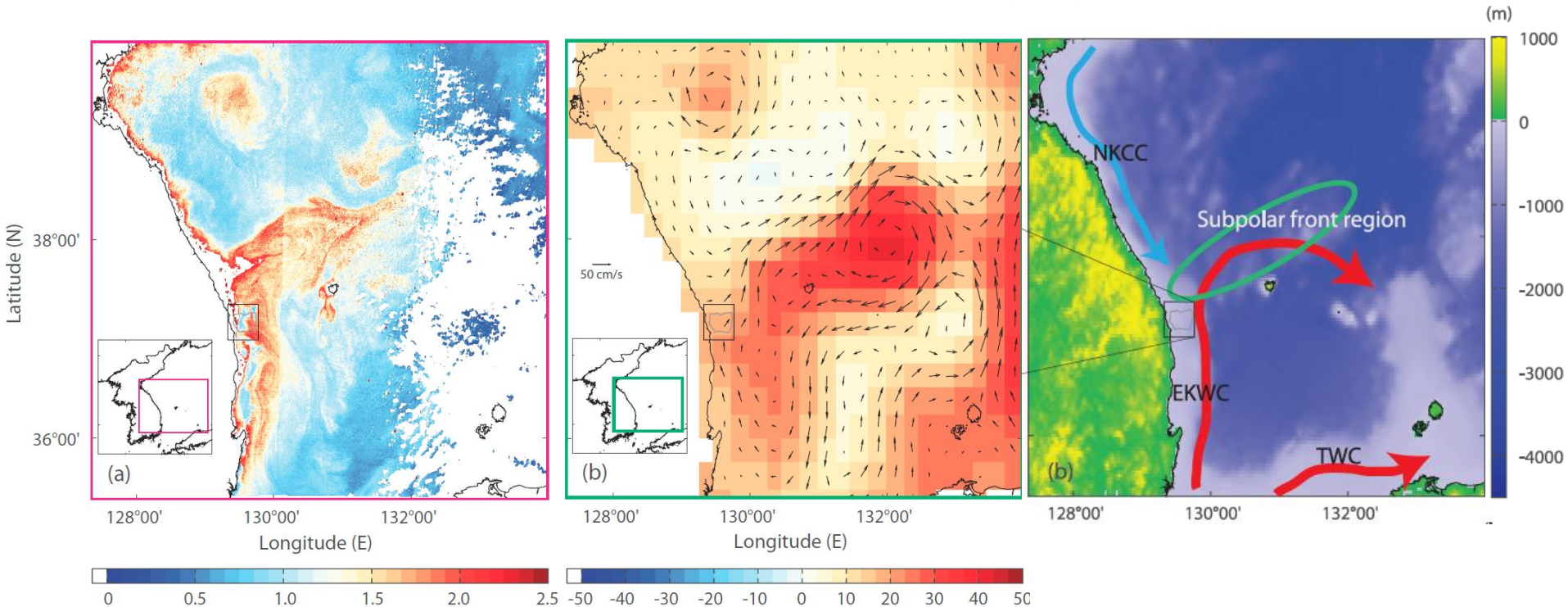


# Diagnostic characteristics of the submesoscale observations of coastal surface currents and chlorophyll concentrations



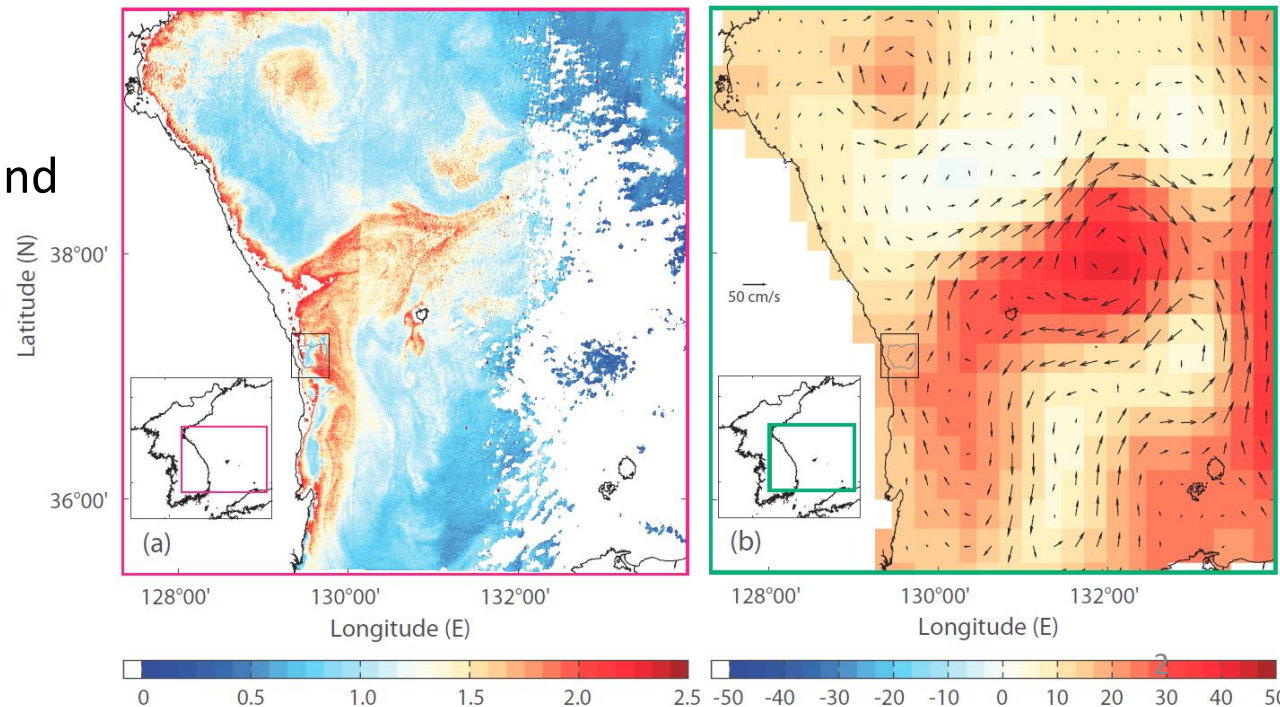
2013.10.12

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# Submesoscale processes and their potential drivers

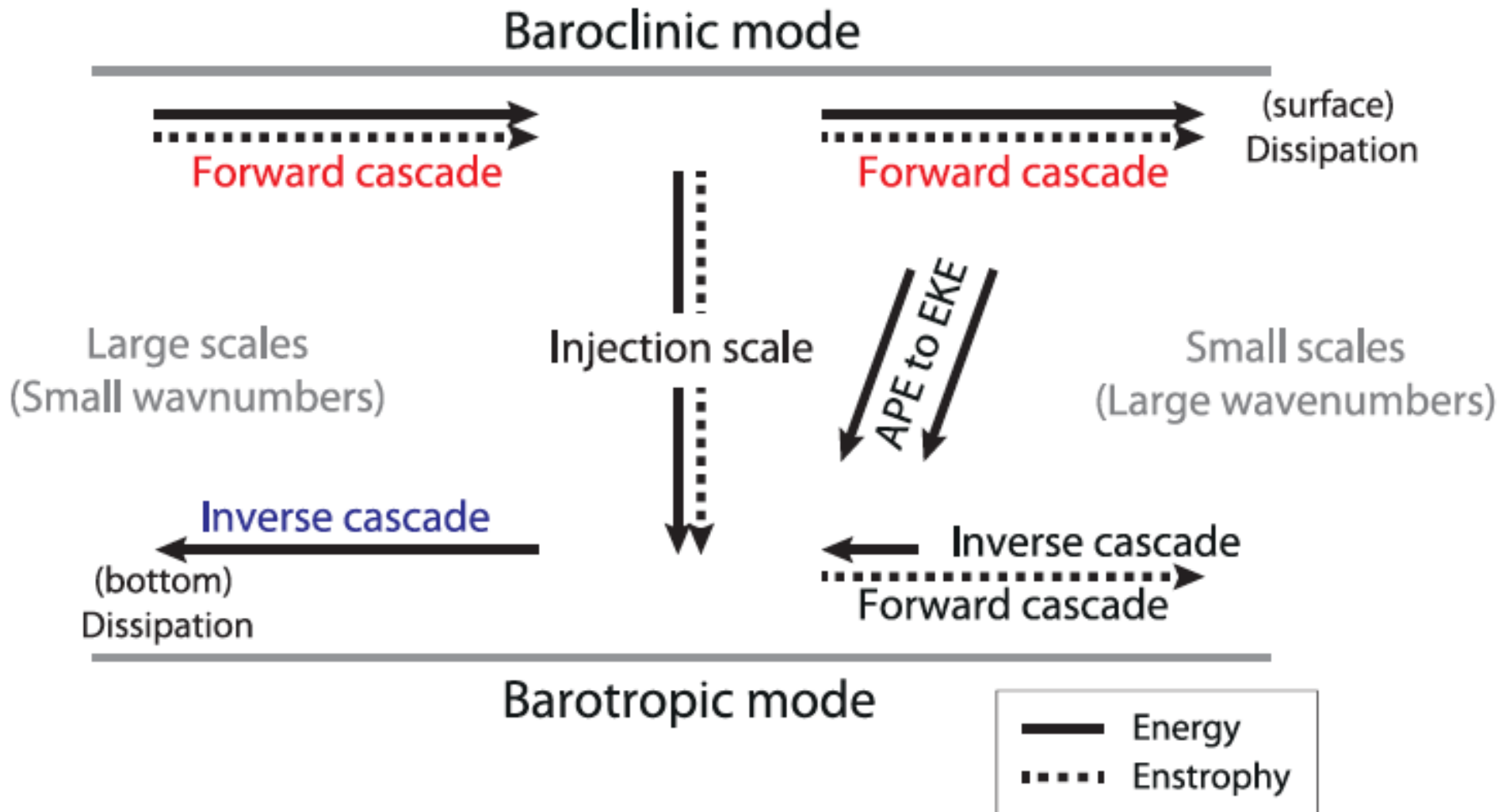
- $O(1)$  Rossby number [ $Ro = \zeta/f$ ]
- A horizontal scale smaller than the first baroclinic Rossby deformation radius;  $O(1-10)$  km
- Frequently observed as fronts, eddies, and filaments
- Potential drivers
  - Baroclinic instability in the mixed layer (mixed layer instability)
  - Frontogenesis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



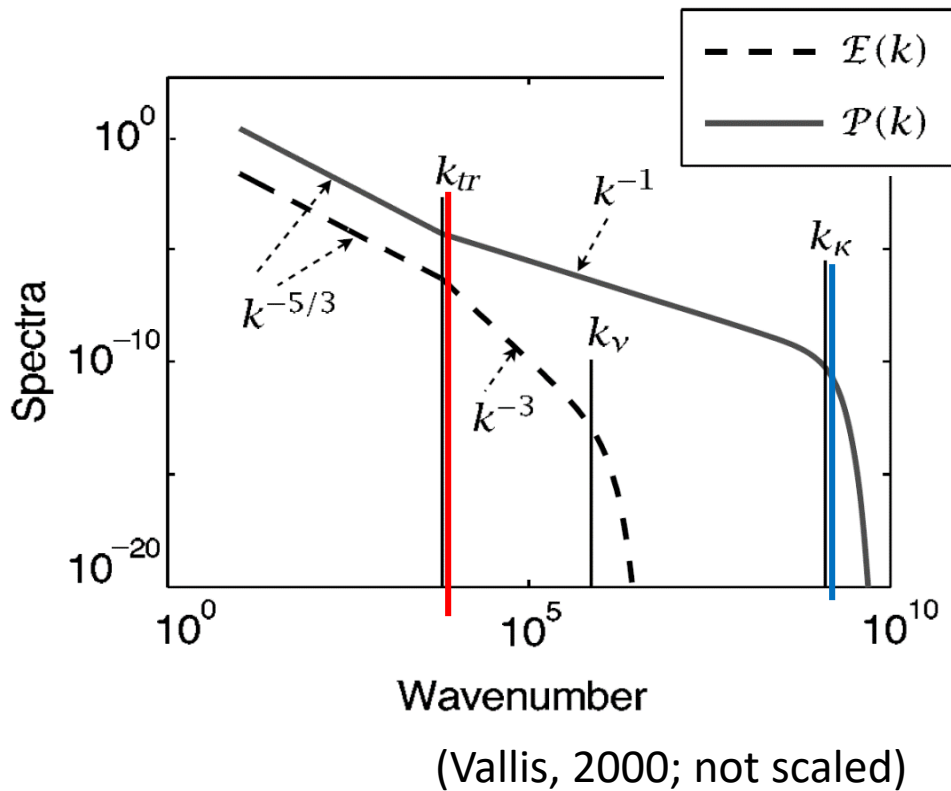
# Outline

- 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



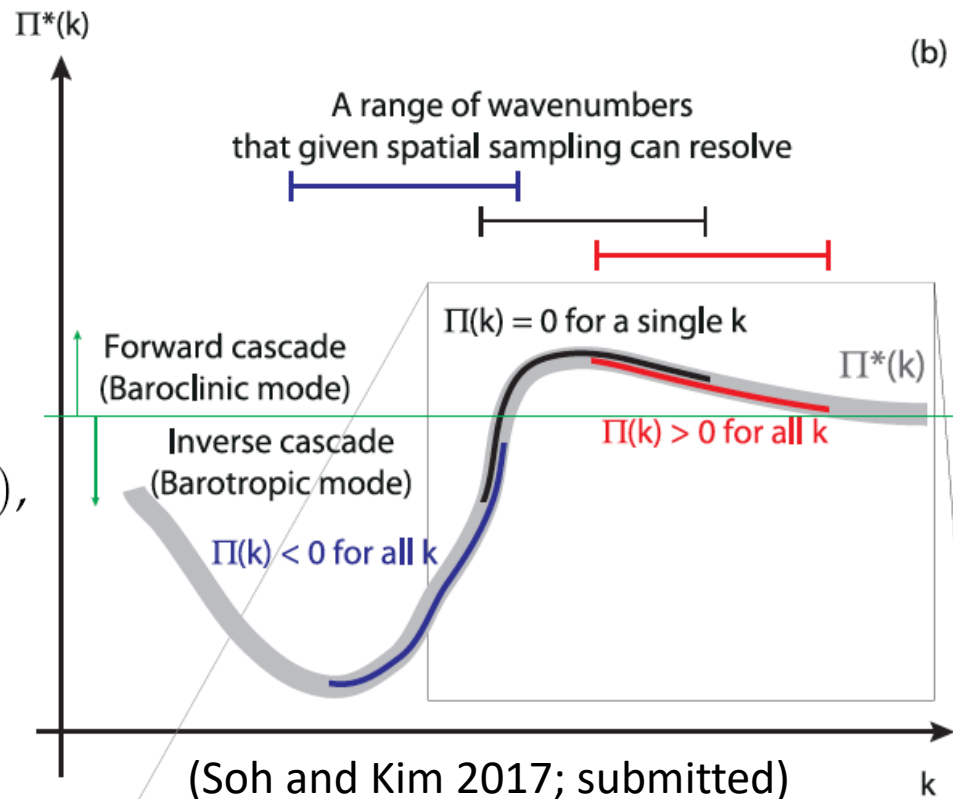
# Kinetic energy (KE) spectra and fluxes (1/2)



- Kinetic energy (KE) spectra of currents [ $\mathcal{E}(k)$ ] and spectra of passive tracers [ $\mathcal{P}(k)$ ; CHL]
- **Transition (injection) scale** and **dissipation scale**

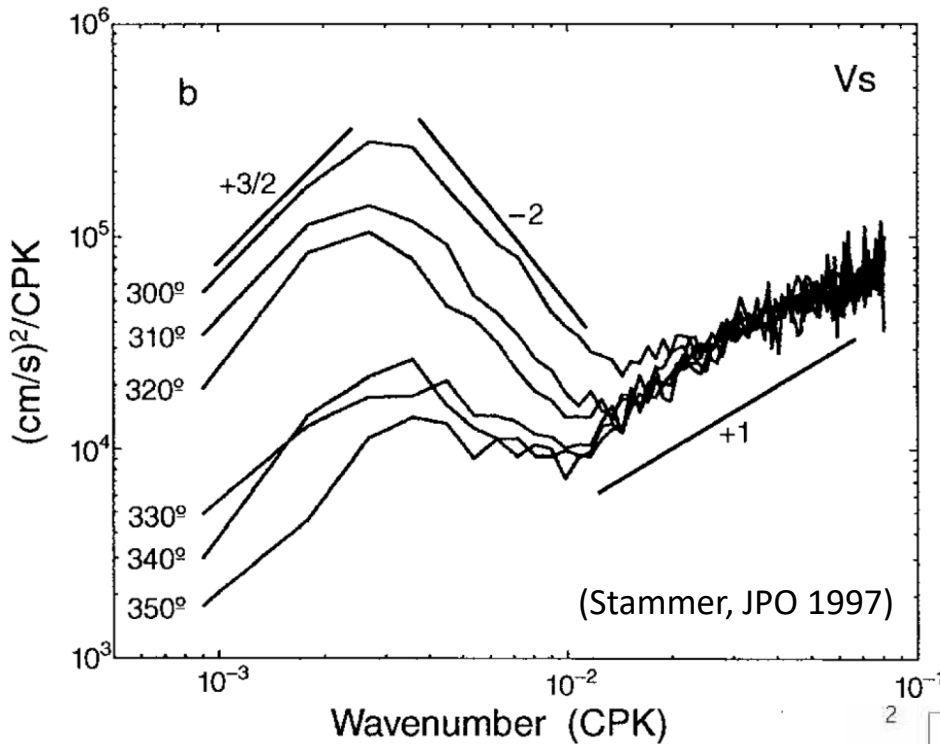
$$\frac{\partial}{\partial t} E(k^*) + \Pi(k^*) = -2\nu\Omega(k^*) + F(k^*),$$

(Frisch 1995)



(b)

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

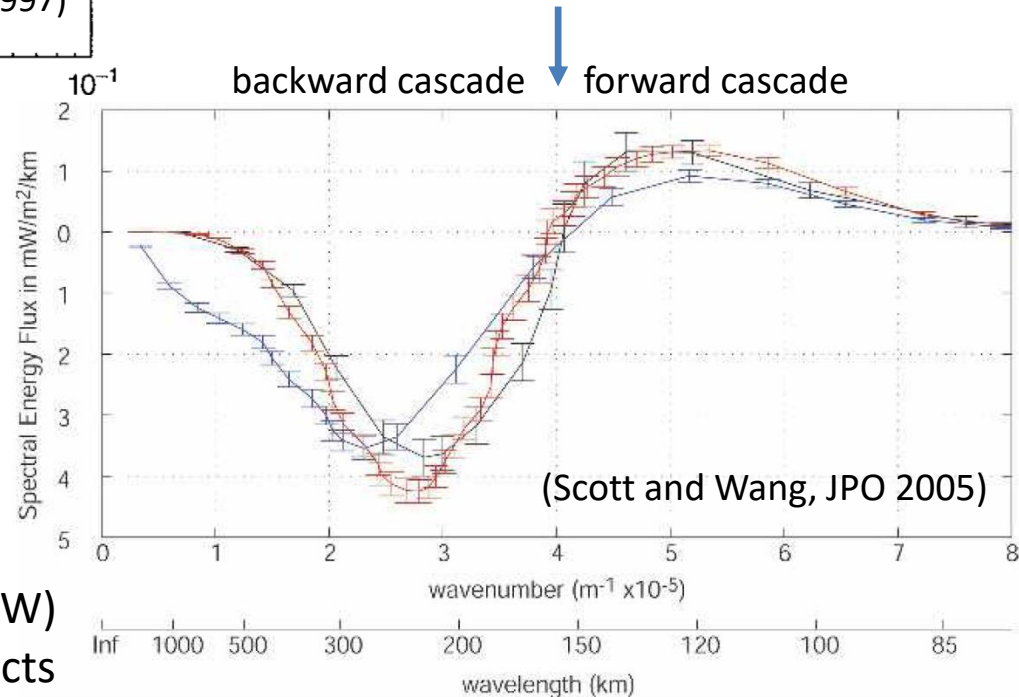


Wavenumber KE spectra of altimeter-derived cross-track geostrophic currents (30N to 40 N)

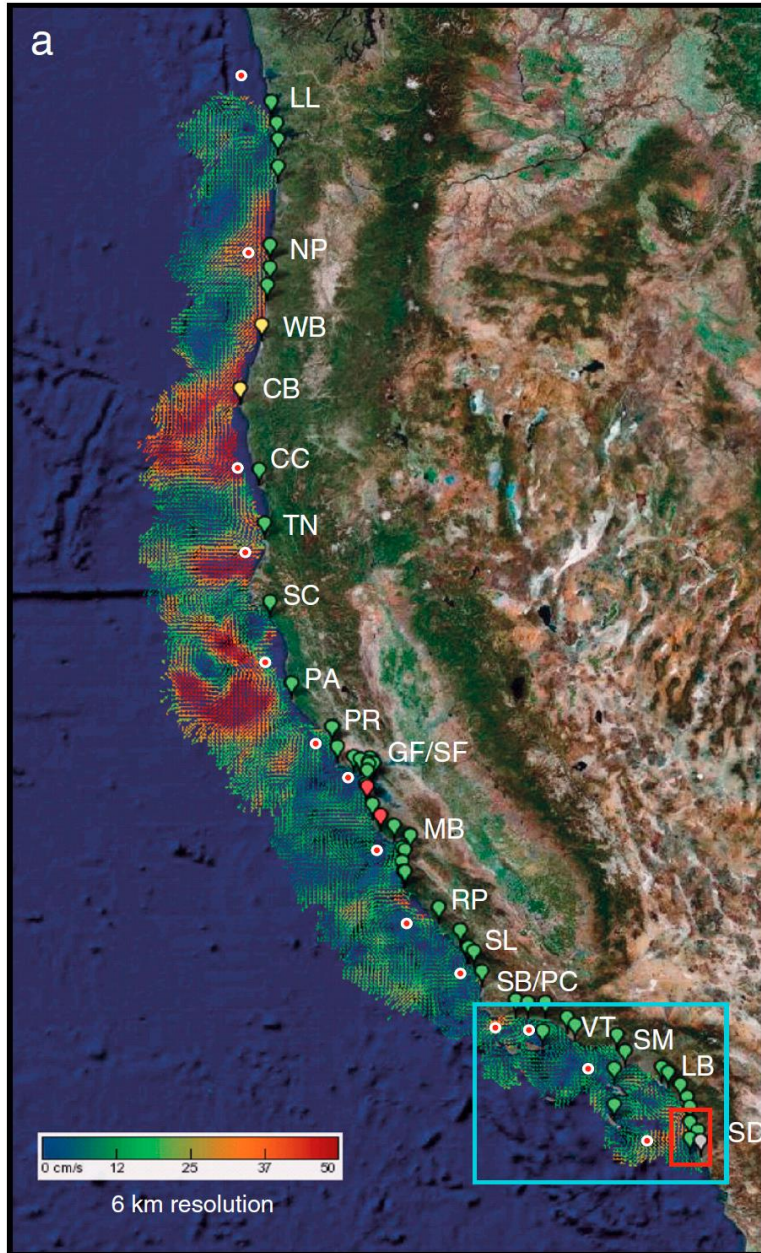
$$S_{u_{\perp}}(k_{\parallel}) = \left(\frac{g}{f_c}\right)^2 (2\pi k_{\parallel})^2 S_{\eta_{\parallel}}(k_{\parallel}),$$

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

- 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?



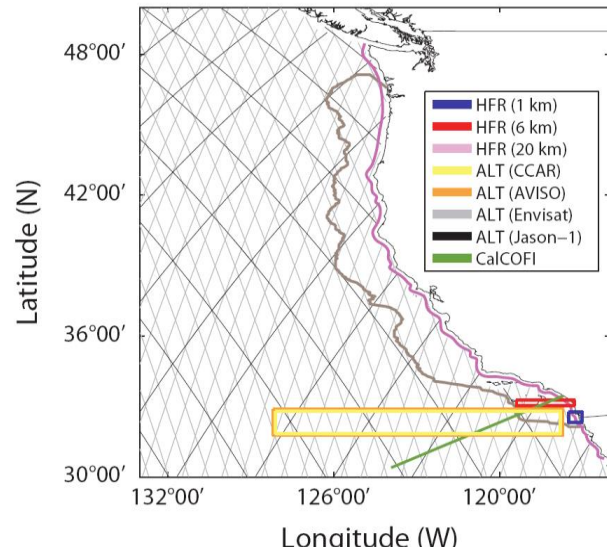
# USWC HFR-derived surface currents



- 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)

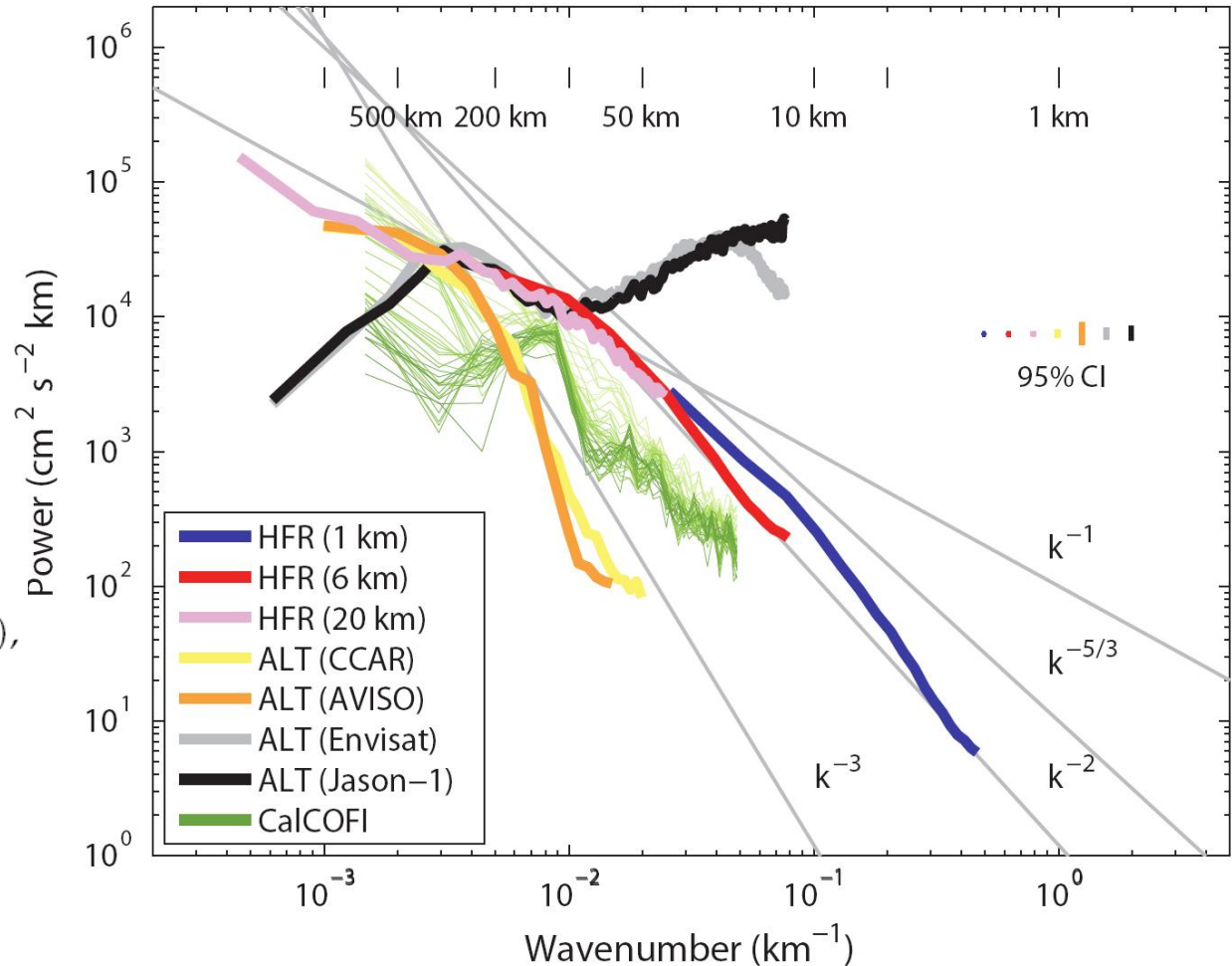


$$S_{u_{\perp}}(k_{\parallel}) = \left(\frac{g}{f_c}\right)^2 (2\pi k_{\parallel})^2 S_{\eta_{\parallel}}(k_{\parallel}),$$

Power spectrum of cross-track geostrophic 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,

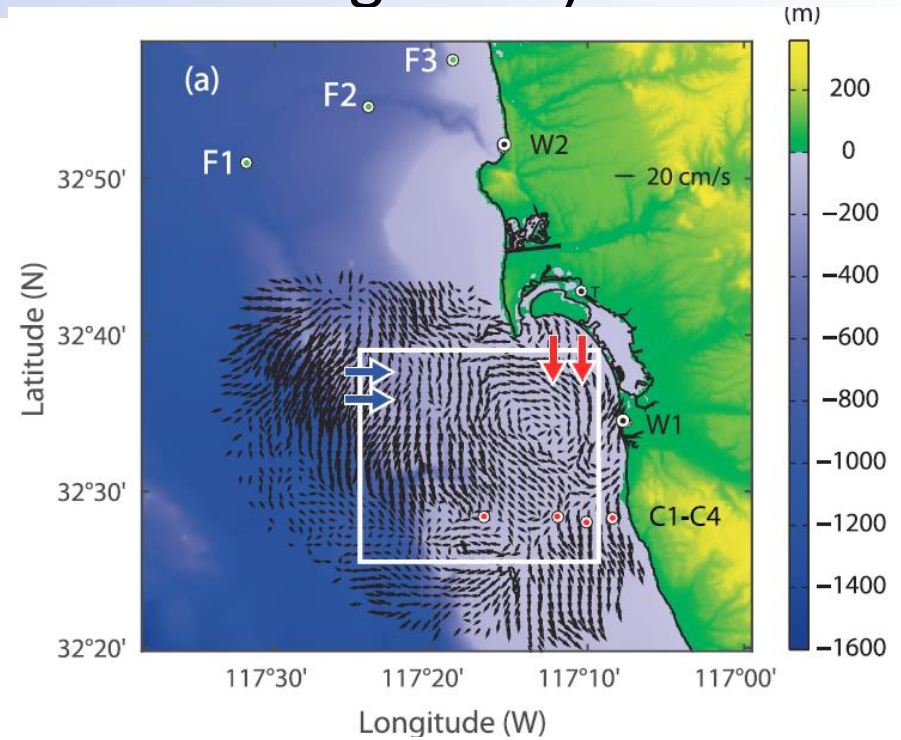
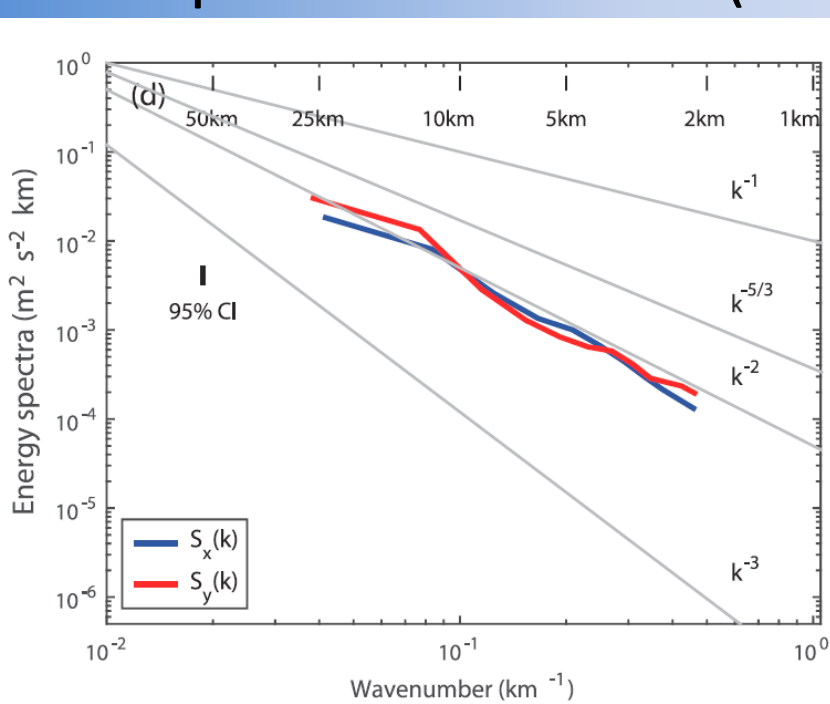
because minimum ageostrophic components are expected.

20 km data are from the coastline axis.

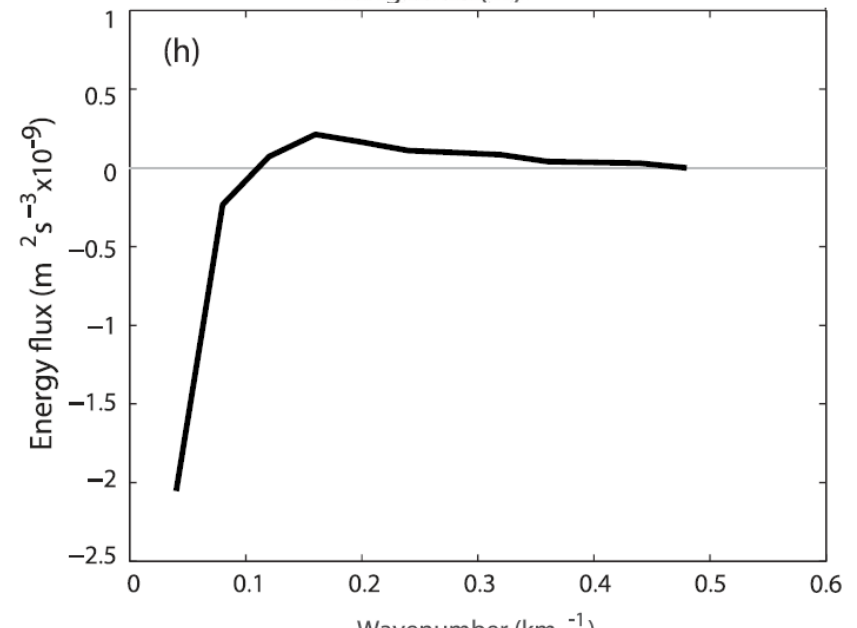
(Kim et al, JGR 2011)



# KE spectra and fluxes (southern San Diego HFR)

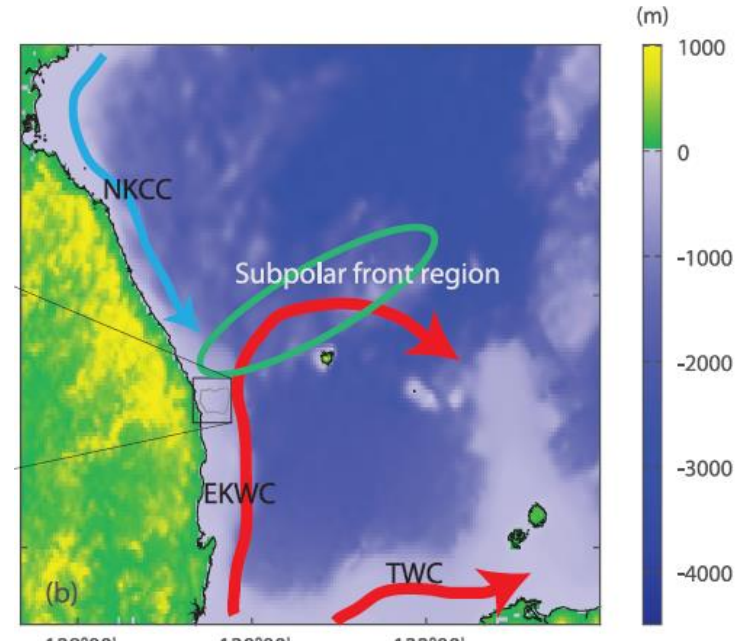
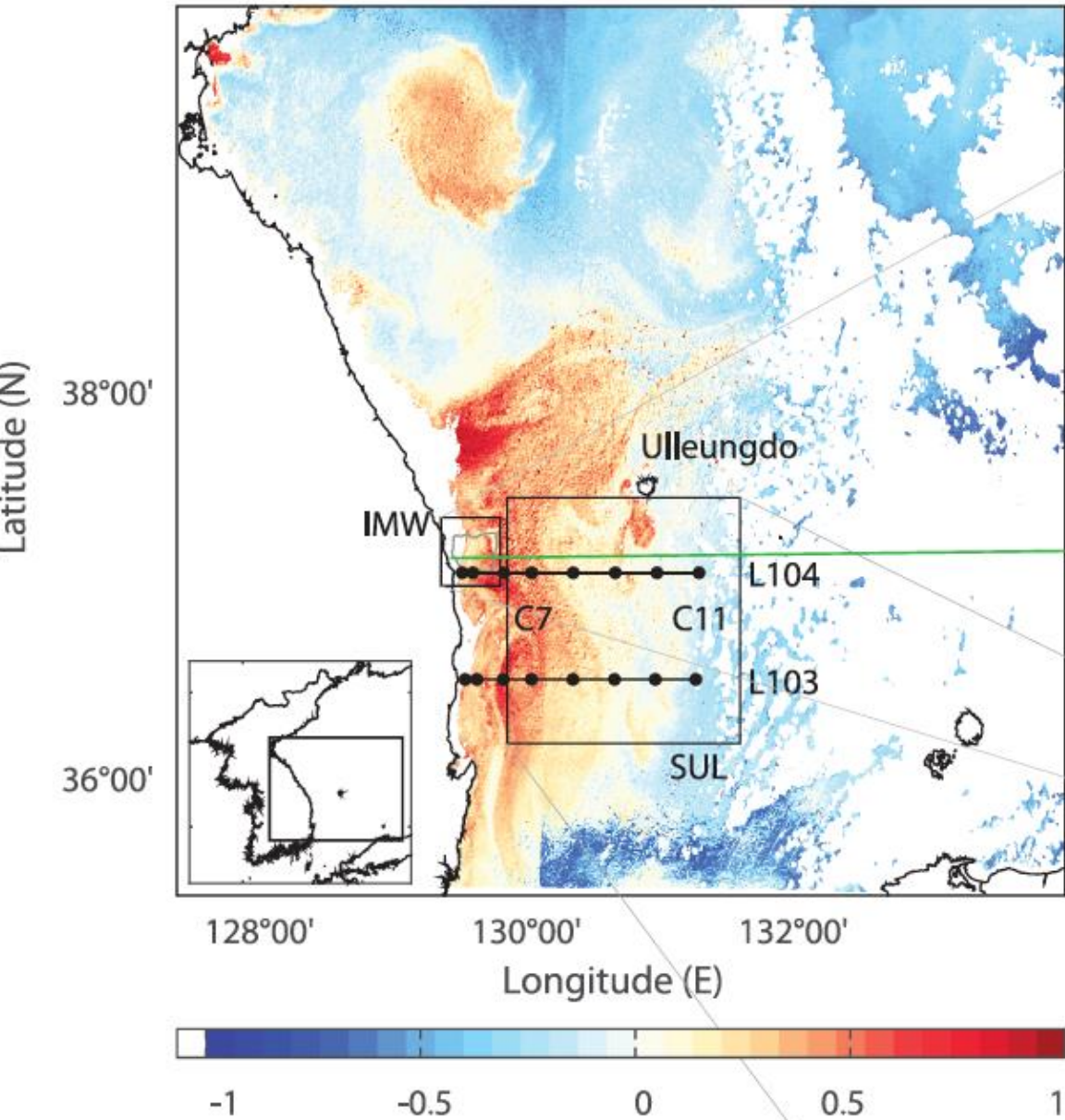


- Decay slopes of KE spectra range between  $k^{-2}$  and  $k^{-3}$
- Zero-crossings of KE fluxes appear  $O(10)$  km



(Soh and Kim 2017; submitted)

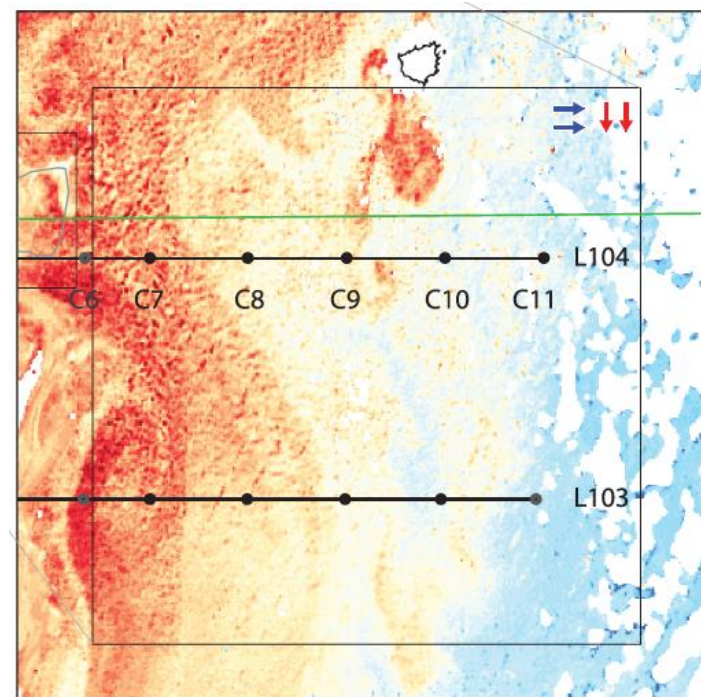
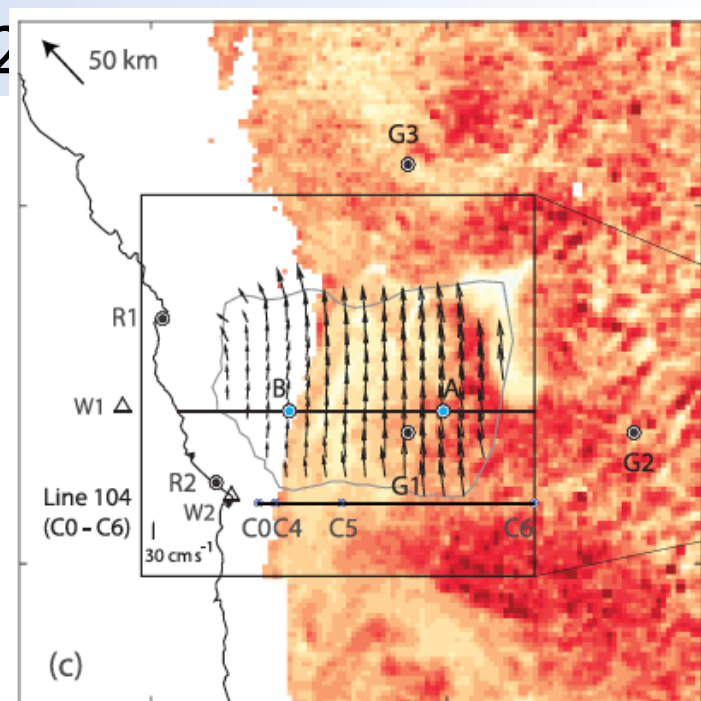
# Study domain and observations (1/2)



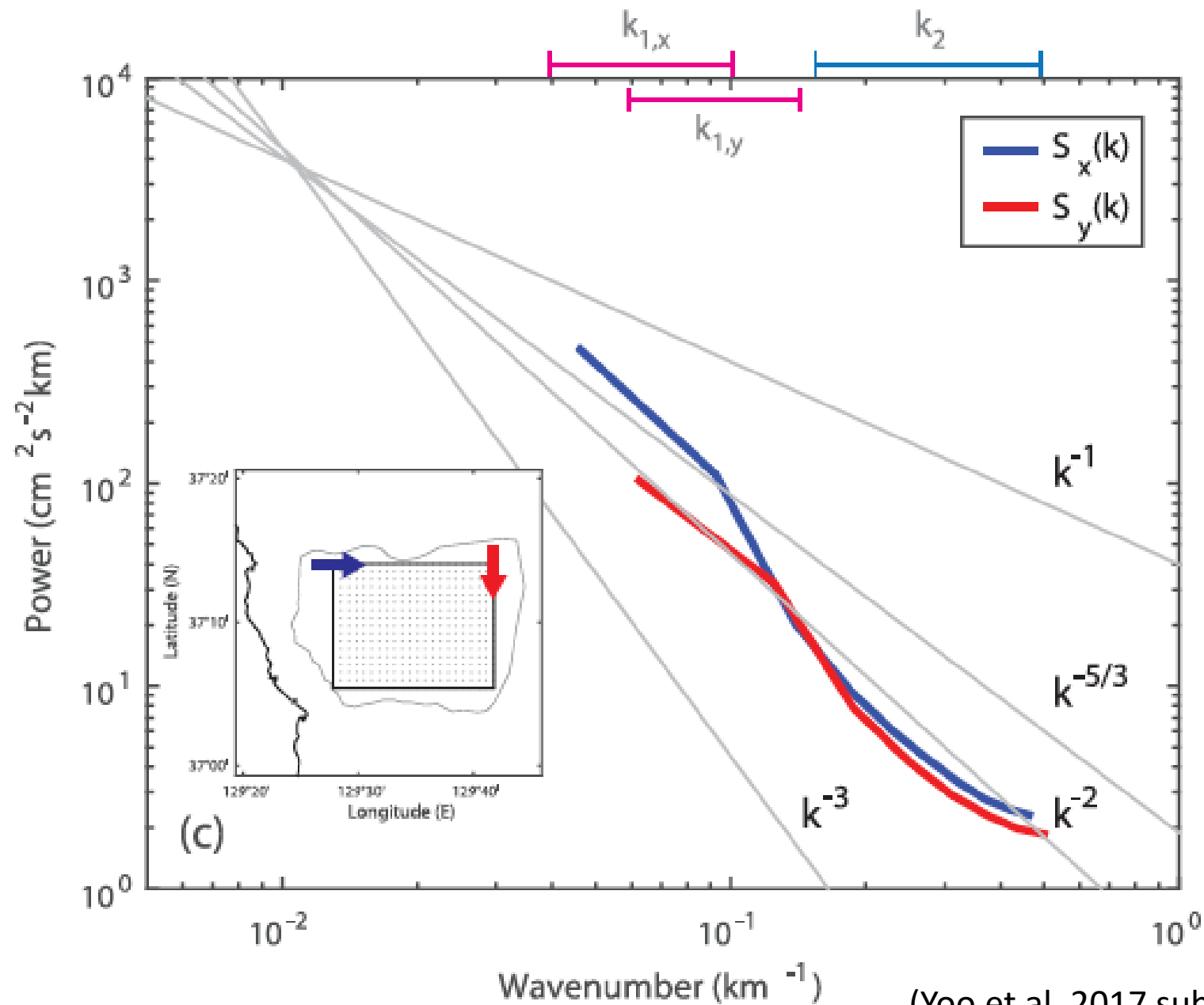
- Surface currents are observed at the verge of the confluence of two regional boundary currents

# 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.

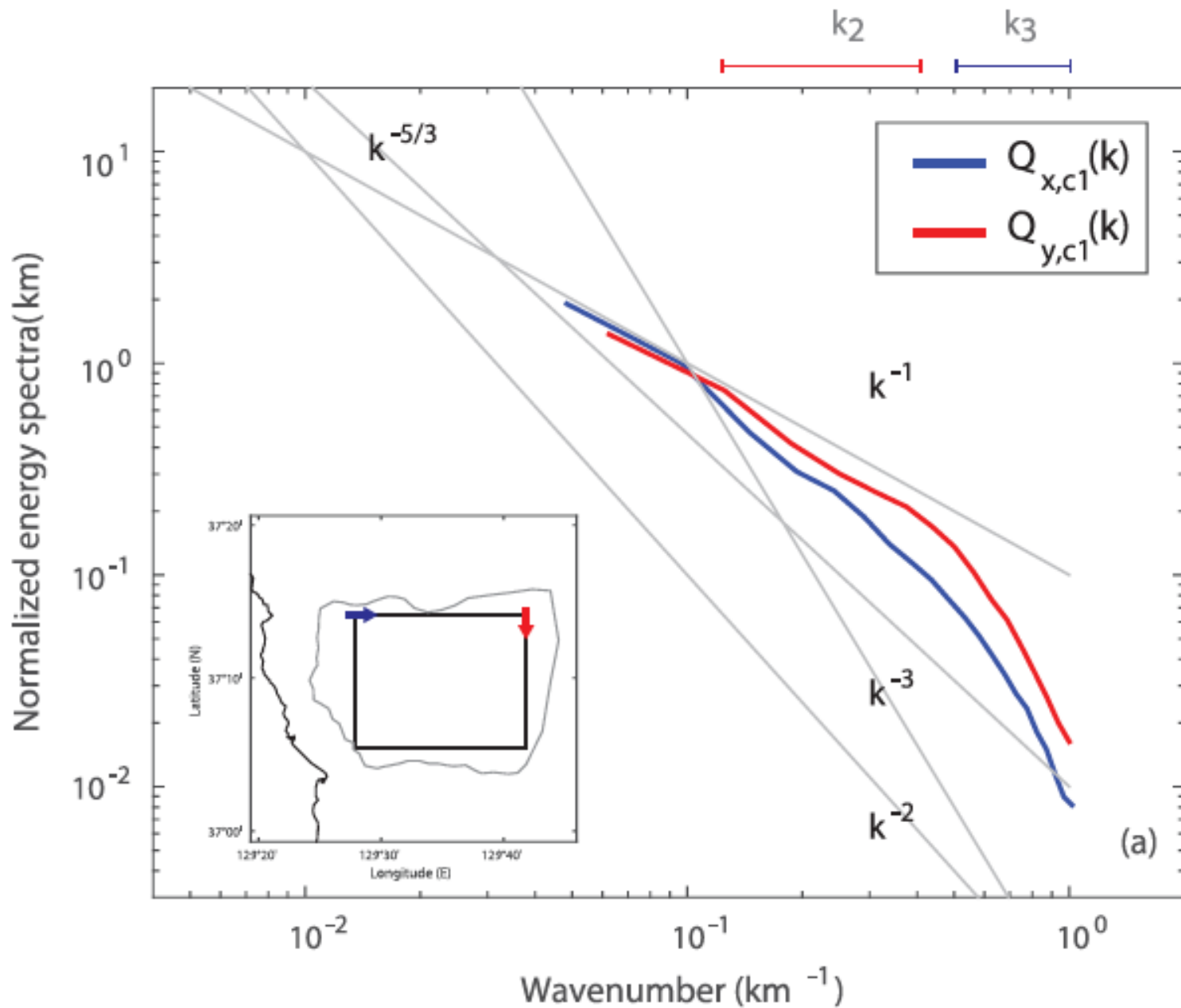


# KE spectra of submesoscale surface currents

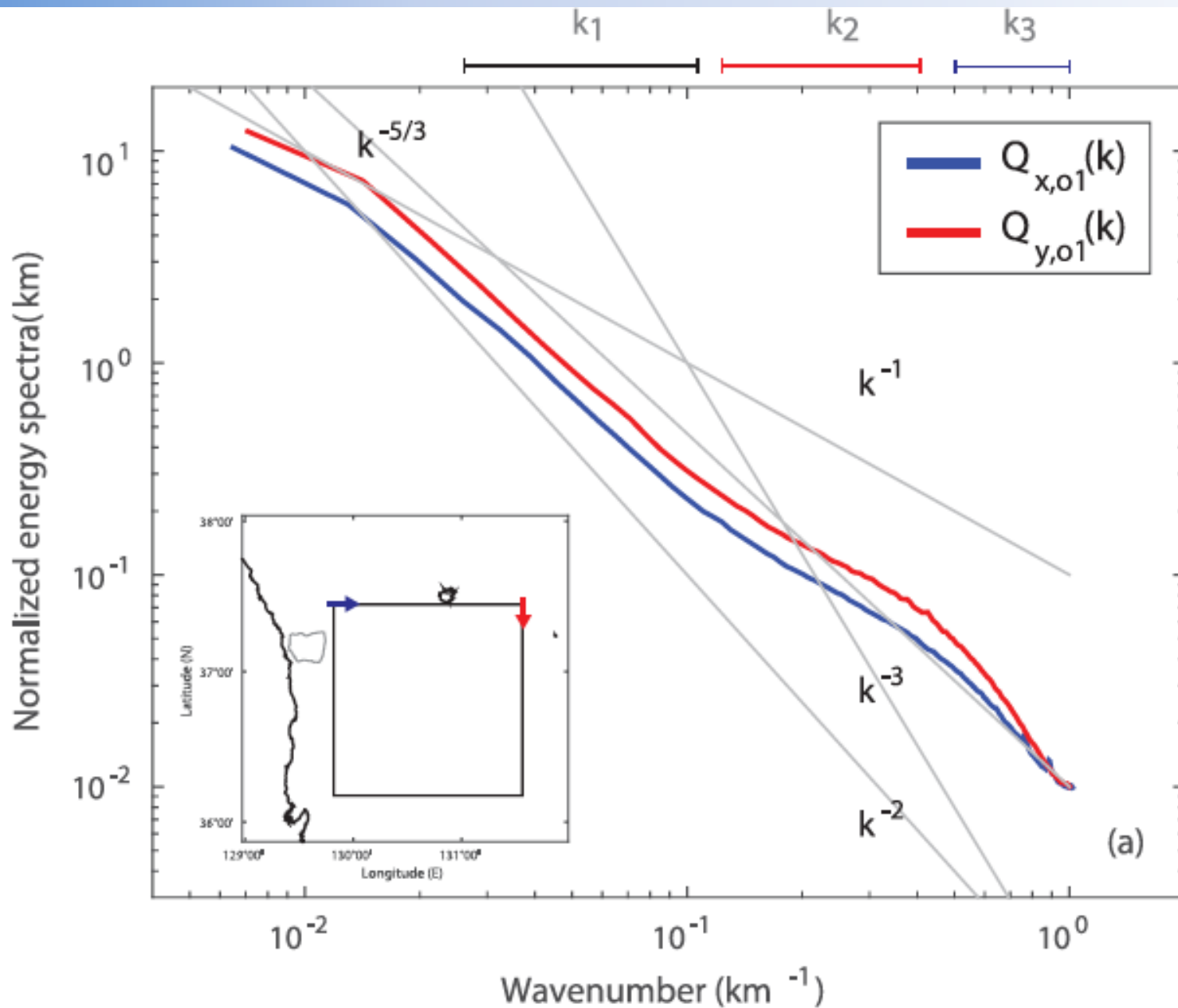


(Yoo et al, 2017 submitted)

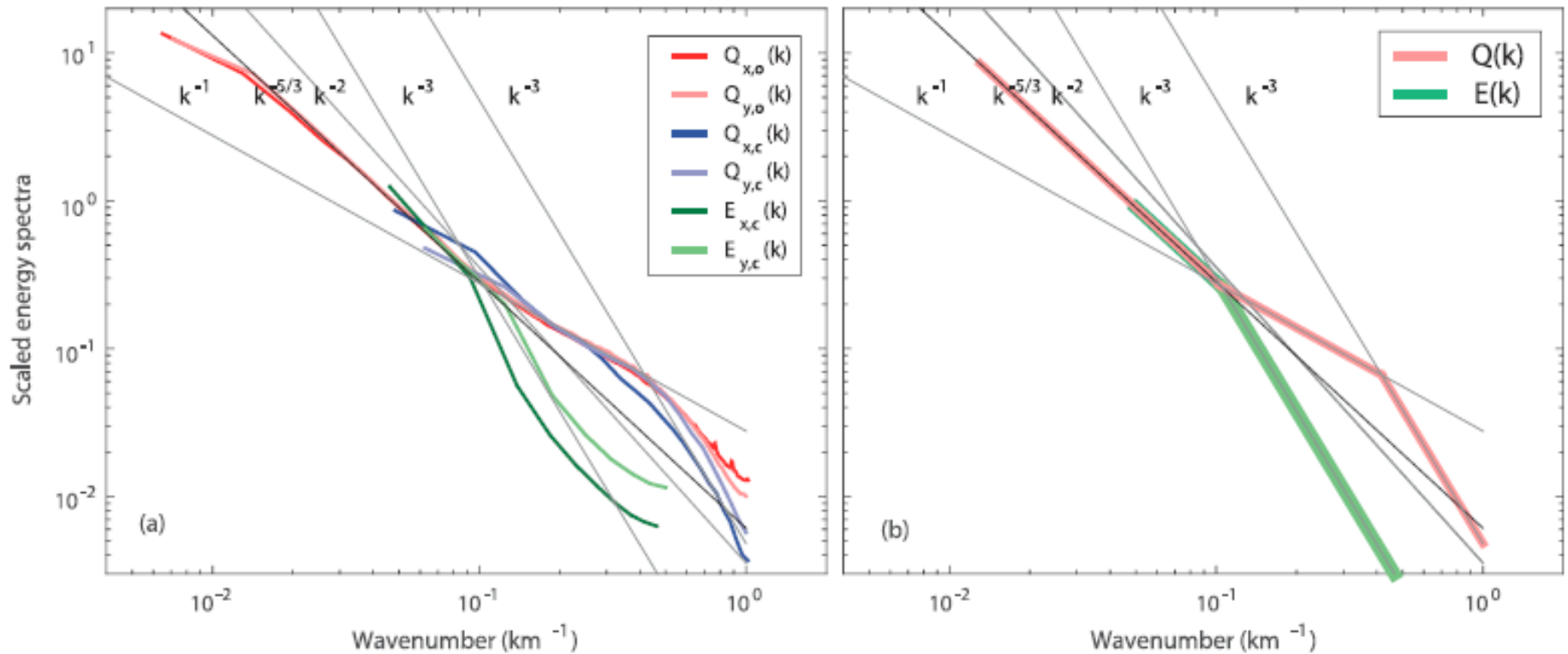
# Spectra of submesoscale surface CHLs (1/2)



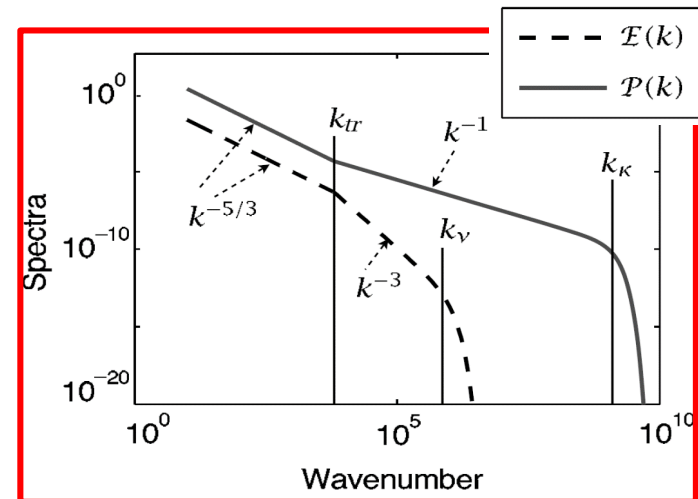
# Spectra of submesoscale surface CHLs (2/2)



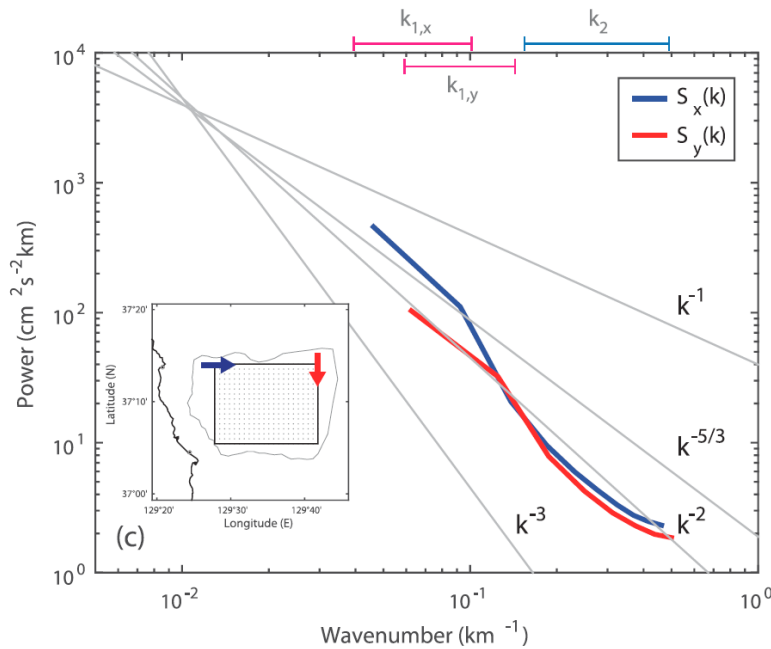
# Scaled (KE) spectra of surface currents and CHLs



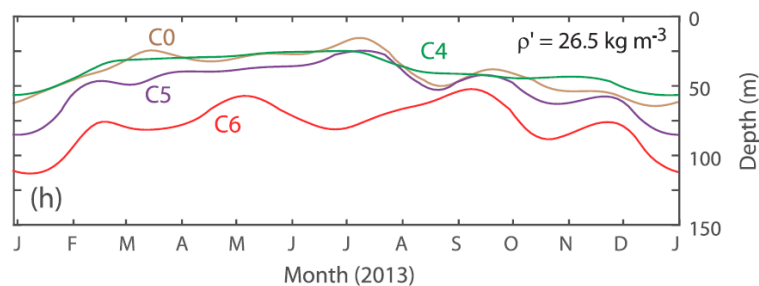
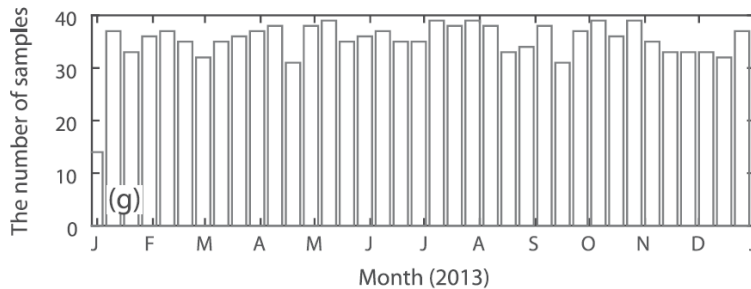
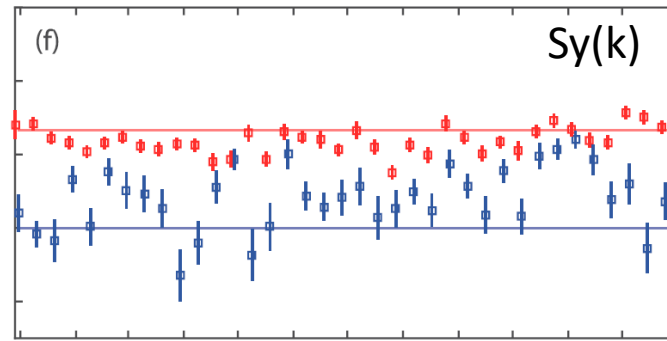
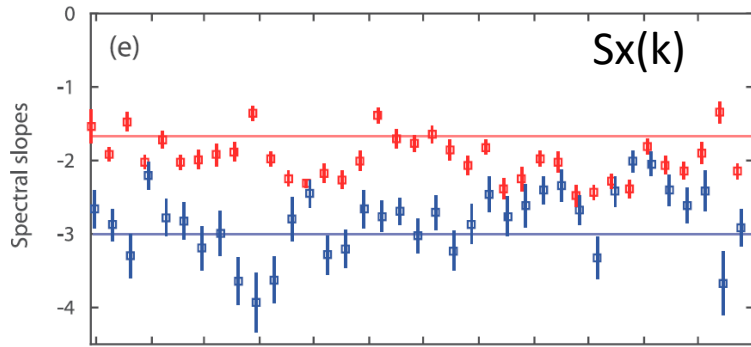
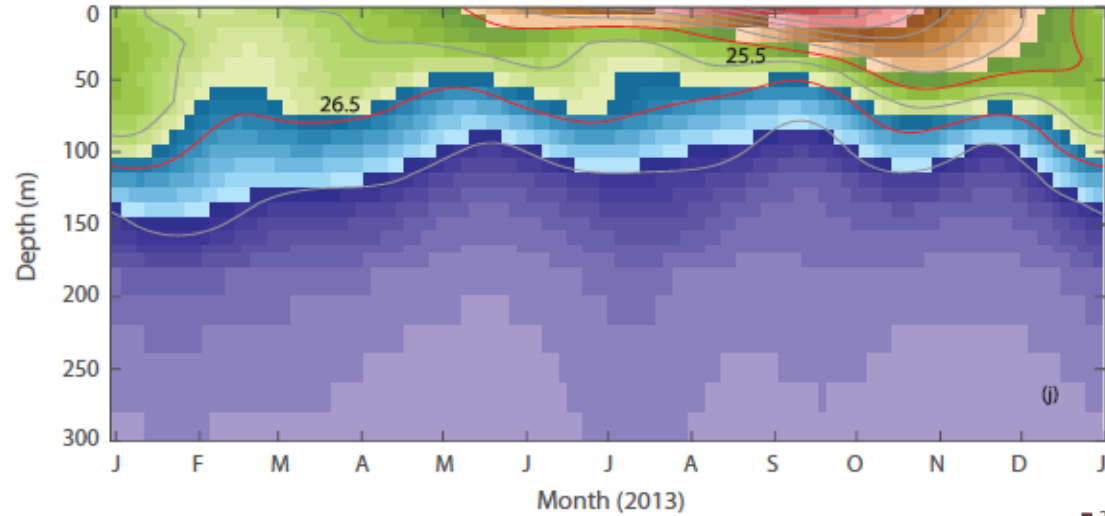
- Transition and dissipation scales appear near 10 km and 2 km, respectively



# KE spectra of surface currents off Imwon

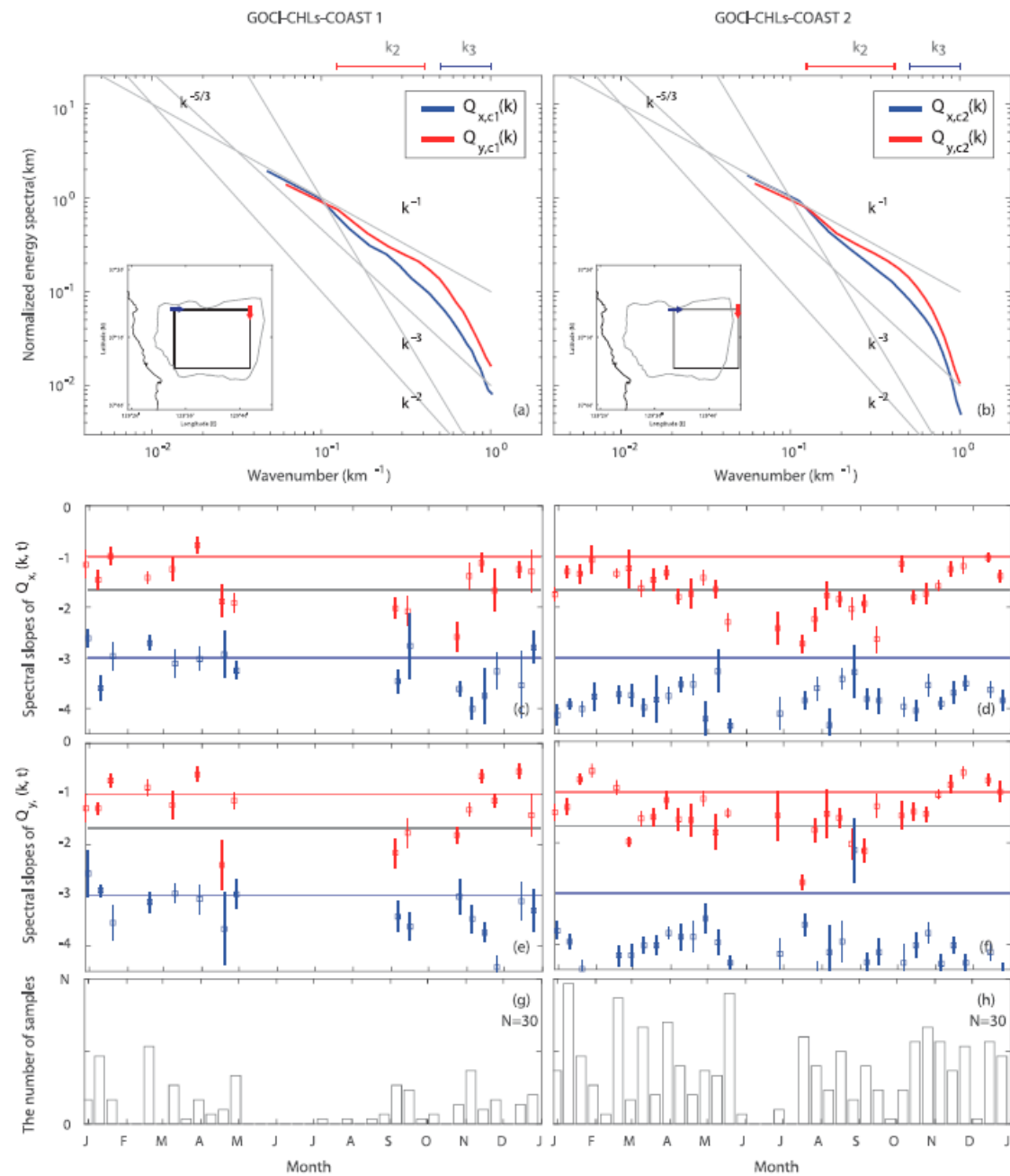


## Temperature profiles at the C6 station

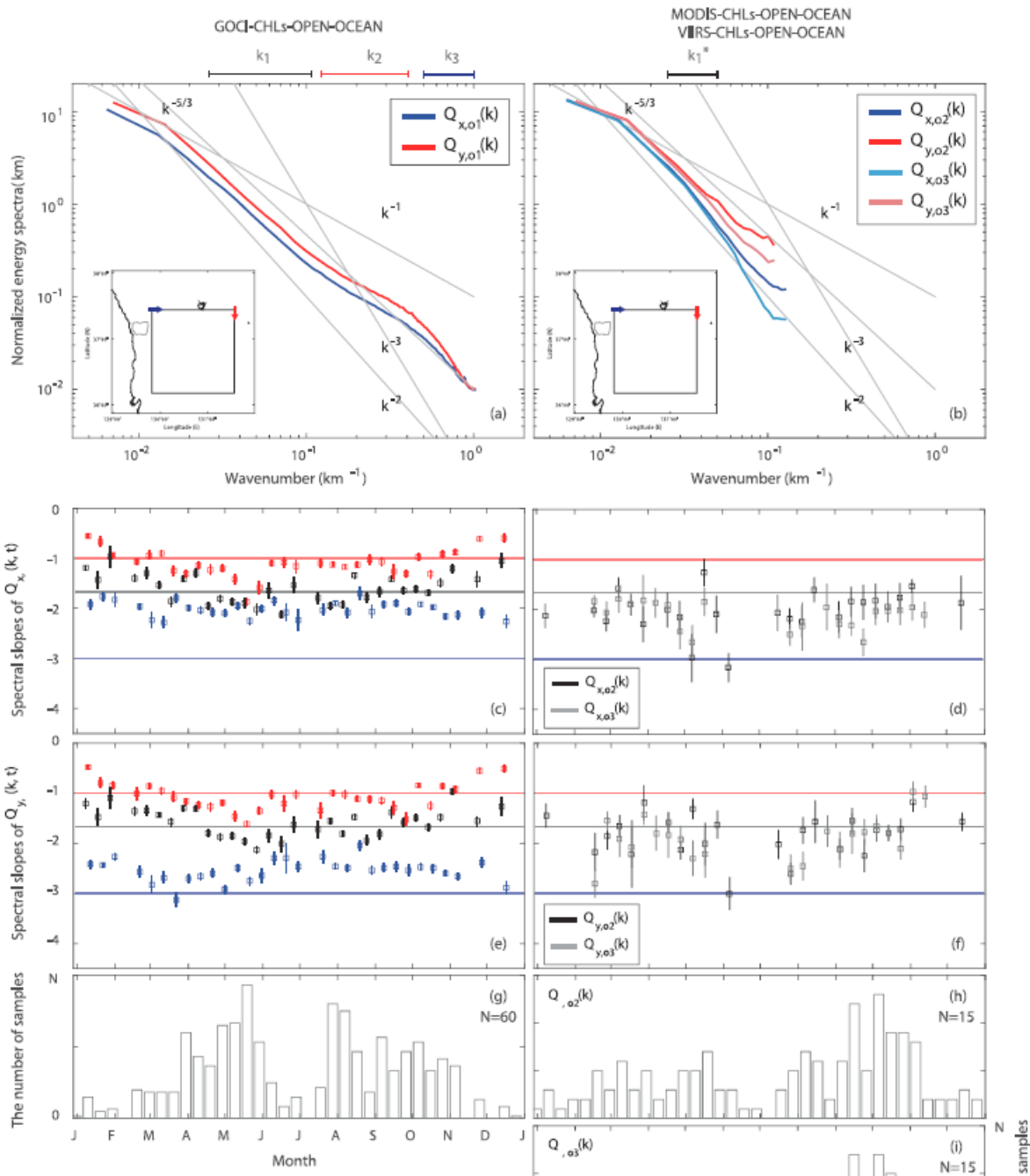




# KE spectra of CHLs (near the coast)



# KE spectra of CHLs (offshore)



# 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  $\sim 10$  km and dissipation scale of  $\sim 2$  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.