A global prediction system for tides and surges

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Background  Bernier and Thompson (2014),

- **Deterministic** and ensemble storm surge prediction for Atlantic Canada
- Ensemble runs provide possible variations due to atmospheric uncertainty

Why global?

- Canada is surrounded by three oceans: Pacific, Atlantic and Arctic
- Free from horizontal boundary conditions
- Geographical variability of the surge prediction / atmospheric uncertainty
Overview

- Long-term goal is to predict **total water level (tide + surge)**

- We have proceeded on following steps
  
  **Step 1:** M2 tide only prediction (2014~2015)
  **Step 2:** Surge only prediction (2015~2016)
  **Step 3:** Tides and surges (2016~ ongoing)
  **Step 4:** Ensemble simulations

- Results
  
  **Step 1:**  
  - Develop a global forward tide model
    - Tidal potential + SAL + IWD
  
  **Step 2:**  
  - Global NEMO forced by GEPS (ctrl run) predicts SSH almost as accurate as MOG2D forced by ECMWF (DAC)
    - The effect of density stratification on surge predictions

  **Step 3:**  
  - Preliminary results for total water level prediction
A global surge and tide prediction system has been developed based on Numerical Ocean Model, NEMO. Because NEMO is an ocean model, the prediction system can be used for different oceanic phenomena:

- **2D Barotropic (Bt)**
- **3D Baroclinic (Bc)**
- **Typical Ocean Model**

### CPP Keys
- key_orca_r12, key_dynspg_ts2, key_mpp_mpi
- key_zdftke, key_dynapg, key_tide, key_tradmp

### Table: Oceanic Phenomena

<table>
<thead>
<tr>
<th></th>
<th>Barotropic Response</th>
<th>Density Stratification</th>
<th>General Circulation</th>
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<tr>
<td>2D Barotropic (Bt)</td>
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The effect of density stratification on global storm surge prediction is studied based on a comparison between Bt and Bc cases (Today’s talk):

- Increases the overall predictive skill of SSH at almost all tide gauges
- The increase in skill for the instantaneous peak surge is small.

1/12° horizontal resolution
Numerical Ocean Model, NEMO

• Momentum equation

\[ \frac{du'_h}{dt} = -f \times u'_h - g \nabla \left[ \eta + \int_{z=0}^{z} \frac{\rho'}{\rho_0} ds + \eta_A + \eta_{SAL} + \frac{p_a}{\rho_0} \right] + \text{Diff} \]

Tidal forcing

Atmospheric forcing

• Density anomaly \( \rho' \) in time relative to climatology \( \rho_b \)

\[ \frac{d\rho'}{dt} + u'_h \nabla_h \rho_b + w' \frac{\partial \rho_b}{\partial z} = K_h \nabla^2 \rho' + \frac{\partial}{\partial z} \left( K_z \frac{\partial \rho'}{\partial z} \right) \]

• Inclusion of baroclinic pressure perturbation

  • More accurately resolve tides, surges, and coastal trapped waves
  • No lengthy model spin-up for general ocean circulation

  • No mean ocean current
  • Slower and more complicated than barotropic model
Hindcast period: Fall 2014

Distribution of tropical storms observed during Fall 2014 based on IBTrACS

- rm track
- Tropical storm
NEMO is forced by GEPS, EC (Houtekamer et al., 2014)

- Control Run Only
- Pressure and wind stress
- 0.45° x 0.45°, hourly
- Blending over 5 hrs

\[ \tau_s = c_{wd} \rho_a W |W|, \]
\[ 10^3 c_{wd} = \begin{cases} 
1.2 & |W| < 11 \text{m/s} \\
0.49 + 0.065|W| & |W| \geq 11 \text{m/s}
\end{cases} \]
GEPS includes Gonzalo. What about the NEMO surge forecast?
Storm Surges recorded by tide gauges

- Tides and low frequency (>20 days) signals are filtered out ---> $\tilde{\eta}$
- NEMO tends to underestimate the surge peaks
- Arrival times of surges are predicted well
\( \gamma^2 \) metric for evaluating prediction skill

- Global tide gauge observations were used to calculate \( \gamma^2 \) metric

\[
\gamma^2 = \frac{\text{Var}(\eta_p - \eta_o)}{\text{Var}(\eta_o)}
\]

Smaller \( \gamma^2 \) means better prediction

- Numerical models are compared using \( \gamma^2 \)

NEMO vs DAC \(\rightarrow\) similar

Bc vs Bt \(\rightarrow\) Bc is better
The effect of density stratification

- Another view to evaluate the effect of density stratification
- The spatial distribution of $\gamma^2$ ratio indicates
  - The predictions by NEMO-BC is better at almost all the stations
  - The largest improvement was found at tide gauge station East London in South Africa
Coastal trapped waves are better predicted

Along shore coordinate

SSH along the coast (Hovmoller diagram)

(a) East London, South Africa \( \gamma_{Bc}^2 = 0.26 \quad \gamma_{Bt}^2 = 0.55 \)

- tide gauge
- NEMO–Bc
- NEMO–Bt

Along shore coordinate

SSH along the coast (Hovmoller diagram)

(a) Bc

- NEMO Bc

(b) Bc–Bt

(NEMO Bc) - (NEMO Bt)
Another case at Naha by Typhoon Vongfong

- The improvement is related to steric height
Summary

• A hindcast study of global storm surges for Fall 2014

• The inclusion of density stratification increases the overall predictive skill of SSH at almost all tide gauges

• The increase in skill for the instantaneous peak surge is small.

• For a further reference, please read

• Next steps - Total water level prediction, Ensemble simulation