On temporal variability of low-mode internal tides in the deep ocean

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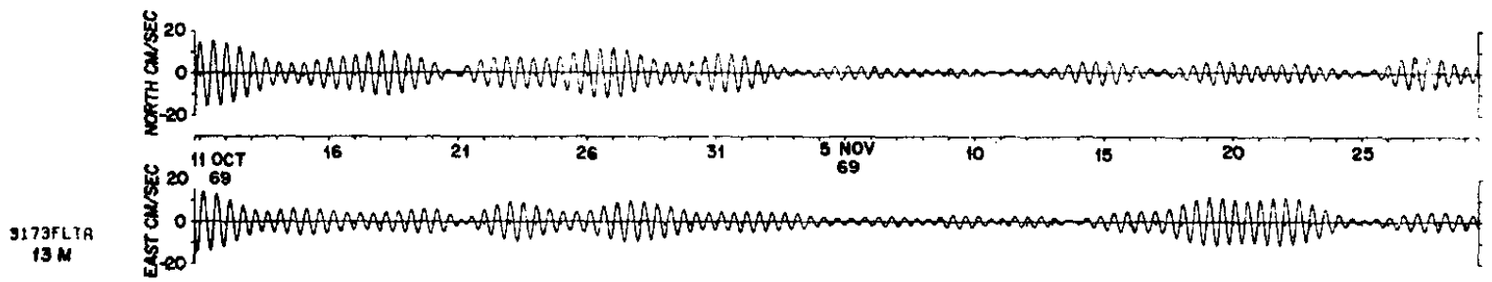
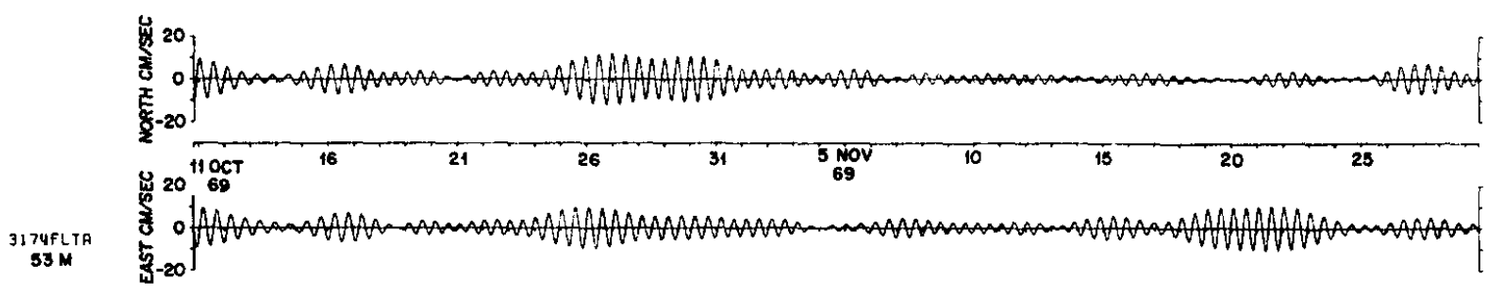
Altimetry for Oceans & Hydrology **Oct. 2010**

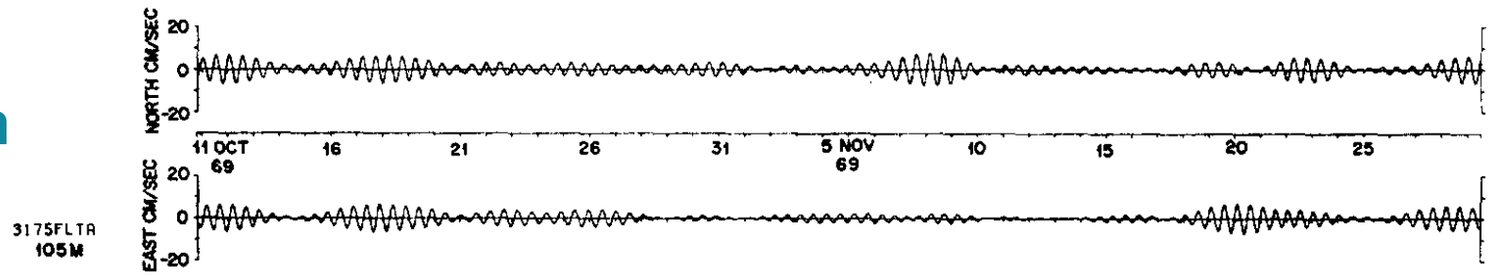
13 m



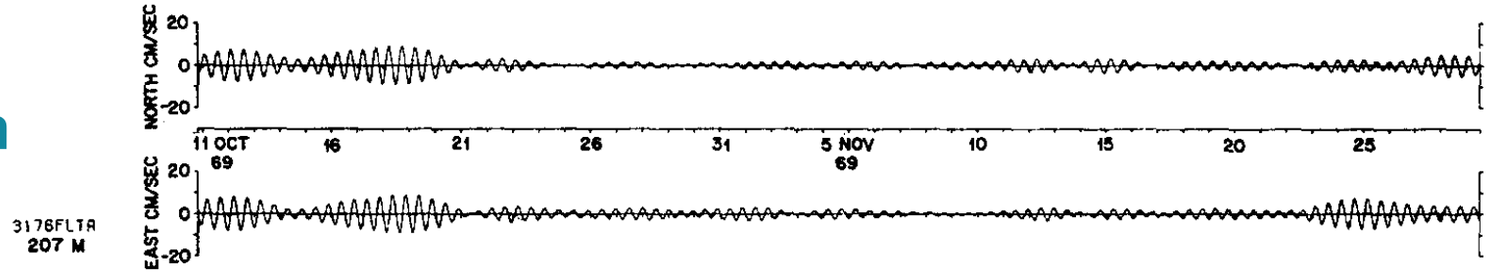
53 m



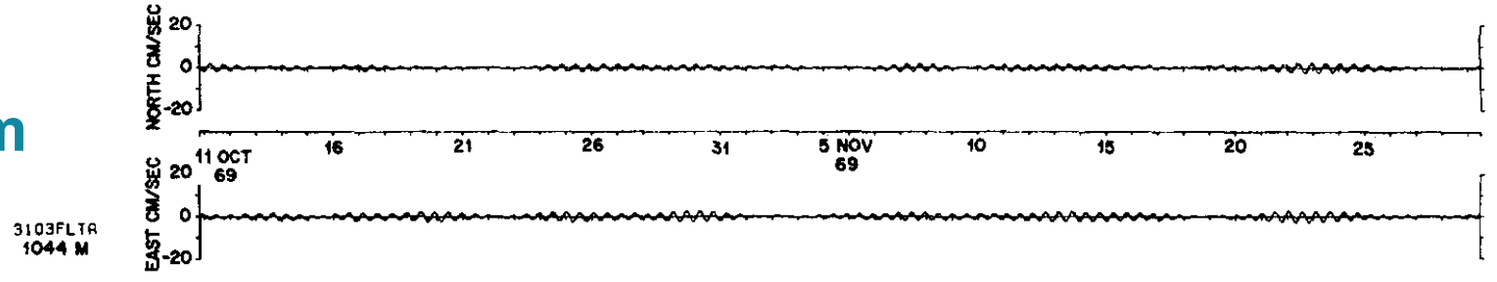
105 m



207 m



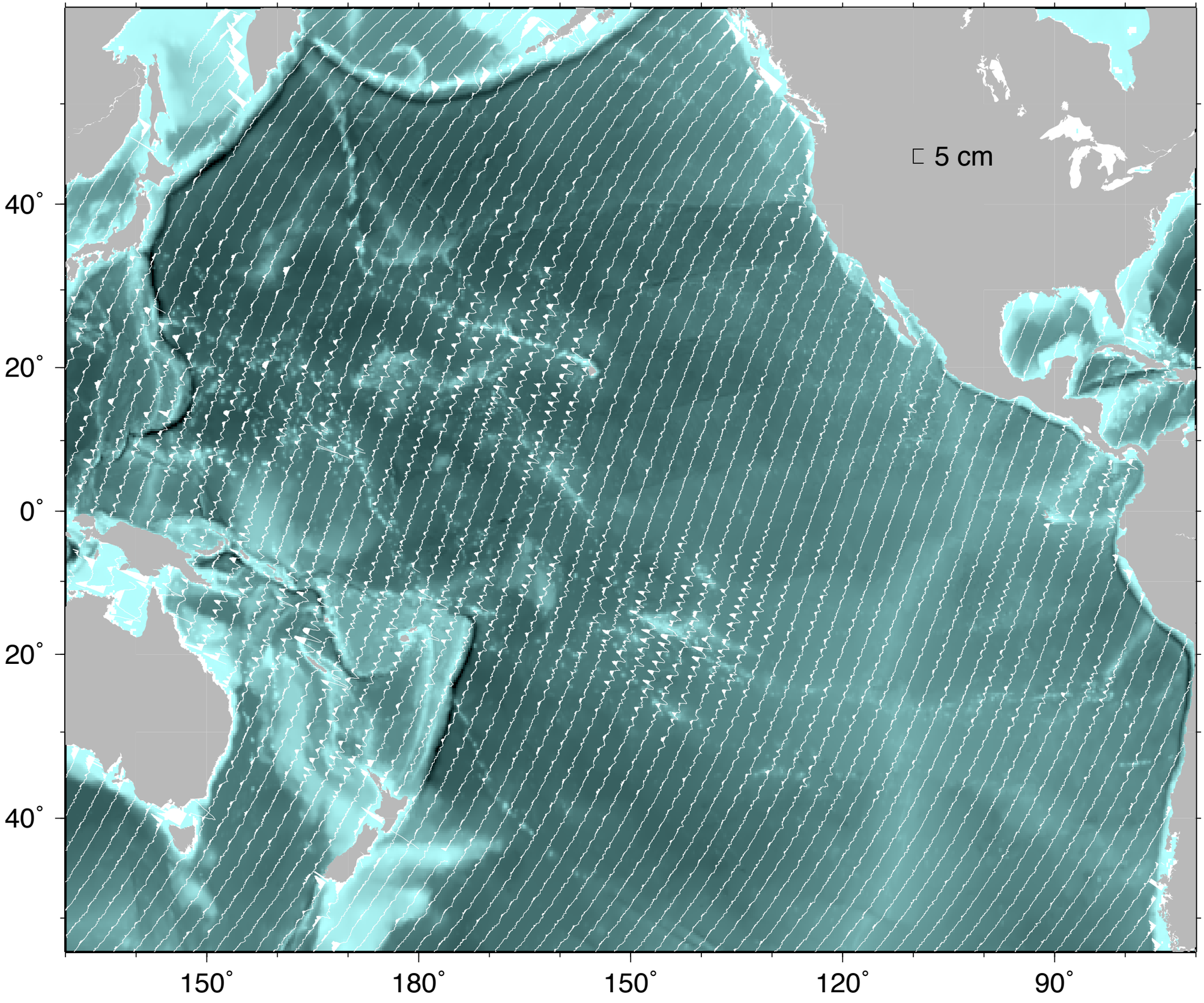
1044 m



Magaard & McKee *Deep-Sea Res.*, 1973.

"No phase-locking was found between barotropic & baroclinic tide."

Altimetric M2 Internal Tide Signals: PacificOcean



Note: Not every “wiggle” is an internal tide!

Outline

→ **INTRODUCTION:**

Contrasting pictures of internal tides: in situ versus satellite altimetry

Is the altimeter picture misleading?
Is there a significant incoherent signal being missed in our altimeter processing?

→ **APPROACH:**

Search for temporal changes in altimetry by partitioning data.

Wavenumber-domain analyses with and without IT "corrections."

→ **INTERESTING EXAMPLES:**

South China Sea

Hawaiian Ridge

Hint: Altimetry detects mostly first mode, not higher modes

This is expected on theoretical grounds.

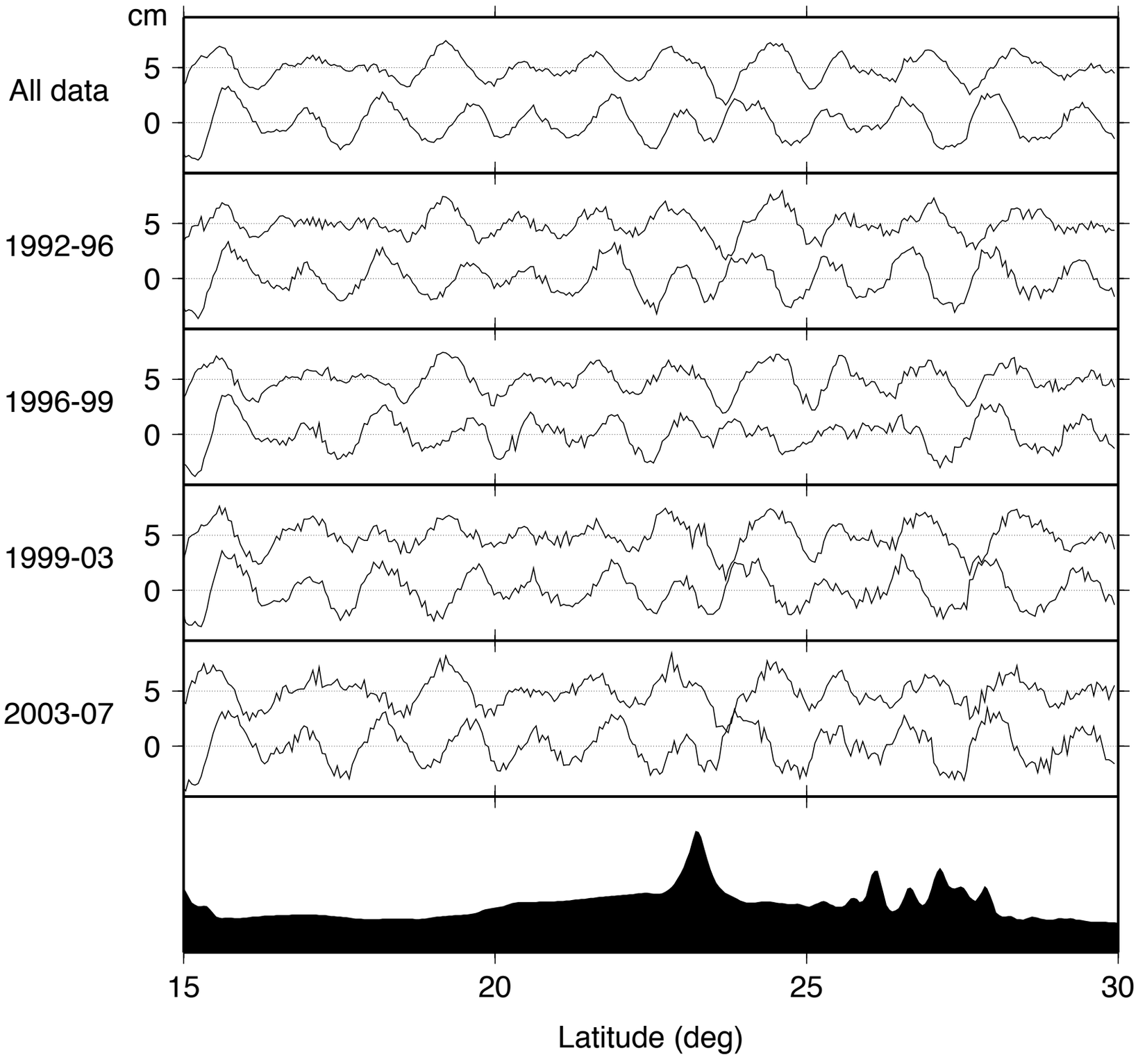
A possible clue to reconciling these different pictures?

Can we detect temporal changes in altimetric internal-tide signals?

- 17 years of T/P-Jason altimeter data
  - Partition data in various way (years, seasons, etc.)
  - Ensure sampling can avoid aliasing problems
    - Each partition ≥ 3 years).
    - Can't look for spring/neap differences
- Estimate tides for each data subset
- High-pass filter to isolate internal tides
- Compare

Major limitation: we'll still detect only 'coherent' temporal changes.

M2 Internal Tide Signals (Hawaiian Ridge)



<– quadrature component

<– in-phase component

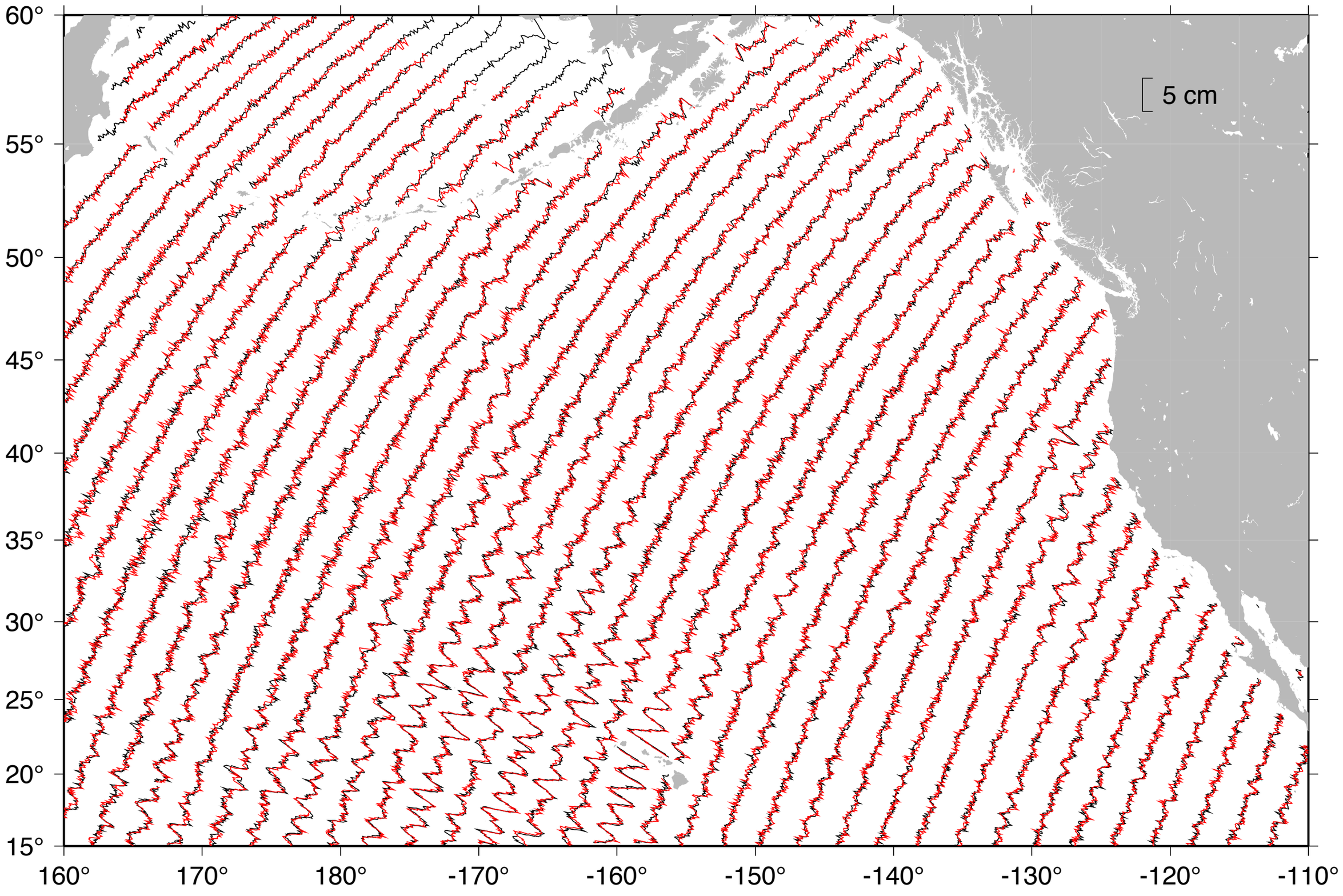
Variances

Signal:	**1.72 cm²**
Differences:	**0.22 cm²**
	0.39 cm²
	0.23 cm²
	0.30 cm²

About half the differences is estimation noise, not tidal.

Mean error bar (before high-pass filtering) for “All” = 0.61 cm; for subsets = 1.27 cm

Altimetric Internal Tide Signals by Season: Winter vs Summer



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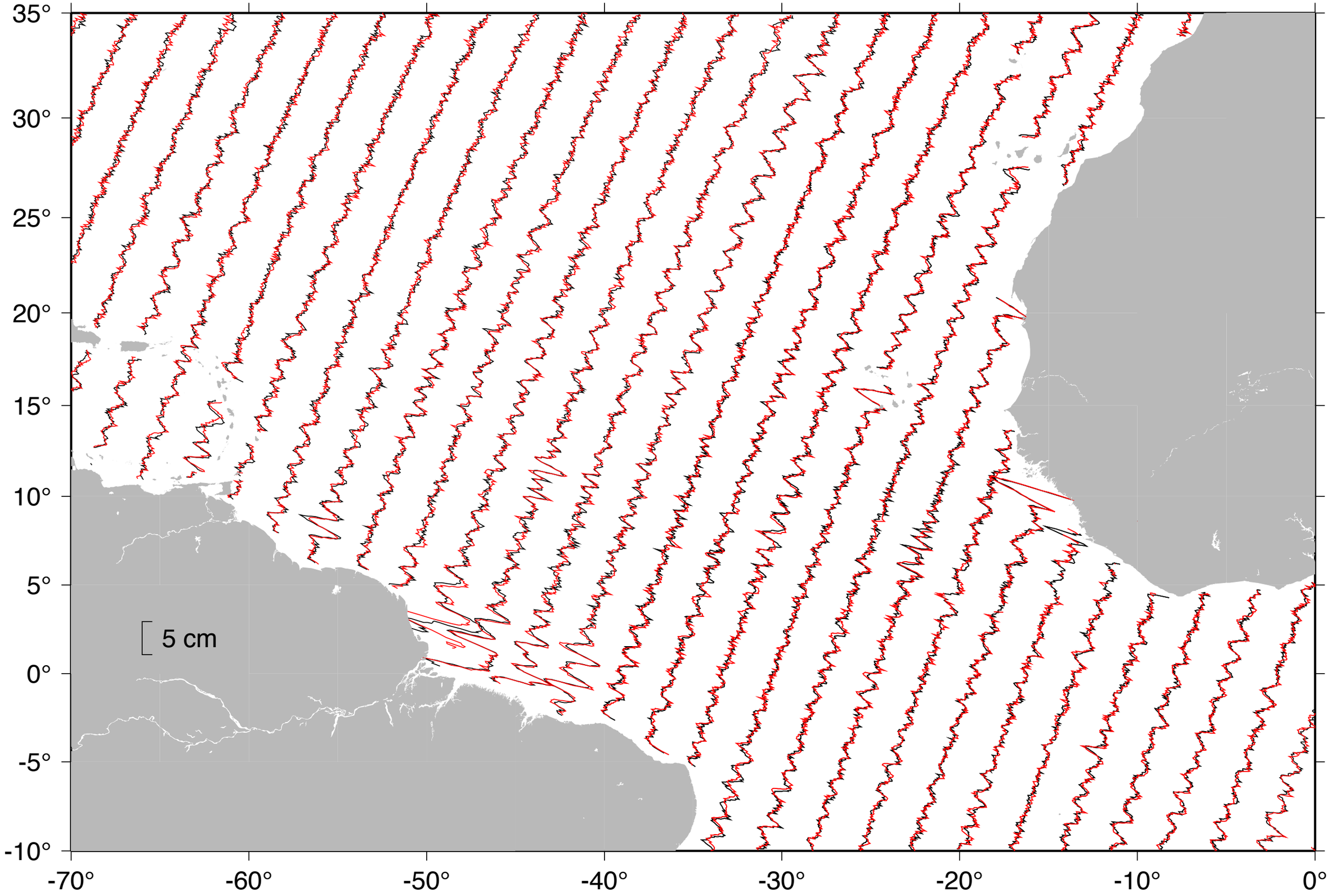

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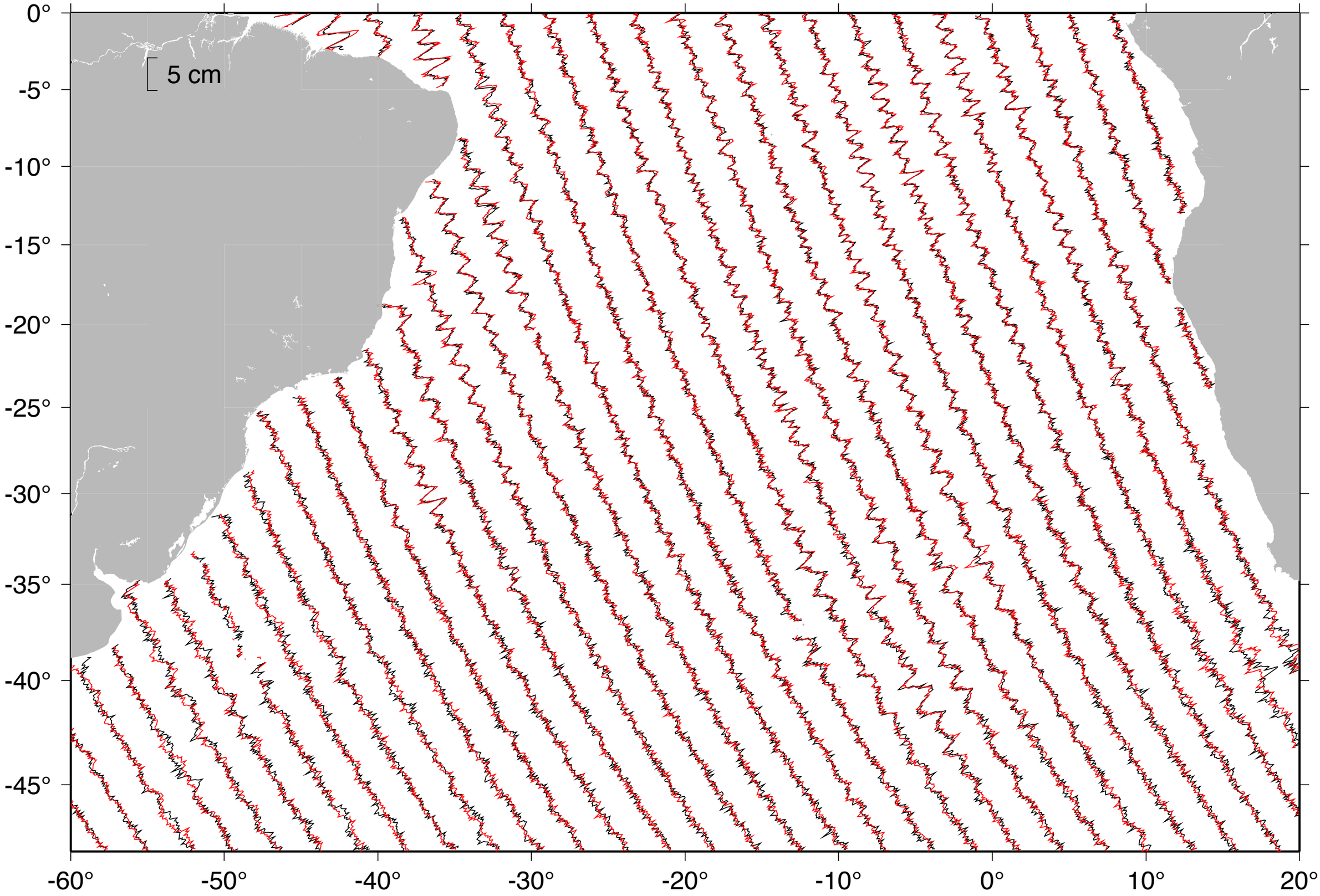

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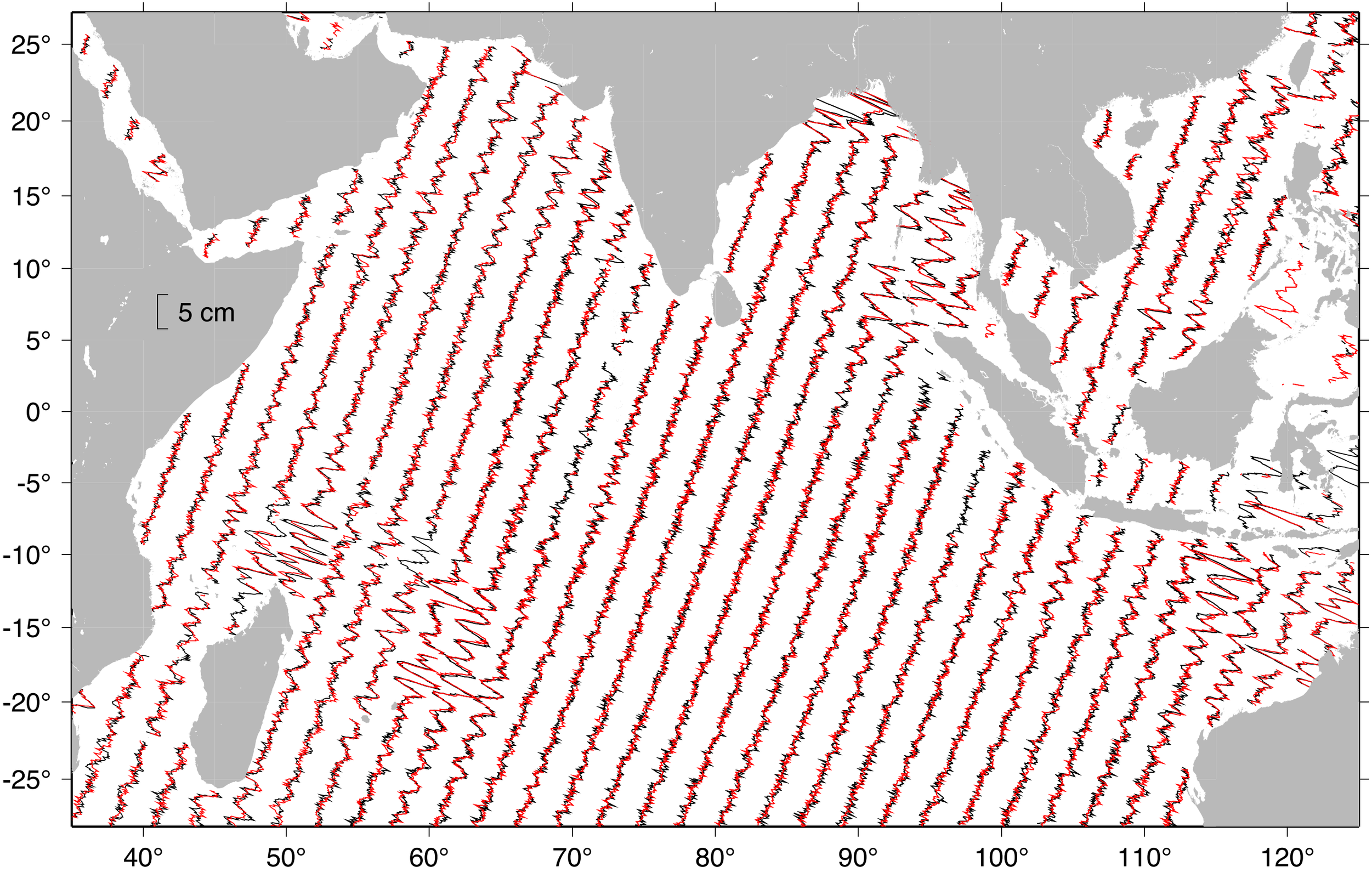

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Spectral Analysis of Along-Track Sea-Surface Heights

Compute along-track SSH spectrum from ~600 repeat cycles, after removing barotropic tides via a good model.

Fu, L., On the wavenumber spectrum of oceanic mesoscale variability observed by the Seasat altimeter, JGR 88, 4331, 1983.

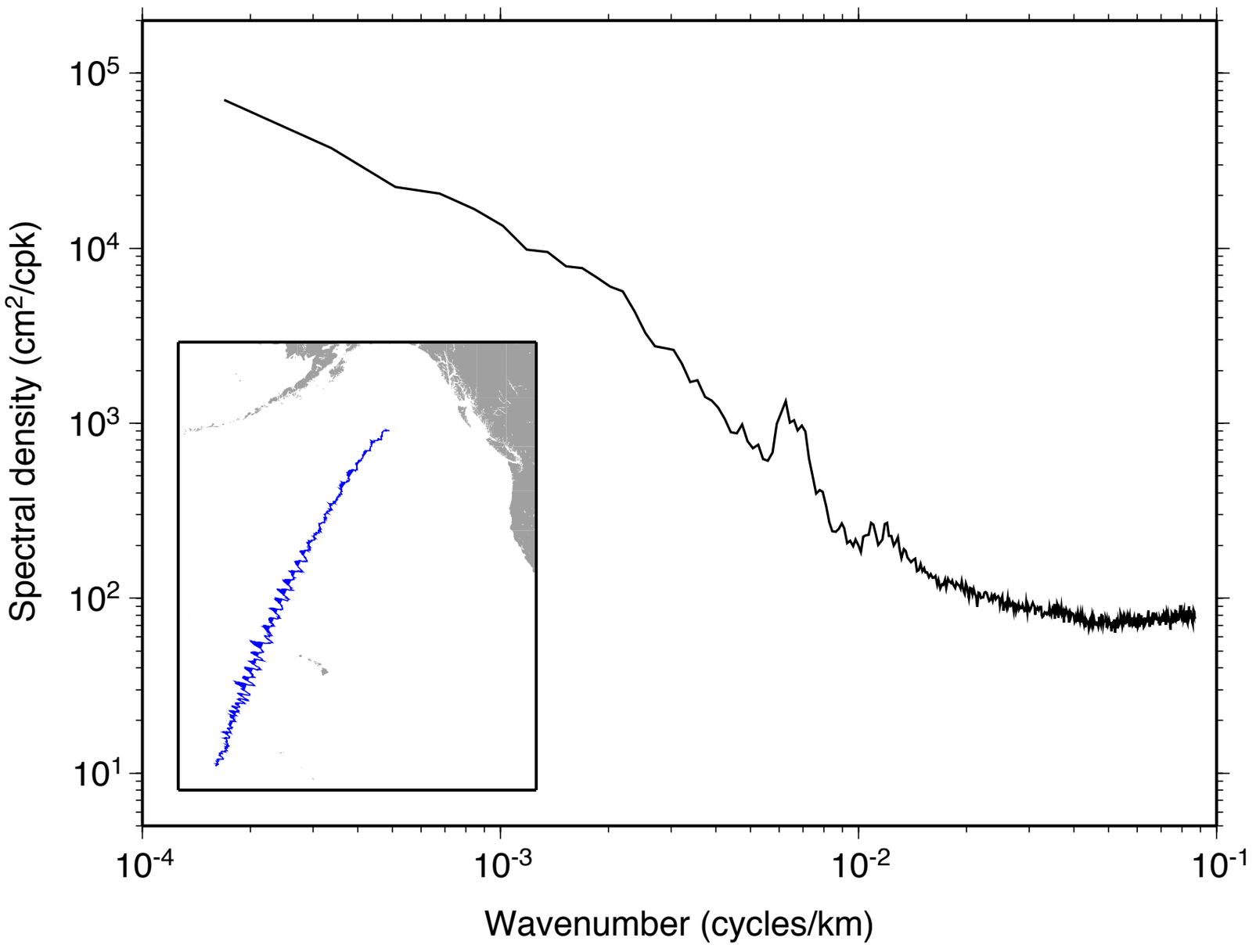
Le Traon, P.-Y. et al., Spatial scales of mesoscale variability in the North Atlantic as deduced from Geosat data, JGR 95, 20267, 1990.

Stammer, D., Global characteristics of oceanic variability estimated from regional Topex/Poseidon altimeter measurements, JPO 27, 1743, 1997.

Compute 2nd spectrum after also estimating and removing along-track tides.

This will remove non-tidal signals only if they remain coherent with the tidal potential over 17 years.

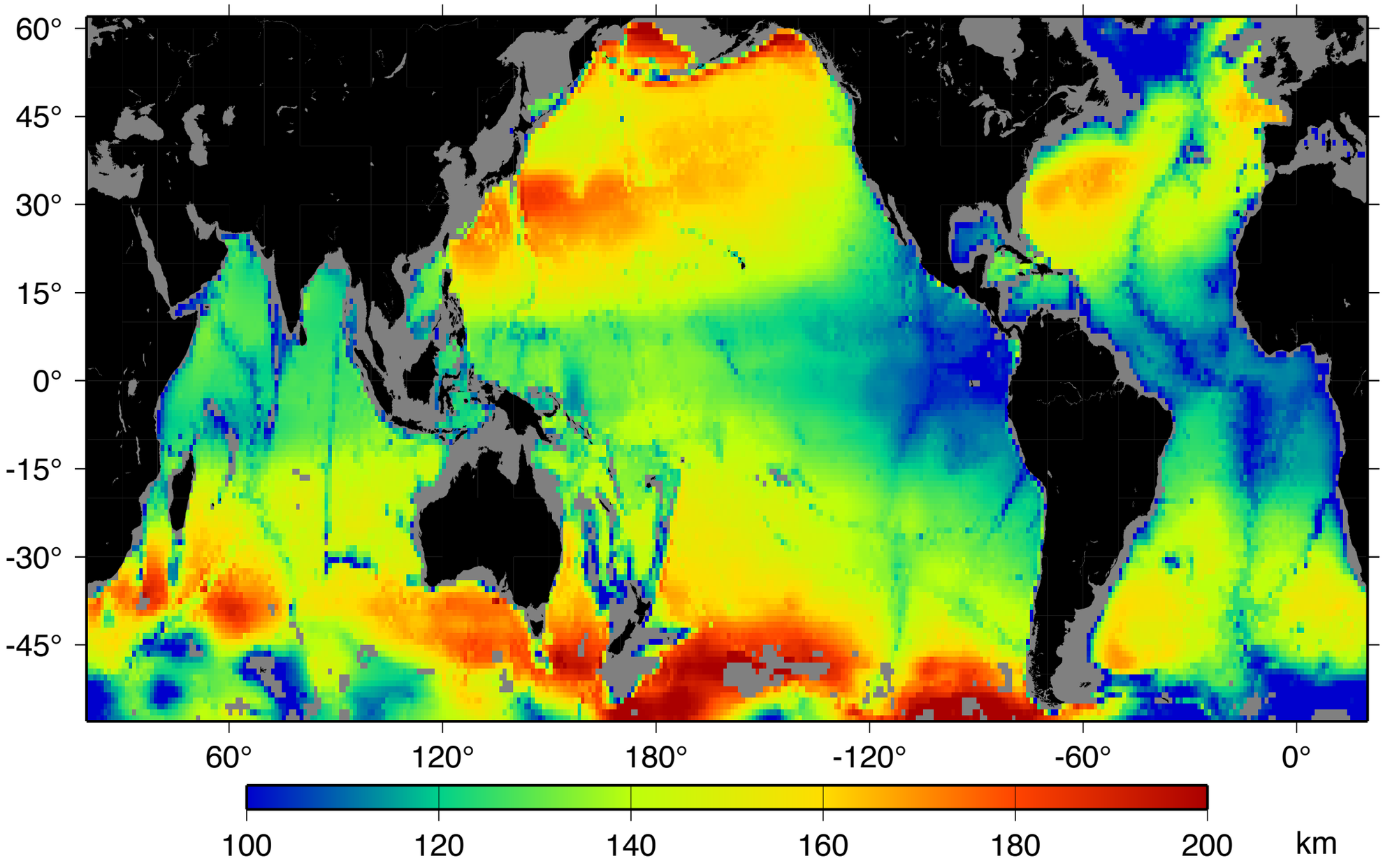
Wavenumber Spectrum of Altimetric Sea-Surface Heights



Observed tidal peaks are:

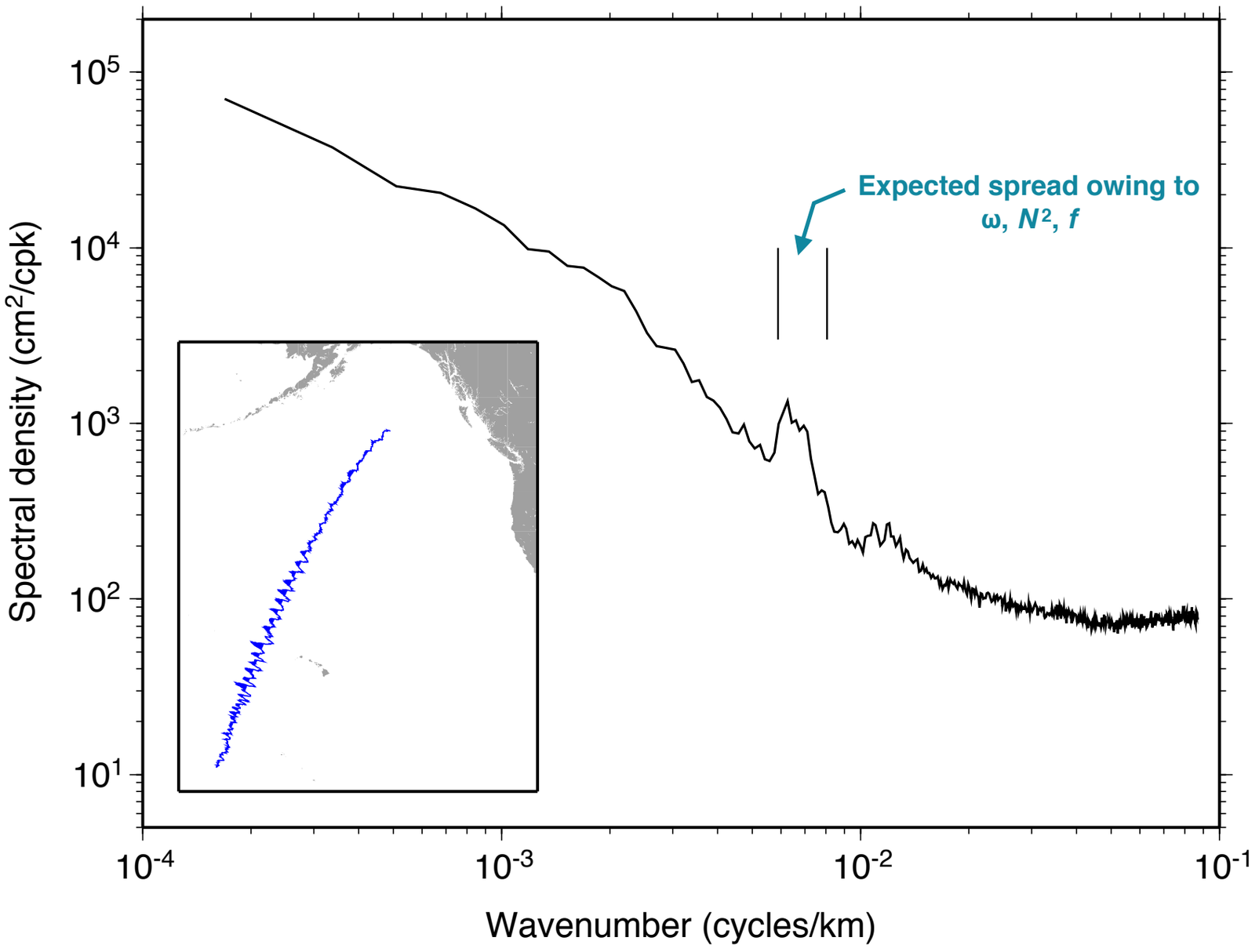
- **Better resolved by long arcs** (long arcs good)
- **Broadened by changes in N^2, f along track** (long arcs bad)
- **Shifted if k not ∥ to track** (long arcs maybe better)
- **Broadened by changes in k along track** (long arcs bad)

WAVELENGTH OF M_2 FIRST BAROCLINIC MODE



Based on mode-1 phase velocities from Chelton et al (JPO, 1998).

Wavenumber Spectrum of Altimetric Sea-Surface Heights



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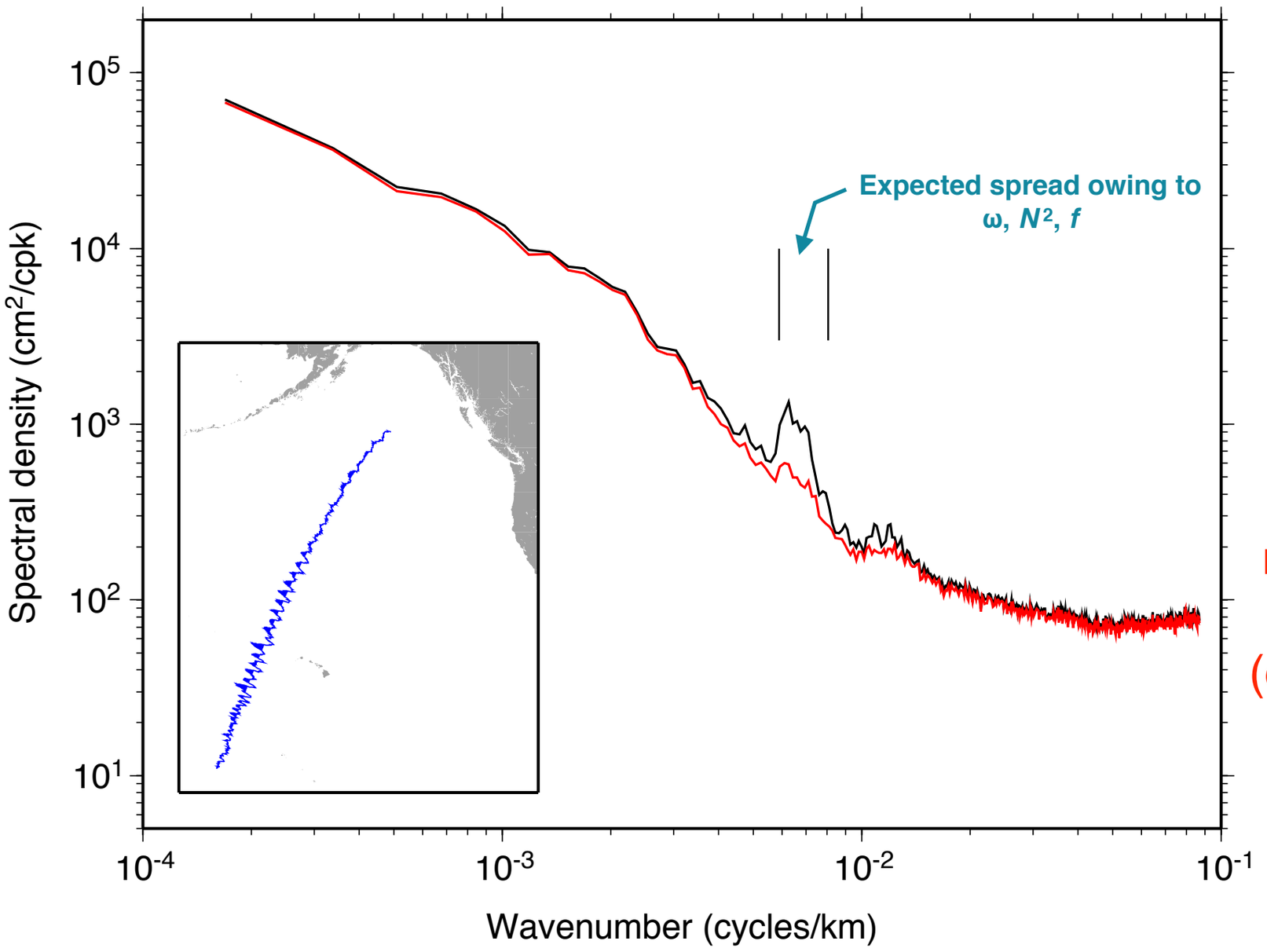
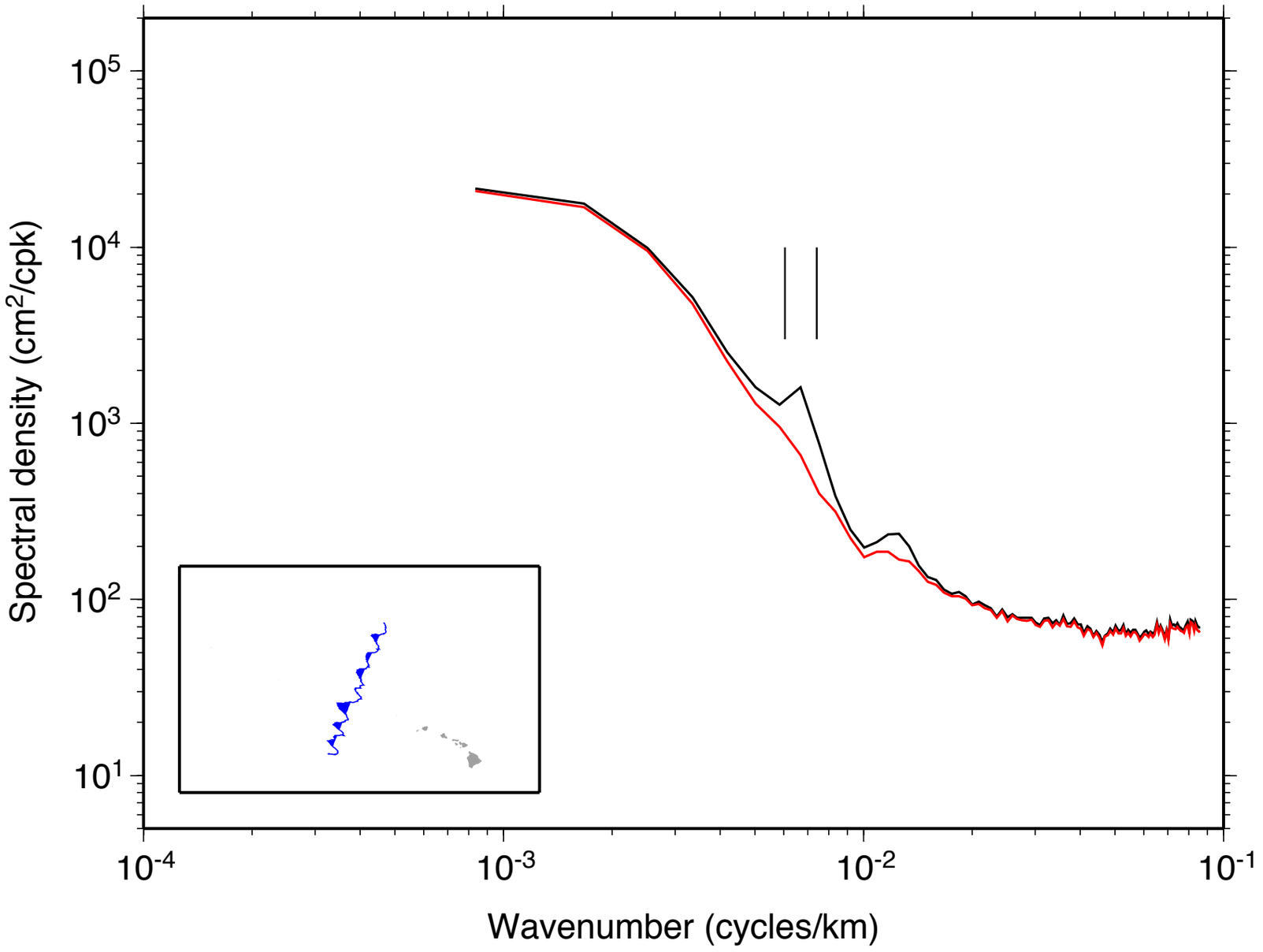


Red curve: after removing estimated along-track tides (coherent over 17 yr)

Variance in tidal peaks (cm²)		
	Full SSH signal	Residual signal
Mode 1	1.22	0.26
Mode 2+	0.26	0.12

Wavenumber Spectrum of Altimetric Sea-Surface Heights

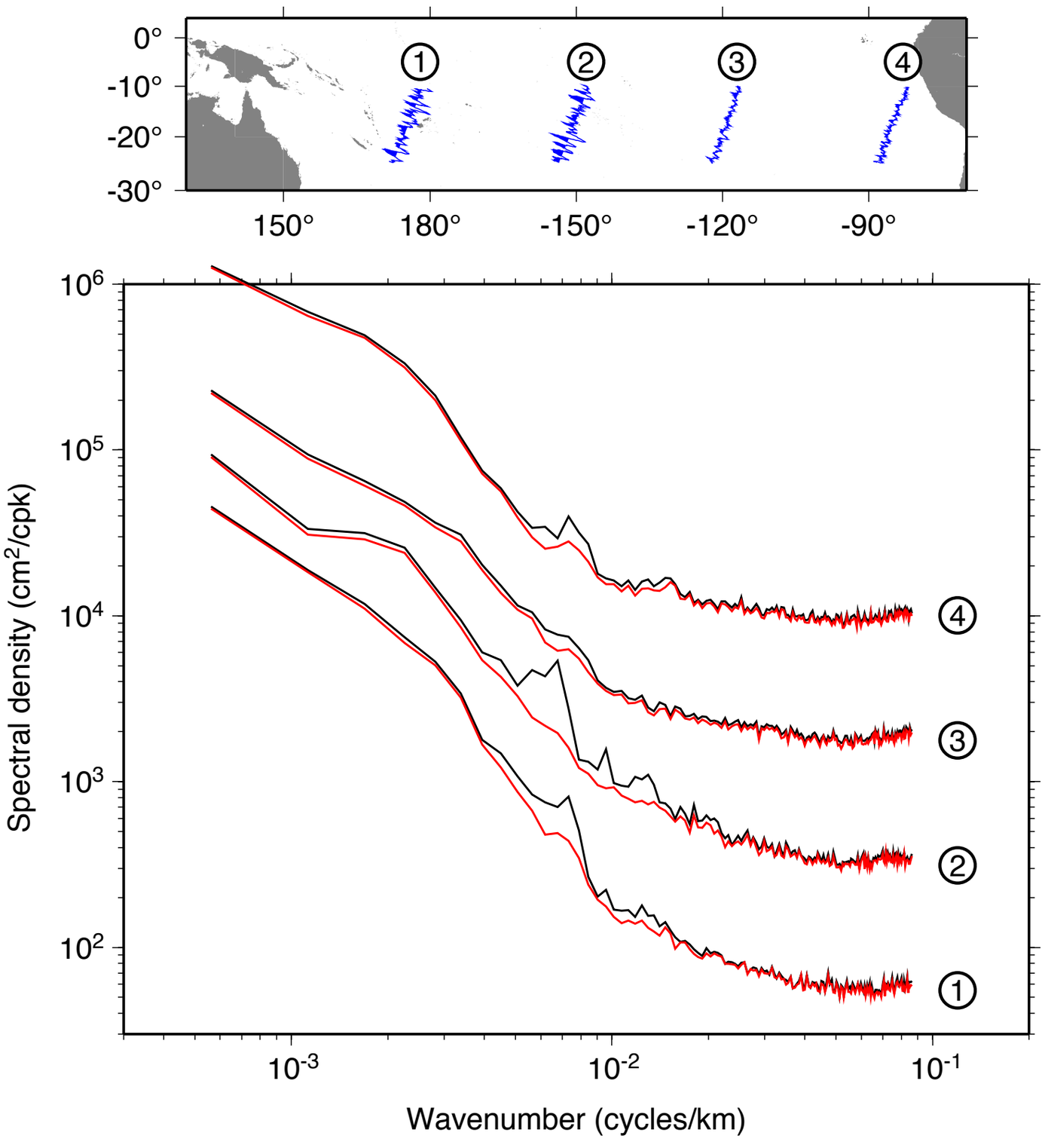


Variance in tidal peaks (cm²)		
	Full SSH signal	Residual signal
Mode 1	1.81	0.15
Mode 2+	0.29	0.10

Previous values on long arc:

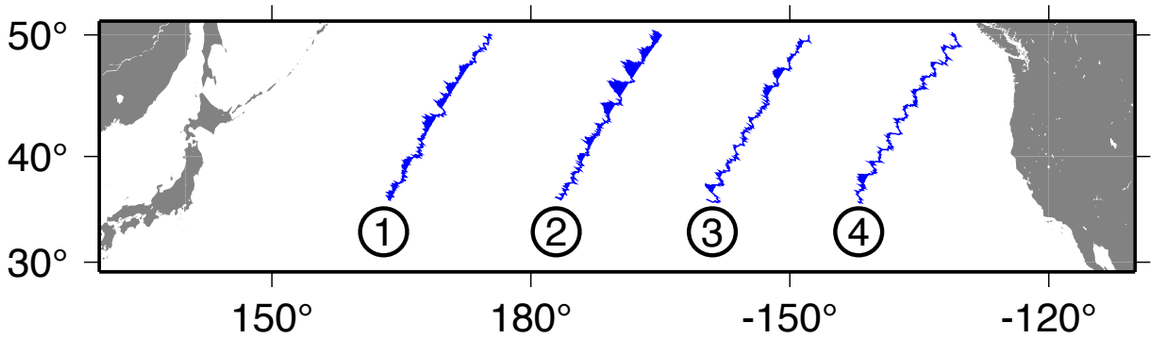
1.22	0.26
0.26	0.12

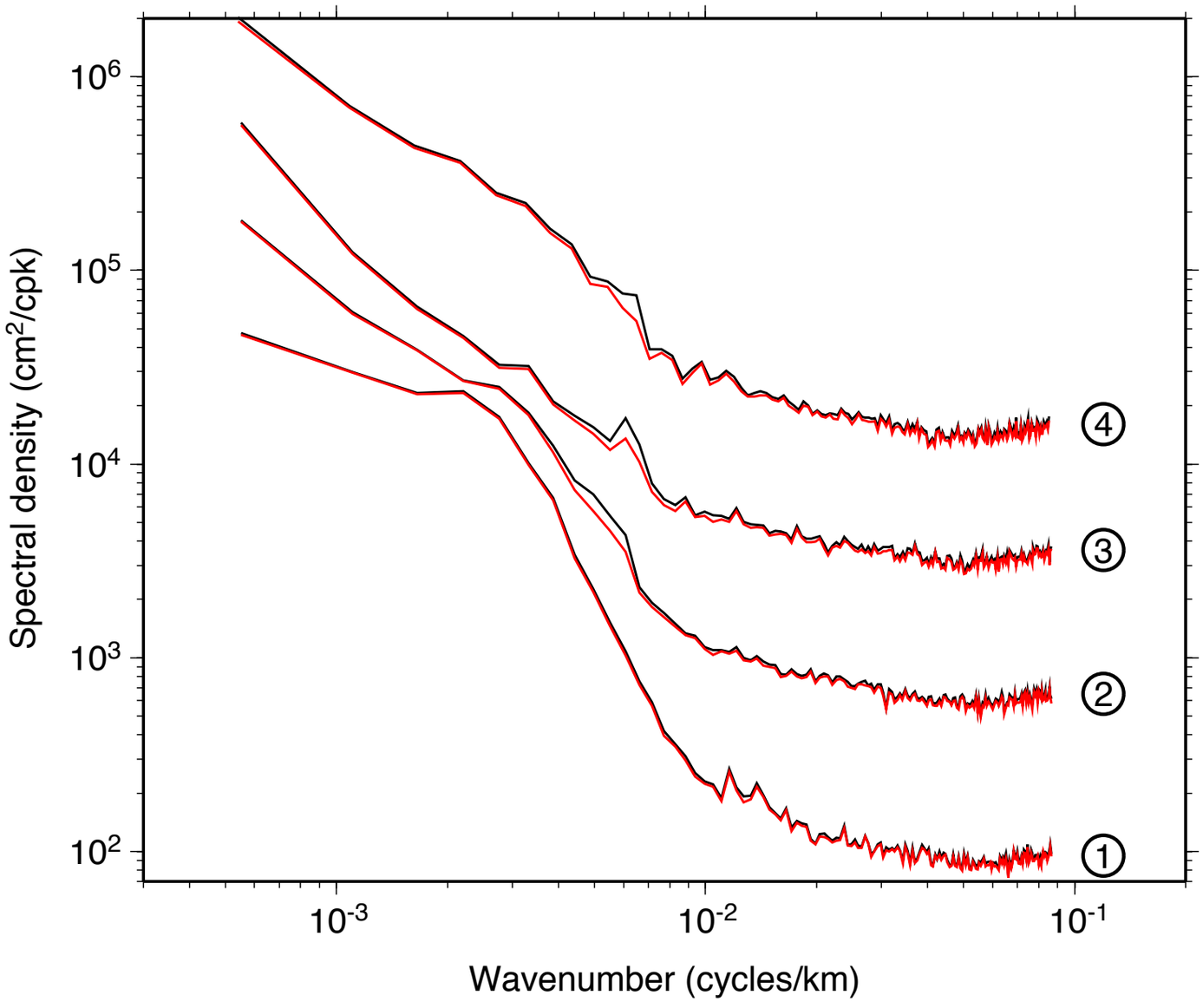
Wavenumber Spectra of Altimetric Sea-Surface Heights



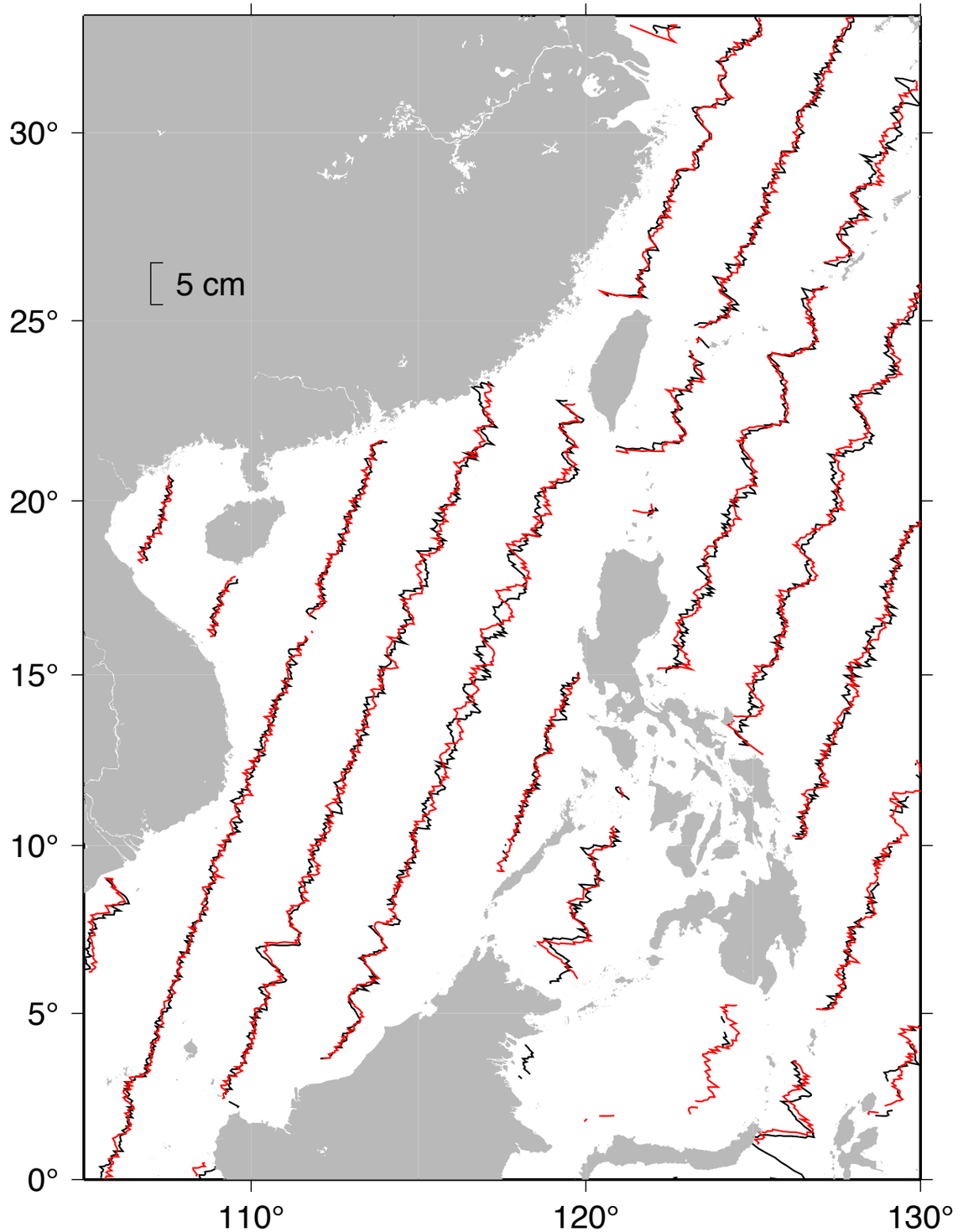
Variance in mode-1 peaks (cm²)		
	Full signal	Residual
Track 4	0.16	0.03
Track 3	0.10	0.02
Track 2	1.10	0.05
Track 1	1.02	0.12

Wavenumber Spectra of Altimetric Sea-Surface Heights

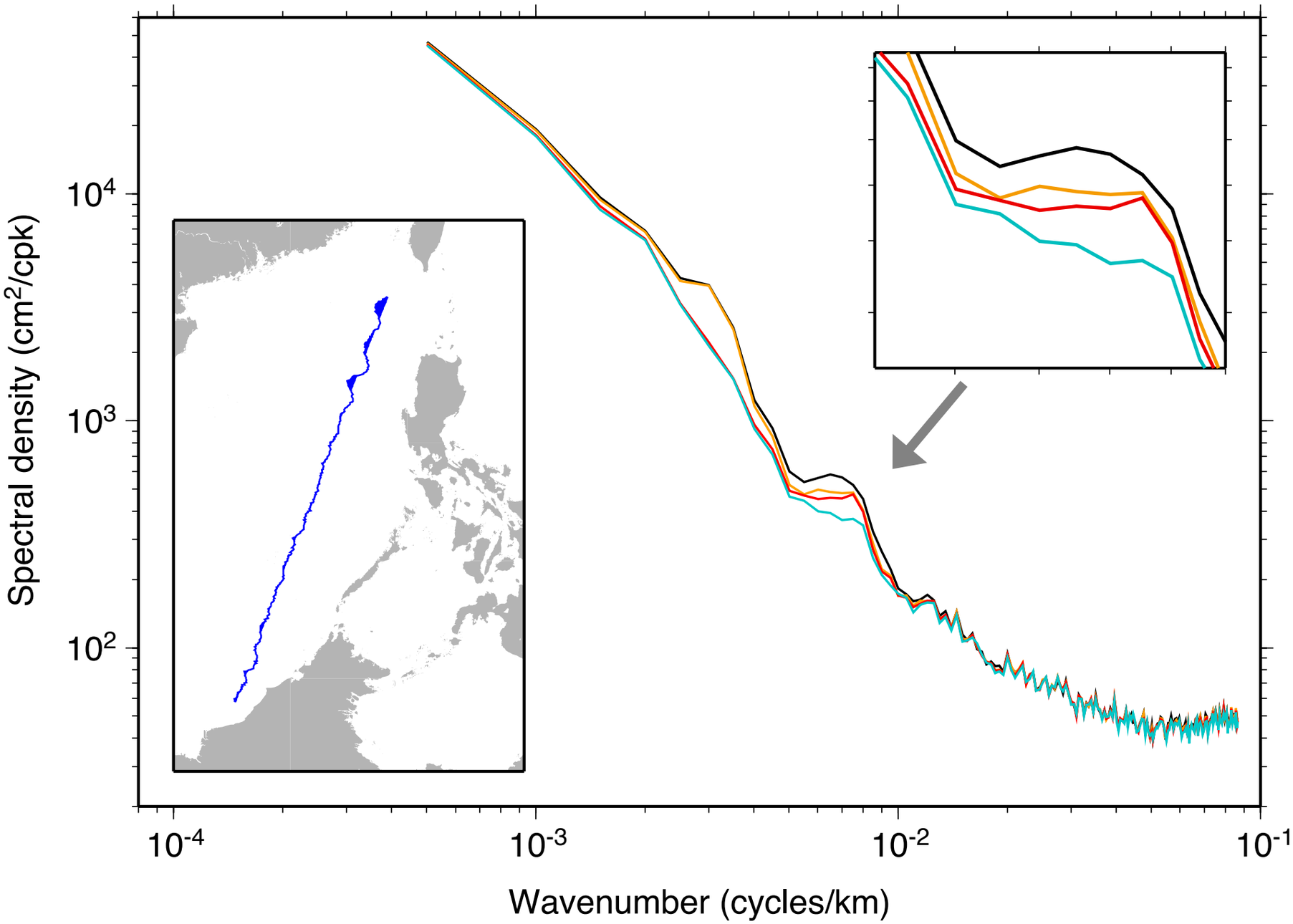




Variance in mode-1 peaks (cm²)		
	Full signal	Residual
Track 4	0.18	0.04
Track 3	0.27	0.12
Track 2	0.32	0.02
Track 1	0.09	0.01


30°
25°
20°
15°
10°
5°
0°
110°
120°
130°
5 cm

Wavenumber Spectra of Altimetric Sea-Surface Heights



Black curve: Barotropic correction only

Orange curve: Barotropic + along-track 2N2 μ2 N2 ν2 M2 S2 K2

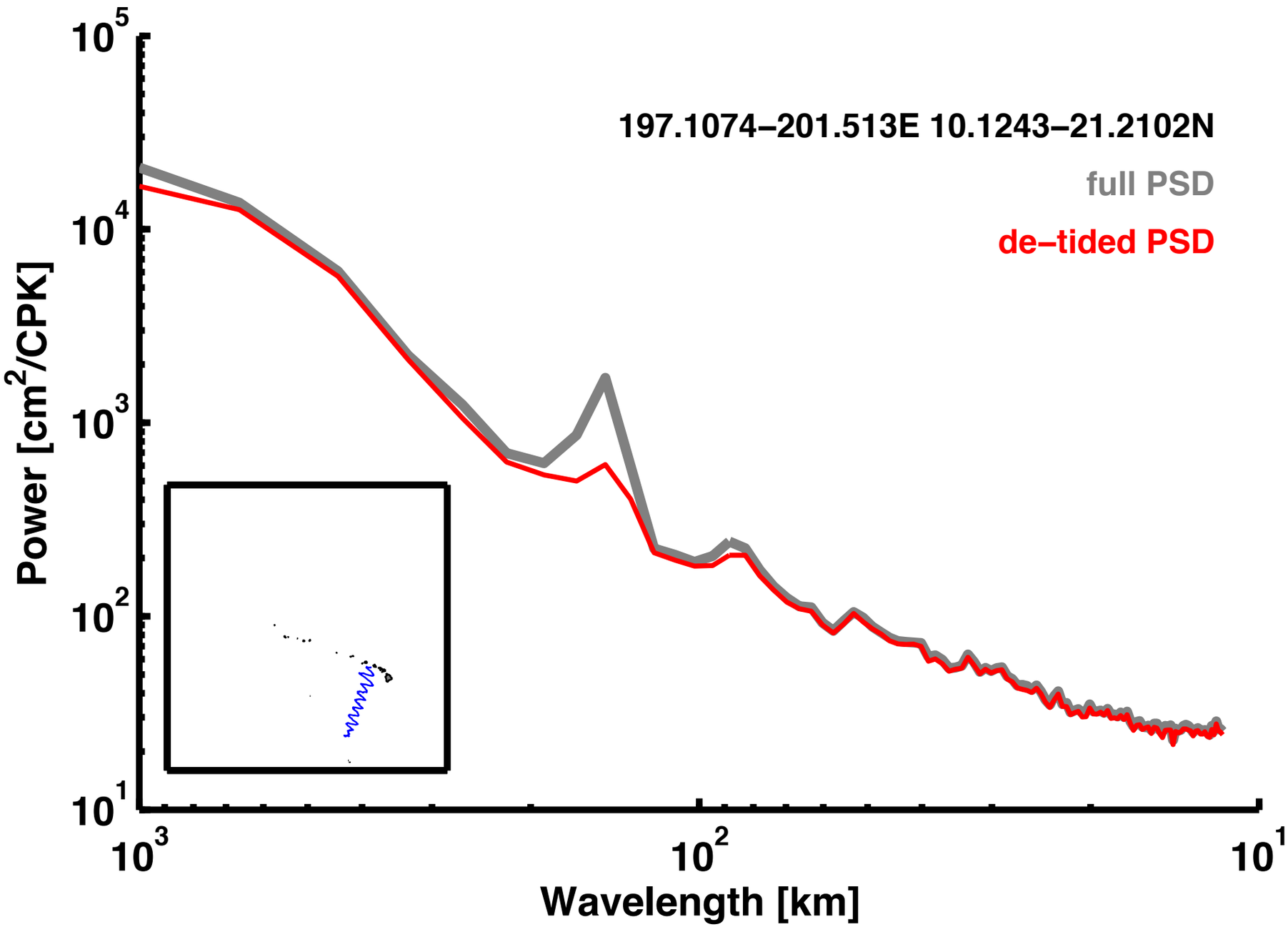
Red curve: As above + Q1 O1 P1 K1

Cyan curve: As above + α2 β2 δ2 Γ2 T2 R2

Variance in residual peak = 0.16 cm²

Is there a "universal" background spectrum?

(revisit Hawaiian Ridge)



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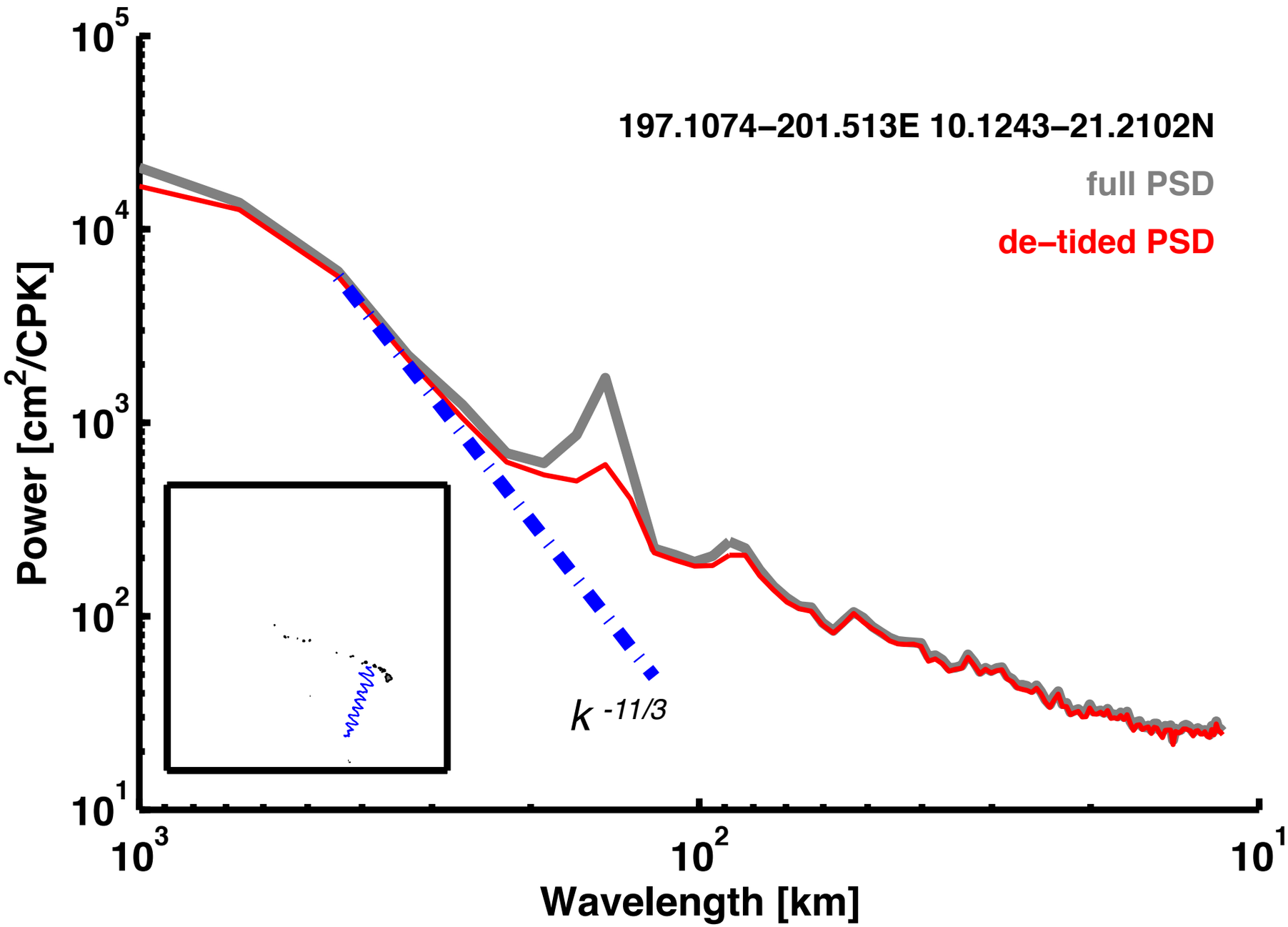

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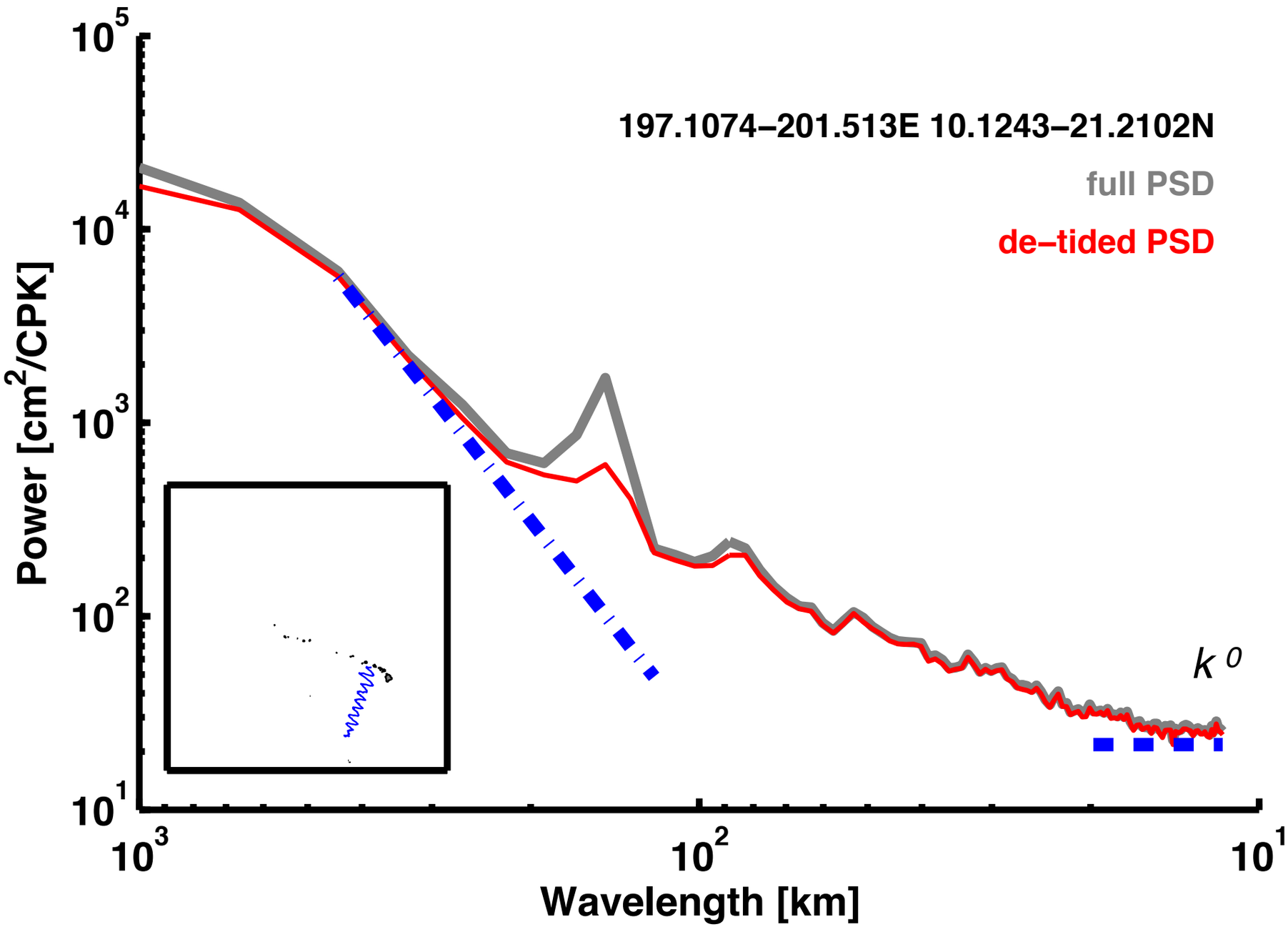

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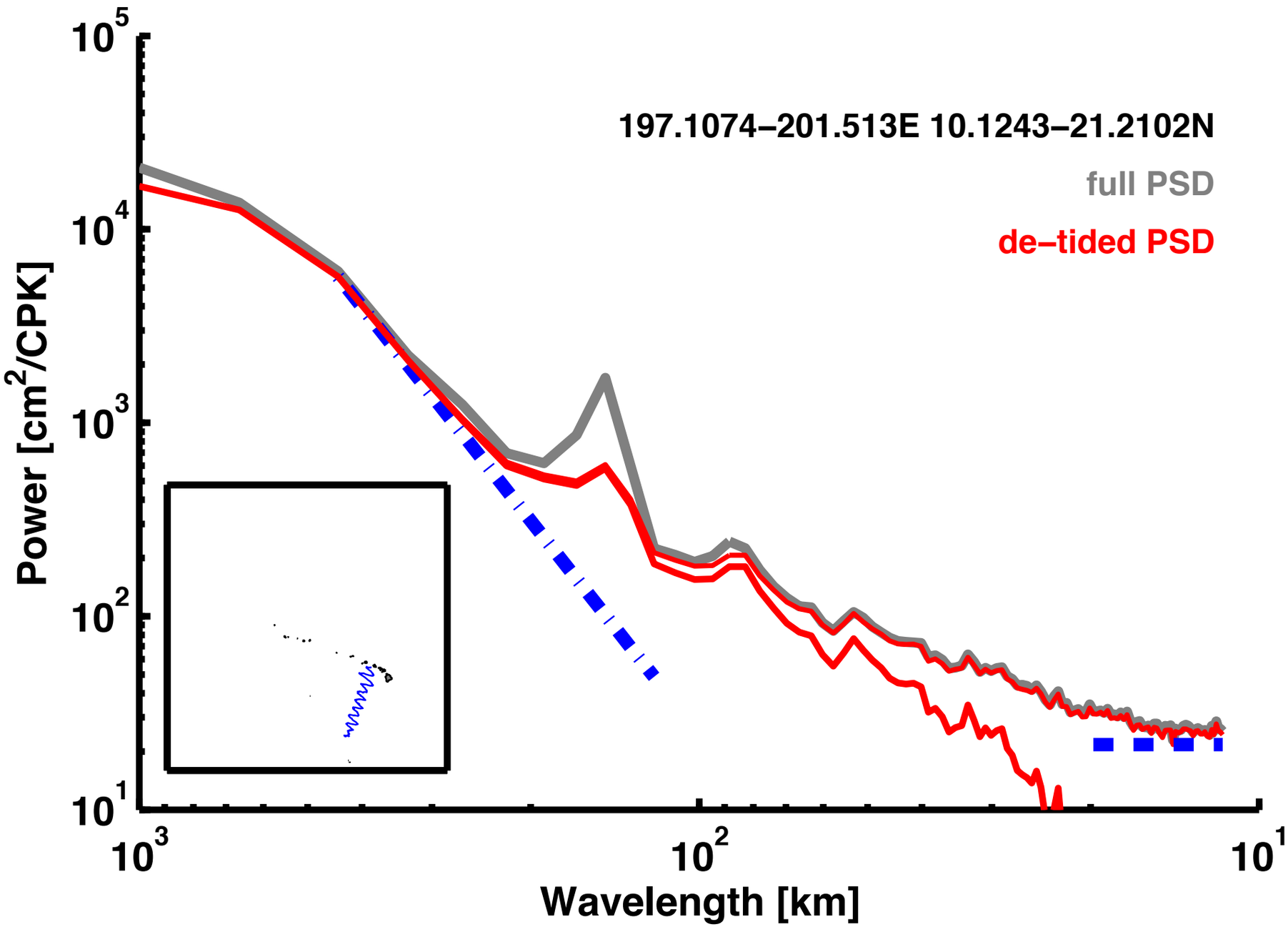

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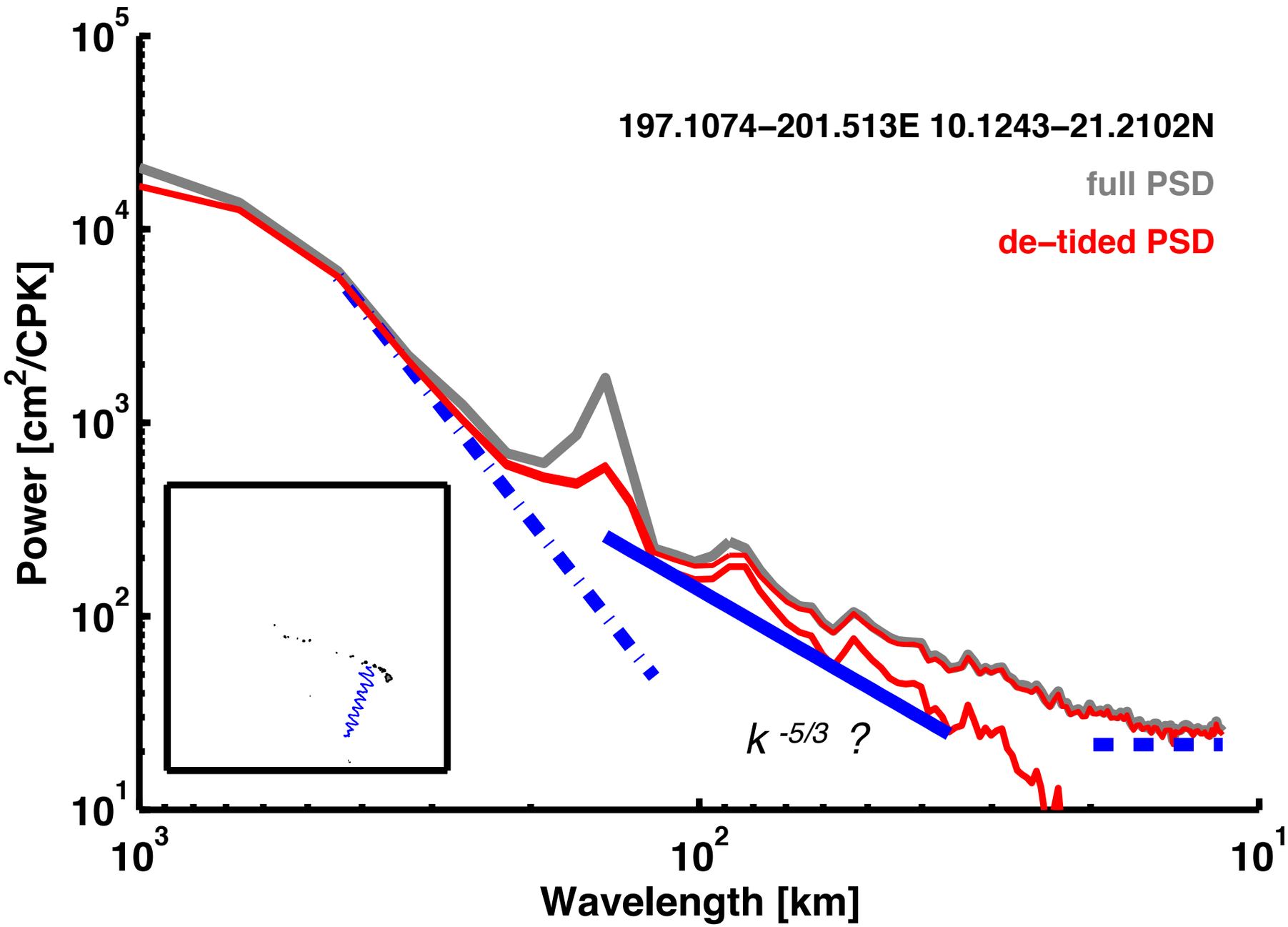

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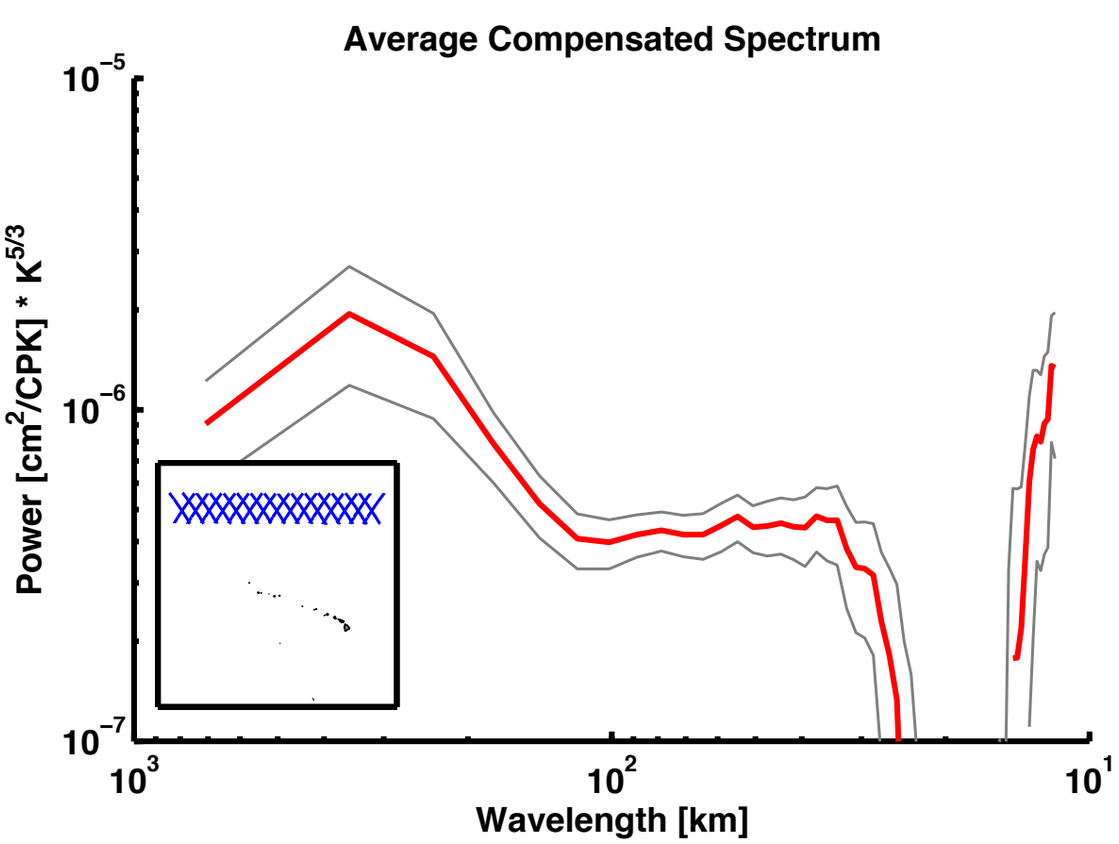

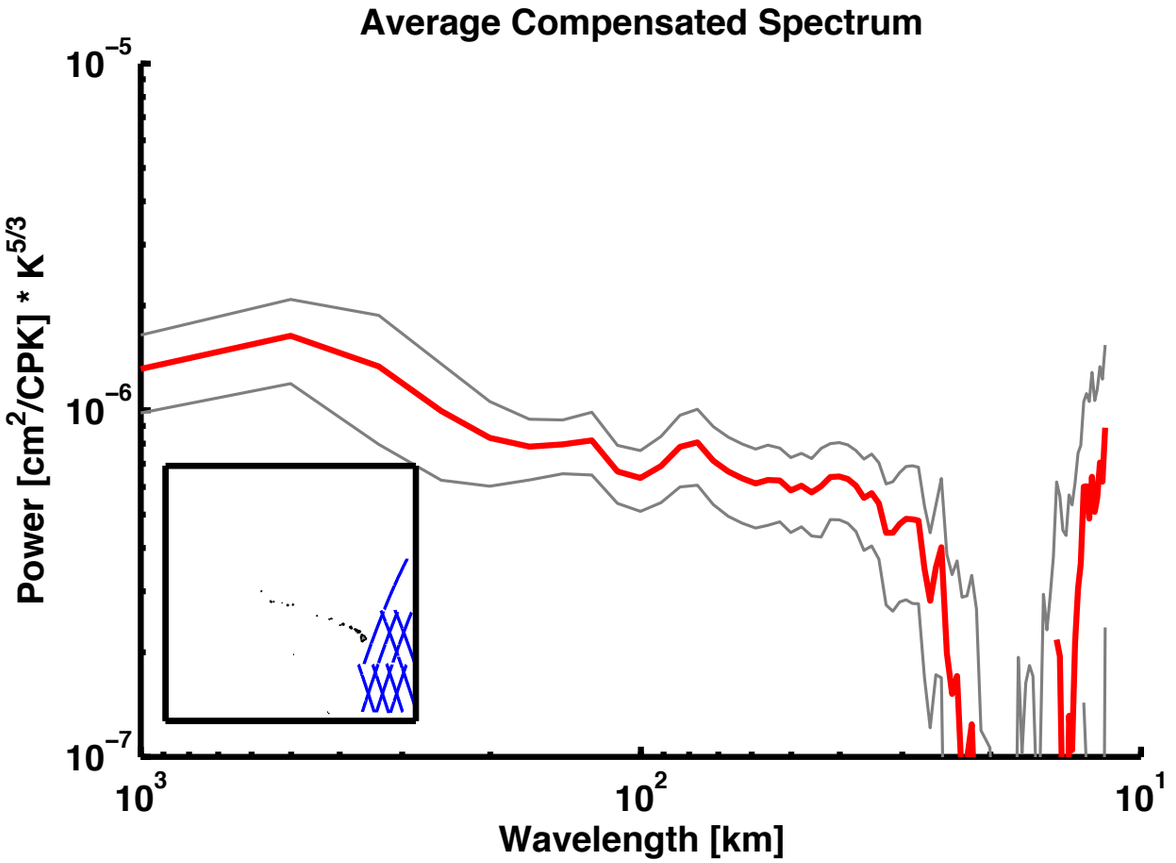

Large scale, L > 120km
k $^{-11/3}$ SQG; k $^{-5}$ QG; spatially variable

Middle scales, 120km > L > 35km
k $^{-5/3}$ ageostrophic SQG; "stratified turbulence"; atm. forcing; broadband noise?

Summary

1. The altimeter detects mostly mode-1 and (much smaller) mode-2 internal-tide signals. This contrasts with in-situ measurements.
2. With some exceptions, mode-1 is mostly (> 90% of variance) phase-locked with the tidal potential. Mode-2 is less temporally coherent.
3. The incoherent part of both modes is generally < 0.2 cm^2 in SSH. (one case was 0.26 cm^2).
4. South China Sea: Shows strong diurnal internal tides; shows strong seasonal modulations of semidiurnals.
5. Hawaiian Ridge: Search for non-tidal spectrum finds $k^{-5/3}$ subrange from 120km to 35km; origins and significance are speculative.