A global prediction system for tides and surges

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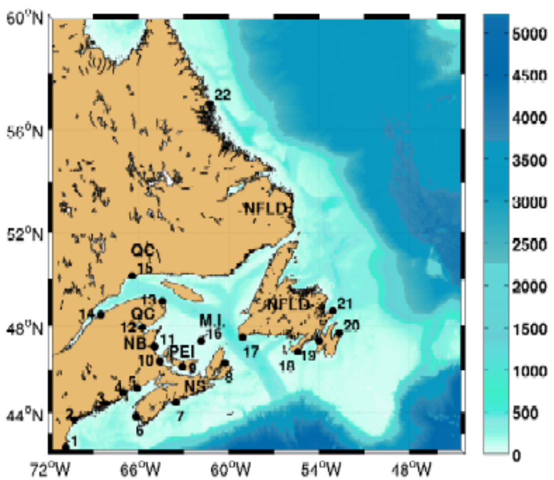
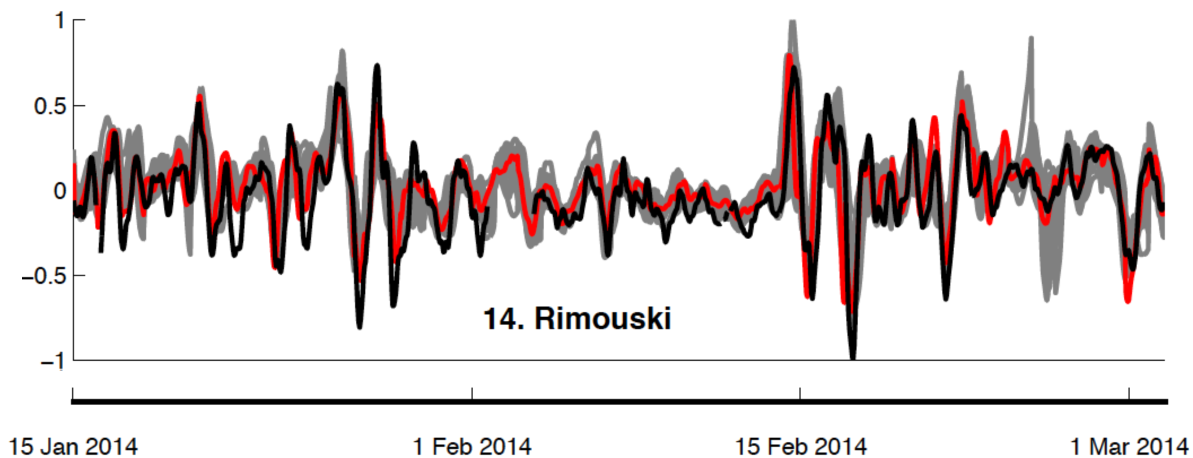
MEOPAR
MARINE ENVIRONMENTAL OBSERVATION PREDICTION & RESPONSE NETWORK

Introduction

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

CONCEPTS_3.1.0b(v3.4)

- 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

Numerical Ocean Model, NEMO

- **A global surge and tide prediction system has been developed based on**

- **1/12° horizontal resolution**

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

- **Because NEMO is ocean model, the prediction system can be**

	Barotropic Response	Density Stratification	General Circulation
2D Barotropic (Bt)	✔		
3D Baroclinic (Bc)	✔	✔	
Typical Ocean Model	✔	✔	✔

- **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.**

Numerical Ocean Model, NEMO

- **Momentum equation**

$$\frac{du_h'}{dt} = -\boldsymbol{f}\times u_h' - g\nabla\left[\eta + \int_z^0 \frac{\rho'}{\rho_o}ds + \eta_A + \eta_{SAL} + \frac{p_a}{\rho_0}\right] + Diff$$

Tidal forcing Atmospheric forcing

- **Density anomaly ρ' in time relative to climatology ρ_b**

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

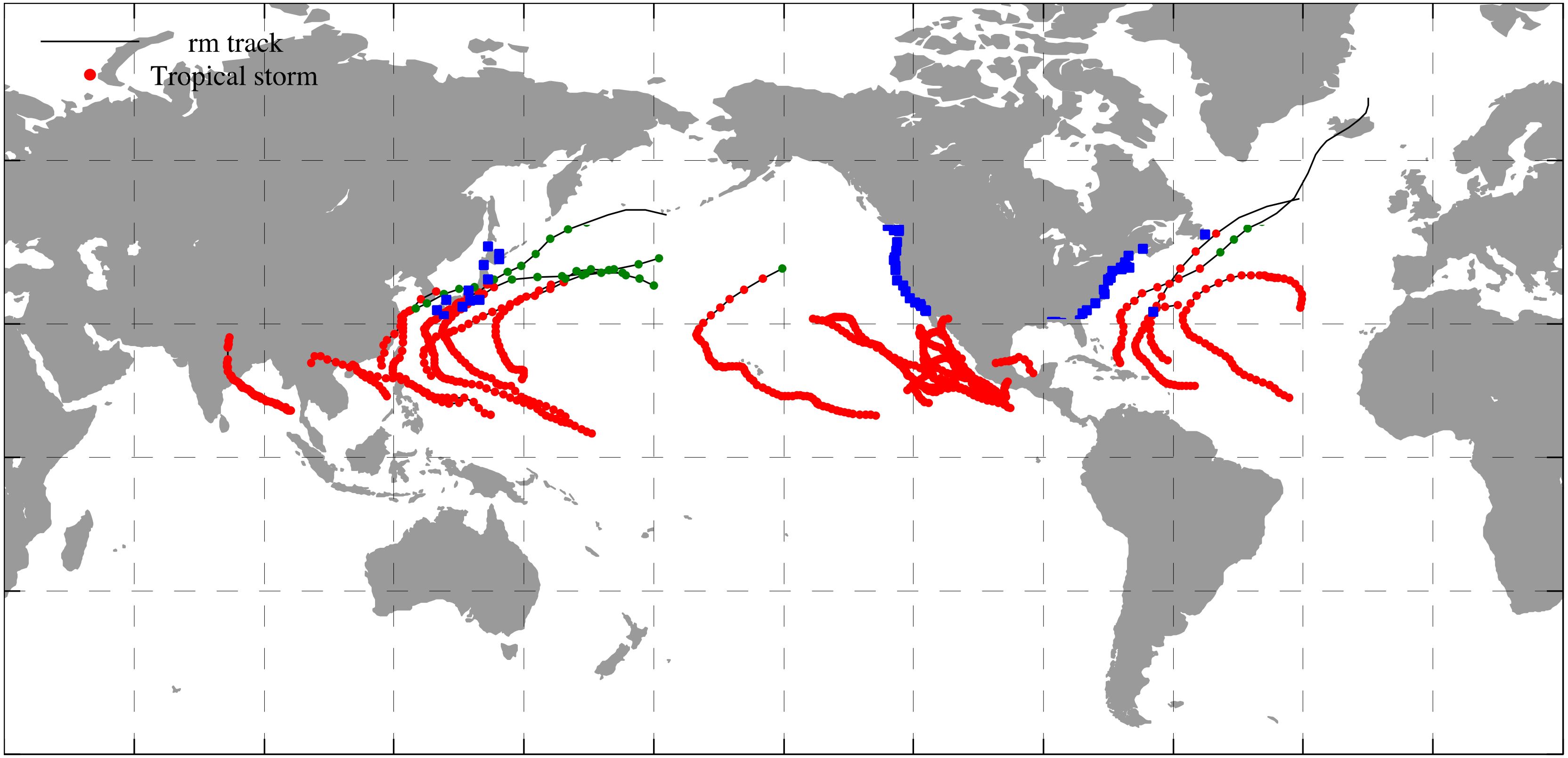
- **Inclusion of baroclinic pressure perturbation**

- **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



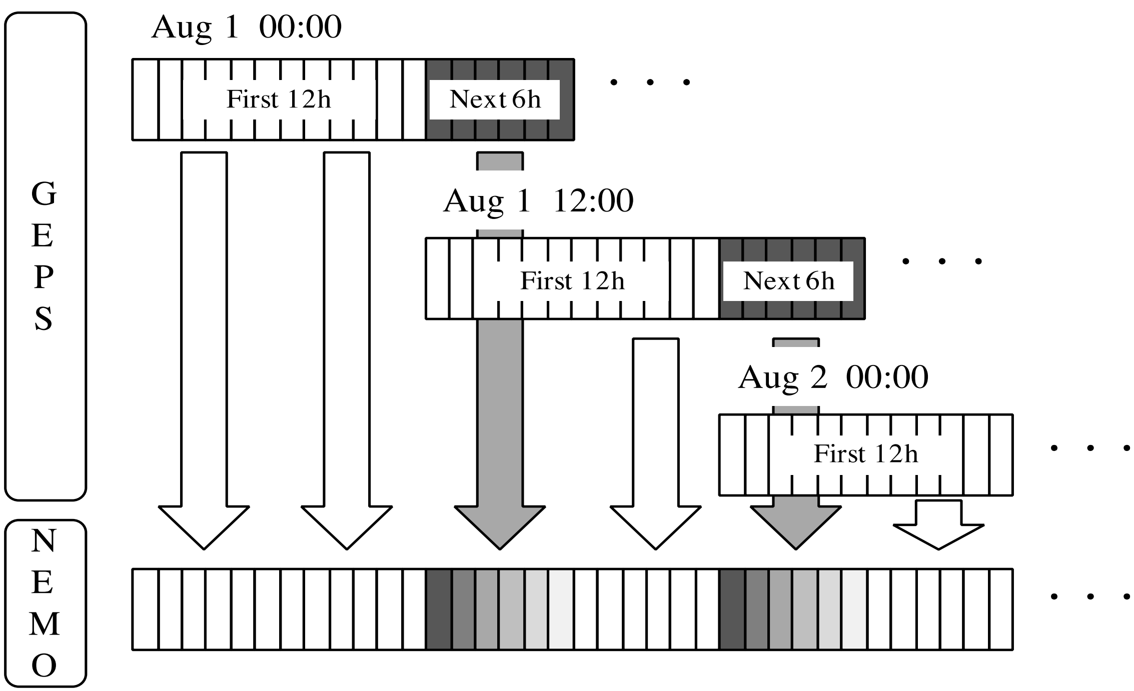
Atmospheric Forcing

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

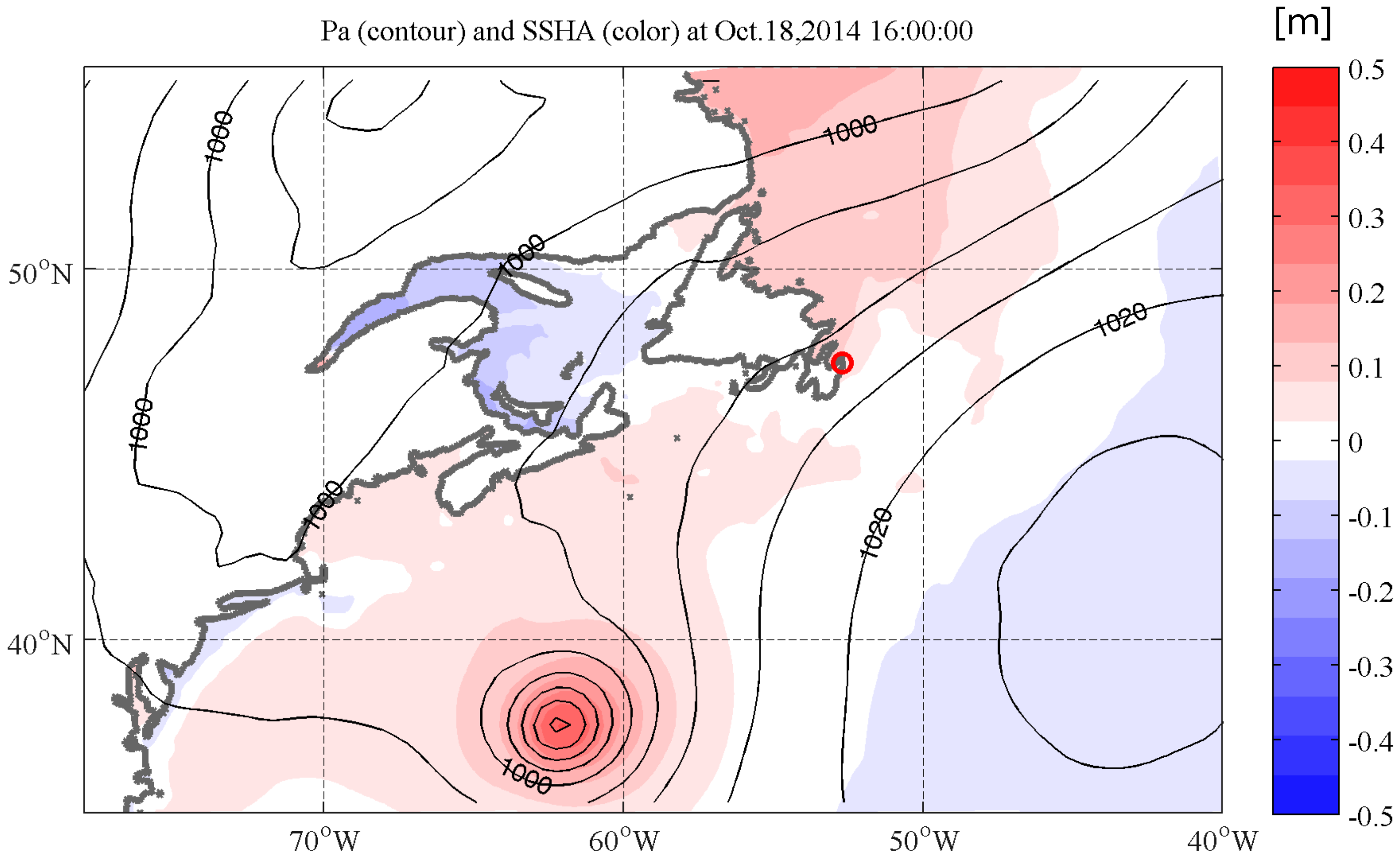
$$\tau_s = c_{wd}\rho_a W|W|,$$

$$10^3 c_{wd} = \begin{cases} 1.2 & |W| < 11m/s \\ 0.49 + 0.065|W| & |W| \geq 11m/s \end{cases}$$



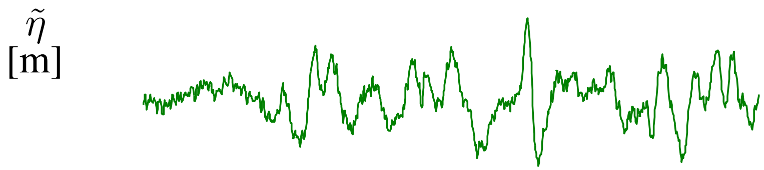
Example: Hurricane Gonzalo (Oct ,2014)

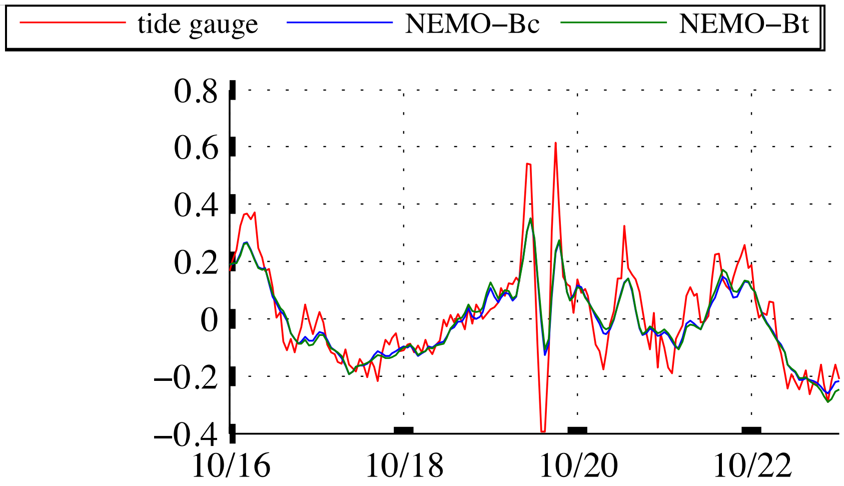
- GEPS includes Gonzalo. What about the NEMO surge forecast?



Storm Surges recorded by tide gauges

- **Tides and low frequency (>20days) signals are filtered out ---> $\tilde{\eta}$**
- **NEMO tends to underestimate the surge peaks**
- **Arrival times of surges are predicted well**





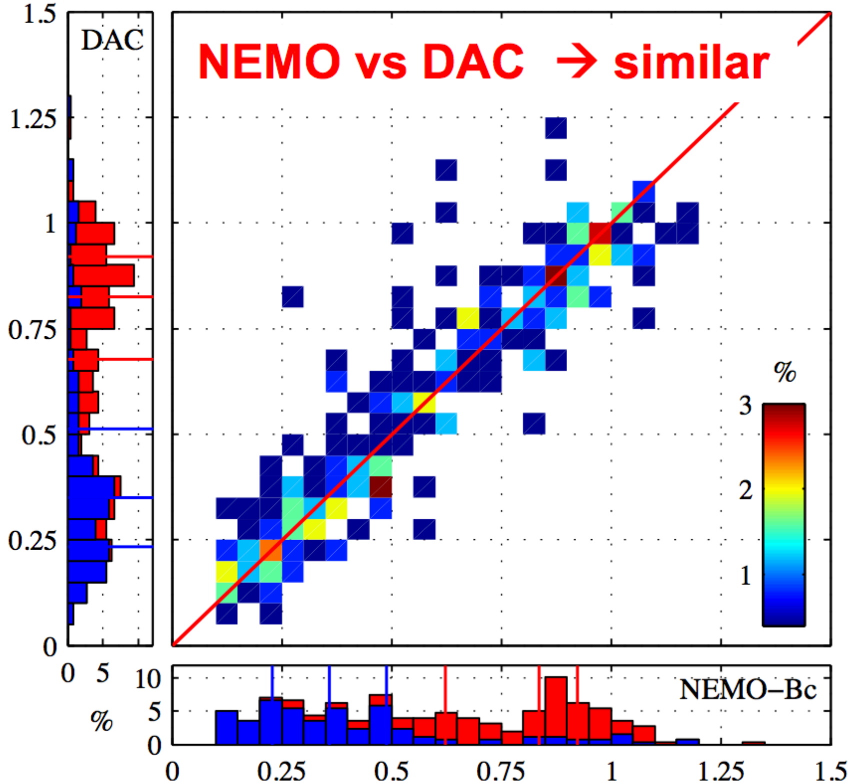
γ^2 metric for evaluating prediction skill

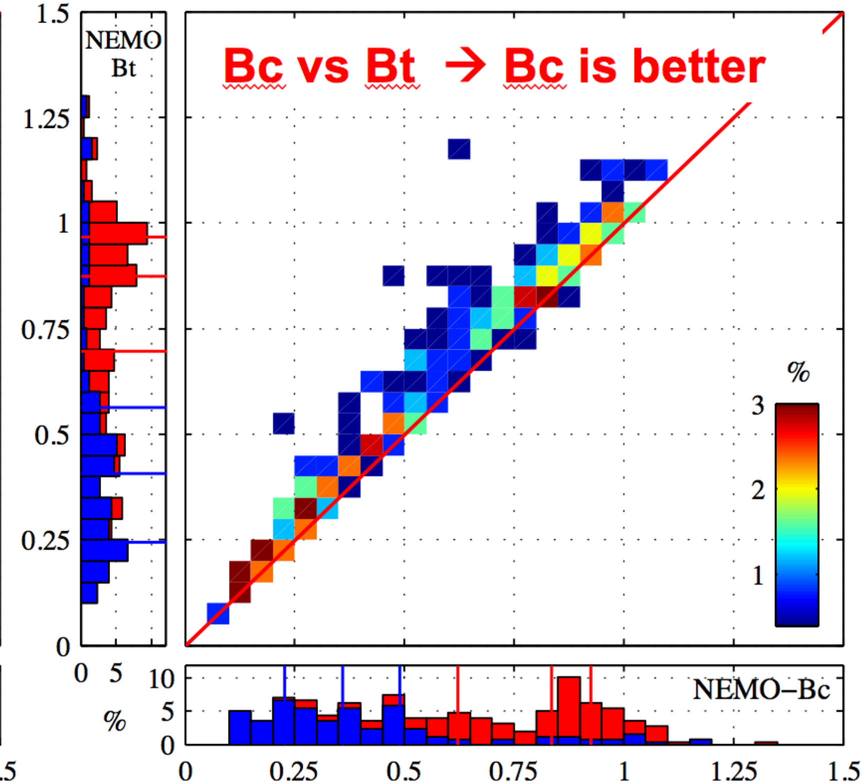
- **Global tide gauge observations were used to calculate γ^2 metric**

$$\gamma^2 = \frac{\mathrm{Var}(\eta_p - \eta_o)}{\mathrm{Var}(\eta_o)}$$

Smaller γ^2 means better prediction

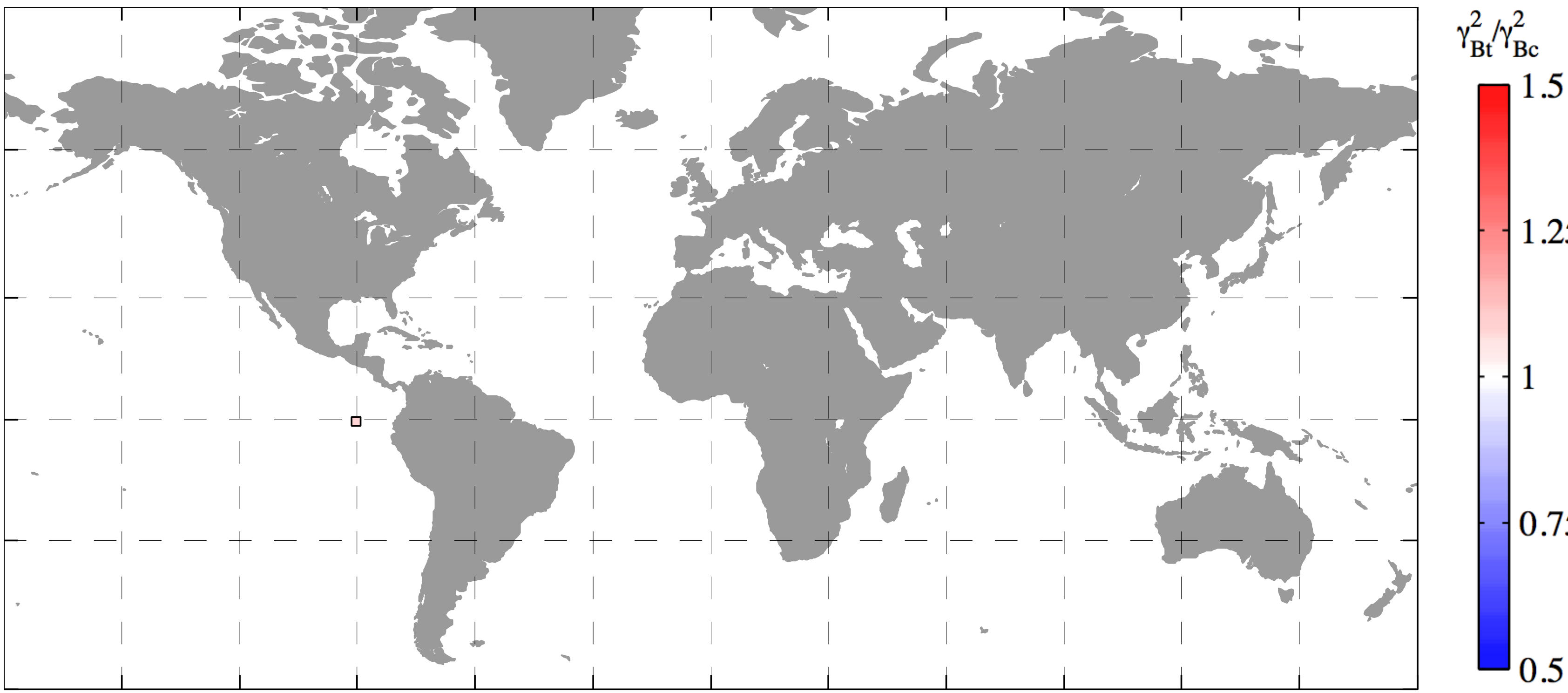
- **Numerical models are compared using γ^2**



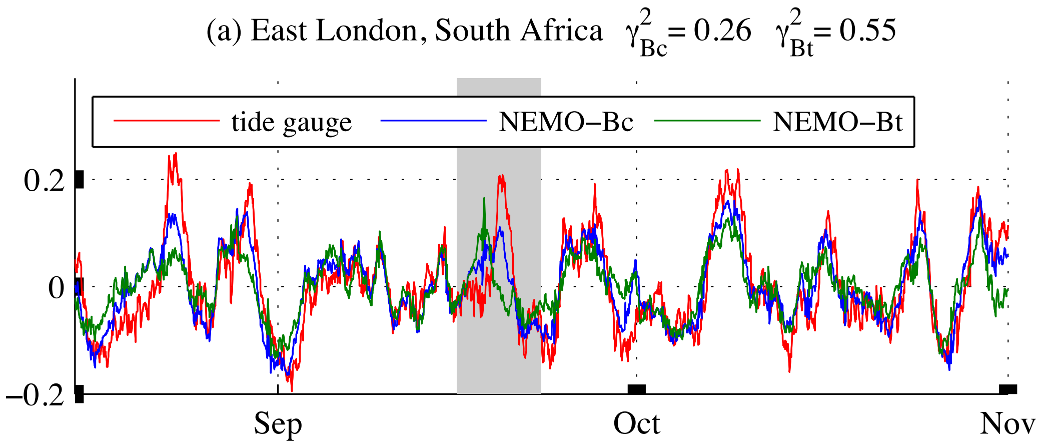


The effect of density stratification

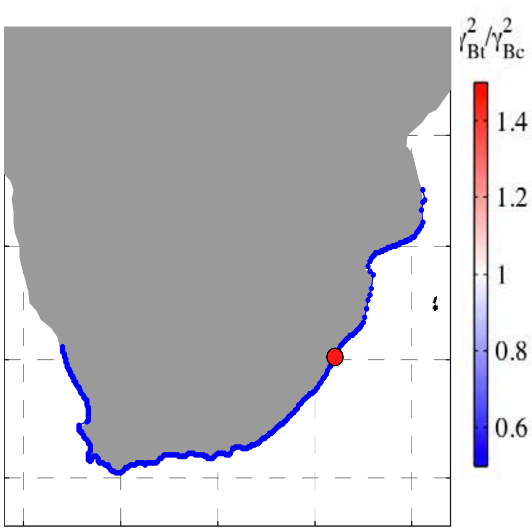
- Another view to evaluate the effect of density stratification
- The spatial distribution of γ^2 ratio indicates
  - The predictions by NEMO-BC is better at almost all the stations
  - The largest improvement was found at tide gauge station East London in South Africa



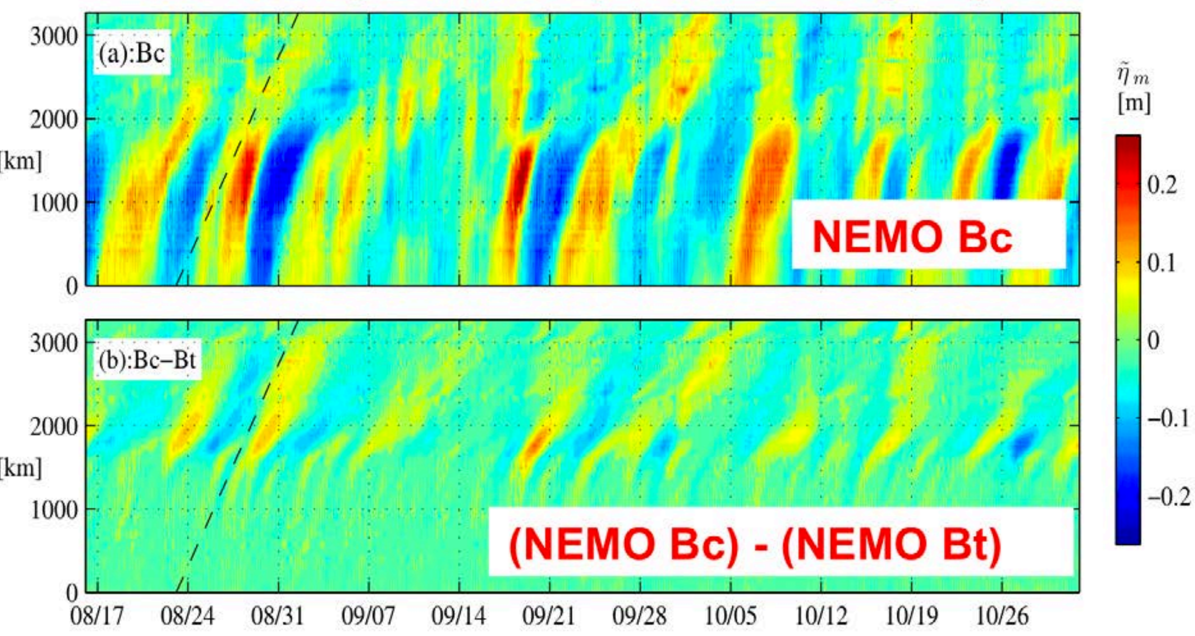
Coastal trapped waves are better predicted



Along shore coordinate

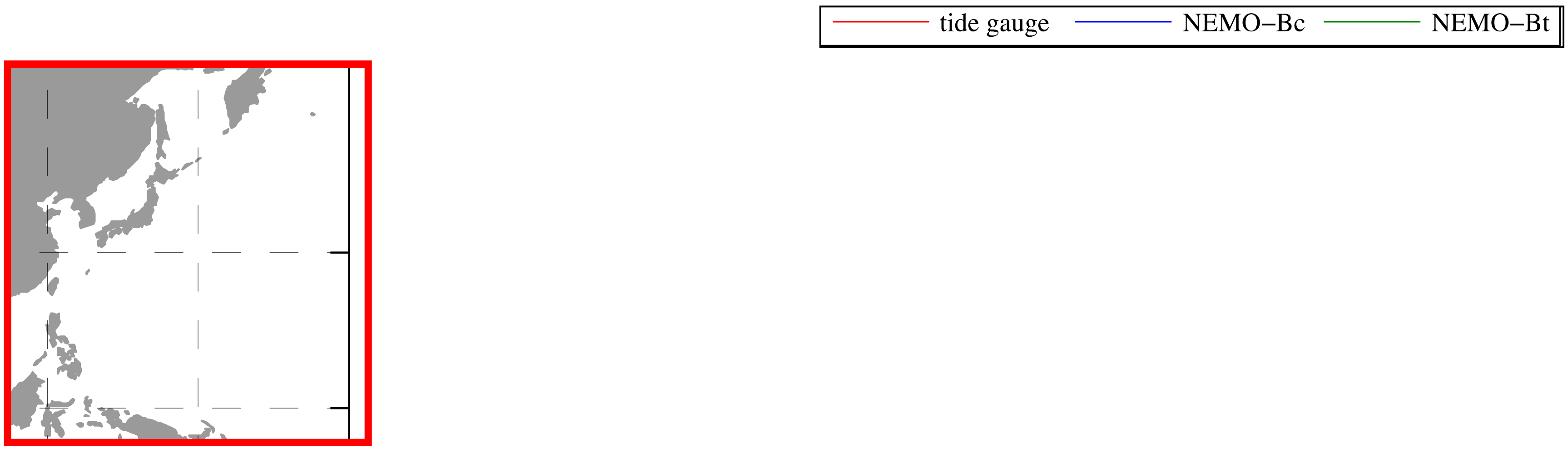


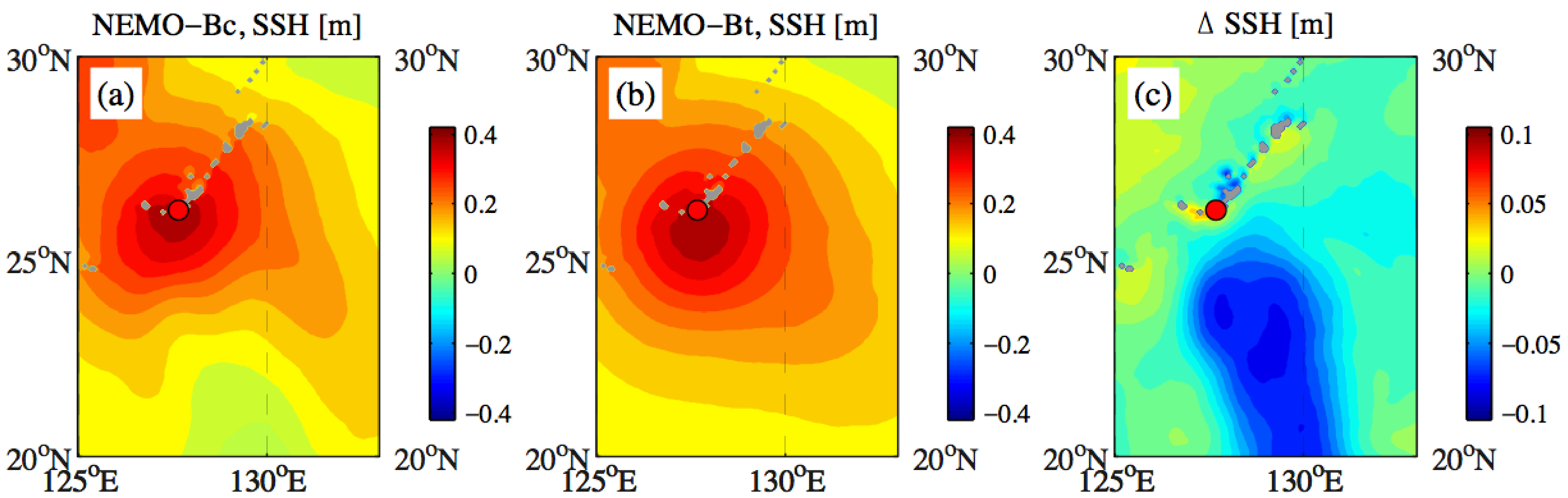
SSH along the coast (Hovmoller diagram)



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**

  Kodaira, T., K. R. Thompson, and N. B. Bernier (2016): The Effect of Density Stratification on the Prediction of Global Storm Surges, Ocean Dynamics, (DOI 10.1007/s10236-016-1003-6).

- **Next steps - Total water level prediction, Ensemble simulation**