Implementation of the new French operational coastal wave forecasting system and application to a wave-current interaction study

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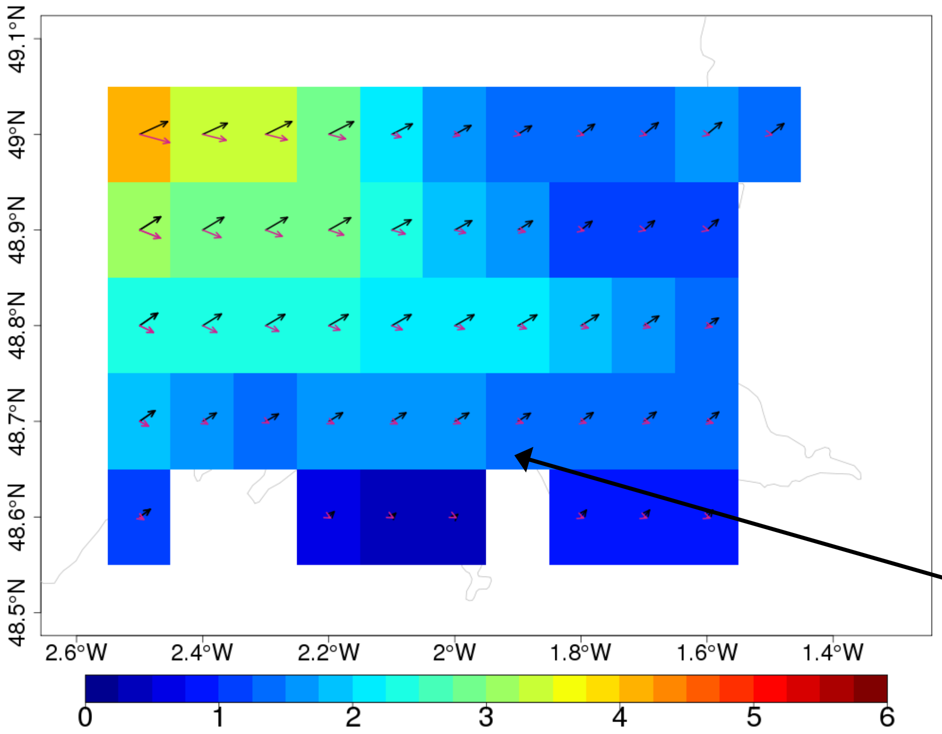
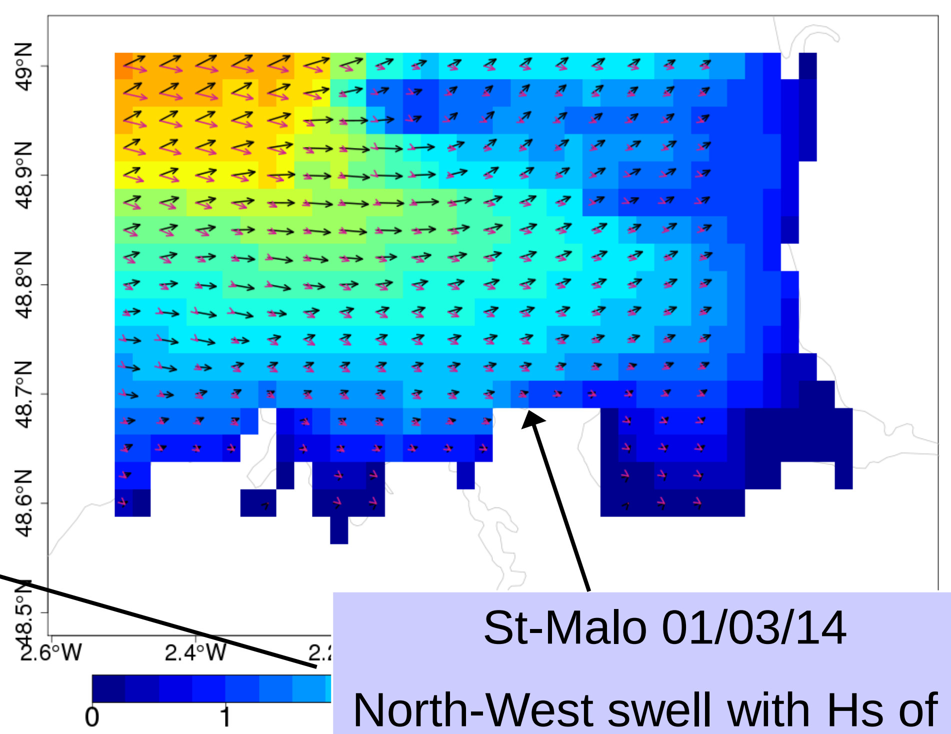
The need of a coastal wave model …

MFWAM Eurat 0.1°



MFWAM Arome 0.025°



St-Malo 01/03/14

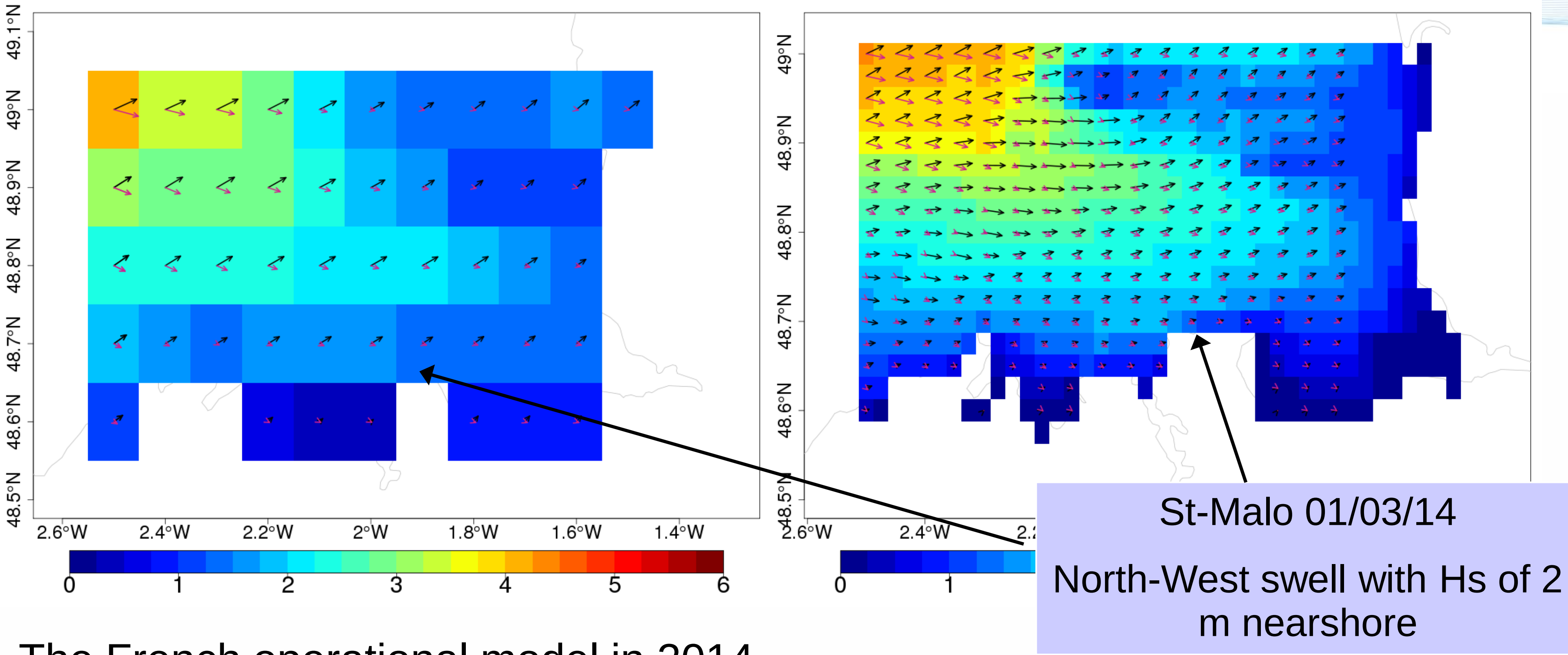
North-West swell with Hs of 2 m nearshore

The French operational model in 2014

The need of a coastal wave model …

MFWAM Eurat 0.1°

MFWAM Arome 0.025°



The French operational model in 2014

Homonim project : implementation of WW3 unstructured grids along the French coastline with a resolution of 200 m

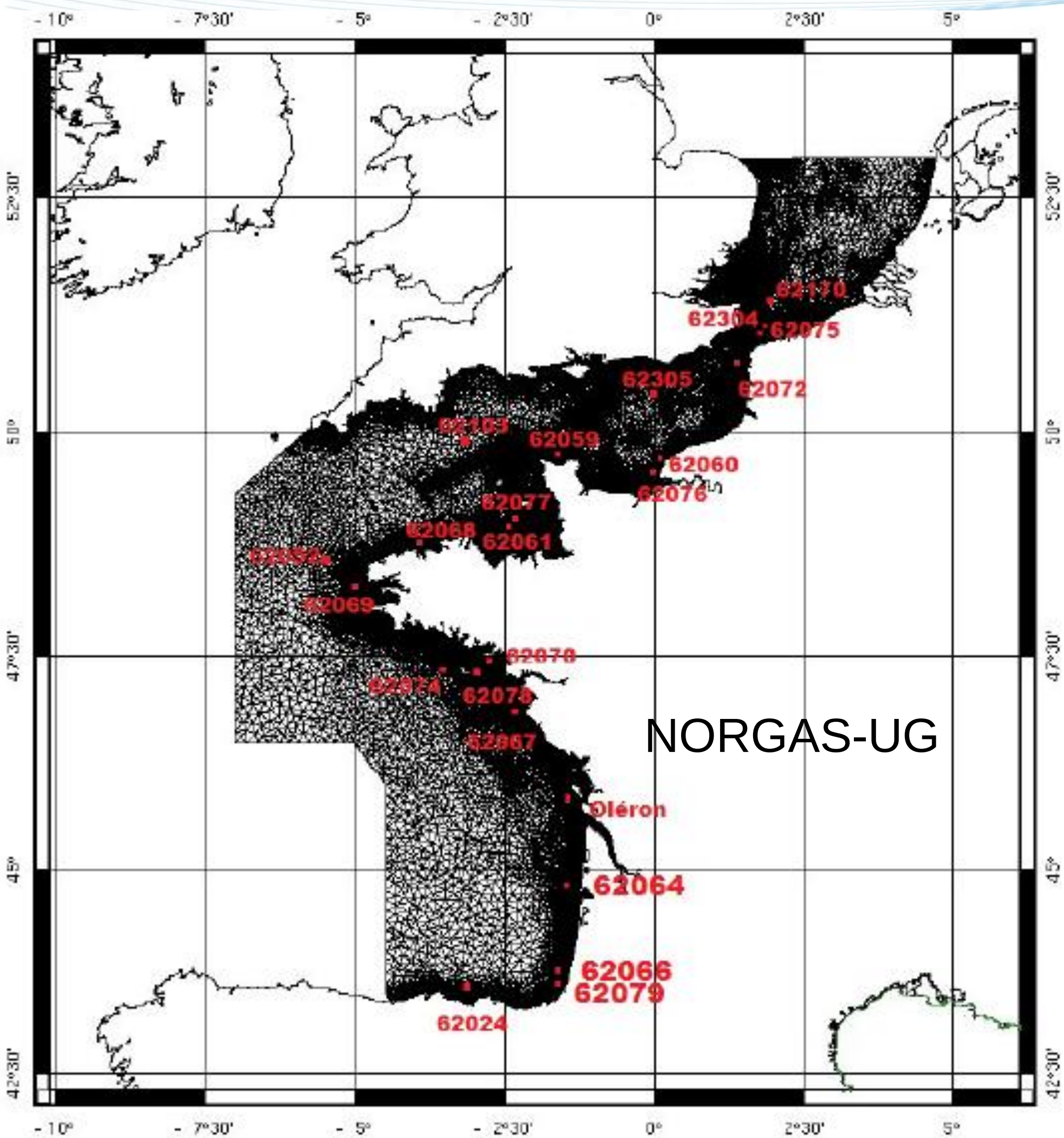
Outline

1. The French operational coastal wave forecasting system
   - The Mediterranean and Atlantic configurations
   - Performances
   - Operational system

2. Impact of currents and water level on waves
   - Between circulation and wave operational grids
   - Between embedded high resolution grids

3. Conclusions and Perspectives

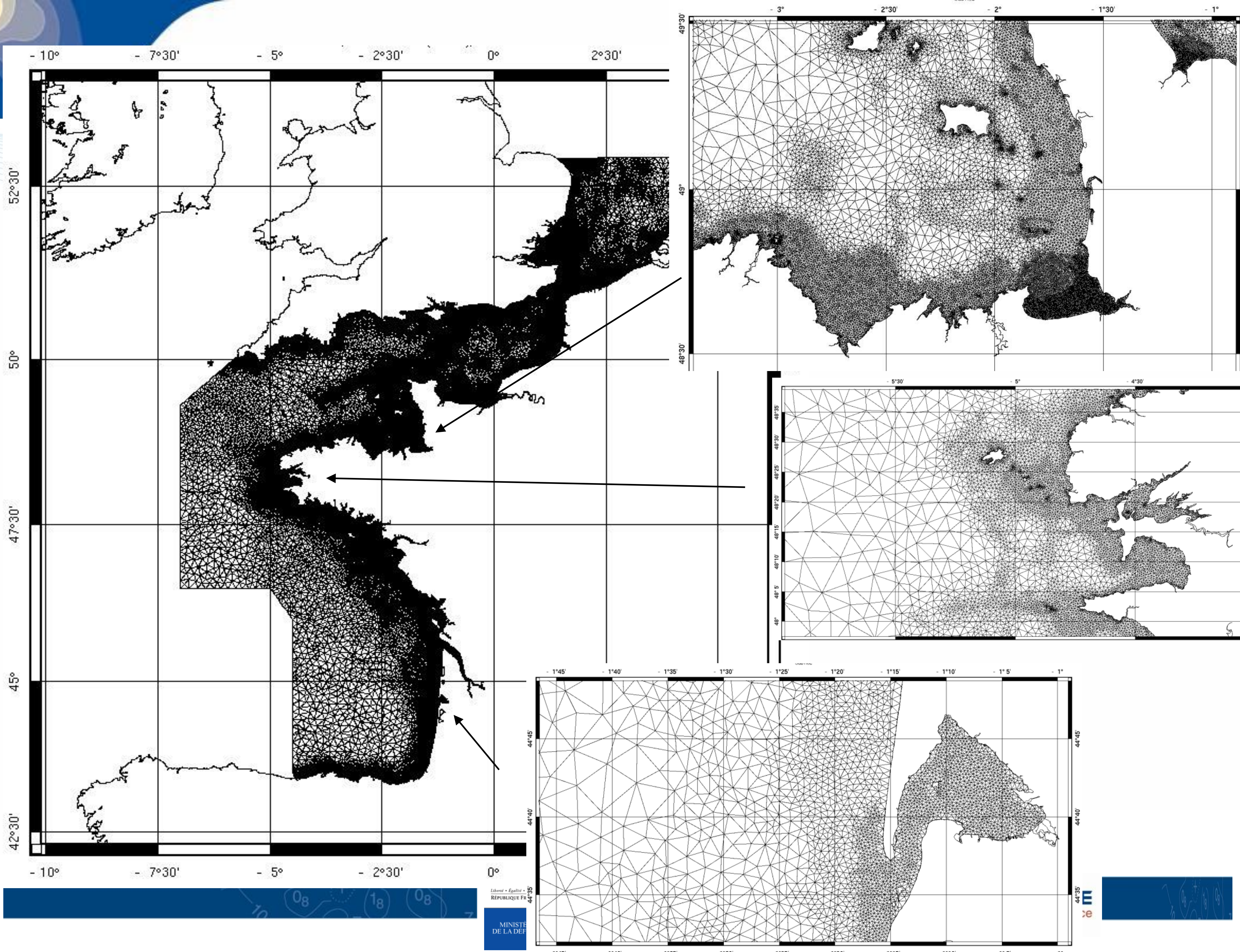
1. The Atlantic and Mediterranean configurations



92757 nodes

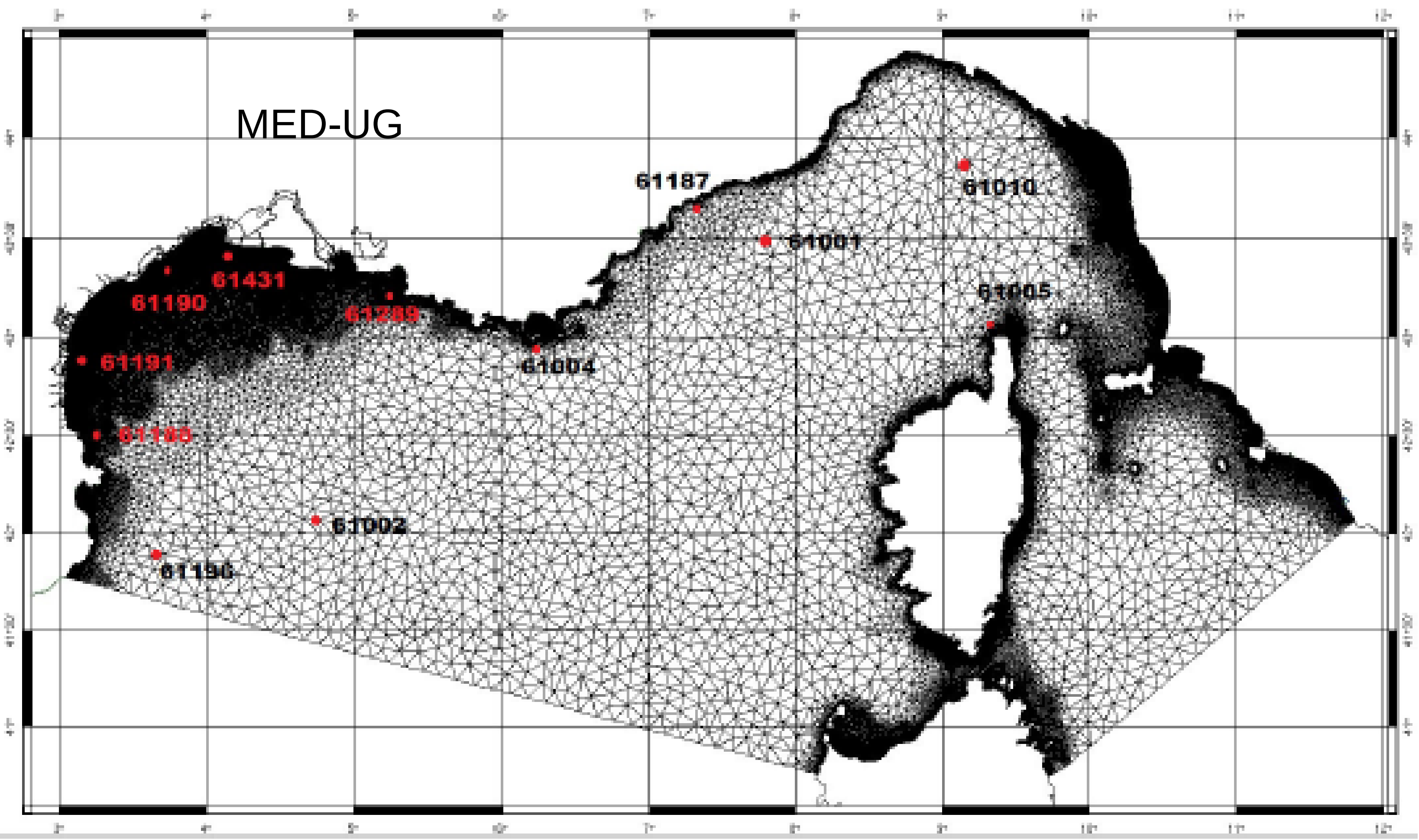
SHOM bathymetry

Resolution of 10 km offshore and around 200 m nearshore



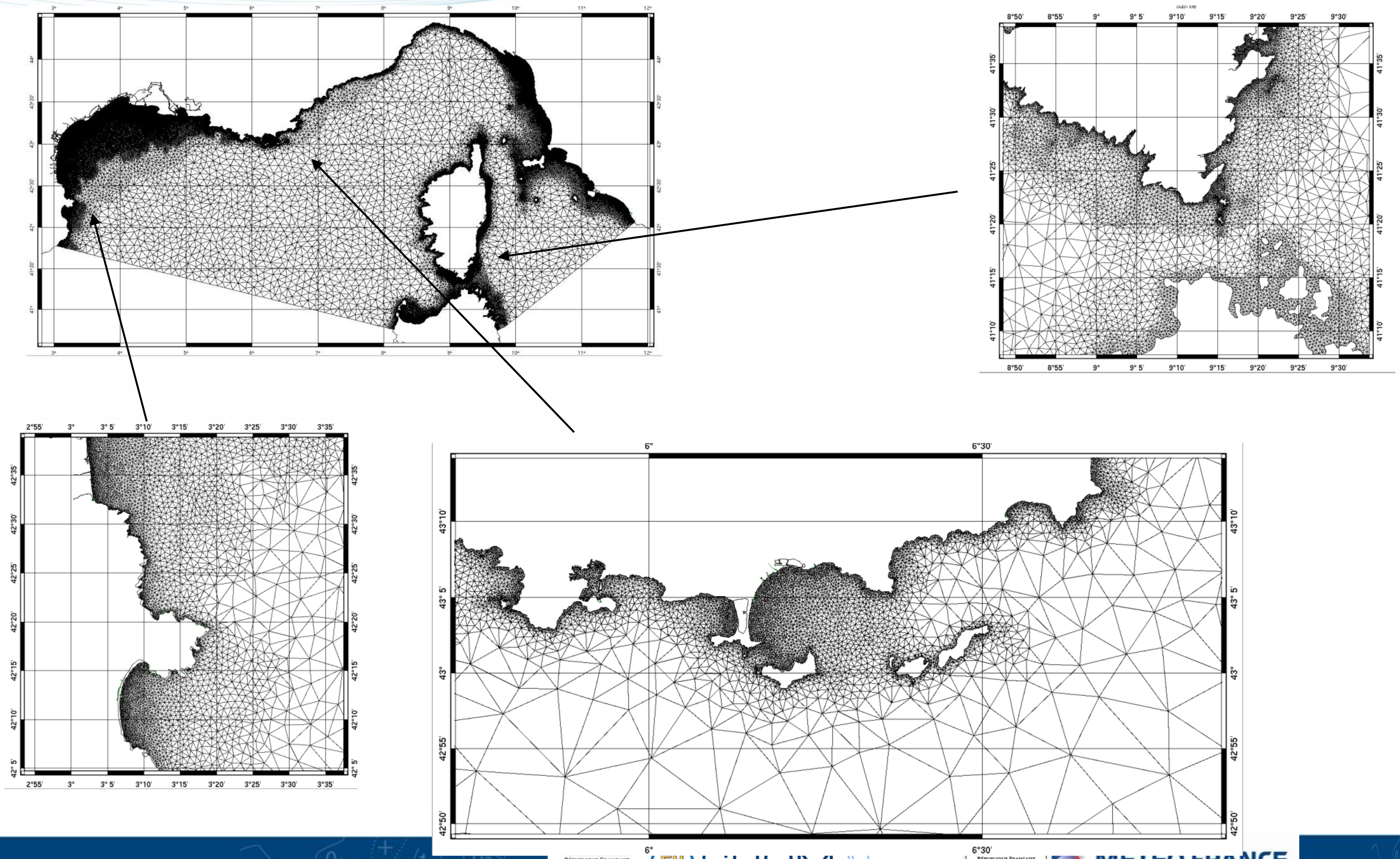
- 10°
- 7°30'
- 5°
- 2°30'
0°
2°30'
52°30'
50°
47°30'
45°
42°30'
- 3°
- 2°30'
- 2°
- 1°30'
- 1°
49°30'
49°
48°30'
- 5°30'
- 5°
- 4°30'
48°35'
48°30'
48°25'
48°20'
48°15'
48°10'
48° 5'
48°
- 1°45'
- 1°40'
- 1°35'
- 1°30'
- 1°25'
- 1°20'
- 1°15'
- 1°10'
- 1° 5'
- 1°
44°45'
44°40'
44°35'

1. The Atlantic and Mediterranean configurations



• 89695 nodes,
• SHOM bathymetry with Litto3D (resolution around 5 meters)
• Resolution of 10 km offshore and around 200 m nearshore

1. The Atlantic and Mediterranean configurations

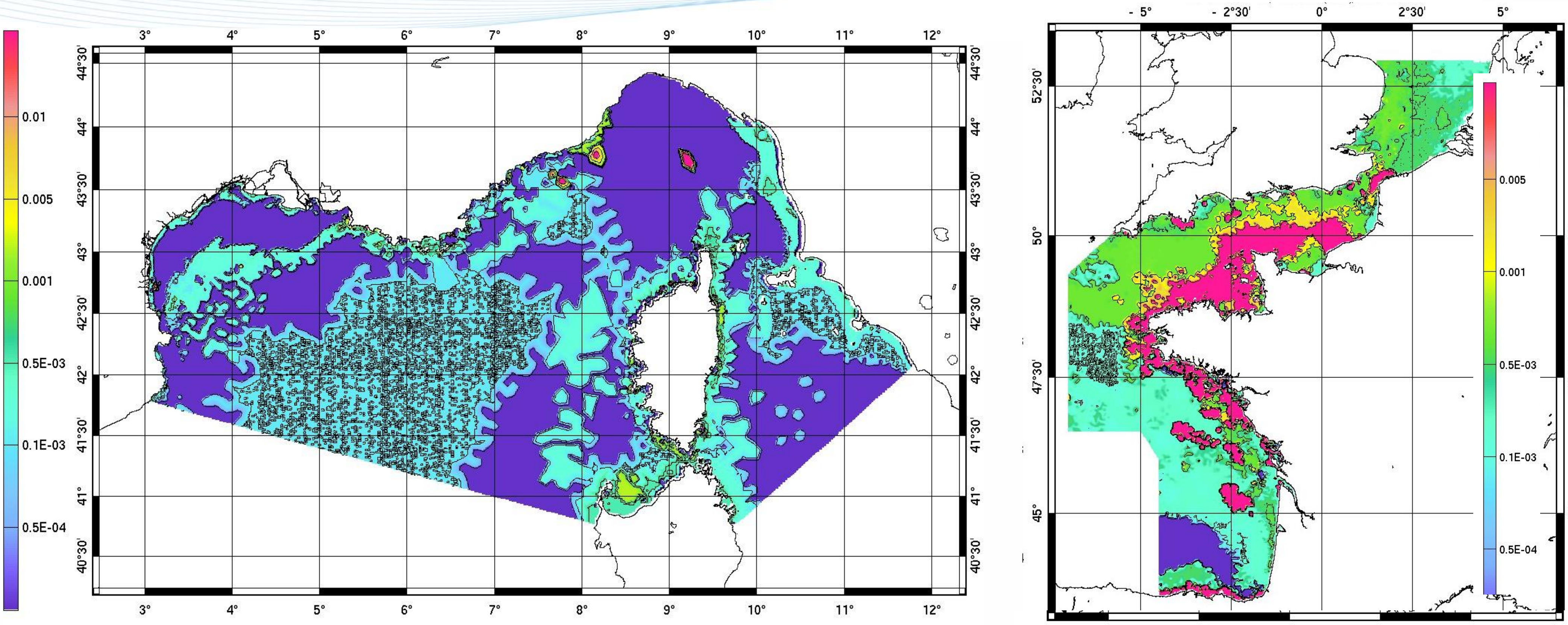


Parameterizations

- TEST 451 for NORGAS-UG and TEST 405 for MED-UG (Ardhuin et al., 2010). Modifications in the wind source and dissipation terms described in Janssen et al. (2014)

TEST	405	451	463
C_{ds}	-2.2	-2.2	-2.8
S_u	0	1	0.6
β_{max}	1.55	1.52	1.52
$z_{0,max}$	0.002	0.0	0.0
Br	0.00085	0.0009	0.0009
f_{FM}	2.5	--	--

- Implicit N scheme (Roland, 2009) for spatial propagation
- Bottom friction parameterization (Ardhuin et al., 2003a). A constant Nikuradse roughness length of respectively 12 cm is applied for rocks
- 24 directions and 30 frequencies exponentially spaced from 0.0345 Hz to 0.5473 Hz at an increment of 10%
- Wind forcing : Arpege 0.1° every 3 hours
- Global wave forcing : MFWAM 0.1° every 3 hours



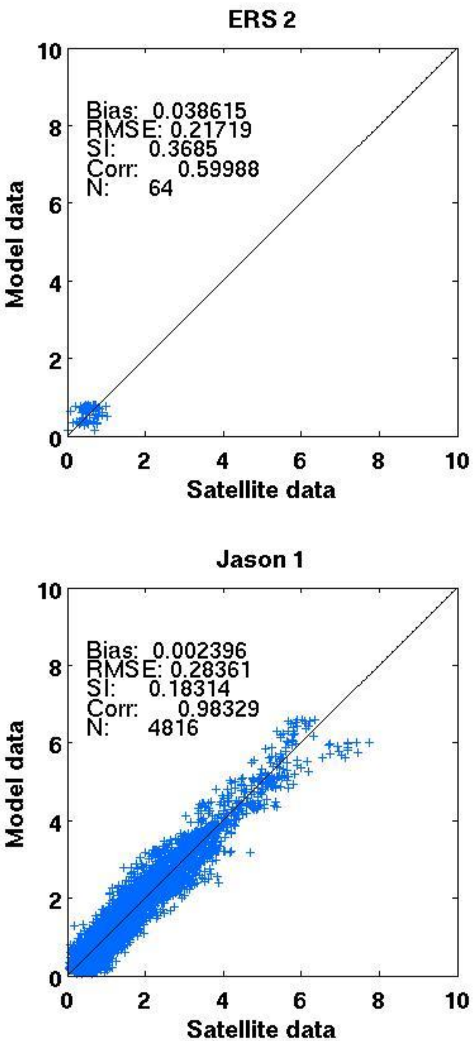
Map of the median grain size D_{50} (m)

Assessement of the performances

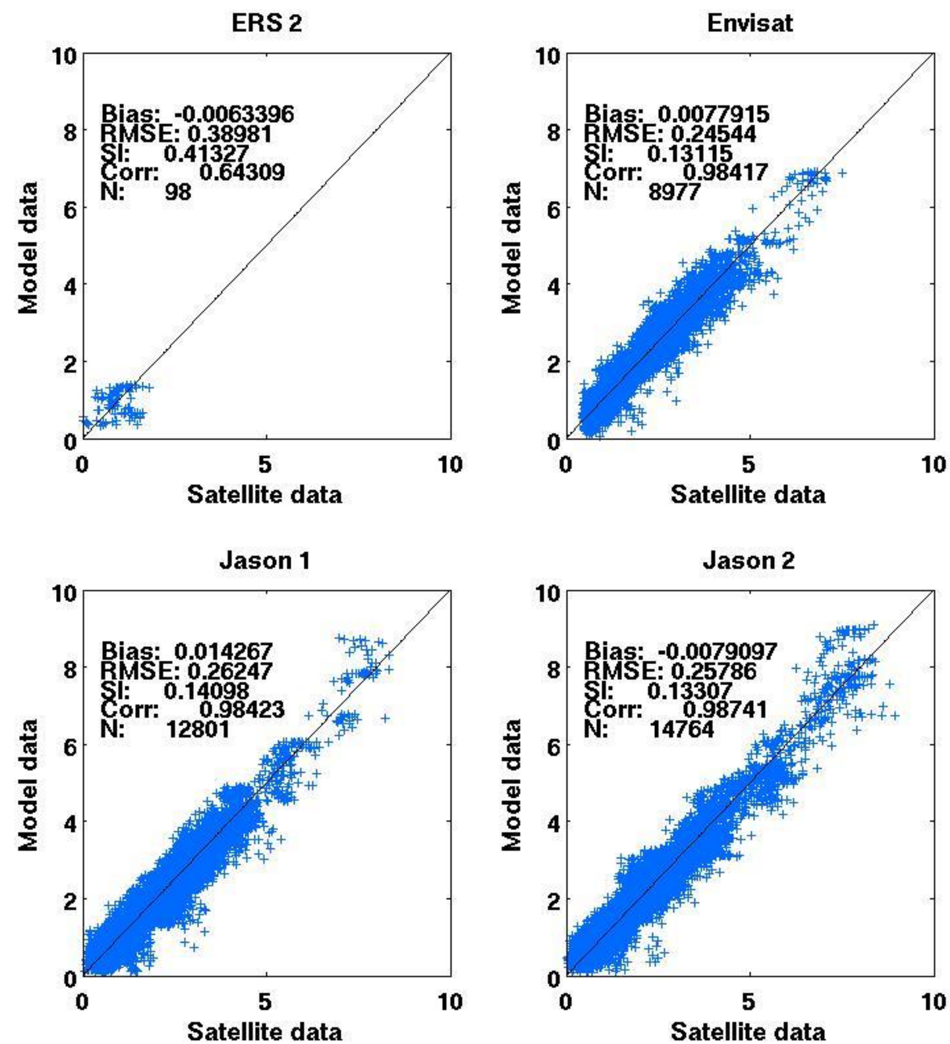
- Hindcasts on eight significant storms over the past twenty years and a long period run of 1-year (July 2011 to June 2012)
- Sensitivity tests on the bottom friction, atmospherical forcings, regional forcings, mesh resolution, spatial propagation scheme and on the addition of the current and water levels changes

Configuration	Satellites/buoys	Bias (m)	RMSE	SI	CORR
MED-UG	ENVISAT	-0.002	0.235	0.134	0.988
	JASON1	0.027	0.231	0.132	0.989
	JASON2	-0.025	0.229	0.154	0.986
	Buoys	-0.005	0.194	0.111	0.937
NORGAS-UG	ENVISAT	0.006	0.210	0.109	0.988
	JASON1	0.01	0.222	0.115	0.989
	JASON2	-0.026	0.207	0.104	0.992
	Buoys	0.0485	0.151	0.172	0.956

Performances on the significant wave height



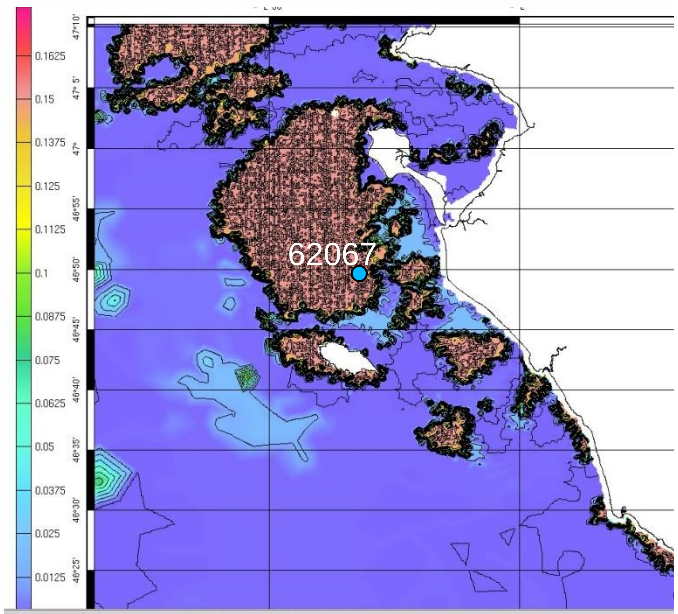
MED-UG



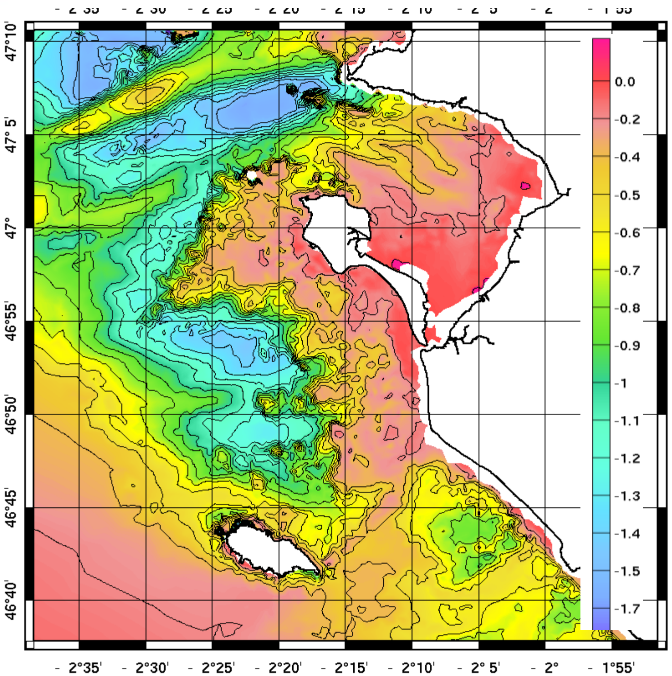
NORGAS-UG

Impact of bottom friction

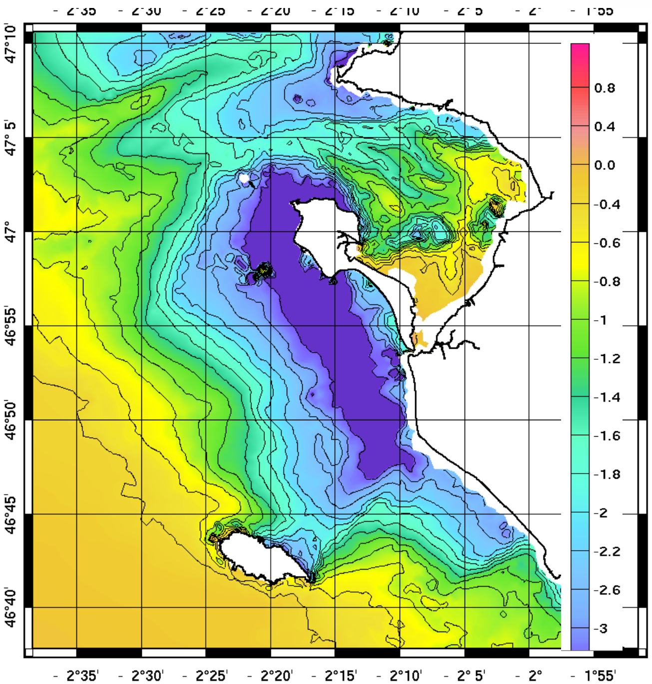
More information in Roland and Ardhuin (2014)



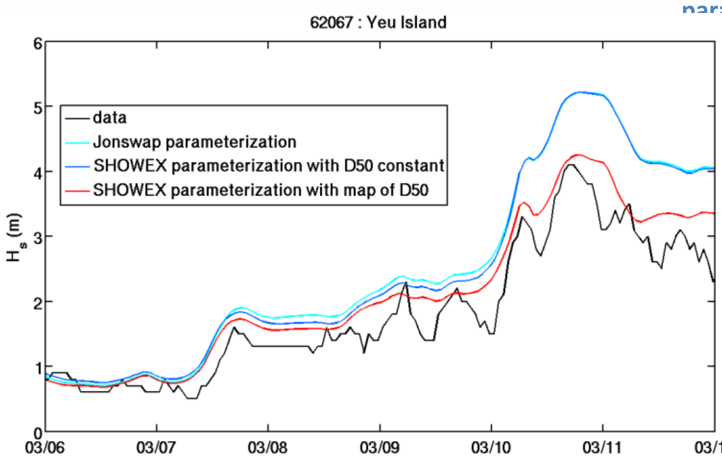
Grain size (in Krumbein Phi scale) at Yeu Island



Difference of Hs between a simulation with Showex parameterization and a Jonswap parameterization



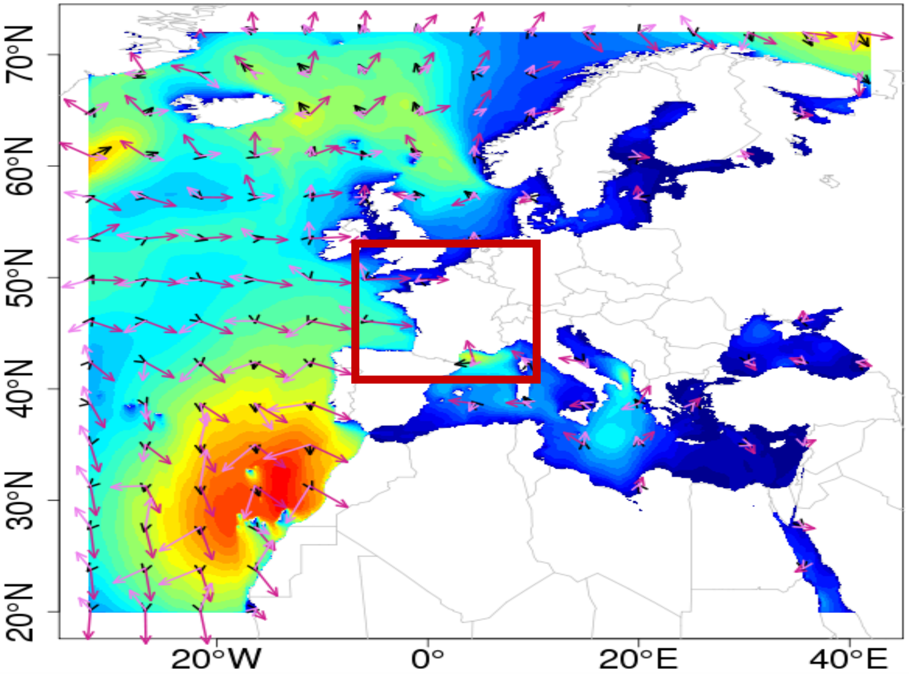
Difference of T01 between a simulation with Showex parameterization and a Jonswap parameterization



Impact of bottom friction parameterization and rocky platform at Yeu Island during Johanna storm.

The operational system

- 5 Runs every day (00h short, 00h, 06h, 12h, 18h) with different length of forecast (from 54 h to 102h)
- Forced by Arpege 0.1° (3hrs of resolution), and by MFWAM spectra (resolution of MFWAM grid 0.1°)



Run (UTC)	Forecast	Availability (UTC)
00 h (court)	*T_0+54 h*	*5h*
00 h	*T_0+102h*	*6h45*
06 h	*T_0+72h*	*13h10*
12 h	*T_0+84h*	*18h15*
18 h	*T_0+60h*	*1h10*

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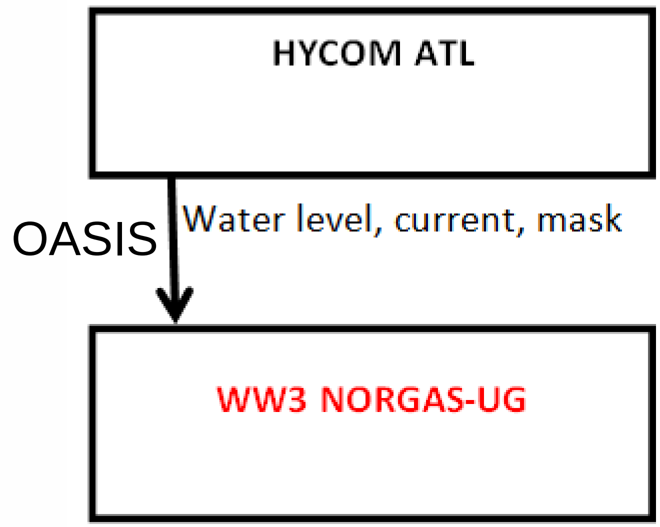
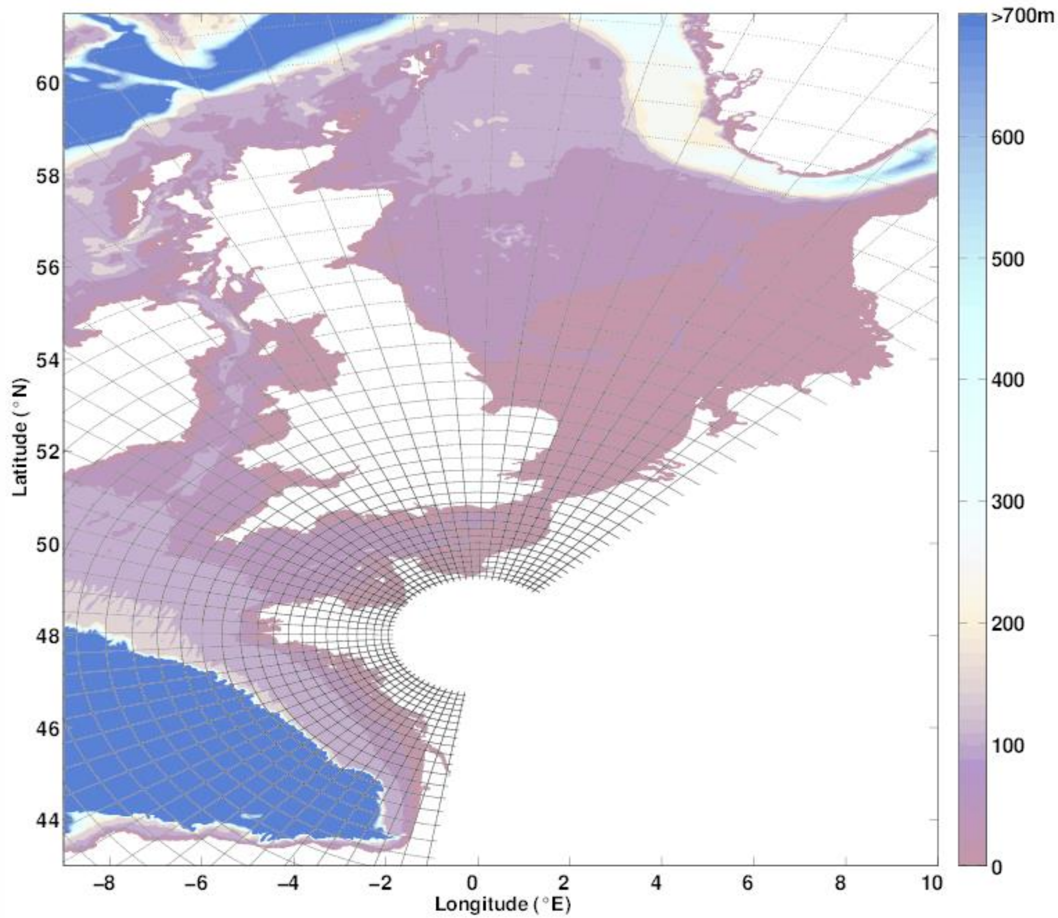
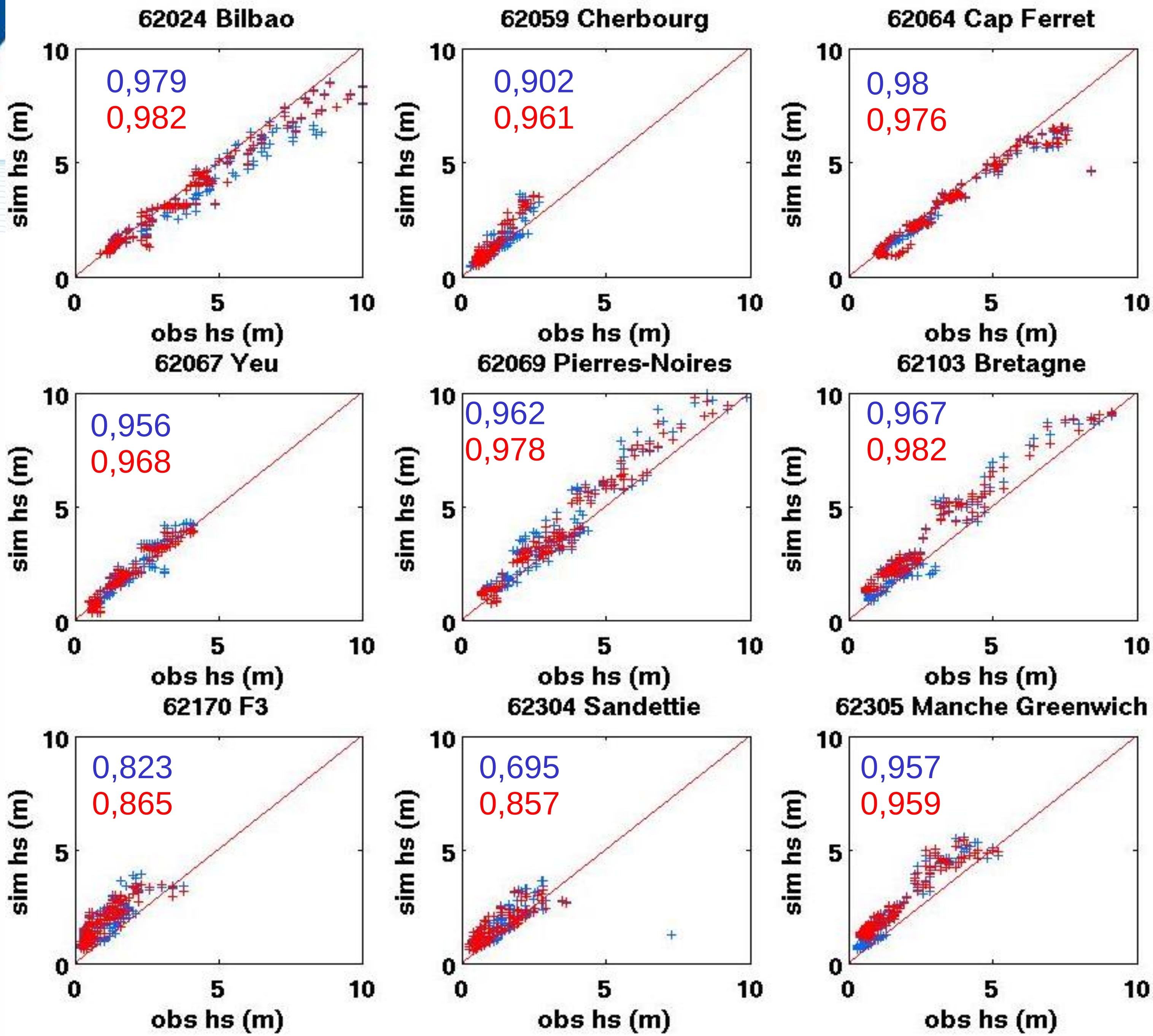
Coupling between operational circulation and wave models



The HYCOM configuration :
- curvilinear, from 2 km to 500 m in coastal areas
- barotropic configuration

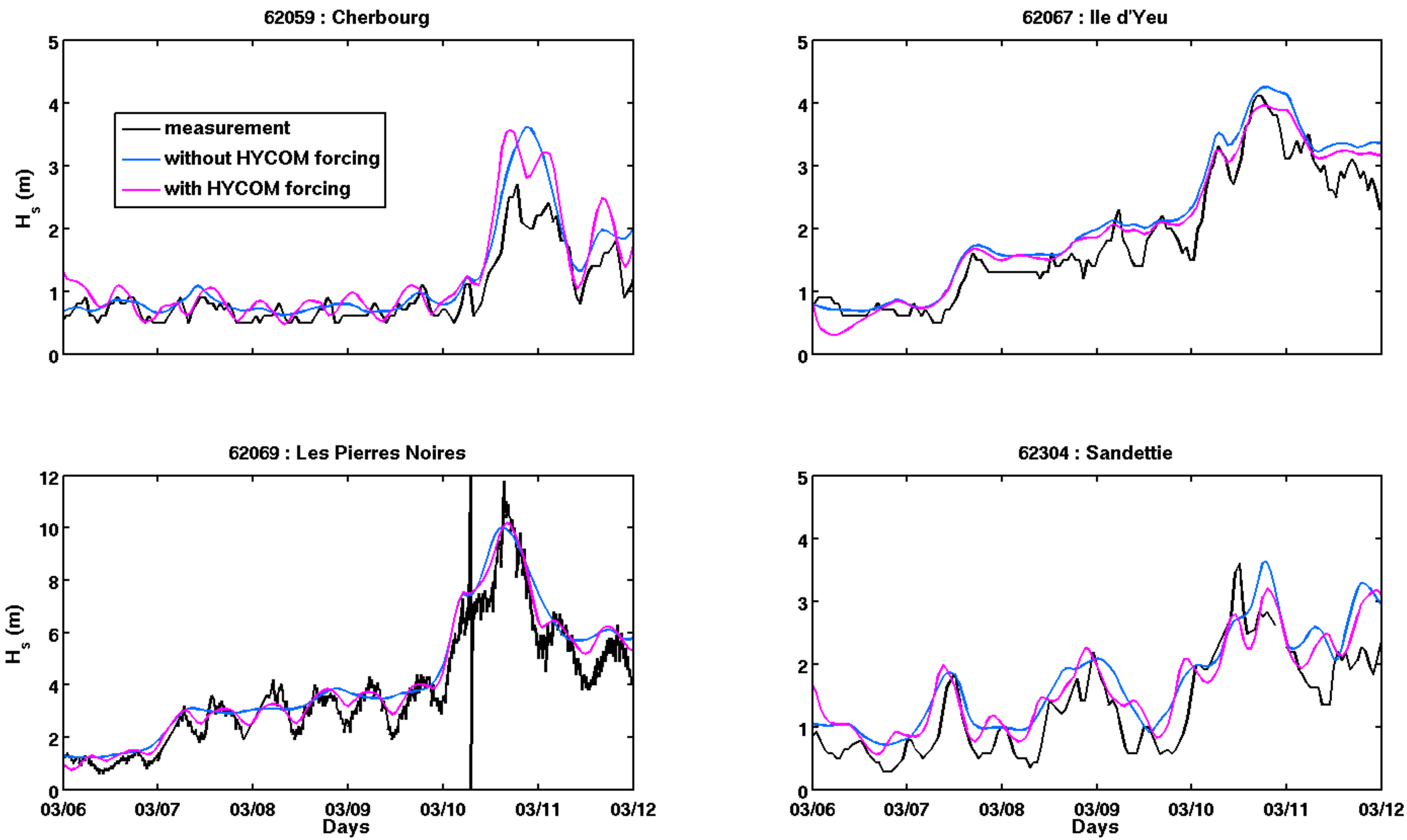


The HYCOM operational circulation grid for Atlantic (ATL). Only one contour each twenty contours is shown



Scatter diagram of H_s at the different buoys for Johanna storm (03/2008). In blue the results without the HYCOM forcing and in red with the HYCOM forcing. The two numbers are the coeff correlation for the two simulations.

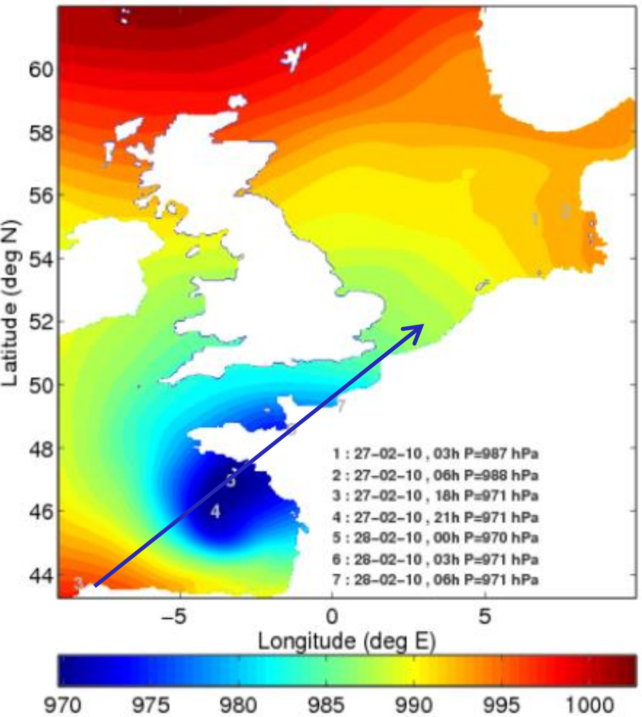
Coupling between operational circulation and wave models



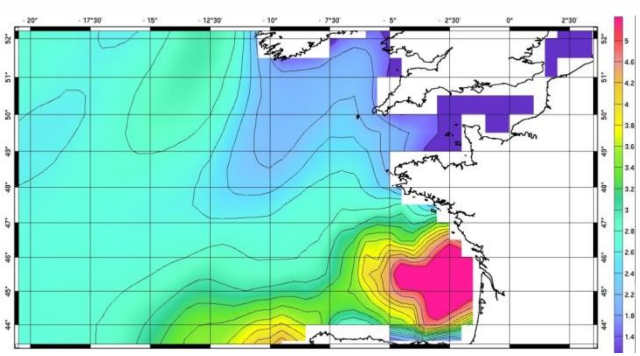
Times series of H_s at the different buoys for Johanna storm (03/2008). In blue the results without the HYCOM forcing and in pink with the HYCOM forcing.

Coupling between operational circulation and wave models

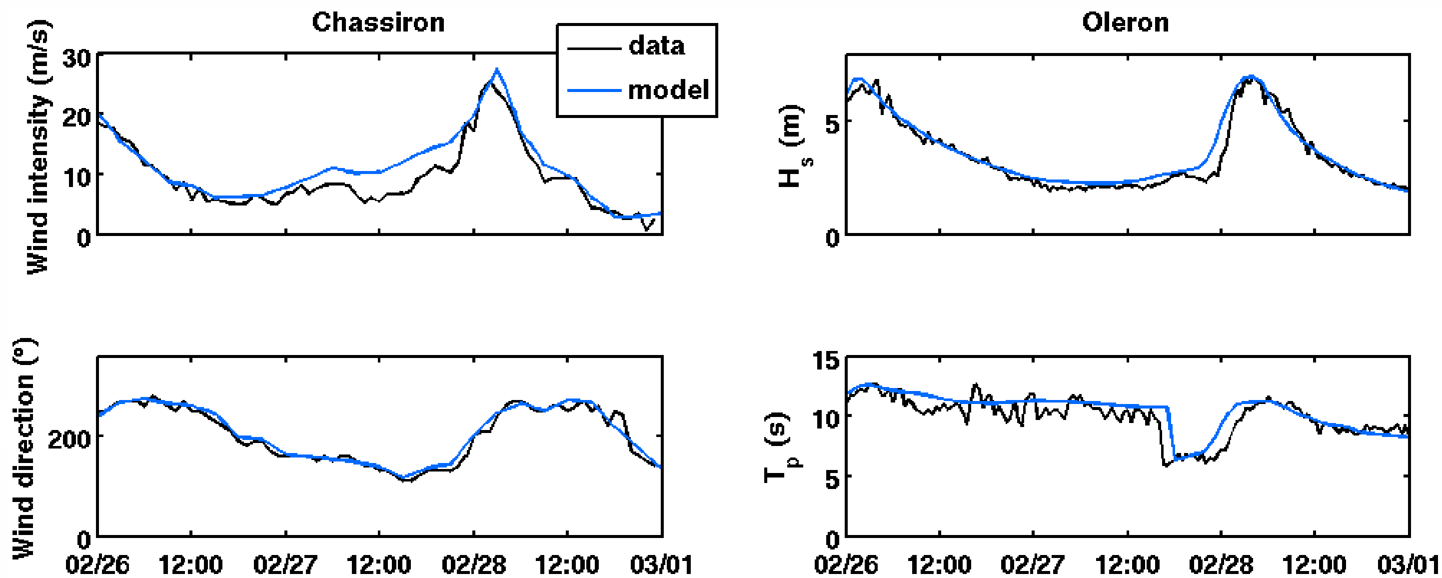
The Xynthia storm 02.28.2010



Pressure field (hPa) on 02.28.2010 0h



Significant wave height on 02.28.2010 0h

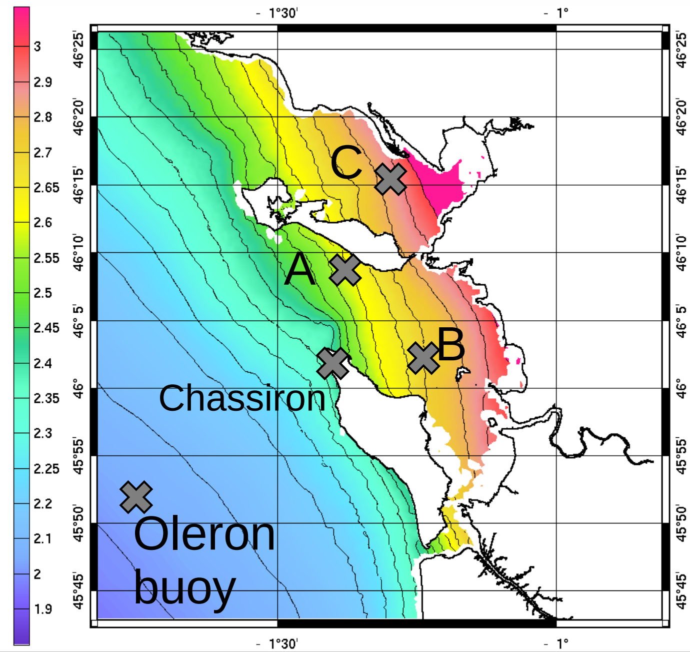


HOMONIM
OBSERVER - ANALYSER - PRÉVOIR

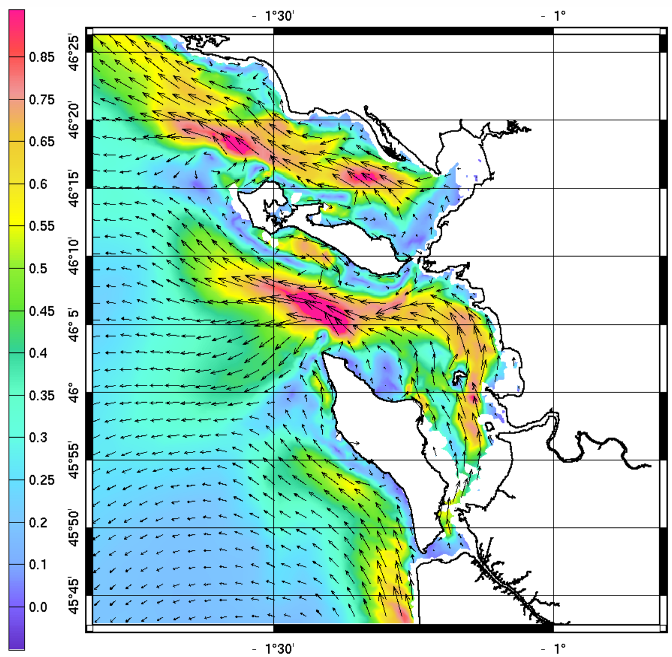
SHOM
L'océan à la carte

METEO FRANCE
Toujours un temps d'avance

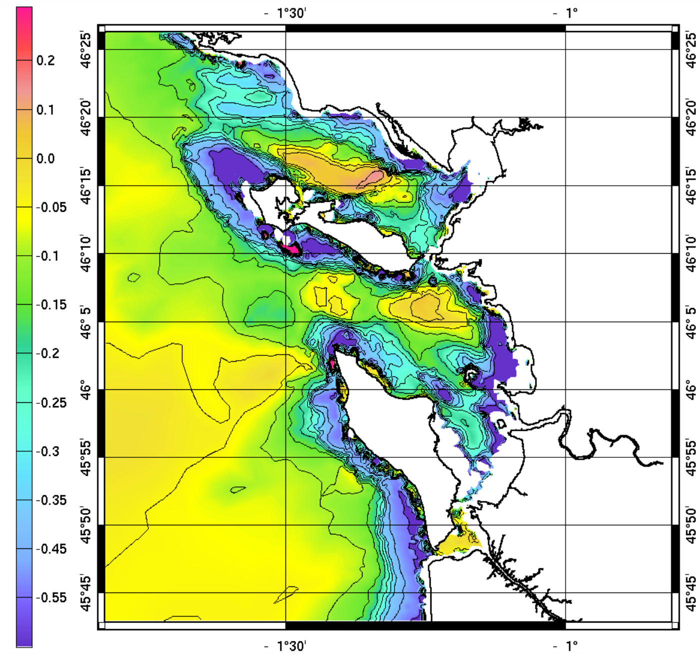
Coupling between operational circulation and wave models



Sea surface height (in m)

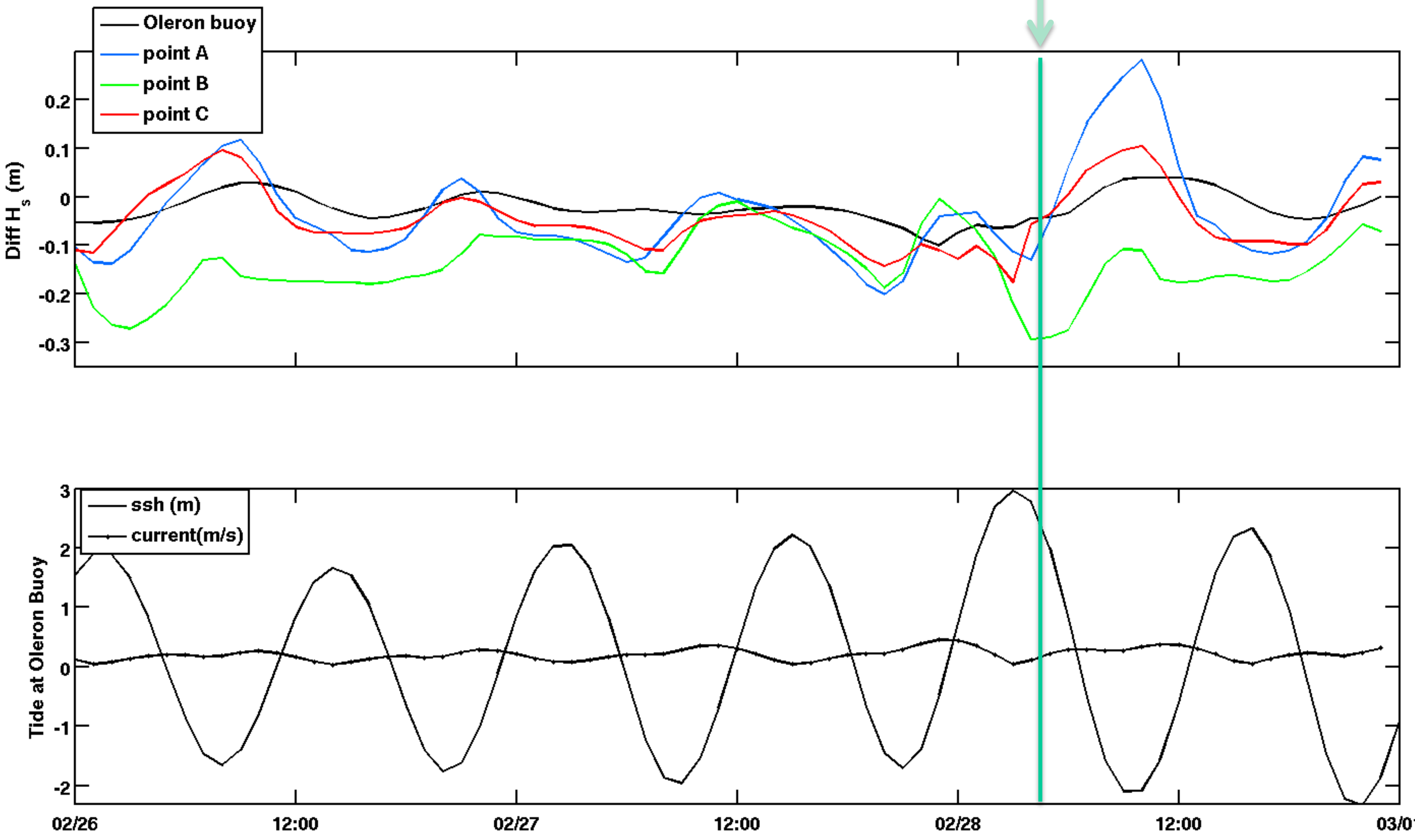


Barotropic current (m/s)



Difference in significant wave height (in m) between a simulation with the HYCOM forcing and without on 02/28 at 5 a.m.

Coupling between operational circulation and wave models



(Up) Effects of current and water level on significant wave heights. Diff hs is the difference of significant wave height between a simulation with the forcing of the circulation model and without, (Bottom) ssh and current at the Oleron Buoy.

Outline

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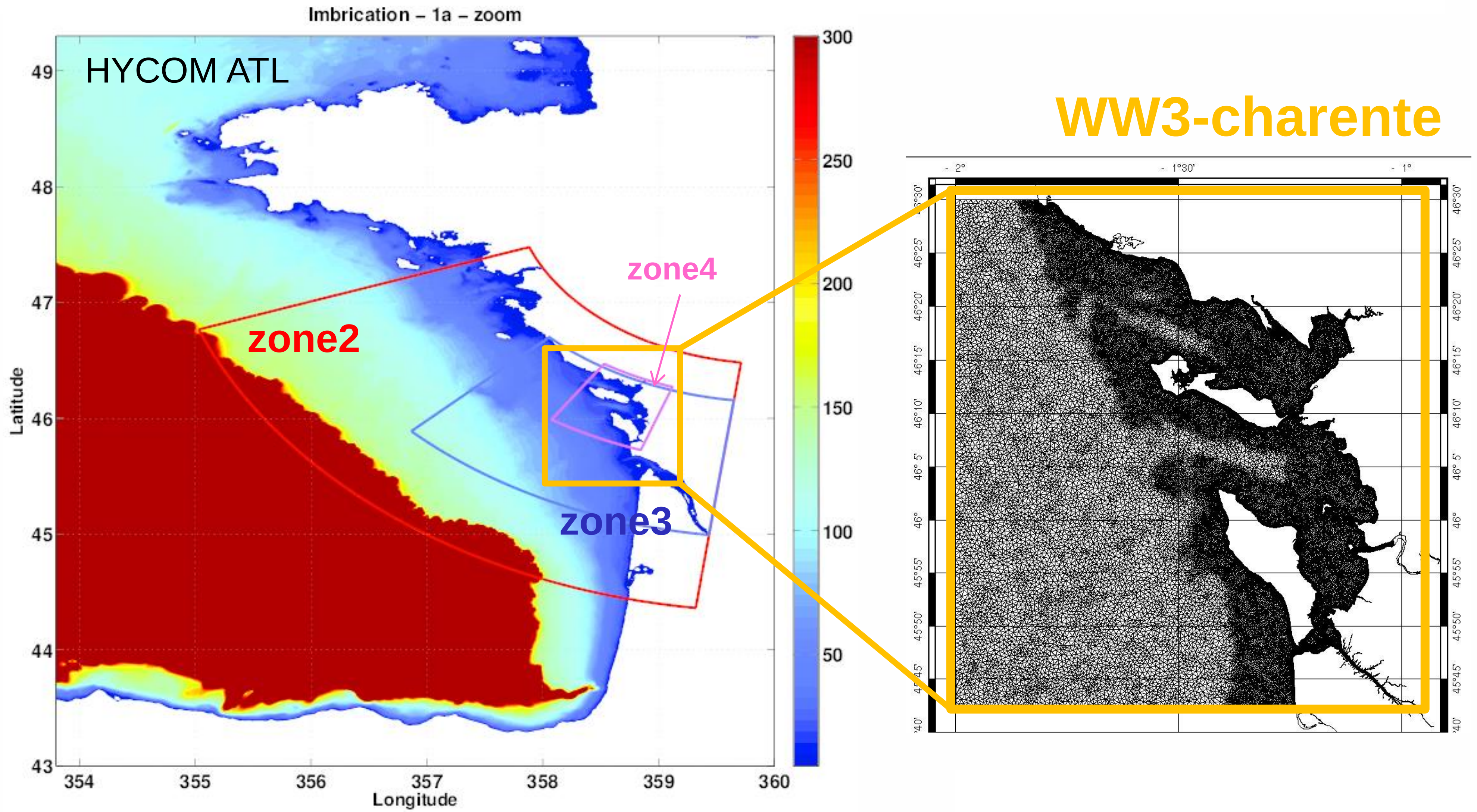
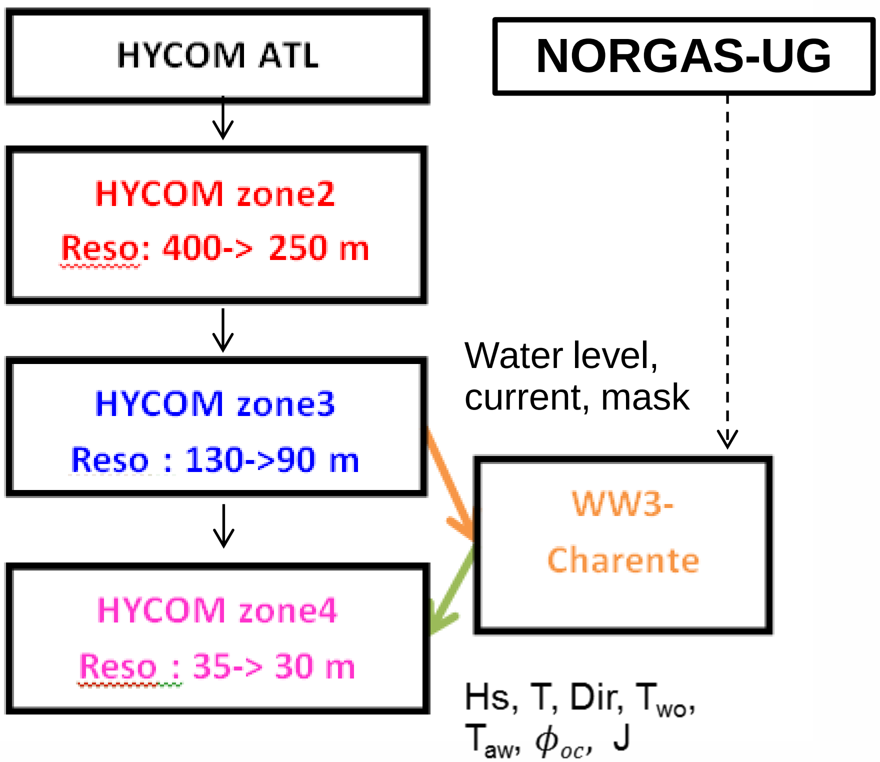
3. **Conclusions and Perspectives**

Coupling between embedded high resolution grids



Coupling between embedded high resolution grids



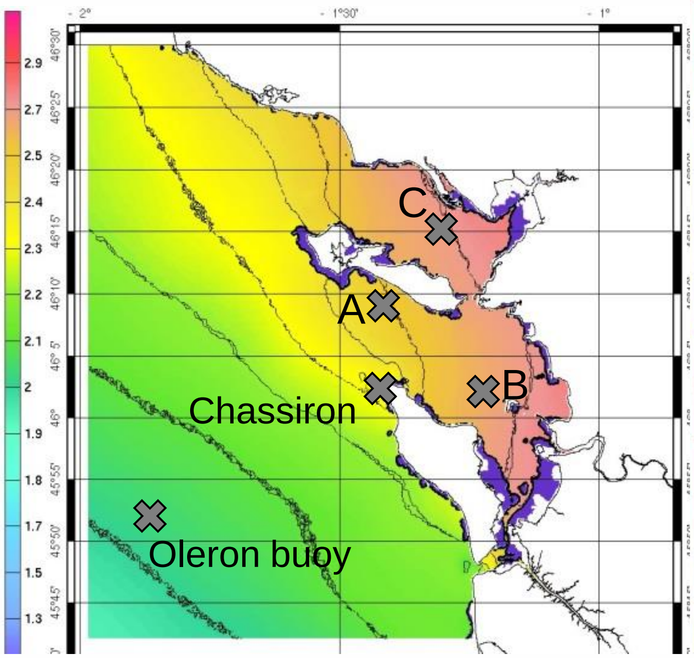
REFERENCE

- WW3-Charente forced by NORGAS-UG

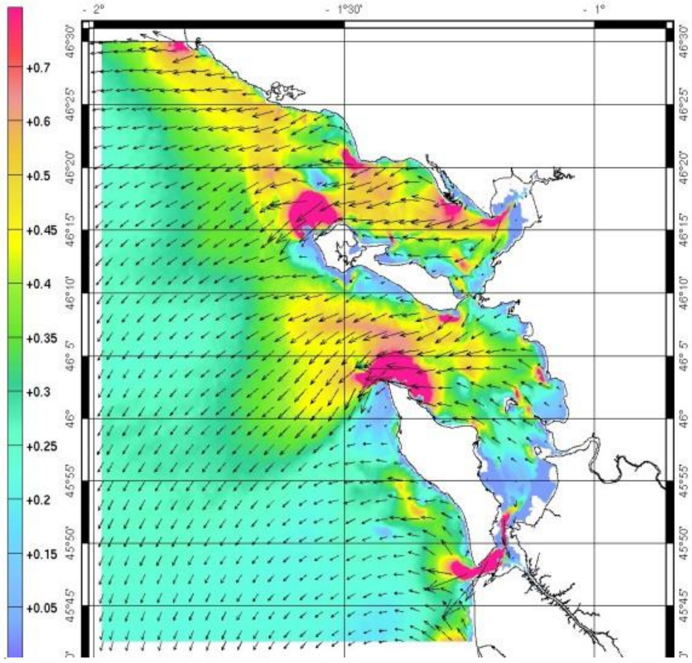
COUPLING SIMULATION:

- REFERENCE simulation with current from HYCOM zone 3
- HYCOM zone 4 with wave-induced current *(results of ssh and current not presented here)*

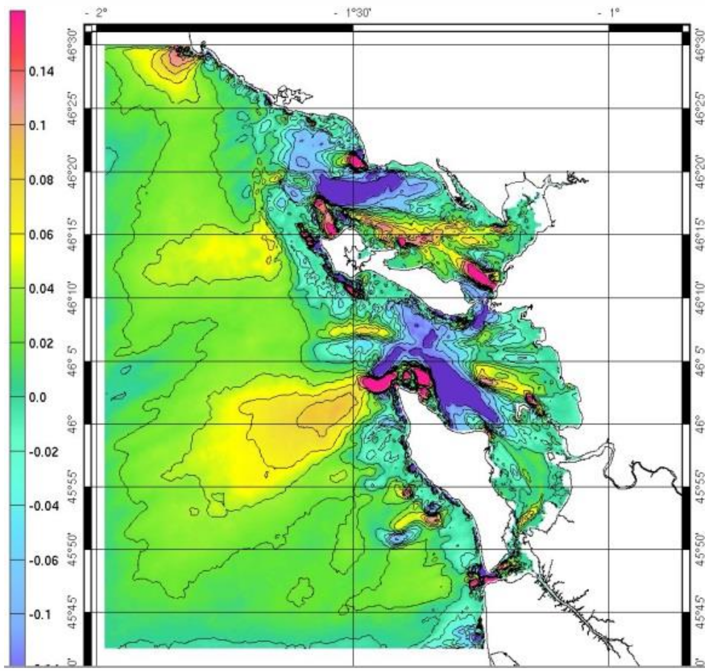
Coupling between embedded high resolution grids



Sea surface height (in m)

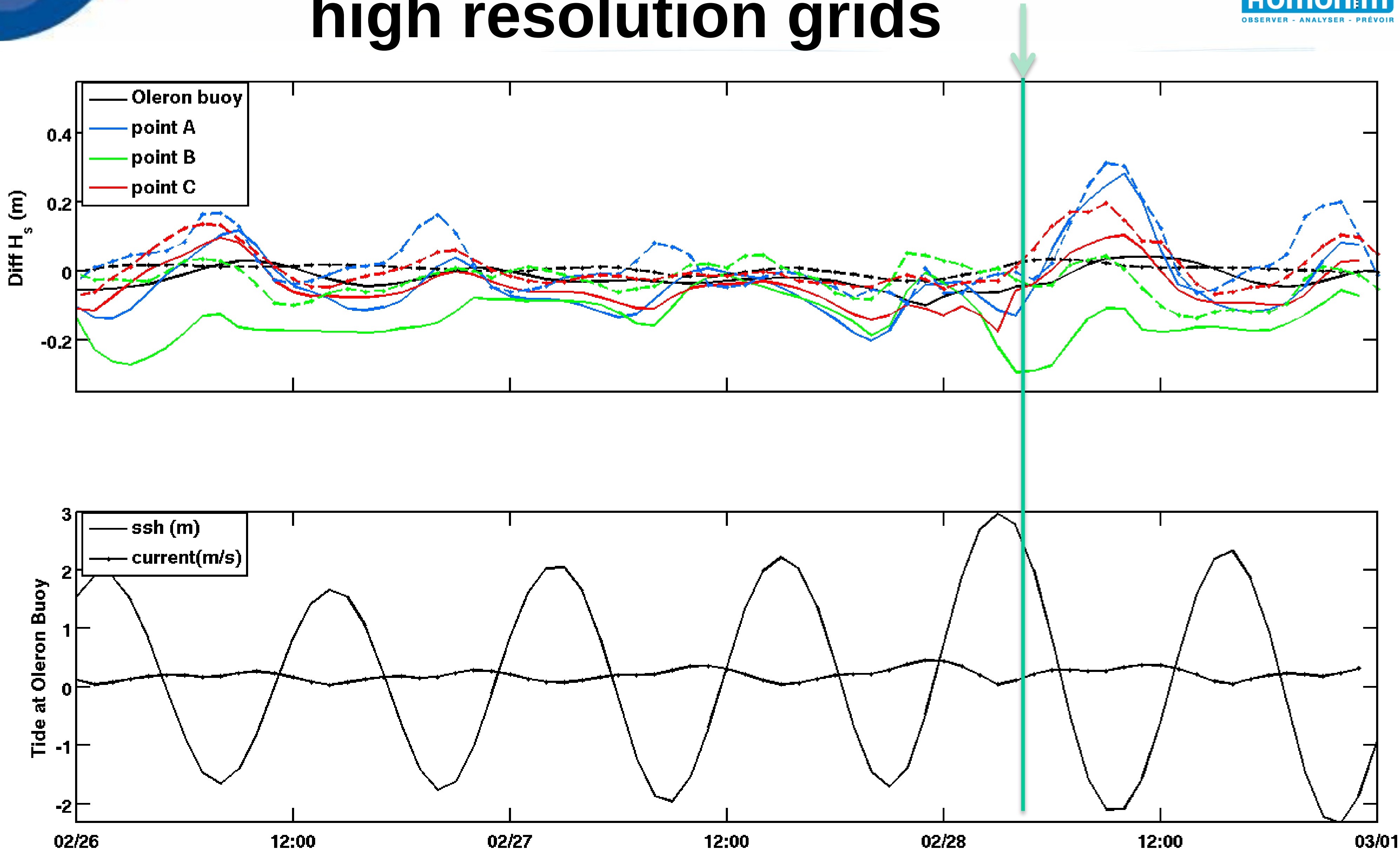


Barotropic current (m/s)



Difference in significant wave height (in m) between a simulation 2 way and 1way on 02/28 at 5 a.m.

Coupling between embedded high resolution grids



(Up) Effects of current and water level on significant wave heights. Diff hs is the difference of significant wave height between a simulation with the forcing of the circulation model and without, for the full line with the NORGAS-UG simulation and for the dashed lines with the Charente simulation.

(Bottom) ssh and current at the Oleron Buoy.

Conclusion

1. **Presentation of the new French operational coastal wave forecasting system and its performances**
2. **A study on the impact of the wave-current interactions on these operational configurations during the Xynthia storm**
   - **Improvement with a refinement around the Pertuis-Charente area and the use of the OASIS coupler and the HYCOM circulation model**

Perspectives

1. **For the wave operational forecasting system :**
   - Add the last ww3 developments : implicit scheme (see presentation of Huchet et al.), triplet parameterization…
   - Coupling with the Hycom 2D model
   - Forcing with the Arome wind model (resolution: 0.025°)
   - New configurations for Antilles, Guyane and La Réunion
2. **Wave/current interaction study :**
   - Study of the wave-induced current, wave-induced surface stress and wave setup during the Xynthia storm
   - Implementation of the HYCOM 3D model in this coupling strategy
   - Study on the Iroise Sea during the 2013-2014 winter storms (PROTEVS campaign)

Thank you

Coupling between operational circulation and wave models

Without HYCOM forcing

	Bilbao	Cherbourg	CapFerret	Yeu	Pierres-N	Bretagne	F3	Sandettie	Manche
Bias	-0.1141	0.1716	-0.0744	0.1147	0.1596	0.2431	0.7484	0.2025	0.4432
Corr	0.9795	0.9029	0.9801	0.9562	0.9616	0.9667	0.8297	0.6949	0.9574
RMSE	0.8057	0.2512	0.5362	0.2655	0.4907	0.7865	0.8651	0.6882	0.7954
SI	0.1589	0.3079	0.1402	0.1789	0.2115	0.2635	0.7246	0.4292	0.4187

With HYCOM forcing

	Bilbao	Cherbourg	CapFerret	Yeu	Pierres-N	Bretagne	F3	Sandettie	Manche
Bias	-0.0970	0.2888	-0.0825	0.0903	0.1422	0.2842	0.8281	0.2638	0.4671
Corr	0.9825	0.9612	0.9768	0.9686	0.9781	0.9826	0.8655	0.8571	0.9599
RMSE	0.7304	0.2957	0.5510	0.2289	0.4275	0.8447	0.8766	0.5188	0.8996
SI	0.1496	0.3838	0.1418	0.1516	0.1710	0.2555	0.7420	0.3511	0.4188

Momentum equations

Quasi-eulerian velocities

Lagrangian velocities

Stokes velocities

Ardhuin et al. (2008b), Michaud et al. (2012) : $(\hat{u},\hat{v},\hat{w}) = (u,v,w) - (U_s,V_s,W_s)$

$$\frac{\partial \hat{u}}{\partial t} + \hat{u}\frac{\partial \hat{u}}{\partial x} + \hat{v}\frac{\partial \hat{u}}{\partial y} + \hat{w}\frac{\partial \hat{u}}{\partial z} - f\hat{v} + \frac{1}{\rho}\frac{\partial p}{\partial x} = [f + (\frac{\partial \hat{v}}{\partial x} - \frac{\partial \hat{u}}{\partial y})]V_s - W_s\frac{\partial \hat{u}}{\partial z} - \frac{\partial J}{\partial x} + F_{m,x} + F_{d,x}$$

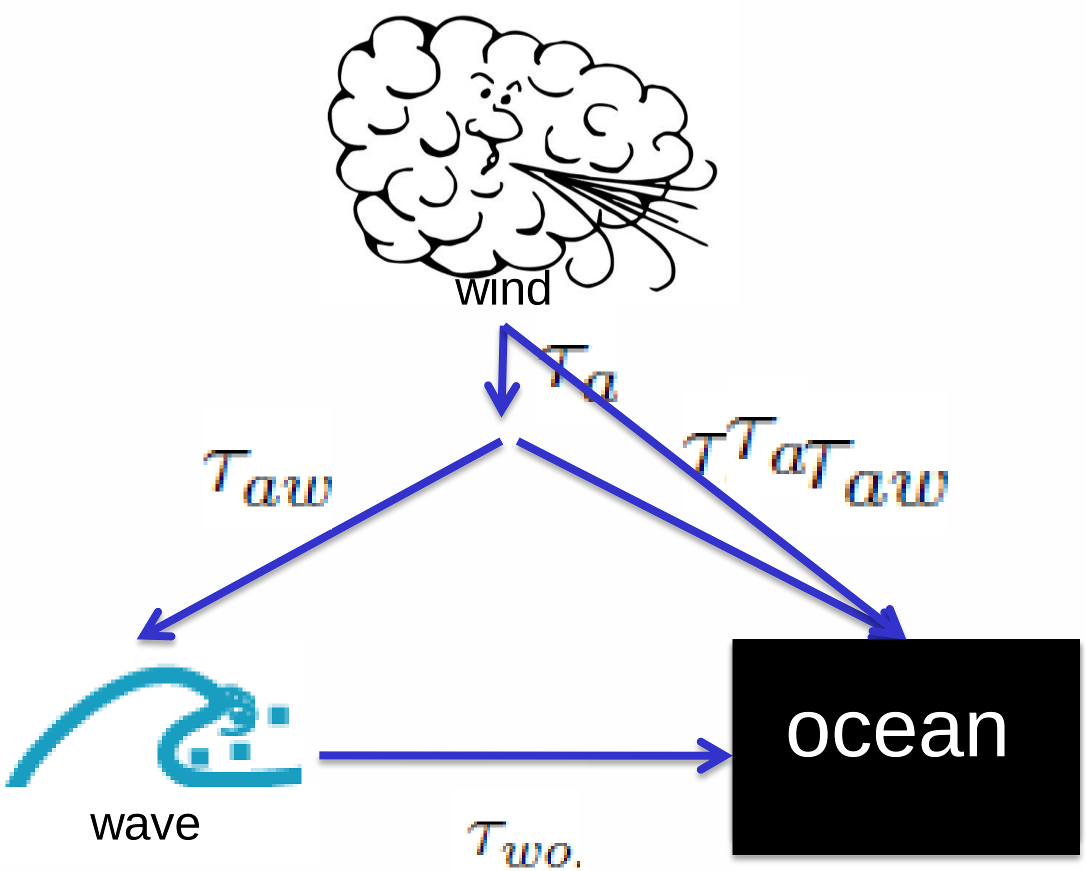
1. **Vortex force:** $([\frac{\partial \hat{v}}{\partial x} - \frac{\partial \hat{u}}{\partial y}]V_s - W_s\frac{\partial \hat{u}}{\partial z}, [\frac{\partial \hat{v}}{\partial x} - \frac{\partial \hat{u}}{\partial y}]U_s - W_s\frac{\partial}{\partial}$
2. **Stokes-Coriolis force:** $(fV_s, -fU_s)$
3. **Wave–induced pressure gradient force** $(-\frac{\partial J}{\partial x}, -\frac{\partial J}{\partial y})$
4. **Wave dissipation force:**

$$(F_{d,x},F_{d,y}) = (F_{d,def,x} + F_{d,fond,x} + F_{d,turb,x}, F_{d,def,y} + F_{d,fond,y} + F_{d,turb,y})$$

5. **Mixing force :** $(F_{m,x},F_{m,y})$

Boundary conditions

$$(F_{d,x},F_{d,y}) = (F_{d,def,x}+F_{d,fond,x}+F_{d,turb,x},F_{d,def,y}+F_{d,fond,y}+F_{d,turb,y})$$



$= \tau_{wo,surf} + \tau_{wo,fond}$

- At the surface :

Momentum flux from wave to current

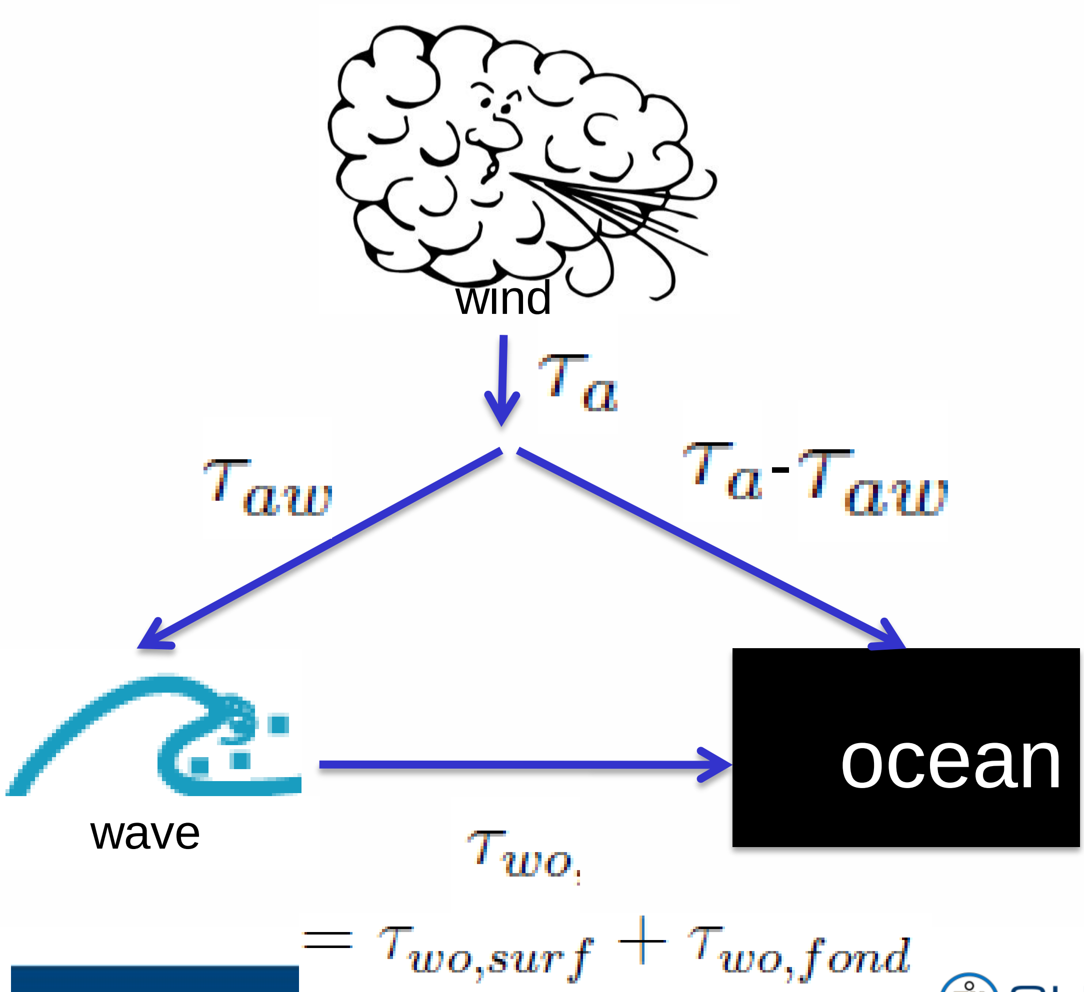
$$\begin{cases} K_z \dfrac{\partial \hat{u}}{\partial z}|_{z=\hat{\eta}} = \boxed{\tau_{a,x}} - \boxed{\tau_{aw,x}} + \boxed{\tau_{wo,surf,x}} \\ K_z \dfrac{\partial \hat{v}}{\partial z}|_{z=\hat{\eta}} = \boxed{\tau_{a,y}} - \boxed{\tau_{aw,y}} + \boxed{\tau_{wo,surf,y}} \end{cases}$$

Momentum flux from atmosphere to current

Momentum flux from atmosphere to wave

Boundary conditions

$$(F_{d,x}, F_{d,y}) = (F_{d,def,x} + F_{d,fond,x} + F_{d,turb,x}, F_{d,def,y} + F_{d,fond,y} + F_{d,turb,y})$$



- Near the bottom

$$\begin{cases} K_z \dfrac{\partial \hat{u}}{\partial z}\Big|_{z=-h} = \rho C_D \Delta_u \sqrt{\Delta_u^2 + \Delta_v^2} \\ K_z \dfrac{\partial \hat{v}}{\partial z}\Big|_{z=-h} = \rho C_D \Delta_v \sqrt{\Delta_u^2 + \Delta_v^2} \end{cases}$$

With $\Delta_u = \hat{u}(z^1) - 1.5U_s$

Longuet-Higgins (1953), Bennis et al. (2011)

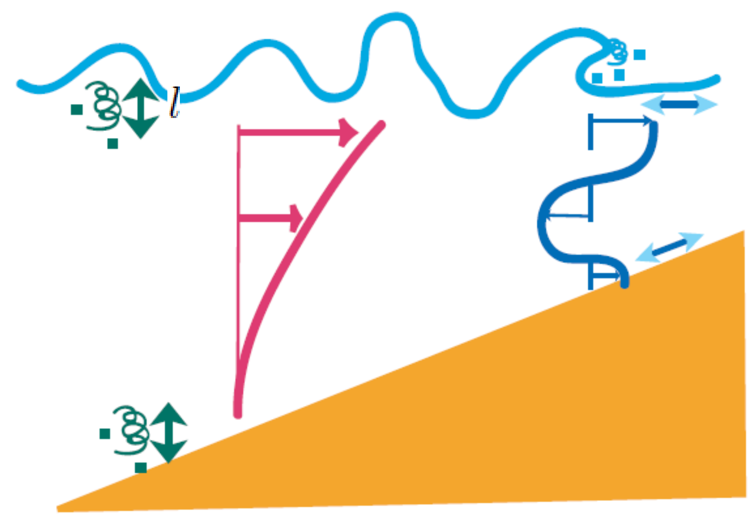
Wave effects on mixing

- At the surface : $K_z \frac{\partial E_k}{\partial z} = \phi_{oc}$

with : $\begin{cases} \phi_{oc} = \alpha {u\star}^3 \\ l = \kappa z_{surf} \\ z_{surf} = 1.6 H_{sw} \end{cases}$

Craig et Banner (1994)

Terray et al. (1996), Rascle et al. (2008)



- Near the bottom :

$$\vec{\tau_{bot}} = \boxed{\vec{\tau_c}}\left[1 + 1.2\left(\frac{\boxed{|\tau_w|}}{|\tau_w| + |\vec{\tau_c}|}\right)^{3.2}\right]$$

Bottom stress linked to current

Bottom stress linked to wave

Soulsby (1995)

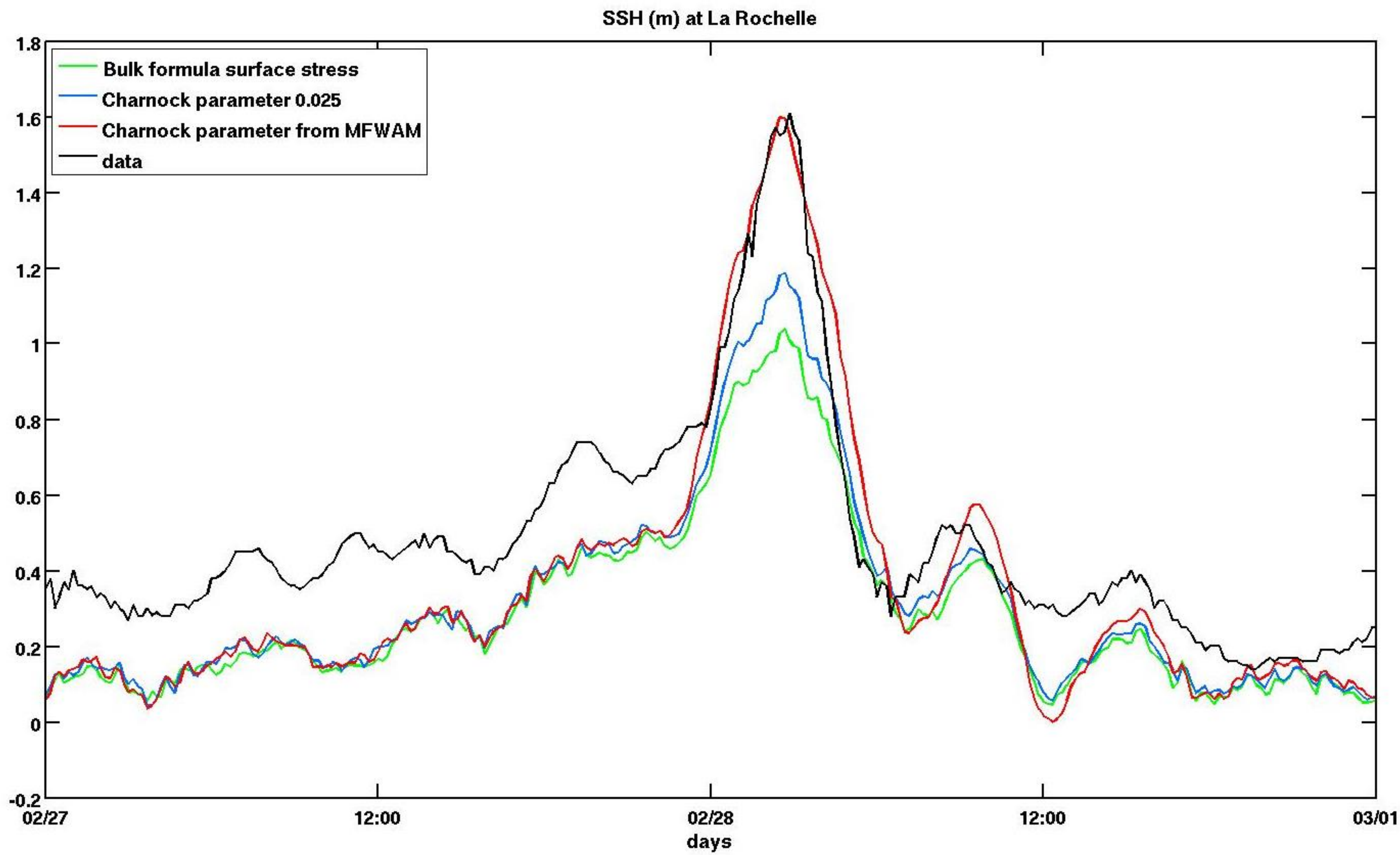
Wave effect on surface stress

Surface stress computed by a bulk formula: $\vec{\tau}_s = \rho_a \cdot C_d \cdot \vec{U}_{10}^{\,2}$

3 possibilities for Cd :

- a drag coefficient constant computed by Pond and Pickard (1998)
- A drag coefficient dependent on the wave age that we consider constant in space and time : $\alpha = 0{,}025$
- A drag coefficient dependent on the wave age calculated by the wave model

Wave effect on surface stress



SHOM L'océan à la carte

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