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

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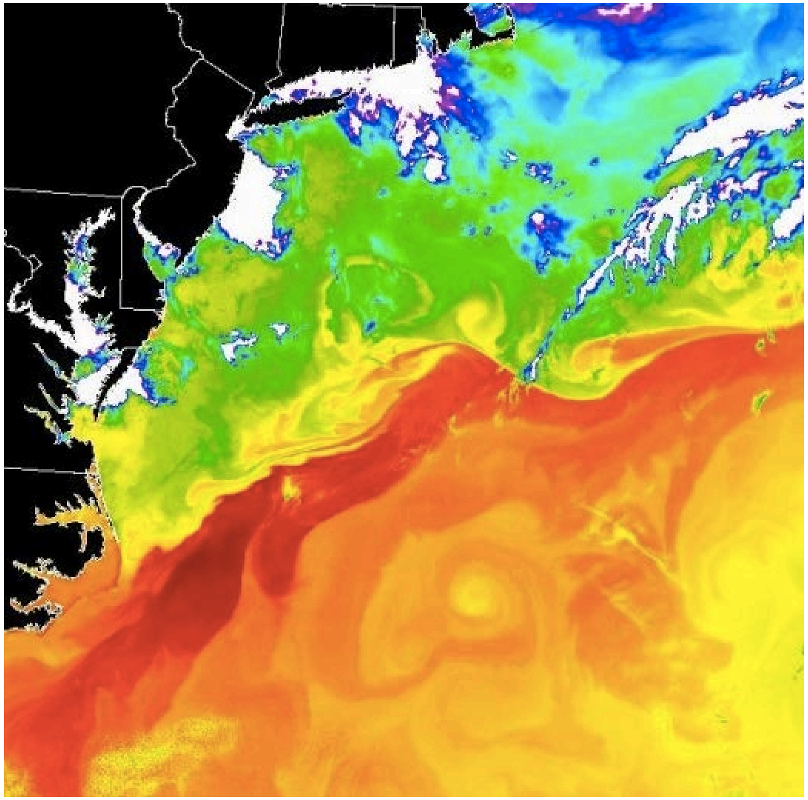
Mesoscale and submesoscale processes

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

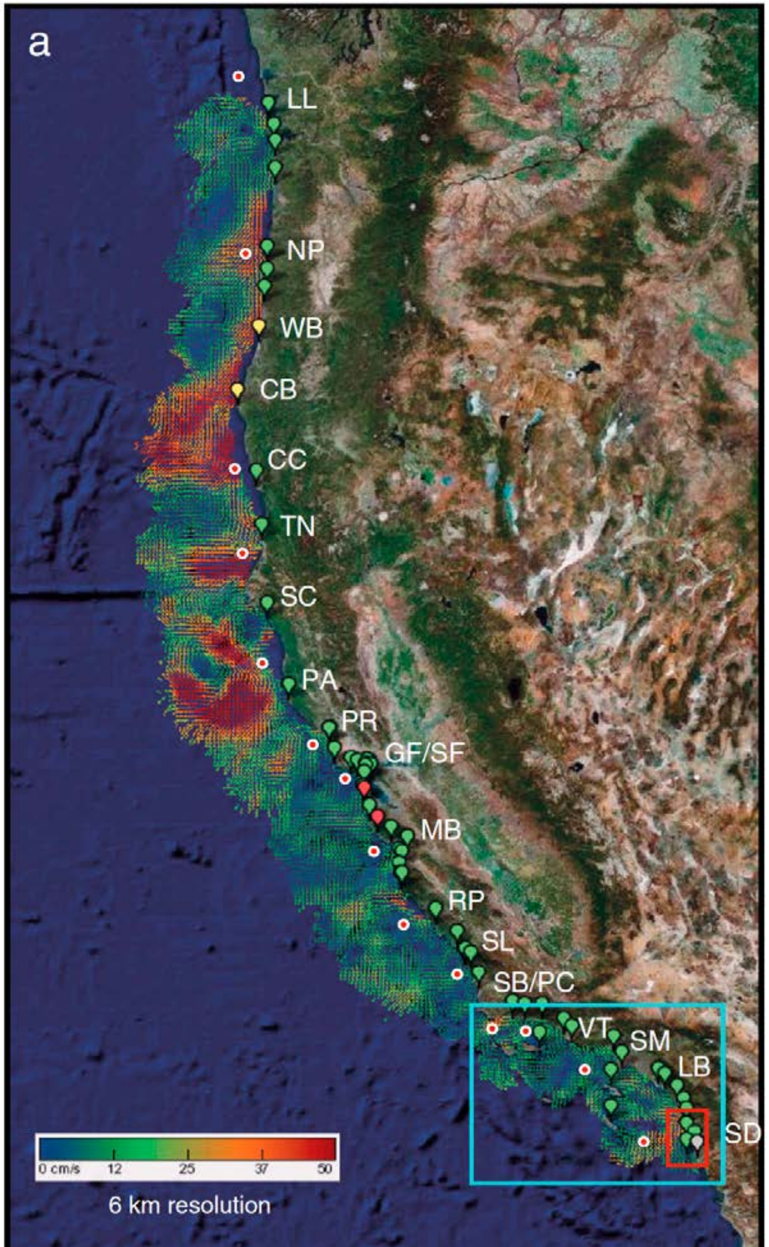


- O(1) Rossby number
- A horizontal scale smaller than the first baroclinic Rossby deformation radius; O(1-10) km
- Frequently observed as fronts, eddies, and filaments
- Potential drivers
  - Baroclinic instability in the mixed layer (mixed layer instability)
  - Frontogenesis associated with mesoscale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

Outline

- An overview of observations
  - US West Coast high-frequency radar network and observed spectral contents
- A science question
- Wavenumber domain kinetic energy spectra and fluxes
  - Surface currents off southern San Diego (USA)
  - Surface currents and chlorophyll concentrations off East/Japan Sea (Korea)
- Summary

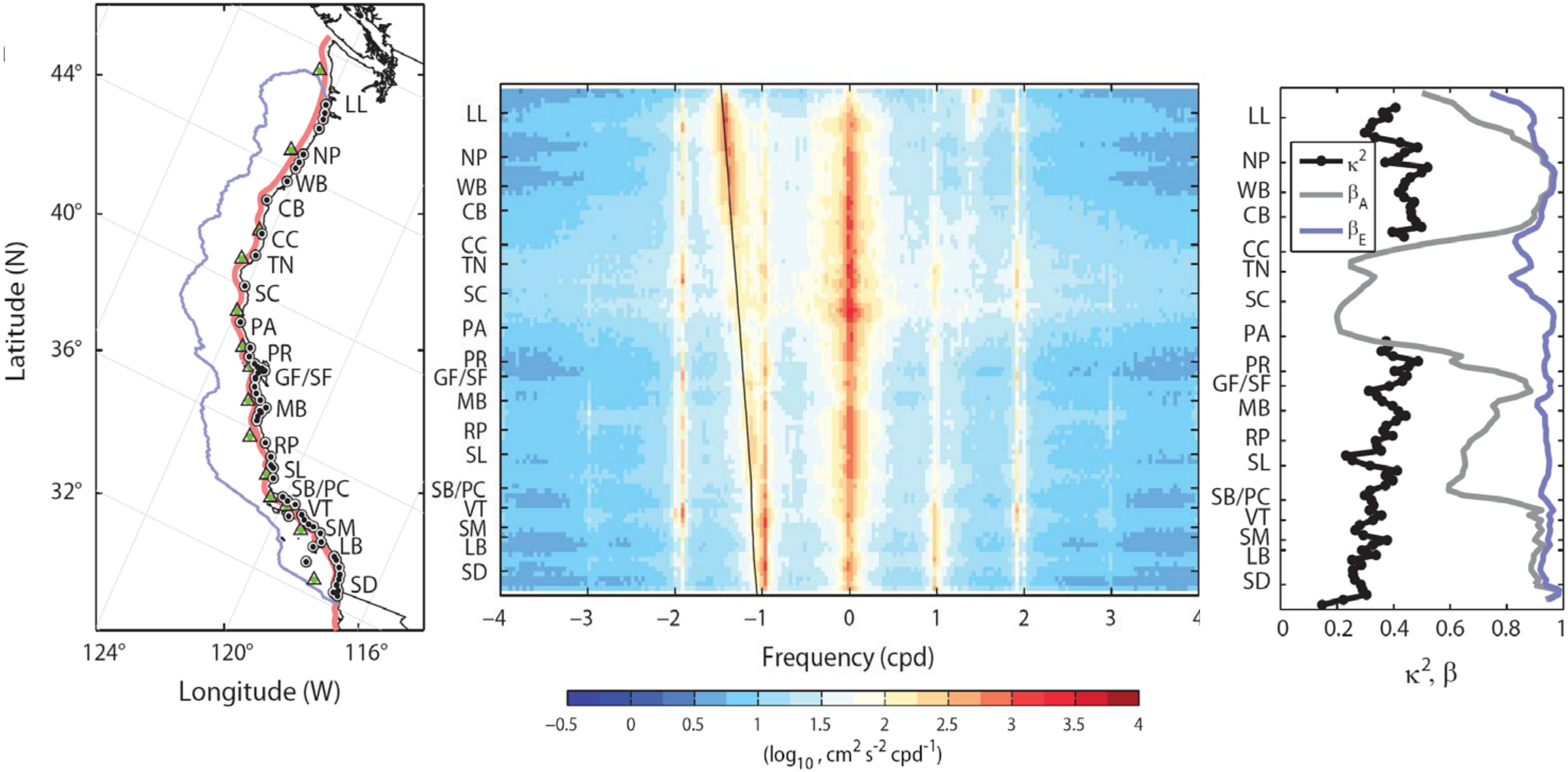
USWC HFR-derived surface currents



- 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)

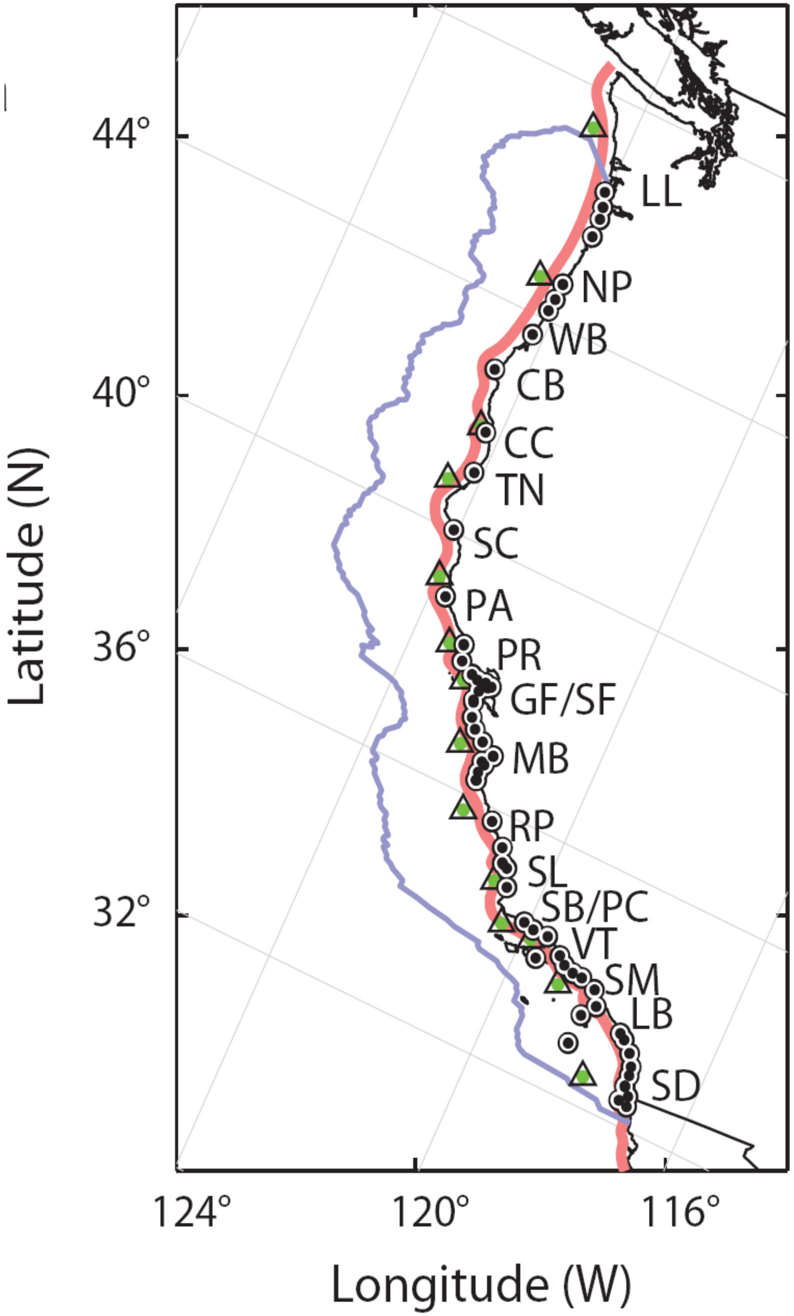
Variance of surface currents (alongshore view)

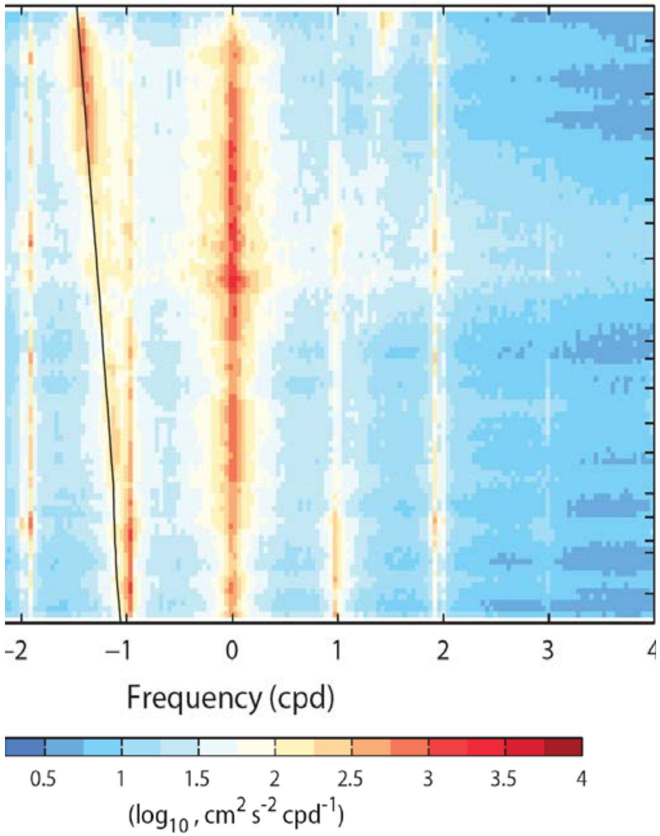


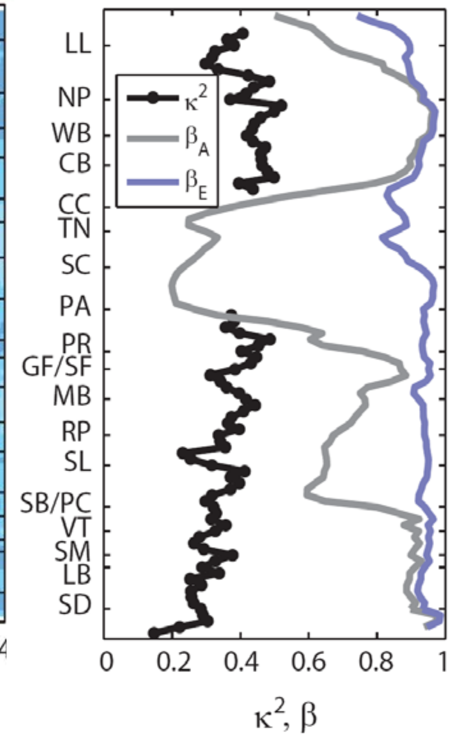
- 60+ compact array HFR (CODAR) system
- Hourly surface current maps (0.5, 1, 2, and 6 km resolution)
- Upper 1 m depth averaged currents
- From nearshore to 50 - 150 km offshore

(Kim *et al*, JGR 2011)

Variance of surface currents (alongshore view)

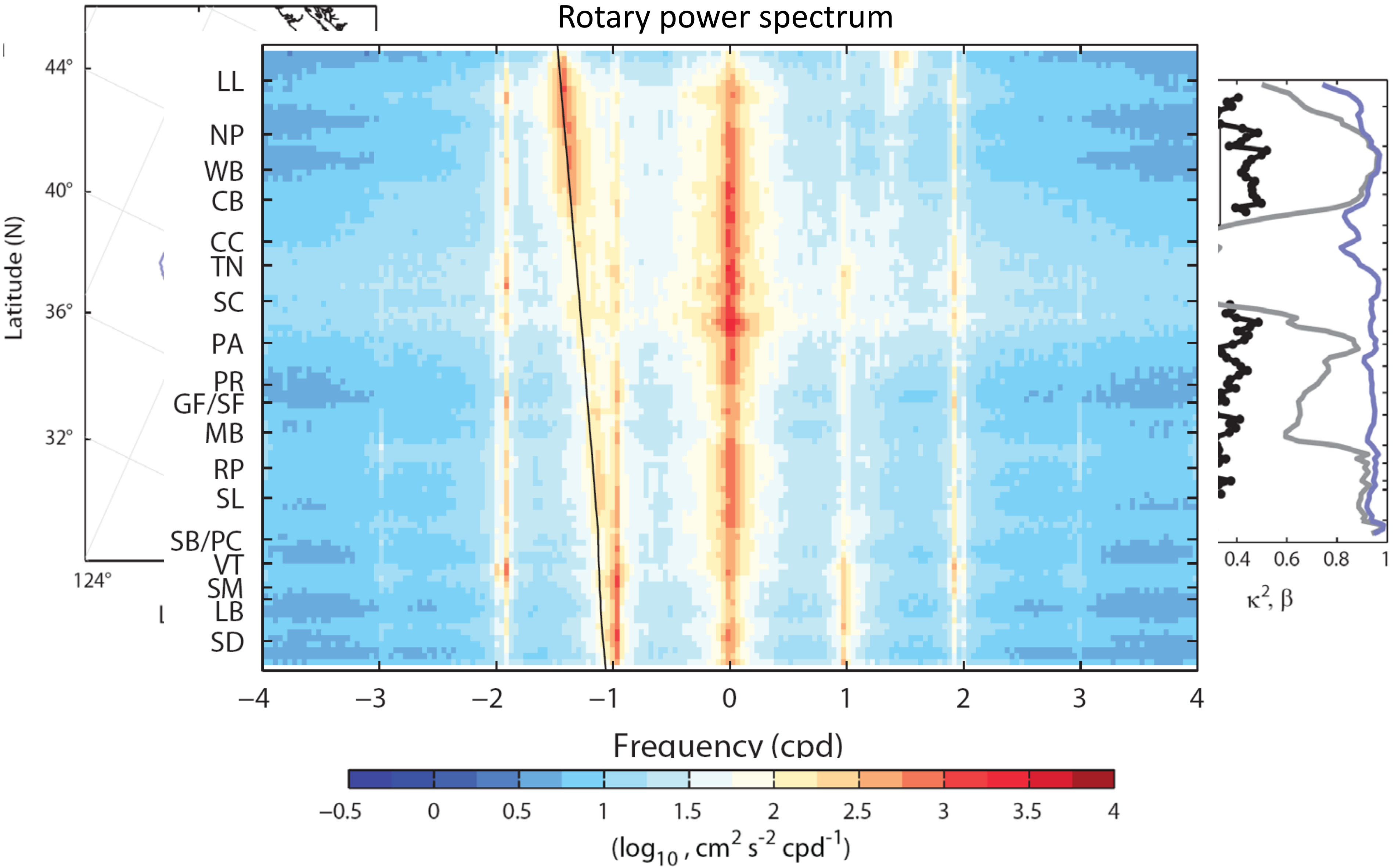






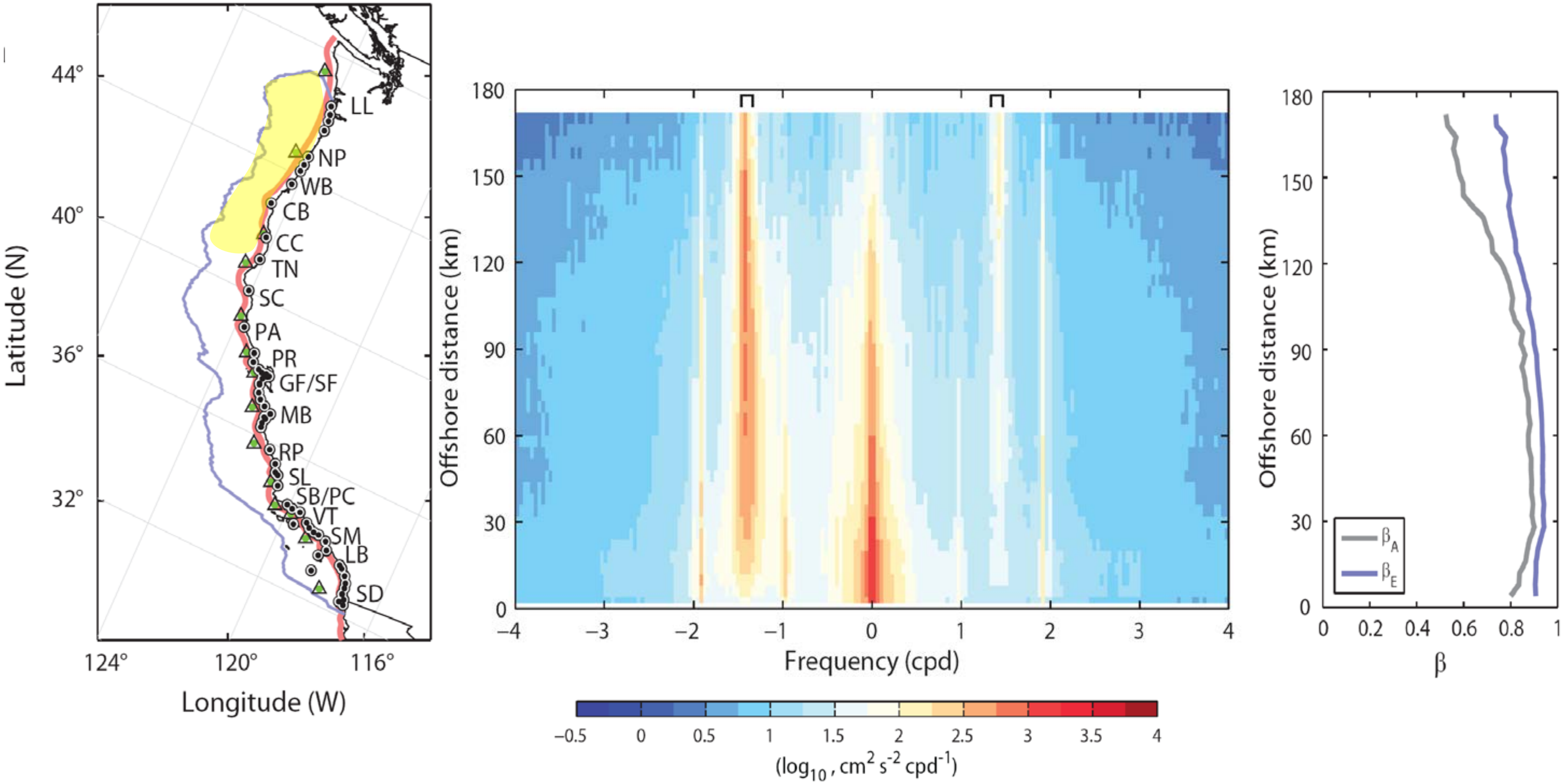
- 61 HFRs, 14 NDBC wind buoys hourly observations (2007 to 2008)
- Effective spatial coverage (blue; 6 km) and coastline axis (red; 25 km apart from shoreline)

Variance of surface currents (alongshore view)



- Variance coherent with tides, wind, low frequency signals, and Coriolis force.
- Regional noise levels

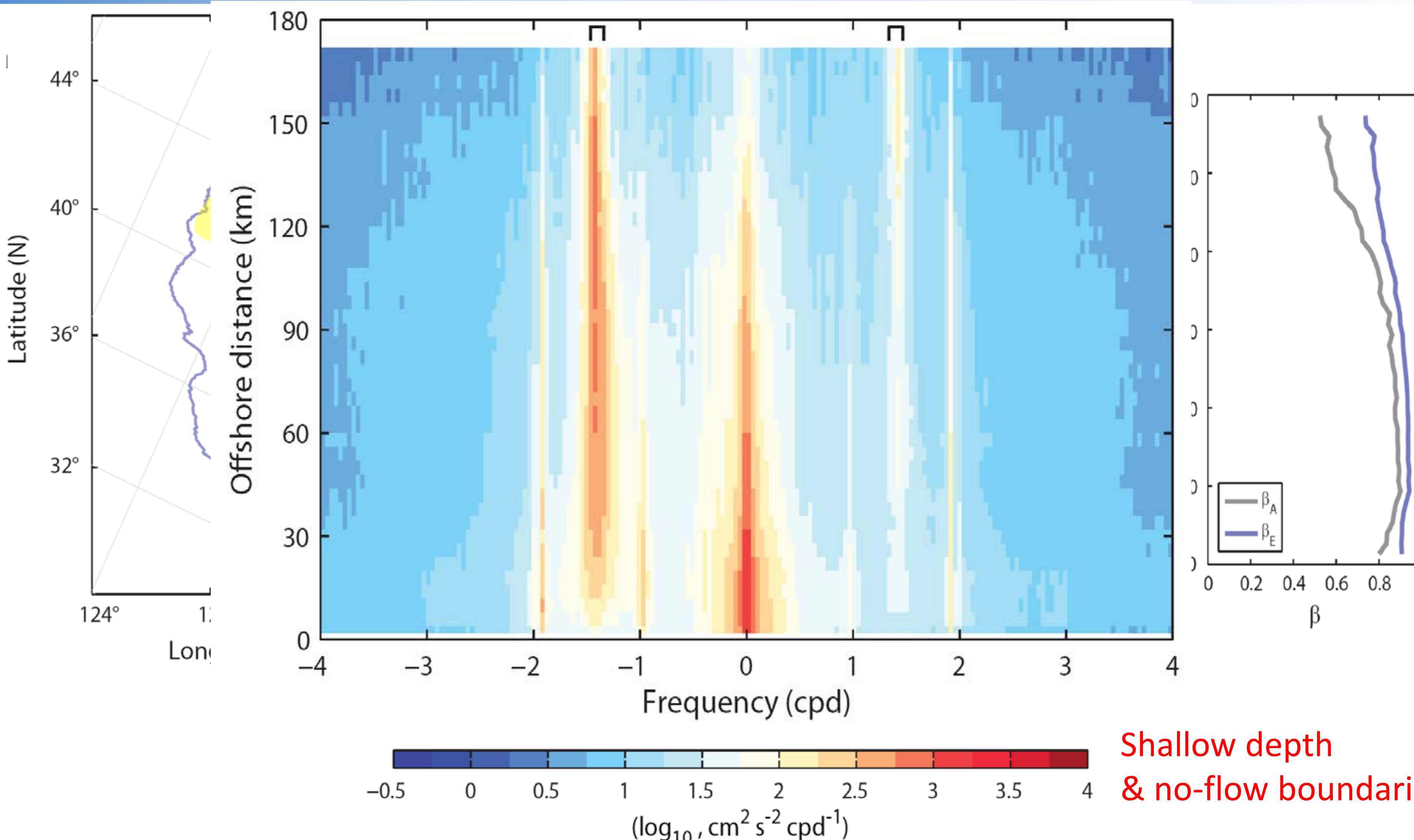
Variance of surface currents (cross-shore view)



- Cross-shore variation of tide-, wind-, low frequency-forced energy
- Low frequency pressure setup against the coast
- Inertial variance gets narrow offshore
- Variance of tide-coherent currents decrease with offshore distance

(Kim *et al*, JGR 2011)

Variance of surface currents (cross-shore view)

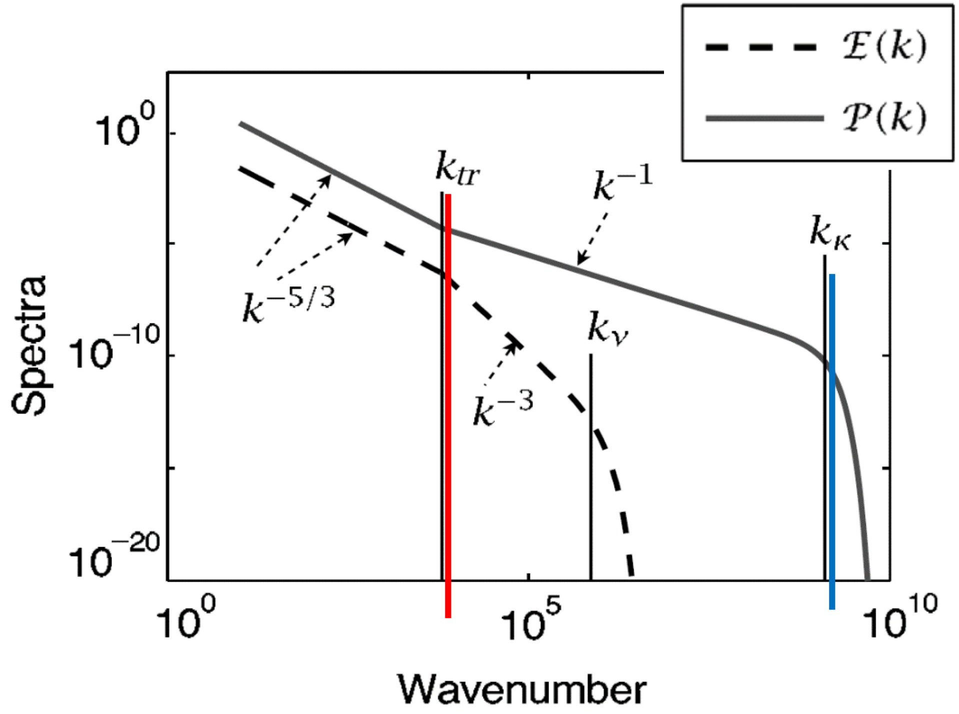


Shallow depth
& no-flow boundaries

- Cross-shore variation of tide-, wind-, low frequency-forced energy
- Low frequency pressure setup against the coast
- Variance of tide-coherent currents decrease with offshore distance.
- Inertial variance gets narrow offshore

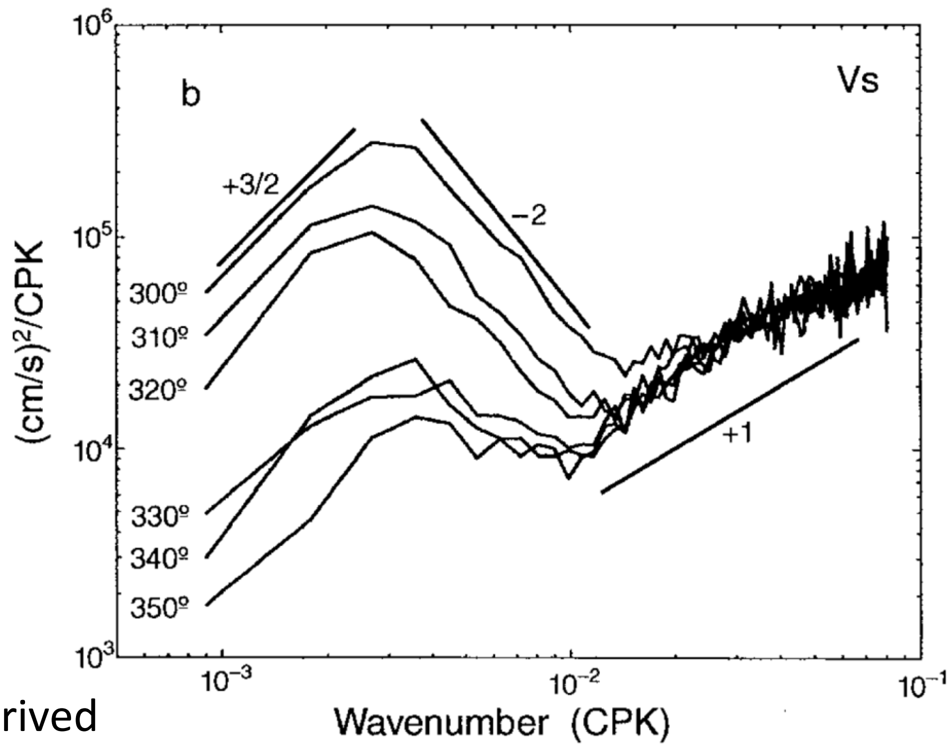
(Kim *et al*, JGR 2011)

Kinetic energy (KE) spectra



(Vallis, 2000; not scaled; 2D turbulence)

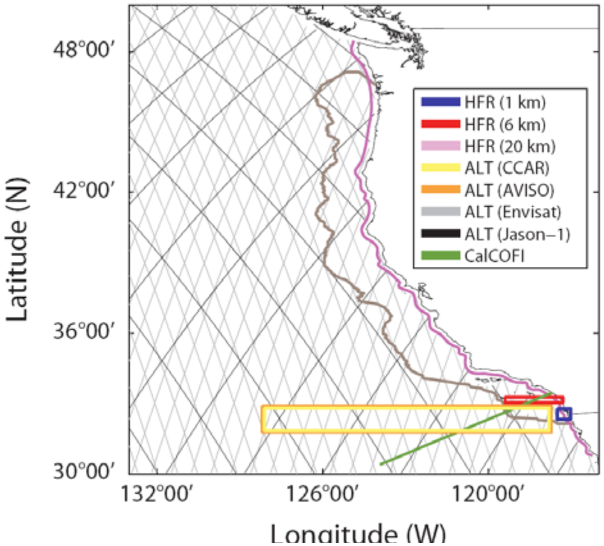
- Kinetic energy (KE) spectra of currents [E(k)] and spectra of passive tracers [P(k); CHL]
- Transition (injection) scale and dissipation scale



- What can be the decay slope of KE spectra below 100 km scale?

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

Kinetic energy spectra (USWC HFR)

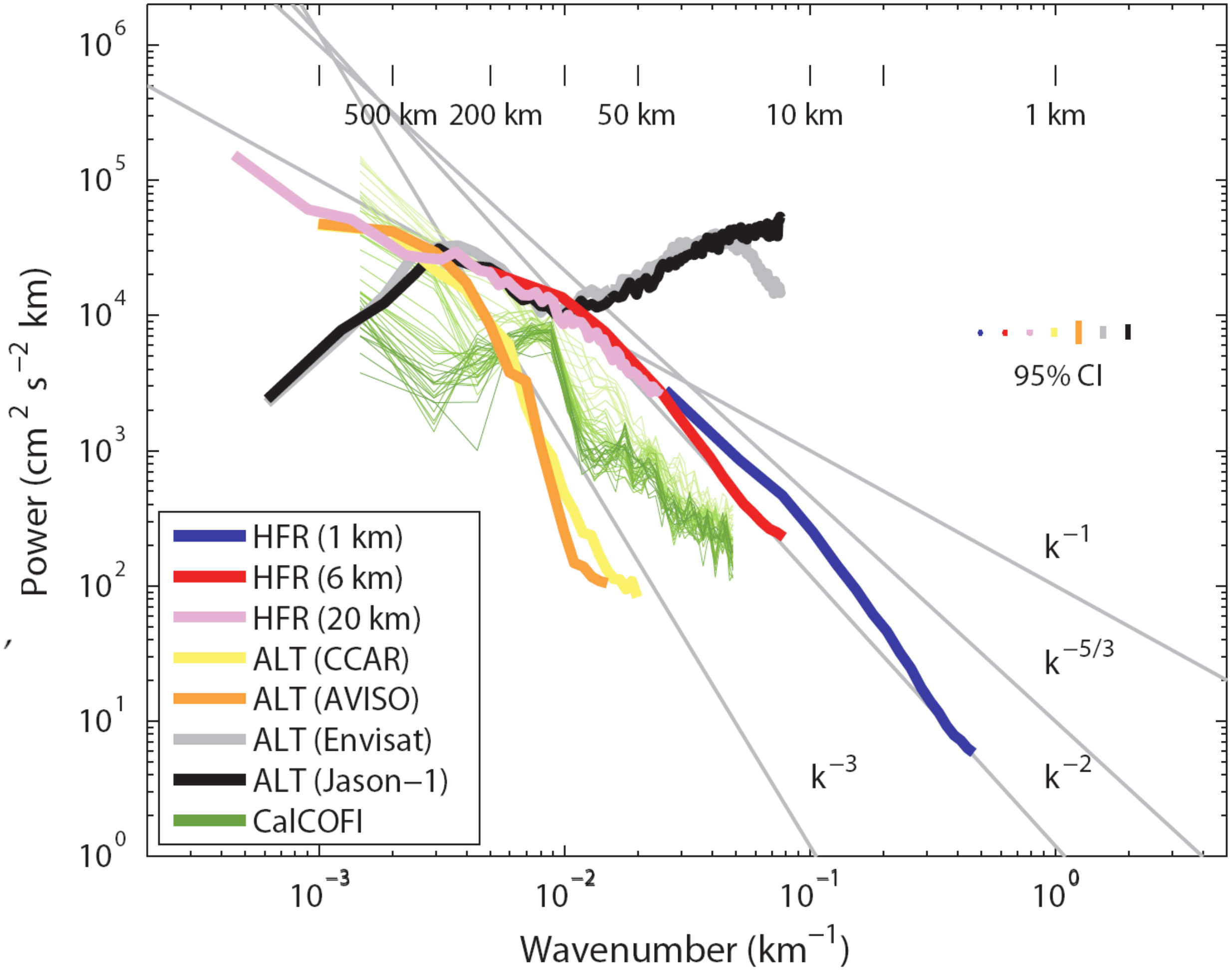


$$S_{\mathbf{u}_\perp}(k_\parallel) = \left(\frac{g}{f_c}\right)^2 \left(2\pi k_\parallel\right)^2 S_{\boldsymbol{\eta}_\parallel}(k_\parallel),$$

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

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

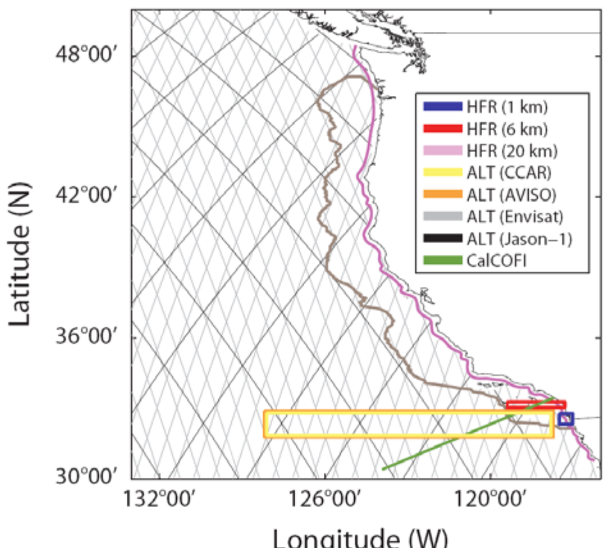
Robust estimate on k-2 spectra with data in other regions.



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)

Kinetic energy spectra (1D; +Spray)



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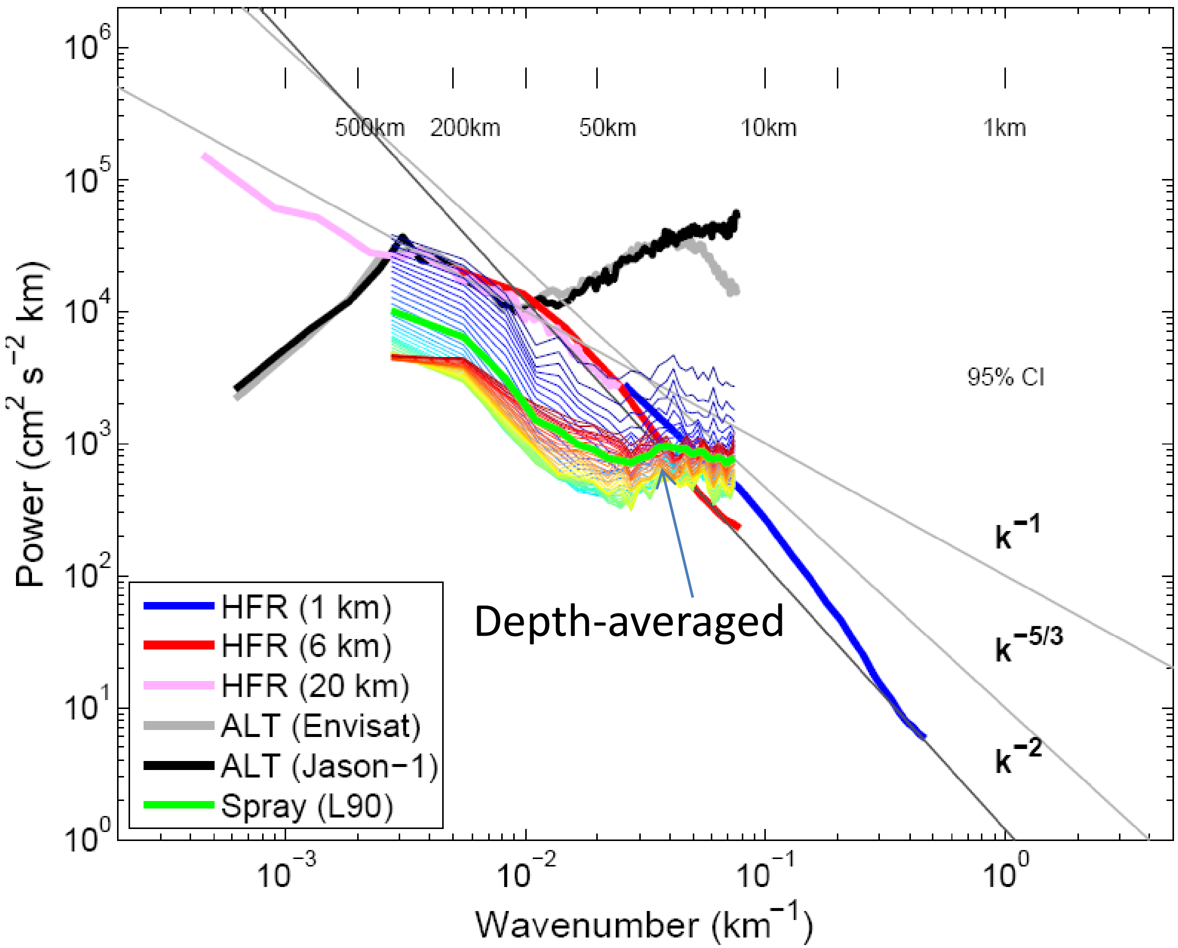

Two kinds of ALT data: Envisat and Jason-1
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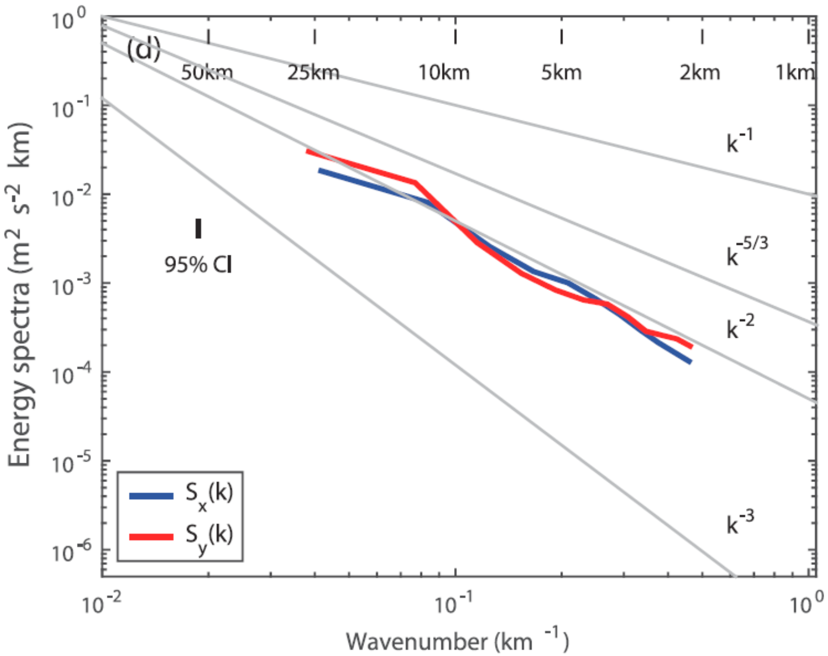
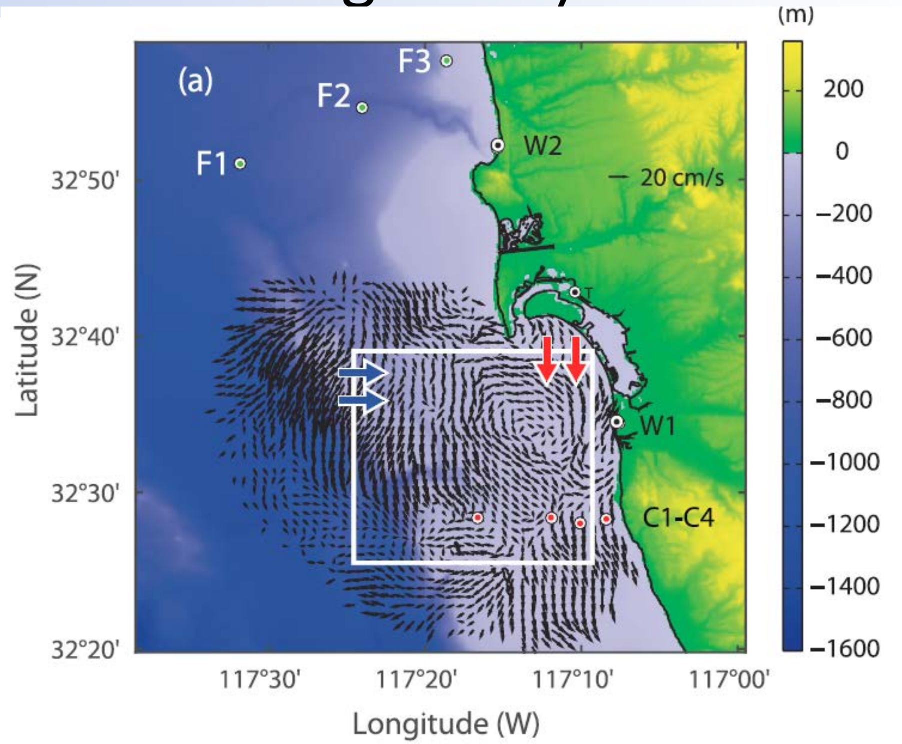
KE spectra and fluxes (southern San Diego HFR)

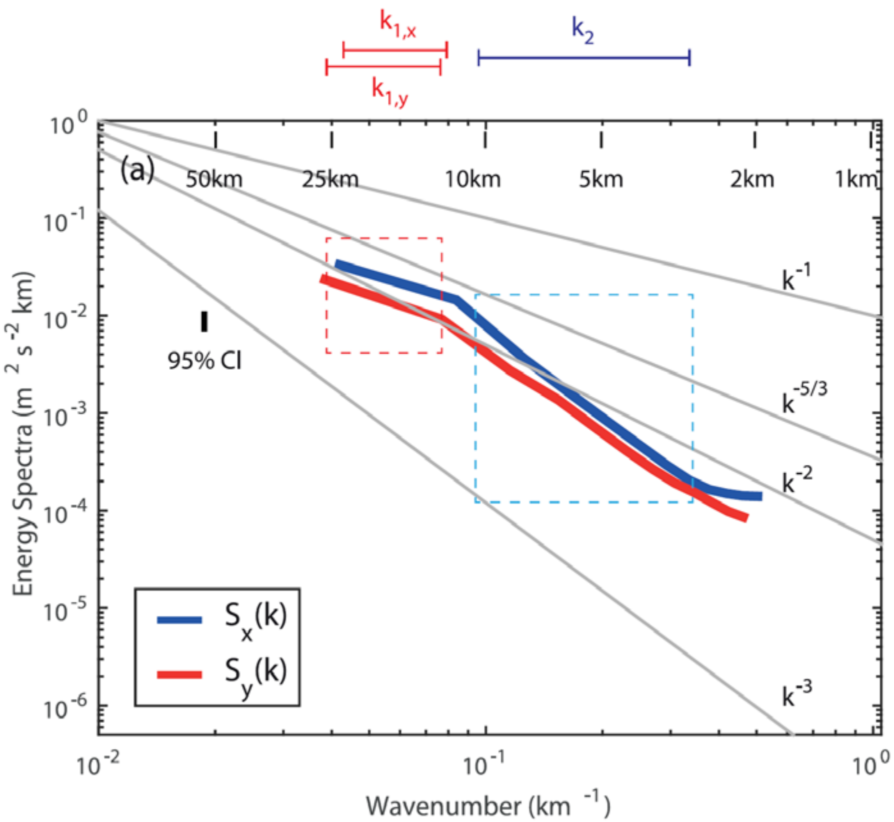


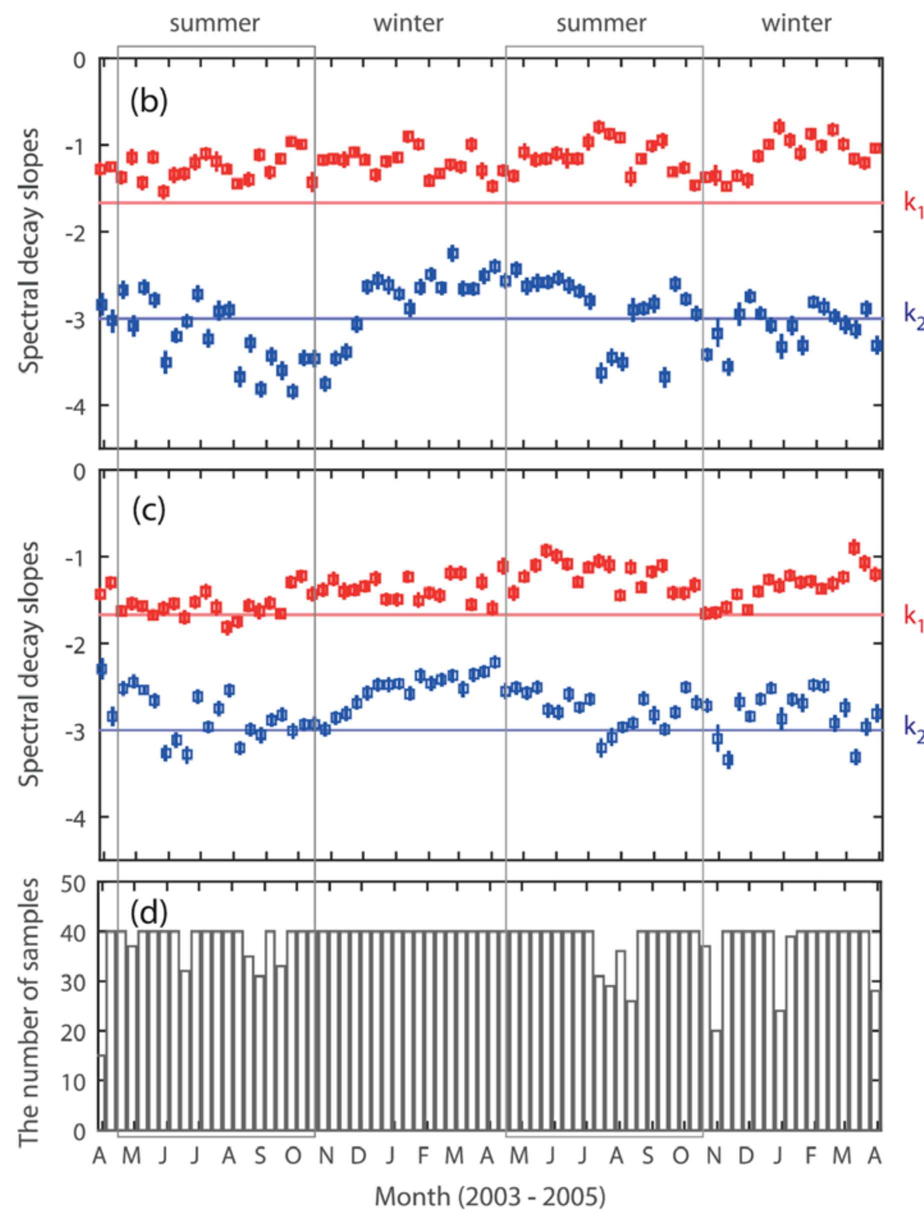


- Decay slopes of KE spectra range between k^{-2} and k^{-3}
- Zero-crossings of KE fluxes appear O(10) km

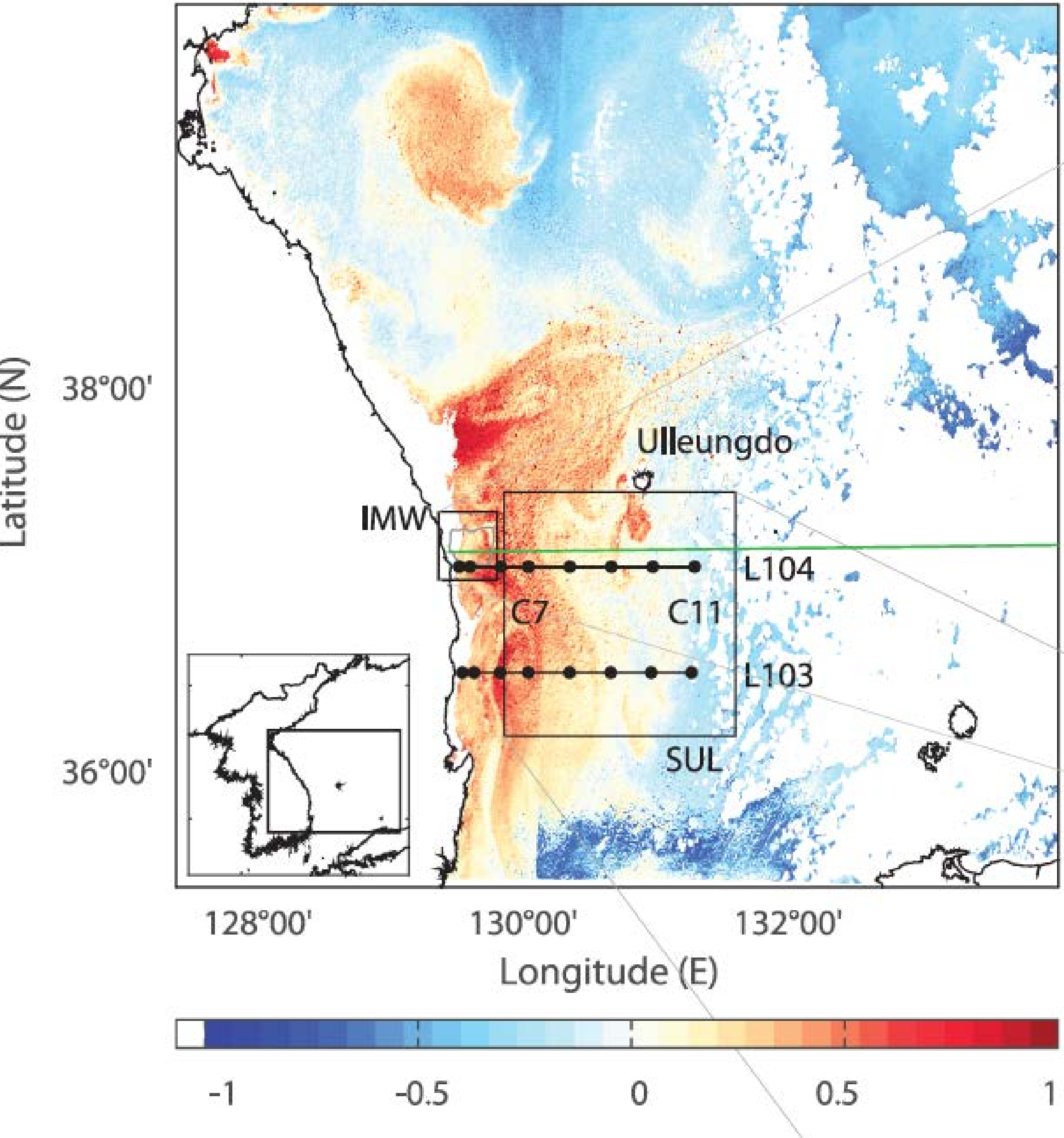
(Soh and Kim 2018 JGR)

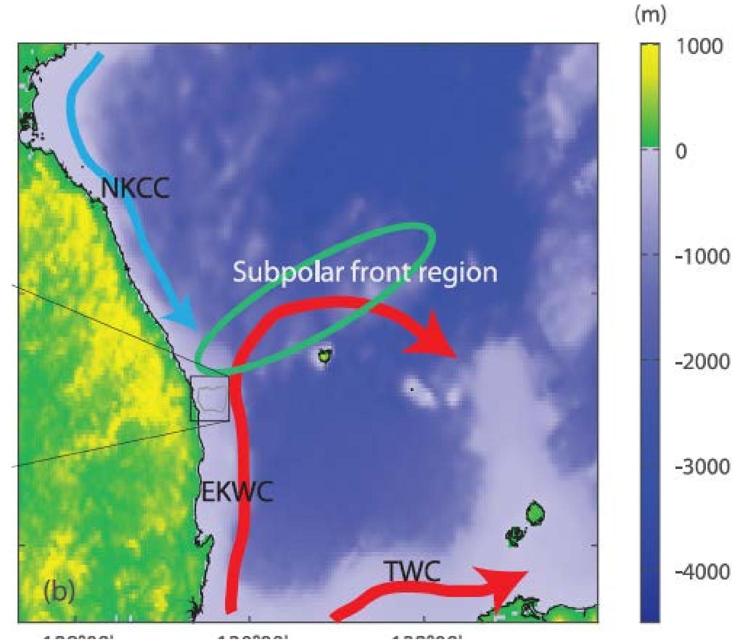
Temporal variability of spectral decay slopes





Study domain and observations (1/2)

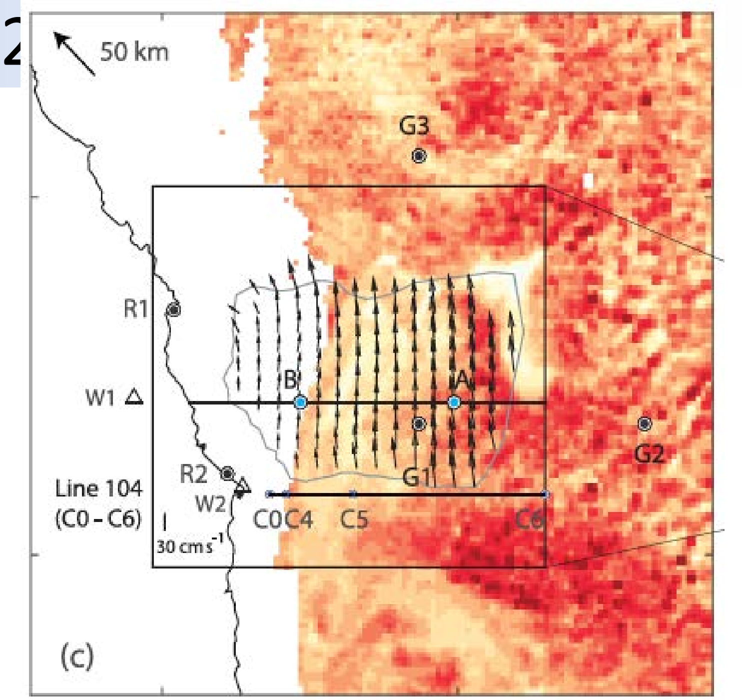


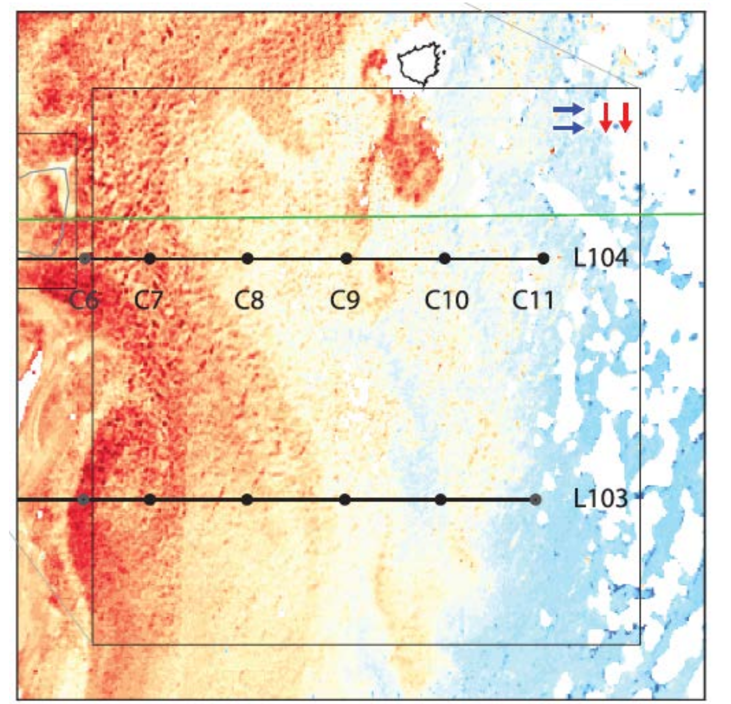


- Surface currents are observed at the verge of the confluence of two regional boundary currents

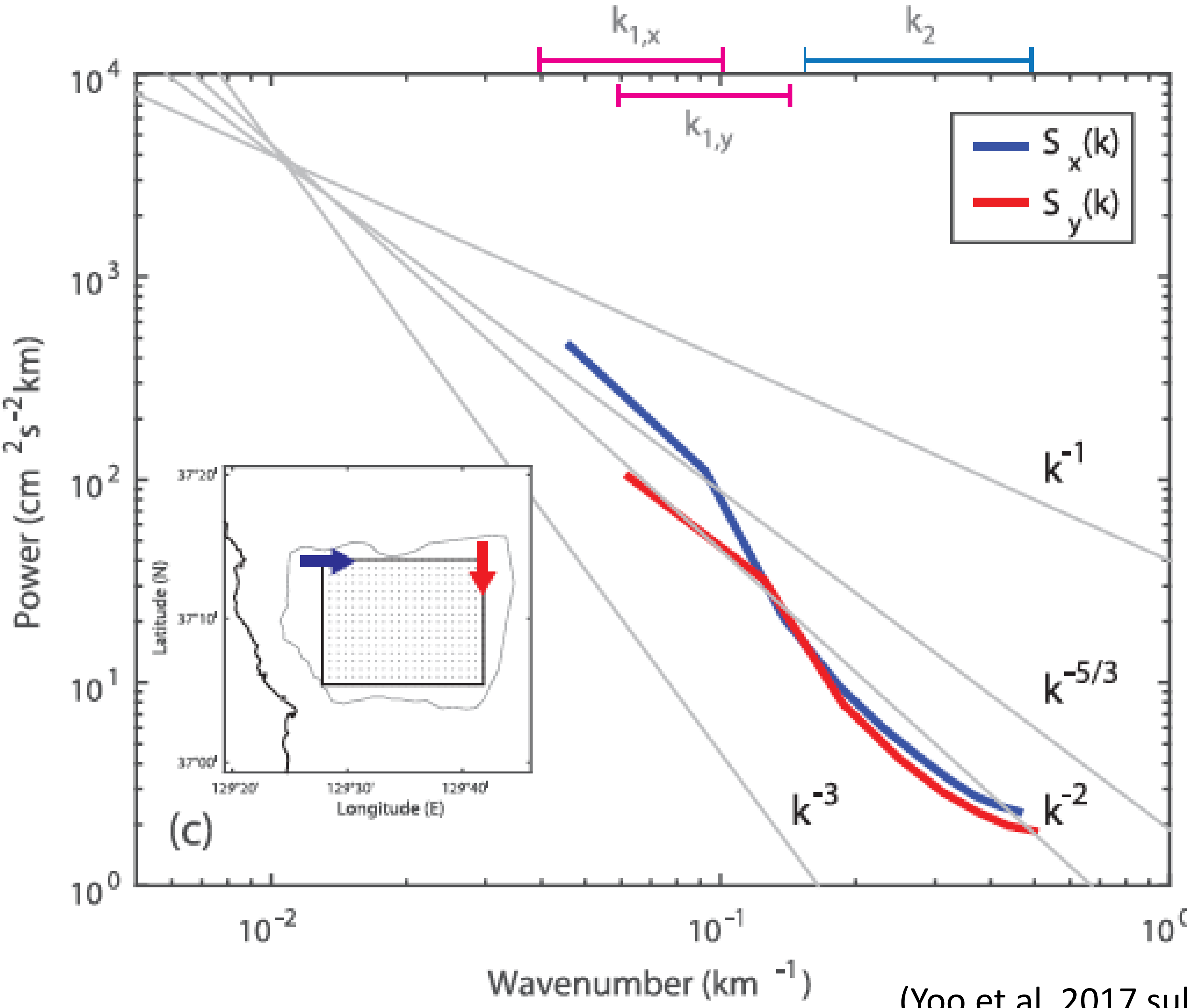
Study domain and observations (2/2)

- Hourly and 1-km resolution HFR-derived surface currents for one year (2013)
- Geostationary Ocean Color Imagery (GOCI)-derived chlorophyll data at resolutions of an hour (during a day; approx. 8 samples a day) and 0.5 km for 5 years (2011 to 2015)
- Bi-monthly CTD (temperature, salinity, and nutrients) sampling at the C0 to C11 stations (1960 to currents) are used to derive the climatology of stratification.



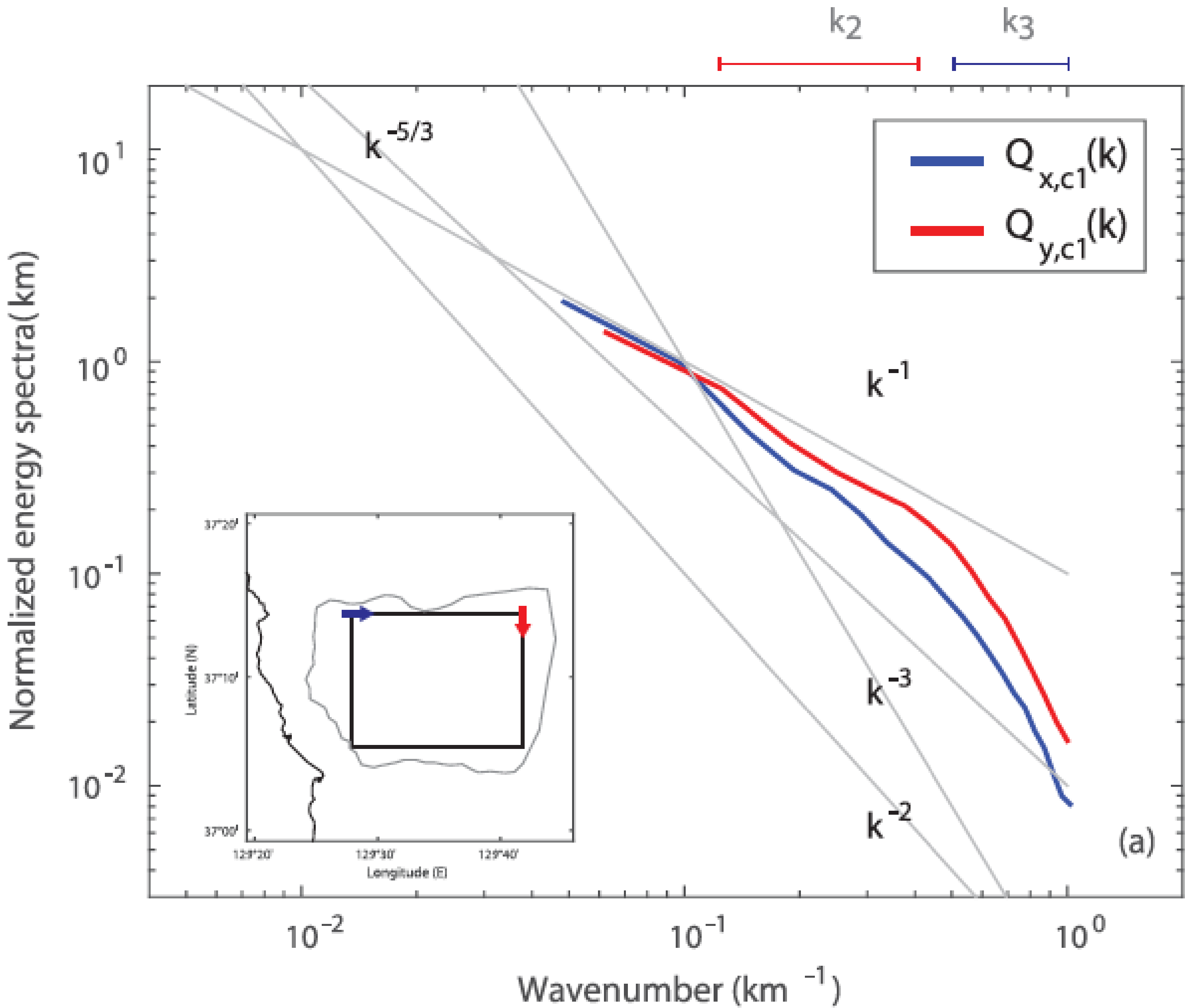


KE spectra of submesoscale surface currents



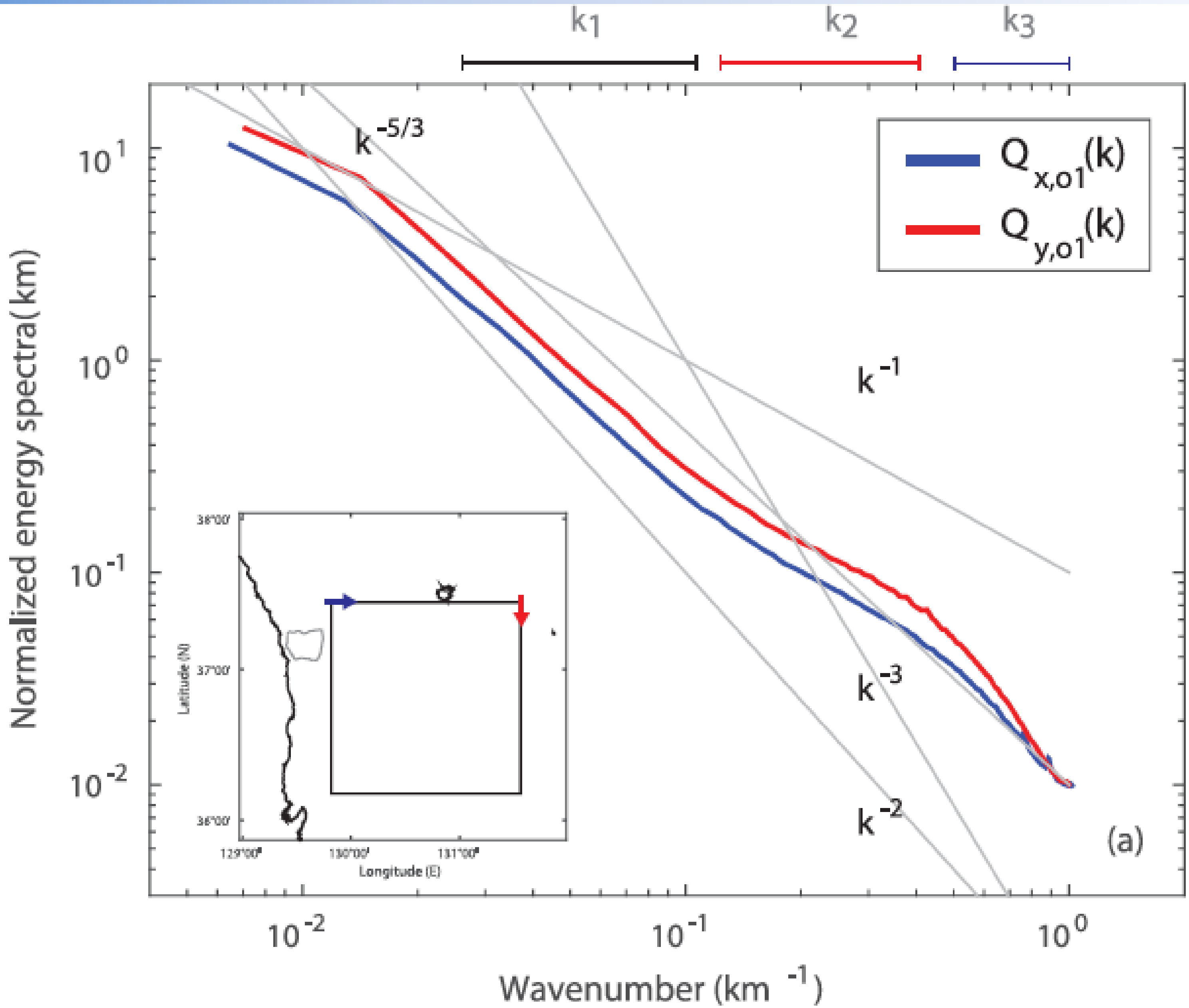
(Yoo et al, 2017 submitted)

Spectra of submesoscale surface CHLs (1/2)



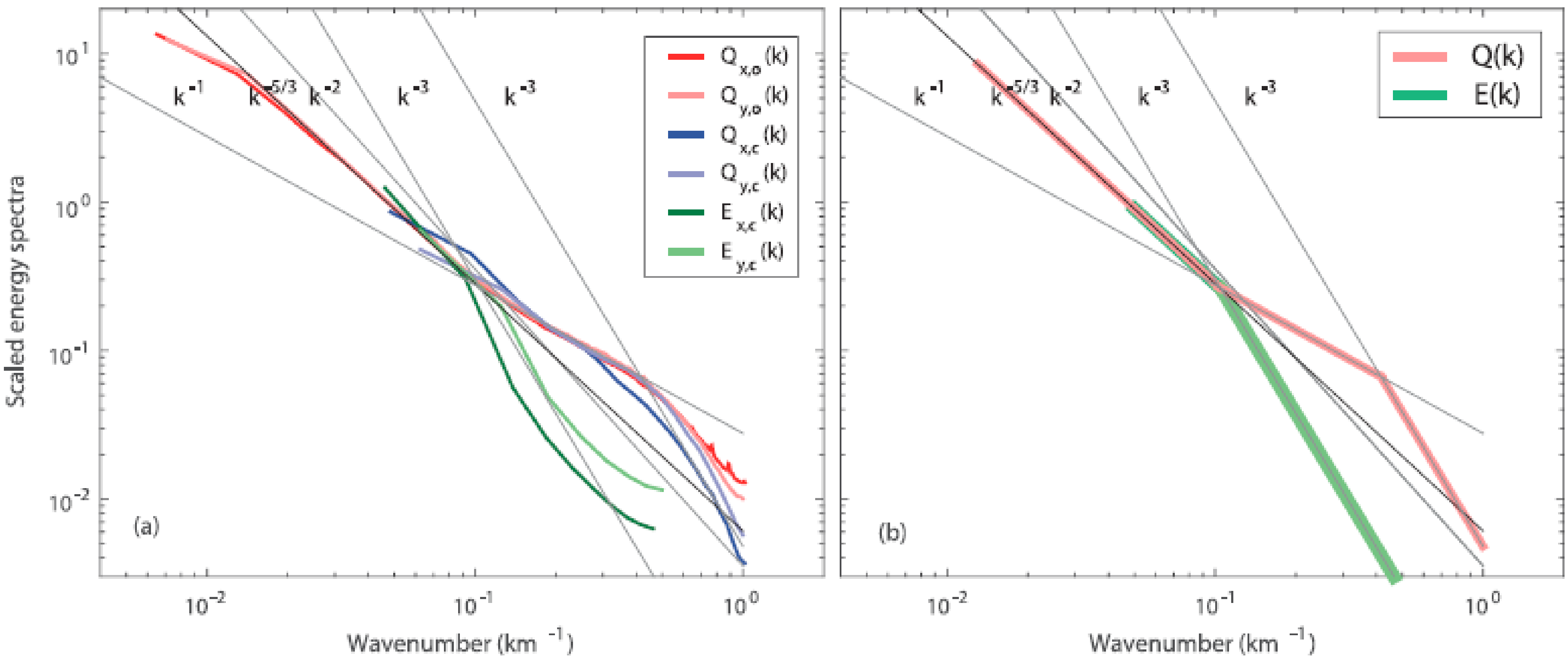
(Lee and Kim, 2017 submitted)

Spectra of submesoscale surface CHLs (2/2)

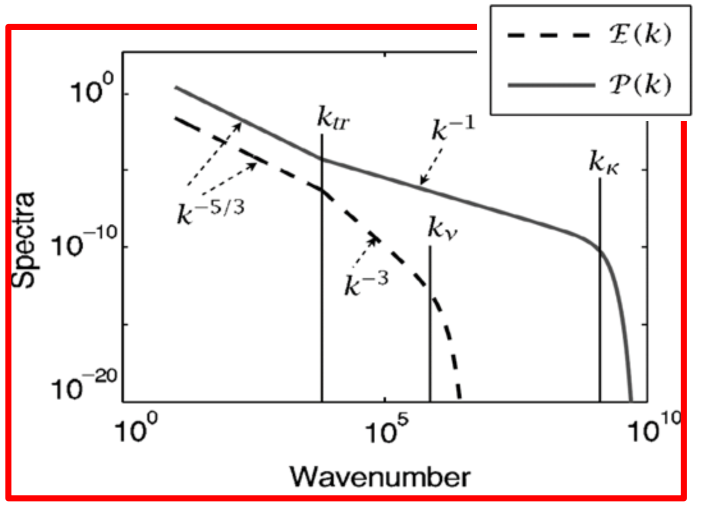


(Lee and Kim, 2017 submitted)

Scaled (KE) spectra of surface currents and CHLs



- Transition and dissipation scales appear near 10 km and 2 km, respectively



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.
- Consistently, the spectra of passive tracers (CHL) exhibit the injection scale of ~10 km and dissipation scale of ~ 2 km under a cautionary consideration of the use of bloomed CHLs as a passive tracer.
- Both results are more consistent with quasi-geostrophic (QG) turbulent theory than others (sQG, semi-QG, fsQG, etc).
- 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.