Modelling storm surges with HYCOM
An improvement of the French warning system

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1. SHOM
2. Météo-France

Workshop on Waves, Storm Surges and Coastal Hazards 2017
I. HOMONIM PROJECT
   CONTEXT
   OBJECTIVES
   A COLLABORATIVE EFFORT

II. STORM SURGE MODELLING WITH HYCOM
   MODEL DESCRIPTION
   PERFORMANCE OF OPERATIONAL CONFIGURATIONS

III. ONGOING AND FUTURE WORK
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   TOWARDS HIGH RESOLUTION AND COUPLED LEVEL/WAVES MODELLING
   NUMERICAL SCHEME AND BOTTOM FRICTION OPTIMIZATION
1. HOMONIM PROJECT

HISTORY, OBSERVATION AND MODELLING OF SEA LEVELS
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

Enhanced operational forecasting abilities
- To develop surges and waves forecasting models

Available and up-to-date Information
- To supply Météo France surges and waves warning system
- To give open access to forecasts for general public

Densification of SHOM tide gauges network

Warning system alert Published by Météo France, 06.02.2014

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

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
2. STORM SURGE MODELLING WITH HYCOM

MODEL AND PERFORMANCE ON METROPOLITAN COASTS
ATLantic Ocean and MEDiterranean 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

<table>
<thead>
<tr>
<th>Indicateur statistique</th>
<th>ATL</th>
<th>MED</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE high tides (cm)</td>
<td>15</td>
<td>N/A</td>
</tr>
<tr>
<td>Phase shift on high tides (min)</td>
<td>16</td>
<td>N/A</td>
</tr>
<tr>
<td>RMSE on storm surge (cm)</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Mean Error on storm event extrema (cm)</td>
<td>-9</td>
<td>-9</td>
</tr>
</tbody>
</table>
HOW TO IMPROVE STORM SURGE MODELLING?

LIMITATIONS OF THE MODEL

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

TOWARDS HIGH RESOLUTION AND COUPLED LEVEL/WAVES MODELLING
THE PERTUIS-CHARENTE CASE - COUPLING METHOD WW3/HYCOM

HYCOM ATL

HYCOM zone2
Reso: 400-> 250 m

HYCOM zone3
Reso : 130->90 m

HYCOM zone4
Reso : 35-> 30 m

NORGAS-UG

WW3-Charente

Water level, current, mask

<table>
<thead>
<tr>
<th>Model</th>
<th>HYCOM</th>
<th>WW3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grids type</td>
<td>Curvilinear ATL (995x718 nodes)</td>
<td>Unstructured NORGAS-UG (92,757 nodes)</td>
</tr>
<tr>
<td>Parent¹</td>
<td>Zone2 (841x696 nodes)</td>
<td>Charente WW3 (50,357 nodes)</td>
</tr>
<tr>
<td>Child 1</td>
<td>Zone3 (1495x1050 nodes)</td>
<td></td>
</tr>
<tr>
<td>Child2</td>
<td>Zone4 (1913x1892 nodes)</td>
<td></td>
</tr>
</tbody>
</table>

| Bathymetry | NMB 500m, 100m, 20m (Biscara et al., 2015) |

<table>
<thead>
<tr>
<th>Model</th>
<th>SHOM version (Baraille and Filatoff, 1995) barotropic formalism wetting &amp; drying</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW3</td>
<td>(Tolman, 2014)</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Physical parametrizations</th>
<th>Bottom friction calculated by a stochastical approach (Boutet et al., 2015)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Wind stress following Charnock formulation (Charnock, 1955)</td>
</tr>
</tbody>
</table>

¹ Similar to grids of the operational system

Table 1: Models and configurations
See Pasquet et al. 2014, Michaud et al. 2015
Storm surge during Xynthia, coupled simulation

Offset of SSH due to coupling

+6 cm La Rochelle
3. ONGOING AND FUTURE WORK

DEVELOPMENTS TO IMPROVE STORM SURGE FORECASTING

2. NUMERICAL SCHEME AND 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

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

\[
\frac{\partial}{\partial t} h + \frac{\partial (hu)}{\partial x} = 0
\]

\[
\frac{\partial (hu)}{\partial t} + u \frac{\partial (uhu)}{\partial x} + g \frac{\partial h}{\partial x} = 0
\]

\[
\tilde{u} = u - \gamma \frac{\partial h}{\partial x}
\]

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

\[
\begin{aligned}
\frac{\partial}{\partial t} h + \frac{\partial (hu)}{\partial x} &= 0 \\
\frac{\partial (hu)}{\partial t} + u \frac{\partial (uhu)}{\partial x} + g \frac{\partial h}{\partial x} &= 0 \\
\frac{\partial E_T}{\partial t} + \frac{\partial}{\partial x} \left( (E_c + 2E_p) \tilde{u} \right) &\leq 0
\end{aligned}
\]

\[\tilde{u} = u - \gamma \frac{\partial h}{\partial x}\]

**Experiment on:**
- LT: Low tides
- HT: High tides
- One month simulation
- Cost function to optimize:
  - RMSE LT + RMSE HT
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DEVELOPMENTS TO IMPROVE STORM SURGE FORECASTING

ONGOING EXPERIMENTS: BOTTOM STRESS OPTIMIZATION AND NEW NUMERICAL SCHEME

Location of the collocation points

2x2 collocation points

Bottom roughness estimation after 93 iterations

2x2 collocation points

- 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)
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)
MODÉLISATION DE LA SURCOTE - FAÇADE ATLANTIQUE

EX D’OSCILLATIONS DE LA SURCOTE OBSERVÉE

La Rochelle

Surcote (cm)

15/05/15 | 16/05/2015 | 17/05/15

OBS
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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
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
  • 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