Equatorial waves across the Pacific, Indian and Atlantic

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I’m doing this “poster” as a series of slides, hoping it will be easier for you to follow.

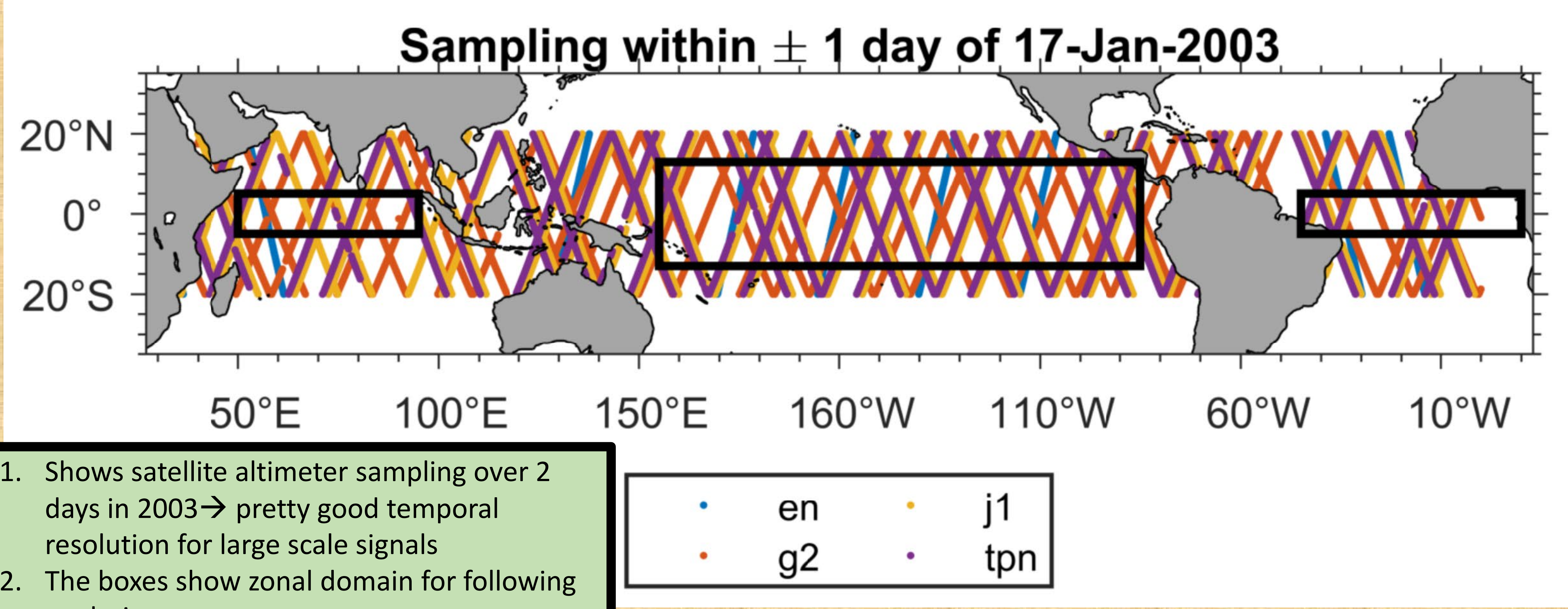
I would be happy to discuss it or describe it in more detail: jfarrar@whoi.edu

Abstract

Oceanic equatorial waves play a fundamental role in ocean adjustment in the tropics, and can rapidly transmit forcing over planetary scales. The long and relatively continuous altimetry record allows us to achieve a high-resolution view of the zonal-wavenumber frequency spectrum of variability in the equatorial Pacific, providing a depiction of the spectrum of SSH variability spanning periods of days to years and Rossby waves to inertia gravity waves. Consistent with previous results, there is clear evidence for equatorial wave vertical and meridional modes resembling linear theory, but the altimetry data reveal some new observational insights. In the Pacific, we find clear evidence for two baroclinic modes and at least seven meridional modes. There has been some doubt as to whether high meridional modes could actually be established, but we find clear evidence for meridional modes up to mode 5 in the inertia-gravity wave spectrum. In the 5th meridional mode, SSH oscillates coherently over a latitudinal range of about 2000 km (10°S to 10°N), but with six sign changes in between.

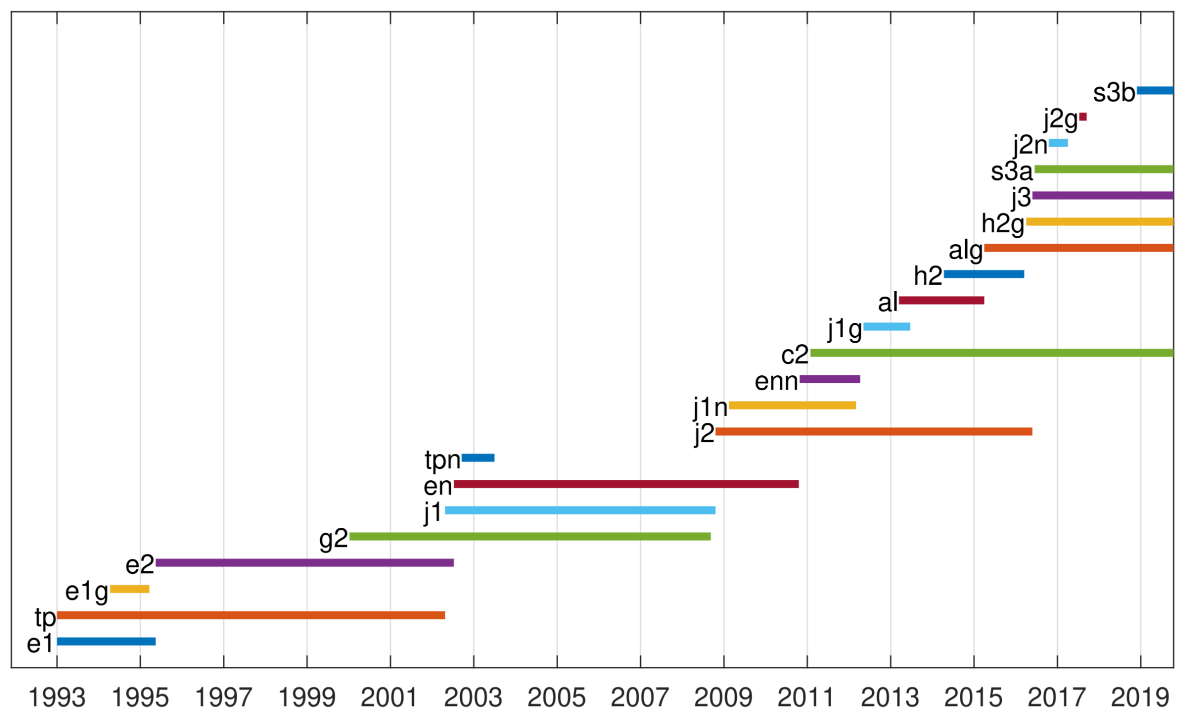
We performed an identical analysis for the Atlantic and Indian Oceans. Major differences from the Pacific are: (1) The inertia-gravity waves and mixed Rossby-gravity waves are substantially weaker in the Indian and Atlantic Oceans than in the Pacific, and (2) The evidence for discrete vertical-meridional equatorial wave modes is not as strong in these basins, which is consistent with other analyses going back to the 1980s.

The satellite altimetry record contains a lot of information at short timescales and large spatial scales

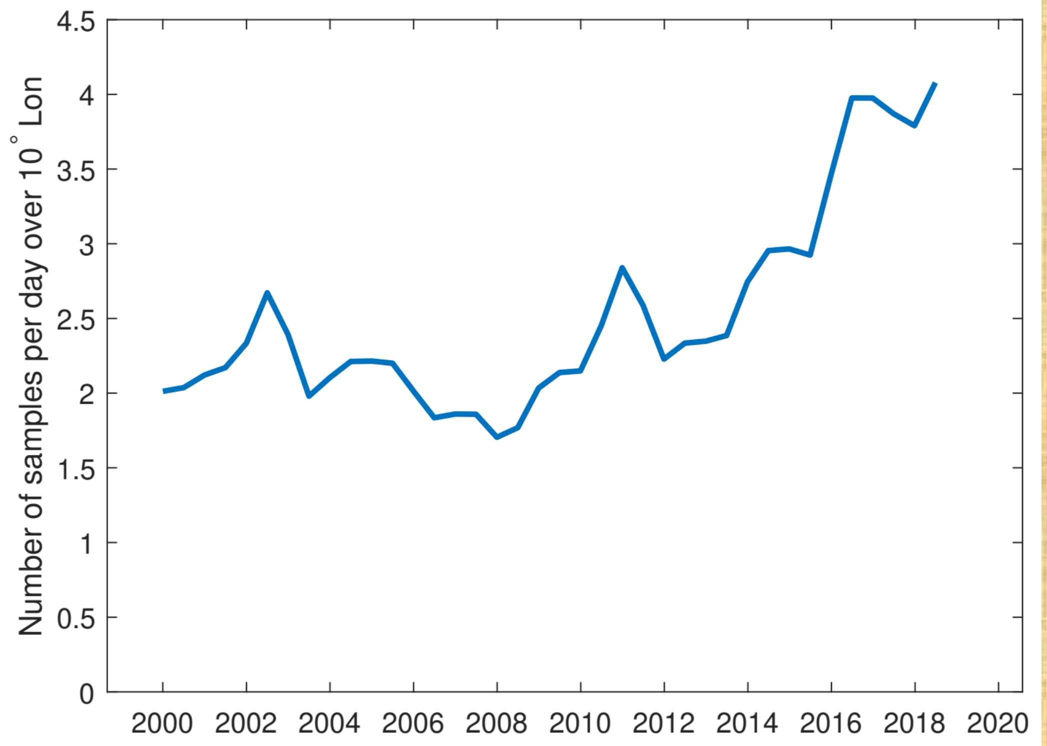


1. Shows satellite altimeter sampling over 2 days in 2003→ pretty good temporal resolution for large scale signals
2. The boxes show zonal domain for following analysis

Here's a depiction of the satellite altimetry sampling over time– it's been steadily getting better

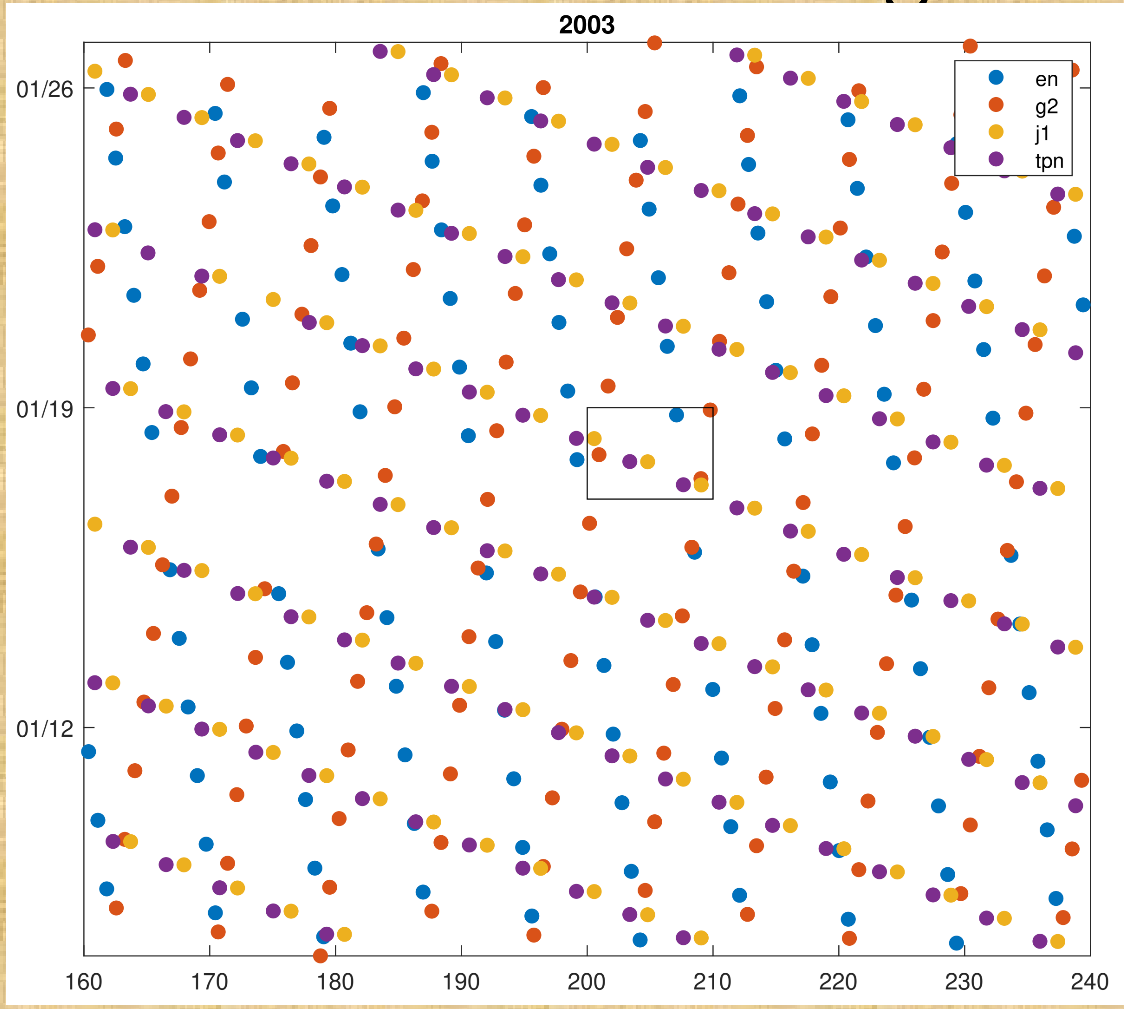


Altimetry satellites in orbit since 1993



Number of samples per day at a given latitude over a 10° longitude interval– it should be adequate for studying periods of days and wavelengths >20° of longitude (>20,000 km)

We estimated the zonal-wavenumber/frequency Fourier coefficients by fitting sinusoids to the data in longitude and time



The details are basically the same as in Farrar and Durland (2012; *J. Phys. Oceanogr.*):

1. We did a "tapered least squares fit" of sinusoids to the data
2. We did the fit on 1-year segments of the record from 2000-2020, for the zonal domain in slide 4.
3. Then we estimated the zonal-wavenumber/frequency spectrum (averaging the spectral estimates from each of the 1-year segments)

Another depiction of the sampling (changes as satellites come and go, but this is typical)– we fit sinusoids to these data

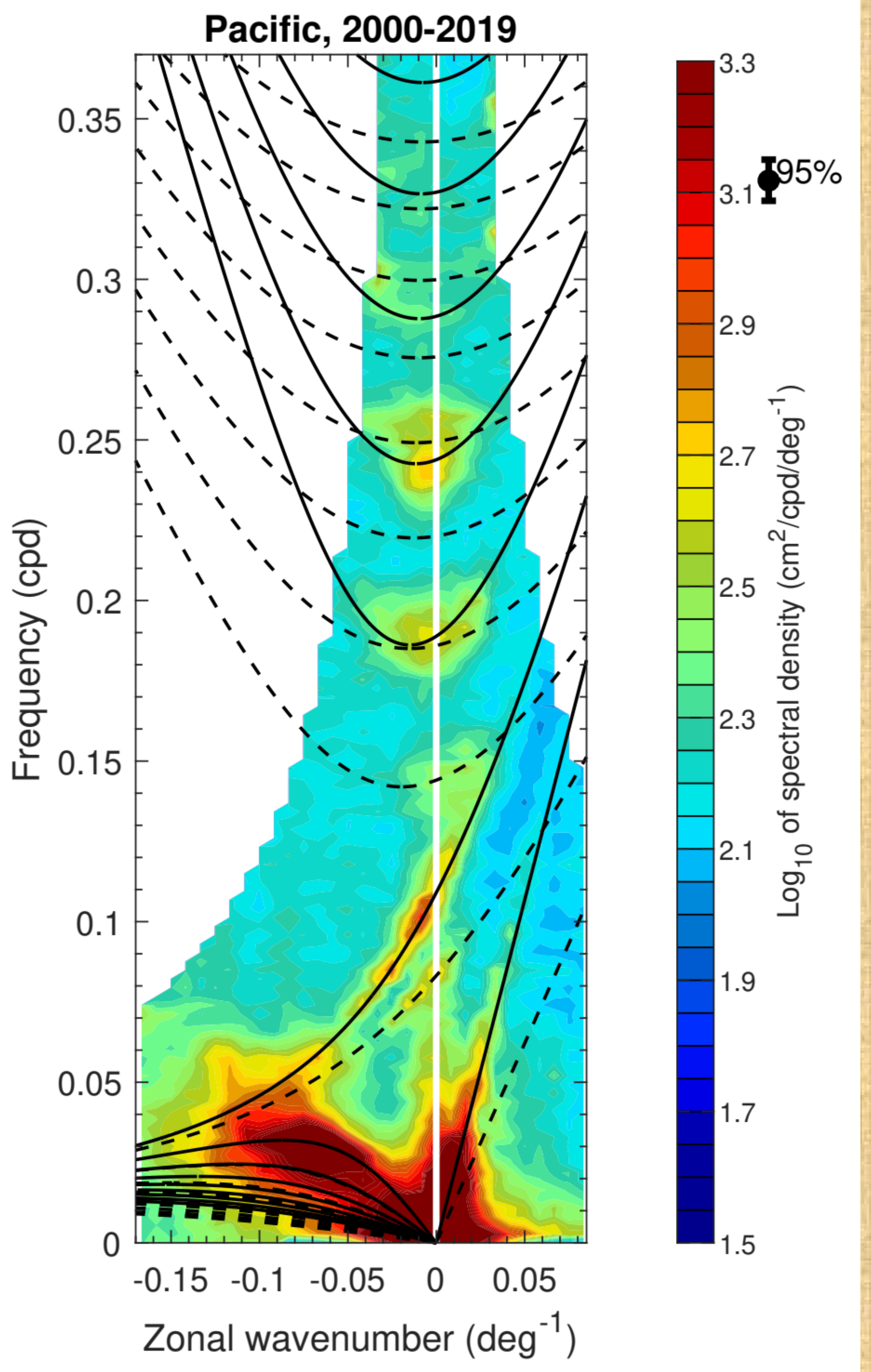
The <u>first main result</u>: zonal-wavenumber/frequency spectrum for the equatorial Pacific (averaged over 5°S-5°N, 2000-2020)

Look at all of these spectral peaks associated with equatorial wave modes. (These are quantitatively consistent with previous results for dynamic height from moorings; Farrar and Durland, 2012.)

The places that are white are wavenumbers and frequencies that were not included in the fit (*motions with both short time scales AND short spatial scales excluded from fit*)

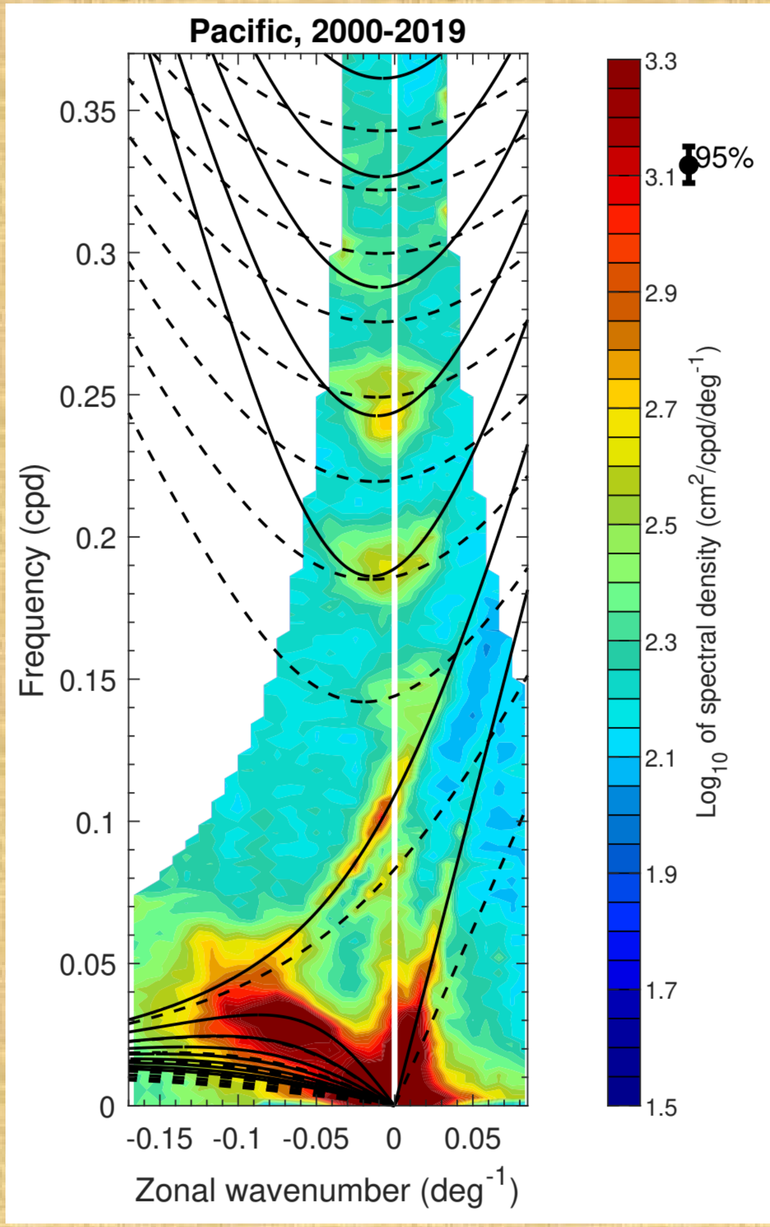
1st baroclinic mode equatorial wave dispersion curves (solid black lines)

2nd baroclinic mode (dashed black lines)



The second main result: we can use cross-spectral estimates to isolate the modal structures

1. The method used is to compute coherence, gain and phase for a given wavenumber-frequency band between a reference latitude and all other latitudes. (The reference latitude is chosen to be one where a given mode is not expected to have a zero crossing.)
2. We computed the cross-spectral quantities using the fitted Fourier coefficients.
3. There are lots of modes– here is one example (next slide).



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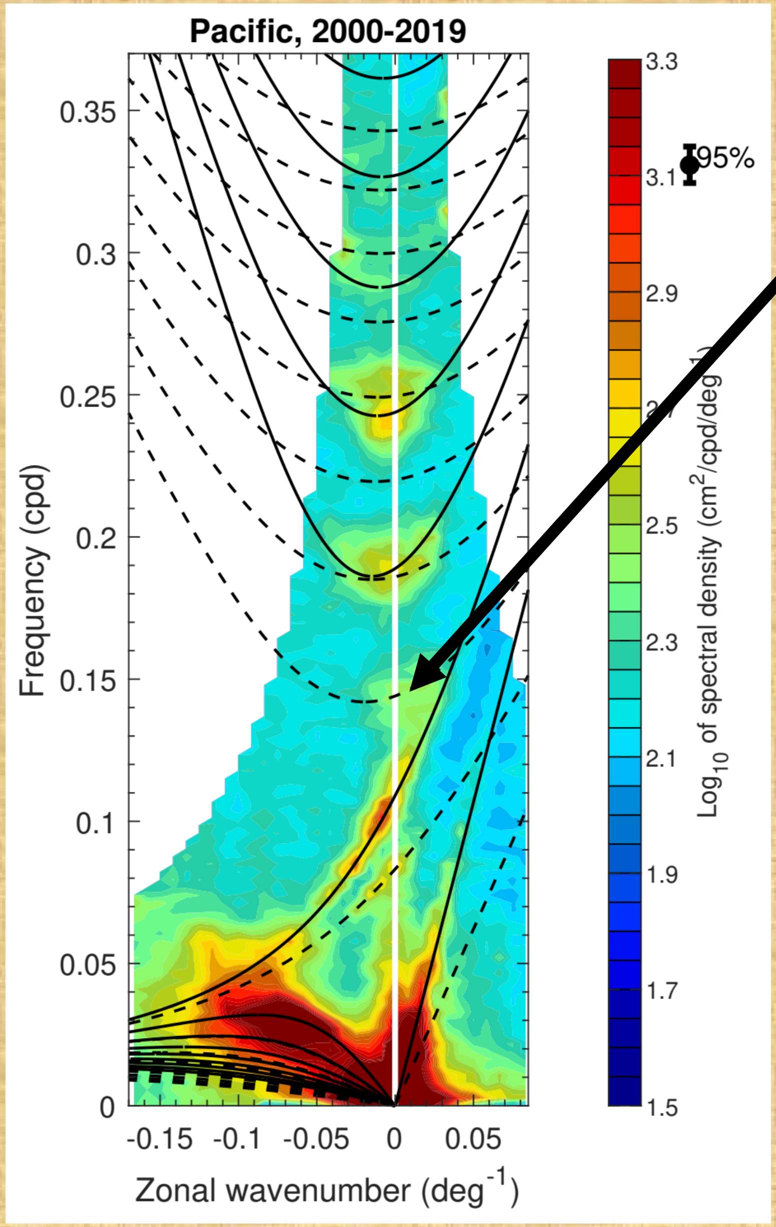
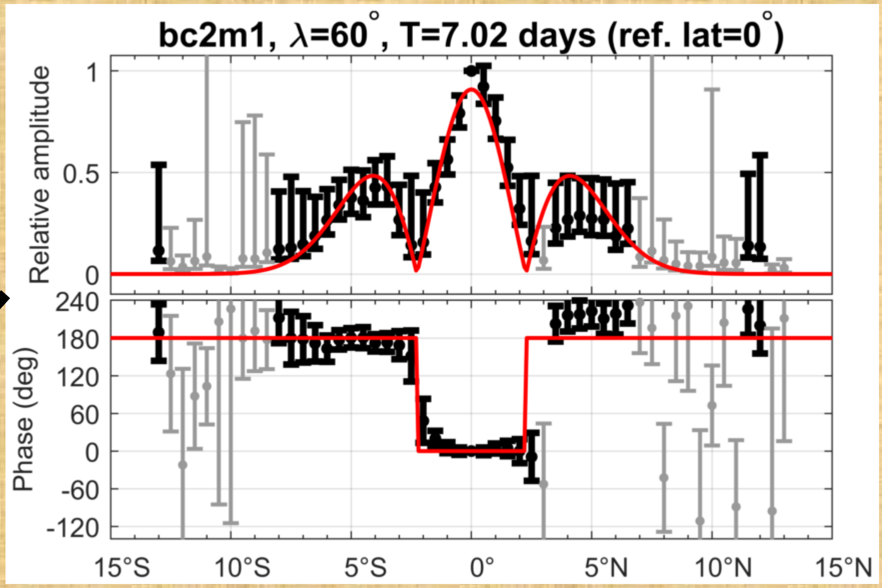
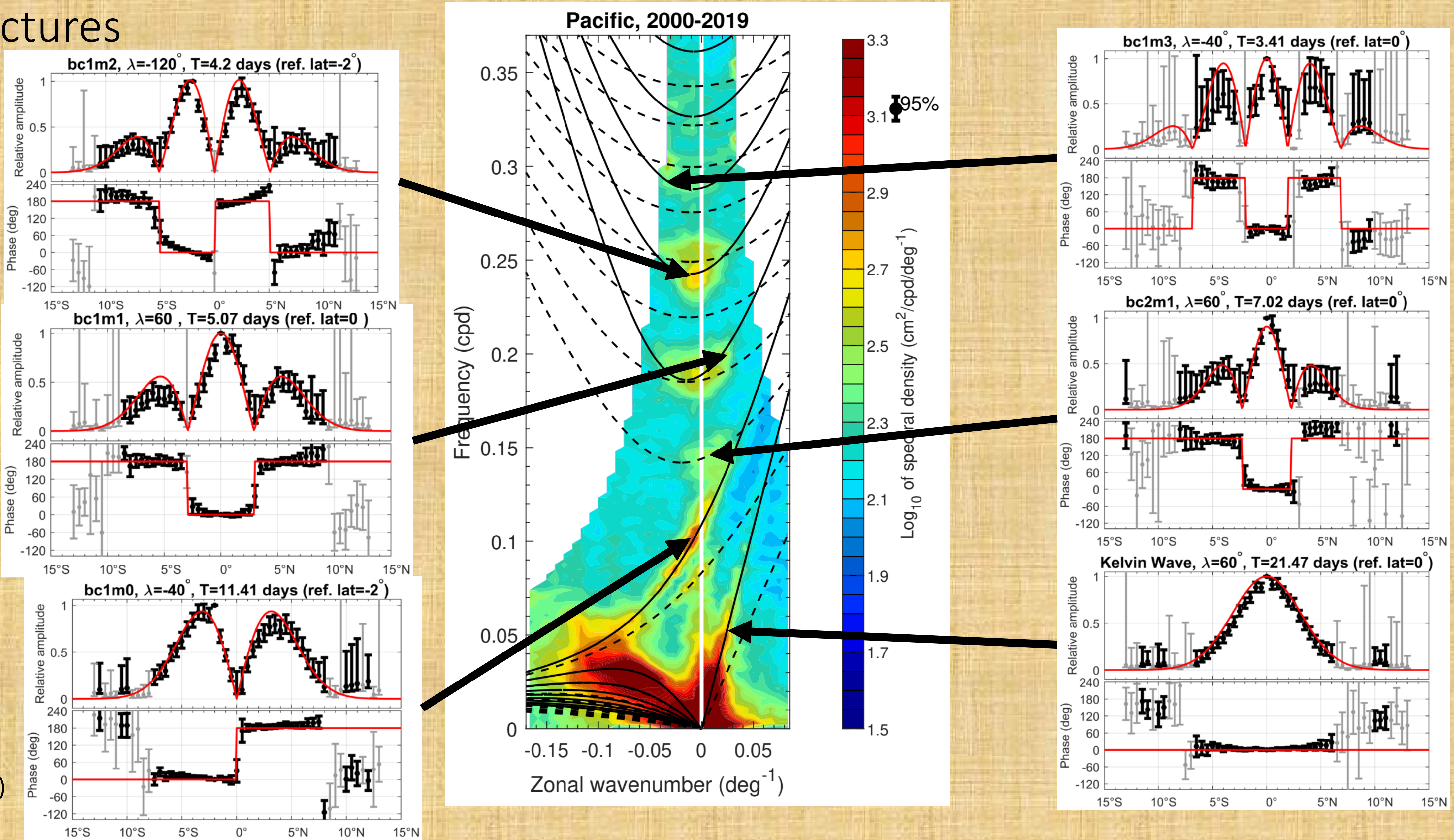




Estimated modal amplitude (top) and phase (bottom) for 2nd baroclinic mode, 1st meridional mode inertia-gravity wave.

1. Black error bars are places where SSH is coherent with reference latitude at 95% confidence. (Grey error bars are still meaningful, but less reliable)
2. Red lines are theoretical modal structures. The 180° phase jump in the bottom panel indicates a zero-crossing of the modal structure.

The <u>second main result</u>: we can use cross-spectral estimates to isolate the modal structures



Inertia-gravity wave, merid. mode 2

Inertia-gravity wave, merid. mode 1

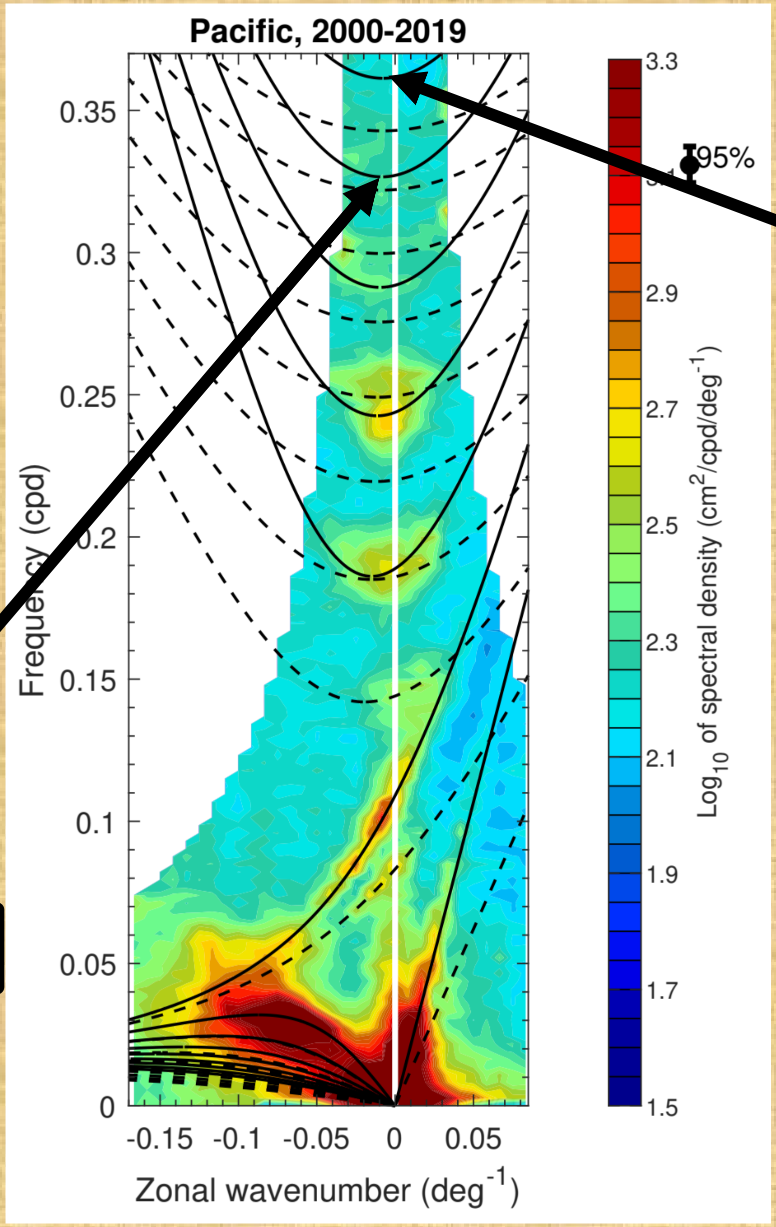
Mixed Rossby-gravity wave (merid. mode 0)

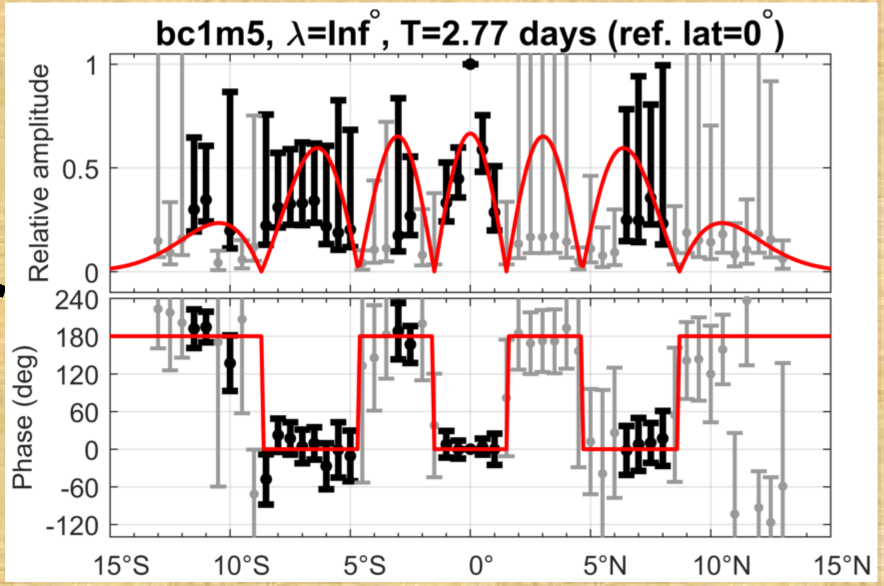
Inertia-gravity wave, merid. mode 3

Inertia-gravity wave, merid. mode 1 (baroclinic mode 2)

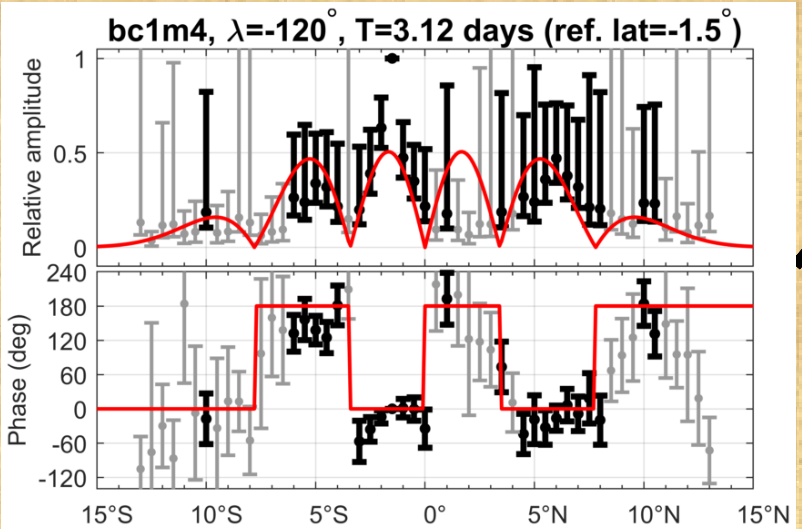
Kelvin wave

The third main result: there is evidence for high meridional modes (like meridional mode 4 and 5)





Baroclinic mode 1, meridional mode 5

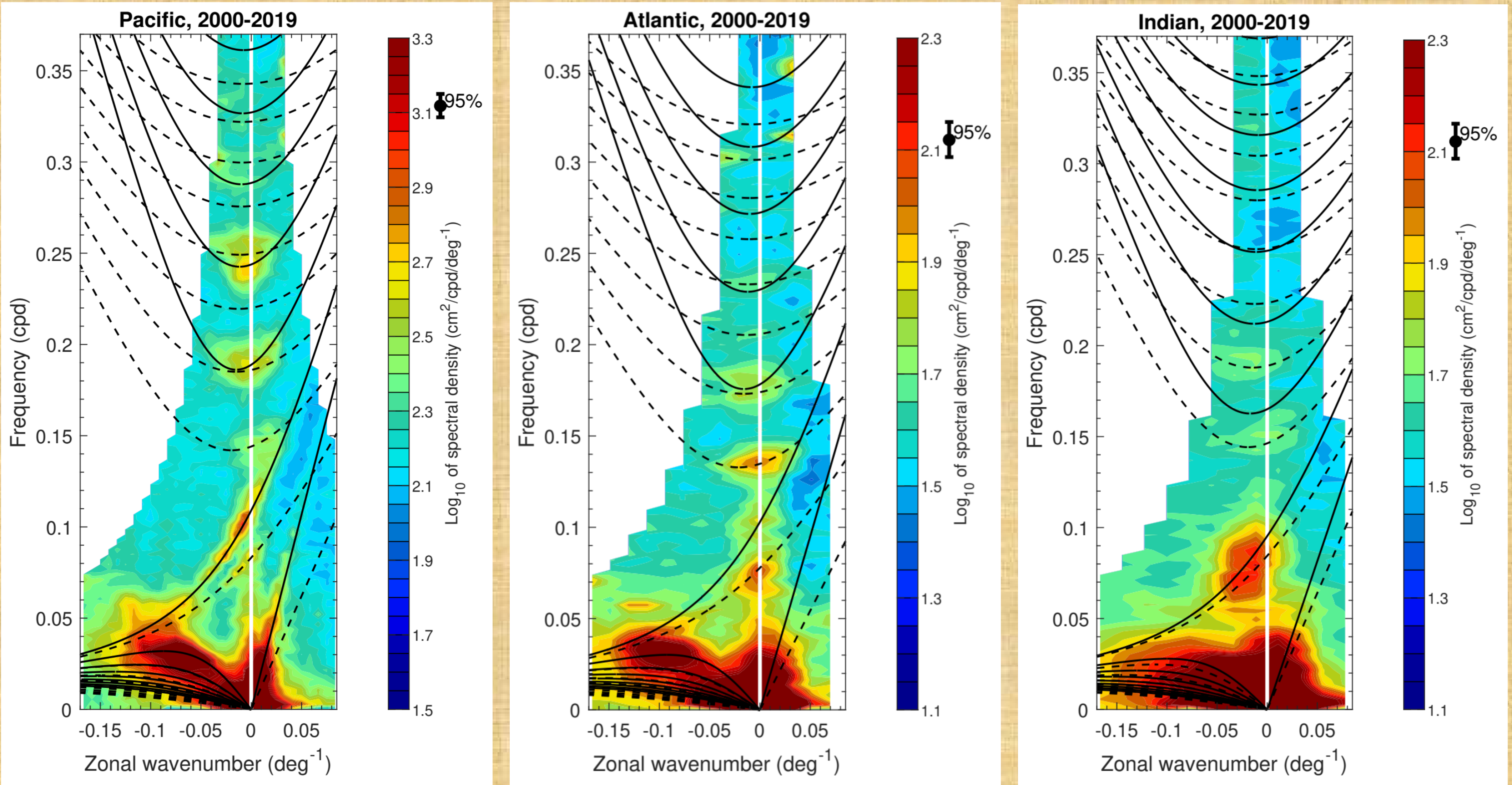


Baroclinic mode 1, meridional mode 4

The amplitude structures of these modes are not really cleanly isolated, but the phase reversals are very clear– there are mode-like oscillations with the expected number of zero crossings occurring roughly at the latitudes where they are expected.

The fourth main result: the equatorial wave SSH signals are weaker in the Atlantic and Indian Oceans

1. Note the change of color scale: the Pacific waves have higher SSH variance
2. The spectrum for the Pacific has better wavenumber resolution because it is ~3 times wider
3. Also, note that different modes are excited



OK, that's it– thank you!

1. The satellite altimetry record contains a lot of information at short timescales and large spatial scales
2. The zonal-wavenumber/frequency spectrum for the equatorial Pacific shows many spectral peaks and ridges associated with equatorial wave modes
3. There are coherent modes of oscillation that closely resemble the theoretical modes– there is even evidence for the 5th meridional-mode gravity wave
4. The equatorial wave SSH signals are weaker in the Atlantic and Indian Oceans

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