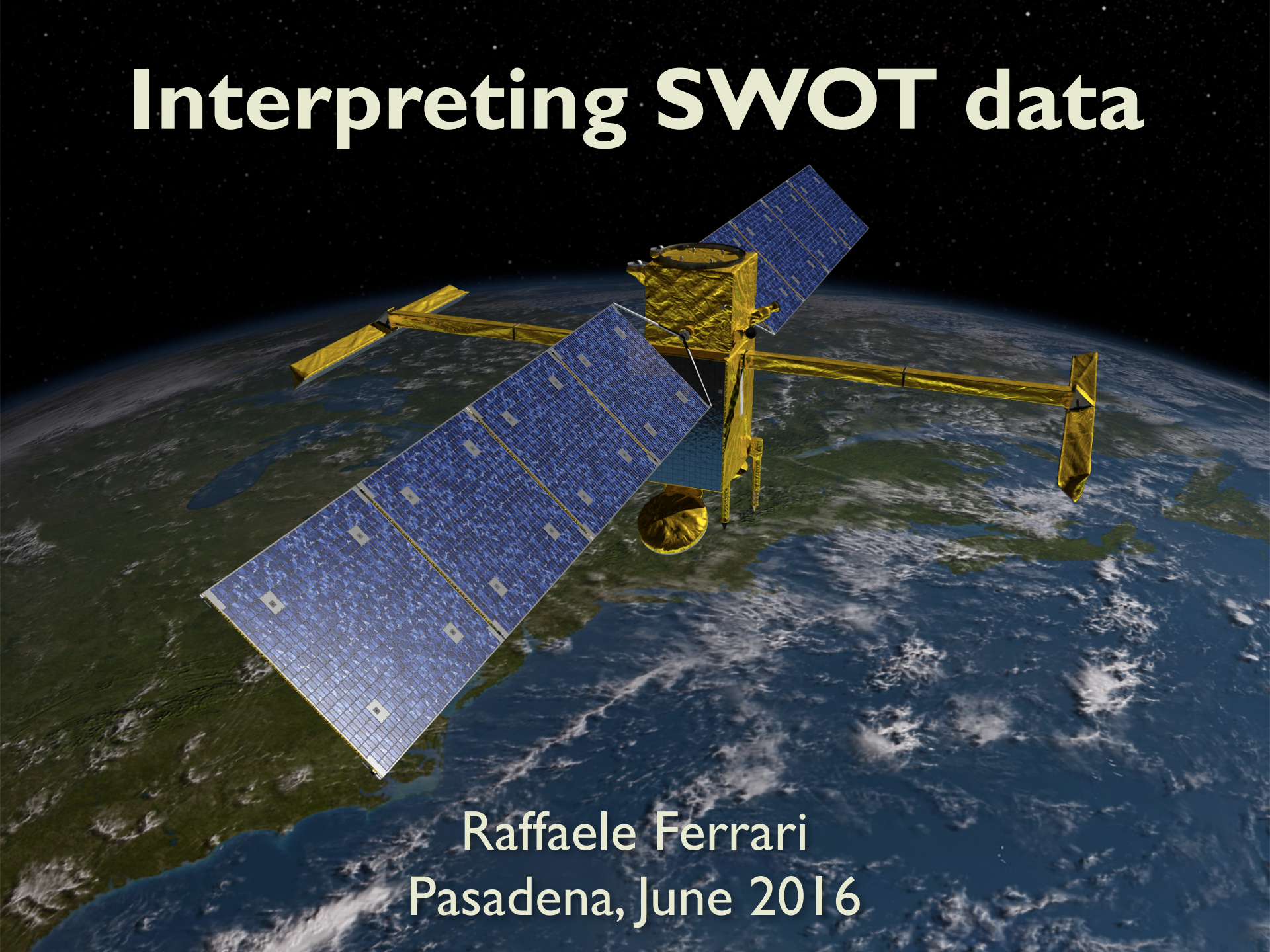
Interpreting SWOT data

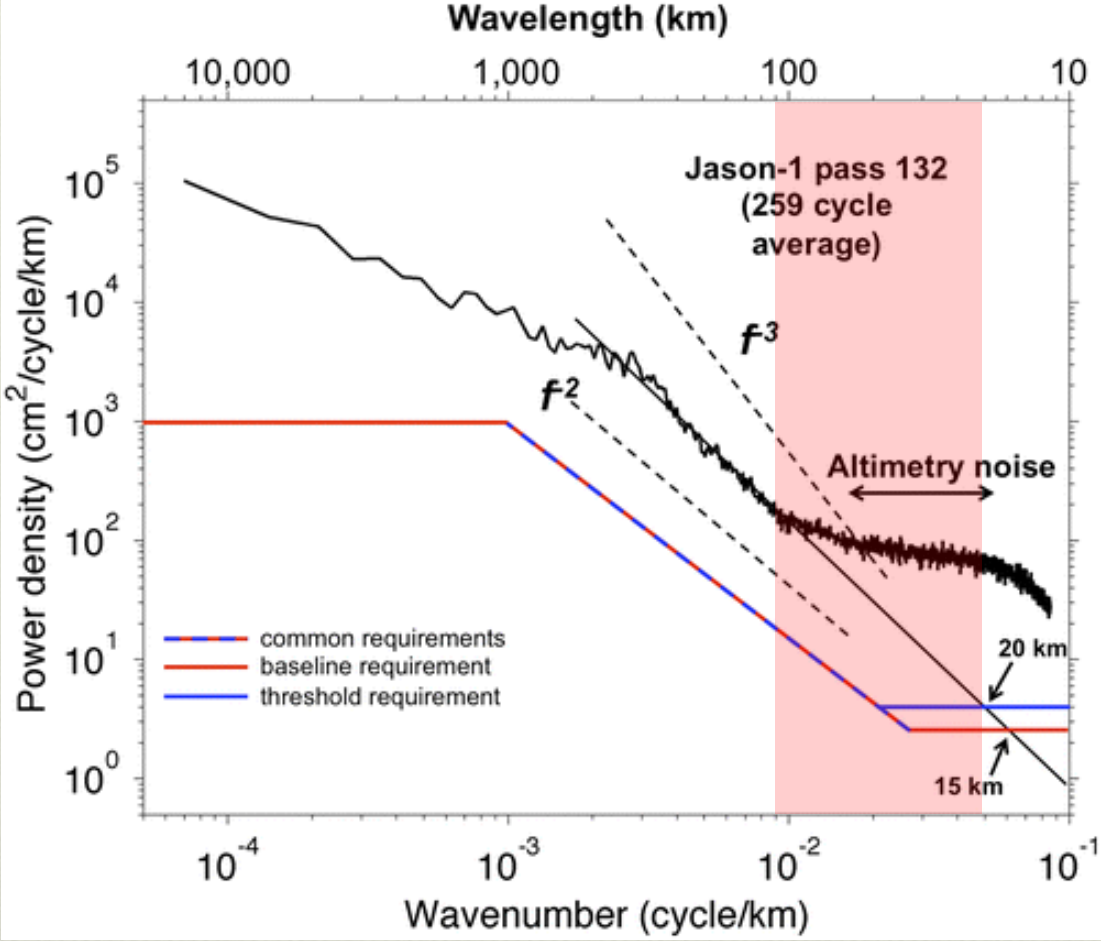


Raffaele Ferrari

Pasadena, June 2016

High wavenumber variability in the ocean

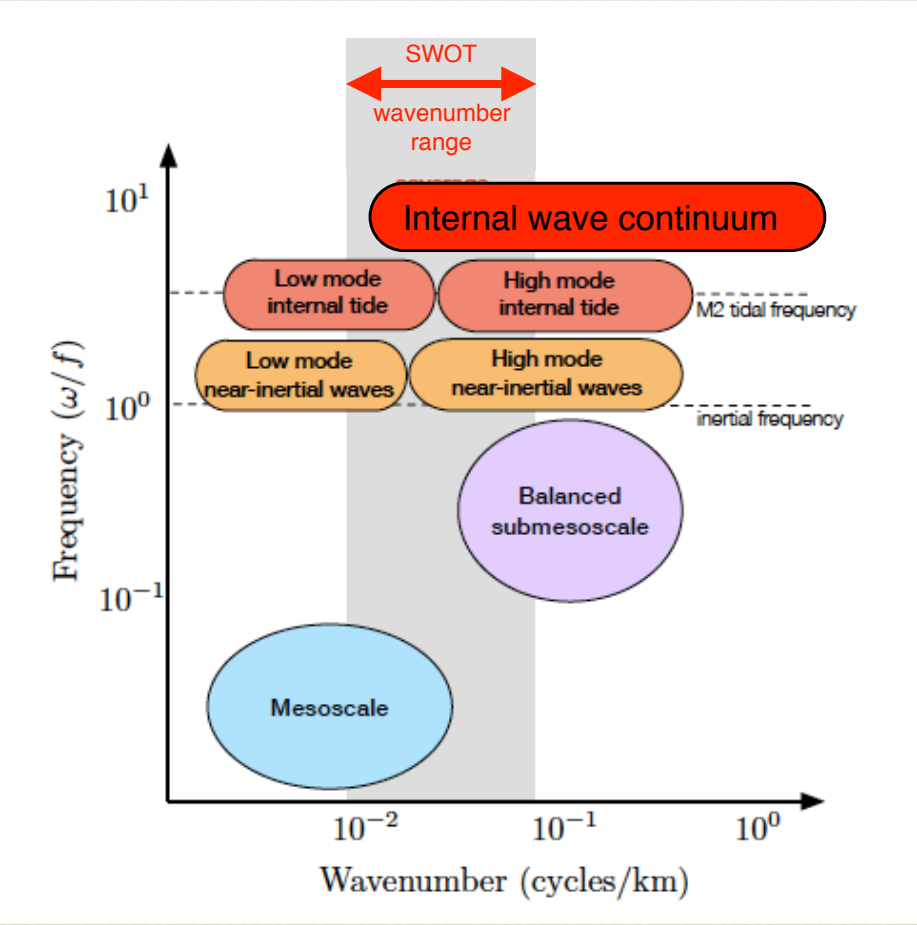
What dynamics dominate SSH variability on scales between 100-20 km?



Fu and Ubelmann (JTECH, 2014)

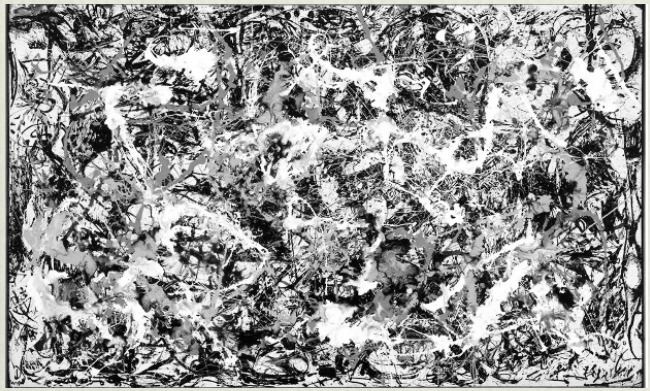
High wavenumber variability in the ocean

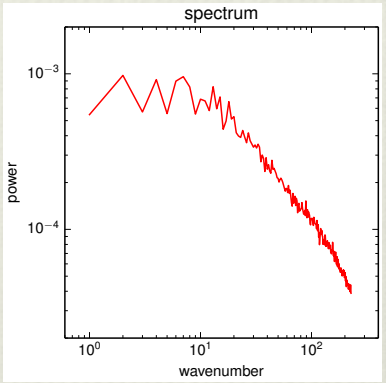
What dynamics dominate SSH variability on scales between 100-25 km?



Beyond a spectral description

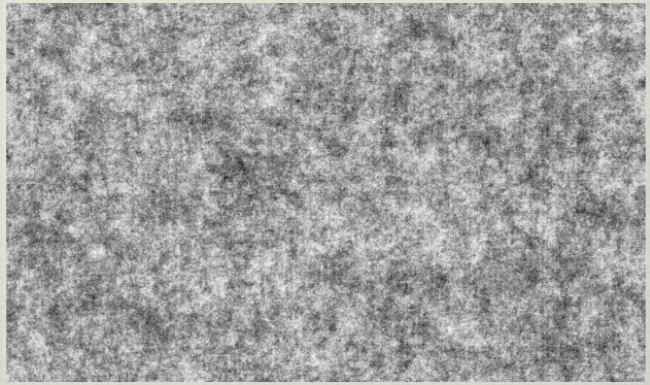
A theory of Jackson Pollock's art





The wide-swath altimeter will return full two dimensional pictures of the surface SSH at the submesoscale

Interpretation of the signals in terms of spectra is very limited

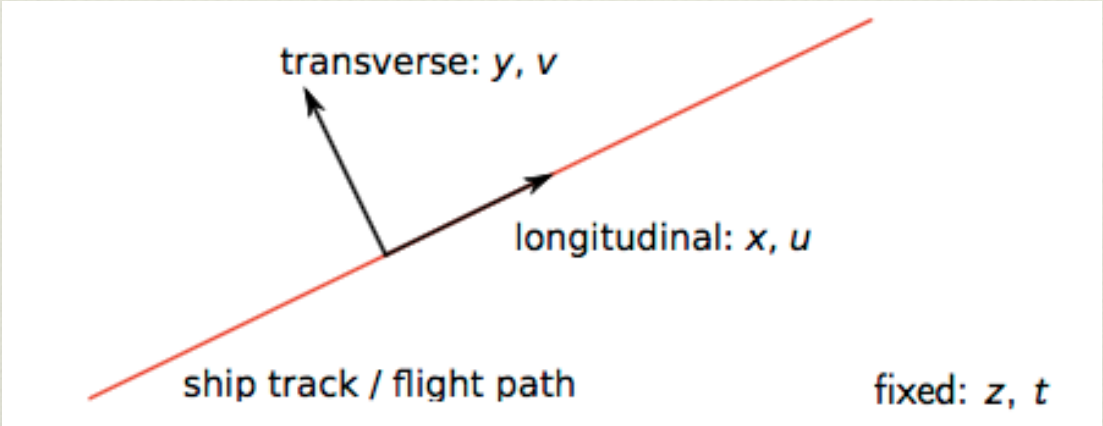


Pollock's painting with randomized phases

Observations of submesoscales

Velocity measurements along 1D tracks

Measurements of along and across track velocities



Spectra of along and across track velocities

$$S^u(k) \equiv \langle |\hat{u}(k)|^2 \rangle, \qquad S^v(k) \equiv \langle |\hat{v}(k)|^2 \rangle$$

Wave-vortex decomposition

1. Helmholtz decomposition: decompose velocity spectra into their divergent and rotational components

$$2K^{rot}(k) = S^v(k) + \frac{1}{k}\int_k^\infty \left[S^v(\kappa) - S^u(\kappa)\right]\,\mathrm{d}\kappa,$$

$$2K^{div}(k) = S^u(k) - \frac{1}{k}\int_k^\infty \left[S^v(\kappa) - S^u(\kappa)\right]\,\mathrm{d}\kappa.$$

2. Wave vortex decomposition: decompose velocity spectra into internal **wave** and **geostrophic** components

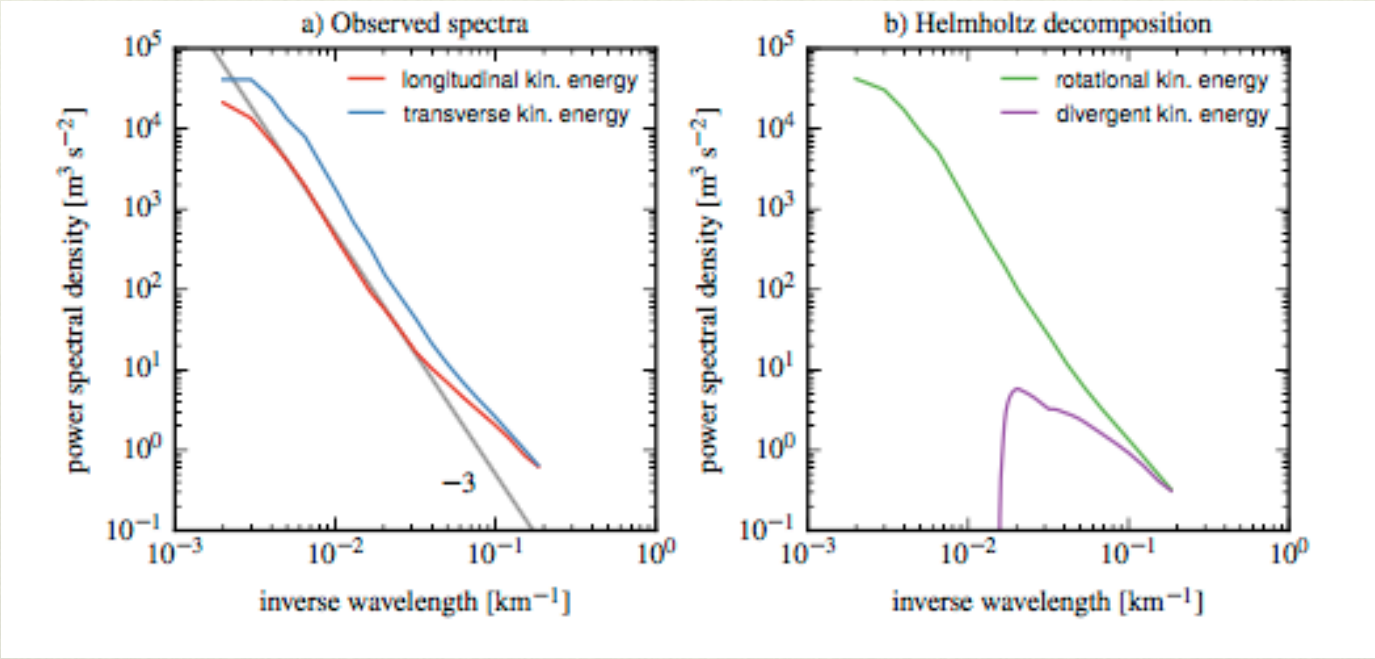
$$E(k) = \frac{1}{2}\left[S^u(k) + S^v(k) + S^b(k)\right] = E_g(k) + E_w(k)$$

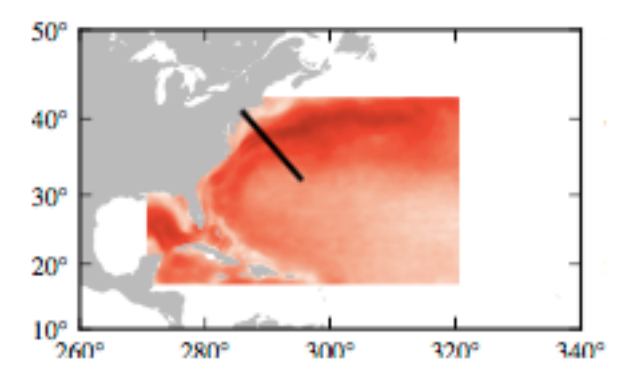
$$E_w(k) = 2K^{div}(k)$$

$$E_g(k) = E(k) - E_w$$

Buhler, Callies and Ferrari (JFM, 2014)

Gulf Stream region (150m depth)

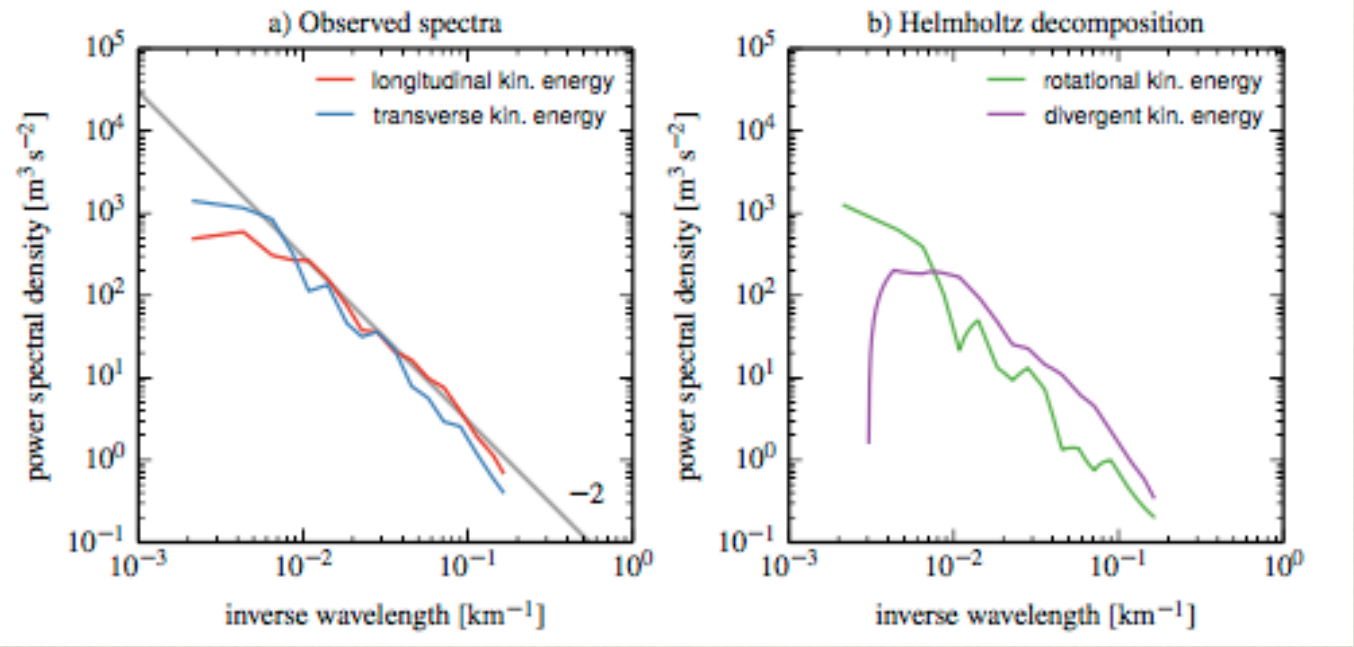


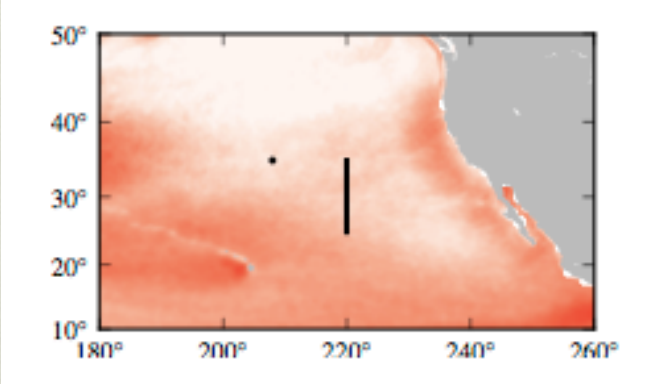


The rotational flow dominates at 10-150 km
The divergent flow becomes comparable at 10 km

Buhler, Callies and Ferrari (JFM, 2014)

Subtropical North Pacific (200m depth)

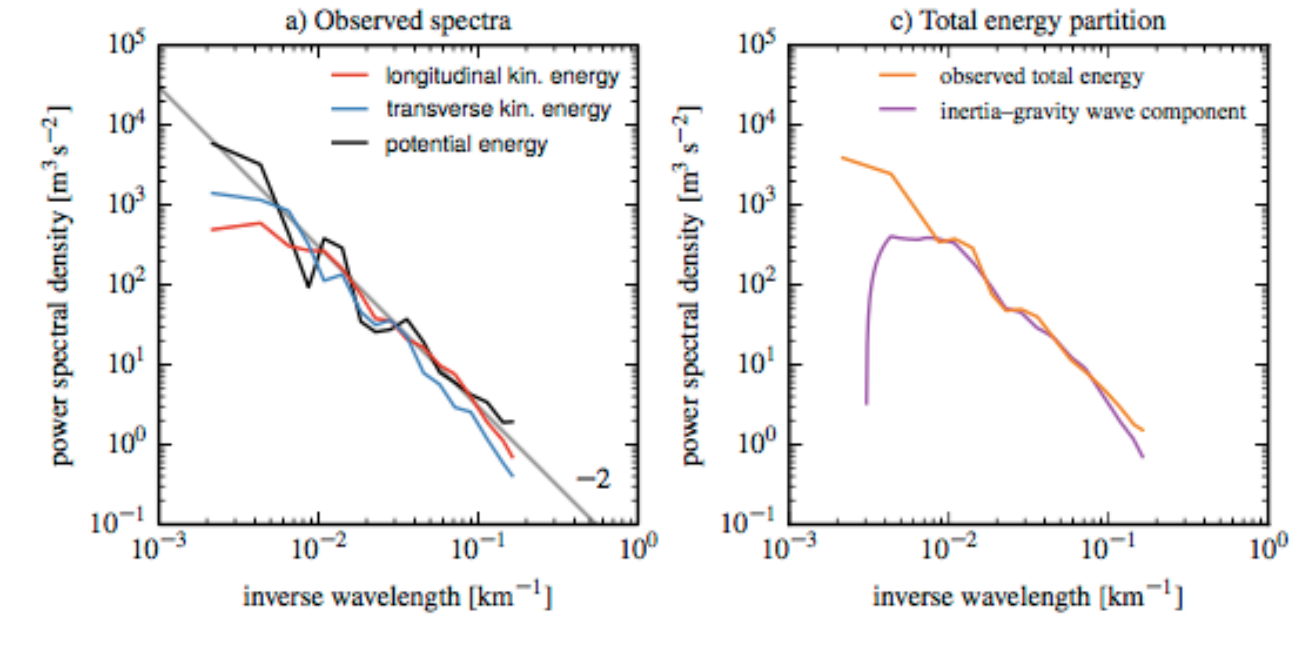


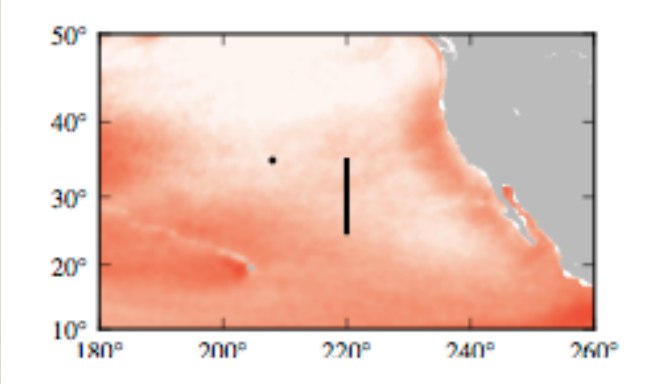


The rotational flow dominates at 100-500 km
The divergent flow becomes slightly large at 10-100 km

Buhler, Callies and Ferrari (JFM, 2014)

Subtropical North Pacific (200m depth)





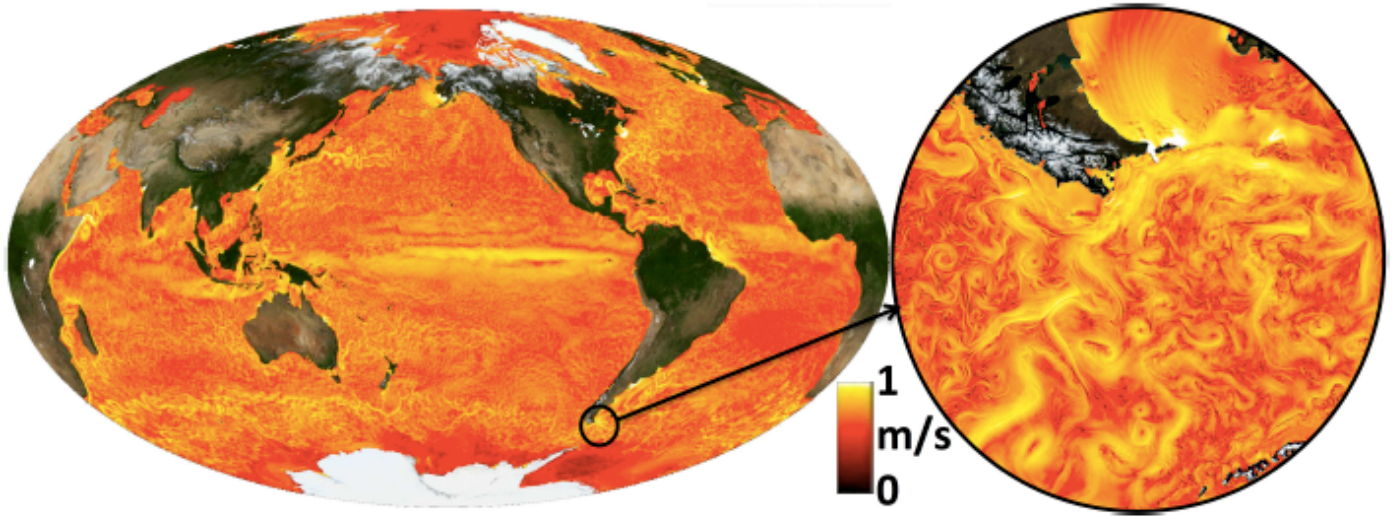
The flow between 10-100 km is consistent with internal waves

Buhler, Callies and Ferrari (JFM, 2014)

Simulations of submesoscales

High resolution simulation

Ocean surface velocity from LLC4320 simulation (*Hill and Menemenlis, 2016*)

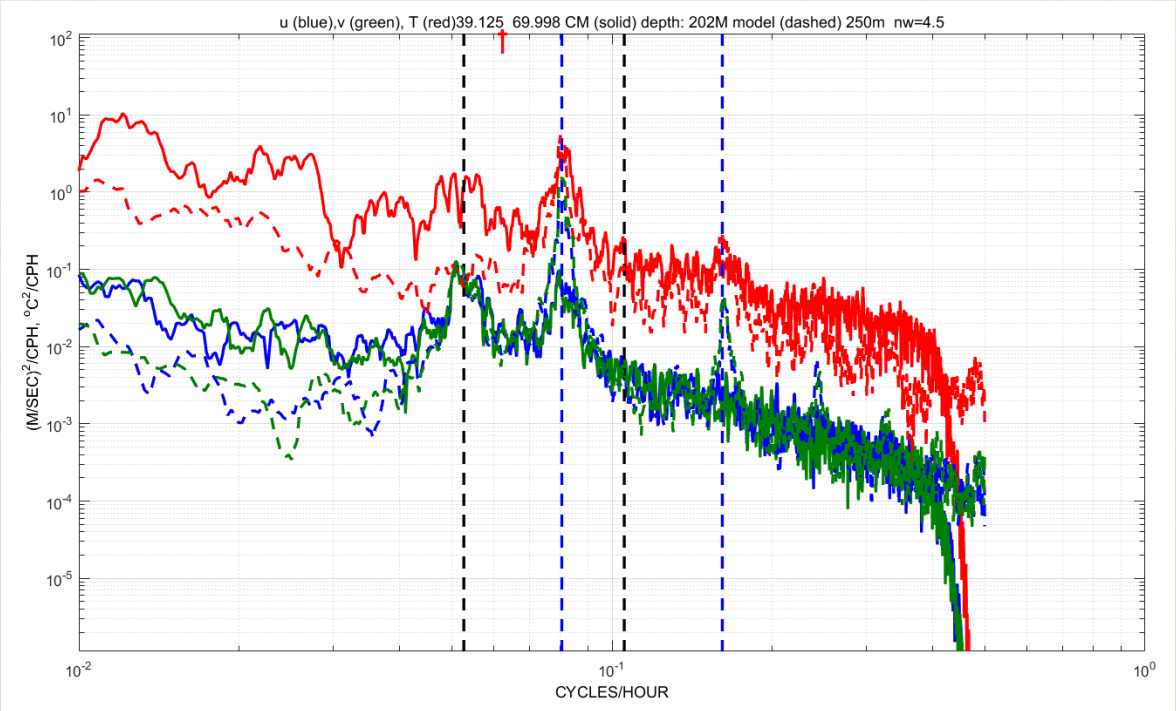


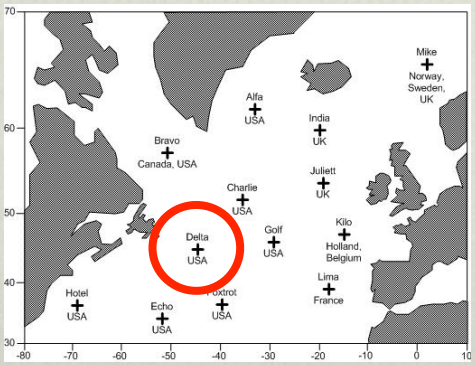
Groundbreaking global MITgcm simulation

- horizontal grid spacing approximately 1 km
- 90 vertical levels starting with a 1 m spacing
- 3 hourly atmospheric forcing
- tidal and atmospheric pressure forcing

LLC430 internal wave field

Frequency spectra at site D





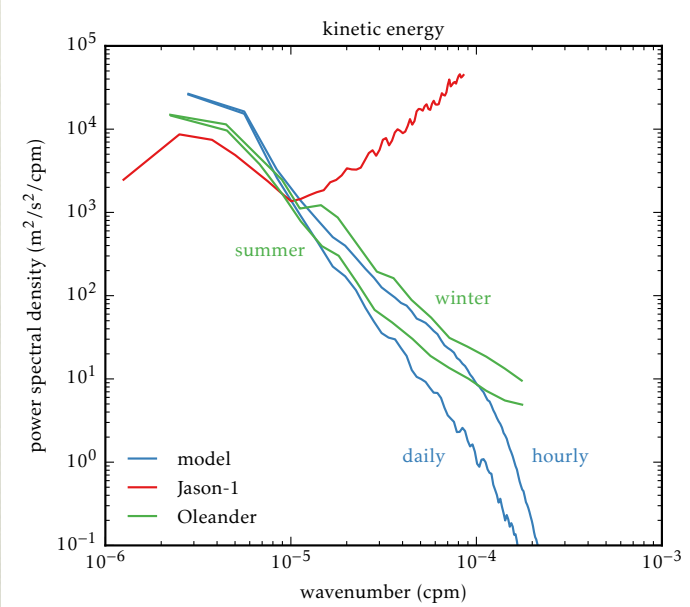
Model reproduces observed spectra

- temperature spectrum (red)
- u-spectrum (blue)
- v-spectrum (green)

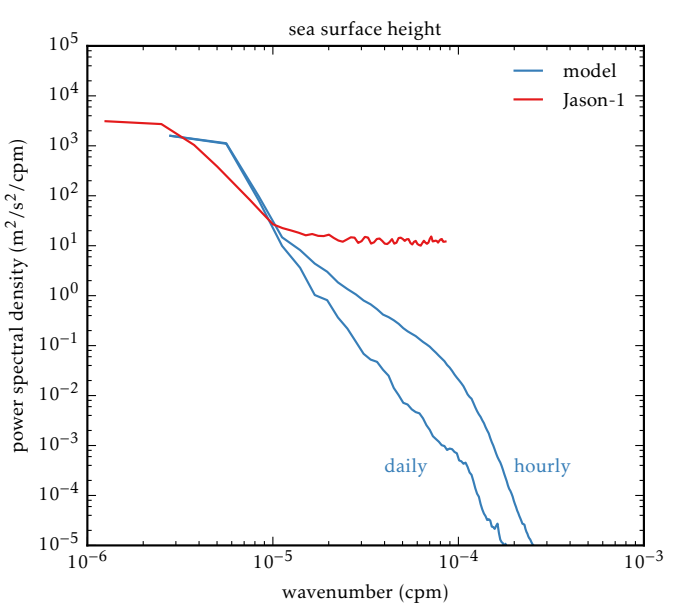
LLC430 surface spectra

Wavenumber spectra in Gulf Stream region

Kinetic energy



SSH



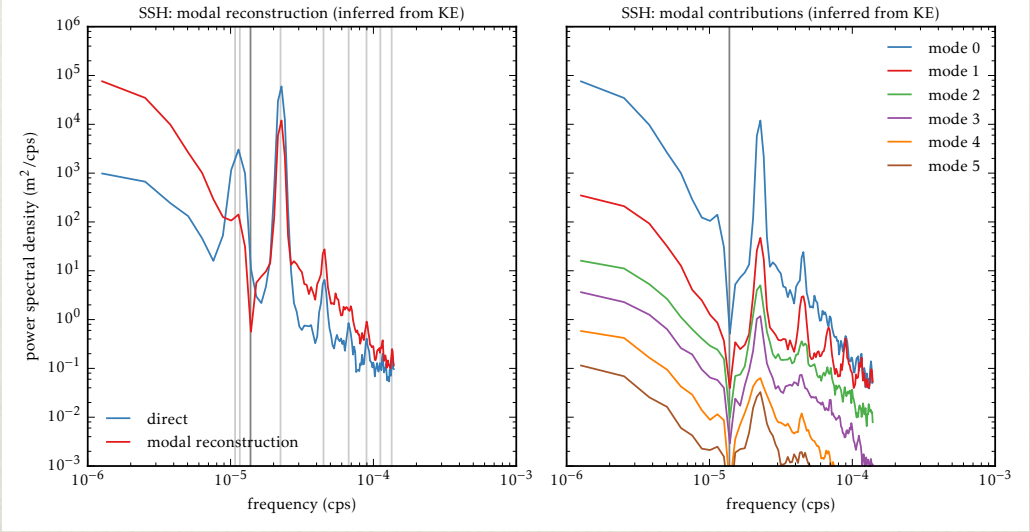
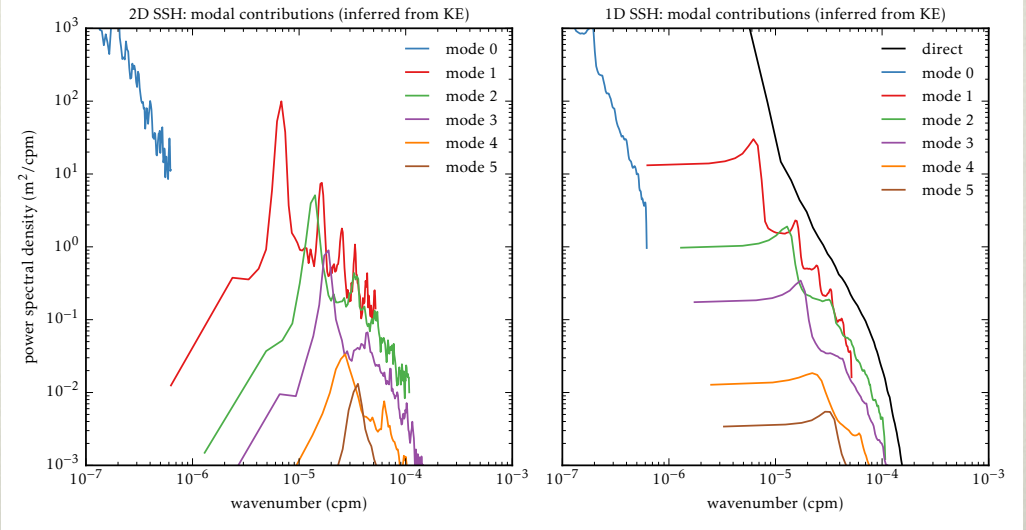
- Internal waves dominate spectra at scales shorter than 100 km
- Waves with frequencies lower than 1.48f project less strongly on SSH than KE
- Waves with frequencies higher than 1.48f project more strongly on SSH than KE

$$SSH_w(k) = \int \frac{(\omega^2 - f^2)^2}{f^2(\omega^2 + f^2)} KE_w(k, \omega)\ \mathrm{d}\omega$$

LLC430 SSH reconstructions

Reconstructing SSH from mooring data

Frequency spectra



Wavenumber spectra