Impact of Tides on the Wavenumber Spectra of an Eddying Global Ocean Circulation Model

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Internal Tides in a Global Ocean Circulation Model

- The model shows localized generation of the internal tide and propagation for 1000's of km as seen by Ray, Alford and others

- The barotropic and internal tidal kinetic energy in the model compares well with historical current meters

- The short wavelength SSH spectrum scales as $k^{-11/3}$ which is qualitatively similar to SQG theory and much flatter than the spectrum expected for QG turbulence

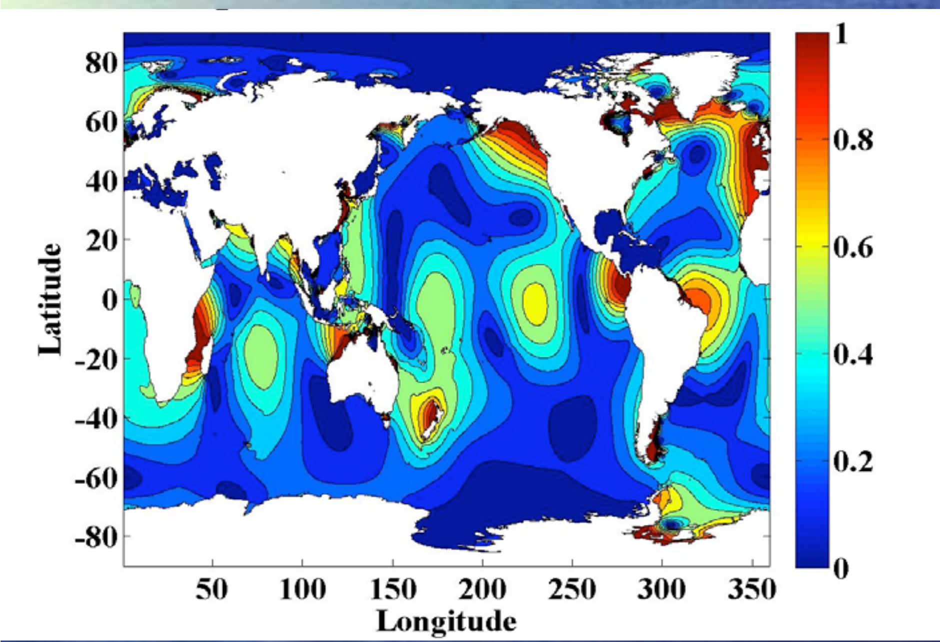
- The presence of energetic internal tidal beams can modify the spectrum with strong peaks near 100-150 km and a flatter spectrum

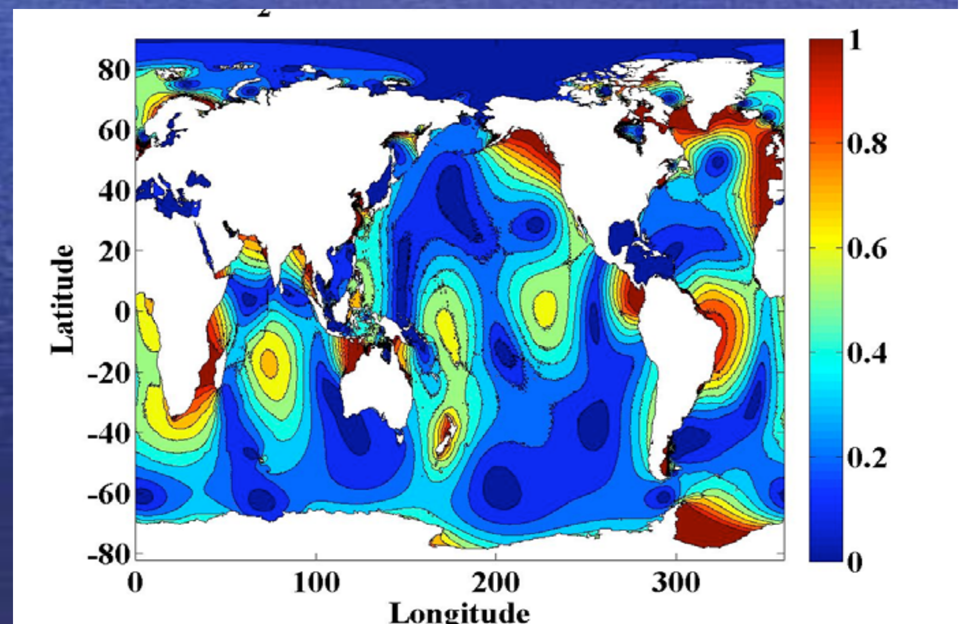
Modeling tides in the global model

- In the global model, the body forces due to the tidal potential, self attraction and loading have been added
- Tidal Forcing with 8 constituents:
  - Semidiurnal M_2, S_2, N_2 and K_2
  - Diurnal O_1, P_1, Q_1 and K_1
- Topographic wave drag is applied to the tidal motions
  - The form of the drag is generalized from the linear topographic wave drag, but tuned to minimize the difference with the 102 pelagic tide gauges using a barotropic version of the model

Comparison of M_2 tide from Inverse Model (TPXO7.2) and HYCOM Simulation

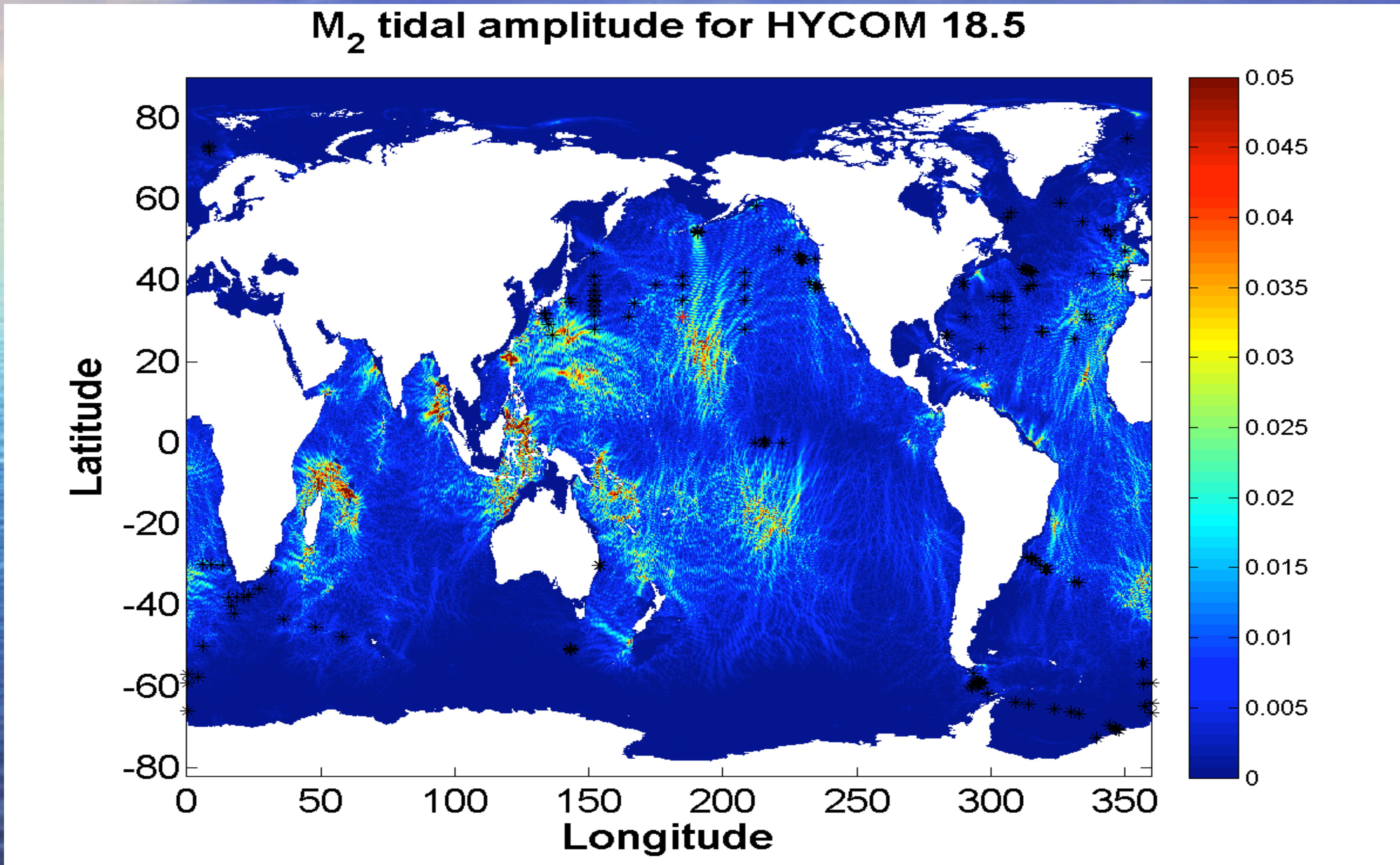
TPXO7.2 M_2 Tidal Model **HYCOM M_2 Tide**





Difference with 102 pelagic tide gauges 7.8 cm rms
Difference with TPXO7.2 model 5.4 cm rms

M_2 tidal amplitude from global model steric sea surface height with the 173 comparison mooring locations



Can we use the wavenumber spectrum of SSH to infer the ocean dynamics?

- From work by Charney and others, for 2D or Quasigeostrophic (QG) turbulence energy is cascaded to large scales (inverse cascade) and enstrophy to small scales which changes the slope of the energy spectrum from -5/3 of homogeneous turbulence to a much steeper -3
  - Based upon the idea that the eddies are generated at large scales

- Frontogenesis can generate eddies at small scales which lead to the theory of Surface Quasigeostrophic (SQG) turbulence in which the inverse cascade is suppressed at smaller scales and the energy spectrum is flatter approaching -5/3

- In the atmosphere airplane transits have provided the wavenumber spectra. In the ocean, can we use the SSH spectra?

Energy and Enstrophy Cascades in QG Turbulence

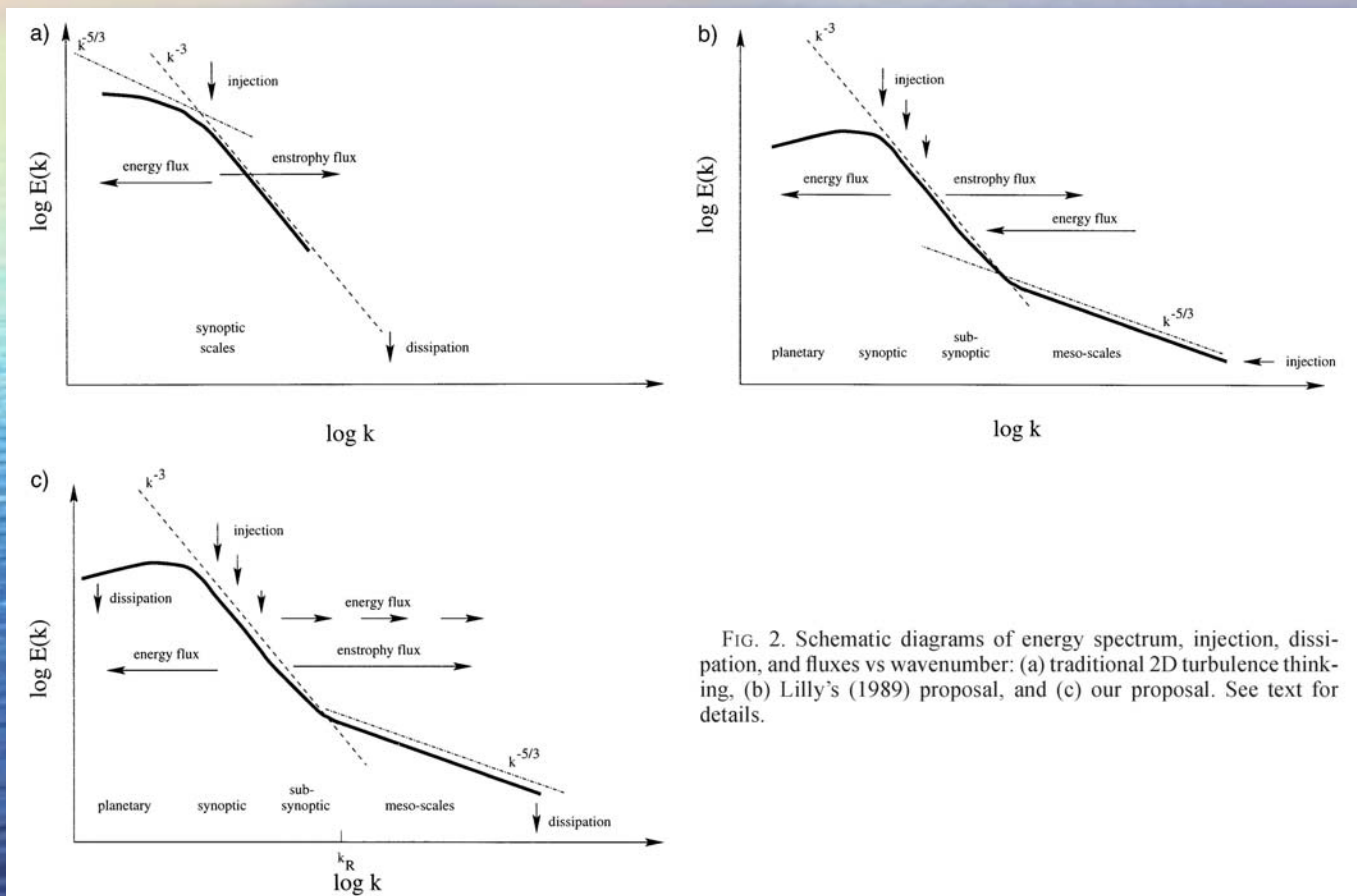


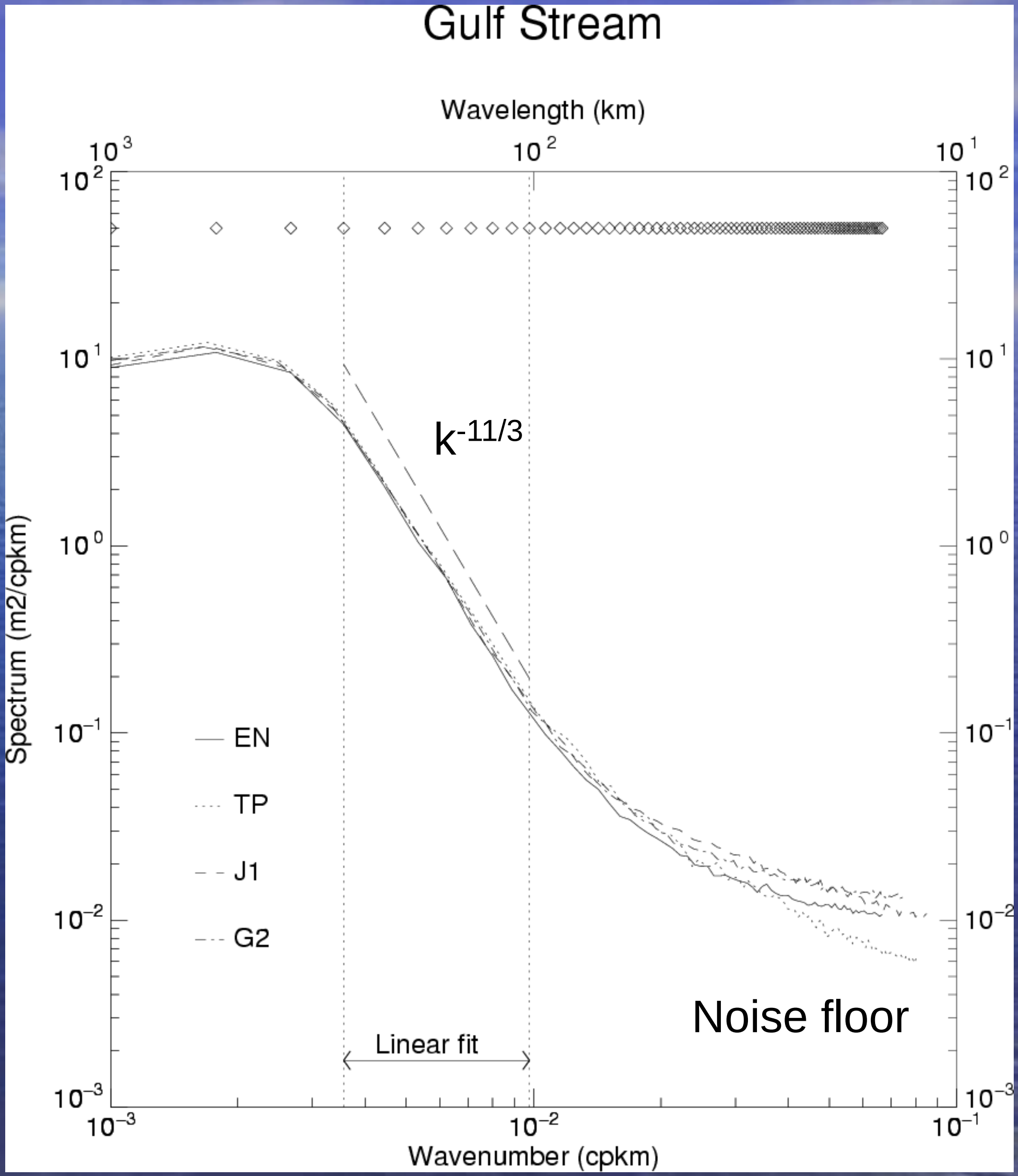
FIG. 2. Schematic diagrams of energy spectrum, injection, dissipation, and fluxes vs wavenumber: (a) traditional 2D turbulence thinking, (b) Lilly's (1989) proposal, and (c) our proposal. See text for details.

QG turbulence has -3 slope with inverse energy cascade

From Tung and Orlando 2003

Altimeter Along-Track Wavenumber Spectra

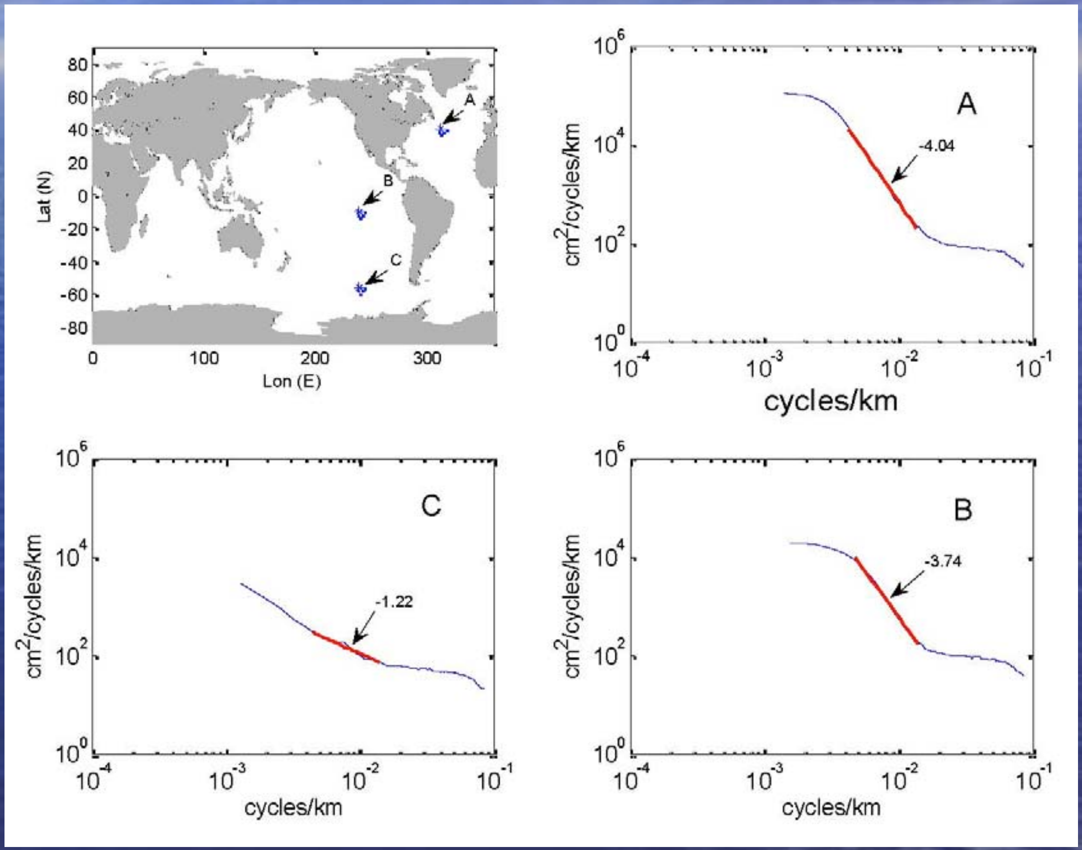
LeTraon, et al (2008) found a $k^{-11/3}$ spectrum between 100-300 km which they suggest is consistent with Surface Quasigeostrophic (SQG) theory with the altimeter noise floor flattening the spectrum at shorter scale



From LeTraon, et al (2008)

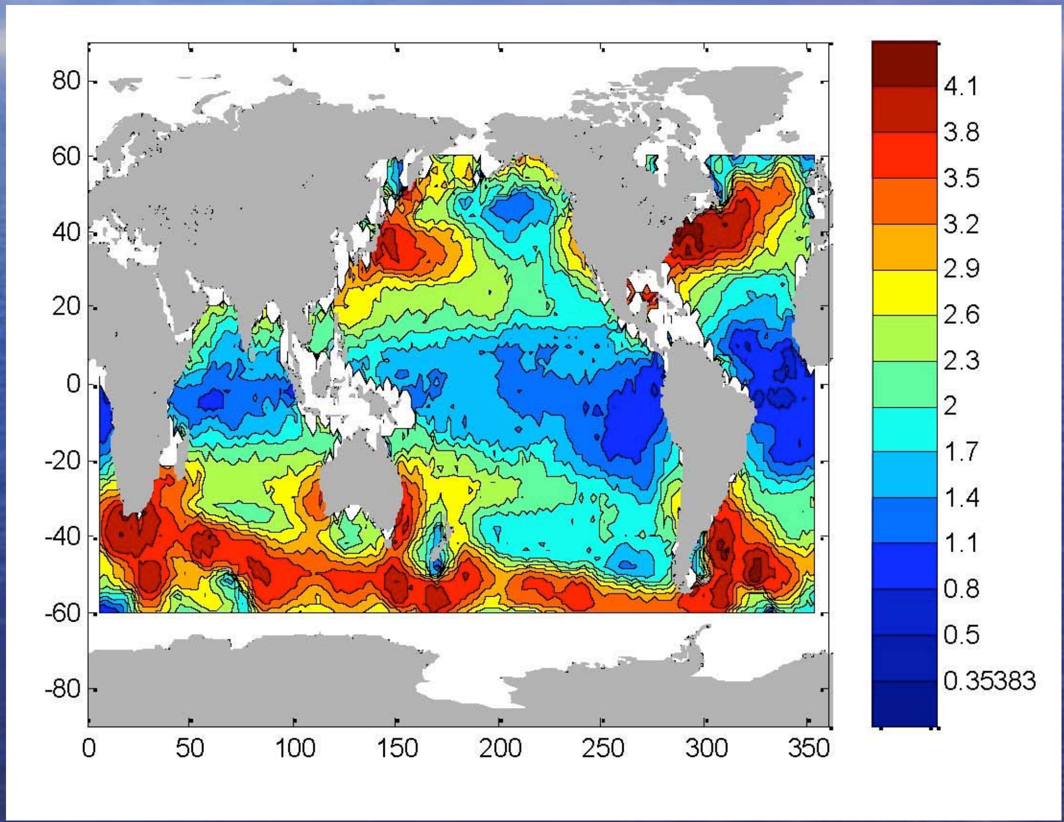
Xu and Fu (2010) estimated the global variability of the mesoscale wavenumber slope from altimetric SSH

- For each 10° x 10° region of the ocean, the wavenumber spectrum for each track longer than 500 km is averaged and the slope of the spectrum estimated for the mesoscale 70 – 250 km
- For quasi-geostrophic (QG) motions, the spectrum should be very steep with a slope of -5
- For surface quasi-geostrophic theory (SQG) the spectrum is somewhat flatter with a slope of -11/3

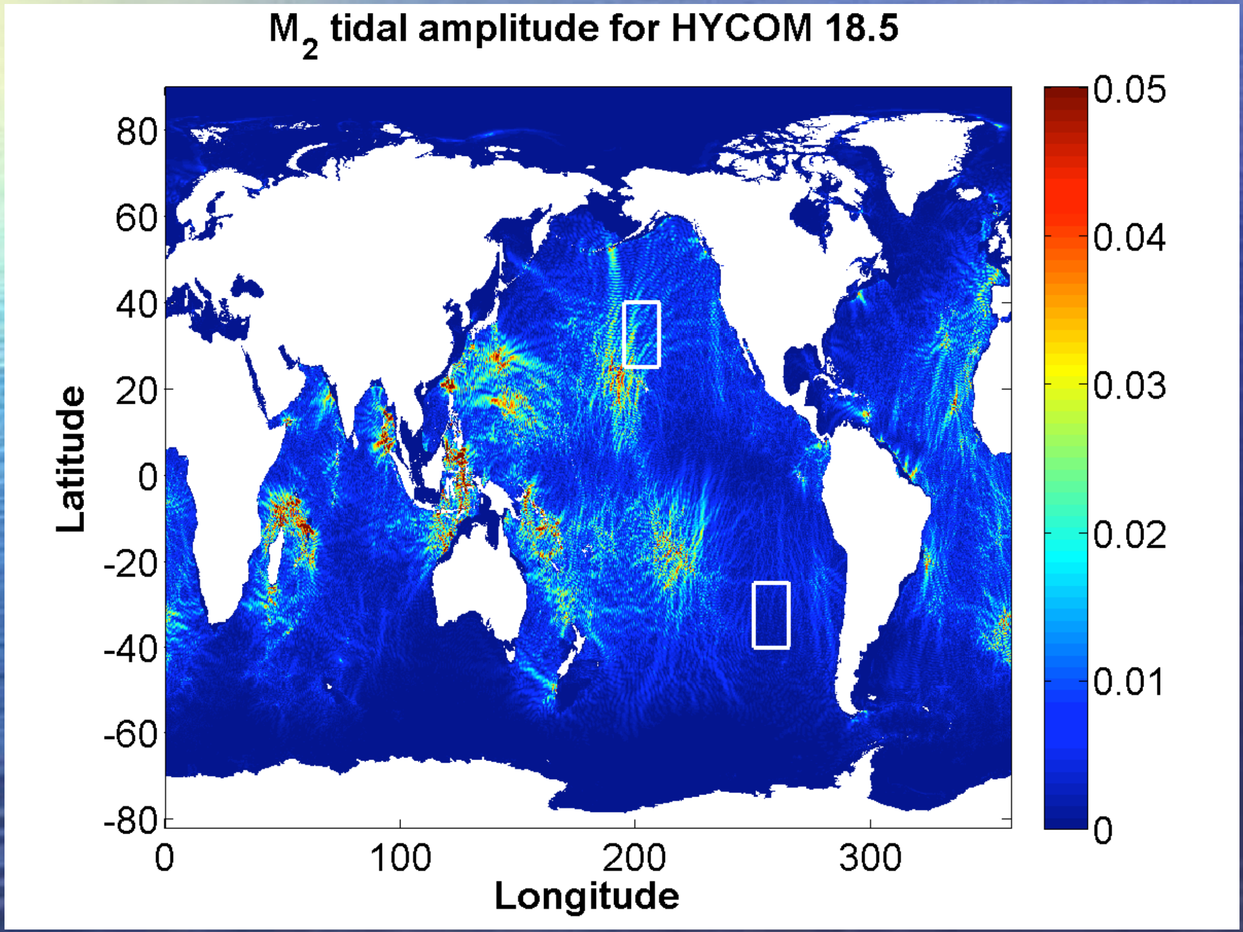


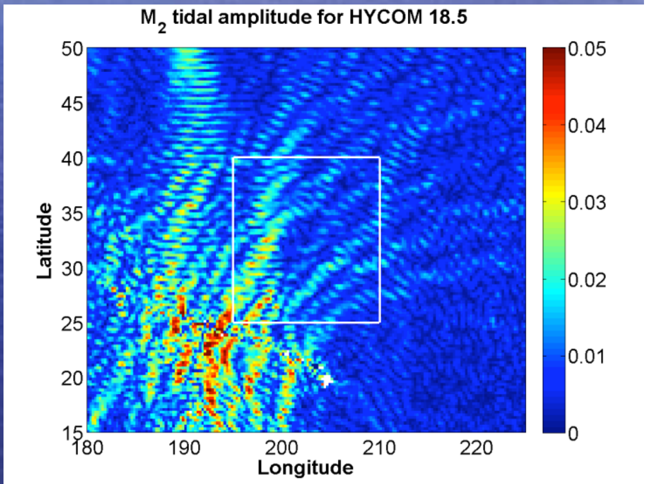
Xu and Fu (2010) estimated the global variability of the mesoscale wavenumber slope from altimetric SSH

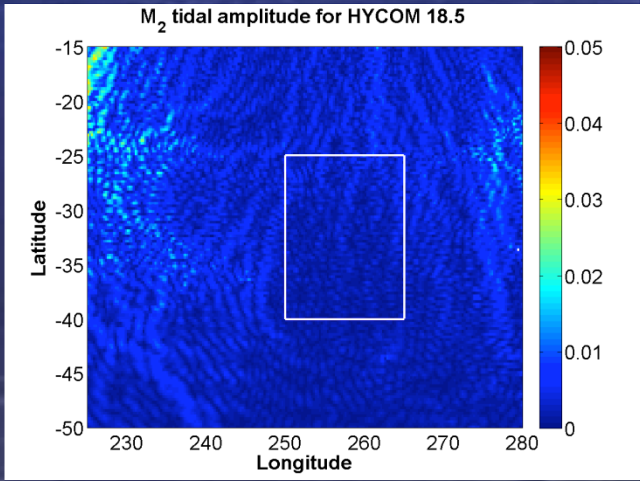
- In the energetic regions of the ocean, western and eastern boundaries and Southern Ocean, the wavenumber spectral slopes are steep consistent with QG and SQG expectations
- In the tropics, the spectral slopes are very flat approaching -1 or flatter
  - Xu and Fu suggest that the regions of weak mesoscale and stronger wind driven flows may respond to direct wind forcing by the atmospheric mesoscale



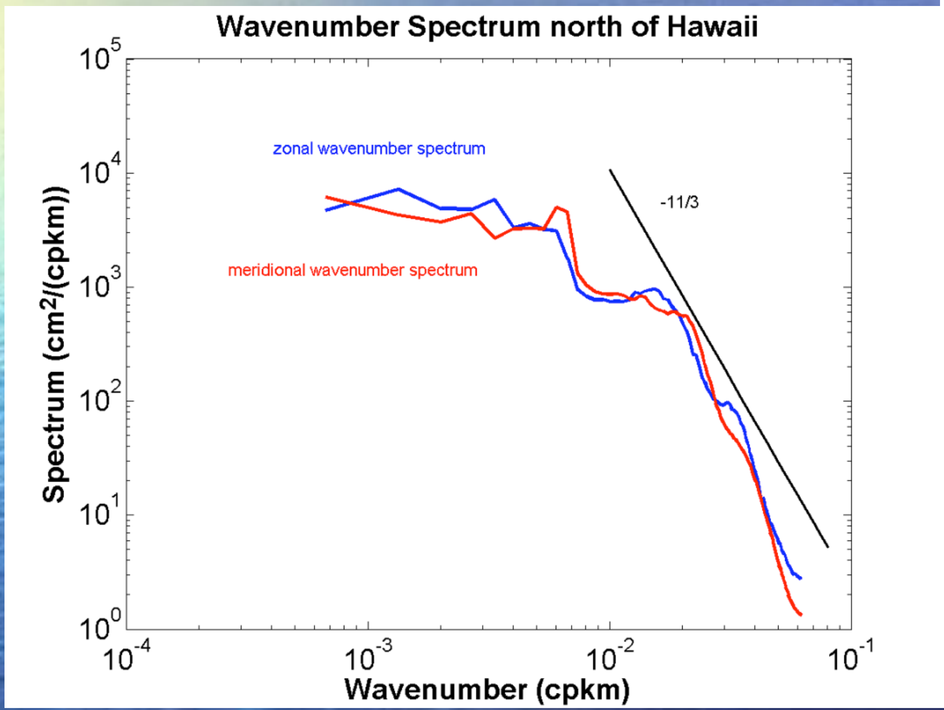
Properties of the model internal tides in the Pacific Ocean

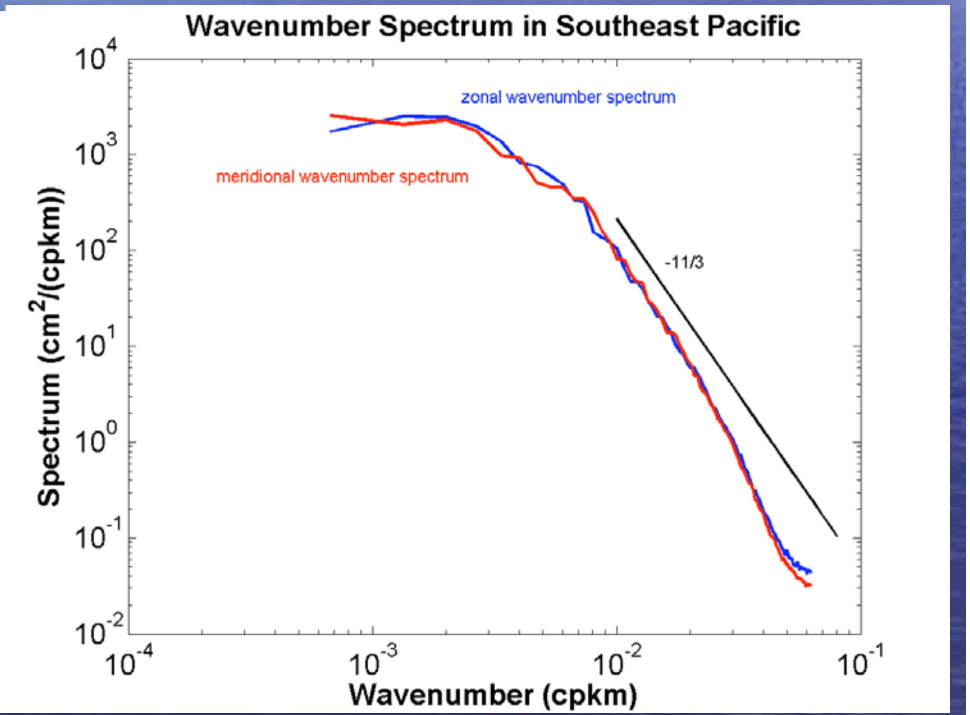






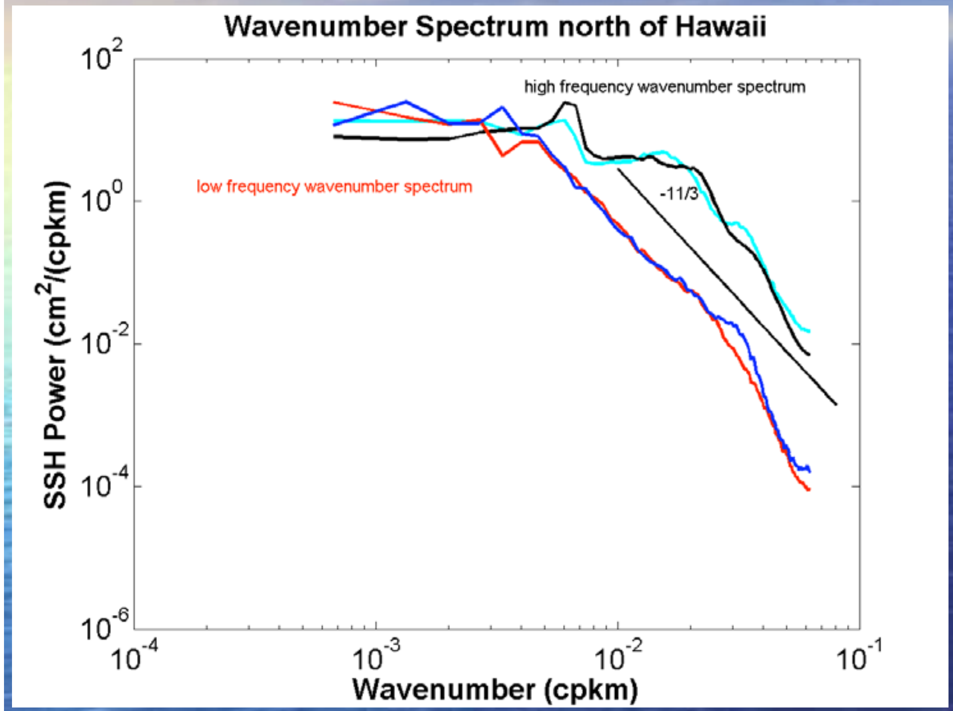
Wavenumber spectrum for the Steric SSH in the Pacific Ocean

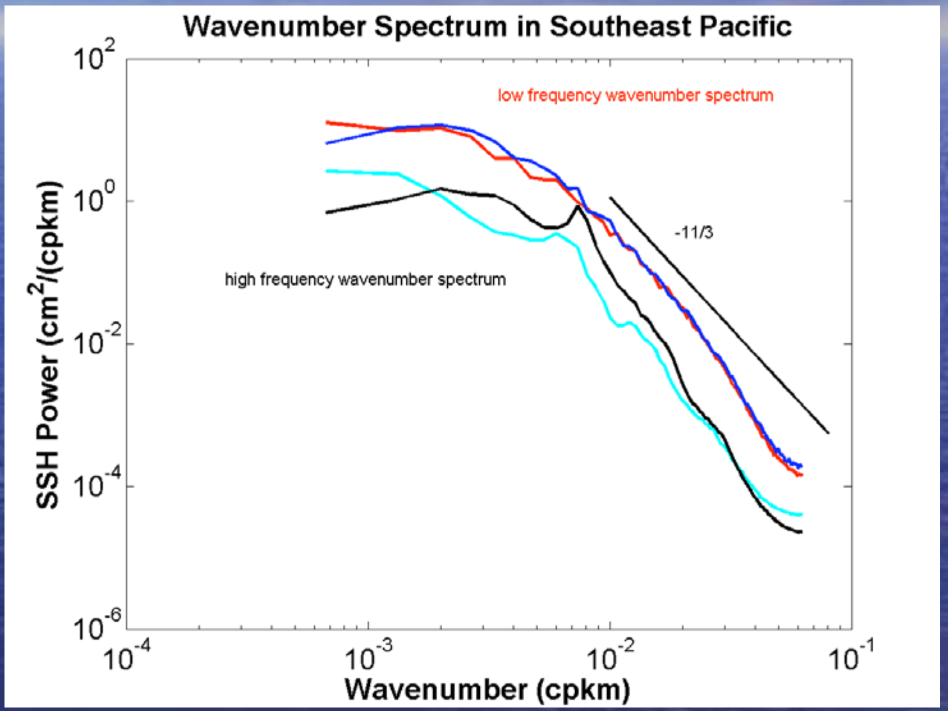




The short scales are slightly steeper than -11/3 which is the prediction for Surface QuasiGeostrophic flow (SQG) as noted for the altimeter data by LeTraon, et al 2008 and the poster by Zaron. The peak around 150 km is associated with the M_2 beams generated near Hawaii.

Wavenumber Spectrum of the internal tide and mesoscale





North of Hawaii in a high internal tide energy region, the spectra are nearly identical for scales greater than 250km. The presence of the M_2 beam is evident in the peak near 140 km and the greater power in the high frequency.

In the Southeast Pacific, a region of low mesoscale and internal tide energy, the high frequency power is much less than the low frequency and a M_2 peak is seen at 120 km

Internal Tides in a Global Ocean Circulation Model

- LeTraon, et al (JPO, 2008) found that the along-track wavenumber spectrum had a $k^{-11/3}$ shape between 100-300 km which is consistent with SQG theory with the altimeter noise floor flattening the spectrum at smaller scales
- The model spectra show a similar $k^{-11/3}$ shape over a larger range 20-300 km with an important difference that the internal tides create a broad peak around 140 km
- The internal tide energy levels can exceed the mesoscale energy which changes the shape of the spectrum