



Internal Solitary Waves in the ocean: a roadmap to model their interactions with other ocean phenomena

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

Before we begin

Most of the contents presented here are work done with/by (in no particular order):



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And others. Thank you. We also acknowledge support from:

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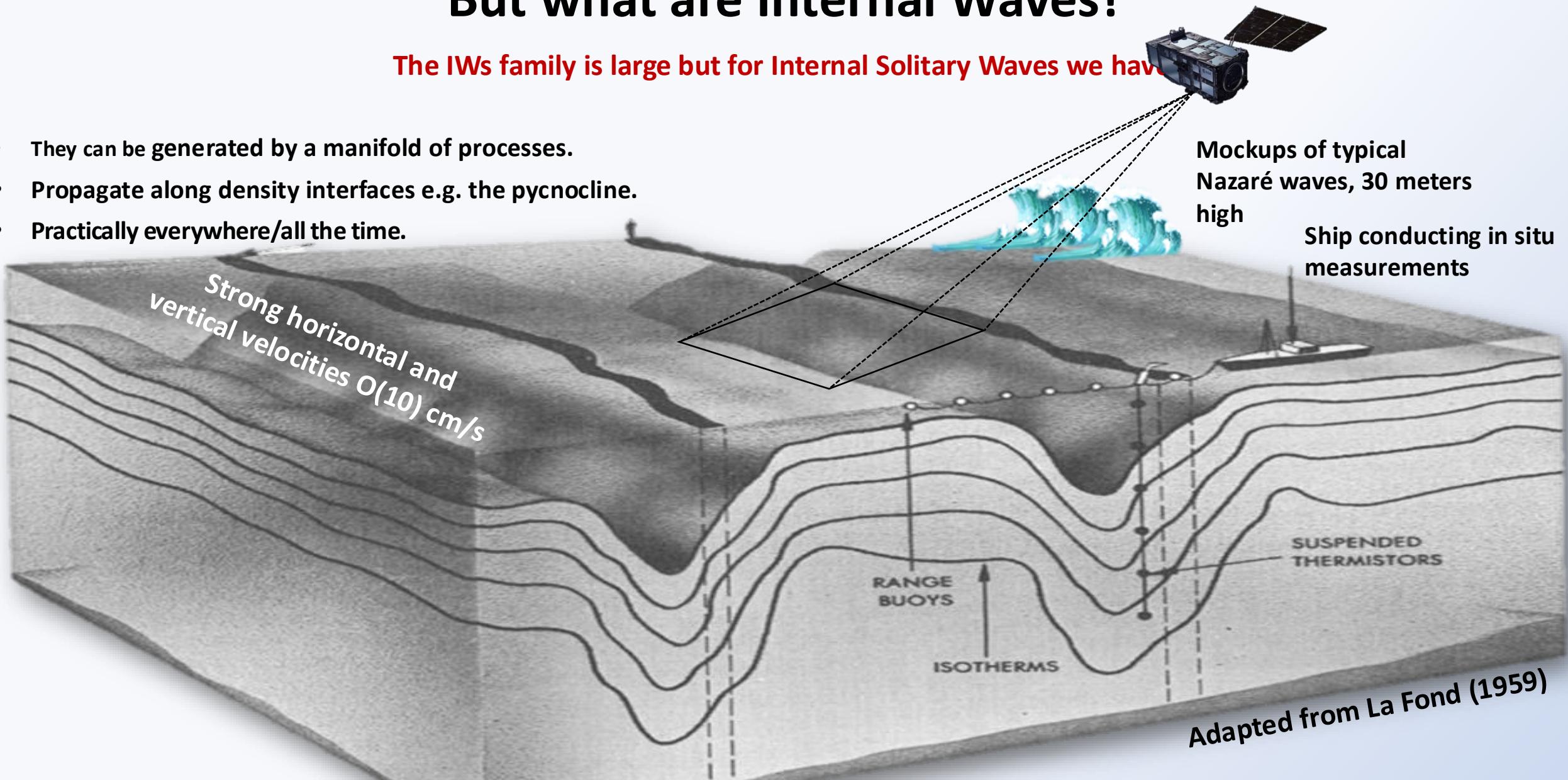
This research was also funded by national and international funds through projects:

- UIDB/04423/2020 and UIDP/04423/2020
- Project THYOCEAN, 2022.00471.CECIND/CP1728/CT0002, <https://doi.org/10.54499/2022.00471.CECIND/CP1728/CT0002>
- Project MIWAVES (PTDC/2022.01215.PTDC), <https://doi.org/10.54499/2022.01215.PTDC>)
- DLR (German Aerospace Center) project OCE3154
- Model-data fusion for the Azores region and the tropical Pacific from MIT Portugal

But what are Internal Waves?

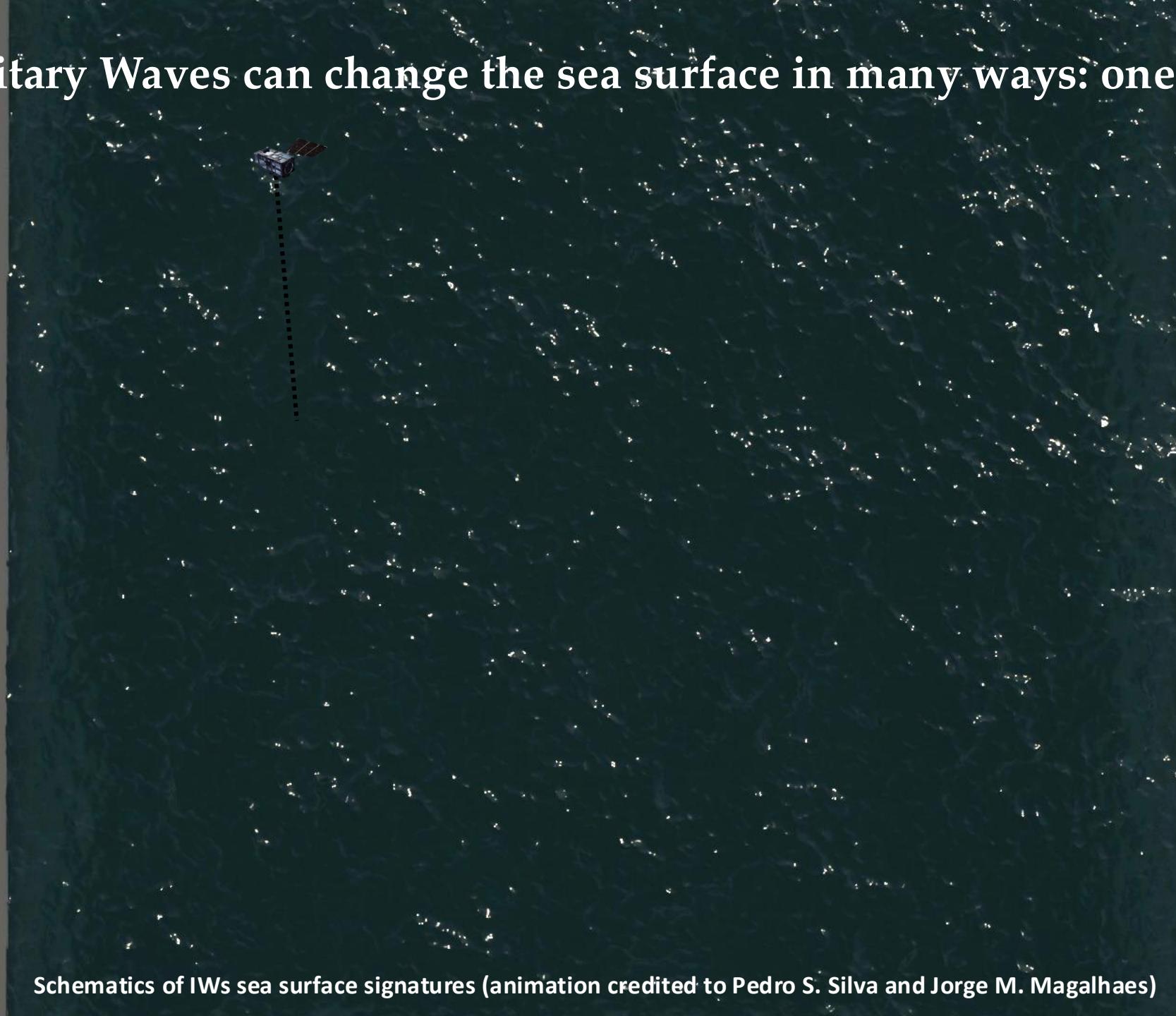
The IWs family is large but for Internal Solitary Waves we have:

- They can be generated by a manifold of processes.
- Propagate along density interfaces e.g. the pycnocline.
- Practically everywhere/all the time.



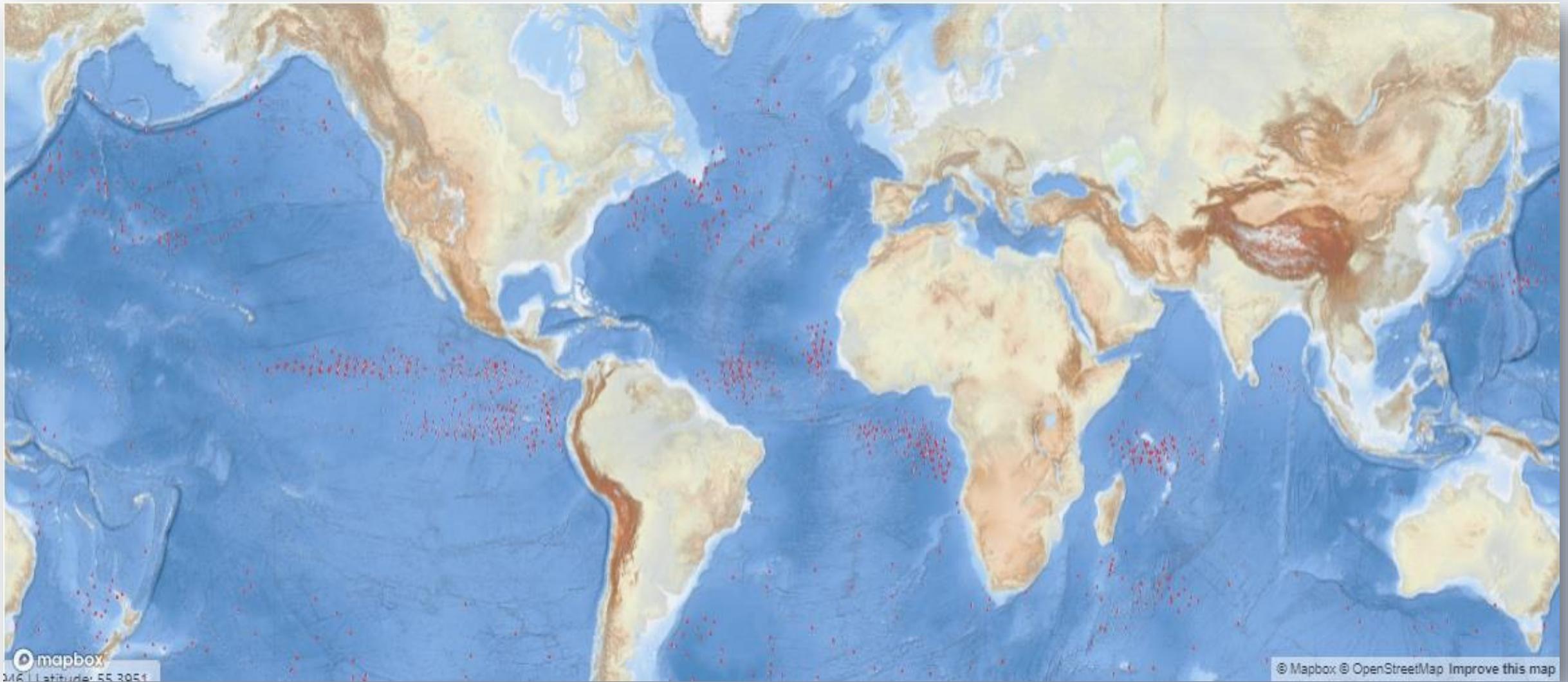
Internal Solitary Waves propagating in the ocean's interior have $O(100)$ meters in amplitude, and last down to a few minutes

Internal Solitary Waves can change the sea surface in many ways: one is roughness



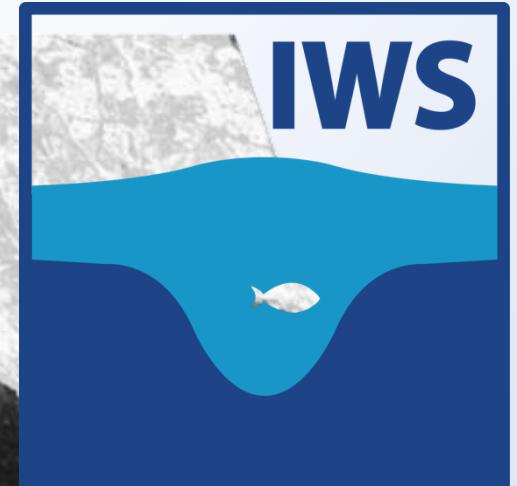
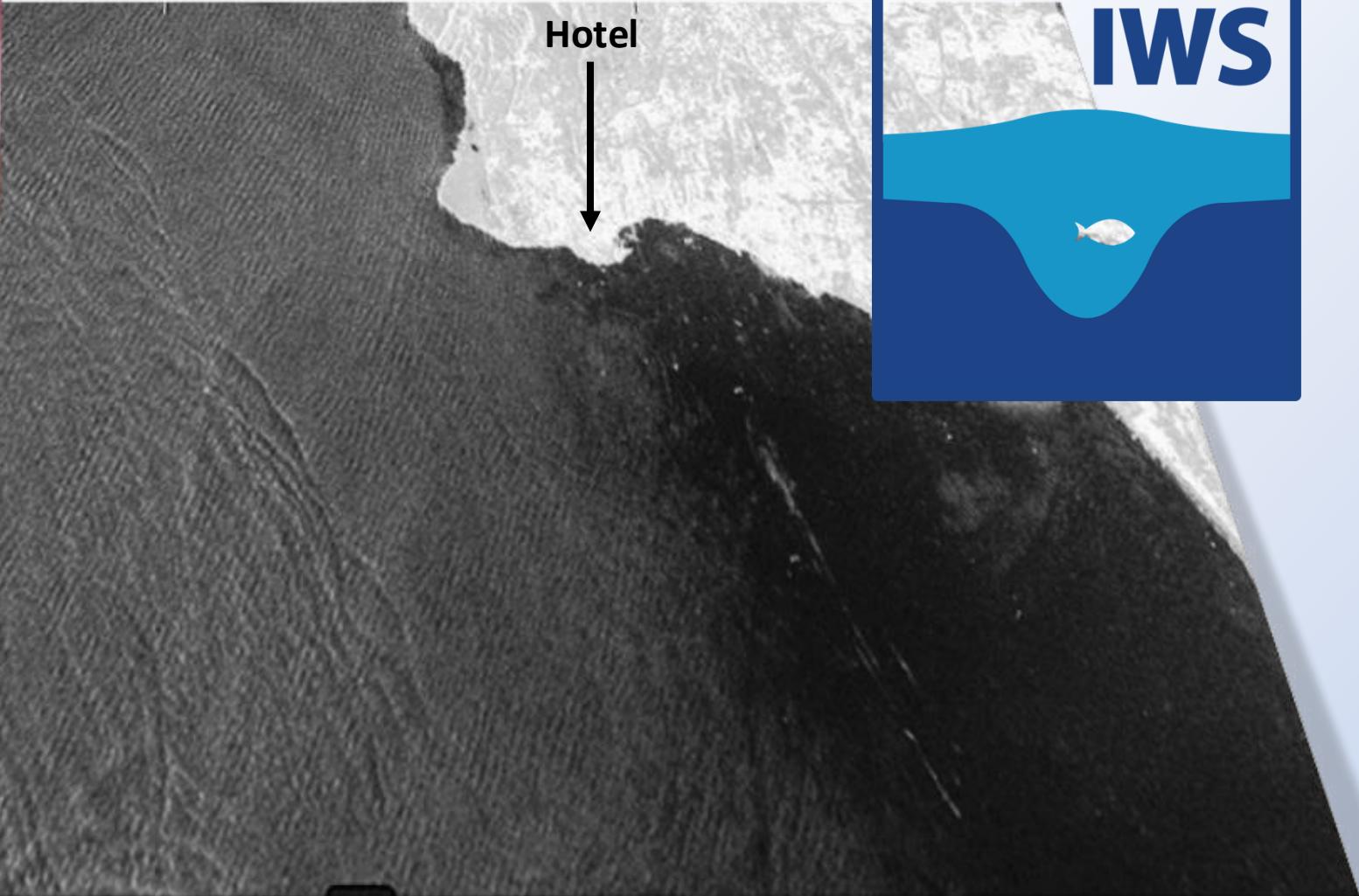
Schematics of IWs sea surface signatures (animation credited to Pedro S. Silva and Jorge M. Magalhaes)

But what may make them especially interesting today is ...



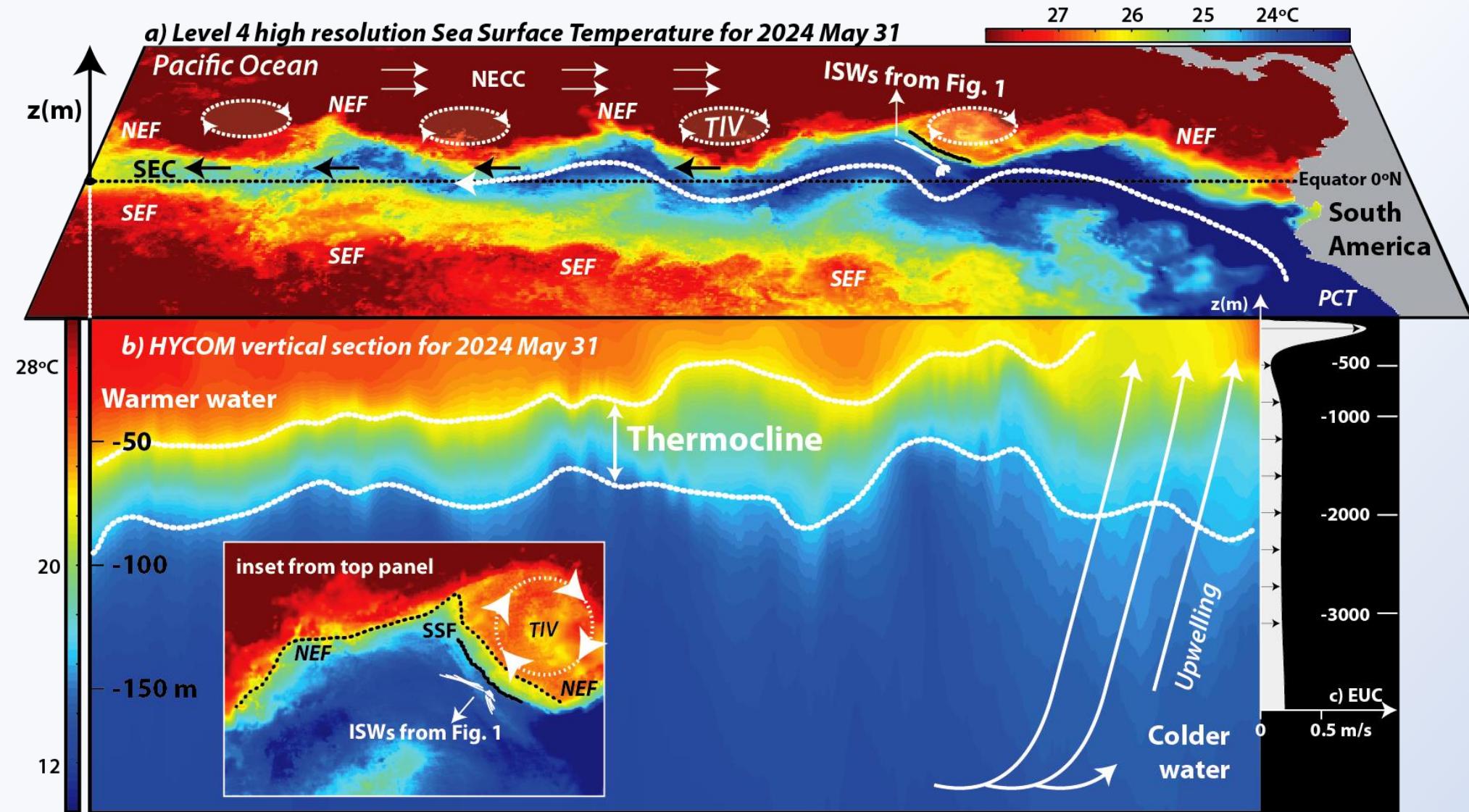
They appear to be a frequent phenomenon as shown by the global map by IWS. <https://services.aircentre.org/iw/map>

IWS meeting



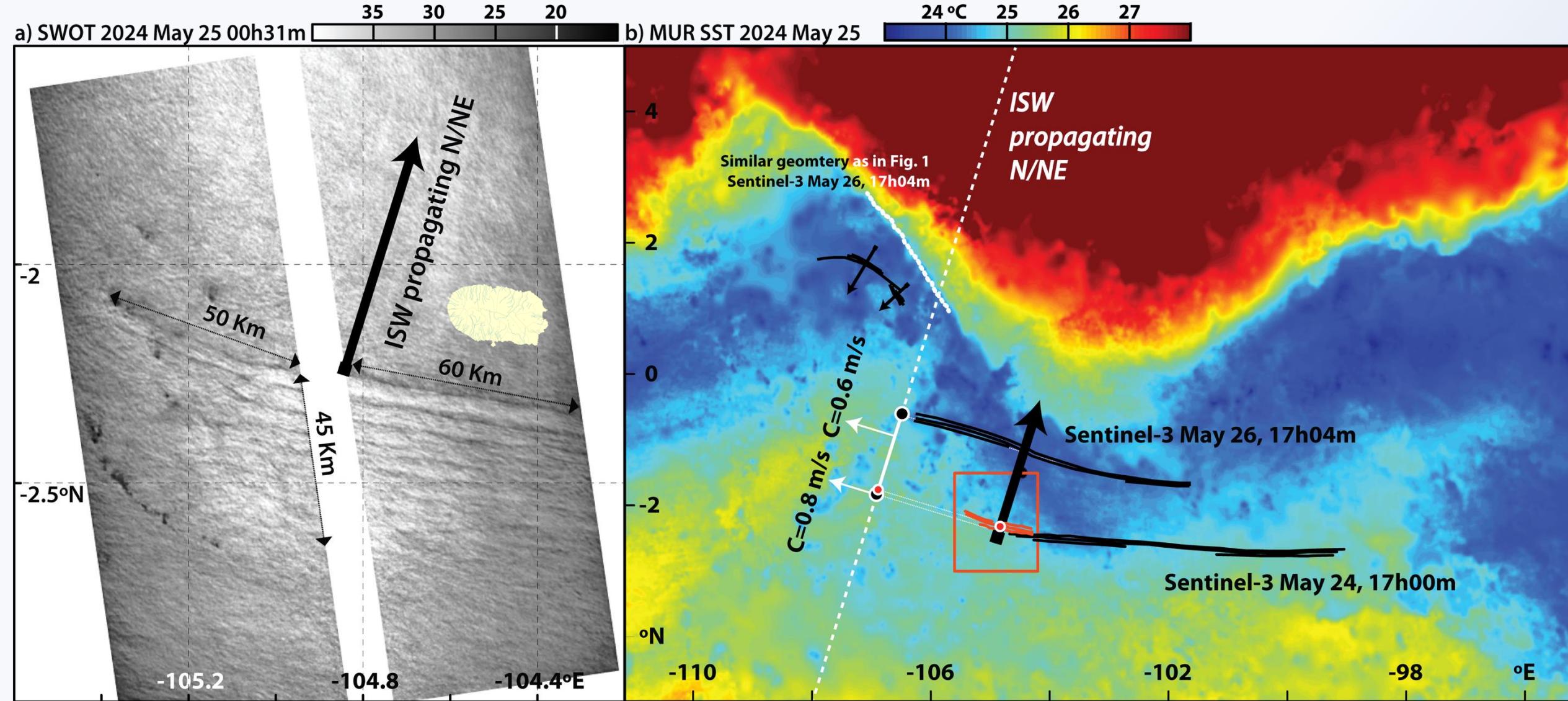
Meeting in Lisbon April 14 to 16

But what may make them especially interesting today is ...



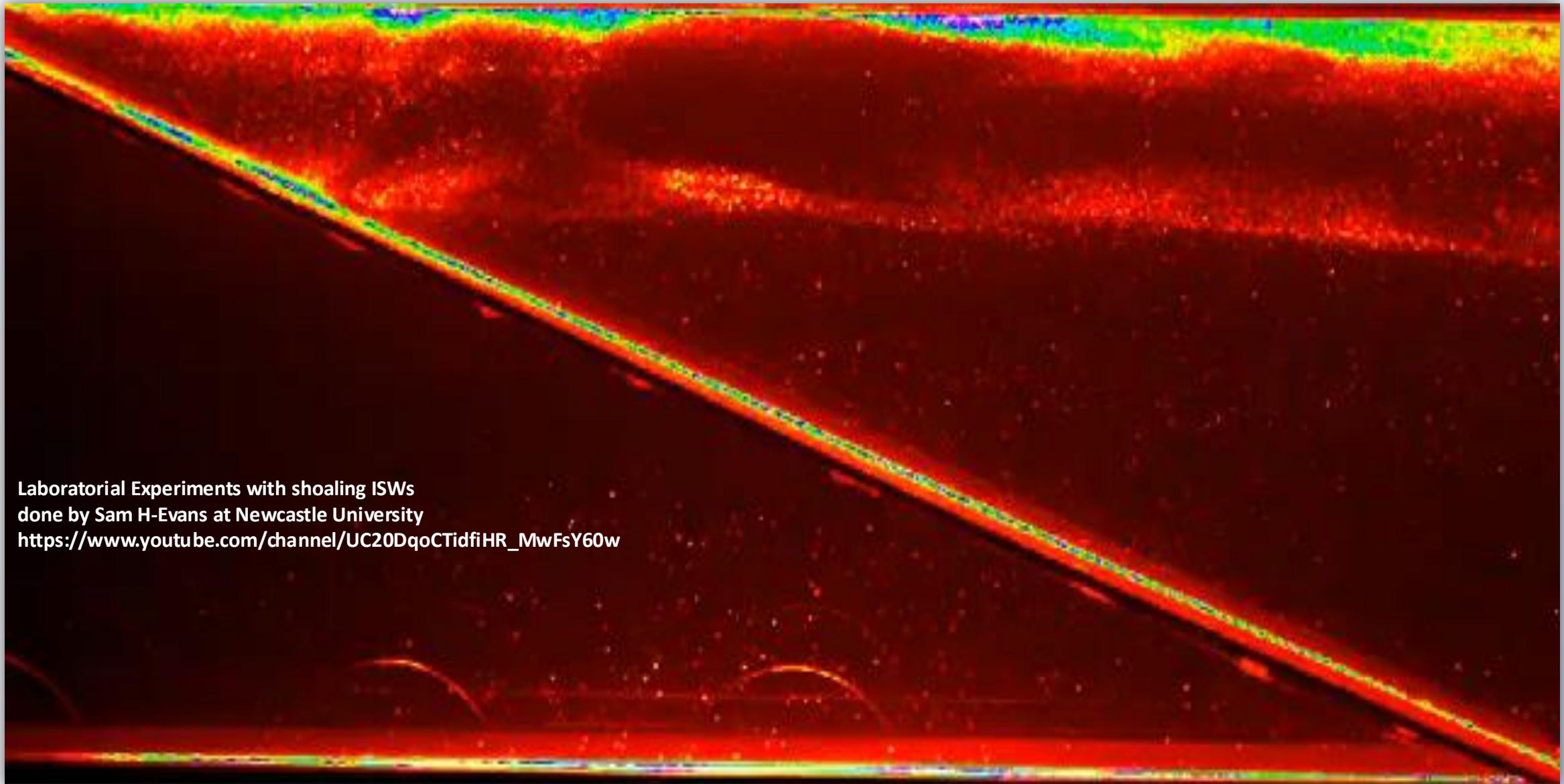
That we now know that they can feed directly on large-scale processes – e.g. the PCT, see more in da Silva et al. (2025)

But what makes them especially interesting today is ...



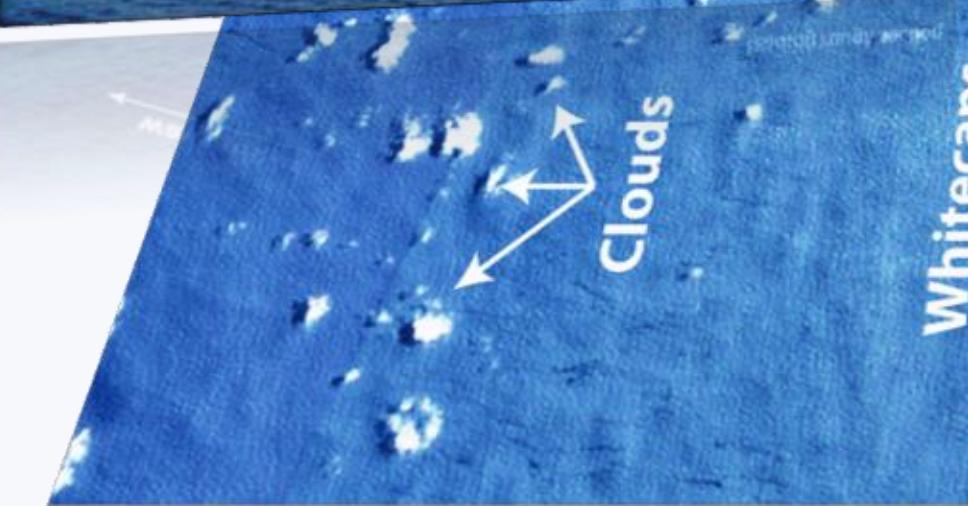
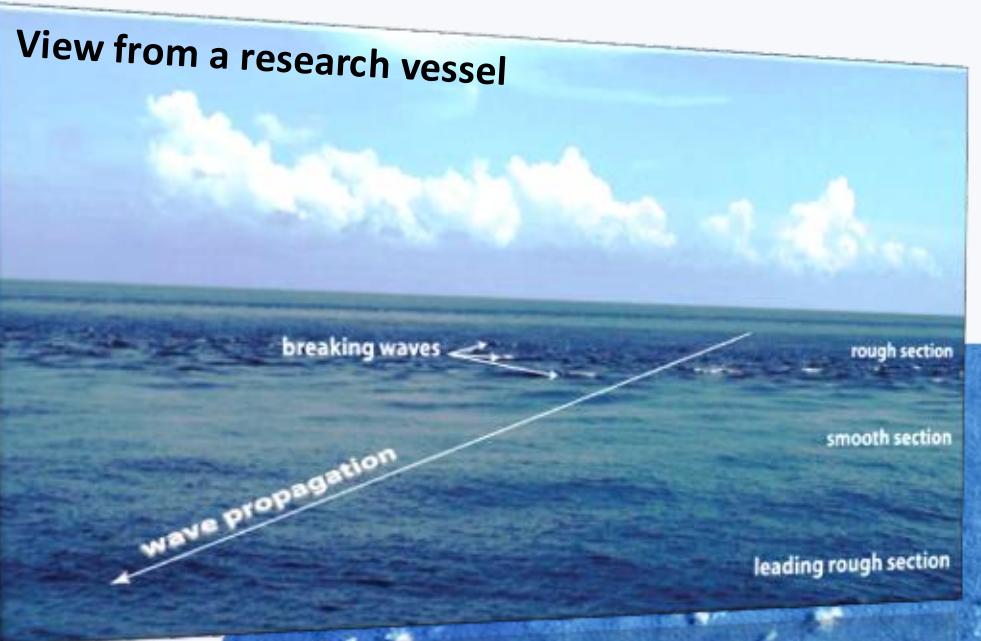
That we now know that they can feed directly on large-scale processes – e.g. the PCT, see Ferreira-Santos et al. (2023) in JPO

But what makes them especially interesting today is ...

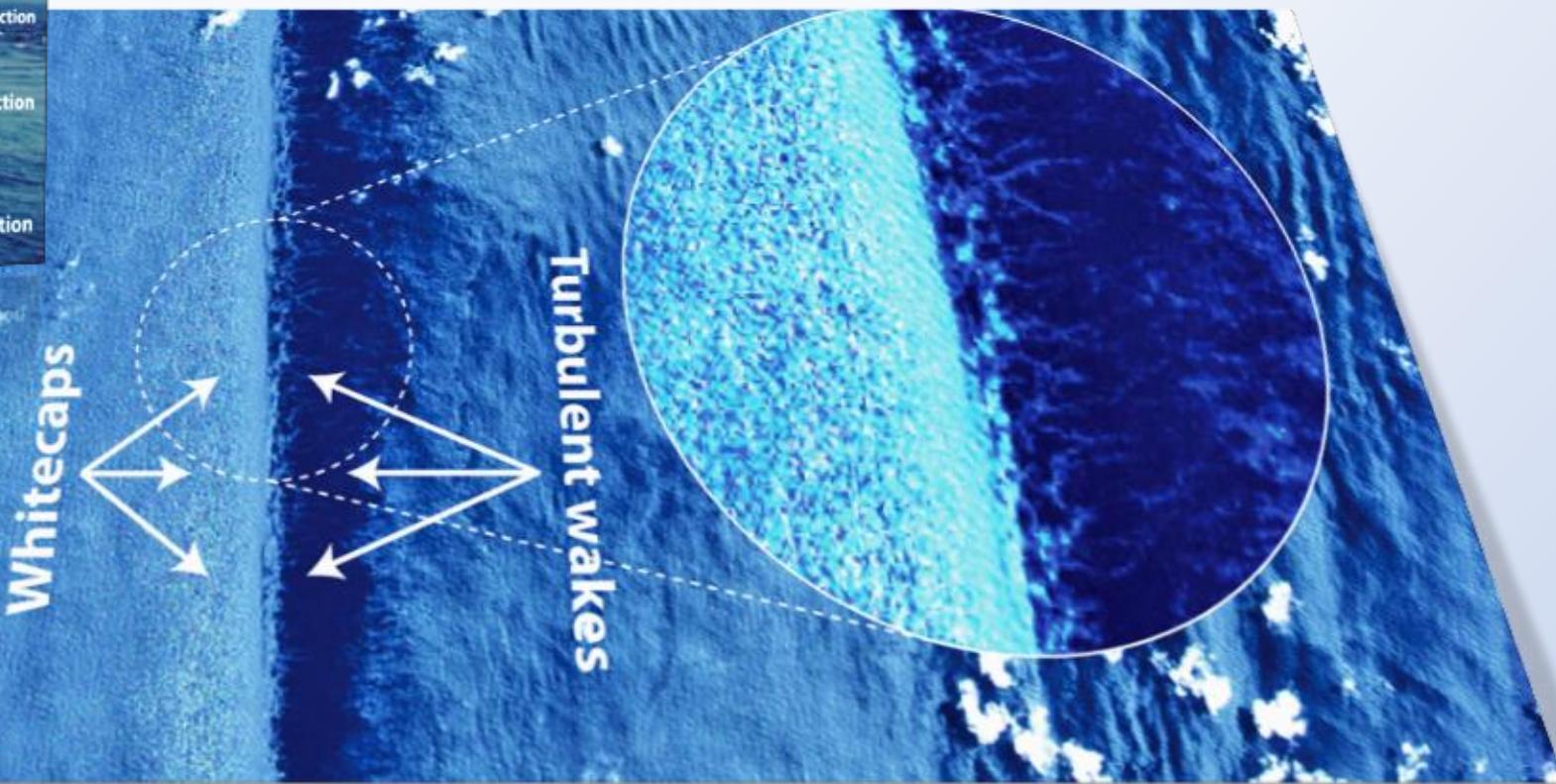


That they mix a lot, both within the water column

But what makes them especially interesting today is ...

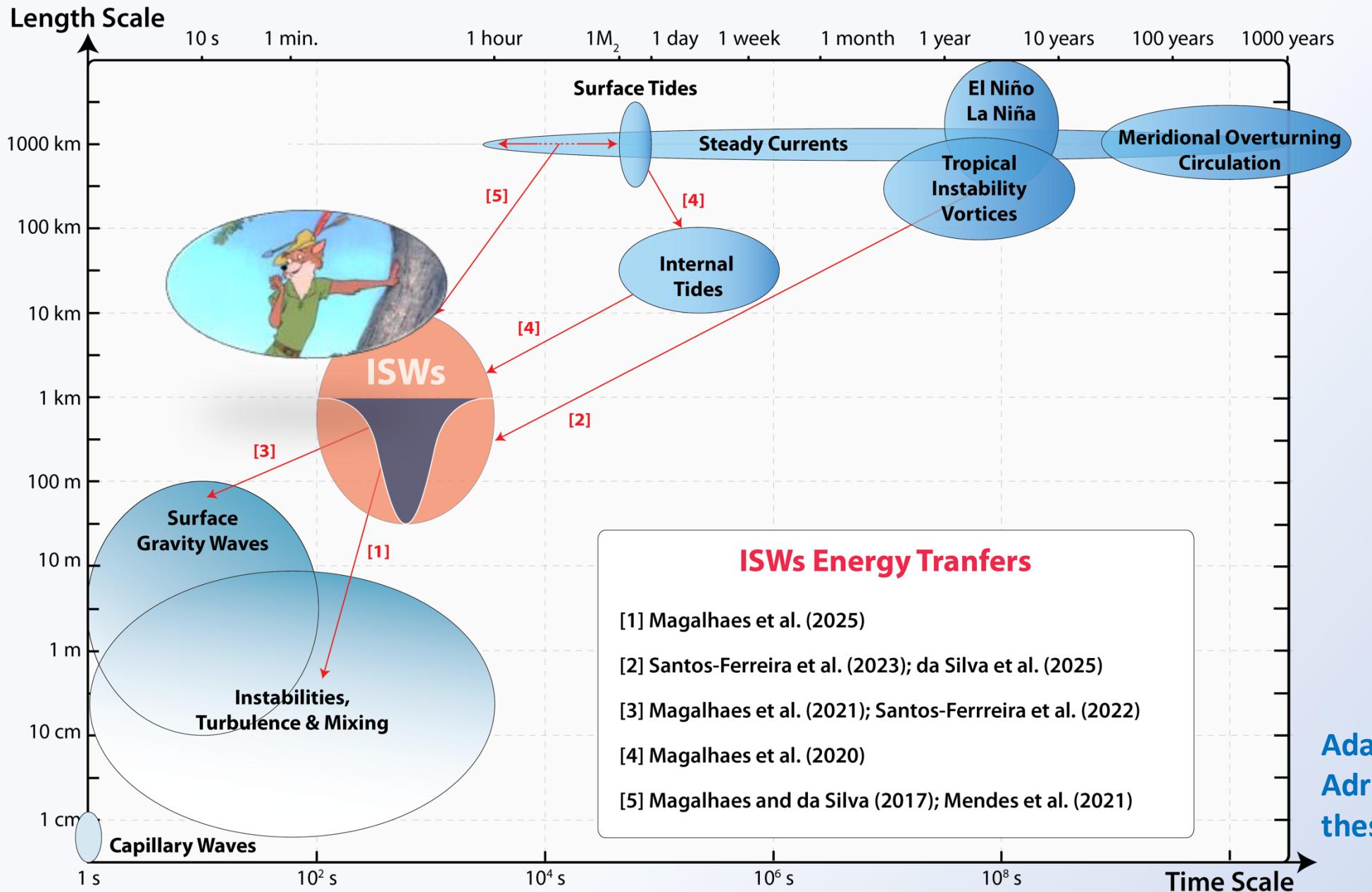


Sentinel-2 image with 10 meter pixel resolution

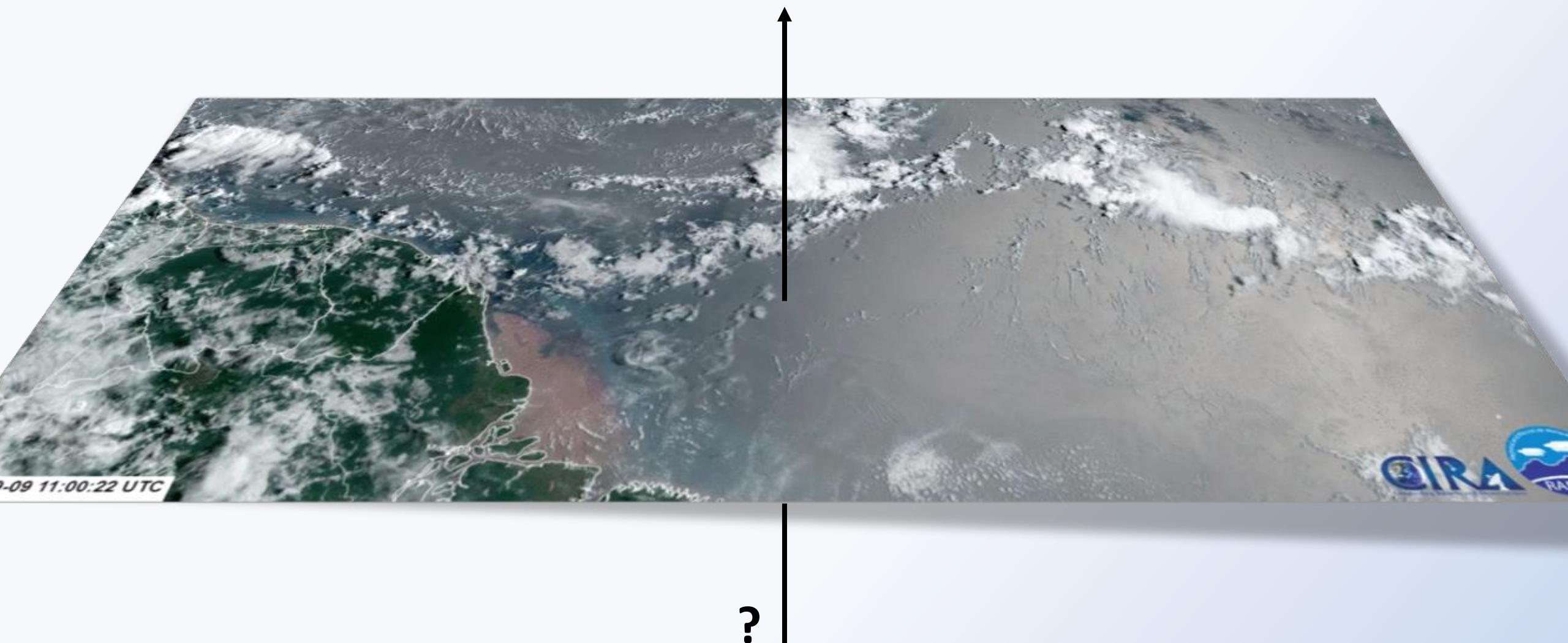


And across the air-sea interface

So in fact, the story should begin here:

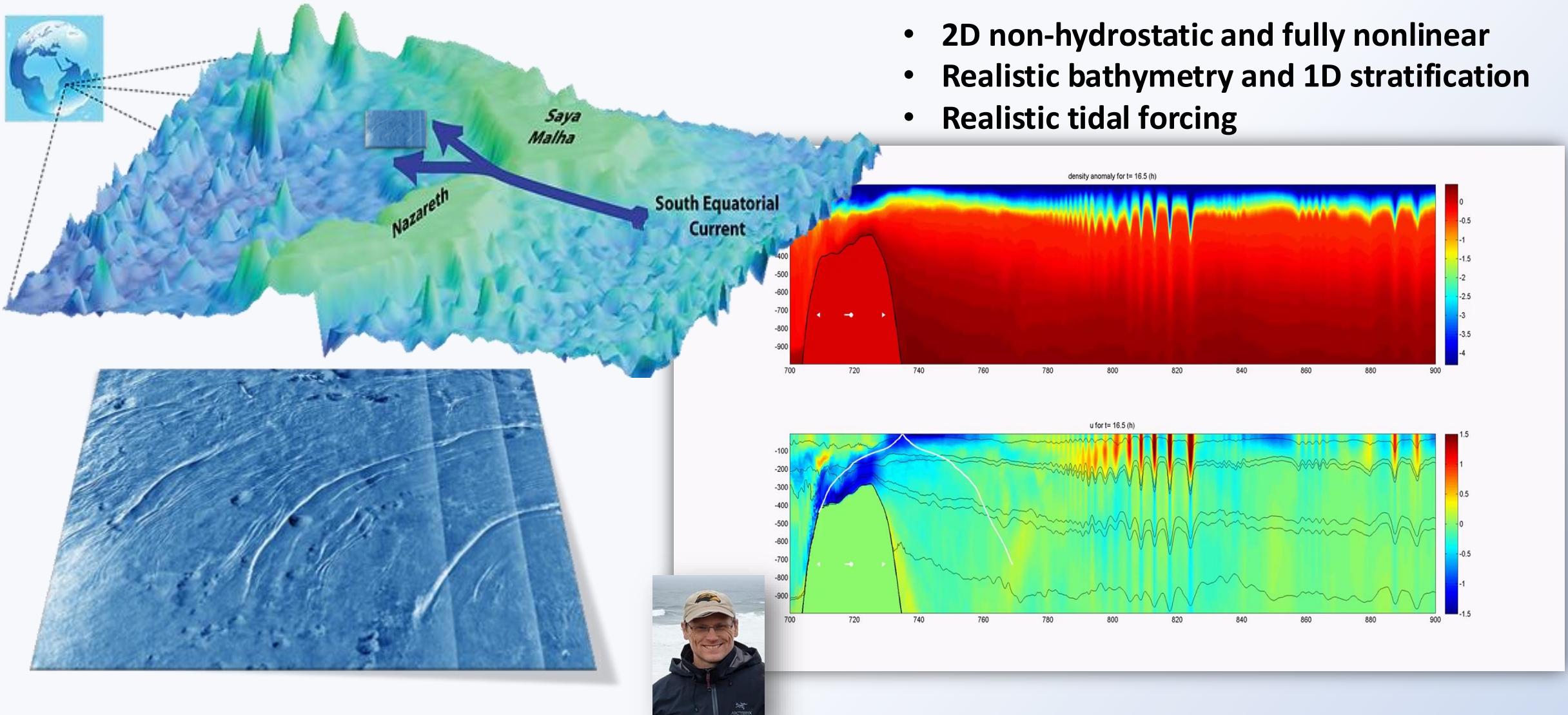


How to learn more?



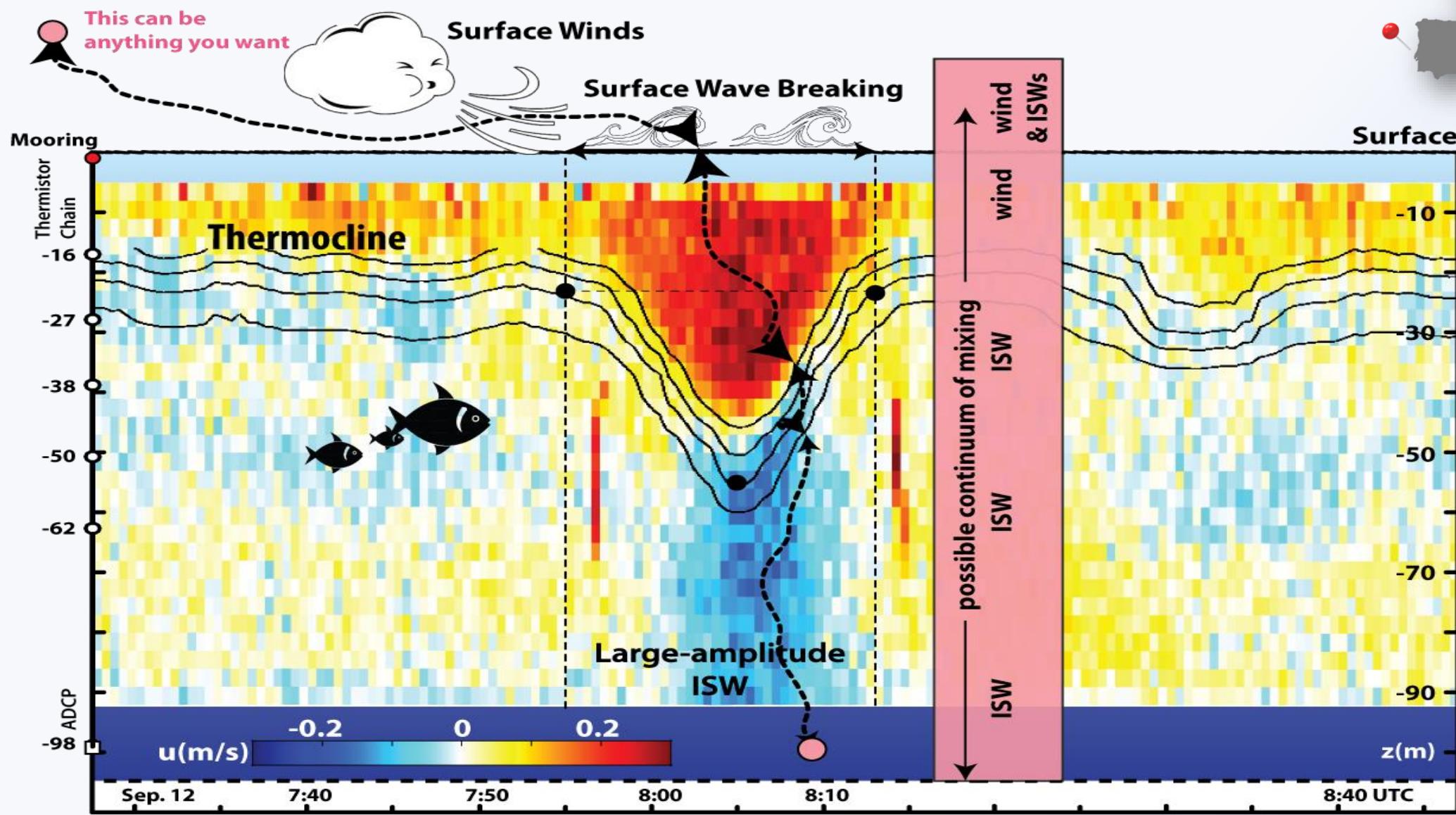
Satellite is amazing, but what is going on underneath?

We need a model



We realized that long ago, so we turned to Maarten Buijsman and he modelled them using MITgcm

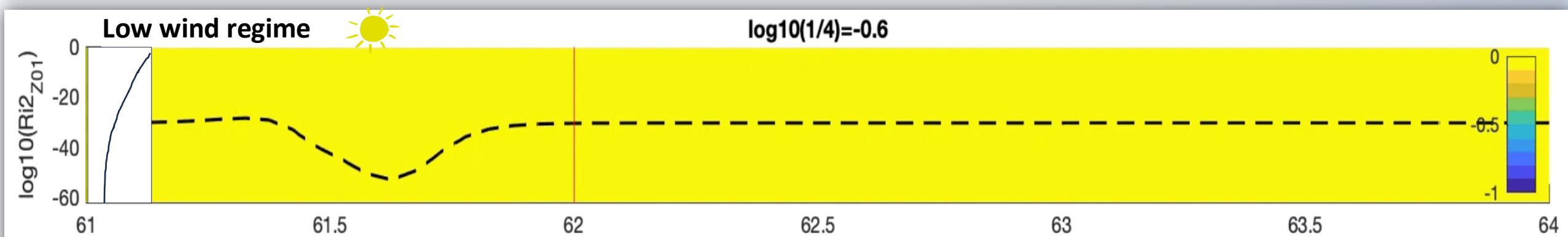
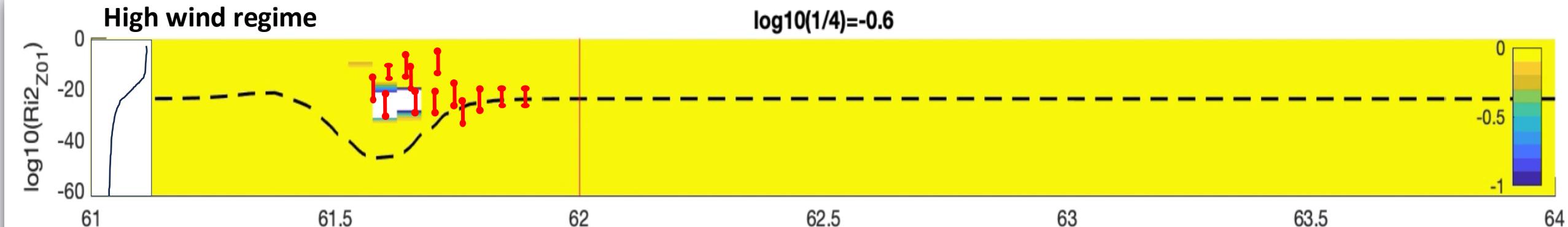
And we continued with MITgcm



Recently we found out that ISWs team up with wind to mix the water column

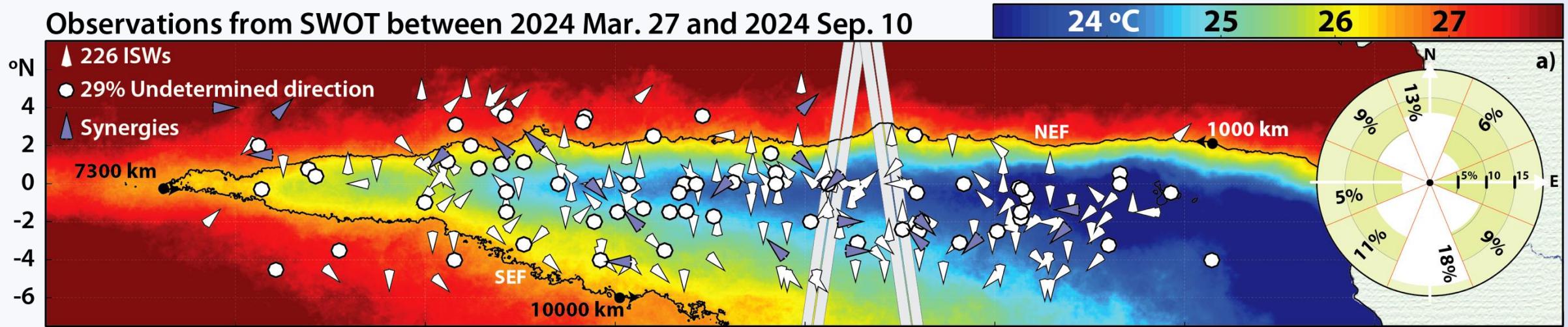
And we continued with MITgcm

- 2D non-hydrostatic and fully nonlinear
- Realistic bathymetry
- Realistic tidal forcing
- **Initialized with analytical DJL model – 2D stratification**



Model is consistent in showing that instabilities are associated with ISWs and weak stratification at the top

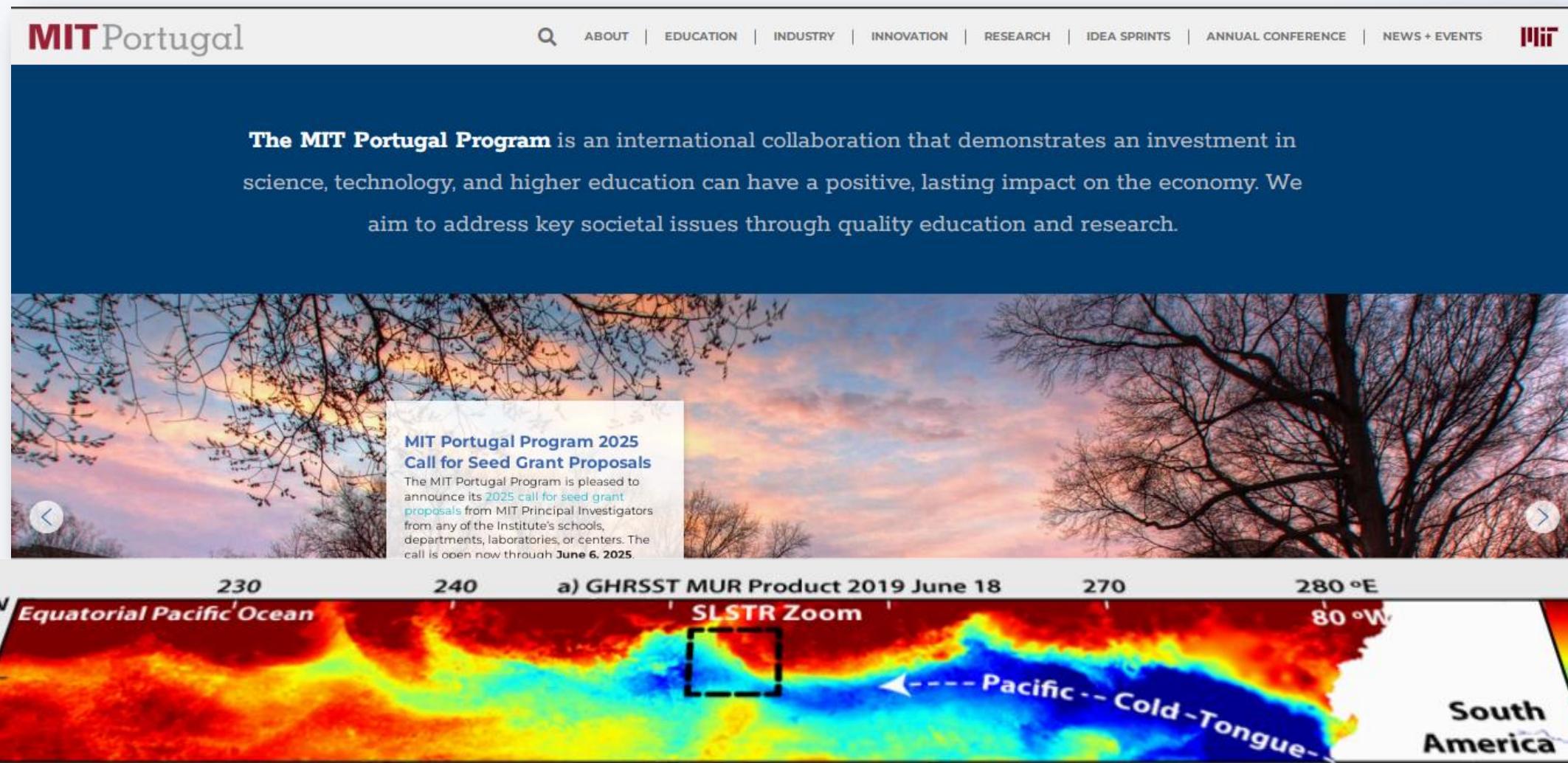
But Cetus began malfunctioning and was shut down while:



e.g. trying to model the ISWs in the Pacific cold Tongue

Fortunately, HPC was recently provided by the AIR Centre

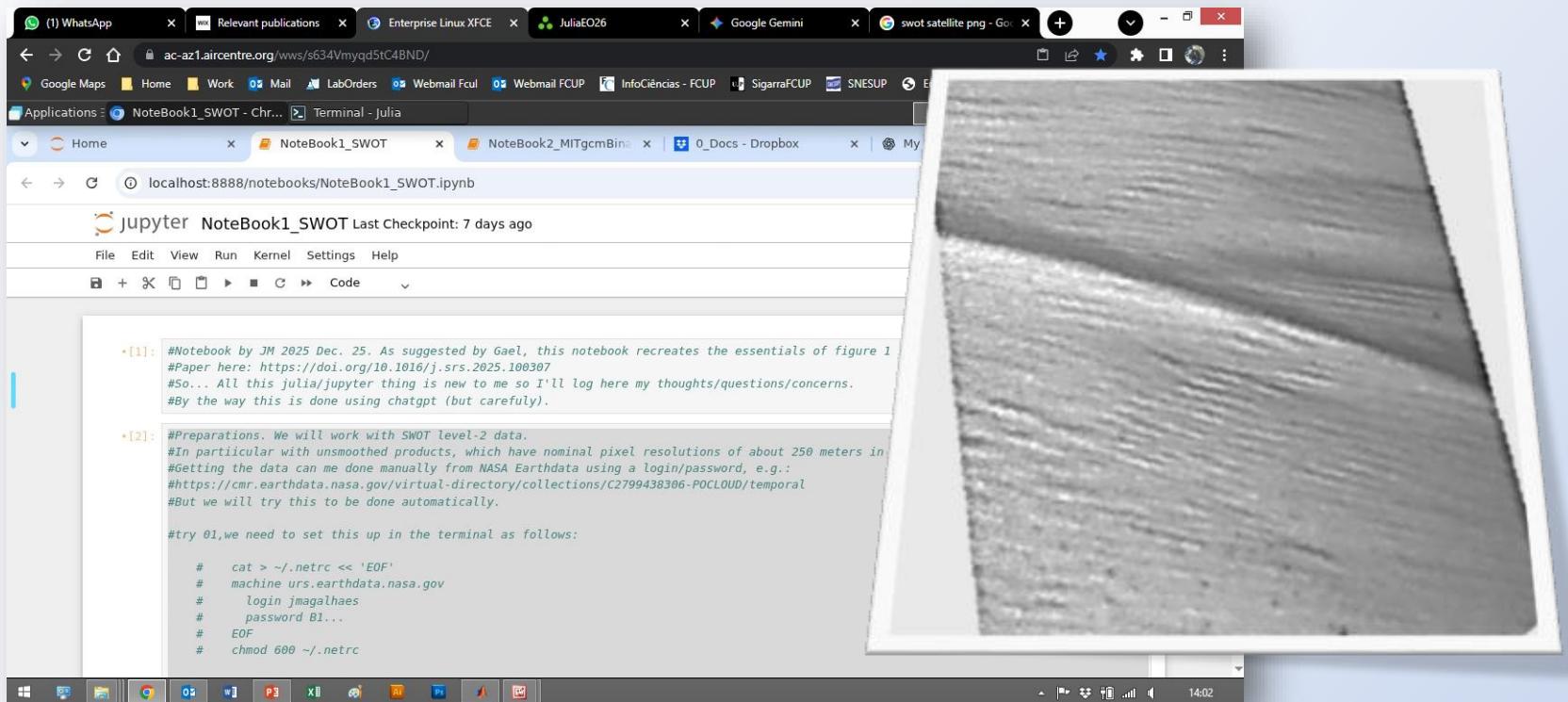
1. Installed MITgcm
2. *Currently trying to model ISW in the Pacific (Gaël's project)*



A few questions you may be able to help with:

1. Put more time into Julia to:

- i. And – not strictly related – the beginnings of a notebook (Julia) to process SWOT data (*noteBook1_SWOT.ipynb*)



```
#Notebook by JM 2025 Dec. 25. As suggested by Gael, this notebook recreates the essentials of figure 1
#Paper here: https://doi.org/10.1016/j.srs.2025.100307
#So... All this julia/jupyter thing is new to me so I'll log here my thoughts/questions/concerns.
#By the way this is done using chatgpt (but carefully).

#Preparations. We will work with SWOT level-2 data.
#In particular with unsmoothed products, which have nominal pixel resolutions of about 250 meters in
#Getting the data can be done manually from NASA Earthdata using a login/password, e.g.:
#https://cmr.earthdata.nasa.gov/virtual-directory/collections/C2799438306-POCLOUD/temporal
#But we will try this to be done automatically.

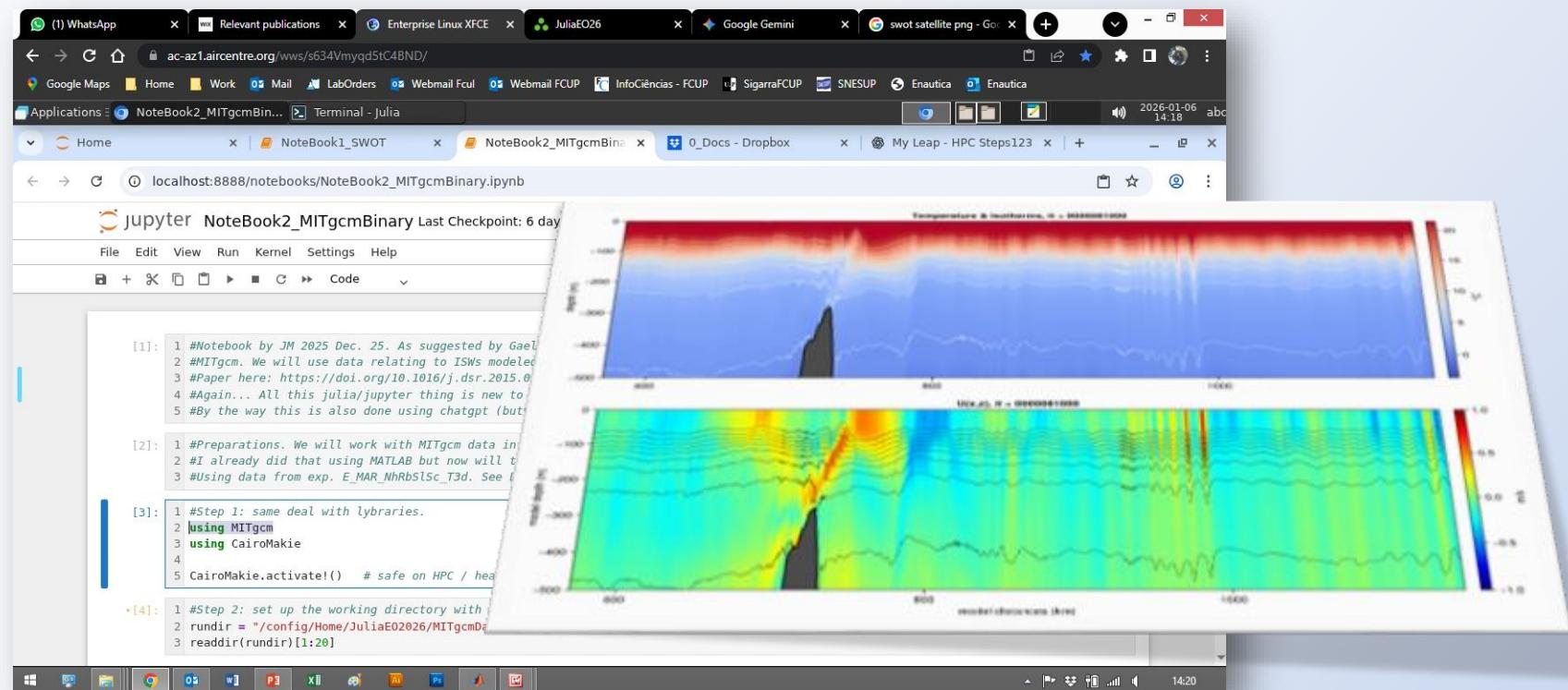
#try 01, we need to set this up in the terminal as follows:

# cat > ~/.netrc << 'EOF'
# machine urs.earthdata.nasa.gov
# login jmagalhaes
# password Bl...
# EOF
# chmod 600 ~/.netrc
```

A few questions you may be able to help with:

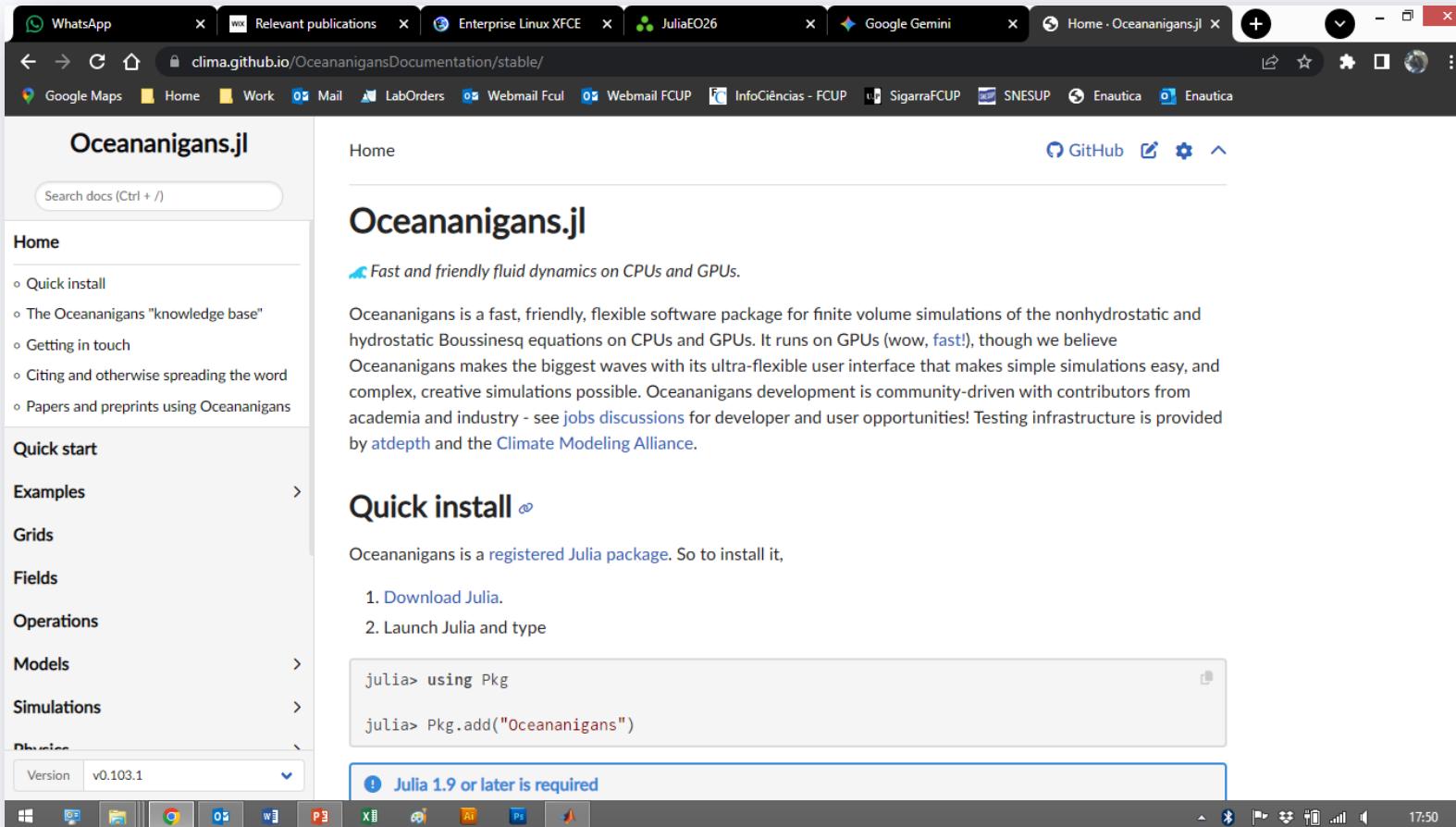
1. Put more time into Julia to:

- ii. The beginnings of a notebook (Julia) to quickly check model runs (*NoteBook2_MITgcmBinary.ipynb*)



A few questions you may be able to help with:

2. Is *Oceananigans* (i.e., sort of *MITgcm* but in *Julia*) worthwhile pursuing?



Thank you!