Small scale variability of sea state and currents: observations, models, theory…

First steps in constraining surface current from sea state data using SWOT, CFOSAT, SKIM and their possible combination

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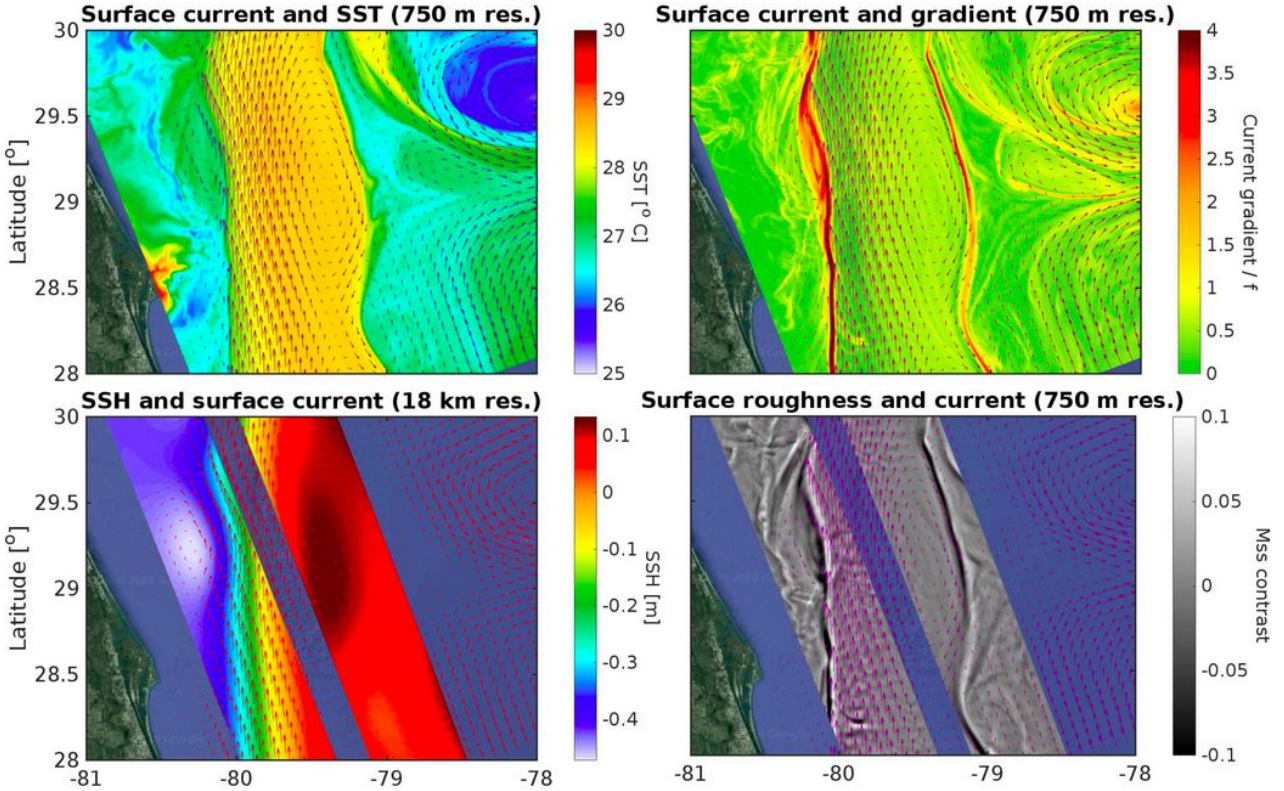
SKIM simulated Level-2d current field, made possible by SWOT Science Team
(and, yes, also a bit ESA's Planck mission)

Ocean wave properties vary on small scales...

.. primarily due to currents.

Well known for
mean square slope (mss)
from SAR and
glitter imagery.

A very good source
of high. Res. :
SWOT LR (250 m) data.
→ divergence
from NRCS maps



(Morrow et al., FMARS 2019)
(Rascle et al. 2016 …)

High resolution SWIM data to prepare for SWOT

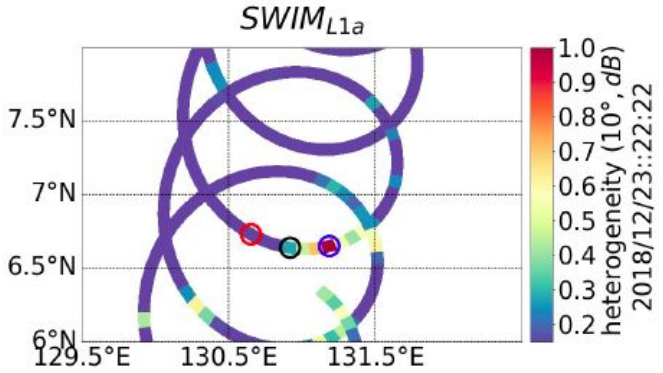
SWIM, on CFOSAT, launched October 2018.

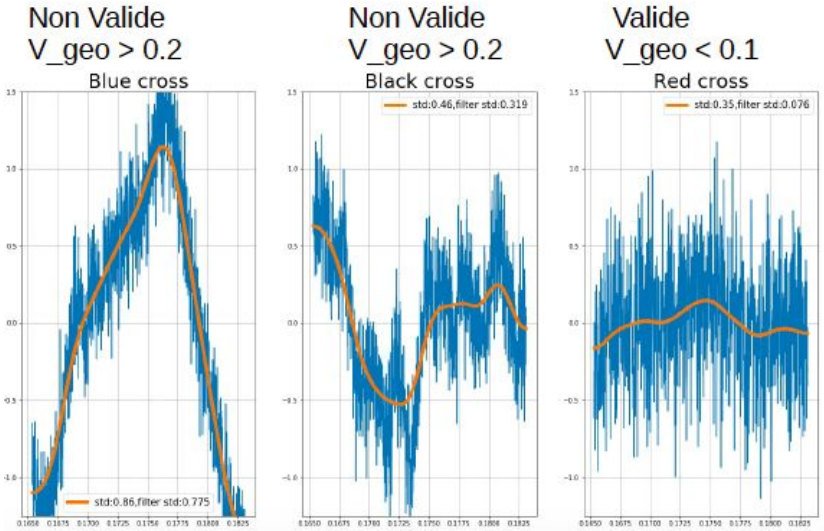
provides Ku-band NRCS at 15 m resolution, integrated over 18 km in azimuth

High range resolution contains waves… but also rain, slicks, fronts, internal waves …

Incidences: 2, 4, 6, 8 and 10°

NRCS is related to mss ,
hence wind and current gradients





(Gressani et al. 2019)

This variability is also strong for wave heights

First known from models thanks to SWOT-ST

(Ardhuin et al. JGR 2017).

Now we can see this in altimeter data thanks to

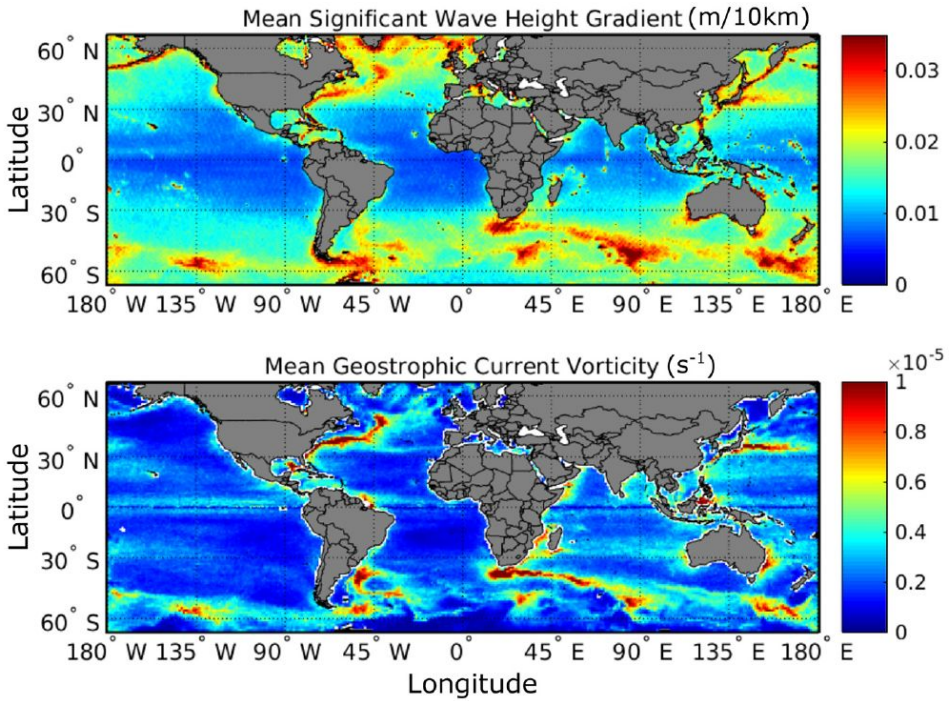
- non-linear data filtering

(Quilfen et al. 2018, Quilfen & Chapron GRL 2019)

- better retracking of nadir data

(LRM: Boy et al. 2016 -> CFOSAT, SAR: S3 data)

NB: ongoing ESA-funded retracking beauty contest (Sea State CCI project) led by M. Passaro (TUM).



(Quilfen et al., RSE 2018)

Come to Brest for User Consultation Meeting, 8, 9 October: https://seastatecci-ucm.sciencesconf.org/.

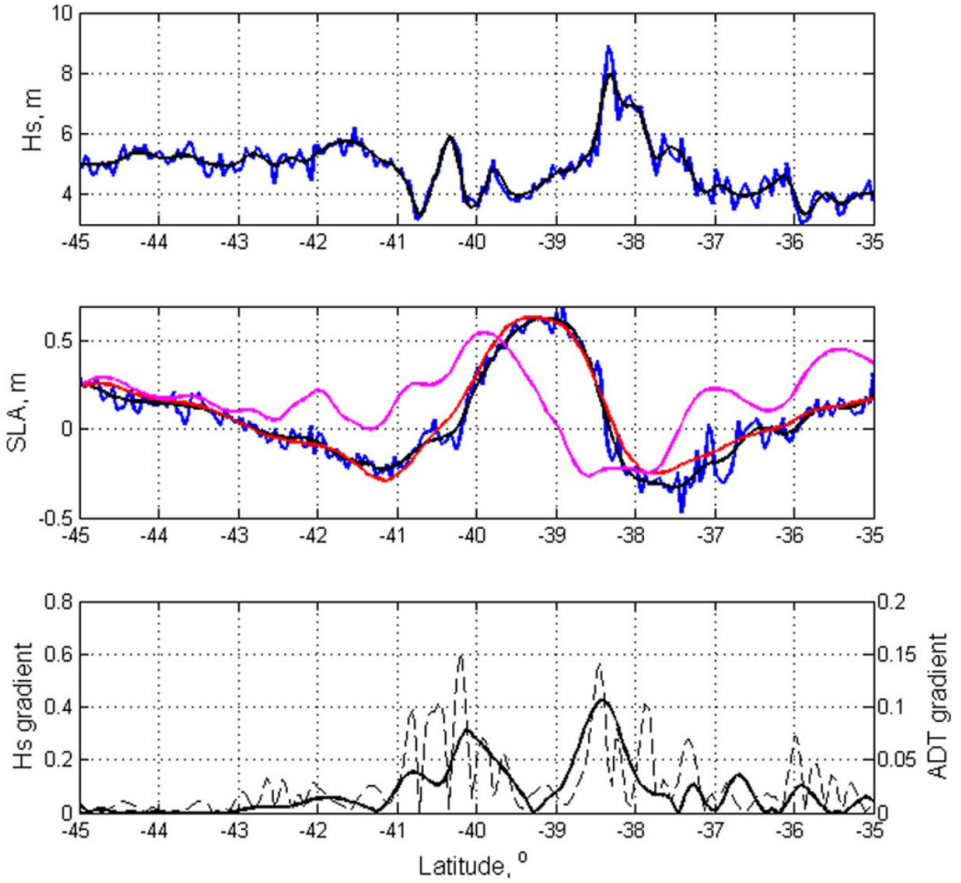
Nonlinear filtering?

Based on the Hilbert-Huang transform
-> Intrinsic Modulation Functions (IMFs)
(Kopsinis and McLaughlin 2009)

The “small scale” first IMFs happen to be dominated by tracker noise.
Here, example from Jason 2 →

Removing these IMFs gives a denoised signal

https://seastatecci-ucm.sciencesconf.org/



(Quilfen et al., RSE 2018)

Nonlinear filtering?

This gives access to L < 100 km: not accessible before!

L~ 30 km for Hs
… but also SSH, NRCS

→SeaState CCI v1 dataset available at https://forms.ifremer.fr/lops-siam/access-to-esa-cci-sea-state-data/

(v2 will be based on retracked data)

→filtering of filtered data: mesoscale effects on waves

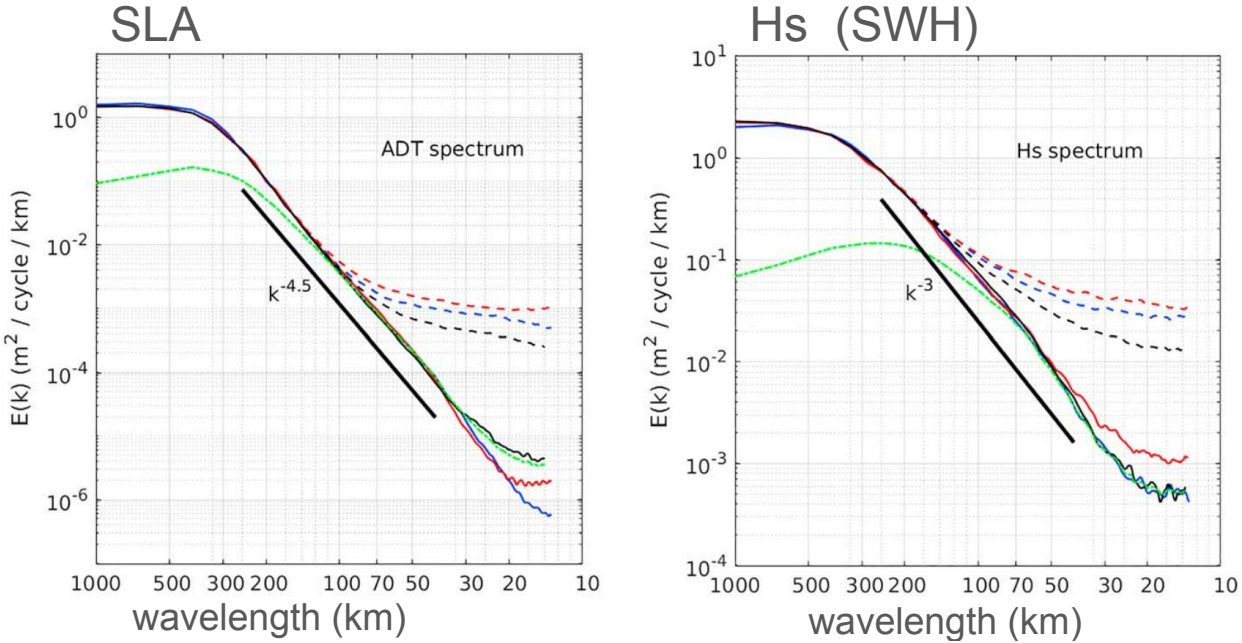


Figure 1. Power spectral density (PSD) as a function of wavenumber (x axis labels in kilometer) for altimeter ADT (left) and Hs (right) measurements: SARAL/Altika (black), Cryosat-2 (red), and Jason-2 (blue), time period 2014–2016, Agulhas region. Dashed lines are for raw 1-Hz data and solid lines for filtered data. The first IMF PSD of filtered ADT (left) and Hs (right) is shown as a dashed-dotted green line (these intrinsic mode functions are computed from the three altimeters merged data set). Solid black lines give the $k^{-4.5}$ (left) and k^{-3} (right) dependence between 250 and 40 km of wavelength. ADT = absolute dynamic topography; IMF = intrinsic mode functions.

(Quilfen & Chapron GRL 2019)

Application to Agulhas current: can we model Hs?

100% Hs enhancement in Agulhas

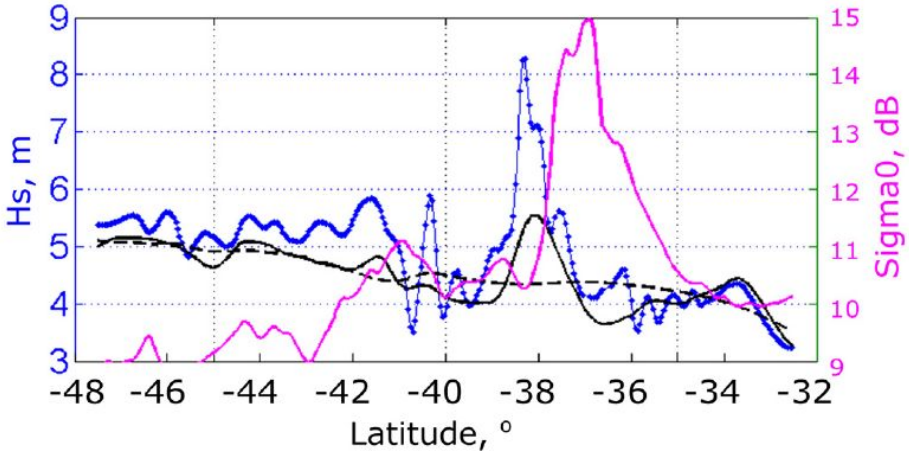
Wave model forced with AVISO current gives only 25% increase

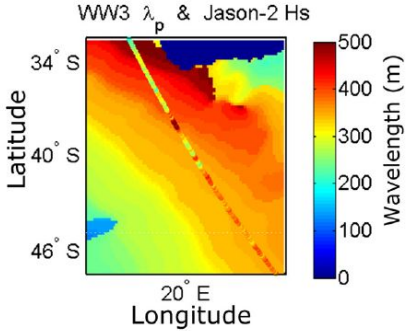
What is wrong?

The model?

The forcing current?

Could we improve on current knowledge from σ^0 and Hs gradients?





Case of long (400 m) swell.

(Quilfen & al. RSE 2019)

Application to Agulhas current: can we model Hs?

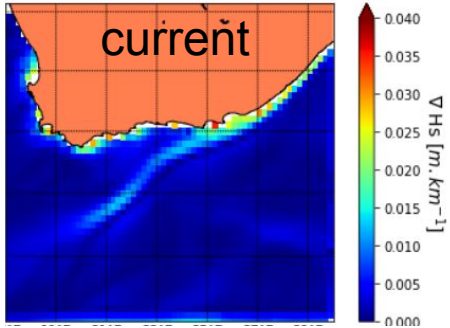
Yes with *properly resolved* currents.
Starting from ROMS (non-assimilating) model run at 1.5 km, and smoothing it

Hs Gradients closer to altimeter data.

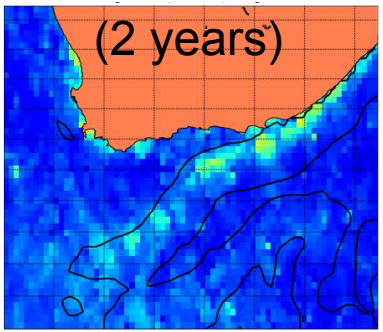
Required current resolution
is ~ 30 km

→ SKIM Level-2c requirement
(SKIM Report for Mission Selection, ESA-EOPSM-SKIM-RP-3550, June 20, 2019)

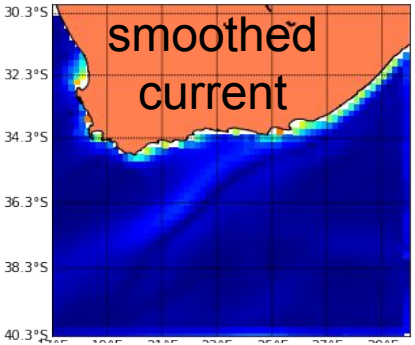
WW3 forced with HR current



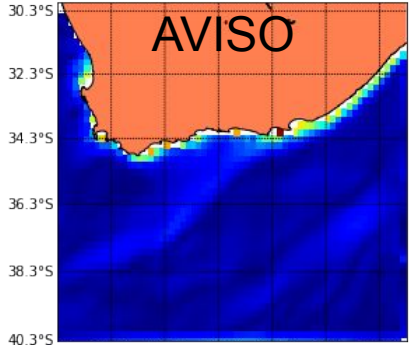
Altimeter data (2 years)



WW3 forced with 140 km smoothed current



WW3 forced with AVISO

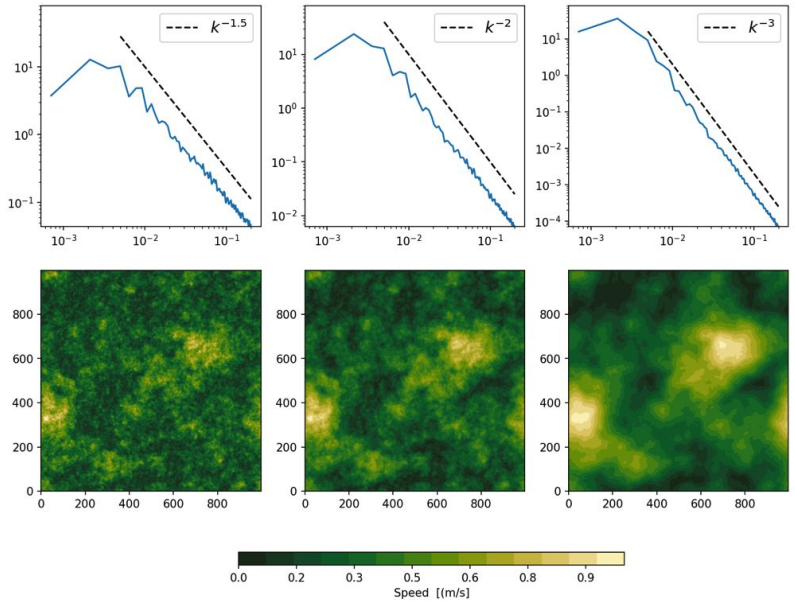


(SKIM Team 2019, Marechal et al., in prep)

How well do we understand these sea state gradients? response to vorticity and divergence: advection & refraction

Synthetic surface currents:

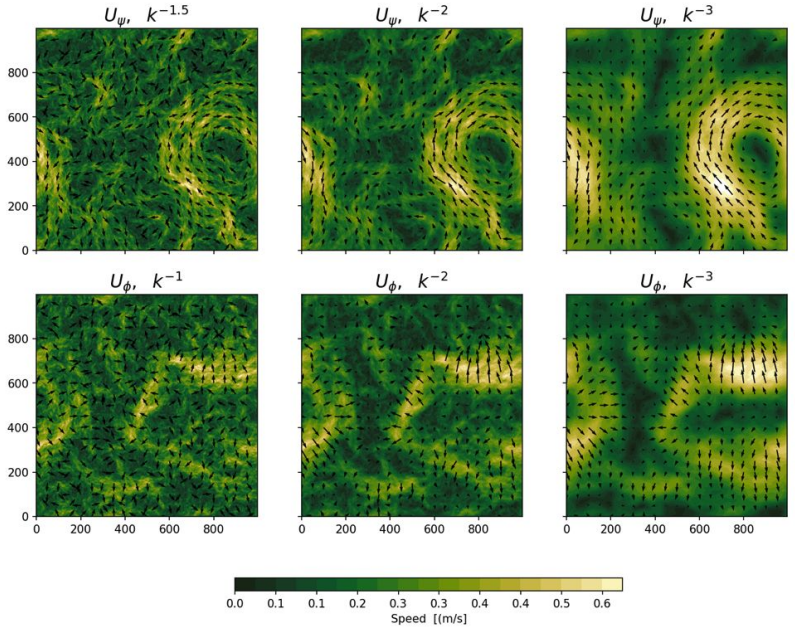
random phase, prescribed spectral slope, fixed variance.



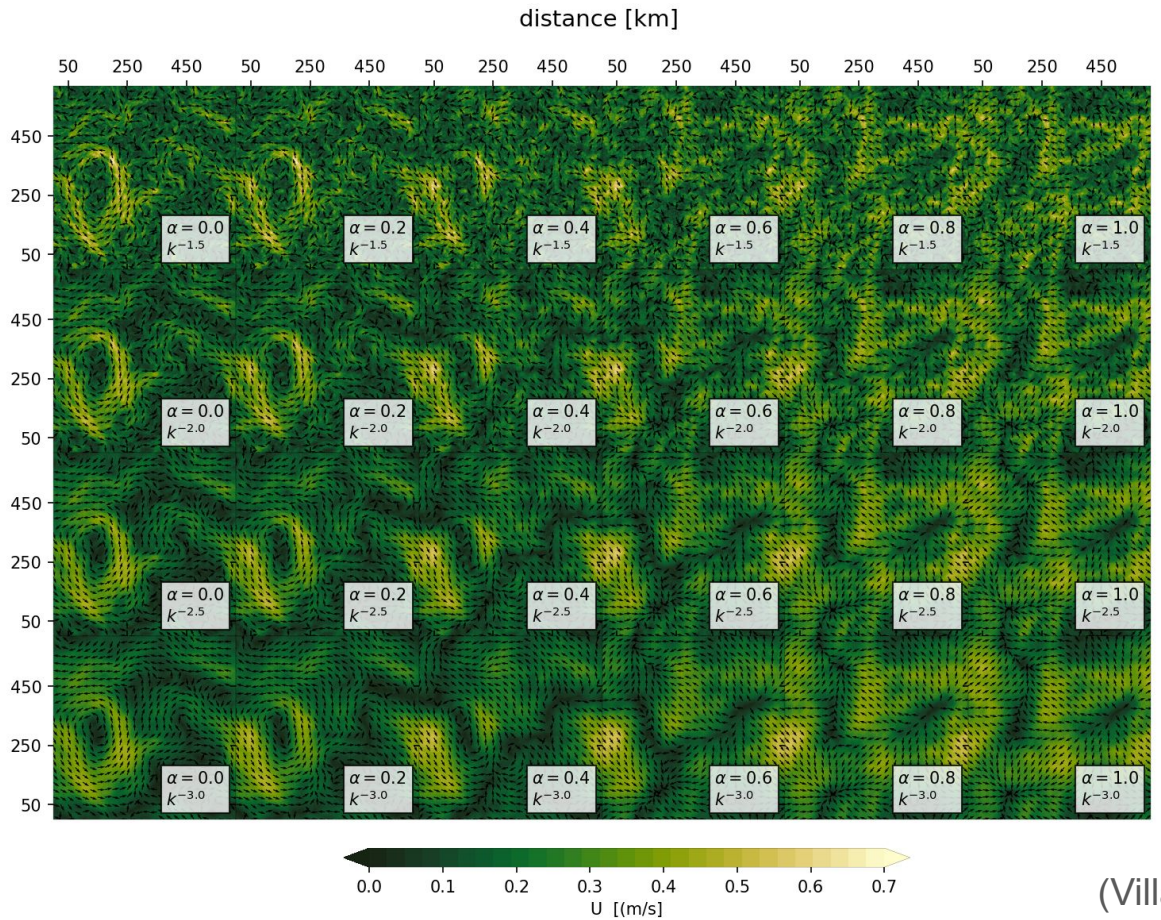
Helmholtz

decomposition

Rotational & divergent component



More vorticity → More divergence



Shallower spectral slope

Steeper spectral slope

Same variance spectra, different vort/div ratio

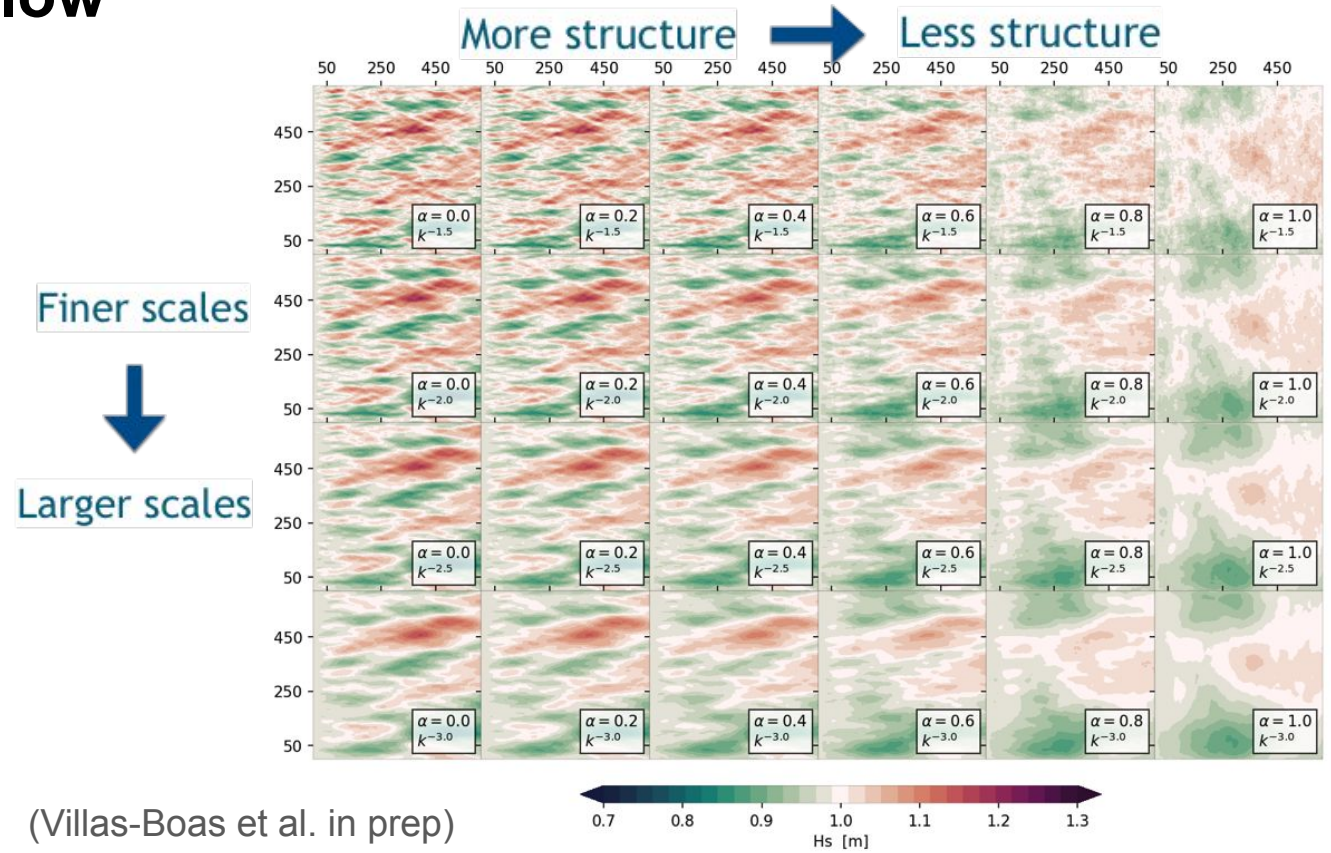
(Villas-Boas et al. in prep)

Gradients of significant wave height are highly dependent on the nature of the flow

Vorticity causes **wave refraction** ⟶ focusing and defocusing of **wave action**

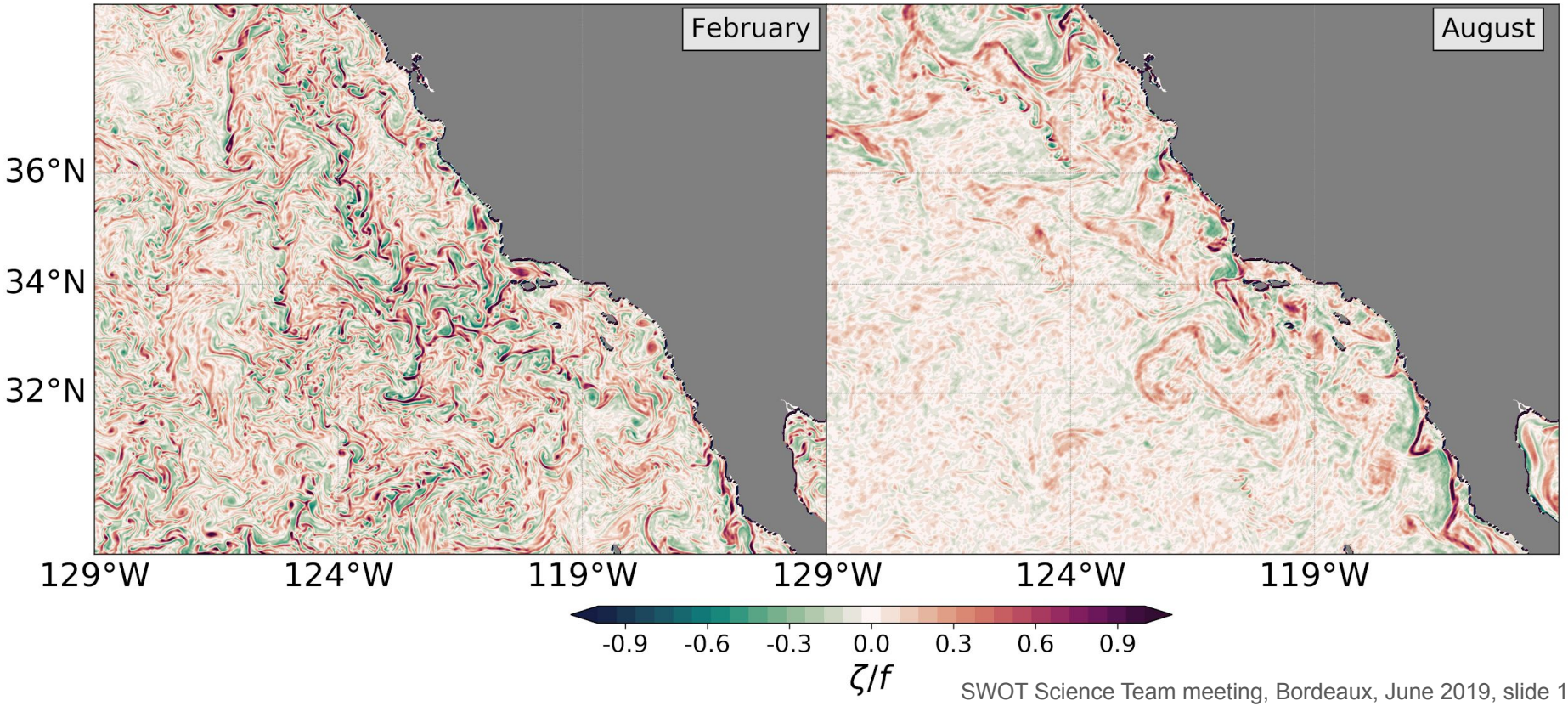
⇒ more **structure** in the significant wave height (Hs) for the flow with more **vorticity.**

Changes of up to **30%** in **Hs** over scales of **tens** of **kilometers.**



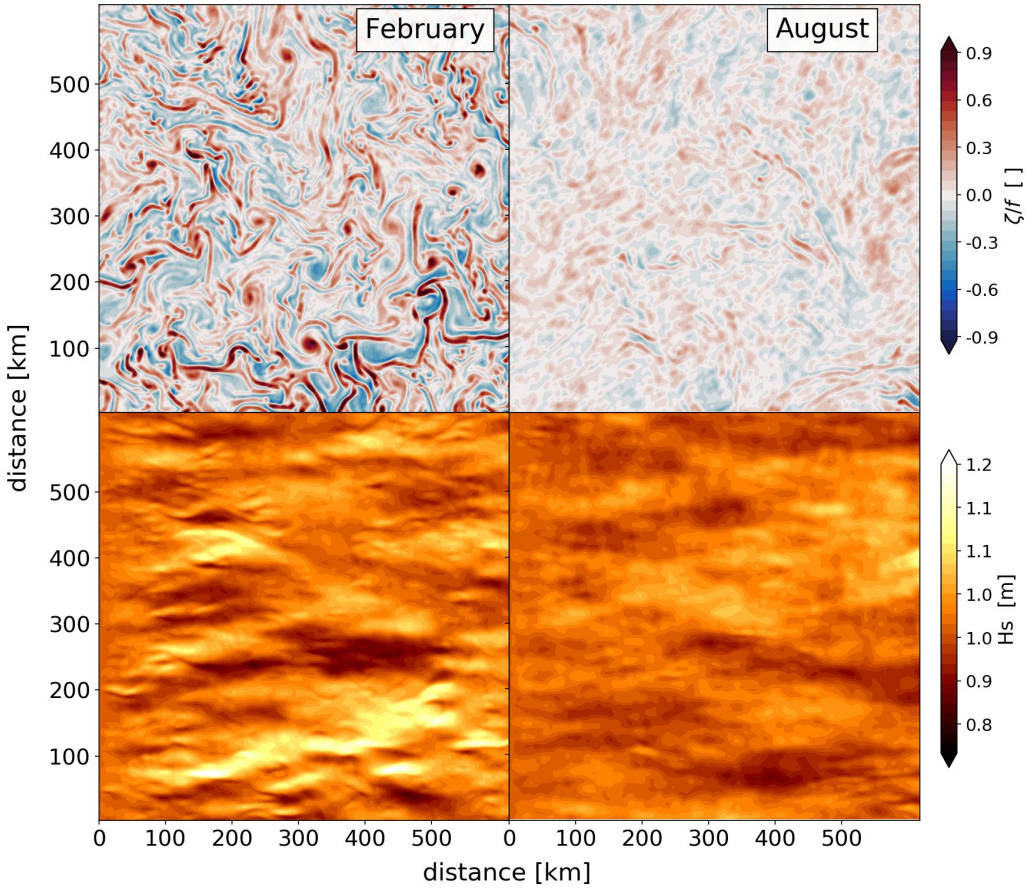
(Villas-Boas et al. in prep)

Seasonal changes in the dominant regime of surface currents may lead to significant changes in the surface wave response



LLC4320 in the California Current region:

Similar setup with realistic currents from the LLC4320 leads to similar spatial gradients in Hs → Stronger gradients in Hs in the winter, when the vorticity is higher.

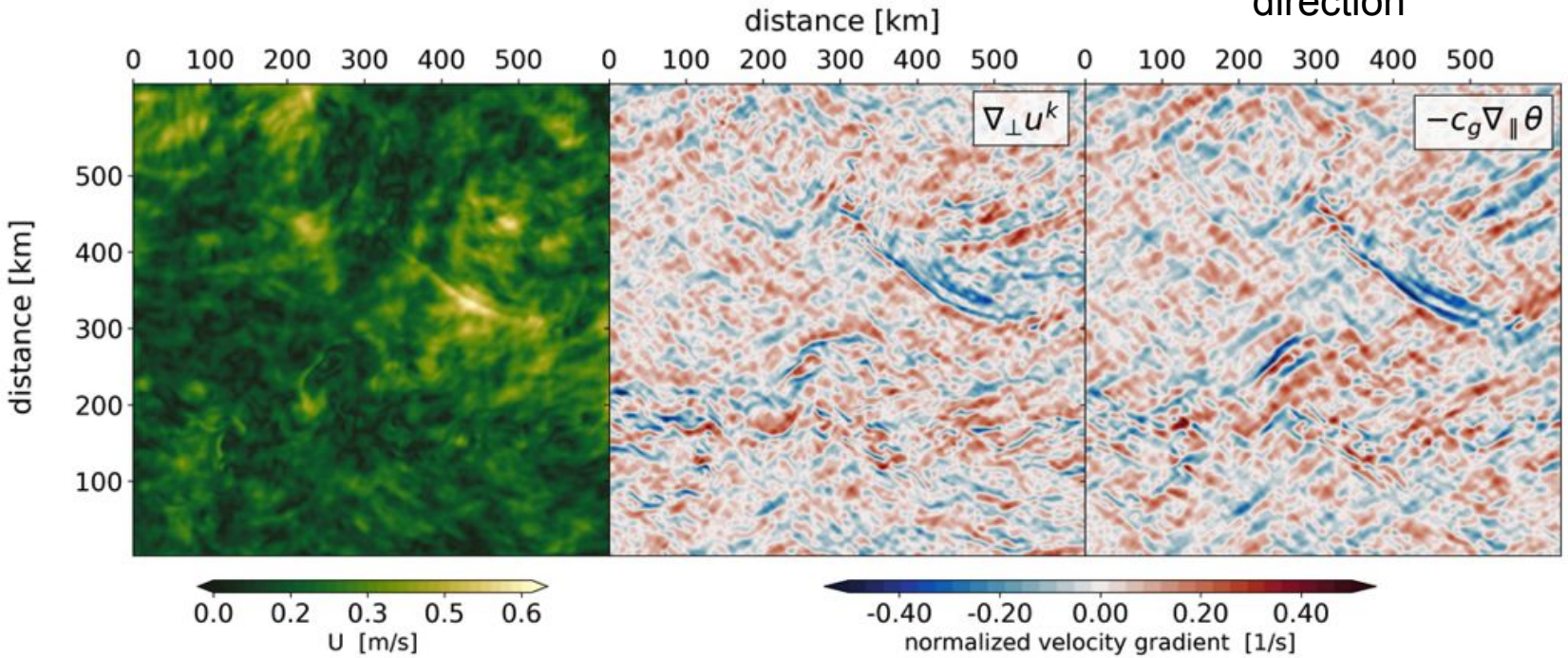


Could the signature of currents on waves be used to infer properties of the flow?

Current speed from the LLC4320

Current gradient from the LLC4320

Current gradient estimated from the gradient of the wave direction



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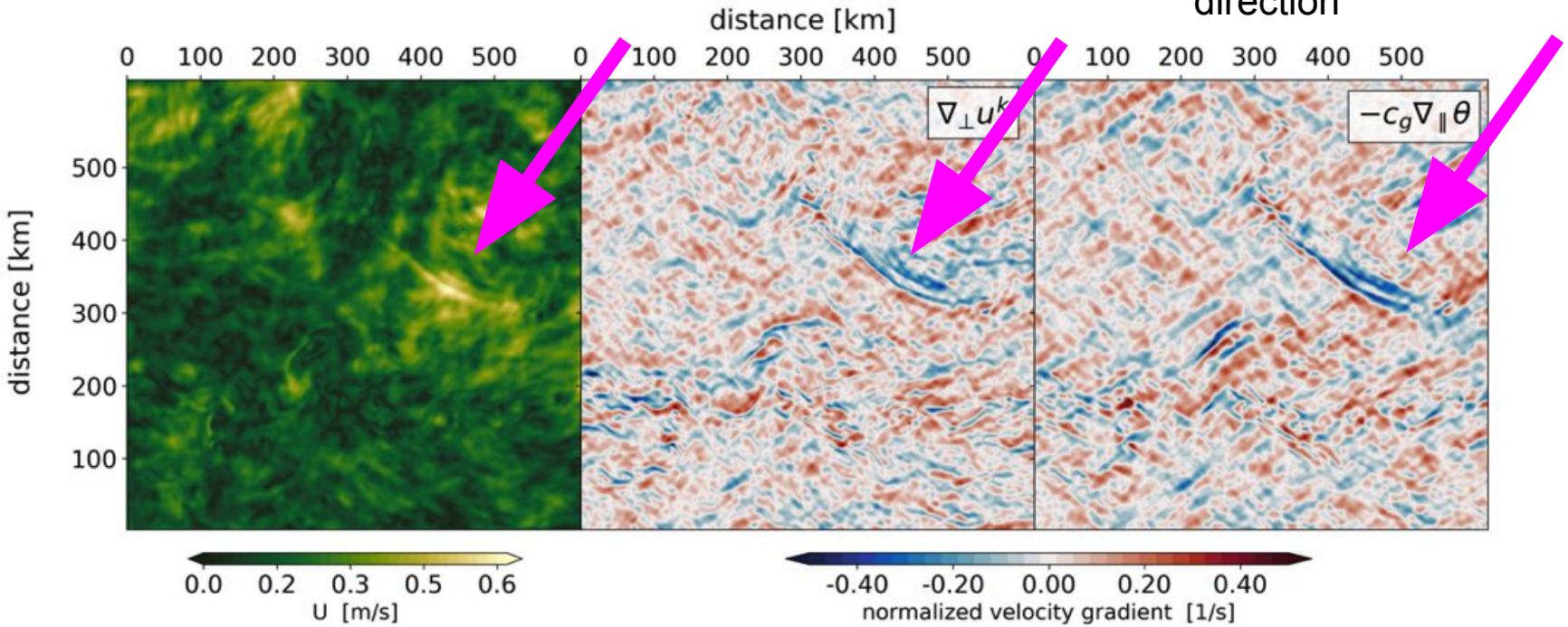


Conclusions

Waves are a main source of **noise** for SWOT, but also **signal** :

- **Wave periods** are super important for total sea level at coast → **nearshore apps.**
- Gradients of heights, mss, directions … contain information on current gradients

Warning: possible correlated errors due to wave-current correlations …

- maybe not an issue for SWOT …
- Main source of error for SKIM with v1 retrieval algorithm (LOPS 2019b)

Future work:

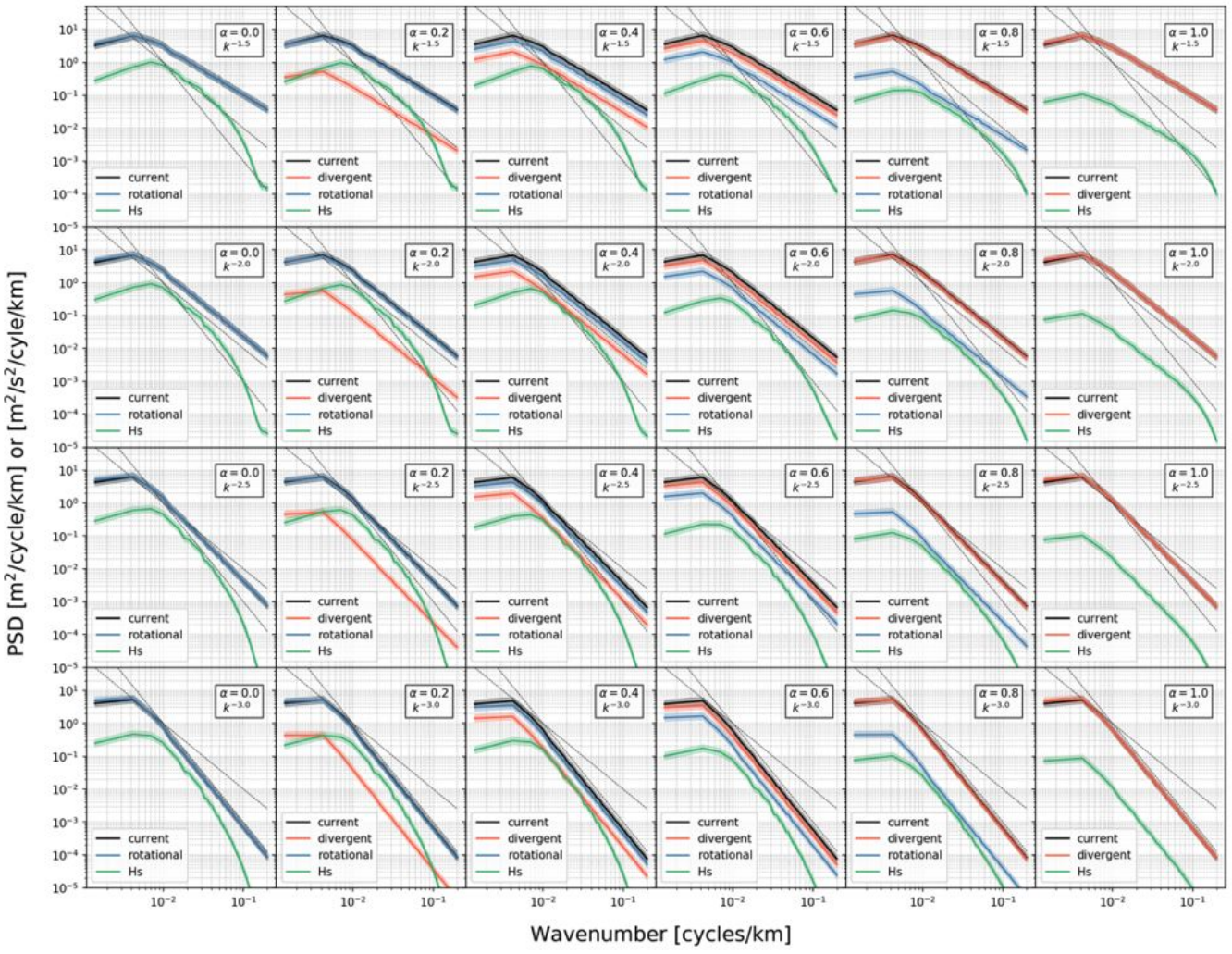
- Quantitative analysis of current-related gradients in Hs, dir, … (Villas-Boas et al., in prep)
- Try to invert current gradients from altimeter Hs gradients (joint SIO&LOPS work, 2019-2020)
- Applications?
  - Separating balanced vs unbalanced motions (related to CNES DEEPSEE project)
  - Refining Doppler retrieval algorithms (SKIM, DopplerScatt …)

Reminder: ESA Sea State CCI User Consultation Meeting: Brest 8 and 9 October

ESA Earth Explorer 9 (selection of SKIM or FORUM) UCM: July 16 & 17, Cambridge UK

Registration for UCM: https://tinyurl.com/EE9UCM

Back-up slides


PSD [m²/cycle/km] or [m²/s²/cyle/km]
Wavenumber [cycles/km]
α = 0.0 k^−1.5
α = 0.2 k^−1.5
α = 0.4 k^−1.5
α = 0.6 k^−1.5
α = 0.8 k^−1.5
α = 1.0 k^−1.5
α = 0.0 k^−2.0
α = 0.2 k^−2.0
α = 0.4 k^−2.0
α = 0.6 k^−2.0
α = 0.8 k^−2.0
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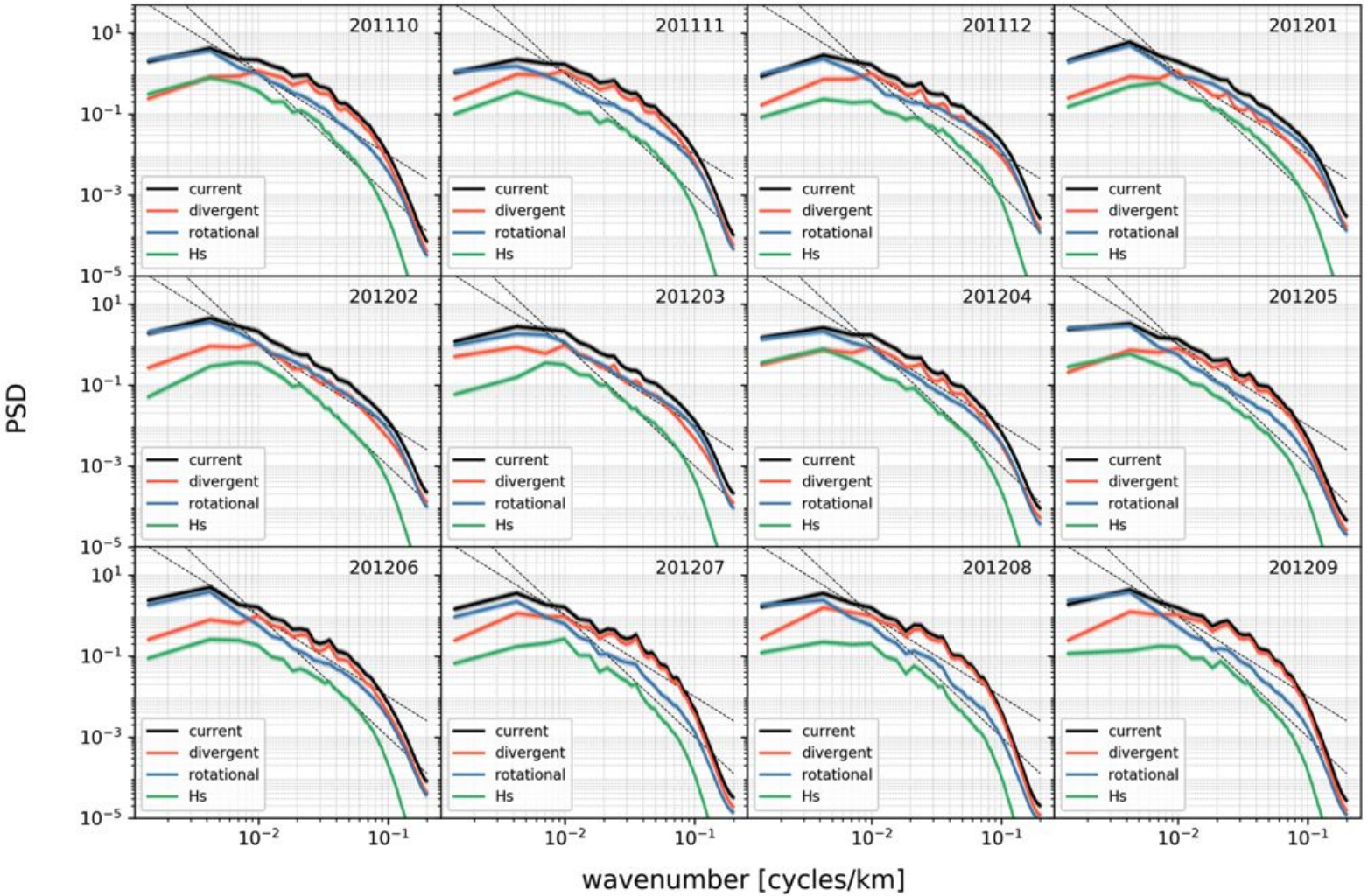
α = 0.8 k^−3.0
α = 1.0 k^−3.0
current
divergent
rotational
Hs

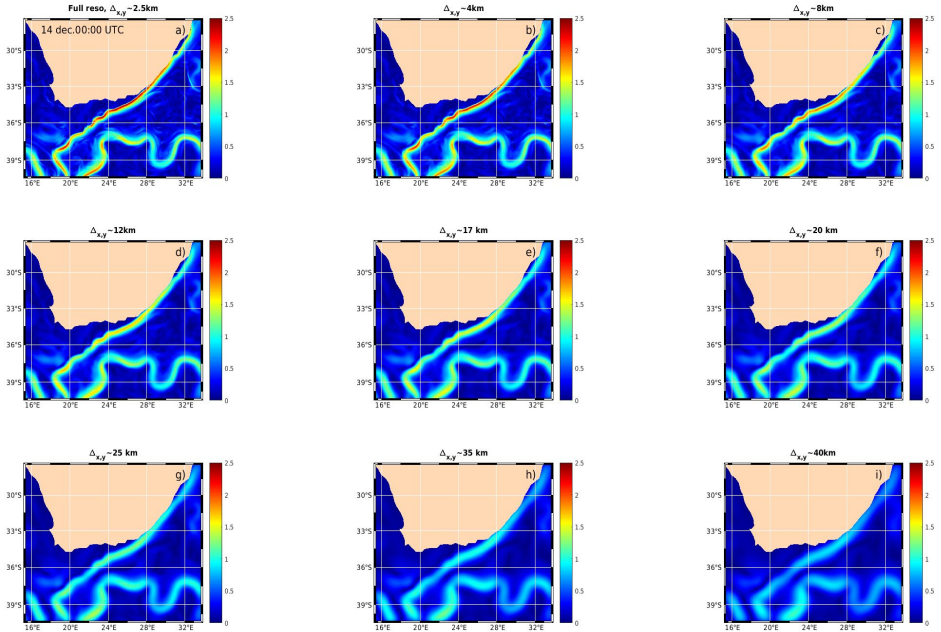

PSD
wavenumber [cycles/km]
201110
201111
201112
201201
201202
201203
201204
201205
201206
201207
201208
201209
current
divergent
rotational
Hs

Importance of current resolution in the spatial Hs variability

A numerical study in Agulhas

Current used :

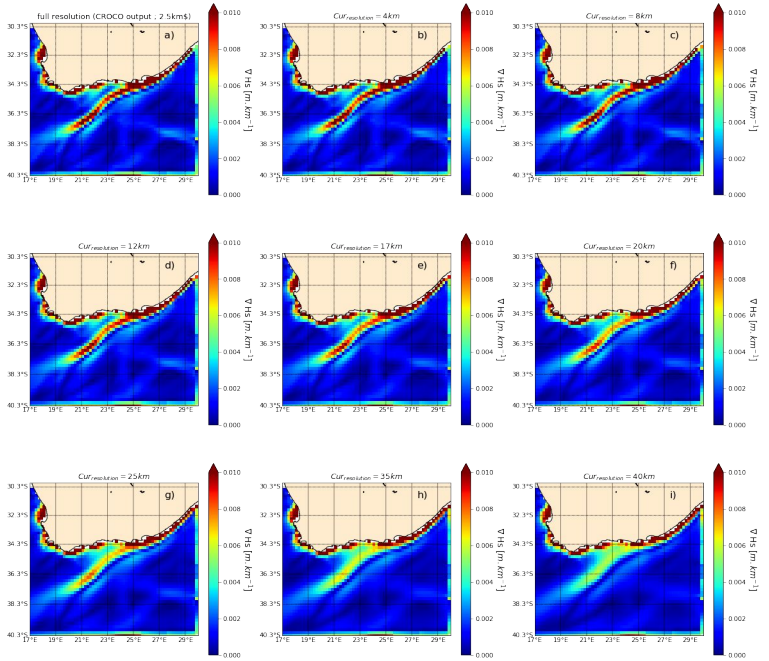
- CROCO (Coastal and Regional Ocean Community model)
  - *The surface currents are obtained from a 1/36deg CROCO simulation (WOES, Western indian Ocean Energy Sink, 1993-2014) made by Pierrick Penven.*
- Resolution : 1/36° x 1/36°
- No data assimilated
- Filtering : convolution by a gaussian filter G(N,σ)



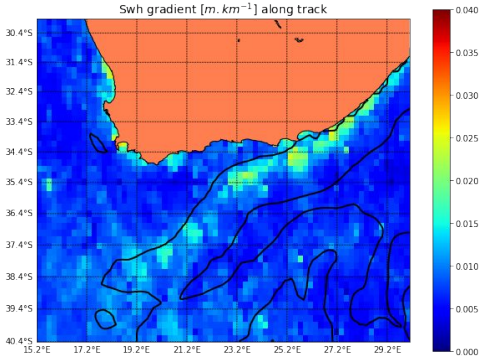
A numerical study in Agulhas

WW3 parametrization :

- Spatial resolution : 0.2° x 0.2°
- Spectral resolution : 32 frequencies, 24 directions
- Geophysical forcing in the domain :
  - wind from ECMWF (forcing each hour)
  - current from CROCO (forcing each 6h)
- Boundary conditions : waves from spectra computed from a global simulation only forced with wind (forcing each 3h)
- **Simulations outputs are averaged on 10 months**



What do **altimetry data** show?

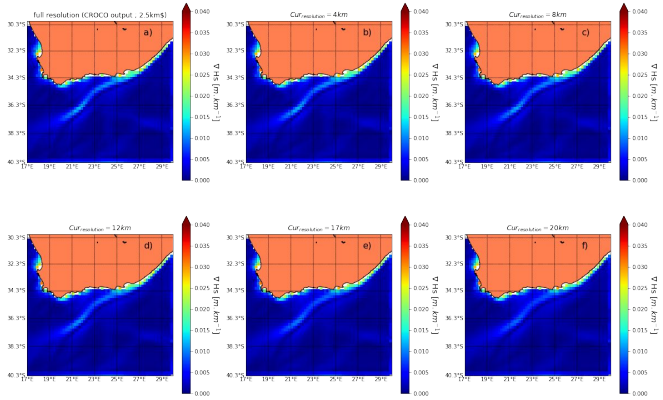


Filtered Hs data (Kopsinis and McLaughlin 2009)

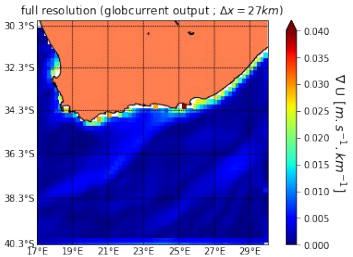
Data from : Jason-2, Jason-3, Saral, Cryosat-2, Sentinel-3a ... interpolated on a 0.2° x 0.2° regular grid

Two years of data

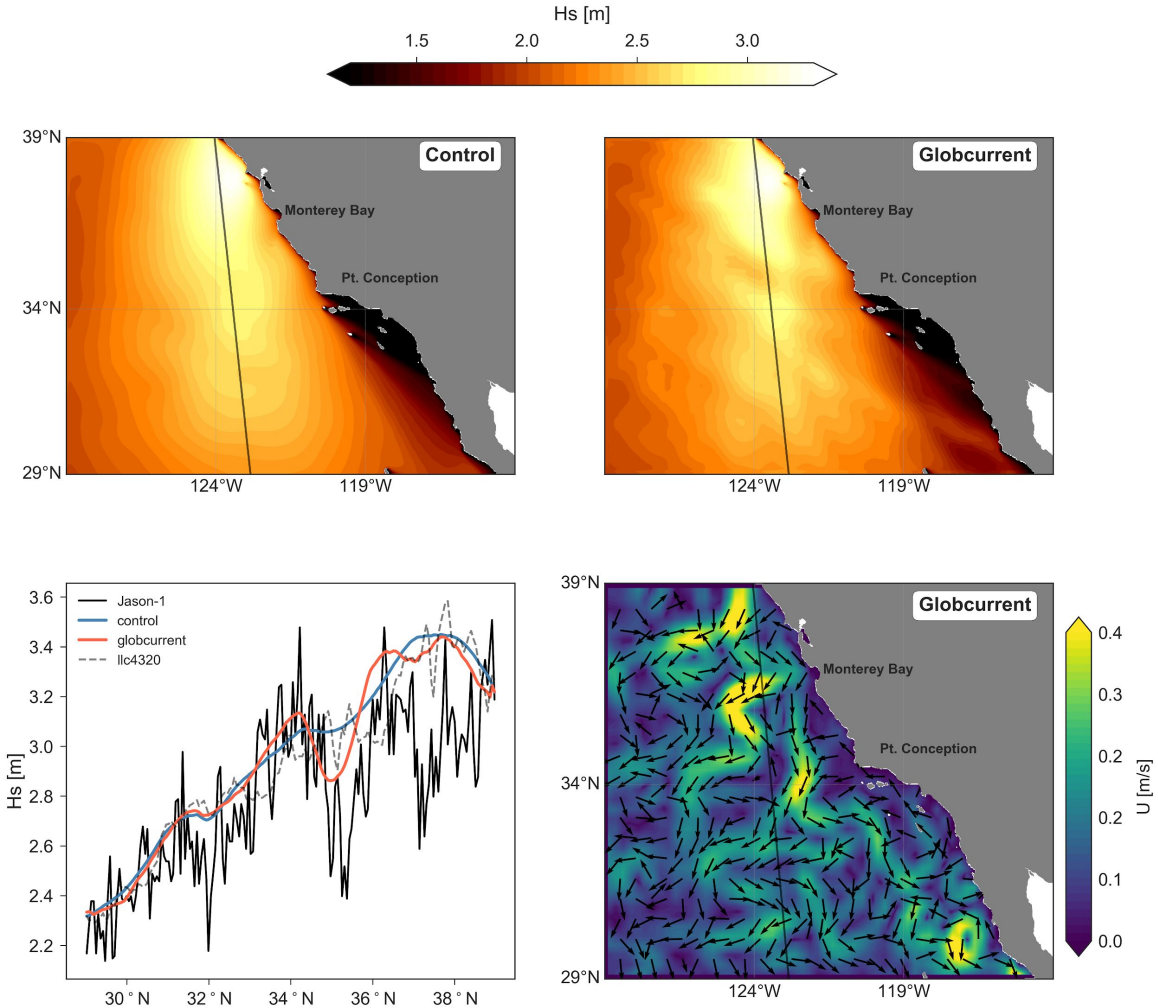
What does **numerical models** reproduce?



Model forced by CROCO (filtered) currents



Model forced by AVISO currents



WAVEWATCH III® forced with geostrophic currents in the California Current region better reproduces the Hs gradients observed from along-track altimetry