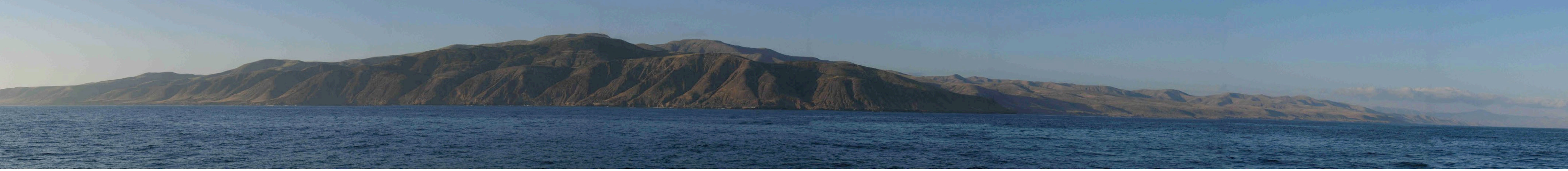
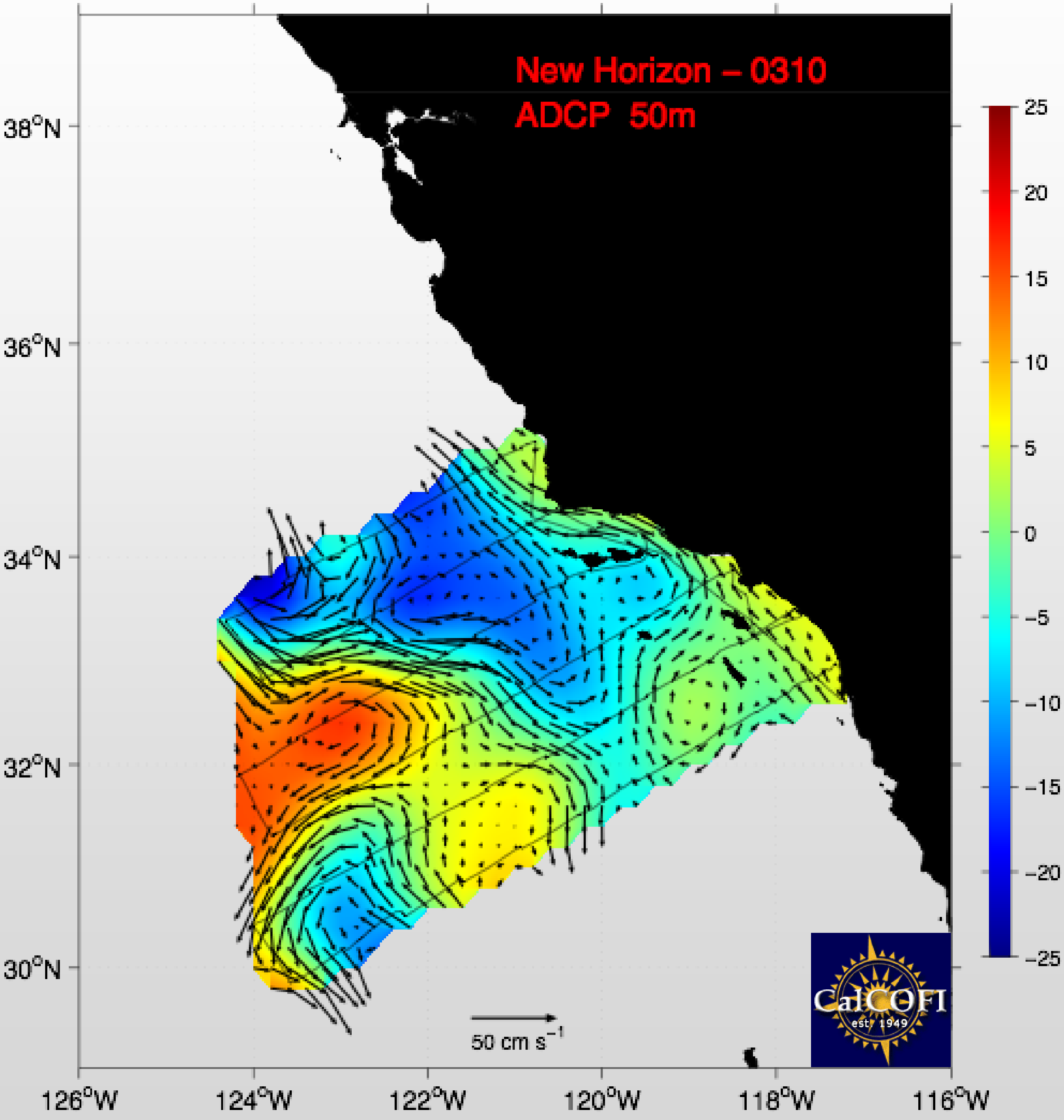


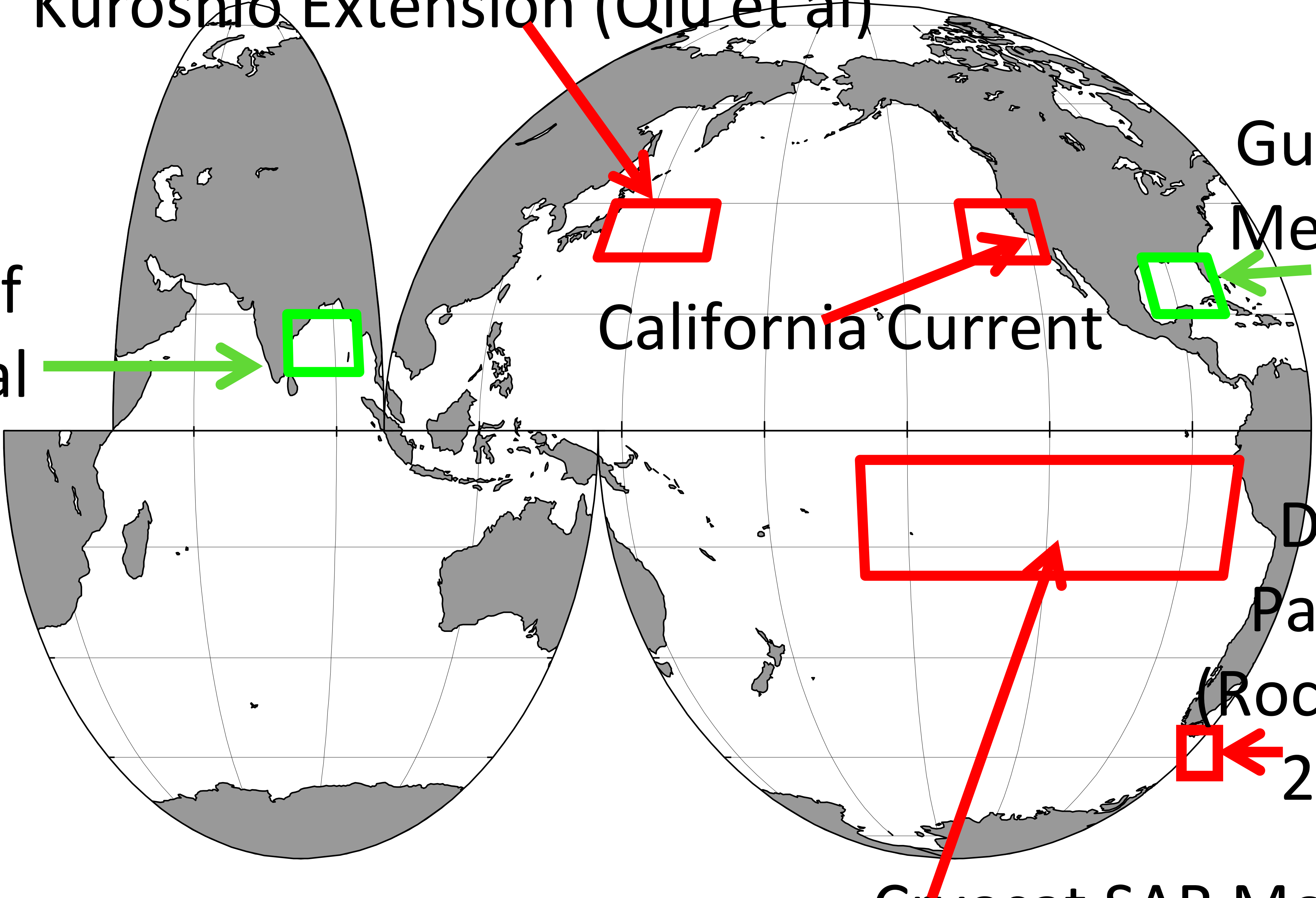
ADCP wavenumber spectra: In the California Current and beyond …



Sarah Gille
Teresa Chereskin
Cesar Rocha
Scripps Institution of Oceanography
Dimitris Menemenlis
Jet Propulsion Laboratory

Funding: NASA Ocean Surface Topography Team & SWOT

Candidate regions for high-wavenumber in situ data



Kuroshio Extension (Qiu et al)

Gulf of Mexico

Bay of Bengal

California Current

Drake Passage (Rocha et al 2016)

Cryosat SAR Mode

In situ observations and model data

In situ observations

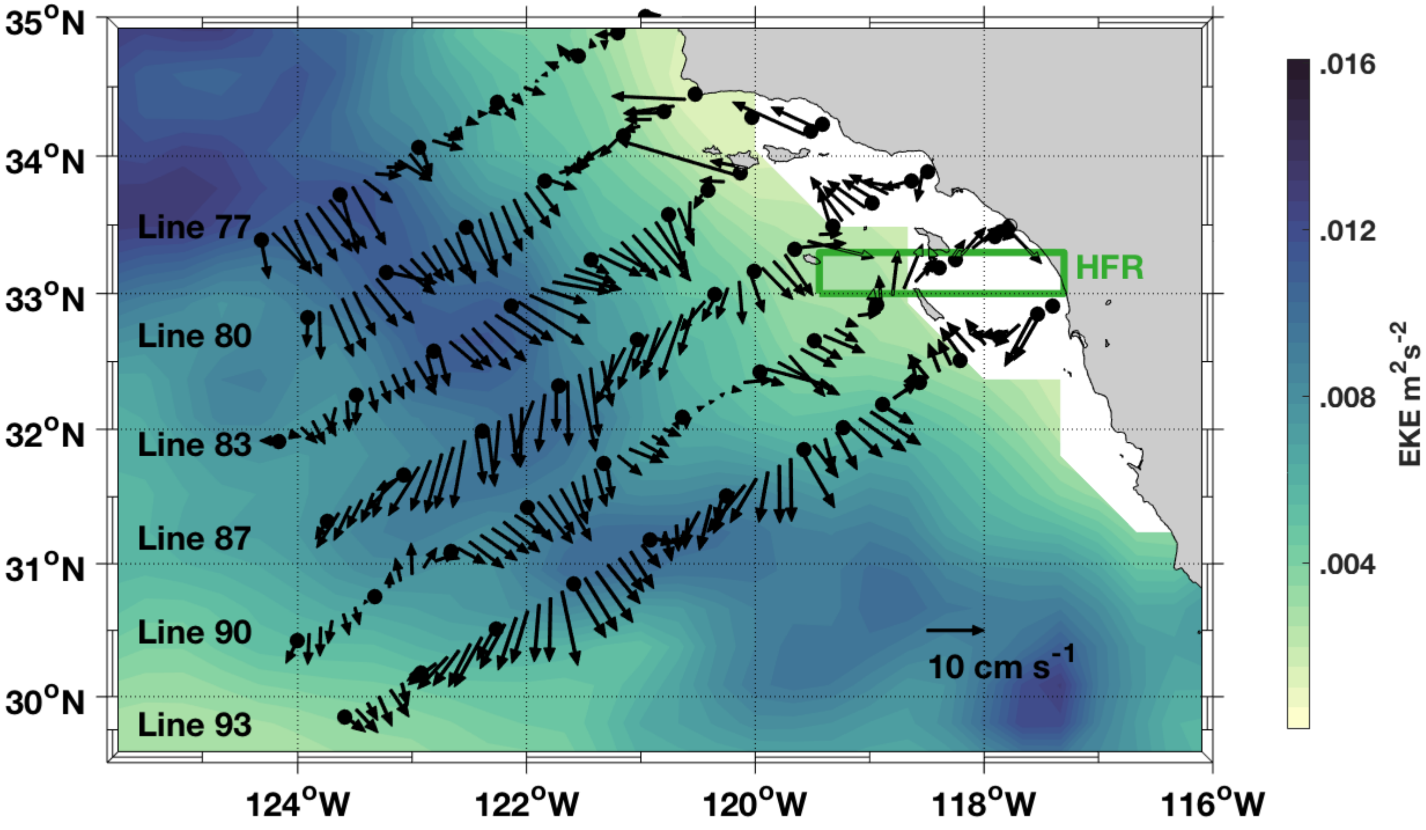
CalCOFI ADCP:

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

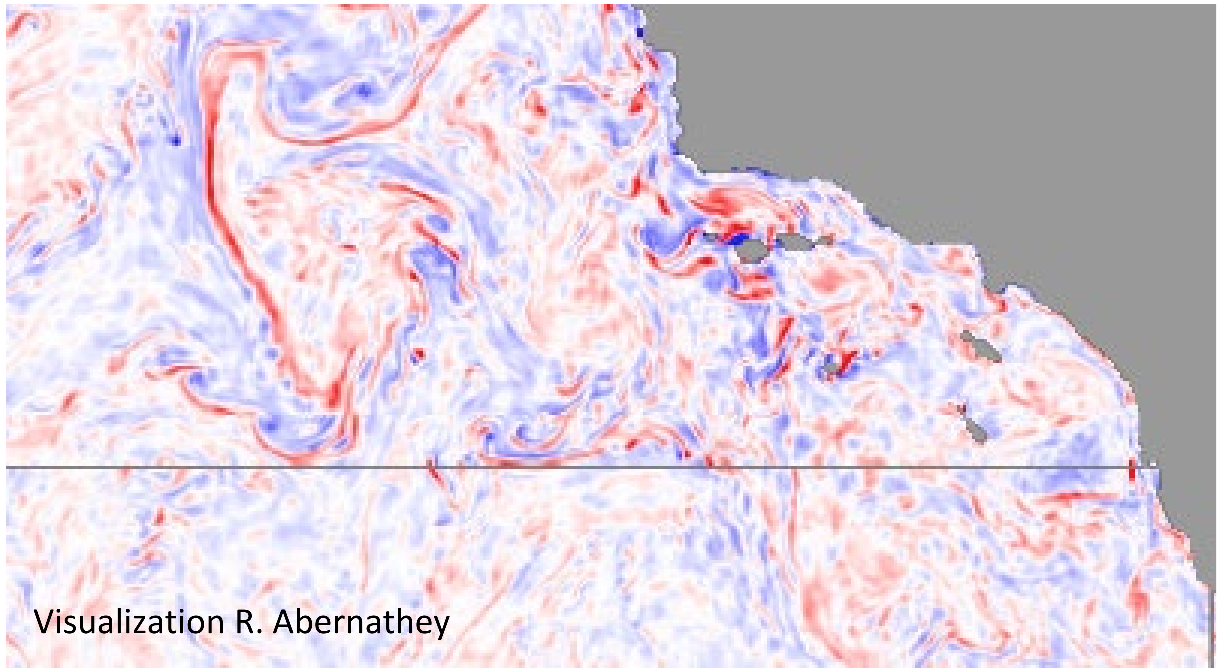
LLC MITgcm simulations:

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

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



Snapshot of surface relative vorticity from LLC 4320



Visualization R. Abernathey

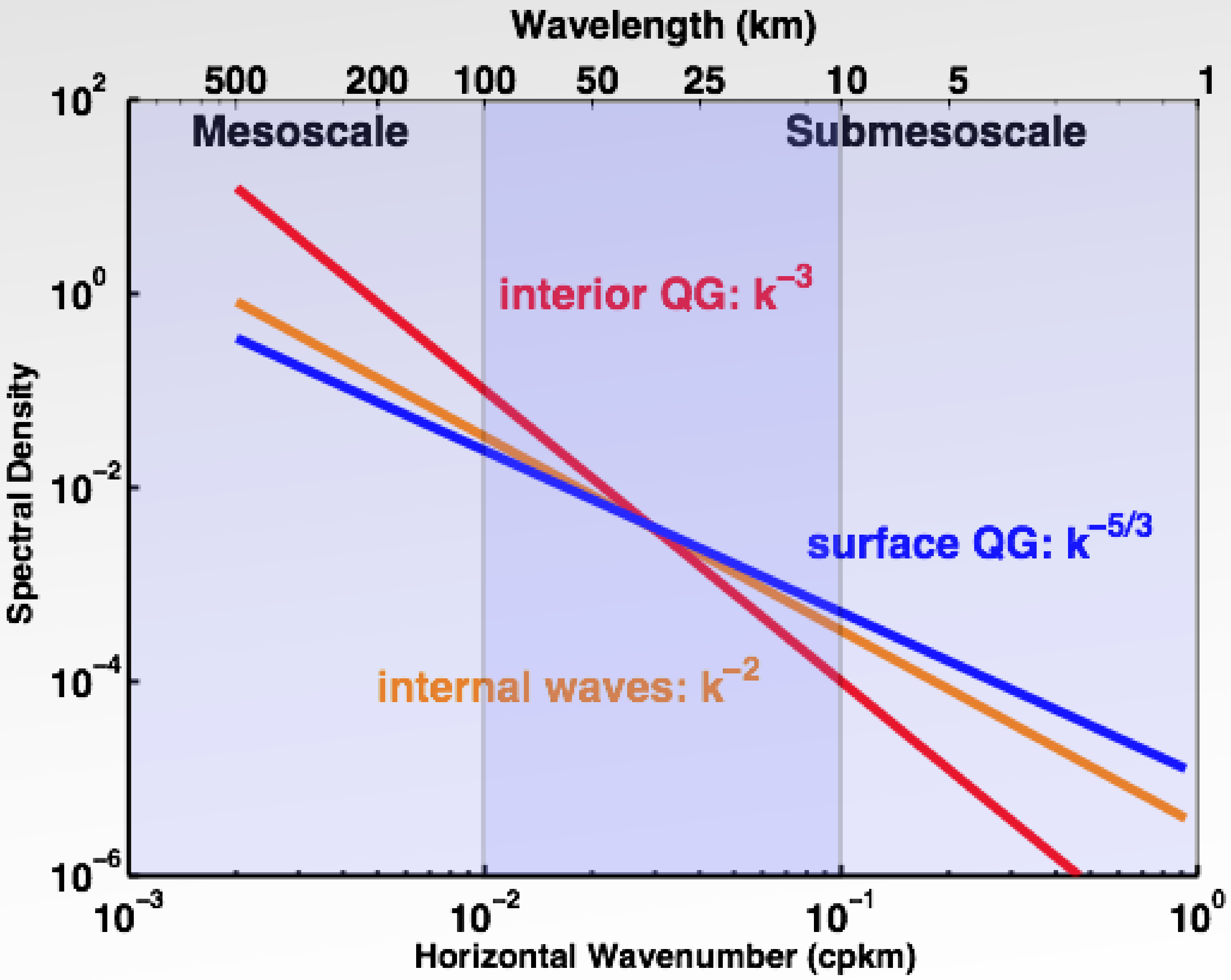
Inferring dynamics from horizontal wavenumber spectra:

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)



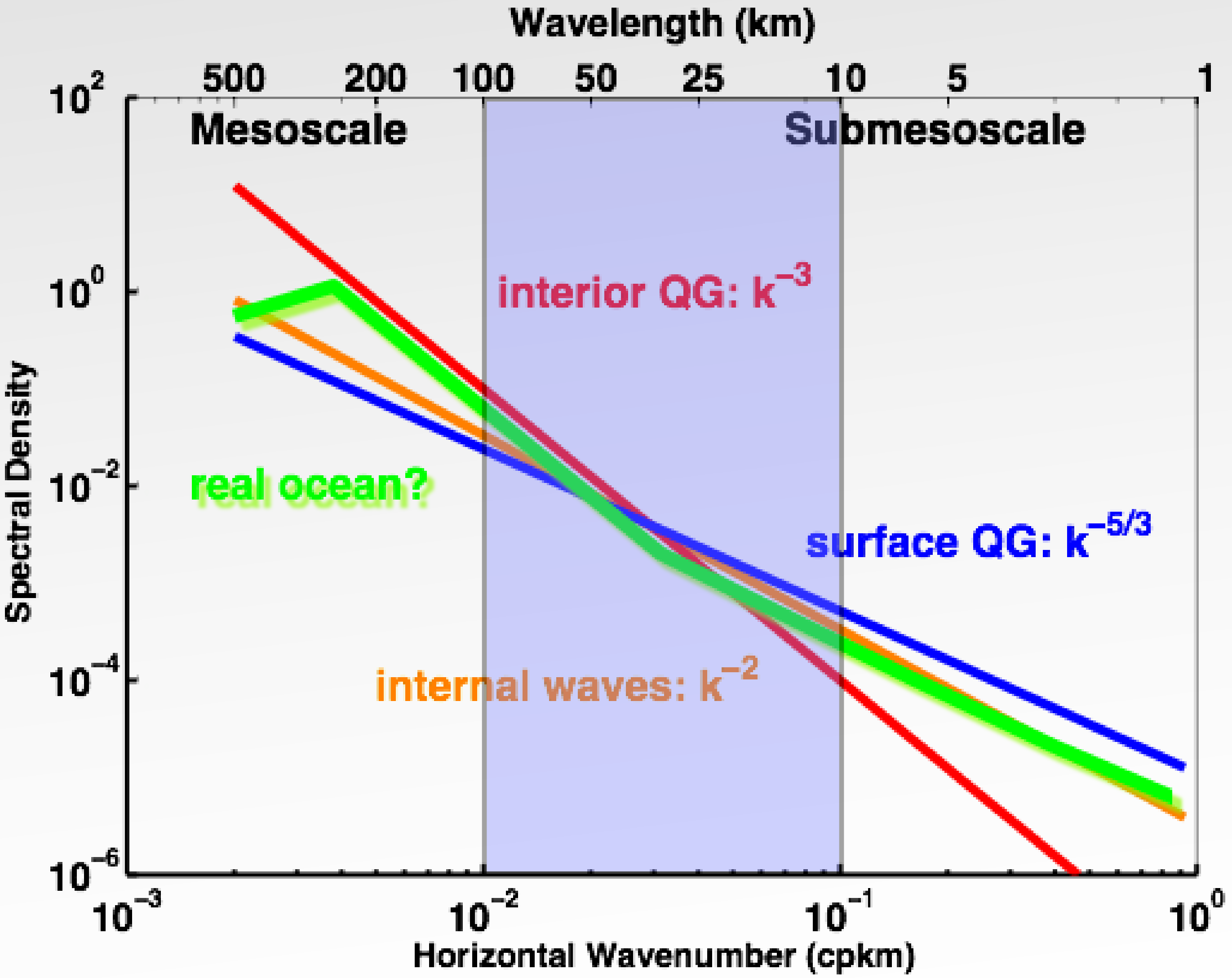
Inferring dynamics from horizontal wavenumber spectra:

What has been observed for kinetic energy spectra?

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

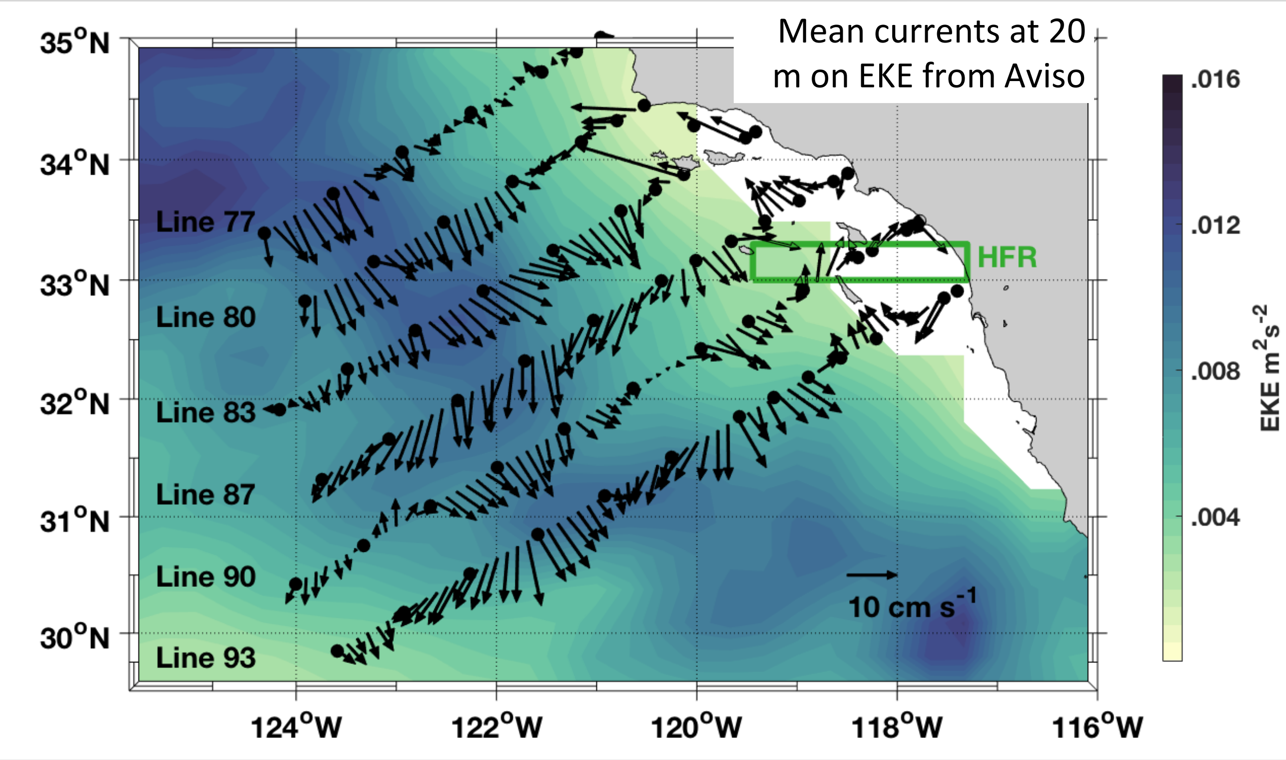
- interior QG (k^{-3}) at meso- to submeso- scales
- k^{-2} at submesoscales

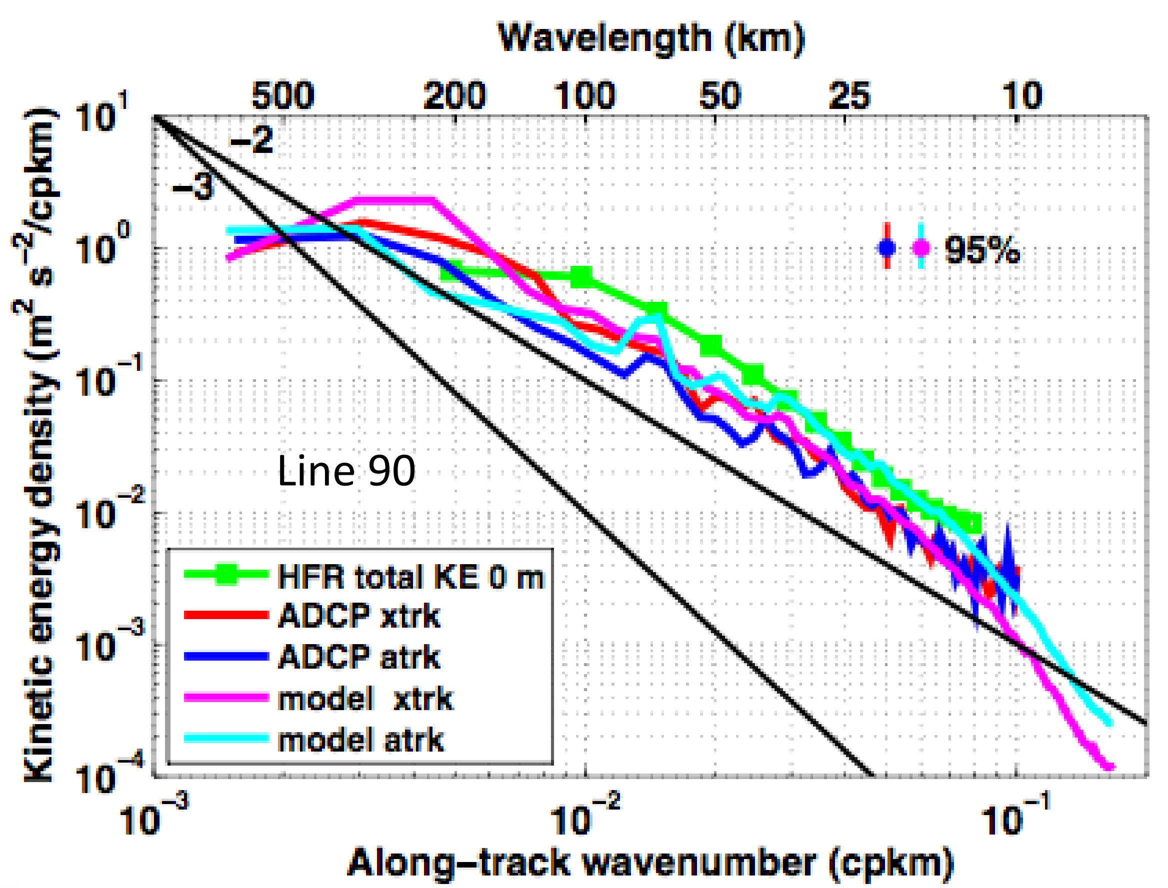
(e.g., Callies & Ferrari, 2013; Rocha et al., 2016)



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


Mean currents at 20 m on EKE from Aviso



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

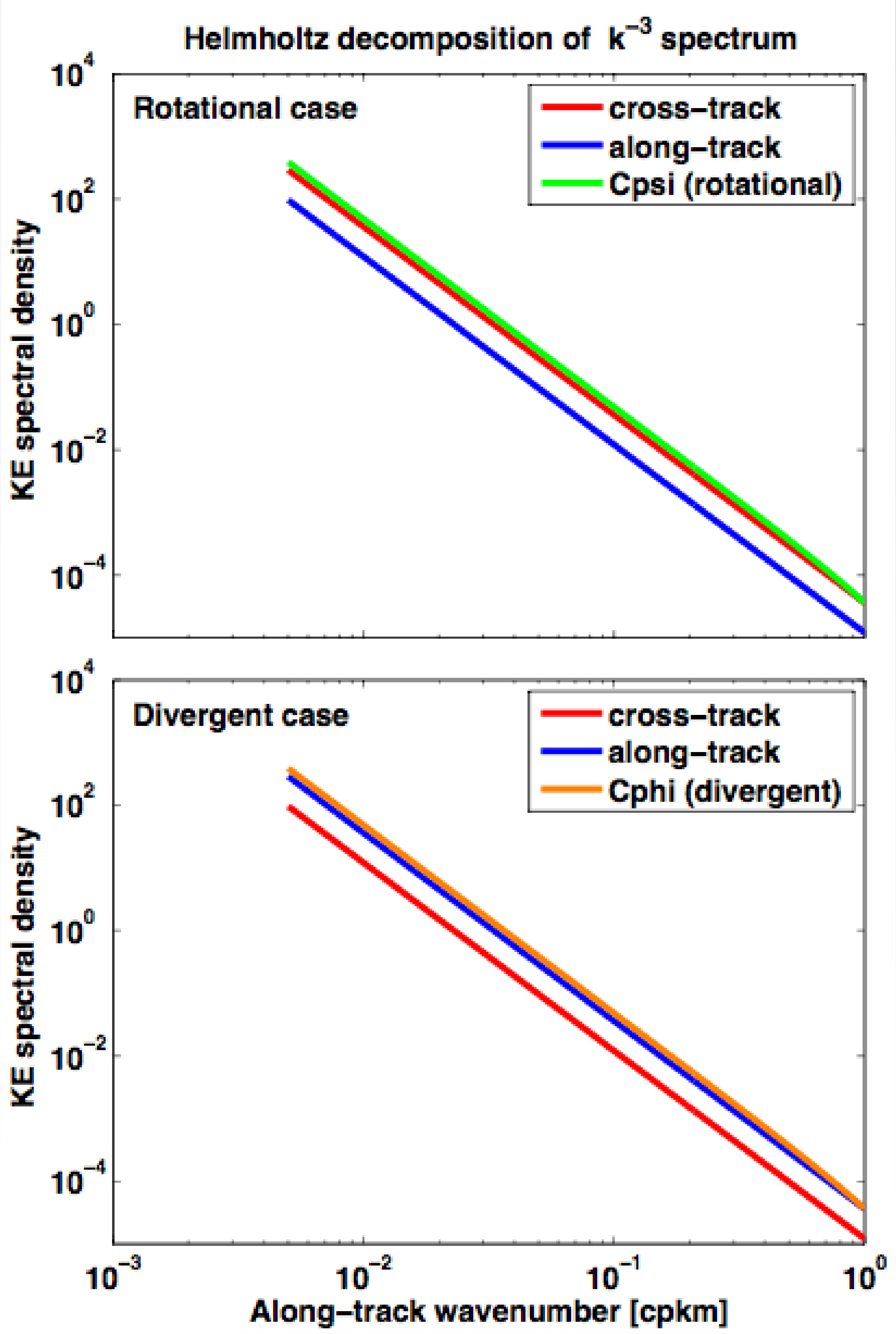
Across-track K_u and along-track K_v are related through the exponent n:

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

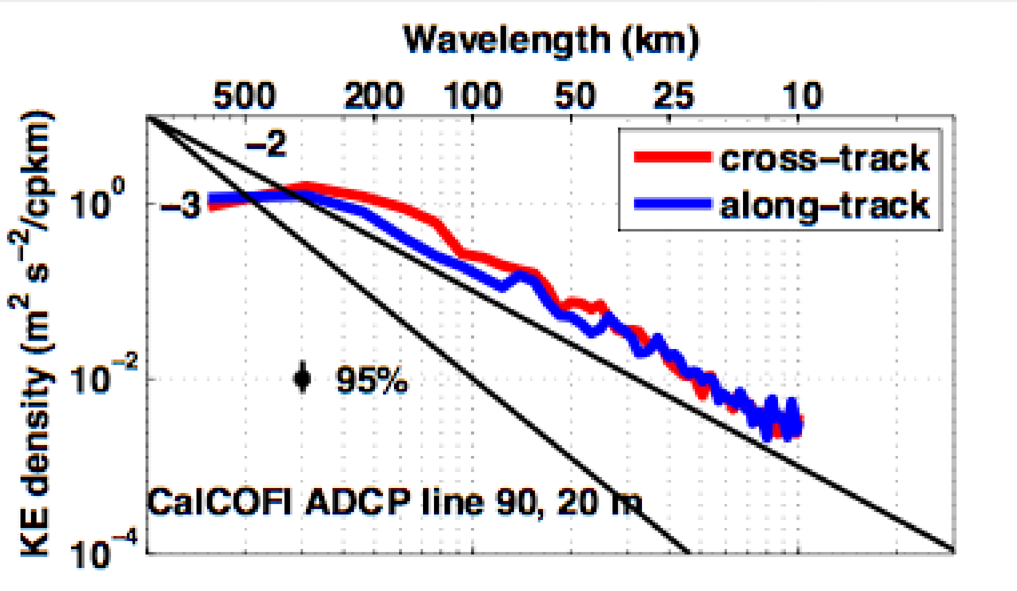
$K_v = n\ K_u$ purely divergent (irrotational)

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

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

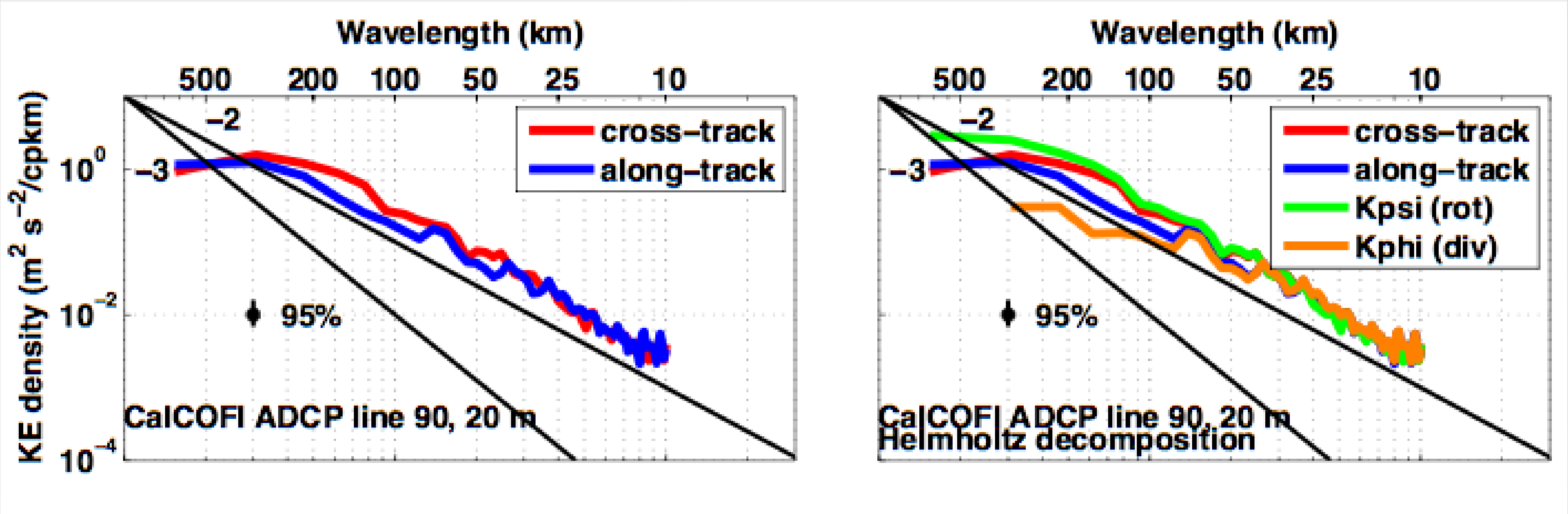


In situ observations



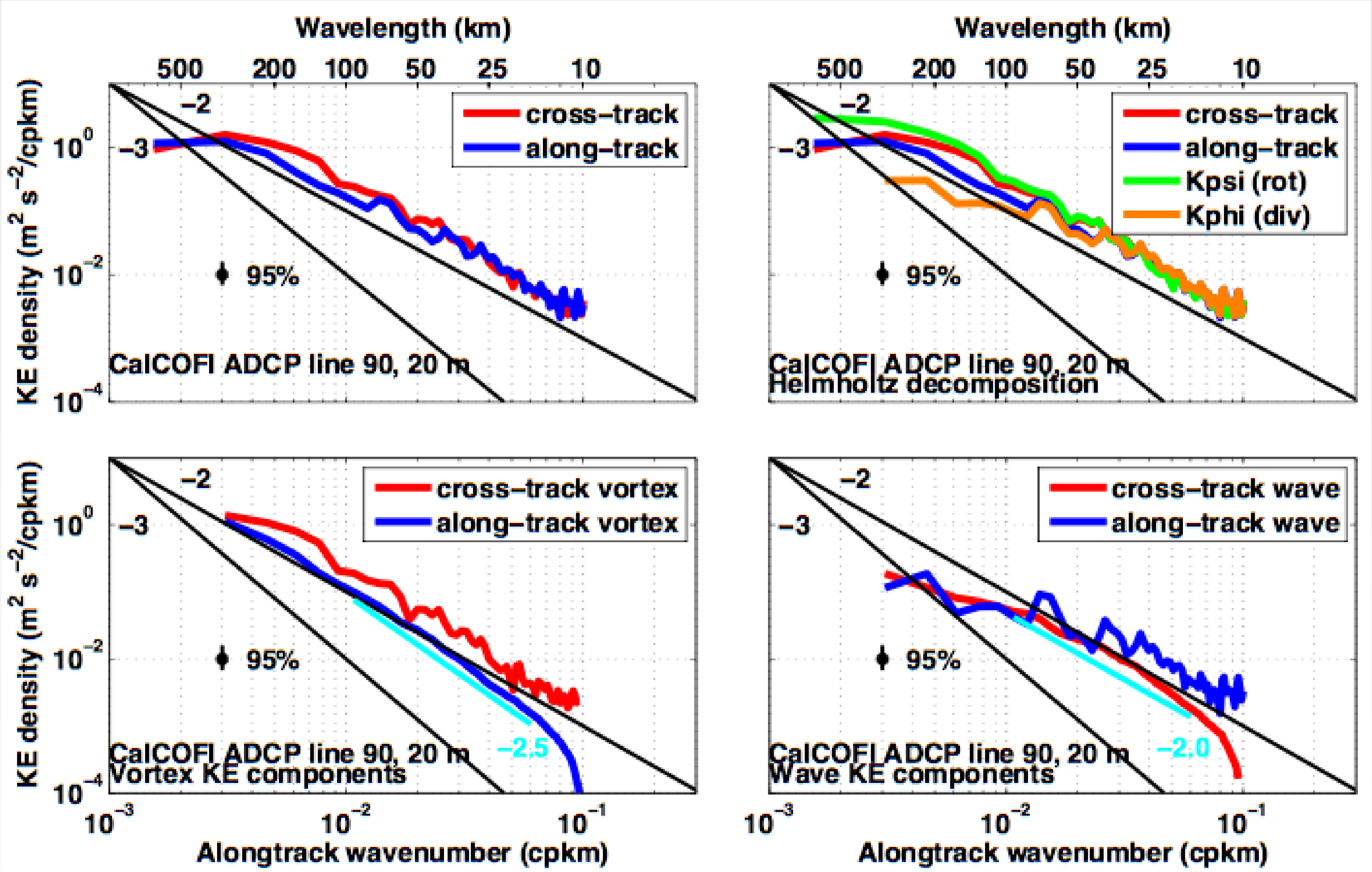
- Slope varies with wavenumber, but is close to -2
- Ratios of cross/along-track components not constant:
  - ADCP ratio ~1.8 [70 km < L < 300 km]
  - ADCP ratio ~ 1 [L < 70 km]

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



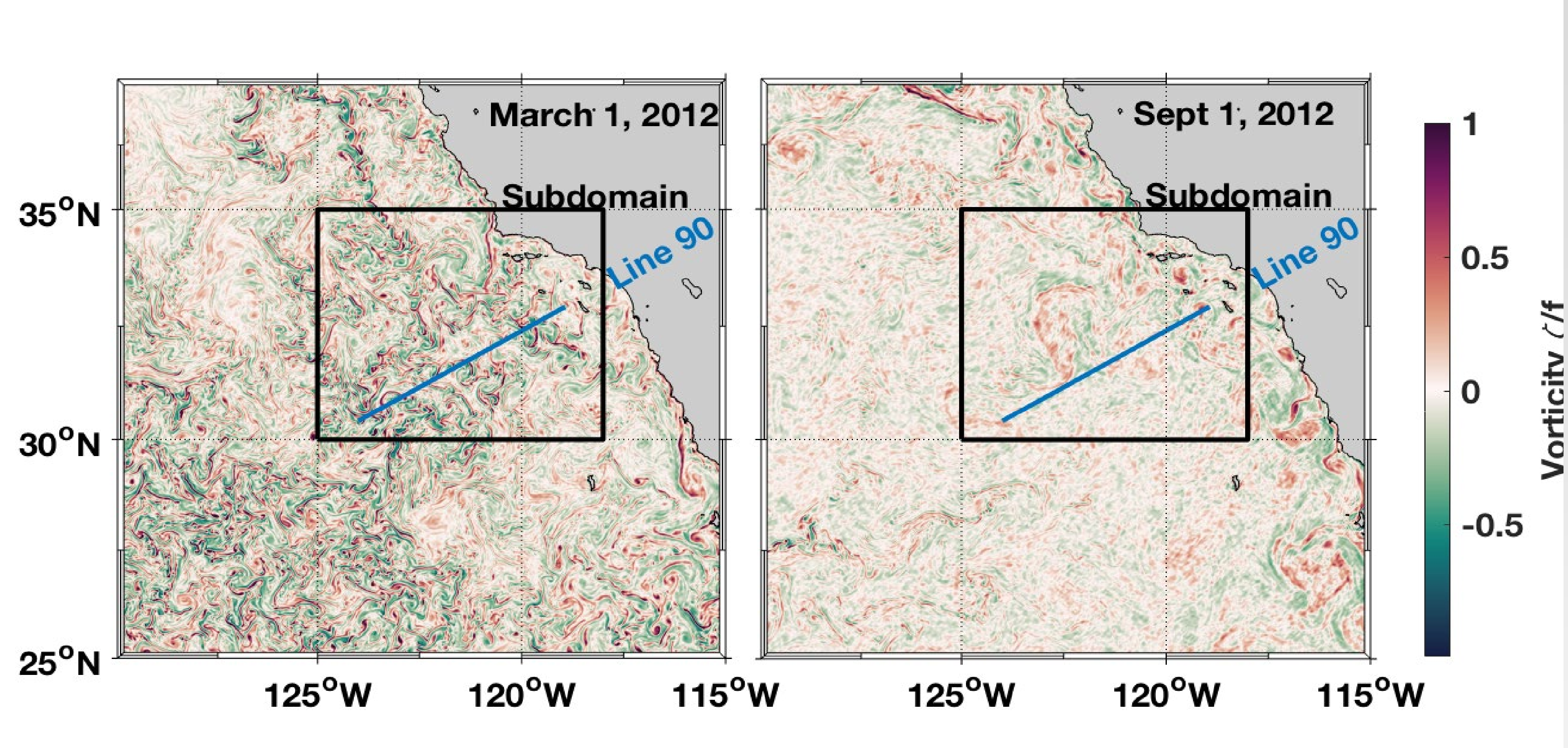
- Assume Garrett Munk for IGW, decompose into wave/vortex components
- Ratios of across/along (vortex) and along/across (wave) are constant (~-2)

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

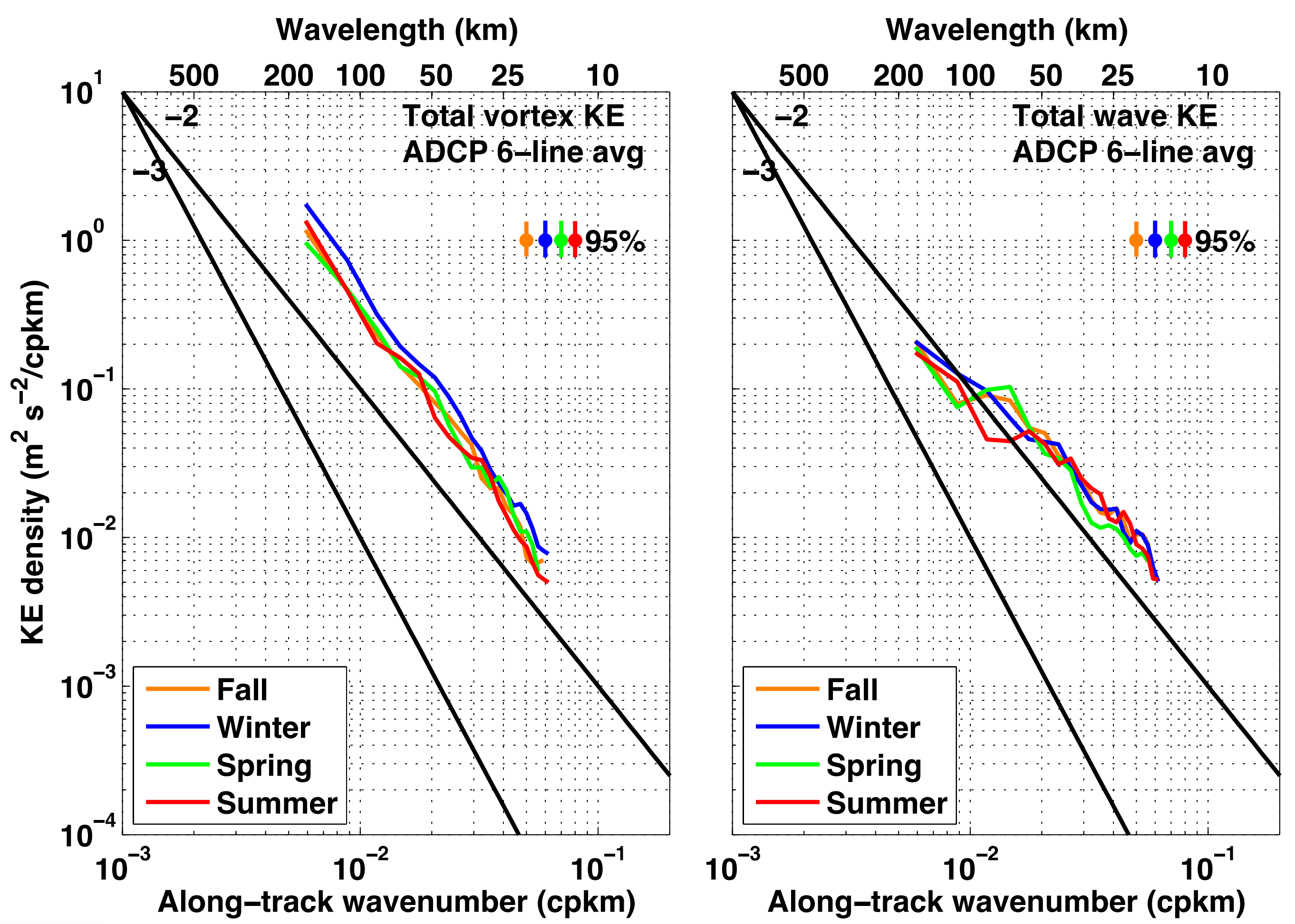
Seasonality in the California Current



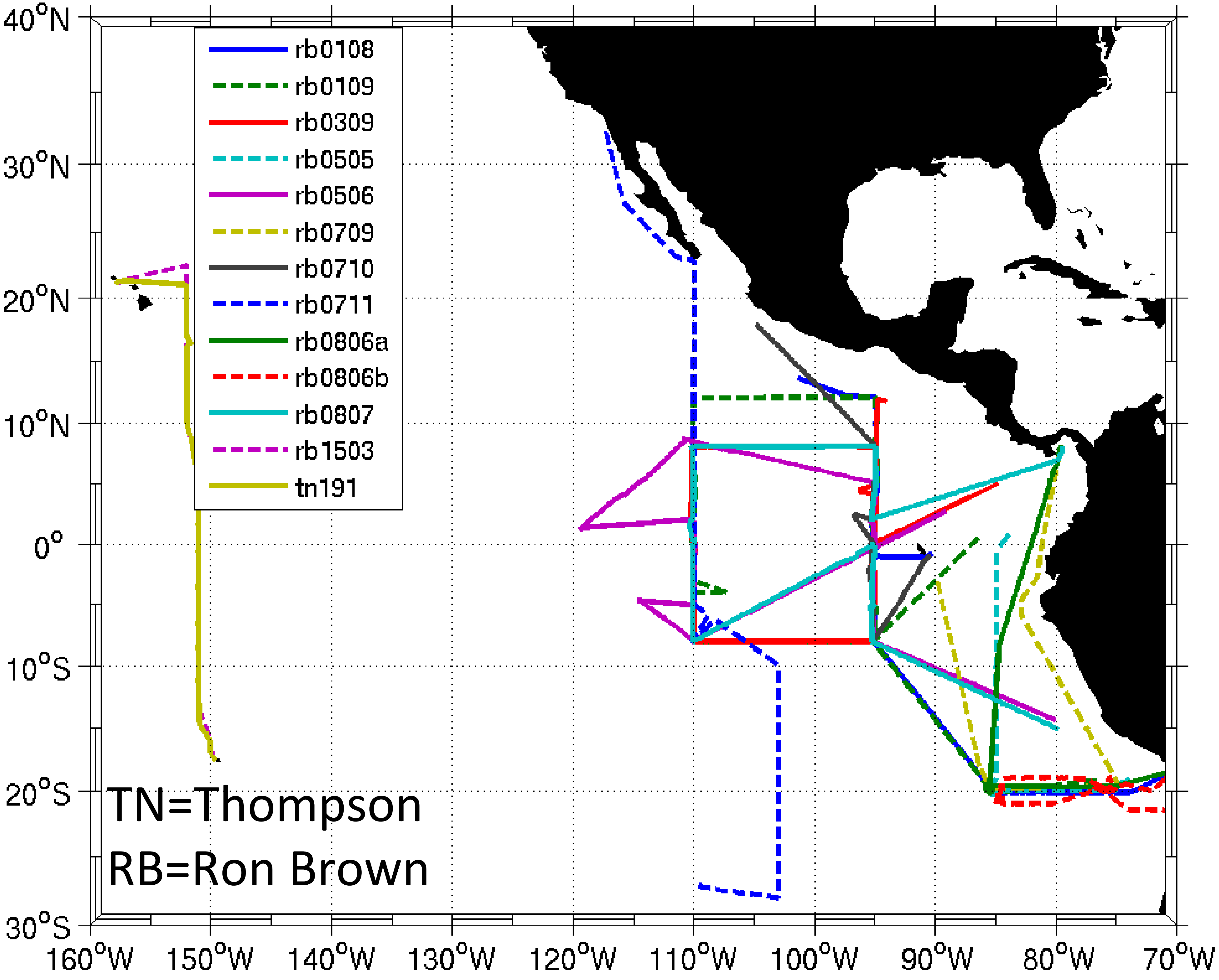
- Seasonality observed in the GS and Kuroshio with strongest submesoscale energy in winter (e.g., Sasaki et al., 2014; Callies et al., 2015; Rocha et al., GRL, 2016)
- CCS region has strong seasonal cycle in winds and upwelling
- Significant differences in vorticity from March to September in llc4320 model

In situ ADCP observations: no significant seasonality in KE spectra

- Separation into vortex and wave components shows no seasonality for either
- Weak seasonality in model spectra as well (not shown)



High-resolution ADCP



TN=Thompson
RB=Ron Brown

- 14 ADCP transects available now
- ~ 15 being processed by U. Hawaii

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.
- Seasonality in model vorticity does not appear in ADCP KE spectra.

- There is no later draft, but this figure is in the manuscript that you have (Fig. 9) and yes, I think it could replace the seasonal one in my La Rochelle talk.

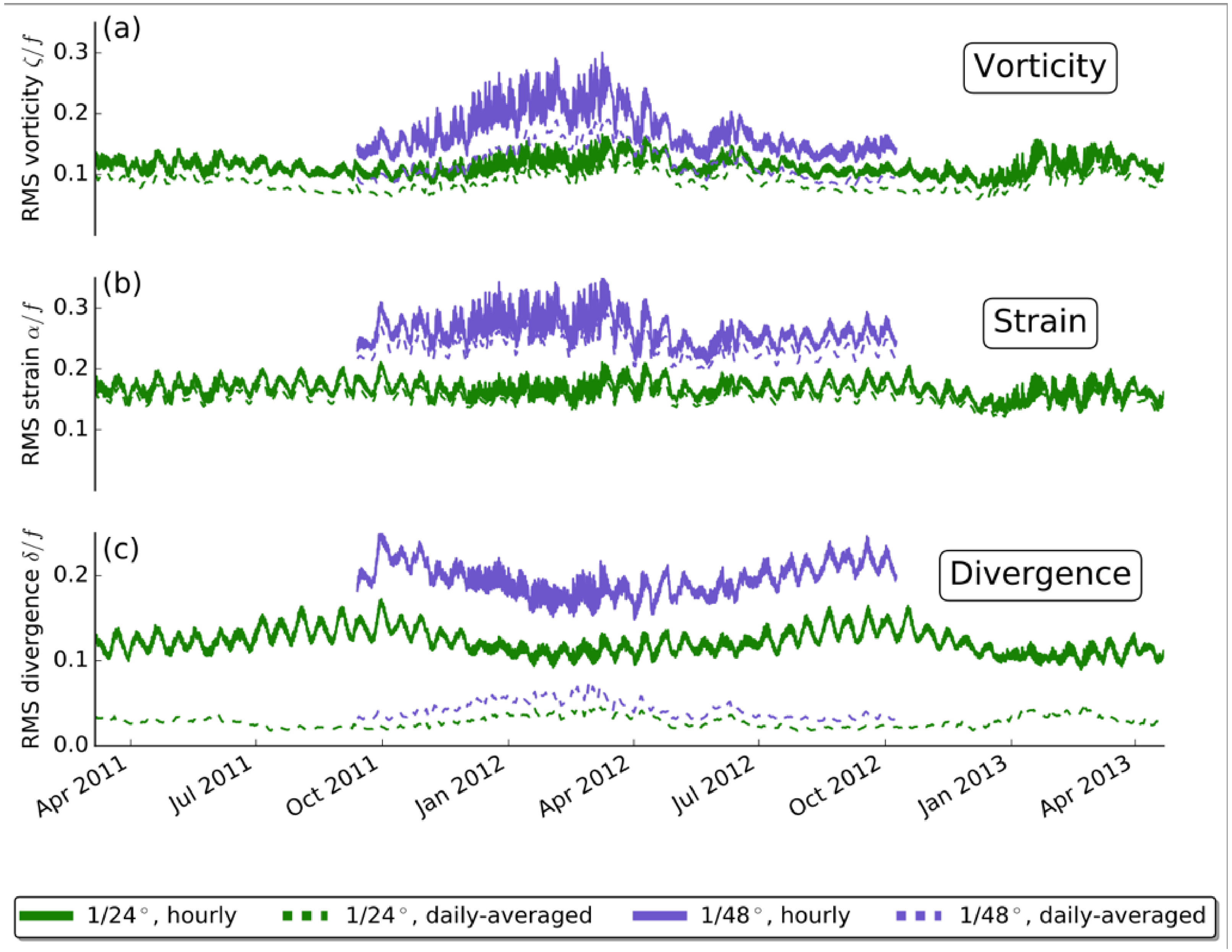
  In the paper,. Fig. 8a is the seasonal KE spectra for line 90 that I used in my talk. For the paper, in order to increase the degrees of freedom in the ADCP spectra, I averaged over all 6 lines. Fig. 8b is the seasonal for the 6-line average. In Fig. 8b there is significantly higher KE in winter at longer wavelengths but not at shorter ones. Note that for these spectra, the common section length is 340 km so the largest scale resolved is reduced relative to line 90.

  We think that the weak seasonality may be due in part to phase cancellation in the vortex (turbulence) and wave (IGW) components. Figure 9 shows the result of using the Buhler decomposition to separate rotational and divergent components, followed by a wave-vortex decomposition to separate vortex (interpreted as turbulence) and wave (intepreted as IGW). The winter vortex KE is significantly larger than the summer vortex KE at almost every waveno. Just barely, but I think it is significant across a large band of wavenos. In summer, part of why we don't see elevated KE in the wave component could be that the mixed layer is shallow, and we don't get close enough to the surface with the ADCP data.

  I'm attaching new (using the full year for llc4320) figures from Cesar from the model, using daily averages that remove the IGWs. So these are useful to look at seasonality in the turbulence component. The model peaks in spring, and the seasonality is absent at 400 m.

  I'm also attaching a new figure from Cesar for the gradient statistics. These are monthly averaged in order to remove the tidal signal that is a distraction in the plot I used in my talk and in the paper draft. Legend is a little confusing. I think that blue is 1/48, orange is 1/24, solid is hourly and dashed is daily-averaged, and then monthly averages were computed. These stats computed over the subdomain that I plotted on the snapshots.

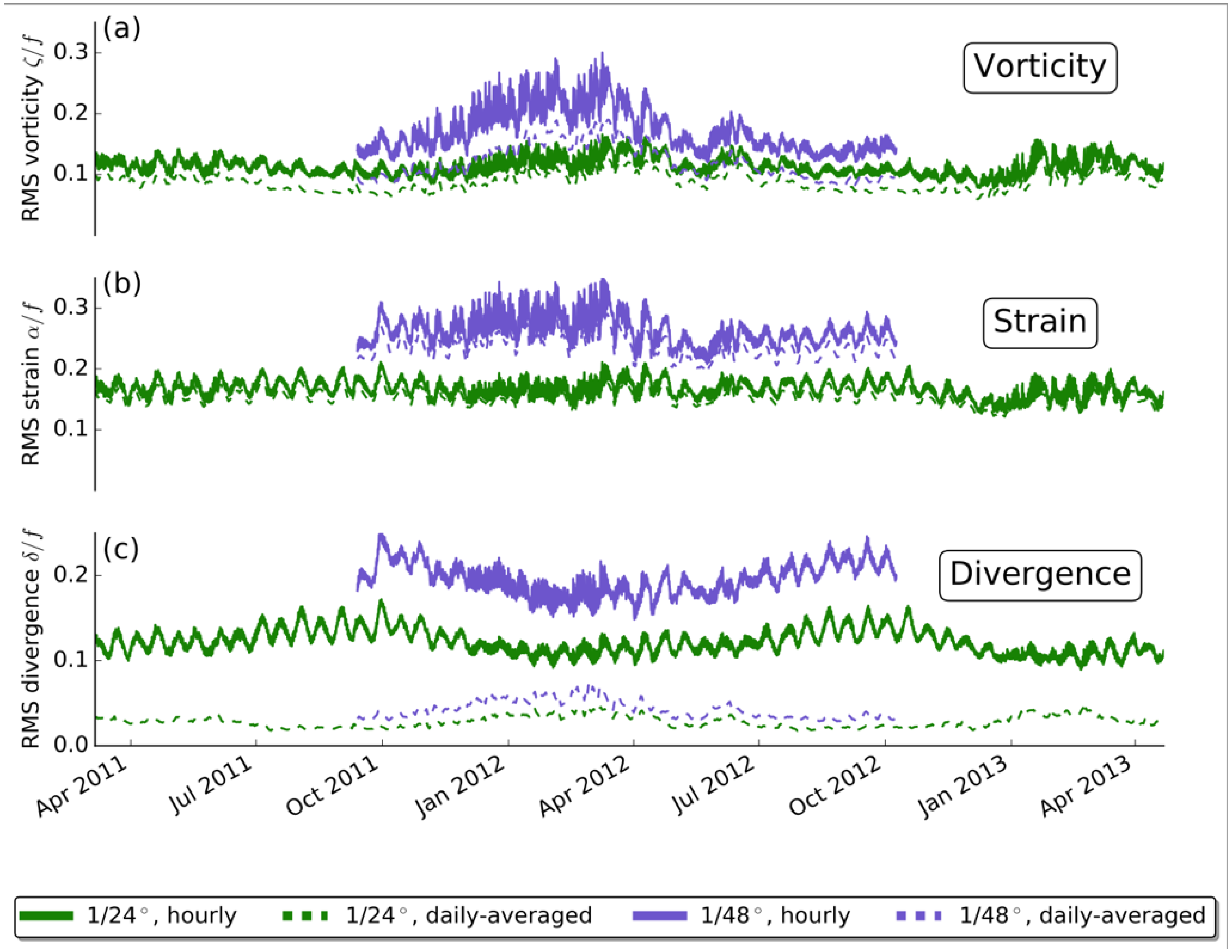
Model: seasonality



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

- 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

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)

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)