Covariability of Equatorial Winds and Sea Surface Height

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period

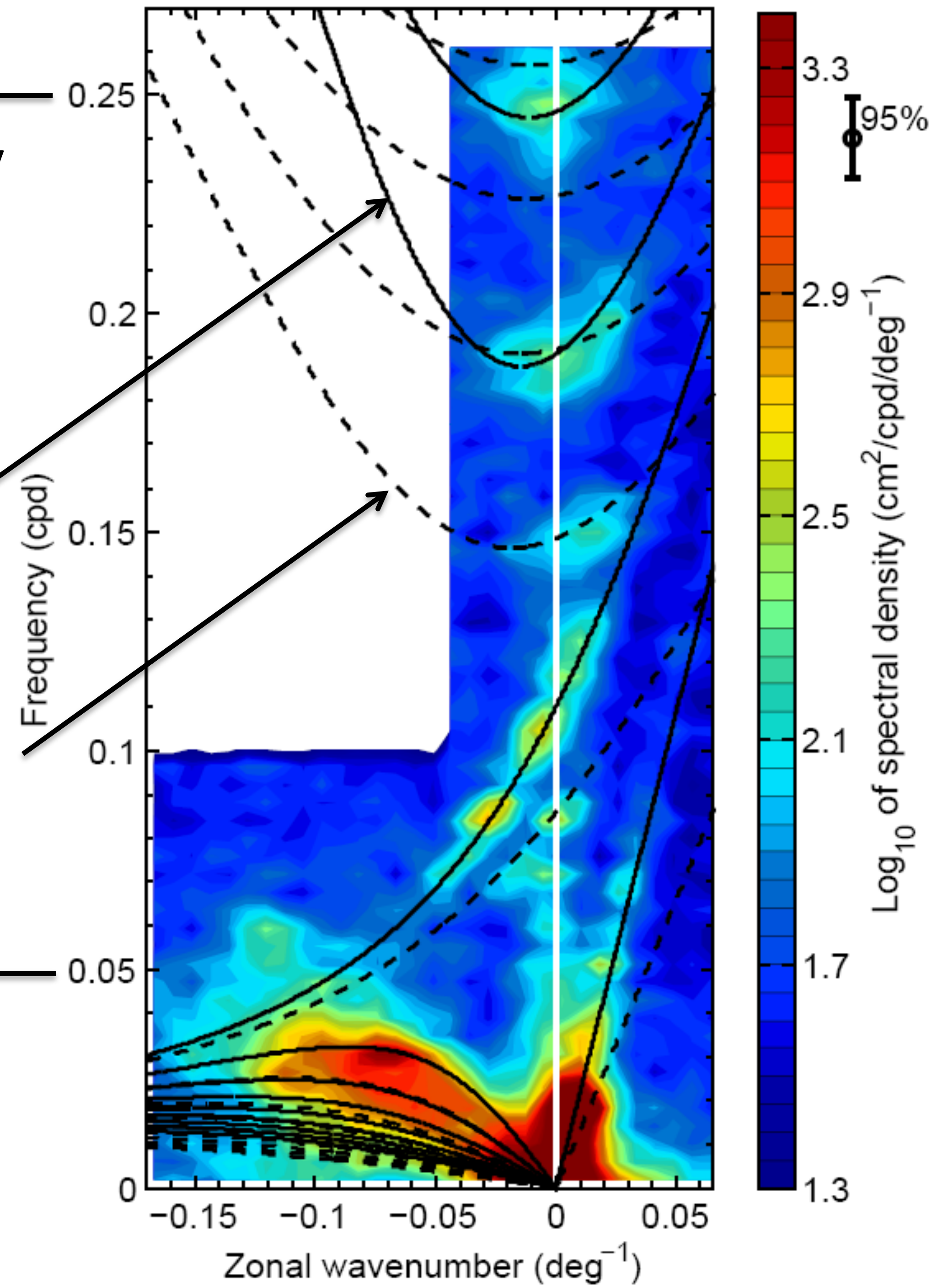
4 day

Zonal-wavenumber/ frequency spectrum of SSH from along-track altimeter data in the equatorial Pacific Ocean (averaged 6°S-6°N, 2000-2005)

Solid dispersion curves: baroclinic mode 1

Dashed dispersion curves: baroclinic mode 2

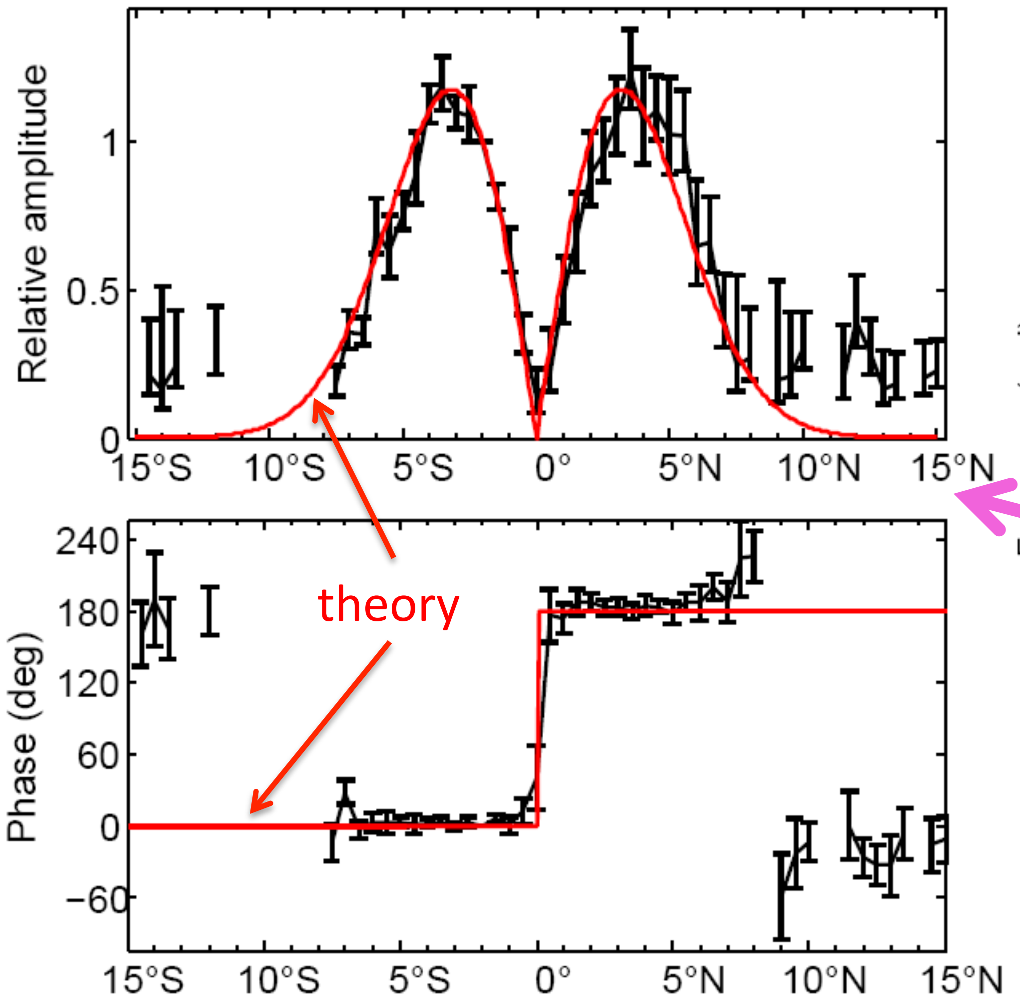
20 day

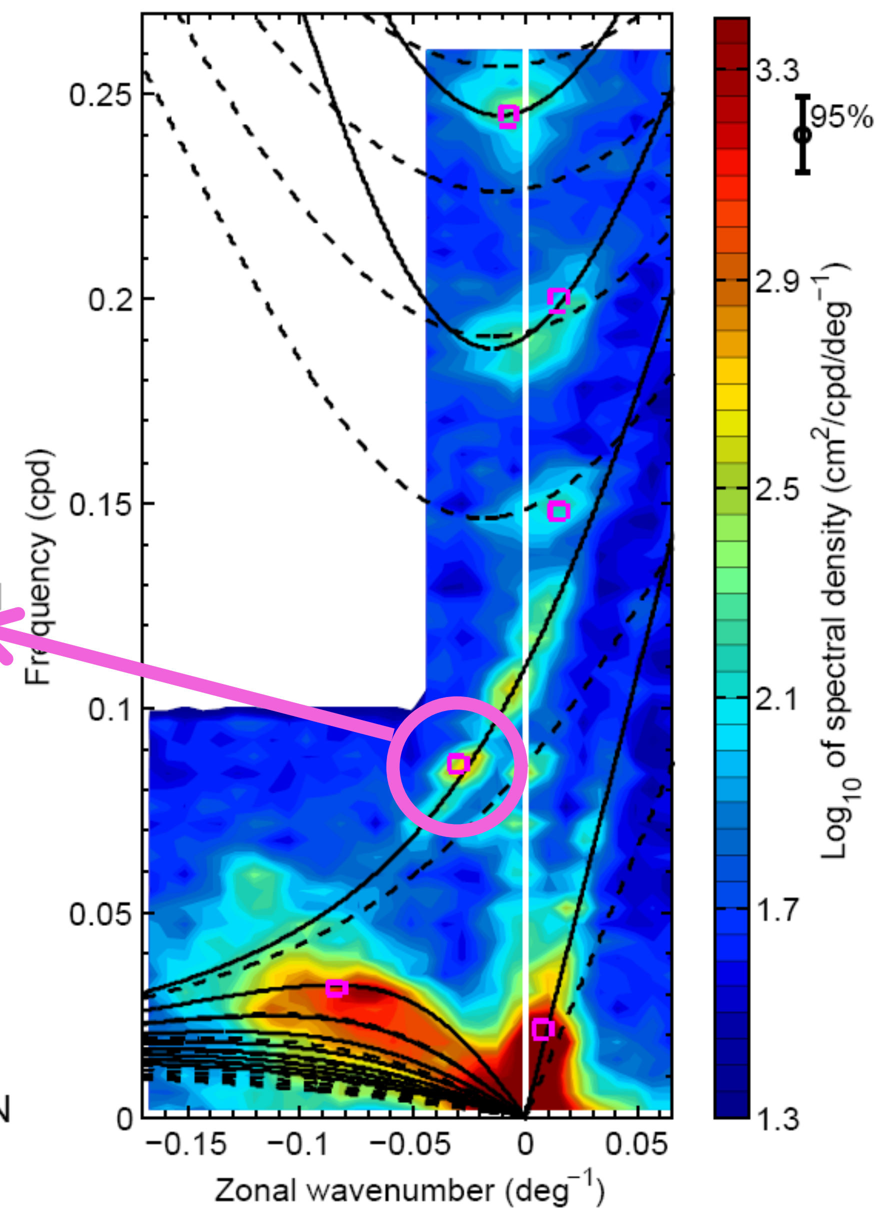


(Comparable spectra of TAO-TRITON dynamic height in Farrar and Durland, *JPO*, Nov, 2012)

The 11-day, 33° Yanai wave (1st baroclinic mode)...

Coherence gain and phase of
SSH relative to 3S



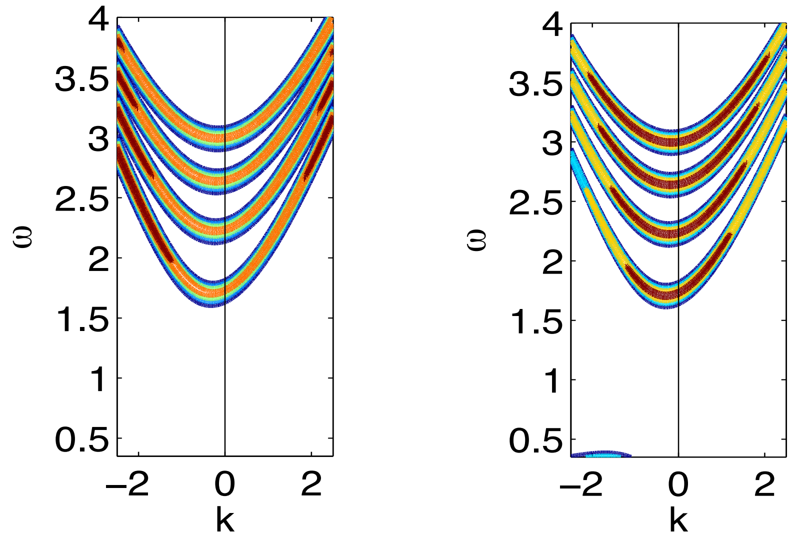


Spectral solutions for forcing that is broadband in zonal wavenumber, frequency and meridional structure

Wavenumber-frequency spectra (Non-dimensional ω, k)

log10 meridionally integrated pressure (SSH) variance

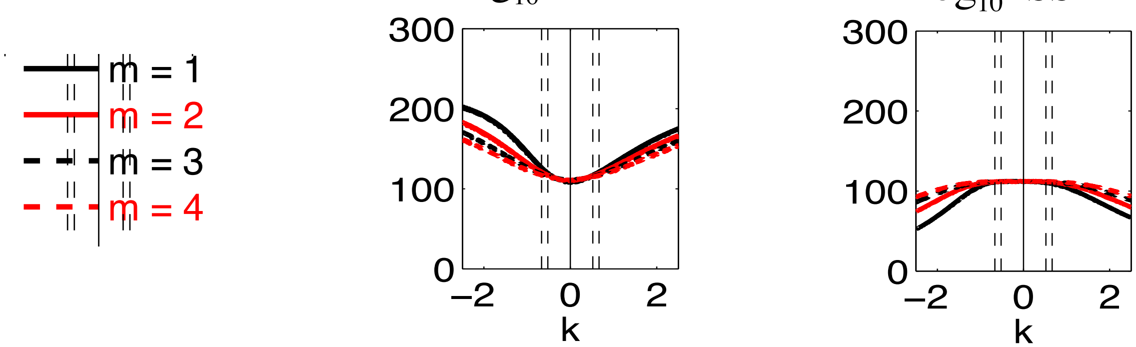
Response to $\boldsymbol{\tau}^x$ | Response to $\boldsymbol{\tau}^y$



Infinite domain, Broadband forcing, No peaks where group velocity vanishes

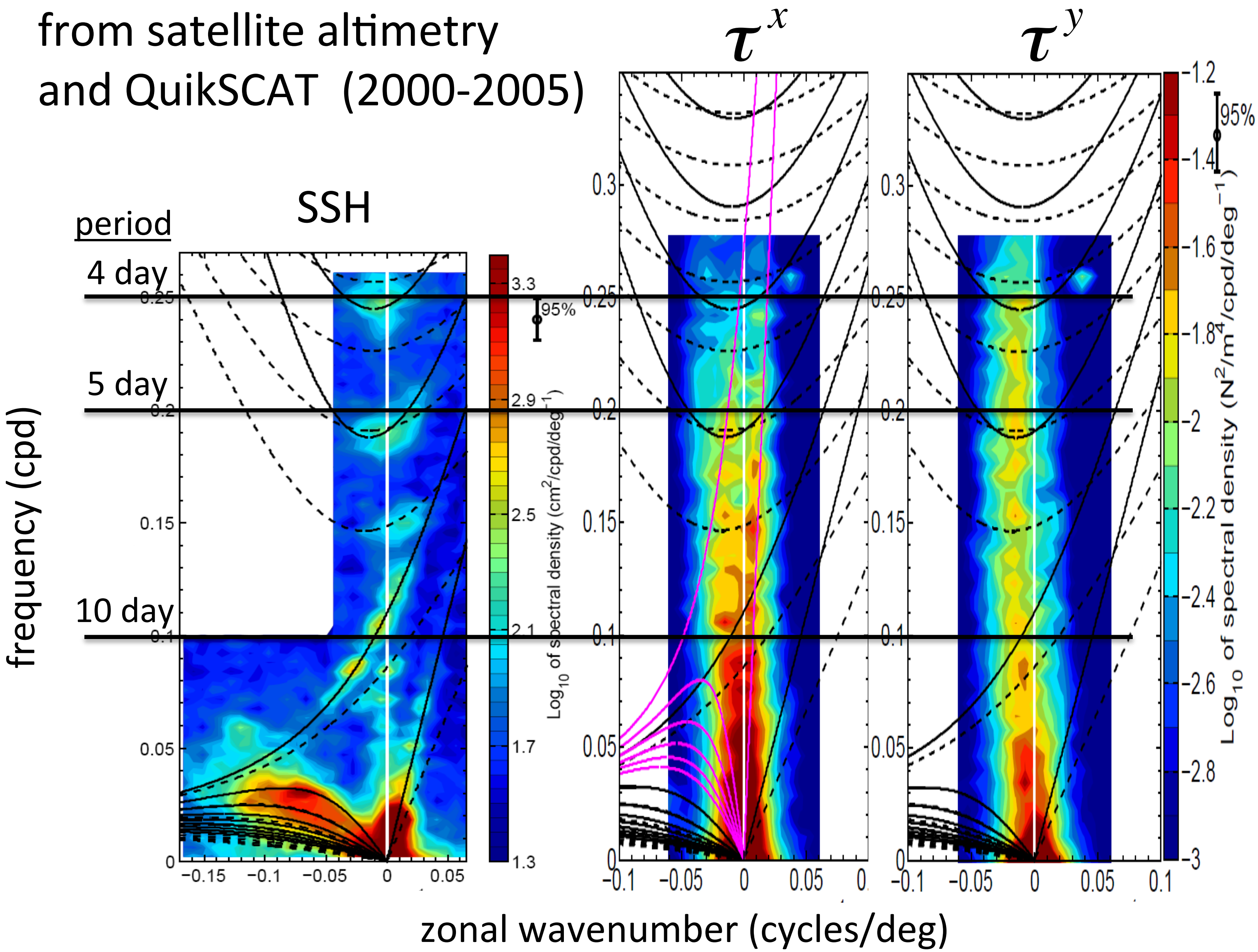
Along dispersion curves (at max resonance)

$\log_{10} |SSH|^2$ | $\log_{10} |SSH|^2$



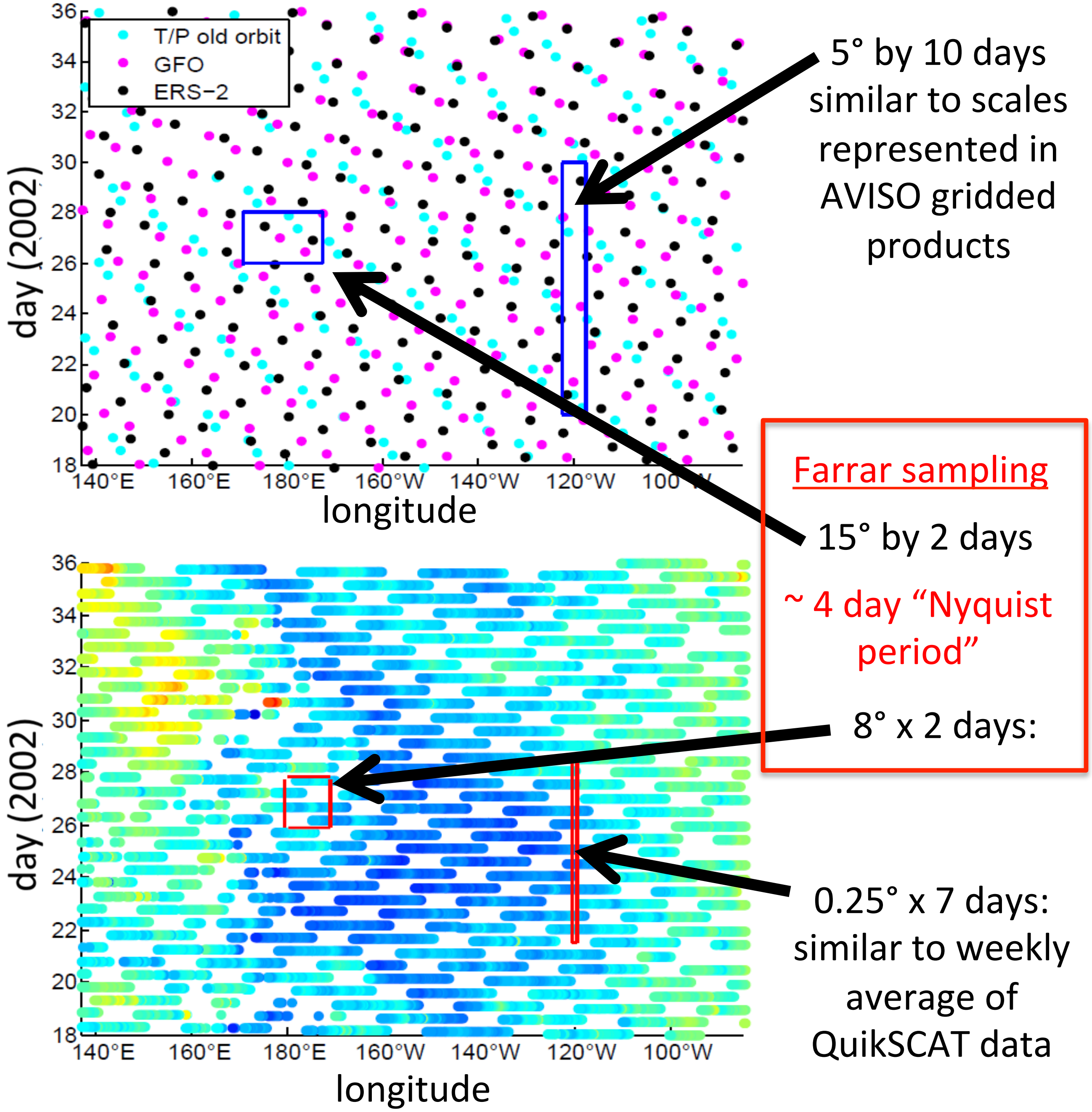
Durland and Farrar, *JPO,* 2012

zonal-wavenumber/frequency spectra for equatorial Pacific from satellite altimetry and QuikSCAT (2000-2005)

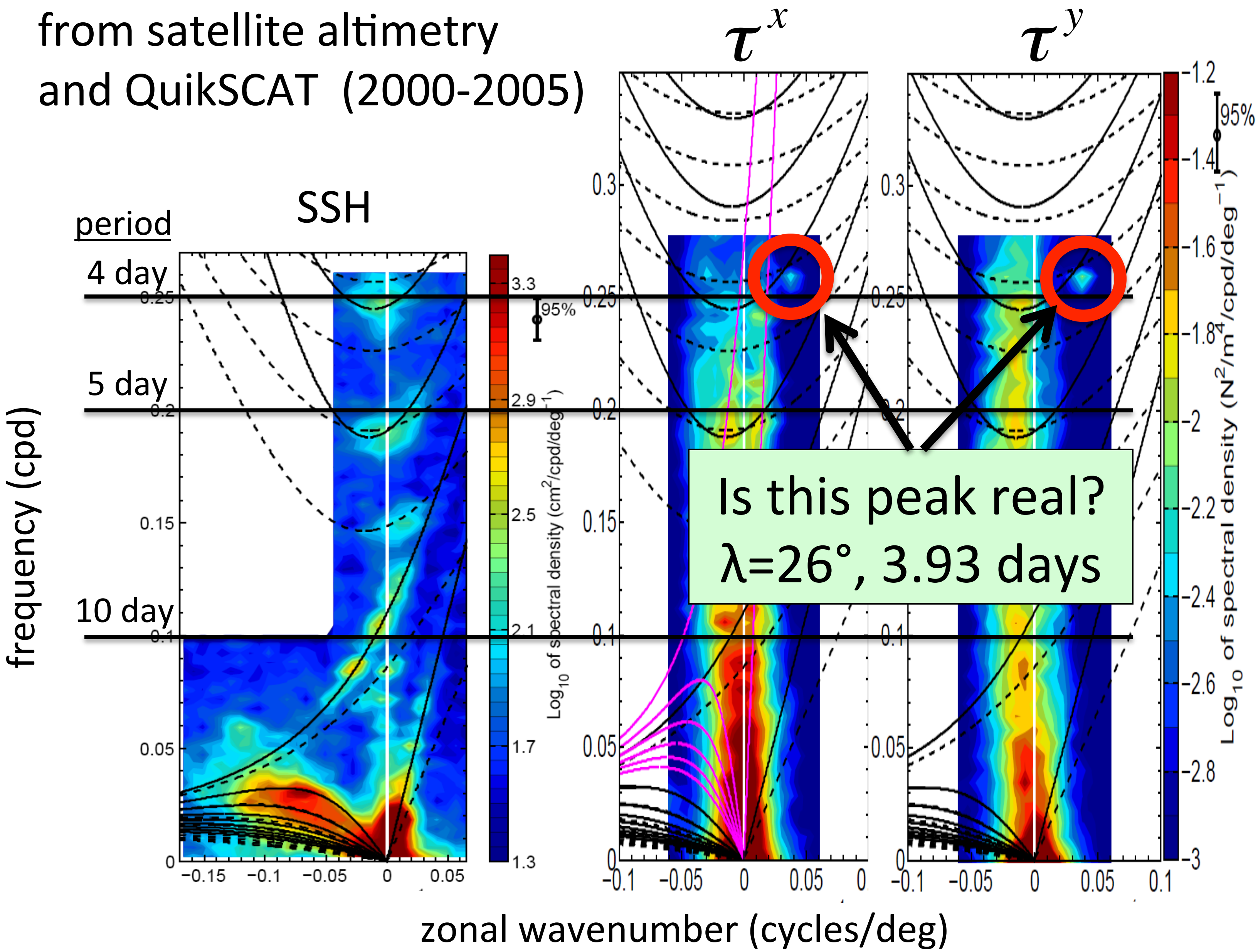


Longitude-time altimetry sampling at 3.5°N

Longitude-time QuikSCAT sampling at 3.5°N



zonal-wavenumber/frequency spectra for equatorial Pacific from satellite altimetry and QuikSCAT (2000-2005)



Resolution Analysis

(Farrar, Schlax, Chelton and Durland, in prep.)

1) How can we decide if a spectral band is *resolved*? Specifically, how well can we determine the Fourier coefficients from the data?

2) How can we tell if unresolved wavenumbers and frequencies of the true variability might contaminate a particular band of our estimate?

Vector of estimated Fourier coefficients

Vector of sampled data

Vector of "true" Fourier coefficients

$$\hat{\alpha} = \Gamma y = \Gamma\left(F^{-1}\alpha + n\right)$$

noise

linear operations performed on raw data to estimate Fourier coefficients

inverse Fourier transform

Assuming the relative phases of the true Fourier coefficients are random,

$$\left\langle \left|\hat{\boldsymbol{\alpha}}\right|^2 \right\rangle = \mathbf{R}\left|\boldsymbol{\alpha}\right|^{\mathbf{2}},$$ where $\mathbf{R} = \left|\Gamma F^{-1}\right|^2$ and $\left|\ \right|^2$ is element-wise

This "resolution matrix" **R** is the basic result

$$\left\langle |\hat{\boldsymbol{\alpha}}|^2 \right\rangle = \mathbf{R}|\boldsymbol{\alpha}|^2$$

Vector of estimated spectral values

Vector of true spectral values

<u>**R** gives us two powerful tools:</u>

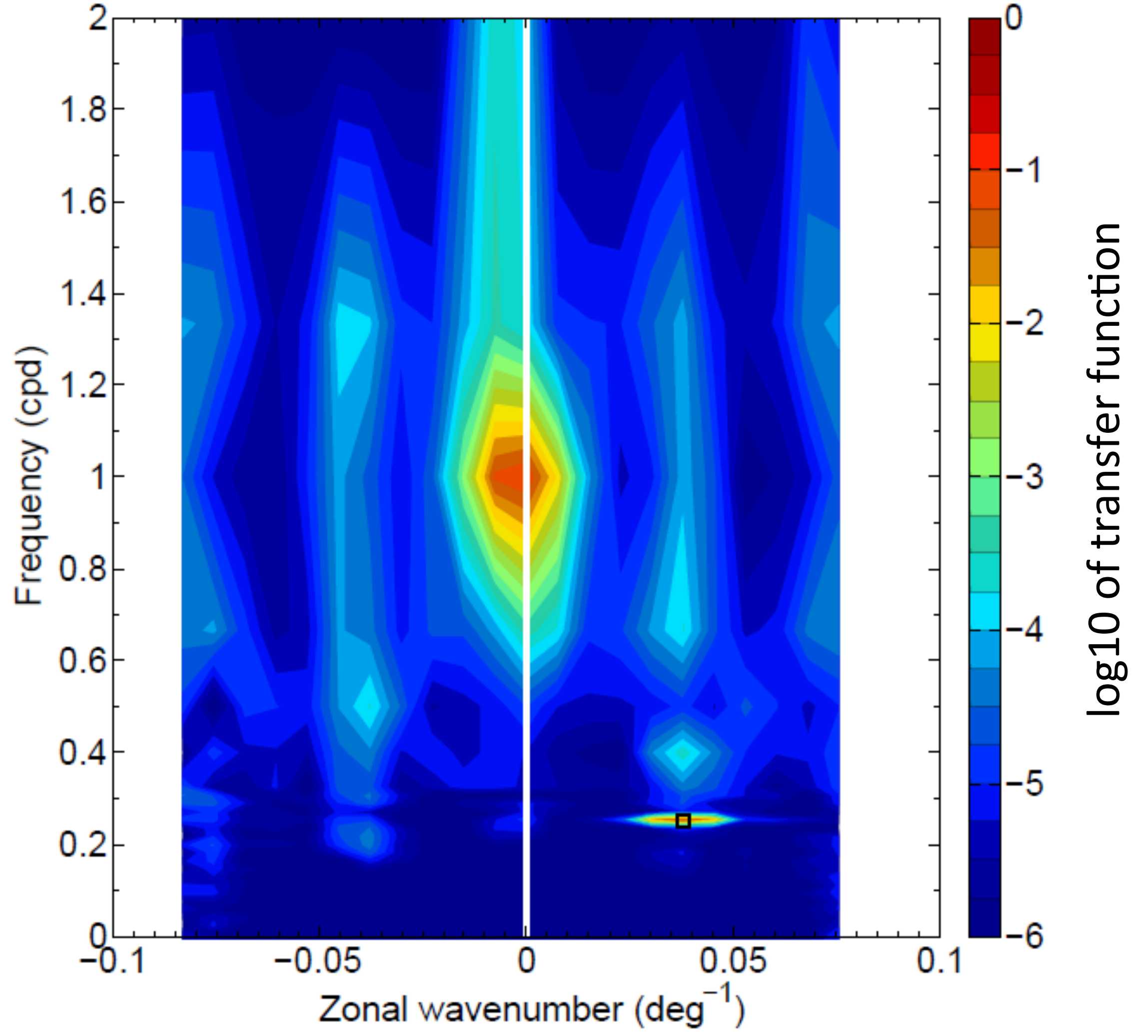
→ A row of **R** tells us how each frequency of the true spectrum influences our estimate at a particular frequency (a "transfer function")

→ A column of **R** tells us the spectrum we would estimate if the true spectrum contained only a single frequency (a "response function")

Row of resolution matrix: tells us the parts of the spectrum contributing to the "alias" peak in our estimate

Our estimate responds strongly to diurnal signals of global scale that propagate westward, passing ~10% of the variance (i.e., ~30% of the amplitude)

Fraction of power contributing to estimate at
$k = 0.038\,\mathrm{deg}^{-1}, \omega = 0.253\,\mathrm{cpd}\ (26^\circ,\ 3.9\ \mathrm{days})$



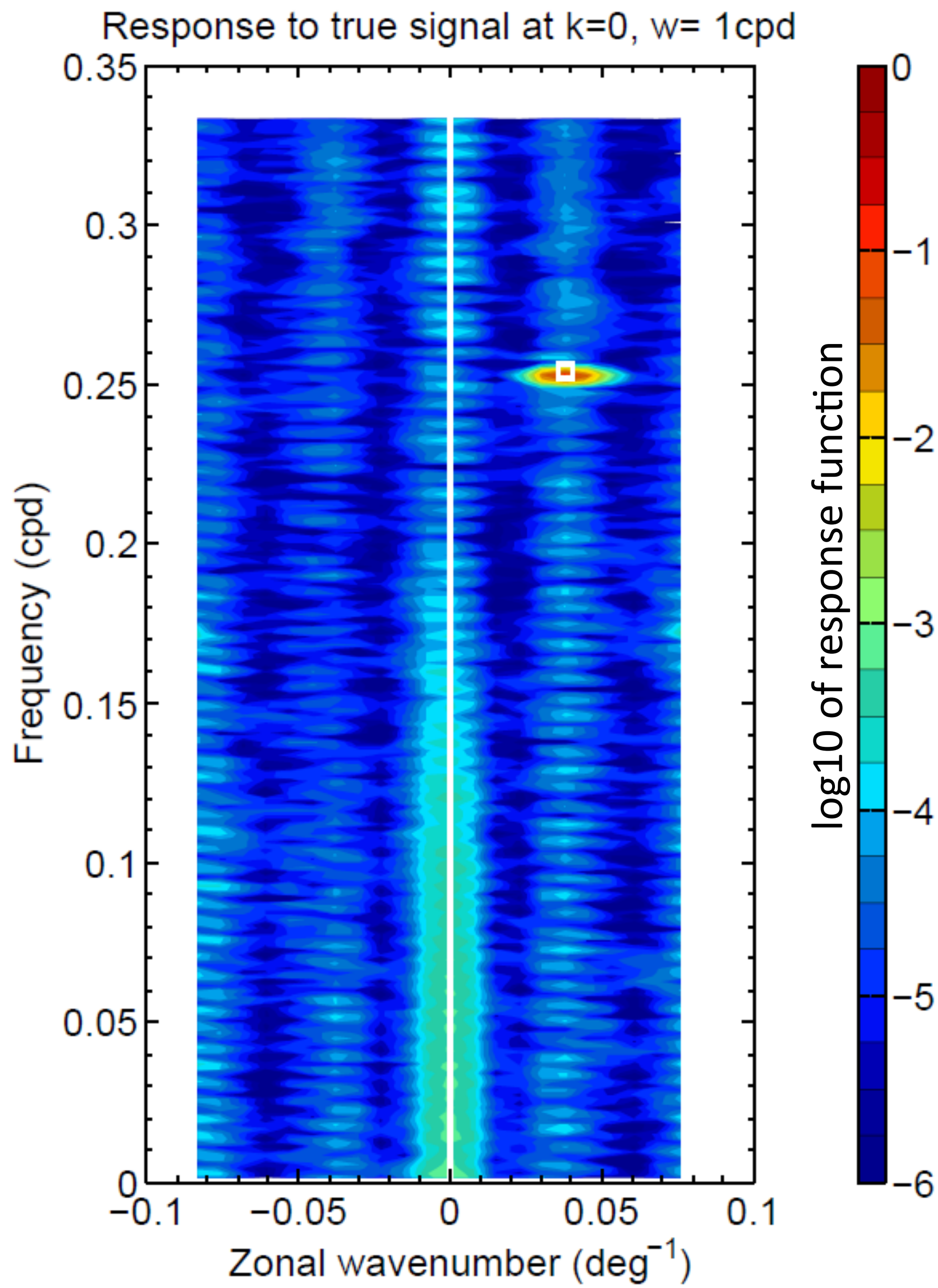
Column of resolution matrix: tells us how each band in our estimate responds to a global-scale diurnal signal

What other bands are contaminated by the diurnal cycle?

Besides the major alias peak we could see in the spectrum, the worst contamination is at basin scales and periods exceeding 7 days, but the alias is ~100 times weaker.

The total variance of the aliasing to low frequencies is comparable, though, because there are lots affected bands (~110 bands).

About 50% of the variance of the global-scale diurnal cycle appears spuriously in my gridded field!

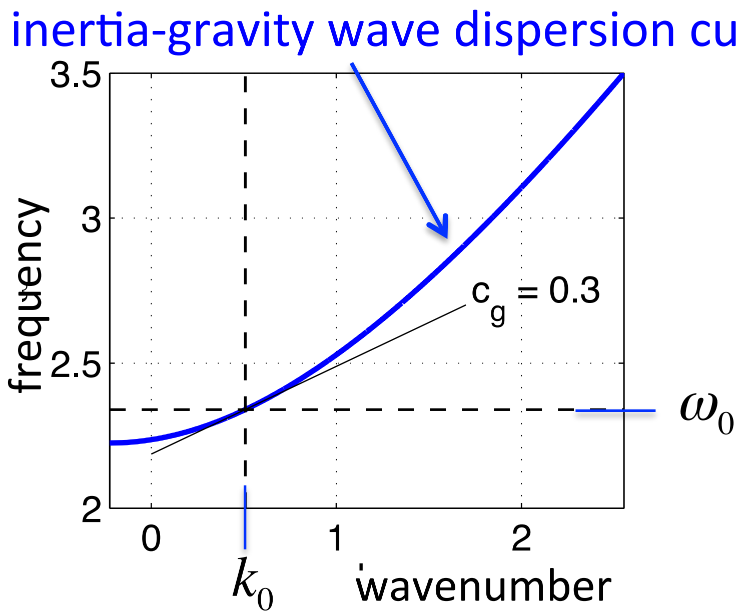


To Do

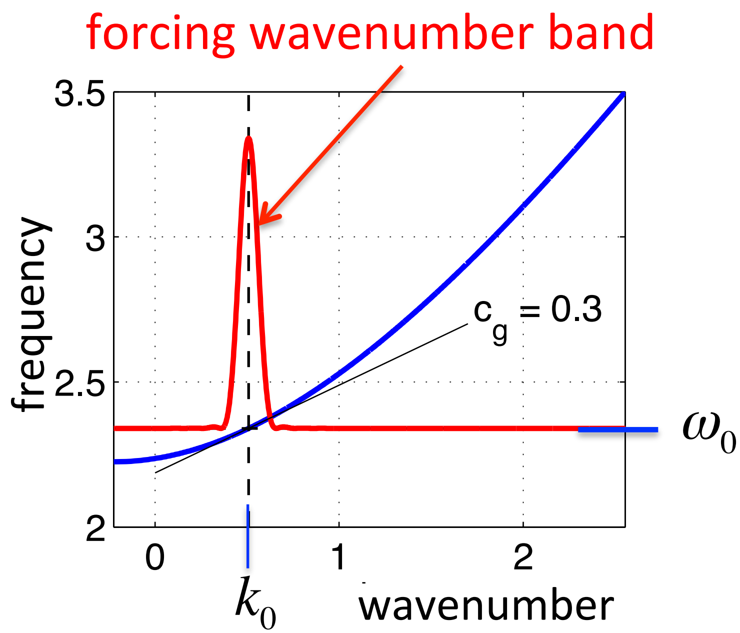
1) Contribute to understanding of zonal, meridional and temporal structure of diurnal and semidiurnal surface winds over oceans, with methods used to characterize oceanic modes.

2) Use resolution matrix to conduct comprehensive examination of possible artifacts in existing gridded products.

Group velocity effect when forcing is isolated in space



Group velocity effect when forcing is isolated in space



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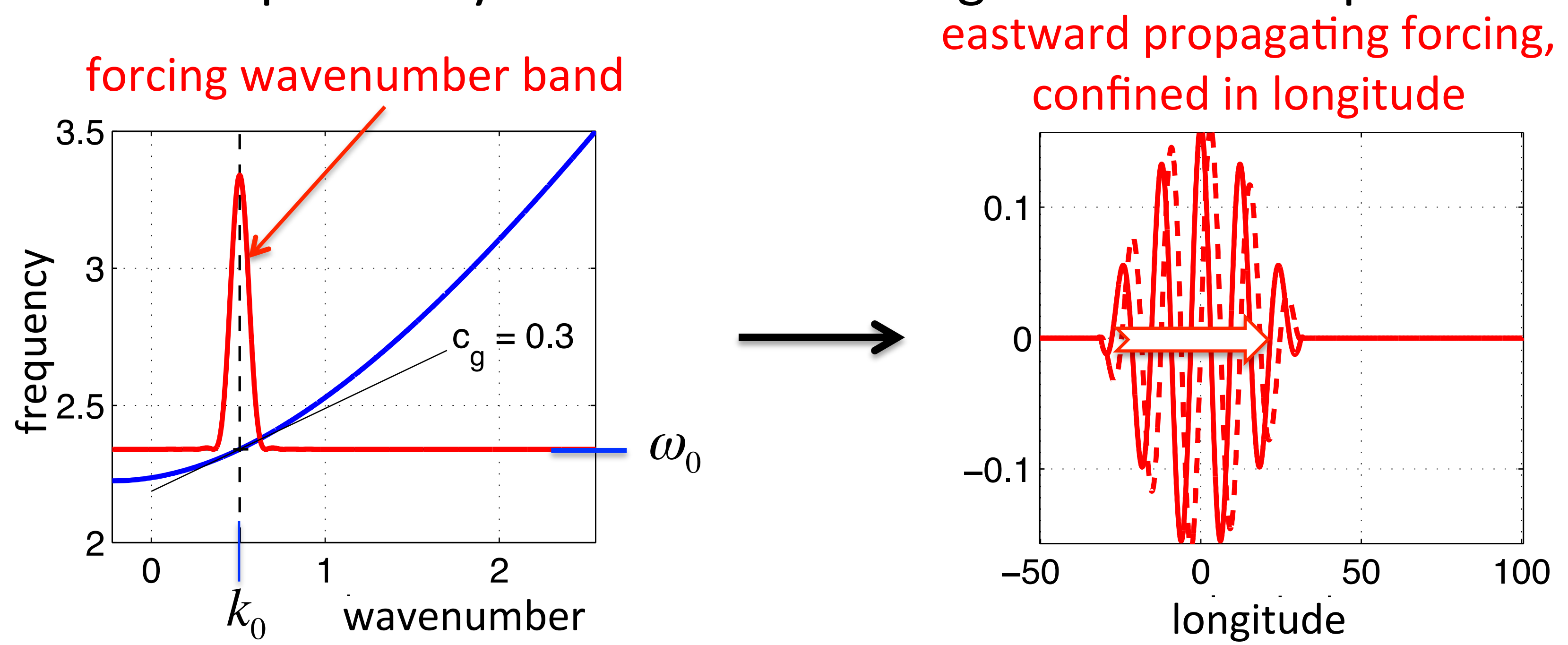

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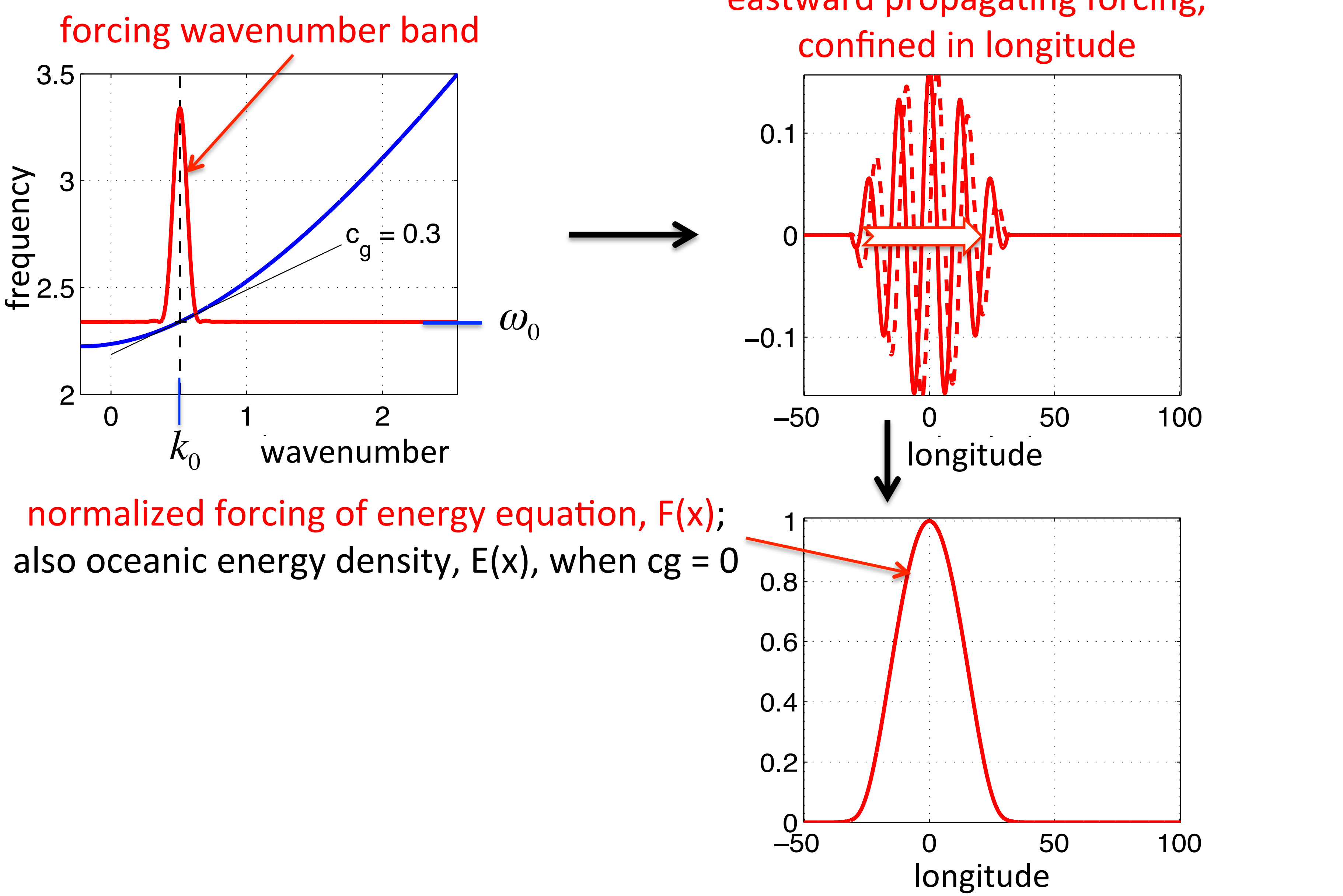

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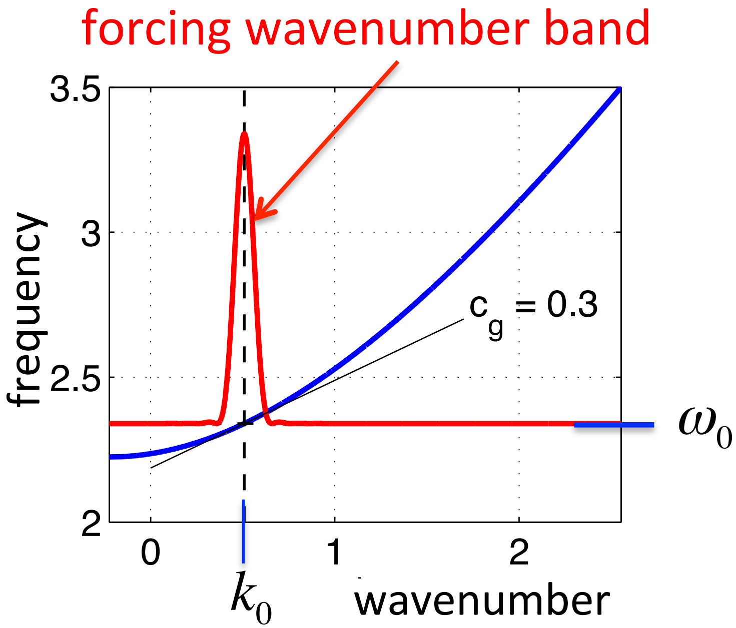
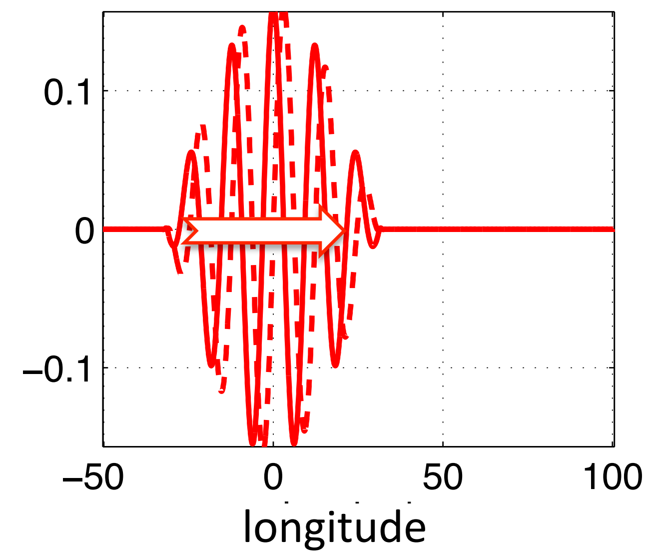
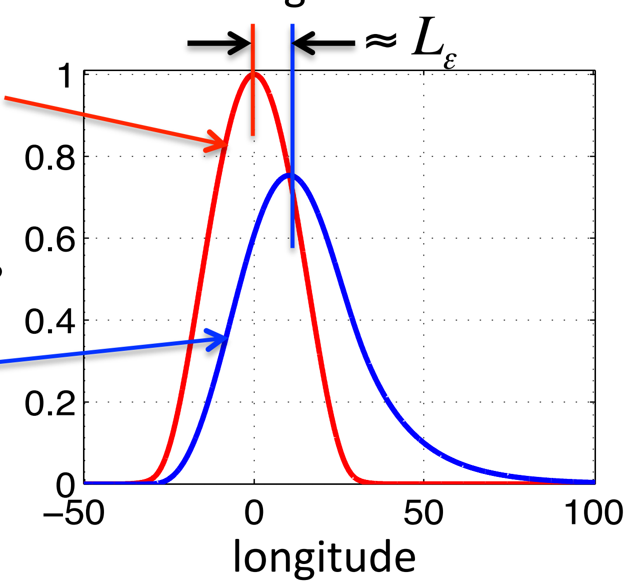




normalized forcing of energy equation, F(x);
also oceanic energy density, E(x), when cg = 0



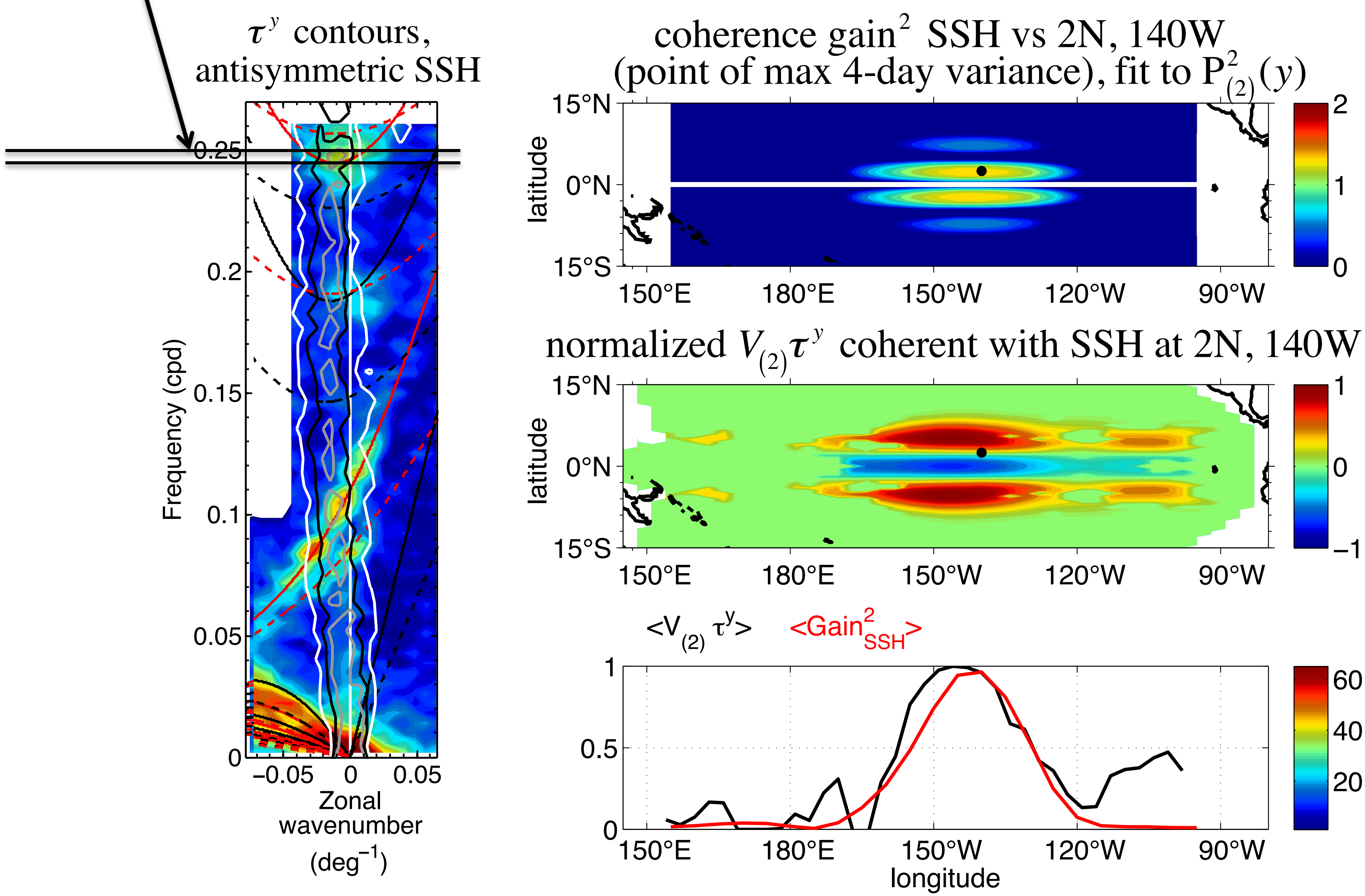
when $c_g \neq 0$, oceanic response energy density is

$$E(x) \approx\propto L_\varepsilon^{-1} \int_0^\infty F(x-\xi)\exp(-\xi / L_\varepsilon)\, d\xi,$$

$$T_\varepsilon = L_\xi / c_g$$

SSH – wind stress comparisons using altimetry & QuikSCAT

4.0 – 4.1 day band, bc mode1, merid mode 2 wave: $c_{gx} = 0.2$ deg/day (0.2 m/s)



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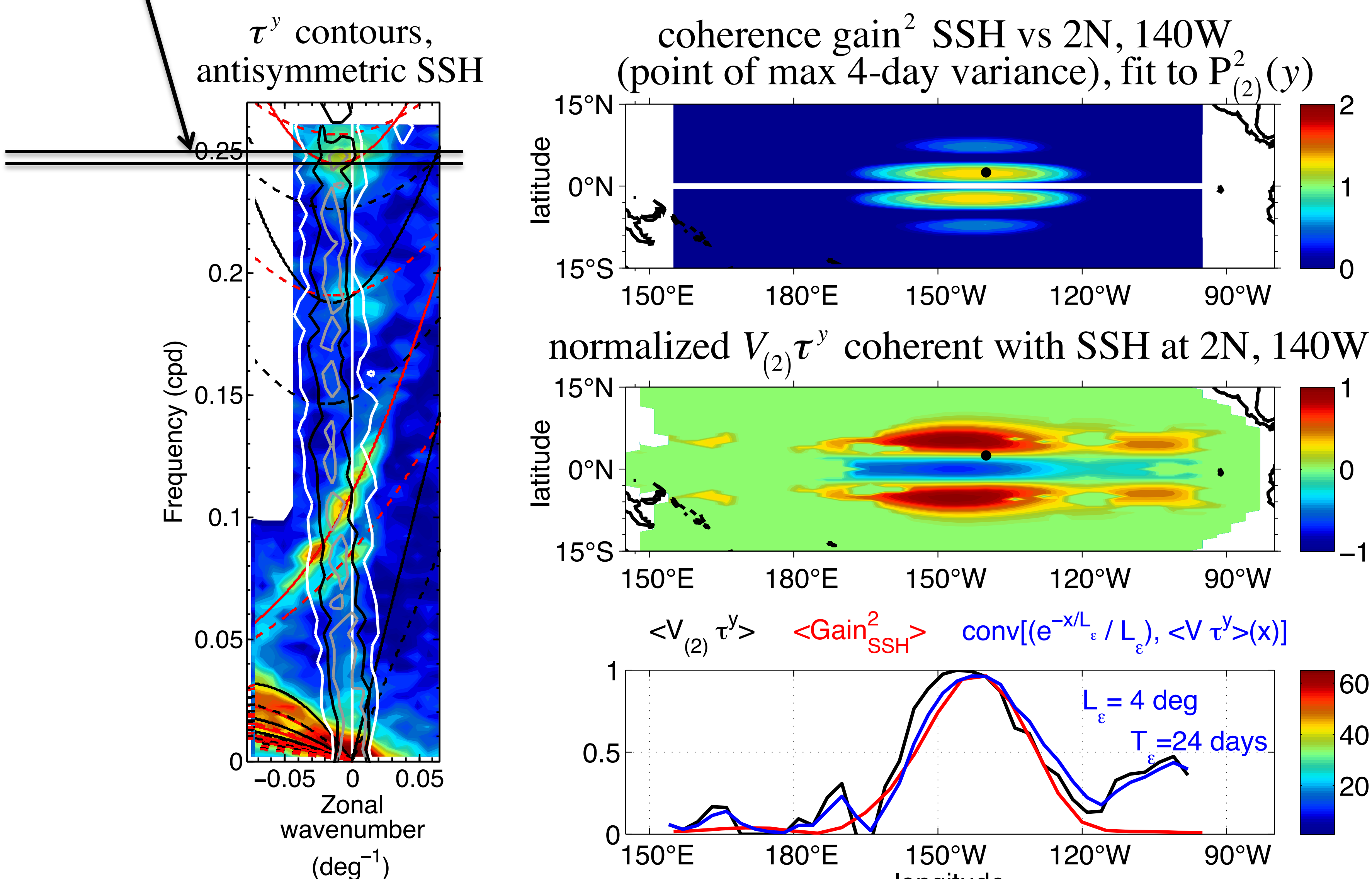
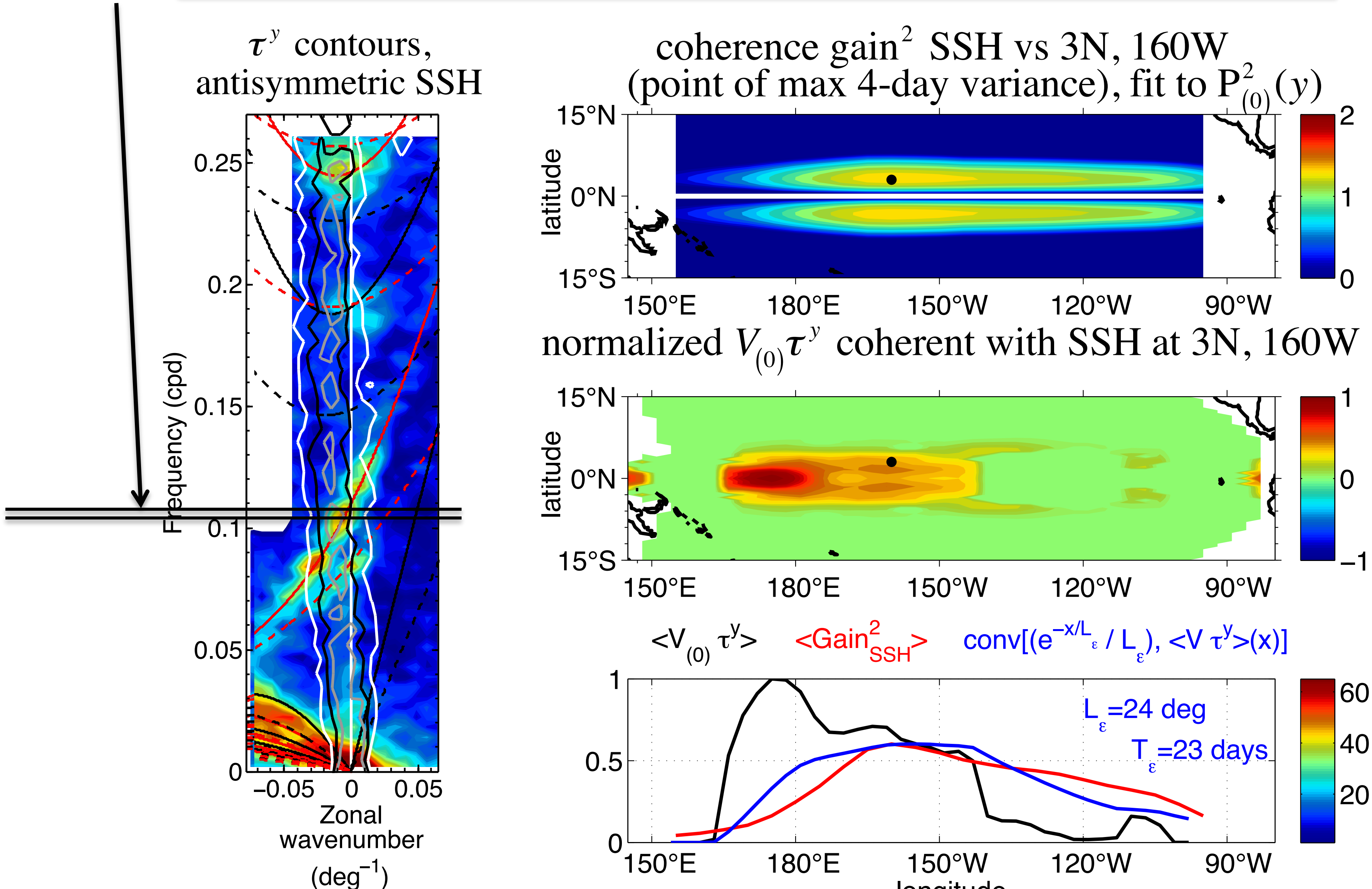


SSH – wind stress comparisons using altimetry & QuikSCAT

9.3 – 9.7 day band, bc mode1, merid mode 0 wave: $c_{gx} = 1.0$ deg/day (1.3 m/s)



To Do Summary

1) Contribute to understanding of zonal, meridional and temporal structure of diurnal and semidiurnal surface winds over oceans.

2) Use resolution matrix approach to conduct comprehensive examination of possible aliases in existing gridded products.

3) Improve spatial wind stress – SSH response model:
   a) vertical modeling – set up of baroclinic modes,
   b) inclusion of "minor forcing" – subtleties of phase variability,
   c) extension from single frequency to frequency band.

4) Extend climatological analysis of equatorial SSH & wind stress variance to describe spatial & temporal (seasonal, intraseasonal, interannual) patterns.

Motivation for studying these high-frequency waves

"Many of the biological processes included in the ecosystem model respond to environmental fluctuations with time scales between 1 and 10 days, which are not typically resolved by basin- to global-scale circulation models."

"Physical control of biological processes in the central equatorial Pacific Ocean"
Freidrichs and Hofmann, DSR, 2001.

High passed wind stress in the equatorial Pacific (11/2002 - 2/2003)

from Maloney and Chelton, 2006

QuikSCAT

ECMWF and Reynolds