COASTAL SURFACE CURRENT MEASUREMENTS USING HIGH-FREQUENCY RADARS FOR STUDIES OF SUBMESOSCALE GEOPHYSICAL TURBULENCE

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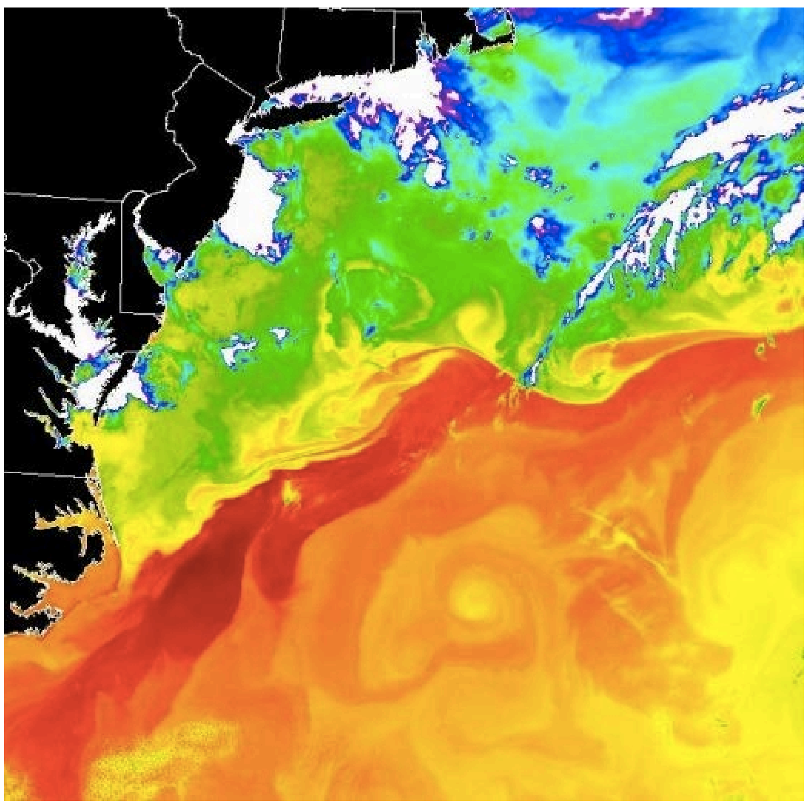
Mesoscale and submesoscale processes

- Small Rossby number [Ro = ζ/f]
- Longer than O(100)km and weekly time scales
- Geostrophic currents

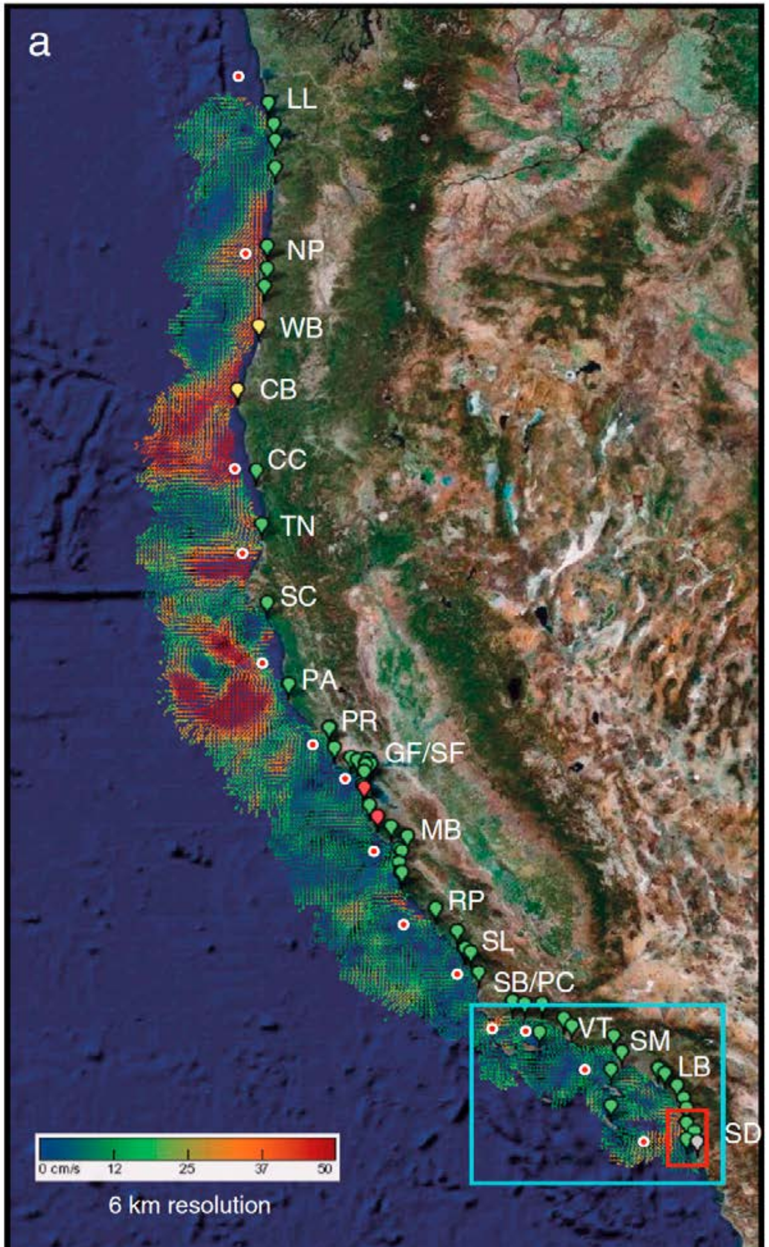


- O(1) Rossby number
- A horizontal scale smaller than the first baroclinic Rossby deformation radius; O(1-10) km
- Frequently observed as fronts, eddies, and filaments
- Potential drivers
  - Baroclinic instability in the mixed layer (mixed layer instability)
  - Frontogenesis associated with mesoscale eddies (strain-induced frontogenesis)
- Oceanic vertical pumps

Outline

- An overview of surface current observations
  - Principles of high-frequency radars
  - Surface current measurements
- A science question
- Wavenumber domain kinetic energy spectra and fluxes
  - Surface currents off southern San Diego (USA)
- Summary

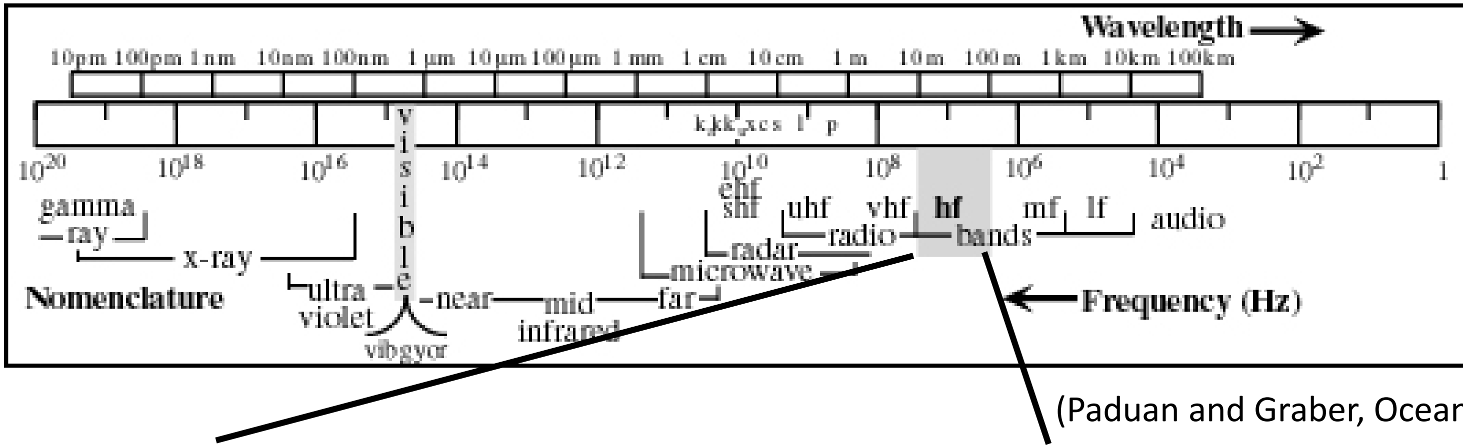
USWC HFR-derived surface currents



- 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)

Radio signals used in high-frequency radar



(Paduan and Graber, Oceanography 1997)

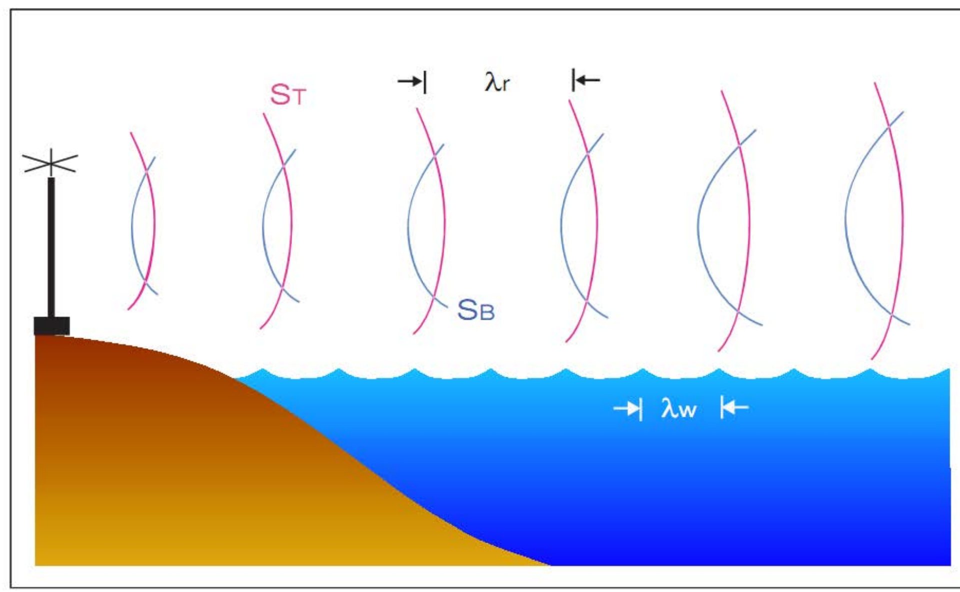
3-30 MHz (between AM radio and TV)

Wavelength (λ_r) : 10 ~ 100 (m)

Bragg backscattering

When the radar signals are backscattered in phase,

$$\lambda_w = \lambda_r / 2$$



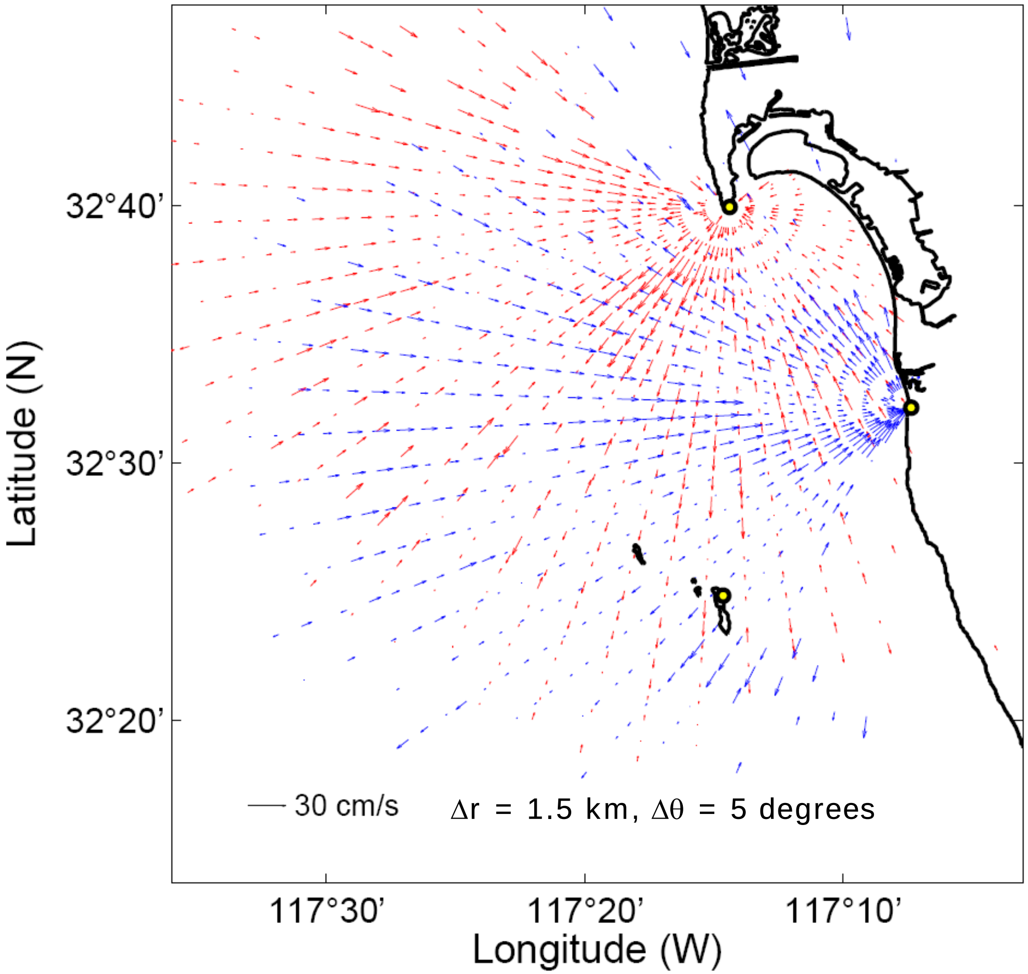
Phased array vs. Compact array

- Phased array
  - Parallel radar array
  - WERA, OSCR
  - Europe, US (FL, GA), Japan
- Compact array
  - Monopole + 2 dipoles
  - CODAR
  - USA (West/East), Korea, Japan

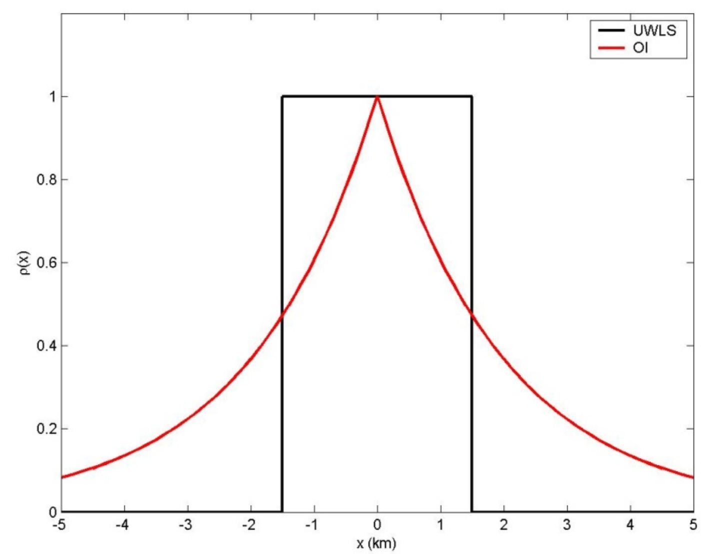
University of Hamburg, Germany

Point Loma, CA USA

Multiple surface radial current maps

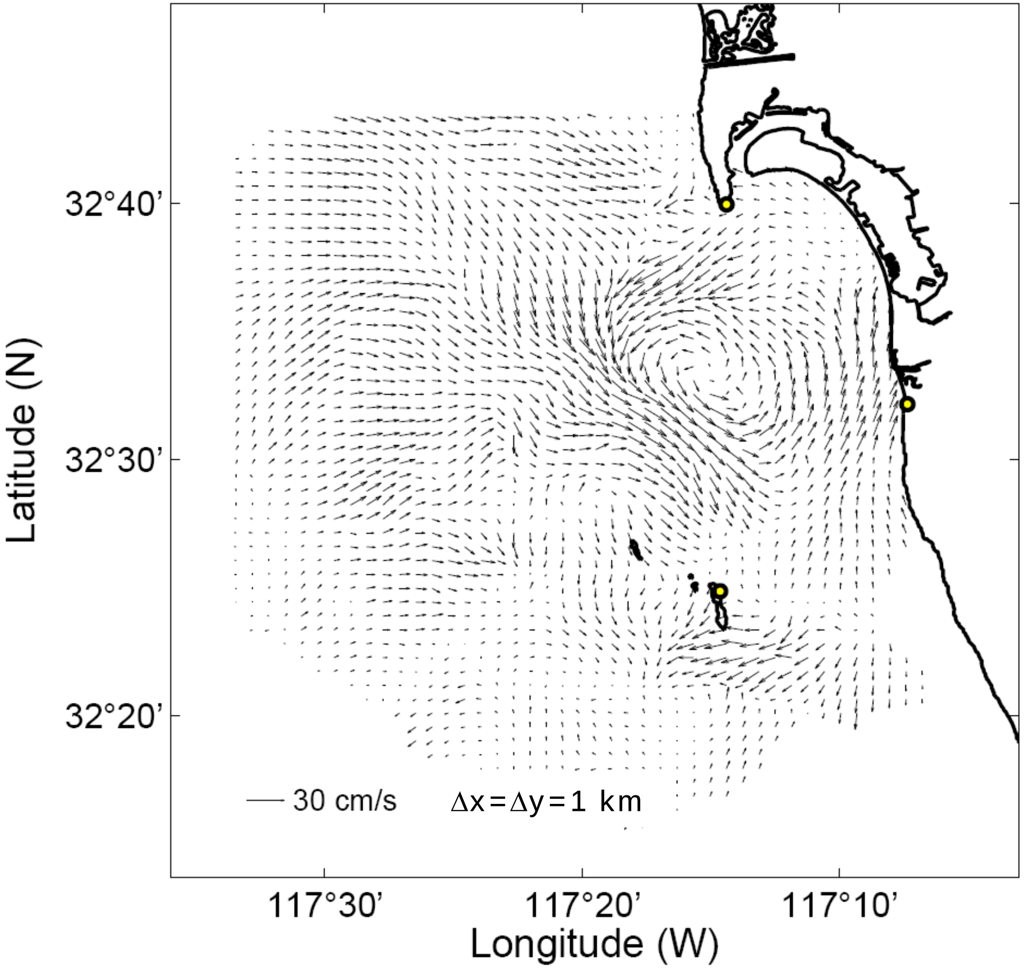


- Vector current map estimates
  - Un-weighted least squares fit (UWLS)
  - Optimal interpolation (OI)



(Kim *et al*, JGR 2008; Kim, CSR 2010)

Improved vector current map

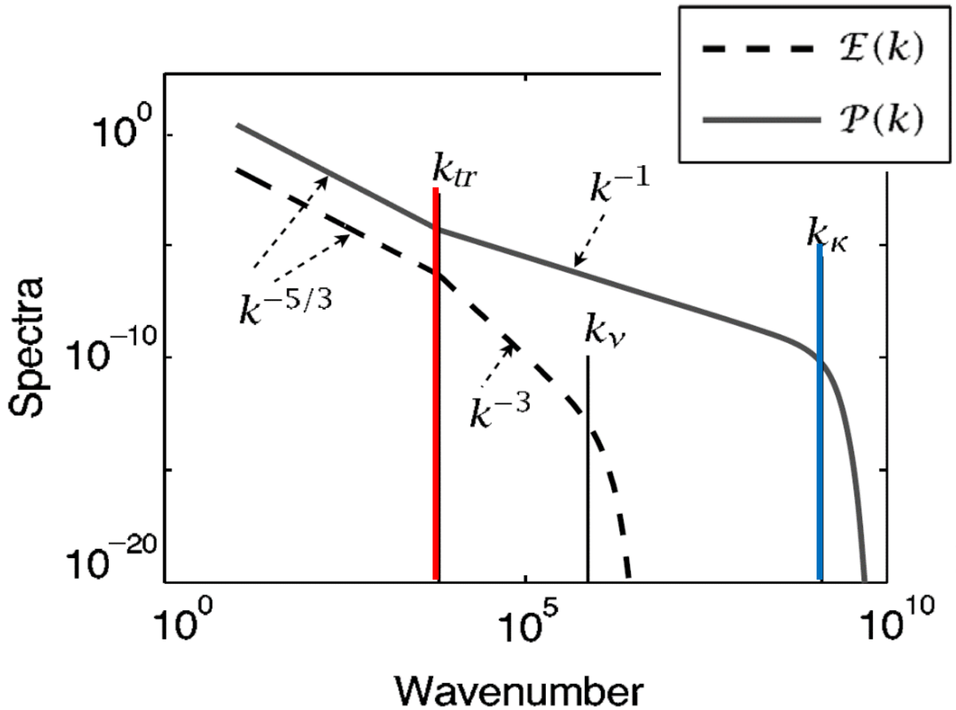


- Optimal interpolation
  - Minimize baseline inconsistency
  - A unified uncertainty definition
  - Divergence and vorticity
  - Velocity potential and stream function

  - Exponential correlation function (based on observed surface currents, estimated from non-biased estimator [e.g., non-OI]) with shorter length scales (e.g., 2 km) leads to minimum level of spatial smoothing.

(Kim *et al*, JGR 2008; Kim, CSR 2010)

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

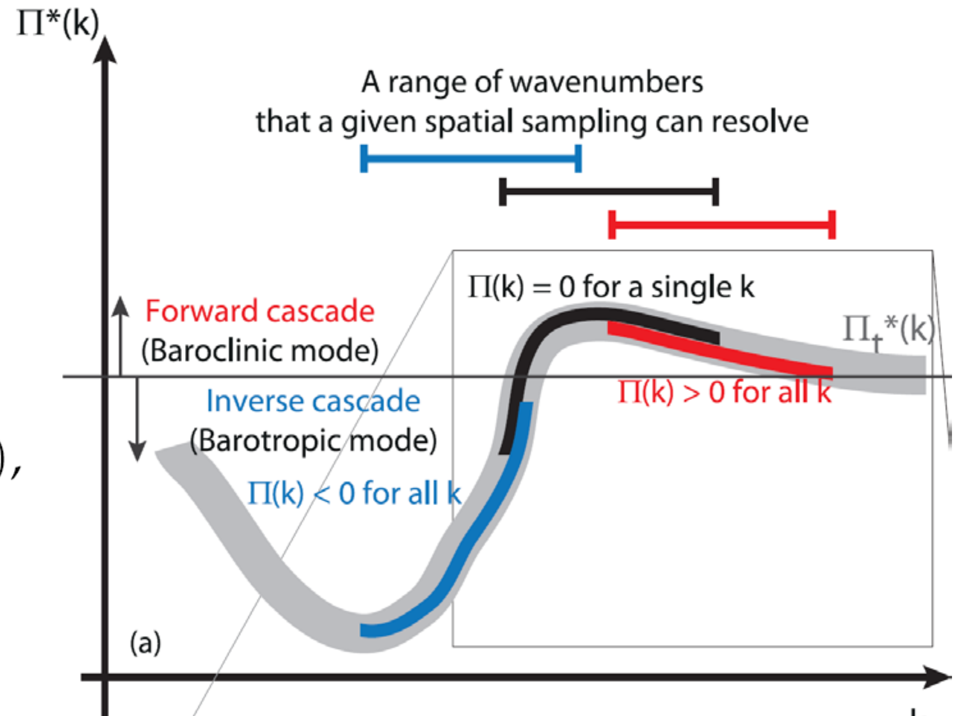


(Vallis, 2000; not scaled)

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

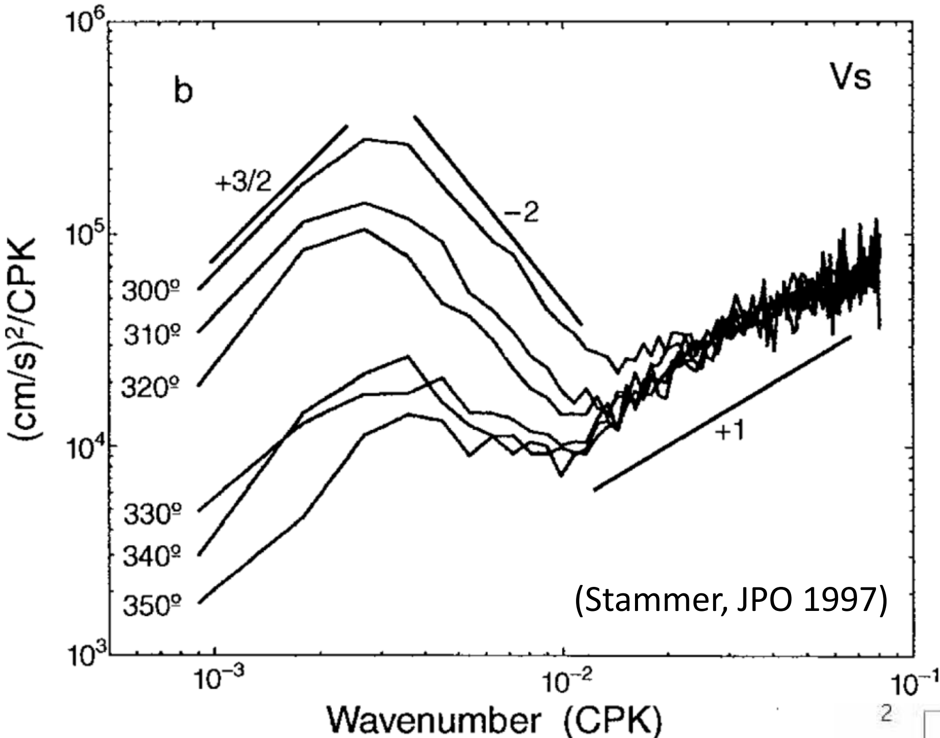
$$\frac{\partial}{\partial t}E(k^*) + \Pi(k^*) = -2\nu\Omega(k^*) + F(k^*),$$

(Frisch 1995)



(Soh and Kim 2018; submitted)

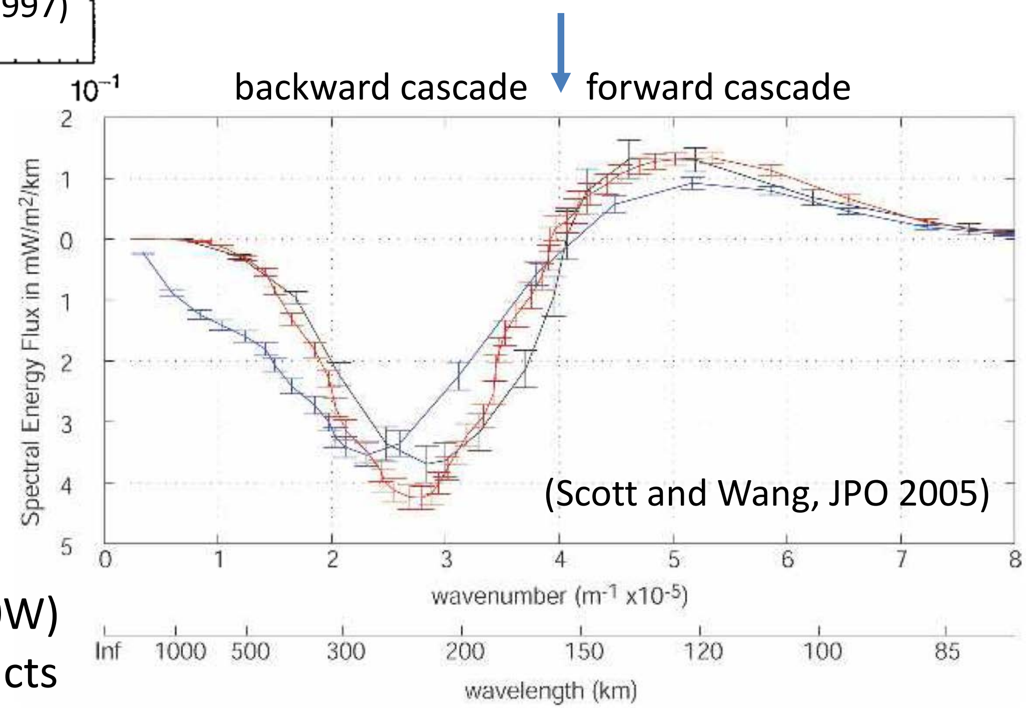
Kinetic energy (KE) spectra and fluxes (2/2)



- 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?

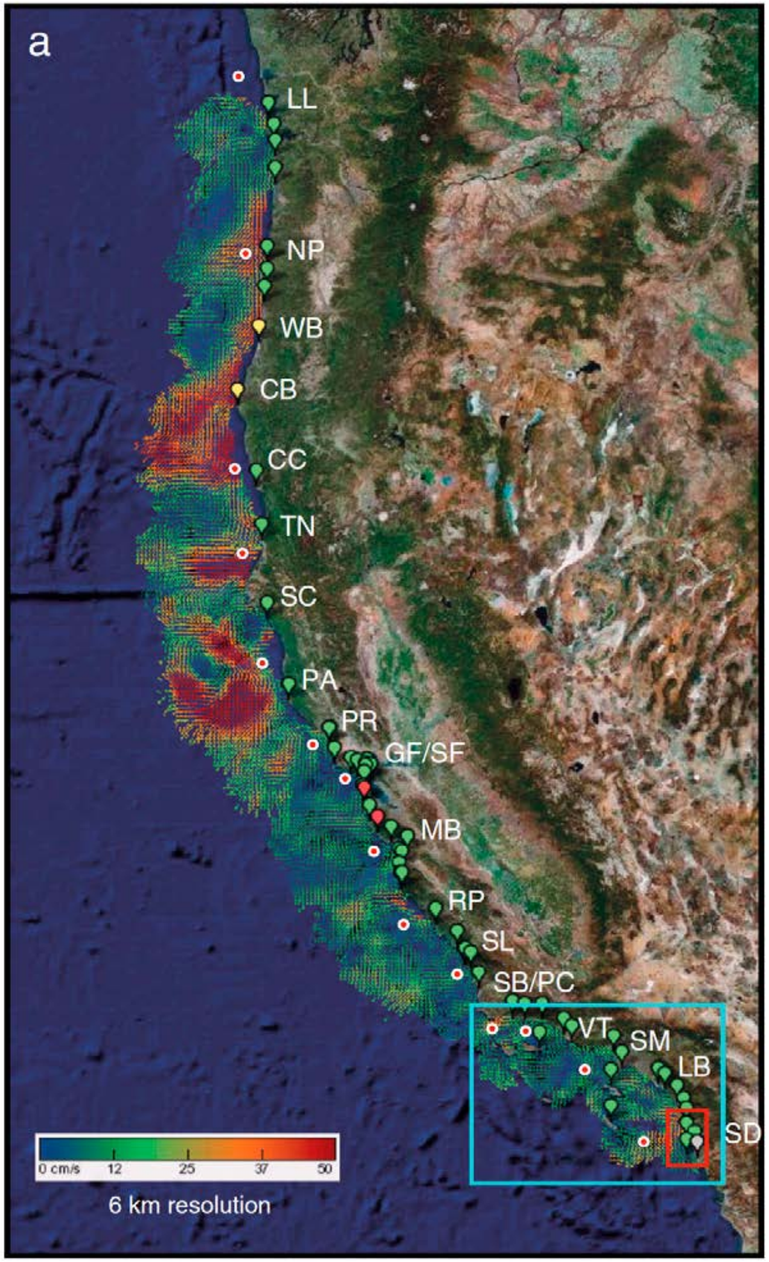
Wavenumber KE spectra of altimeter-derived cross-track geostrophic currents (30N to 40 N)

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



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

USWC HFR-derived surface currents



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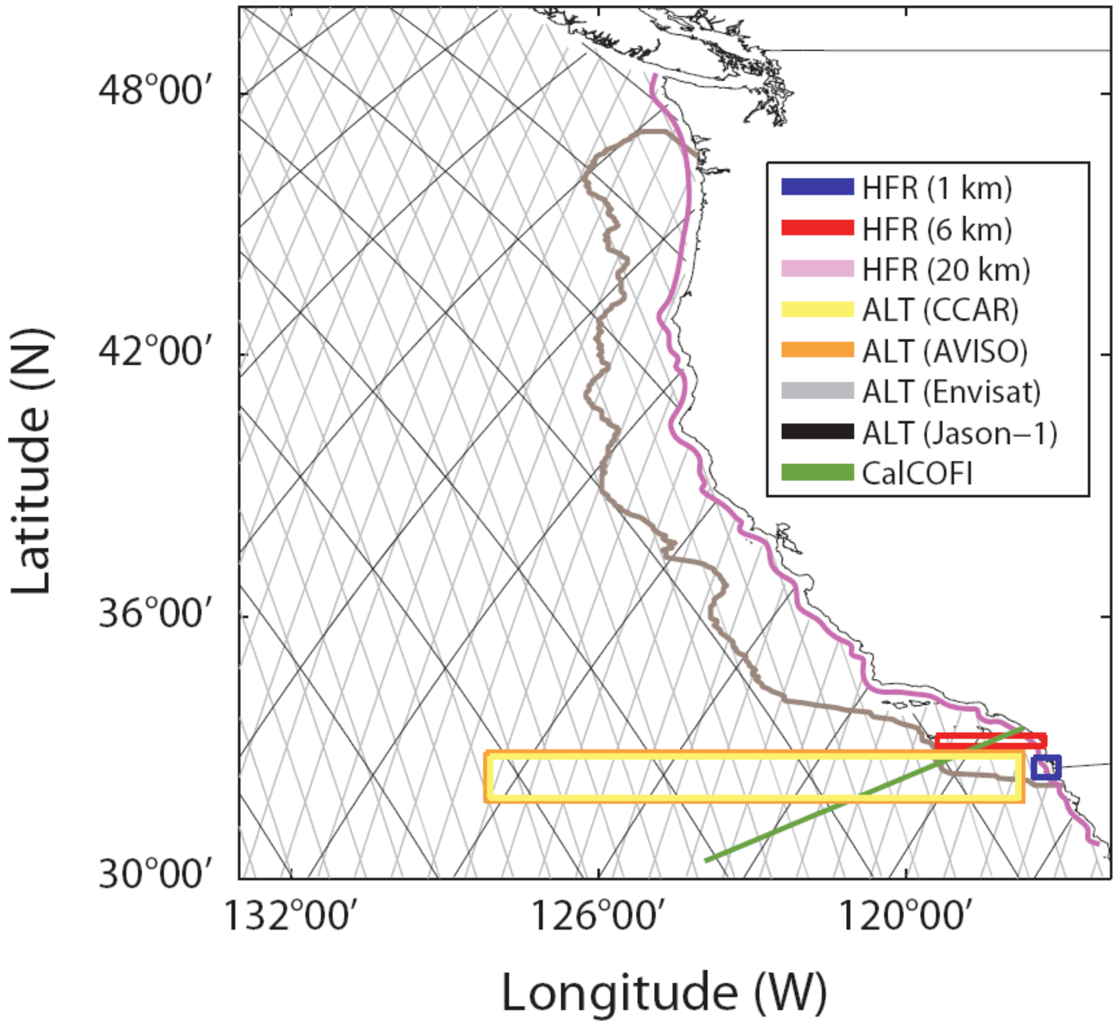
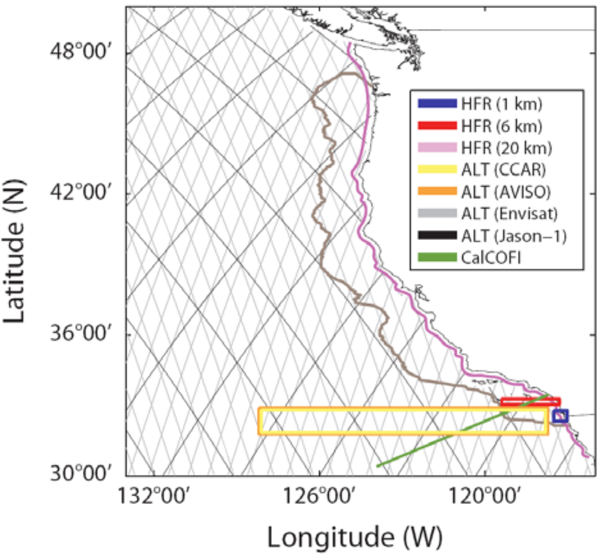
(Kim et al, JGR 2011, Kim and Crawford, GRL 2014)

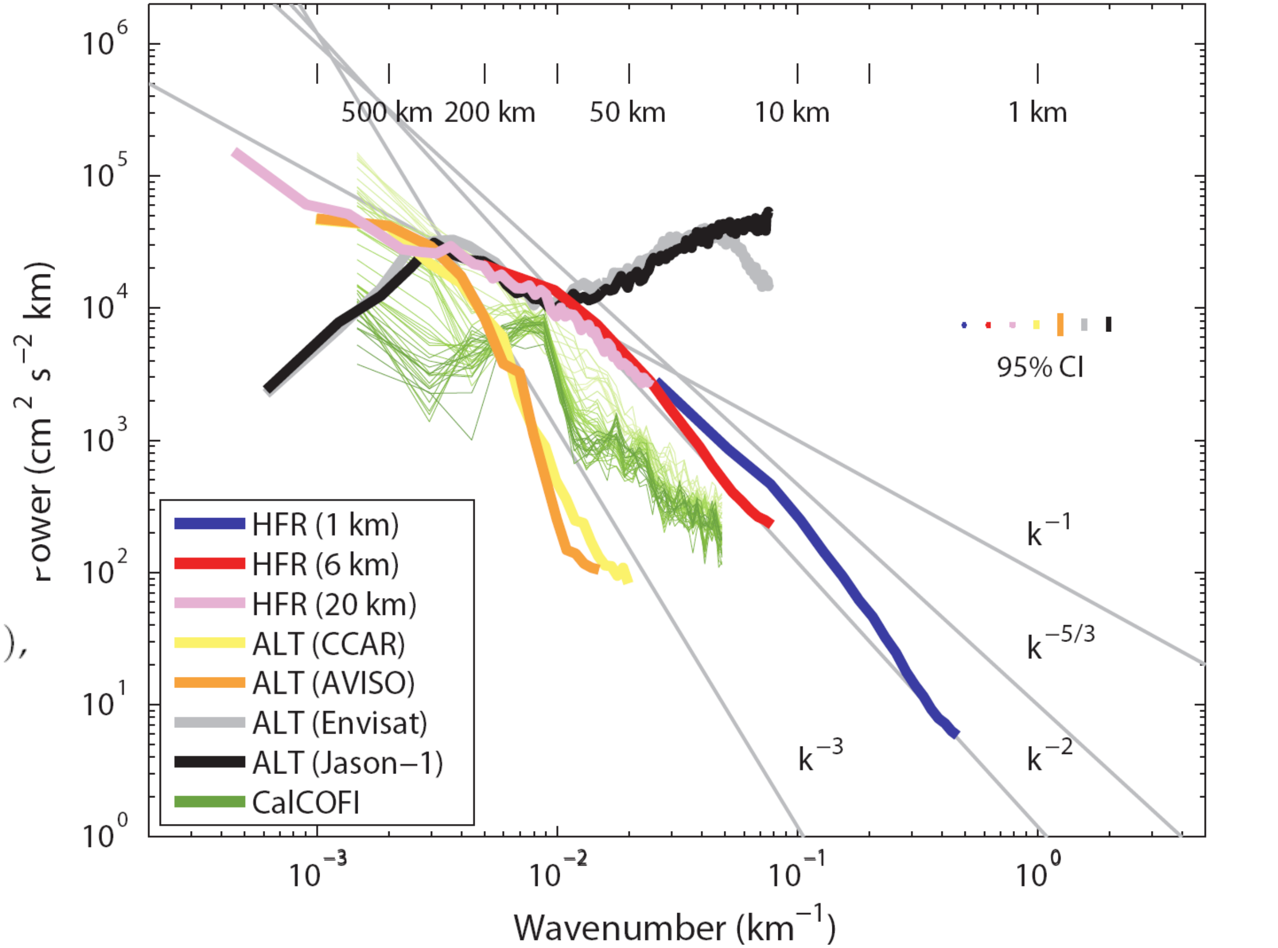
Sampling domain in computation of energy spectra



- 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

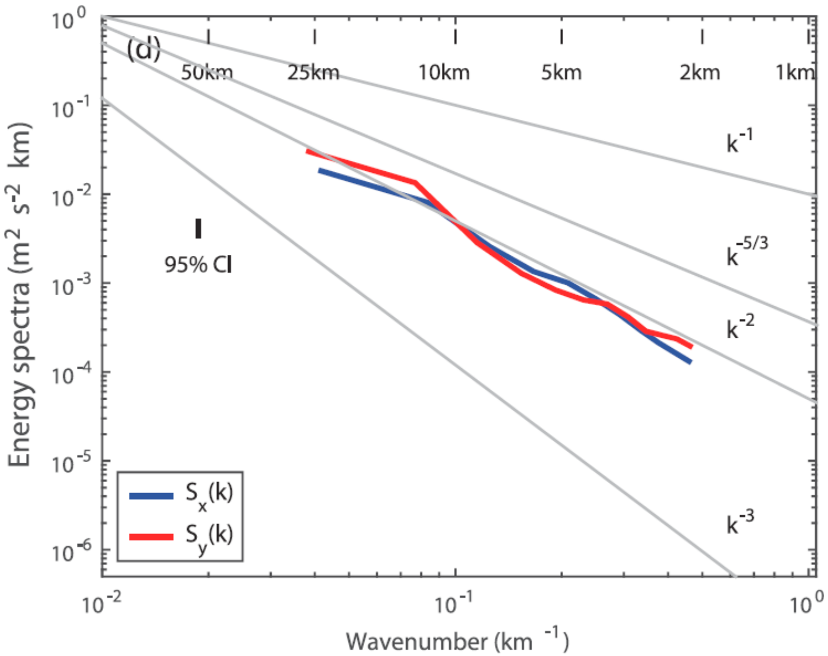
K^{-2} power law related to sub-mesoscale.

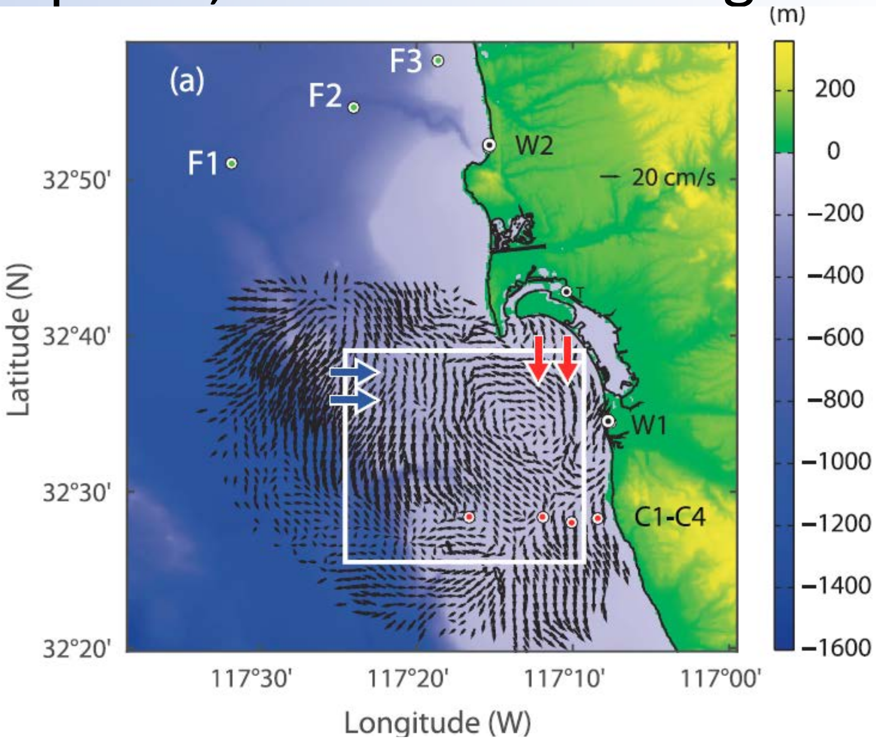
Robust estimate on k-2 spectra with data in other regions.

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 ageostrophic components are expected.
20 km data are from the coastline axis.

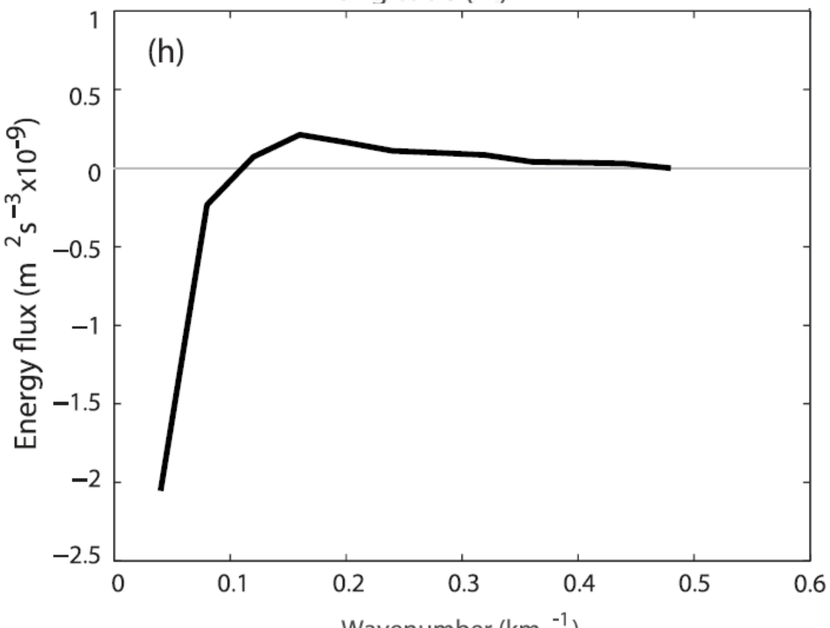
(Kim et al, JGR 2011)

KE spectra and fluxes (an hour snapshot; southern San Diego HFR)



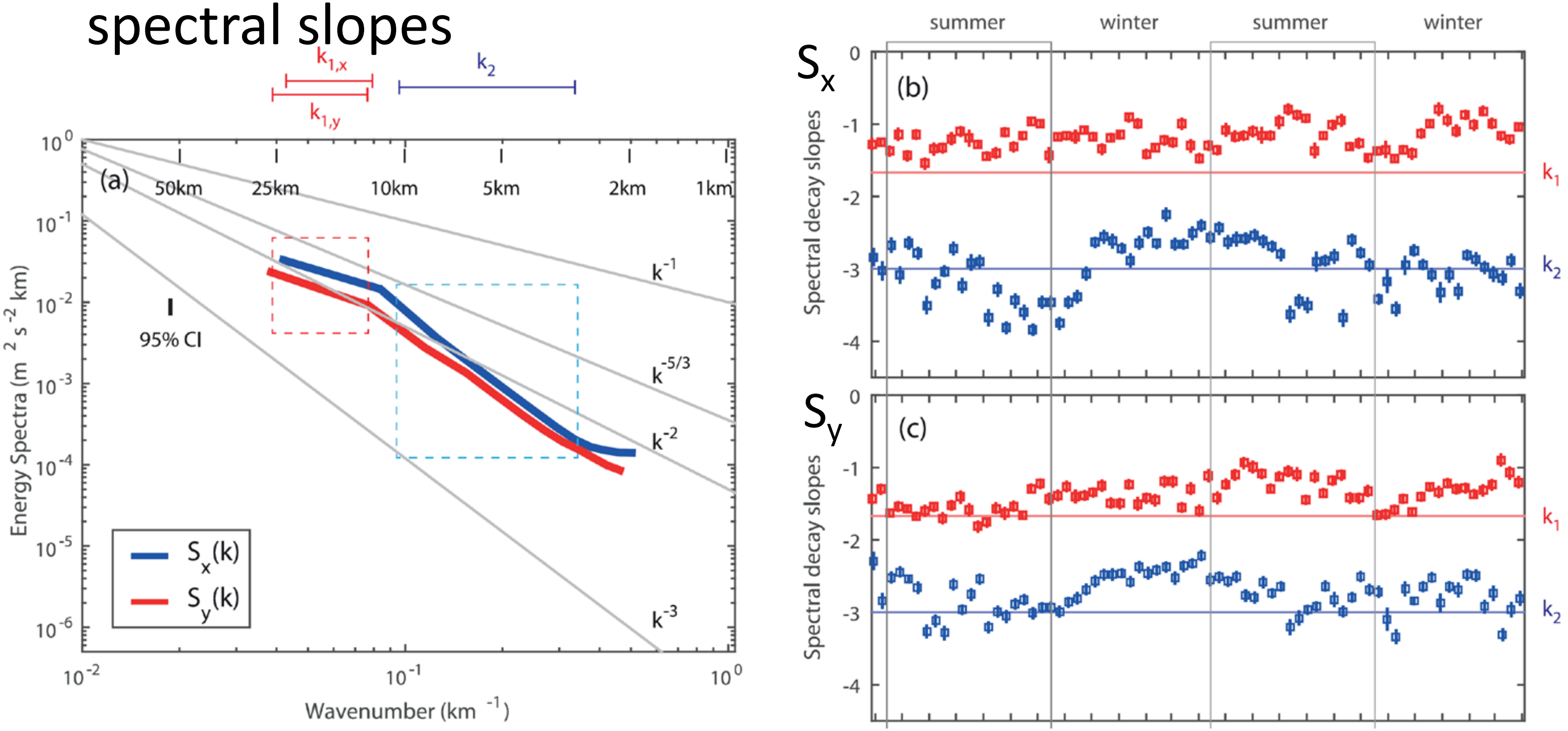


- Decay slopes of KE spectra range are close to k^{-2} (and between k^{-2} and k^{-3} for 2-yr avg.)
- Zero-crossings of KE fluxes appear O(10) km



(Soh and Kim 2017; submitted)

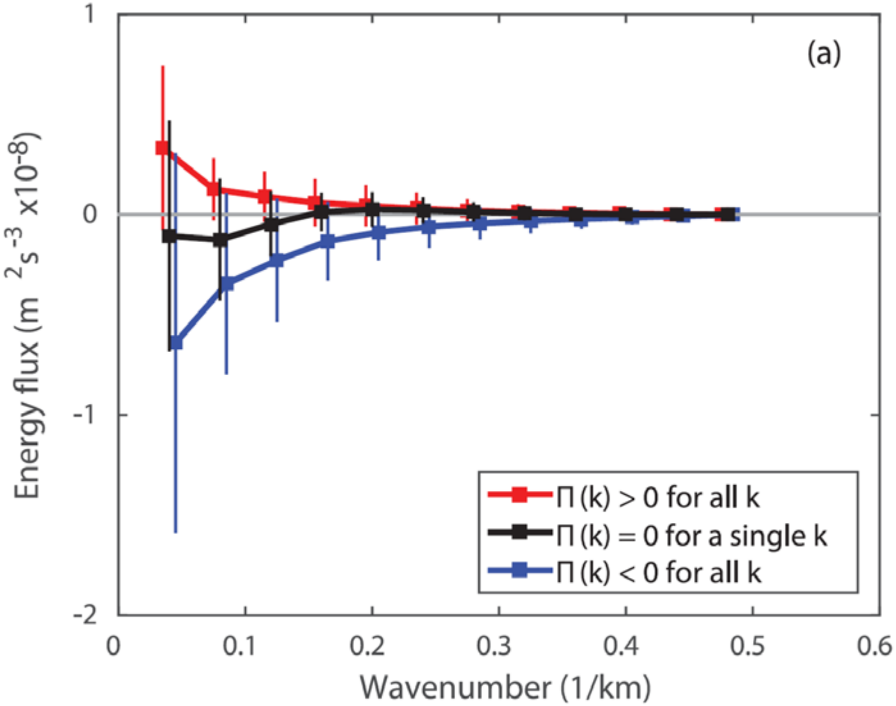
KE spectra (2yr-avg.) and temporal variability of spectral slopes

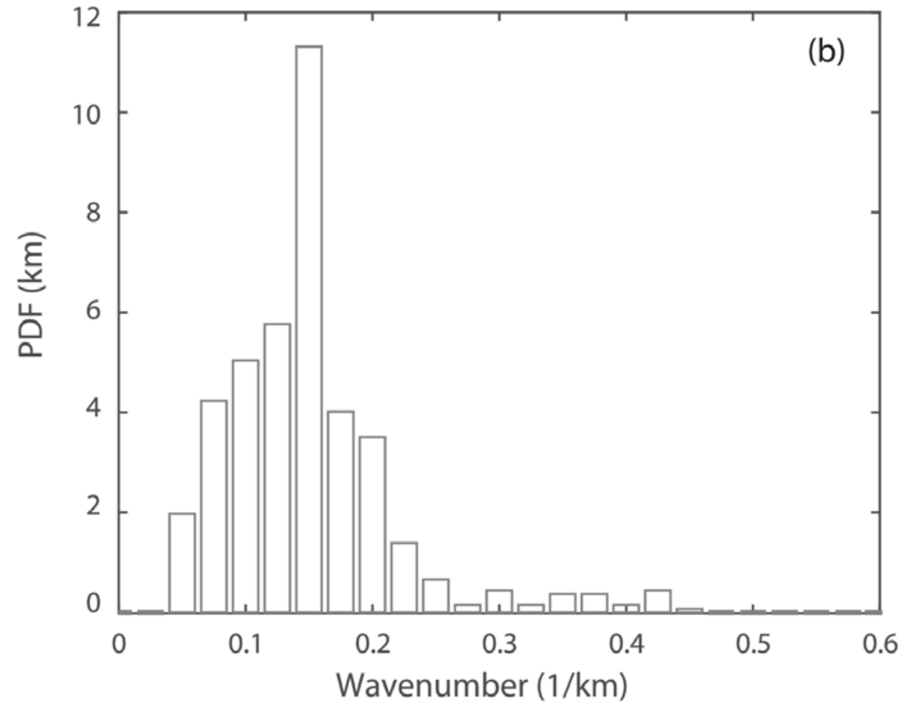


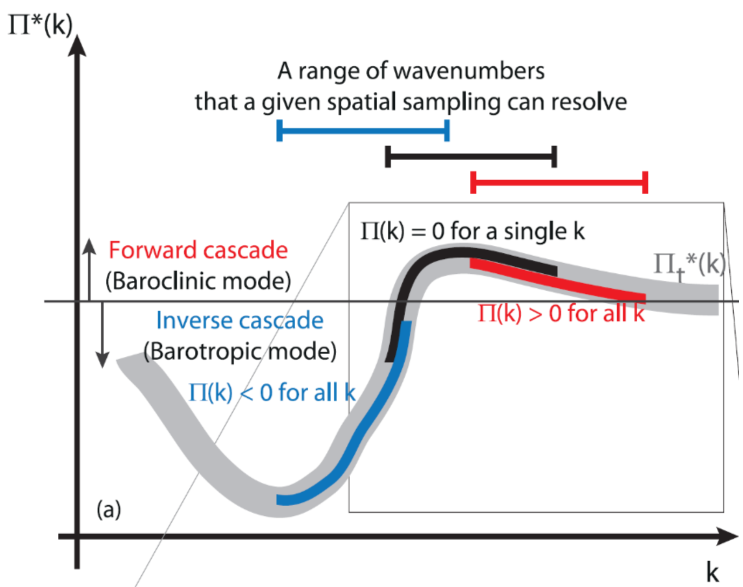
- Anisotropy and weak seasonality in the spectral slopes.
- Callies et al reported the seasonality of slopes appears at the scales of 20-100 km and follows GM below 20 km. (close to k-2)
- Spectral slopes get steeper near O(10)km scale.

(Soh and Kim 2017; submitted)

KE fluxes and PDFs of zero-crossing wavenumbers



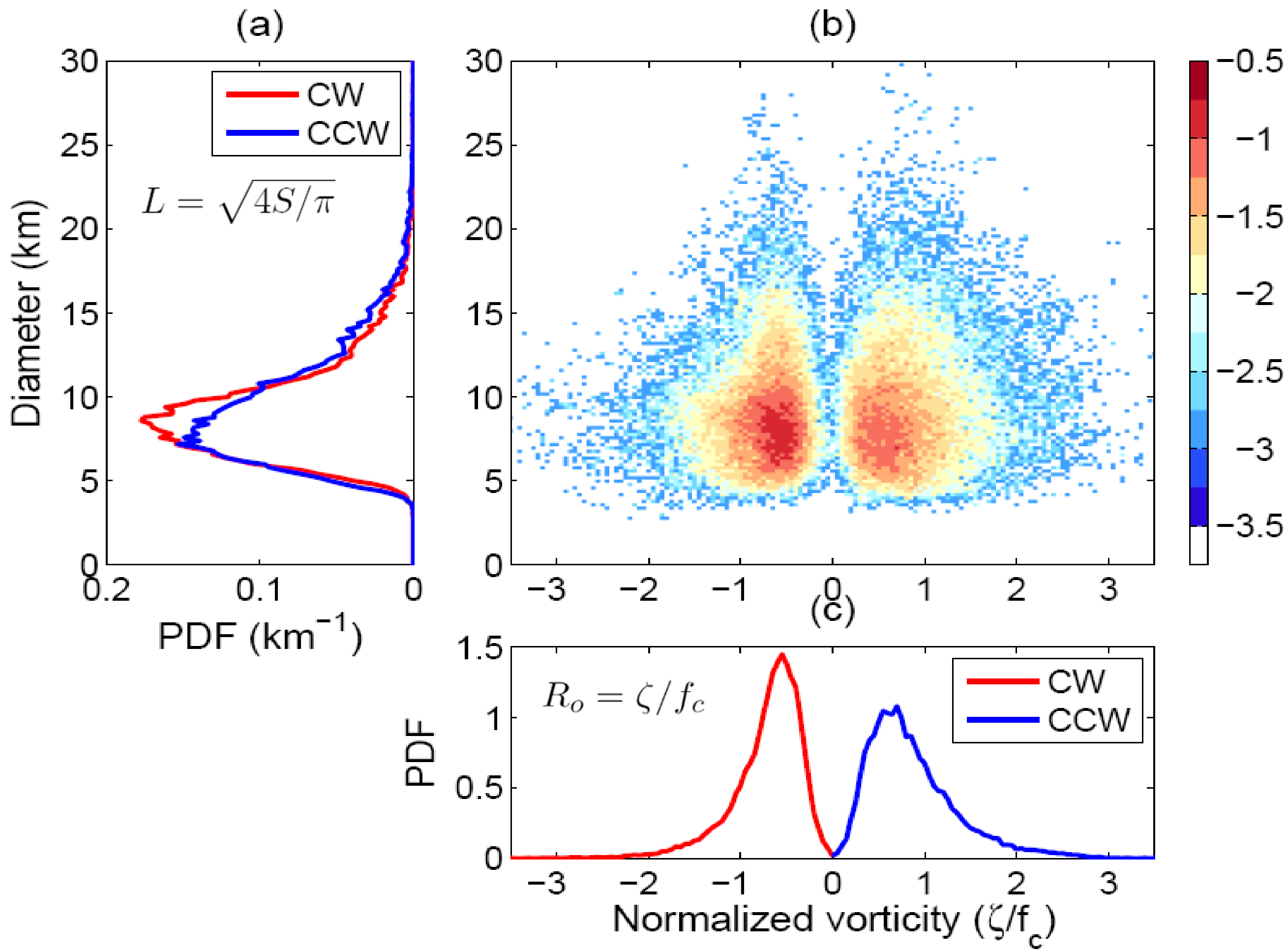




- Injection scales are between 5 to 10 km

(Soh and Kim 2017; submitted)

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

- High-frequency radar-derived surface currents report hourly and O(1) km spatial scale ocean surface's dynamical variables, which can be a tool to examine the submesoscale geophysical turbulence.
- 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.