The sea surface height spectrum of internal waves reconstructed from ADCP and altimetry

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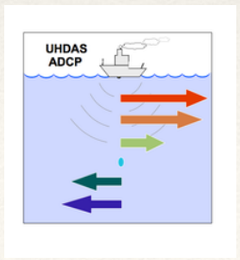
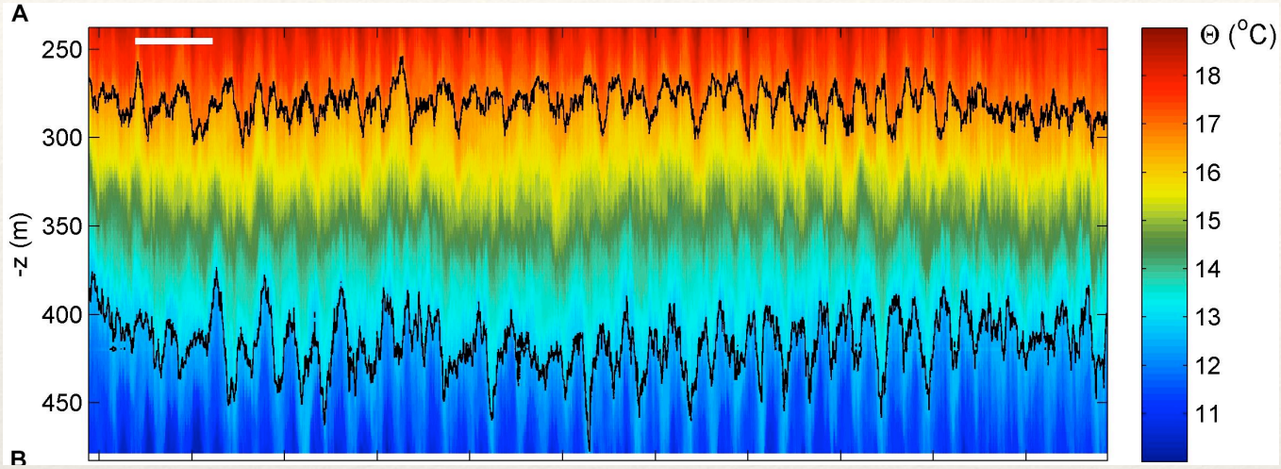


Internal waves

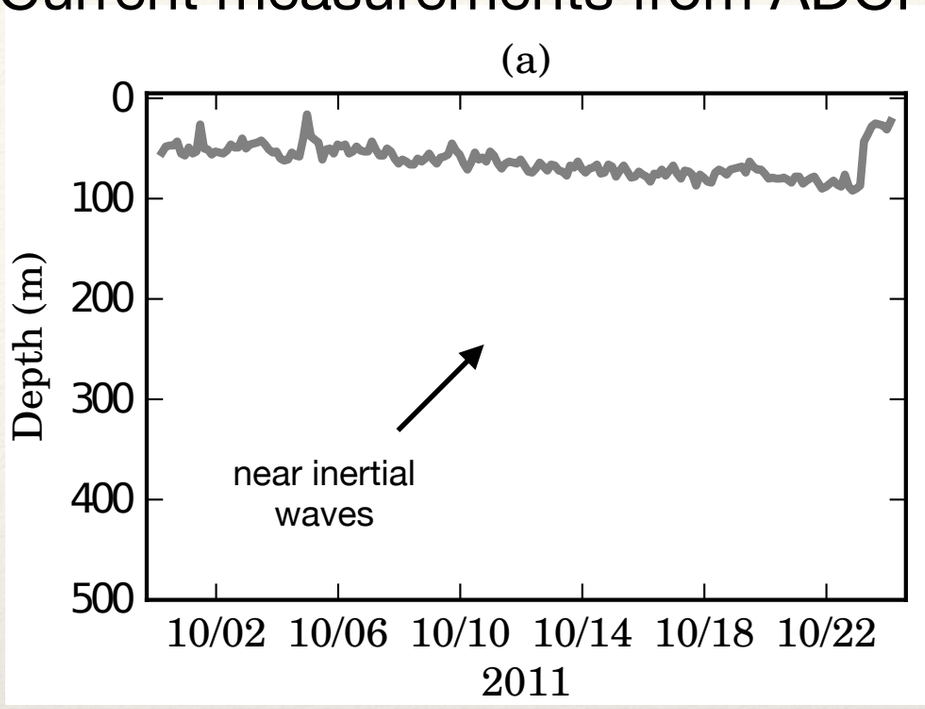
Internal wave from in situ potential temperature



from Pang et al, 2008

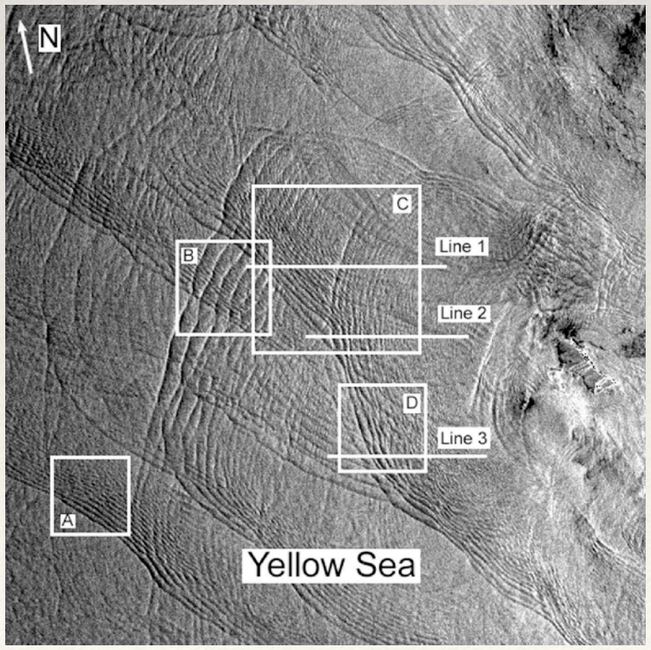
x: time over several days

Current measurements from ADCP

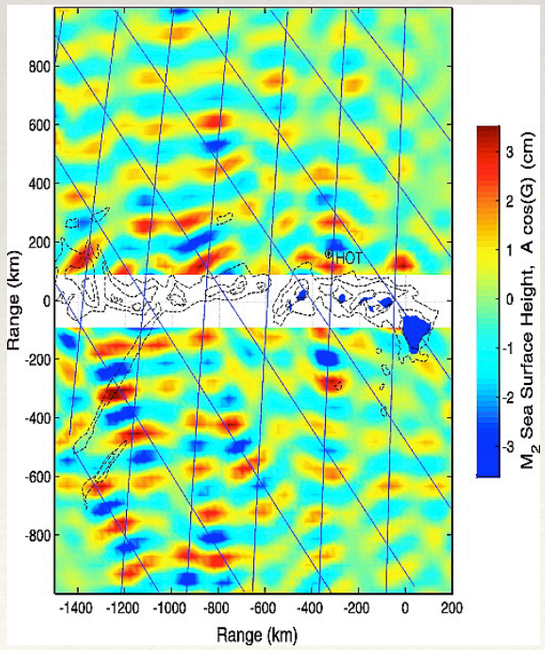


- Gravity and buoyancy forces
- Internal waves span kilometers to meters; periods from minutes to days (inertial frequency, f).
- Not geostrophic, but fully **divergent** motions affected by rotation.
- Large signal in temperature/density data and in currents
- Can be seen from space

Internal tides from space: SAR



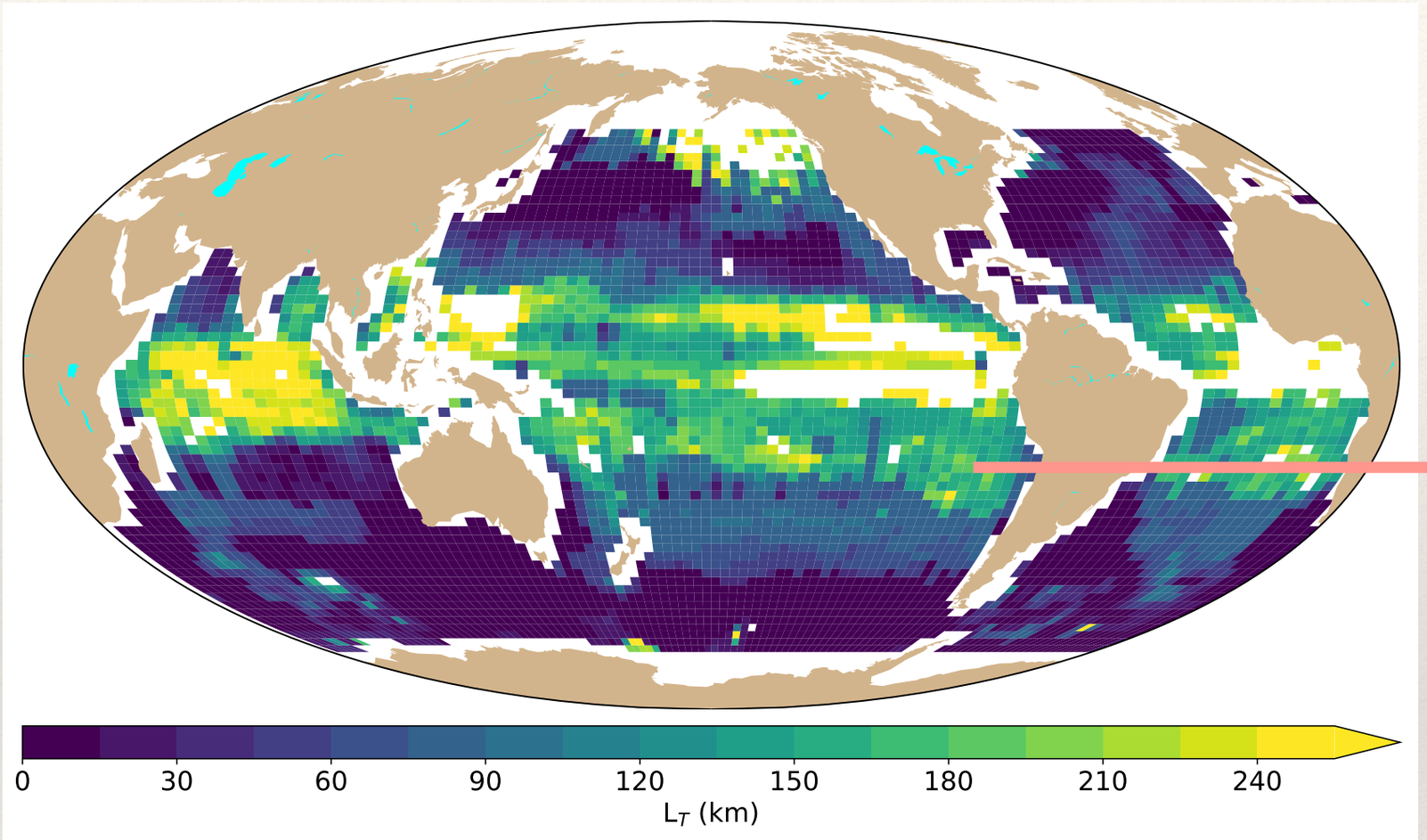
from Ming-Kuang et al, 2000



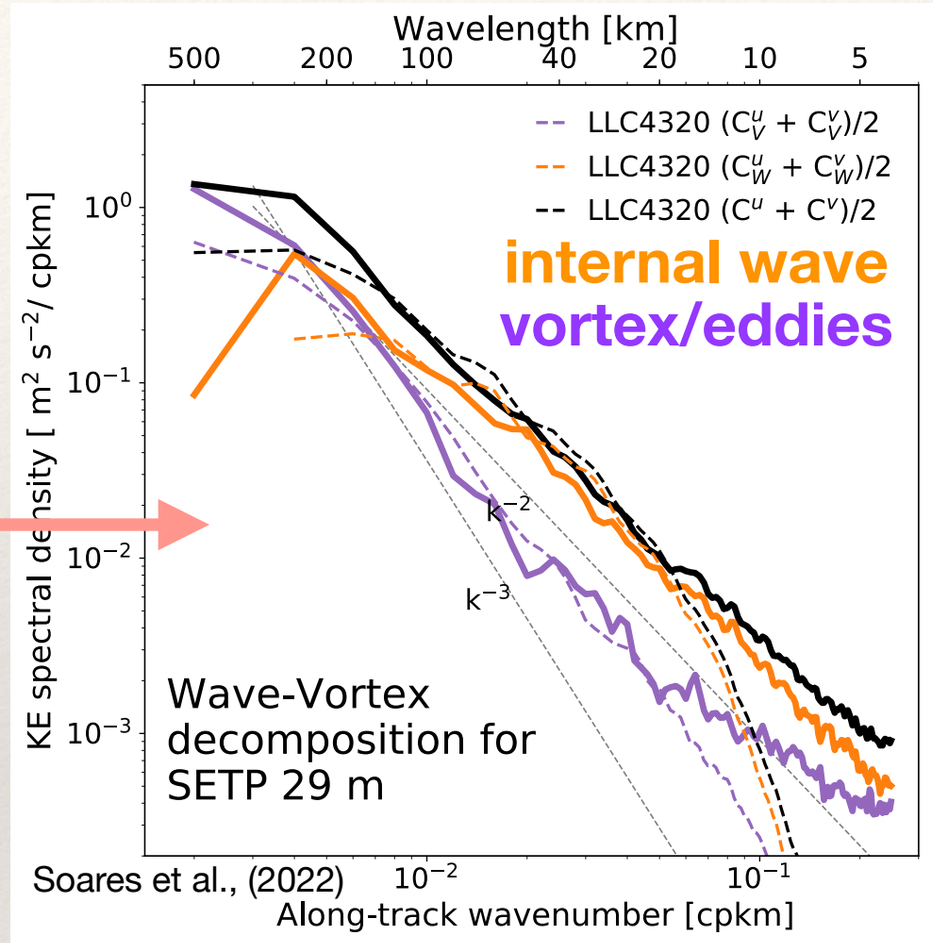
from Dushaw 2002

Tropical oceans have large internal waves

Model transition scale: eddies => waves



ADCP observations vs model

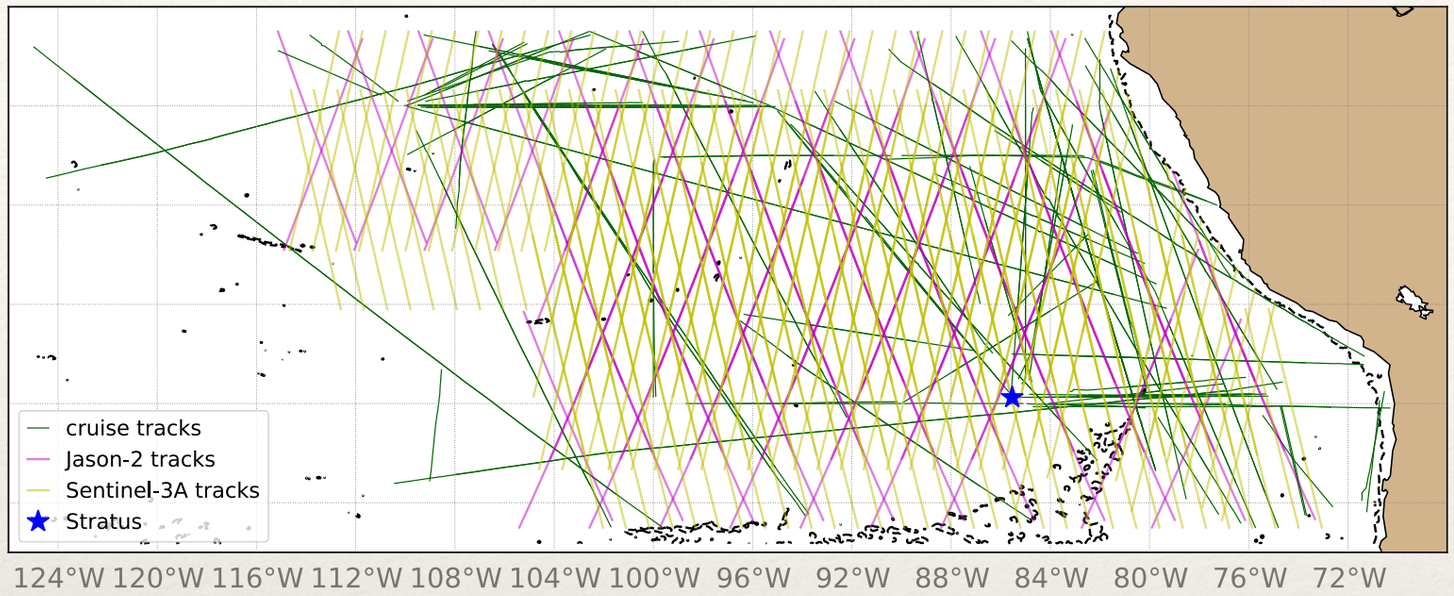


Results from Qiu et al., 2018

model is thin dashed lines above

Internal waves dominate at submesoscales in the tropics

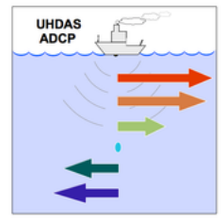
Data sets: ADCP, altimetry, mooring



WHOI air-sea group

STRATUS mooring

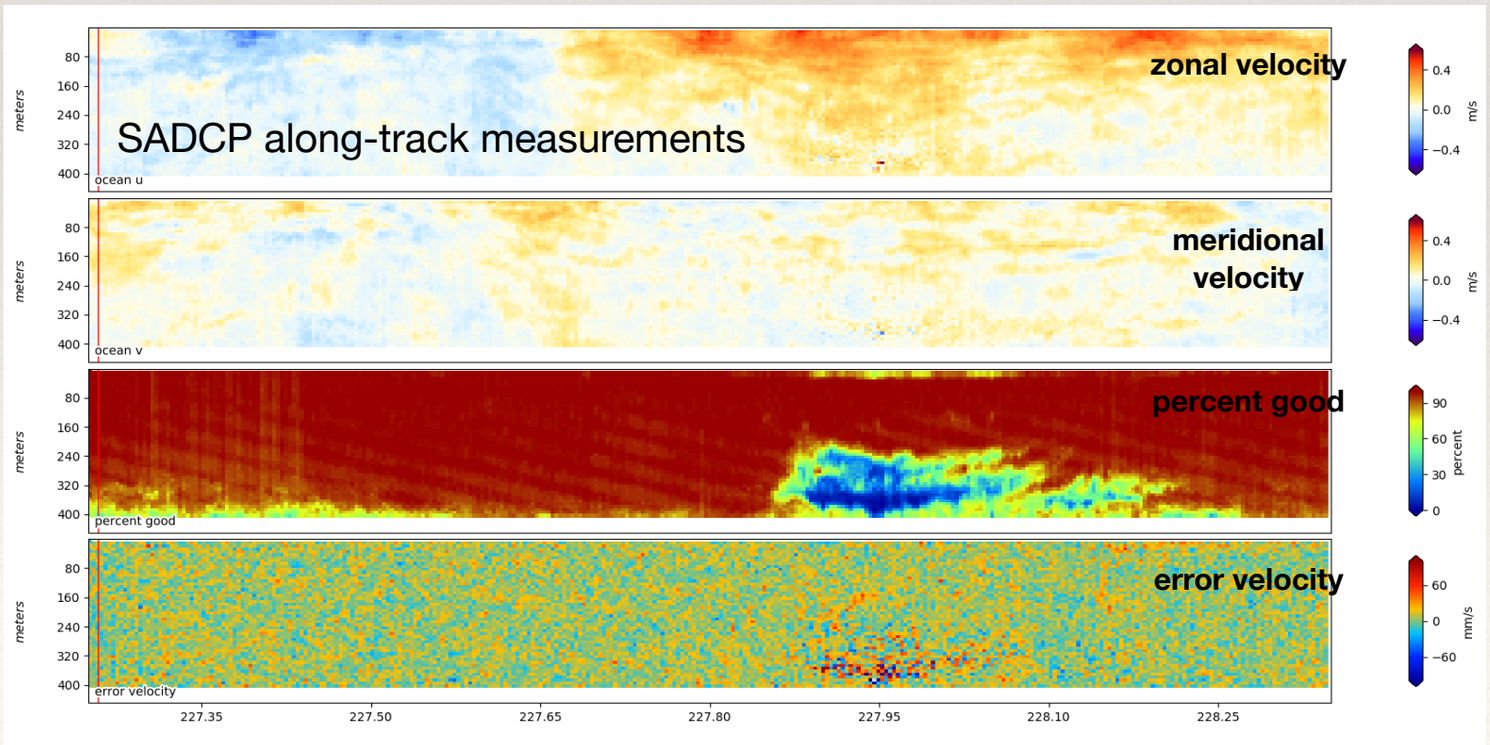
UHDAS



Underway along-track shipboard ADCP

https://sealevel.jpl.nasa.gov

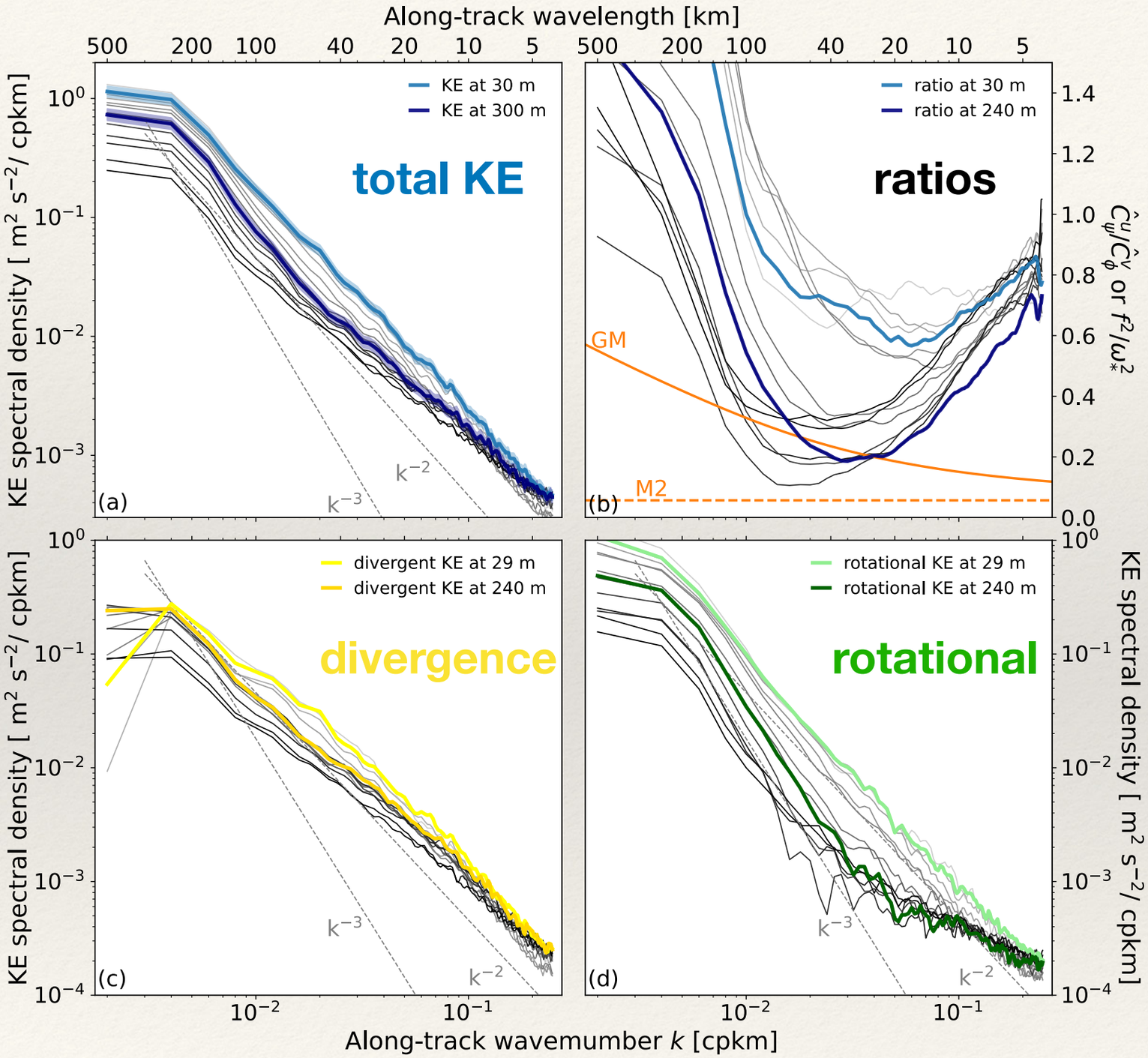
Along-track altimetry from Jason-2 and Sentinel-3 w/ ALES retracker



Southeast Tropical Pacific (SETP):

- KE wavenumber spectra from S-ADCP
- frequency spectra from STRATUS mooring
- SSH spectra from altimetry

Helmholtz decomposition in the southeast Tropical Pacific



The ratio of rotational to divergent energy is proportional to an inverse frequency ω of the wave field

We seek to understand if the larger rotational energy is from a wave field with different dominant frequencies or increased "balanced" submesoscale activity

Many depths are plotted, 30 m and 240 m are highlighted

Modification of the Bühler et al wave-vortex decomposition

wave $$KE_W = \hat{K}^{\psi}(k) + \hat{K}^{\phi}(k)$$

wave $$\hat{K}^{\psi}(k) = \frac{f^2}{\omega^2}(k)\,\hat{K}^{\phi}(k)$$

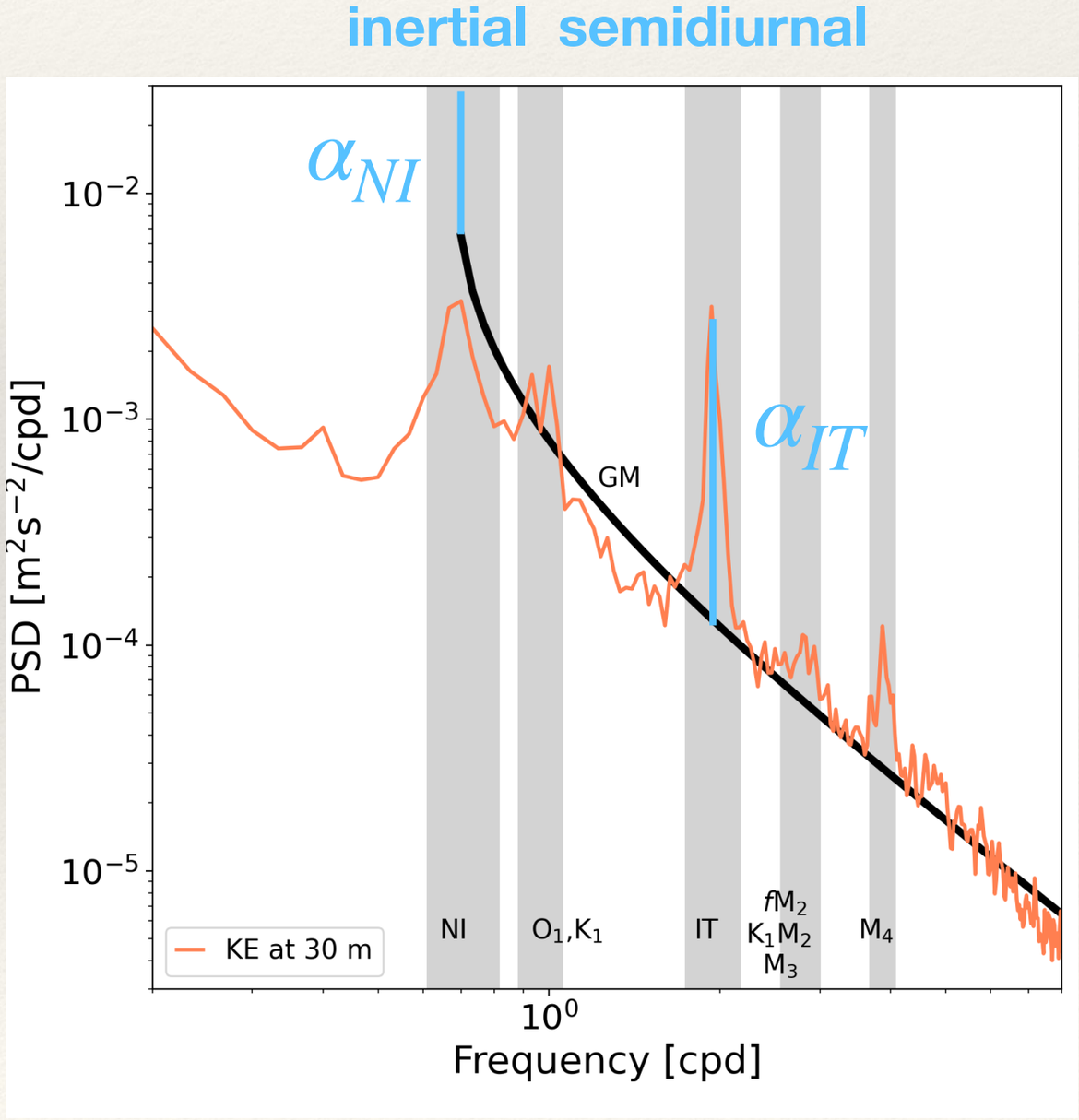
Usually given by Garrett-Munk (GM) $$\gamma_{GM}(k) = \frac{f^2}{\omega^2}$$

3 wave components: NI, IT, GM continuum.
Key assumptions for NI & IT:
- represented as delta peaks
- estimated as GM fractions (alpha) using STRATUS
- no dependence on wavenumber k

$$\frac{f^2}{\omega^2}(k) = \frac{\hat{K}_{\psi}}{\hat{K}_{\phi}} = \frac{\frac{\gamma_{GM}}{\gamma_{GM}(k)+1} + \frac{\alpha_{NI}\gamma_{NI}}{\gamma_{NI}+1} + + \frac{\alpha_{IT}\gamma_{IT}}{\gamma_{IT}+1}}{\frac{1}{\gamma_{GM}+1} + \frac{\alpha_{NI}}{\gamma_{NI}+1} + \frac{\alpha_{IT}}{\gamma_{IT}+1}}.$$

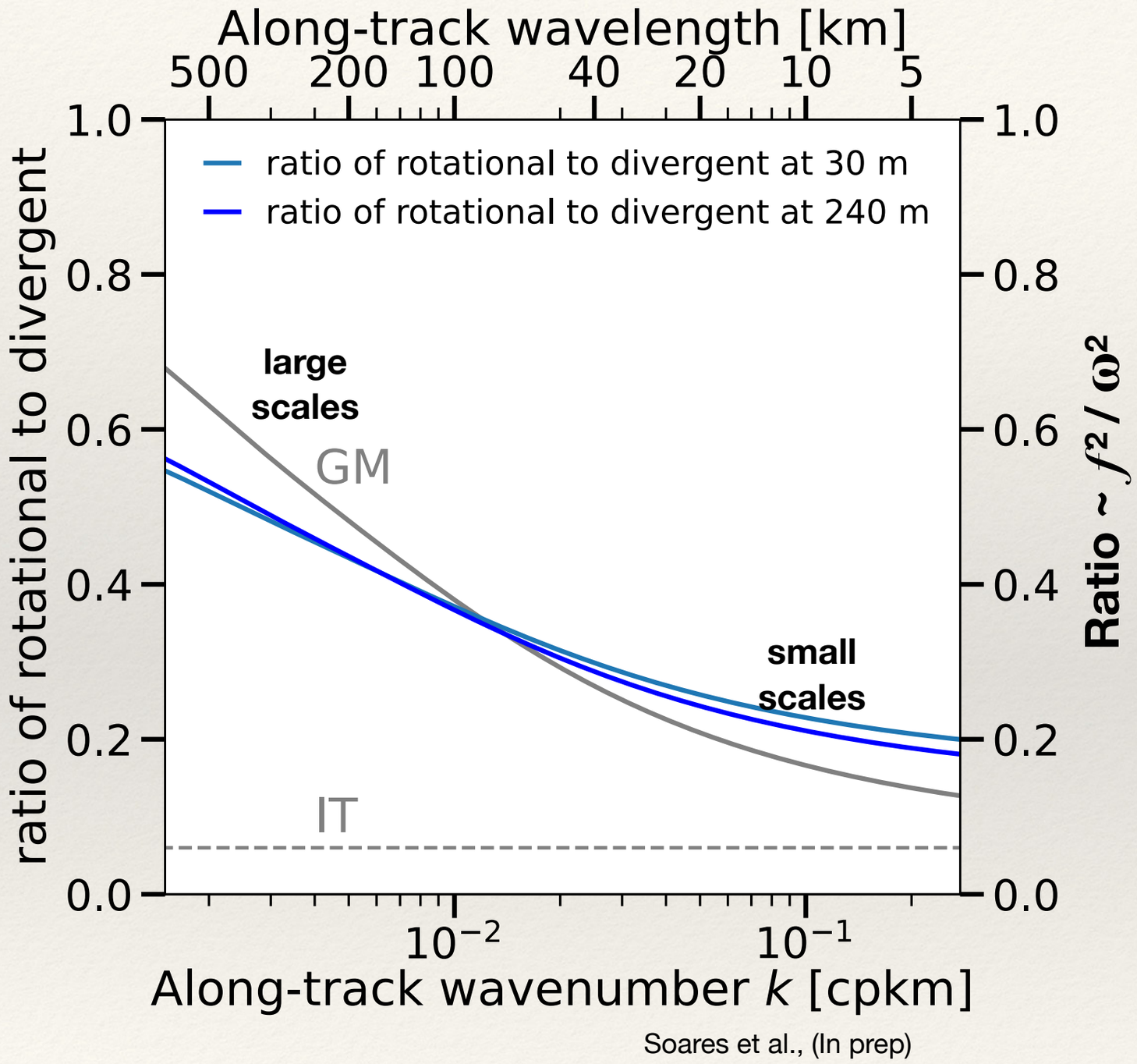
Combine moorings (frequency) with SADCP (wavenumber)

Frequency spectra from STRATUS mooring in the SETP



Mooring based wave decomposition

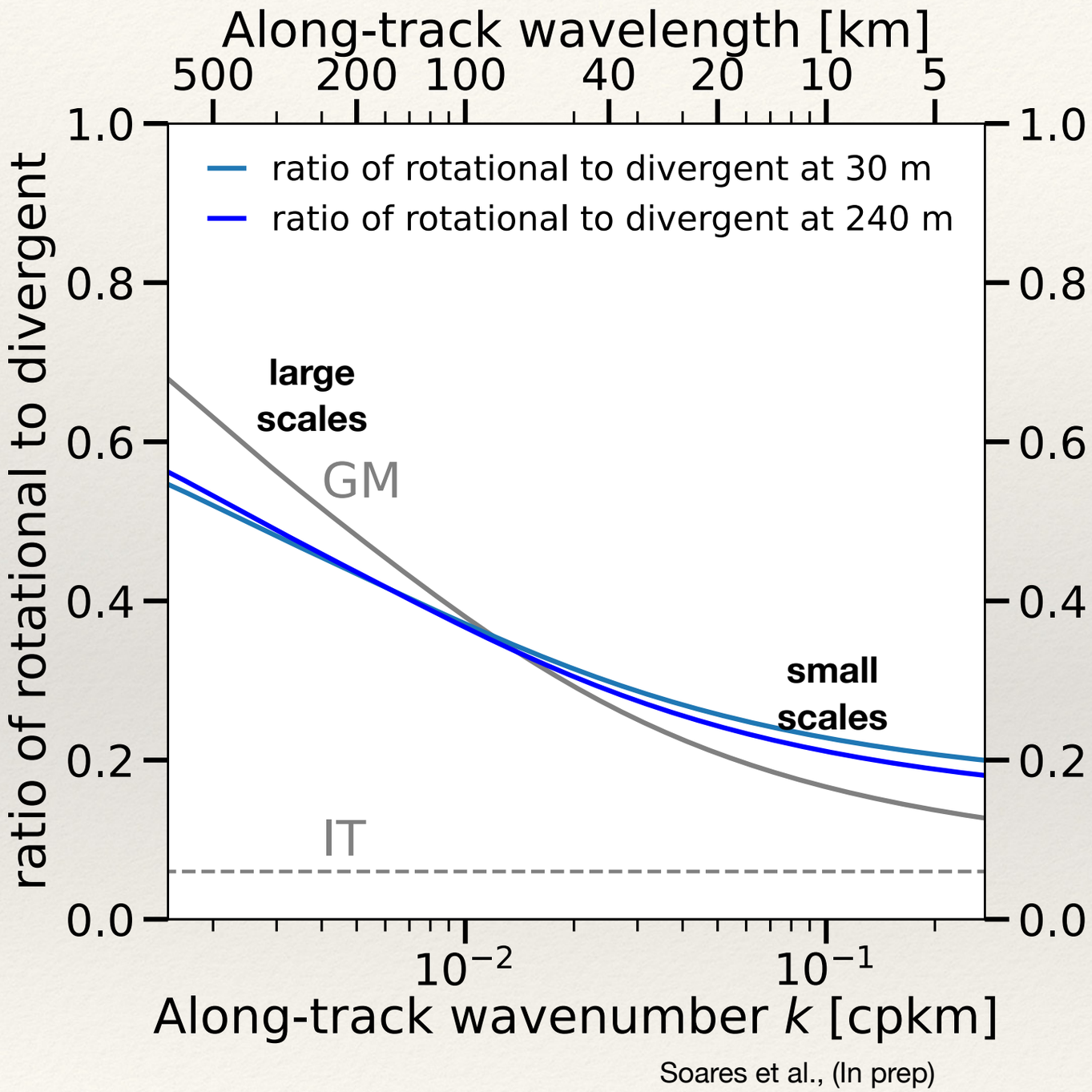
STRATUS mooring



Soares et al., (In prep)

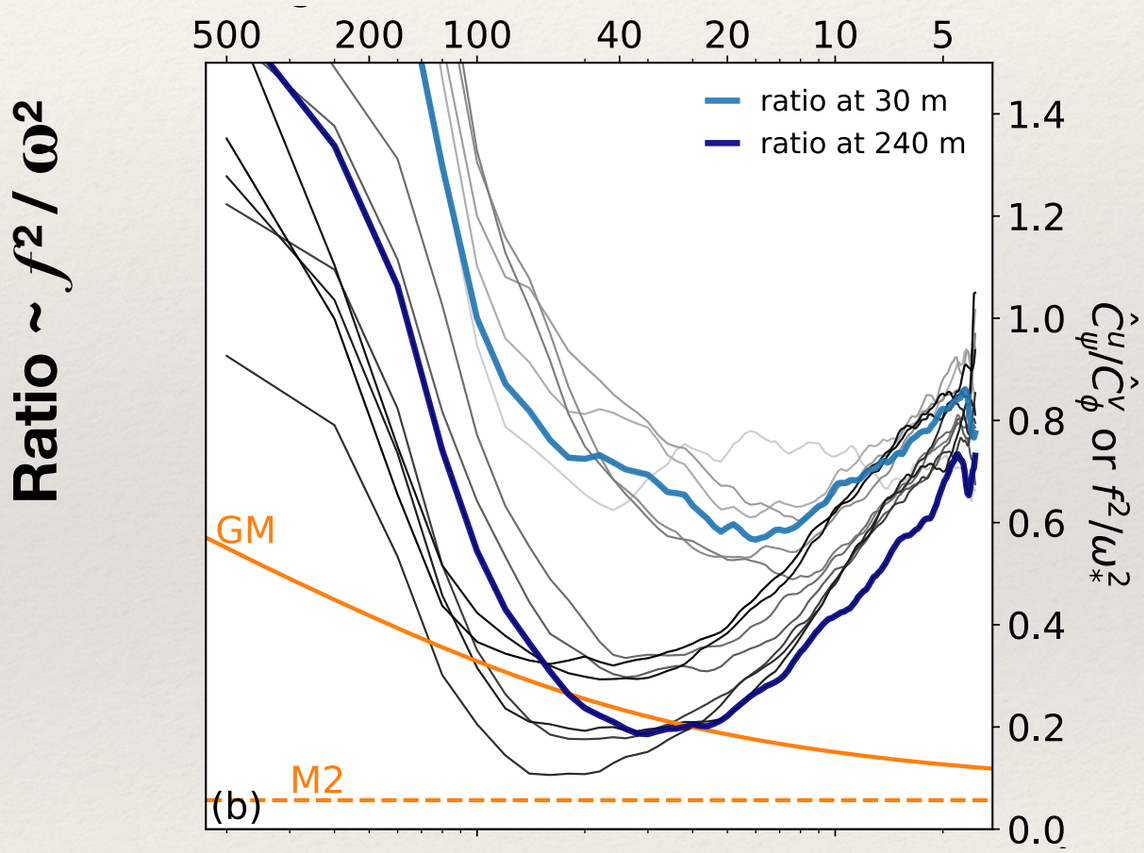
- GM underestimates **wave KE** at small scales and overestimates at large scales.
- More Near-Inertial waves at small scales.

Diagnosing the Helmholtz decomposition



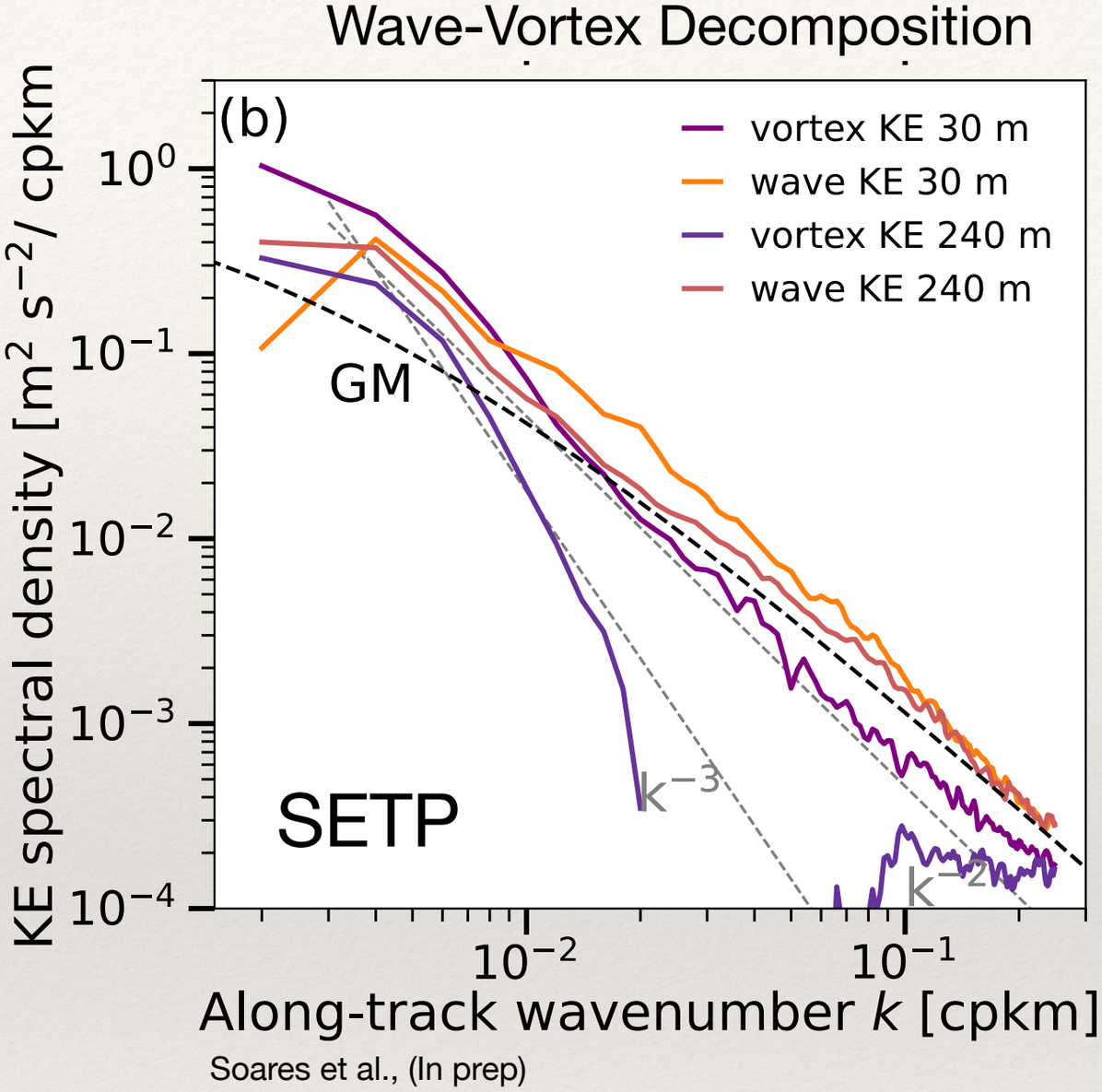
Soares et al., (In prep)

Corrections too small to explain near-surface behavior

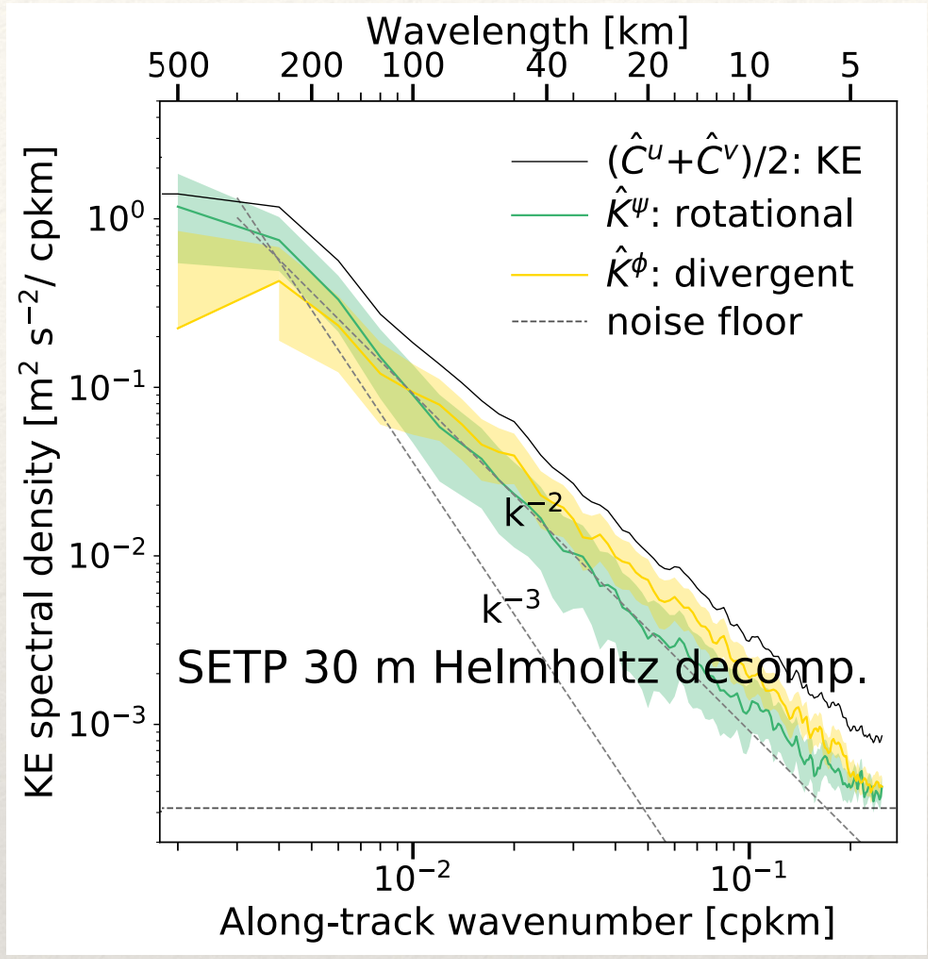


Near-surface high ratios mostly from enhanced vortex flows

Wave and vortex kinetic energy spectrum



Soares et al., (In prep)



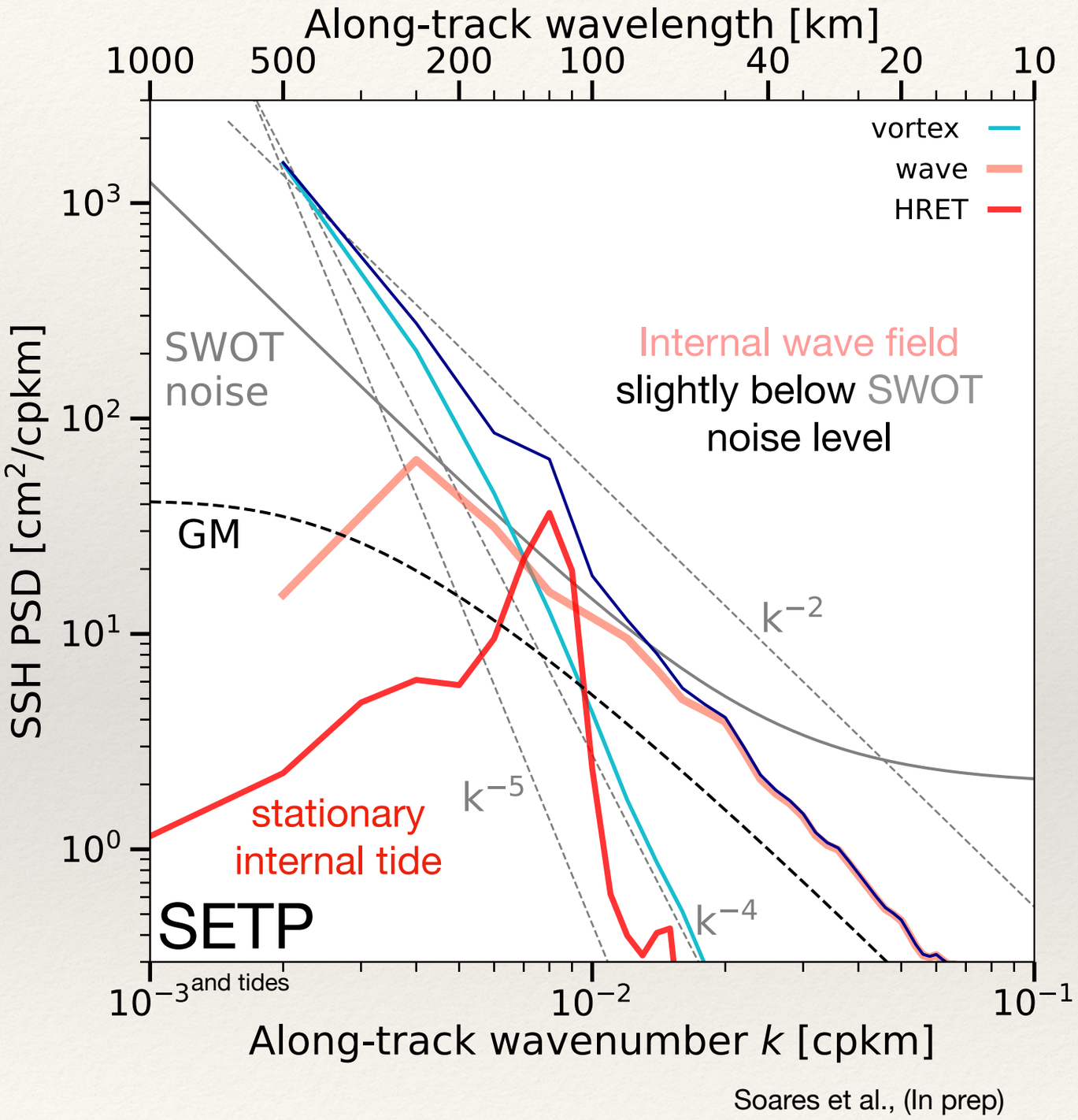
Soares et al., (2022)

The new **wave-vortex decompositions** shows:

The GM is an accurate way to get the **total wave KE** in the southeast tropical Pacific

2-3 times more energy in the wave component than GM spectrum

Sea Surface Height (SSH) from ADCP



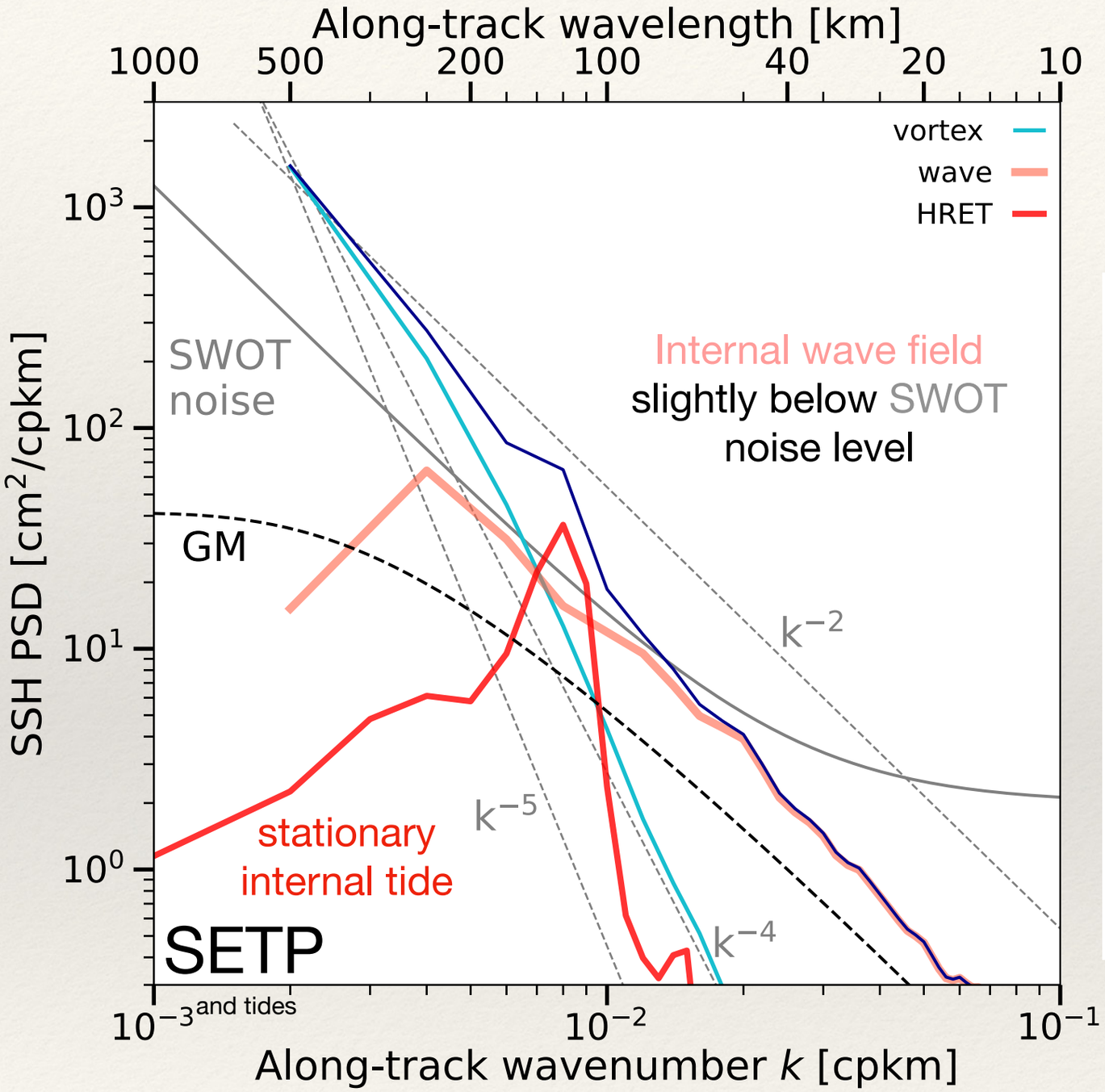
Soares et al., (In prep)

- We can use the GM spectrum to empirically estimate the **SSH signature of background waves from ADCP data.**

$$SSH\left(k\right) = \mathscr{C}\left(k\right) KE\left(k\right)$$

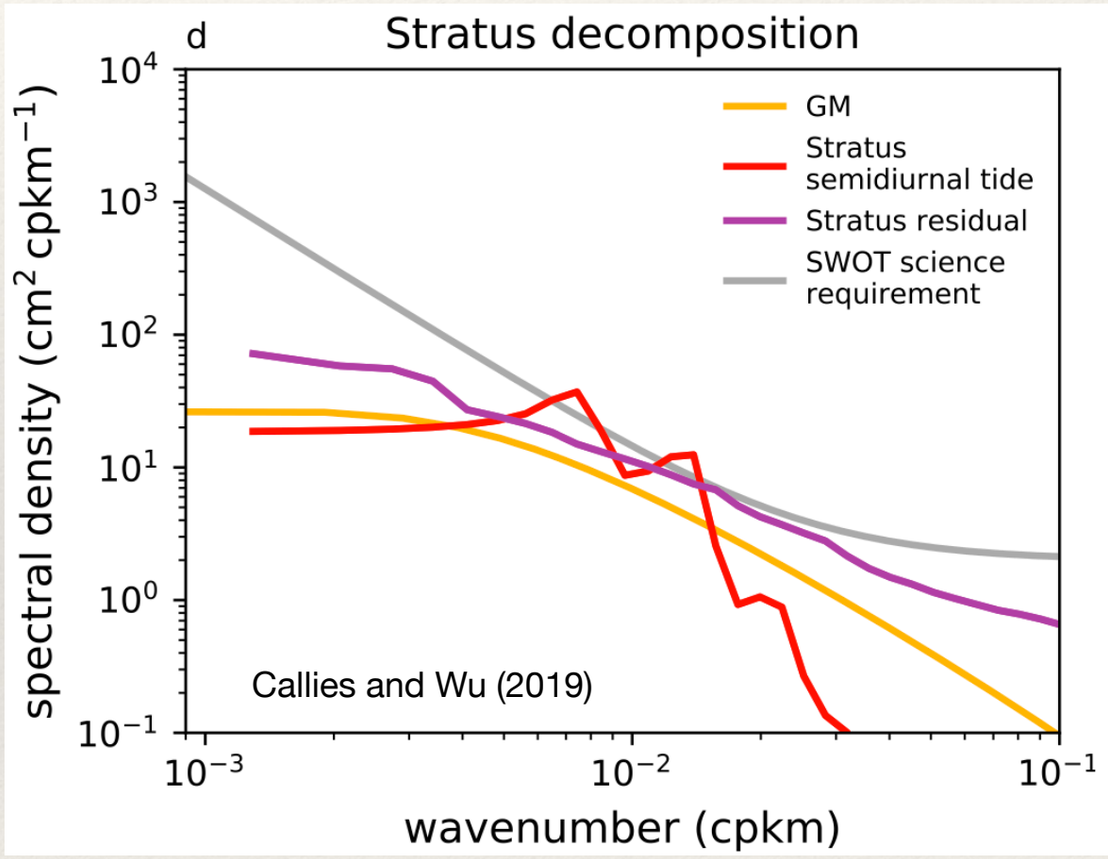
- We combine
  - wave SSH
  - vortex SSH inferred from geostrophy
  - model (Zaron, 2019) that captures the stationary internal tide which we don‘t resolve.

Sea Surface Height (SSH) from ADCP

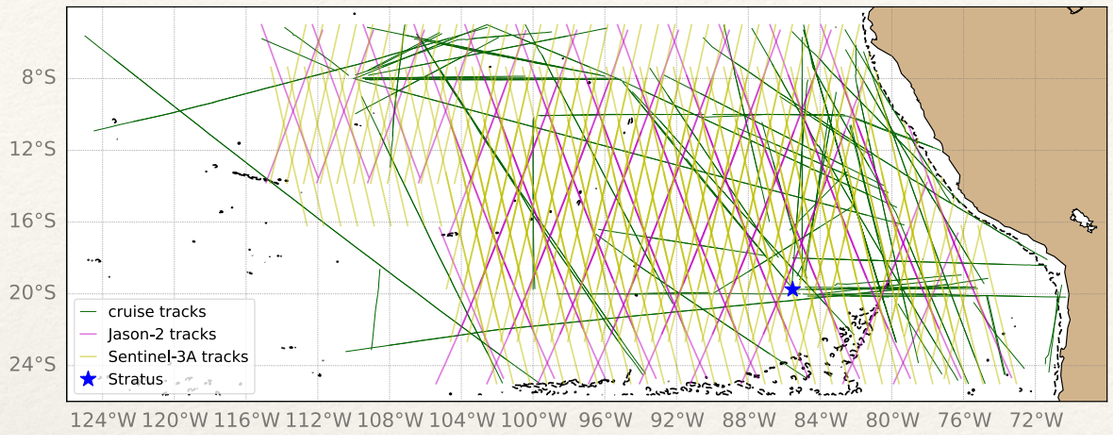


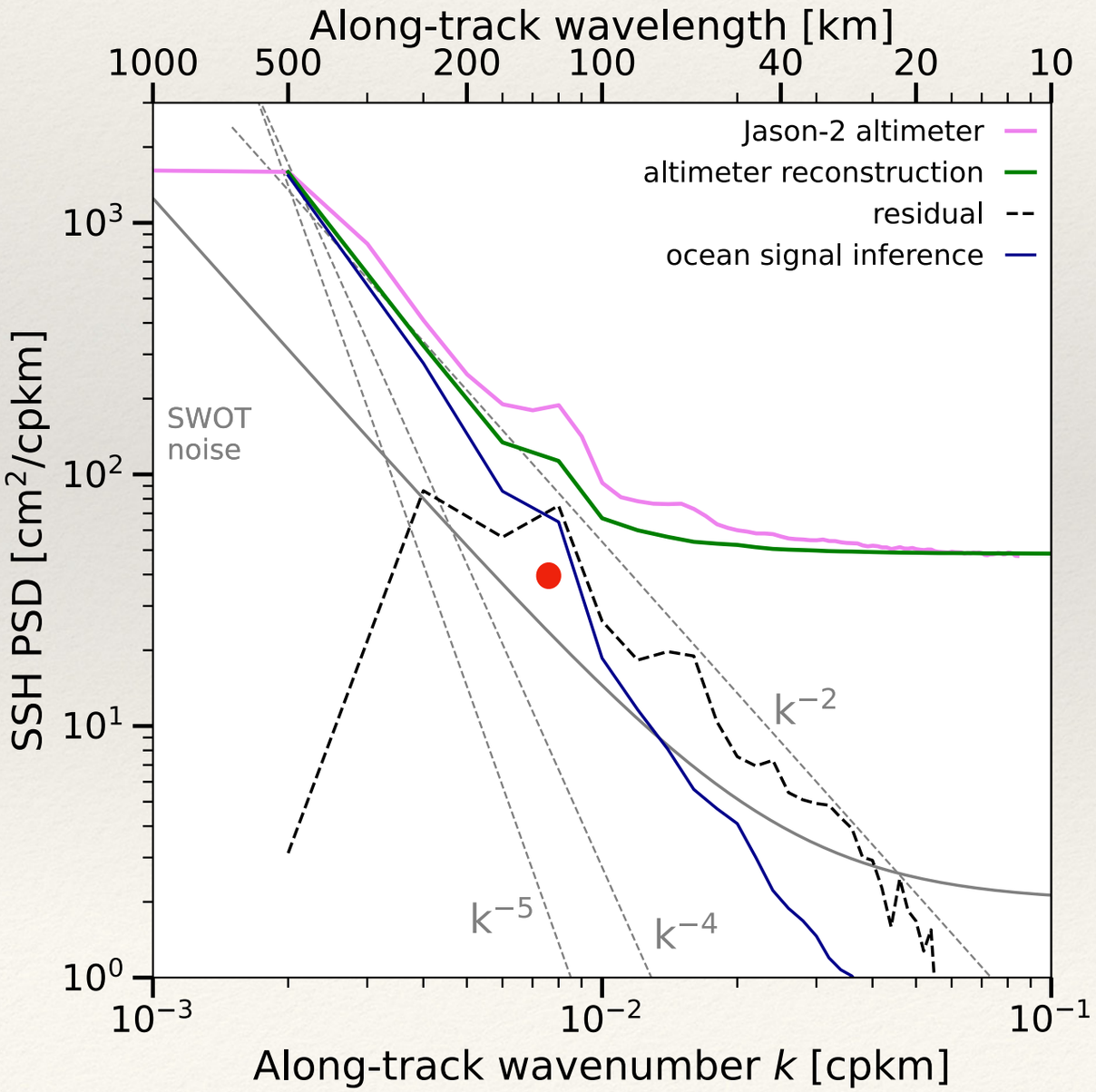
Soares et al., (In prep)

Agreement with estimate based on moored buoyancy analysis by Callies and Wu (2019)



Comparison with altimetry





Satellite has ~10-40% more energy than reconstructions (in situ conversion + stationary internal tide + noise)

The residual approximates the non-stationary internal tide component near the mode-1 wavelength

The **non stationary internal tide (residual -- line)** is **larger than the stationary internal tide**.

Summary

At the meso to submesoscale range…

- In the tropics:
  - There are **mostly internal waves**. In situ current measurements indicate that **near-inertial waves are important** at small scales, but…
  - We made a reconstruction of the oceanic **SSH** using in situ currents and when we compare with altimetry the **non-stationary internal tides arises as the largest signal, overwhelming the continuum**.
- The **method** outlined here can be applied to **other regions** where there are i) sufficient ADCP transects, ii) data to constrain the frequency spectrum, and iii) a suitable internal wave model (e.g. GM) can be identified. **Caveat**: there are other important limitations and assumptions too.
- It may be possible to use **SWOT** to study the **internal wave continuum** in the southeast tropical Pacific.

Thank you!