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. Improve the representation of the model bathymetry. One of the disadvantages of terrail-following models is the inaccurate representation of the model's bathymetry due to the smoothing process necessary to maintain numerical stability. New bathymetric data, different smoothing algorithms and grid refinement are investigated to reduce the error in bathymetry for a more accurate representation.
2. Assesment of initial and open boundary conditions. A 'hot start' approach is used to initialize the model and improve the model's dynamics for short term forecasts. In this approach the model is spun-up for several days and the output is used as initial conditition for the model's forecast. In a continuos effort to improve the represenation of the models' OBC's, space depdendent nuding, barotropic variable corrections and tide filtering are further investigated to improve the model's forecast and dynamics.
3. Implement a new operational system with two-way grid refinement. Two-way grid refinement has been implemented and analyzed to improve the model's dynamics while optimizing computer resources. The new system uses a coarse grid with a significantly extended domain to model meso and sub-mesoscale variability off the shelf and a much finer grid is then used to model the smaller coastal scales across the continental shelf all the way into the near-shore.

WORK COMPLETED

1. Correction to barotropic velocities: During the assessment of initial and open boundary condition an error was found in the computation of barotropic velocities. The barotropic velocities are computed by integrating the horizontal velocity

components in the vertical direction divided by the depth. To avoid mass conservation errors, the depth must be the one used by the model (ROMS), but the depth from the AmSeas model was being used. This error was fixed by using ROMS matlab functions to compute this integral using layer thickness (Hz) which yields a value consistent with ROMS mass conservation properties. This has significant consequences that affect both initial and boundary conditions, and its extremely important because the barotropic mode in ROMS is used to correct the baroclinic field to enforce conservation properties. Figures 1 and 2 show velocity time series of a 30 day simulation and figure 3 shows a best aggregate (first day of forecast) velocity time series showing the difference between the outputs before and after the correction to barotropic velocties.

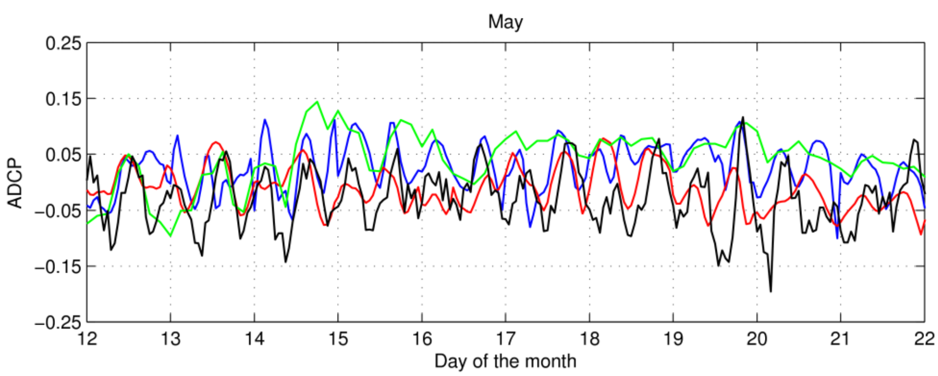


Figure 1: U-component of velocity at mid-depth at St. John's ADCP. ROMS before (blue), and after the correction to barotropic velocties in (red), AmSeas in (green) and the observed velocity by the ADCP in (black).

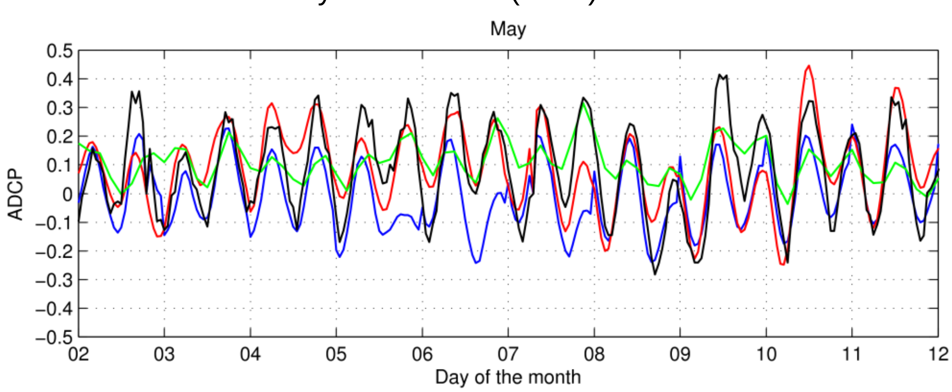


Figure 2: U-component of velocity at mid-depth at St. Thomas' ADCP. ROMS before (blue), and after the correction to barotropic velocties in (red), AmSeas in (green) and the observed velocity by the ADCP in (black).

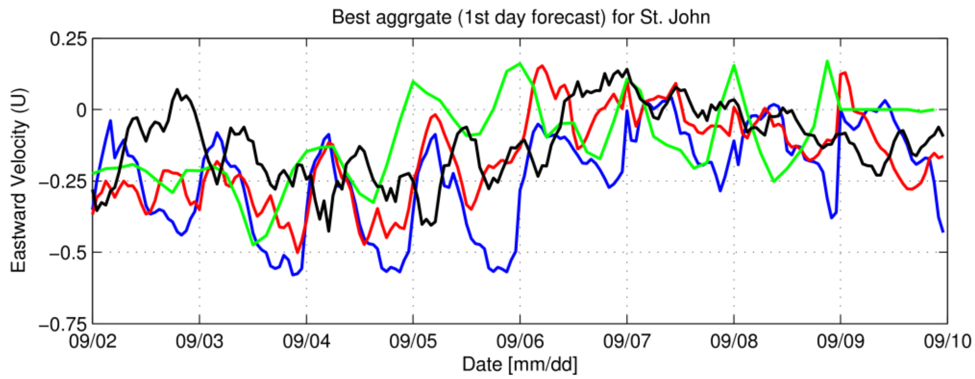


Figure 3: Best aggregate U-component time series of velocity at mid-depth at St. John's ADCP. ROMS before (blue), and after the correction to barotropic velocties in (red), AmSeas in (green) and the observed velocity by the ADCP in (black).

2. ROMS 2-way nested operational system: In order to improve the accuracy of the model's bathymetry, a new system has been established using ROMS 2-way grid refinement. In this approach, a fine grid is used to model the coastal regions and is nested into a coarser grid which is used to model large scale phenomena and used to downscale the solution smoothly from AmSeas to the near-shore. Two ROMS simulations are solved at each step, one coarser and larger domain takes boundary conditions off-line from AmSeas. A finer domain solved with ROMS is on-line nested to the intermediate ROMS domain. This approach has the advantage that the solution at the interface bewteen the parent/child grids conserves mass exactly and the flow may change directions without deviating from the parent grid solution. Furthemore the finer grid allows to model coastal scales at higher resolution for the same computational power and the meso-scale variability is propagated smoothly from the boundaries of the parent grid to the child grid. Figure 4 shows a surface velocity time series south-west of Puerto Rico and figure 5 shows color contours of surface velocity with superimposed vectors at Mona passage from ROMS offline nested to AmSeas, ROMS nested and the observed velocities by the HFR.

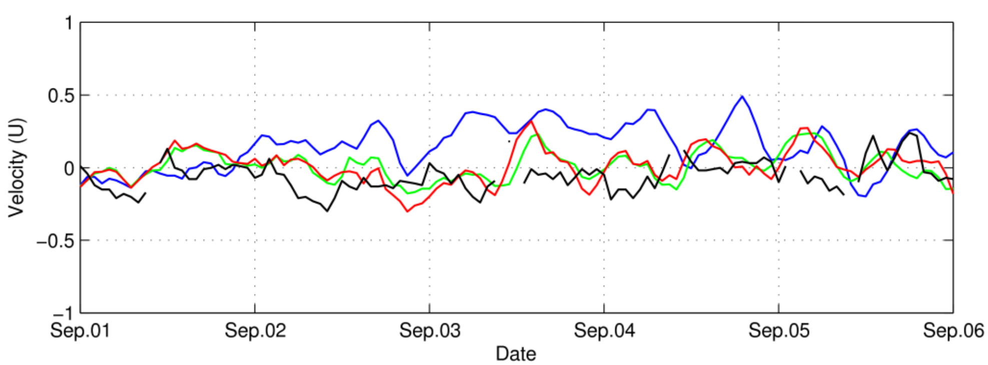
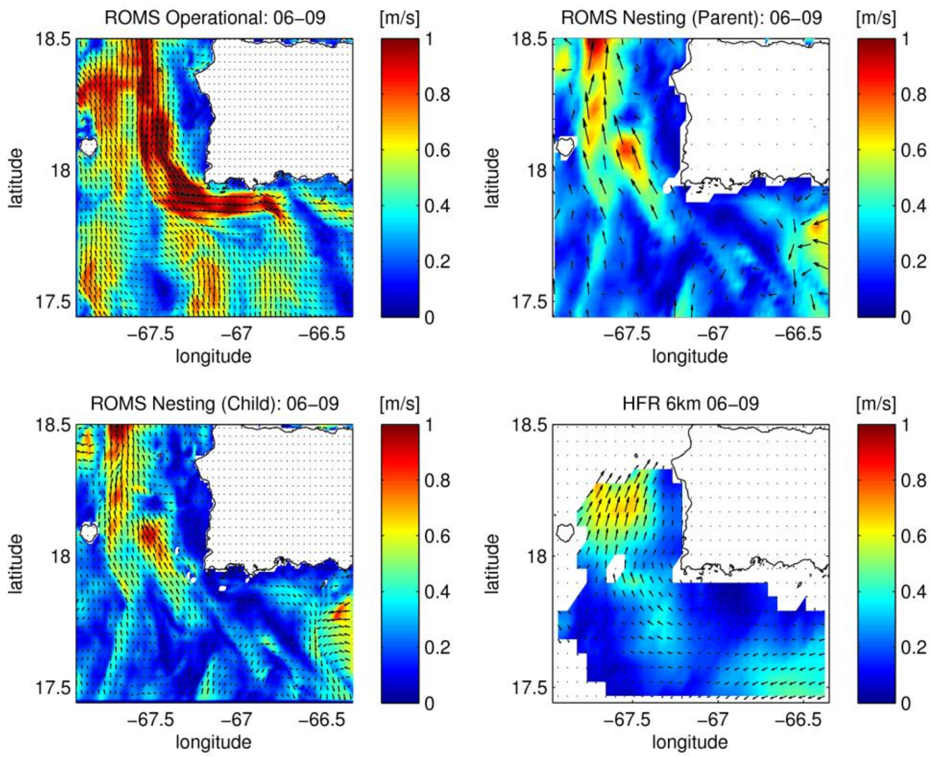


Figure 4: Surface velocity (U) time series at Mona passage. ROMS offline nested to AmSeas is shown in (blue), ROMS with two-way nesting parent grid (red), child grid (green) and the observed velocity by the HFR in (black).



<u>Figure 5</u>: sea surface velocity vectors superposed to color contours of velocity magnitude: ROMS offline nested to AmSeas (operational) and ROMS two-way nested to an intermediate domain solved in ROMS. Results are compared with observations of HFR at Mona passage.

3. <u>Assessment of initial and open boundary conditions</u>: In order to elucidate the differences of different treatments of initial and open boundary conditions, a validation of a 10 day best aggregate output was performed. The configurations used for this validation were: 1) ROMS operational version 2) ROMS with space-dependent nudging to OBC's (ROMS CLIM) 3) ROMS with space dependent nudging and tide filtering (ROMS CLIM + TF) 4) ROMS with space dependent nudging, tide filtering and hot start (ROMS CLIM + TF +HS). Table 1 below summarizes the statistcs of SSH at different NOAA tide gauge locations.

Sea Surface Height Validation at NOAA Tide Stations					
Location	Statistic	ROMS OP	ROMS CLIM	ROMS CLIM+TF	ROMS CLIM+TF+HS
San Juan	CC	0.9152	0.921	0.9133	0.91
	RMSE	0.051	0.048	0.05	0.05
Mona	CC	0.6389	0.7211	0.5903	0.6393
	RMSE	0.0368	0.0346	0.0434	0.0414
Mayaguez	CC	0.9221	0.9347	0.9246	0.8876
	RMSE	0.0431	0.0454	0.0475	0.0544
Magueyes	CC	0.04972	0.6024	0.5509	0.6308
	RMSE	0.484	0.0428	0.0457	0.0405
Arecibo	CC	0.8811	0.8275	0.8184	0.8337
	RMSE	0.0674	0.0771	0.0786	0.0755
Fajardo	CC	0.6169	0.6155	0.6021	0.5944
	RMSE	0.1402	0.1404	0.1421	0.1436
Charlotte Amalie	CC	0.7947	0.7683	0.7275	0.6256
	RMSE	0.0341	0.0376	0.0407	0.0453
Average	CC	0.688374286	0.770071429	0.732442857	0.731628571
	RMSE	0.122371429	0.060842857	0.064	0.064385714

Table 1: Validation of SSH at NOAA tide gauges with ROMS operational configuration, ROMS with climatology nudging, tide filtering and hot start.

MAJOR OUTCOMES

1. **Correction to barotropic velocity**: Computing barotropic velocties correctly is crucial because the barotropic mode in ROMS is used to enforce conservation properties. Calculating the barotropic velocities using the vertical column thickness in ROMS terrain-following formulation yields more realistic and stable results because the flow does not need to adjust the barotropic and baroclinic modes. Furthermore it eliminates spurious currents generated in shallow water were the discrepancies in bathymetry between ROMS and AmSeas is greater.
2. **Assesment of initial and open boundary conditions**: The hot start initialization offers several advantages to operational modelling, conserving the existing structures which are in equilibrium and thus eliminate spurius oscillations during the ramp-up period (first day of hindcast). However, the spin-up simulation is important and the boundary conditions must be properly posed so that the ocean state does not deviate from the actual state. When imposing the open boundary conditions, the space dependent nudging time scales imposed using the climatology files in ROMS dampens some of the oscillations present close to the boundaries yielding more accurate results, especially in SSH. On the other hand, tide filtering improves the behavior of SSH near the boundaries but it does not offer a clear advantage in the 3D currents. Nevertheless, it yields more accurate SSH signals in locations of mixed tides eliminating semi-diurnal frequencies which are often overestimated by the model when barotropic signals are not filtered.
3. **Dynamics of downscaling and 2-way nesting**: The implementation of a 2-way nested ocean modelling system offers two major advantages to the ocean current

forecast: 1) it allows a better representation of the bathymetry at a low computational cost and 2) it eliminates inconsistencies at the boundaries from the child/parent grids. The latter also implies that the flow is able to respond to sudden changes at the boundaries from inflow to outflow or vice versa. As a result, the behaviour at the boundaries is greatly improved and preliminary validations show a better represention of the surface currents when compared to the HFR observations.

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 harbors 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 trajecories 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

2016 Ocean Sciences Meeting

Title: “Predicting drifter trajectories and particle dispersion in the Caribbean using a high resolution coastal ocean forecasting system”

Session (poster): *Coastal Seas and Deep Ocean Connections: Observing and Modeling for Process and Climate Studies II Posters*