The Puerto Rico Operational Regional Ocean Modeling System

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LONG-TERM GOALS

The coastal ocean forecasting system aims at integrating *in situ* and remote observations with the 3 dimensional ocean currents modeled with the Regional Ocean Modeling System (ROMS) to provide an accurate representation of the ocean circulation for the coastal areas of Puerto Rico and the United States Virgin Islands. The high resolution modeled currents supplement observations from High Frequency radars and Acoustic Doppler Current Profilers, providing additional spatial coverage of surface and subsurface ocean currents. Moreover the ROMS ocean model currently provides 3 times the spatial and temporal resolution than the AmSeas NCOM model, allowing to capture tidal oscillations more accurately as well as resolving more complex baroclinic shelf current dynamics with more accuracy, especially in narrow channels (1-10km wide).

MILESTONES / OBJECTIVES

1. **Assessment of open boundaries and tide filtering techniques:** The open boundary conditions and tide forcing methodologies are assessed to characterize the model performance under different configurations. There are two ways to impose tidal dynamics for a limited area model: 1) by specifying the time evolution of sea level and transports at the open boundaries or 2) spectrally by specifying the harmonic phases and amplitudes of the most energetic tidal constituents for the domain under study. A case study is performed to assess the model performance by comparing the interior solution from ROMS to the external values from AmSeas, as well as a validation of sea surface height at NOAA tide stations.

2. **Assessment of ROMS initialization:** Short-term ocean forecasts are largely constrained by their initial conditions, since the time it takes for the largest ocean scales to reach equilibrium in a high-resolution ocean model is of the same order than the length of the forecast. Consequently, daily re-initialization of the ROMS model from the AmSeas forecast field greatly constraints the model performance to that of AmSeas. Most operational forecasting systems use some data assimilation scheme to improve the model's initial condition, however all schemes are based on the premise that the initial forecast before the assimilation is good, otherwise large corrections to the initial field may yield lower forecast skill. Therefore, this assessment aims to quantify the error growth of the ROMS model by using a 'hot start' initialization, in which the previous day forecast is used to initialize the next forecast cycle.

3. **Grid and computational domain study:** A grid sensitivity study is performed to quantify the model performance under different boundary condition configurations. This comprehensive assessment aims to better understand the role of the grid resolution and its interaction with different configurations of boundary conditions. Additionally, a domain sensitivity study is performed to complement the grid sensitivity study. The model performance is validated with observations, and several suggestions are made for the ROMS model resolution and domain taking into account model integration time, refinement coefficient ratio, availability of high-resolution products (e.g. NDFD), bathymetric features, persistent currents and systematic model errors.

WORK COMPLETED

1. **Validation of PROROMS v4.0:** Significant changes have been performed to the Puerto Rico Operational Regional Ocean Modeling System configuration with the aim of improving the model's forecast skill. A comprehensive assessment of the model's initialization, boundary conditions, domain extension and grid resolution was performed to determine the optimal configuration. All simulations and validations shown in this report were performed during a 30-day period starting January 10th and ending February 9th, 2017.
    a. **Boundary conditions and tide filtering:** To assess the role of the open boundary conditions and tide forcing, 3 different cases are considered: 1) Barotropic open boundary conditions, sea surface height and barotropic velocities, are prescribed at the open boundaries from AmSeas without harmonic forcing from OTPS (NOTIDE). 2) The low-pass filtered sea surface height and barotropic velocities from AmSeas are prescribed at the open boundaries and harmonic forcing from OTPS is used to simulate the high-frequency variability (SMOOTH). 3) Sea surface height and barotropic velocities at the boundary are de-tied by subtracting the solution of OTPS from AmSeas (T TIDE).

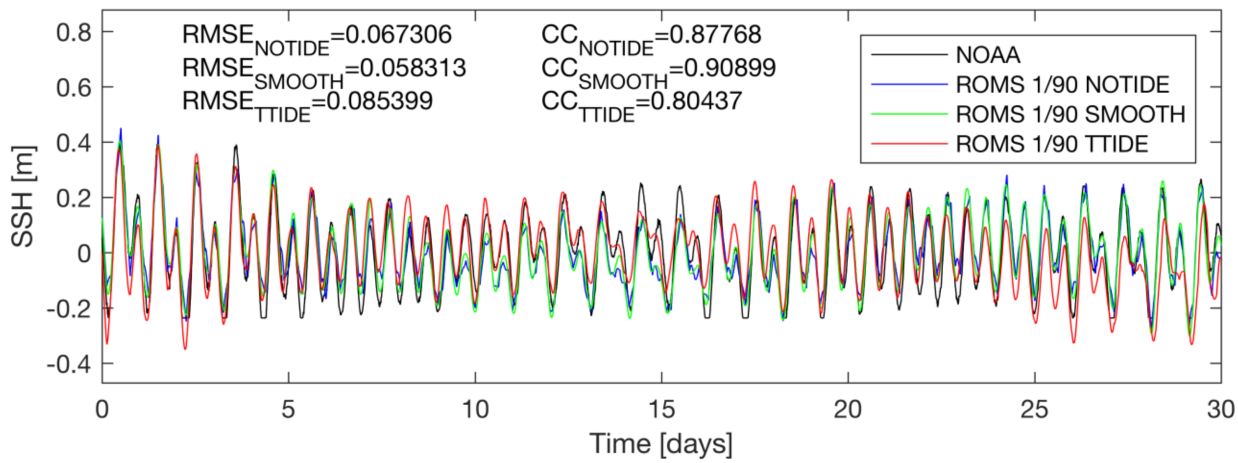

Figure 1. SSH validation at the San Juan NOAA tide station.

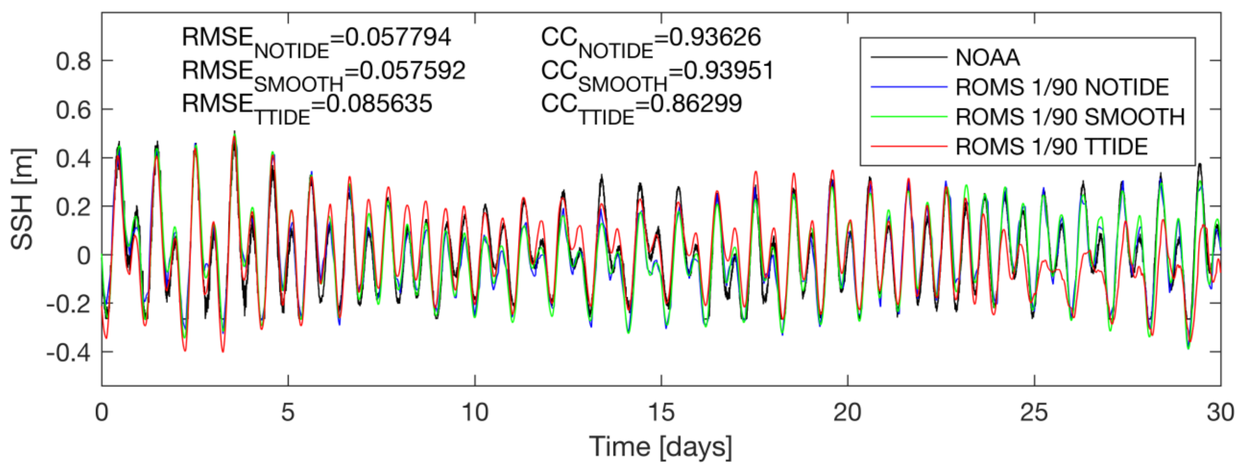

Figure 2. SSH validation at the Arecibo NOAA tide station.

2. **Implementation of PROROMS v4.0:** Significant changes to the Puerto Rico Operational Regional Ocean Modeling System have been performed with the aim of increasing the system's reliability. A new implementation of the https protocol by the National Center for

Environmental Protection does not permit data extraction via Matlab's NetCDF interface. Consequently, the system could extract the necessary portion of AmSeas domain and instead had to download the data to a local repository. A third party toolbox (NCTOOLBOX) provides read-only access to common data model data sets and allows access to NetCDF and OpenDAP. The system now queries the dataset at the NCEP server via OpenDAP and if no files are found it proceeds to download the files via ftp from the high-reliability servers.

MAJOR OUTCOMES

1. **Open boundary conditions for a tidally driven coastal model:** The role of the barotropic boundary conditions and its impact on the model performance is now well understood from this assessment. Figure 1 and 2 show the SSH validation at the San Juan and Arecibo NOAA tide gauges respectively. ROMS SMOOTH case shows better performance at San Juan, with a lower RMSE and a higher CC, indicating lower phase and amplitude error. Validation at the Arecibo site shows similar performance of the SMOOTH and NOTIDE cases, while the TTIDE case shows significantly lower performance.

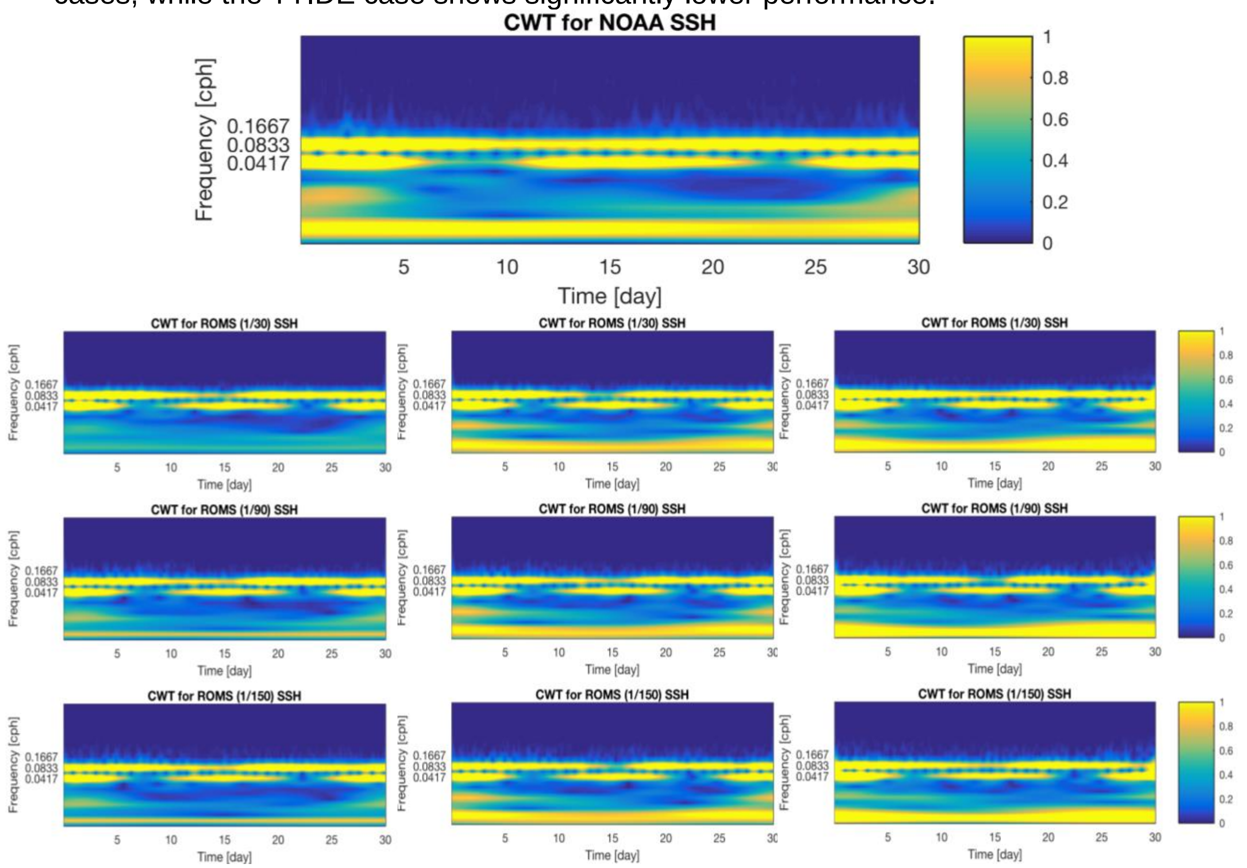

Figure 3. Continuous Wavelet Transform spectra of SSH at San Juan NOAA station. Horizontal grid resolution increases top to bottom. First column left to right shows the case of harmonic forcing only (BENCH), the middle column shows the case of OTPS with the low-pass filtered AmSeas(SMOOTH) and the last column shows the case of OTPS with de-tied AmSeas(TTIDE).

Figure 3 shows the wavelet power spectra of SSH at the San Juan tide station. Color contours show the energy content in time for each frequency, in which the top band corresponds to the higher semi-diurnal frequency, the one below corresponds to the diurnal frequency and the bottom is the low-frequency variability which comes belongs to the wind response. Clearly, the forcing from AmSeas is responsible for the low-frequency response in

ROMS. A similar trend is found for surface ocean currents, with the SMOOTH case having the best performance among the cases considered, as shown in figure 4.

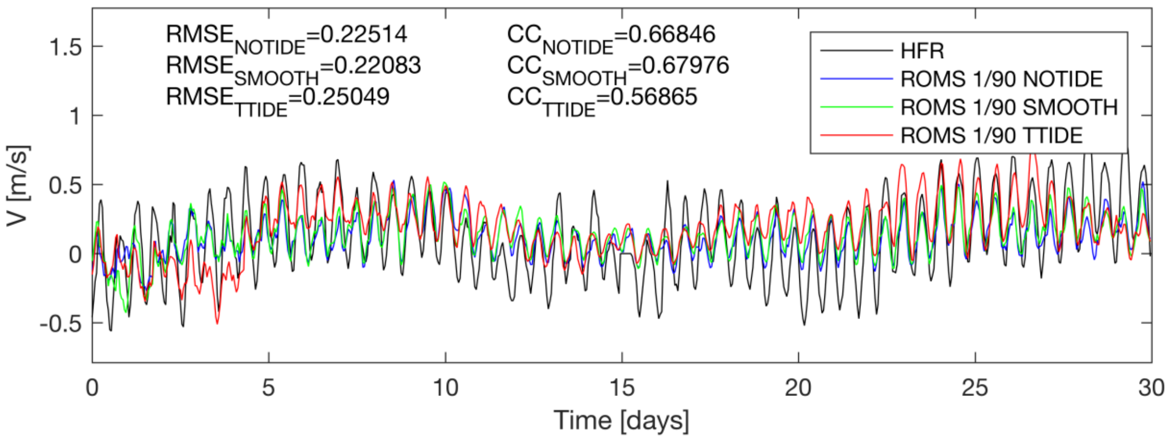

Figure 4. Validation of surface northward velocity (V) with the 6km HFR at Mona Passage.

2. **Considerations for grid resolution:** A grid sensitivity experiment was performed to elucidate the advantages in model performance with increasing resolution.

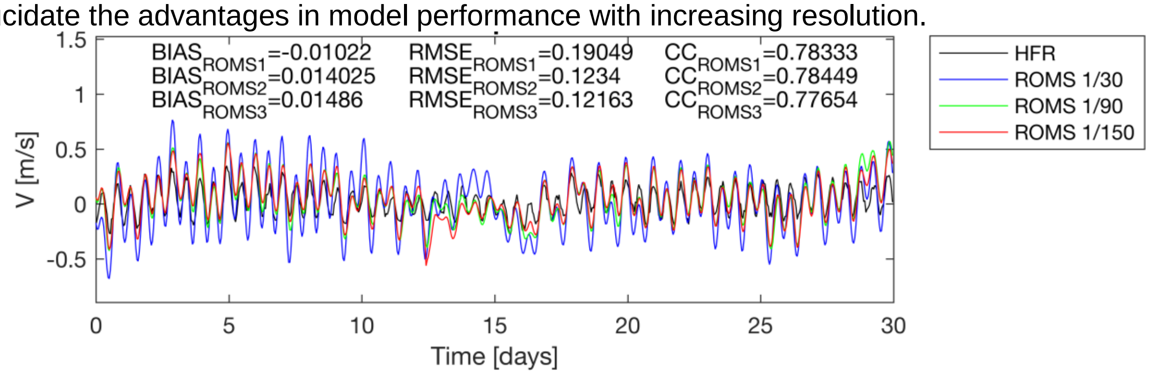

Figure 5. Mid-depth northward velocity (V) validation at the Vieques CariCOOS buoy.

Figure 5 shows the validation of mid-depth northward velocity (V) at the Vieques buoy. There is a decrease of 7cm/s in RMSE when going from the 1/30 to 1/90 degree resolution grid, while no significant difference is found when going from 1/90 to 1/150 degrees. Figure 6 shows the validation of surface currents, which do not reduce the error with increasing resolution, although a substantial increase in CC is found. Given the exponential scaling of computational time with horizontal grid resolution, a 1.2km horizontal resolution (1/90 degree) is suggested for the ocean model.

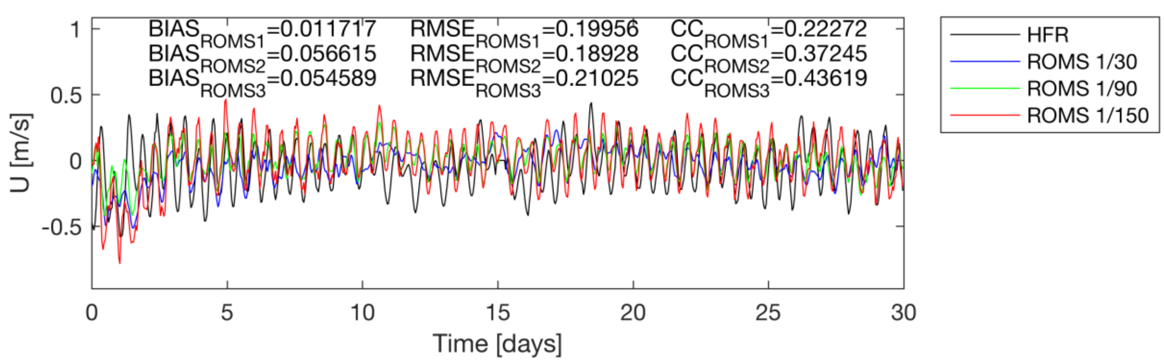

Figure 6. Surface eastward velocity (U) validation with the 6km HFR south of Puerto Rico.

3. **Considerations for domain extension** Extending the current computational domain decreases the influence of the boundary conditions, and yields a increase in performance for longer simulations. However, several other factors need to be taken into consideration. Placing the open boundaries at coastal land areas may be problematic if the land mask is not properly matched between parent and child grids. Availability of the high resolution winds from NDFD is limited mostly to the current domain, extending the domain further would mean winds from COAMPS would be necessary. Another concern is the quality of the boundary conditions, which for the Eastern boundary and shallow regions in general have been problematic. In the northern part of the domain, the depths of the basin go over 8km deep and data from AmSeas is only available up to 5km.

4. **Initialization:** The 'hot start' initialization procedure is not suggested without any correction to the background field, since systematic model errors can grow significantly in time. While using initial conditions from AmSeas constraints the error, it also allows the coastal model to improve the current circulation in near-shore regions and small channels.

RELATED PROJECTS

All projects dealing with ocean circulation in the coastal zone of PR/USVI are directly related to the Puerto Rico Operational Regional Ocean Modeling System. These include:
<u>Estuary and harbor scale ocean modeling</u>: Modeling ocean circulation at estuaries and at harbor scales requires the prescription of initial and boundary conditions. Both the AmSeas NCOM and the ROMS model may be used to initialize the model, but the high resolution ROMS model offers several advantages:

1. The higher resolution allows to solve high frequency dynamics more accurately and the discrepancy between bathymetries at this resolution can cause several problems to the harbor-scale model.
2. Accurate ocean data may not be available in estuaries for the AmSeas NCOM model.

<u>Particle Tracking modeling</u>: Modeling trajectories of passive and active tracers in the coastal areas of PR/USVI is directly related to the ocean circulation and thus to the ROMS forecasts. Besides modeling particle trajectories as passive tracers being advected, ROMS offers several advantages over the AmSeas model:

1. Higher temporal/spatial resolution to resolve tidal dynamics.
2. Online and offline coupling simulations.
3. Capability to resolve active tracers (biochemical processes, larvae dispersion, etc)

REFERENCES

J. Wilkin, "Technical Review of the CariCOOS operational ROMS forecast system", CariCOOS technical report (2016).

PUBLICATIONS & PRODUCTS

Solano, M., Gonzalez, J., Canals, M., Capella, J., Morell, J., Leonardi, S. "Spectral analysis of one-way and two-way downscaling applications for a tidally driven coastal ocean forecasting system". **European Geosciences Union General Assembly. Vienna, April 23-28, 2017**