Barotropic Rossby waves seen radiating from tropical instability waves in the Pacific Ocean

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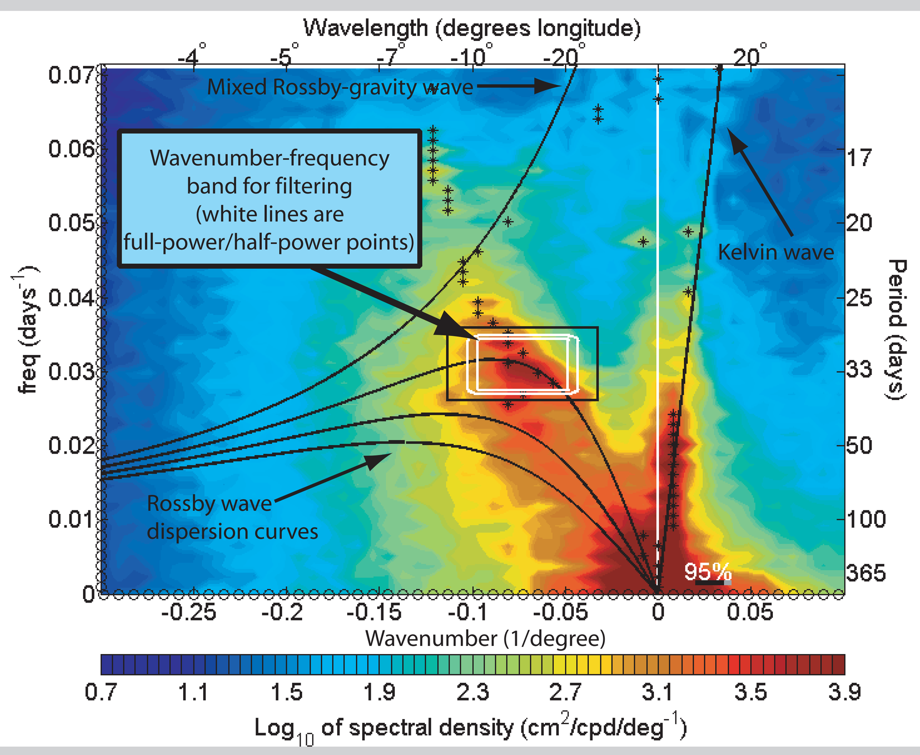
Abstract

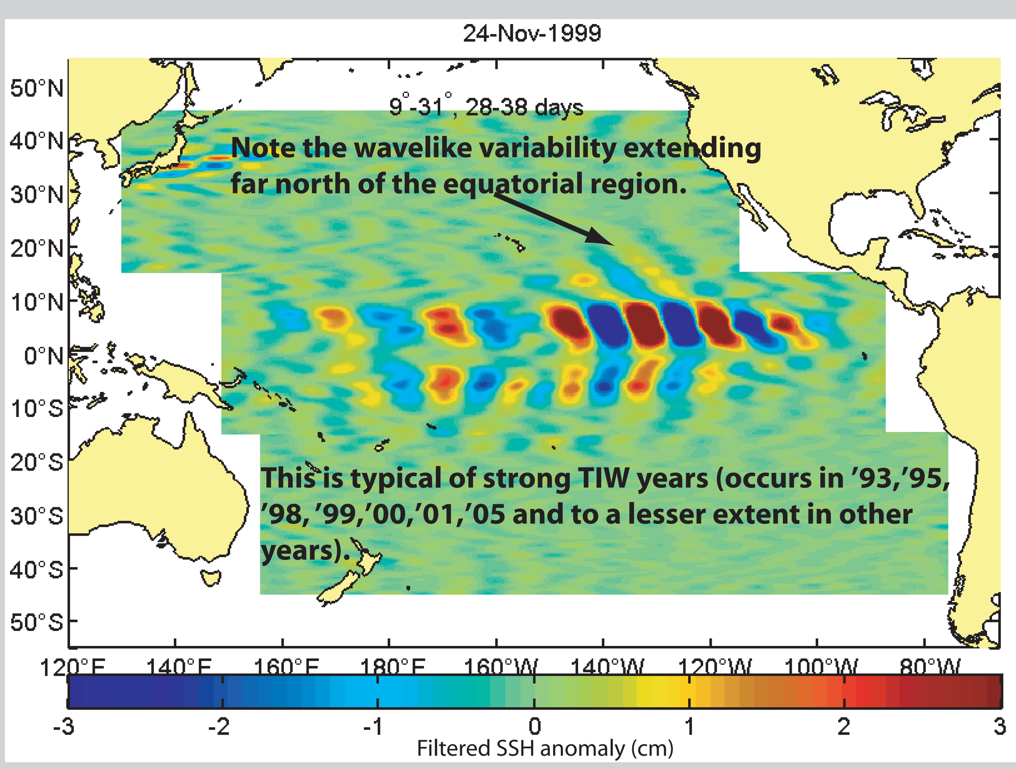
Tropical instability waves (TIWs) are triggered by instabilities of the equatorial current systems, and their sea-level signal, with peak amplitude near 5°N, is one of the most prominent features in the dynamic topography of the tropics. Almost all studies of tropical instability waves, whether observational, theoretical, or numerical, have focused on this near-equatorial variability. We show that there is sea-level variability as far north as Hawaii (i.e., 20°N) that is coherent with the sea-level variability near the equator due to tropical instability waves. Using cross-spectral techniques, it is shown that this off-equatorial variability obeys the dispersion relation for barotropic Rossby waves over a fairly broad range of frequencies. This is a robust result, and it is concluded that the off-equatorial disturbances are barotropic Rossby waves. The dispersion relation and observed wave properties further suggest that the waves are carrying energy away from the instabilities and toward midlatitudes.

Introduction

Tropical instability waves (TIWs) occur during the boreal fall and winter months when the equatorial current system becomes unstable. The waves extract energy from the large-scale currents and have been studied by many investigators. These instabilities have been ascribed a large range of wavelengths and periods, but spectra of sea surface height show a distinct peak at wavelengths of 10-17° of longitude and periods of 30-35 days (e.g., Farrar, 2008 and figure below). Peak amplitudes in sea surface height are found near 5°N (e.g., Lyman et al., 2005; Farrar, 2008). **Almost all previous studies of tropical instability waves have focused on the immediate vicinity of the equator (~7°N-7°S). This study uses the Aviso gridded sea surface height anomaly product to investigate variability associated with these waves in regions much further from the equator.**

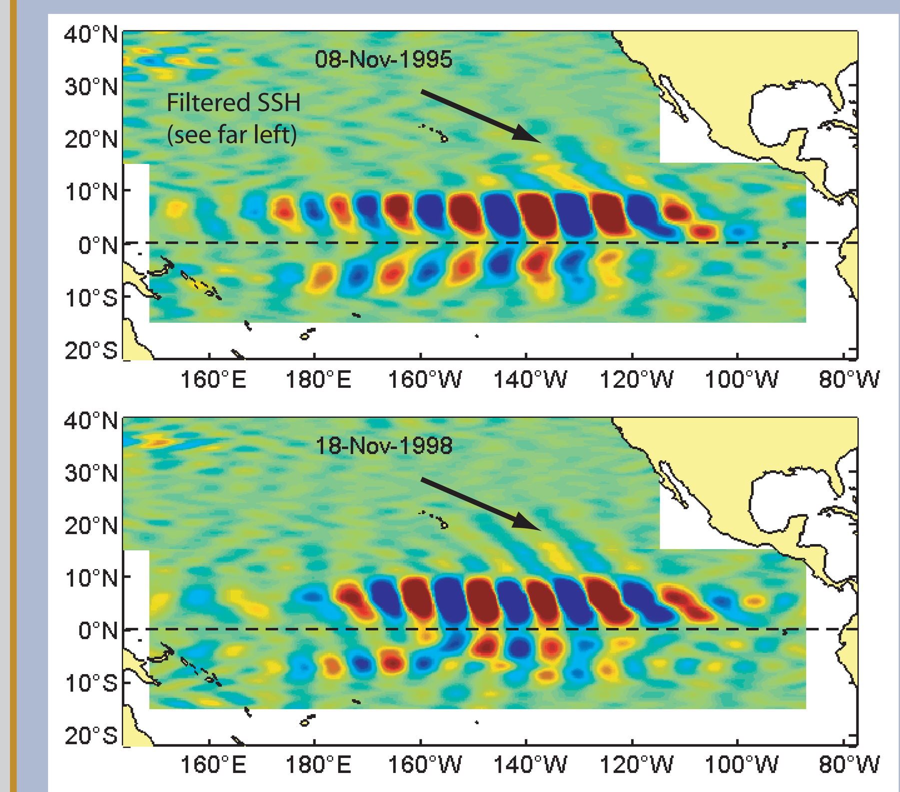


The figure above shows the zonal wavenumber-frequency spectrum of sea surface height, averaged over 7.5°S to 7.5°N. (That is, the wavenumber-frequency spectrum was calculated on each latitude and this is the average of those spectra.) **We can examine the time-space behavior of the most energetic tropical instability wave variability by band-pass filtering SSH for the wavenumbers and frequencies shown in the box on the figure above. A snapshot of the filtered field is below.**



Variability on 10-20°N associated with Tropical Instability Waves (TIWs): Properties and a hypothesis

(1) Here are examples from two other years- this signal on 10-20°N is a robust feature



This wave pattern seen on 10-20°N is a regular feature, and it appears to be linked with tropical instability wave activity. It occurs during the peak of the tropical instability wave season, and it is most prominent during years with strong tropical instability waves.

One would be justified in questioning whether this wavelike variability on 10-20°N could be an artifact of the filtering. First, note that each latitude is processed independently, so it is not possible that the large amplitude signal near 5°N is 'ringing' to produce the signal at 10-20°N. This issue is also addressed in panel 2 below.

(3) Hypothesis: Radiation of barotropic Rossby waves

The figure on the right is from Cox (1980), showing a snapshot of the barotropic stream function in the first GCM simulation of tropical instability waves. Noted only in passing, Cox interpreted this as meridional radiation of barotropic Rossby waves from the instabilities near the equator.

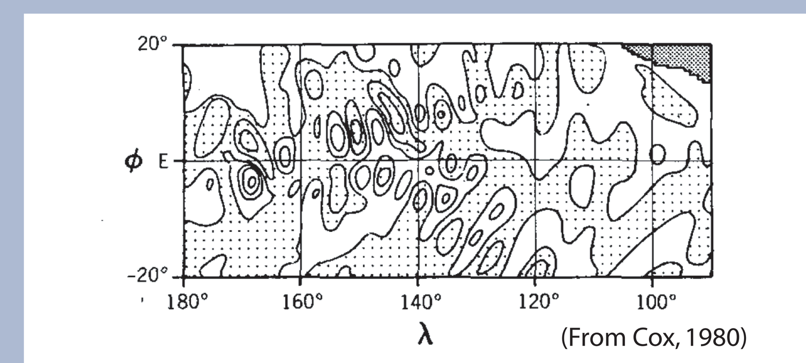


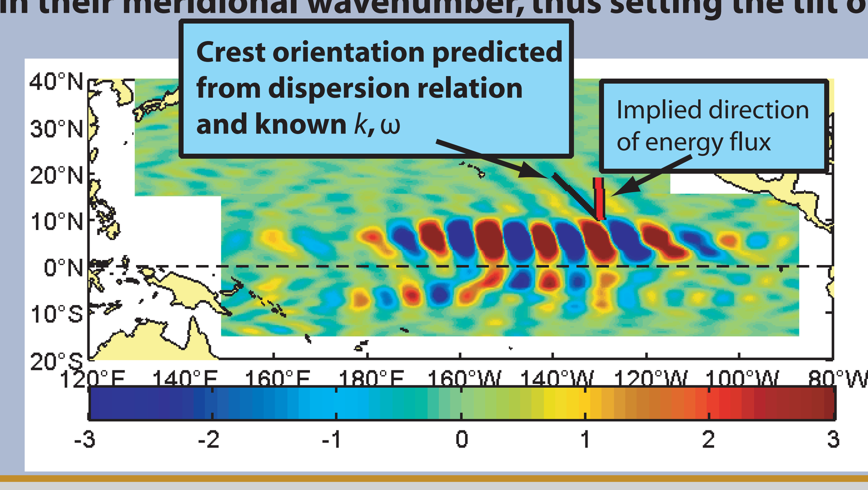
FIG. 12. Frequency band pass filtered mass transport stream-function, indicating vertically averaged flow from the model in the middle of January. The contour interval is 10^{13} cm³ s⁻¹ with counterclockwise flow indicated by stippling.

Hypothesis and test: The SSH variability seen on 10-20°N is associated with barotropic Rossby waves carrying energy away from the site of the instabilities near the equator. If so, the waves should obey the dispersion relation for barotropic Rossby waves, and their zonal wavenumber and frequency should match those of the TIWs. This would constrain their meridional wavenumber, thus setting the tilt of the wave crests.

Frequency, ω, known
Zonal wavenumber, *k*, known

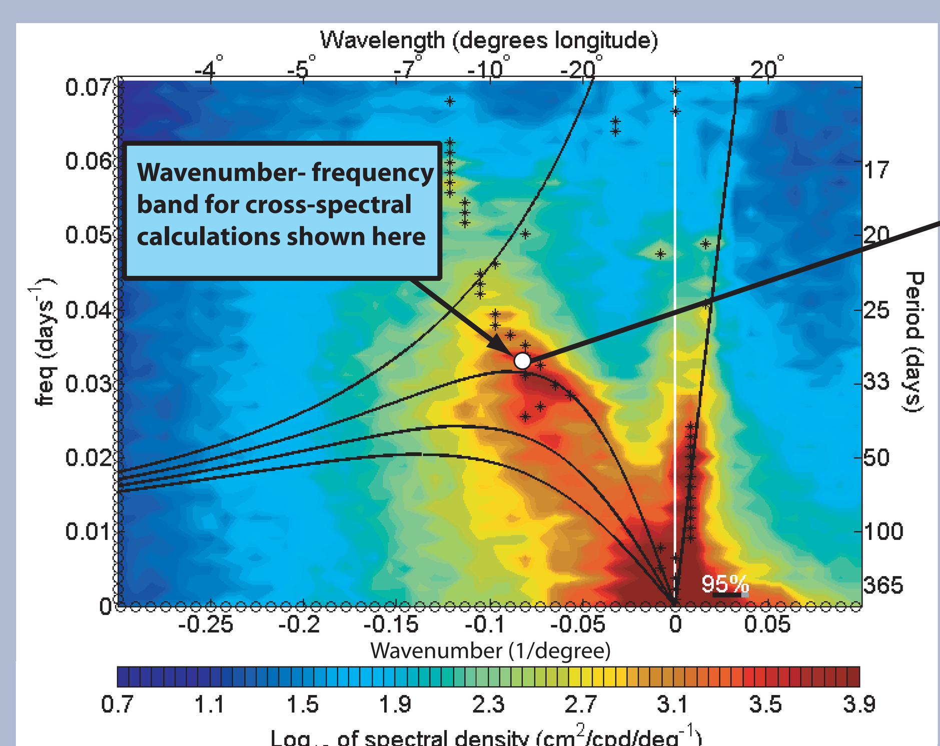
$$\omega = \frac{-\beta k}{k^2 + l^2} \rightarrow l = \pm\sqrt{\frac{-\beta k}{\omega} - k^2}$$

Predicted slope of wave crests $\rightarrow \frac{L_y}{L_x} = \frac{k}{l}$

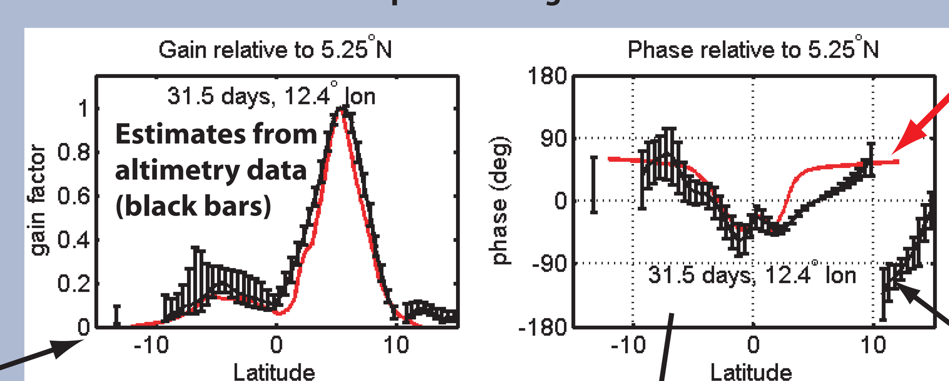


(2) A spectral description of TIWs and associated off-equatorial variability

This SSH variability seen on 10-20°N is coherent with the TIW variability. This can be shown by computing the cross-spectrum of SSH for each latitude against 5°N, where the TIW signal is strongest. This allows us to assess whether variability at TIW wavenumbers and frequencies found at other latitudes is coherent with the TIWs at a statistically significant level. It also allows us to extract the meridional structure of this coherent variability (i.e., amplitude and phase relative to 5°N, e.g., Farrar, 2008).



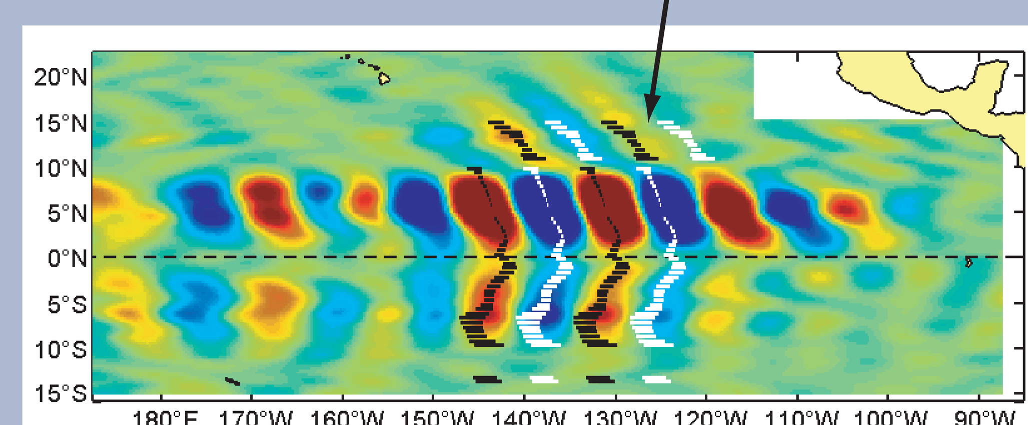
Cross-spectral gain and phase relative to 5.25°N. Error bars are shown when the coherence amplitude is significant at 95% confidence.



Theoretical prediction for meridional structure of TIWs from Lyman et al. (2005), based on linear stability analysis of GCM currents (Red lines)

This is the off-equatorial signal seen in the filtered fields

The cross-spectral estimates of the wave structure give essentially the same story as the filtered fields. The meridional phase structure in the plot above is repeated below at half-wavelength intervals.



Discussion

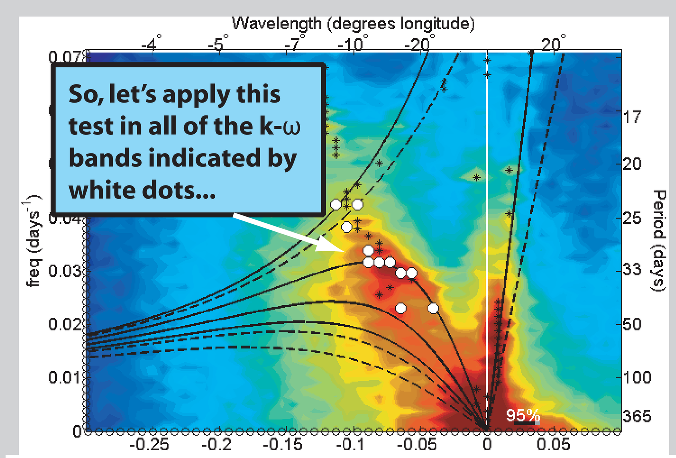
The cross-spectral estimates of meridional phase structure allow a more objective and convincing test of the hypothesis that this variability on 10-20°N, coherent with TIW variability near the equator, is due to radiation of barotropic Rossby waves from the site of the instability. The key thing to note is that the rate of change of phase with latitude is the *definition* of meridional wavenumber. That is,

$$\theta \equiv kx + ly - \omega t \longrightarrow \frac{\partial \theta}{\partial y} = l$$

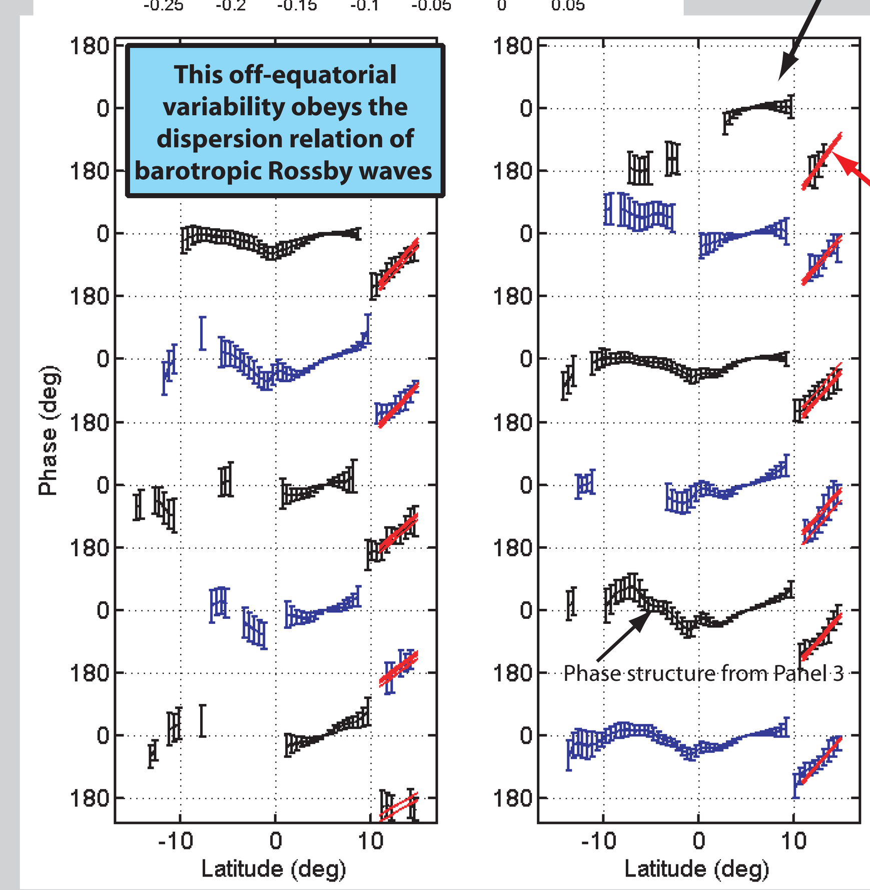
So, the question of whether the variability seen on 10-20°N obeys the dispersion relation for barotropic Rossby waves is essentially the same as asking whether:

$$\frac{\partial \theta}{\partial y} = l \overset{?}{=} \sqrt{\frac{-\beta k}{\omega} - k^2}$$

k, ω, are independent variables of the cross-spectral phase estimate. These can be used to predict the slope of phase with latitude (red lines below). This compares well with the observed phase behavior.



Phase relative to 5°N at values of *k*, ω, indicated by white dots at right



Phase slope predicted by the barotropic Rossby wave dispersion relation for the zonal wavenumber/ frequency of each estimate

Conclusion: There appears to be northward radiation of barotropic Rossby waves over a broad range of wavenumbers and frequencies associated with TIWs.

References:

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