Continuous transition of kinetic energy spectra and fluxes between mesoscale and submesoscale

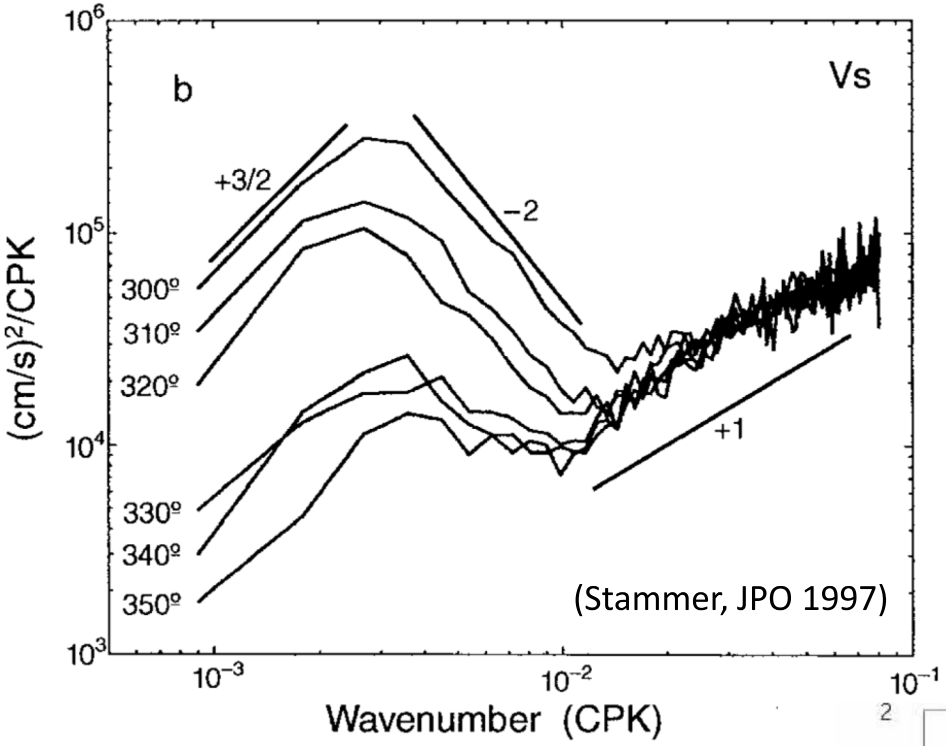
Hyun Sup Soh[1] and Sung Yong Kim[1]

[1]Department of Mechanical Engineering
Korea Advanced Institute of Science and Technology (KAIST), Republic of Korea
syongkim@kaist.ac.kr; http://efml.kaist.ac.kr

Outline

- Motivation
  - Kinetic energy spectra and fluxes
- Diagnostic characteristics of submesoscale coastal surface observations
  - Energy spectra of surface currents off the US West Coast
  - Kinetic energy fluxes of surface currents off the southern San Diego, USA
  - Injection scales
- Summary

Kinetic energy (KE) spectra and fluxes (1/2)



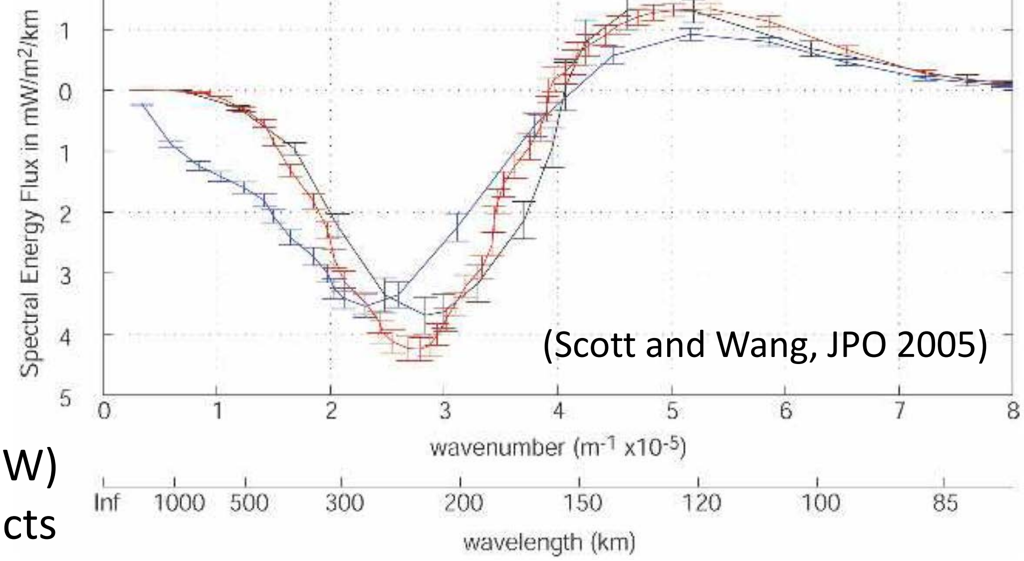
(Stammer, JPO 1997)

- What can be the decay slope of KE spectra and the injection scales to have zero crossing in the KE flux below 100 km scale?

Wavenumber KE spectra of altimeter-derived cross-track geostrophic currents (30N to 40 N)

$$S_{\mathbf{u}_\perp}(k_\parallel) = \left(\frac{g}{f_c}\right)^2 \left(2\pi k_\parallel\right)^2 S_{\boldsymbol{\eta}_\parallel}(k_\parallel),$$

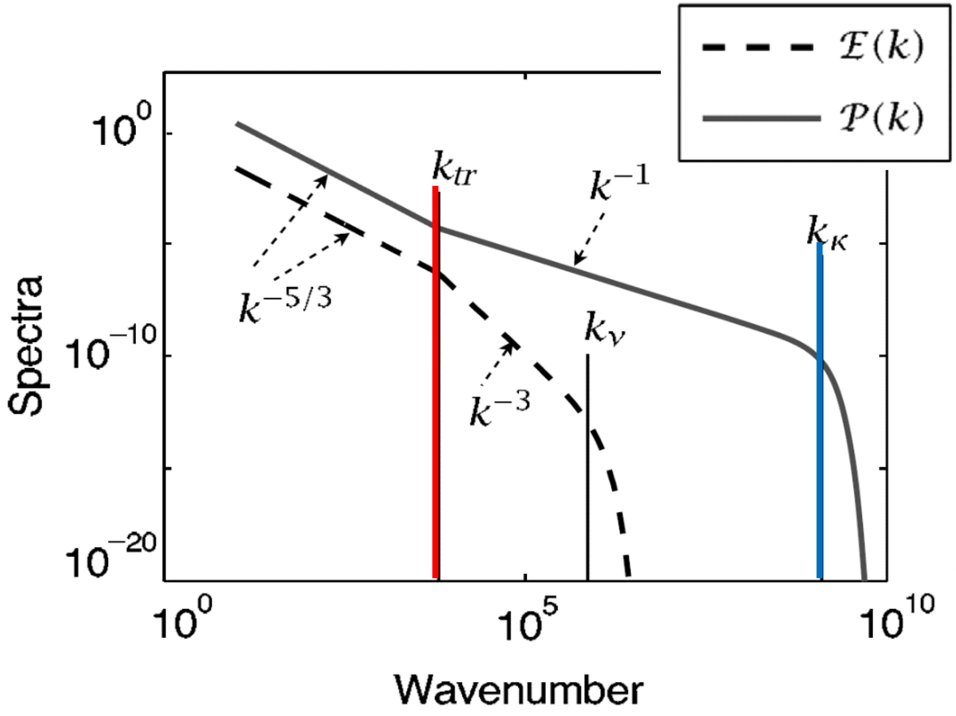
backward cascade ↓ forward cascade



(Scott and Wang, JPO 2005)

Kinetic energy flux in ACC region (57S, 120W)
Optimally interpolated 1/3° AVISO products

Kinetic energy (KE) spectra and fluxes (2/2)

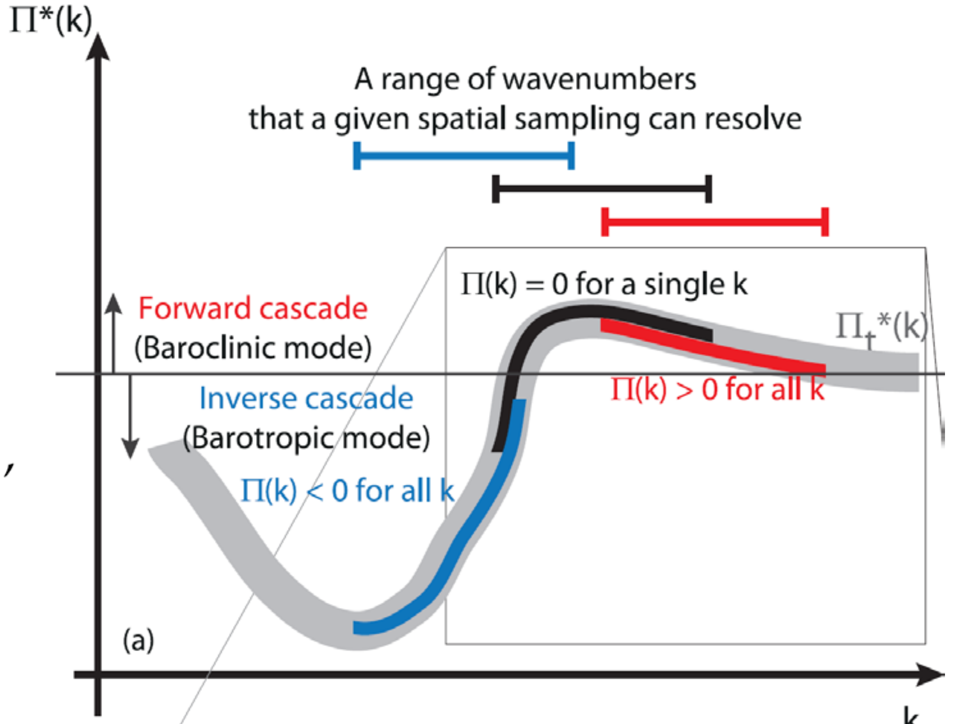


(Vallis, 2000; not scaled)

$$\frac{\partial}{\partial t}E(k^*) + \boxed{\Pi(k^*)} = -2\nu\Omega(k^*) + F(k^*),$$

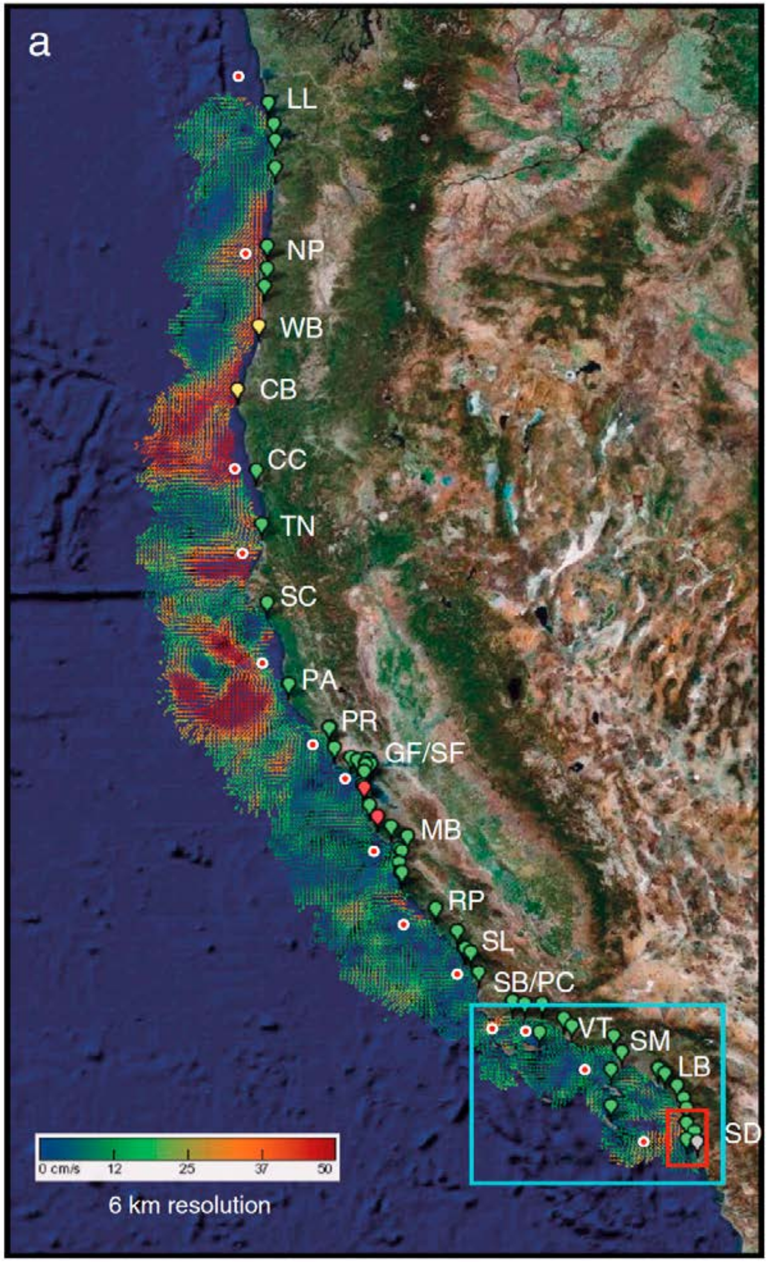
(Frisch 1995)

- Kinetic energy (KE) spectra of currents [E(k)]
- Energy spectra of passive tracers [P(k);]
- Transition (injection) scale and dissipation scale



(Soh and Kim 2018; JGR)

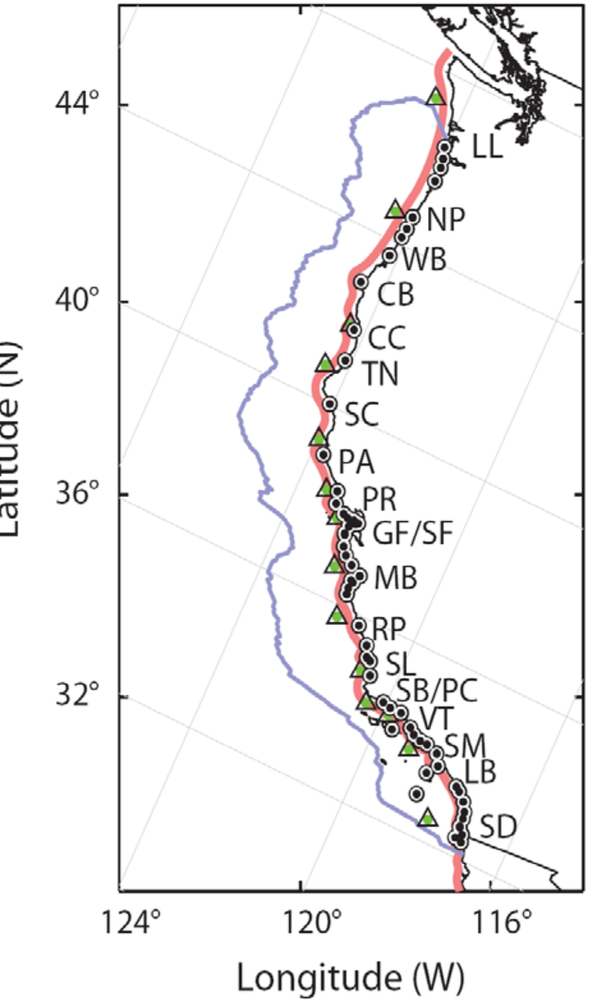
USWC HFR-derived surface currents

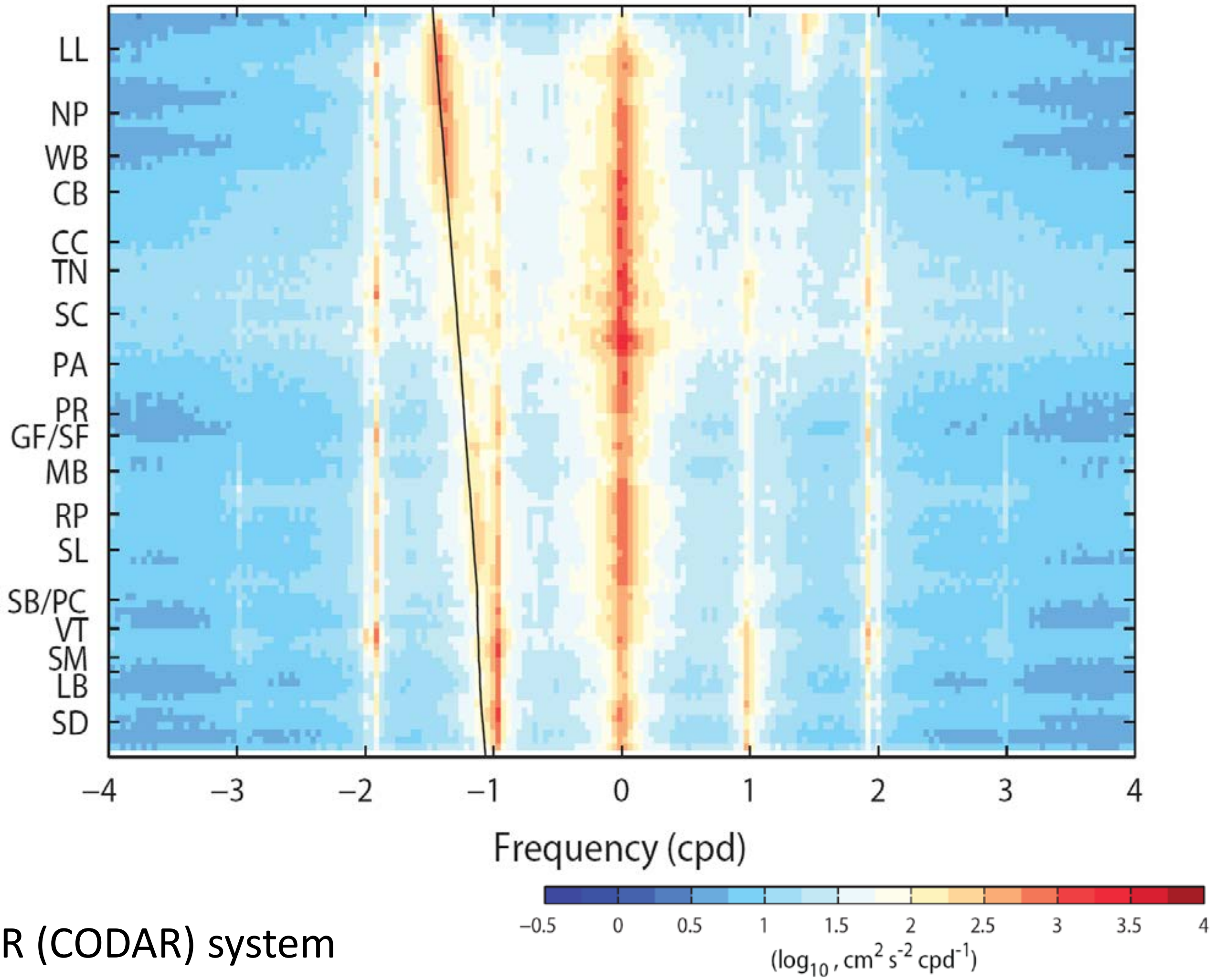


- A network of high-frequency radars (HFRs) along the coast over 2500 km of US West Coast provides km resolution and hourly surface current maps which cover about 150 km offshore from shoreline as the upper 1 m depth averaged currents.
- Due to low signal-to-noise ratio of satellite remote sensing near coastal regions, coastal surface current maps provide a useful resource to investigate the submesoscale processes in a view of statistics and dynamics.

(Kim et al, JGR 2011, Kim and Crawford, GRL 2014)

Variance of surface currents (alongshore view)

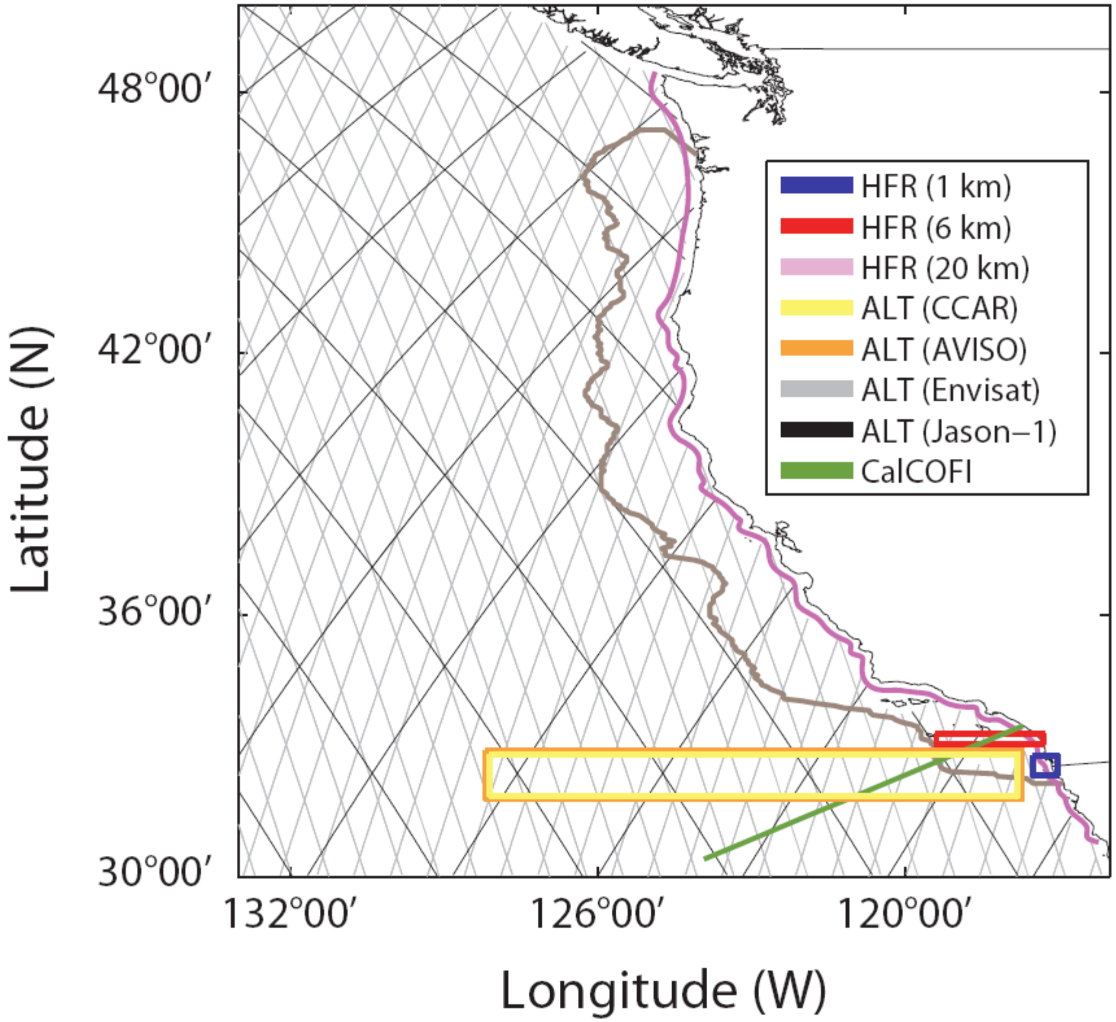




- 60+ compact array HFR (CODAR) system
- Hourly surface current maps (0.5, 1, 2, and 6 km resolution)
- Upper 1 m depth averaged currents; From nearshore to 50 - 150 km offshore
- Variance coherent with tides, wind, low frequency signals, and Coriolis force.
- Regional noise levels

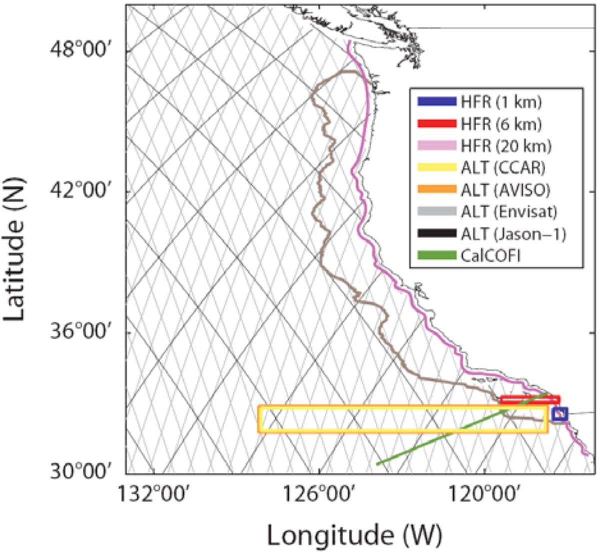
(Kim *et al*, JGR 2011)

Sampling domain in computation of energy spectra



- HFR surface currents (1, 6, and 20 km resolution; hourly) off southern California and on coastline axis (USWC)
- Gridded ALT products [CCAR (daily) and AVISO (weekly)] and along-track altimeter (ALT; Envisat/Jason-1; weekly) on NE Pacific
- CalCOFI shipboard ADCP (Line 90; quarterly)
- SoCAL was chosen because it contains relatively minimum ageostrophic components.

KE spectra (USWC HFR; Altimeters; Shipboard ADCPs)

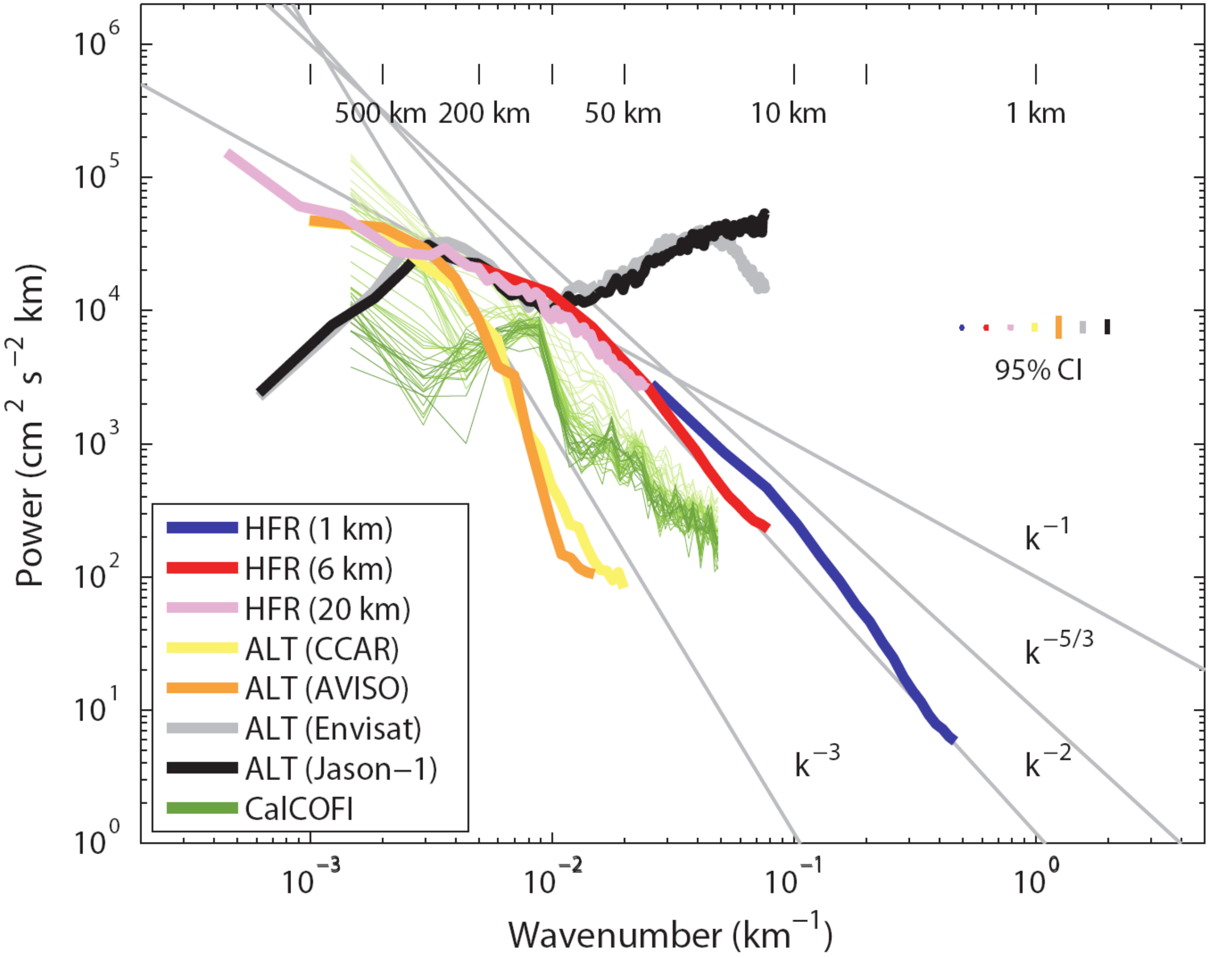


$$S_{\mathbf{u}_\perp}(k_\parallel) = \left(\frac{g}{f_c}\right)^2 \left(2\pi k_\parallel\right)^2 S_{\boldsymbol{\eta}_\parallel}(k_\parallel),$$

Power spectrum of cross-track geostropic currents from along-track SSHAs

K^{-2} power law related to sub-mesoscale.

Robust estimate on k-2 spectra with data in other regions.



Two kinds of ALT data: Envisat and Jason-1
HFR data with three resolutions:
1 km and 6 km data are sampled from SoCAL,
because minimum ageostropic components are expected.
20 km data are from the coastline axis.

(Kim et al, JGR 2011)

Scale-by-scale energy budget equation

$$\frac{\partial}{\partial t}E(k^*) + \Pi(k^*) = -2\nu\Omega(k^*) + F(k^*),$$

(Frisch 1995)

where

$$E(k^*) = \frac{1}{2}\sum_{|\mathbf{k}|<k^*} |\hat{\mathbf{u}}(\mathbf{k})|^2,$$

Cumulative kinetic energy

$$\boxed{\begin{aligned}\Pi(k^*) &= \langle \mathbf{u}_< \cdot (\mathbf{u}\cdot\nabla\mathbf{u})\rangle, \\ &= \langle \mathbf{u}_< \cdot (\mathbf{u}_< \cdot \nabla\mathbf{u}_>)\rangle + \langle \mathbf{u}_< \cdot (\mathbf{u}_> \cdot \nabla\mathbf{u}_>)\rangle,\end{aligned}}$$

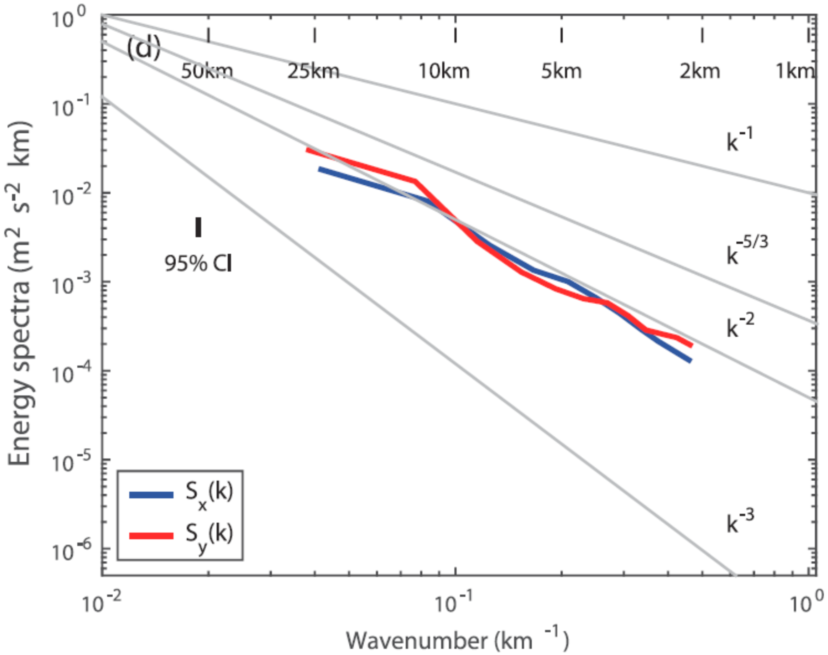
Cumulative advective kinetic energy flux

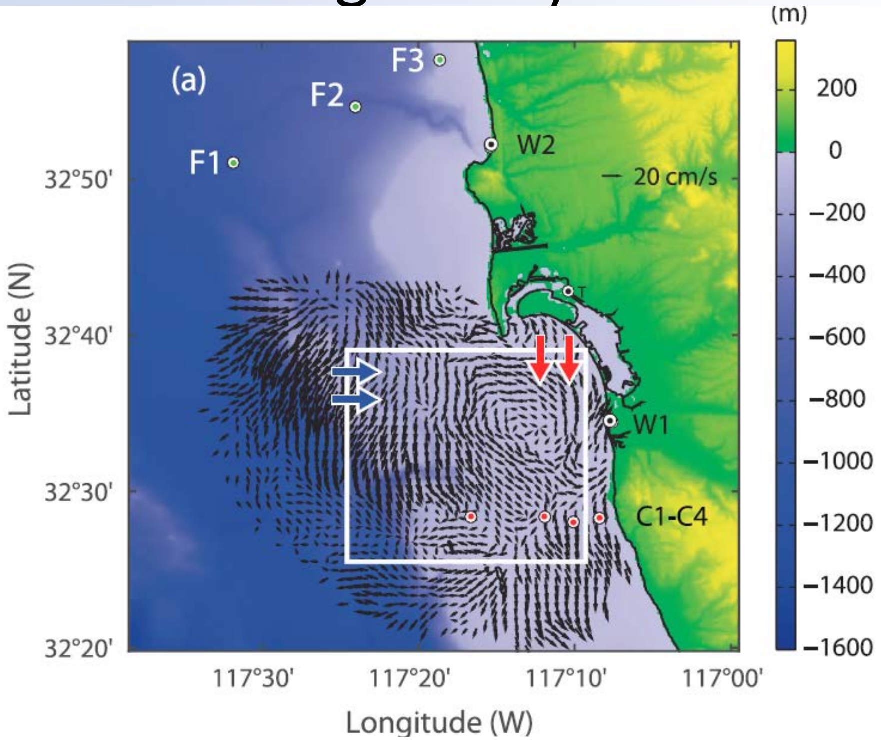
$$\Omega(k^*) = \frac{1}{2}\sum_{|\mathbf{k}|<k^*} \mathbf{k}^2|\hat{\mathbf{u}}(\mathbf{k})|^2,$$

Cumulative enstrophy

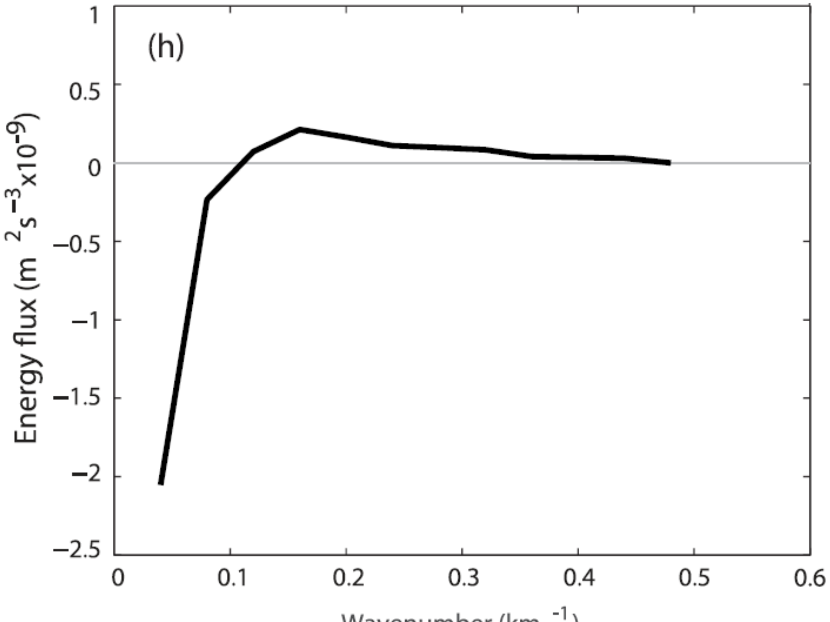
$$\begin{aligned}\mathbf{u}(\mathbf{x}) &= \mathbf{u}_<(\mathbf{x}) + \mathbf{u}_>(\mathbf{x}), \\ &= \sum_{|\mathbf{k}|<k^*} \hat{\mathbf{u}}(\mathbf{k})e^{i\mathbf{kx}} + \sum_{|\mathbf{k}|>k^*} \hat{\mathbf{u}}(\mathbf{k})e^{i\mathbf{kx}},\end{aligned}$$

KE spectra and fluxes (southern San Diego HFR)



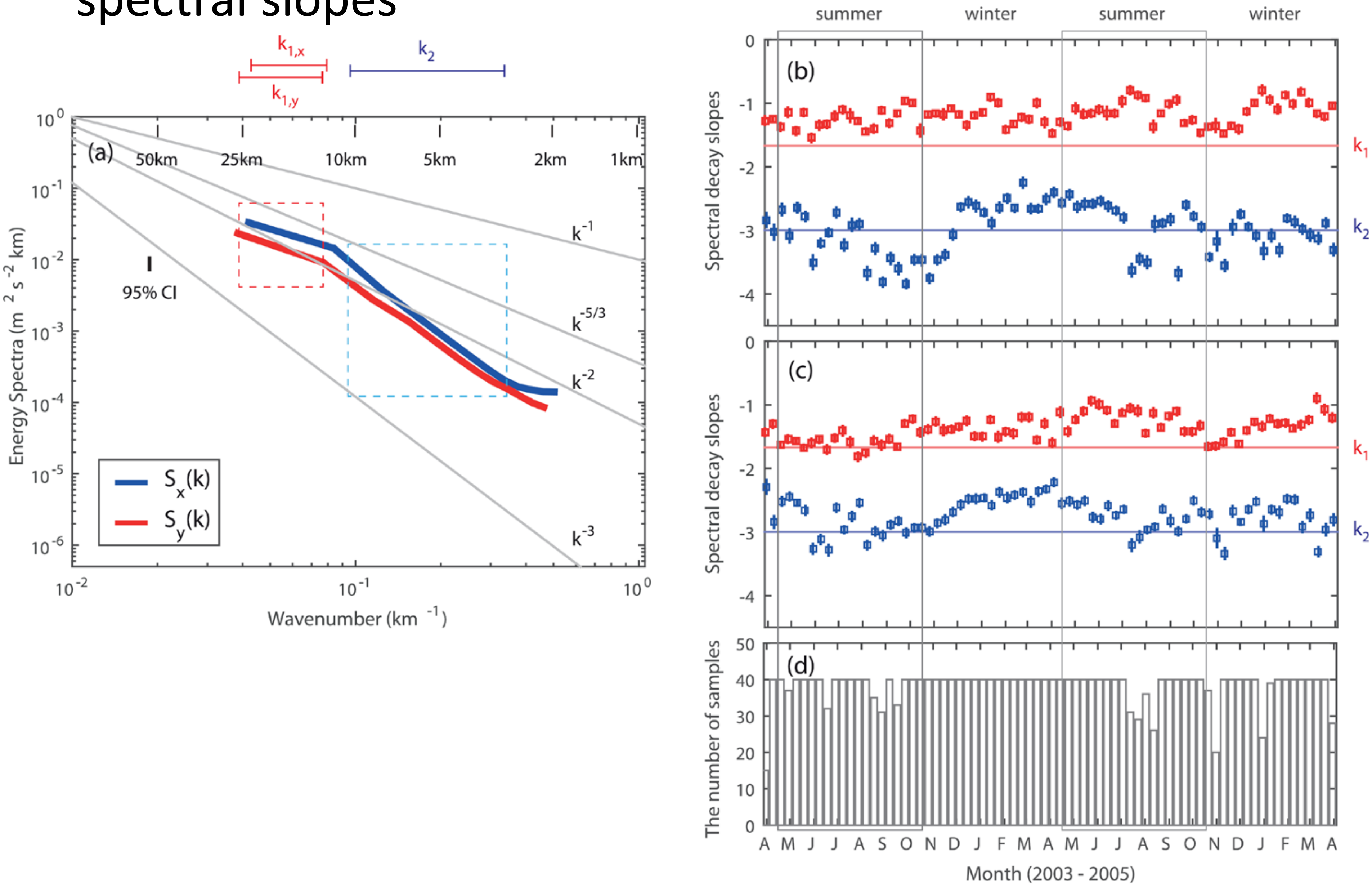


- Decay slopes of KE spectra range between k^{-2} and k^{-3}
- Zero-crossings of KE fluxes appear O(10) km

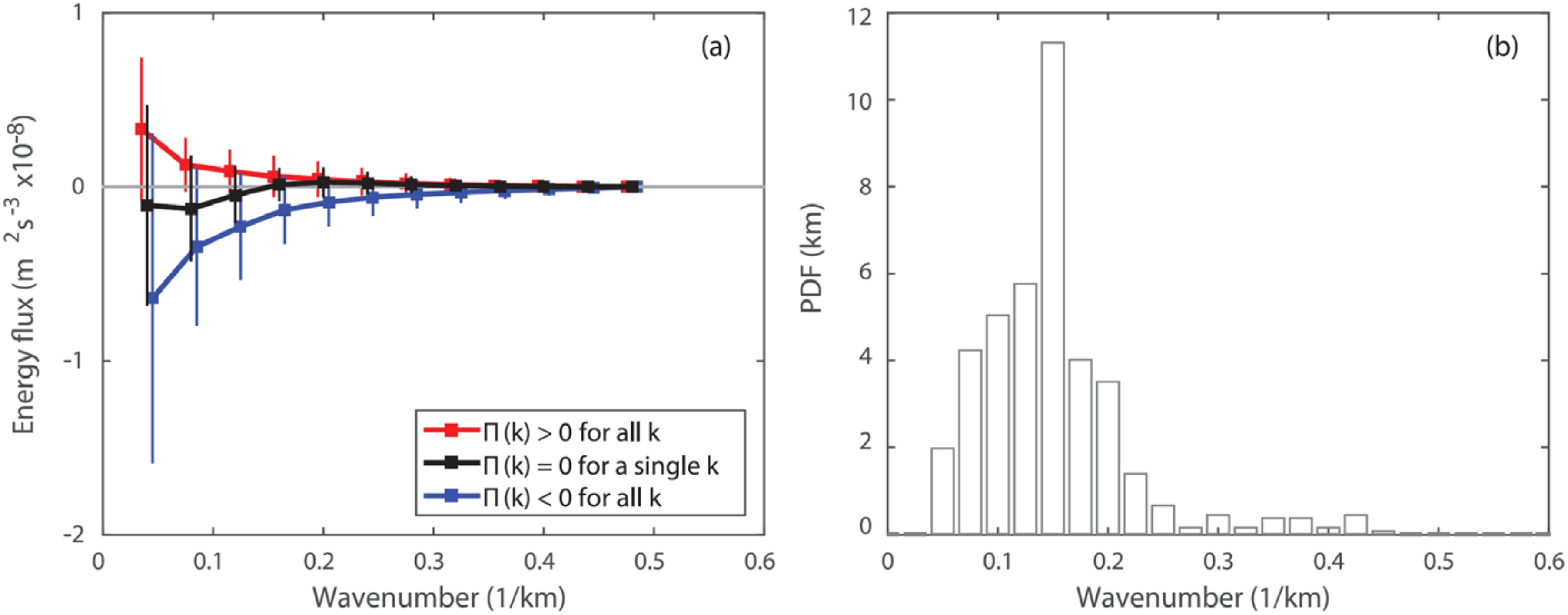


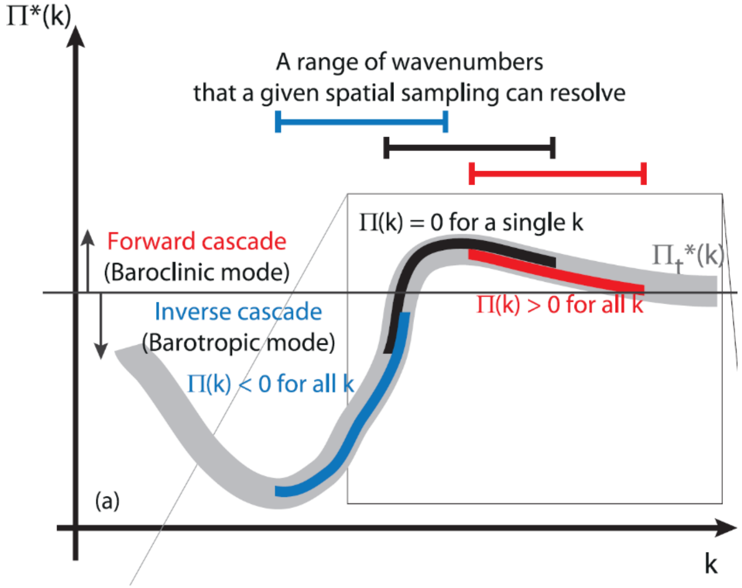
(Soh and Kim 2018; JGR)

Yearly-averaged KE spectra and temporal variability of spectral slopes



KE fluxes and PDFs of zero-crossing wavenumbers

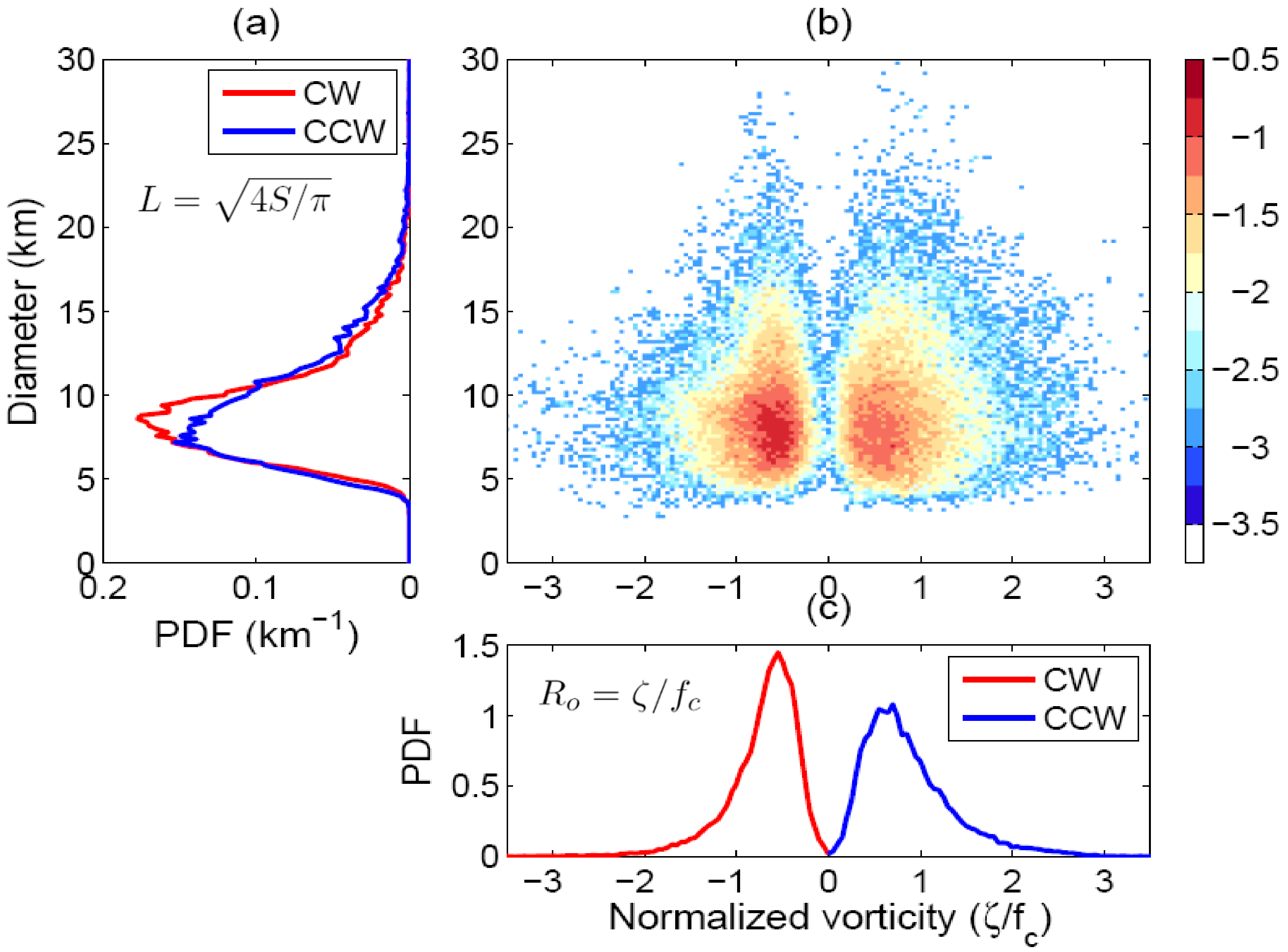




- Injection scales are between 5 to 10 km

(Soh and Kim 2018; JGR)

PDFs of Rossby numbers and eddy size



- About 700 eddies are identified for each rotation.
- O(0.5-1) Rossby number at the center of eddies
- 5-20 km diameter (L)

(Kim, 2010 CSR)

Summary

- Kinetic energy (KE) spectra and fluxes of submesoscale surface currents show the decay slopes of k^{-2} and k^{-3} and the injection scale as O(10) km.
- The baroclinic instability in the mixed layer plays a dominant role in the regional submesoscale driver rather than the mesoscale eddy-derived surface frontogenesis at a scale of O(100) km.
- The near-future satellite-derived high-resolution observations (e.g, SWOT, SKIM, and WaCM projects) would be good resources to understand (coastal) submesoscale processes and have synergy through integrated observations and analysis.