Variability of internal tides: A view from altimetry

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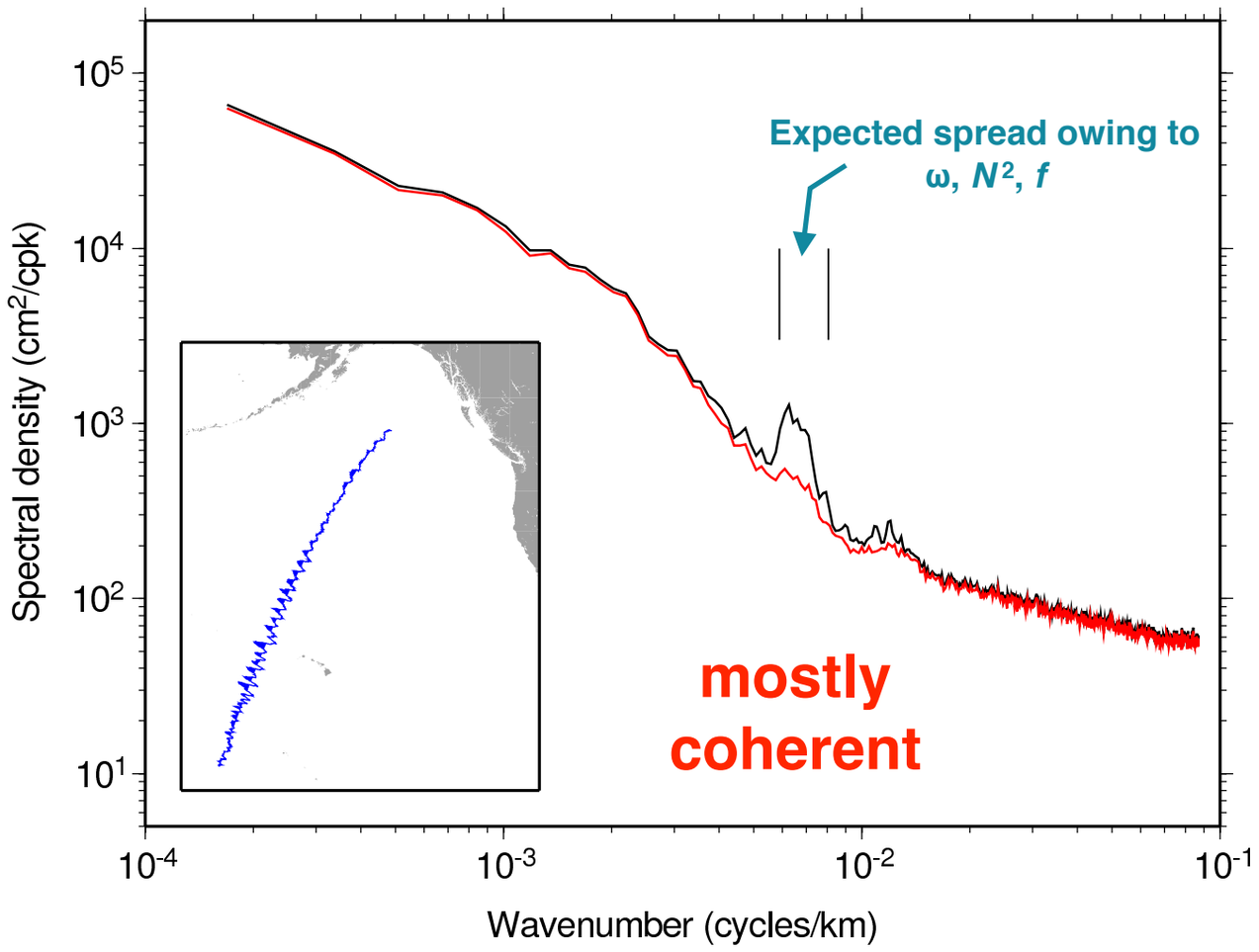
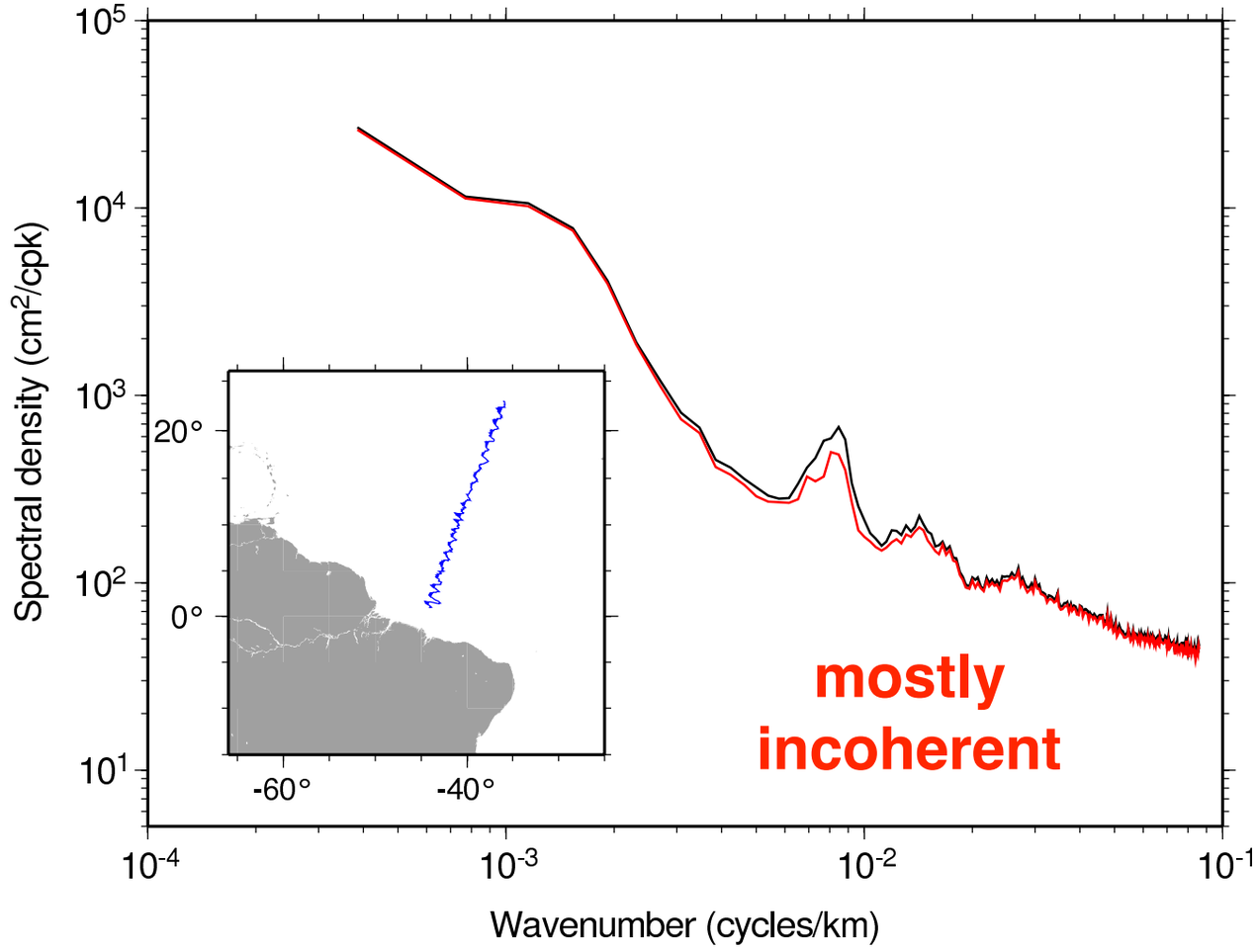
Wavenumber Spectrum of Altimetric Sea-Surface Heights

Spectral peaks in SSH from internal tides
(mostly semidiurnal mode-1)

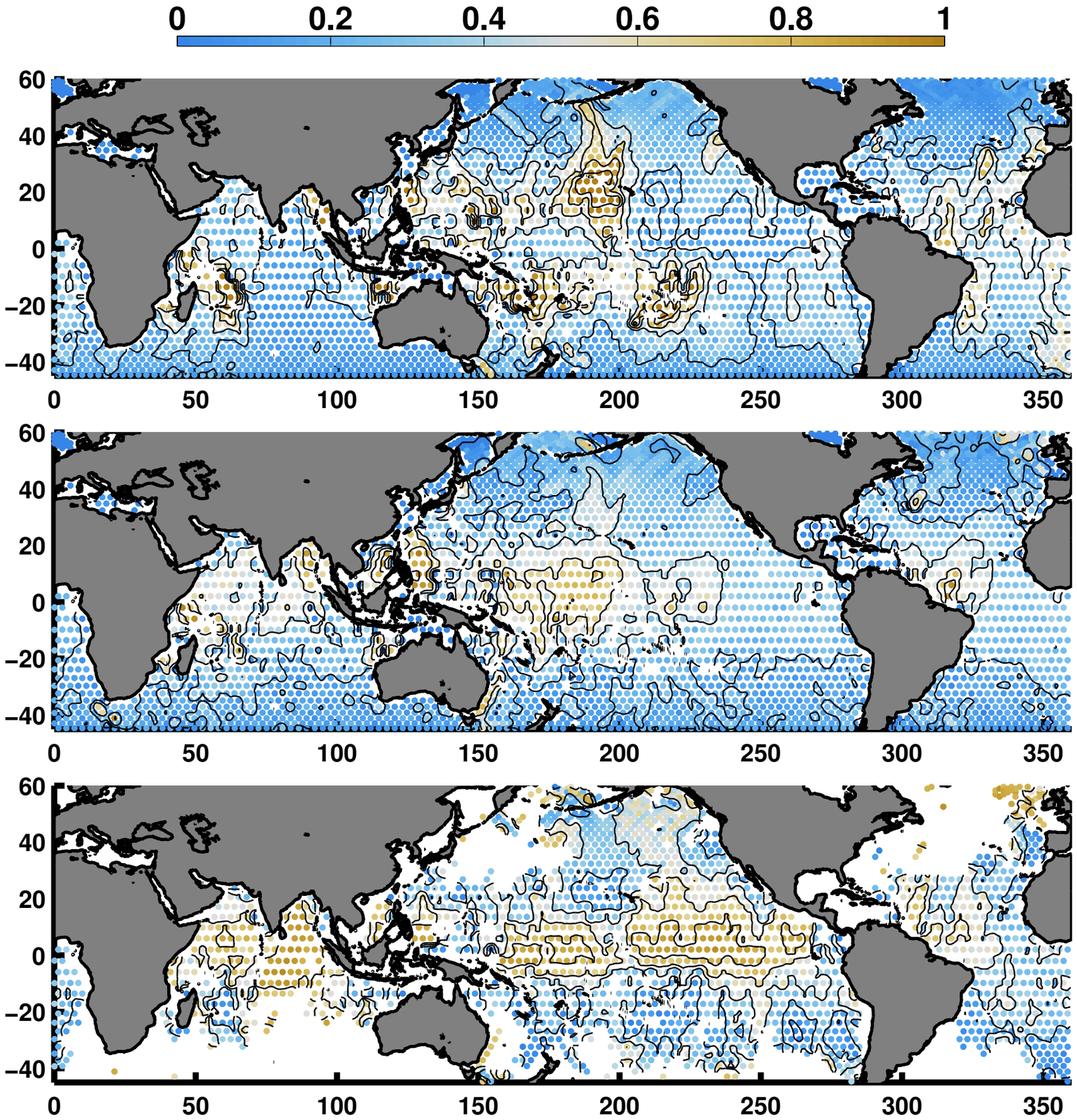




Black curves: spectra using barotropic tide model
Red curves: spectra after removing estimated along-track tides (coherent over 17 y)

Is the ocean mostly like left panel, or right panel? Why?

Ray & Zaron, *GRL*, 2011.



RMS amplitude (cm) of stationary tide

RMS amplitude (cm) of non-stationary tide

Ratio of variances non-stationary / total

Zaron, "Mapping the nonstationary internal tide with satellite altimetry," JGR-Oceans, 2017.

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2016GL070567

Key Points:
- A concept of ITOT is proposed to monitor global ocean warming
- ITOT detects ocean warming by measuring travel time changes of internal tides
- ITOT based on satellite altimetry is feasible and useful

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Citation:
Zhao, Z. (2016), Internal tide oceanic tomography, *Geophys. Res. Lett.*, *43*, 9157–9164, doi:10.1002/2016GL070567.

Received 22 APR 2016
Accepted 18 AUG 2016
Accepted article online 22 AUG 2016
Published online 10 SEP 2016

Internal tide oceanic tomography

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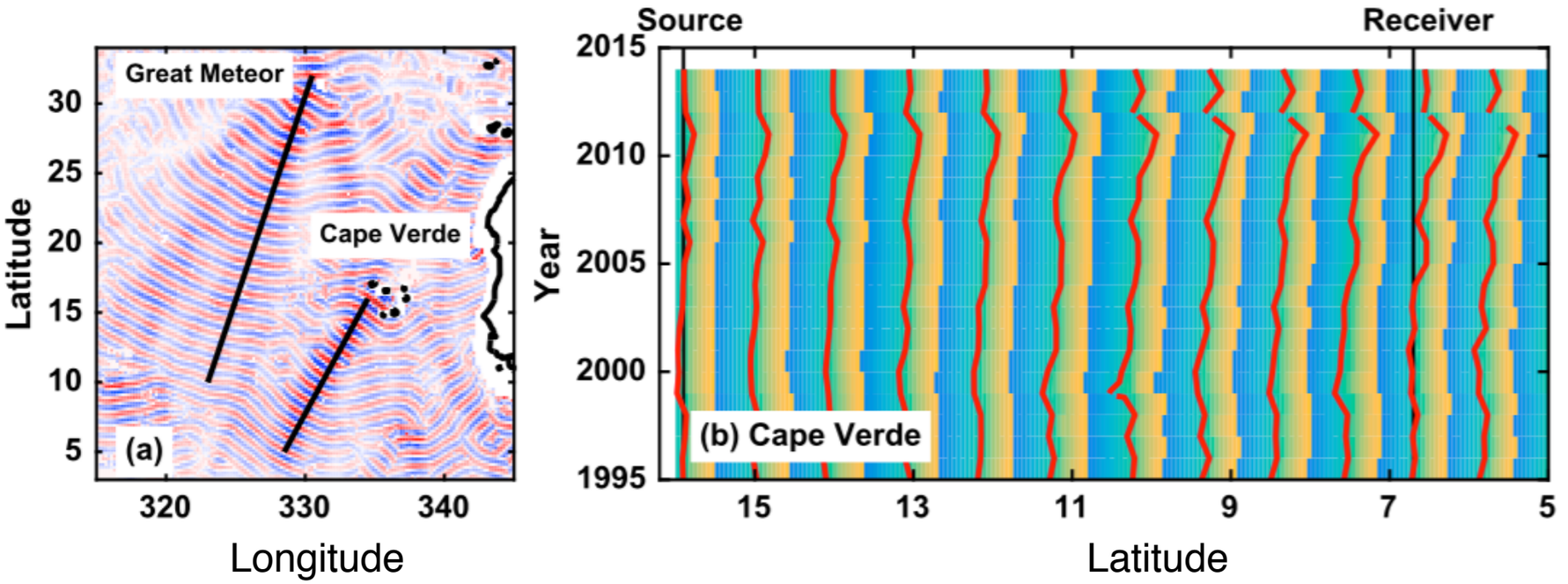
Abstract A concept of internal tide oceanic tomography (ITOT) is proposed to monitor ocean warming on a global scale. ITOT is similar to acoustic tomography, but that work waves are internal tides. ITOT detects ocean temperature changes by precisely measuring travel time changes of long-range propagating internal tides. The underlying principle is that upper ocean warming strengthens ocean stratification and thus increases the propagation speed of internal tides. This concept is inspired by recent advances in observing internal tides by satellite altimetry. In particular, a plane wave fit method can separately resolve multiple internal tidal waves and thus accurately determines the phase of each wave. Two examples are presented to demonstrate the feasibility and usefulness of ITOT. In the eastern tropical Pacific, the yearly time series of travel time changes of the M_2 internal tide is closely correlated with the El Niño–Southern Oscillation index. In the North Atlantic, significant interannual variations and bidecadal trends are observed and consistent with the changes in ocean heat content measured by Argo floats. ITOT offers a long-term, cost-effective, environmentally friendly technique for monitoring global ocean warming. Future work is needed to quantify the accuracy of this technique.

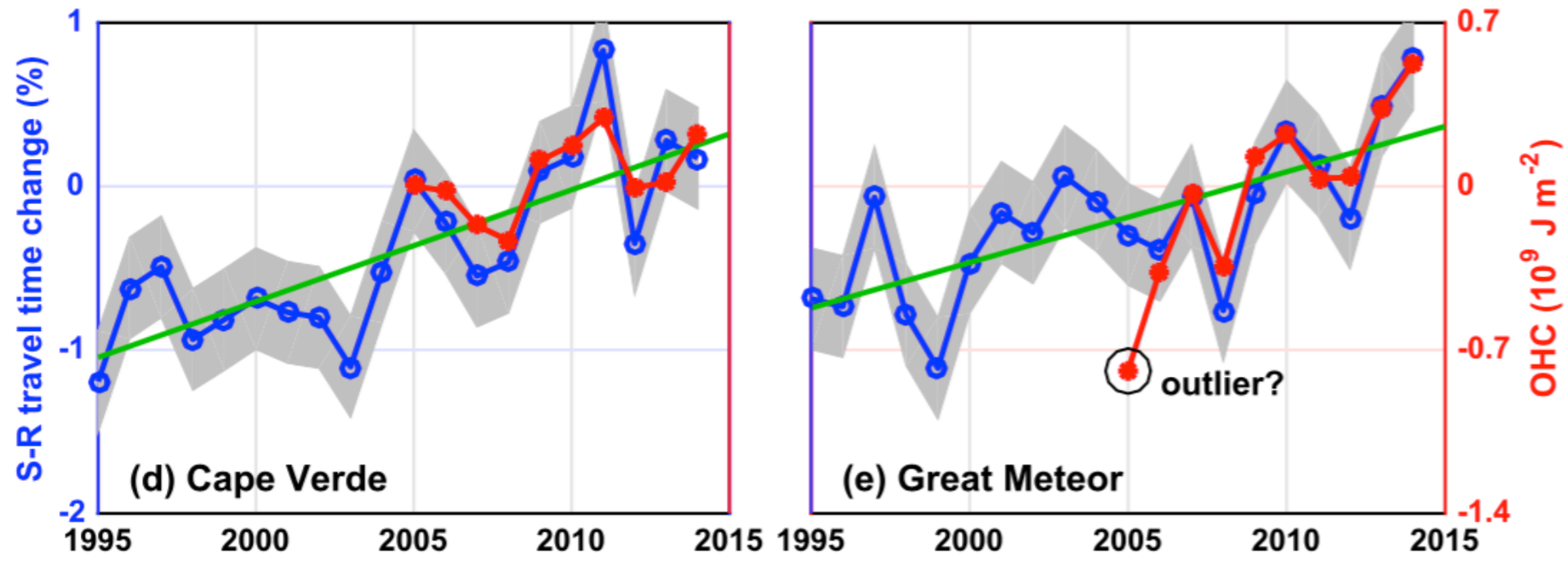
1. Concept

More than 90% of the heat gain of the Earth's climate system is stored in the ocean [*Levitus et al.*, 2012]. Heat entering the ocean at the sea surface is redistributed at depth by various ocean processes such as mixing and advection [*Liang et al.*, 2015]. Most of the heat is stored in the upper 700 m layer, and about 10% goes into the abyssal ocean [*Purkey and Johnson*, 2010; *Wunsch and Heimbach*, 2014]. Previous studies have suggested the

Analysis of 2 internal tide beams in the Atlantic

Z. Zhao (GRL, 2016)





Blue – wave travel time, deduced from altimetry.

Red – mean ocean heat content anomaly, from Argo.

Wavenumber spectra
ascending T/P-J tracks
equatorial Pacific

85
47
9
98
60
22
111
73
35
124
86
48
10
99

10^5
10^4
10^3
10^2
10^1

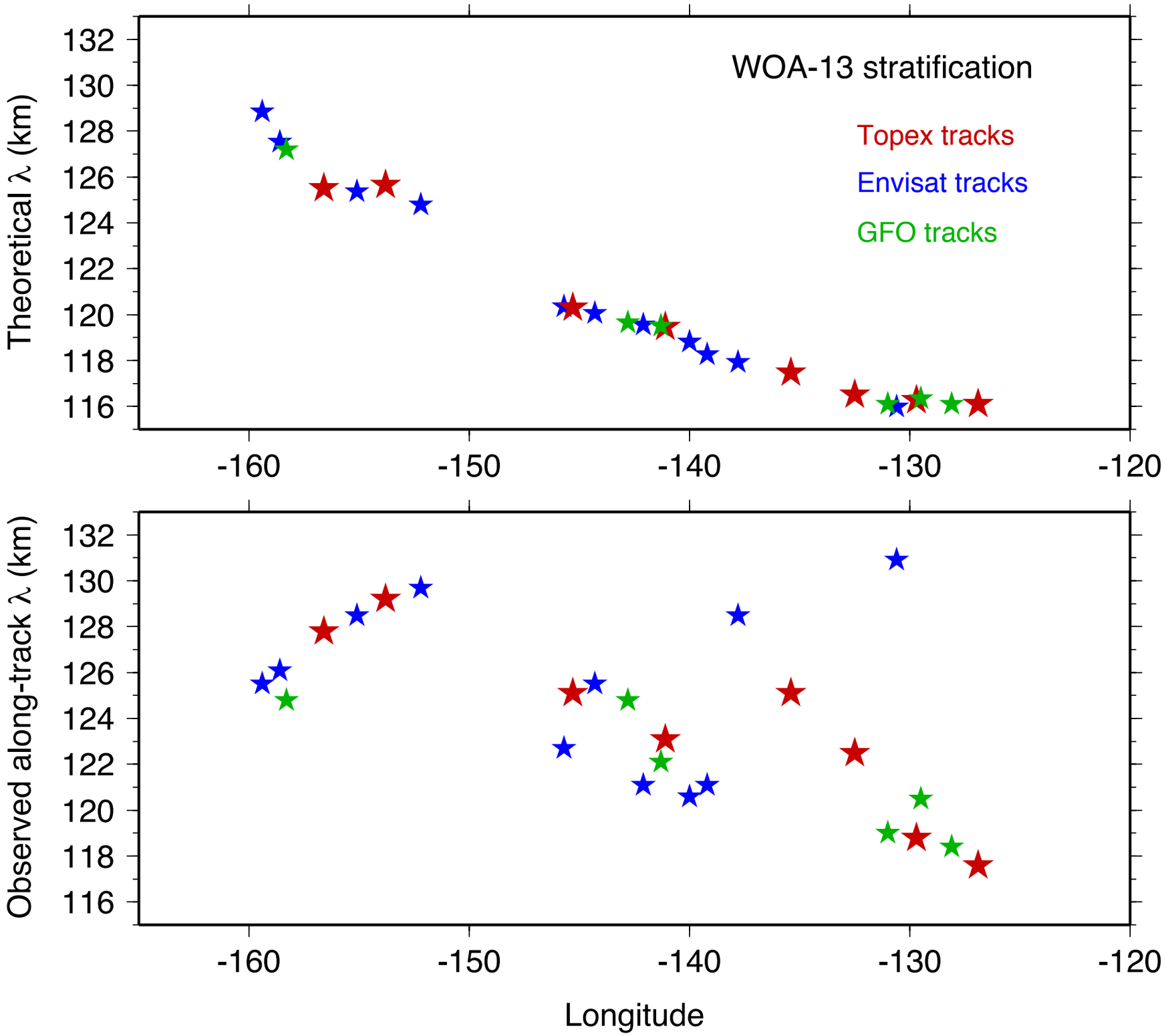
Spectral density (cm^2/cpk)

10^{-4}
10^{-3}
10^{-2}
10^{-1}

Wavenumber (cycles/km)

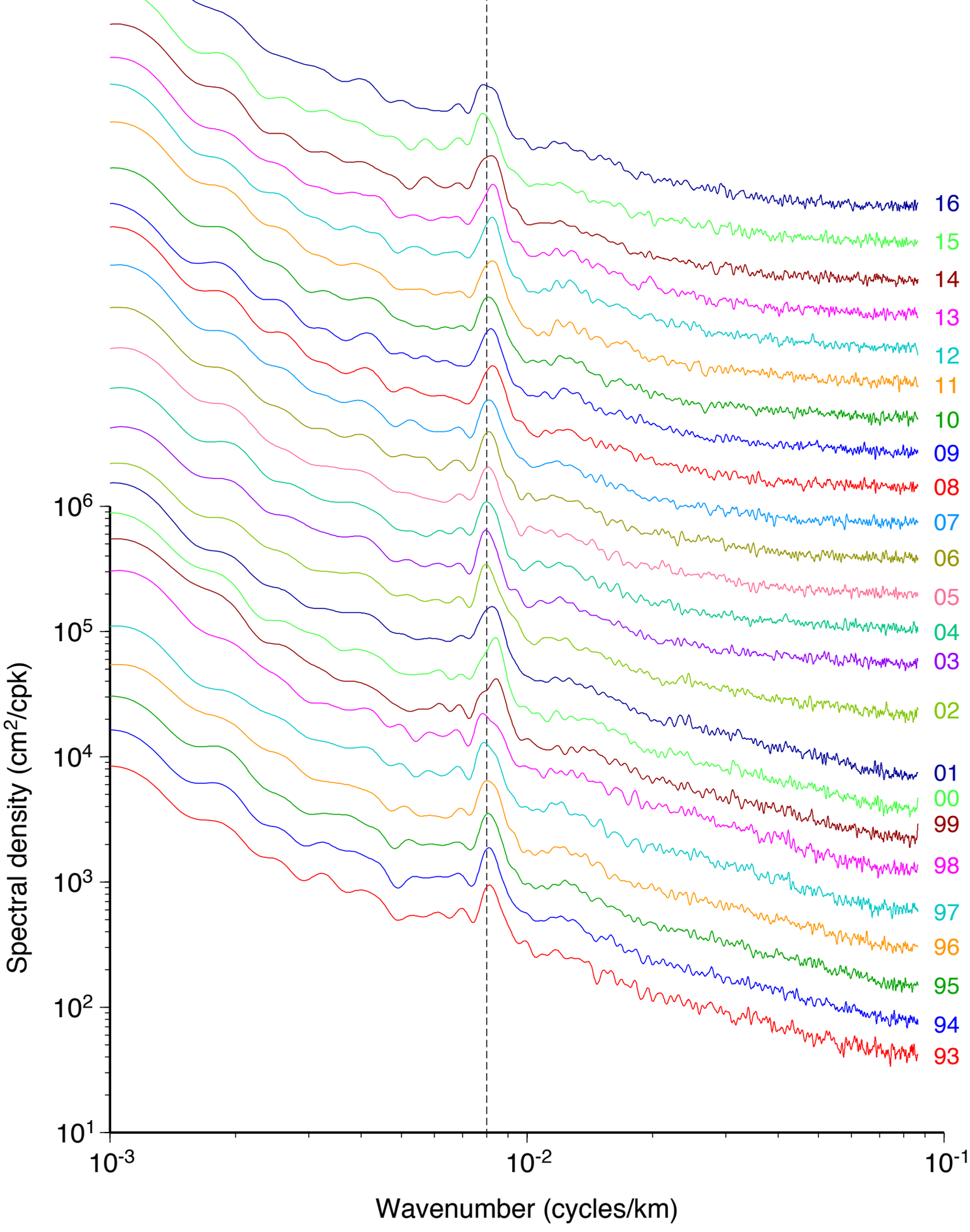
10°
0°
10°
180°
160°
140°
120°

Peak mode-1 wavelengths

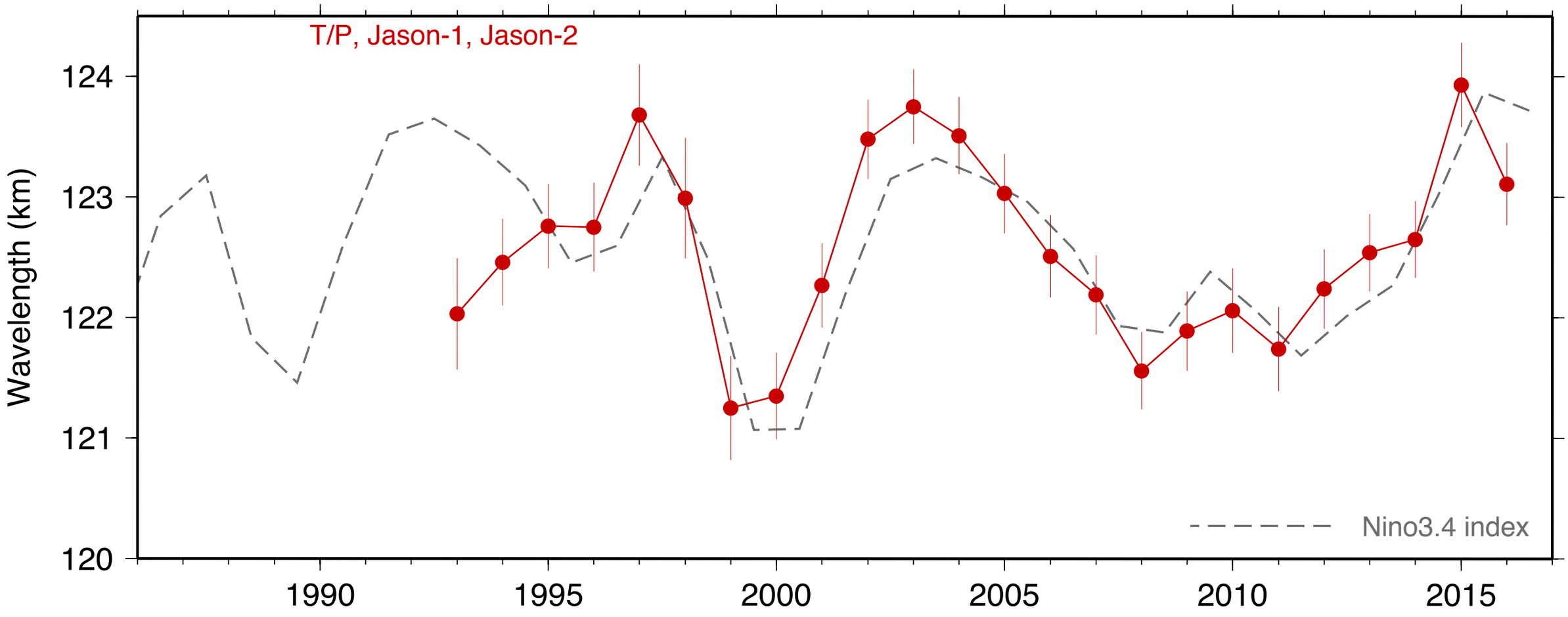


Wavenumber spectra by year

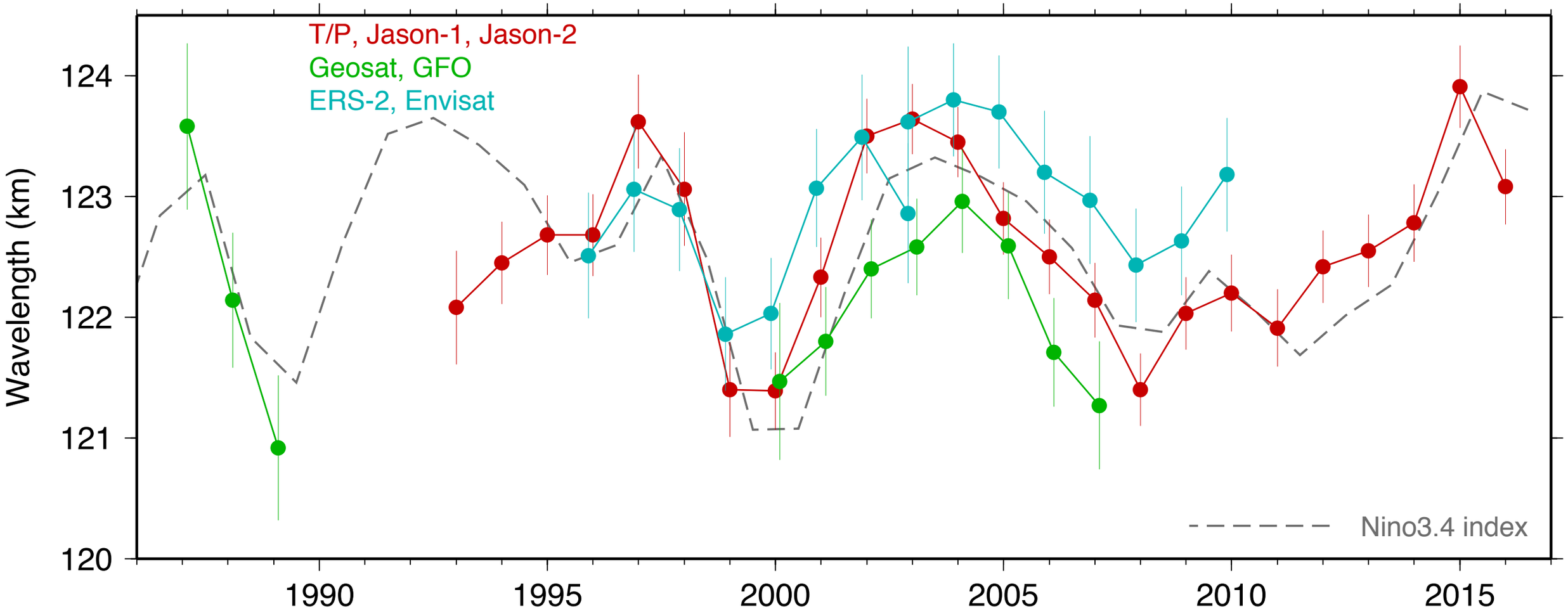
"Averages" of 8 T/P-J tracks



Peak mode-1 wavelengths vs. time



Peak mode-1 wavelengths vs time



M_2 Internal Tide Theoretical Wavelengths

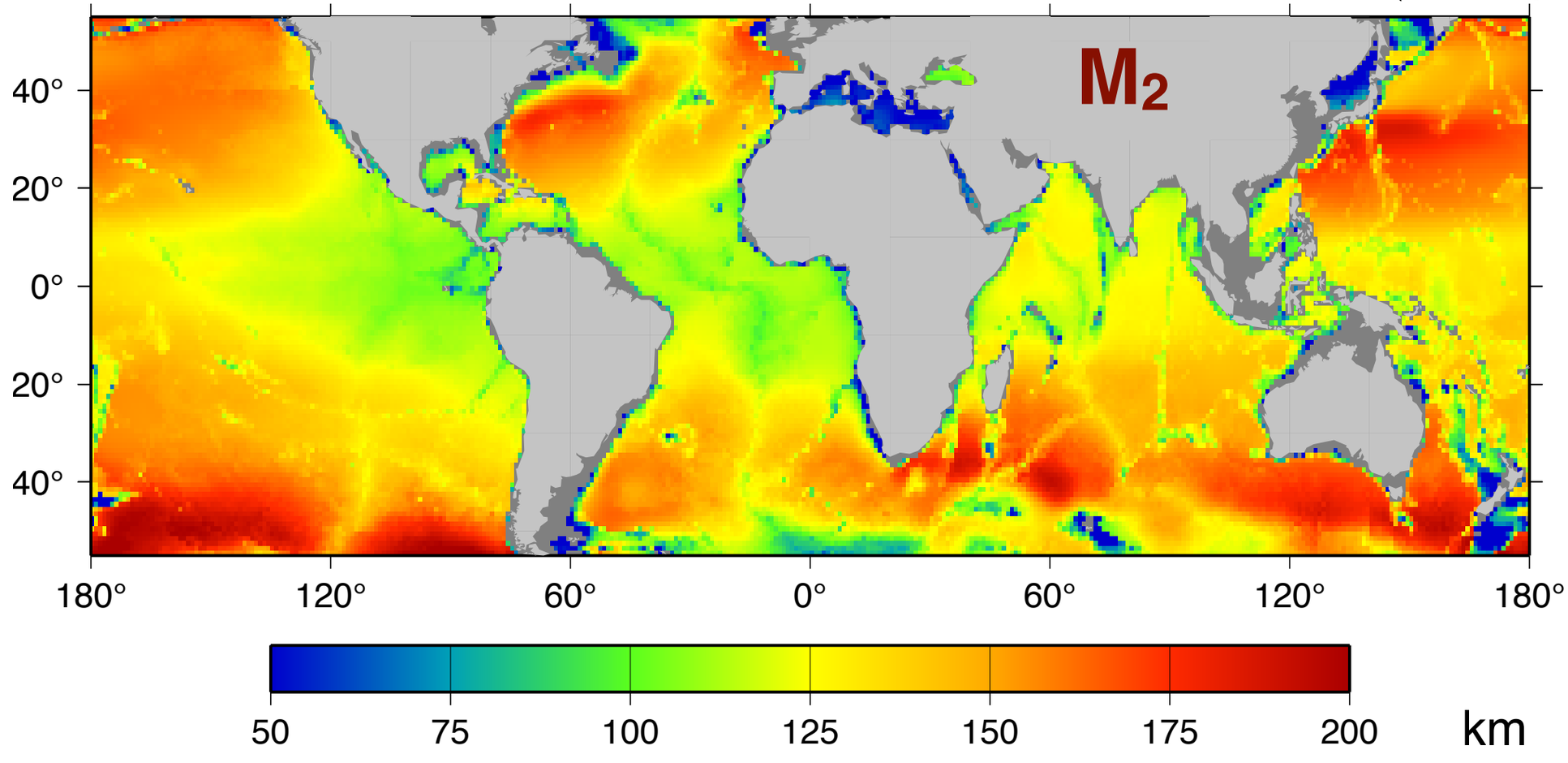
$$\frac{d^2\Phi(z)}{dz^2} + \frac{N^2(z)}{c^2}\,\Phi(z) = 0$$

$$\text{with} \quad \Phi(0) = \Phi(-H) = 0$$

Buoyancy freq. N^2 defined by WOA13 temp & salinity

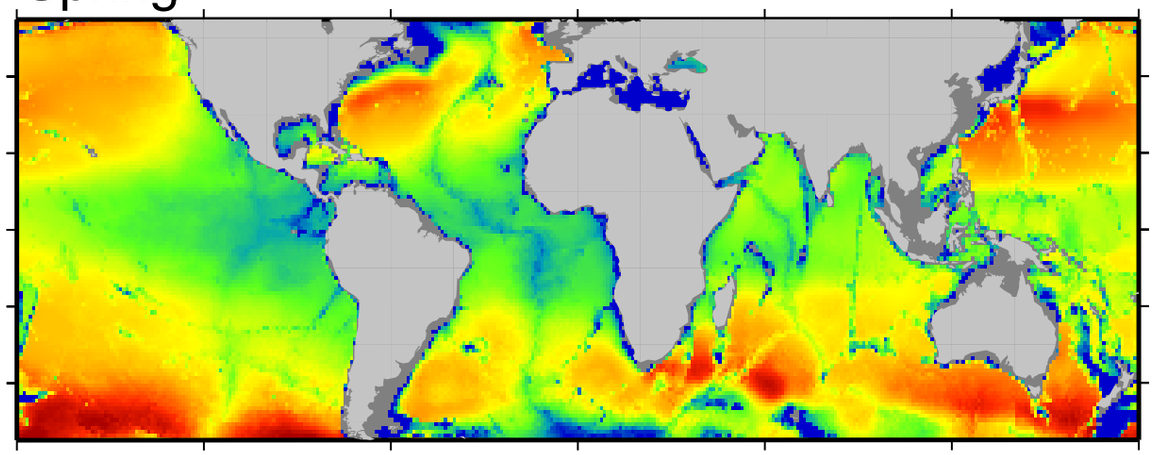
$$\text{tidal phase velocity} \quad c_p = \frac{\omega}{(\omega^2 - f^2)}\,c$$

$$\text{tidal wavelength} \quad \lambda = \frac{1}{(\omega^2 - f^2)}\,c$$

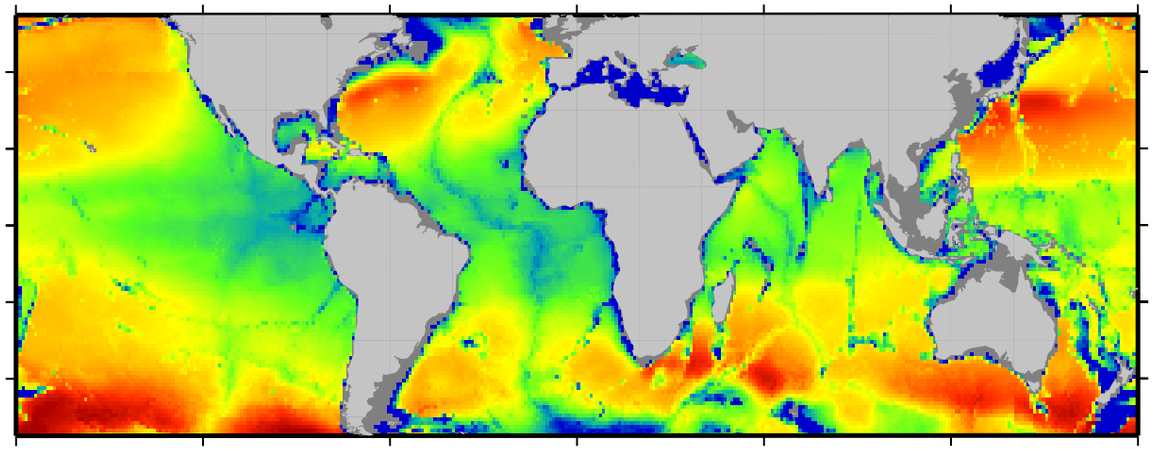


M_2 Internal Tide
Theoretical Wavelengths

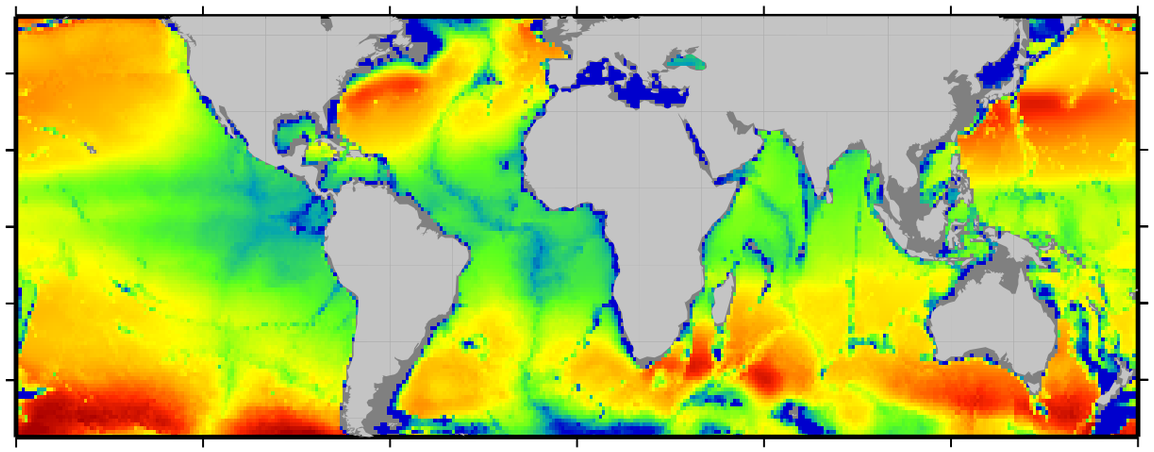
Spring



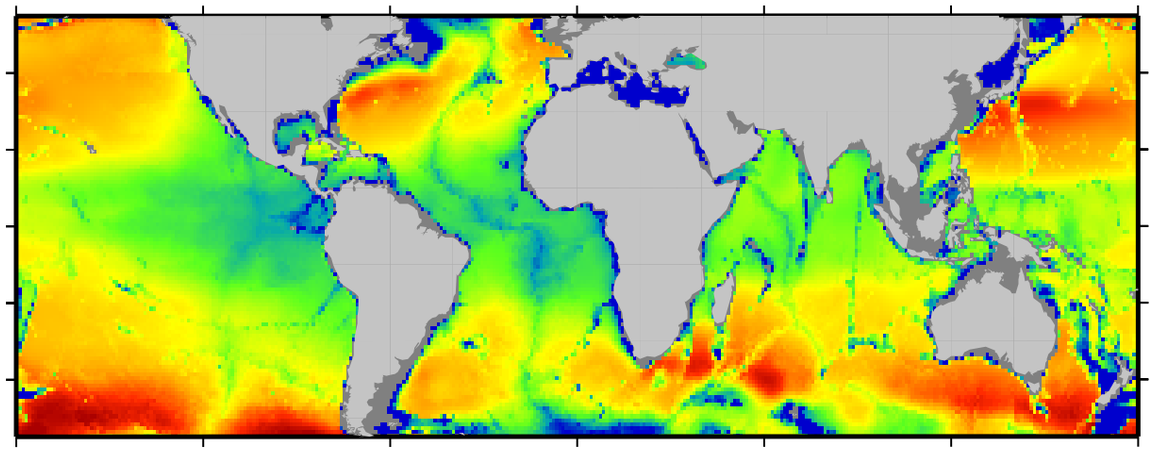
Summer

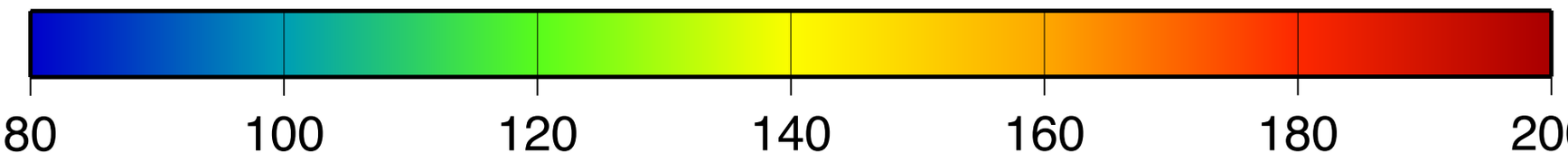


Autumn

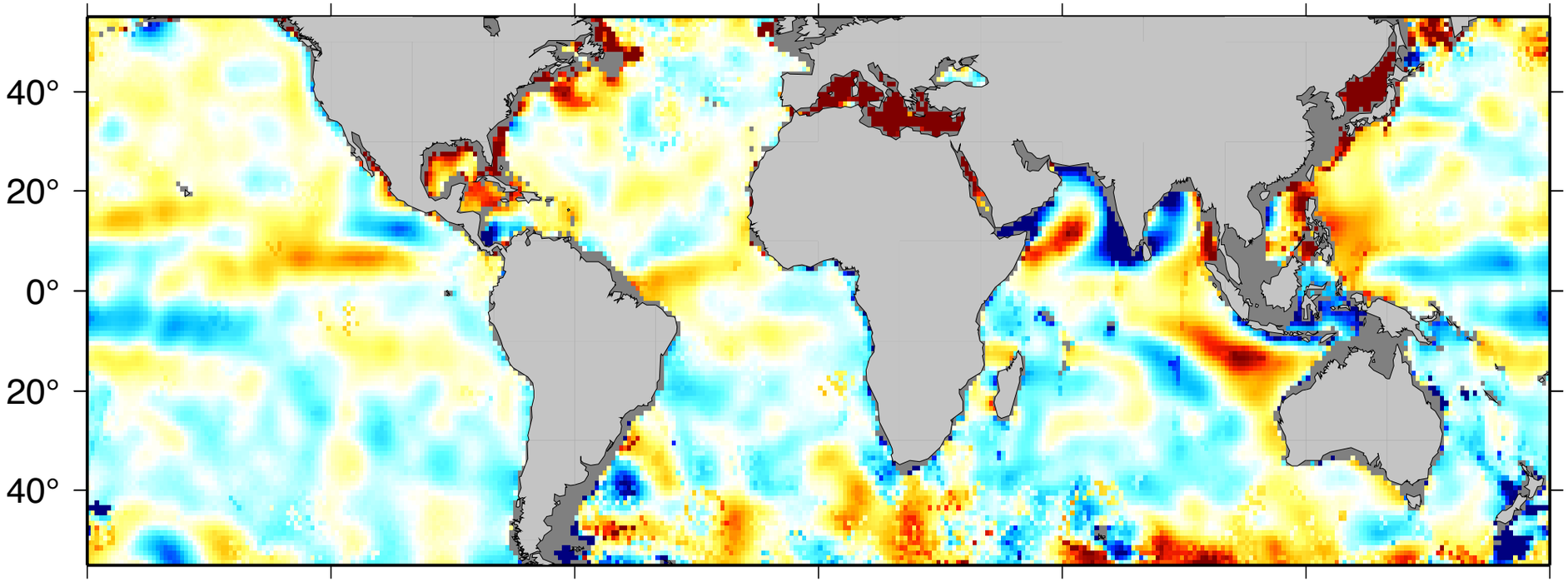


Winter

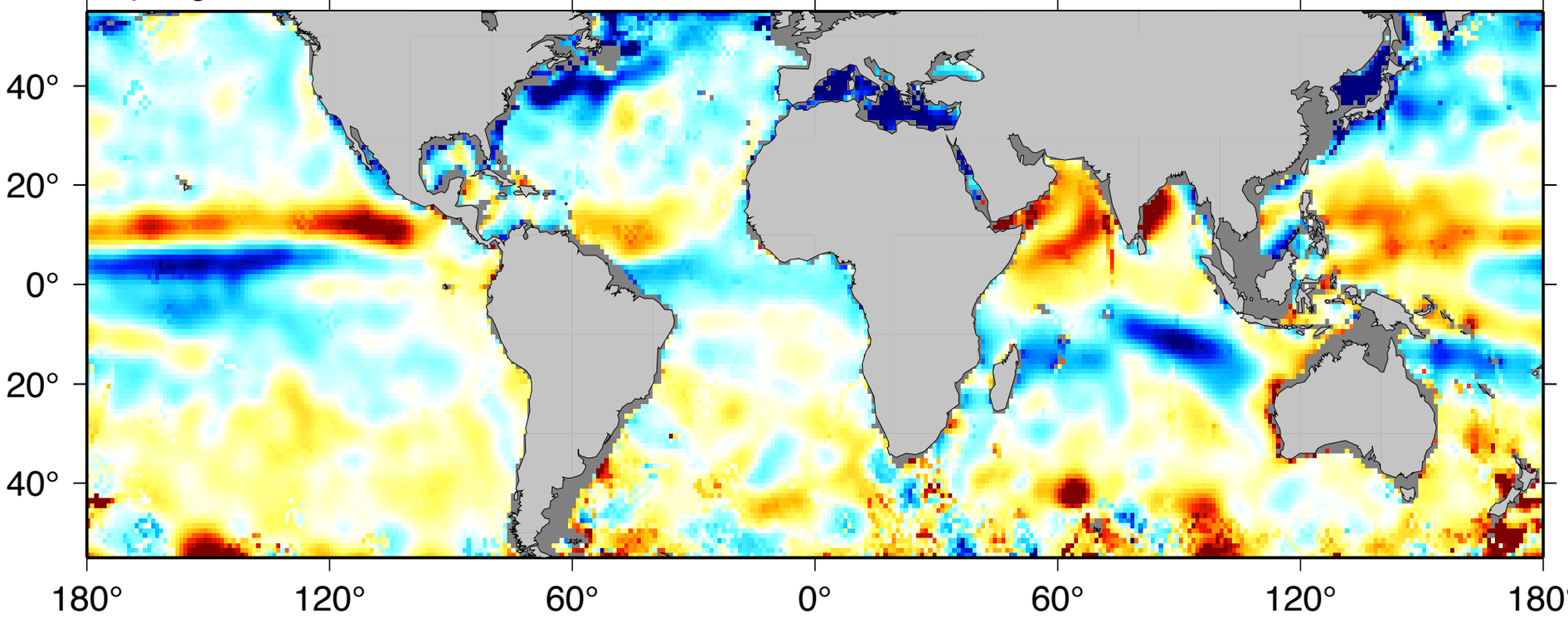


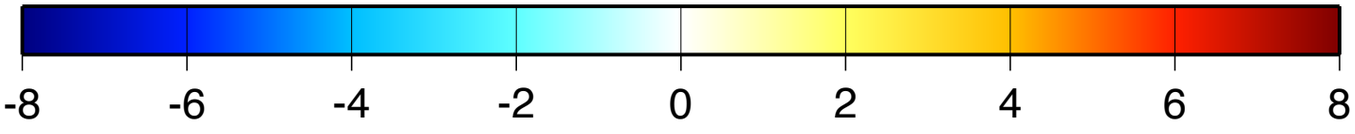


Summer minus Winter



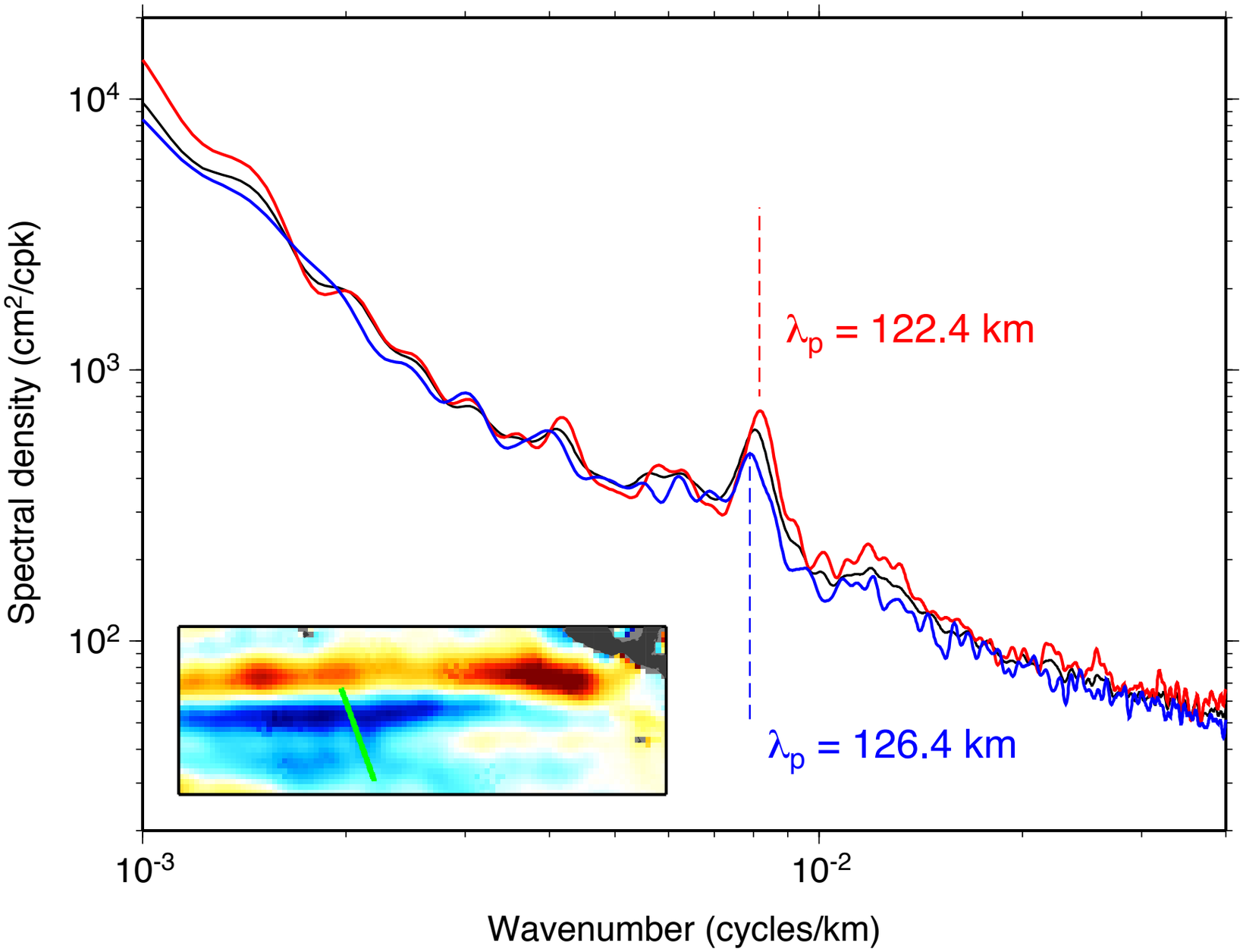
Spring minus Autumn





W - J, F, M
V - A, M, J
S - J, A, S
F - O, N, D

T/P-Jason Wavenumber Spectra by Season

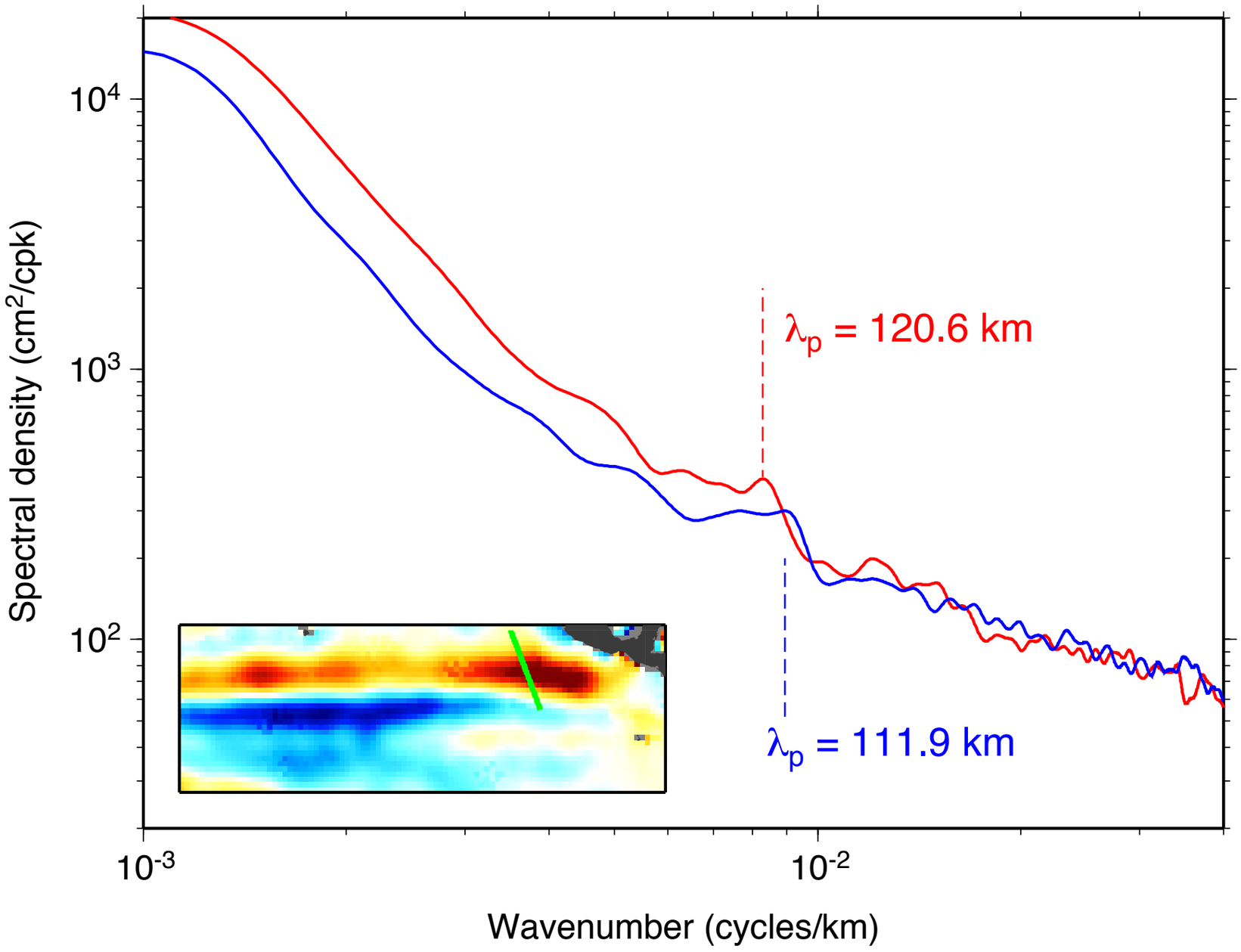


red - spring

blue - autumn

black - all

T/P-Jason Wavenumber Spectra by Season



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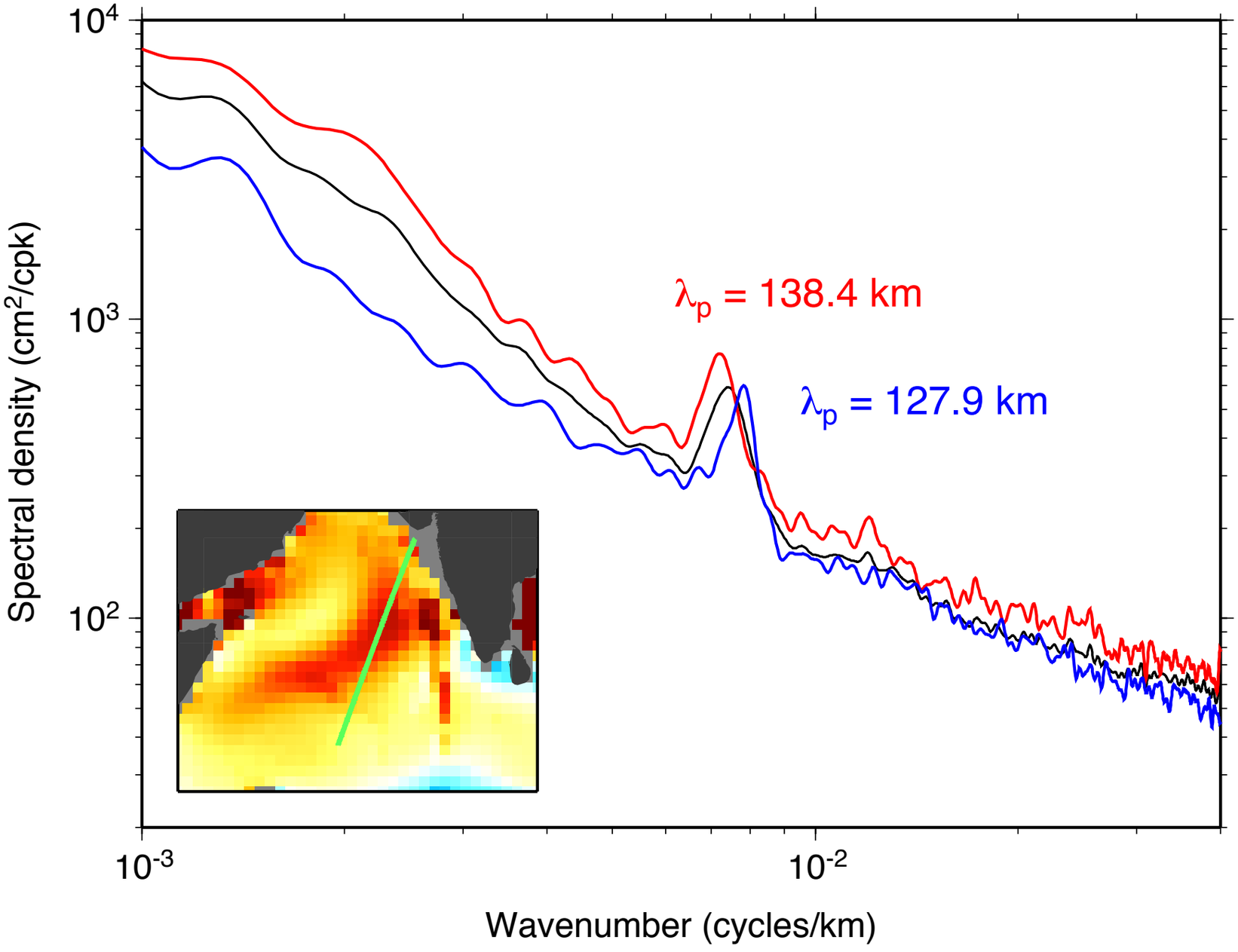

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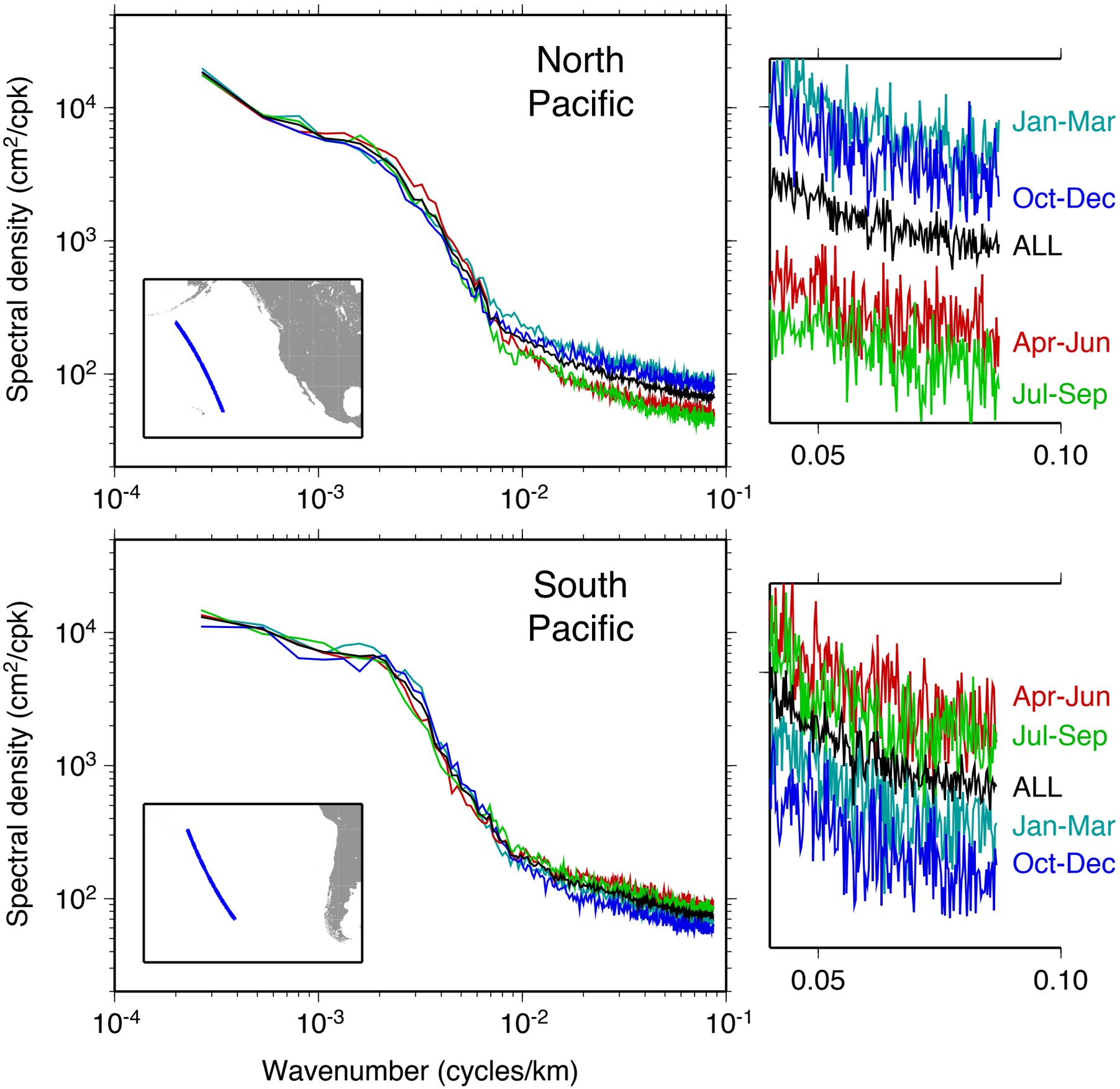
Altimeter Noise Floor by Season