Energy spectra and pathways of submesoscale coastal surface currents

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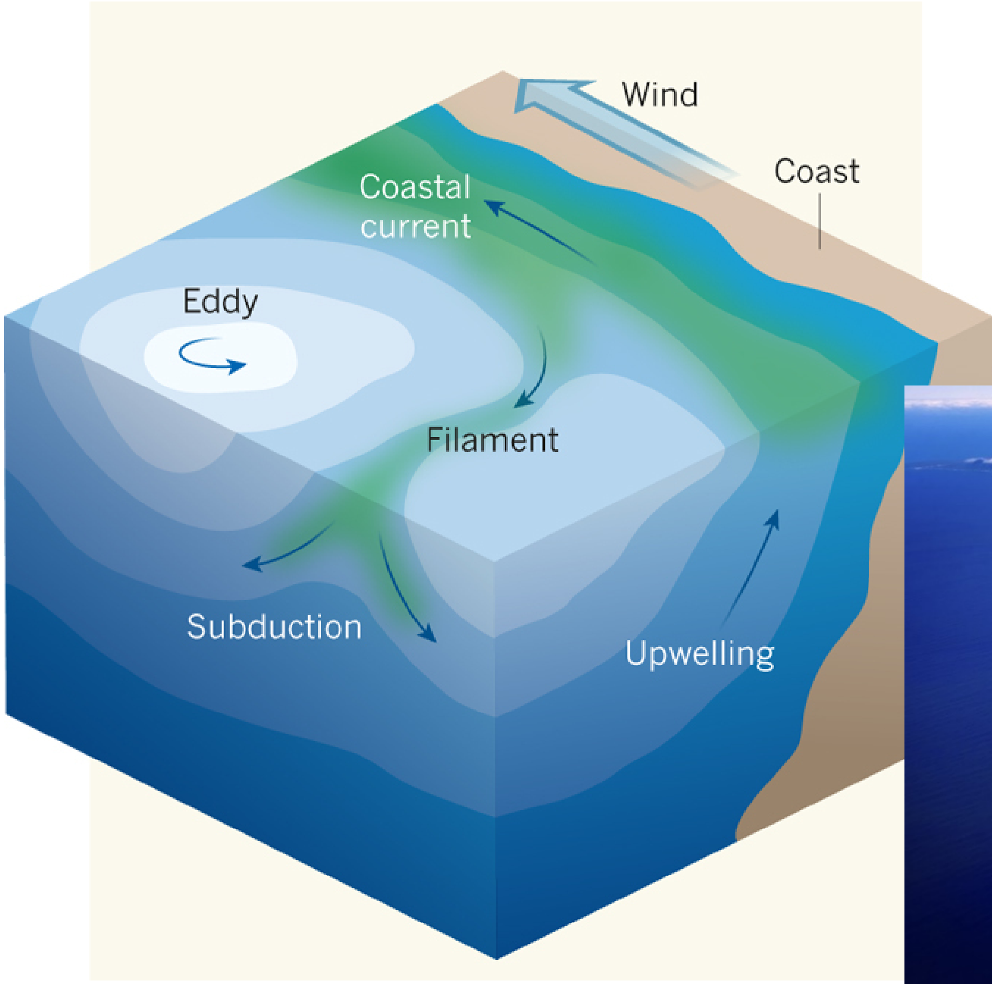

(A. Mahadevan, Nature 2014)

(An aerial image of red tide)

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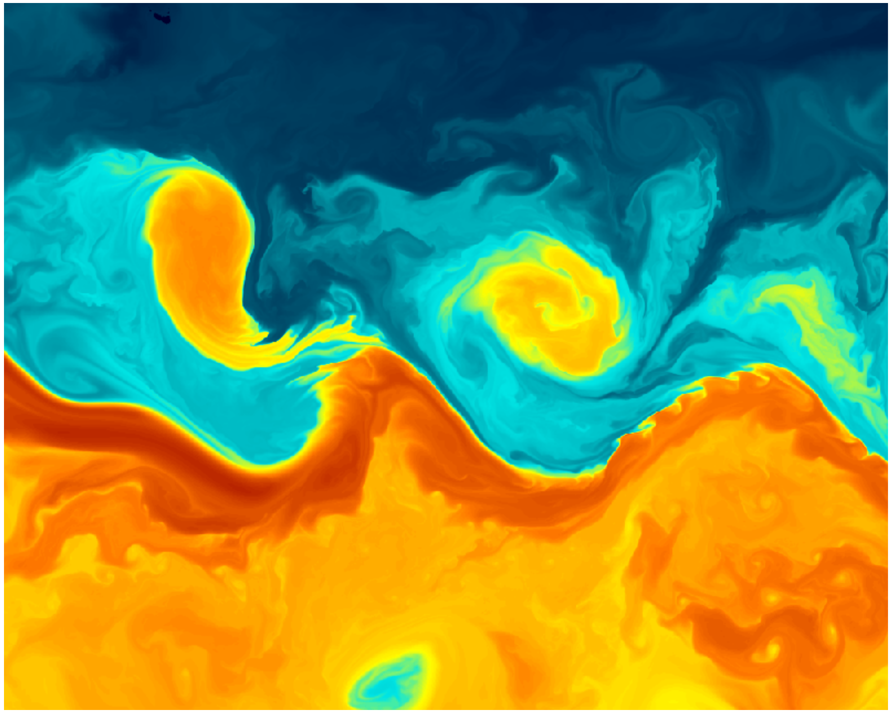
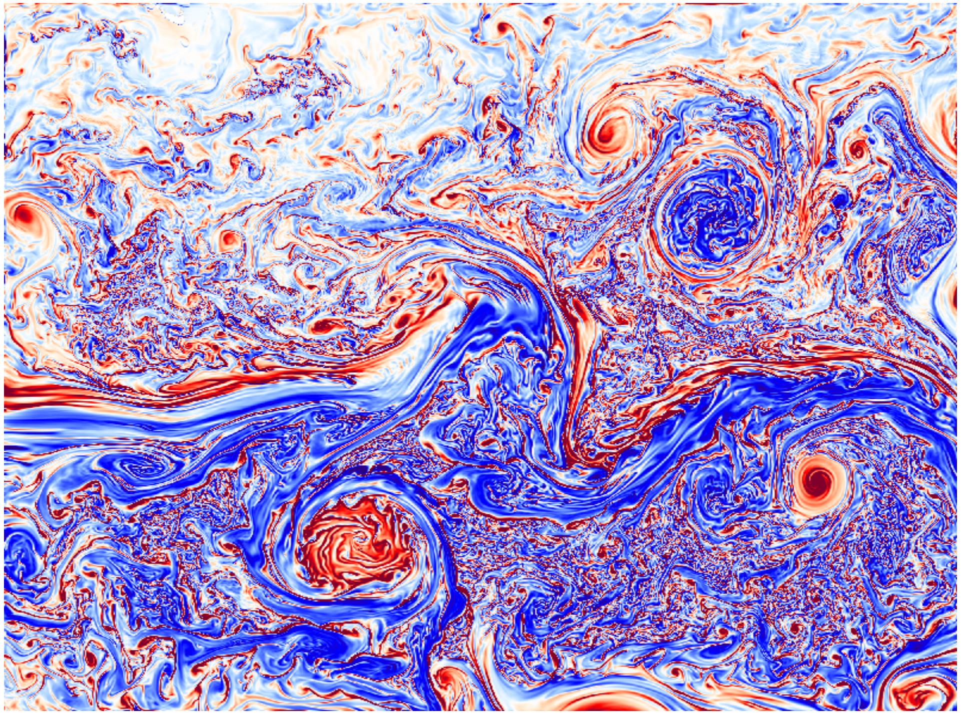

(J. Gula @ UCLA)

- 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

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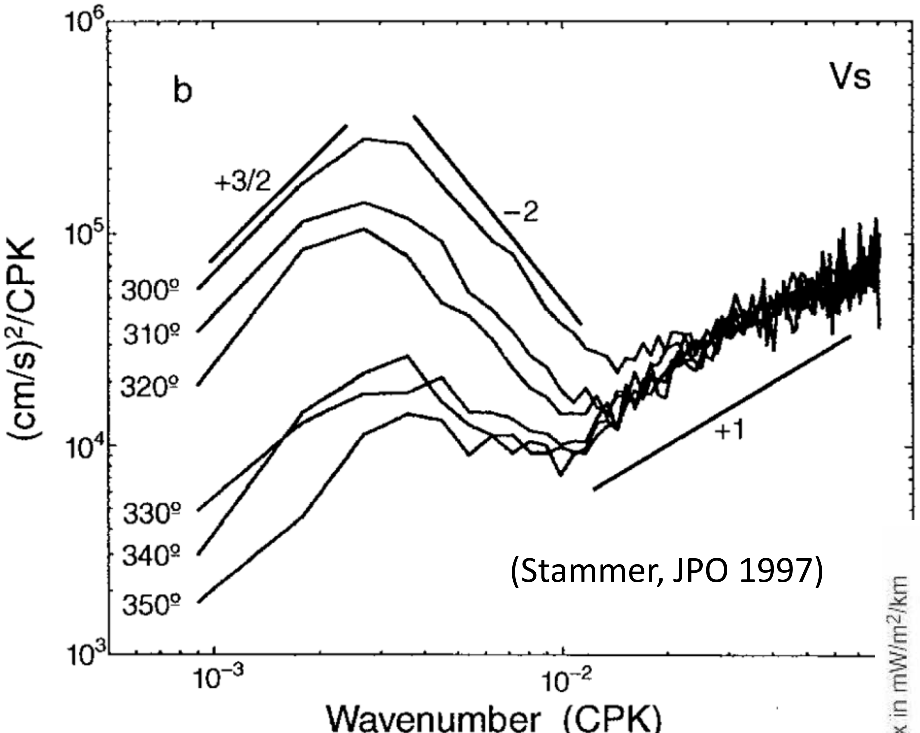
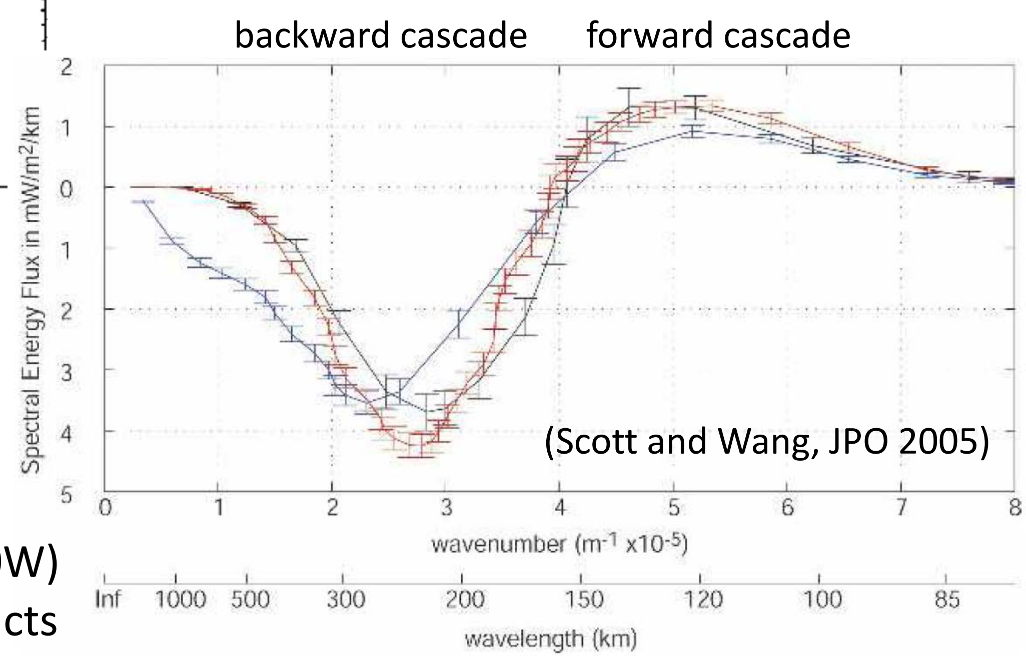


(Stammer, JPO 1997)

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

- What can be the slope of energy spectra and kinetic energy flux below 100 km scale?



(Scott and Wang, JPO 2005)

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

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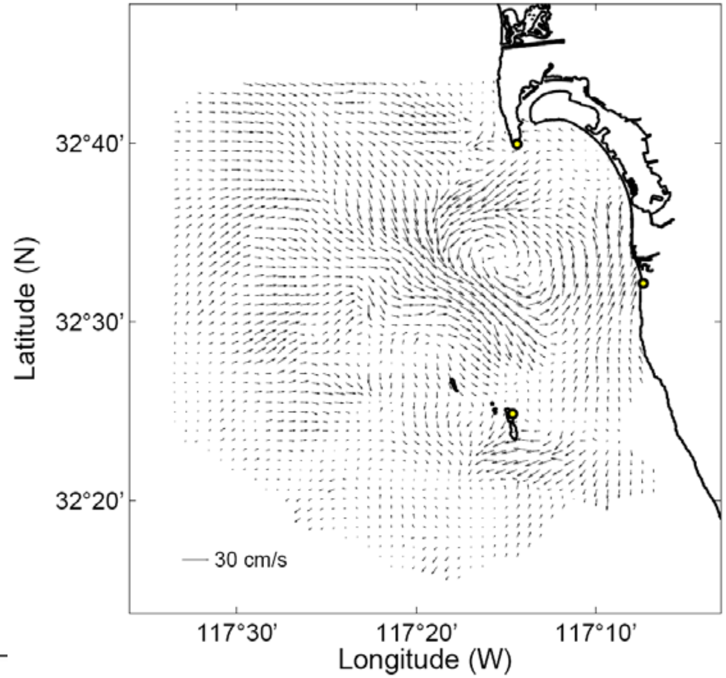
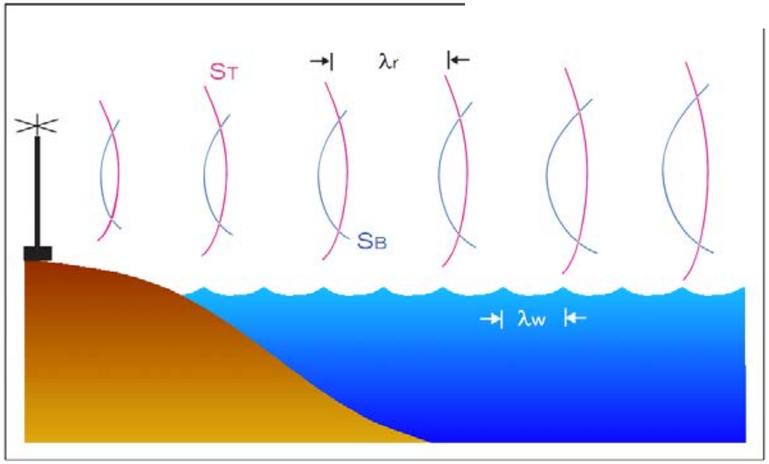
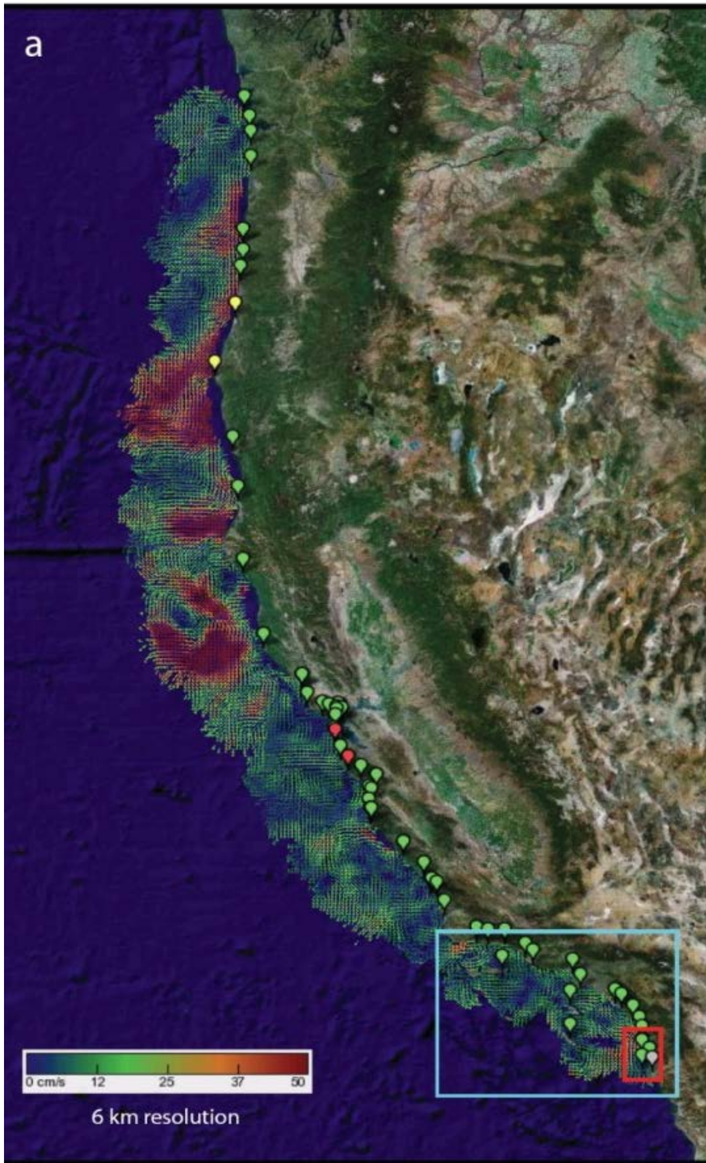
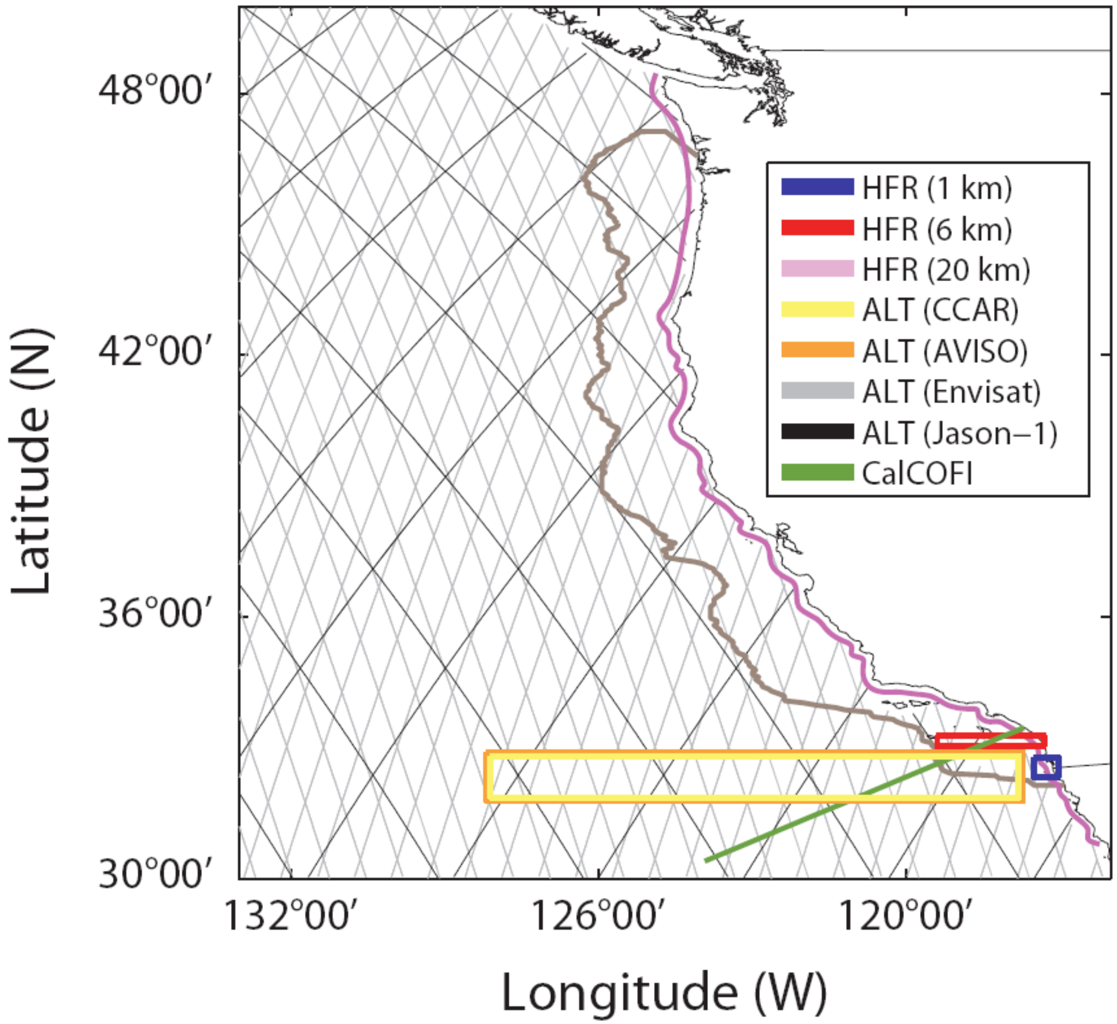






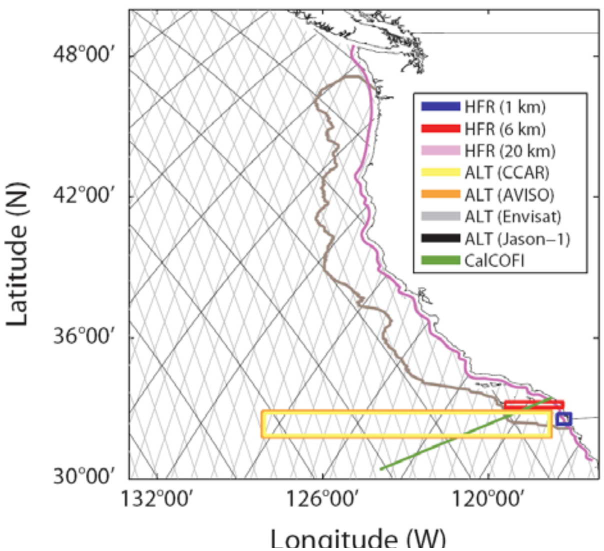
(Kim et al JGRC 2011; Kim and Crawford GRL 2014)

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.

Energy spectra in the wavenumber domain (1D)

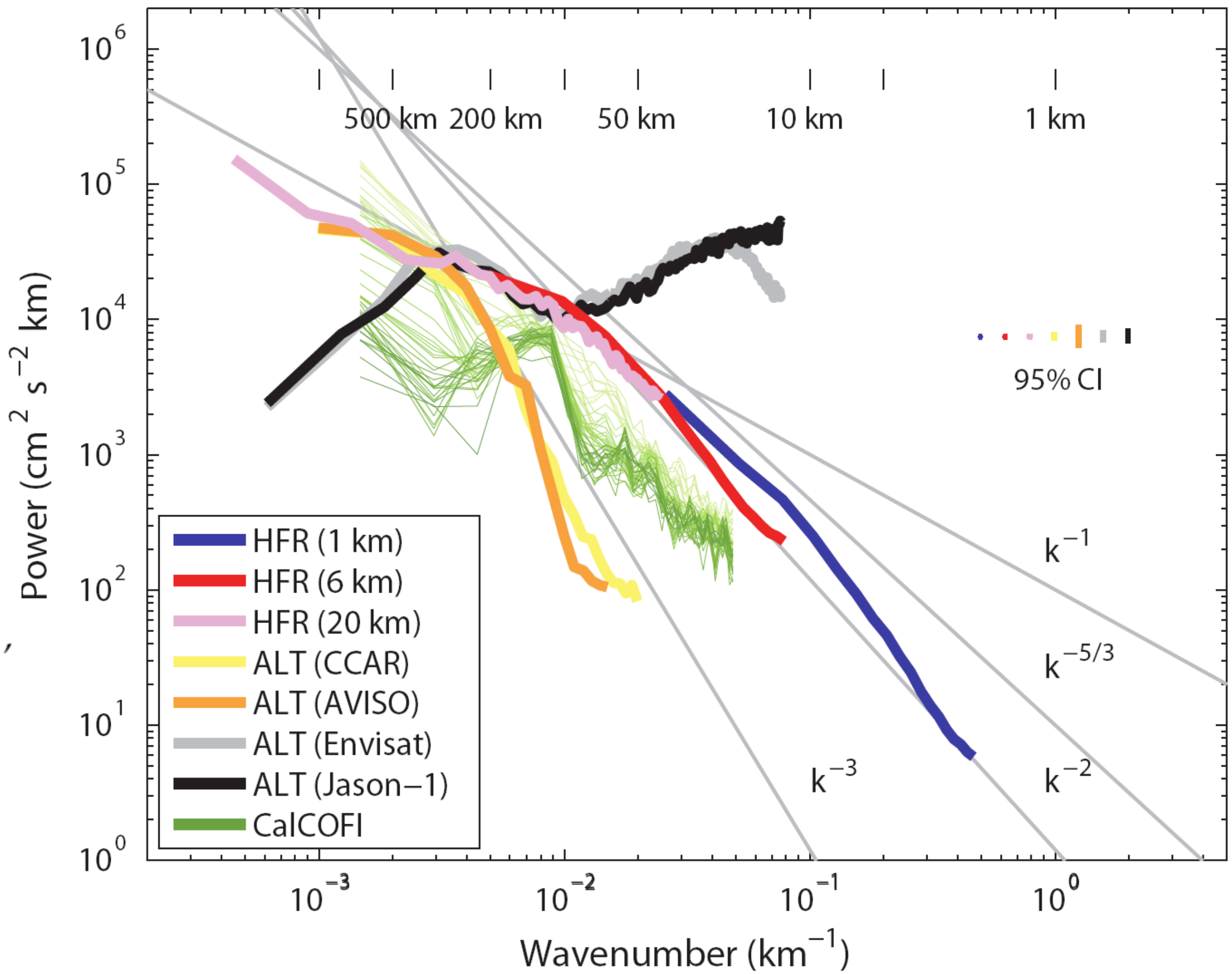


$$S_{\mathbf{u}_\perp}(k_\parallel) = \left(\frac{g}{f_c}\right)^2 \left(2\pi k_\parallel\right)^2 S_{\boldsymbol{\eta}_\parallel}(k_\parallel),$$

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.

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

$$\Pi(k^*) = \langle \mathbf{u}_< \cdot (\mathbf{u}\cdot\nabla\mathbf{u})\rangle,$$ Cumulative advective kinetic energy flux

$$= \langle \mathbf{u}_< \cdot (\mathbf{u}_< \cdot \nabla\mathbf{u}_>)\rangle + \langle \mathbf{u}_< \cdot (\mathbf{u}_> \cdot \nabla\mathbf{u}_>)\rangle,$$

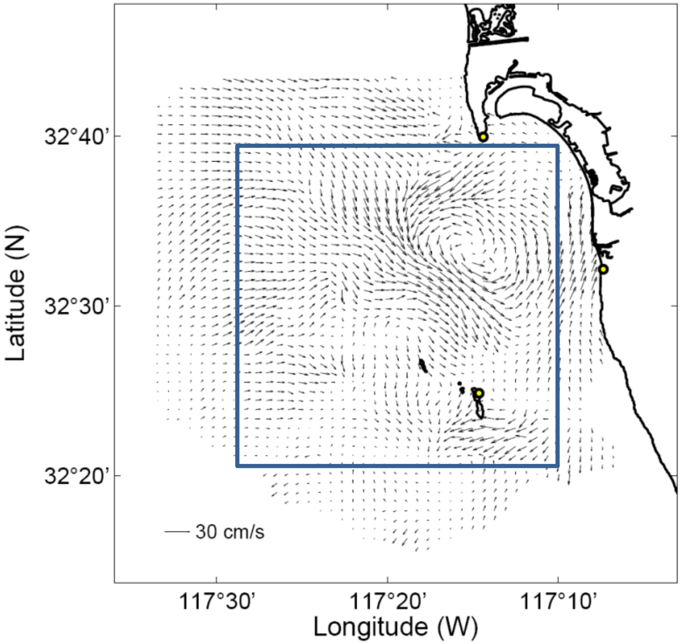
$$\Omega(k^*) = \frac{1}{2}\sum_{|\mathbf{k}|<k^*} \mathbf{k}^2|\hat{\mathbf{u}}(\mathbf{k})|^2,$$ Cumulative enstrophy

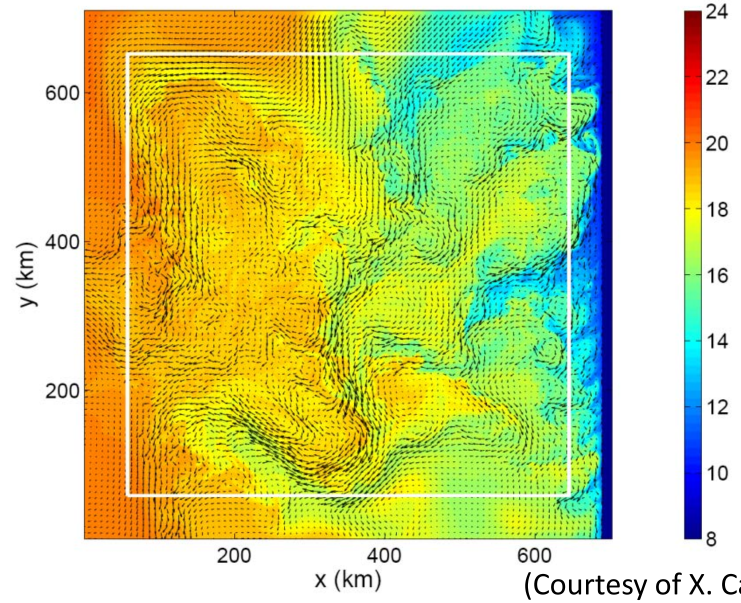
$$\mathbf{u}(\mathbf{x}) = \mathbf{u}_<(\mathbf{x}) + \mathbf{u}_>(\mathbf{x}),$$

$$= \sum_{|\mathbf{k}|<k^*} \hat{\mathbf{u}}(\mathbf{k})e^{i\mathbf{k}\mathbf{x}} + \sum_{|\mathbf{k}|>k^*} \hat{\mathbf{u}}(\mathbf{k})e^{i\mathbf{k}\mathbf{x}},$$

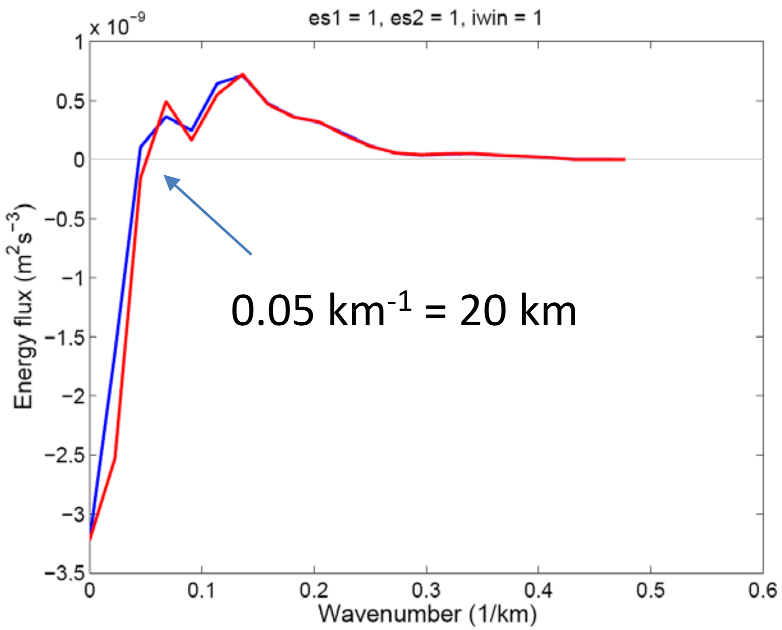
- Surface currents from HFR observations (1 km) and sub-mesoscale model (0.75 km; X. Capet *et al*, 2009) off southern California

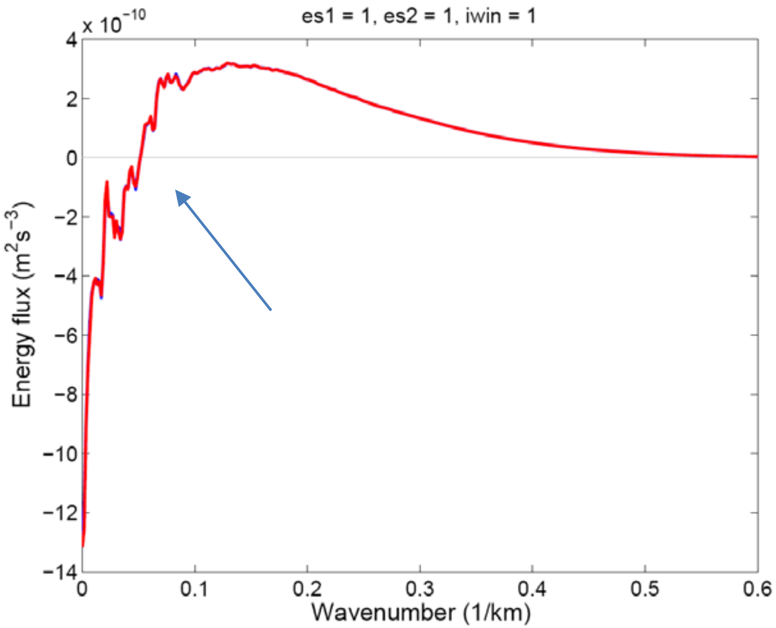
Comparison of advective kinetic energy flux [Π(k*)]





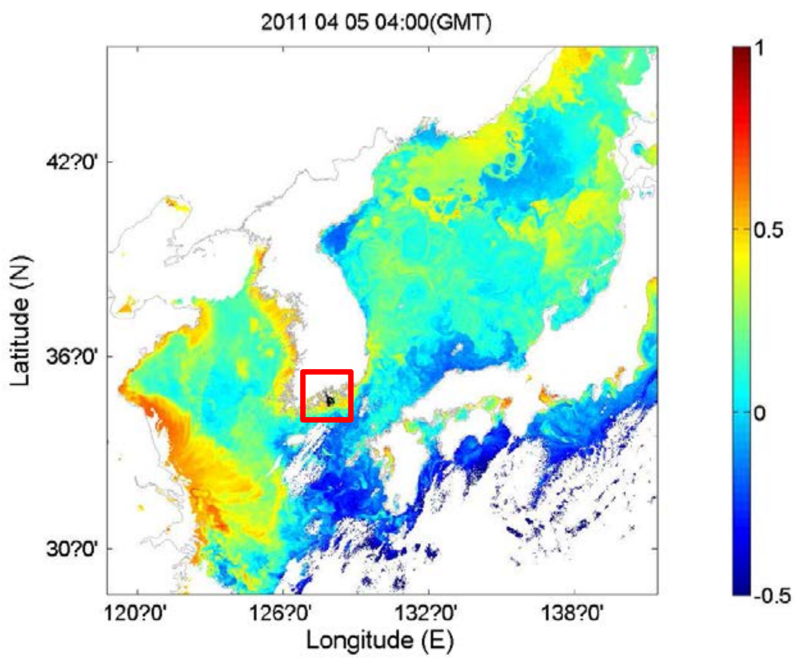
(Courtesy of X. Capet)

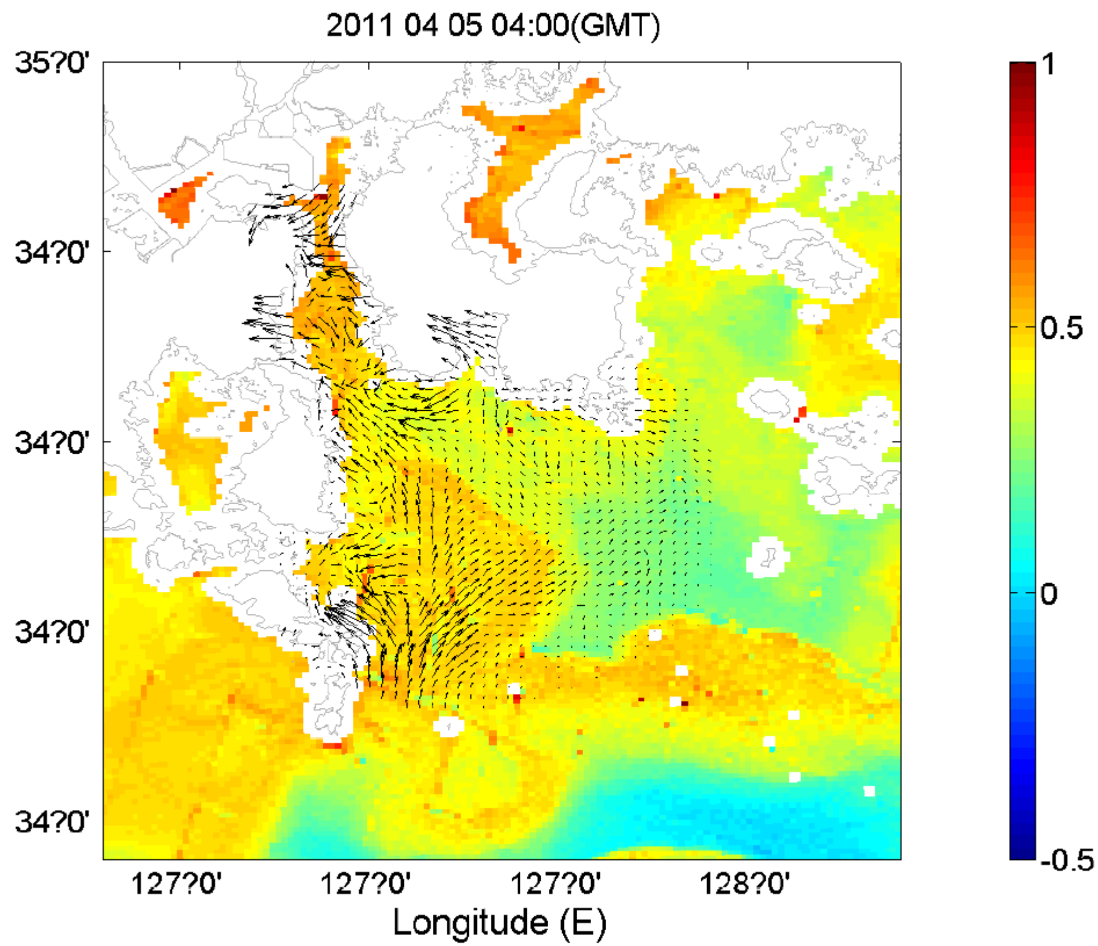




Submesoscale process studies

- have benefited from primarily idealized numerical models and theoretical frameworks because they require the use of high-resolution observations of less than one hour in time and O(1-10) km in space.





Summary

- Scale continuity between sub-mesoscale and mesoscale. Due to the noise at 100 km scale in altimeter observations, studies on energy spectra and flux below that scale can be explored with sub-mesoscale observations.
- Resolving sub-mesoscale processes can lead parameterization on the global-scale and climate-scale numerical simulations and modelling.