Global Variability of the Wavenumber Spectrum of Oceanic Mesoscale Turbulence

Yongsheng Xu and Lee-Lueng Fu

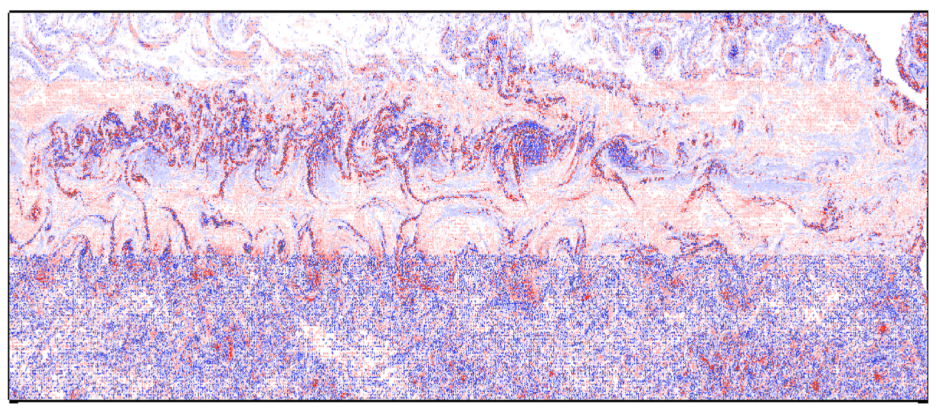
(Jet Propulsion Laboratory, California Institute of Technology)

Abstract

The shape of the wavenumber spectrum of sea surface height is controlled by a dynamic equilibrium of the energy of ocean circulation. The existence of a universal wavenumber spectral slope in the mesoscale band is a fundamental prediction of the mesoscale turbulence theories. Here we show that the first global survey of the wavenumber spectra of sea surface height from the Jason-1 satellite observations has revealed complex spatial variability and significant departure from the predictions of existing theories over many parts of the world's oceans. There is no place in the ocean where the wavenumber spectral slope obeys the k^{-5} power law of the traditional classical quasi-geostrophic (QG) turbulence theory. Near the edge of the core regions of high eddy energy, agreement is observed with the $k^{-11/3}$ power law of the surface quasi-geostrophic (SQG) turbulence theory. However, the observations in the vast ocean interior of low eddy energy exhibit substantial differences from the predictions of existing theories of oceanic mesoscale turbulence. These surprising results have shed light on the limitations of the existing turbulence theories and therefore, their predictions of the energy cascade pathway from large scale forcing to small scale dissipation, which is critical for the understanding of ocean mixing, the ocean's meridional overturning circulation, and the global climate variability.

Ocean Mesoscale Turbulence and Theoretical Predictions

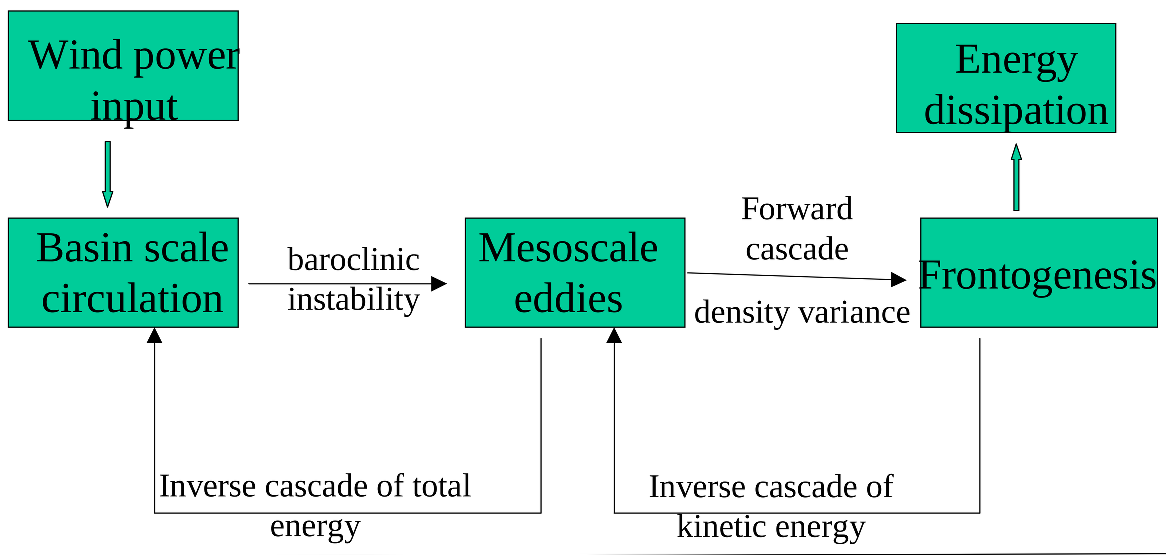
Definition & properties



snapshot of the surface relative vorticity from the 7km resolution simulation, in the central-eastern tropical Pacific

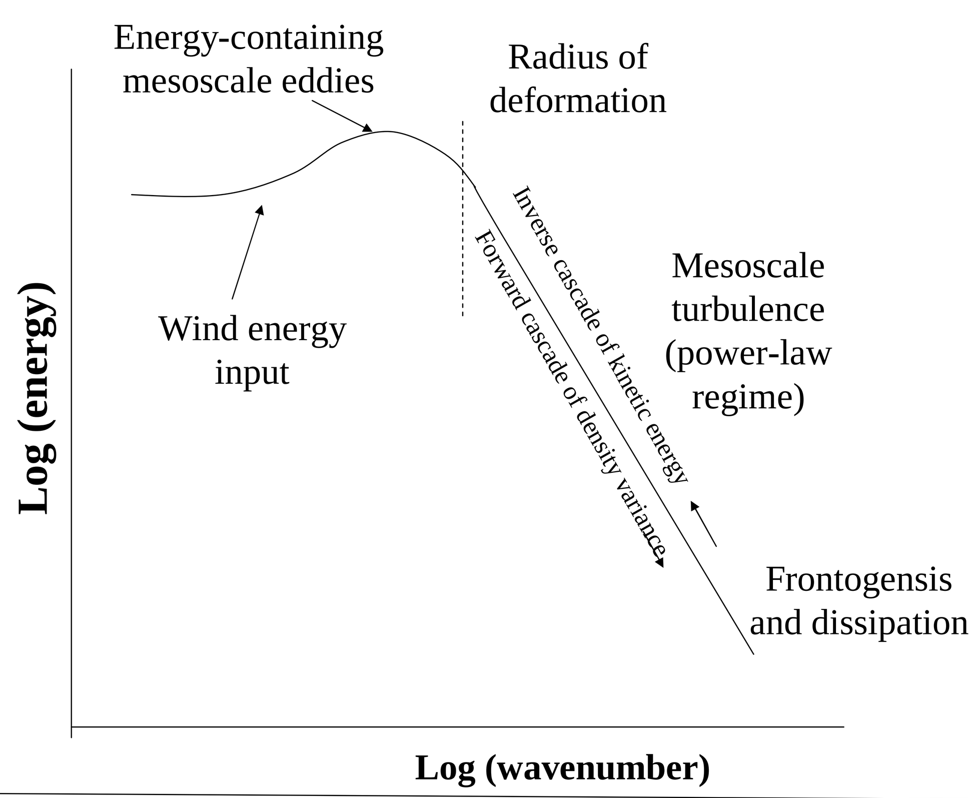
- **Defined as chaos motions that have wavelengths from 10-300 km**
- **Theoretical wavenumber spectral slope:**
  - **QG ~ k^{-5}**
  - **SQG ~$k^{-11/3}$**
  - **Frontogenesis ~ k^{-2}**

Energy cycle of ocean circulation



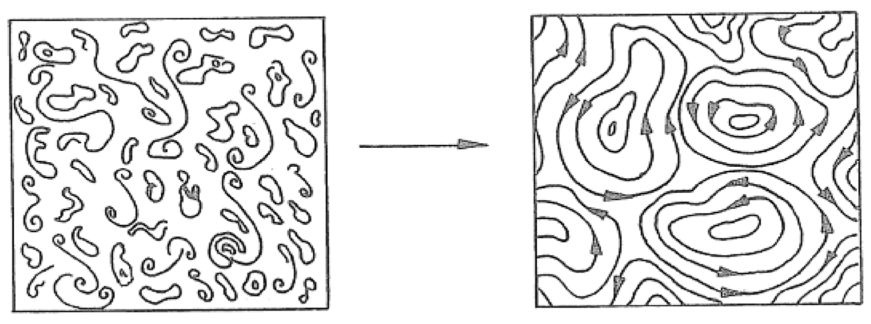
- **Wind power input was balanced by energy dissipation**
- **Inverse energy cascade: refill energy to mesoscale eddies and general ocean circulation**

Ocean energy balance: spectral perspective



- **Ocean energy balance is a key component for understanding how the climate system works**

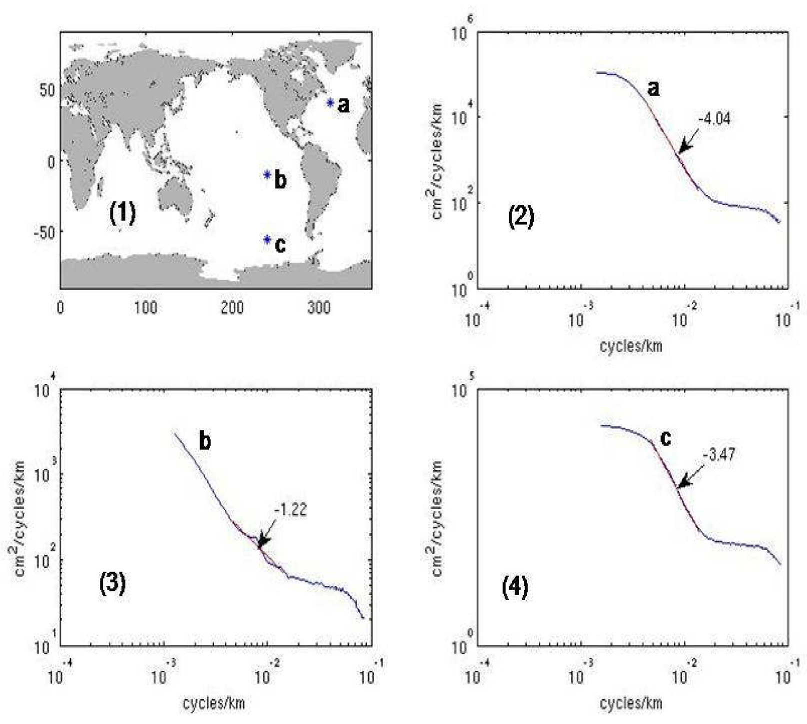
Inverse energy cascade



- **Mesoacle turbulence can convert to meoscale eddies through inverse energy cascade**

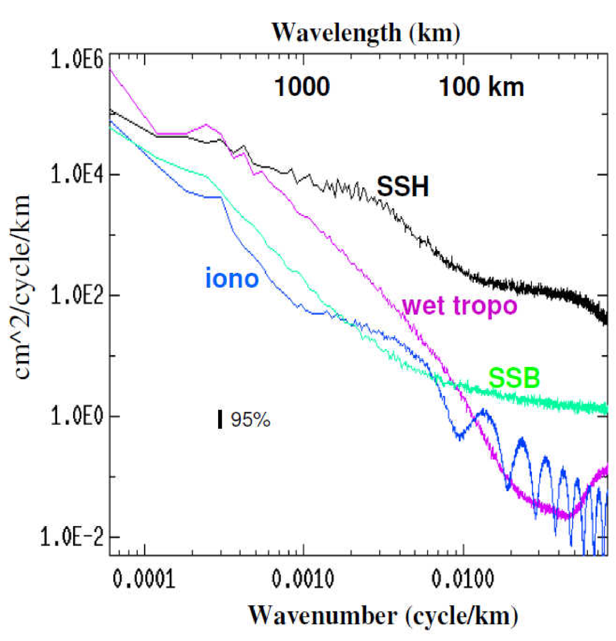
Our Findings From Satellite Altimetry Observations

Computing method

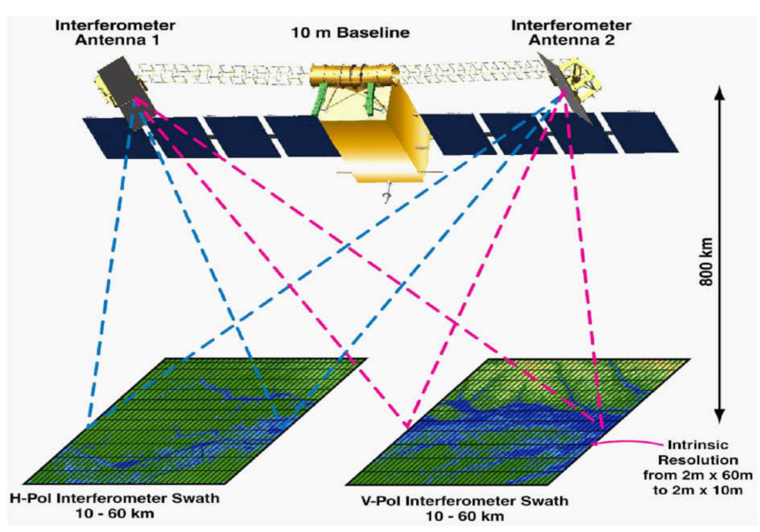


1. **We conducted the first global survey of the variability of Sea Surface height spectral slopes for mesoscale turbulence wavenumber band (70-250km)**
2. **The slope at 2 deg x 2 deg grid point is obtained by averaging all the spectra in a 10 X 10 deg box centered at that point.**

Perspectives



Jason-1: instrumental noise prevents the resolution of ocean signals at wavelengths below 50-100 km. Media errors do not affect the mesoscale signals.



Principle of the SWOT (Surface Water Ocean Topography) mission: radar interferometry holds a promise for studying ocean dynamics down to 10 km wavelengths

Major findings

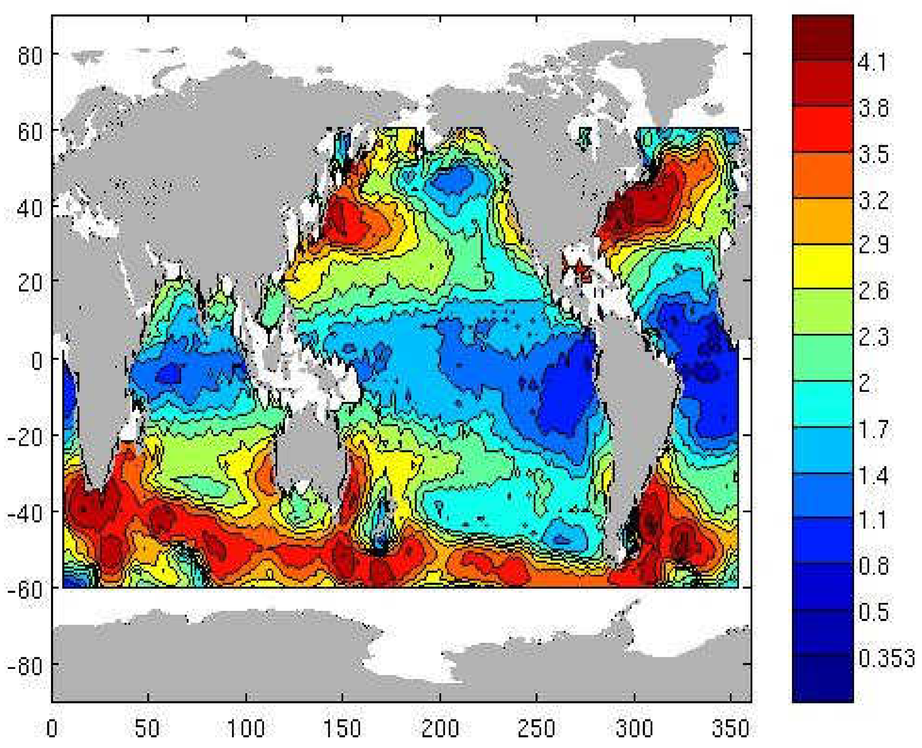
1. no place obeys QG power law (k^{-5})(QG only applies in the ocean interior).

2. SQG power law ($k^{-11/3}$): transition zone from current core to adjacent regions.

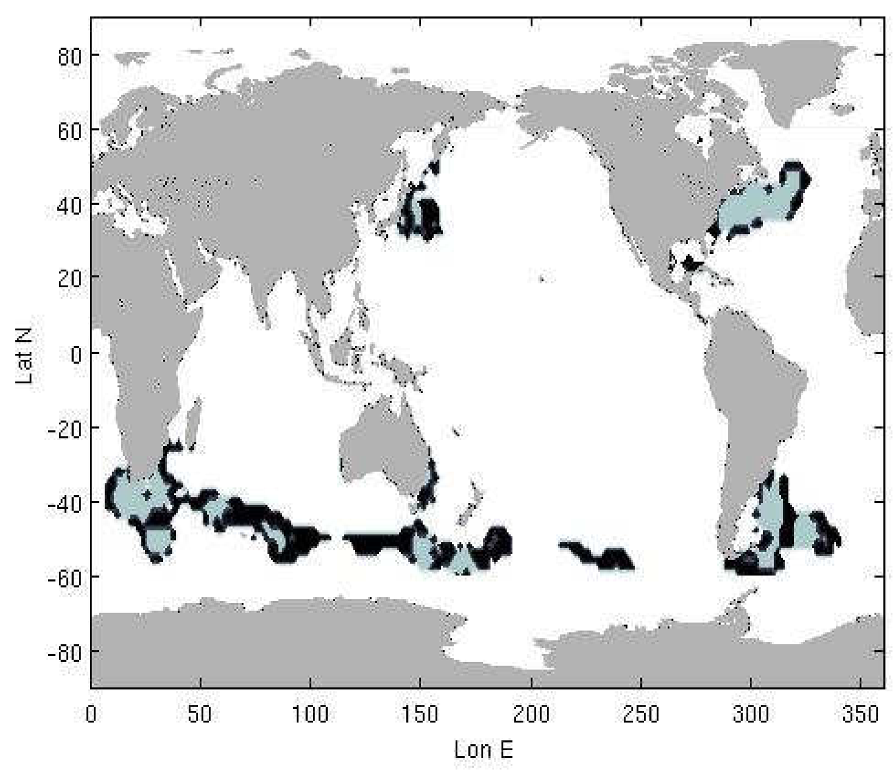
3. Core regions of current systems: consistent with frontogenesis (k^{-4})

4. The vast ocean interiors have spectral exponent of -1 ~ -2, reflecting the ocean's linear response to stochastic wind forcing, consistent with previous theoretical studies.

Significance: observations presented in the work serve as a test bed for new theories and ocean general circulation models



The global distribution of the spectral slopes of SSH wavenumber spectrum estimated from the Jason-1 altimeter measurements. The sign of the slopes was reversed to make the value positive.



The black color represents areas where the spectral slopes follow the SQG $k^{-11/3}$ power law within the 95% confidence level. The gray color represents the areas where the spectral slopes are steeper than $k^{-11/3}$, and the white color represents the areas where the spectral slopes are flatter than $k^{-11/3}$.