Long-range Radiation of Barotropic Rossby Waves from the Equatorial Pacific Ocean

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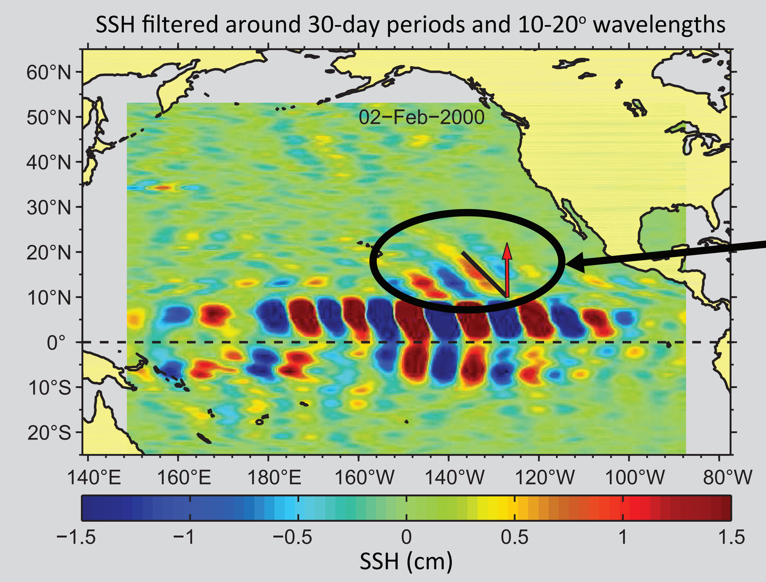
Introduction

Analysis of sea-surface height (SSH) anomalies from satellite altimetry shows variability throughout the North Pacific that is coherent with Tropical Instability Waves. In the tropics (10N-20N) this variability has regular phase patterns that are consistent with barotropic Rossby waves having northward energy propagation (Farrar, J. Phys. Oceanogr., 2011). Further north, the phase patterns become confused and the variance decreases, but hot spots of coherent variability reemerge in the Gulf of Alaska and south of the Aleutian Islands. Ray-tracing calculations and comparisons with numerical simulations support the conclusion that this remote (and seemingly isolated) variability can indeed be attributed to barotropic Rossby waves generated near the equator and undergoing bathymetric refraction as they propagate northward. This sort of barotropic wave variability, coupled to mesoscale instabilities and occurring at similar space and time scales, contributes to the mesoscale variability observed in SSH.

(1) Previous evidence for radiation of barotropic Rossby waves from tropical instability waves

With a variety of analyses of satellite altimetry, Farrar (2011) showed evidence of barotropic Rossby waves radiating from the northern edge of the TIW region to at least 20°N. The figure below shows the product of one such analysis: a snapshot of westward propagating sea surface height (SSH) signals in the TIW period band from a time late in the TIW season. The phase lines sloping upward from right to left on 10-20°N in the eastern Pacific satisfy the dispersion relation for barotropic Rossby waves, and the group velocity calculated from this dispersion relation is almost due northward, with a magnitude of 50 cm/s, or 0.4 deg. latitude per day.

SSH field (cm) on 2 February 2000 after bandpass filtering to isolate westward-propagating variability having zonal wavelengths of 10°-25° of longitude and periods of 29-37 days. The thick black line indicates the orientation of wave crests expected for a barotropic Rossby wave having the same zonal wavelength and frequency as the dominant TIW signal, and the red arrow shows the expected group velocity (50 cm/s).

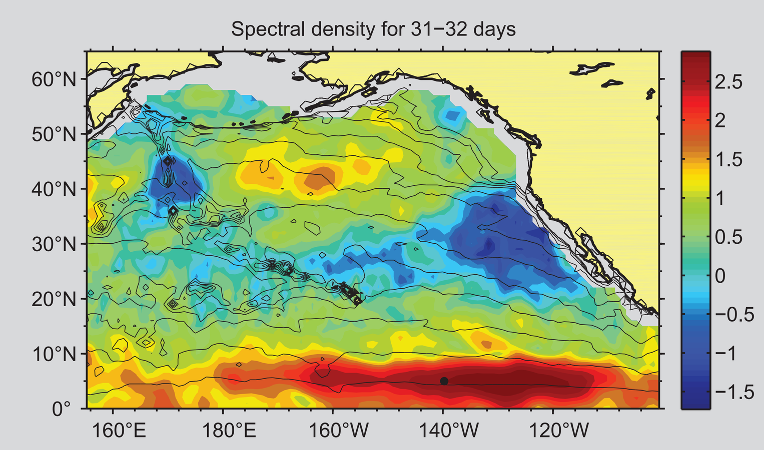


On the basis of a more extensive analysis than that shown above, Farrar (2011) concluded that barotropic Rossby waves radiate away from the TIW region to at least 20°N. The figure above hints at variability of similar frequency and wavenumber even farther north than 20°N, but we must be careful not to read too much into fields that have been prefiltered in zonal wavenumber. For example, refraction by topography could alter the zonal wavenumber of a barotropic Rossby wave, an effect that is likely to be increasingly important with distance from the source region.

(2) 30-day SSH variability in the North Pacific Ocean

We are interested in assessing the extent to which the 30-day barotropic Rossby waves radiating northward from the equatorial instabilities contribute to varibility in remote regions. Standard theory (e.g., quasigeostropic theory) suggests that baroclinic variability cannot exist poleward of about 6°N. The spectral density of SSH at 30-day periods (figure below) shows SSH variance at these periods is predominantly concentrated in the equatorial waveguide. The variance remains somewhat elevated near 10-20°N in the eastern Pacific where Farrar (2011) identified barotropic Rossby waves radiating away from the unstable equatorial currents; the 30-day variance drops substantially on 20-30°N, but it increases again in the far north Pacific near 30-50°N.

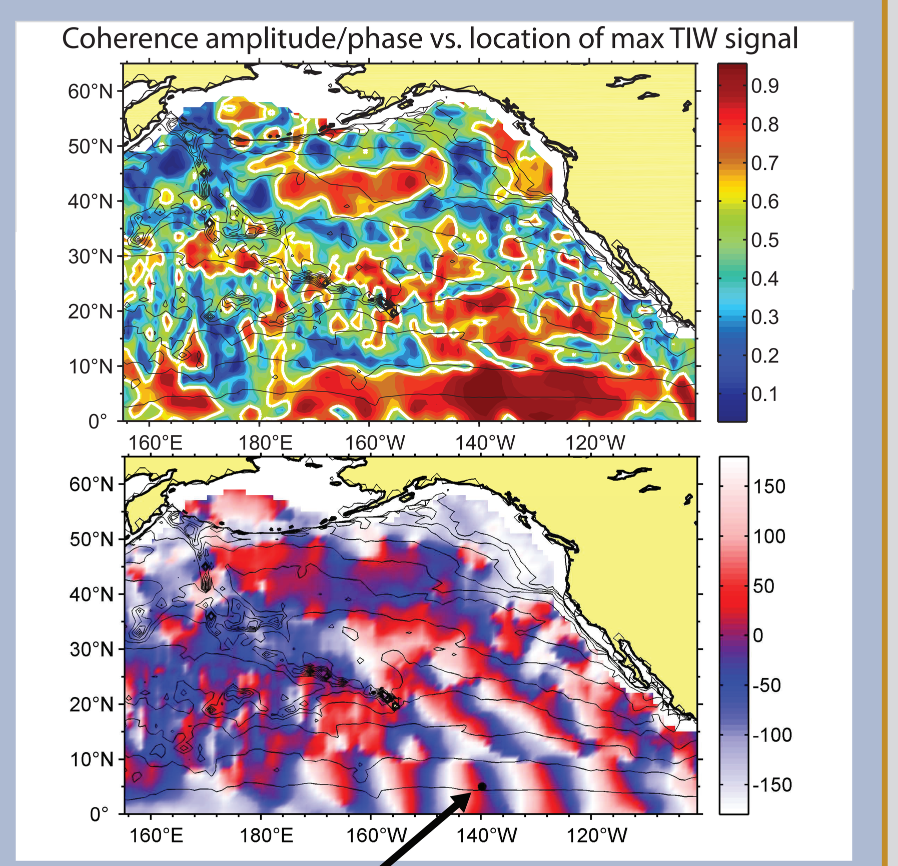
Could the patch of elevated 30-day SSH variance near 30-50°N be a result of the barotropic Rossby waves emanating from the equatorial region?



(3) Long-range coherence of SSH with tropical instability wave variability (30-day periods)

Because we expect the wavenumber of the the barotropic Rossby waves to vary as they encounter changes in topography and Beta along their propagation pathway, an analysis in terms of wavenumber and frequency (as was used above and in Farrar, 2011) is not appropriate for examination of long-range propagation (e.g., because variability can disappear and reappear in a particular wavenumber-frequency band as the wavenumber changes from refraction). However, we do expect the frequency of the waves to be preserved as they propagate, so an analysis in the frequency domain is more appropriate for assessing remote signatures of the barotropic Rossby waves.

The figure to the right shows that 30-day SSH variability is coherent with the SSH signal of tropical instability waves, even at locations more than 4000 km from the site of these equatorial instabilities. The map of coherence amplitude is patchy, but there are large regions where the coherence amplitude is large and statistically significant, and these regions correspond fairly well to the regions of elevated variance in the 30-day period band (compare to panel 2 above). We hypothesize that this patchiness in coherence and variance is a result of focusing and defocusing of the barotropic Rossby waves as they propagate. (Note that direct atmospheric forcing is an implausible way of explaining the coherence of the high-latitude SSH variability with the 30-day TIW signal because the TIW signal is from an intrinsic instability of the equatorial current system, not a linear response to atmospheric forcing.)



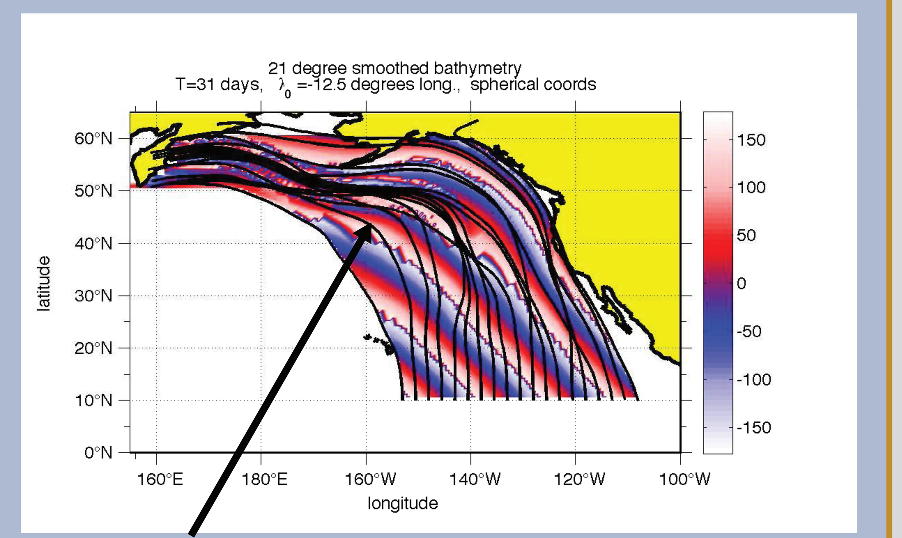
Maps of coherence amplitude (top) and phase (bottom) of SSH with the 30-day SSH signal at 5°N, 140°W (location of max TIW signal).

Regions with coherence amplitudes deemed significant at 95% confidence are outlined in white (upper panel).

The SSH variability is coherent with the SSH signal of tropical instability waves over large regions that are more than 4000 km from the TIW region (e.g., the region near 42°N, 160°W).

(4) Interpretation of the observed amplitude, phase, and long-range coherence with ray tracing

To get some insight into the observed relationships, we performed ray-tracing calcuations of 30-day barotropic Rossby waves on a sphere with variable bathymetry. The rays were initialized at 10°N, where there is a clear break between the TIW and barotropic Rossby wave phase patterns (panels 1-3 above and Farrar, 2011). The ray tracing is inviscid, does not account for boundary reflections, and allows rays to cross unrealistically. The ray-tracing also cannot adequately represent the wave scattering expected over abrupt changes in topography. Nevertheless, the qualitative results are illuminating.



Convergence of rays, which implies increasing wave amplitude, roughly corresponds to region of elevated variance in SSH at 30-day periods (panel 2 above)

The region of regular phase patterns immediately north of the TIW regions mimics the observations reasonably well. This is a region of gradually sloping bathymetry, where the planetary beta effect dominates and changes slowly with latitude. Farther north, the planetary beta decreases more rapidly with latitude, the bathymetry becomes both more important and more irregular, and significant refraction occurs. In particular, the refraction leads to a strong convergence of the rays in a region south of Alaska that is very close to the region of elevated coherent variability seen in the observations. The preliminary evidence supports a conclusion that 30-day variability south of Alaska could indeed represent energy transmitted via barotropic Rossby waves from the equatorial region.

Acknowledgments:
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Primary reference:
Farrar, 2011: Barotropic Rossby waves radiating from tropical instability waves in the Pacific Ocean, *J. Phys. Oceanogr.*