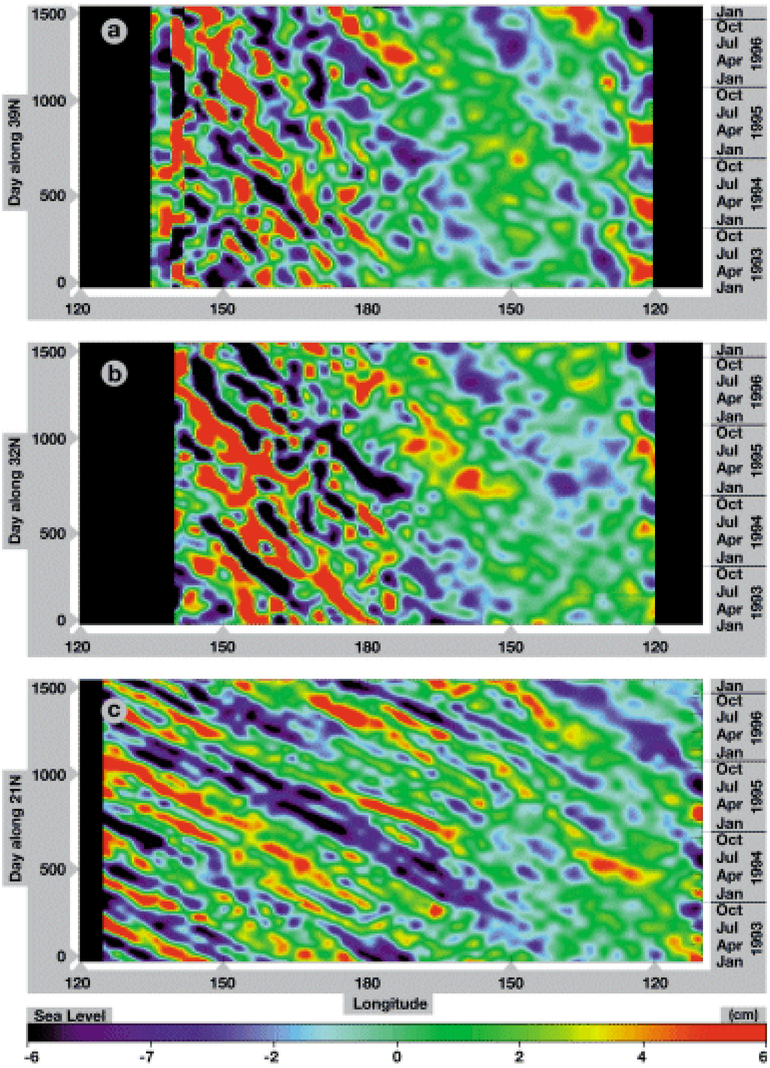

Figure 2
Time-longitude plots of seasonal sea level variability (periods longer than 100 days) from T/P data along 21°N (a), 32°N (b) and 39°N (c) in the North Pacific.

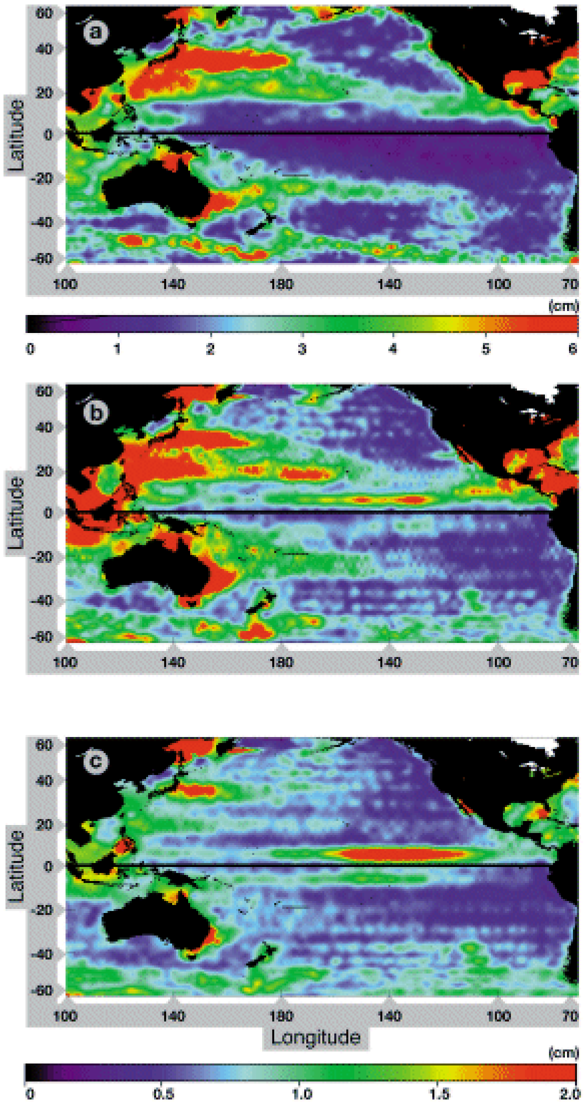

Figure 3
Maps of the standard deviation of T/P sea level variability for periods longer than 100 days (a), periods between 50 and 100 days (b) and periods between 30 and 50 days (c) (in cm).

Another research topic of great interest is how the modified Rossby wave theory of Killworth et al [1997] and deSzoeke and Chelton [1998] alters the critical latitude for Rossby waves of a given frequency. From the simple 3-layer model, it has been found that mean shear and advection allow Rossby waves of a given frequency to propagate at much higher latitudes than is predicted by the classical theory. This will be investigated in more detail for the continuously stratified model to map the maximum Rossby wave frequency on a 1 deg global grid based on analysis of the historical hydrographic data.

Interannual Rossby Waves

In addition to energetic seasonal baroclinic Rossby waves, the 5+ years of T/P data are beginning to reveal smaller-amplitude interannual signals associated with the El Niño-Southern Oscillation (ENSO) phenomenon. These signals will be investigated with special attention devoted to an attempt to project the waves back in time to estimate their time of origin at the eastern boundary. Jacobs et al [1993] have argued that sea level anomalies in the midlatitude western North Pacific deduced from GEOSAT and ERS-1 data were associated with the 1982-83 ENSO event. If the speedup of seasonal Rossby waves observed by Chelton and Schlax [1996] and modeled by Killworth et al [1997] and deSzoeke and Chelton [1998] for nondispersive seasonal Rossby waves is correct and applicable also to interannual Rossby waves, then the signal observed by Jacobs et al [1994] should have been generated by the 1986-87 ENSO event instead.

Intraseasonal Rossby Waves

At periods shorter than 100 days, there is evidence for very energetic westward propagating sea level signals at low latitudes (equatorward of about 20 deg latitude). The nature of this intraseasonal variability is distinctly different for periods longer and shorter than 50 days.

At the shortest periods, there are two bands of 30-50 day variability that are symmetric about the equator along 5°N and 5°S between about 160°E and 100°W (see Figure 3c). The energy is considerably higher north of the equator. However, the 30-50 day variations along these two latitudes are generally highly coherent and phase locked, as shown by the example in Figure 4. The space-time characteristics of these signals suggest that they are dispersive meridional mode-1 equatorially trapped, baroclinic, Rossby waves. The generation mechanism for these signals, as well as their dispersive characteristics, will be studied from a combination of additional data analysis and modeling. It is likely that these sea level signals are the well-known tropical instability waves generated by the horizontal shear between the North Equatorial Current and the Equatorial Countercurrent. The symmetry of these waves about the equator has heretofore not been observed from in situ or altimeter data. Another interesting feature of these signals that will be investigated in detail is that their amplitudes are modulated annually and interannually.

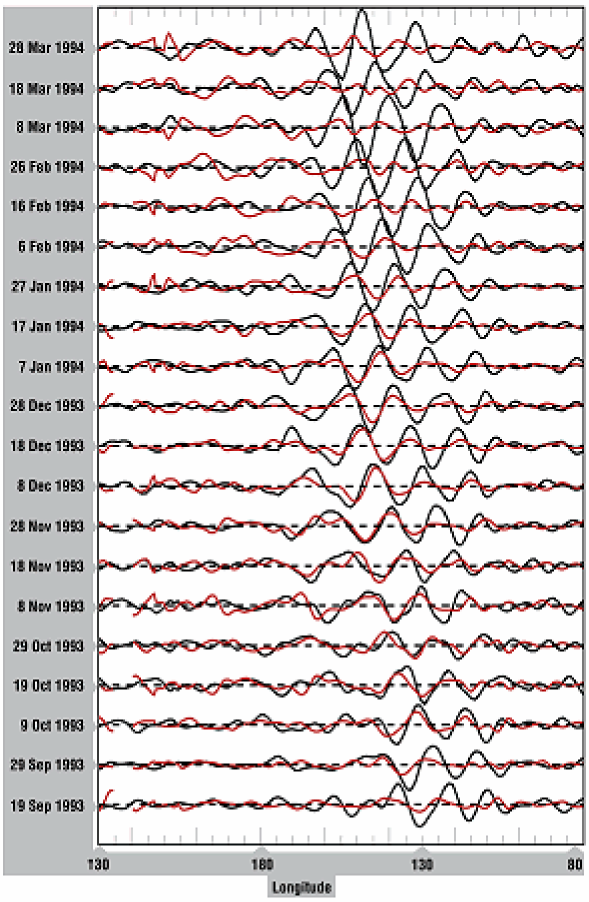

Figure 4
Stack plot of sea level profiles along 5°N (black lines) and 5°S (red lines) at 10-day intervals during a 6-month period from mid September 1993 to late March 1994 (spacing 5 cm).

The geographical distribution of 50-100 day Rossby waves (Figure 3b) is distinctly different from that of 30-50 day waves. In particular, there is a band of energetic 50-100 day variability that spans most of the Pacific along 5°N with no apparent counterpart along 5°S. In addition, there is a band of energetic 50-100 day variability along 9°N that extends only from Central America to about 110°W. There is also a band of 50-100 day variability extending west from Hawaii to the western boundary of the Pacific. The characteristics and generation mechanisms for these various bands of 50-100 day signals will be investigated from a combination of continued data analysis and modeling.

References :

- Chelton, D. B., and M. G. Schlax, 1996: Global observations of oceanic Rossby waves. *Science, 272*, 234-238.
- Chelton, D. B., R. A. deSzoeke, M. G. Schlax, K. El Naggar and N. Siwertz, 1998: Geographical variability of the first-baroclinic Rossby radius of deformation. *J. Phys. Oceanogr.*(in press).
- deSzoeke, R. A., and D. B. Chelton, 1997: The modification of long planetary waves by homogeneous potential vorticity layers. *J. Phys. Oceanogr.*(submitted).
- Jacobs, G. A., H. E. Hurlburt, J. C. Kindle, E. J. Metzger, J. L. Mitchell, W. J. Teague, and A. J. Wallcraft, 1994: Decade-scale trans-Pacific propagation and warming effects of an El Niño anomaly. *Nature, 370*, 360-363.
- Killworth, P. D., D. B. Chelton and R. A. deSzoeke, 1997: The speed of observed and theoretical long extra-tropical planetary waves. *J. Phys. Oceanogr., 27*, 1946-1966.