Wavenumber Spectra in Drake Passage from models, altimetry, and ADCP: Connecting theory to observations

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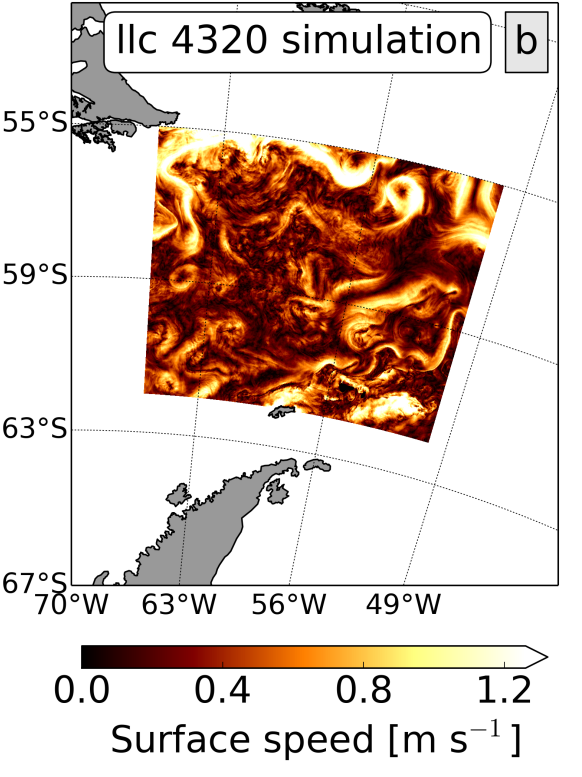
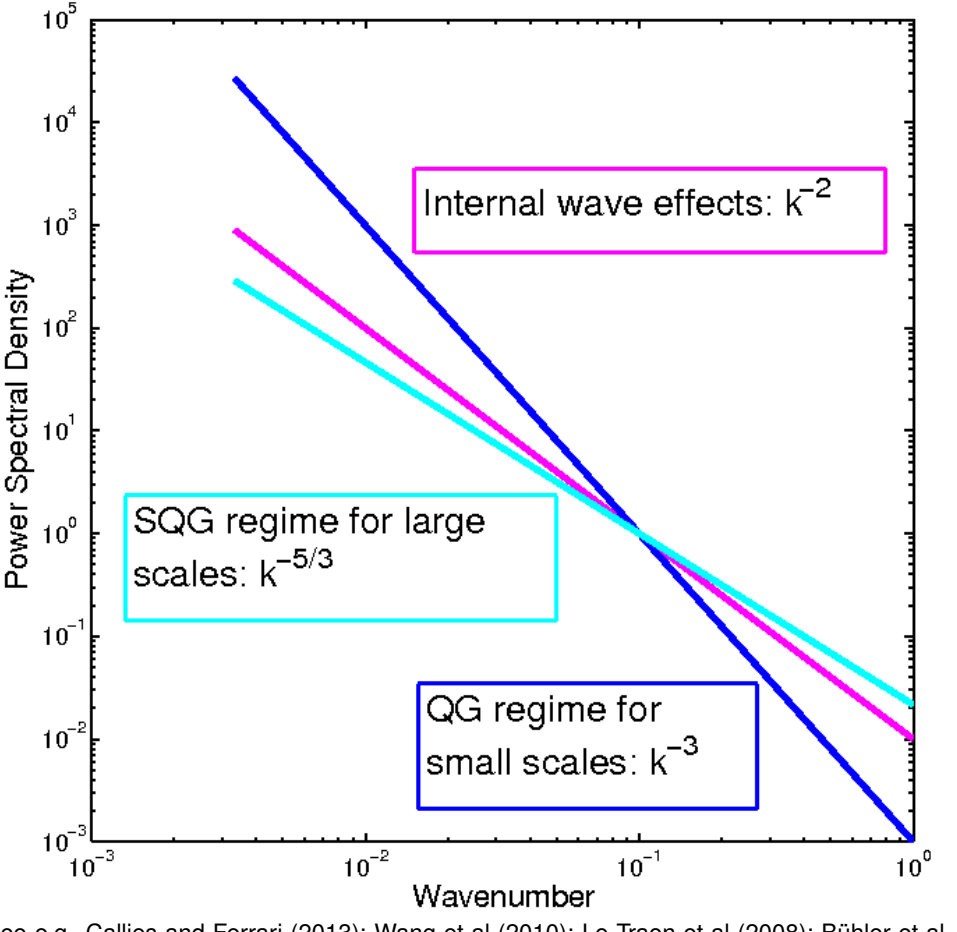
Funding: NASA Ocean Surface Topography Science Team, SWOT SDT



MITgcm at 1 km resolution, Dimitris Menemenlis

Hypotheses: What to expect for velocity spectra?

- Quasi-geostrophy predicts k^{-3}.
- Surface quasi-geostrophy predicts $k^{-5/3}$.
- Internal tides can alter spectral slopes: k^{-2}.



See e.g. Callies and Ferrari (2013); Wang et al (2010); Le Traon et al (2008); Bühler et al (2014)

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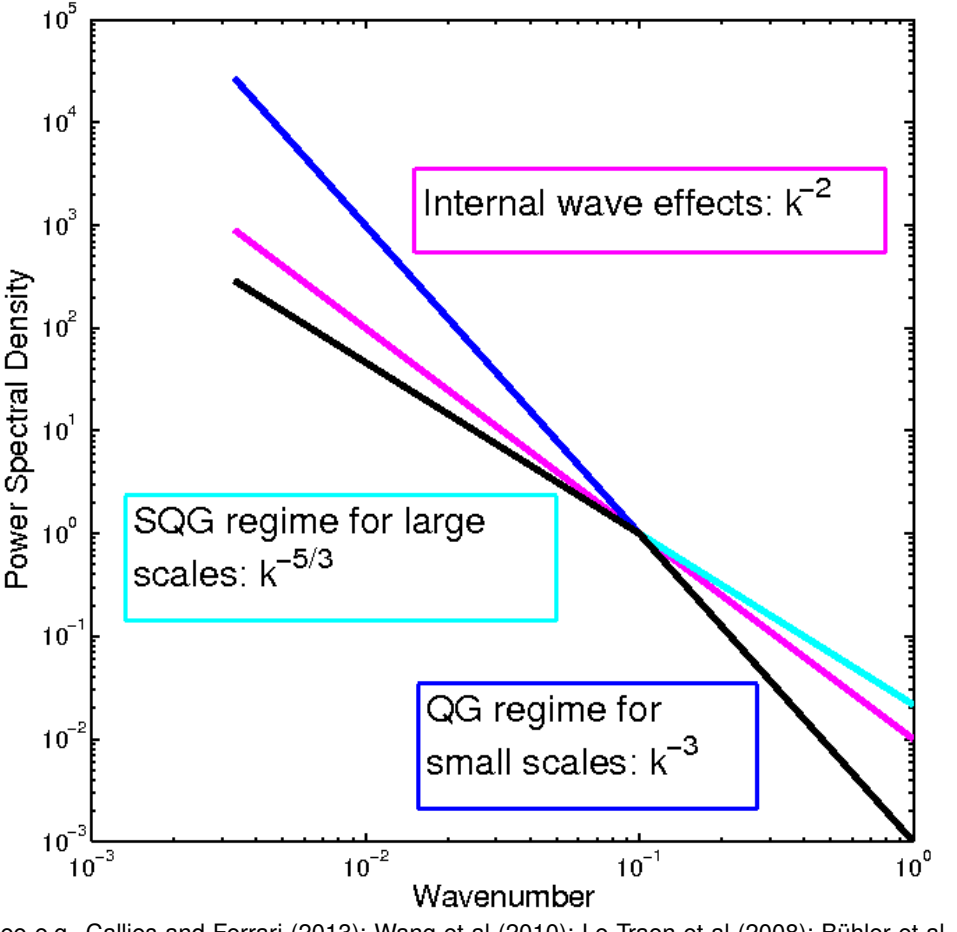

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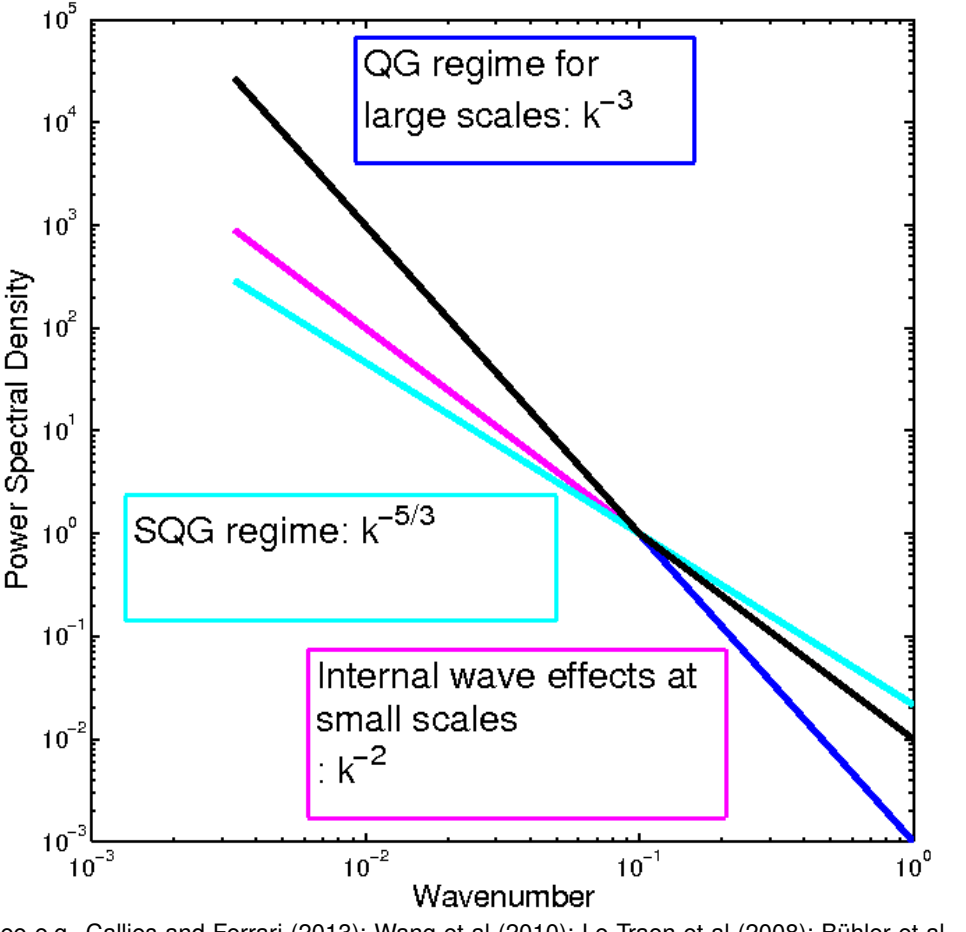
- Callies and Ferrari hypothesize SQG for large scales and QG-like behavior at smaller scales.
- But in Gulf Stream they find QG-like behavior for large scales, k^{-2} for small scales.



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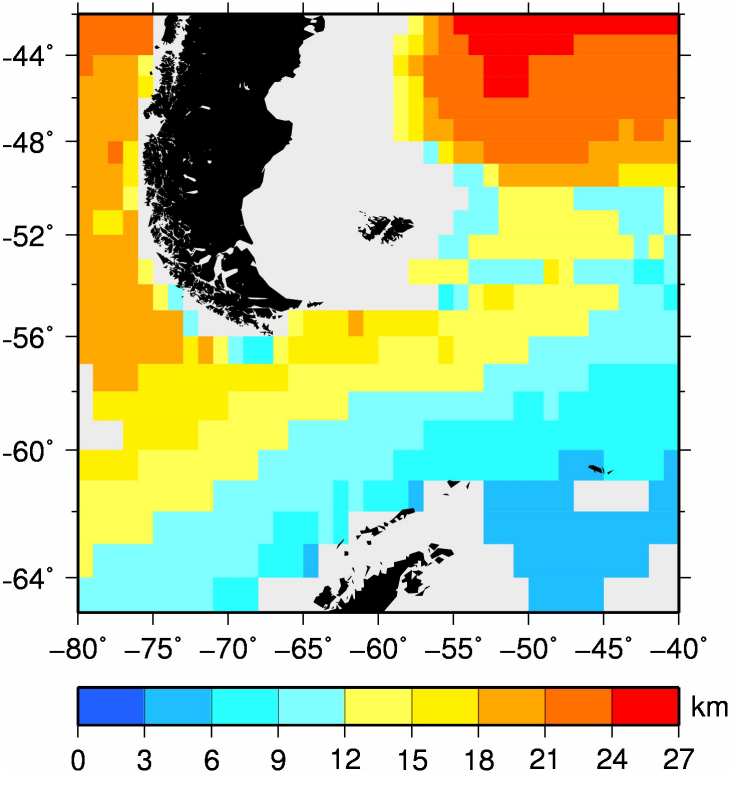
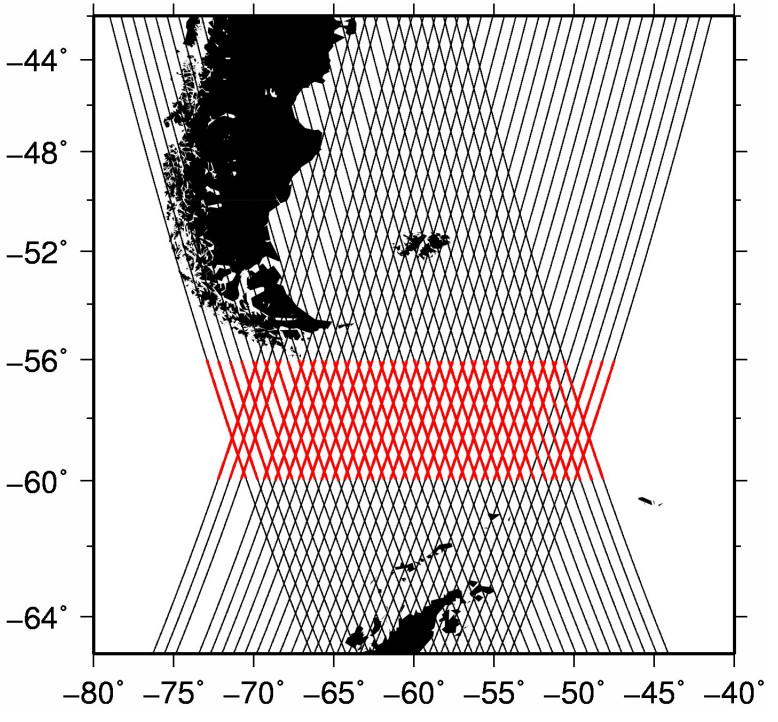
Challenges for wave number spectra in the Southern Ocean



adapted from Chelton et al, JPO, 1998

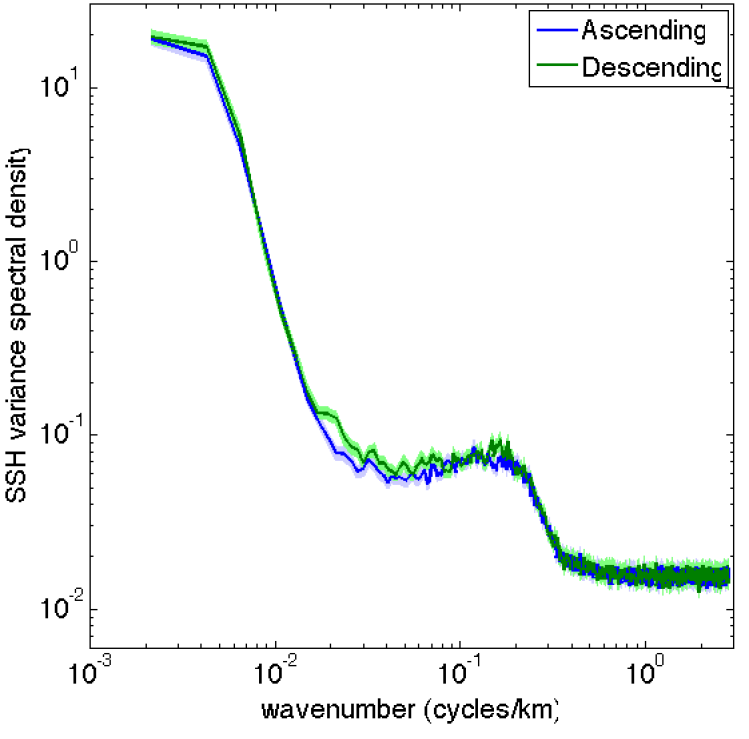
- Rossby radius is small, so expect small-scale mesoscale processes, plus high winds and high sea state.
- Take advantage of new data from AltiKa, ship, and 1-km MITgcm output.
- What do spectral slopes tell us about dynamics (at high wavenumbers and low wavenumbers)?

Altimeter sampling: AltiKa in Drake Passage



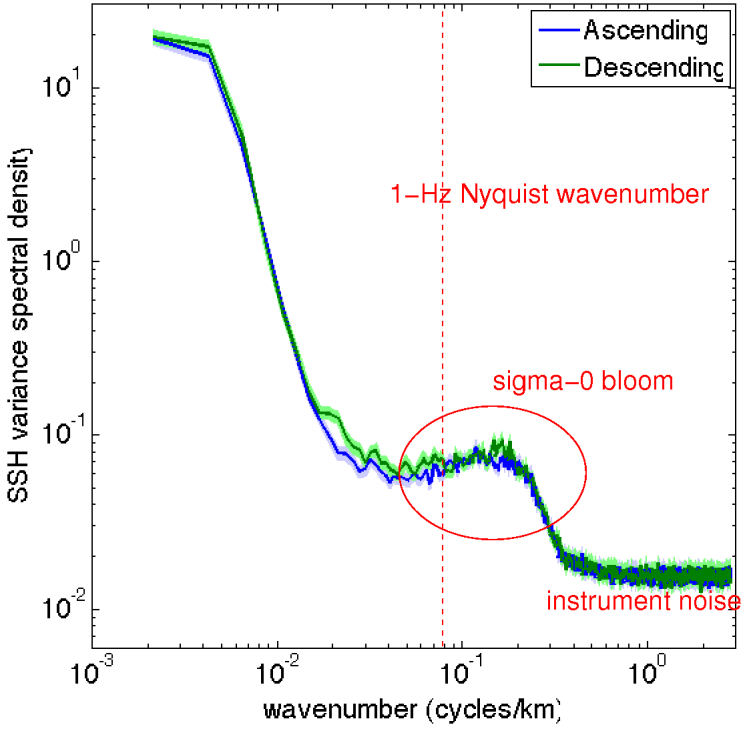
- 15 cycles of AltiKa
- 40 Hz data = 176 m spacing between postings
- Environmental corrections at 1 Hz = 7 km
- Wavenumber spectra computed between 56°S and 60°S

Wavenumber spectra from AltiKa in Drake Passage



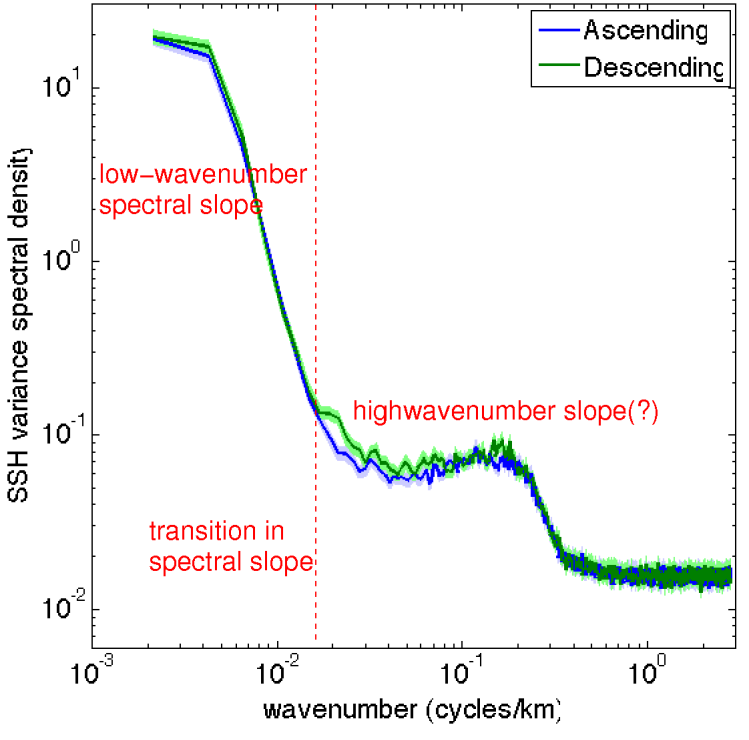
- Note: for geostrophic velocities, sea surface height spectral slopes are 2 units steeper than velocity spectral slopes.

Wavenumber spectra from AltiKa in Drake Passage



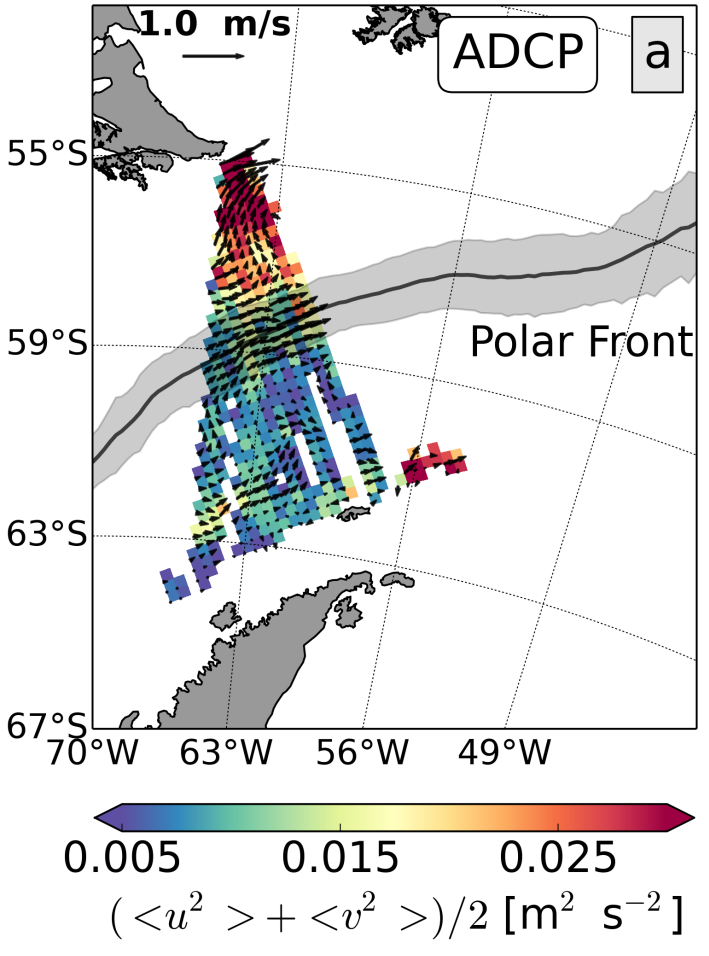
- Spectral bump attributable to sigma-0 blooms.
- Environmental corrections not resolved for scales smaller than 1-Hz Nyquist wavenumber.
- High wavenumbers represent white noise floor for instrument?

Wavenumber spectra from AltiKa in Drake Passage

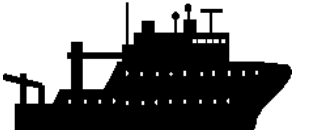


- What is wavenumber slope for scales between 200 km and 50 km? Is this consistent with QG or SQG dynamics?
- Where does the transition in spectral slope occur? Are there changes with depth consistent with SQG?
- When velocities are available, what is ratio of cross-transect to along-transect velocity spectra? Is it equal n for a k^{-n} slope, consistent with divergence free, isotropic flow? (see Bühler et al 2014)
- What happens at higher wavenumber? Are slopes consistent with any theory?

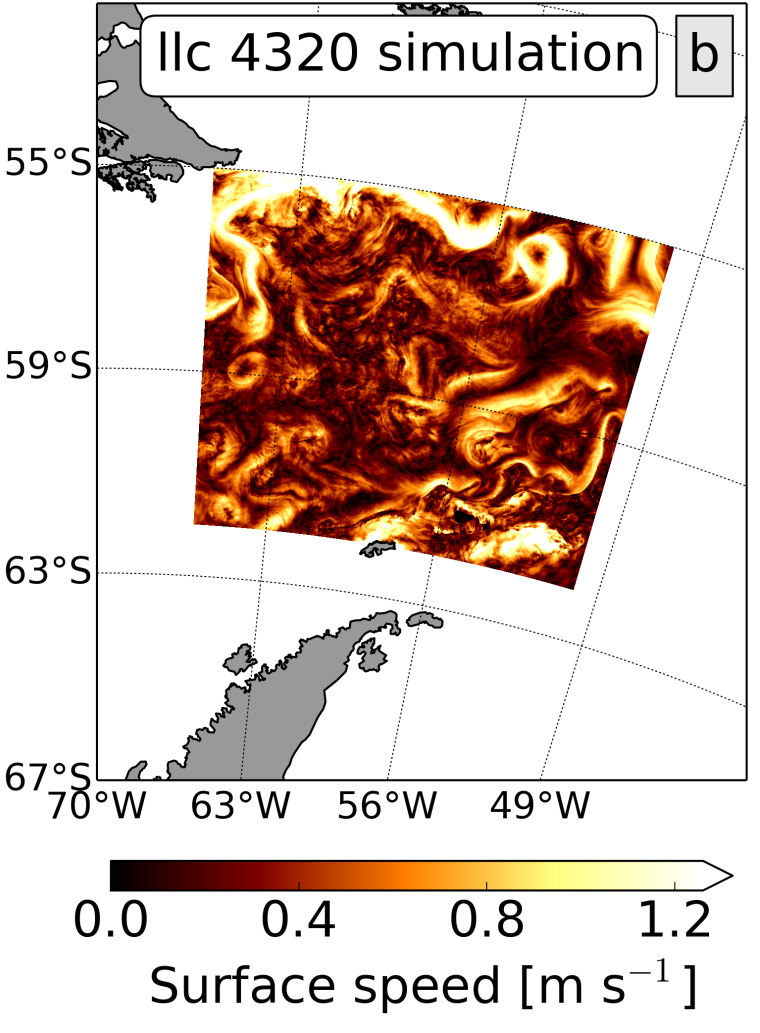
Acoustic Doppler Current Profiler (ADCP) from the Gould



- 20-22 transects annually.
- 2-day crossing.
- ADCP velocity data recorded as 5-minute averages; typically averaged to 5 or 10 km
- Vertical range:
  - — 300 m since 1999
  - — 1000 m since 2004, with OS38.
- Also includes thermosalinograph (TSG) with 5 m temperatures.

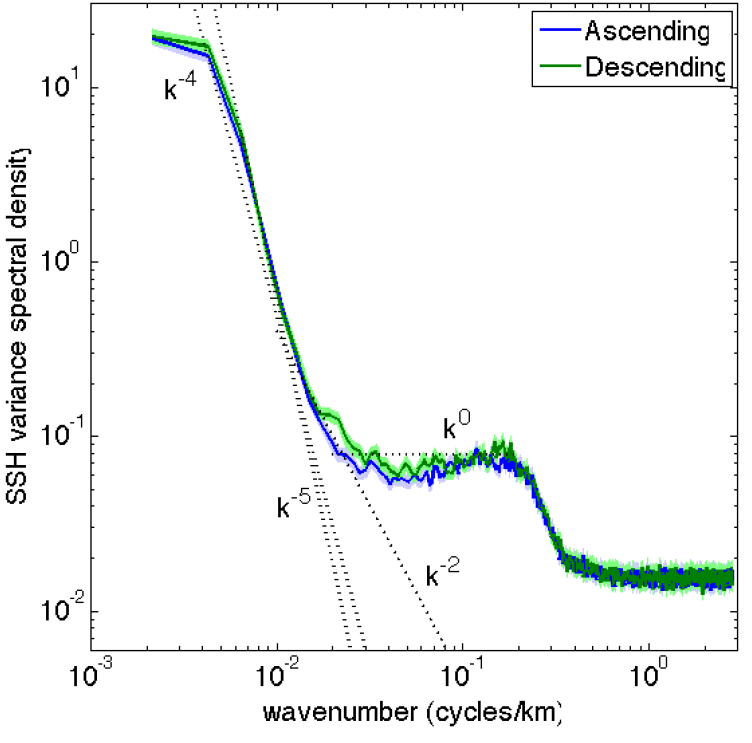


MITgcm at 1 km grid spacing



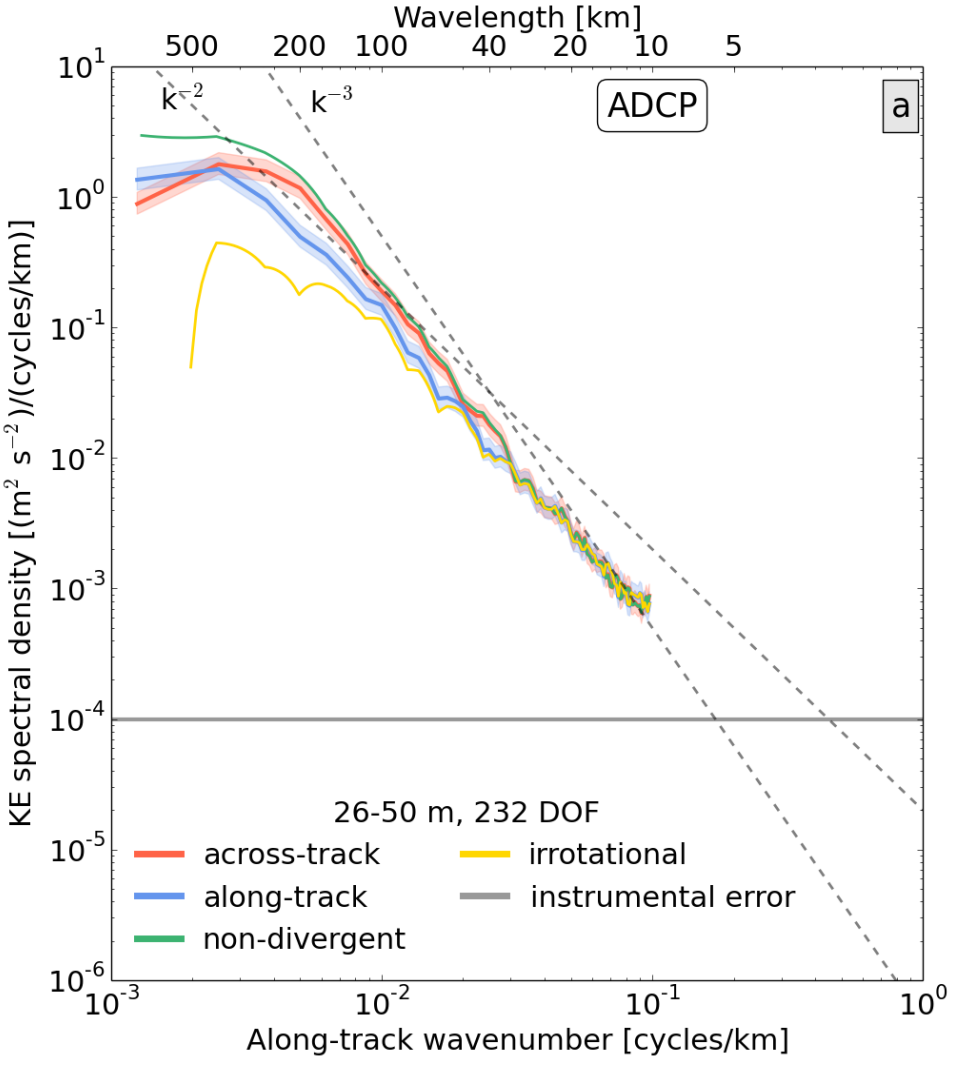
- Global model.
- 85-day simulation.
- Spun up from 1/24° model, which was spun up from 1/12° model.
- Includes tides and internal waves.

Wavenumber spectra from AltiKa in Drake Passage



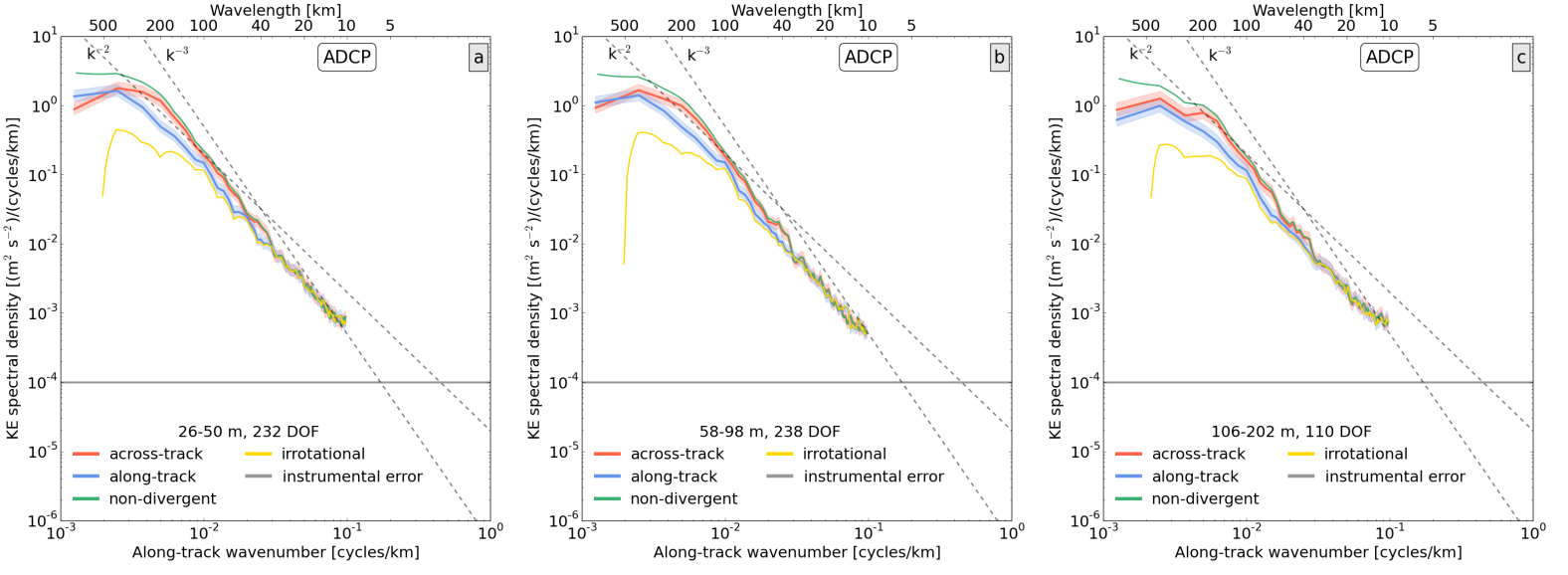
- Spectral slopes betwen k^{-4} and k^{-5} for sea surface height in 200 to 50 km band.
- Spectral slope drops to k^{-2} between 50 and 30 km.

Velocity spectra from ADCP: 26-50 m depth



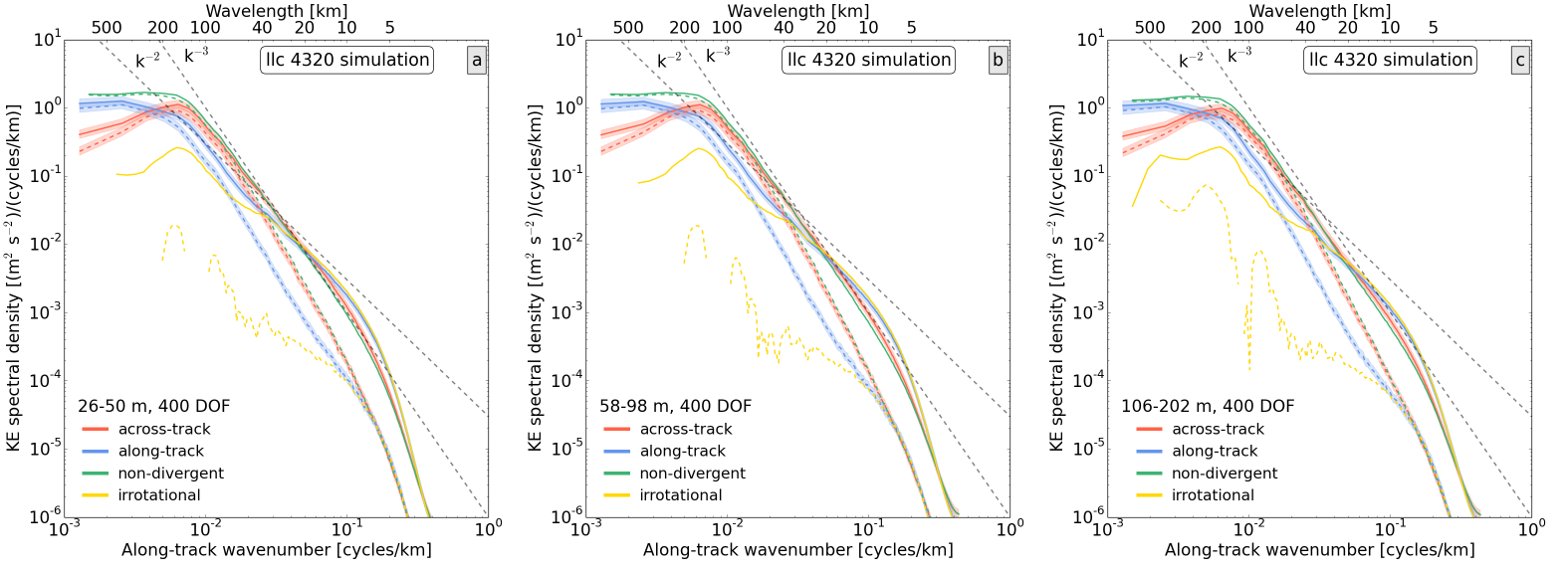
- Spectral slopes from ADCP between k^{-2} and k^{-3}.
- Ratio between cross track and along track velocities: $\sim$1.5—less than 3, implies anisotropic or ageostrophic motions.
- For low wavenumbers, similar results inferred in Gulf Stream (Callies and Ferrari, 2013; Wang et al, 2010)

Velocity spectra from ADCP: no variations with depth



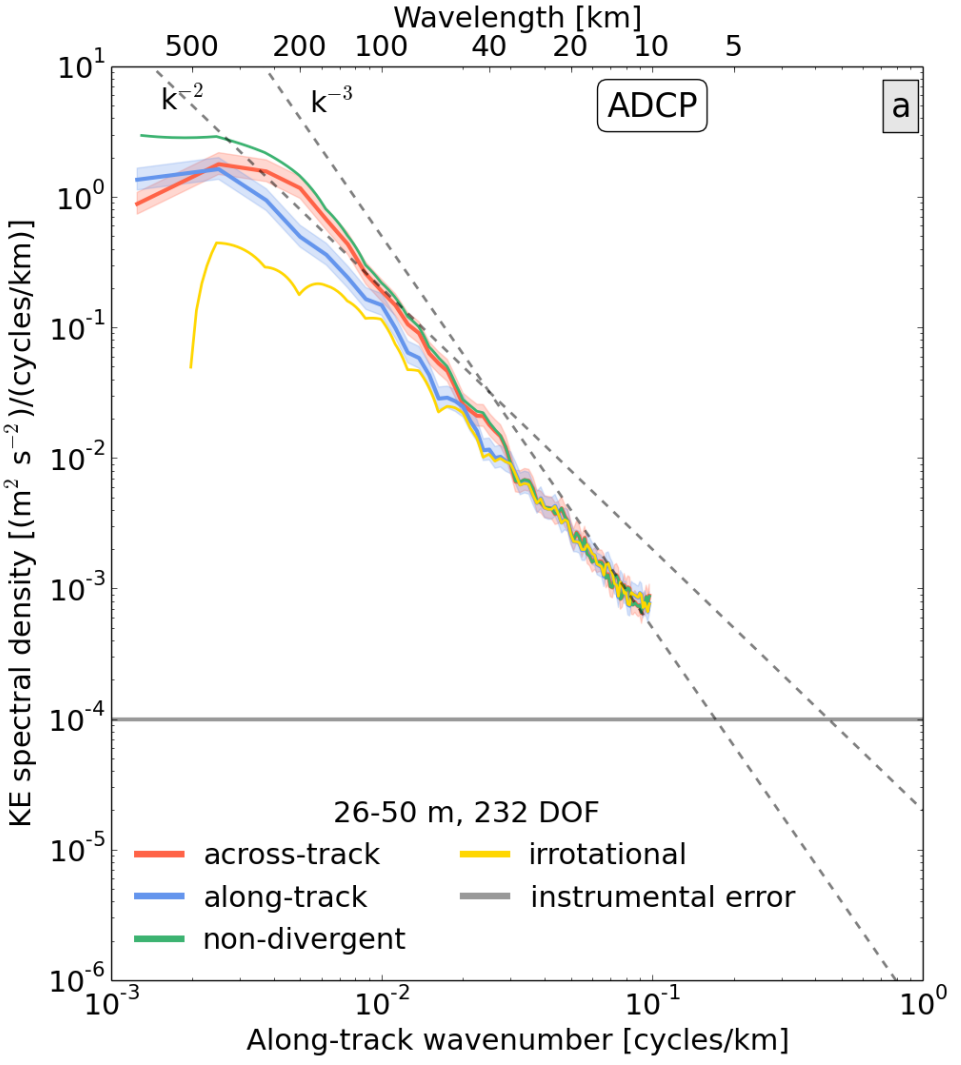
- Low wavenumber spectral slopes (200 km to 40 km scales) do not vary with depth, nor do ratios of cross-track to along-track spectra.
- Consistent with QG but not SQG.

Model spectra consistent with ADCP spectra



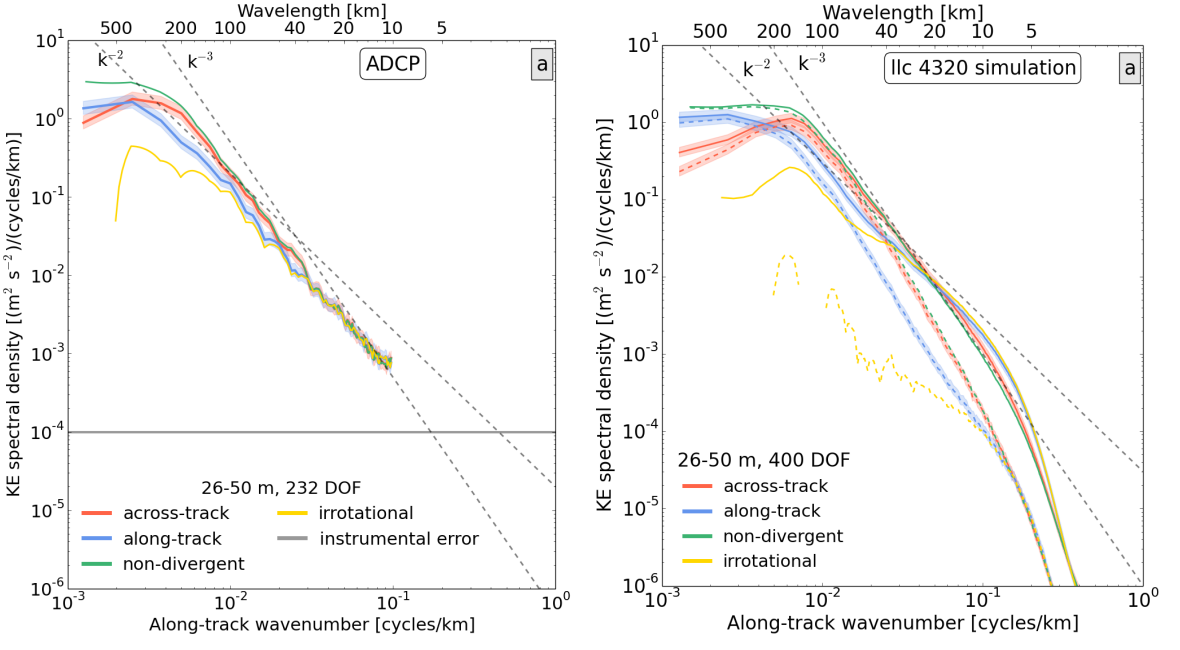
- Low wavenumber spectral slopes (200 km to 40 km scales, solid blue and red lines) do not vary with depth.
- Spectral slopes and ratios resemble ADCP data.
- High wavenumber spectral drop off (scales smaller than $\sim$5 km) attributed to grid-scale diffusive processes.

Velocity spectra from ADCP: higher wavenumbers



- For scales smaller than 40 km, spectra flatten slightly, cross-track and along-track spectra converge.
- These traits are consistent with horizontally divergent motions.
- Helmholtz decomposition splits into horizontally non-divergent and irrotational parts: non-divergent dominates for large scales, but not for small scales.

High wavenumbers: ADCP and model



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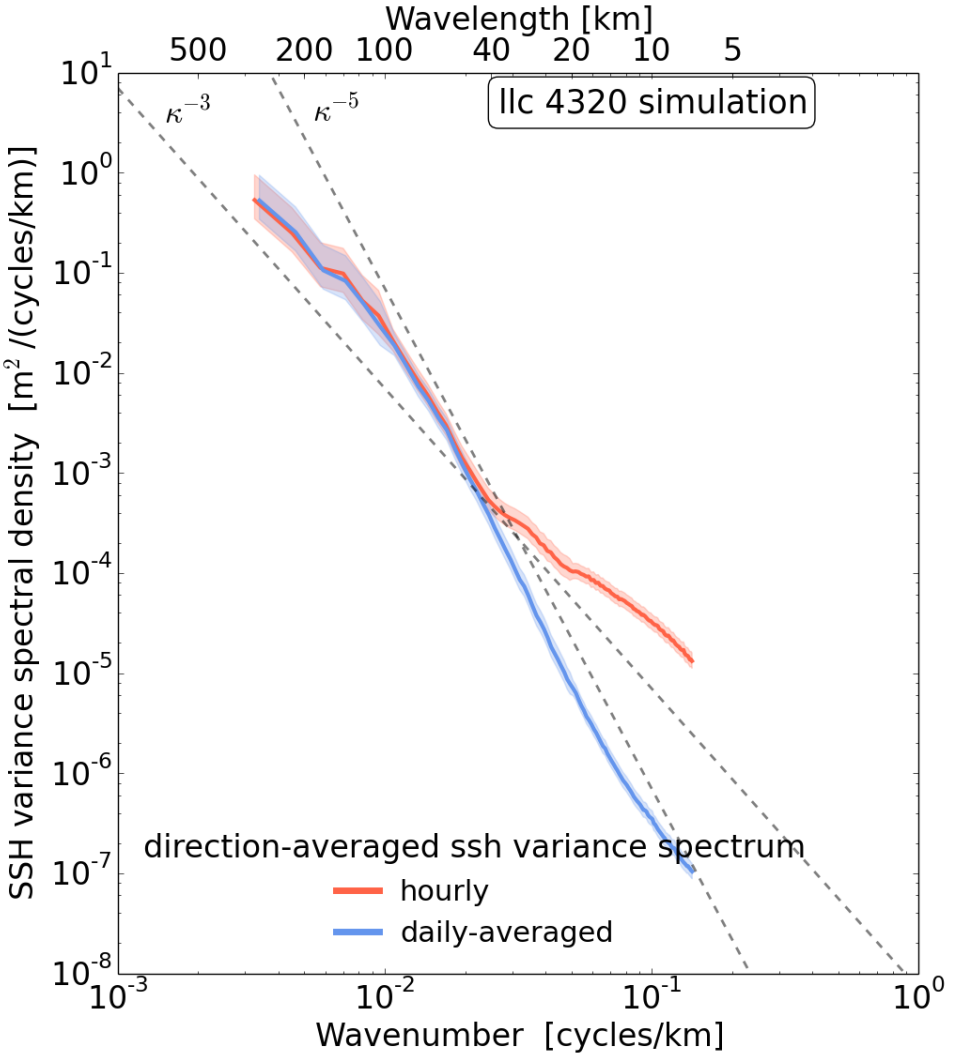
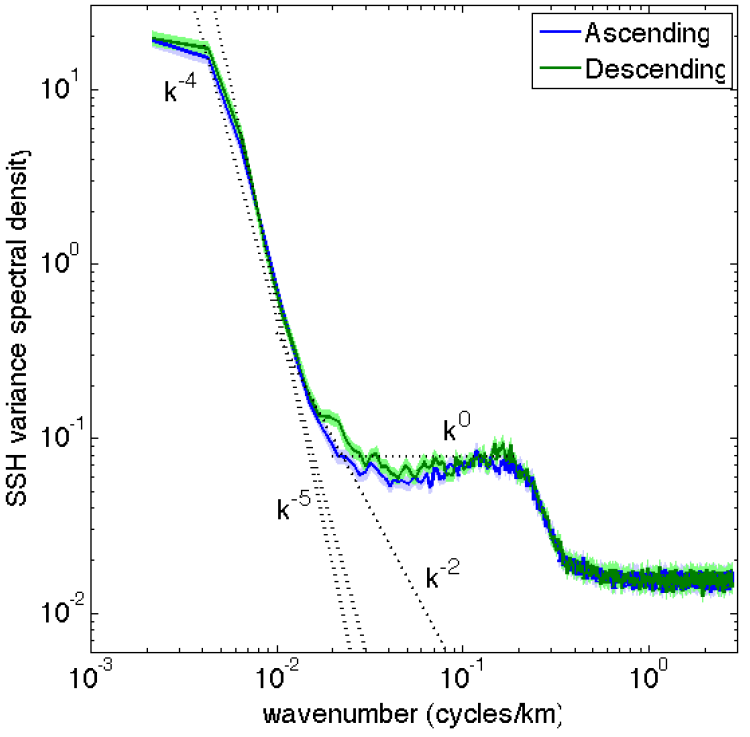
- For scales smaller than 40 km, model and ADCP both show irrotational motions (yellow) to be significant.
- In model, averaging to daily means (dashed lines) suppresses much of high-wavenumber variability.

Sea surface height spectra from model



- Sea surface height spectrum from model resembles AltiKa spectrum.
- Spectral flattening for scales shorter than 40 km suppressed by daily averaging—essentially suppressing tides and internal waves.

Summary



- For scales larger than 40-70 km, spectra are consistent with quasi-geostrophy (k^{-3} for velocity, k^{-5} for sea surface height).
- Neither ADCP nor model indicates variability with depth—no clear signature for surface quasi-geostrophy.
- For smaller scales, spectra flatten slightly, and velocity components converge. Appears to be consistent with divergent, irrotational motions associated with tides and internal waves.
- *Numerous details and caveats.* See Rocha et al, On the horizontal wavenumber spectra in Drake Passage: The 10-200 km range, in prep for JPO, 2014