Characterizing Submesoscale Variability in the Southern California Current System

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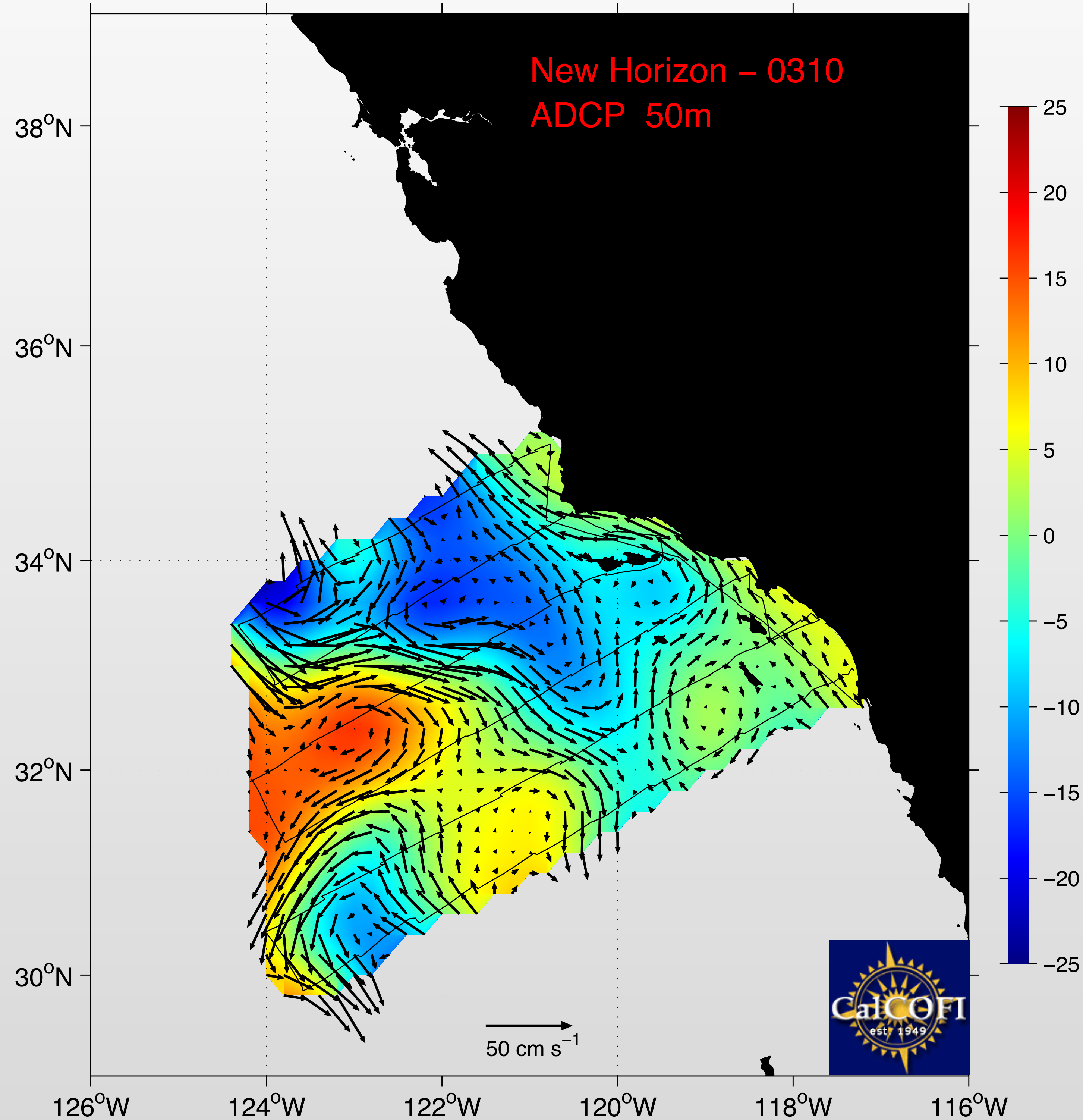


In situ observations and model data

In situ observations

CalCOFI ADCP:

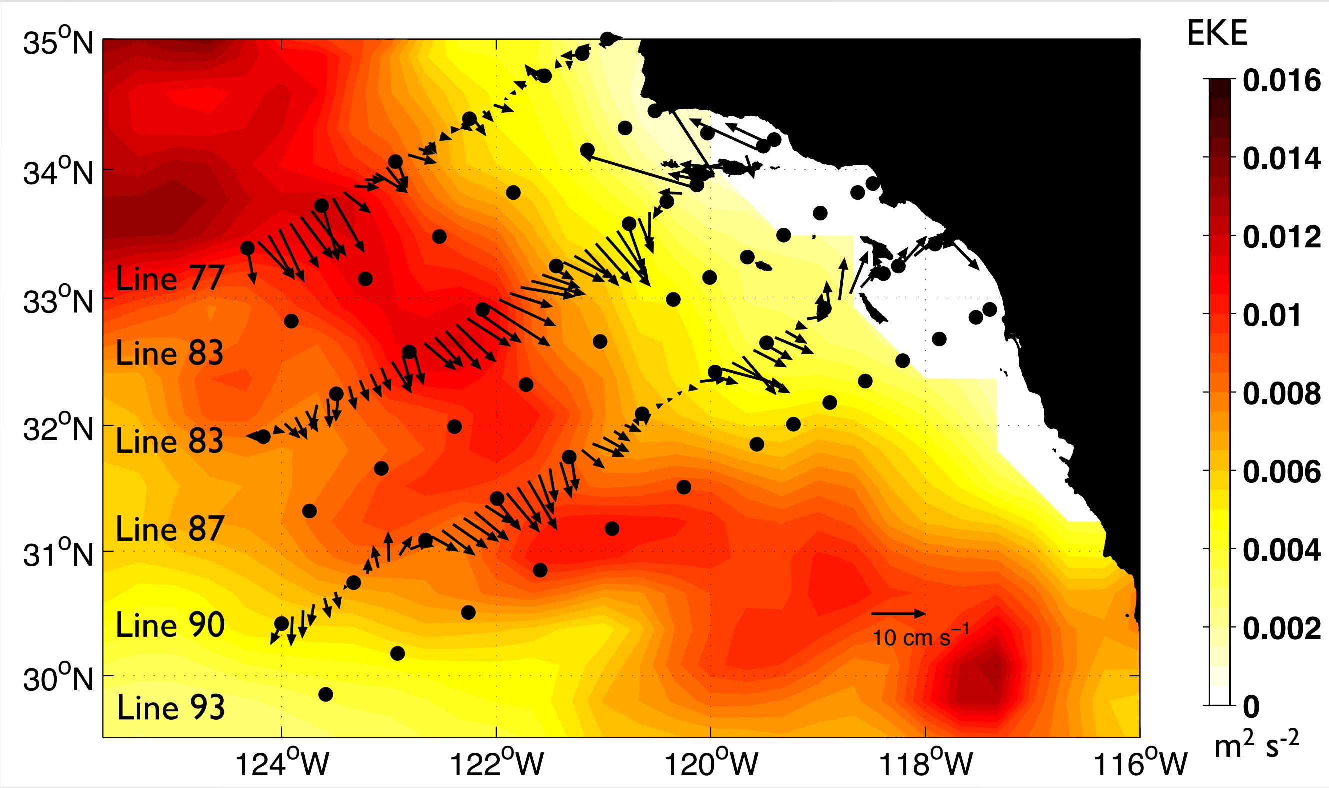
- sampled 4x/year along 6 lines
- horizontal resolution: 5 km
- depth range: 20 m to 300 m
- time interval: 1993-2004

LLC MITgcm simulations:

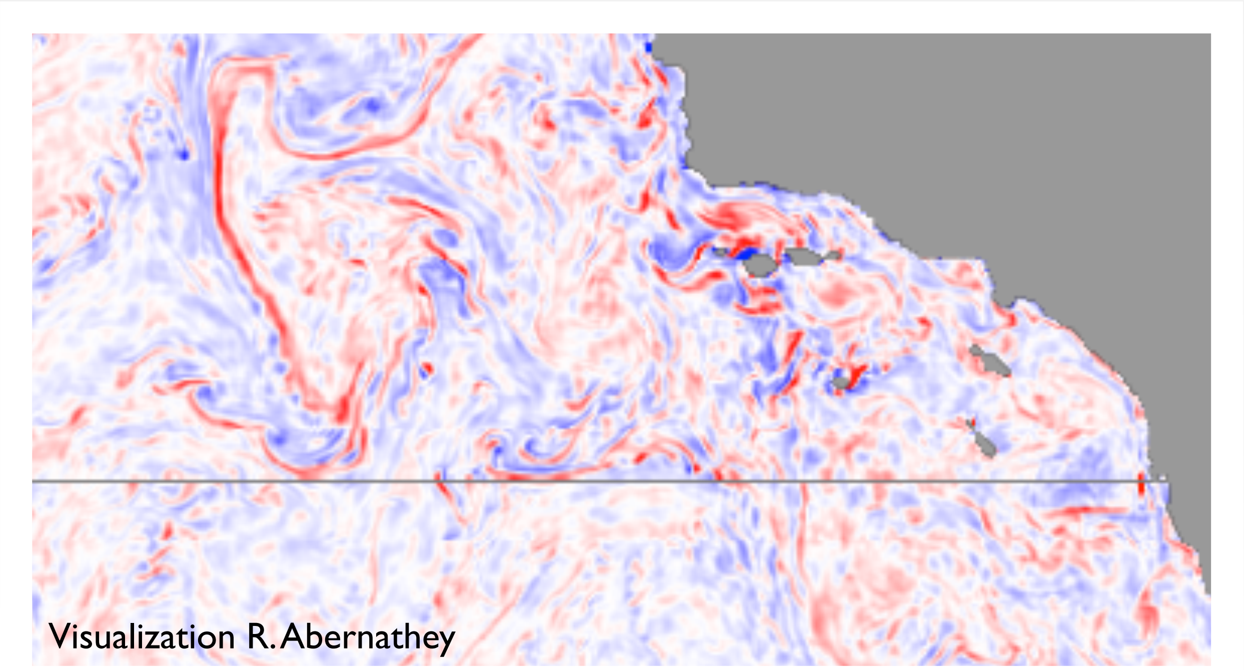
- global
- forced with tides & ECMWF
- 90 vertical levels
- LLC 2160: 1/24° (2 years)
- LLC 4320: 1/48° (1year)

(Poster: High-wavenumber variability in the California Current from new altimeters, SC2-009)

11-year mean currents at 20 m on EKE from Aviso



Snapshot of surface relative vorticity from LLC 4320



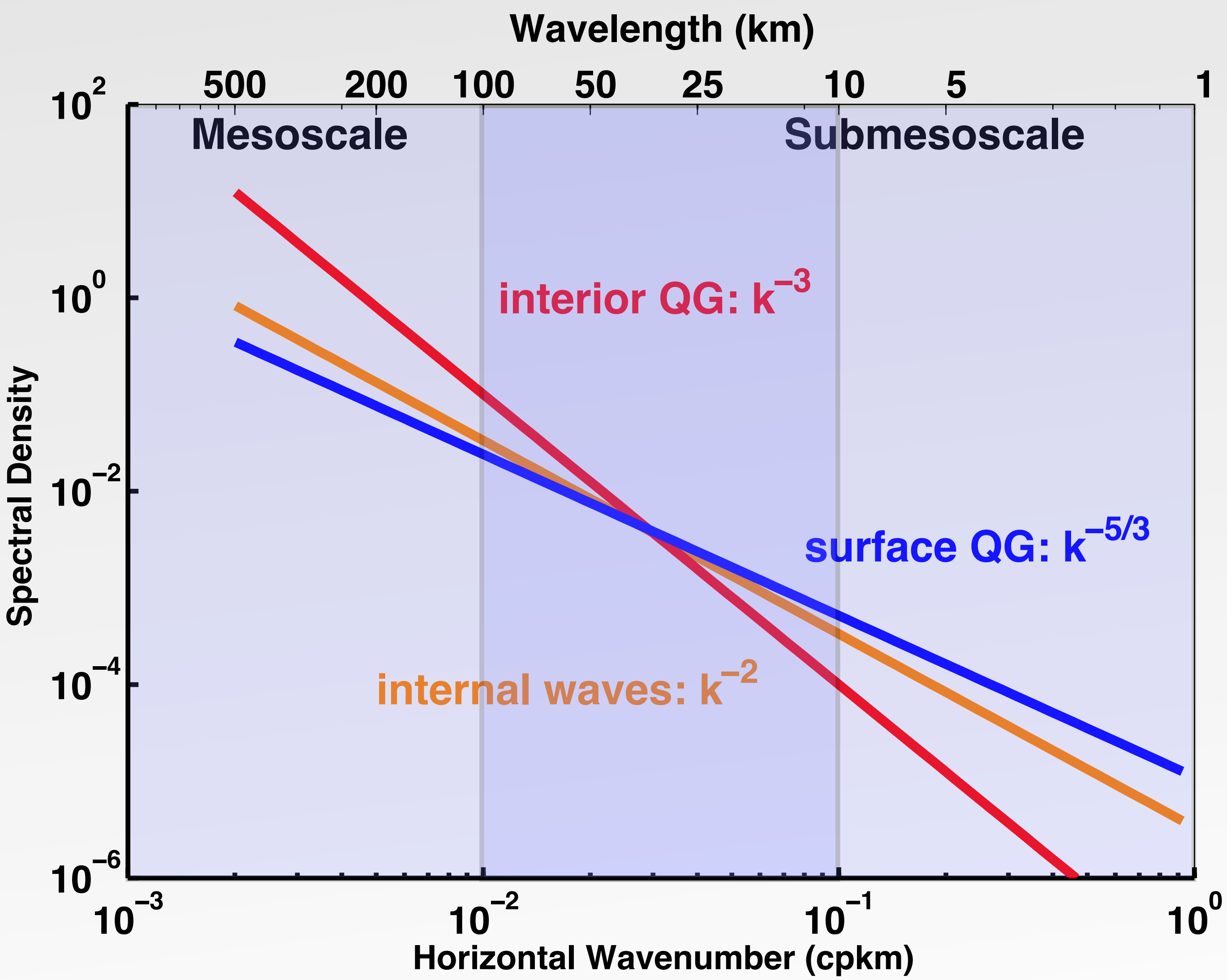
Inferring dynamics from horizontal wavenumber spectra:

What do we expect for kinetic energy spectra?

Isotropic Quasi-Geostrophy:

- interior QG predicts k^{-3} (Charney, 1970)
- surface QG predicts $k^{-5/3}$ (Blumen, 1978)

Ageostrophic motions can project onto similar scales, e.g., inertia-gravity waves k^{-2} can flatten QG spectral slopes (Garrett & Munk, 1975)



Inferring dynamics from horizontal wavenumber spectra:

What has been observed for kinetic energy spectra?

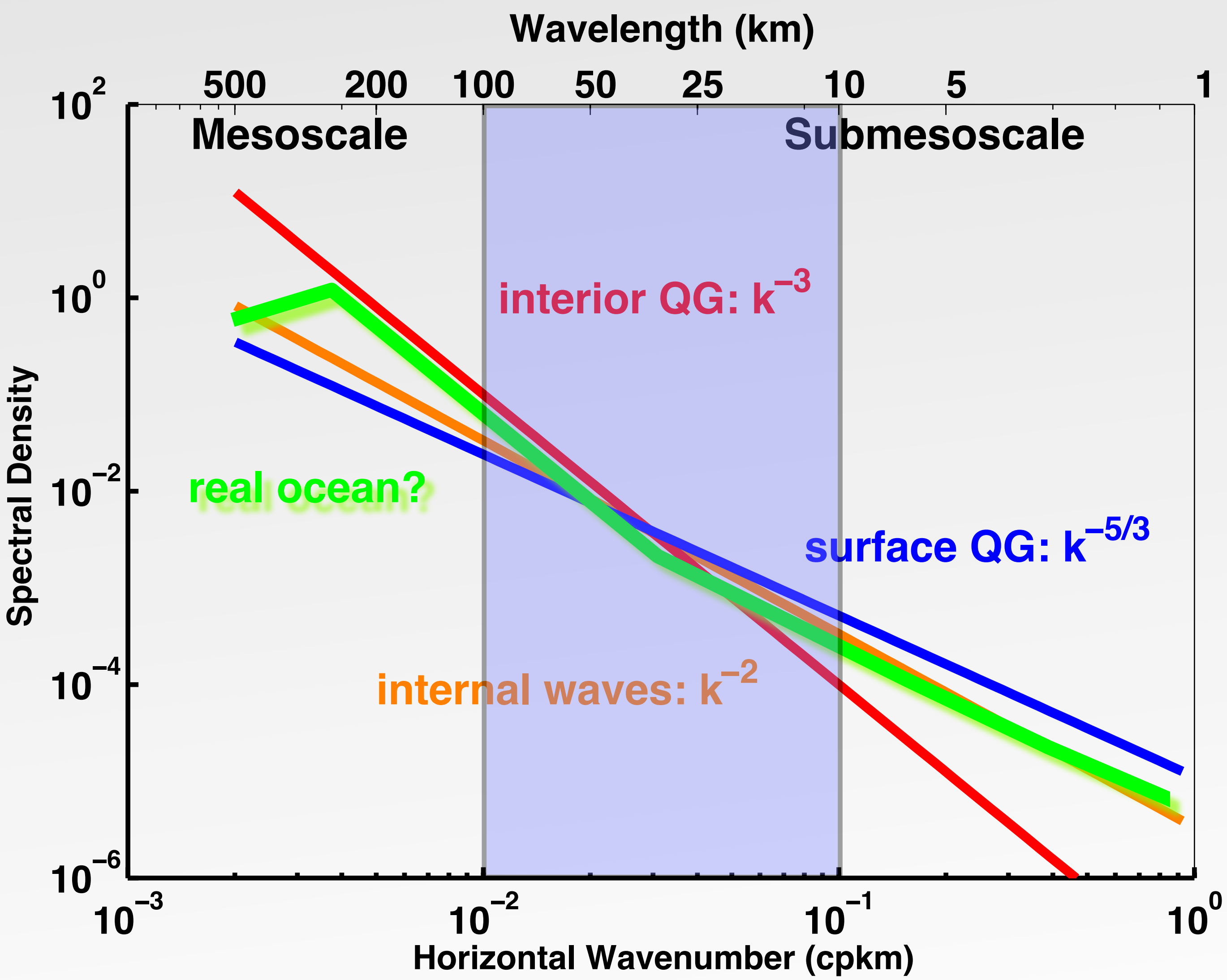
Real ocean spectra from strong baroclinic jets (Gulf Stream, ACC) are consistent with

- interior QG (k^{-3}) at meso- to submeso- scales
- k^{-2} at submesoscales

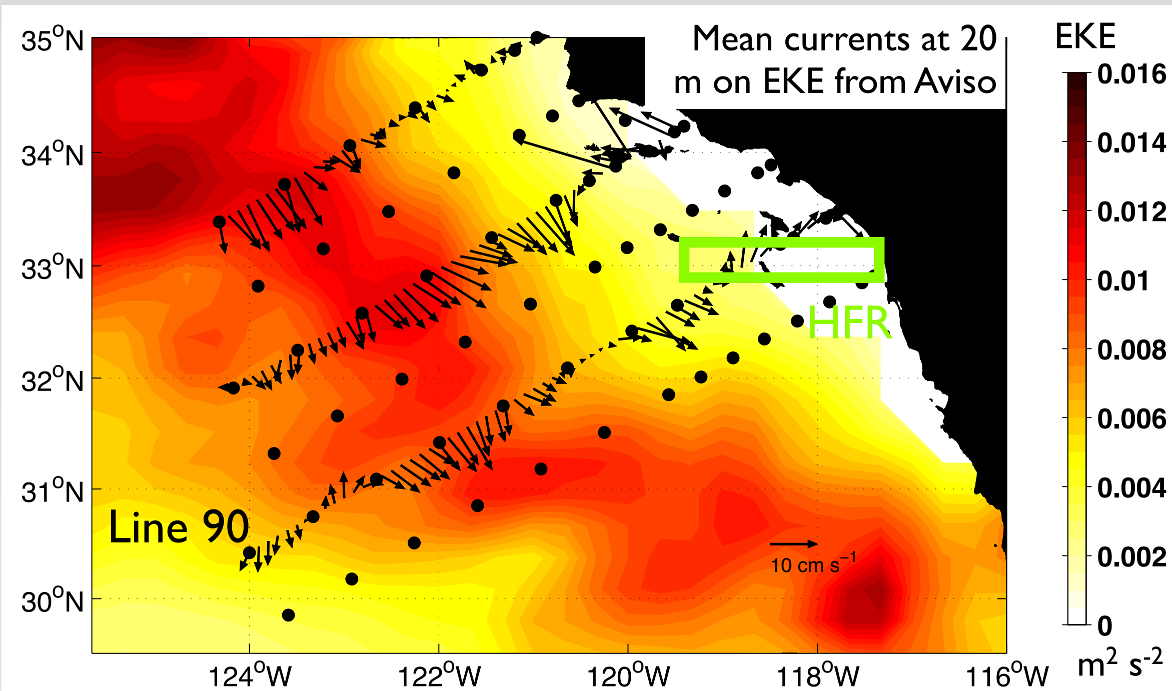
(e.g., Callies & Ferrari, 2013; Rocha et al., 2016)

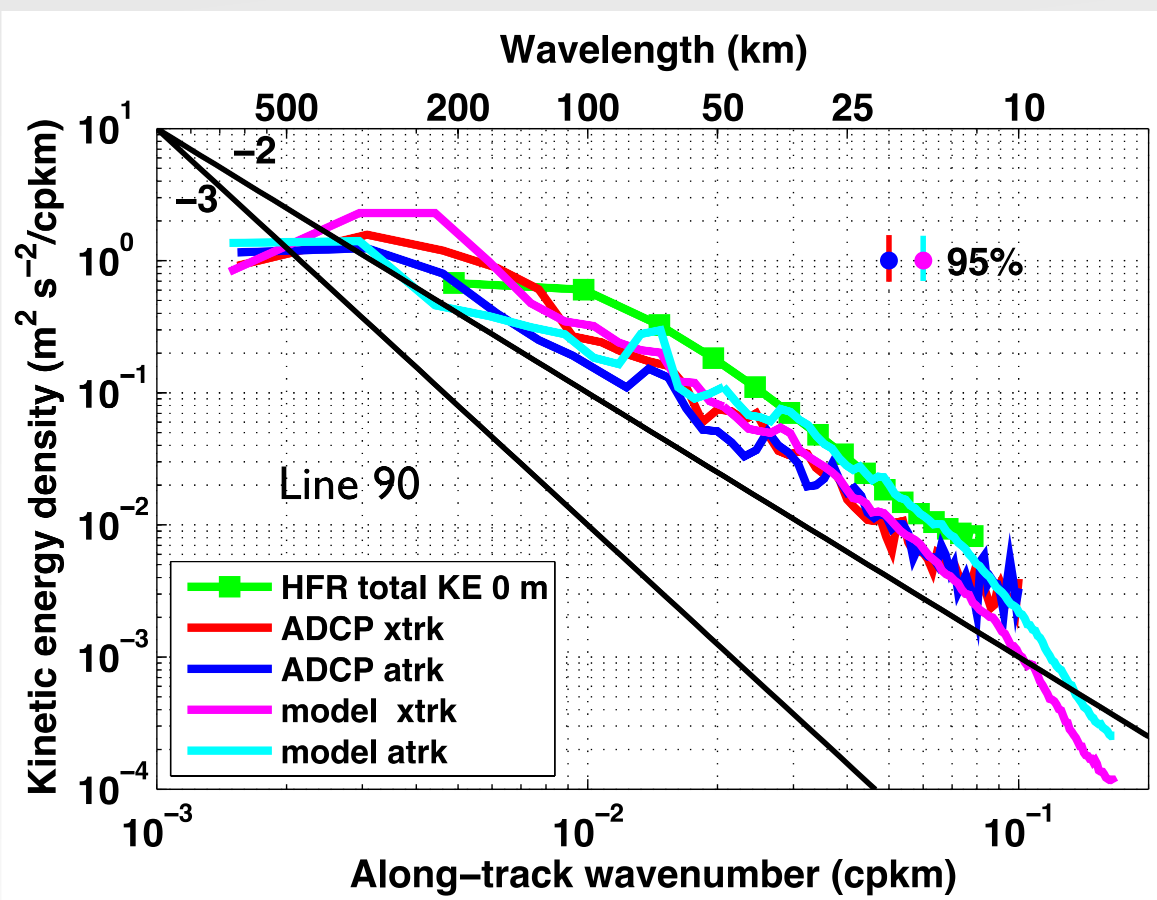
Is this ubiquitous?

What do we find in weak mean flow regions such as eastern boundary currents?



In situ observations and model data: KE spectra





Line 90 across/along-track KE spectra:

- ADCP & LLC4320 model at 20 m have similar shape and energy levels
- Slope varies with wavenumber; about -2 for submesoscales
- Total surface KE from HFR has similar energy/slope as ADCP/model spectra

(HFR courtesy Song-Yong Kim; Kim et al. 2011)

Inferring dynamics from horizontal wavenumber spectra:

Some properties of isotropic spectra:

•The 1-D (alongtrack) spectra will follow the same power law as 2-D (k^{-n})

•Ratio of across/along track KE components is useful diagnostic

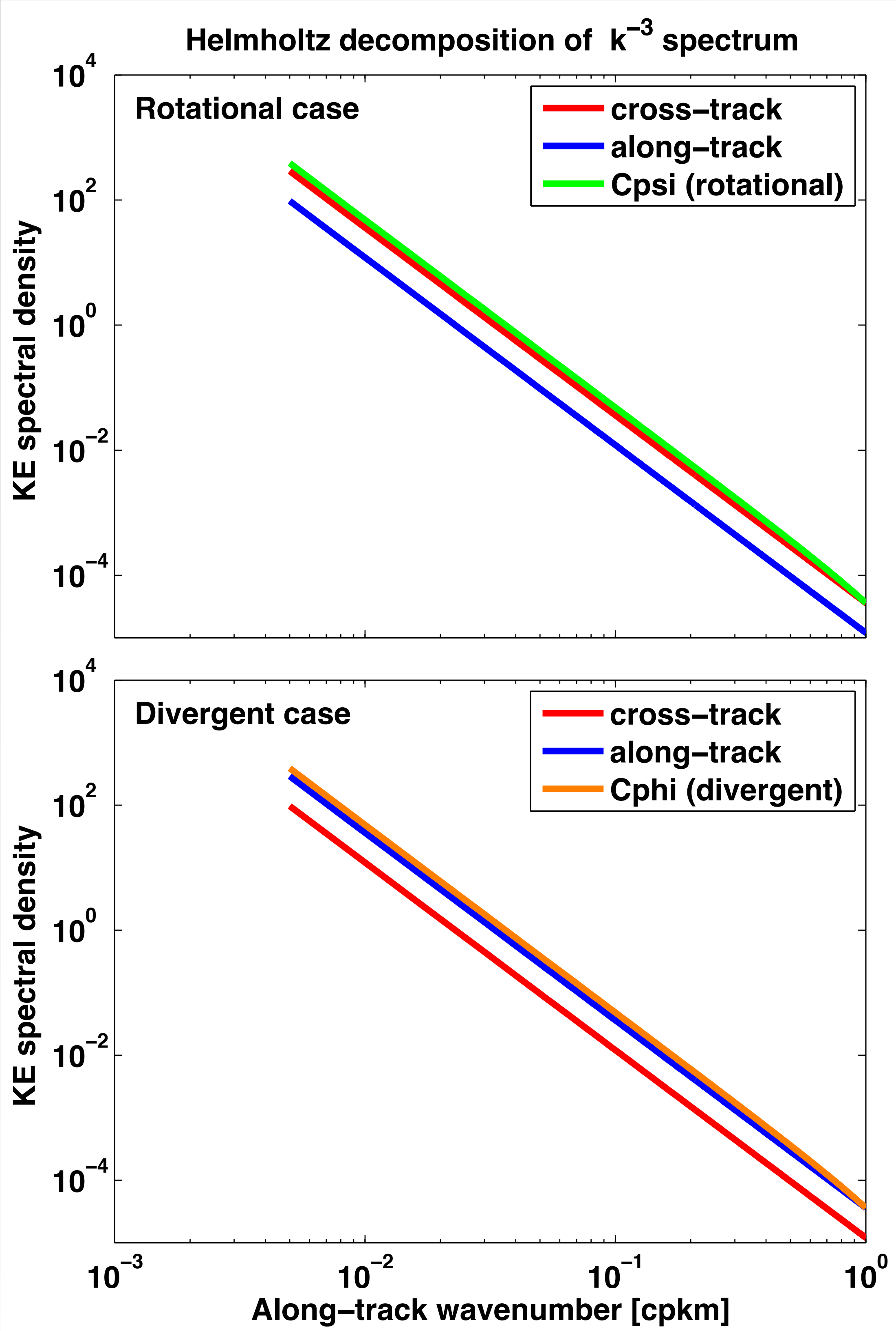
Across-track K_u and along-track K_v are related through the exponent n:

$K_u = n\,K_v$ purely rotational (nondivergent)

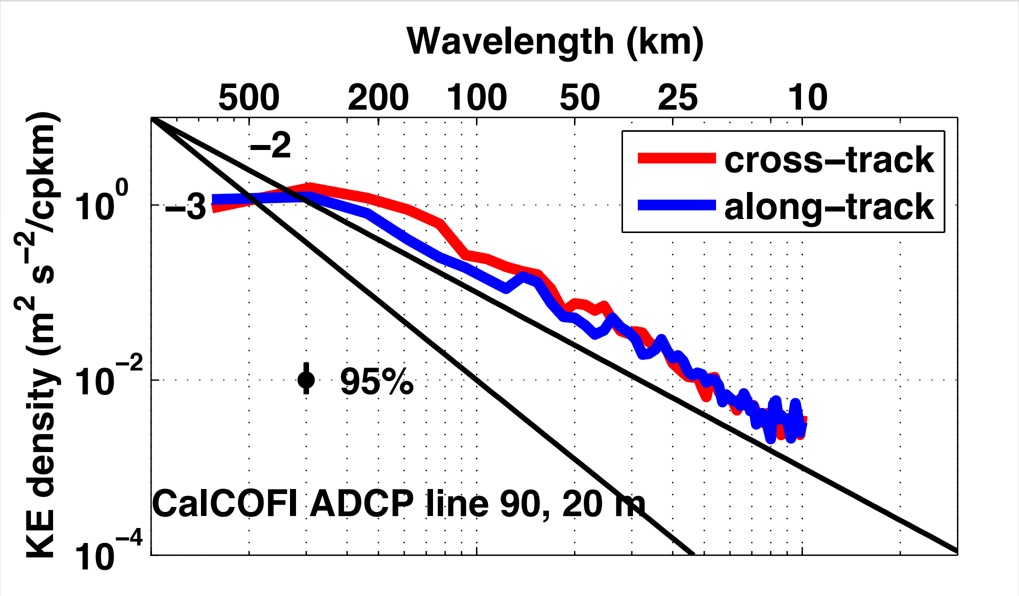
$K_v = n\,K_u$ purely divergent (irrotational)

•Helmholtz decomposition of 1-D spectra separates rotational and divergent components (Buhler et al., 2014)

(e.g., Callies & Ferrari, 2013; Buhler et al., 2014; Rocha et al., 2016)

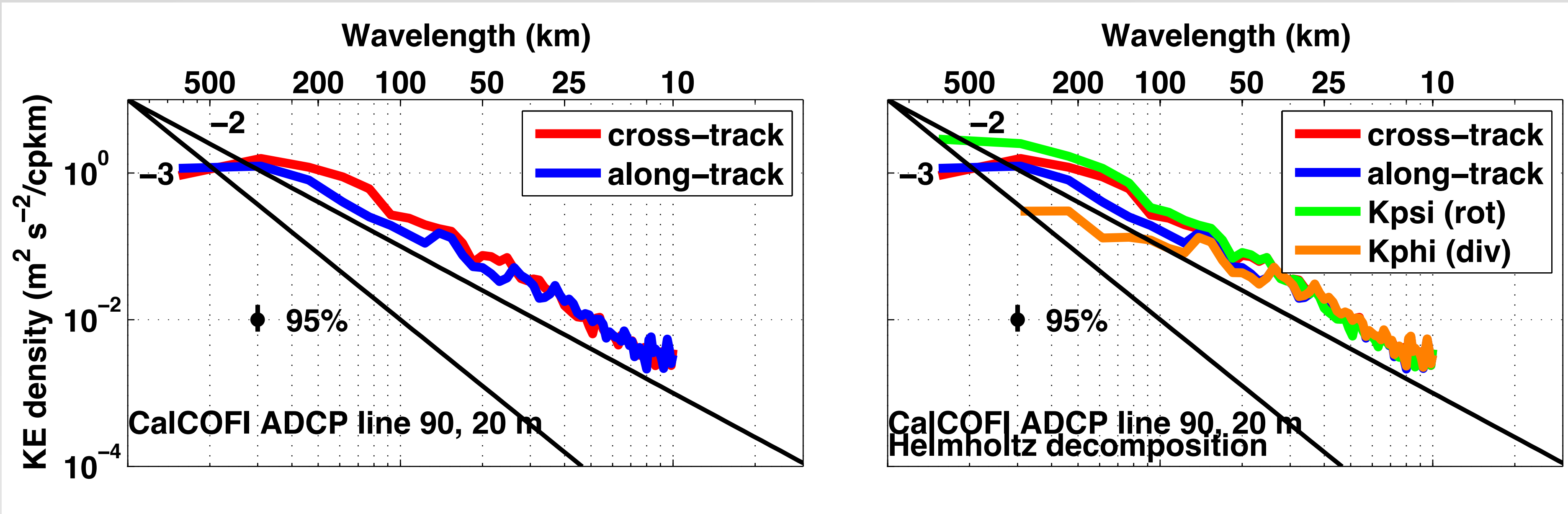


In situ observations



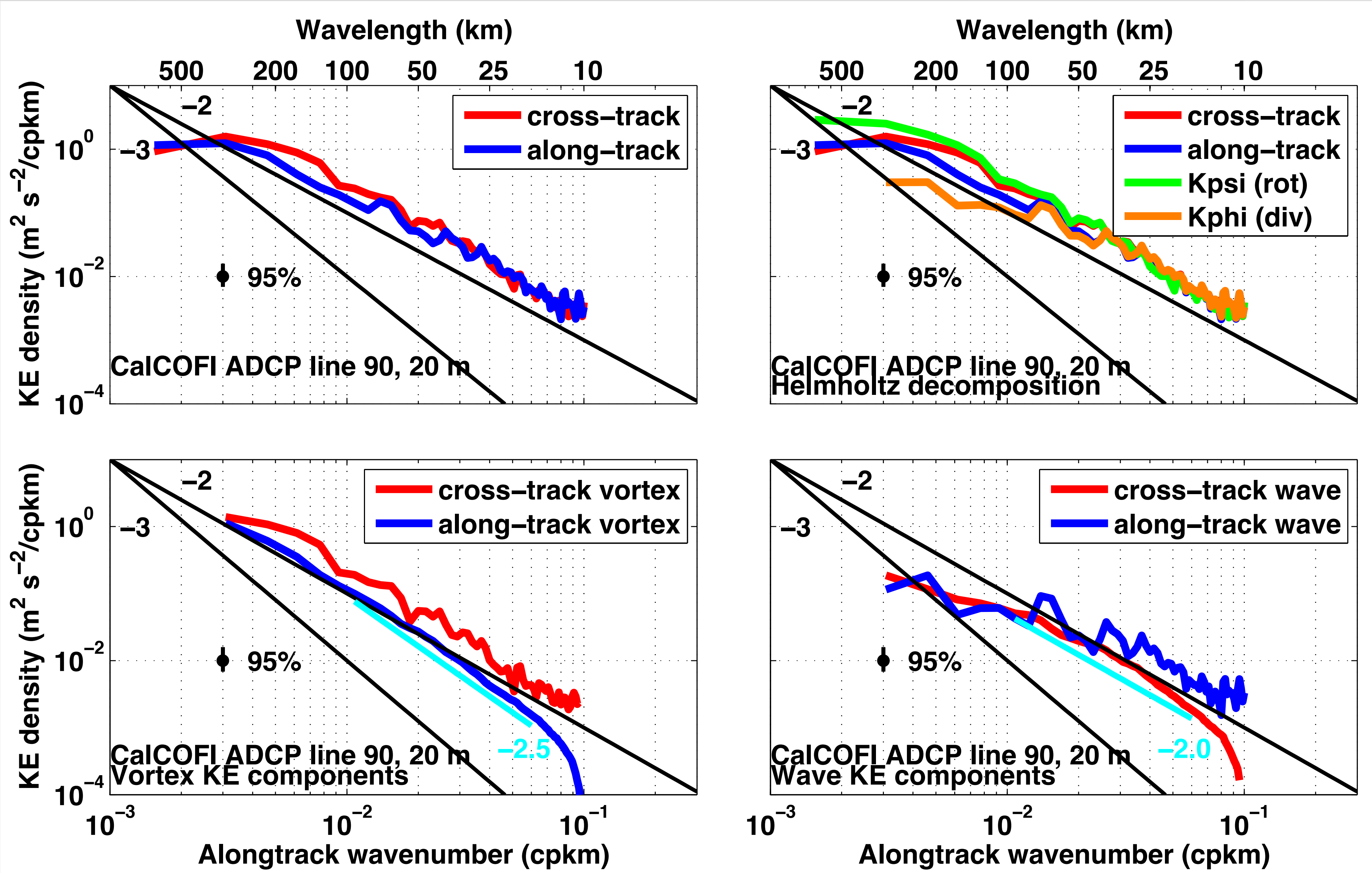
- Slope varies with wavenumber, but is close to -2
- Ratios of cross/along-track components not constant:
  - ADCP ratio ~1.8 [70 km < L < 300 km]
  - ADCP ratio ~ 1 [L < 70 km]

In situ observations



- Slope varies with wavenumber, but is close to -2
- Ratios of cross/along-track components not constant:
    - ADCP ratio ~1.8 [70 km < L < 300 km]
    - ADCP ratio ~ 1 [L < 70 km]
- Helmholtz decomposition:
    - Rotational dominates for L > 70 km
    - Divergent contributes equally, for L < 70 km

In situ observations



- •Assume Garrett Munk for IGW, decompose into wave/vortex components
- •Ratios of across/along (vortex) and along/across (wave) are constant (~-2)

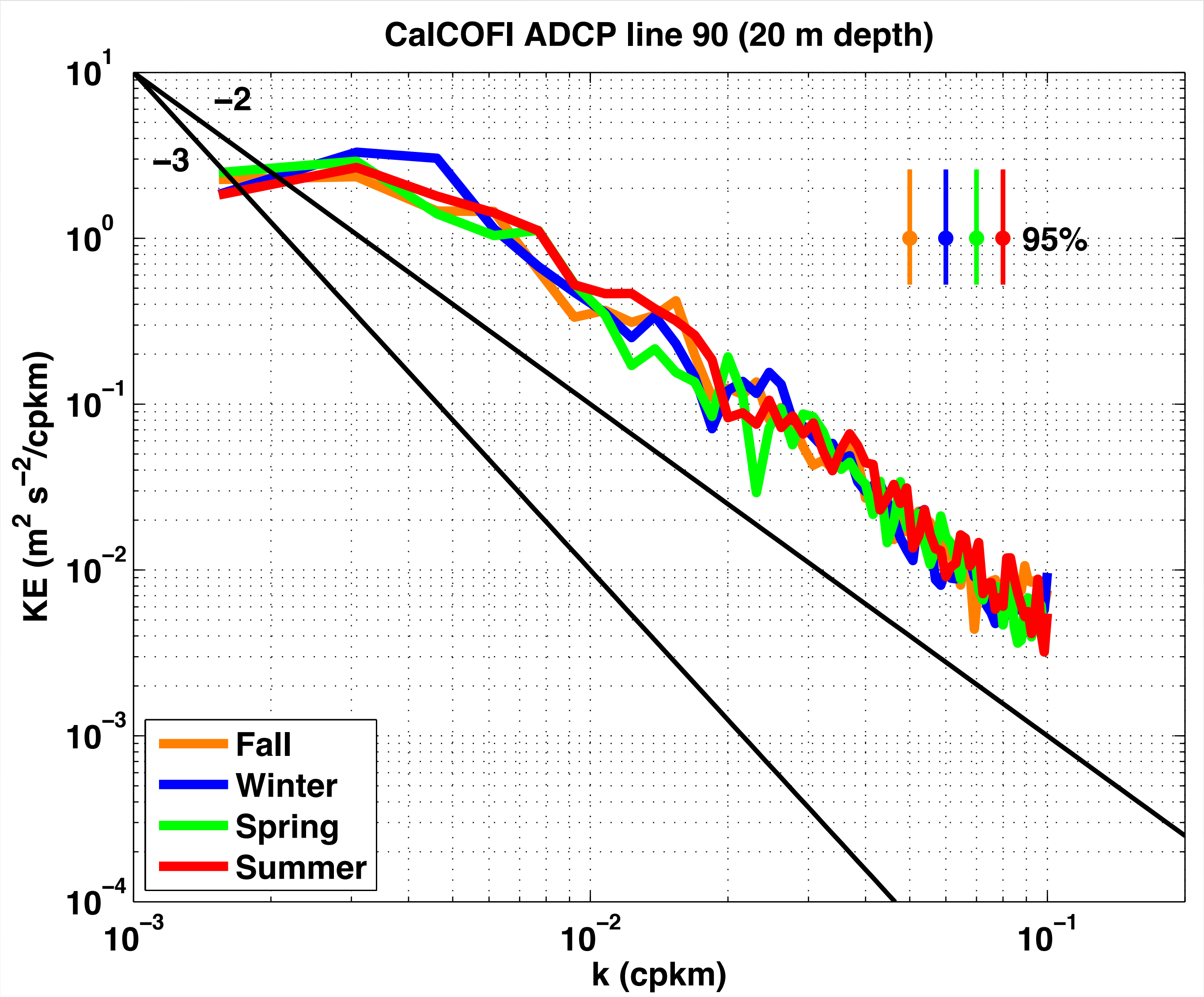
Transition in dynamics occurs at ~70 km, but without a change in slope. Diagnosing wave/vortex decomposition:

Geostrophy dominates at large scales; energy low compared to ACC

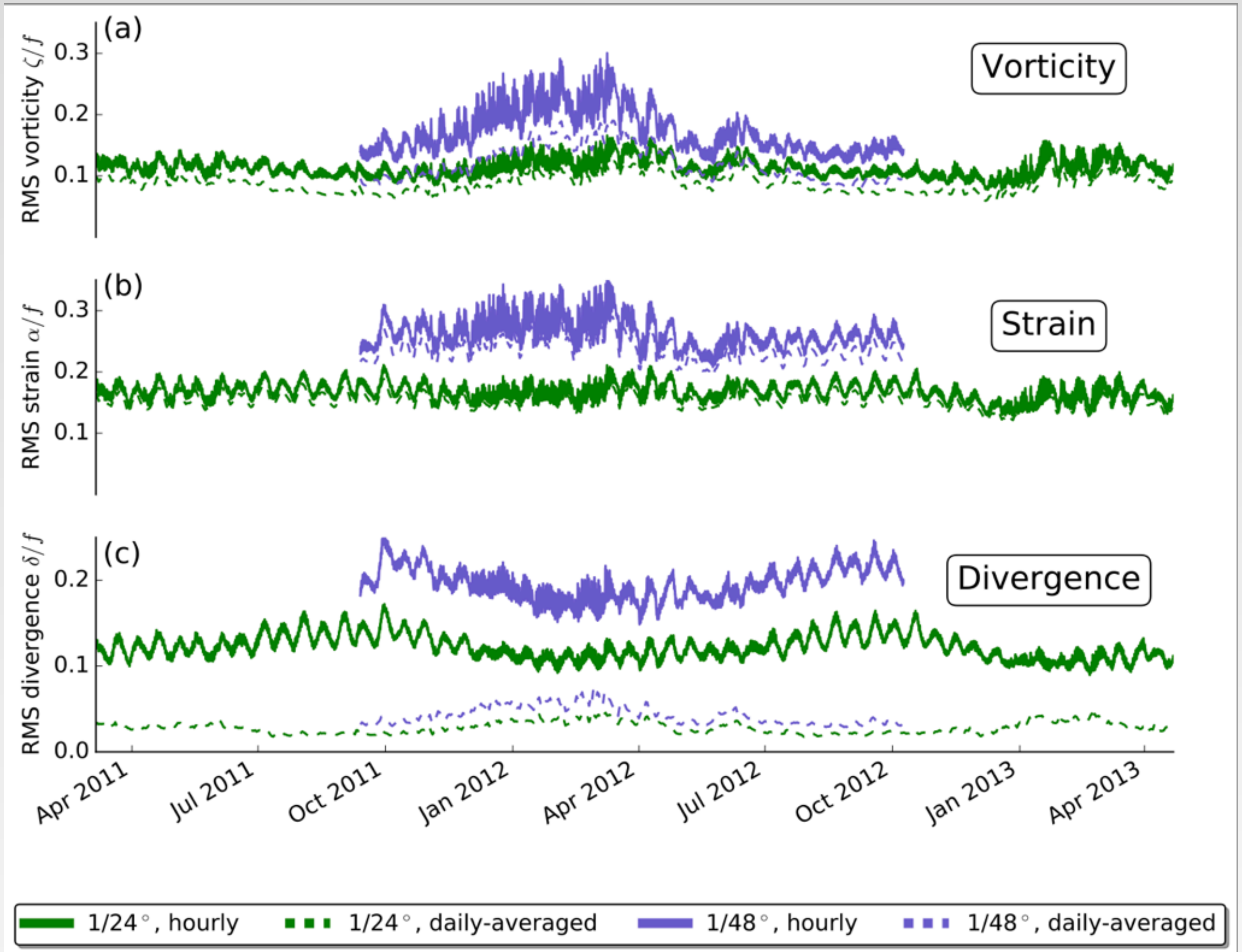
IGW contributes about 50% at small scales; energy as high as in ACC

In situ observations: seasonality

- Seasonality observed in the GS and Kuroshio with strongest submesoscale energy in winter (e.g., Sasaki et al., 2014; Callies et al., 2015; Rocha et al., GRL in press)
- CCS region has strong seasonal cycle in winds and upwelling
- No significant seasonality in ADCP spectra
- Weak seasonality in model spectra as well (not shown)



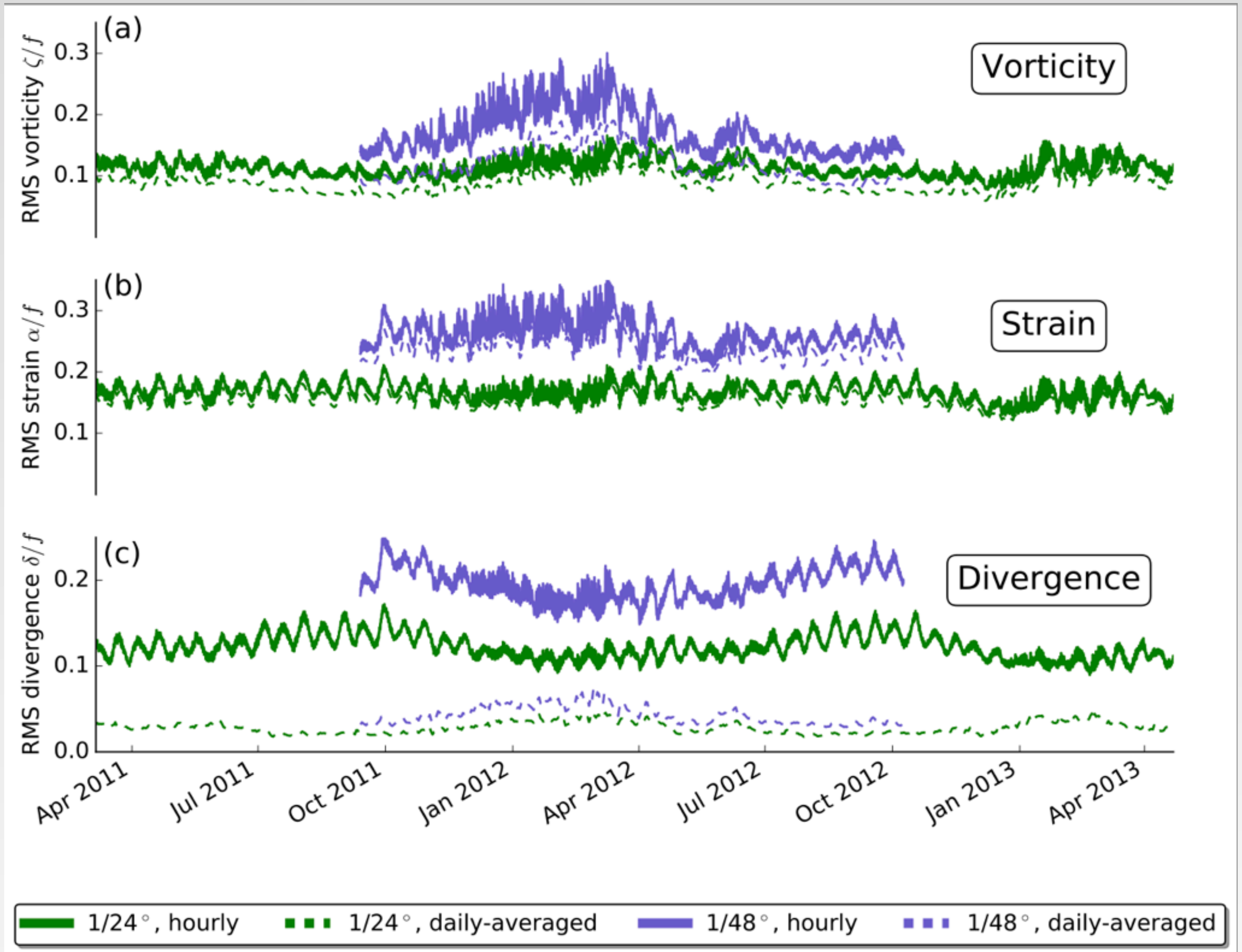
Model: seasonality



- 2nd order statistics (RMS vorticity, strain, divergence) highlight submesoscales
- Vorticity and strain rate peak in late winter/early spring
- Divergence is out of phase (peaks in late summer/early fall)
- Daily averaging reduces IGW component
- Divergence dramatically reduced and in-phase with vorticity and strain

(for Kuroshio, see Rocha et al. GRL in press)

Model: seasonality



- There is a phase cancellation between submesoscale turbulence and inertia-gravity waves that reduces seasonality in KE spectra
- Requires a model that includes realistic tidal forcing

(for Kuroshio, see Rocha et al. GRL in press)

Conclusions

- KE spectra in the southern California Current System follow an approximately -2 power law at submesoscales
- At large scales (L > 70 km), the CCS KE is dominated by balanced geostrophic motions. Ageostrophic motions begin to contribute equally at scales L < 70 km.
- Slope does not distinguish a transition as the diagnosed vortex and wave contributions each have -2 slopes.
- Submesoscale turbulence and waves undergo out-of-phase seasonal cycles: turbulence peaks in late winter; waves peak in late summer.
- This phase cancellation implies a seasonal modulation of the accuracy of geostrophic velocity estimated at submesoscales from high resolution altimeters such as SWOT.