Using a Tandem Flight Configuration between Sentinel-6 and Jason-3 to Compare SAR and Conventional Altimeters in Sea Surface Signatures of Internal Solitary Waves

S6-JTEX final meeting – ESA ESTEC

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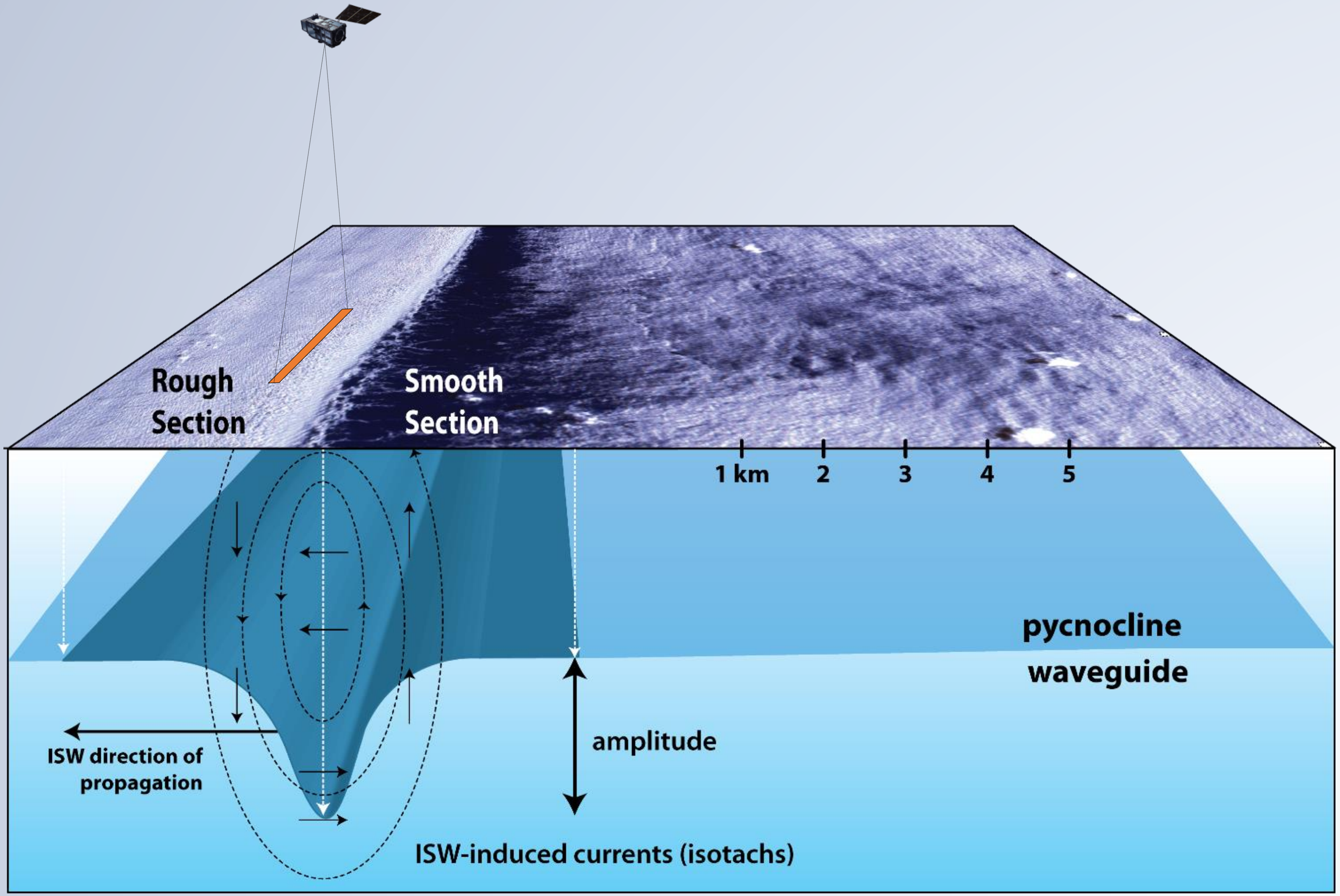
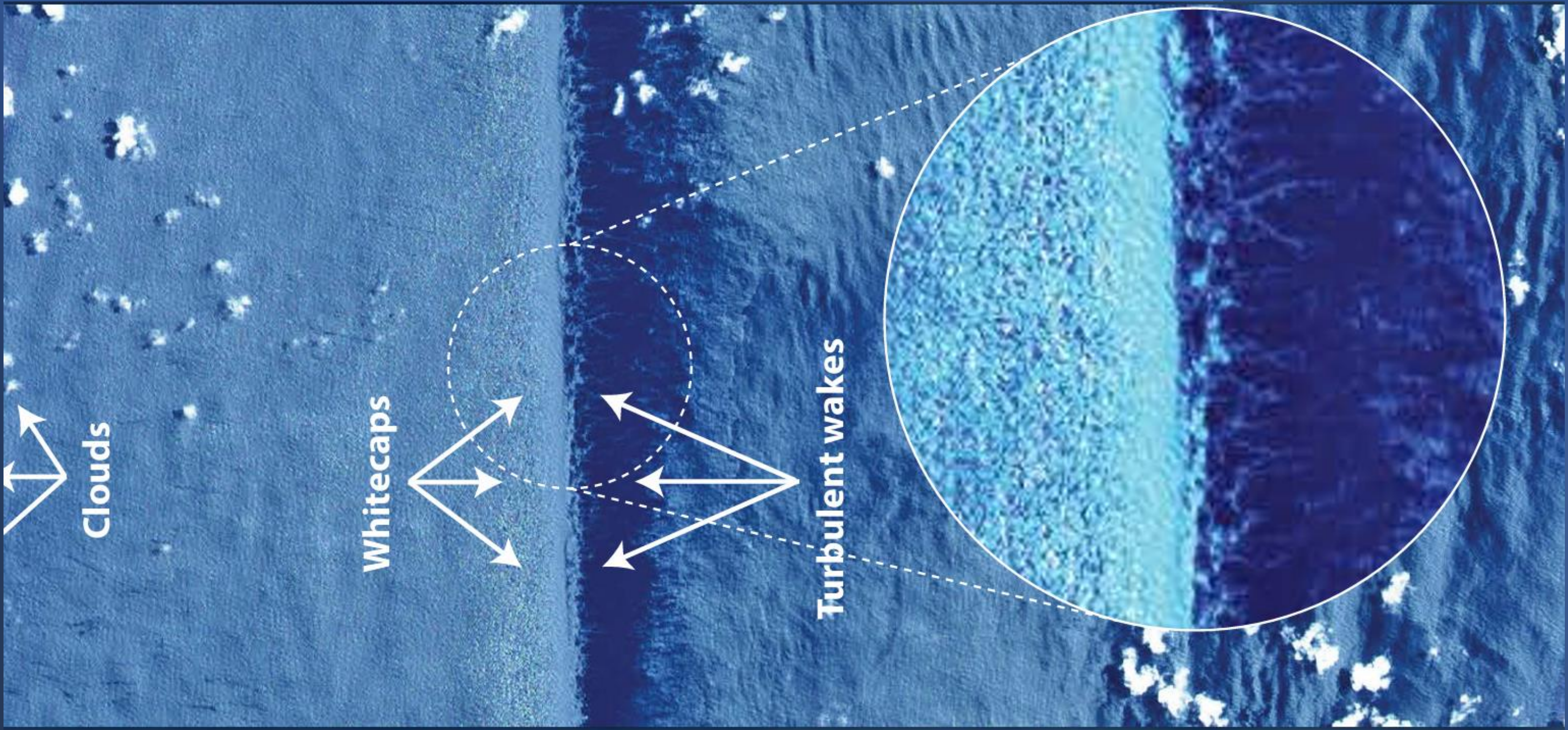
https://jorgemrmagalhaes.wixsite.com/internal-waves-/contact

A surface soliton is shown propagating in a narrow water channel, which was recreated in an experiment similar to that of Sir Scott Russell in 1834. Note how the solitary wave propagates ahead of the boat as it decelerates and comes to a full stop. See more at http://ramanujan25449.blogspot.com/2017/05/solitones.html.

What’s an Internal Solitary Wave? Why would it leave a signature in SAR altimeter?



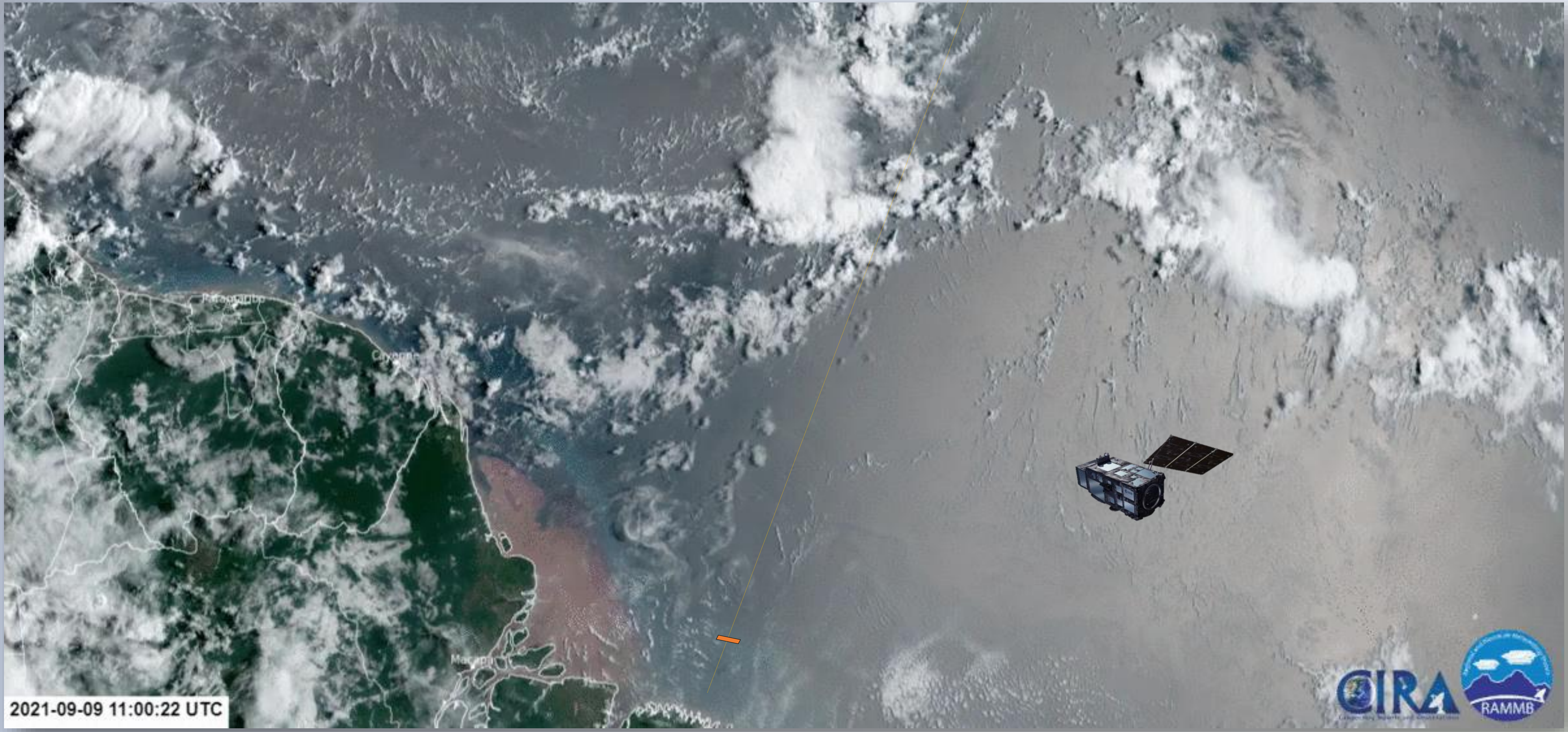


Sentinel-2 optical image (https://odl.bzh/sPxDcyYH) highlighting the surface turbulence of a large-scale internal solitary wave propagating in the South China Sea (from right to left). Note the whitecaps ahead of the wave and the smooth (slick-like) section behind it (in dark blue), and what appear to be the turbulent wakes (visible as whitish filaments of foam) that stretch from the whitecaps into the slick-like section.

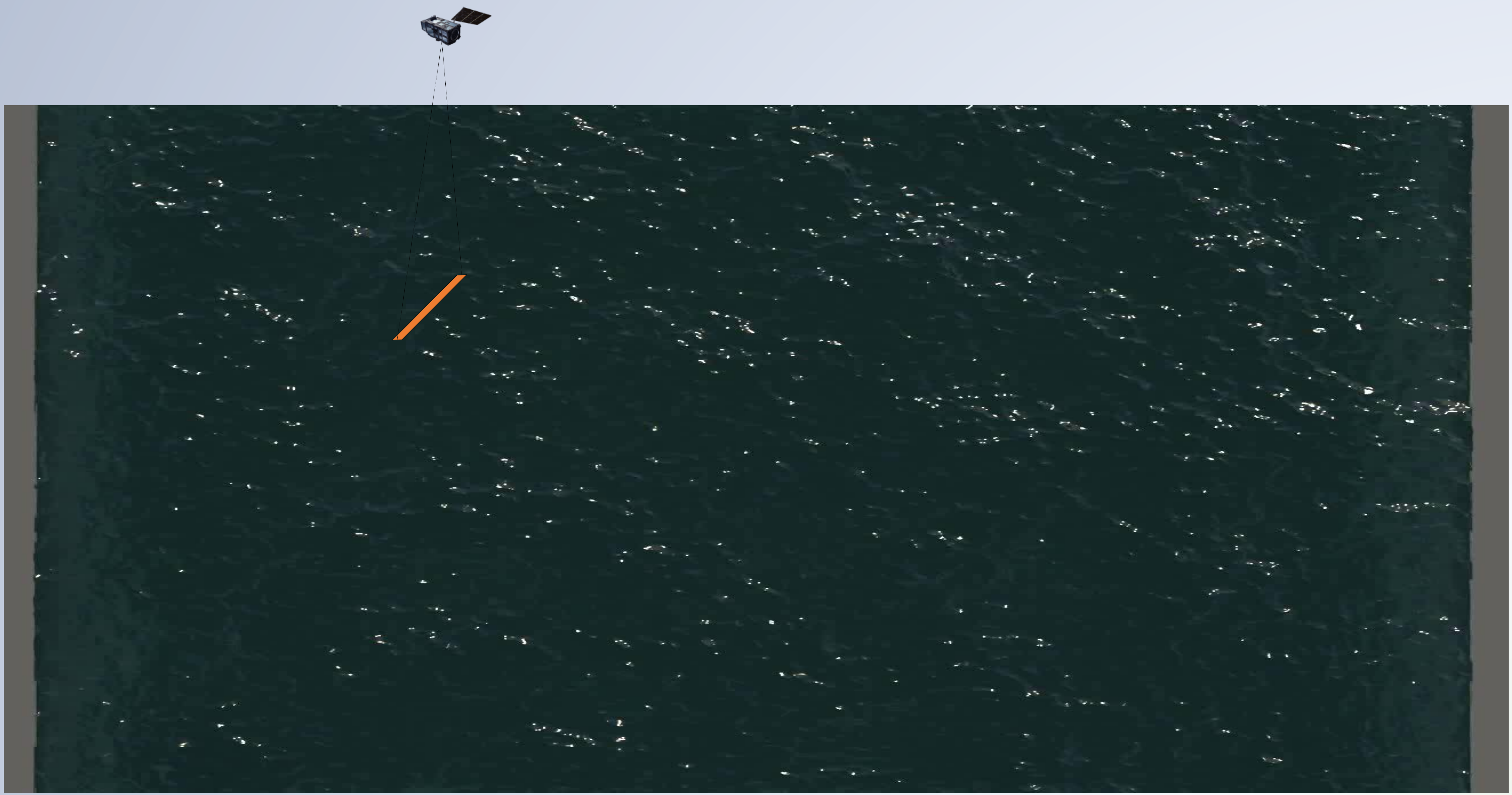
Photograph taken from a ship in the South China Sea on 27 April 2008 showing sea surface signatures of ISWs. The band of reduced sea surface roughness is followed by enhanced sea surface roughness containing breaking waves.
Courtesy: Guozhen Zha.

ISWs are a known phenomenon off the Amazon Shelf

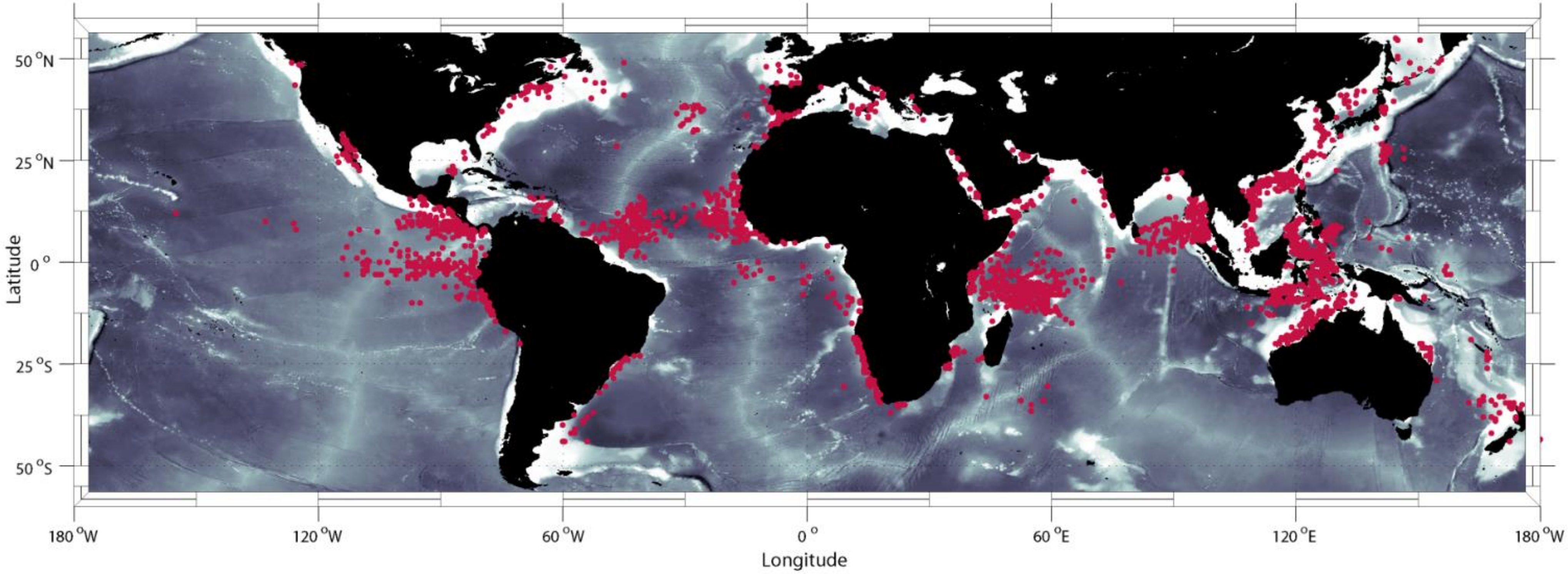
Data from GOES available at: https://www.star.nesdis.noaa.gov/GOES/sector.php?sat=G16&sector=taw



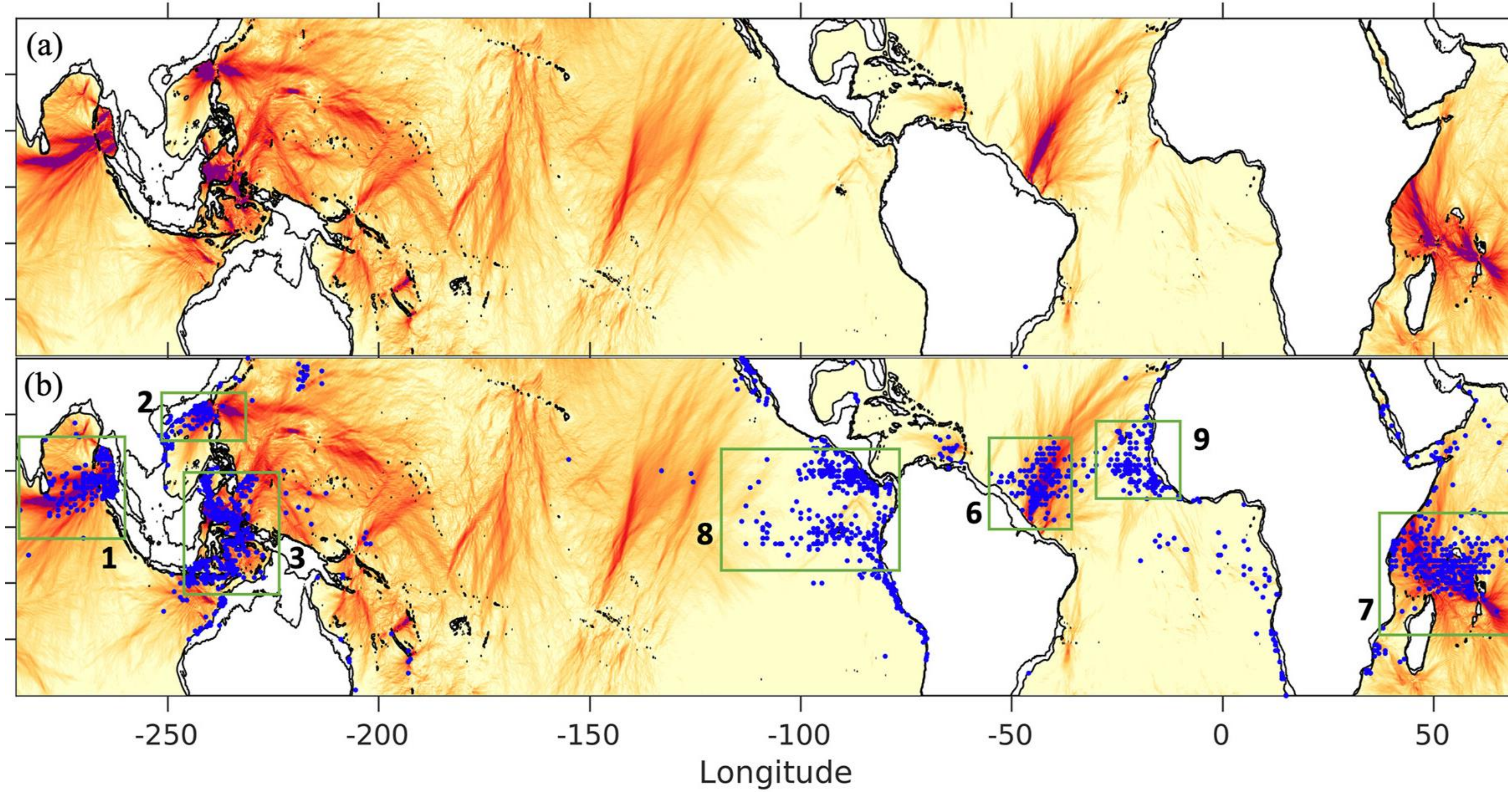
What's an Internal Solitary Wave? Why would it leave a signature in SRAL?



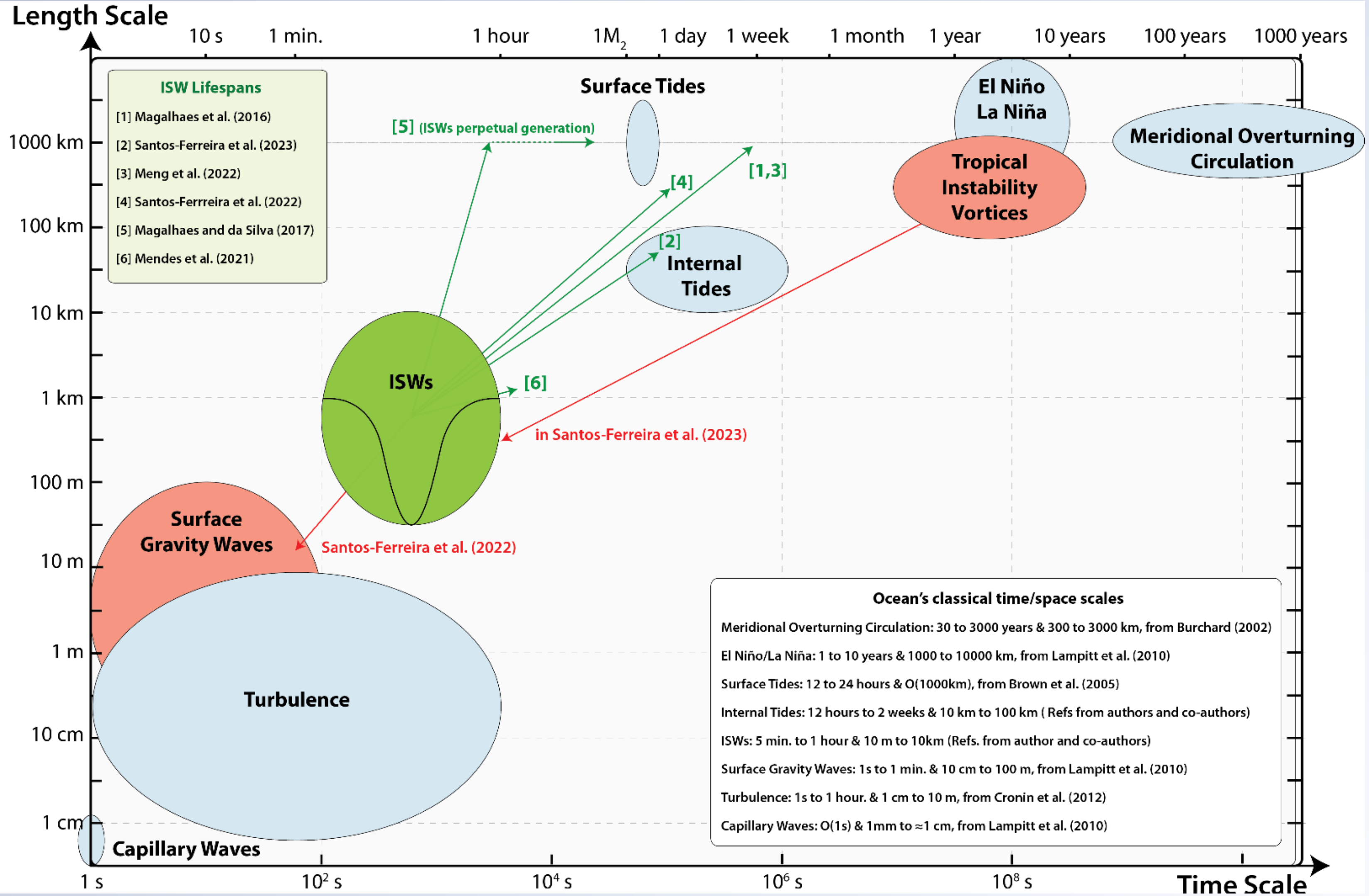
Schematics of IWs sea surface signatures (animation credited to Pedro S. Silva)



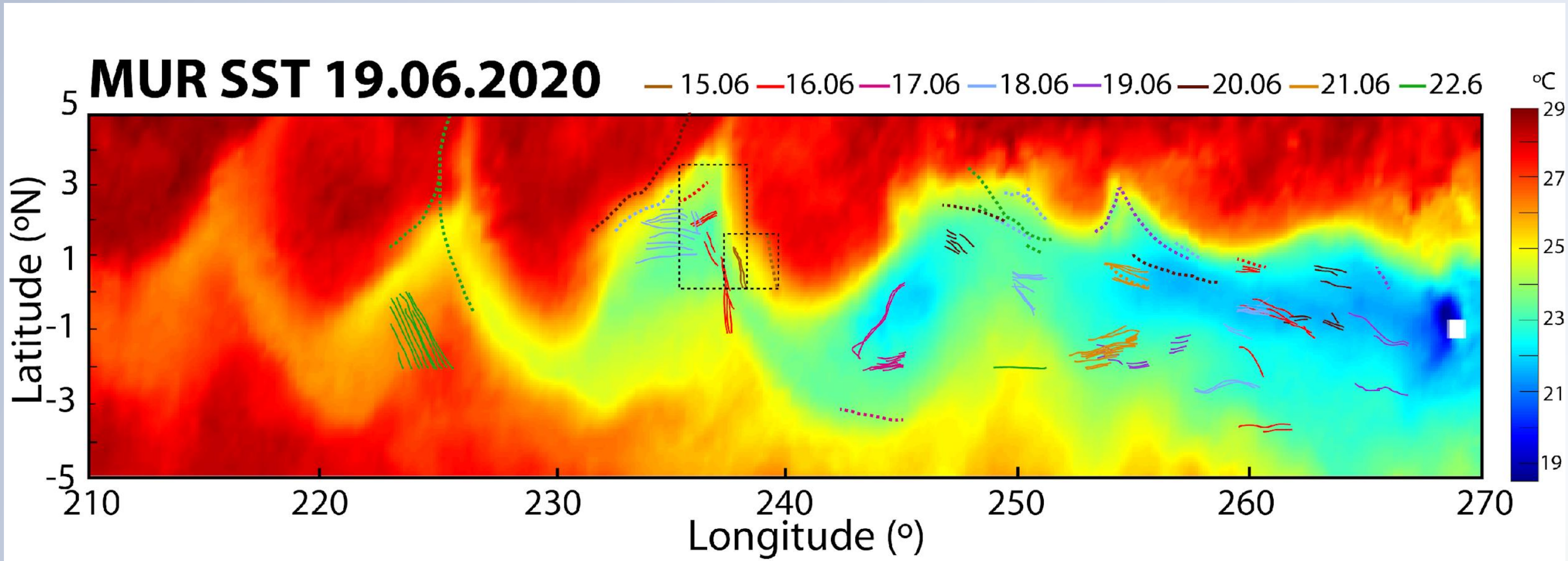
Jackson et al., 2012



(a, b) Colormaps of time-mean and depth-integrated supertidal energy fluxes in global Hybrid Coordinate Ocean Model on a logarithmic scale compared with (b) observations of nonlinear internal waves (blue dots) captured by 250-m resolution Moderate-Resolution Imaging Spectrometer imagery. Solano et al., 2023.

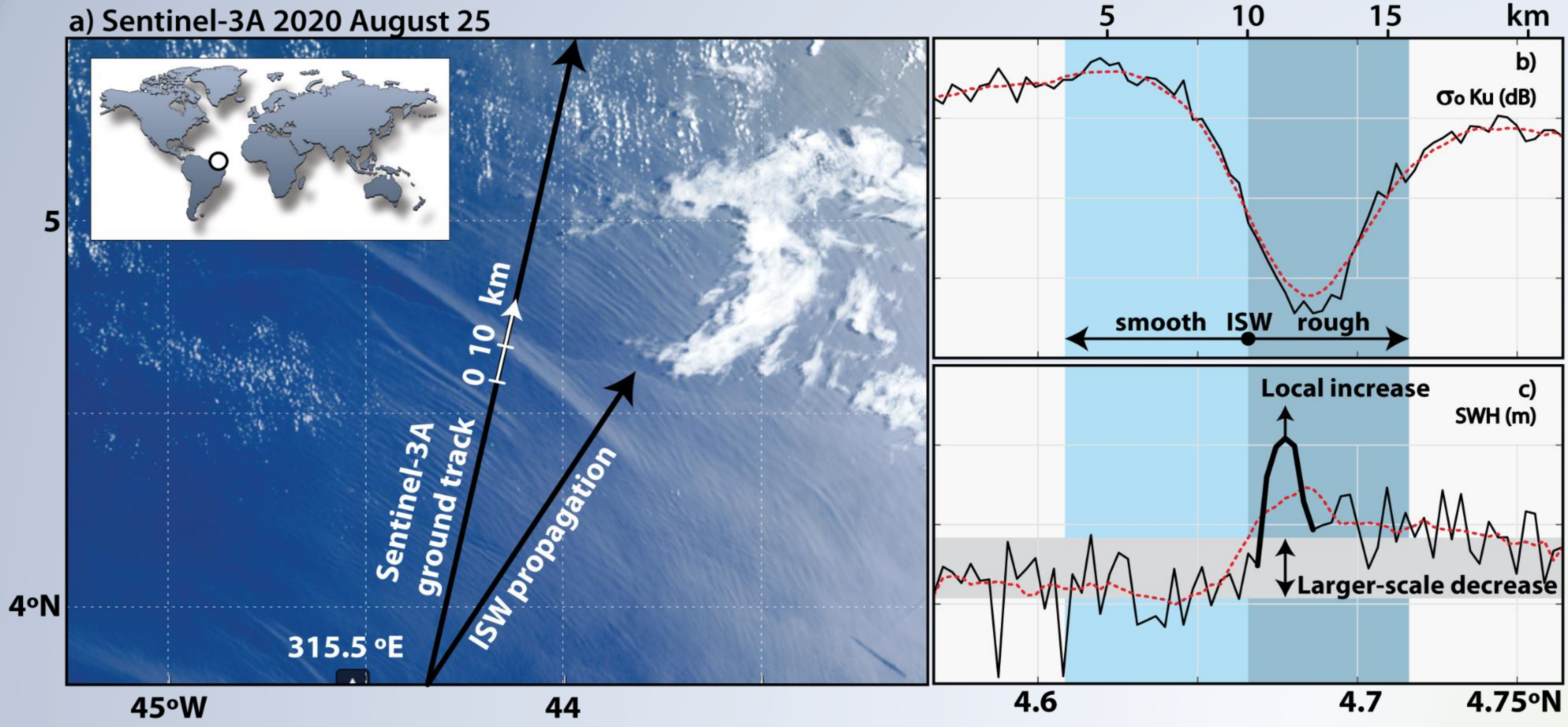


Classical time and space scales for selected ocean processes (adapted from Lampitt et al. 2010 and other authors as indicated in the lower-right inset). Those for ISWs are highlighted together with an extended view of their scales considering alternative criteria (in green arrows according to the inset in the top-left). The arrows in red represent novel views for energy transfers involving Internal Solitary Waves (ISWs) presented in Santos Ferreira et al. (2023)

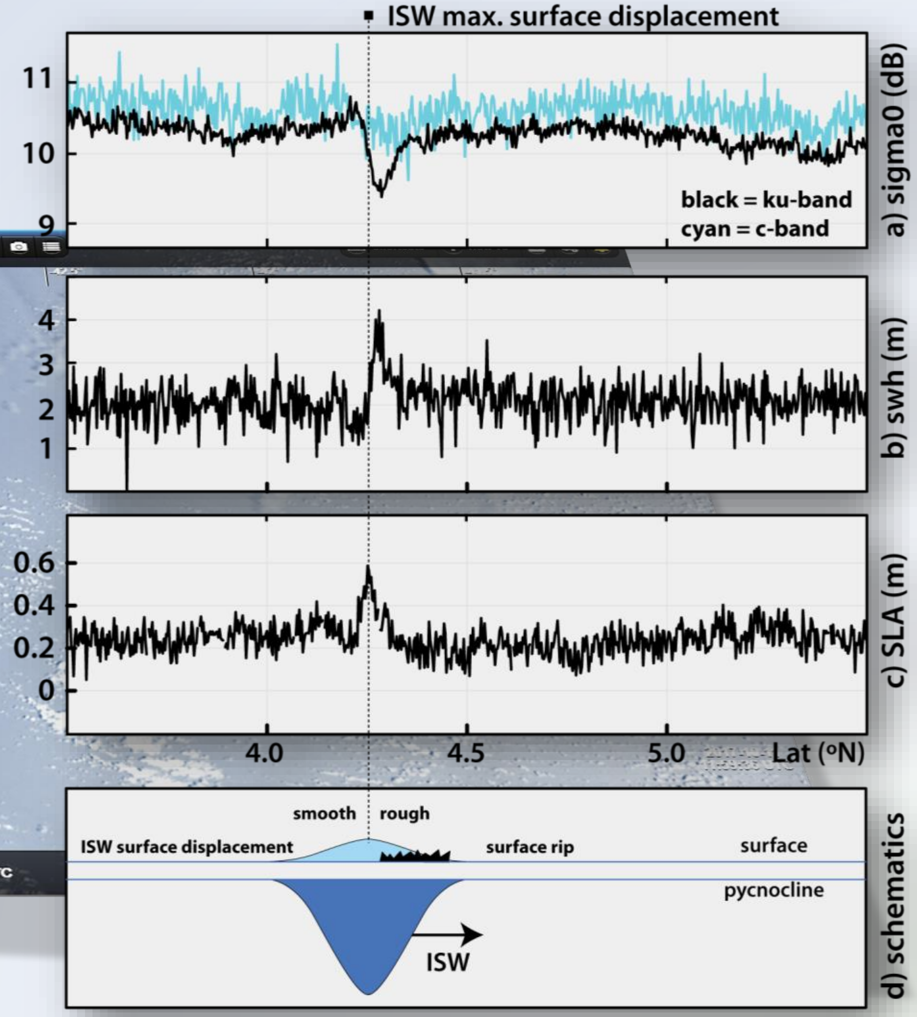


Spatial distribution of the fronts (dotted lines) and ISW packets (solid lines), identified in the visible imagery of Sentinel-3, between 15 June and 22 June 2020. The colour for each day is identified in the upper part of the map. The dashed dark rectangles show the location of some OLCI images given in Santos-Ferreira et al. (2023). A MUR SST image, dated 19 June 2020, is shown in the background.

In the recent years we've learned from ESA projects that…

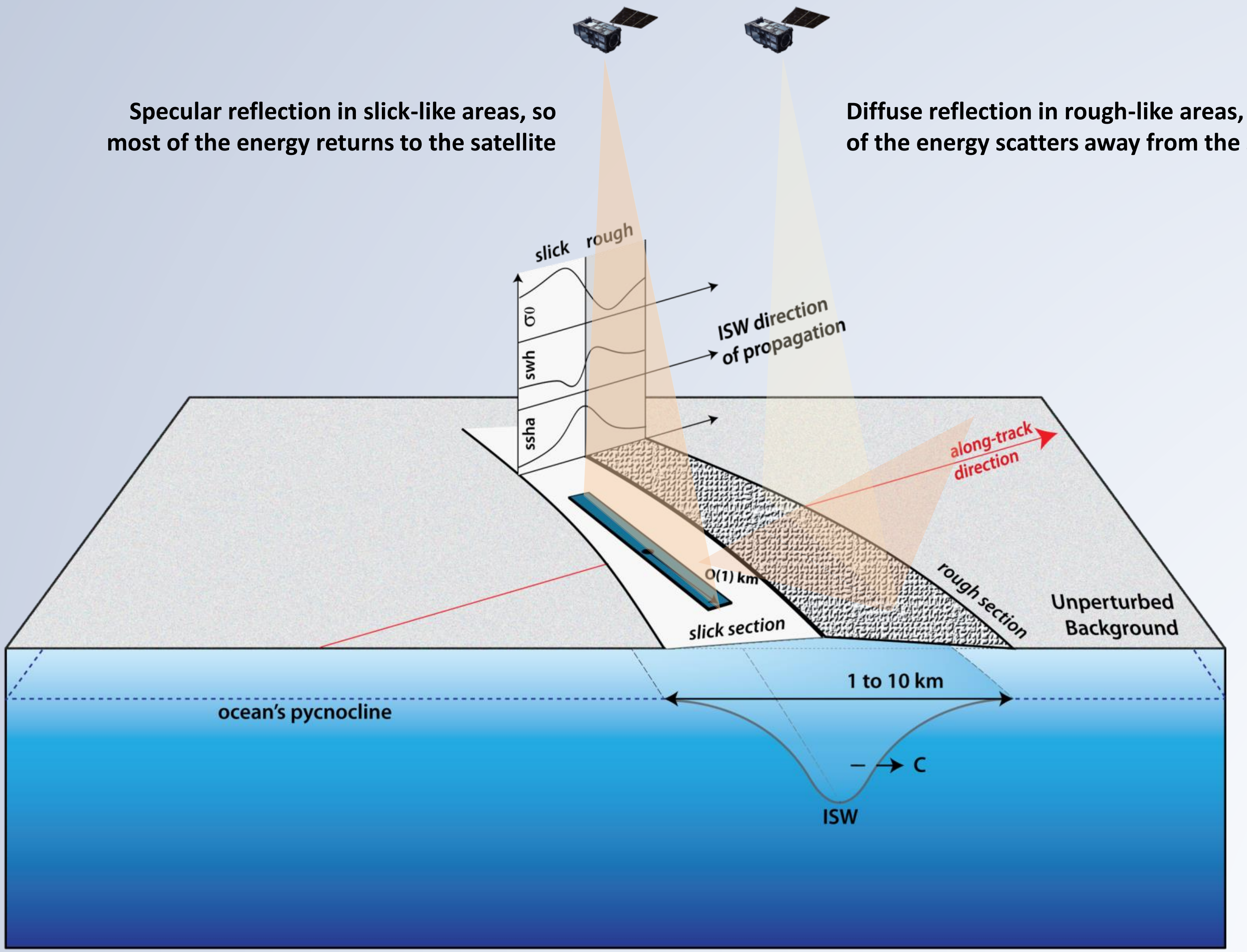


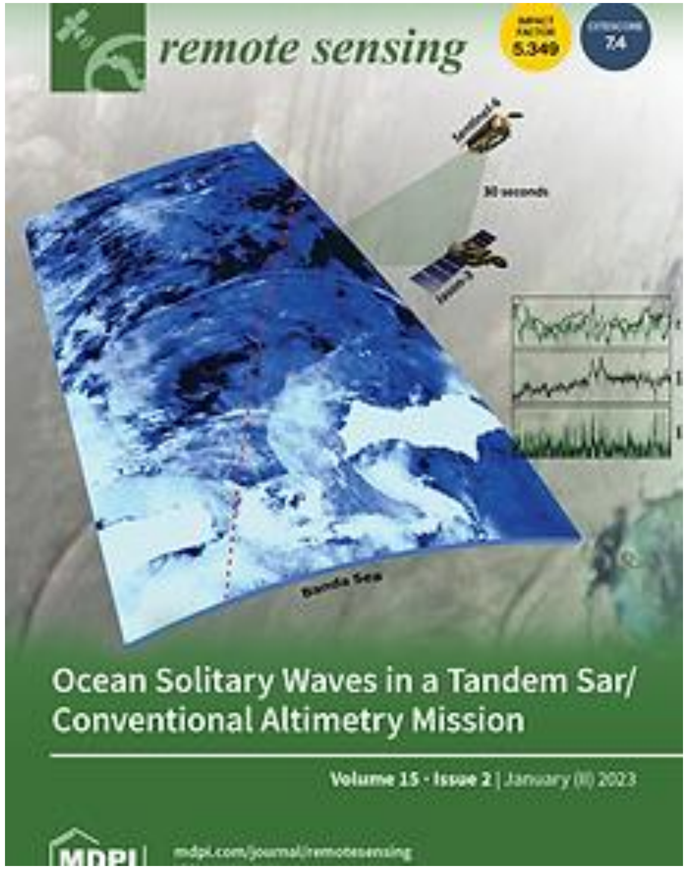
But there is also a clear signature in SLA!



But this interpretation would have been much harder without Sentinel-3 visual aid

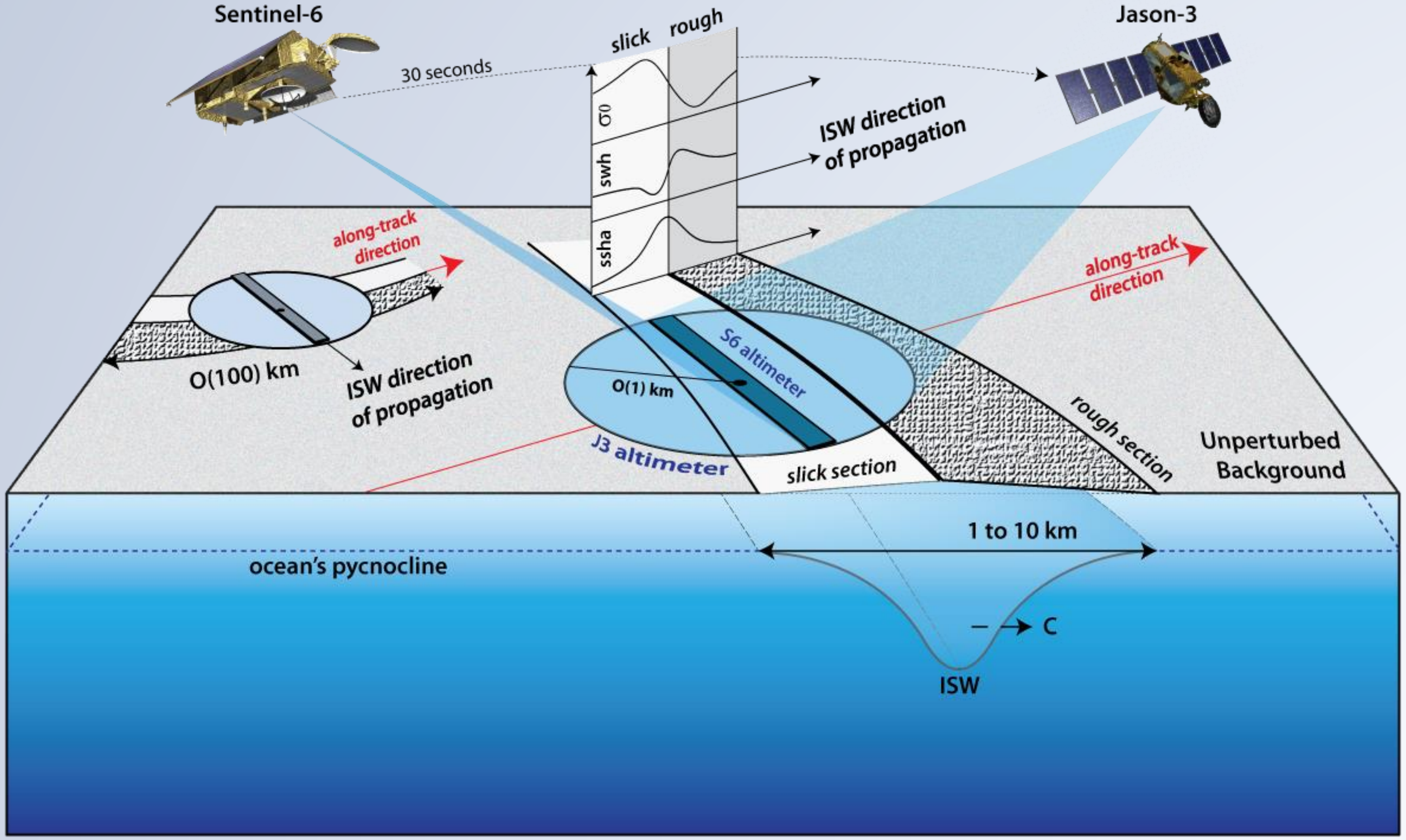
Interpretation of Altimetry signatures of Internal Solitary Waves





Lessons learned from the S6-JTEX Project with ESA/CLS

Importance of the geometry of observation: satellite track versus ISW propagation

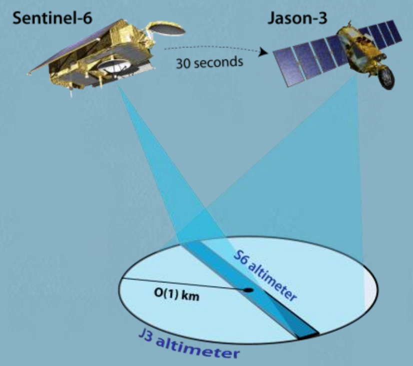


Internal waves provide a natural laboratory in which backscatter changes rapidly in spatial scales between those of conventional and SAR altimeters.

We just need to know that they are *there* – important e.g., to know how they are oriented in relation to the altimeter ground track.

Case Studies

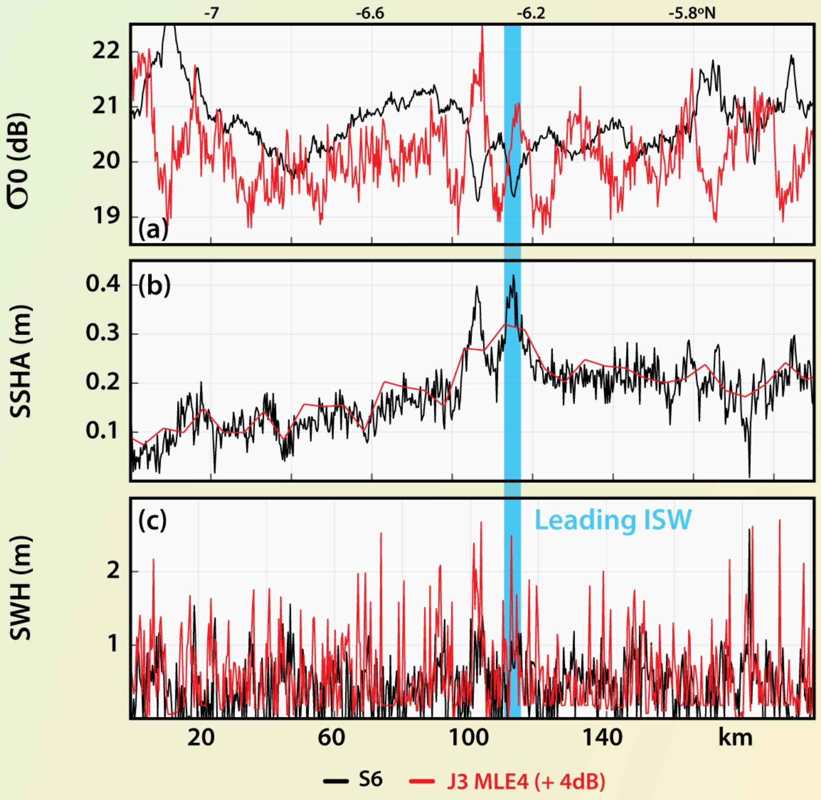
S6/J3 do not carry imaging sensors….



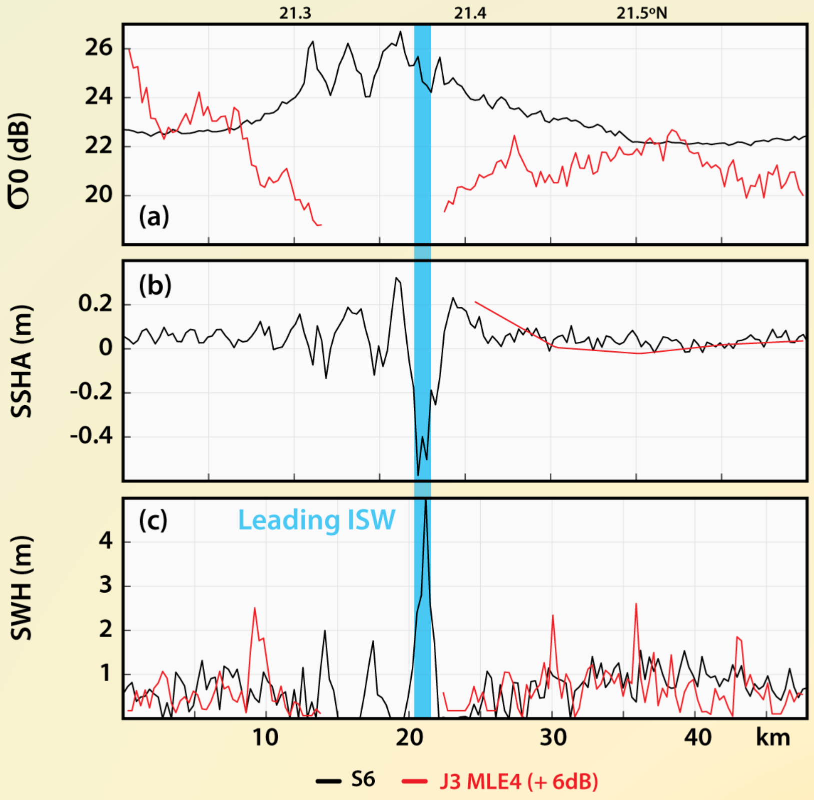
We don't know really what's down there!

- **Except if …. we use synergies with other satellites (not only but also Sentinel-3)**

Case Study 1: Banda Sea



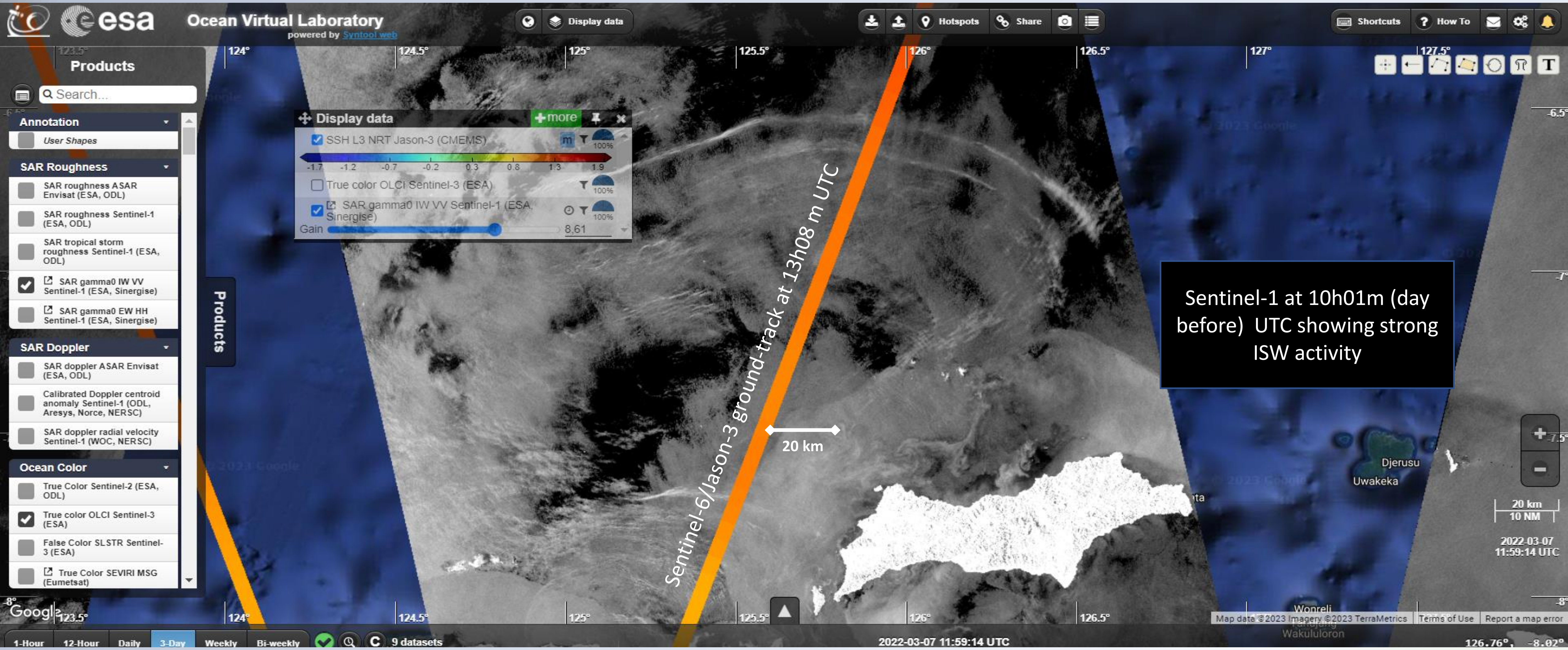
Case Study 2: SCS



So there is a Question to answear:

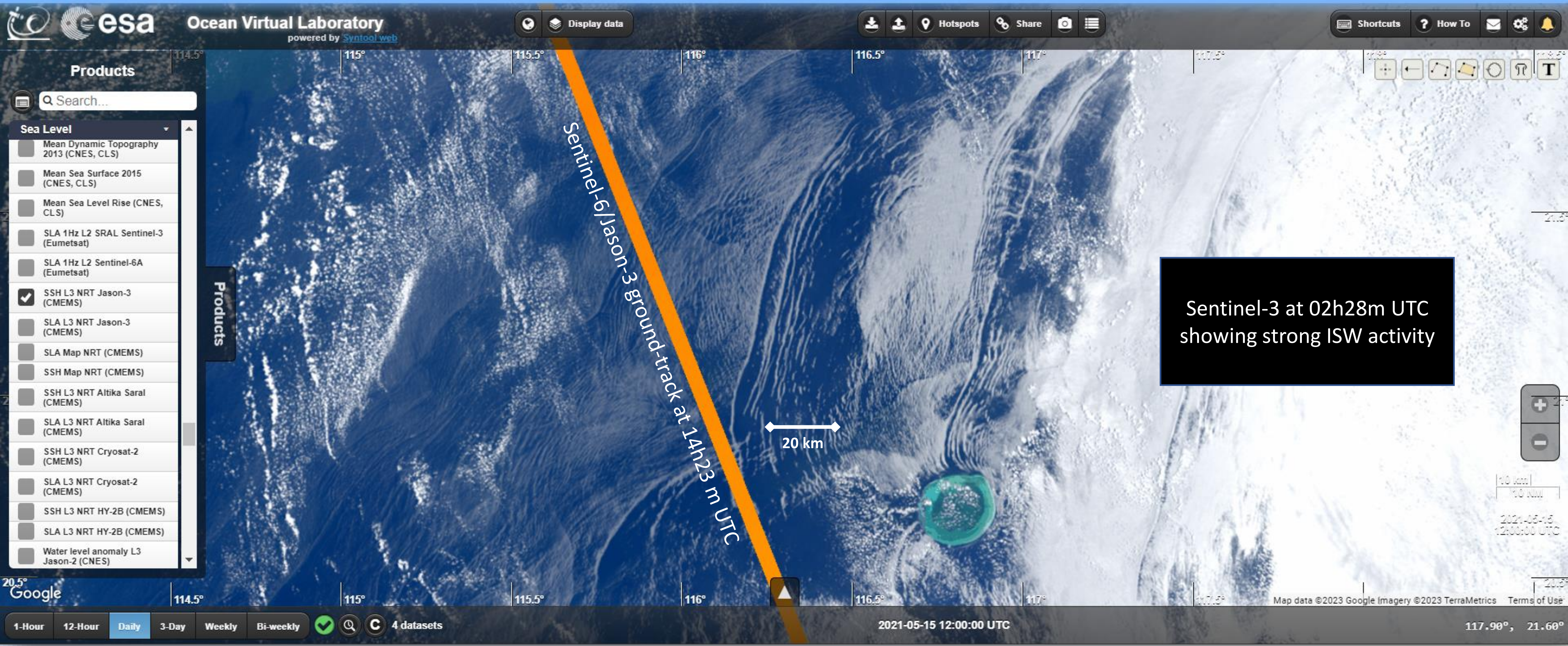
Why is Sigma0 yielding opposite signals between Sentinel-6 and Jason-3? And why is sometimes data not available for Jason-3?

First things first, let’s see what we are looking at:



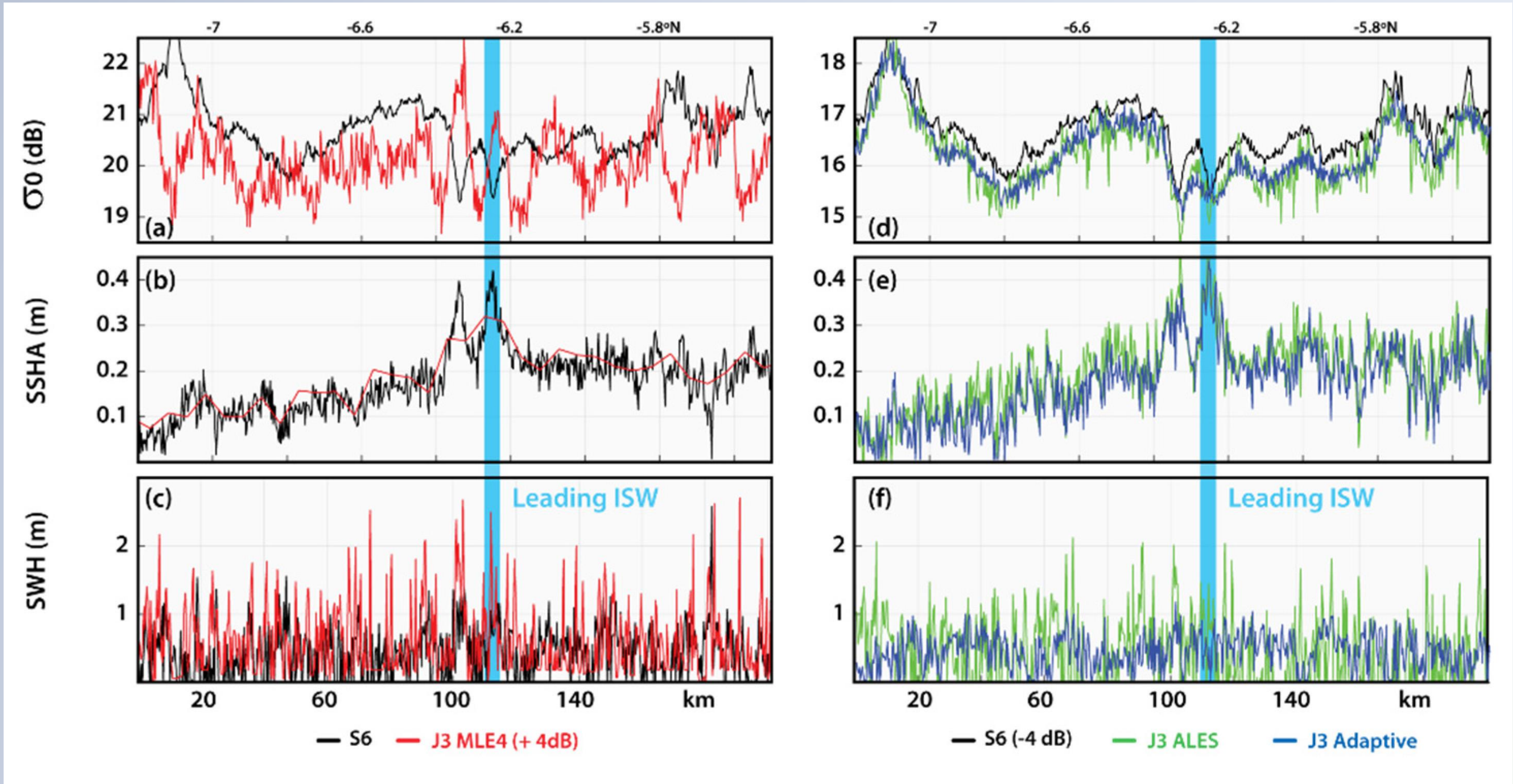
In the Banda Sea we know that we have ISWs that are larger, farther apart, and conveniently aligned with the altimeter ground track
https://odl.bzh/u6glz7hn

First things first, let's see what we are looking at:

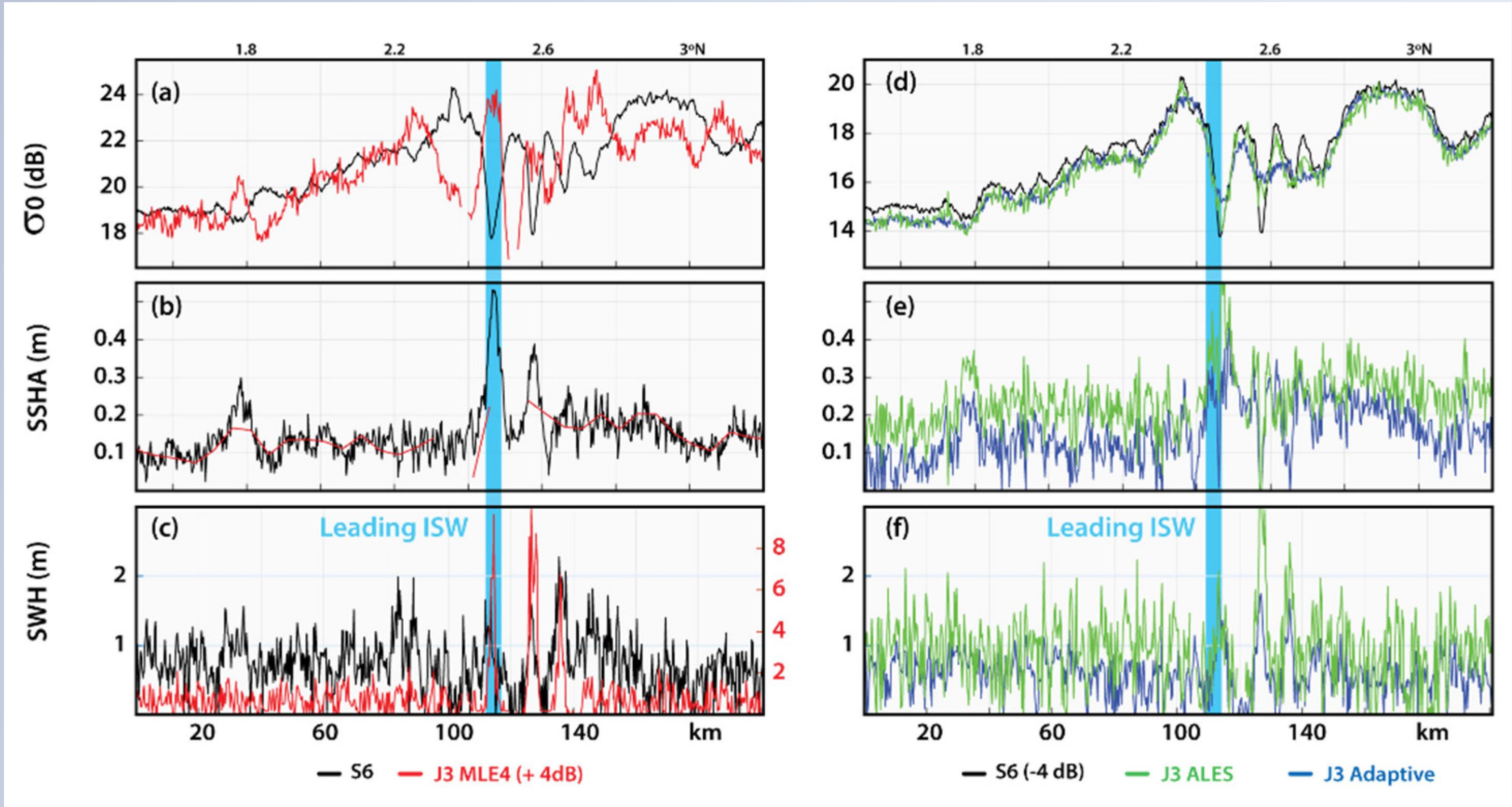


In the South China Sea we know that we have ISWs that are much smaller, closer together, and at and angle with the altimeter ground track
https://odl.bzh/BwOMXsng

Case Study 1: Banda Sea

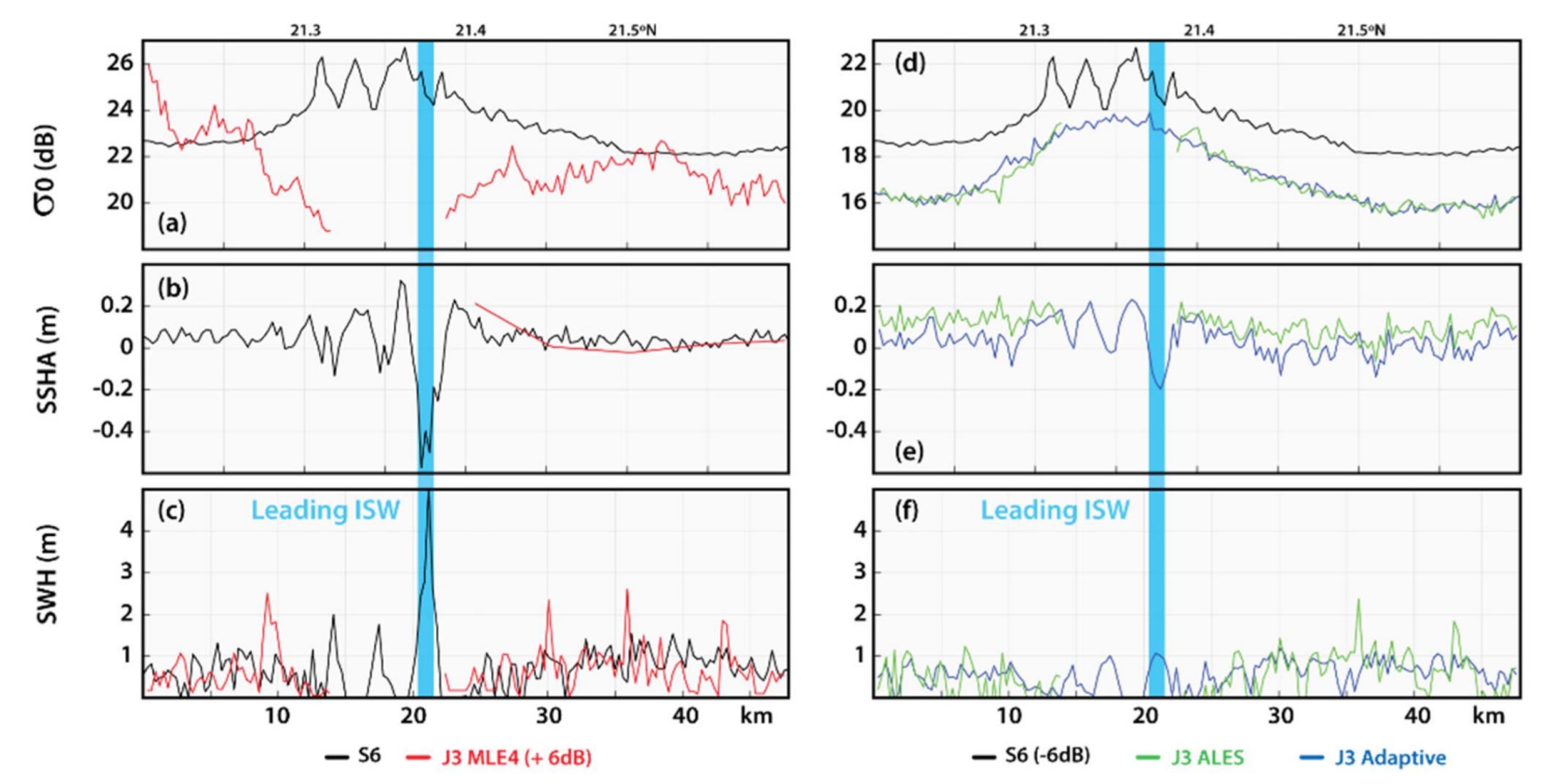


Case Study 3: Celebes Sea



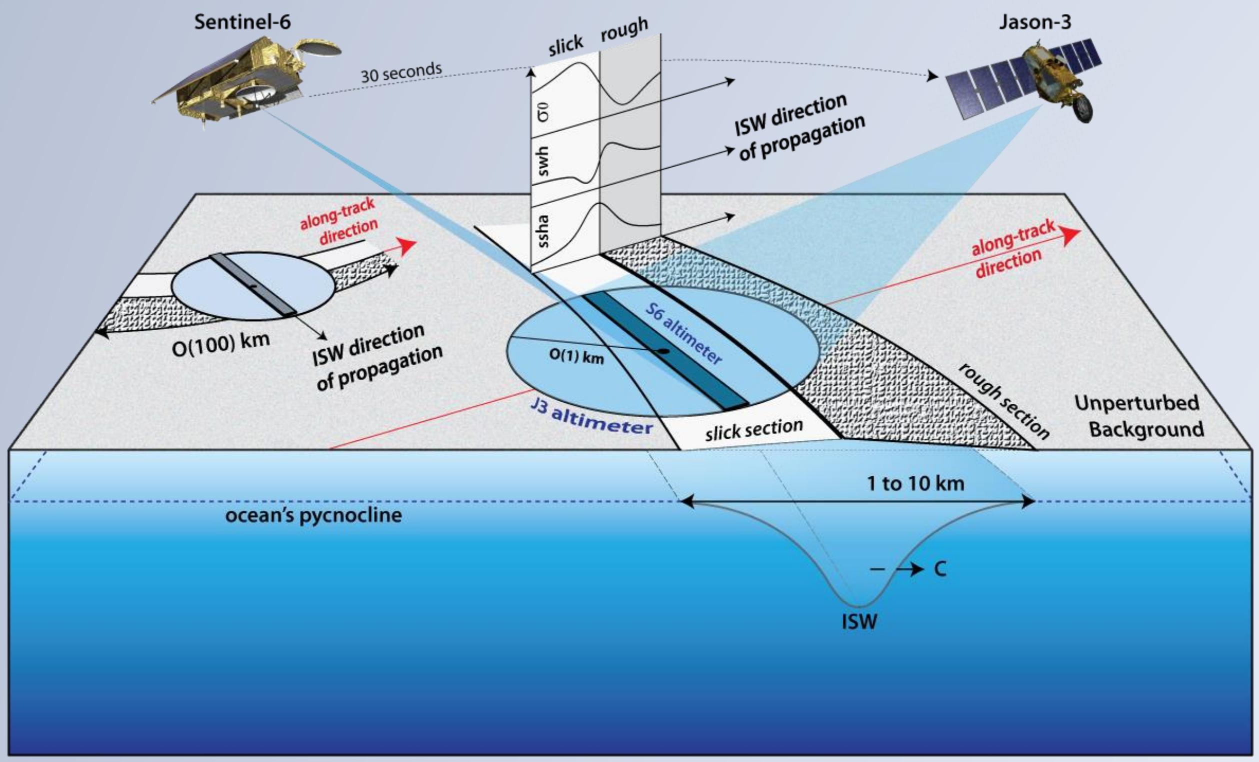
Similar to Case Study 1, but in the Celebes Sea (5 January 2022). Note that in this case, the broken lines in panel (a,b) indicates missing data in MLE4 level-2 products.

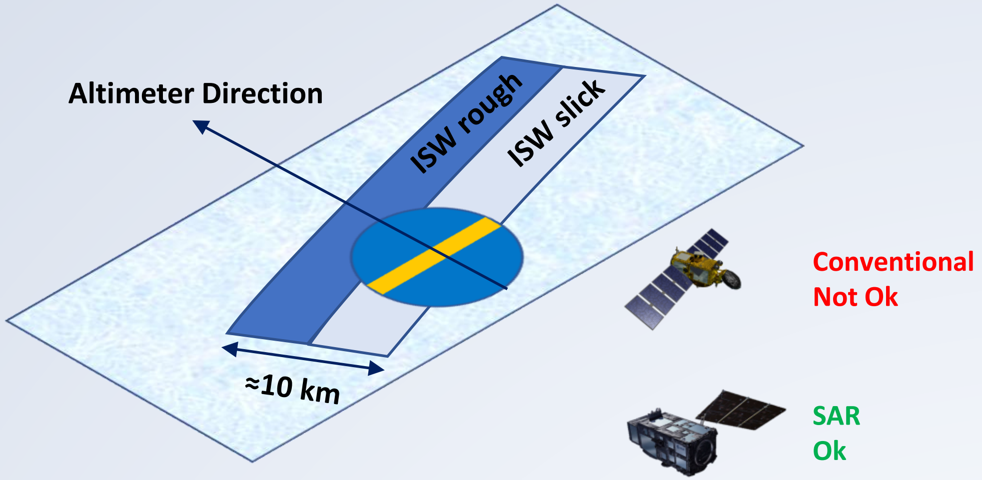
Case Study 2: South China Sea

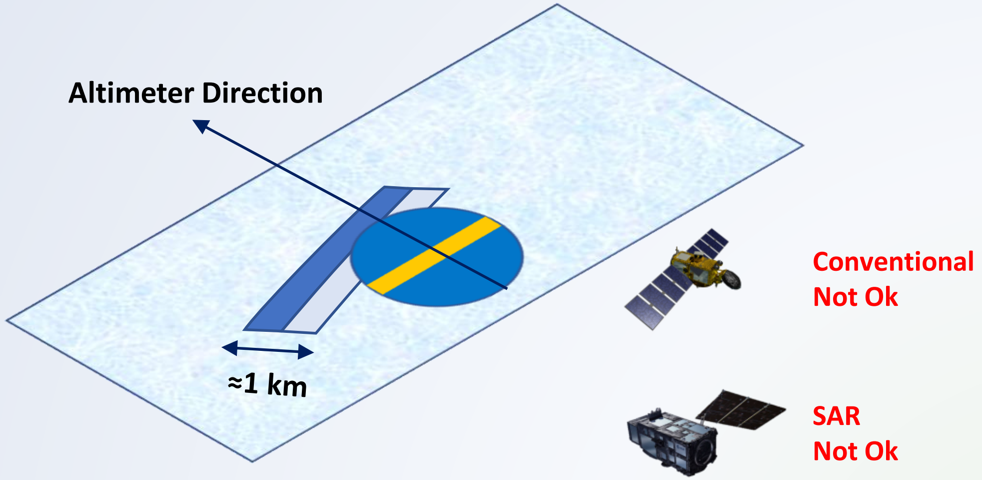


Same as before but in the South China Sea (15 May 2021). Note that in this case, the broken lines indicate missing data in MLE4 level-2 products in panels (a–c) and in the ALES retracker in panels (e,f).

How far in spatial detail can we go with altimeters?

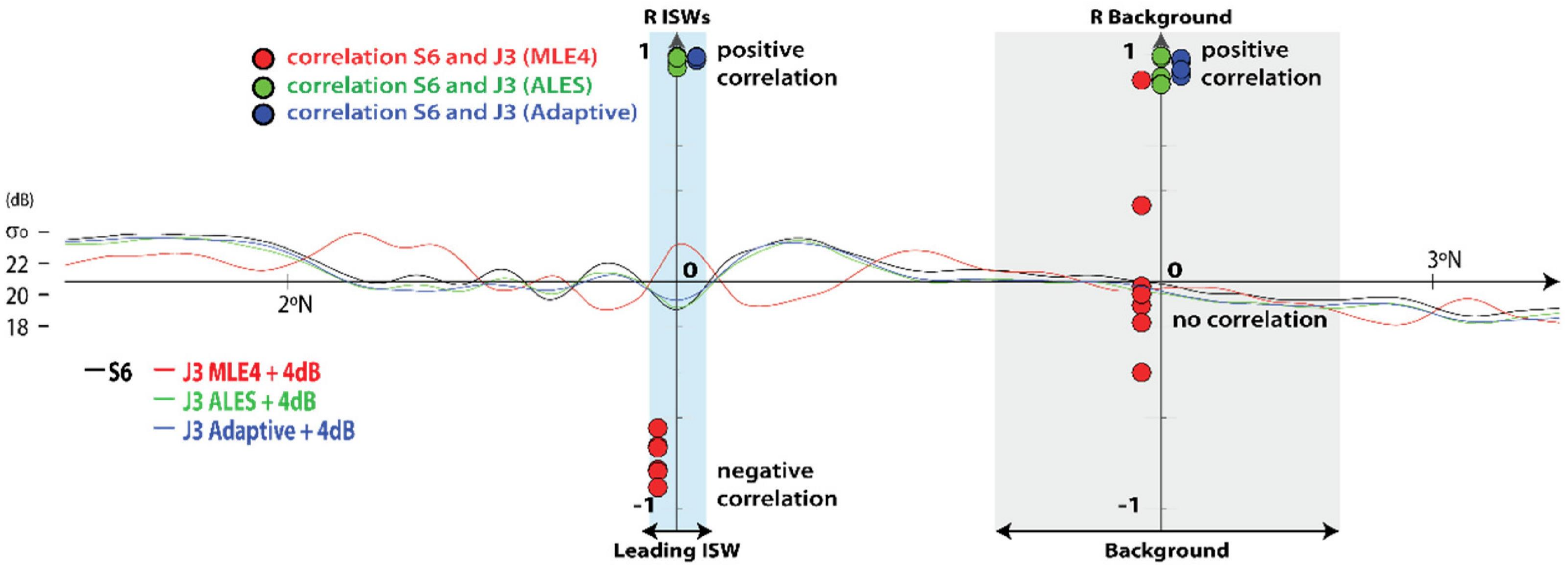




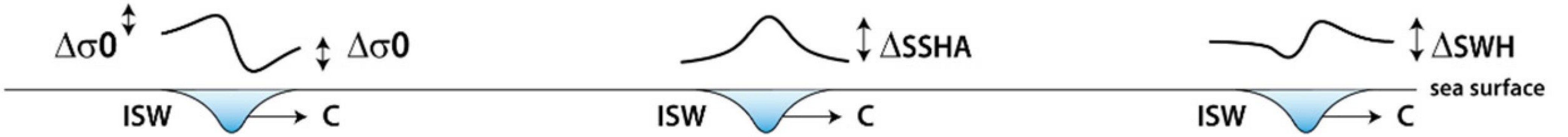


It's just a matter of sampling. The larger footprints in the conventional altimeters get mixed contributions in scales between 1 and 10 km, while SAR altimeters seem to be able to sample them correctly. However, both seem to fail close to scales of about 1 km or if there is a bad alignment between features and altimeter.

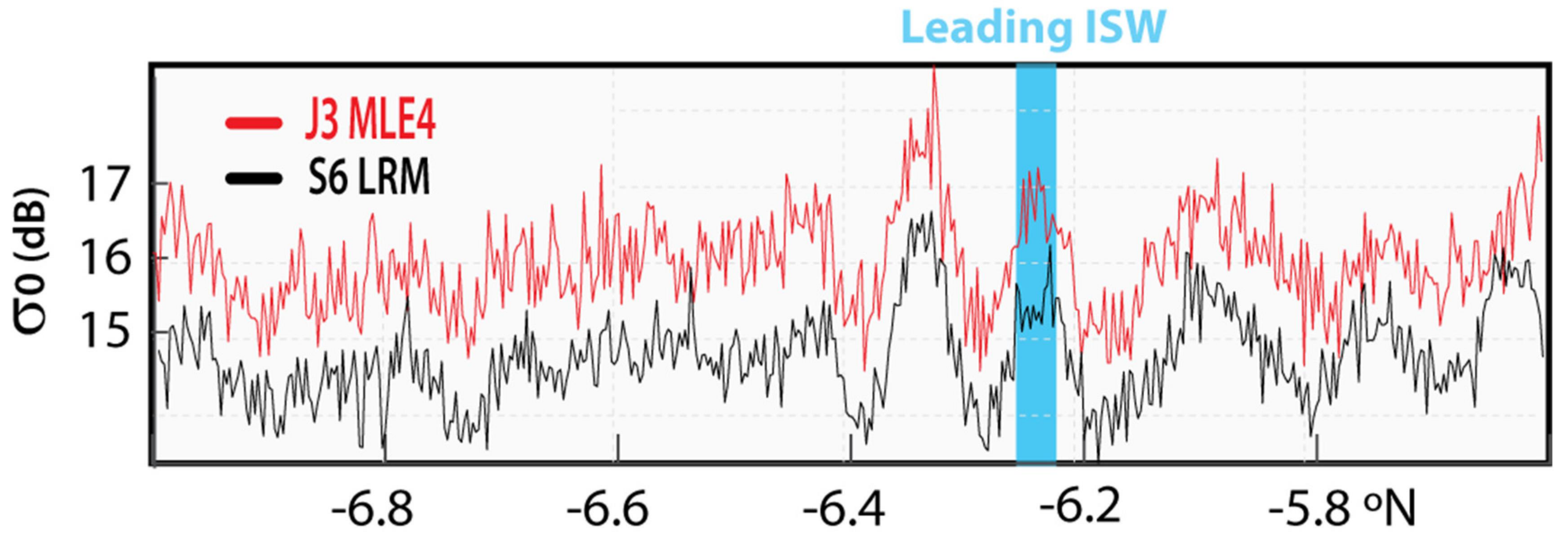
Summary of Altimeter Signals Correlations



Green and blue circles represent correlations between Sentinel-6 and Jason-3 (ALES/Adaptive, respectively), and red circle represent correlations between Sentinel-6 and Jason-3 (MLE4). Two sets of correlation coefficients are shown, listed as follows: on the left for the leading ISWs (R_{ISWs}), and on the right for the waves' background conditions ($R_{Background}$). A representative case is show for the Celebes Sea using data smoothed with a running mean of about 10 km.



Supervised Cases	Δσ0 S6	Δσ0 J3MLE4	Δσ0 J3ALES	Δσ0 J3 Adaptive	ΔSSHA S6	ΔSSHA J3MLE4	ΔSSHA J3ALES	ΔSSHA J3 Adaptive	ΔSWH S6	ΔSWH J3MLE4	ΔSWH J3ALES	ΔSWH J3 Adaptive
2021 Apr. 05 Banda Sea	+0.5/-0.5	-1/+1	+0.5/-0.5	+0.5/-0.5	+0.2	+0.1	+0.2	+0.1	1.3	1.8	1.4	0.5
2021 Jul. 13 Banda Sea	+0.5/-0.5	-1/+1	+0.5/-0.5	+0.5/-0.5	+0.1	+0.1	+0.1	+0.1	1.1	1.4	2.0	1.0
2021 Sep. 11 Banda Sea	+0.5/-0.5	-2.5/ +2.5	+0.5/-0.5	+0.5/-0.5	+0.2	+0.1	+0.2	+0.1	1.5	1.7	1.5	1.2
2021 Oct. 10 Banda Sea	+0.5/-1	-3/+3	+0.5/-1	+0.5/-0.5	+0.1	+0.2	+0.1	+0.2	1.1	1.5	1.4	0.9
2022 Mar. 08 Banda Sea, Fig. 3	+1/-1	-2/+2	+1.5/-1.5	+0.5/-1	+0.2	+0.1	+0.2	+0.2	1.1	2.3	1.5	0.7
2022 Jan. 05 Celebes Sea, Fig. 4	+4/-5	-7/+5	+4/-5	+3/-2	+0.4	NA	0.3	0.4	1.7	9.9	2.0	1.9
2021 May 15 S. China Sea, Fig. 5	+2/-2	NA	NA	+0/-0	-0.7	NA	NA	-0.4	5	NA	NA	1.0



Comparing σ_0 for Sentinel-6 (S6) level-2 products (at 20 Hz) in LRM (i.e., conventional altimeter) modes, and data from MLE4 in Jason-3 (J3).

Summary:

- The SAR altimeter in Sentinel-6 shows detailed sea surface signatures of large-scale (i.e., in the kilometre-scale) ISWs that are consistent with those presented previously for the SAR altimeter in Sentinel-3.

- SAR and conventional altimeters are either negatively or positively correlated in ISW-like signals, when using the standard MLE4 or the alternative ALES/Adaptive retrackers in Jason-3 (respectively).

- The sharper along-track resolution in Sentinel-6 (of about 300 m) can sample the details of ISWs structure.

- However, the larger footprint in the conventional Jason-3 (typically a few kilometres wide) cannot resolve the same level of detail and eventually is contaminated with conflicting contributions between distinct sections of the same ISW or even multiple ISWs altogether.

- The same applies when ISWs propagate at an angle with a SAR altimeter, since the across-track resolution (which is still a few kilometres wide) can also illuminate either distinct sections of the same wave or a series of them at the same time.

- ALES and the Adaptive retrackers, which explore more focused views of the conventional waveforms (namely in the leading edge), can perform in the same level of SAR altimeters when dealing with sharp transitions in ocean radar backscatter (at least down to the kilometre scale).

Motivation:

Evaluate the operational capability for monitoring ISW amplitudes (hence energy and possibly mixing) from new generation altimetry

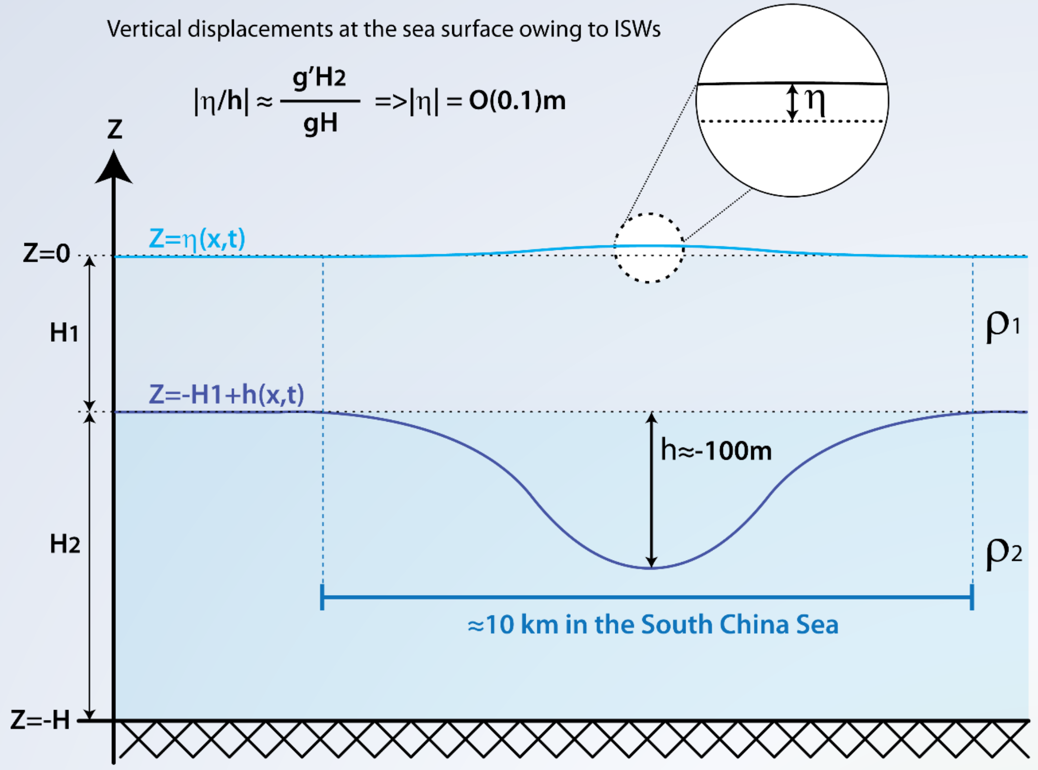
Simple Two Layer Theory

Internal Solitary Wave

Stratification → c ; Amplitude → η

$$u_1 = \frac{c\,\eta}{(h_1 + \eta)}$$

Stratification → h_1 ; Amplitude → η



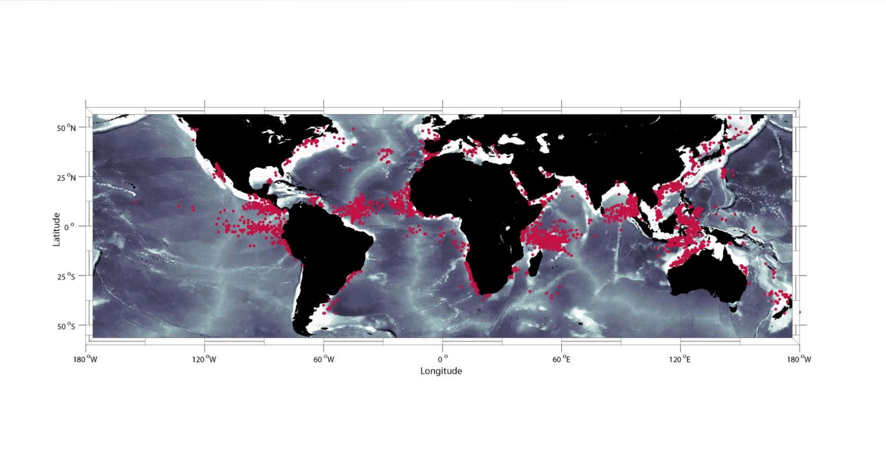
SAR altimeter → h

Formulation (two-layer model)

$$h = SLA \,.\, g\,\frac{H}{g' H_2}$$

$$u_1 = \frac{ch}{(H_1 + h)}$$

- Use a method based on horizontal morphology of internal solitary waves (e.g. sigma0 profile from Sentinel-6) and assume a fully nonlinear theory to estimate wave parameters (amplitde, velocities, etc.), based on stratification (ARGO progam)
- Estimate amplitude from independent method: assume hydrostatic and use SLA.
- Develop a method to interate until convergence is reached.
- If necessary use weakly nonlinear theory (e.g. KdV) or even linear for some cases in open ocean.
- Produce a monthly global product of Internal Solitary Wave energetics and mechanical mixing?



Thank you!