Global spectral characteristics from 1Hz along-track altimetry

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Spectral analysis of L3 SLA

- In preparation for the future SWOT mission we analyzed the spectral signature of existing along-track observations in order to tease-out the spatial boundary between geostrophically balanced and unbalanced motions from 1D observations.

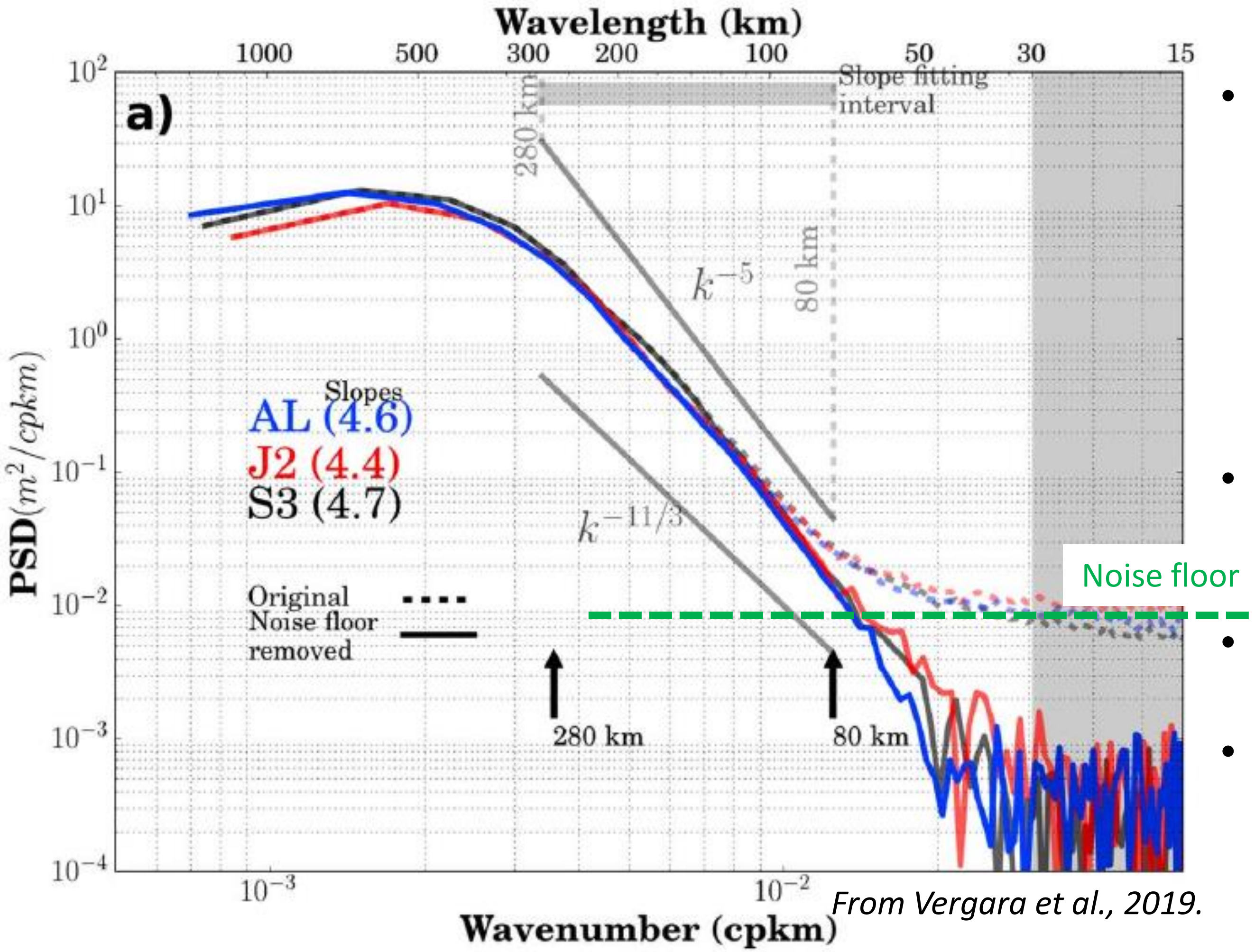
- We adapt our previous analysis in order to increase the statistical confidence of our results in a spectral region that is close to the observability limit of current-generation altimeters.

Objectives:

- We use global L3 Sea Surface Height (SSH) observations in order to characterize the mesoscale to sub-mesoscale spectral transition.

- To revise previous results on spectral analysis of SSH.

Spectral slope – individual fit



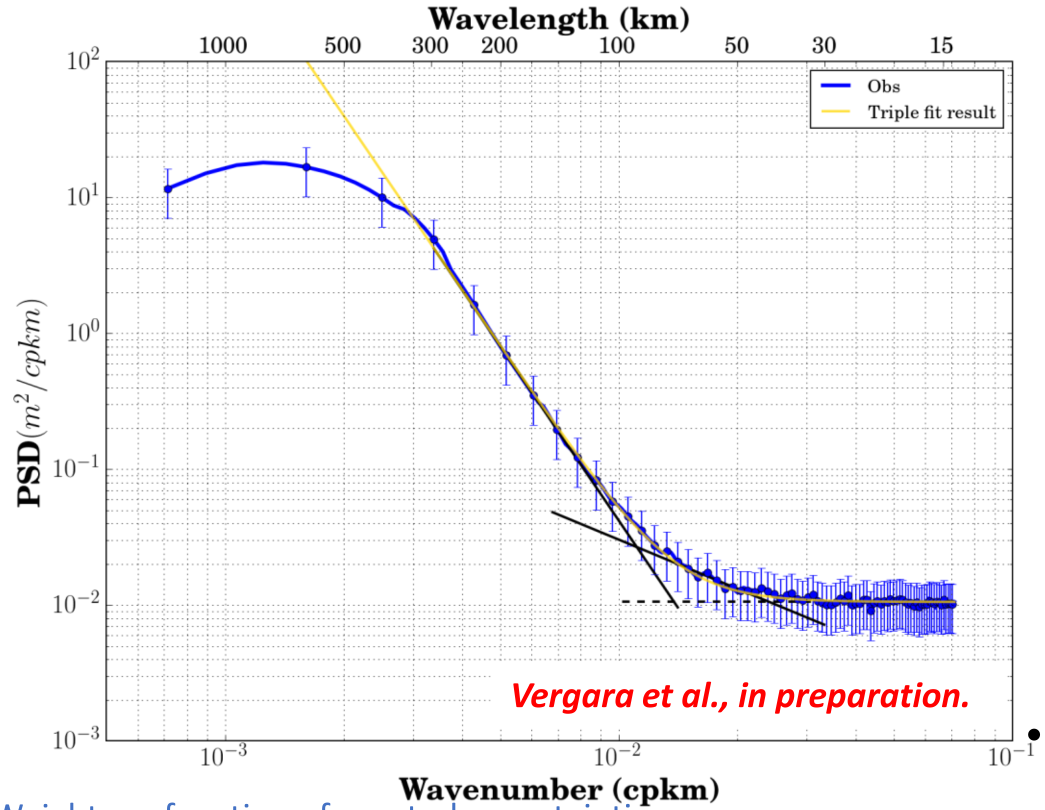
From Vergara et al., 2019.

- Analysis of the spectral characteristics (noise level, spectral slope) is done "piecewise", focusing on given spectral wavelength ranges:
  - a **mesoscale wavelength range** (either fixed : Dufau et al., 2016; Xu and Fu, 2012; or geographically dependent: Vergara et al., 2019),
  - **noise level** (30-15km).
- Spectral slopes and noise levels are then fitted independently.

- In reality, spectral estimates at adjacent frequencies are not completely independent due to spectral leakage
- Eg : applying a windowing function on the FFT (even the sampling frequency aliases the spectral estimates but the effect is minor in comparison).

- Alternative : analyze the full spectrum range at once, in order to properly describe its characteristics.

Optimal non-linear fit



Weights as function of spectral uncertainties

$$S = \sum_{i=1}^{m} W_{ii}\left(y_i - f(x_i, \beta\,)\right)^2$$

Observed spectrum

Model f(x)

- Instead of using a standard least-squares fit over a defined wavelength range, we fit a non-linear model to the wavenumber spectral curve, composed of the sum of three straight lines (f(x)).
- By applying an optimal interpolation algorithm we find the coefficients that minimize the deviations from the observed spectra (function *S*).
- This methodology also takes into account the chi-square confidence intervals (CI) obtained from spectral estimates (95% CI is depicted by the blue bars in the figure).

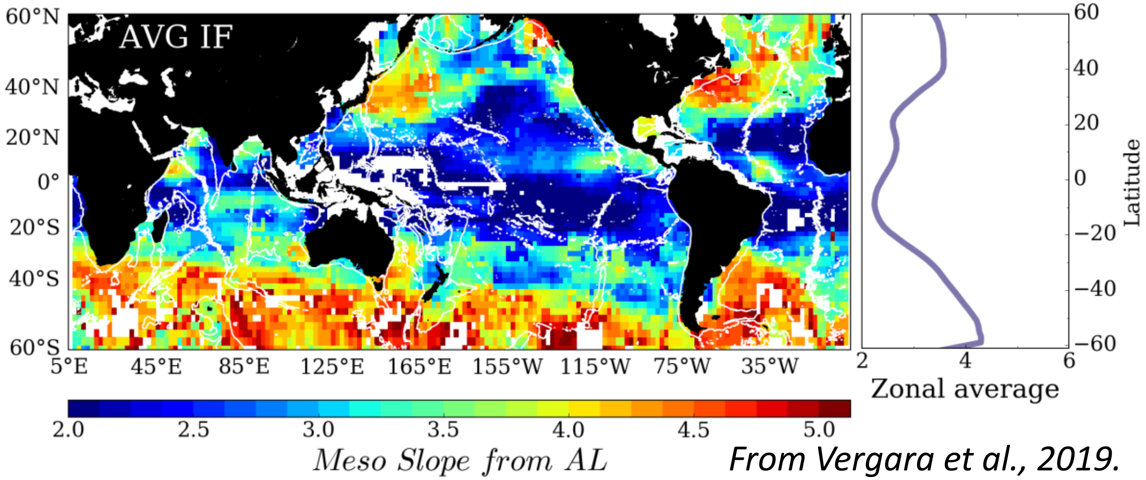
Model used to fit the observations:

$$f(x) = x^{a_1}/10^{-b_1} + x^{a_2}/10^{-b_2} + x^{0}/10^{-b_3}$$

- The model is constructed using three straight lines: two lines that capture the spectral shape in the meso and sub-mesoscale wavelength range and a flat line (slope=0) that captures the noise level (assuming a white noise floor).
- This model allows for the characterization of a second spectral slope between the “mesoscale region” and the noise level (30-15 Km). This wavelength range is likely a combination of geophysical signal and MSS errors.

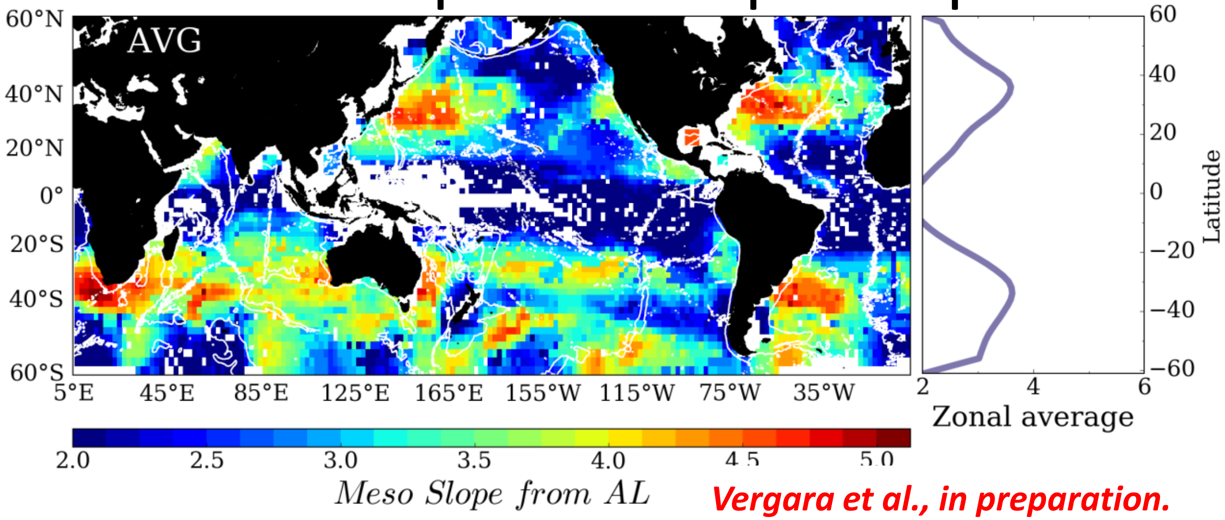
Results on mesoscale spectral slope

Mesoscale spectral slope - individual fit



From Vergara et al., 2019.

Mesoscale spectral slope - triple fit



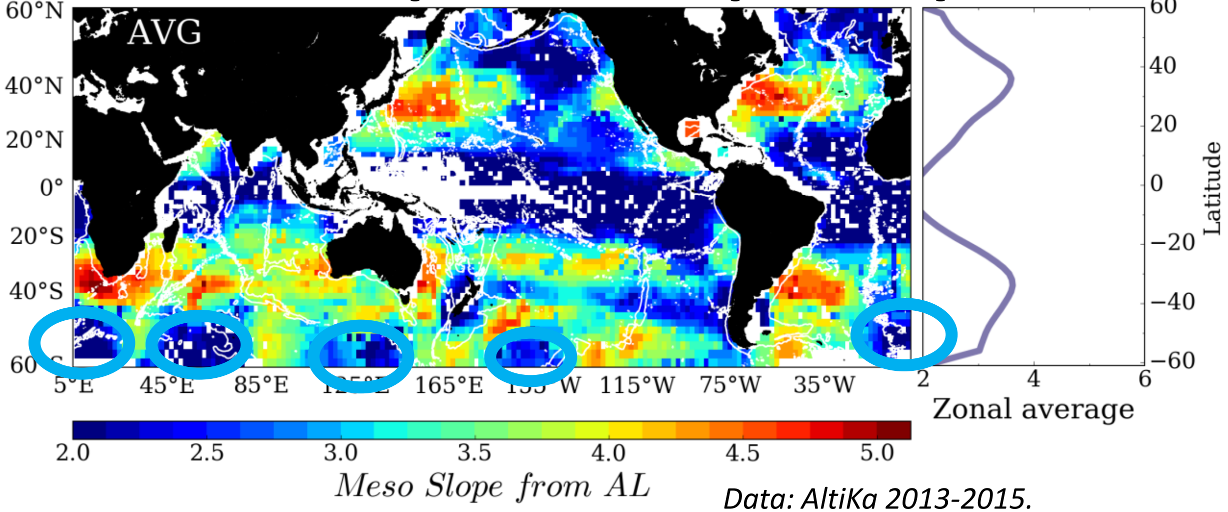
Vergara et al., in preparation.

Data: AltiKa 2013-2015. White contours on both figures correspond to the 3000m depth contour. Blank spaces correspond to either not enough long segments or algorithm not converging.

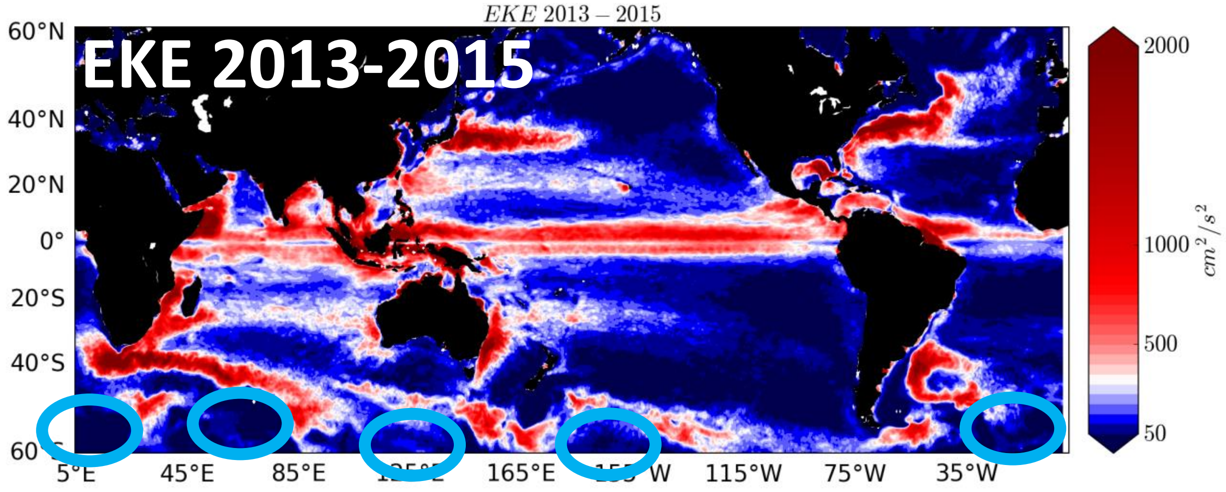
- Spectral slope values are compared between the original least square methodology and the new optimal fit approach.
- On average, both methodologies show the lowest values in the intertropical band, that increase in the mid-latitudes and finally decrease towards high latitudes.
- In the intertropical band we observe very similar spectral slope values between the two methodologies. This suggests that the spectral shape in this region is simple enough to be captured by a single straight line fit and a predefined noise floor (30-15 km).
- Towards the poles, we observe a more complex structure in the case of the triple fit in comparison with the individual fits. With the triple fit, steeper spectral slope values occur over highly energetic regions on both hemispheres.

Mesoscale spectral slope & EKE

Mesoscale spectral slope - triple fit



Data: AltiKa 2013-2015.



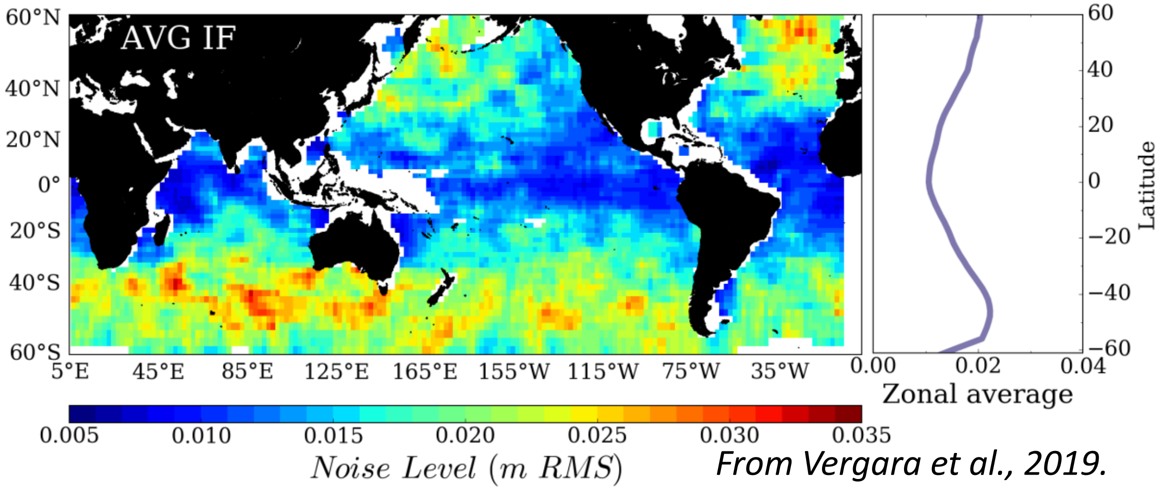
Data: AVISO

Vergara et al., in preparation.

- Low spectral slope values obtained by the multiple fit in the ACC are collocated with regions of low kinetic energy -**blue circles**. Conversely, again in the ACC, high spectral slope values are collocated with spots of high kinetic energy. This spatial variability is not observed for the single fit results, which depicts the ACC as a uniform region with spectral slope values around $\mathbf{k^{-5}}$.
- This result suggests that the complexification in our analysis of the spectral shape (multiple fit instead of a single one) is able to better separate the spatial variability of the eddy regime in the ocean, and therefore better reflects the spatial variability of the kinetic energy cascade regime.

Noise levels

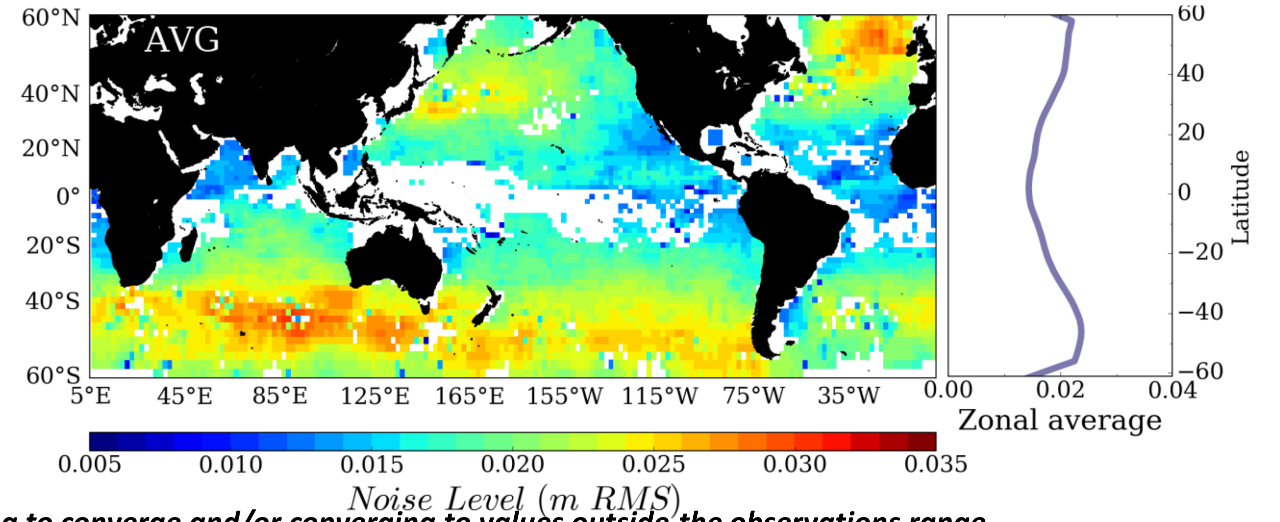
Noise level - individual fit



From Vergara et al., 2019.

Noise level - triple fit

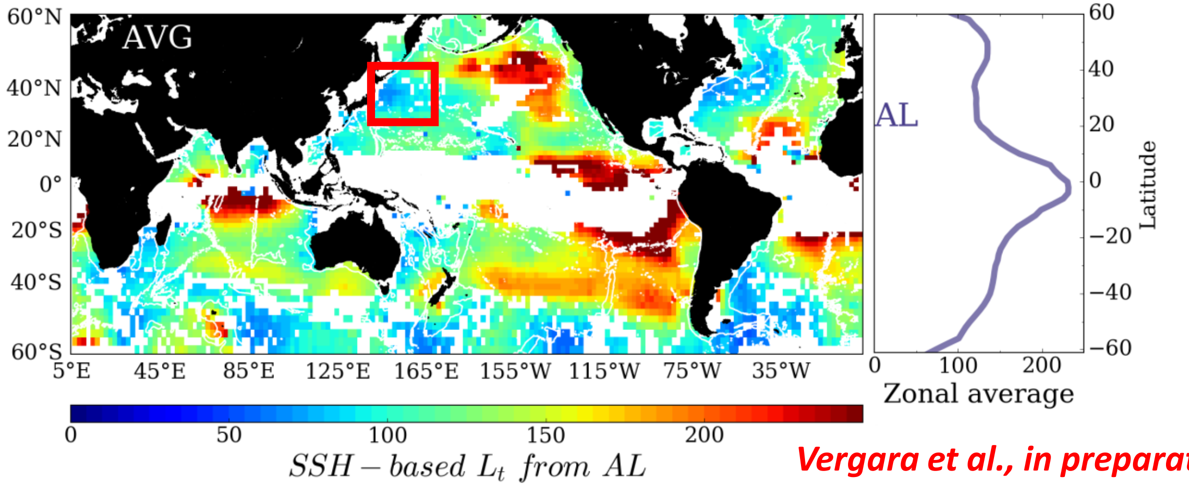
Vergara et al., in preparation.



Blank spaces correspond to either not enough long segments, algorithm failing to converge and/or converging to values outside the observations range.

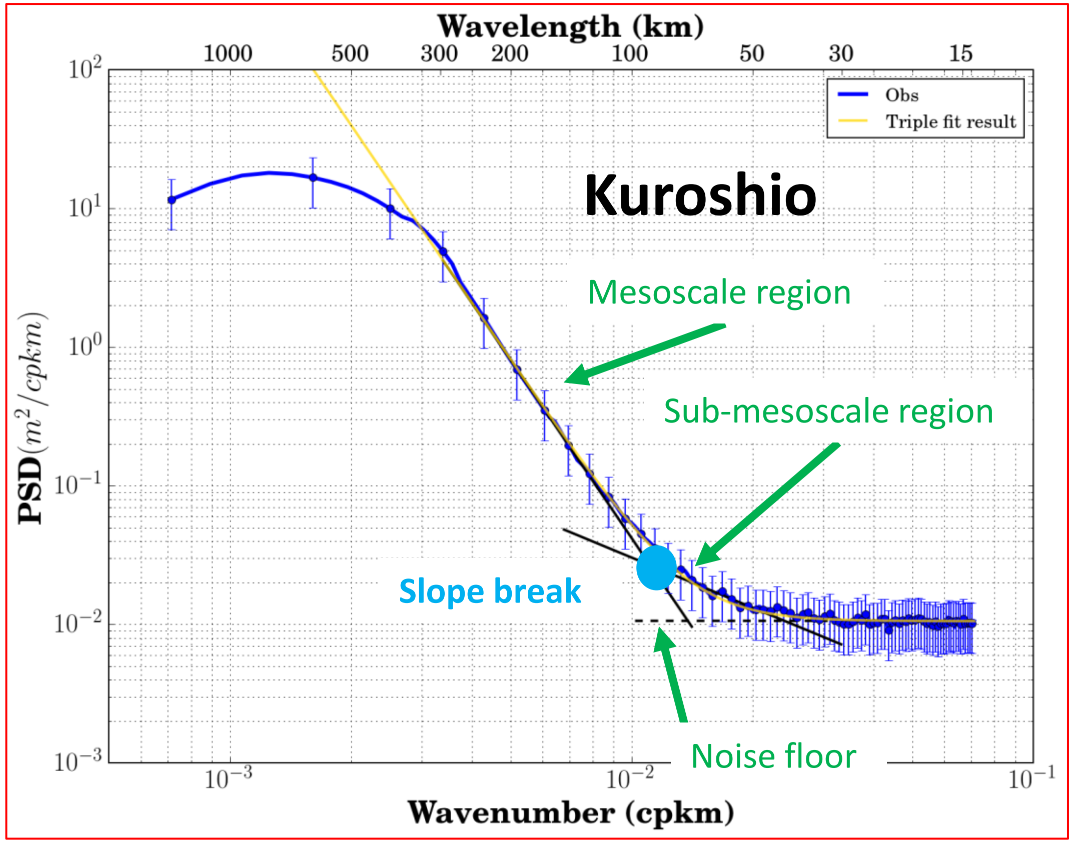
- We observe very similar noise levels for both methodologies on average, with the lowest values occurring in the mid to low latitudes and increasing progressively towards the poles.
- Although the spatial distribution of high and low values is similar between both methodologies in the mid to high latitudes, the optimal fit converges towards noise values that are 30 to 40% higher than the results from Vergara et al 2019 in the intertropical band.
- The methodology with independent fits (Xu and Fu, 2012; Dufau et al., 2016; Vergara et al. 2019), uses the average PSD value between 30 - 15 km whereas the optimal fit includes the spectral confidence intervals to weight the data in the least square fit. So the observed differences are for 2 reasons : (1) when computing the average we assign the same statistical weight to all the observations (including outliers) for the individual fit and (2) by least square fitting the complete spectrum at once, we have a better error estimation, including the error induced by the observations at adjacent frequencies in our noise estimates (neighboring spectral estimates are not independent **-> spectral leakage**)

Slope break towards sub-mesoscales



Vergara et al., in preparation.

Data: AltiKa 2013-2015. White contours correspond to the 3000m depth contour. Blank spaces correspond to either not enough long segments or algorithm not converging.



- With the 3-fit model parameters, we can estimate the wavelength at which the mesoscale spectral slope breaks towards an intermediate slope, before becoming flat (white noise floor).
- We observe that this “slope break wavelength” has a distinctive spatial distribution that tends to be concomitant with high and low kinetic energy spots.
- Overall, the slope break occurs at wavelength values below 100km in high kinetic energy regions and higher than 200km for the low kinetic energy regions.
- This spectral wavelength of the mesoscale slope break marks the boundary where the kinetic energy regime is dominated by the geostrophically balanced motions. Further interpretation of this result compared to “transition scales” estimated from models is part of our current work.

Ongoing work

- Redefining the methodology for analyzing the spectral characteristics of alongtrack altimetry reveals unexplored potential for existing data and opens exciting perspectives for the oncoming SWOT mission.

- The geographical distribution of the spectral slope values is well collocated with the regions of high and low kinetic energy: **high spectral slope values correspond with high energy regions and flat slopes with low kinetic energy spots**.

- By modeling the full spectral shape from altimetry, we can observe a **break of the mesoscale spectral slope towards a shallower intermediate slope before reaching the white noise level** at 15-30 km. This could indicate the transition from a regime dominated by geostrophically balanced motions to a regime where the energy from unbalanced motions or altimetric errors dominates the SSH spectrum at wavelengths smaller than 150km.

- Our estimates of noise level are around 30% higher in the intertropical band compared to the 30-15km average method. Differences between current and previous methods are low in the mid to high latitudes.

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