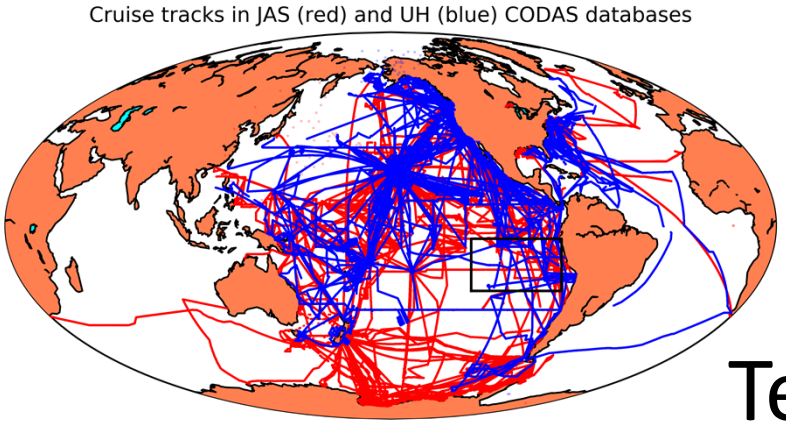
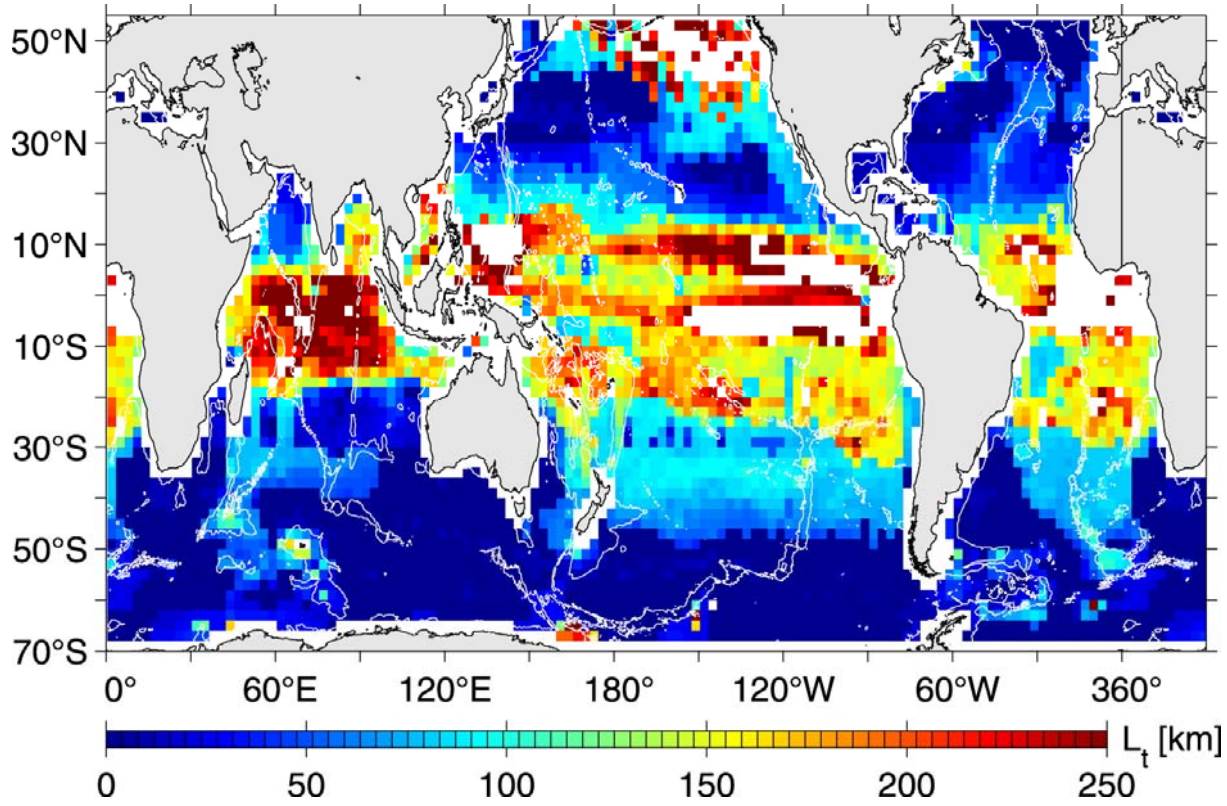
The transition from balanced motions to internal waves: Using ADCP data to guide understanding



Sarah Gille,
Teresa Chereskin, Saulo Soares
(with many others)
Scripps Institution of Oceanography

Transition scale (L_T): global model (llc4320)

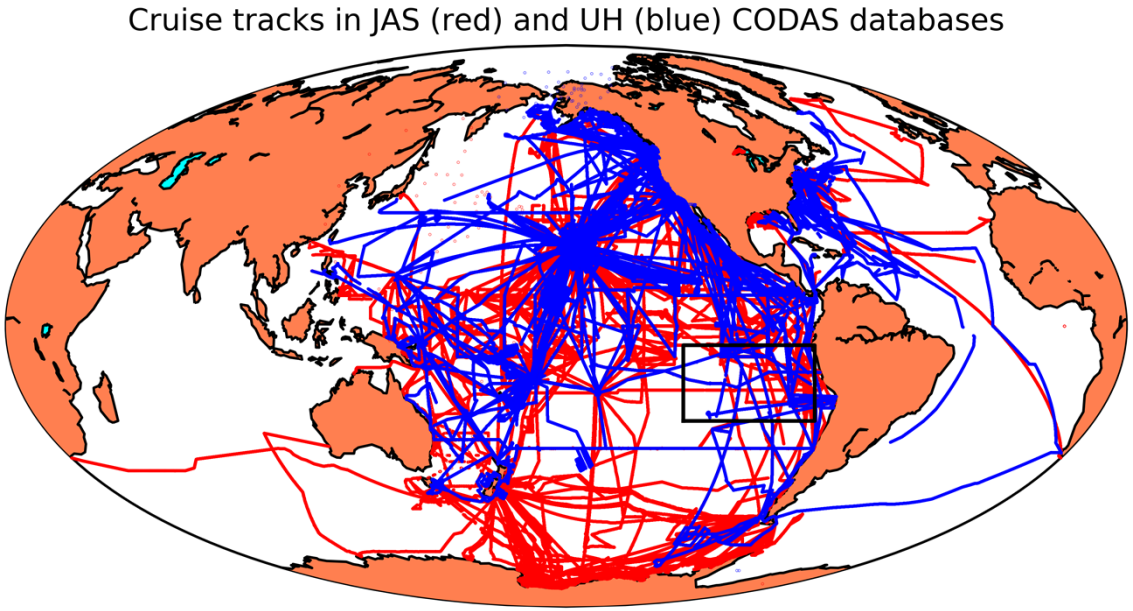


- Spatial variations in L_T. Computed by integrating 2D spectra
- Geostrophy dominates for scales > L_T.
- Small L_T: western boundaries, Antarctic Circumpolar Current.
- Large L_T in tropics
- Does this one-year simulation reflect reality?

Qiu et al, 2018

Shipboard Acoustic Doppler Current Profiler Data for in situ L_T

- Underway shipboard data collected on GO-SHIP hydrographic cruises
- Favor uninterrupted transects (continuous steaming, no stations)…
- But these are often transits, with no chief scientist badgering anyone to process data
- So, we launched a data processing effort ....

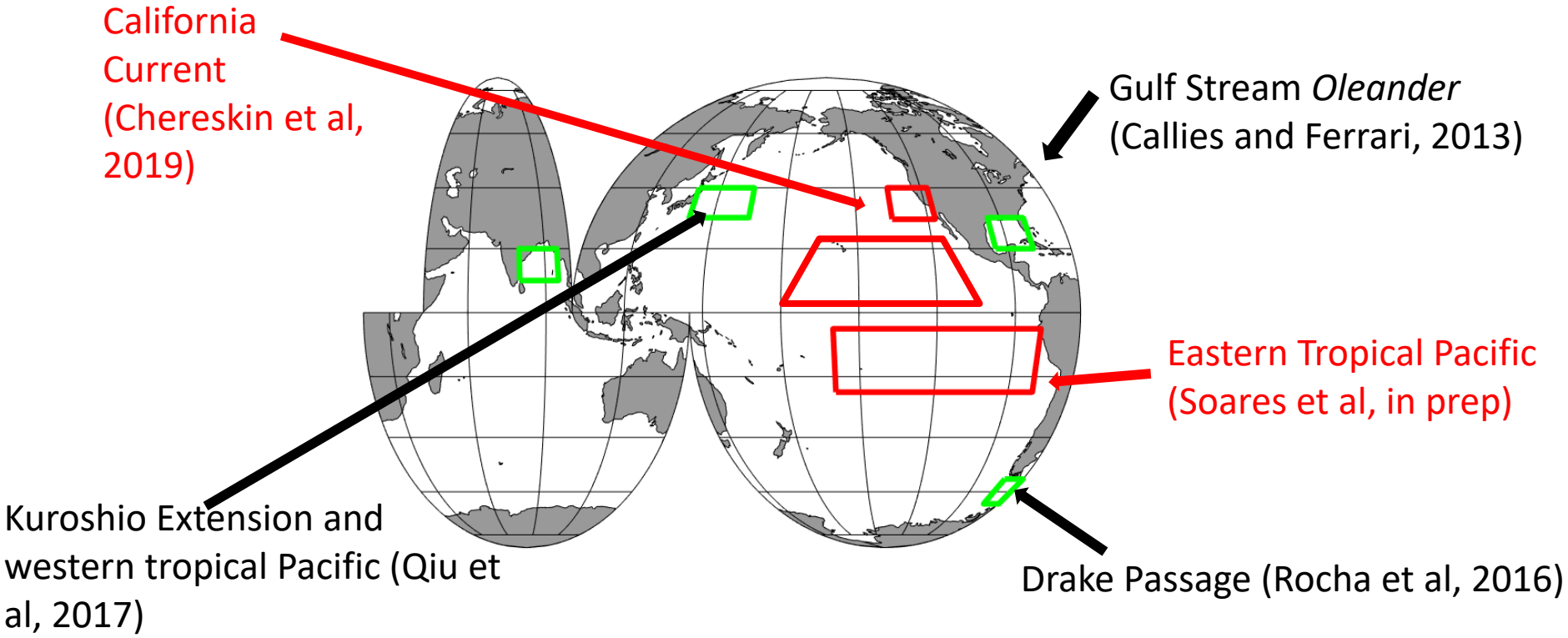


Archived ADCP data

UH CODAS: not processed

JAS-ADCP: processed

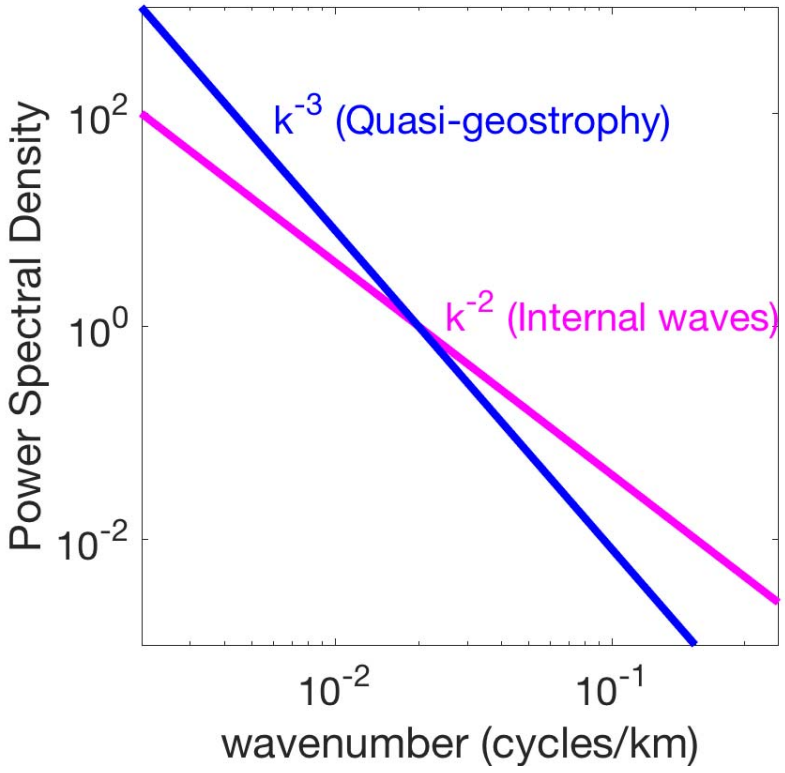
Acoustic Doppler Current Profiler analysis: Transition scale (L_T) in red boxes



What do we expect for kinetic energy spectra?

Gulf Stream, Kuroshio and Drake Passage:
Clear distinction between large-scale (balanced, QG, k^{-3}) and small scale (k^{-2})

(e.g., Callies & Ferrari, 2013;
Rocha et al., 2016; Qiu et al., 2017)

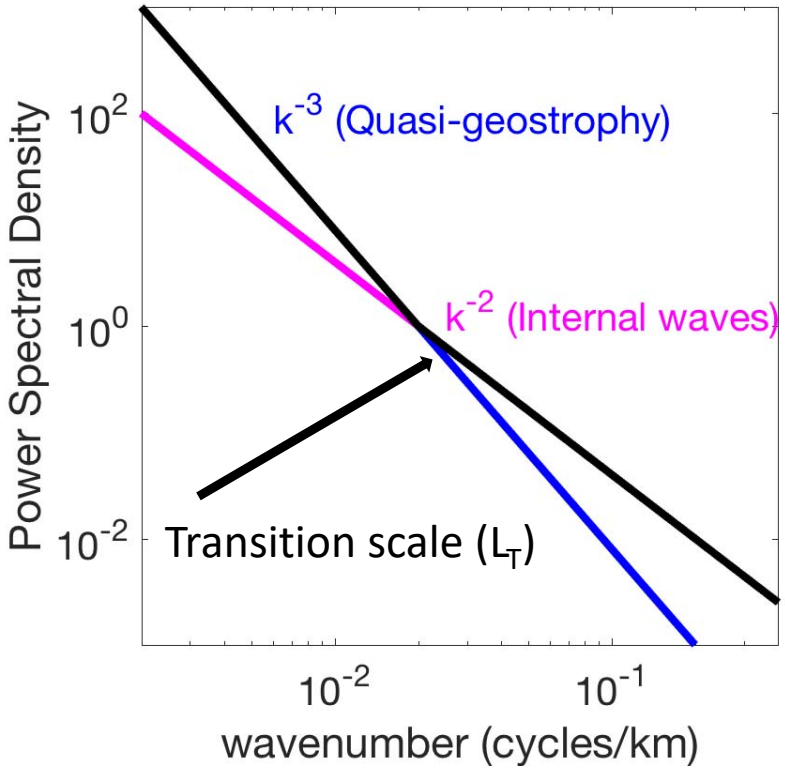


What do we expect for kinetic energy spectra?

Gulf Stream, Kuroshio, and Drake Passage:
Clear distinction between large-scale (balanced, QG, k^{-3}) and small scale (k^{-2})

Can change in spectral slope to identify transition from balanced to unbalanced flow.

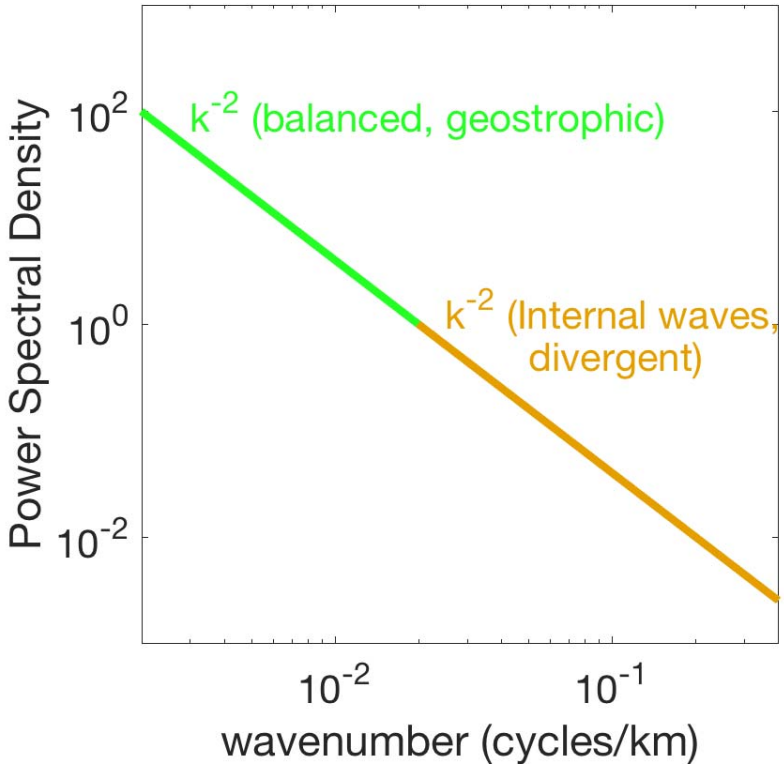
(e.g., Callies & Ferrari, 2013;
Rocha et al., 2016; Qiu et al., 2017)



What do we expect for kinetic energy spectra?

In California Current and tropical Pacific:
No spectral slope distinction between large-scale (balanced, k^{-2}) and small scale (k^{-2})

Rely on Helmholtz decomposition to distinguish balanced, rotational flow from unbalanced, more divergent flow.



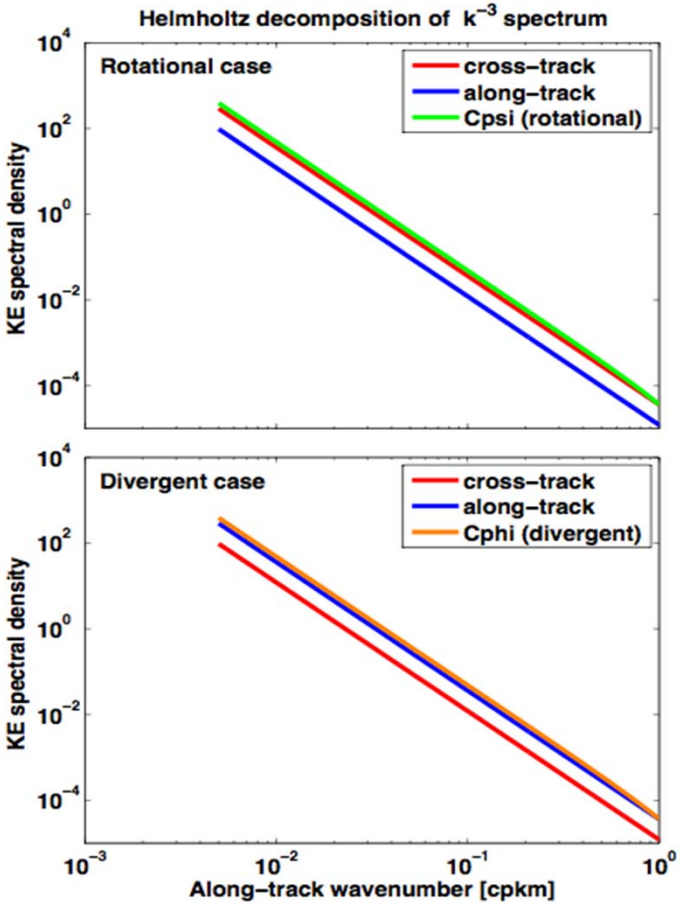
Inferring dynamics from horizontal wavenumber spectra:

- For 1-D (alongtrack) spectra, across-track K_u and along-track K_v are related through the exponent n:

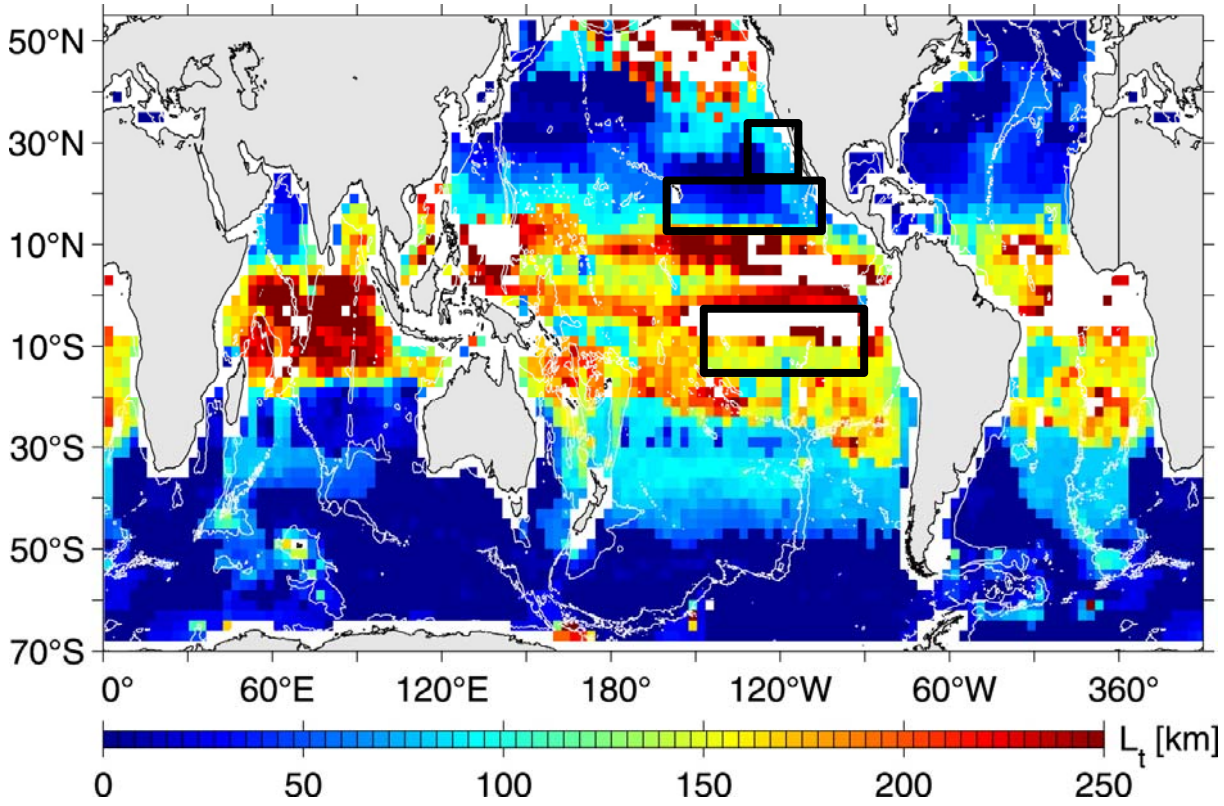
  $K_u = n\ K_v$ purely rotational (nondivergent)

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

- Helmholtz decomposition of 1-D spectra separates rotational and divergent components (e.g., Callies & Ferrari, 2013; Buhler et al., 2014; Rocha et al., 2016)



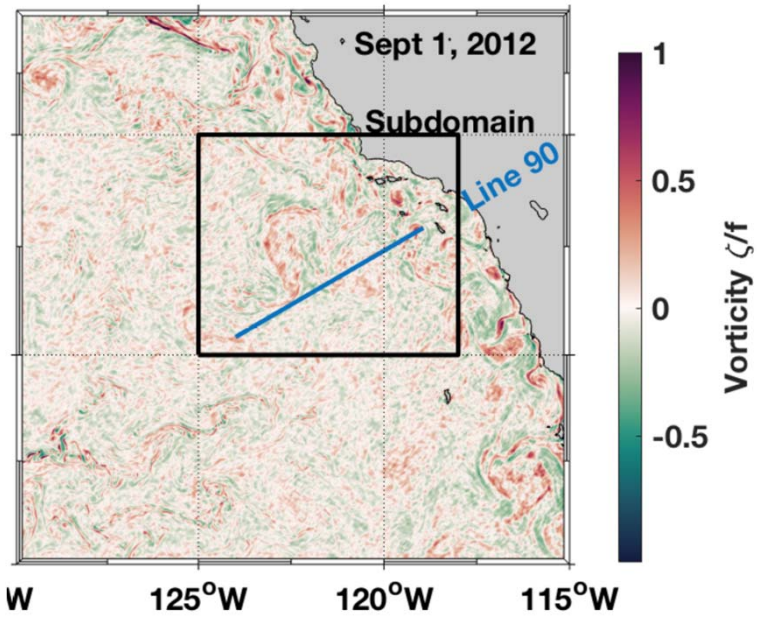
L_T predictions (llc4320): 3 regions



- California Current: 100 km
- Tropical Pacific north of equator: 50 km
- Tropical Pacific south of equator: > 150 km

Qiu et al, 2018

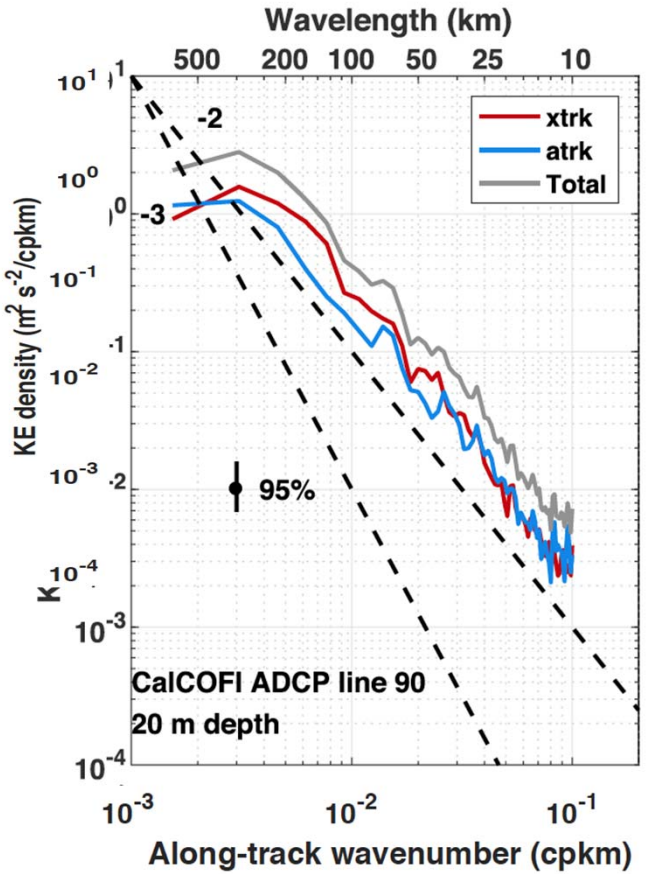
Characterizing the California Current



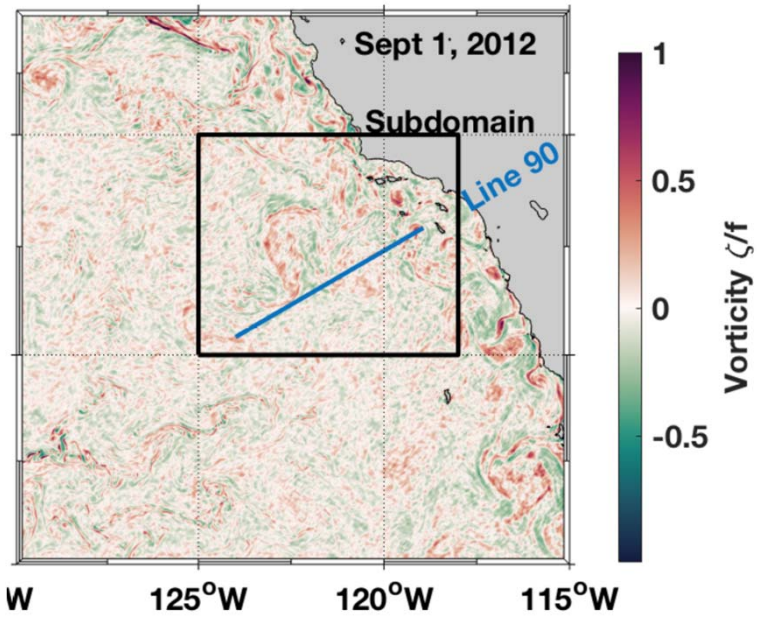
Acoustic Doppler Current Profiler data: 1993-2004, 39 cruises

Chereskin et al, JGR-Oceans, 2019

Spectra for cross-track and along-track components



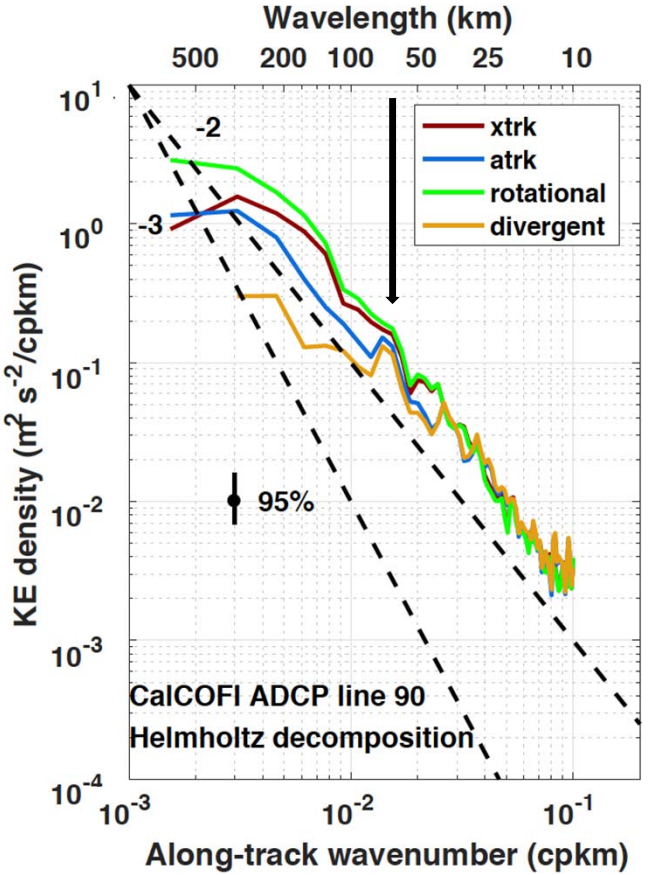
Characterizing the California Current



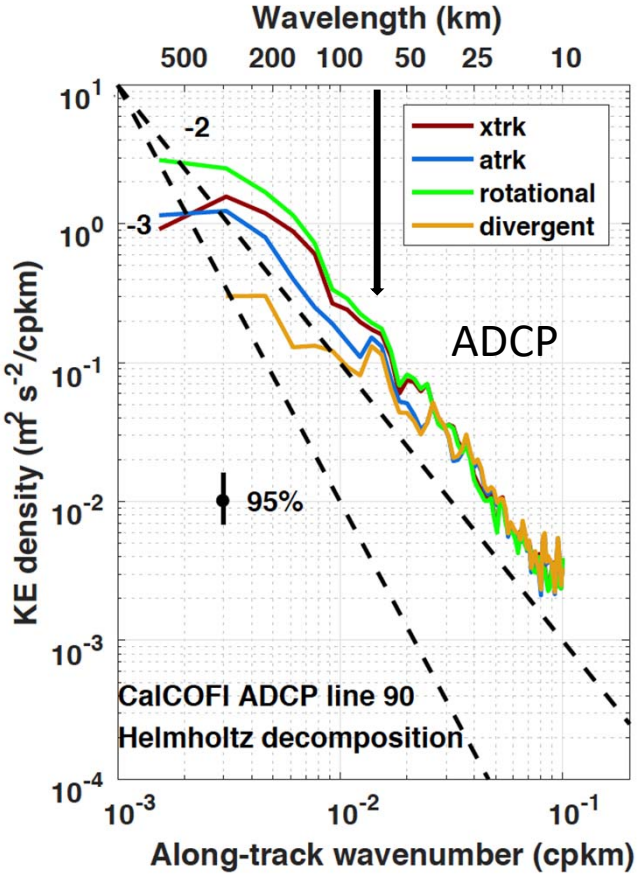
Acoustic Doppler Current Profiler data: 1993-2004, 39 cruises

Chereskin et al, JGR-Oceans, 2019

Helmholtz decomposition to separate rotational and divergent components.
$L_T \approx 70$ km

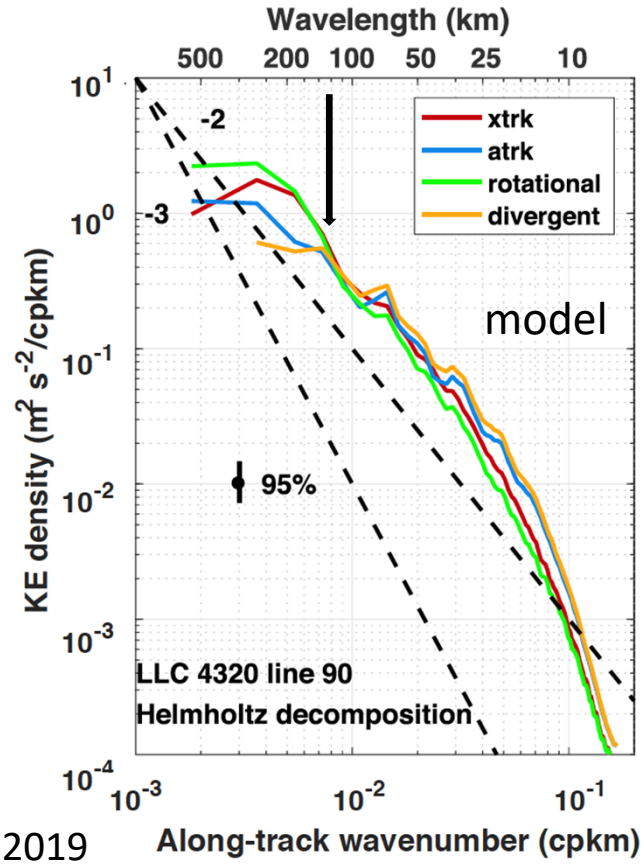


Model (llc4320) analysis



ADCP: 70 km

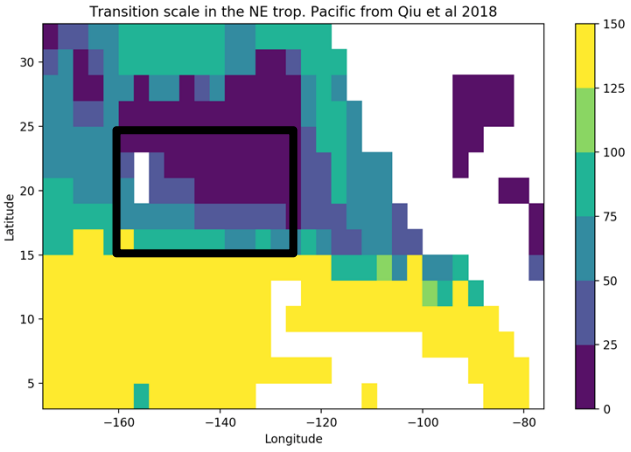
Model (Helmholtz decomposition or coherence): 140 km (appears longer than Qiu et al estimate)

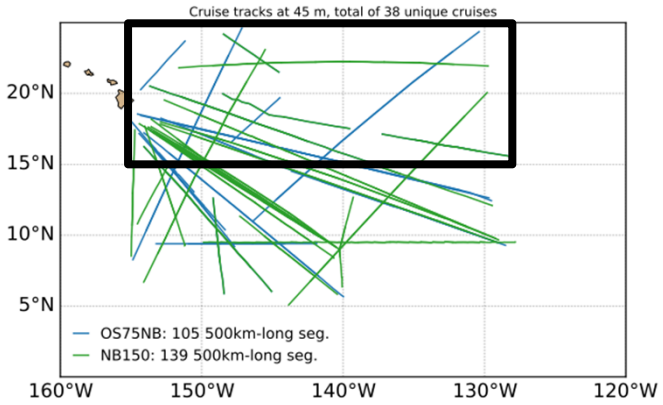


Chereskin et al, JGR-Oceans, 2019

Northeast Tropical Pacific: >15°N

Qiu et al, 2018

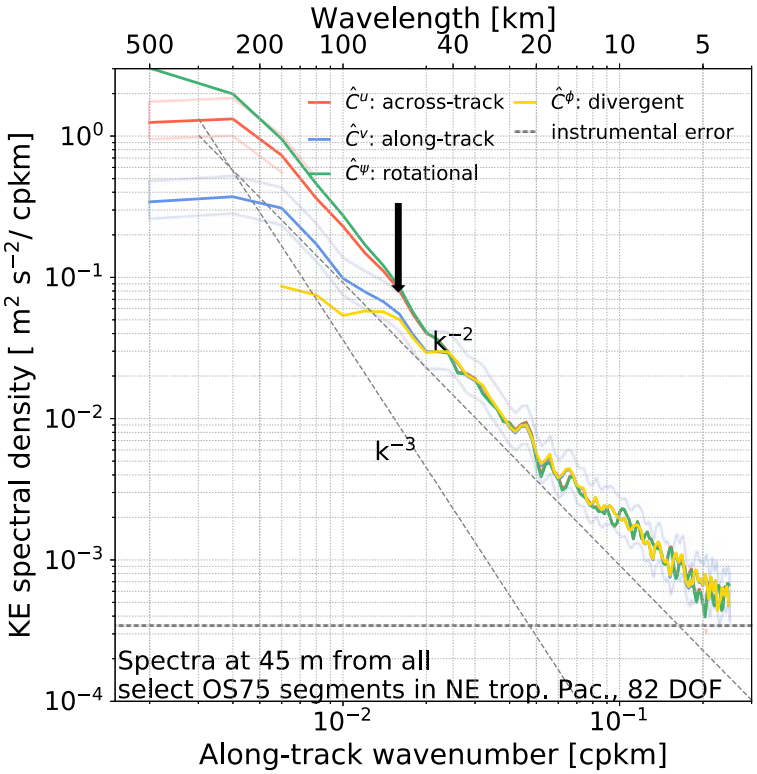




Model $L_T \approx 50$ km

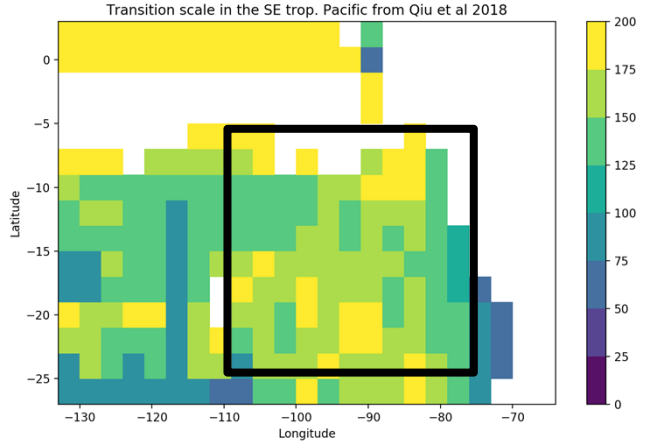
ADCP ≈ 70 km

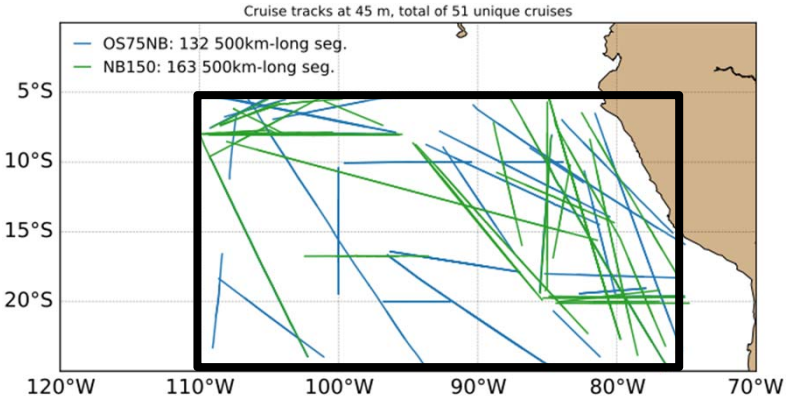
Model scales shorter than ADCP



Southeast Tropical Pacific: >15°N

Qiu et al, 2018

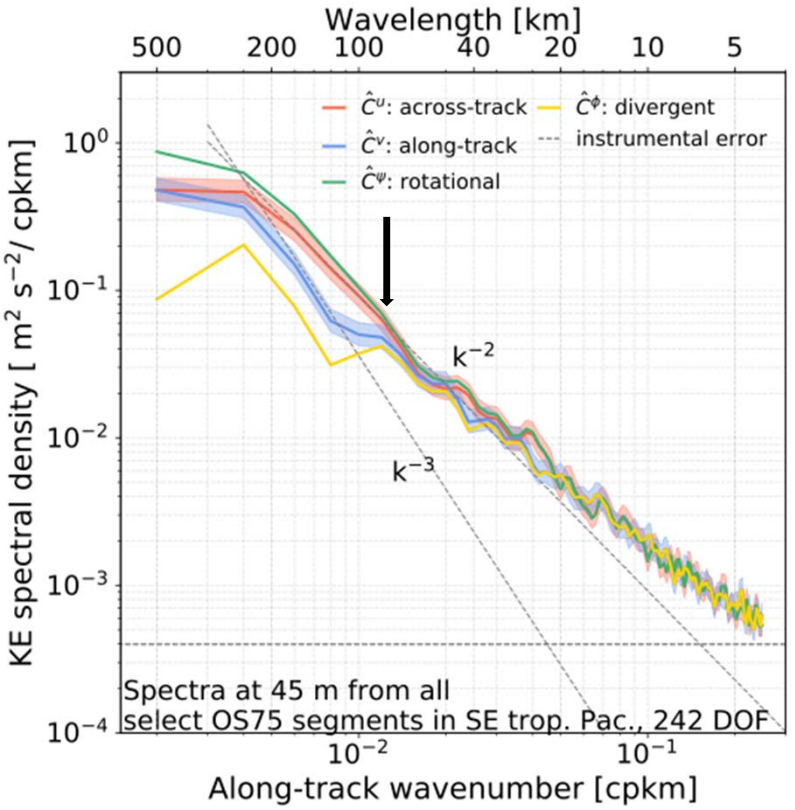




Model L_T >125km

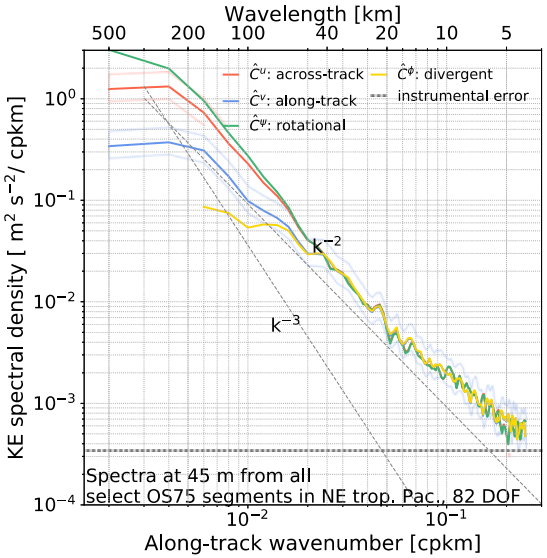
ADCP ≈ 80 km

Model scales longer than ADCP



Conclusions

- Cleaning up ADCP data → JAS-ADCP. Addressing technical details (e.g. 75kHz performance similar to 150 kHz performance)
- In California Current and in tropics, KE spectra from ADCP follow k^{-2} power law, with L_T ≈70 km, consistently.
- Model spatial structure not in ADCP data.



Region	L_T (km) ADCP	L_T (km) model
California Current	70 km	100 km
NE tropical Pacific	70 km	50 km
SE tropical Pacific	80 km	150 km

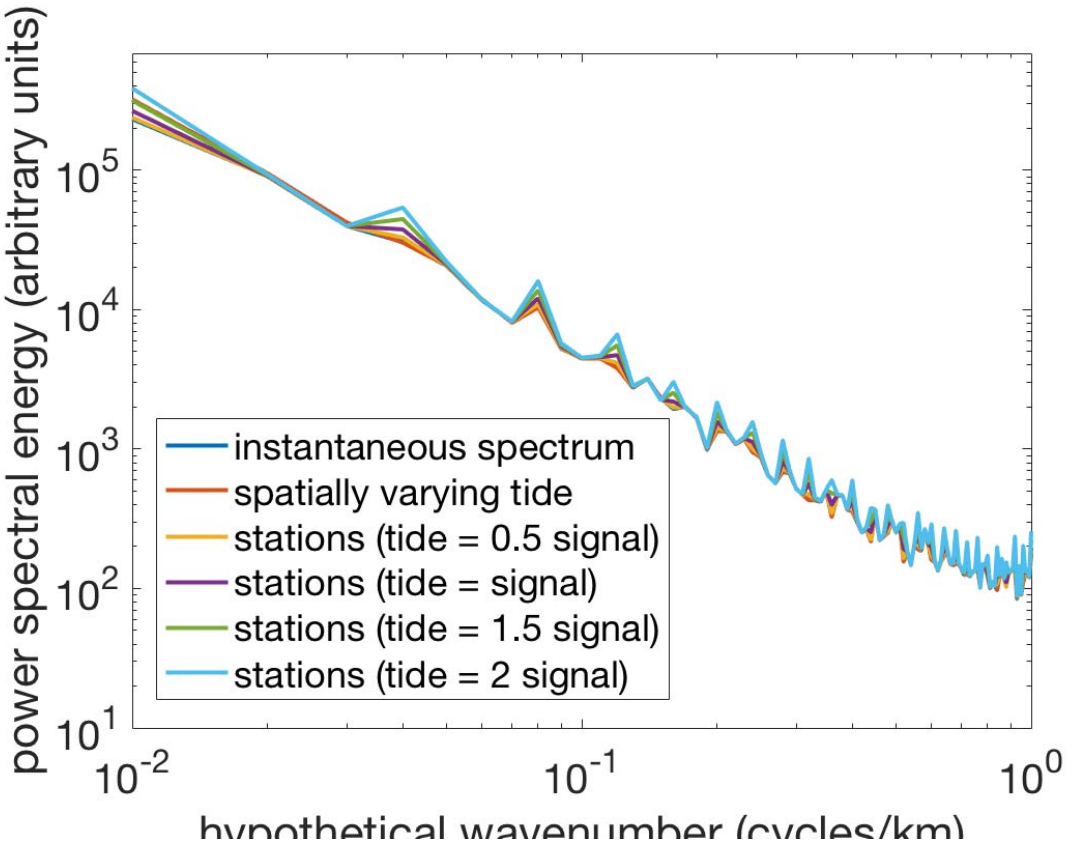
What if the ship stops for stations?

Thought experiment:
Suppose a ship samples an ocean with a tide that varies in time and has a large-scale spatial structure

Model with autoregressive process.

Ship spends half its time on station and half its time steaming.

Signal due to stopping for stations depends on amplitude of tide relative to variance of signal



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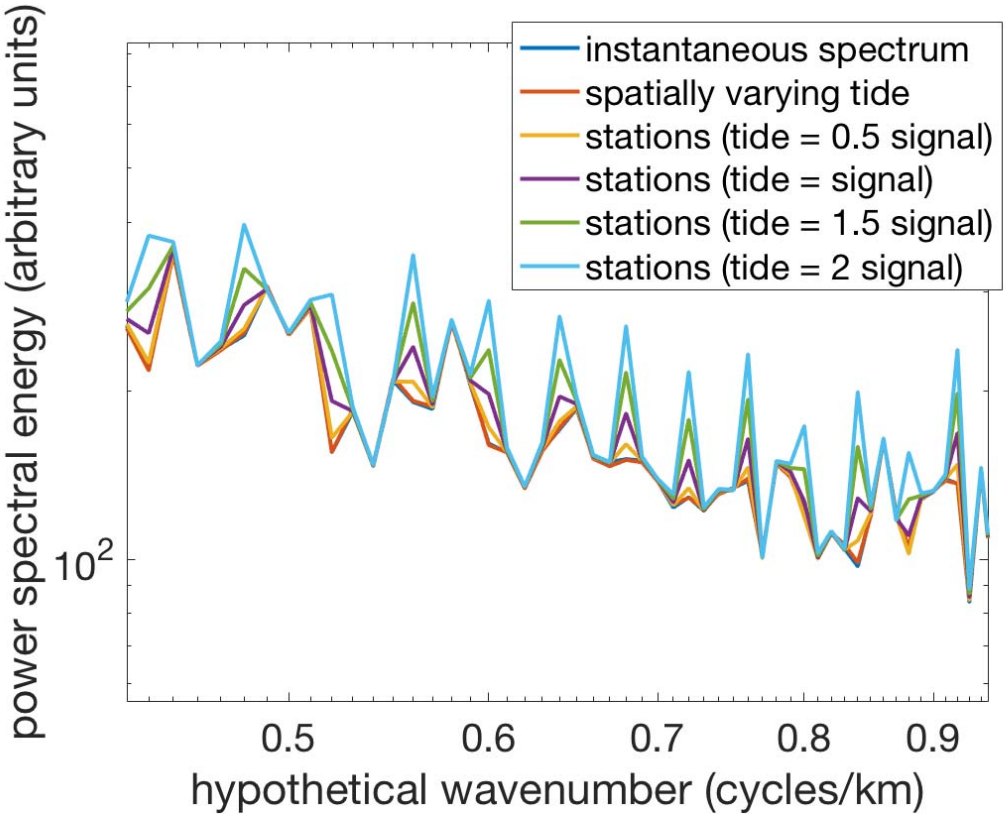
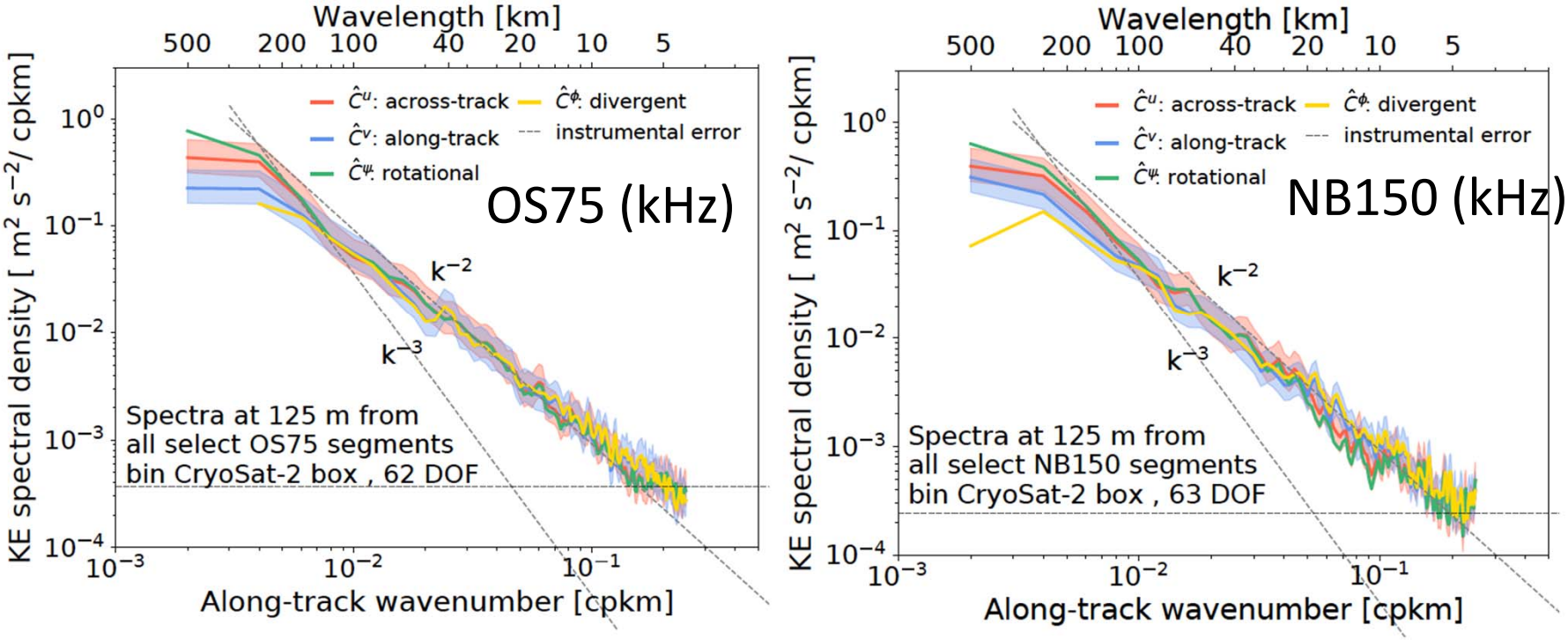


Does frequency of ADCP matter?



- No major differences between different frequency ADCP sampling

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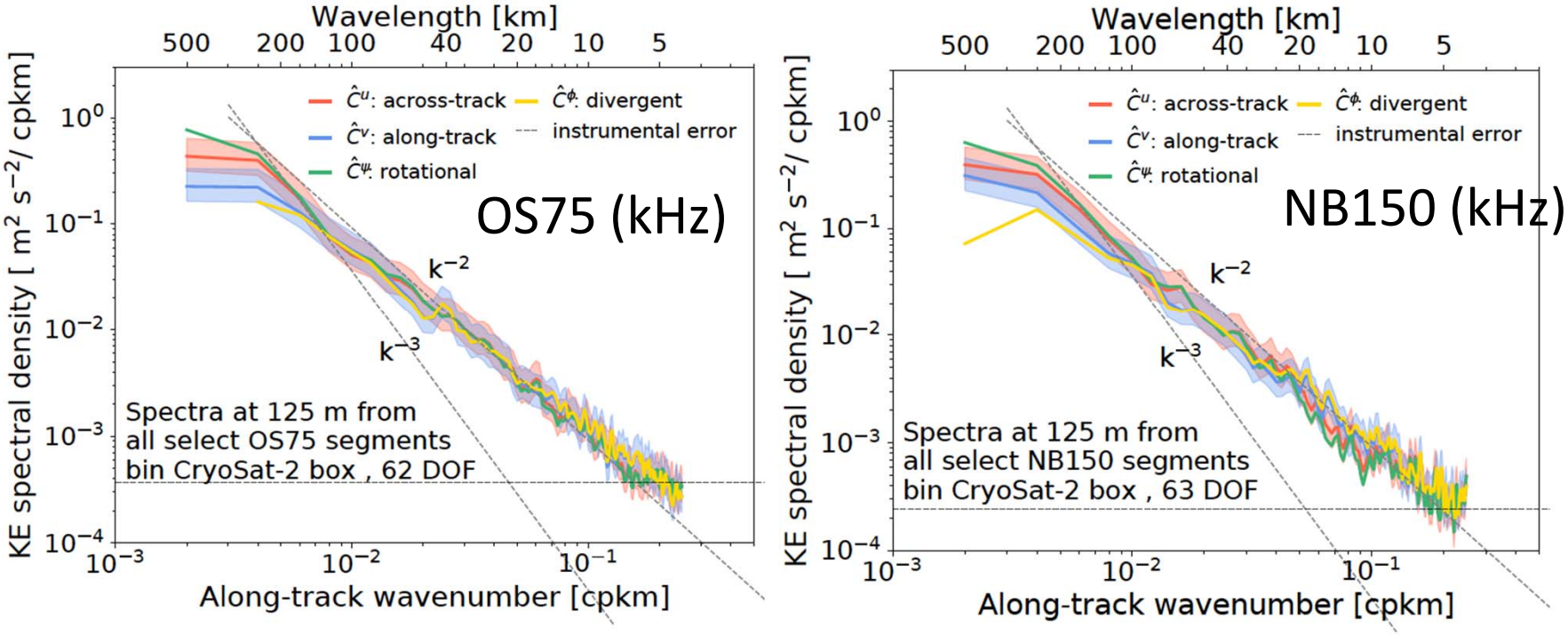
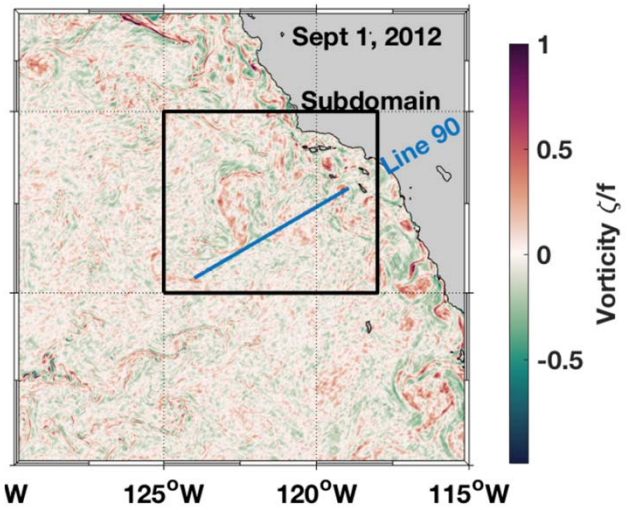
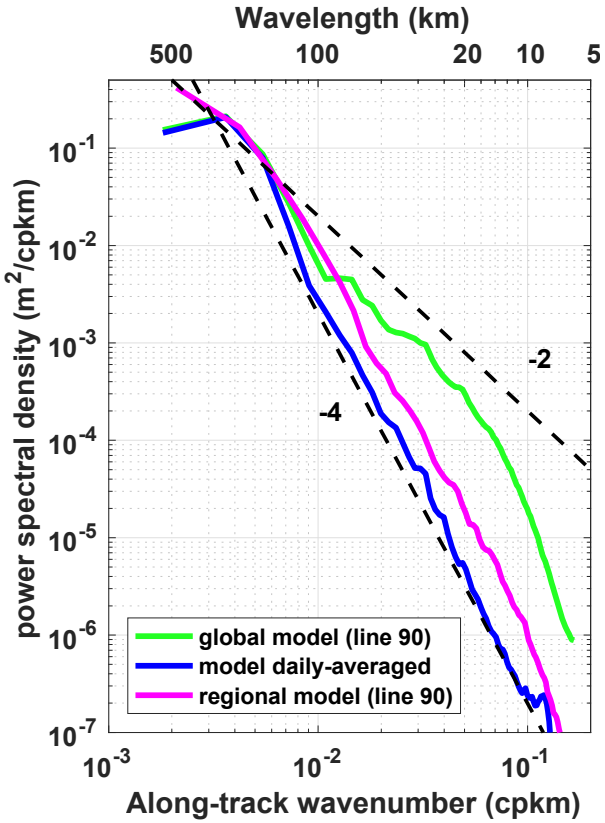


- No major differences between different frequency ADCP sampling

Sea surface height wavenumber spectra

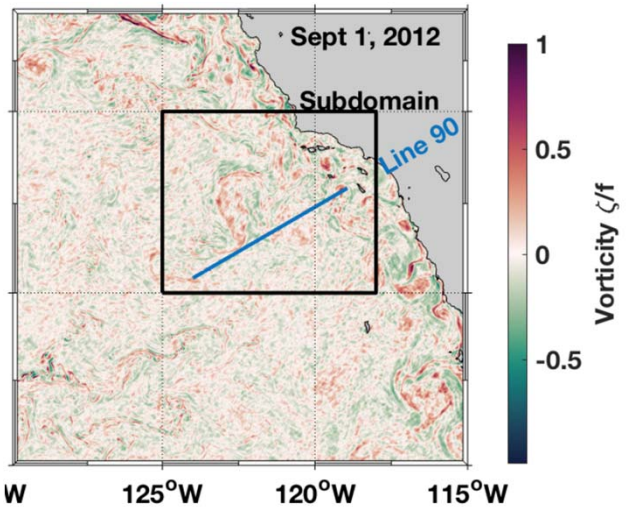


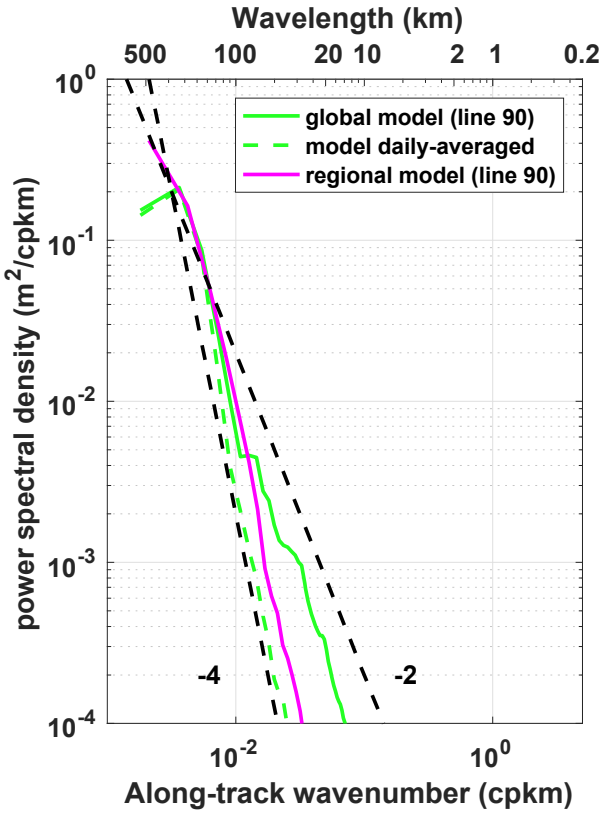


- Global model: spectra from hourly output vs daily averages
- Regional model: less energetic than global model at high wavenumbers--- more like daily averages

Adapted from Chereskin et al, JGR-Oceans, 2019

Sea surface height wavenumber spectra





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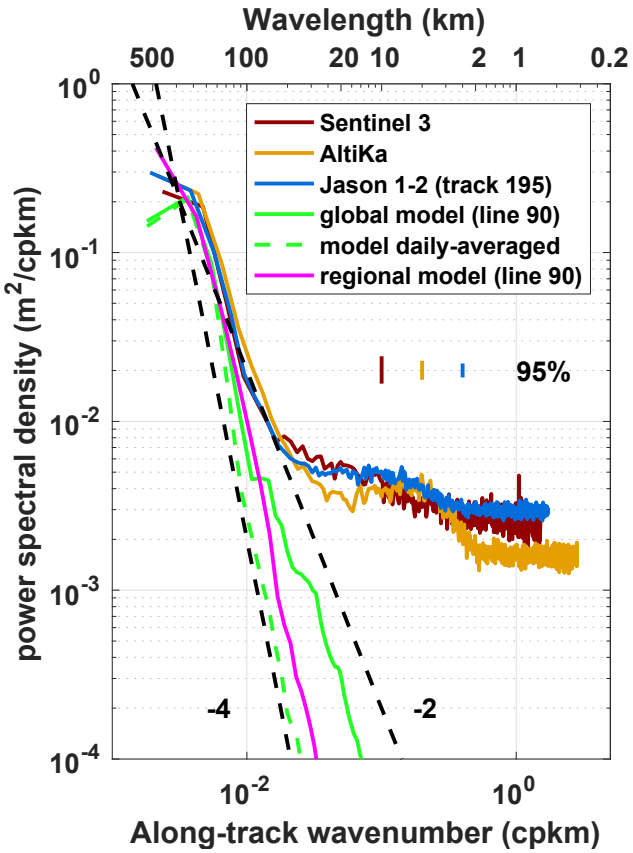
Sea surface height wavenumber spectra

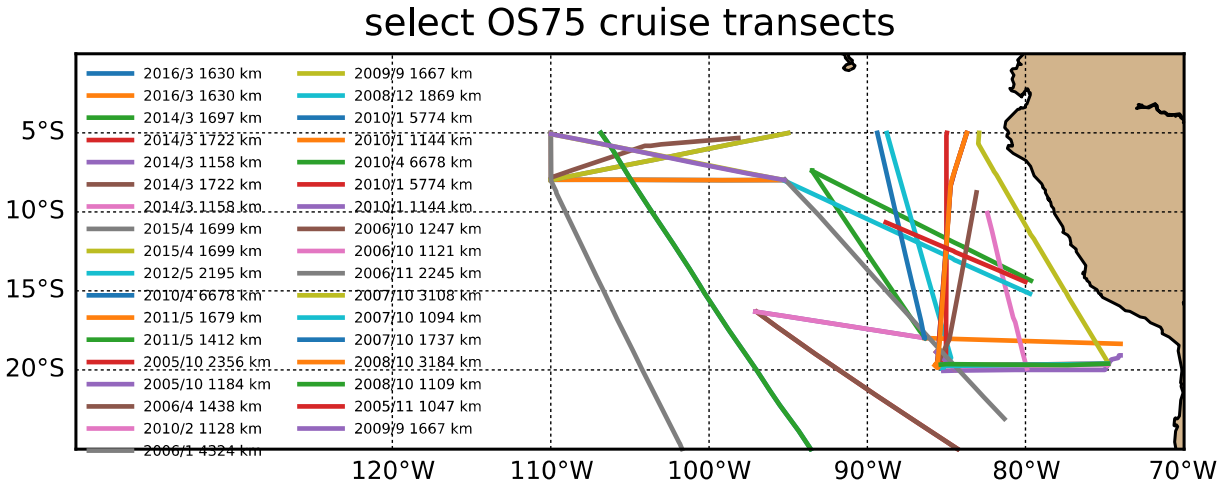
- Global model: spectra from hourly output vs daily averages
- Regional model: less energetic than global model at high wavenumbers--- more like daily averages
- Altimeter spectra more energetic than models from 100-50 km and flatten out (implying “noise”) for scales smaller than ~50 km.



Adapted from Chereskin et al, JGR-Oceans, 2019

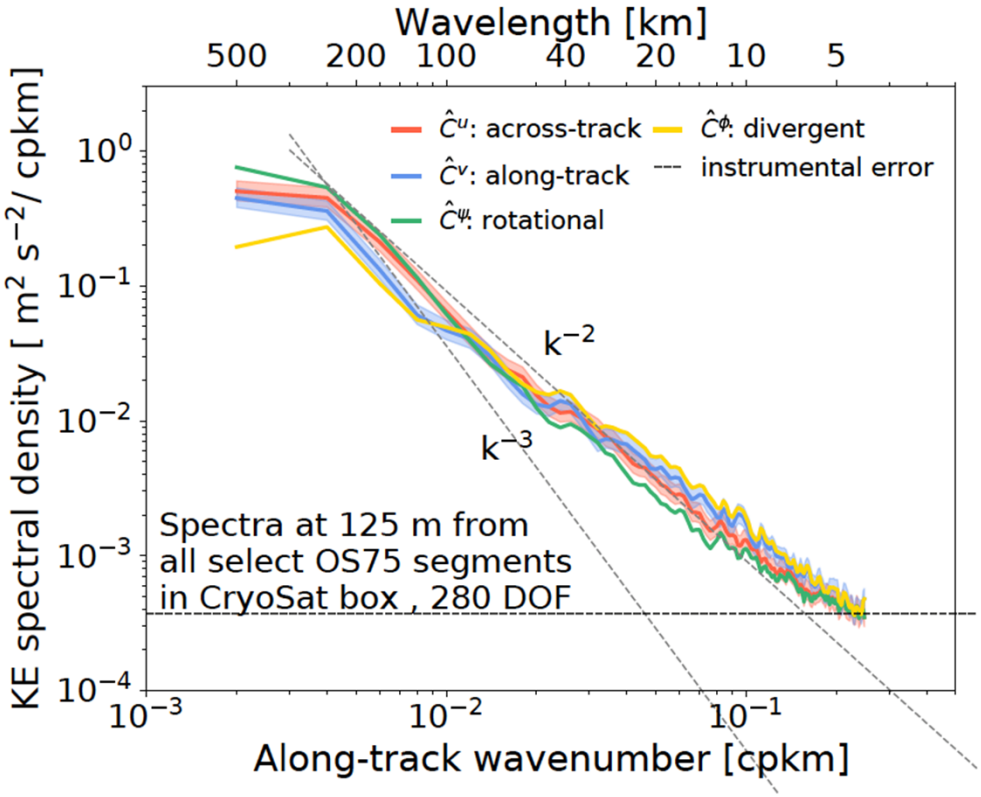
ADCP: Ocean Surveyor 75 kHz

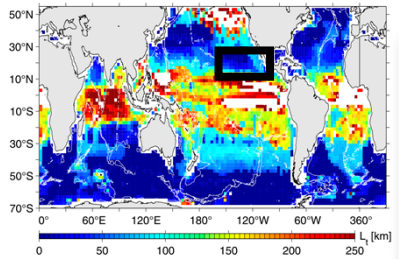
- What characterizes spectra?
- What transition do we see from geostrophic to ageostrophic motions?

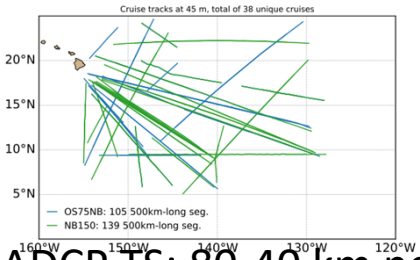


Spectral slopes: little variation with wavenumber

- k^{-2} spectra
- Flattens for scales < 15 km
- Ratio of along-track to cross-track near 1, except for scales > 100 km
- Transition scale > 100 km

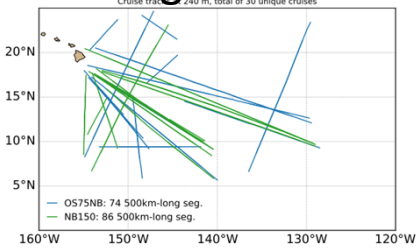






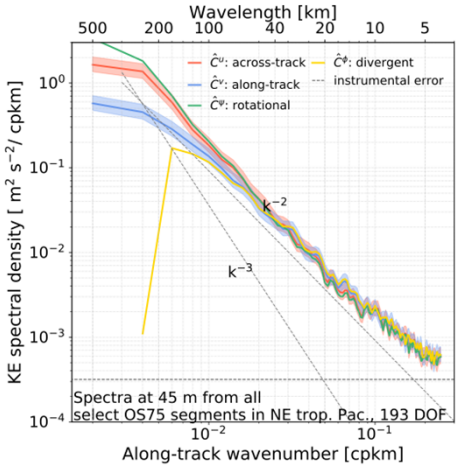
ADCP TS: 80-40 km near surface; very uncertain

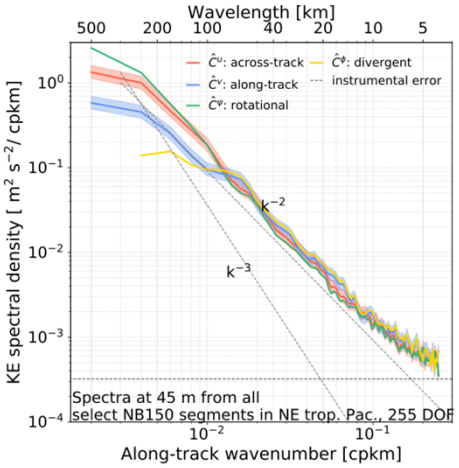
Thermocline TS: 200-100 km
Much higher confidence



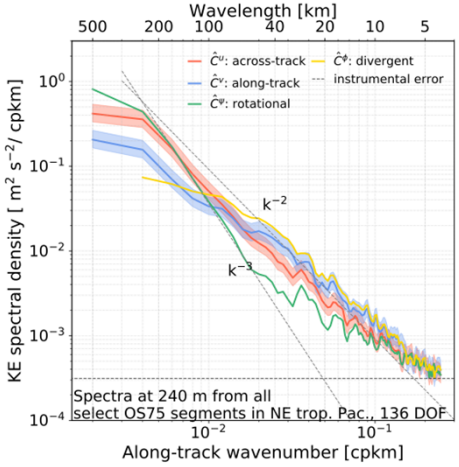
NE tropical Pacific: Expected transition scale (L_T) is ~50 km

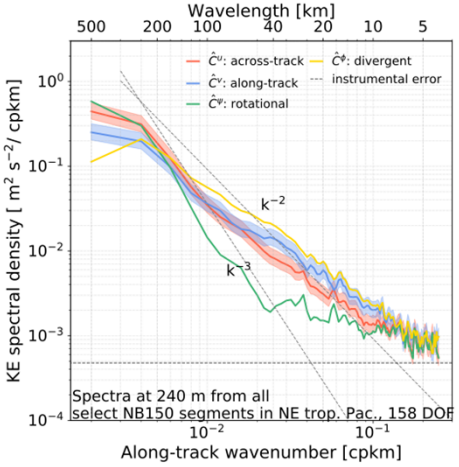
45 m depth

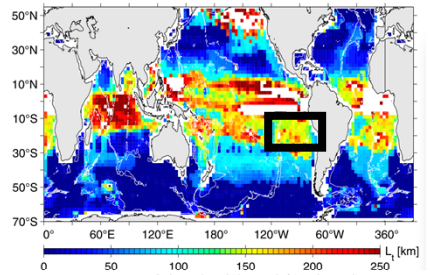




240 m depth



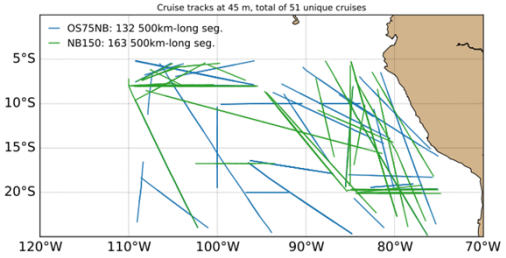




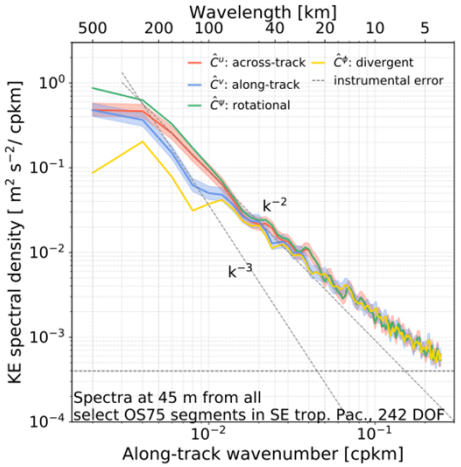
SE tropical Pacific: expected transition scale (L_T) is ~150 km

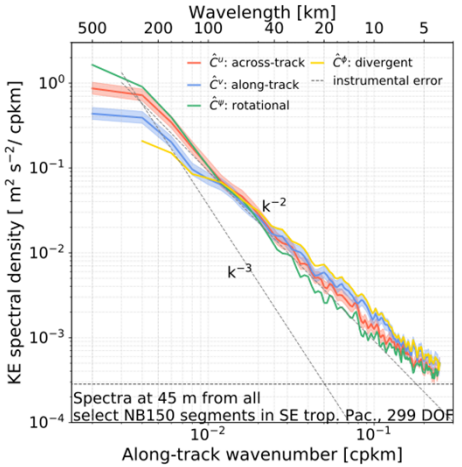
ADCP TS: likely ~80 km near surface; highly uncertain

Thermocline TS: very likely >150 km
Much higher confidence



45 m depth





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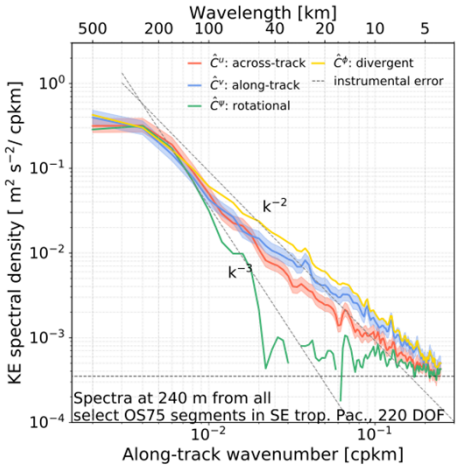
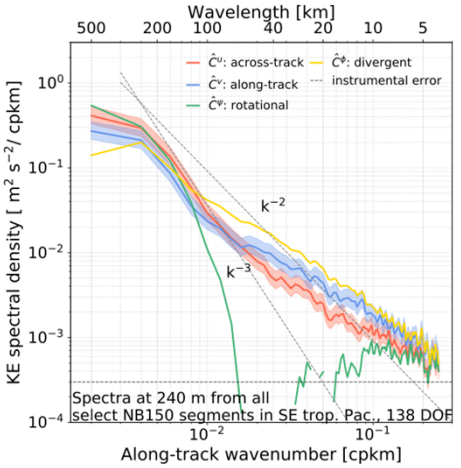
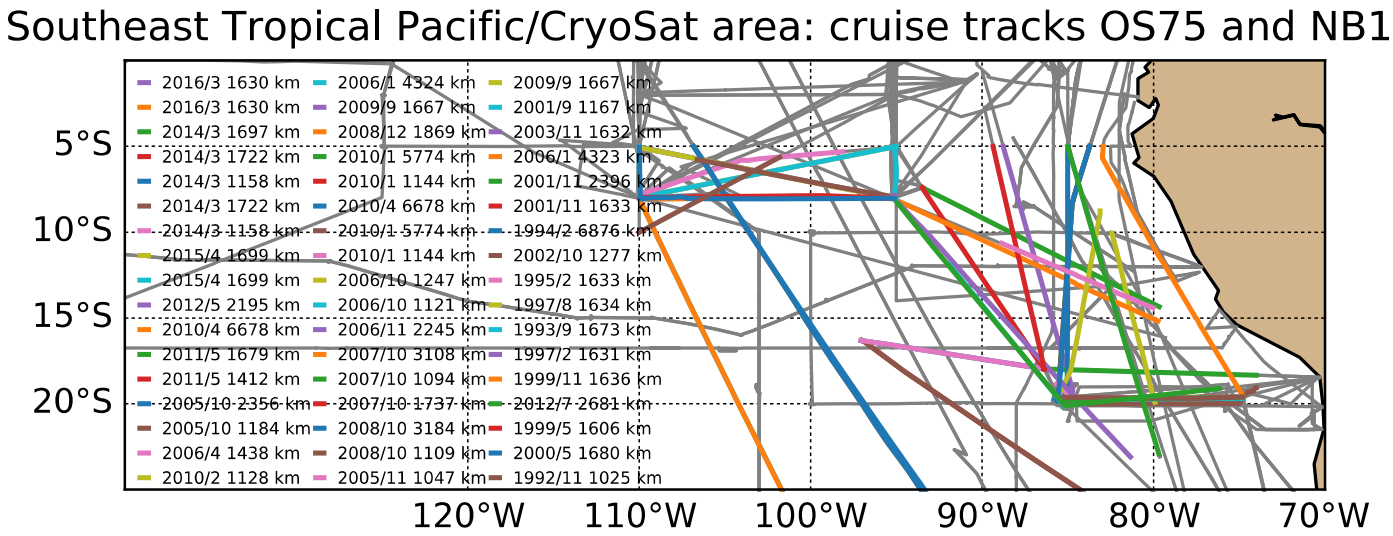




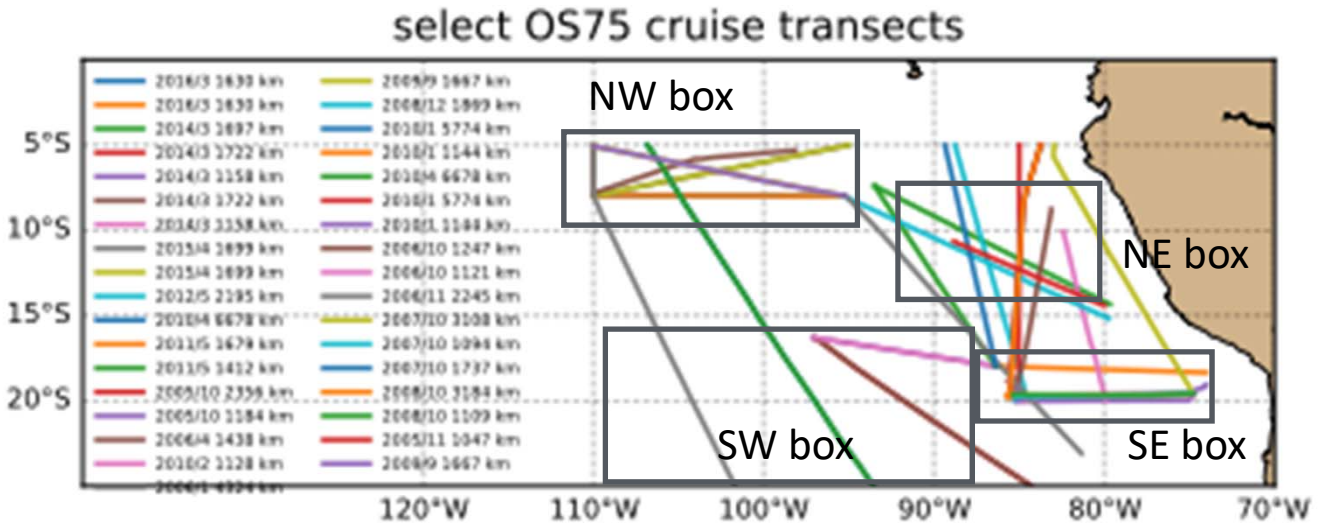
Tracks in the tropical Pacific



More questions

- Does frequency of ADCP matter? (NB150 vs OS75)
- How robust are the spectral estimates? (Are there regional variations?)

Are there regional variations? Look at sub-domains



- 4 sub-domains (CC from top right): NE box, SE box, SW box & NW box
- Examine the 125 m spectra

Regional sub-domains largely agree

More along-track energy: more divergent component