Coastal Sea Sates
Modeling and Observations

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kindly presented by Fabrice Collard

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More stuff at **http://wwz.ifremer.fr/iowaga**

Integrated Ocean Waves for Geophysical and other Applications

IOWAGA is mostly funded by FP7-ERC

A few words on numerical wave modelling …

Wave models predict the **statistical properties** of the sea surface via the directional wave spectrum. From this we derive the **significant wave height** (Hs) and many other parameters (mean square slope, velocities, spectrum of infragravity waves …) that can also be of used for **remote sensing**.

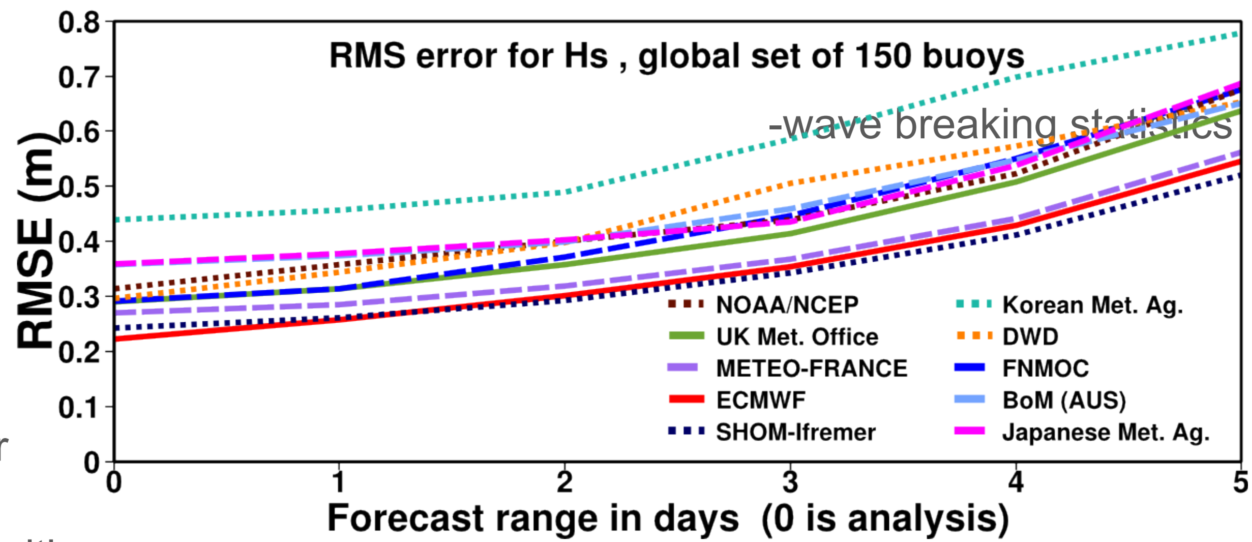
Efforts today, in the IOWAGA project and elsewhere, focus on :

- improving models
- extending their capabilities:

-wave breaking statistics

…

Example of improvement:
- new **parameterizations** (Ardhuin et al. JPO 2010) without data assimilation at SHOM-Ifremer & METEO-FRANCE lead to better results that old parameterizations with D.A. at ECMWF , for forecasts beyond 1 day



JCOMM wave model verification. Picture adapted from J.-R. Bidlot
See JCOMM web site for more

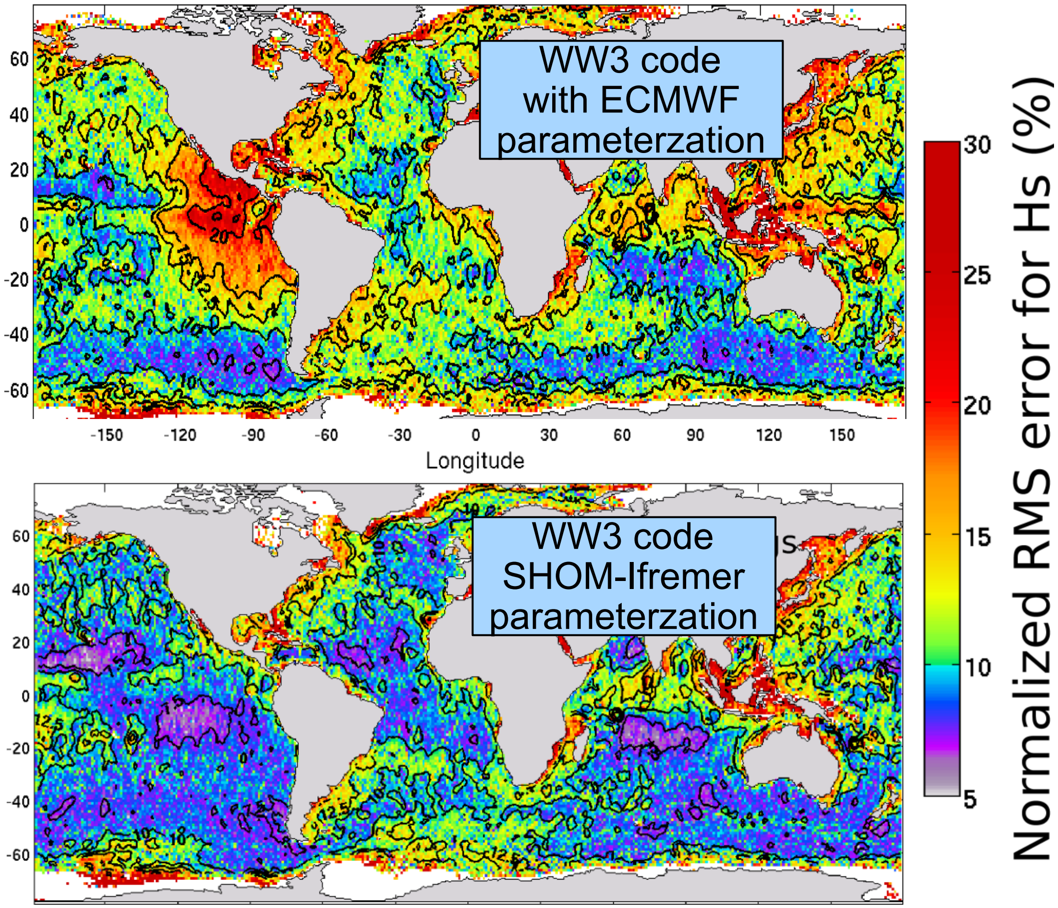
*NB: All three models (Ifremer, ECMWF & Meteo-France) use the **same winds** (but different resolutions)*
Differences with others are mostly due to driving winds...

1

The global view: Storms and swells

A summary of recent progress

New parameterizations for wave breaking and dissipation are the biggest improvement thanks the the analysis of Envisat's ASAR (Ardhuin, Chapron & Collard GRL 2009)



Global mean normalized RMS error for Hs, using various parameterizations :

11.1% (SHOM-Ifremer 2008)

12.7% (ECMWF 2005)

13.8% (ECMWF 1992)

(compared to all 2008 data from JASON, GFO & Envisat, along-track averaged over 1 degree)

Largest errors now:

- western boundaries of oceans
- marginal ice zone
- **coastal areas**

(resolution + winds + ?)

2

So, what is so peculiar about coastal areas?

2. Coastal sea states are different …

and very diverse!!

If coastal is defined by « short distance from the shoreline » …

then the most prominent feature is the variability in « wave age »: for the same wind speed you can get Hs=14 m or Hs=0.5 m …

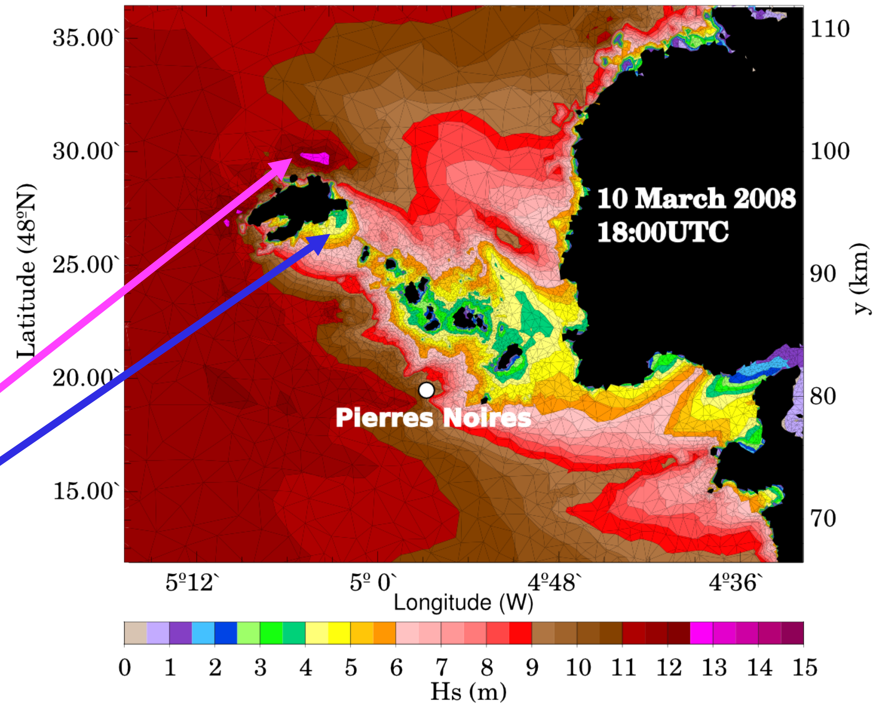
→ Very different sea states can still correspond to the same altimeter measurements (Hs and sigma0)

→ SSB estimates are more likely to be wrong in coastal areas

→ Sea states can change dramatically within the altimeter footprint due to

Strong tidal currents

island sheltering



Example of wave model snapshot (unstructured WAVEWATCH III routinely used for www.previmer.org)

…

A 10-year database (+ forecasts) is at www.tinyurl.com/yetsofy

see also wwz.ifremer.fr/iowaga

2. Coastal sea states are different … and very diverse!!

If coastal is defined by « shallow water » …
then the wave height and slope statistics can also be different (change in dispersion properties …)

→ Impact on SSB?
Couldbe visible in Southern North Sea during Northerly storms (waves with long periods)

So,
How good are coastal wave models?
Can they be useful for remote sensing ?

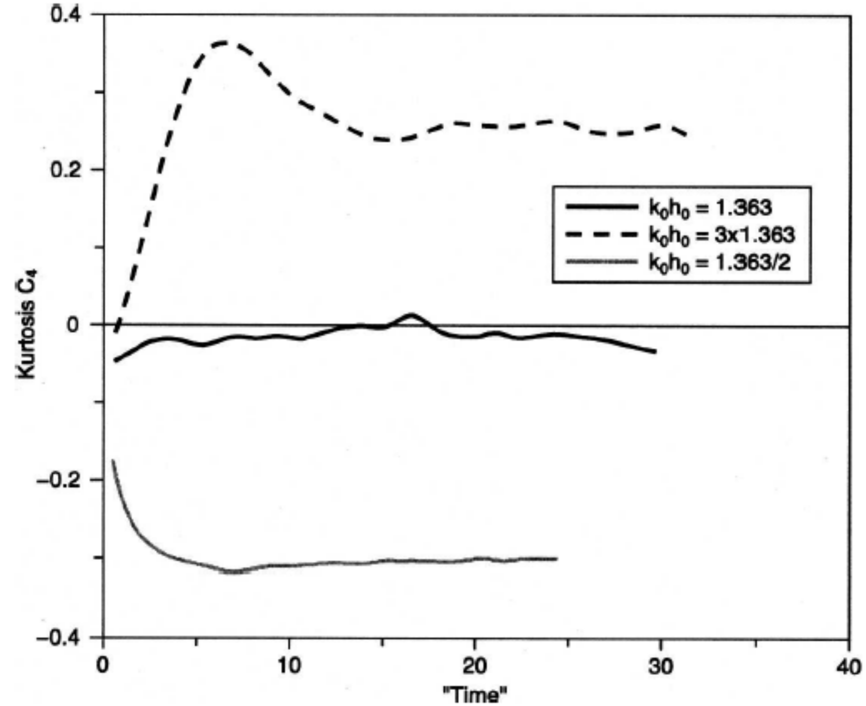


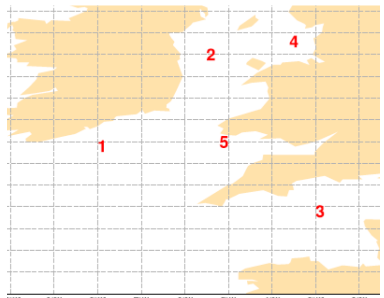
FIG. 5. Time evolution of kurtosis for BFI = 1. For deep-water ($k_0h_0 = 3 \times 1.363$) nonlinearly focused waves, there results positive kurtosis while for shallow water ($k_0h_0 < 1.363$) we have defocusing giving a negative kurtosis.

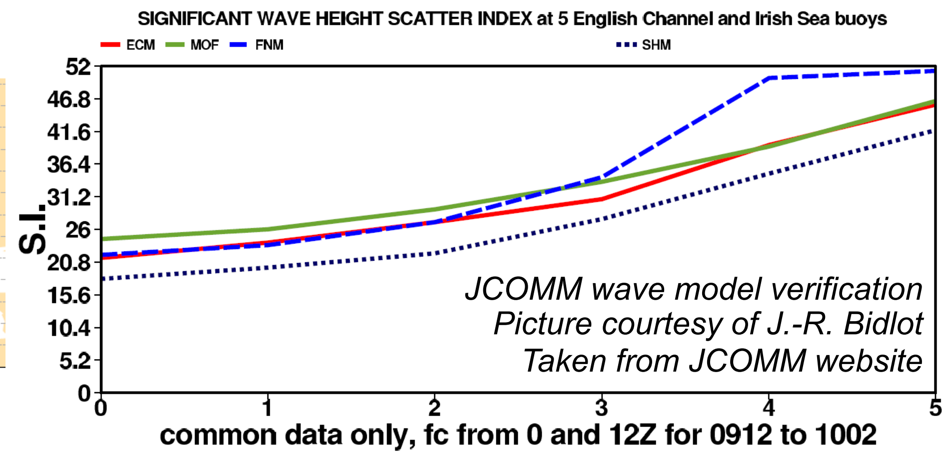
Numerical model result, taken from Janssen and Onorato (J. Phys. Oceanogr. 2007)

2. Coastal wave models …

they can be pretty good

For sheltered coastlines,
Model results are not so
Good as offshore... one
Among the worst places
are the Channel, Northern
Mediterranean …





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Scatter indices for Hs there are in the
Range 17 to 30% … even with the best
models.

Many reasons for this:
- winds are more poorly predicted by NWP centers
- currents can be important and are not so well known
  (few forecast centers actually take currents
  into account: only SHOM-Ifremer at present)

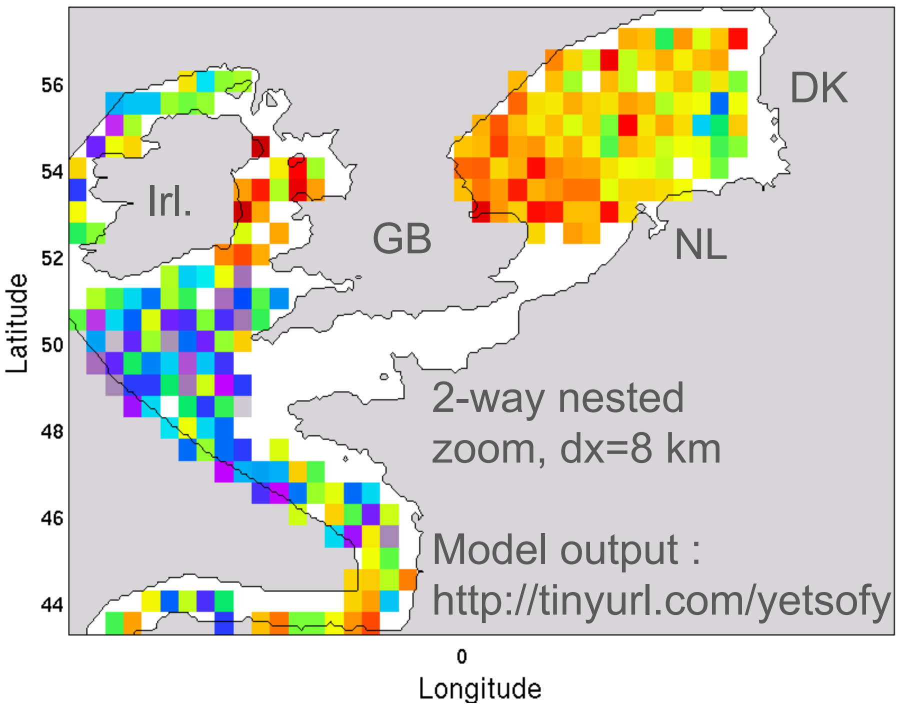
- the dynamics of waves are more complex
(younger waves, bottom friction …) and still
not so well modelled.

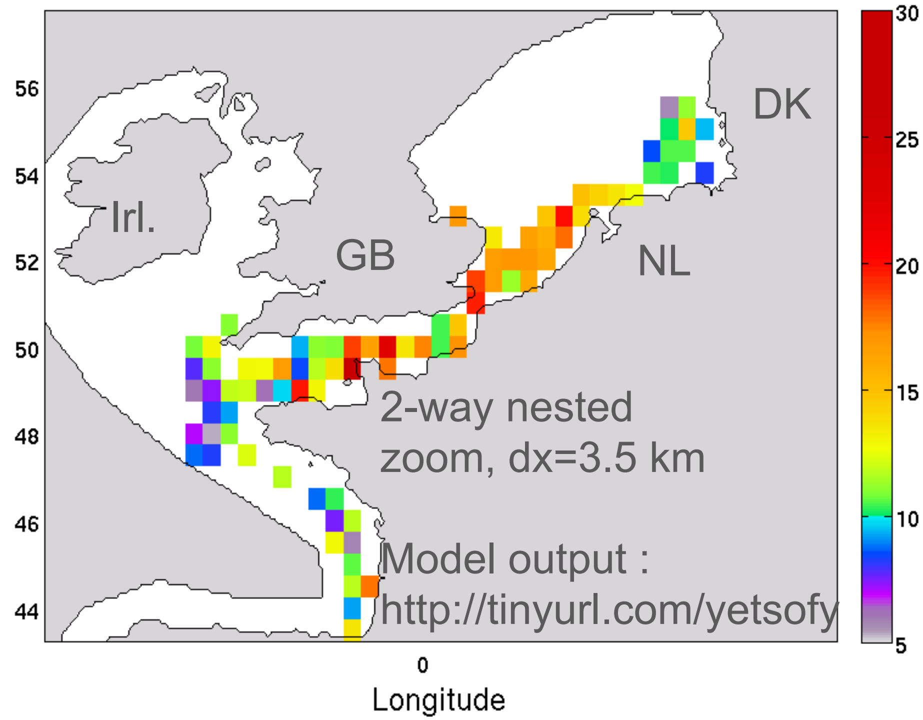
15% error is still not too bad for some applications

2. Coastal wave models …

they can be pretty good

Model resolution is an issue … but not the main one
Below: validation of Hs against all altimeters from the 2-way nested grids of the SHOM-Ifremer





For these runs (all year 2008) not tidal current was used. Finer resolution from 8 to 3 km does not improve significantly the southern North Sea results.

(NB: model – satellite statistics are computed for grid squares of 0.5°, much larger than model resolution)

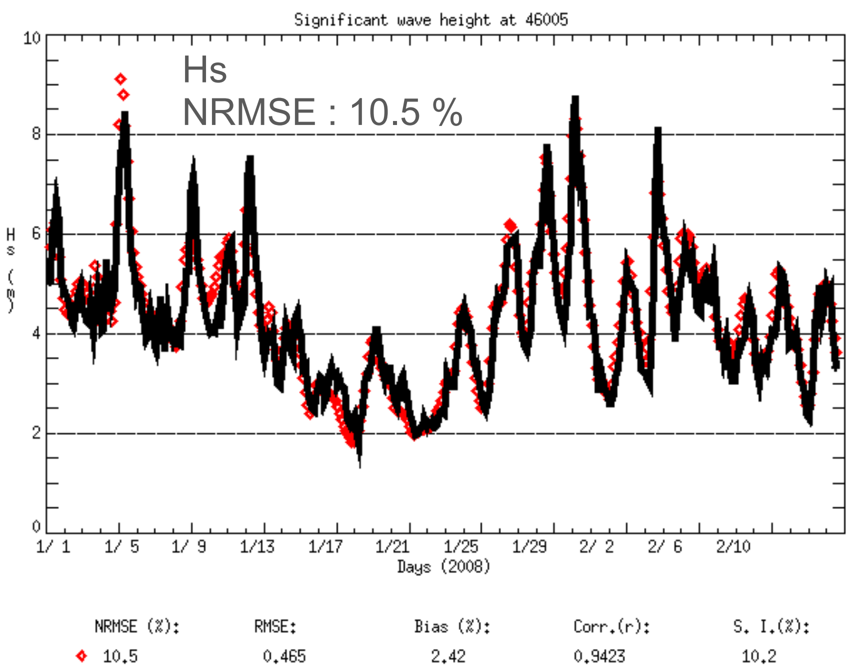
2. Coastal wave models …

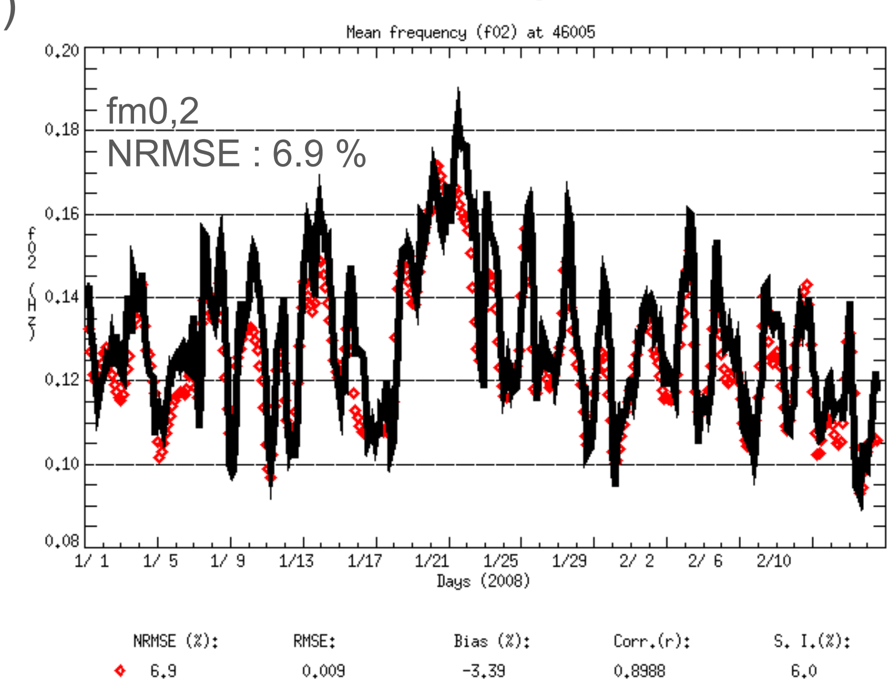
Beyond Hs

Many different quantities can be estimated from the wave spectrum.
Of particular engineering interest is the mean wave frequency fm0,2=1/Tm0,2
(because the rms wave-induced velocity at the sea surface is 1.57*Hs*f02)

$$T_{m0,p} = \left[\frac{\int_0^{f_{\max}} \int_0^{2\pi} f^p E\left(f,\theta\right) \mathrm{d}\theta \mathrm{d}f}{\int_0^{f_{\max}} E(f) \mathrm{d}f} \right]^{-1/p}$$

Validation in North-West Pacific (offshore)



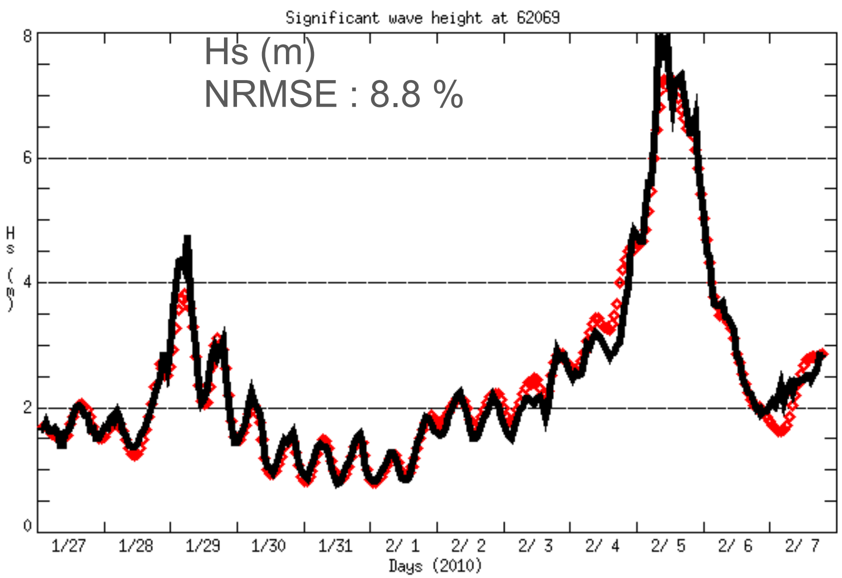


Example of validation for Hs and fm02 at offshore buoy 46005 (North-West pacific) in 2008
Fm0,2 is underestimated by 4% on average at 46005 because there is still too much swell energy (low frequency) arriving there … Model and data are averaged over 3 hours.

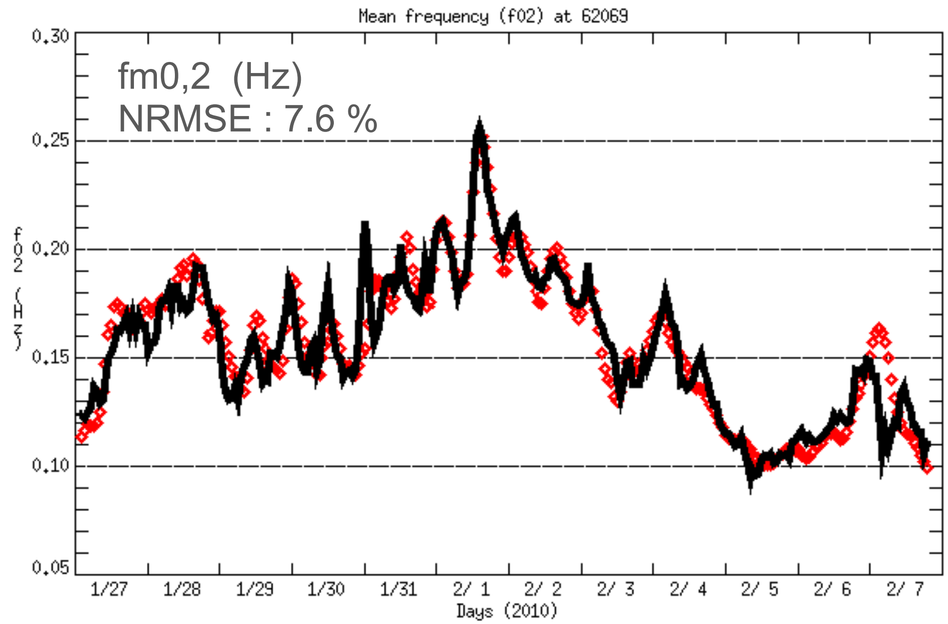
2. Coastal wave models …

Beyond Hs

Validation in North-West Atlantic (coastal)



NRMSE (%):	RMSE:	Bias (%):	Corr.(r):	S. I.(%):
8.8	0.254	-0.58	0.9862	8.8



NRMSE (%):	RMSE:	Bias (%):	Corr.(r):	S. I.(%):
7.6	0.012	0.18	0.9326	7.5

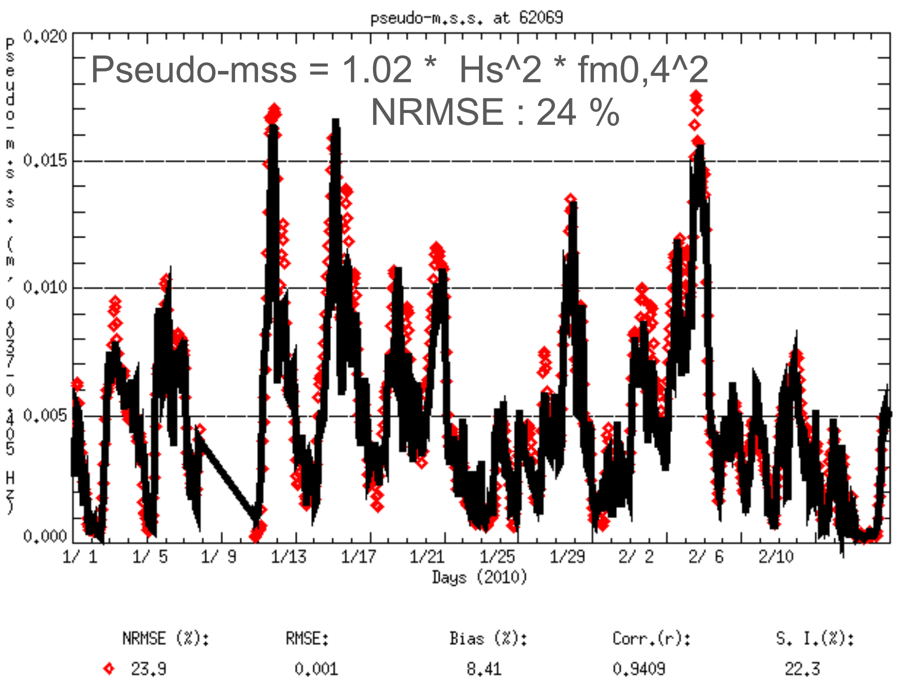
Example of validation for Hs and fm02 at buoy « Pierres Noires » (WMO 62069) in 2010
Periodic modulations are caused by tidal currents. These are HOURLY time series and statistics !!

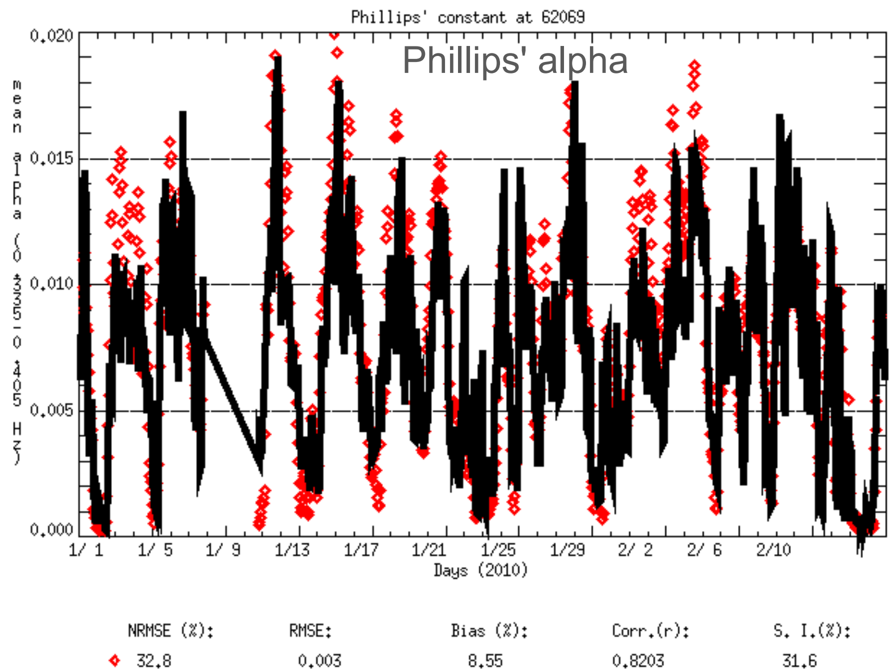
2. Coastal wave models …

Beyond Hs

Many different quantities can be estimated from the wave spectrum.
For remote sensing the high frequency tail is very important
(backscatter of radar, brightness temperature ...)
Unlike ECMWF parameterizations, latest wave dissipation functions (Ardhuin et al. JPO 2009, 2010) have a good skill for estimating the higher moments of the frequency spectrum :

Validation in North-East Atlantic (coastal: « Pierres Noires »)





NB: mss is a **quadratic** parameter, thus an error twice bigger compared to Hs is actually really good!!

3

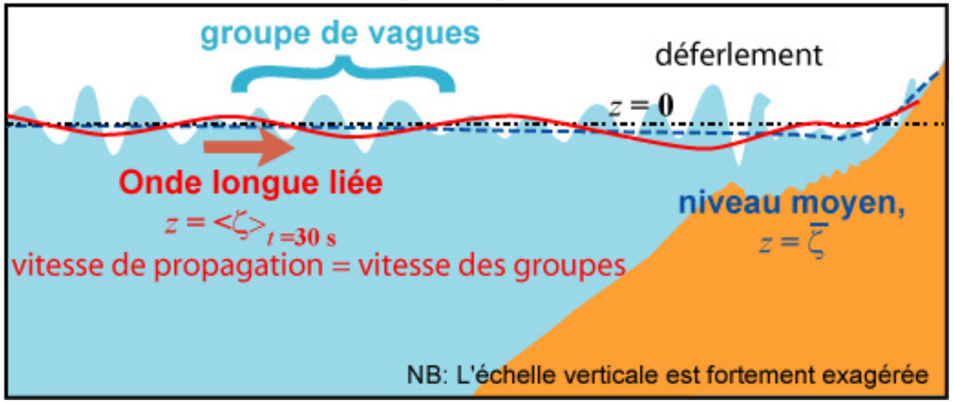
Perspectives: Taking wave models seriously

3. Estimating new parameters

Ocean waves define the sea surface motions in the frequency range 0.05 to 10 Hz (wavelengths of 600 m to millimeters)

Waves also drive larger scale motions (infragravity waves) because they are nonlinear

IG waves are generated
as « bound waves » by the nonlinear difference interaction of « normal waves » of frequencies f1 and f2
and wavenumbers k1 and k2:
→ f_IG = f1 – f_2 (0.001 to 0.05 Hz)
→ and k_IG = k1 -k2



At this stage the wavelength of IG waves is the lenght of wave groups (0.5 - 3 km). Forced IGs are strongly amplified at the coast (amplitude can reach 1 m on the beach face). Where waves break, these IG waves are realeased as free modes, mostly trapped on continental shelves. Free waves have the same frequency (0.001 to 0.05 Hz) … but the wavelength is now much larger :

For D= 4000 m and a typical f_IG=0.02 Hz, this gives L_IG = 9 km

3. Estimating new parameters

The energy level of forced IG waves can be predicted pretty well with a good wave model using the well-known second order theory

$$E_{2d}(f) = 2 \int\int\int T^2(f'+f, -f, \theta-\theta')E(f'+f,\theta)E(f',\theta')\mathrm{d}f'\mathrm{d}\theta\mathrm{d}\theta' \quad (1)$$

where $$T(f_1, f_2, \Delta_\theta) = \frac{\frac{(r_1+r_2)\left[r_2\left(k_1^2-r_1^4\right)+r_1\left(k_2^2-r_2^4\right)\right]+2(r_1+r_2)^2(k_1 k_2\cos(\Delta_\theta)-r1r2}{(r_1+r_2)^2-r_d^2} - k_1k_2\cos(\Delta_\theta) + r_1^2r_2^2}{r_1r_2} + (r_1^2 + r_2^2)$$

and
$$\begin{aligned} k_1\tanh(k_1D) &= (2\pi f_1)^2/g \\ k_2\tanh(k_2D) &= (2\pi f_2)^2/g \end{aligned}$$

$$\begin{aligned} r_1 &= (2\pi f_1)/\sqrt{g} \\ r_2 &= (2\pi f_2)/\sqrt{g} \\ k_d &= k_1^2 + k_2^2 - 2k_1k_2\cos(\Delta_\theta) \\ r_d &= \sqrt{k_d\tanh(k_dD)} \end{aligned}$$

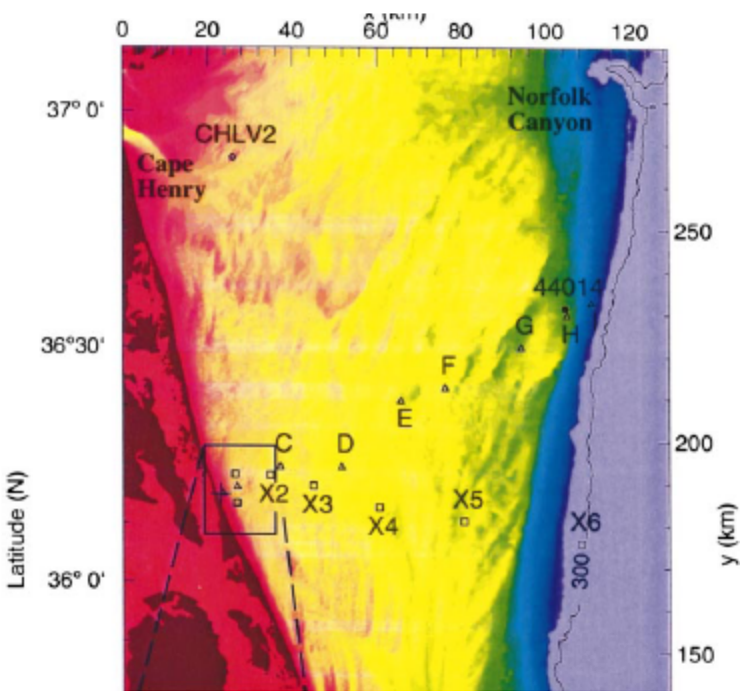
This can be measured with bottom-mounted pressure sensors (Herbers et al. JPO 1992, 1994)
Models can also be verified with forecast of seiching motions in small harbors, where IG waves get amplified.

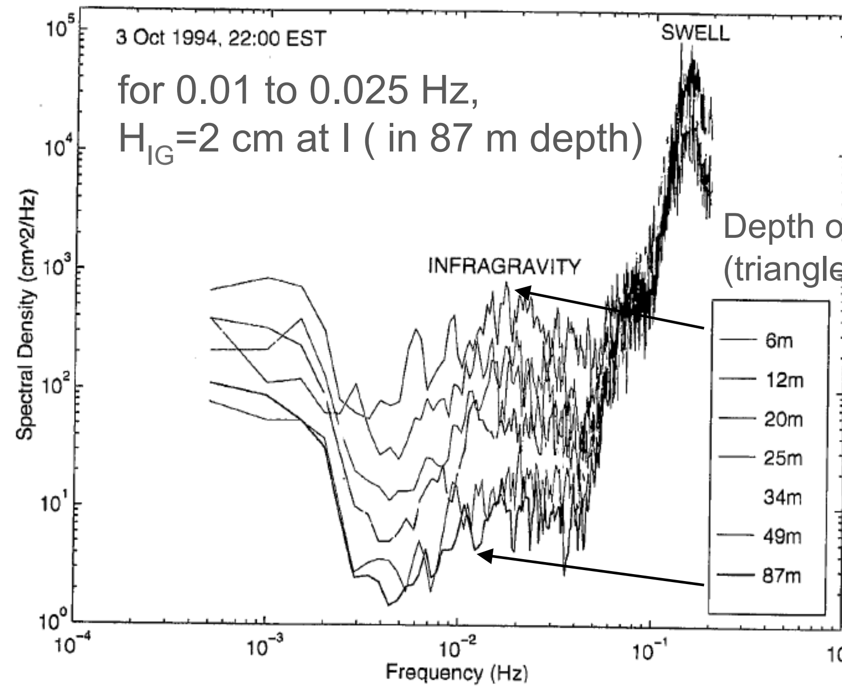
BONUS SLIDE: Infragravity waves and Sea level remote sensing

Some numbers

1. The frequency spectrum of IG waves is generally very broad.

Example from the U.S. East Coast with bottom pressure measurements across the shelf during the DUCK94 experiment.
(from Evangelidis 1996)





for 0.01 to 0.025 Hz,
H_{IG}=2 cm at I (in 87 m depth)

Depth of sensors
(triangles on map)

A
B
C
D
E
F
G
H
I

The highest recorded value in 87 m depth was 12 cm during DUCK94.
(data courtesy of T.H.C. Herbers, NPS, Monterey).

3. Estimating new parameters

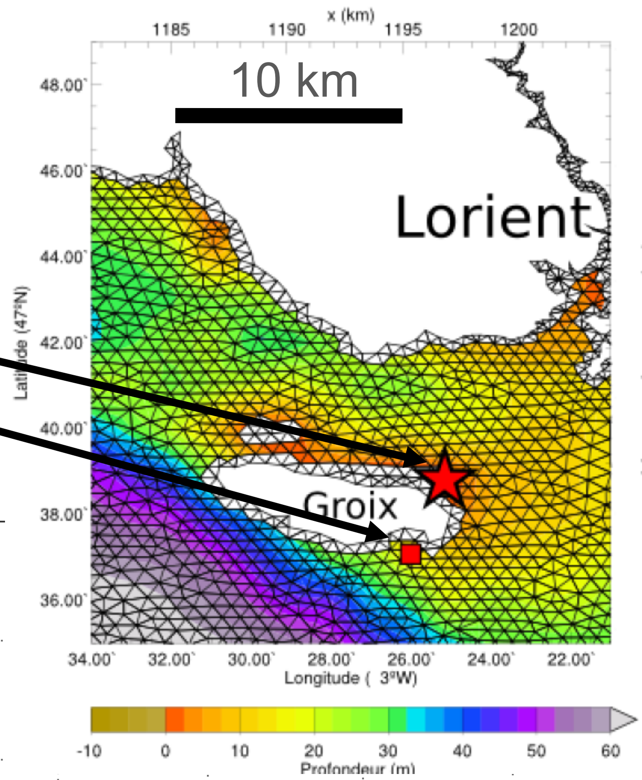
We verify the estimate of the IG significant wave height in the case of Port Tudy harbor (Groix, France) which has a resonance at a period =of 270 s

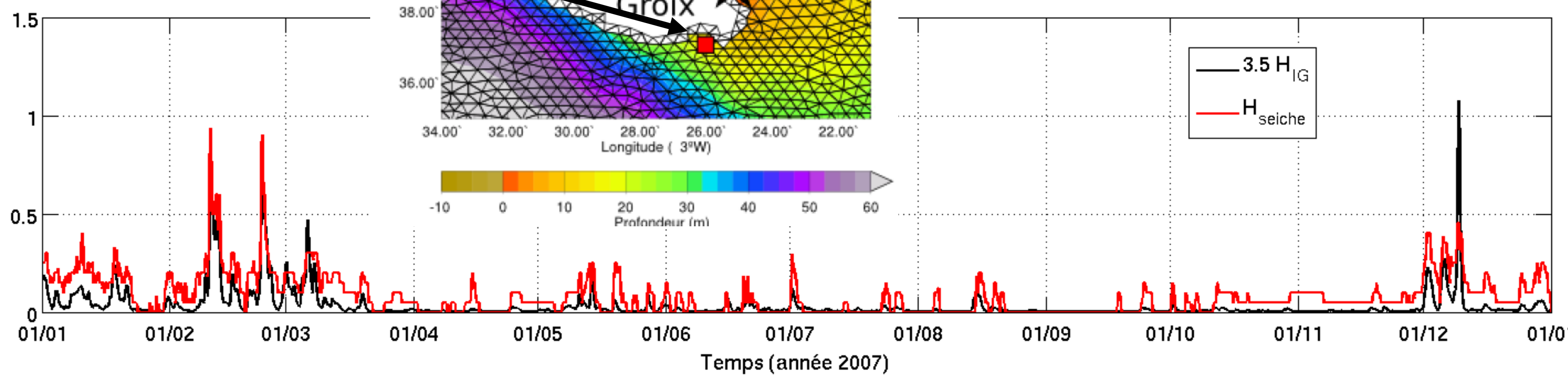
$$H_{IG} = 4\sqrt{\int_{f_{\min}}^{f_{\max}} E_{2d}(f)\mathrm{d}f}$$

We thus take fmin=0.003 and fmax=0.005 Hz.

The seiche is roughly proportional to H_{IG} (H_{seiche} ~ H_{IG}) as expected.

Forced IG waves are amplified by shoals to the East of Groix, and released as free edge wave trapped around the island. (wavelength > 3 km)





3. Estimating new parameters

The detailed modelling of free IG waves from forced IG forcing is still a challenge but

- significant progress has been made in the wave → IG transformation models (e.g. Reniers et al., Coastal Engng 2010)

- There is a need for IG wave modelling for seismic studies (Webb, Nature 2007)

- The wave models themselves are now getting better spectra (frequency and directional).

→ A stochastic modelling of IG waves appears feasible; but will require important validation efforts and model developments for the forced → free transformation, and new numerical techniques for an efficient propagation of the fast IG waves.

→ This can be useful for flagging future HR altimetry data, especially in coastal areas. NB: high IG level do not only occur with big waves, but also with gentle but long-period swells! A good proxy is Hs * Tp^2