Modelling storm surges with HYCOM

An improvement of the French warning system

A. Pasquet[1] H. Michaud[1] R. Baraille[1] D. Jourdan[1] L. Biscara[1] S. Casitas[1]
D. Paradis[2] P. Ohl[2] A. Dalphinet[2]

1. SHOM
2.Météo-France

Workshop on Waves, Storm Surges and Coastal Hazards 2017

OUTLINE

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DEVELOPMENTS TO IMPROVE STORM SURGE FORECASTING

TOWARDS HIGH RESOLUTION AND COUPLED LEVEL/WAVES MODELLING

NUMERICAL SCHEME AND BOTTOM FRICTION OPTIMIZATION

1. HOMONIM PROJECT

HISTORY, OBSERVATION AND MODELLING OF SEA LEVELS

OBSERVER - ANALYSER - PRÉVOIR

OBJECTIVES

IMPROVING THE FRENCH WAVES AND SURGE WARNING SYSTEM

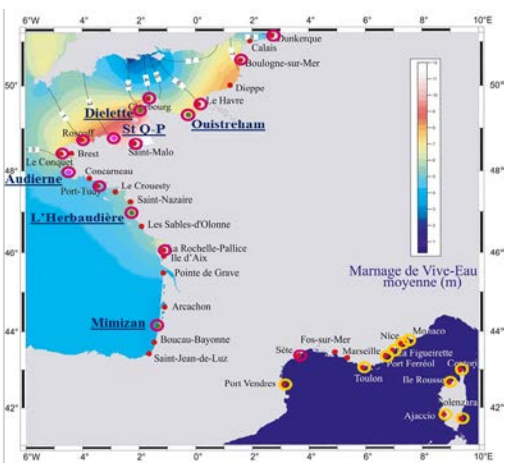
The HOMONIM project is part of the governmental action plan for flooding risks assessment and management.

Objectives — **To better anticipate flooding from the sea**

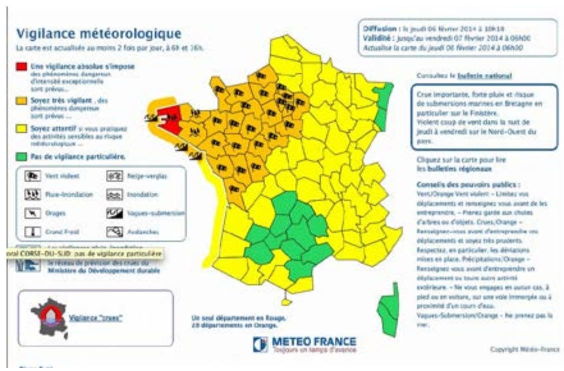
Expected benefits — **To improve warning systems on French metropolitan and overseas coasts**

A reference database

- **To extend tide gauges network**
- **To produce fit-for-purpose digital elevation models**



Densification of SHOM tide gauges network



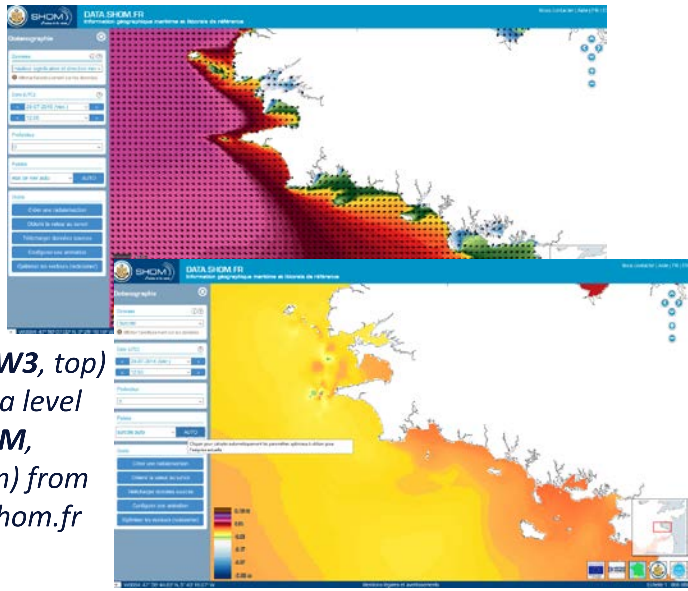
Warning system alert Published by Météo France, 06.02.2014

Available and up-to-date Information

- **To supply Météo France surges and waves warning system**
- **To give open access to forecasts for general public**

Enhanced operational forecasting abilities

- **To develop surges and waves forecasting models**



*Hs (**WW3**, top) and sea level (**HYCOM**, bottom) from data.shom.fr*

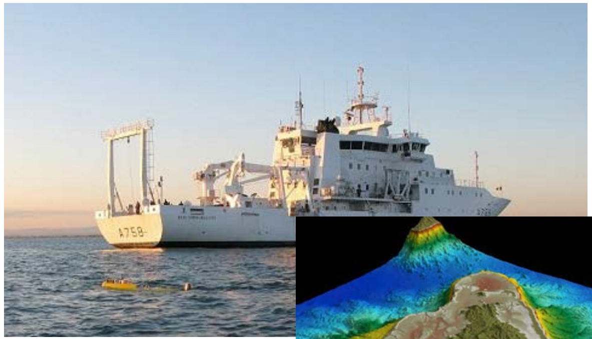
A COLLABORATIVE EFFORT

EXPERTISE AND MISSIONS OF SHOM AND METEO FRANCE

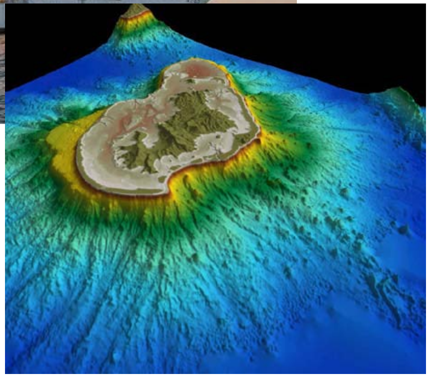
SHOM

Marine and coastal geographic reference data

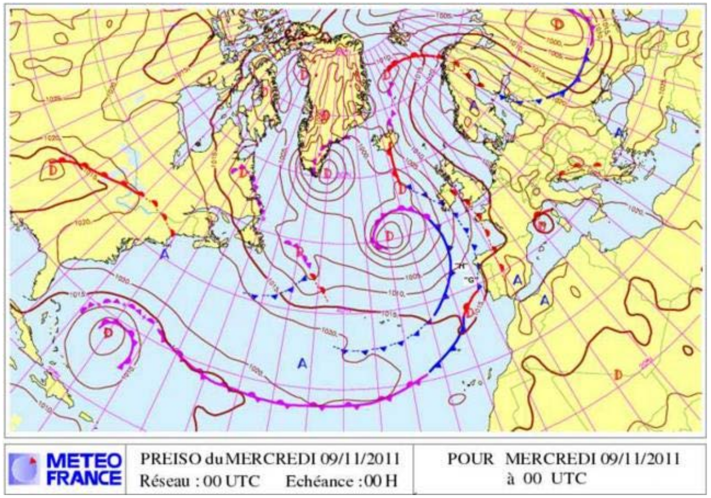
- **Hydrography and safety navigation (DTM, Tide predictions, …)**
- **Sea level and currents monitoring (*REFMAR, RONIM*)**
- **Operational Ocean modelling**
- **Defense and Civil operational support**



Beautemps-Beaupré



Regional DEM of Mayotte Island



METEO FRANCE

Meteorology and climate

- **Atmosphere and sea state observation**
- **Meteorological and air-sea interface modelling**
- **Weather, waves and storm surge Warning system operation**
- **Data diffusion**

STORM SURGE AND SEA STATE FORECASTING ON FRENCH COASTS

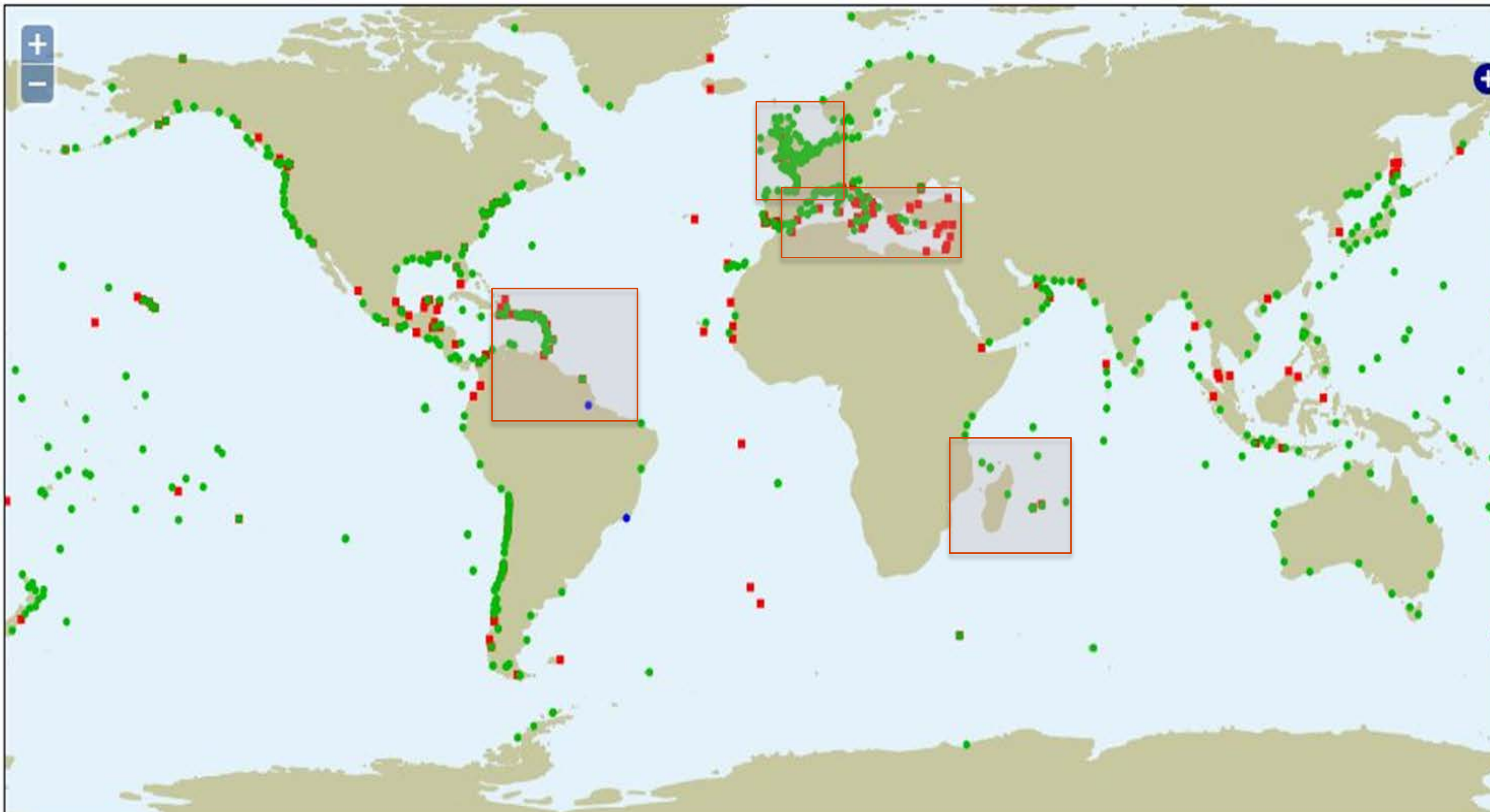
METROPOLITAN AND OVERSEAS CONFIGURATIONS OF HOMONIM I & II PHASES

IOC

Sealevel stations

Status at 2017-09-07 07:36 GMT

- Station is offline, or data is outdated
- Station is online
- Station is not available at this site

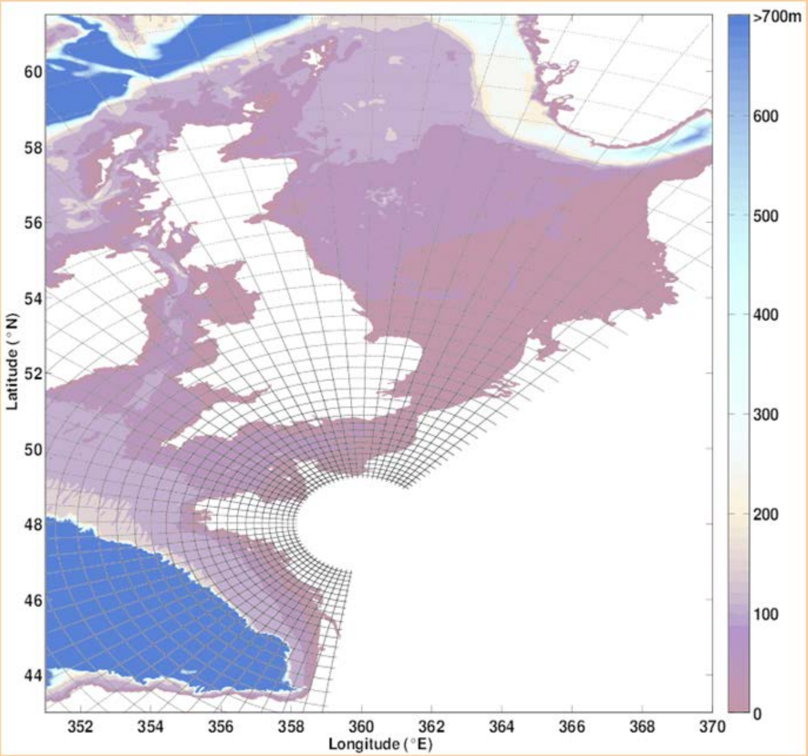


2. STORM SURGE MODELLING WITH HYCOM

MODEL AND PERFORMANCE ON METROPOLITAN COASTS

DESCRIPTION AND PERFORMANCE OF HYCOM

METROPOLITAN CONFIGURATIONS



Indicateur statistique	ATL	MED
RMSE high tides (cm)	15	N/A
Phase shift on high tides (min)	16	N/A
RMSE on storm surge (cm)	8	8
Mean Error on storm event extrema (cm)	-9	-9

Performance of HYCOM

ATLantic Ocean and MEDiterraneen Sea facades

- Operated since January 2014, yearly updates
- Barotropic version of HYCOM
- Curvilinear bipolar grids
- DTM specifically updated, 500m to 100m resolution
- Evaluation of tides and surge level modelling on 1 year long simulation and storm events, using reanalyzed atmospheric forcing

Specifications of ATL configuration

- 0,4 to 1 km resolution
- Active Wetting & Drying
- Tidal forcing NEA 2011 (17 components , LEGOS)
- Force WW3 with sea levels and currents
- Geographically variable bottom friction

HOW TO IMPROVE STORM SURGE MODELLING ?

LIMITATIONS OF THE MODEL

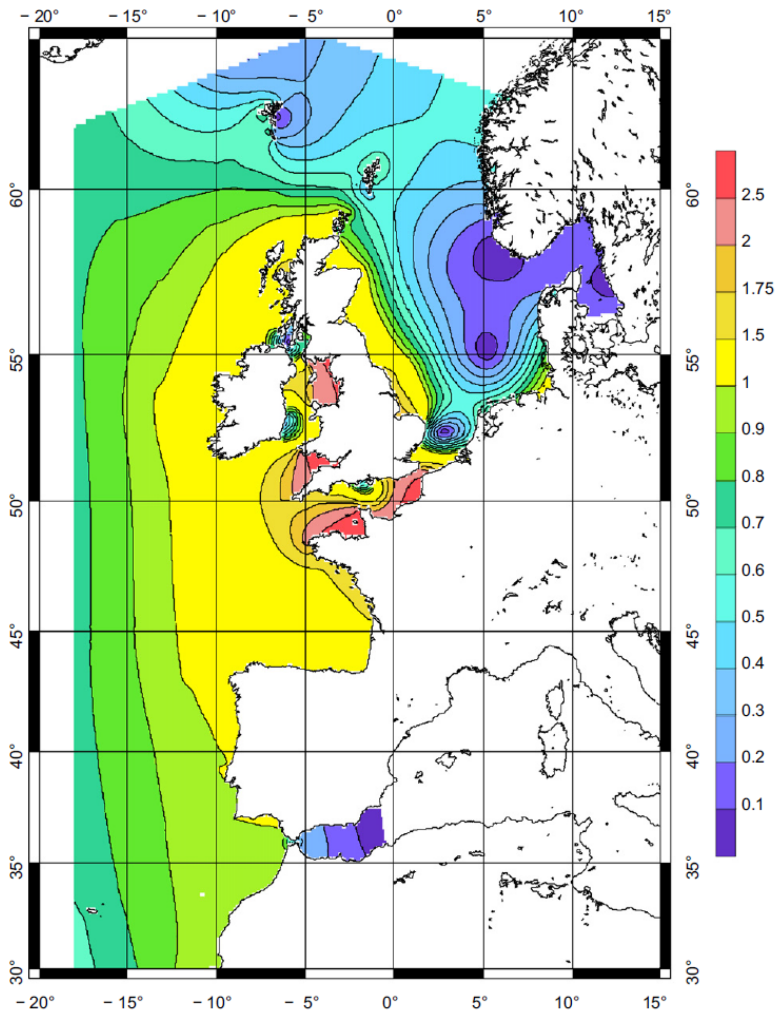


Fig. 2. Amplitude of the M_2 tide computed from T-UGOm 2D. Units in meters.

Dynamics of the semi-diurnal and quarter-diurnal internal tides in the Bay ofBiscay. Part 1: Barotropic tides. I.L. Pairaud,, F. Lyard, F. Auclair, T. Letellier, P. Marsaleix. Continental Shelf Research 28 (2008) 1294– 1315

External / induced by the formalism

- Barotropic formalism
- Limited number of spectral components (17 from NEA 2011)
- Atmospheric forcing quality (model, real time)
- Bathymetry
- Oscillation of observed storm surge

Inherent to configuration and physical parameterization

- On tides
  - ***Bottom friction***
  - *Boundary tidal forcing quality*
  - *Resolution and domain extension*
- On storm surge
  - *Wind stress parameterization*
  - ***Resolution***
  - ***Wave set-up***

3. ONGOING AND FUTURE WORK

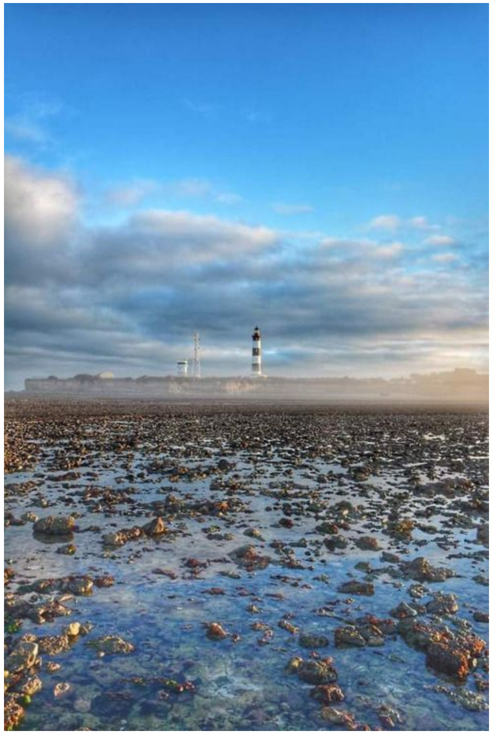
DEVELOPMENTS TO IMPROVE STORM SURGE FORECASTING

1. TOWARDS HIGH RESOLUTION AND COUPLED CURRENTS/LEVEL/WAVES MODELING

TOWARDS HIGH RESOLUTION AND COUPLED LEVEL/WAVES MODELLING

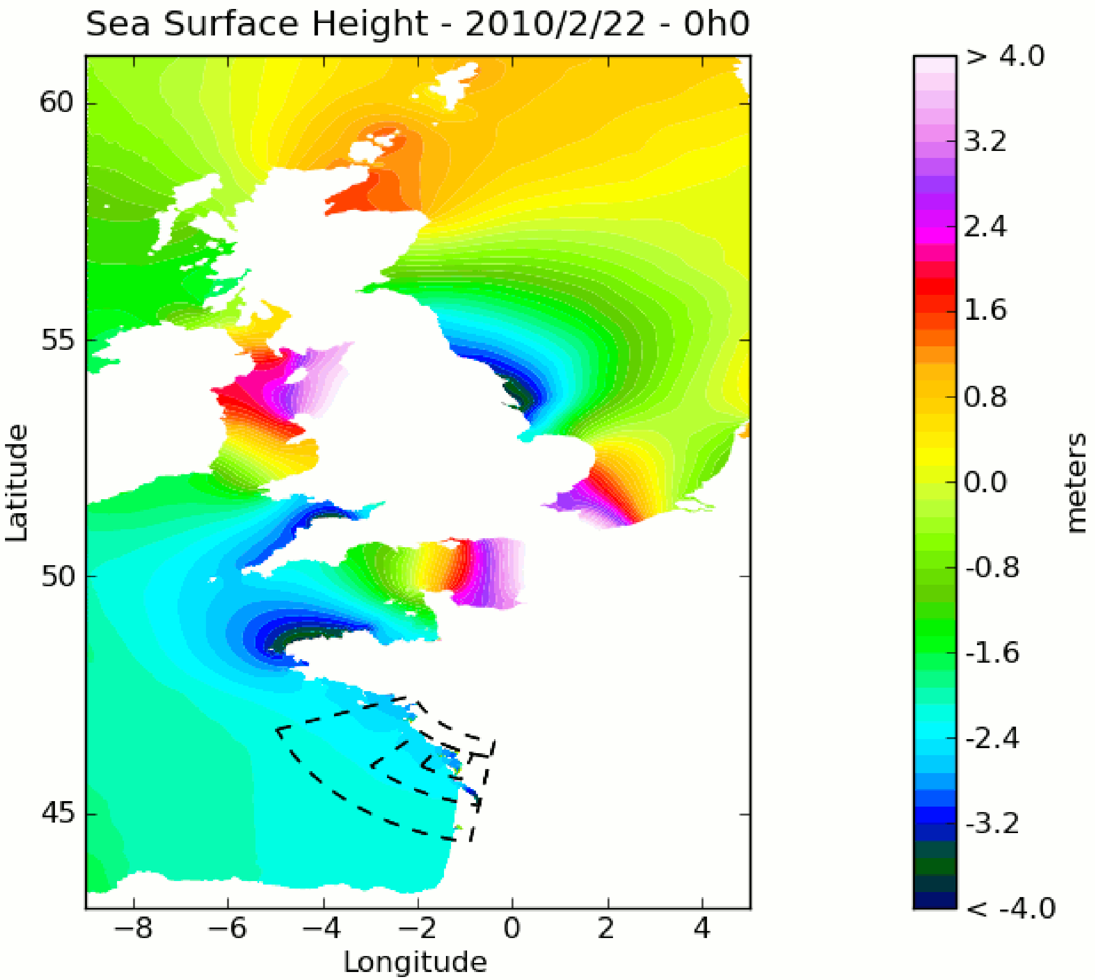
THE PERTUIS-CHARENTE CASE - EMBEDDED CONFIGURATIONS IN HYCOM

- Resolution up to 30m on the **Pertuis Charente** area
    - *Intertidal areas*
    - *Molluscs growing and tourism*
- Coupler **OASIS MCT 3.0** *



Source:http://grandboute.tumblr.com

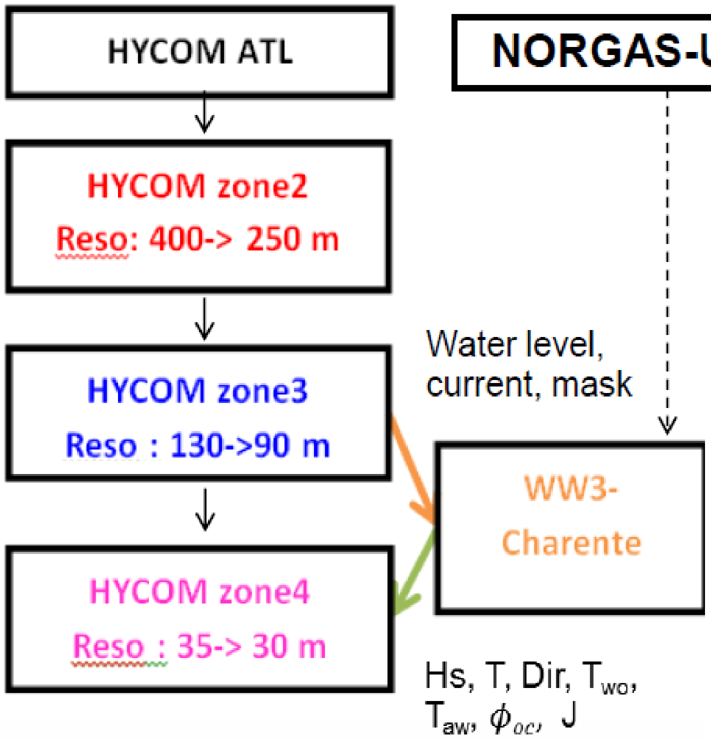
Light on the foreshore and the lighthouse of Chassiron, Oléron Island

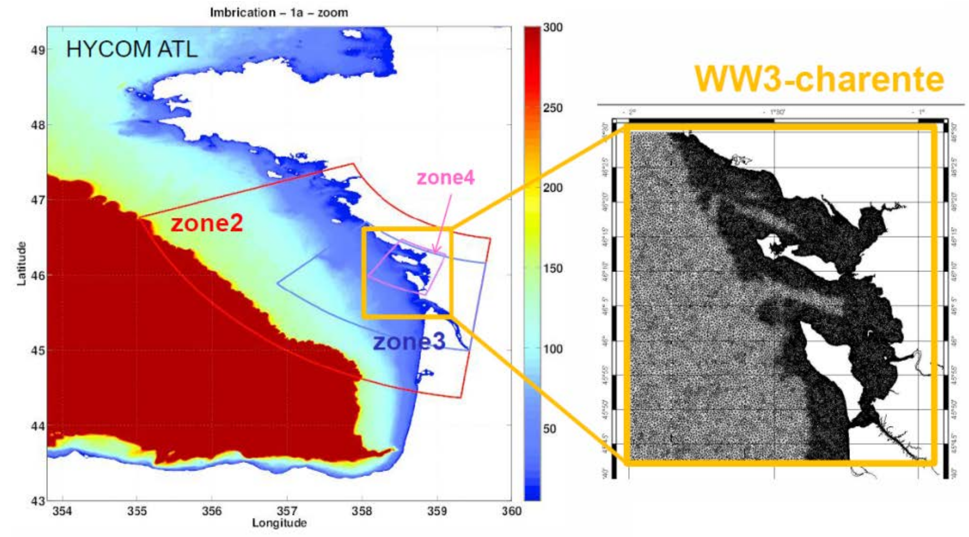


* Craig A., Valcke S., Coquart L., 2017, *Development and performance of a new version of the OASIS coupler, OASIS3-MCT_3.0*, Geosci. Model Dev., https://doi.org/10.5194/gmd-2017-64

TOWARDS HIGH RESOLUTION AND COUPLED LEVEL/WAVES MODELLING

THE PERTUIS-CHARENTE CASE - COUPLING METHOD WW3/HYCOM





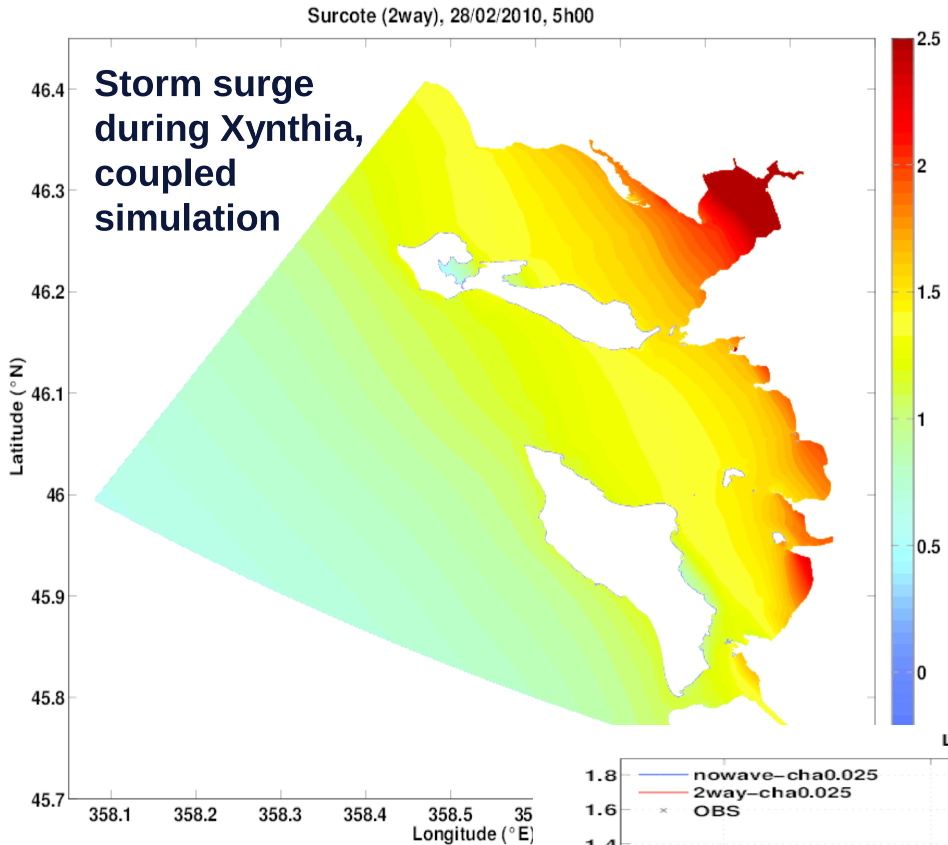
Model	HYCOM	WW3
Grids type Parent[1] Child 1 Child2 Child3	Curvilinear ATL (995x718 nodes) Zone2(841x696 nodes) Zone3 (1495x1050 nodes) Zone4(1913x1892 nodes)	Unstructured NORGAS-UG (92,757 nodes) Charente WW3 (50,357 nodes)
Bathymetry	NMB 500m, 100m, 20m (Biscara et al., 2015)	
Model	SHOM version (Baraille and Filatoff, 1995) barotropic formalism wetting & drying	WW3 (Tolman, 2014)
Physical parametrizations	Bottom friction calculated by a stochastical approach (Boutet et al. , 2015) Wind stress following Charnock formulation (Charnock, 1955)	TEST 451 (see Ardhuin et al. 2010) Implicit N scheme (Roland, 2009) Bottom friction parameterization (Ardhuin et al., 2003a) with a realistic map of D50. A constant Nikuradse roughness length of respectively 12 cm is applied for rocks

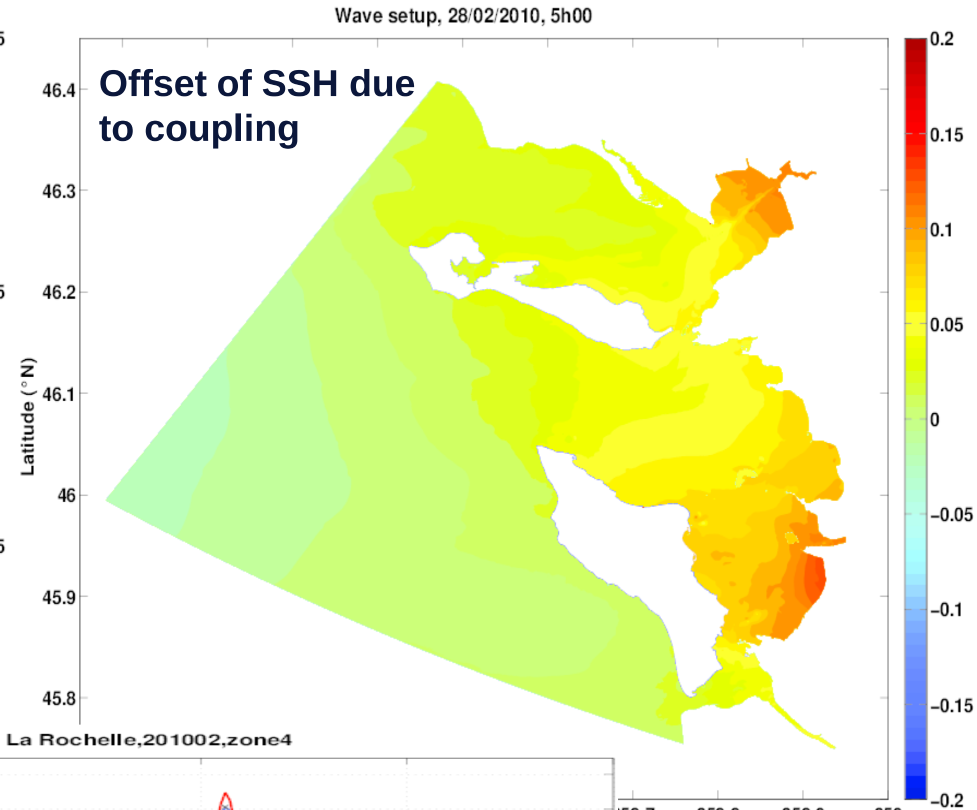
Table 1: Models and configurations

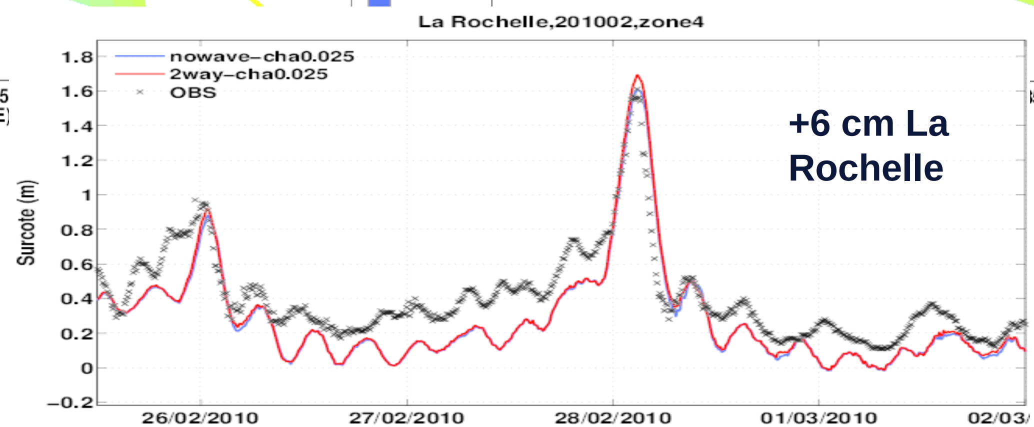
[1] Similar to grids of the operational system
See Pasquet et al. 2014, Michaud et al . 2015

TOWARDS HIGH RESOLUTION AND COUPLED LEVEL/WAVES MODELLING

THE PERTUIS-CHARENTE CASE - COUPLING METHOD WW3/HYCOM







3. ONGOING AND FUTURE WORK

DEVELOPMENTS TO IMPROVE STORM SURGE FORECASTING

2. NUMERICAL SCHEME AND BOTTOM FRICTION OPTIMIZATION

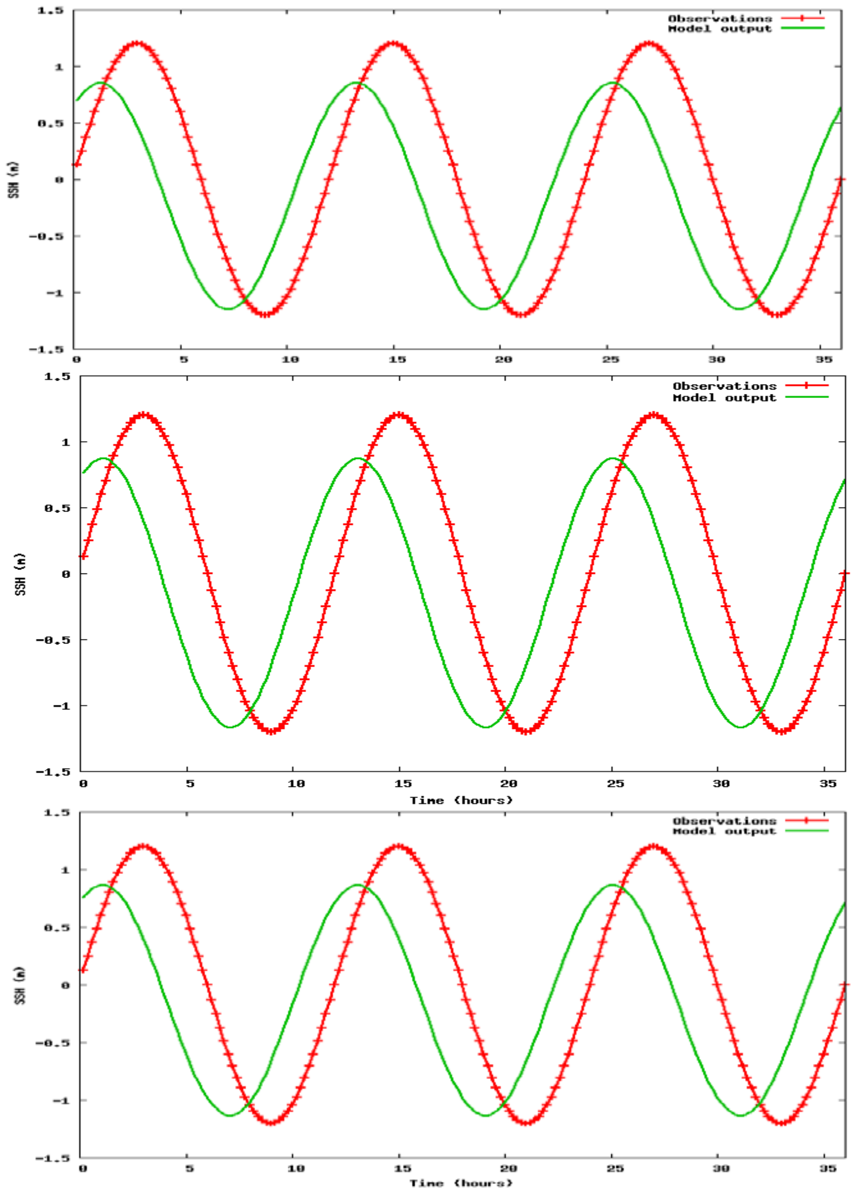
DEVELOPMENTS TO IMPROVE STORM SURGE FORECASTING

STOCHASTIC APPROACH FOR BOTTOM FRICTION OPTIMIZATION

Methodology to improve tidal model performance for each new configuration/model update

Key criteria of the method ?

- **Physical parameter to optimize**
  - Bottom roughness
- **Choice and availability of observation data**
  - Tide gauges obs or prediction, HF radars
- **Cost function choice (error to minimize)**
  - Physical error:
    - Phase error
    - Amplitude error
    - Bias error
  - Example of cost function : statistical indicator
    - RMSE on low and high tides extrema
- **Minimization method**
  - Stochastic methods*, iterative process



* Spall J.C. (2000), *Adaptive Stochastic Approximation by the Simultaneous Perturbation Method*, IEEE Transactions on Automatic Control, vol.45, pp.1839-1853

Boutet M., Lathuilière C., Hoang H.S., Baraille R. (2014), *Estimation of friction parameters in a barotropic tide model using stochastic methods*, Tellus A

SHOM

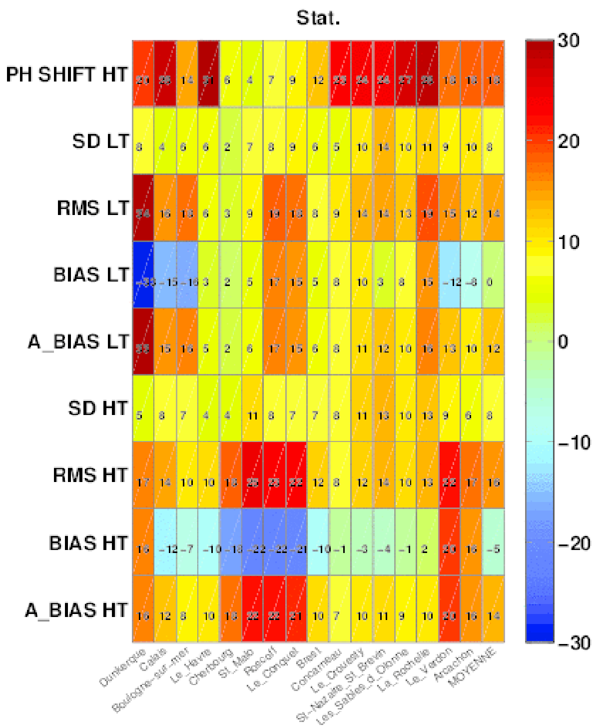
Improvement of tides modelling using :

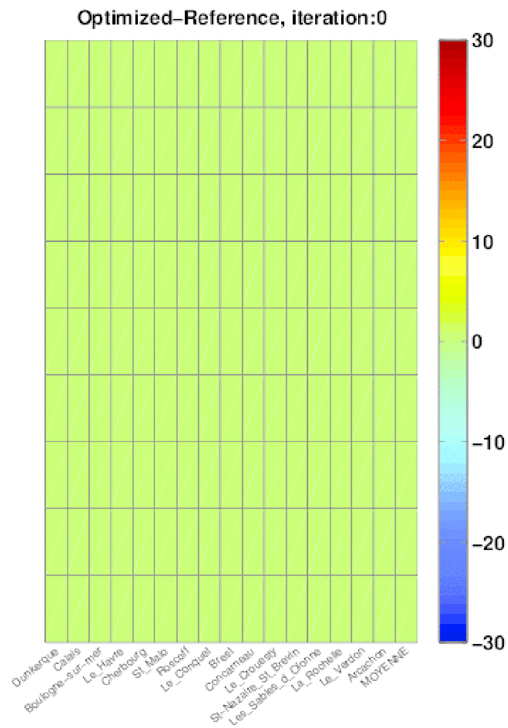
- **Stochastic approach for bottom friction optimization**
- **New numerical scheme**

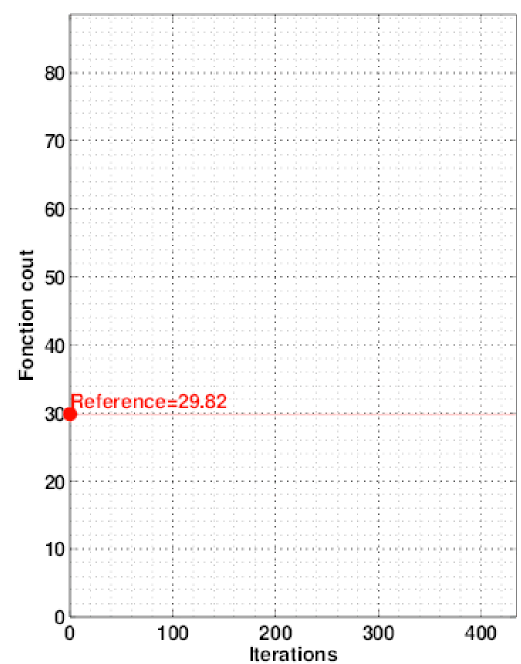
$$
\begin{cases}
\dfrac{\partial}{\partial t} h + \dfrac{\partial (h\tilde{u})}{\partial x} = 0 \\
\dfrac{\partial (hu)}{\partial t} + u\dfrac{\partial (uh\tilde{u})}{\partial x} + g\dfrac{\partial h}{\partial x} = 0 \\
\tilde{u} = u - \gamma \dfrac{\partial h}{\partial x}
\end{cases}
\quad \Rightarrow \quad
\frac{\partial E_T}{\partial t} + \frac{\partial}{\partial x}\left(\left(E_c + 2E_p\right)\tilde{u}\right) \leq 0
$$

Experiment on :

- **LT : Low tides**
- **HT: High tides**
- **One month simulation**
- **Cost function to optimize :**
  - **RMSE LT + RMSE HT**
- **Collocation points : from 2x2 to 20x20**







DEVELOPMENTS TO IMPROVE STORM SURGE FORECASTING

ONGOING EXPERIMENTS : BOTTOM STRESS OPTIMIZATION AND NEW NUMERICAL SCHEME

Improvement of tides modelling using :

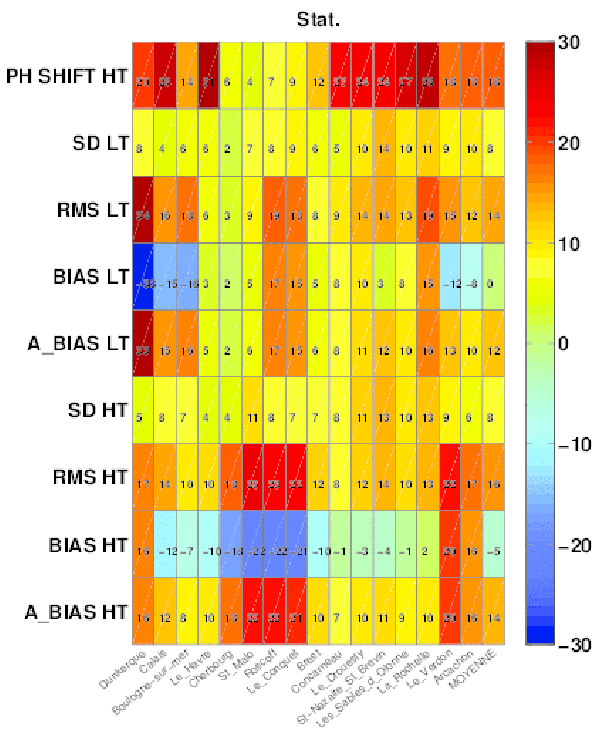
- **Stochastic approach for bottom friction optimization**
- **New numerical scheme**

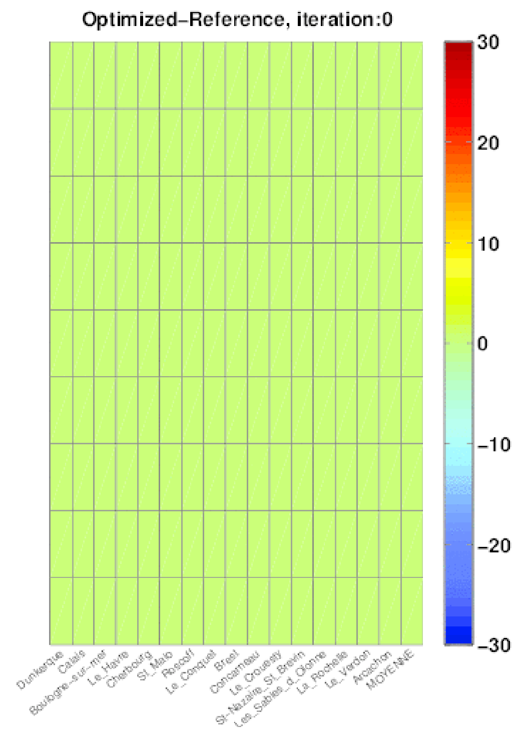
$$\begin{cases} \dfrac{\partial}{\partial t}h + \dfrac{\partial(h\tilde{u})}{\partial x} = 0 \\ \dfrac{\partial(hu)}{\partial t} + u\dfrac{\partial(uh\tilde{u})}{\partial x} + g\dfrac{\partial h}{\partial x} = 0 \\ \tilde{u} = u - \gamma\dfrac{\partial h}{\partial x} \end{cases}$$

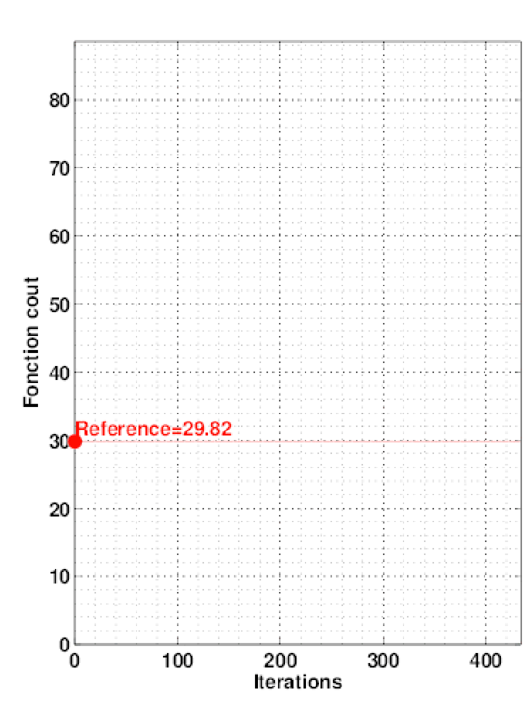
$$\Rightarrow \quad \frac{\partial E_T}{\partial t} + \frac{\partial}{\partial x}\left(\left(E_c + 2E_p\right)\tilde{u}\right) \leq 0$$

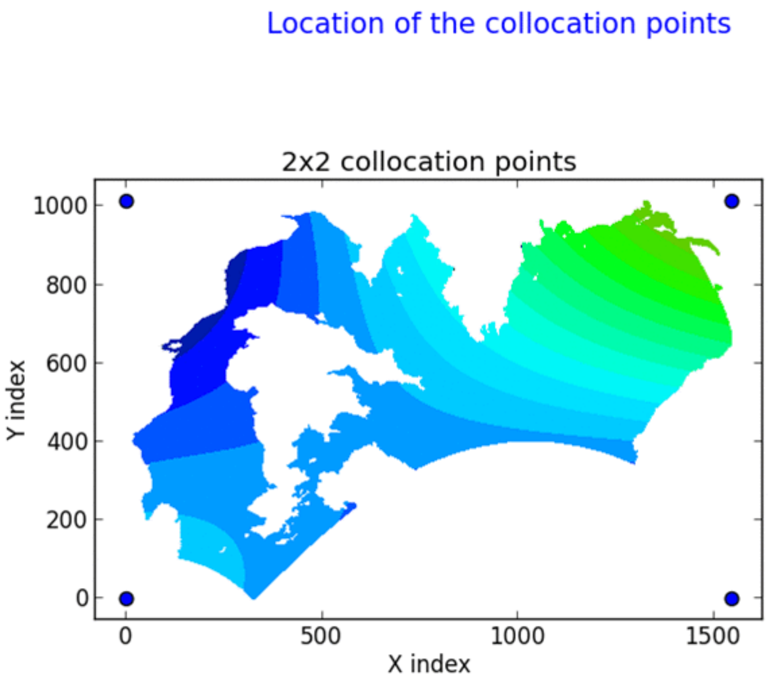
Experiment on :

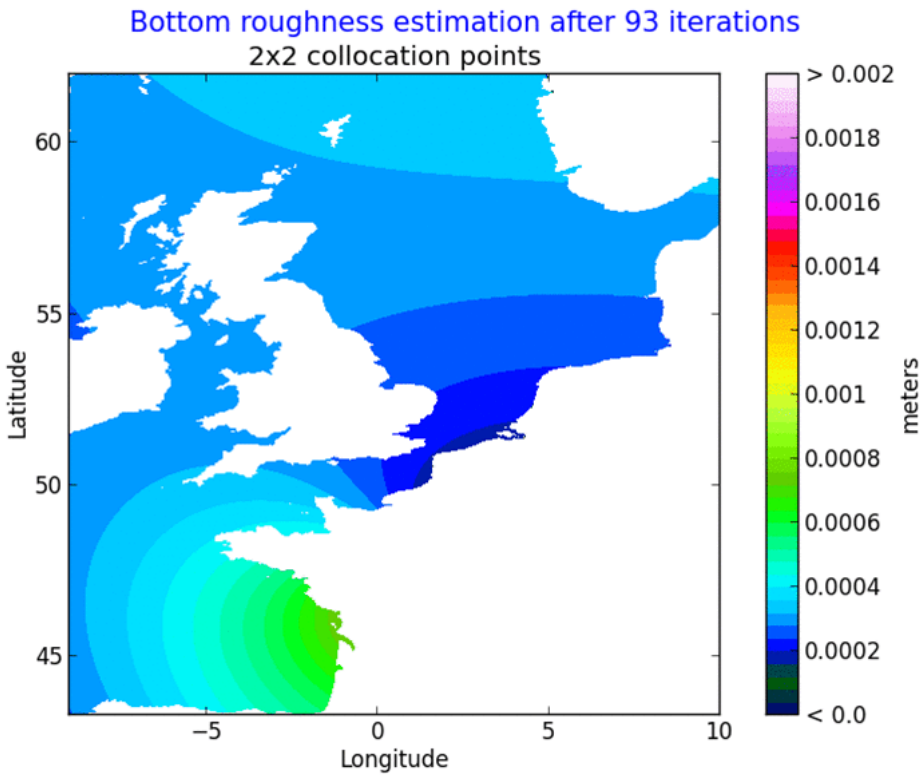
- **LT : Low tides**
- **HT: High tides**
- **One month simulation**
- **Cost function to optimize :**
  - **RMSE LT + RMSE HT**
- **Collocation points : from 2x2 to 20x20**









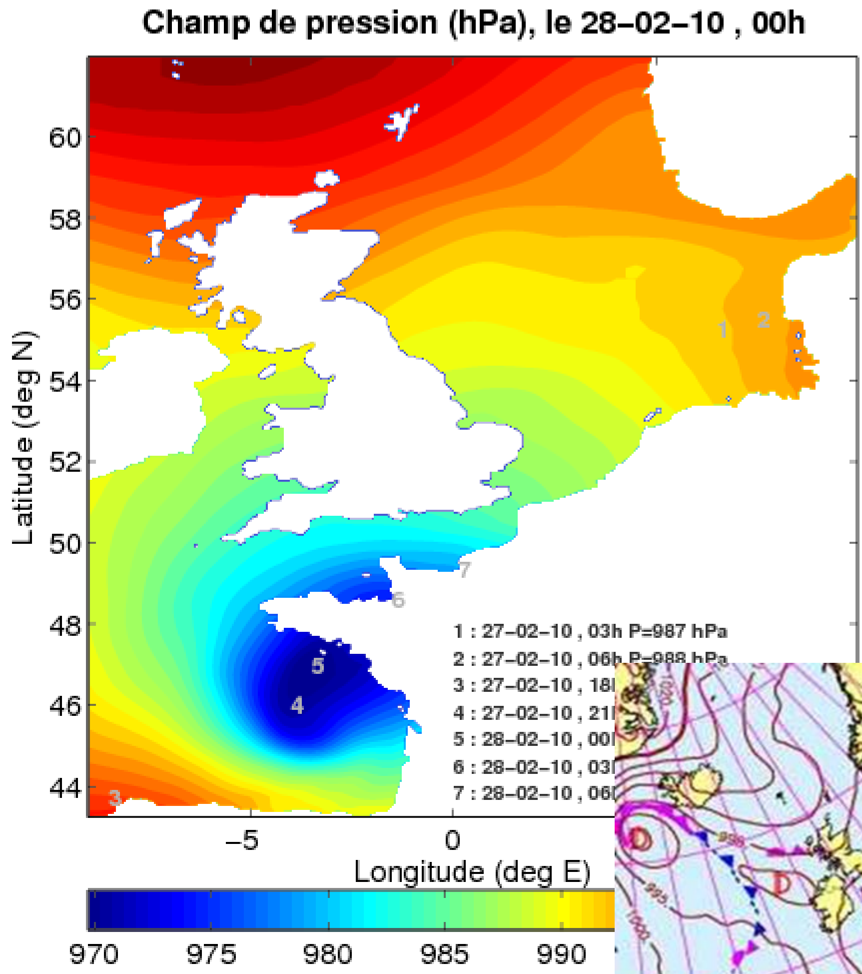


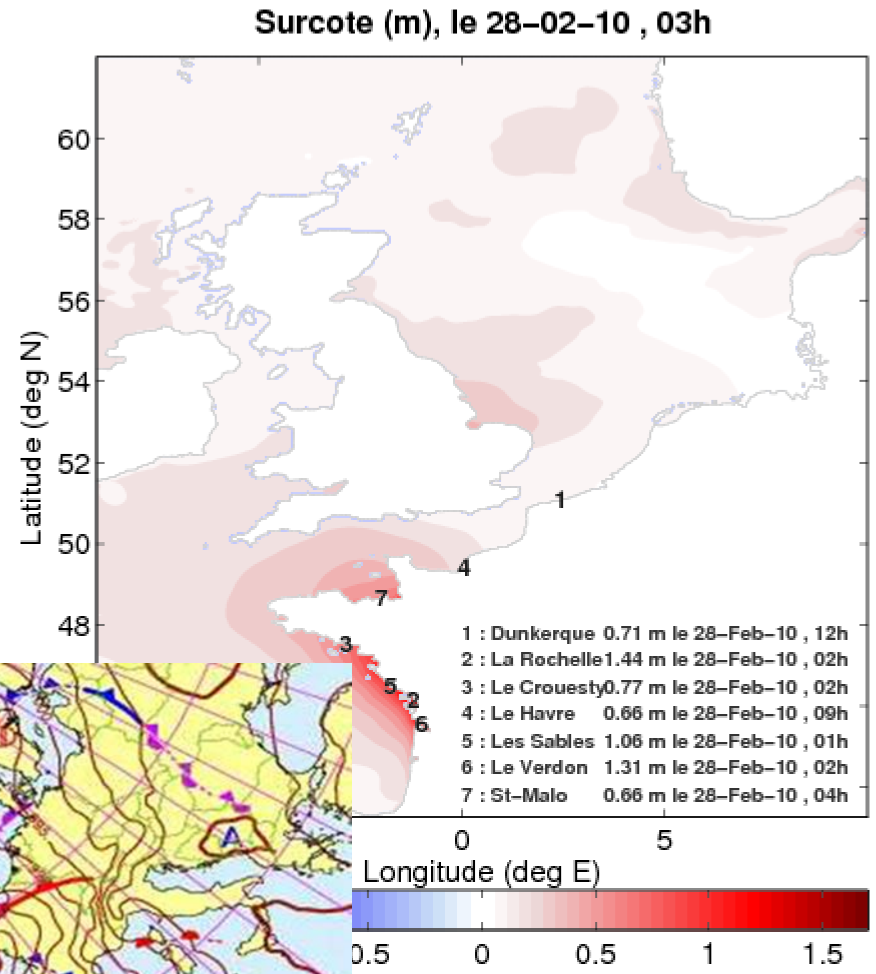
● Point involved in the bottom roughness optimization process

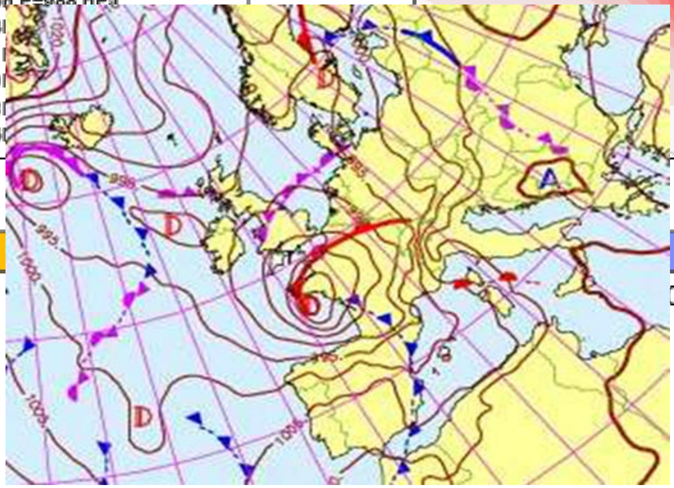
● Constant value of the bottom roughness

THANK YOU FOR YOUR ATTENTION !

- Hycom grid Arakawa C, pressure and velocity shifted
- Numerical scheme: semi-implicit on time, implicit on pressure
- Decreasing of total energy for the numerical scheme demonstrated
- Linear stability
  - 1D linearised around a zero velocity field
  - Linearisation around a constant velocity field
  - Coriolis
- For Euler scheme, gmin = 0.5 Dt
- Higher orders to test (MUSCL, IMEX)

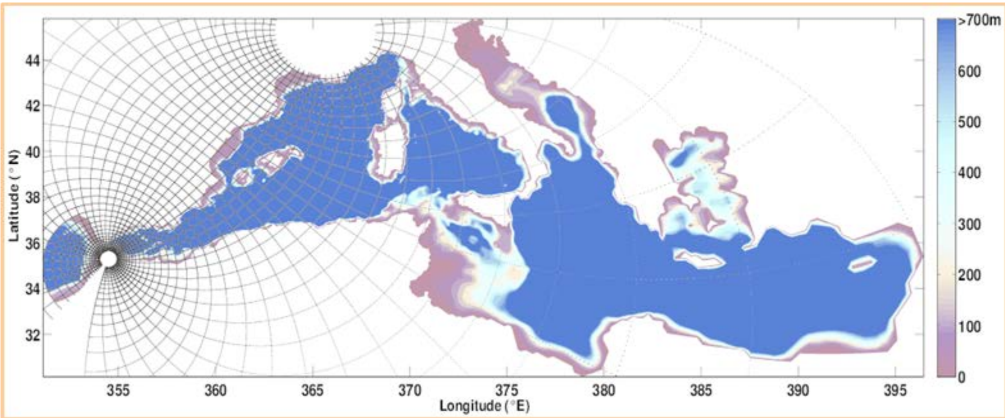

Champ de pression (hPa), le 28-02-10 , 00h
Latitude (deg N)
Longitude (deg E)
1 : 27-02-10 , 03h P=987 hPa
2 : 27-02-10 , 06h P=988 hPa
3 : 27-02-10 , 18h
4 : 27-02-10 , 21h
5 : 28-02-10 , 00h
6 : 28-02-10 , 03h
7 : 28-02-10 , 06h
970
975
980
985
990

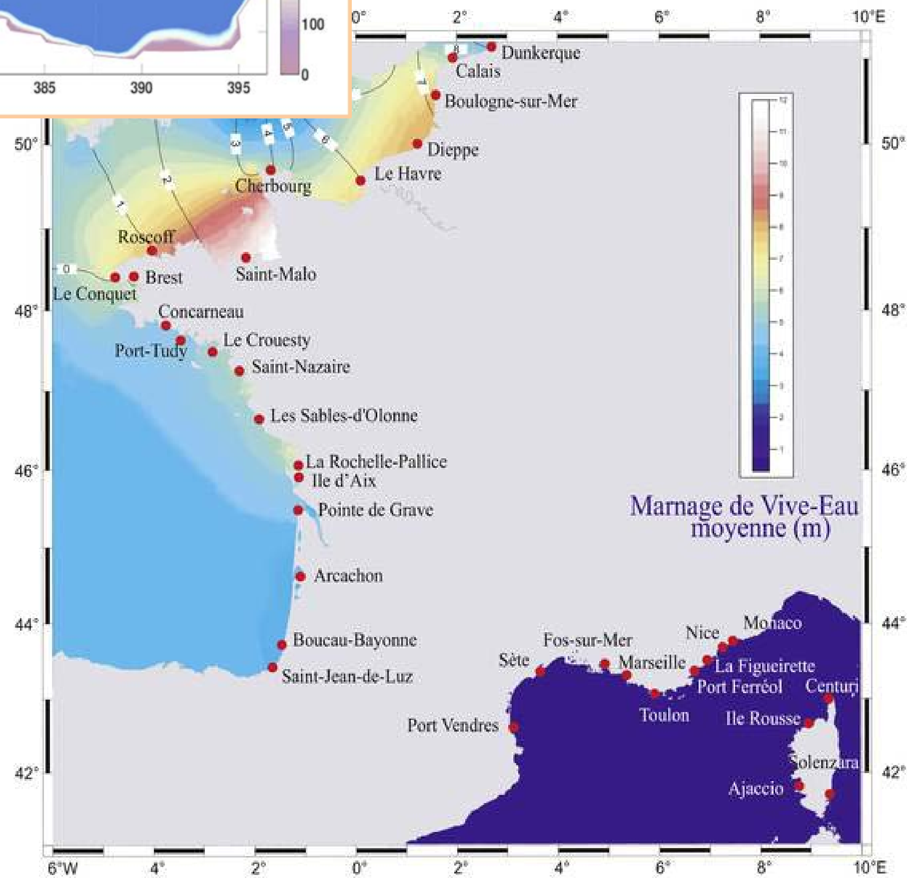

Surcote (m), le 28-02-10 , 03h
Latitude (deg N)
Longitude (deg E)
1 : Dunkerque 0.71 m le 28-Feb-10 , 12h
2 : La Rochelle 1.44 m le 28-Feb-10 , 02h
3 : Le Crouesty 0.77 m le 28-Feb-10 , 02h
4 : Le Havre 0.66 m le 28-Feb-10 , 09h
5 : Les Sables 1.06 m le 28-Feb-10 , 01h
6 : Le Verdon 1.31 m le 28-Feb-10 , 02h
7 : St-Malo 0.66 m le 28-Feb-10 , 04h
0.5
0
0.5
1
1.5



La Faute-sur-Mer after Xynthia storm, February 2010 (website actu.fr

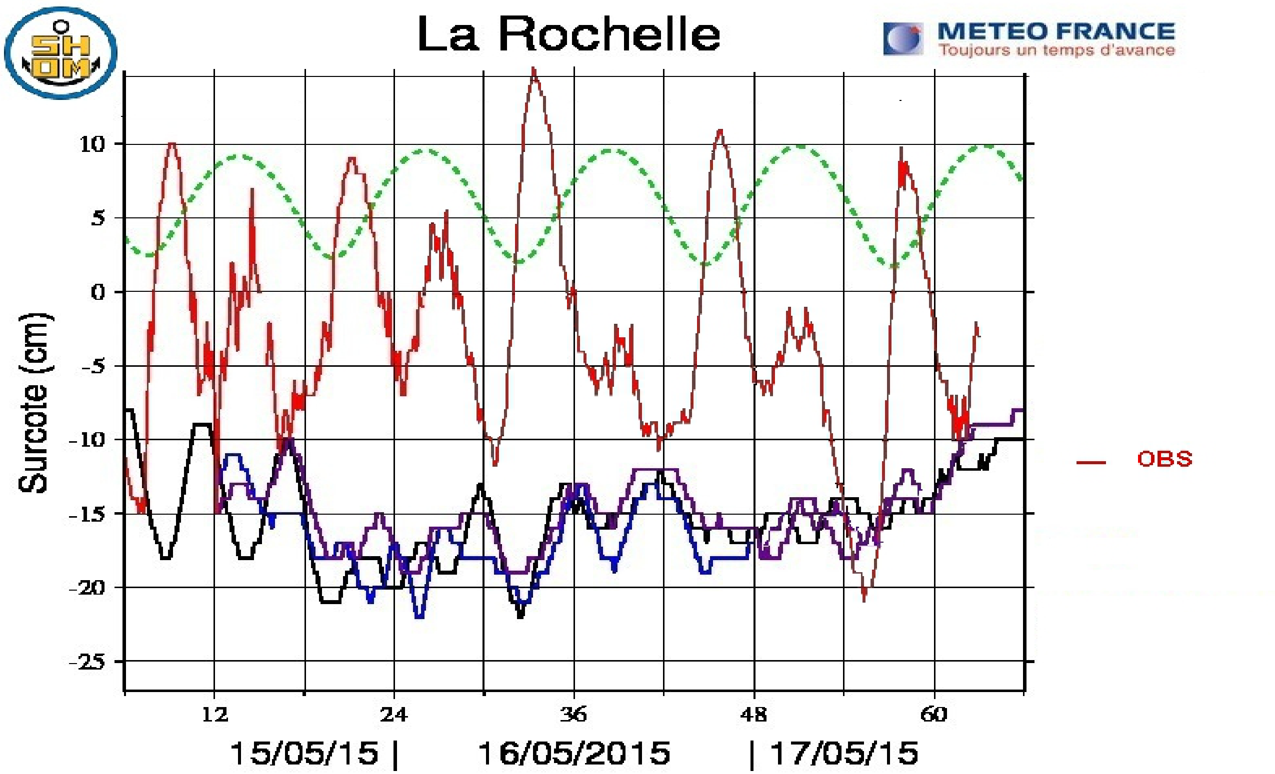
- ❑ Maillage hérité de Hycom grid, décalé vitesse-pression
- ❑ Schéma semi-implicite en temps, implicite sur la pression
- ❑ Démonstration de la décroissance de l'énergie totale pour le schéma numérique
- ❑ Etude de stabilité linéaire
  - 1D linéarisé autour d'un champ de vitesse nul
  - Linéarisation autour d'une vitesse constante quelconque
  - Coriolis
- ❑ Pour un schéma d'Euler, $\gamma_{min} = 0.5\,\Delta t$
- ❑ Montée en ordre (MUSCL, IMEX)


>700m
600
500
400
300
200
100
0
Latitude (°N)
44
42
40
38
36
34
32
355
360
365
370
375
380
385
390
395
Longitude (°E)


Dunkerque
Calais
Boulogne-sur-Mer
Dieppe
Le Havre
Cherbourg
Roscoff
Saint-Malo
Brest
Le Conquet
Concarneau
Le Crouesty
Port-Tudy
Saint-Nazaire
Les Sables-d'Olonne
La Rochelle-Pallice
Ile d'Aix
Pointe de Grave
Arcachon
Boucau-Bayonne
Saint-Jean-de-Luz
Port Vendres
Sète
Fos-sur-Mer
Marseille
Toulon
Nice
Monaco
La Figueirette
Port Ferréol
Centuri
Ile Rousse
Solenzara
Ajaccio
Marnage de Vive-Eau moyenne (m)
6°W
4°
2°
0°
2°
4°
6°
8°
10°E
50°
48°
46°
44°
42°

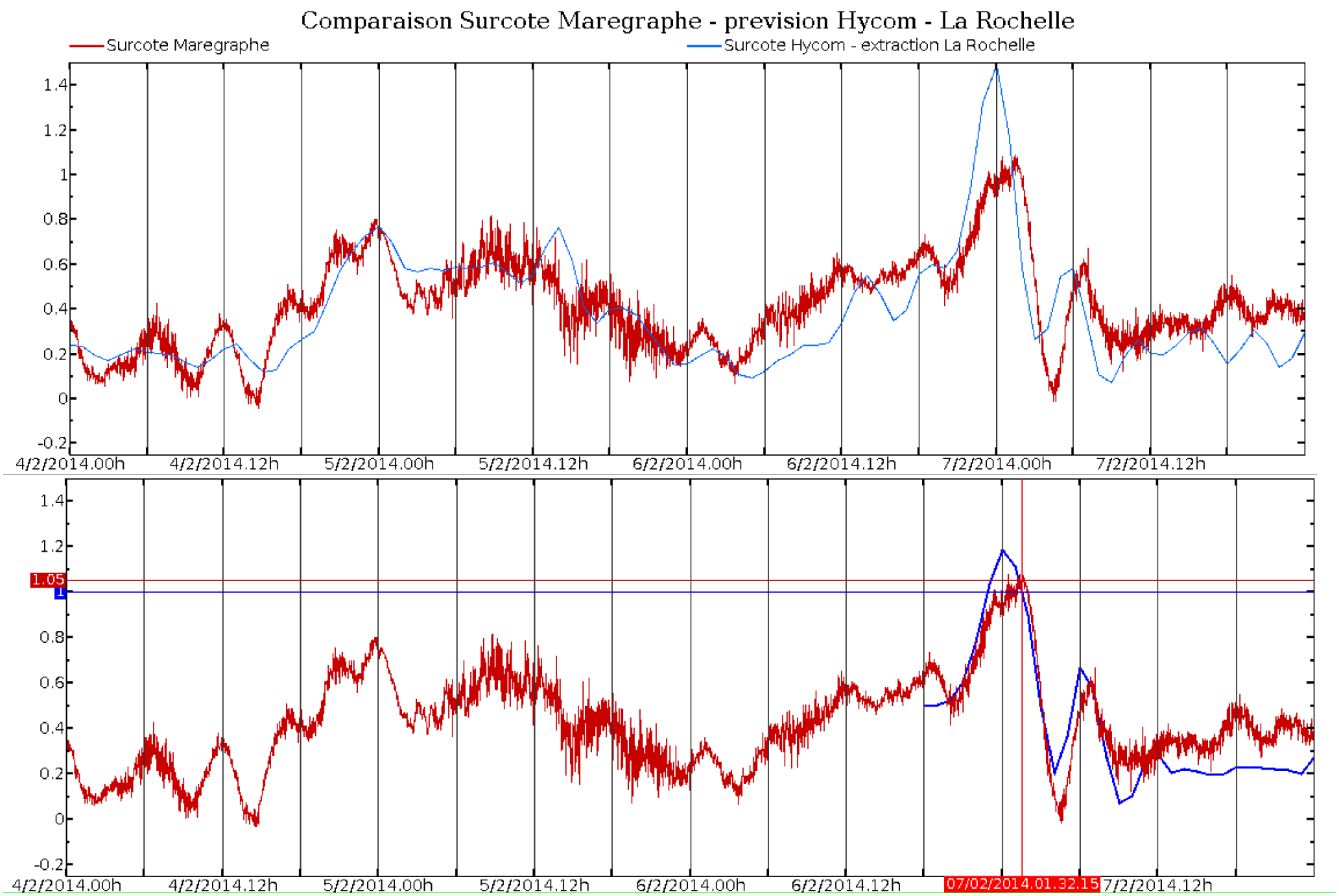
MODÉLISATION DE LA SURCOTE - FAÇADE ATLANTIQUE

EX D'OSCILLATIONS DE LA SURCOTE OBASERVÉE



MODÉLISATION DE LA SURCOTE - FAÇADE ATLANTIQUE

EX D'ERREUR DÛE AU RÉSEAU UTILISÉ



SHOM L'océan en référence

Homonim

MINISTÈRE DE LA TRANSITION ÉCOLOGIQUE ET SOLIDAIRE

MINISTÈRE DE L'INTÉRIEUR

METEO FRANCE

Modelling storm surges with HYCOM

An improvement of the french warning system

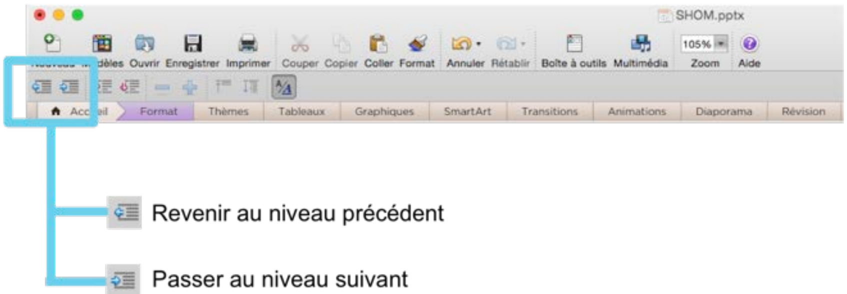
SHOM

A. Pasquet	*Storm surge modelling*
S. Casitas	*Storm surge modelling*
H. Michaud	*Sea state modelling*
R. Baraille	*Modelling expert*
L. Biscara	*DTM production*
A. Fauvaud	*Data diffusion*
D. Jourdan	HOMONIM *Project leader*

Collaborators : Météo France, PreviMar

A. Dalphinet
P. Ohl
D. Paradis

Workshop on Waves, Storm Surges and Coastal Hazards 2017



LOREM IPSUM DOLOR SIT AMET, CONSECTETUR ADIPISCING ELIT.

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  - X Suspendisse lectus tortor, dignissim sit amet, adipiscing nec, ultricies sed, dolor. Cras elementum ultrices diam. Maecenas ligula massa, varius a, semper congue, euismod non, mi. Lorem ipsum dolor sit amet, consectetur adipiscing elit.
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      - _ *Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed non risus. Suspendisse lectus tortor, dignissim sit amet, adipiscing nec, ultricies sed, dolor. Cras elementum ultrices diam.*
        - *Maecenas ligula massa, varius a, semper congue, euismod non, mi. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed non risus. Suspendisse lectus tortor, dignissim sit amet, adipiscing nec, ultricies sed, dolor. Cras elementum ultrices diam. Maecenas ligula massa, varius a, semper congue, euismod non, mi.*

Les présentations powerpoint

Vous avez la possibilité d'écrire sur 7 niveaux.

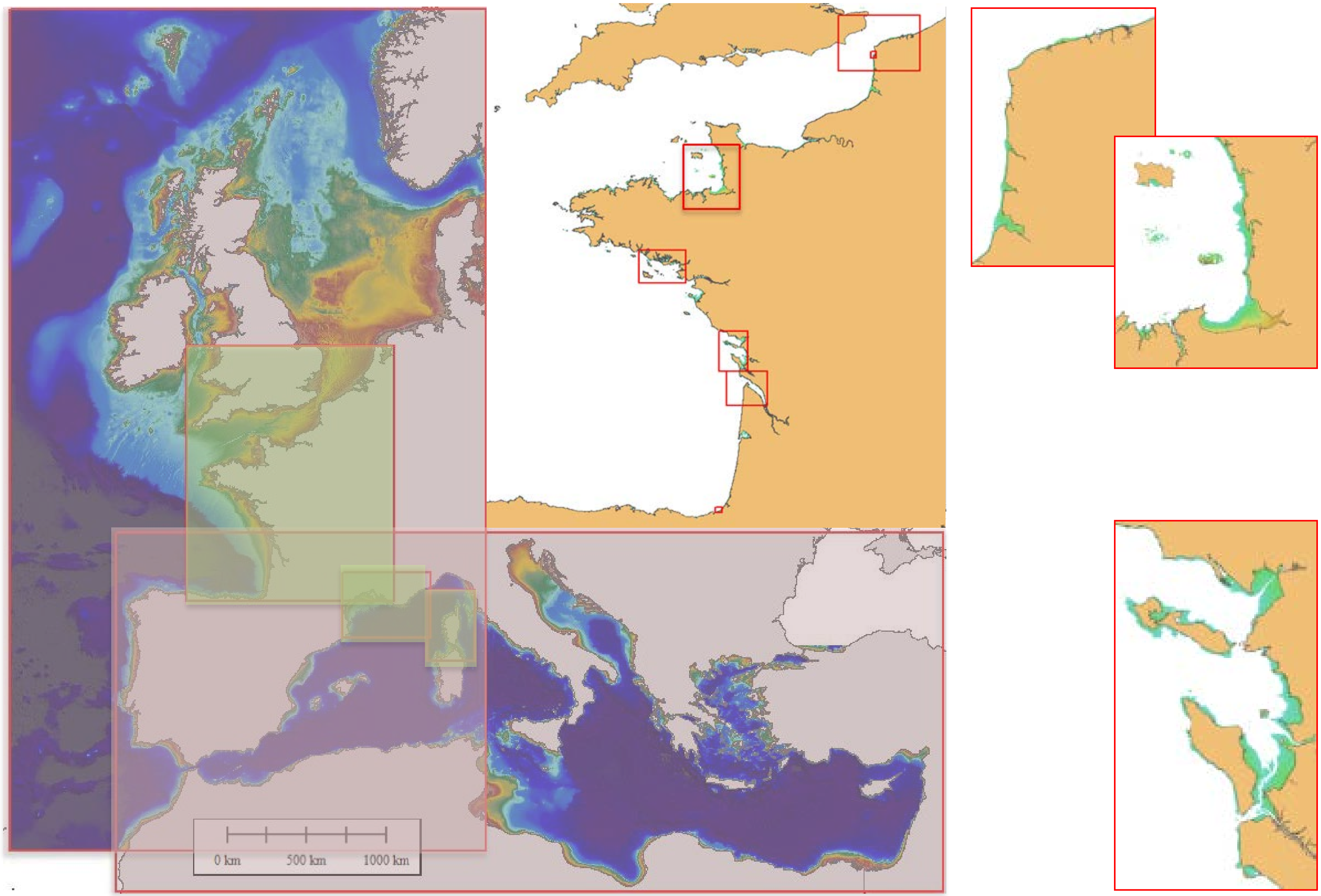
- Pour augmenter ou diminuer le niveau de l'ensemble du paragraphe, sous l'onglet Accueil, dans le groupe Paragraphe, cliquez sur Augmenter le niveau de liste ou Réduire le niveau de liste.

NIVEAU 1

Niveau 2

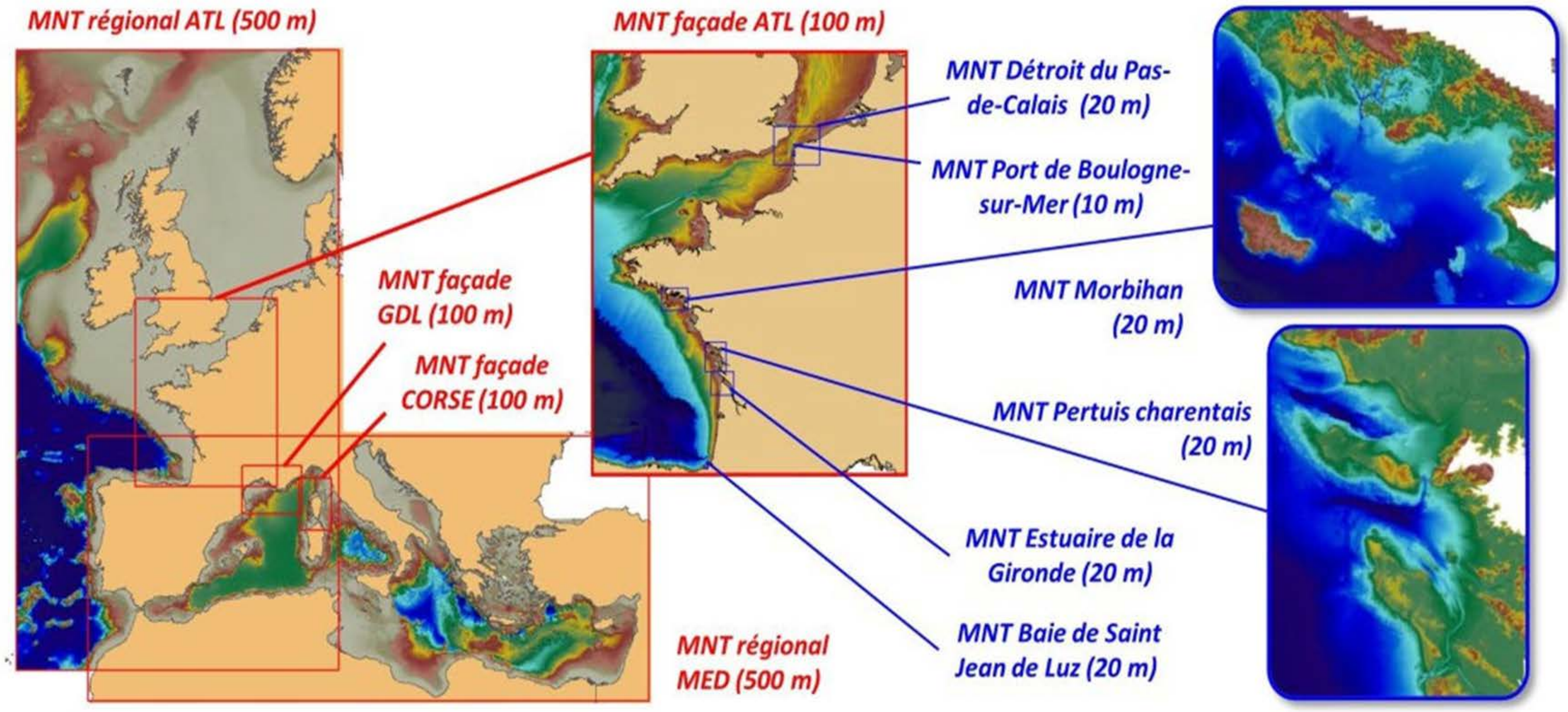
- Niveau 3
  - X Niveau 4
    - Niveau 5
      - _ *Niveau 6*
        - *Niveau 7*

DEDICATED , UP-TO-DATE DTM



DEDICATED , UP-TO-DATE DIGITAL TERRAIN MODELS

REGIONAL (500M) TO HIGH RESOLUTION (20M) DTM



DTMs produced by SHOM for the HOMONIM(500m, 100m) and TANDEM (20m) projects on metropolitan facades