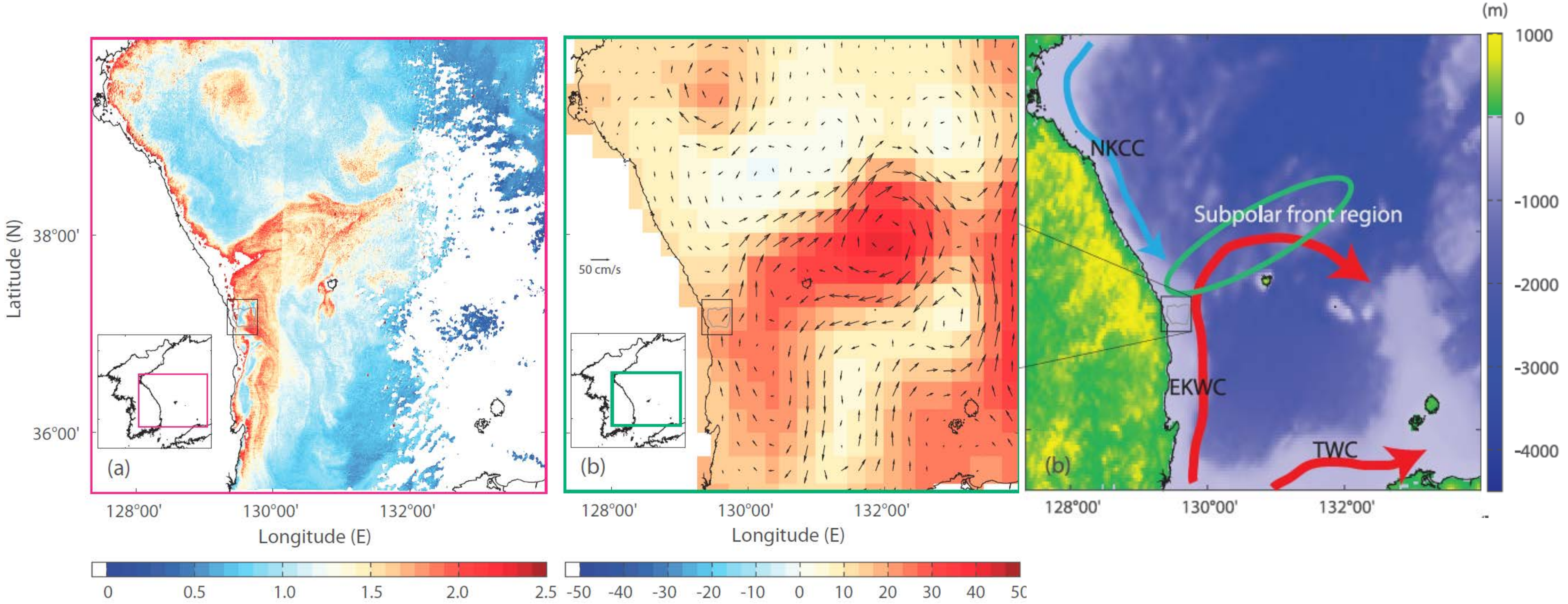
Spectral descriptions of geophysical ocean turbulence in an observational view



2013.10.12

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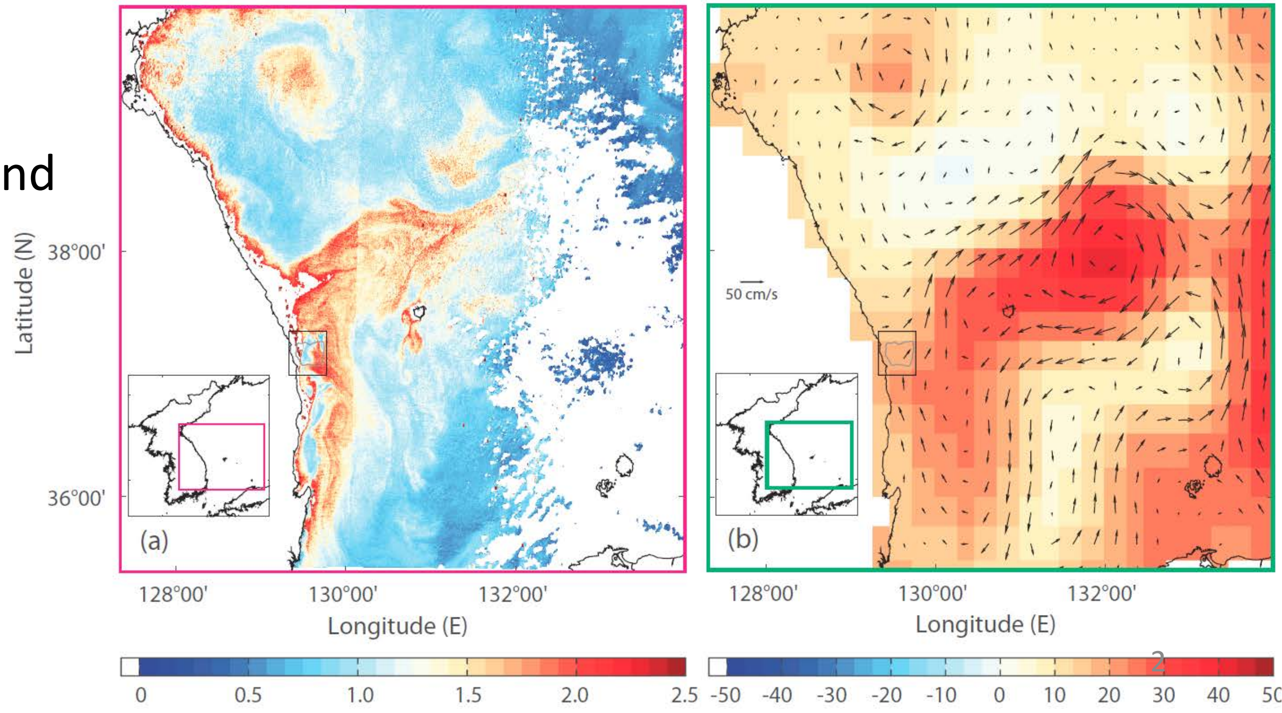
Submesoscale processes and their potential drivers

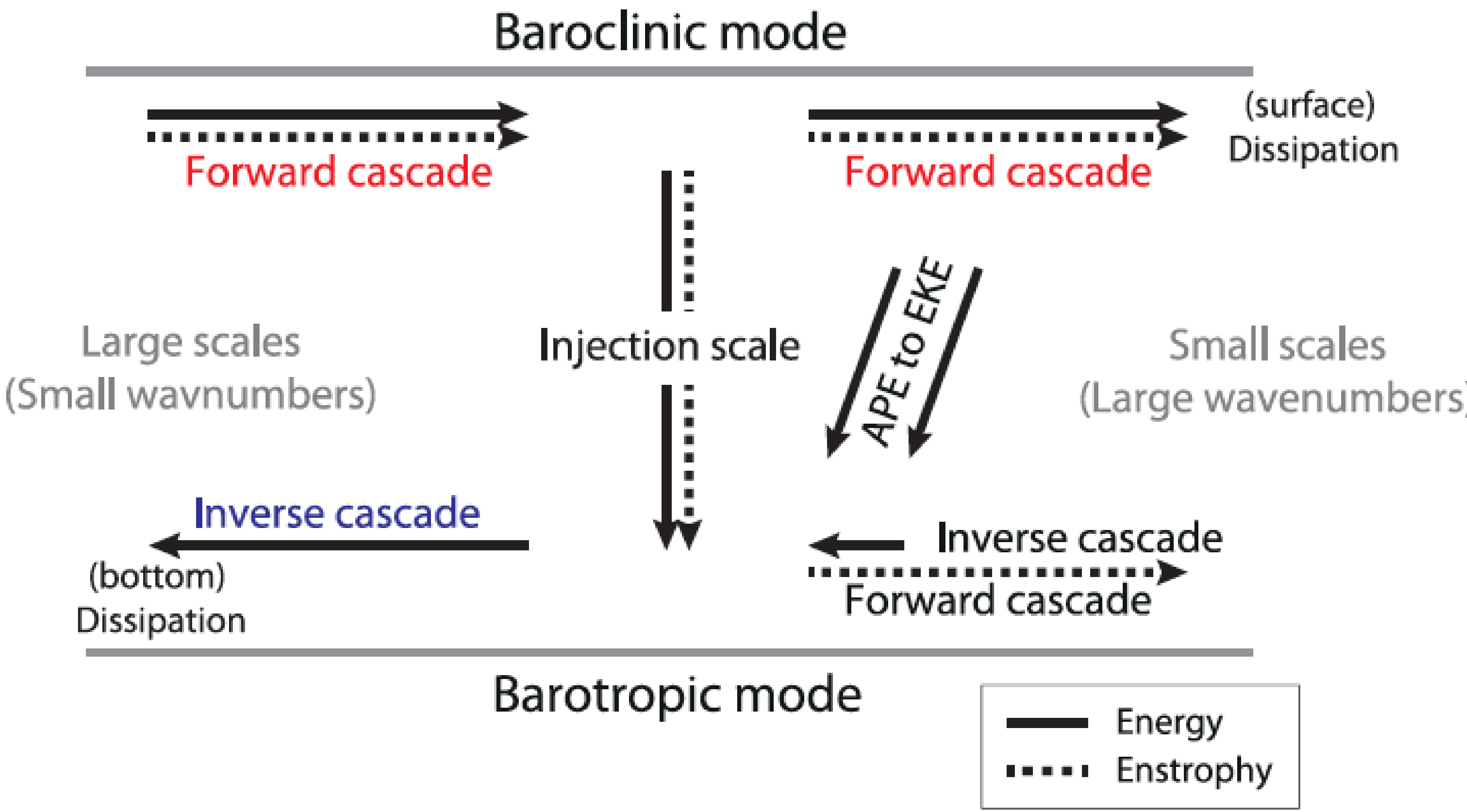
- O(1) Rossby number [Ro = ζ/f]
- A horizontal scale smaller than the first baroclinic Rossby deformation radius; O(1-10) km
- Frequently observed as fronts, eddies, and filaments
- Potential drivers
  - Baroclinic instability in the mixed layer (mixed layer instability)
  - Frontogenesis associated with mesoscale eddies (strain-induced frontogenesis)
  - Topographic wakes
  - Turbulent thermal wind



Outline

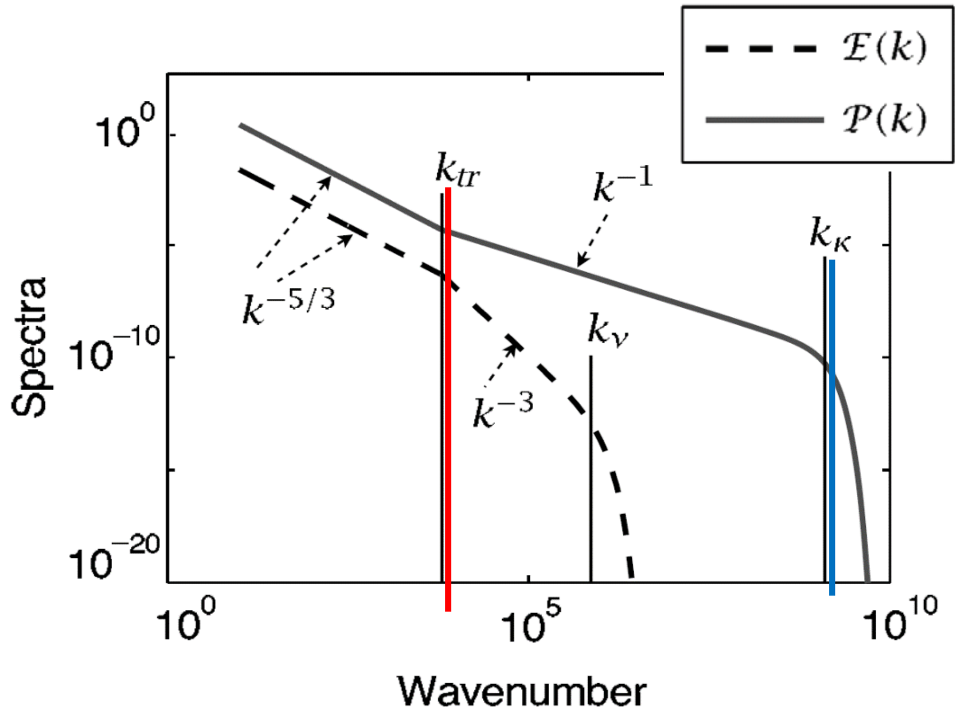
- Introduction and review
  - Forward and inverse energy cascades
  - Examples of submesoscale surface observations
- Observations of surface currents and passive tracers
  - Geophysical signals – frequency domain spectra and seasonal variation of CHLs
  - Injection and dissipation scales from the wavenumber domain energy spectra
- Summary

Forward and inverse energy cascades



(Modified from Ferrari and Wunsch 2009

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

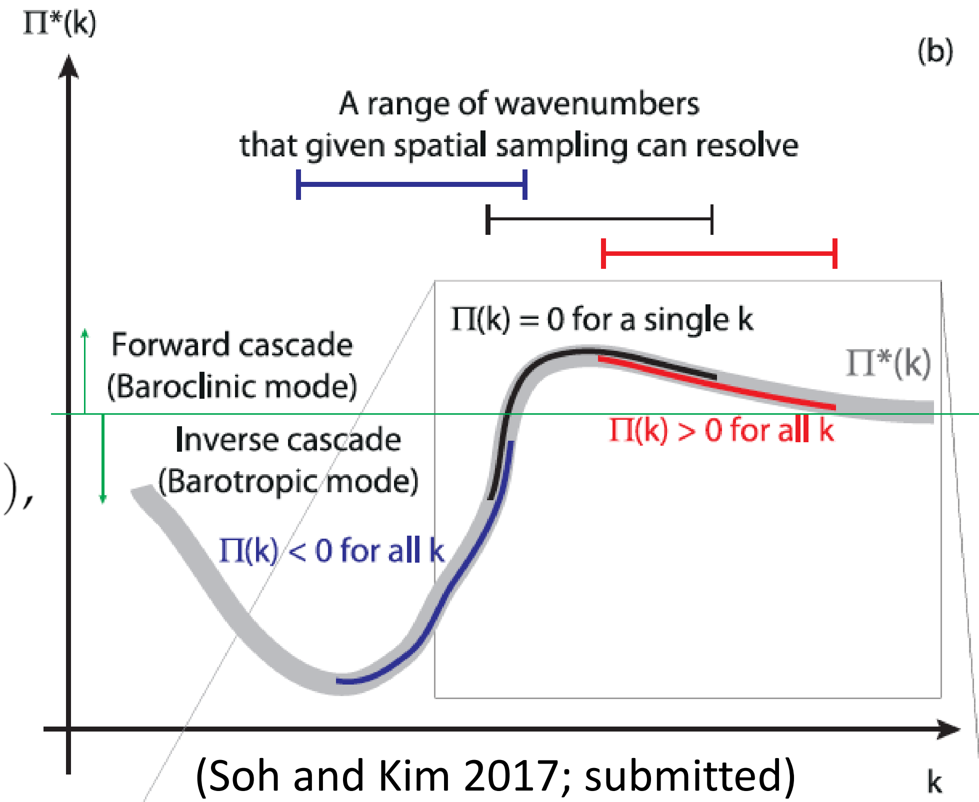


(Vallis, 2000; not scaled)

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

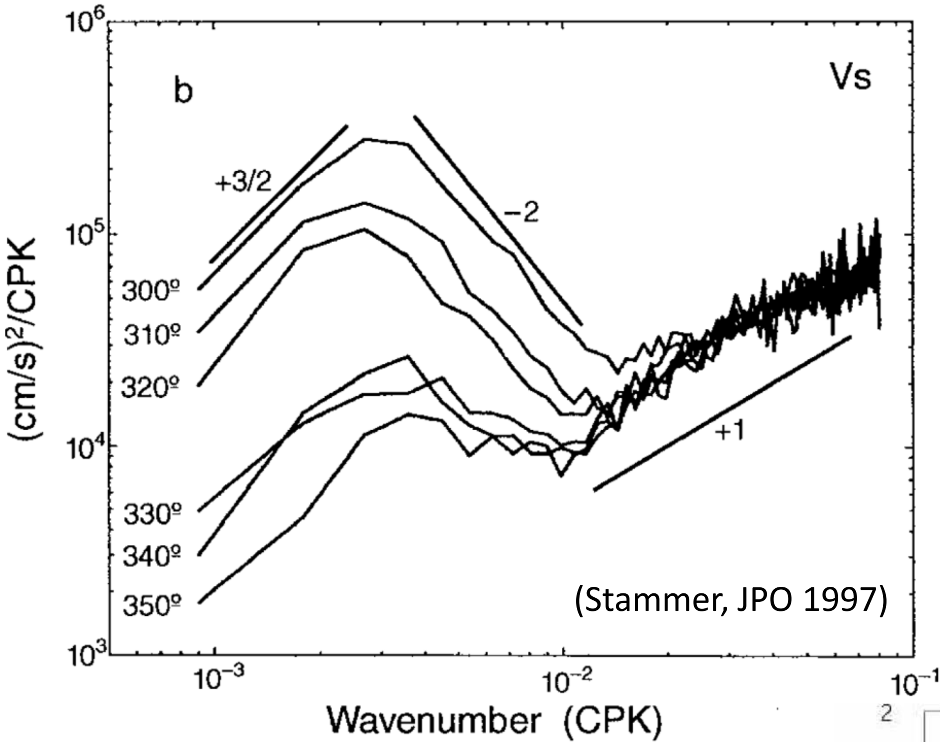
$$\frac{\partial}{\partial t}E(k^*) + \Pi(k^*) = -2\nu\Omega(k^*) + F(k^*),$$

(Frisch 1995)



(Soh and Kim 2017; submitted)

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

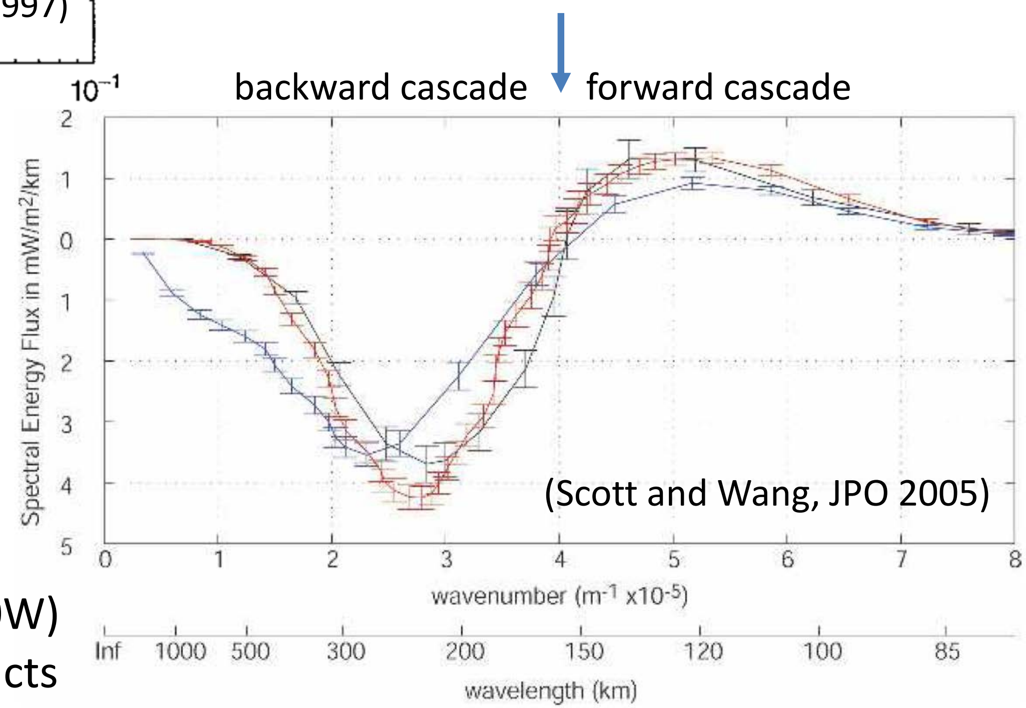


(Stammer, JPO 1997)

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

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

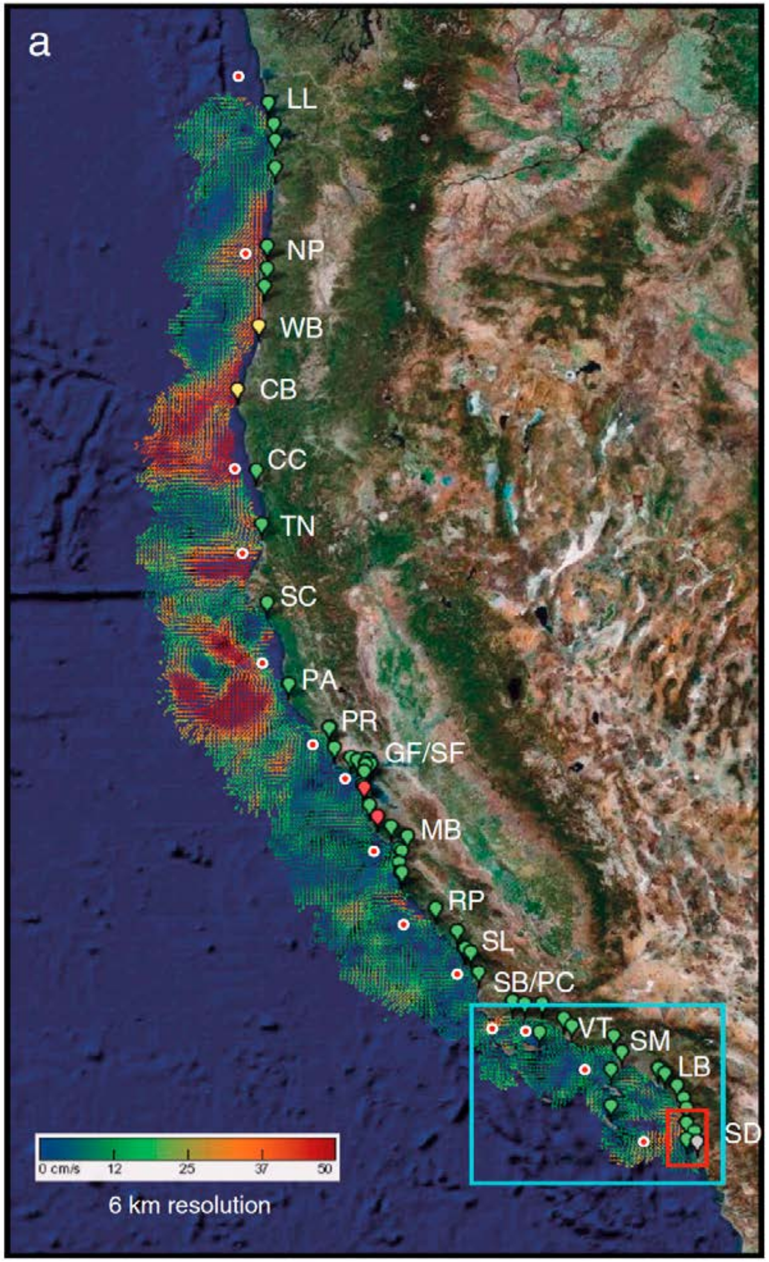
- What can be the decay slope of KE spectra and the injection scales to have zero crossing in the KE flux below 100 km scale?



(Scott and Wang, JPO 2005)

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

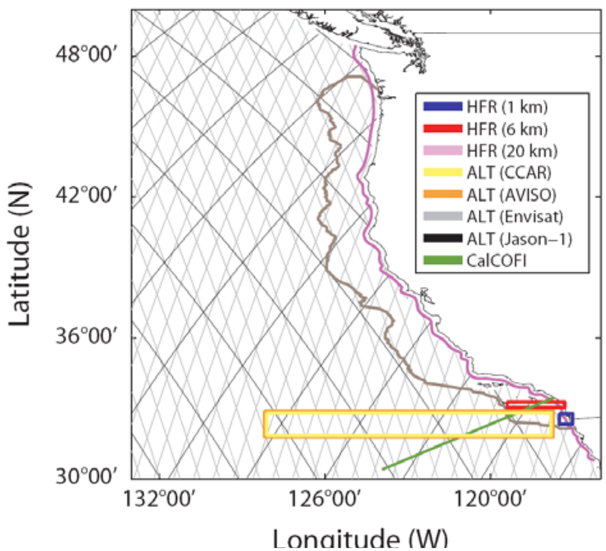
USWC HFR-derived surface currents



- 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)

KE spectra (USWC HFR; Altimeters; Shipboard ADCPs)

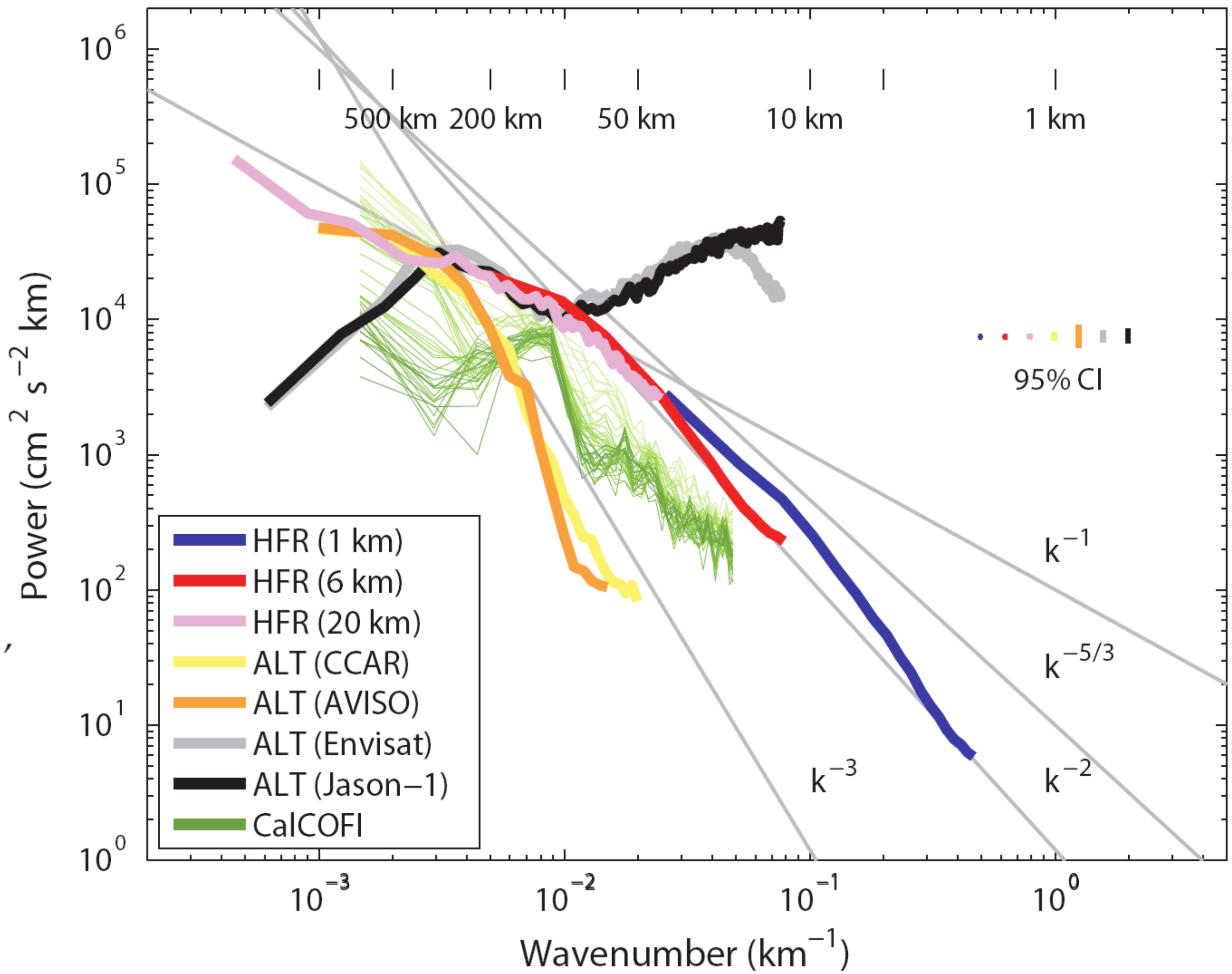


$$S_{\mathbf{u}_\perp}(k_\parallel) = \left(\frac{g}{f_c}\right)^2 (2\pi k_\parallel)^2 S_{\boldsymbol{\eta}_\parallel}(k_\parallel),$$

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

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

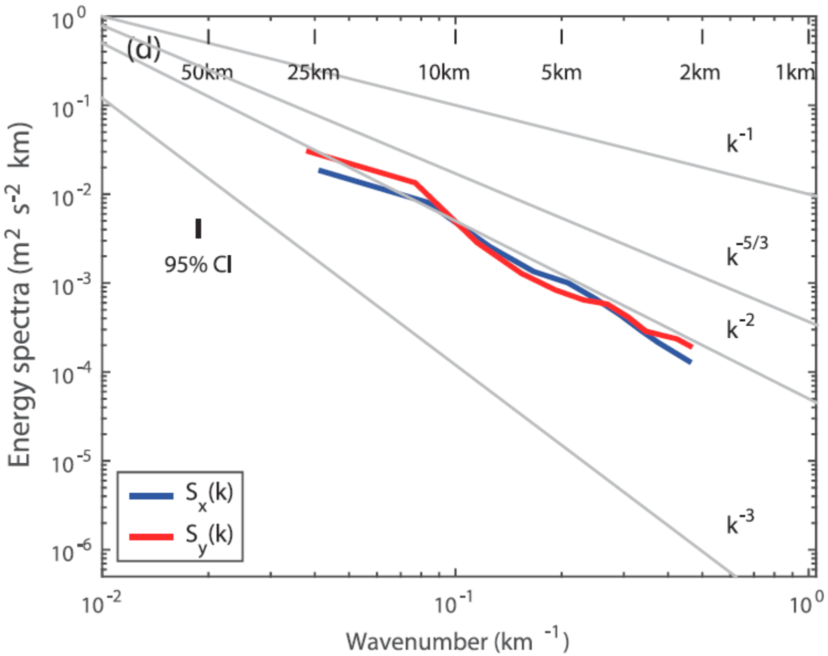
Robust estimate on k-2 spectra with data in other regions.

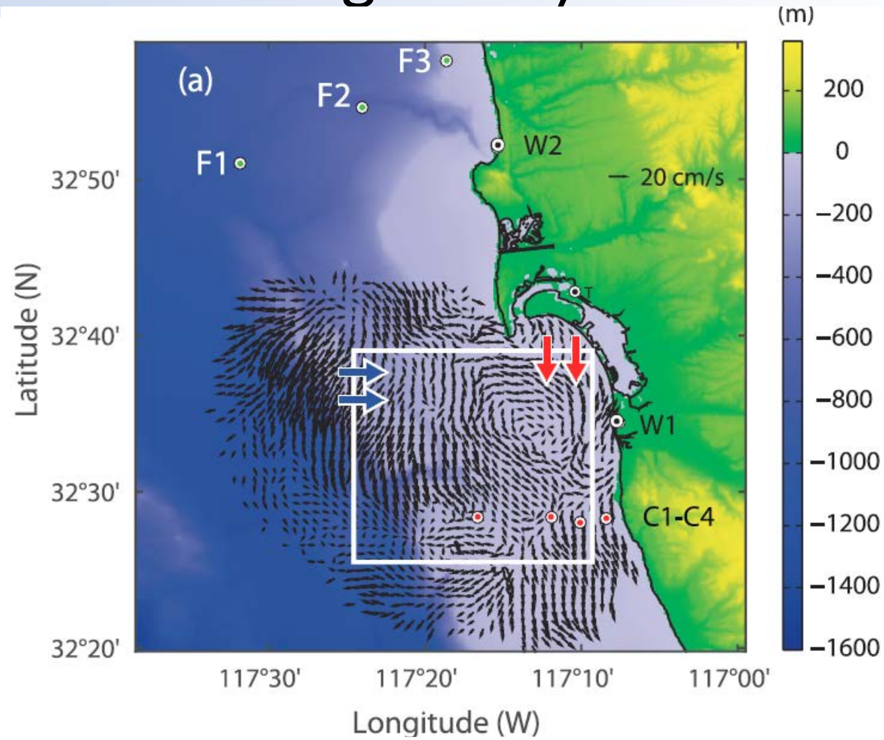


Two kinds of ALT data: Envisat and Jason-1
HFR data with three resolutions:
1 km and 6 km data are sampled from SoCAL,
because minimum ageostropic components are expected.
20 km data are from the coastline axis.

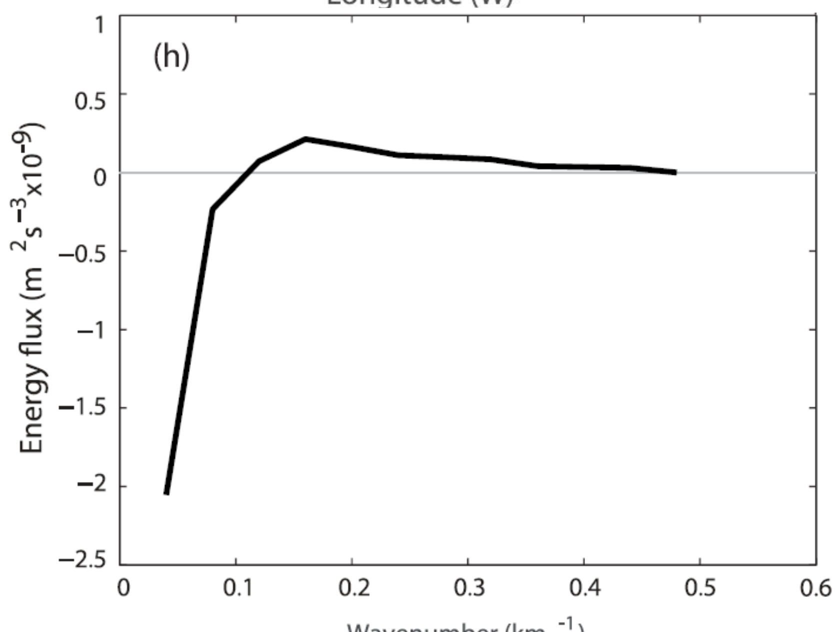
(Kim et al, JGR 2011)

KE spectra and fluxes (southern San Diego HFR)



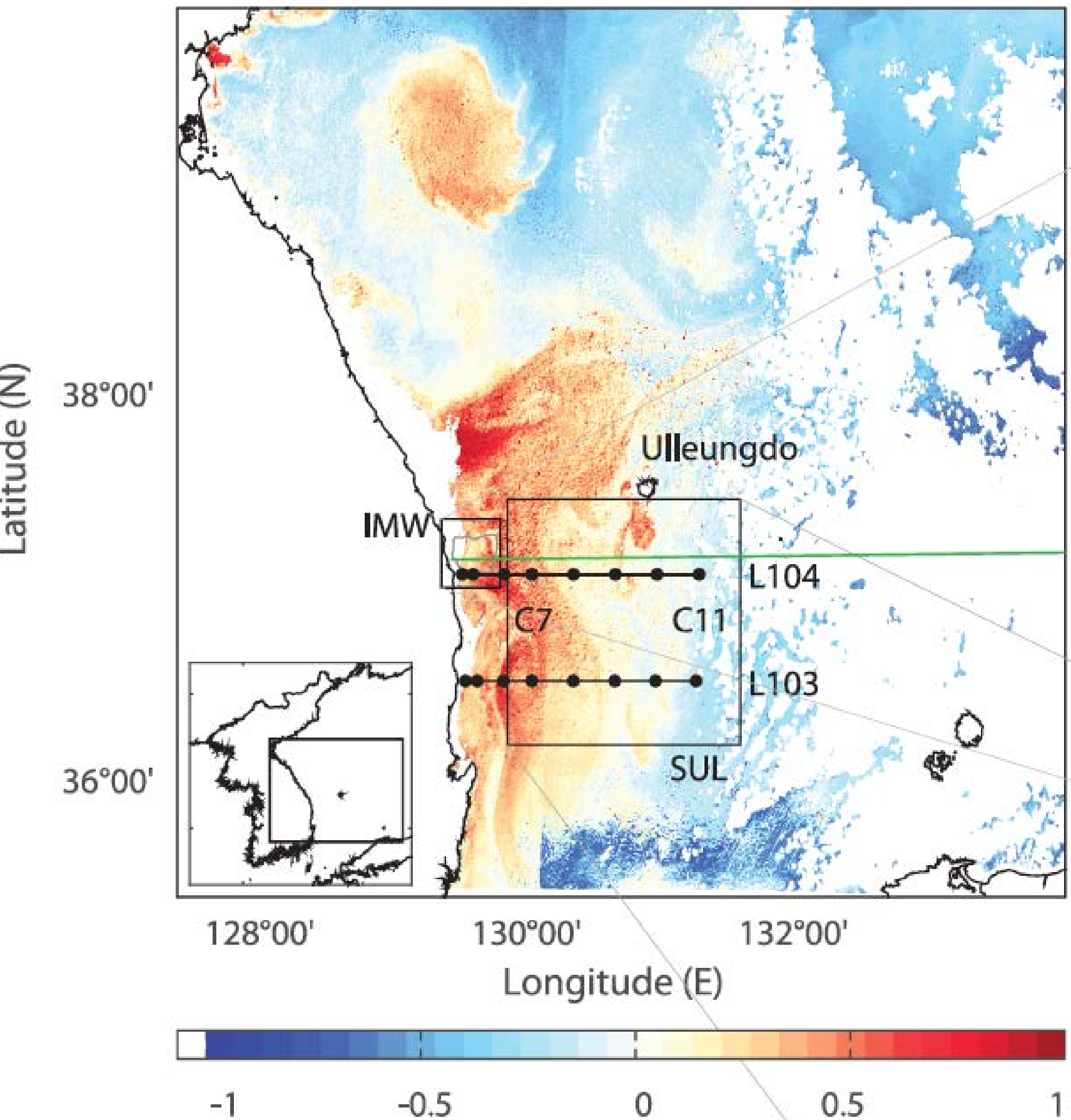


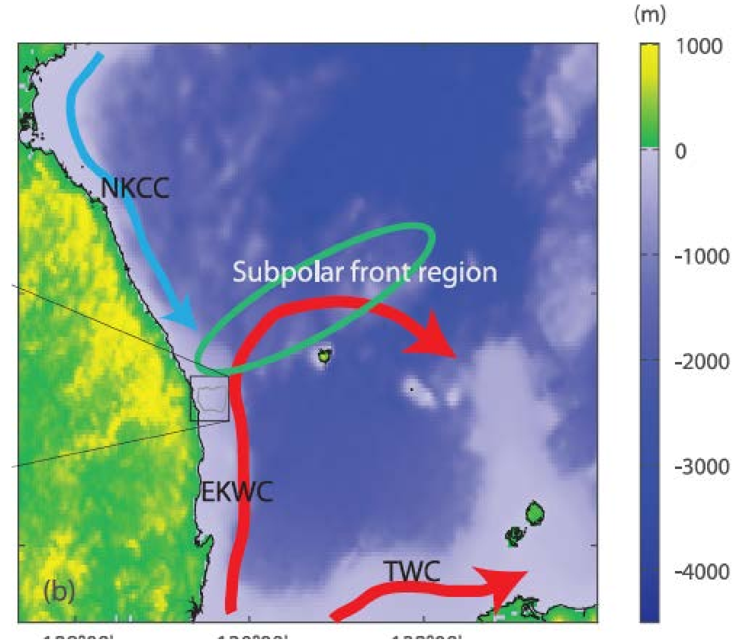
- Decay slopes of KE spectra range between k^{-2} and k^{-3}
- Zero-crossings of KE fluxes appear O(10) km



(Soh and Kim 2017; submitted)

Study domain and observations (1/2)

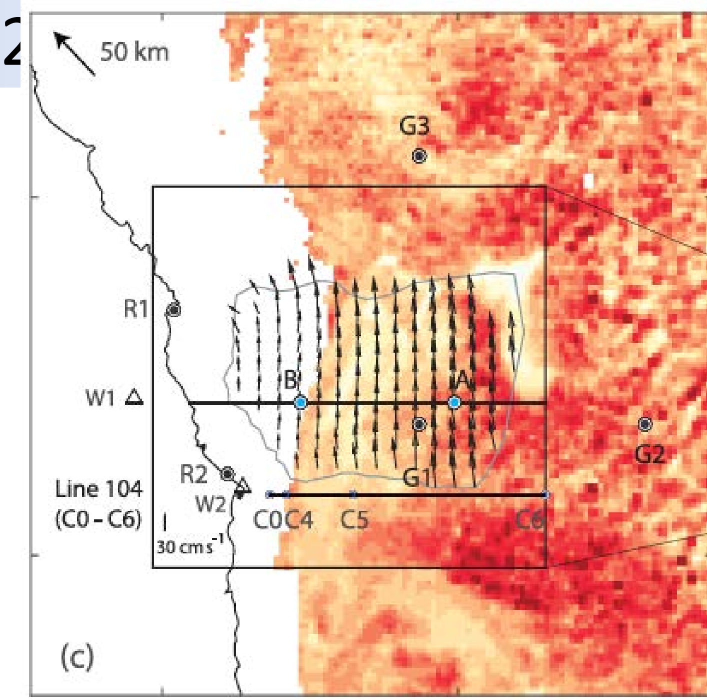


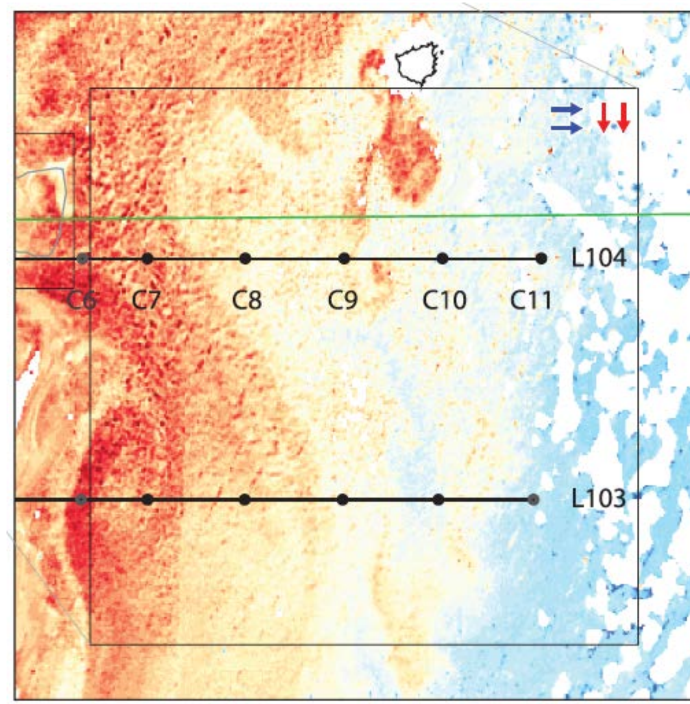


- Surface currents are observed at the verge of the confluence of two regional boundary currents

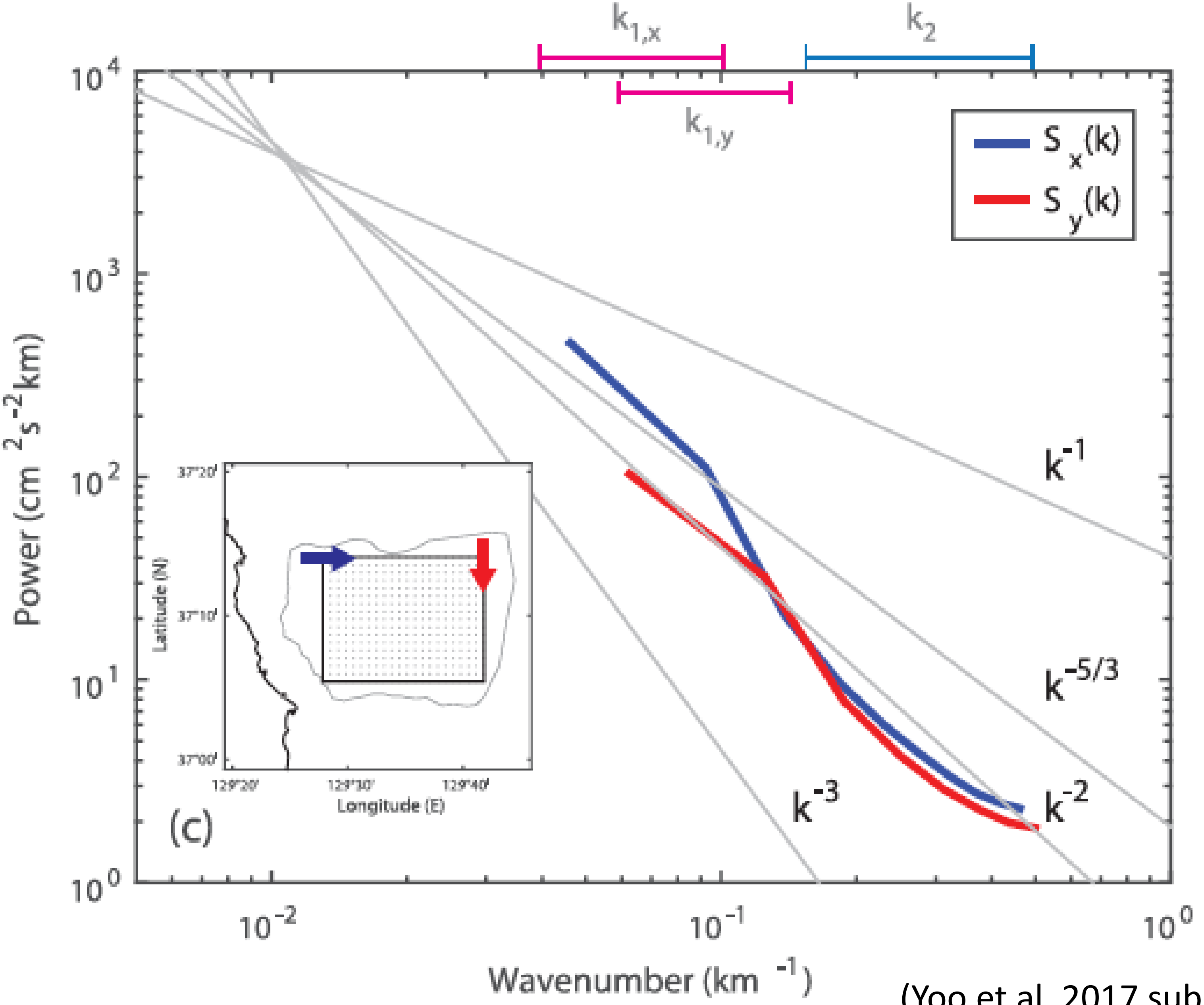
Study domain and observations (2/2

- 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.



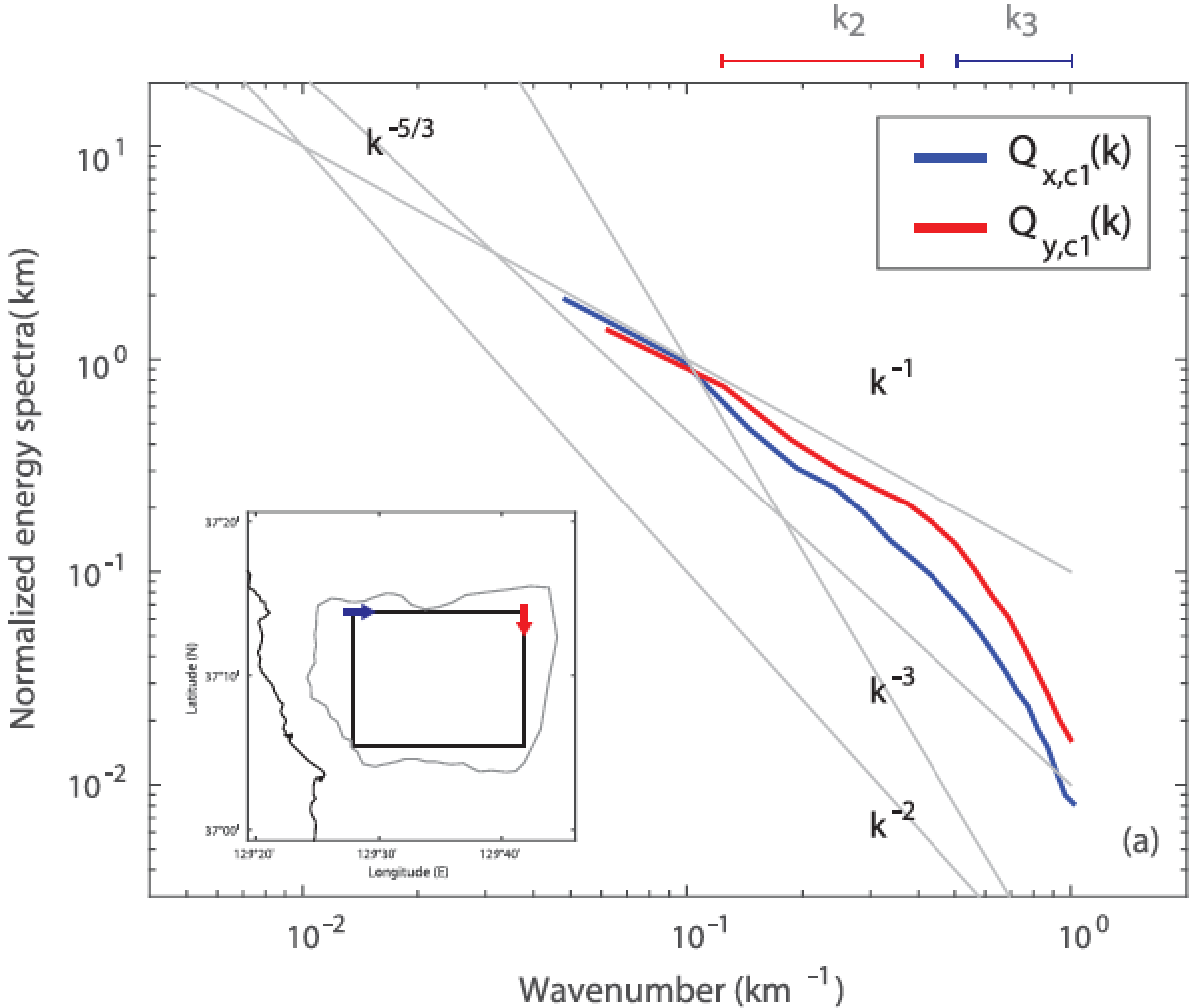


KE spectra of submesoscale surface currents



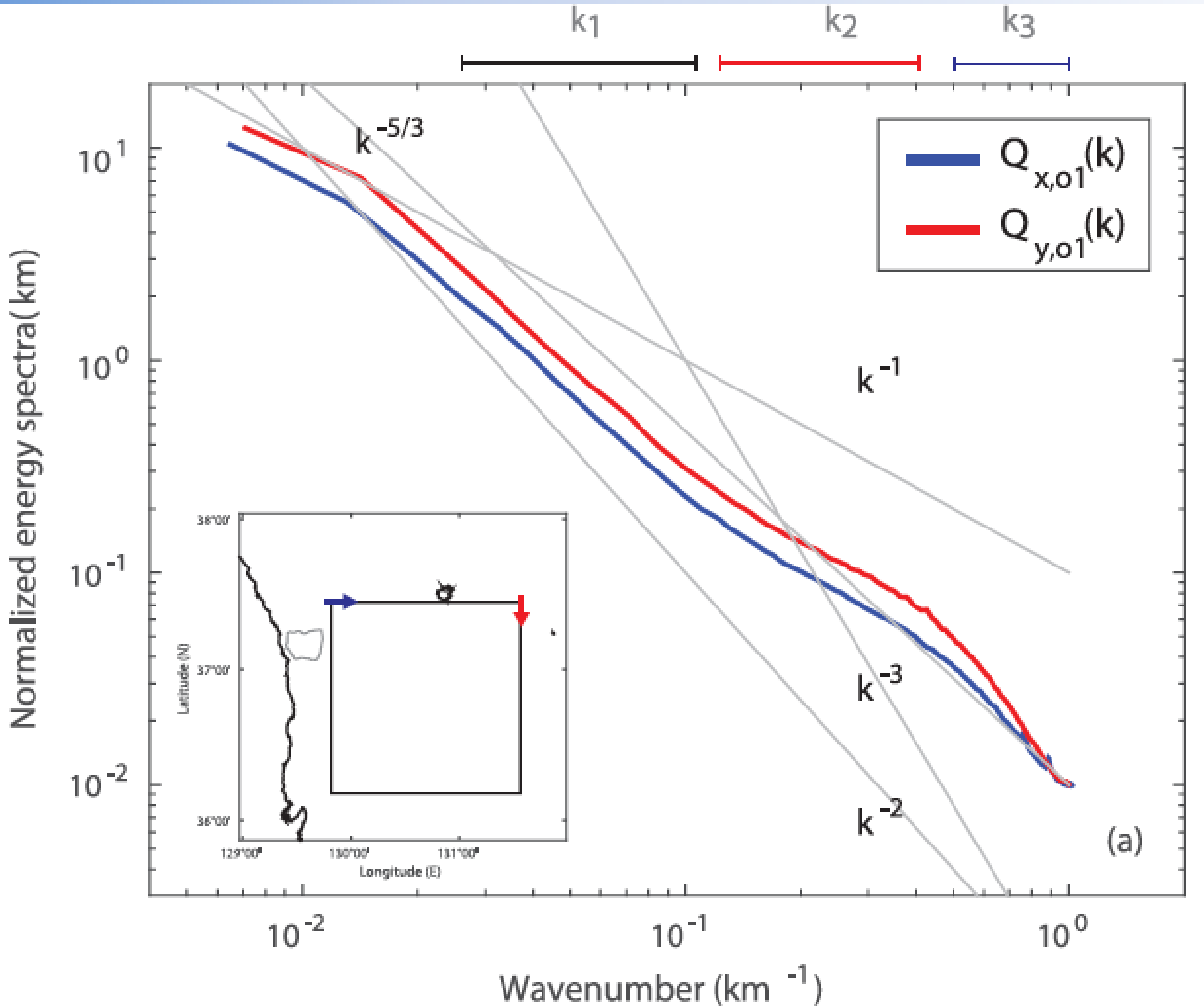
(Yoo et al, 2017 submitted)

Spectra of submesoscale surface CHLs (1/2)



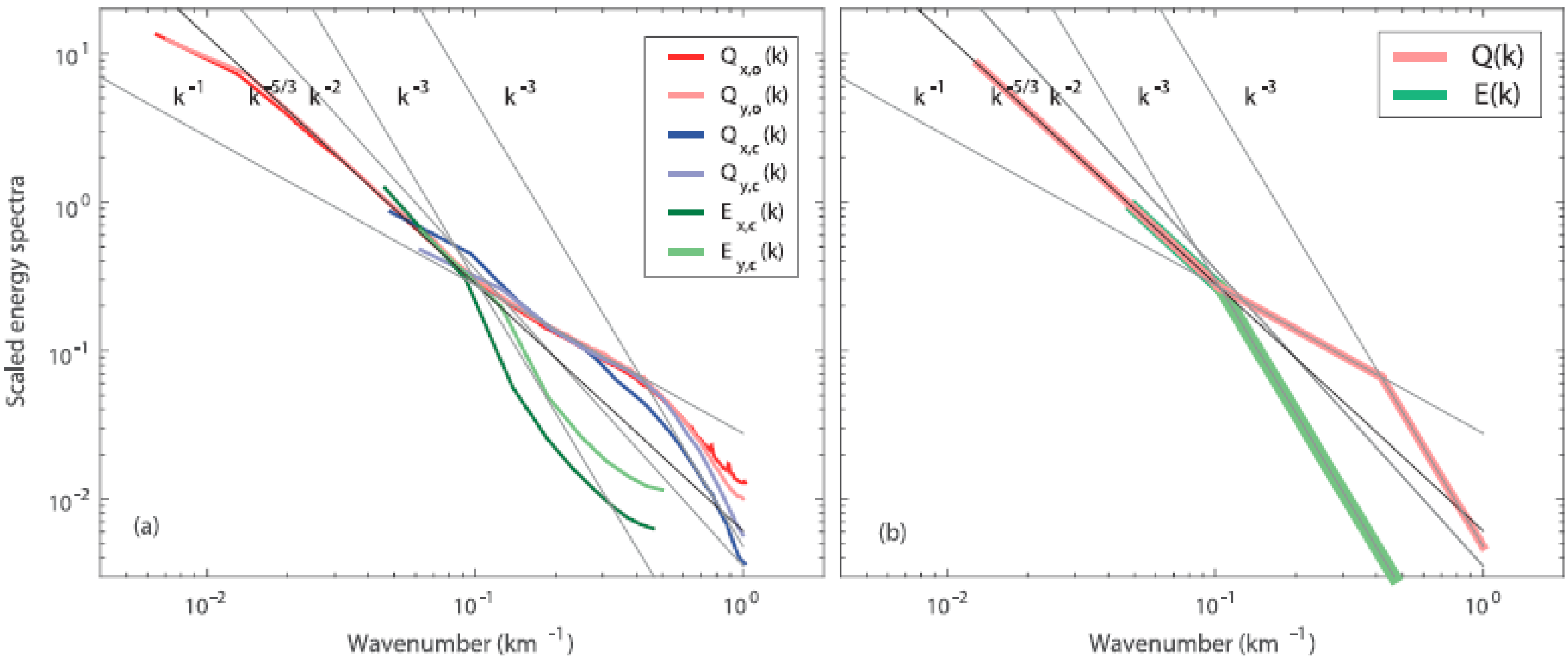
(Lee and Kim, 2017 submitted)

Spectra of submesoscale surface CHLs (2/2)

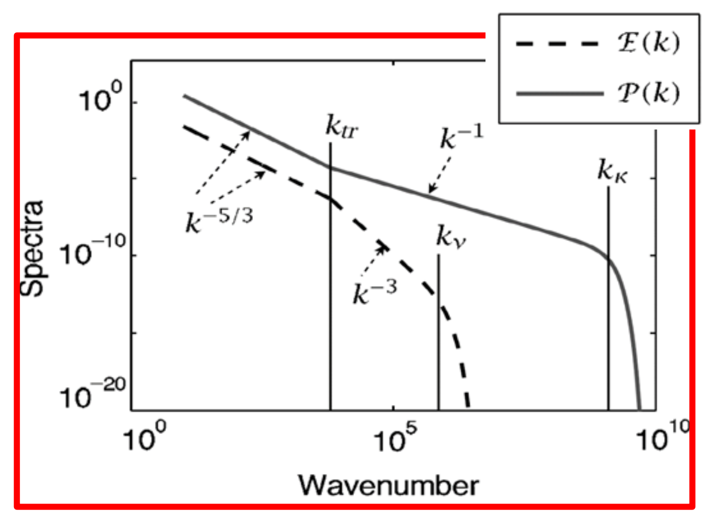


(Lee and Kim, 2017 submitted)

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.