The dynamics of short-term ocean climate variability

D.B. Chelton and R.A. De Szoeke
(Oregon State University, USA)

The objectives of this research are to develop more complete descriptions and dynamical understandings of phenomena observed in the TOPEX/POSEIDON (T/P) and Jason-1 altimeter data. This will be accomplished through combined analyses of the altimeter data and analytical and numerical modeling. 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. The emphasis will be on investigations of tropical instability waves and midlatitude Rossby waves.

Tropical Instability Waves

At periods shorter than 50 days, there are very energetic westward propagating signals in the sea surface height (SSH) field at low latitudes (equatorward of about 10˚) in the Pacific. The variability is concentrated in two bands that are symmetric about the equator along 5˚N and 5˚S between about 100˚W and 160˚E (see figure 1).
The amplitudes of the SSH anomalies are several times larger north of the equator. The variability along these two latitudes is often highly coherent, although the phase relation varies from year to year. These SSH signals are largest from June through January. They are small or absent altogether in March and April and were absent during the 1997-98 El Niño.

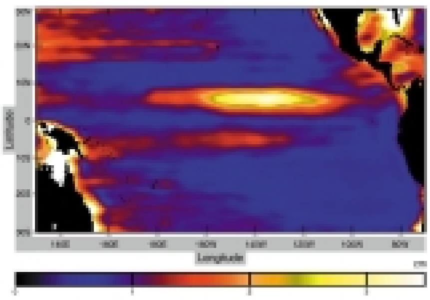

Figure 1: Map of the standard deviation of sea surface height (SSH) from 7 years of band-pass filtered T/P data for periods between 25 and 50 days.

The SSH anomalies along 5˚N are the well-known tropical instability waves (TIWs) that are generated by shear instabilities in the equatorial current system. The coherence with SSH anomalies along 5˚S suggests a latitudinal structure of TIWs that has not previously been noted. This latitudinal structure as well as the dispersive characteristics of these transequatorial TIWs and the reasons for the annual and interannual modulations of their amplitudes will be studied from a combination of additional data analysis and modeling.

An important question that can now be addressed from satellite data is the horizontal eddy flux of heat associated with TIWs. Measurements by the TRMM Microwave Imager (TMI) since December 1997 provide all-weather observations of sea surface temperature (SST) simultaneous with the most recent two years of T/P observations of SSH. The SST signatures of TIWs on both sides of the equator are clearly evident in the TMI data [Chelton et al., 2000].

An example of the superposition of SSH contours on a map of SST for the 3-day period centered on 9 December 1998 is shown in figure 2. There is an obvious, strong correspondence between the two fields. There are also some interesting differences, for example the cusps with no SSH counterparts east of about 110°W. These relations will be investigated in detail from the combined altimeter and SST datasets.

The relationships between SST perturbations T' and SSH perturbations h' (and the associated perturbation geostrophic velocity components u' and v') will be investigated statistically. This will include an estimation of the surface zonal and meridional eddy heat fluxes <u'T'> and <v'T'>. The total horizontal eddy heat flux requires knowledge of the vertical distribution of <u'T'> and <v'T'>. The vertical

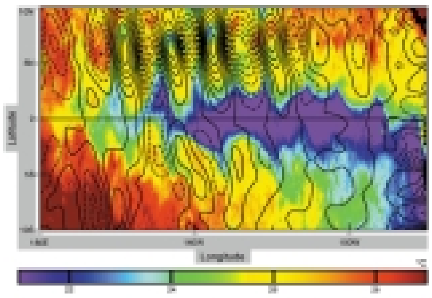

Figure 2: Example showing the superposition of SSH anomalies (contours, with a contour interval of 1 cm) and sea surface temperature on 9 December 1998.

scale of the coherent eddy heat flux signals can be estimated from T' and h'. Through the hydrostatic relation, h' is proportional to the perturbation pressure field p' while T' is proportional to dp'/dz.
The relation between SST and SSH therefore provides an estimate of the vertical scale of SST anomalies. This can be obtained from the slope of a straight-line fit to a scatter plot of h' versus T'. Alternatively, the vertical scale can be estimated from the ratio <h'T'>/<h'h'>.
The geographical variation of this vertical scale estimate will be compared to gross environmental parameters such as thermocline depth. The combination of the surface eddy heat flux components and a vertical scale will be used to estimate the total horizontal eddy heat flux.

Rossby Wave Dispersion

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. T/P observations of SSH have revealed that Rossby waves are 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 left panels of figure 3). Westward propagating SSH anomalies with very similar phase speed characteristics are also evident in ocean general circulation models such as the global model developed by the Parallel Ocean Program (POP) at the Los Alamos National Laboratory (see upper and middle right panels of figure 3).

From analytical modeling for the case of a continuously stratified ocean, Killworth et al. [1997] have shown 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 and POP model simulation (see bottom panels of figure 3). A simple 3-layer model [de Szoeke 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.

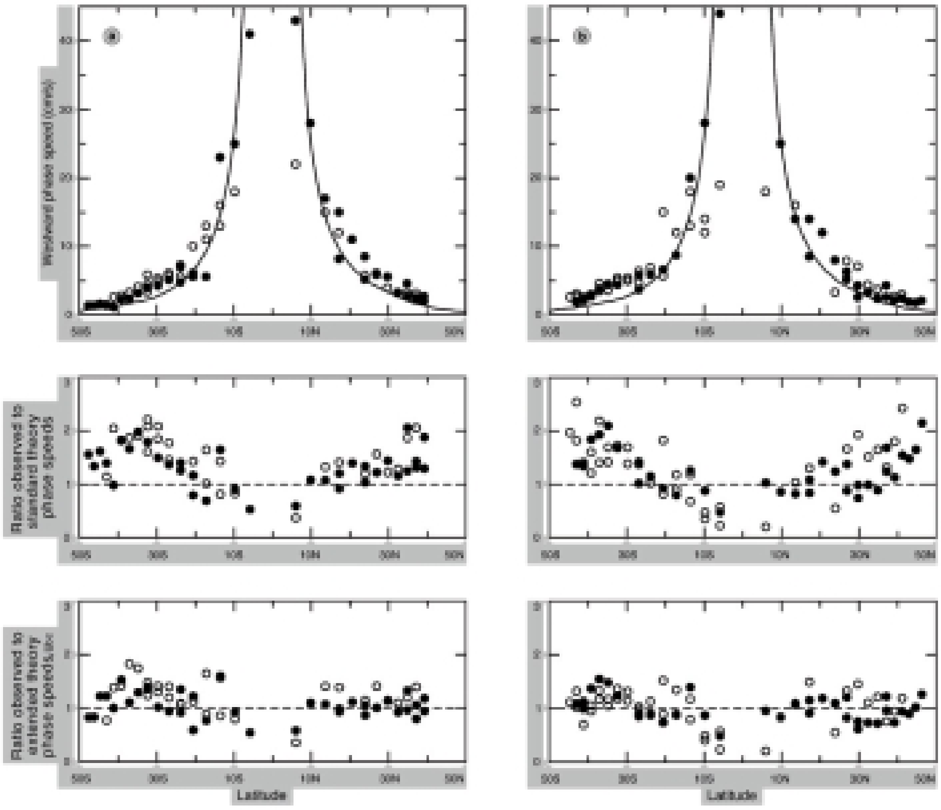

Figure 3: Phase speeds estimated from 7 years of T/P data (a) and 3 years of Run 11 of the POP model (b) based on the classical theory (solid line) and from the T/P and POP SSH fields in the Pacific (solid circles) and the Atlantic and Indian oceans (open circles). The ratios of the observed phase speed to the phase speed predicted based on the classical theory and the extended theory of Killworth et al. [1997] are shown in the middle and bottom panels, respectively.

The long T/P data record provides the first opportunity for global analysis of the frequency-wavenumber characteristics of the westward propagating signals observed in the T/P data.
The frequency-wavenumber spectra of SSH anomalies along 24˚N and 24˚S are shown in figure 4.
Over the range of wavenumbers resolvable in SSH fields constructed from T/P data, it is apparent that the dispersion relation for the extended theory of Killworth et al. [1997] (black circles) is in much better agreement with the observed spectra than is the dispersion relation for the classical theory (white circles). The coarse ground track spacing of the T/P orbit does not resolve wavelengths shorter than about 5˚ of longitude. The overlapping T/P and Jason-1 missions with an interleaved ground track pattern will double the zonal spatial resolution.
The frequency-wavenumber spectral characteristics will be examined at these higher wavenumbers (shorter wavelengths) to determine the adequacy of the Killworth et al. [1997] theory for the dispersion of Rossby waves in the presence of a vertically sheared background mean flow.

Midlatitude Interannual Rossby Waves

The 8.5 years of T/P data are beginning to reveal interannual signals associated with the El Niño phenomenon. Jacobs et al. [1993] argued that Rossby waves originating along the eastern boundary of the

North Pacific in association with the 1982-83 El Niño may have perturbed the Kuroshio Extension a decade later. This hypothesis will be testable with unprecedented capability from the long, continuous data record afforded by the merged T/P and Jason-1 datasets. The major El Niño that occurred in 1997-98 has imprinted a strong signature on the sea surface height field in the midlatitude eastern Pacific. This signal will be tracked over the next decade as the eastern boundary manifestation of this El Niño event propagates westward toward the Kuroshio Extension. In addition to testing the Jacobs et al. (1993) hypothesis for the longevity of El Niño generated Rossby waves, the systematic westward propagation of the midlatitude SSH anomalies associated with the 1997-98 El Niño event will allow a further quantitative test of the faster phase speed predicted by the Killworth et al. [1997] theory.

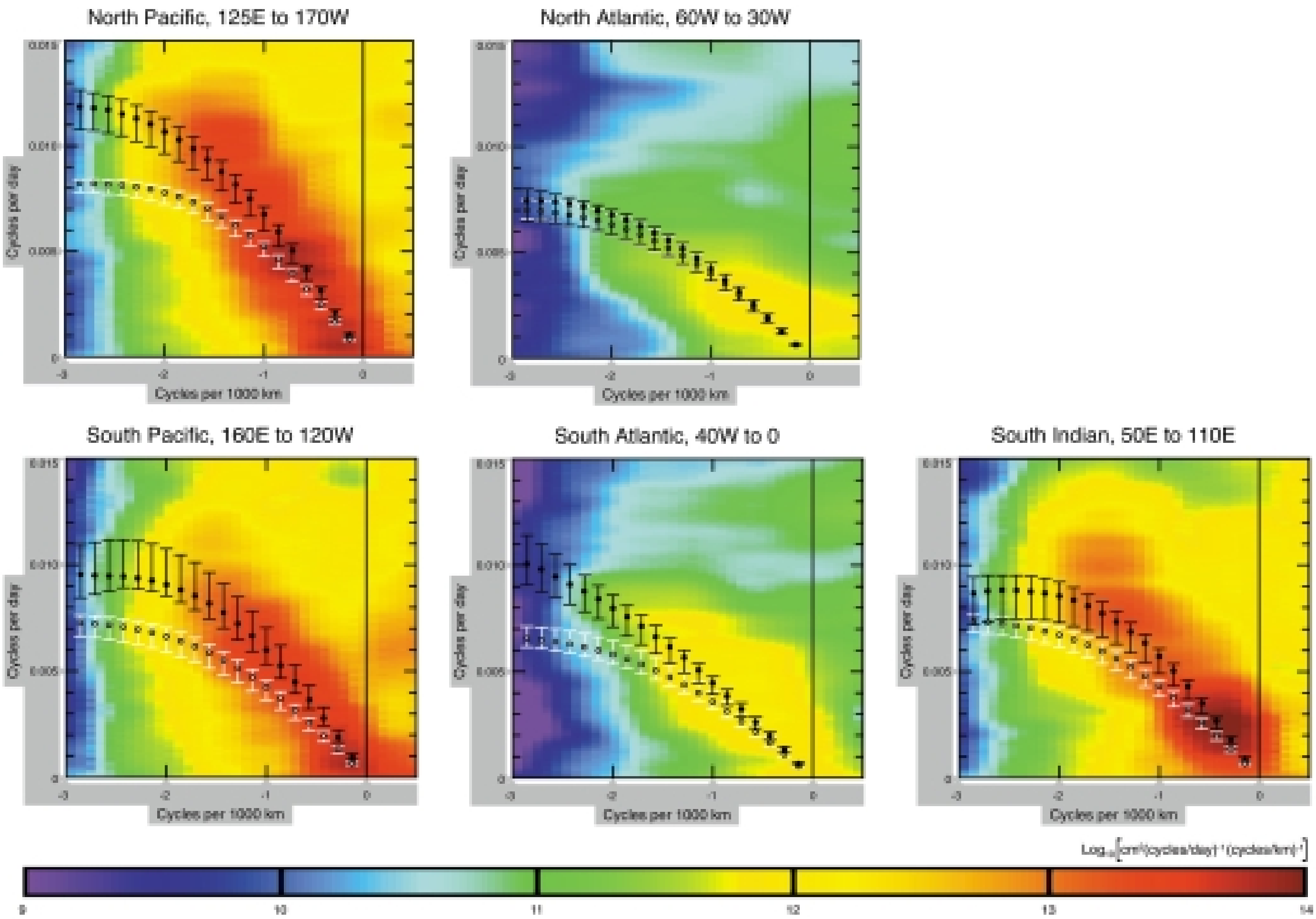

Figure 4: Frequency-wavenumber spectra computed from 7 years of T/P data along 24˚N and 24˚S over the longitude ranges labeled on each panel. The dispersion relation computed from the classical theory and the extended theory of Killworth et al. [1997] are shown by the white and black circles, respectively. These circles and the associated confidence intervals at each wavenumber correspond to the median and central 75% of the distribution of individual estimates along the longitudinal section over which the spectra were computed.

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Corresponding author:
Dudley B. Chelton
College of Oceanic and Atmospheric Sciences
104 Oceanography Administration Building
Oregon State University, Corvallis OR 97331-5503 - USA
E-mail: chelton@oce.orst.edu