A Broadband View of the Sea Surface Height Wavenumber Spectrum

(The contribution of surface waves to the SSH variability)

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with Luc Lenain, Bruce Cornuelle, Sarah Gille (sgille@ucsd.edu), and Matt Mazloff

Villas Bôas, A. B., L. Lenain, S. T. Gille, M. R. Mazloff, and B. D. Cornuelle, 2022. A broadband view of the sea surface height wavenumber spectrum, *Geophys. Res. Lett.*, **49**, e2021GL096699, doi:10.1029/2021GL096699.

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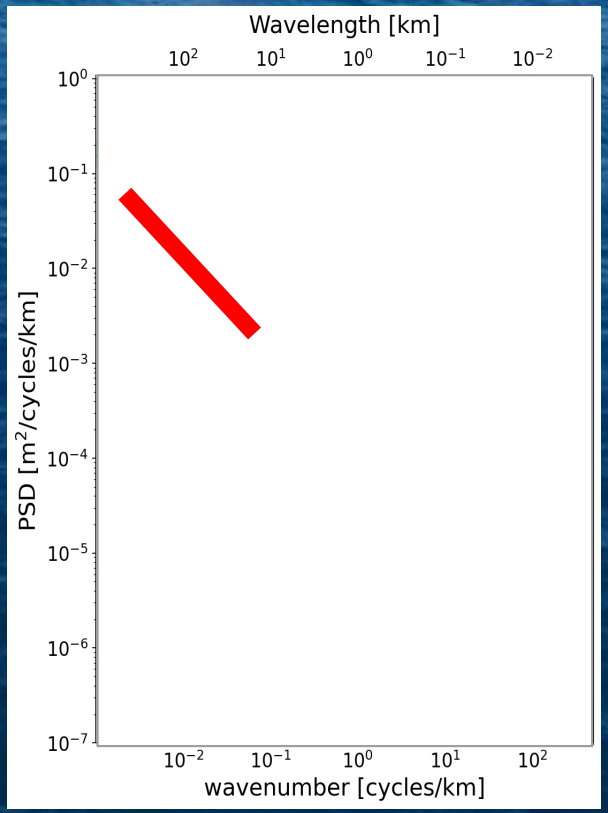
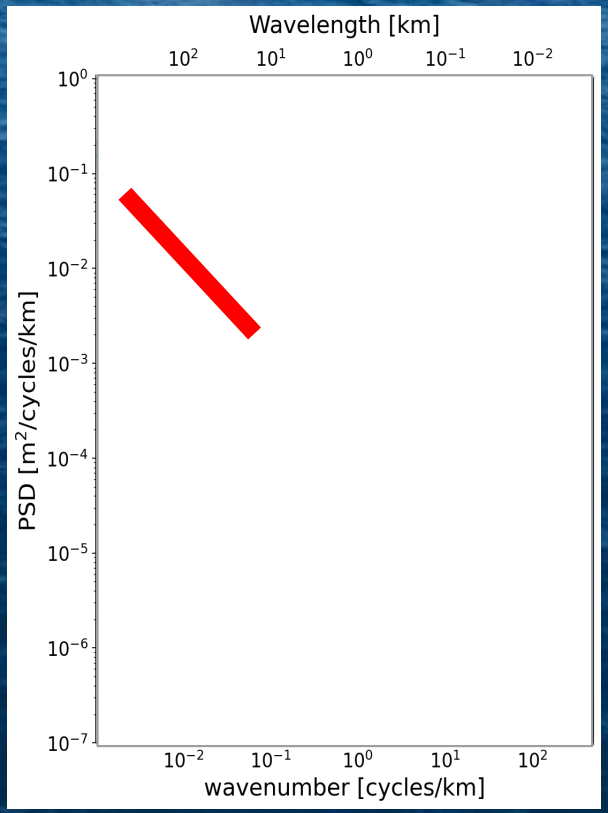
This is how we usually picture the SSH spectrum:

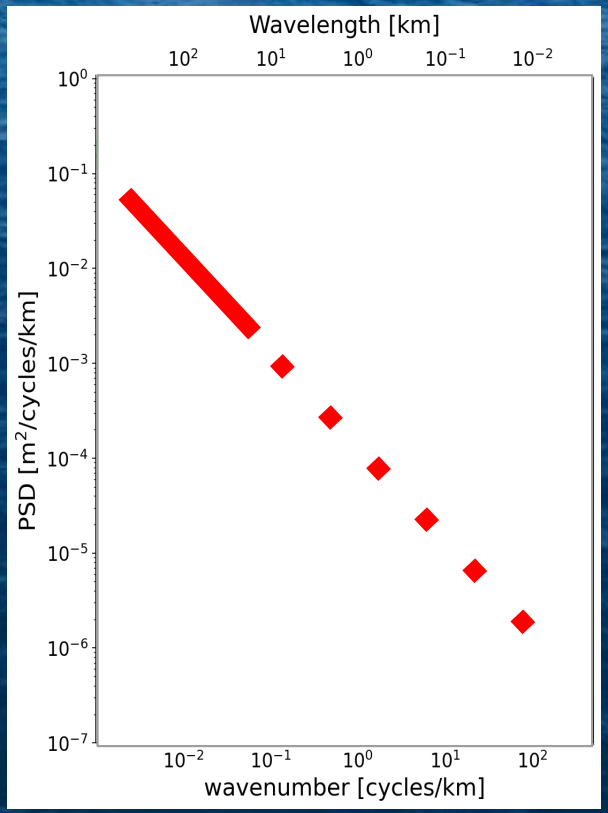


This is how we usually picture the SSH spectrum:

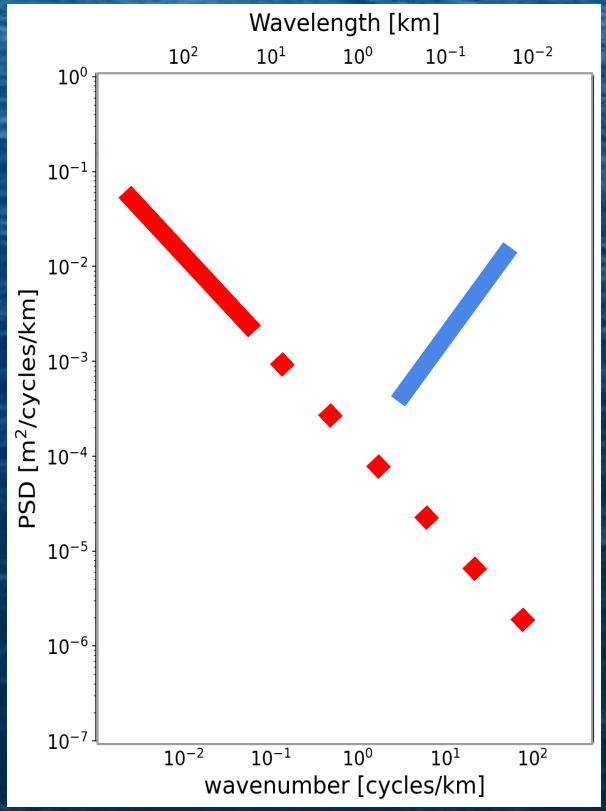
- Red spectrum: variance decreases with wavenumber
- Consistent with QG turbulence theory



It's tempting to extrapolate …

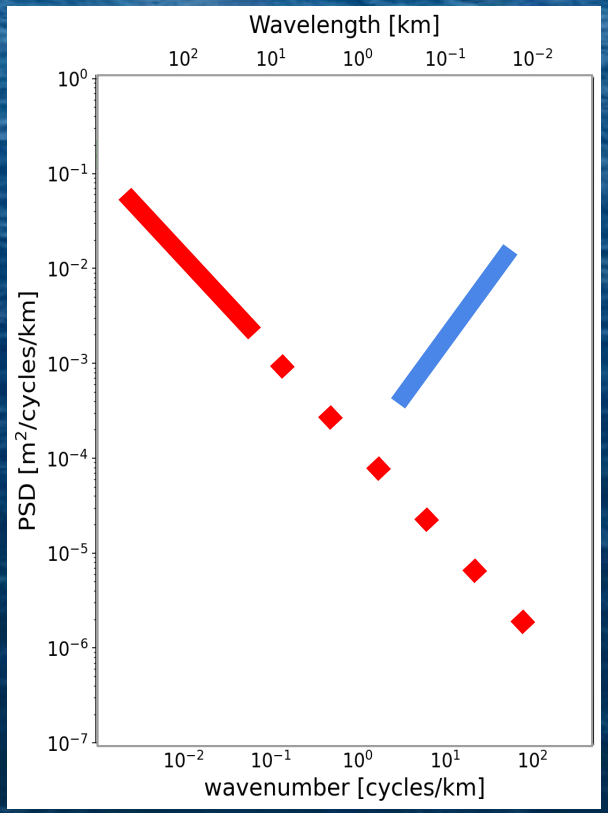


but … surface waves!



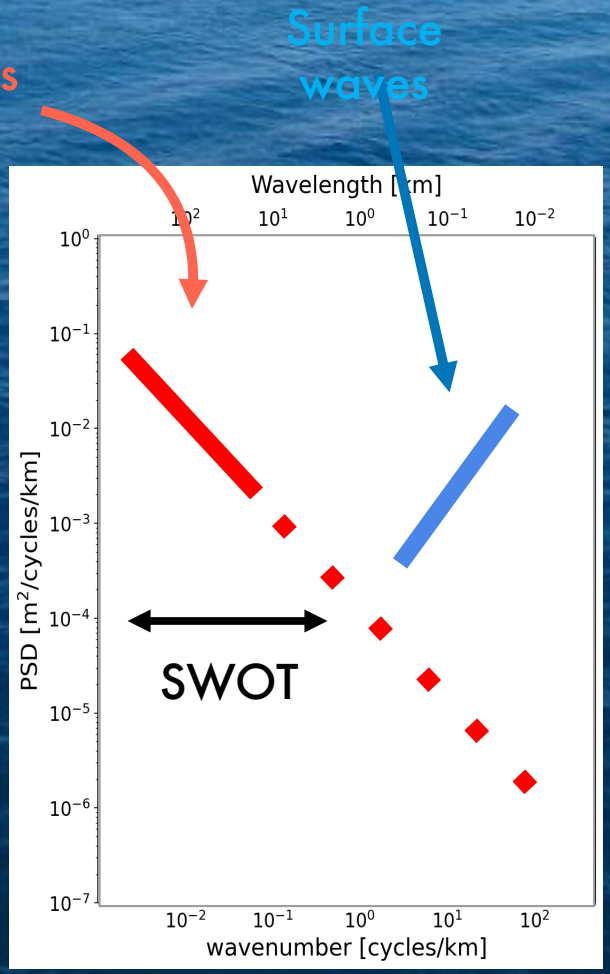
but … surface waves!

- At scales from 1-500 m the SSH is dominated by *surface gravity waves*
- Blue spectrum: variance *increases* with wavenumber

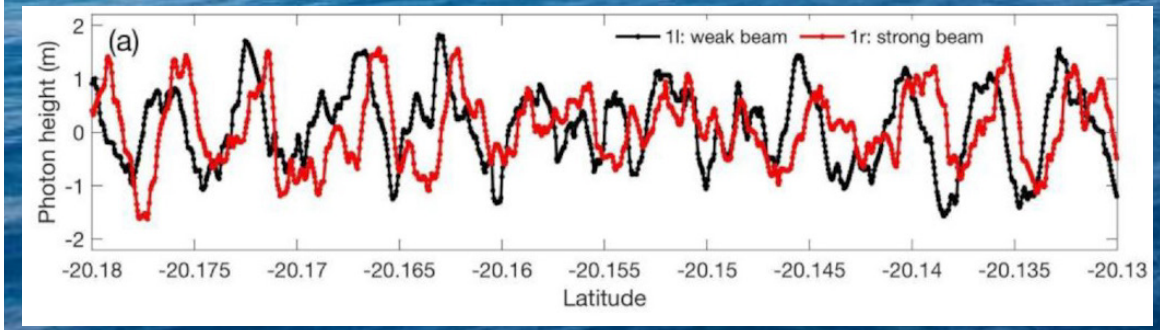


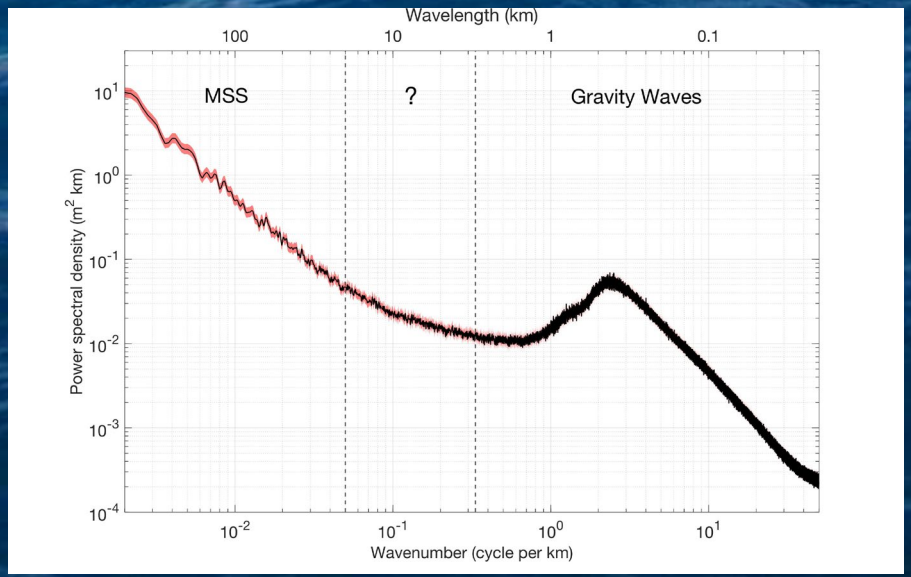
So what?

- Scale separation between QG turbulence and surface wave dynamics:
  - The red and blue zones have been traditionally explored independently
- But ICESat2 resolves scales where many processes overlap, as will SWOT
- Our goal: connect red and blue segments of the spectrum



Spaceborne laser altimetry: ICESat-2





Geophysical Journal International

Geophys. J. Int. (2021) **226,** 456–467
Advance Access publication 2021 March 02
GJI Gravity, Geodesy and Tides

doi: 10.1093/gji/ggab084

Assessment of ICESat-2 for the recovery of ocean topography

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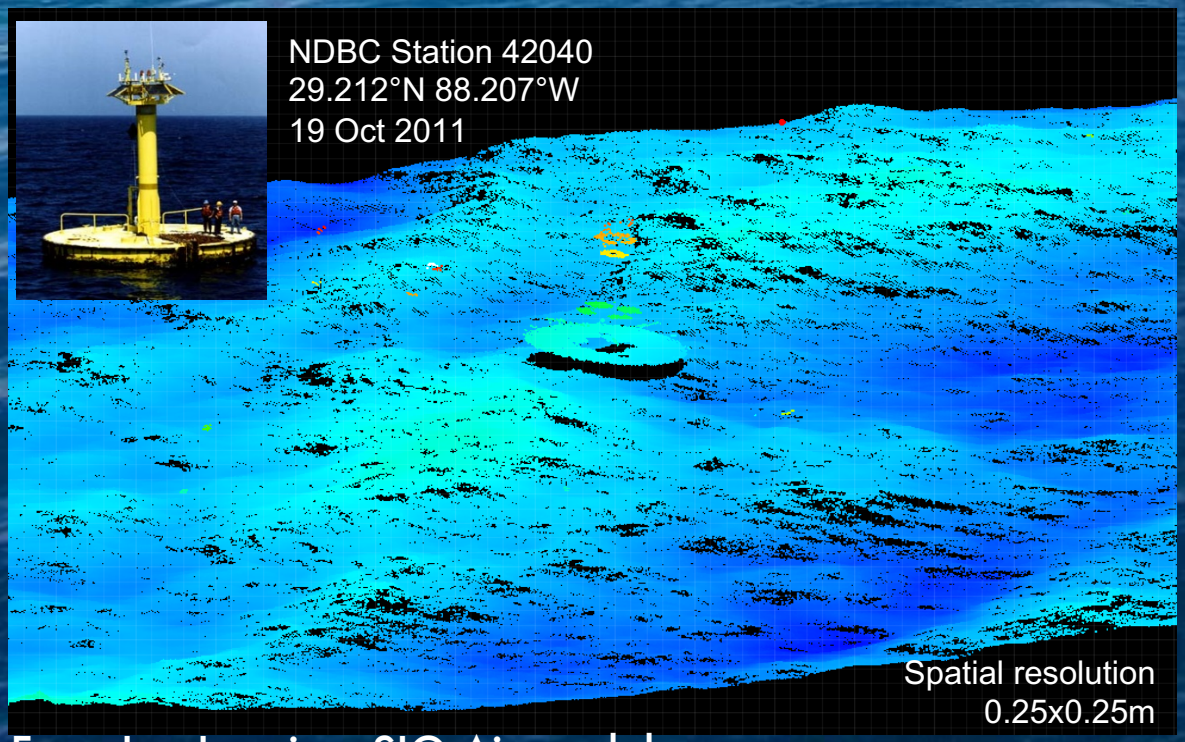
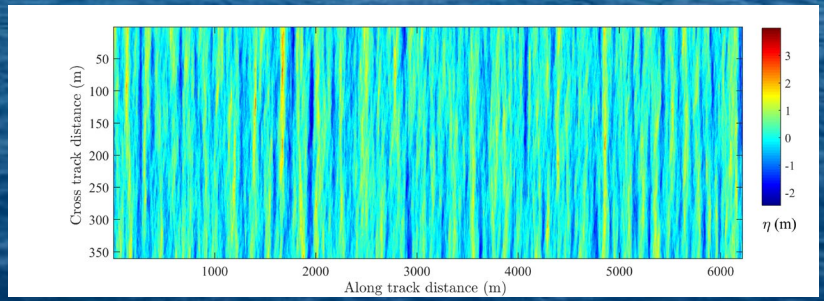
- How does ICESat-2 view the ocean surface?

https://doi.org/10.1093/gji/ggab084

Airborne laser altimetry: Modular Aerial Sensing System (MASS)



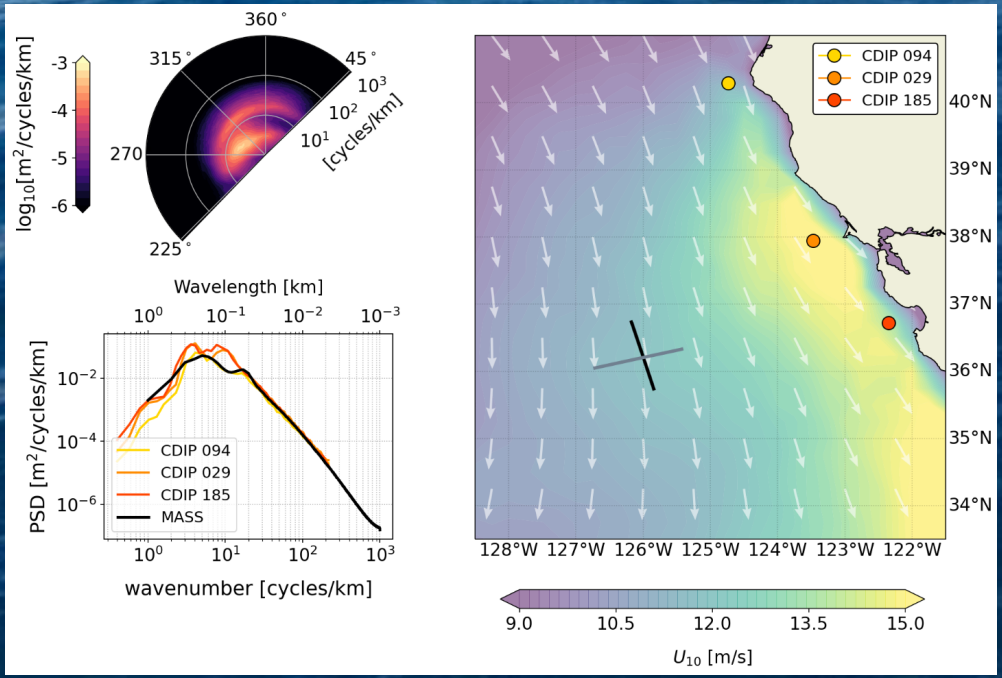
From Luc Lenain - SIO Air-sea lab



- Scanning Lidar (~ 500 m swath)
- Measures the SSH with sub-meter horizontal resolution
- Resolves the 2D wave field

SWOT pre-launch airborne campaign (April 9, 2019)

- Measurements from the Scripps Institution of Oceanography (SIO) MASS

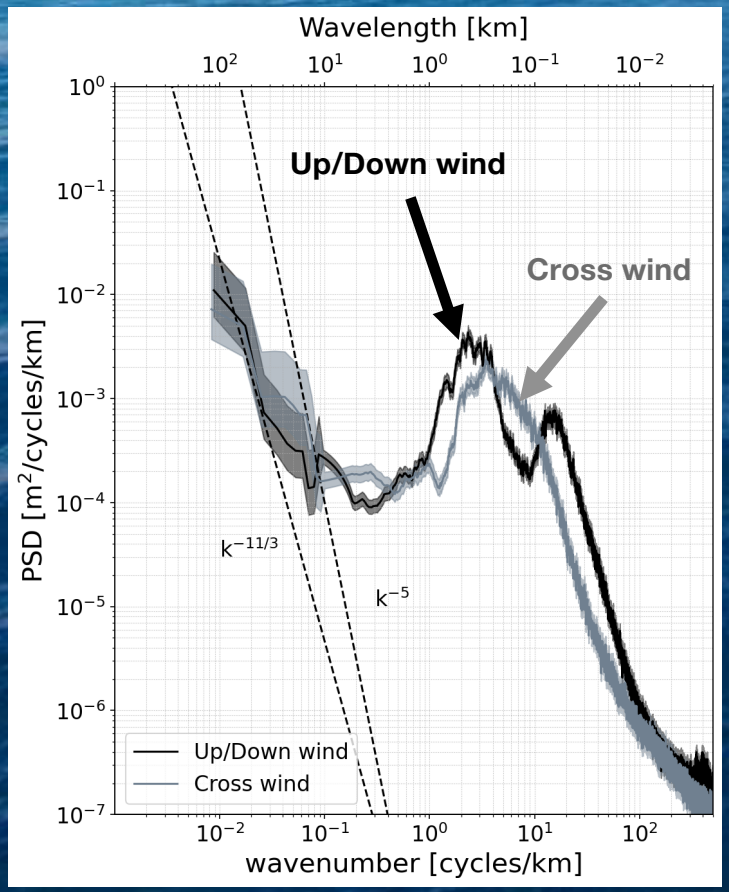


- Strong winds 11-15 m/s
- Swath width: ~ 500 m
- Hs = 3 m

Sea:
T_p = 6 s
λ_p = 60 m
θ_p = 321°

Swell:
T_p = 11 s
λ_p = 200 m
θ_p = 308°

Across-track averaged spectrum



Villas Bôas et al. (2022)
https://doi.org/10.1029/2021GL096699

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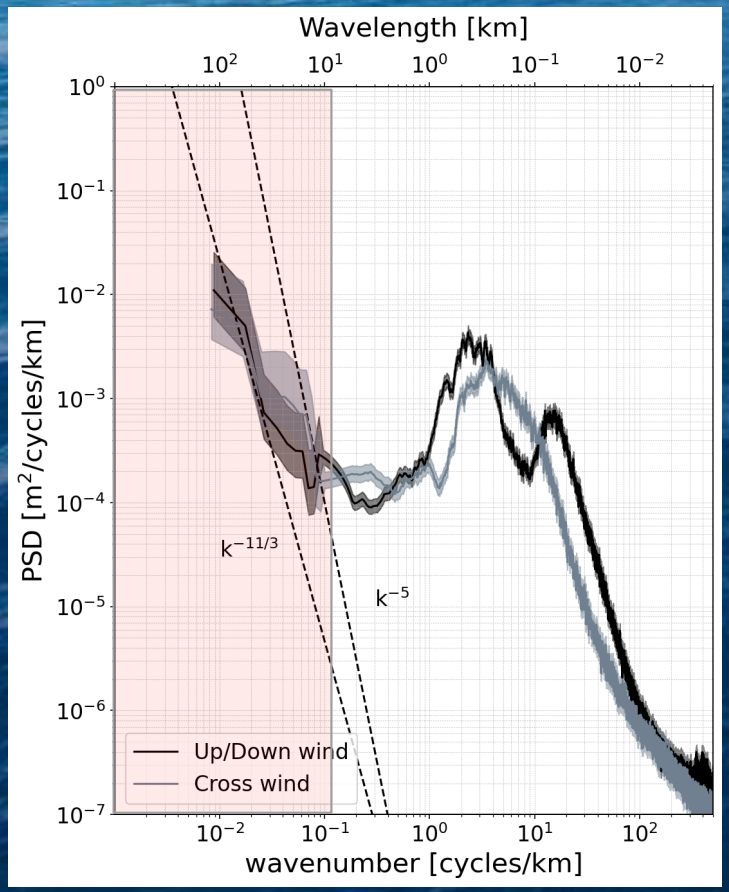

- The red zone ($k < 10^{-1}$ cycles/km)
  - The spectrum from MASS is red and typical of mesoscale turbulence + Garrett-Munk spectrum
  - Falls with a $k^{-11/3}$ to k^{-5} slope

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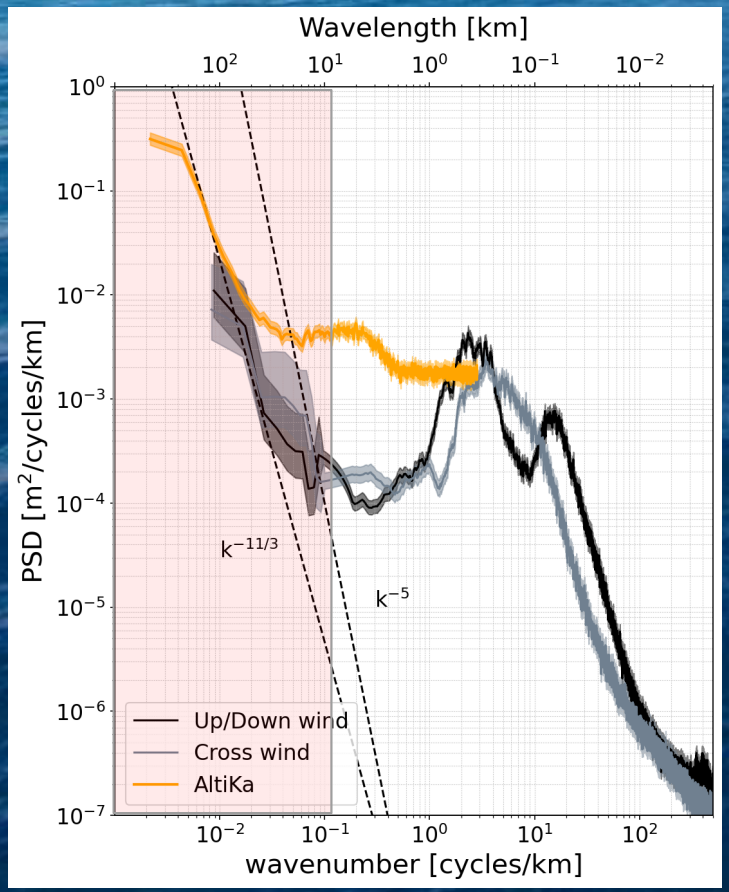

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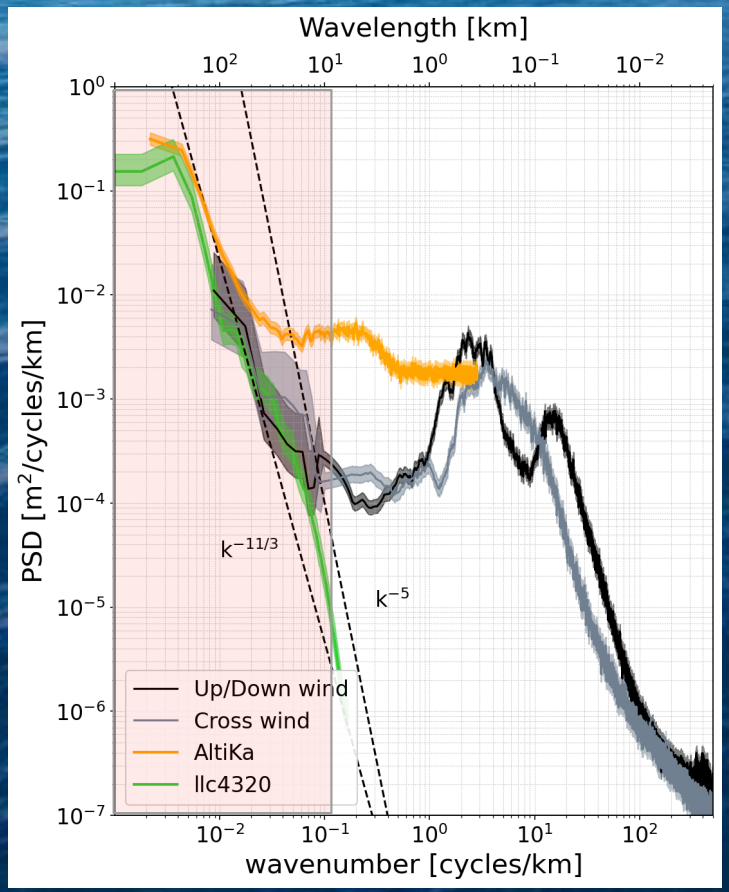

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  - Consistent with the llc4320

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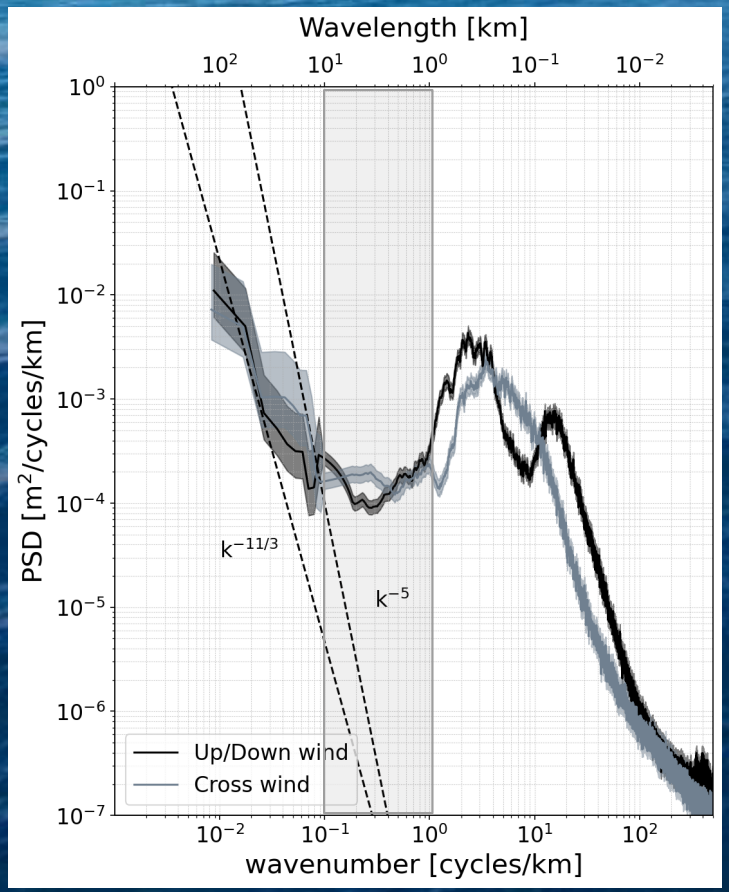
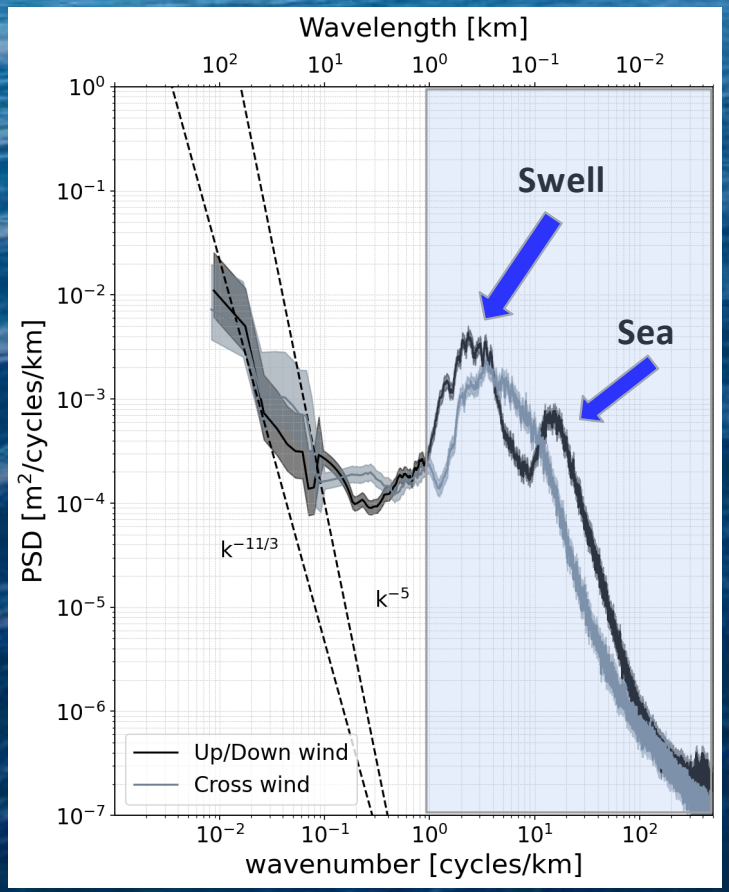


- The gray zone ($10^{-1} < k < 1$ cycles/km)
  - The spectrum flattens out becoming fairly white
  - Many dynamical processes could be contributing to the SSH variance at these scales
  - Consistent with energy levels from Infra-Gravity waves (e.g., Ardhuin et al, 2013; Aucan & Ardhuin, 2013)

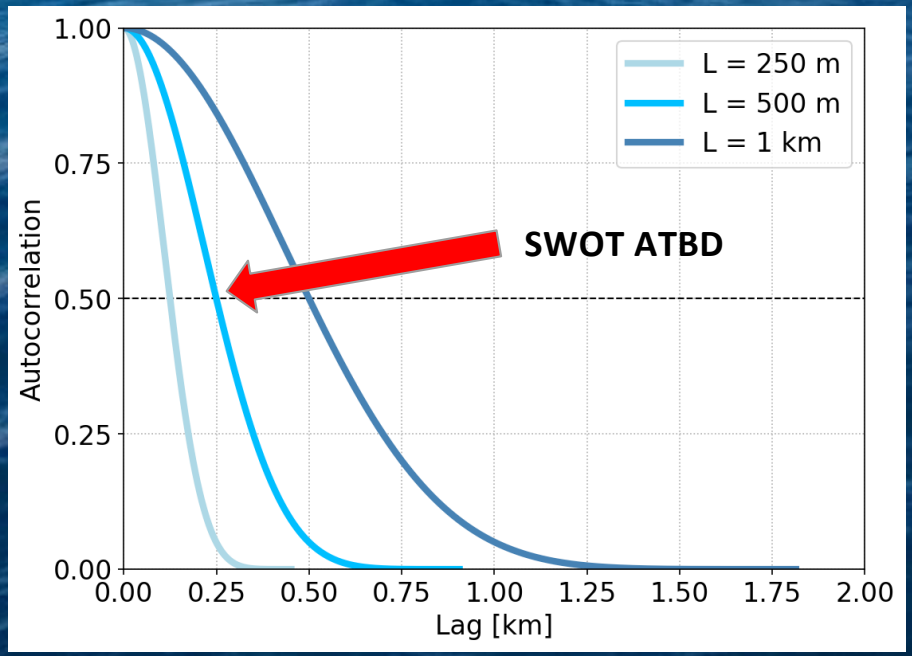
Across-track averaged spectrum



- The blue zone (k > 1 cycles/km)
  - At high wavenumbers the spectrum is blue and dominated by surface waves
  - We see both the swell and sea peaks
  - Up/down-wind and cross-wind are remarkably different

Filtering the surface wave signal

- Blackman-Harris window in the azimuth direction



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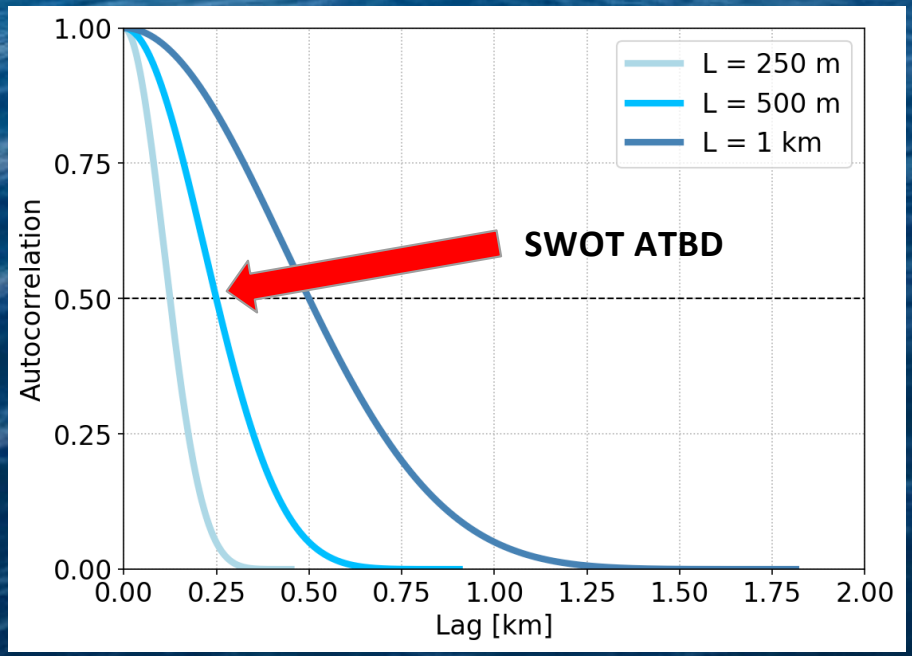
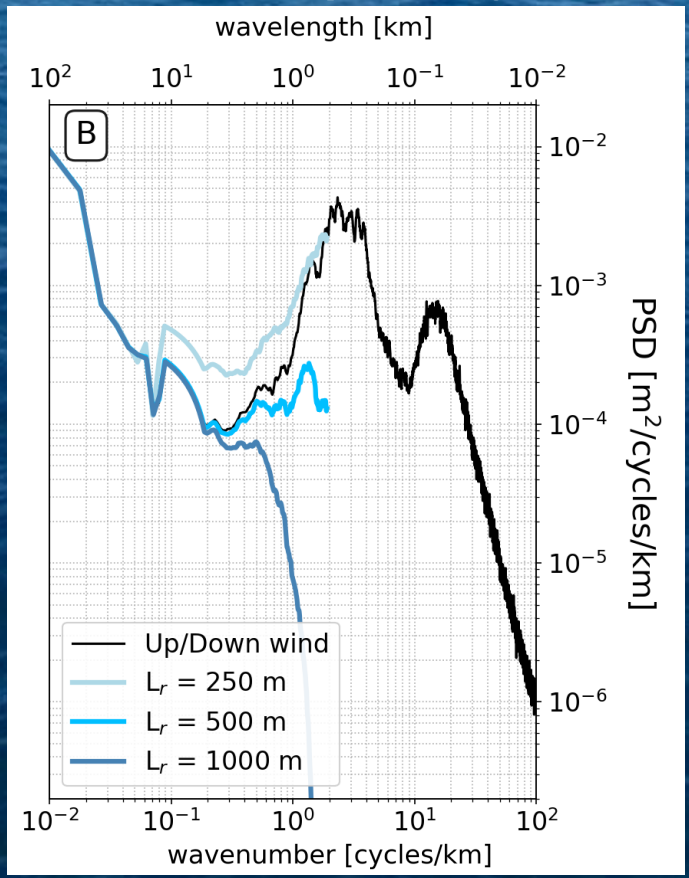


250 m posting



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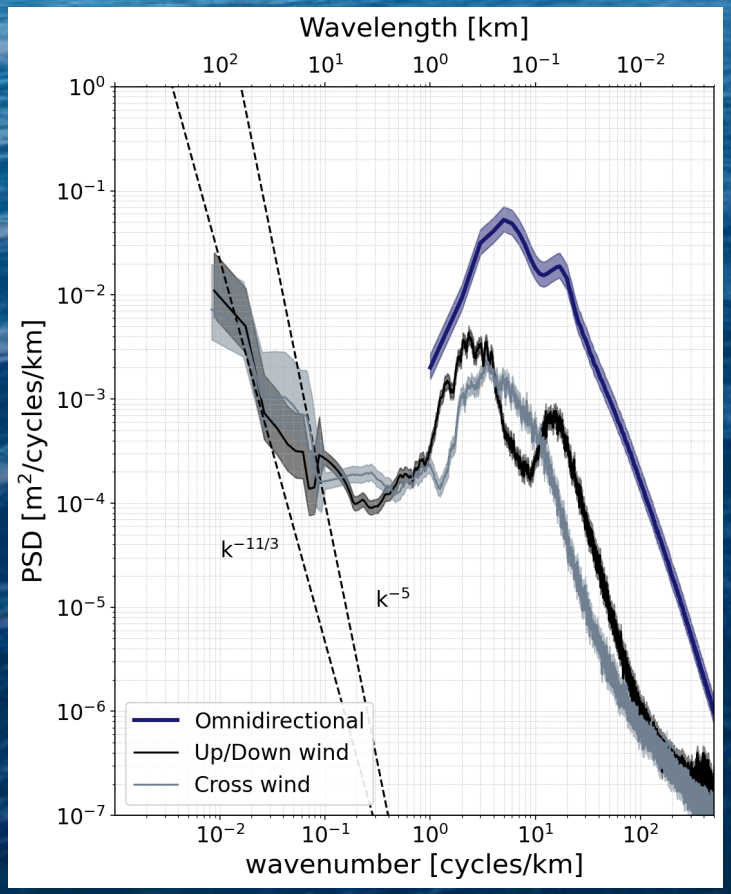
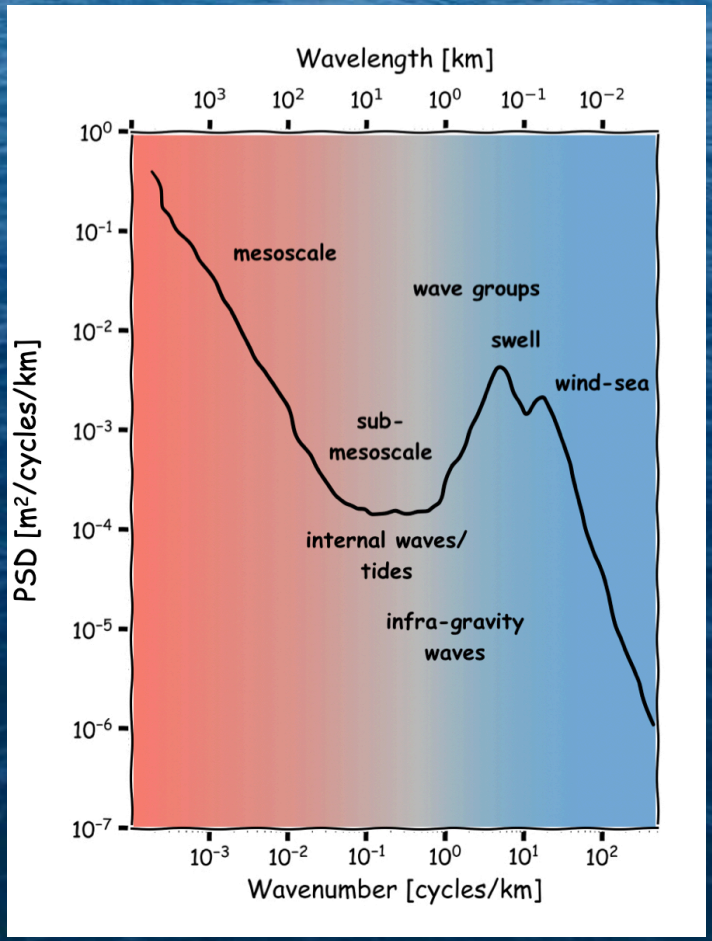


- The blue zone (k > 1 cycles/km)
  - The peak is shifted towards lower wavenumbers (especially for the swell)
  - The variance is much lower in comparison to the omnidirectional spectrum

Take aways

- The variance in the **surface wave** band can be **over 20 times larger** than the variance at submesoscales.
- Without directional wave information, it could be challenging to interpret the SSH variability at scales from 1 km to 100s of meters
- SWOT's OBP filter should remove most of the surface wave energy. The potential for aliasing will depend on dominant wavelength, height, and direction.
    - Higher waves → filtering is less effective
    - Higher relative angle → filtering is less effective



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