Forcings and wave model results…

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Short course on ocean waves

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Outline

1. the wave action equation

Sources of errors :

forcing, parameterizations (next lecture) ,
numerical approximations

2. winds

4. currents

5. ice

Material : « Waves in geosciences »

http://tinyurl.com/wavesgeo

Stopa (Ocean Modelling 2018)

Ardhuin et al. (Ocean Modelling 2014, JGR 2017)

1

The wave action equation

The wave action equation

The action spectrum is defined by $N(k,\theta,\phi,\lambda,t) = E(k,\theta,\phi,\lambda,t)/\sigma$

And is the solution of a transport equation with **source term** :

$$\frac{\partial N}{\partial t} + \nabla_x \cdot \dot{\mathbf{x}} N + \frac{\partial}{\partial k}\dot{k} N + \frac{\partial}{\partial \theta}\dot{\theta} N = \frac{S}{\sigma},$$

$$\dot{\mathbf{x}} = \mathbf{c}_g + \mathbf{U}\ ,$$

$$\dot{k} = -\frac{\partial \sigma}{\partial d}\frac{\partial d}{\partial s} - \mathbf{k} \cdot \frac{\partial \mathbf{U}}{\partial s}\ ,$$

$$\dot{\theta} = -\frac{1}{k}\left[\frac{\partial \sigma}{\partial d}\frac{\partial d}{\partial m} + \mathbf{k} \cdot \frac{\partial \mathbf{U}}{\partial m}\right]\ ,$$

The wave action equation

The source term represent many different effects...

- generation by the wind
- non-linear evolution
- dissipation due to breaking
- dissipation due to bottom friction
- scattering and reflection … (this could have been in the LHS)

$$S = \boxed{S_{ln} + S_{in}} + S_{nl} + S_{ds} + \boxed{S_{bot}} + S_{db} + S_{tr} + S_{sc} + S_{ref} +$$

Why separate different source terms ?

- different processes → different parametrizations
- the source term ITSELF can be an interesting result …

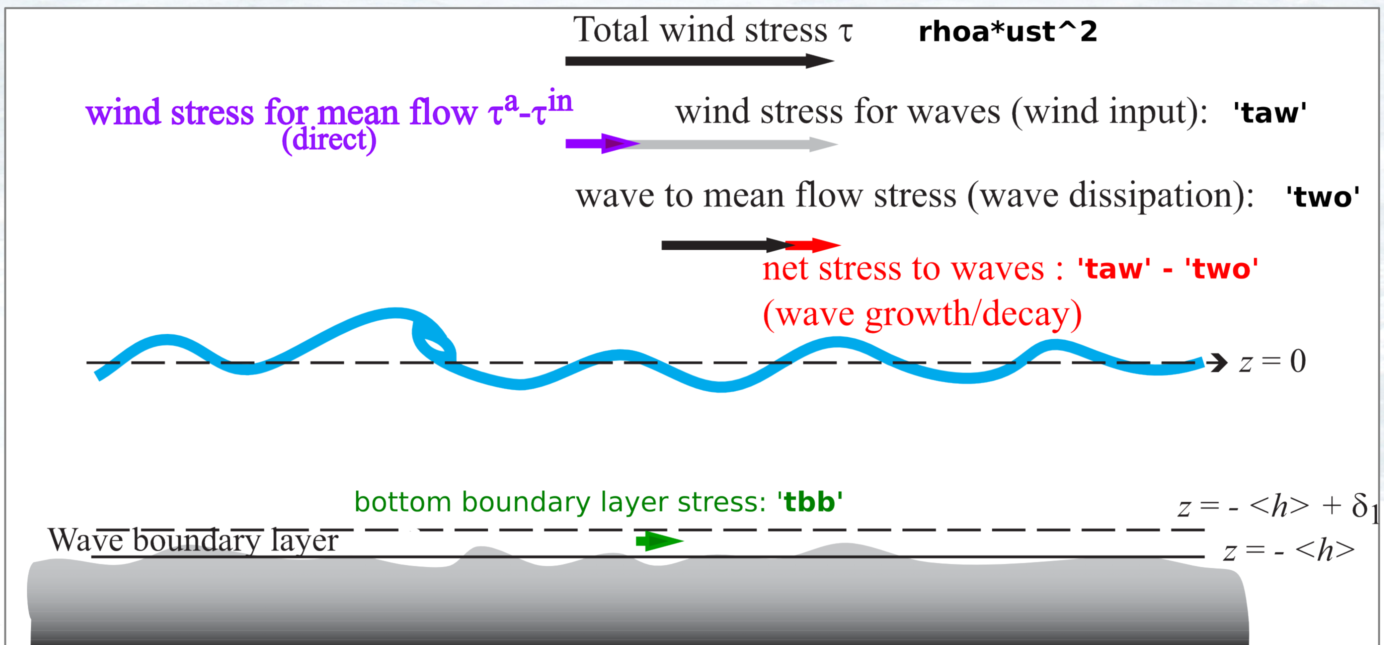
The wave action equation

$$S = \boxed{S_{ln} + S_{in}} + S_{nl} + S_{ds} + \boxed{S_{bot}} + S_{db} + S_{tr} + S_{sc} + S_{ref} +$$

Indeed, a source term S_a can be associated to

- **a flux of energy phi_a = sum of (S_a df dth)**
- **(vector) flux of momentum tau_a,x = sum of (S_a/C cos(theta) df dth)**

These fluxes are needed for coupling with ocean, ice, atmosphere



The wave action equation

As a result the output of WW3 can be :

- full spectra (and associated source terms) + 2nd order option

- 1D spectral data : E(f), th1(f), p2l(f) …

- « bulk » parameters (scalar / vector), with one value at each grid point. These are defined

- from the spectrum (e.g. Hs, Tm0,-1 …)

- from the source terms (e.g. tauw, phioc …)

2

Winds

Wind « forcing »

Wind is usually quatified by the 10-minute average wind speed U_{10} and direction at 10 m height

or by the wind stress vector...

Wind speed measurements are more common… but not at 10m

Wind is also influenced by waves :

Edson et al., J. Phys. Oceanogr. (2013)

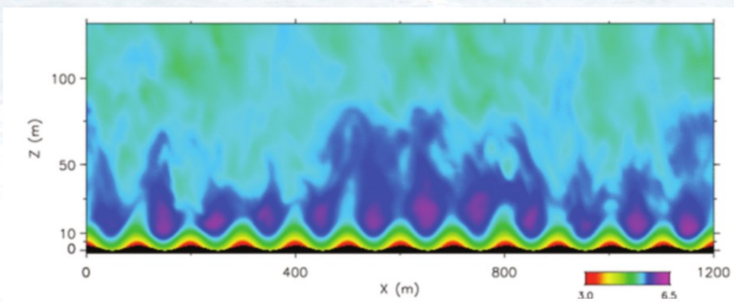


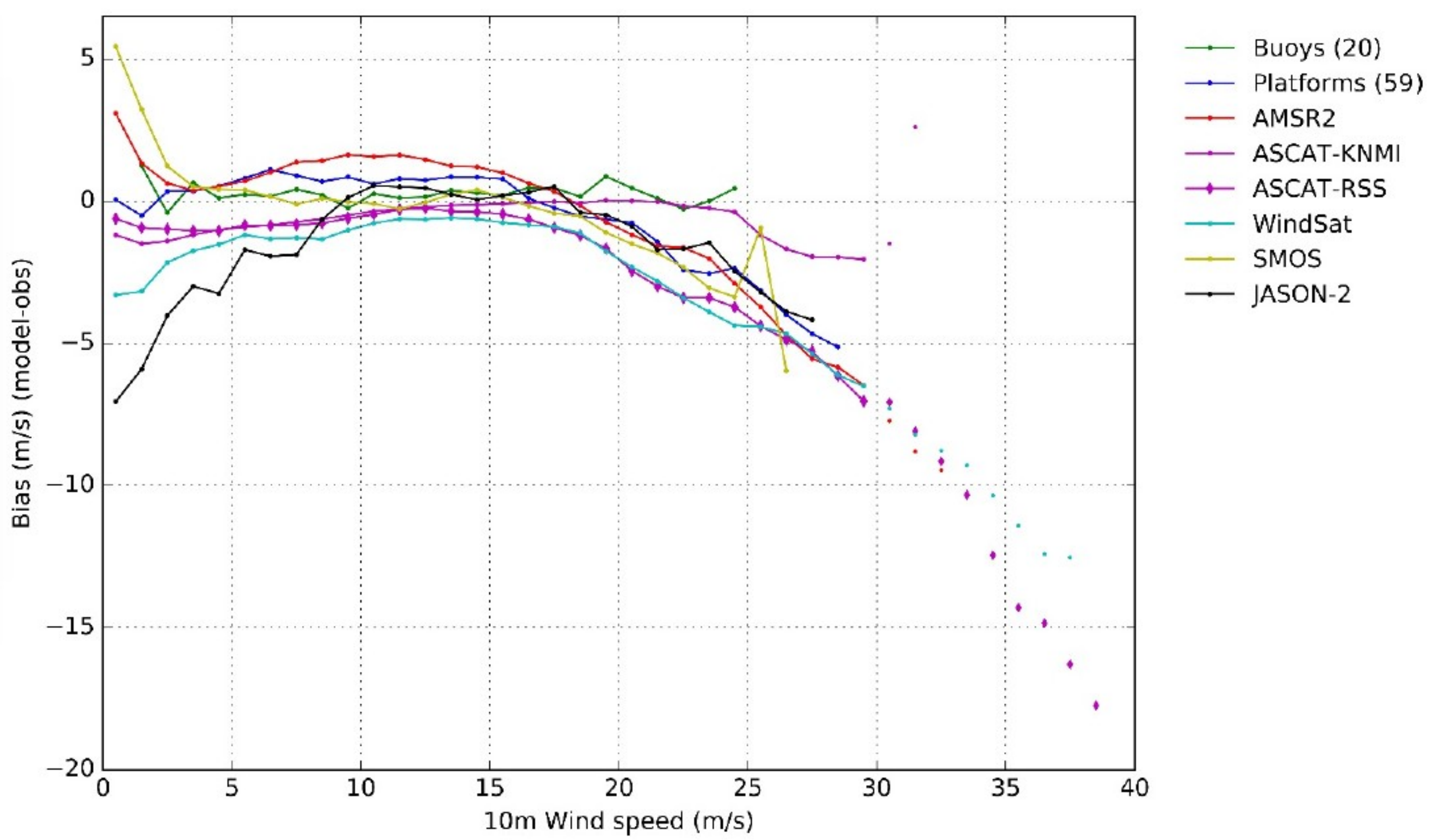
FIG. 13. An LES snapshot of the instantaneous horizontal winds in a neutrally stratified boundary layer with mean 10-m wind speed of 5 m s^{-1} and a wave age of c_p/U of 2.2. The color bar indicates the range of winds speeds 3.0 and 6.5 m s^{-1}. The wave height and wavelength are set to 1.6 and 100 m, respectively. Maximum wind speeds denoted by purple shading are found at a height of approximately 20 m.

Wind « forcing »

Wind measurements can come from in situ or satellites…

Wave models are usually driven by modeled winds

(not enough satellite data)



Pineau-Guillou et al. (Quart. J. Roy. Met. Soc. 2018)

Wind « forcing »

For a long time the issue was resolution …

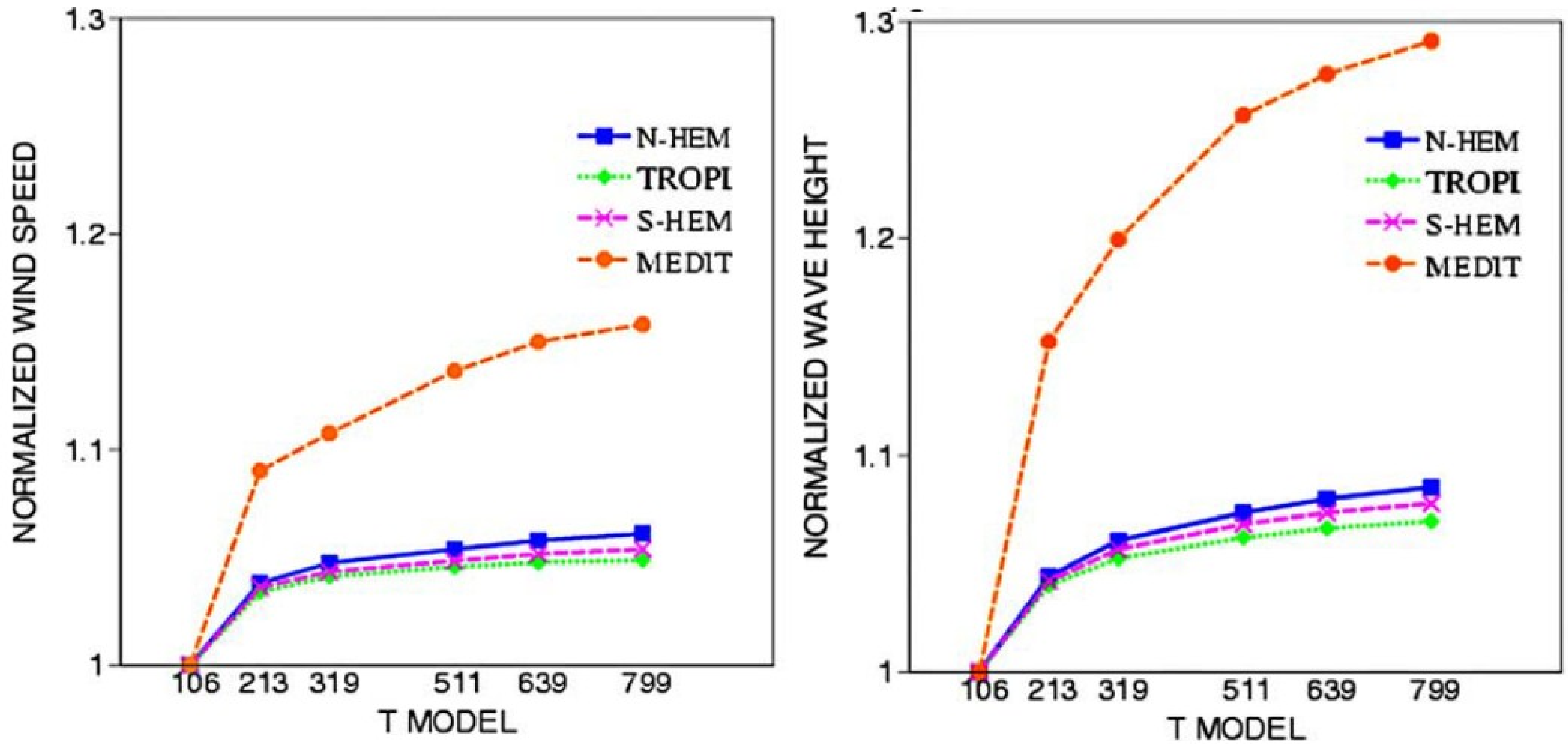
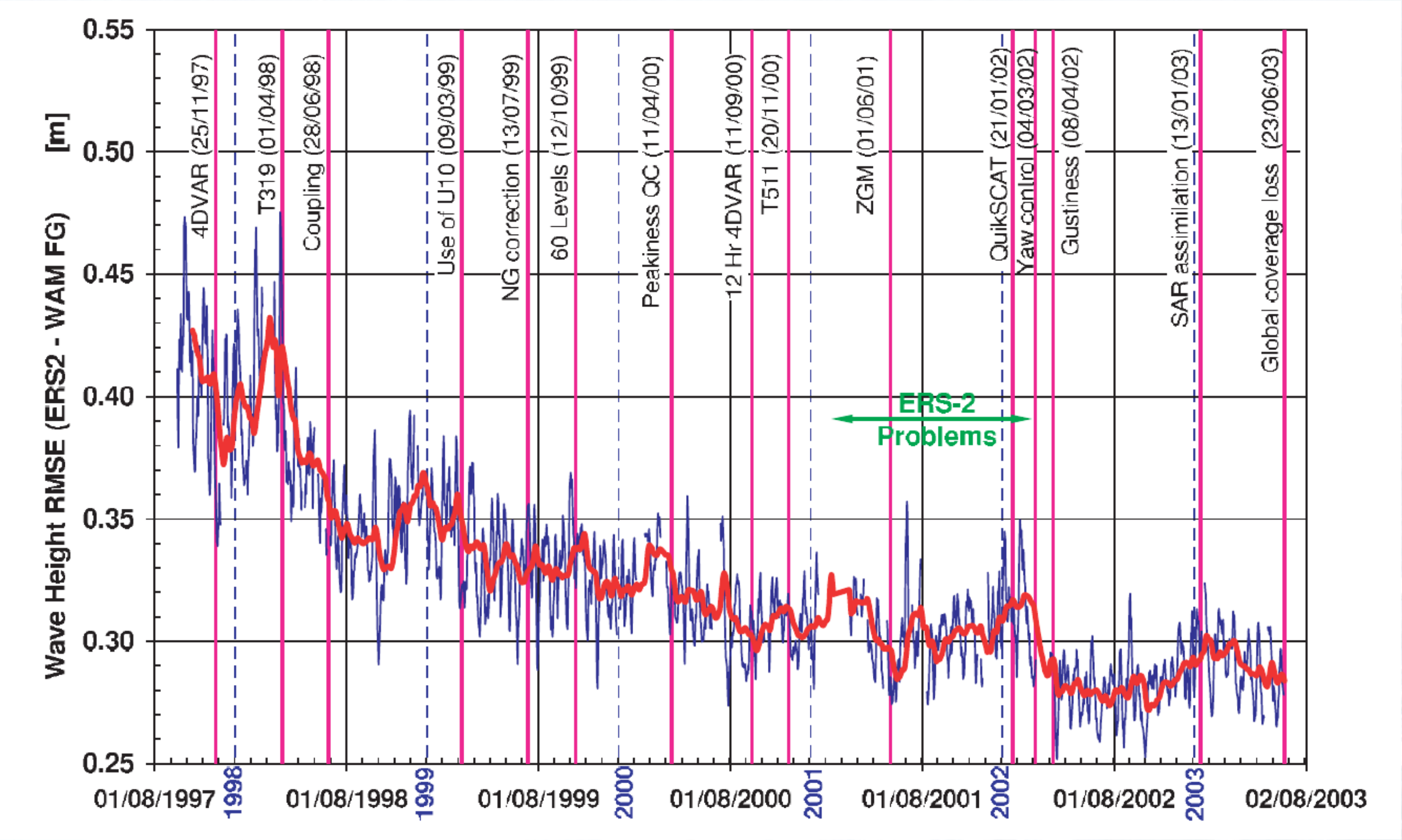


Figure 8.3: Average wind and wave height in the Northern Hemisphere, Southern Hemisphere and Mediterranean sea, obtained in different runs of the ECMWF model in which the spatial resolution is changed. The resolutions of Gaussian grids T106, T213, T319, T511, T639, et T799 correspond to 188, 94, 63, 39, 31, and 25 km. Wind speed and wave height values have been divided by the values obtained for the coarsest of these grids. Taken from (Cavaleri and Bertotti, 2006, ©Elsevier).

Stopa (Ocean Modelling 2018)

Wind « forcing »

But there are many other factors that improved the atmospheric models...



Janssen (Tech. Memo, ECMWF 2005)

Wind « forcing »

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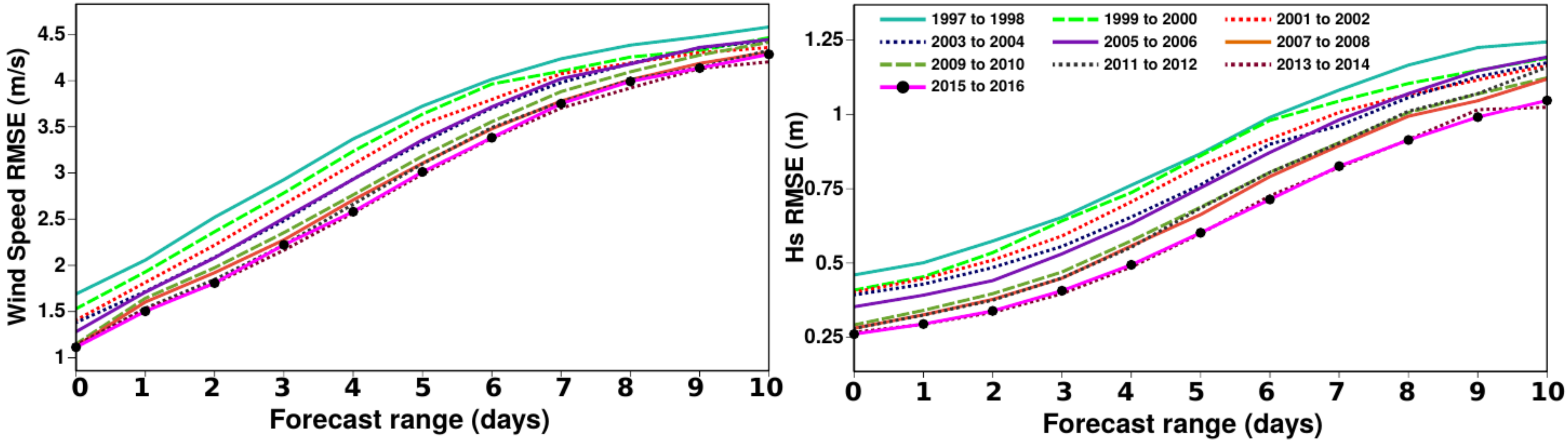
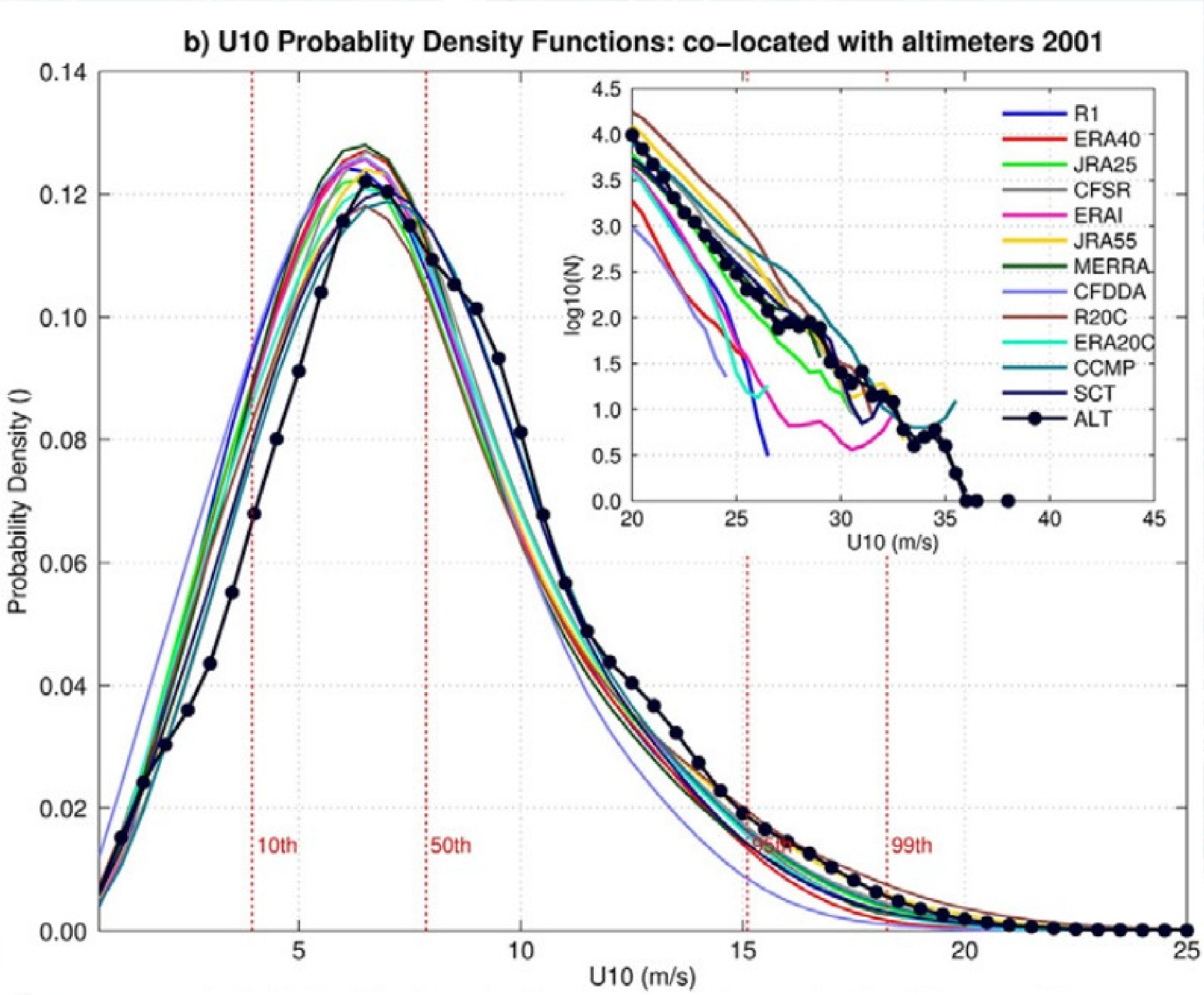


Figure 8.2: Root mean square error (RMSE) as a function of the forecast range, 0 corresponding to the analysis, in the operational systems ran at ECMWF. These modeled wind speed and wave heights are compared to buoy measurements over a year centered in winder (August to July). Only every other year is shown (Picture courtesy of J. Bidlot).

Wind « forcing »

It is particularly important to get the high winds



Stopa (Ocean Modelling 2018)

Wind « forcing »

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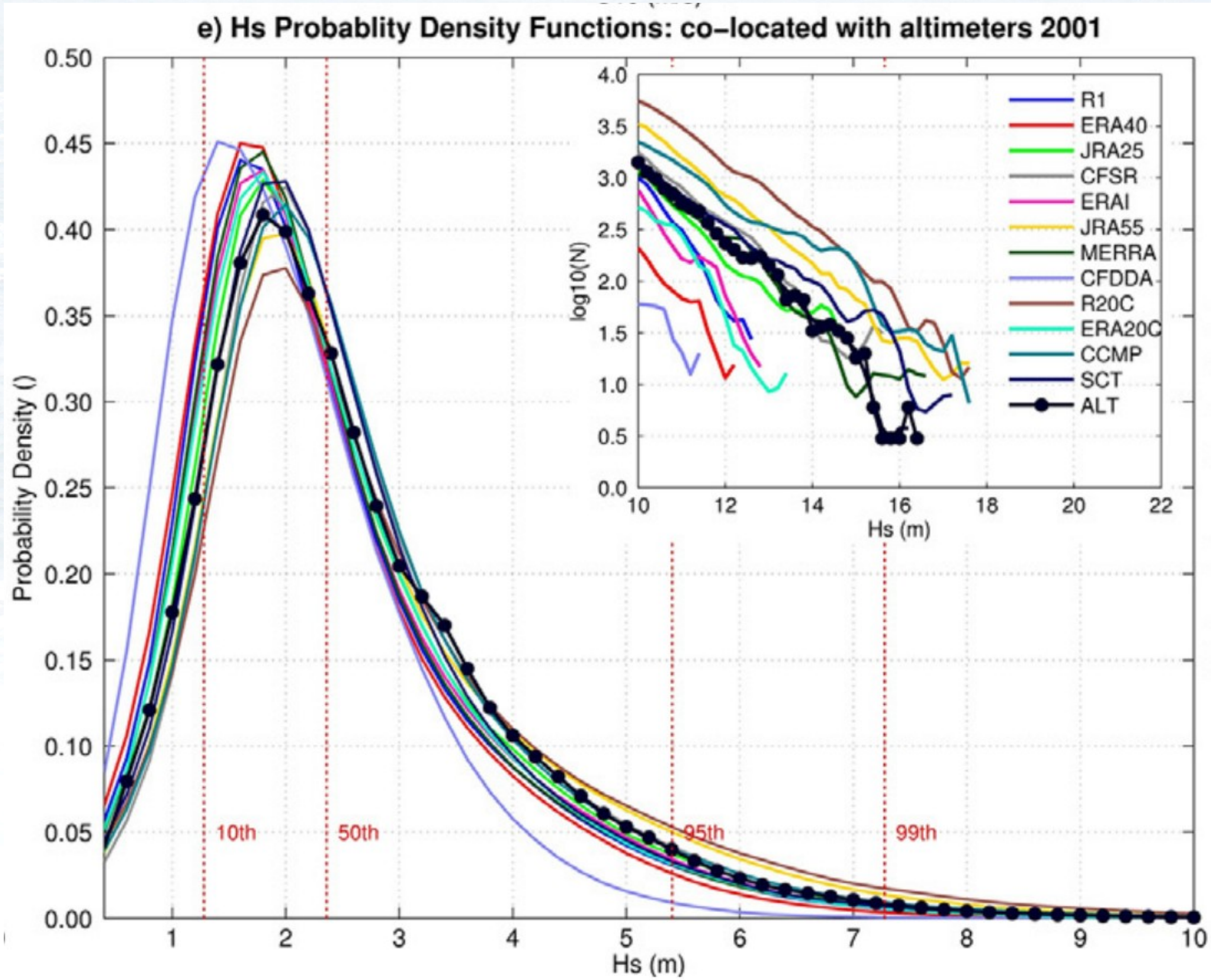


Stopa (Ocean Modelling 2018)

Wind « forcing »

Given these uncertainties … we need to tune the wave model to the different wind fields :

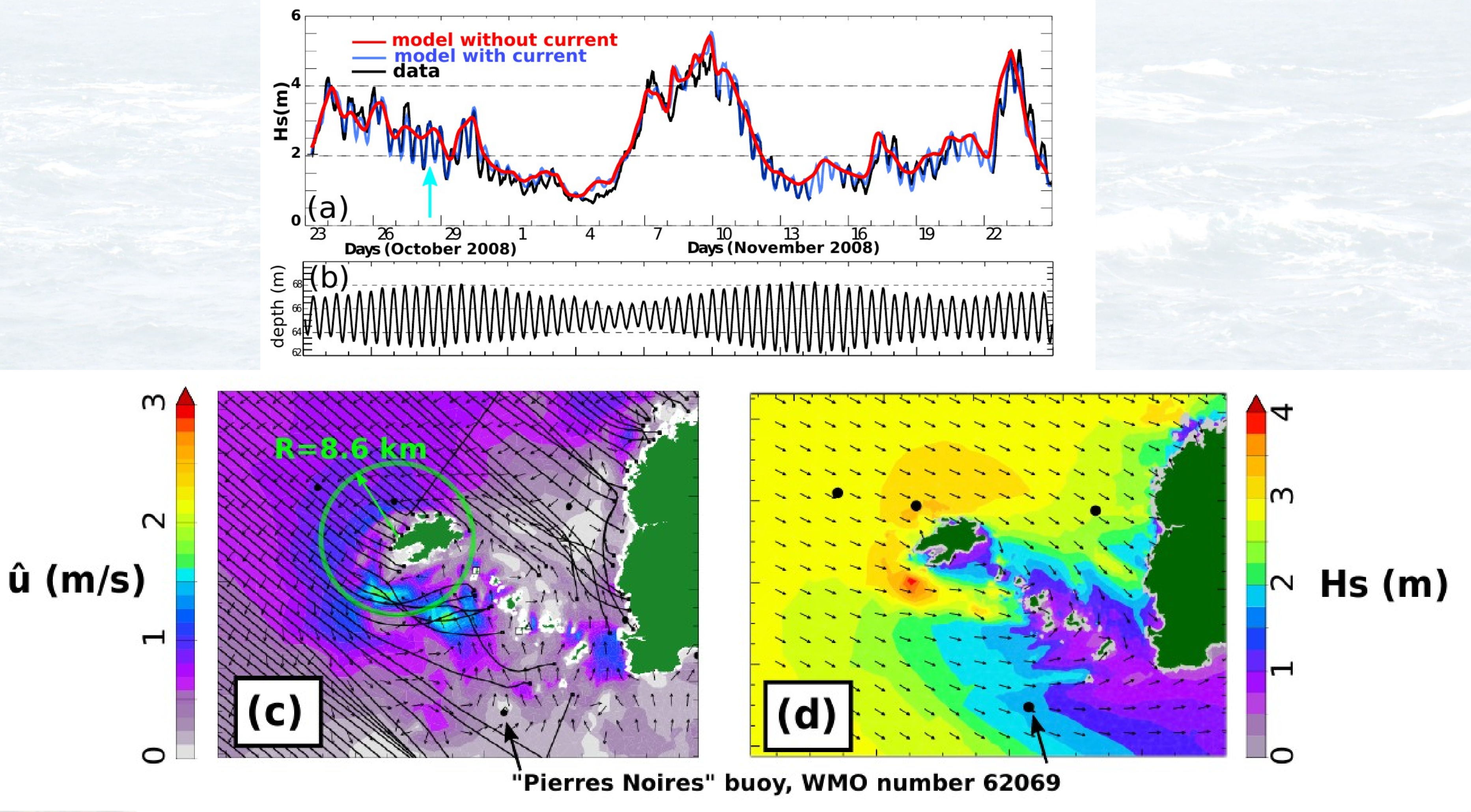
$$S_{\mathrm{in}}(k,\,\theta) = \frac{\rho_a}{\rho_w}\frac{\beta_{\mathrm{max}}}{\kappa^2}\mathrm{e}^Z Z^4\left(\frac{u_*}{C}\right)^2 \times \max[\cos(\theta - \theta_u),\,0]^p \sigma F(k,\,\theta)$$

2

Currents

Currents

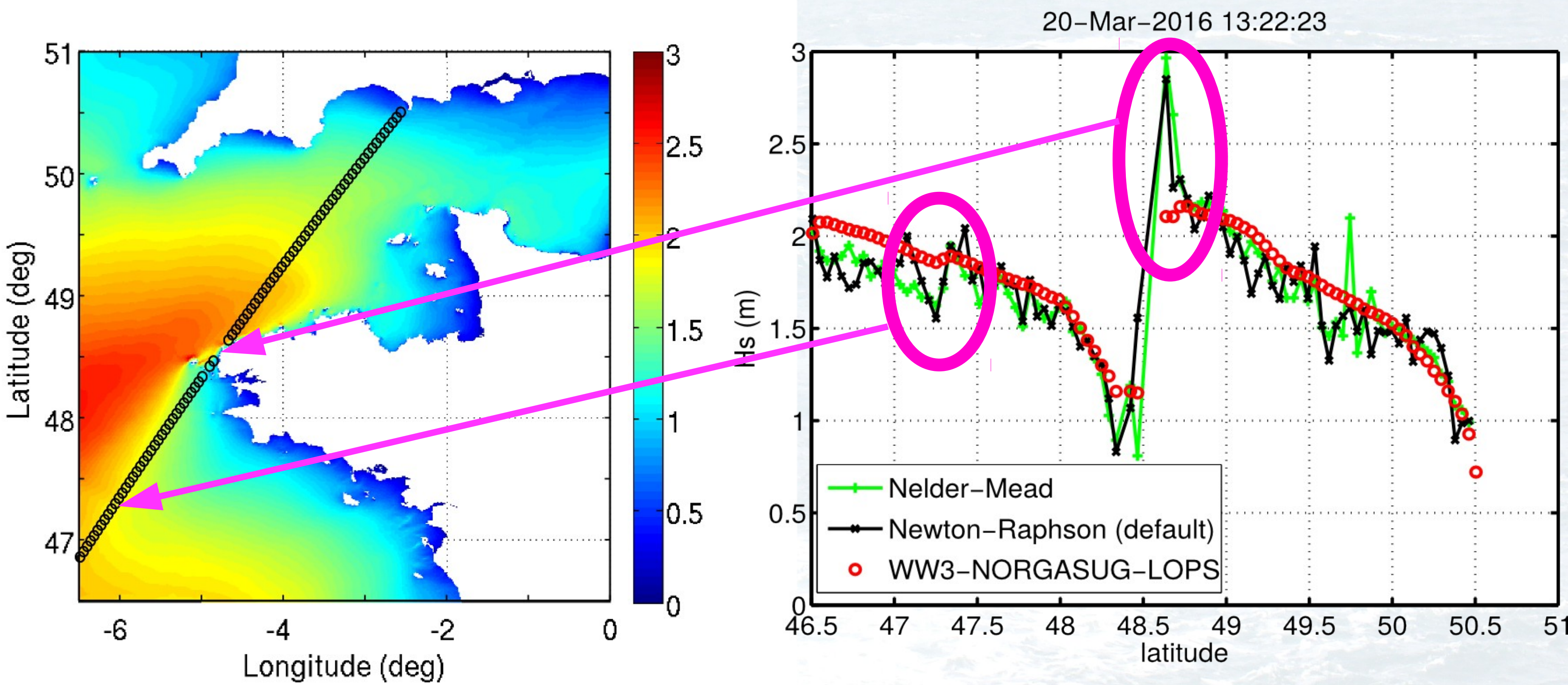
2 – Tidal currents can have a clear influence via refraction :



Ardhuin et al. (J. Phys. Oceangr. 2012)

Currents

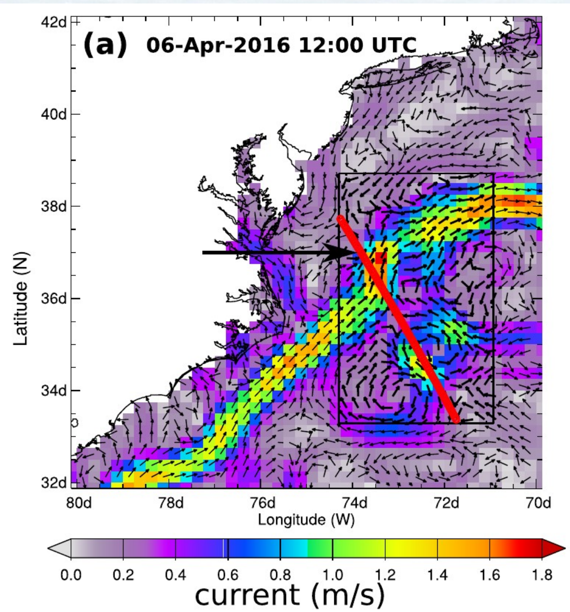
2 – Tidal currents can have a clear influence via refraction : Is it enough ?

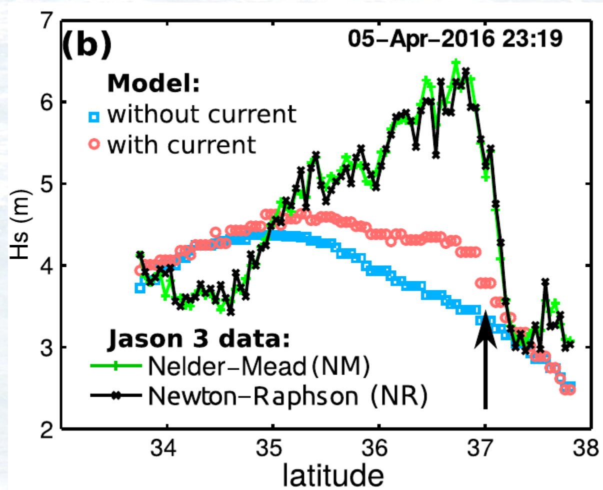


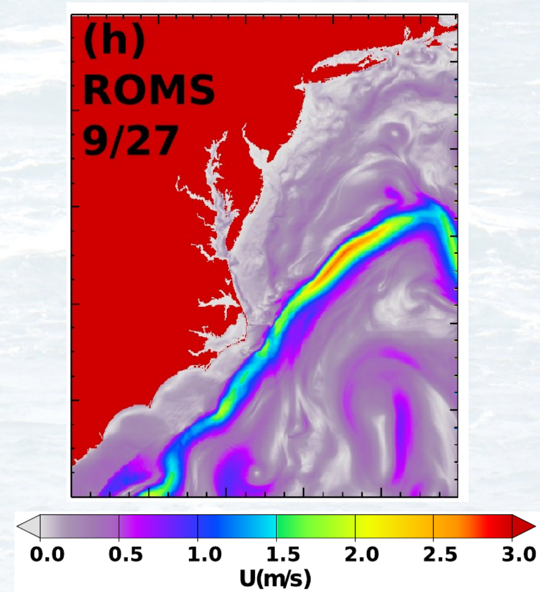
In these two regions, it is possible that the current gradient is not well resolved in the tide model we use…
but how can we be sure that it is not just noise in the altimeter data ?

Currents

We expect western boundary currents to have strong impact on waves (Gulf Stream, Agulhas, Kuroshio, …)





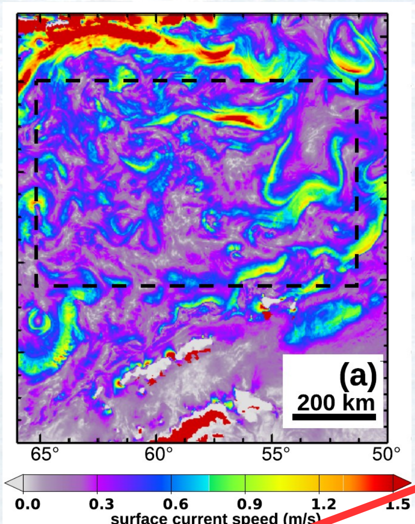


Ardhuin et al. (J. Geophys. Res. 2017)

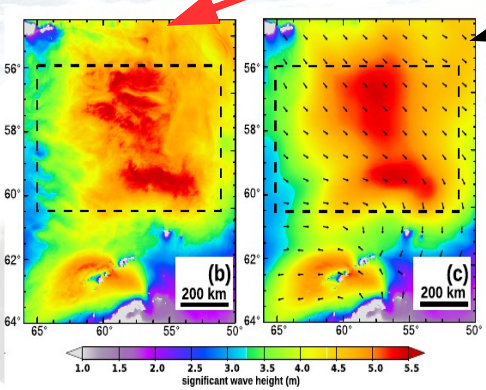
But we do not have measurements with high enough resolution :
- left : currents from satellite altimetry (Globcurrent)
- middle : measured wave heights and impact of these current in model
- right : modeled currents … faster and sharper gradients.

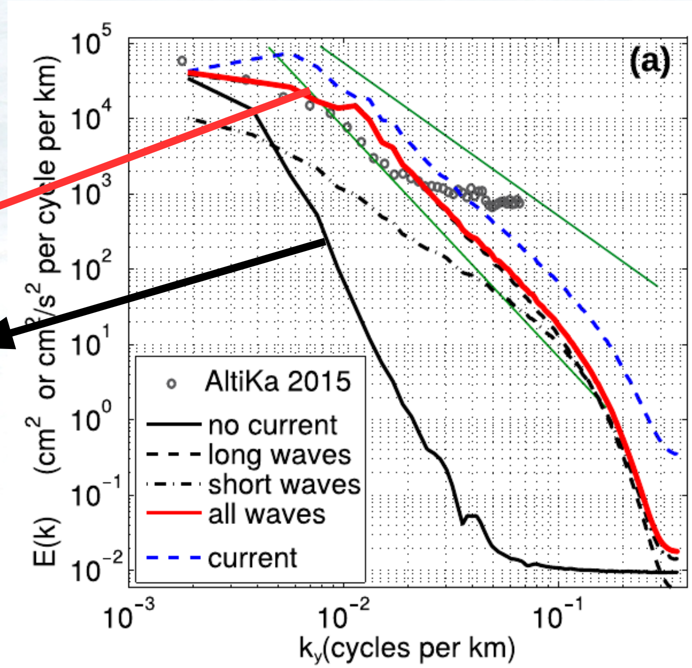
Currents

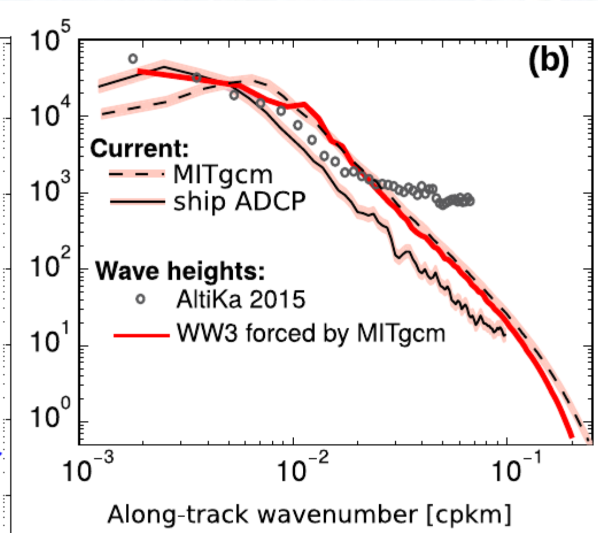
But there are currents everywhere that will also impact the waves…
Here is an example from Drake Passage (South of Chile)
We use currents from the MITgcm llc4320 simulation (see Rocha et al. 2017)



Currents from that model are a bit to high at 100 km wavelength (0.01 cycles per km). With current Hs gradients are a bit too high too. But without current, model has very weak gradients.







Ardhuin et al. (J. Geophys. Res. 2017)

Summary

1) **Wind errors** are the main sources of **wave errors**
2) There is no « ground truth » for wind speeds :
we **re-tune the wave model** to different winds (or correct the winds)
→ Stopa (2018)

3) Currents are important too and can create large differences.

4) Currents can have effects on very small scale : wave height gradients are probably dominated by currents

5) Except for tidal currents, we have no good data for **currents** at **scales < 200 km**