An Operational 3D Hydrodynamic Model
of Puerto Rico and U.S. Virgin Islands

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LONG-TERM GOALS

The main goal of the CARICOOS coastal circulation group is to develop an operational forecasting model for Puerto Rico and the U.S. Virgin Islands that will provide high-resolution predictions of water levels, currents, temperature, and salinity. Due to the success of the application of FVCOM in the deep ocean (Chen et al., 2009), the continental shelf (Rego and Li, 2010), and estuaries (Zheng and Weisberg, 2010), FVCOM has been selected as the numerical engine of the CARICOOS circulation forecasting system. The final product will be a web based data visualization system with real-time model validation metrics that allows CARICOOS stakeholders to preview forecasted circulation fields up to 4 days into the future at an unprecedented spatial resolution for the region.

MILESTONES / OBJECTIVES

1. Construct a finer hydrodynamic mesh optimized for operational prediction and implement bathymetric smoothing based on the terrain slope to eliminate spurious pressure-gradient errors. - **completed**
2. Implement forcing of WRF-NMM atmospheric variables (wind and heat flux) - **completed**
3. Compare AMSEAS and Global HYCOM for initial and boundary conditions - **completed**
4. Conduct long-term FVCOM simulations for rigorous model validation and comparison with the AMSEAS model - **completed**
5. Finalize AMAZON EC2 virtual computer set-up for FVCOM - **completed**
6. Deploy FVCOM in operational mode - **completed**

WORK COMPLETED

Mesh optimization (objective 1): A mesh of the PRVI model has been refined and optimized (Figure 1) and spatial resolution now varies from 100m to 10km. The vertical coordinate distribution has 33 sigma levels with higher resolution near the surface and the bottom to better represent momentum, heat transfer, and bottom friction in the boundary layers. The vertical sigma levels are specified as hybrid with a transitional depth of 160 m. In regions deeper than 160 m it has 5 layers with a thickness of 5 meters each near the surface and 5 layers of 5 meters each near the seabed, while the remaining layers are uniformly distributed. In regions shallower than 160 m the sigma coordinates are uniformly distributed.

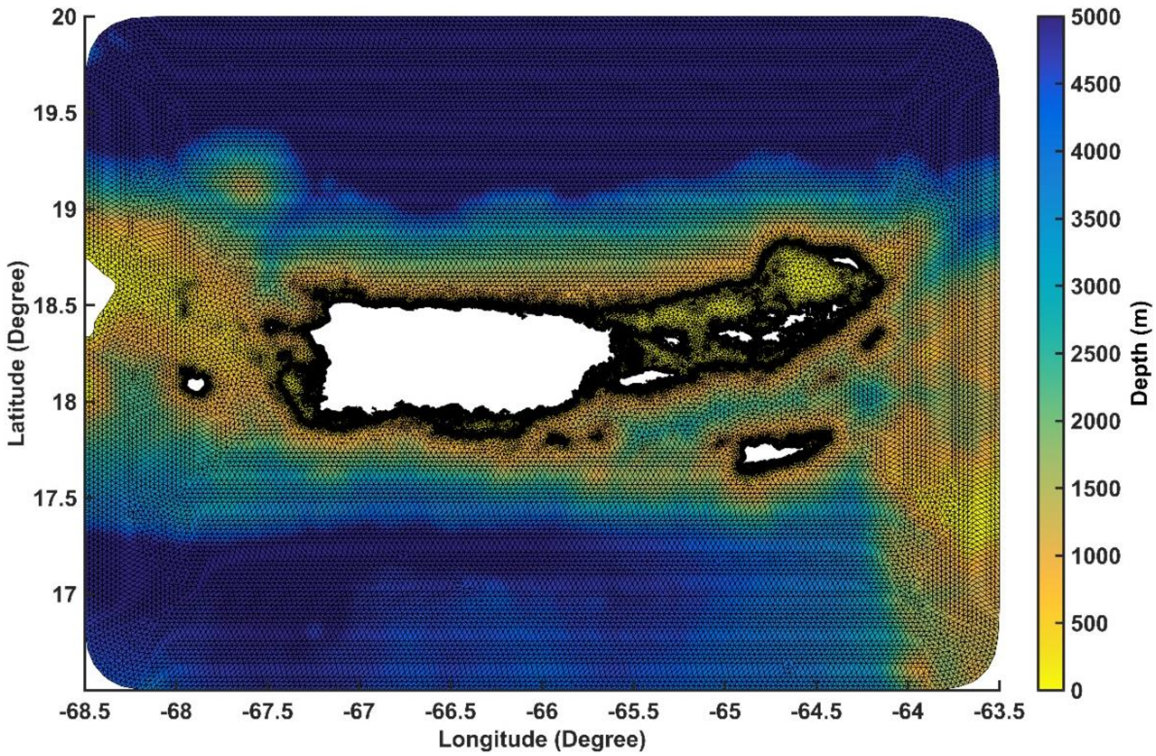

Figure 1: Final PRVI model mesh. This mesh has been nested within Global HYCOM using offline coupling.

Atmospheric forcing (objective 2): The CARICOOS WRF-NMM operational models with 2 km and 6 km spatial resolution and 1 hour temporal resolution provide FVCOM with spatially-varying 10 m wind speed, sea level atmospheric pressure, 2 m relative humidity, 2 m air temperature, surface downward longwave radiation and surface net short wave radiation. FVCOM uses these parameters in the bulk parameterization scheme (Fairall et al., 2003) to compute surface net heat fluxes.

Baroclinic structure (objective 3): Subtidal elevation, temperature and salinity come from the HYCOM + NCODA Global 1/12° model. Horizontal and vertical interpolation methods are carried out to translate from HYCOM + NCODA Global 1/12° Analysis coordinates to the model coordinates. Also, the salinity and temperature at the open boundaries are determined, with nudging, from HYCOM + NCODA Global 1/12° Analysis. No baroclinic velocities are prescribed in the open ocean boundary – the model is allowed to adjust its baroclinic velocity structure using the provided hydrographic structure. Initial salinity and temperature fields are prescribed using standard levels from HYCOM + NCODA Global 1/12° Analysis, and the model is started from rest. After the first simulation each subsequent model run uses the most recent restart file as initial conditions.

U Current Component FVCOM vs AMSEAS Willmott Skill January 2017 to July 2017		
Station	FVCOM	AMSEAS
Ponce Buoy, PR1	50	41.84
San Juan Buoy, PR2	55.23	40.47
Vieques Buoy, PR3	52.92	25.16
USVI Buoy, VI1	47.08	33.18
Bajo de Sico	70.04	35.46

V Current Component FVCOM vs AMSEAS Willmott Skill January 2017 to July 2017		
Station	FVCOM	AMSEAS
Ponce Buoy, PR1	41.5	26.8
San Juan Buoy, PR2	40.7	21.1
Vieques Buoy, PR3	71.8	37.8
USVI Buoy, VI1	59.0	31.6
Bajo de Sico	63.4	44.7

Figure 2. Model performance from a 6-month long simulation, comparing CARICOOS FVCOM vs. AMSEAS

Long-term model validation (objective 4): The model was run for a six month period in order to demonstrate its performance during long integration intervals (e.g. no divergence from climatology) as well as to compare its performance against the NCOM AMSEAS model. The validation was conducted at all CARICOOS buoys and at 44 HF Radar stations. Figure 2 shows the results of the comparison at all buoys and at Bajo de Sico (HFR), using the Willmott skill as the model performance metric. From this analysis it is clear that the CARICOOS FVCOM model provides superior forecast capabilities than NCOM AMSEAS. Further details will be provided in Adail Rivera's MSc. Thesis (in preparation).

Cloud-computing based FVCOM simulations (objective 5): The model has been implemented in an AMAZON EC2 instance. The instance in which the model was run in operational mode for several months is a *c4.8xlarge* type with 36 virtual CPUs and 60 GB of RAM. The operating system running on the amazon EC2 is Centos 7 for AMAZON EC2 instances. Operational simulations in AMAZON EC2 have been paused until funds become available to restart the HPC instance.

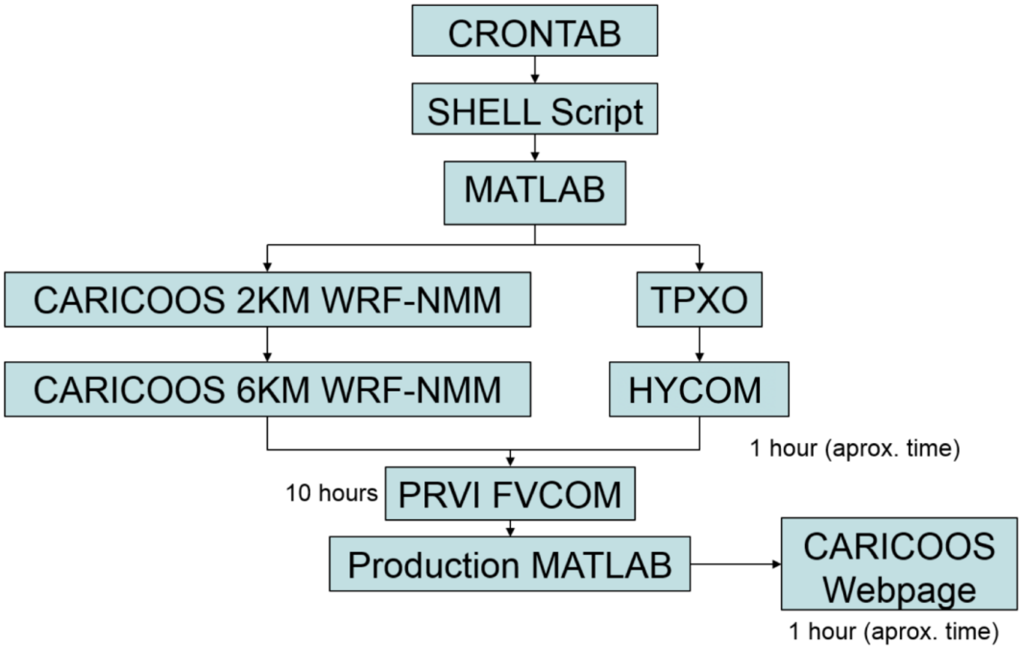

Figure 3: PRVI model operational flowchart scheme (using CPU run-times at CARICOOS' *Corriente* machine)

<u>Operational launch of FVCOM (Objective 6):</u> The CARICOOS FVCOM model was finally launched in operational mode in late May 2018. A simple flowchart describing the operational scheme of the PRVI model is presented in figure 3. It can be seen that it takes approximately 12 hours (in CARICOOS' *Corriente* machine) for the data download, preprocessing, running, and product production and publication components of the forecasting system.

MAJOR OUTCOMES

An operational 3D circulation model for PR/USVI has been designed, implemented and validated. Figures 4, 5 and 6 shows examples of the online model interface. The model is now fully “operational” although it will also be installed in CAOSE’s/CARICOOS’s *Caribe* machine to provide system redundance in separate physical locations (Magueyes Island, Mayaguez).

The CARICOOS FVCOM web page has a variety of tools for data visualization, including real-time model validation using HF Radar and buoy observations (figure 5). Model forecasts are also provided at specific locations (Figure 7).

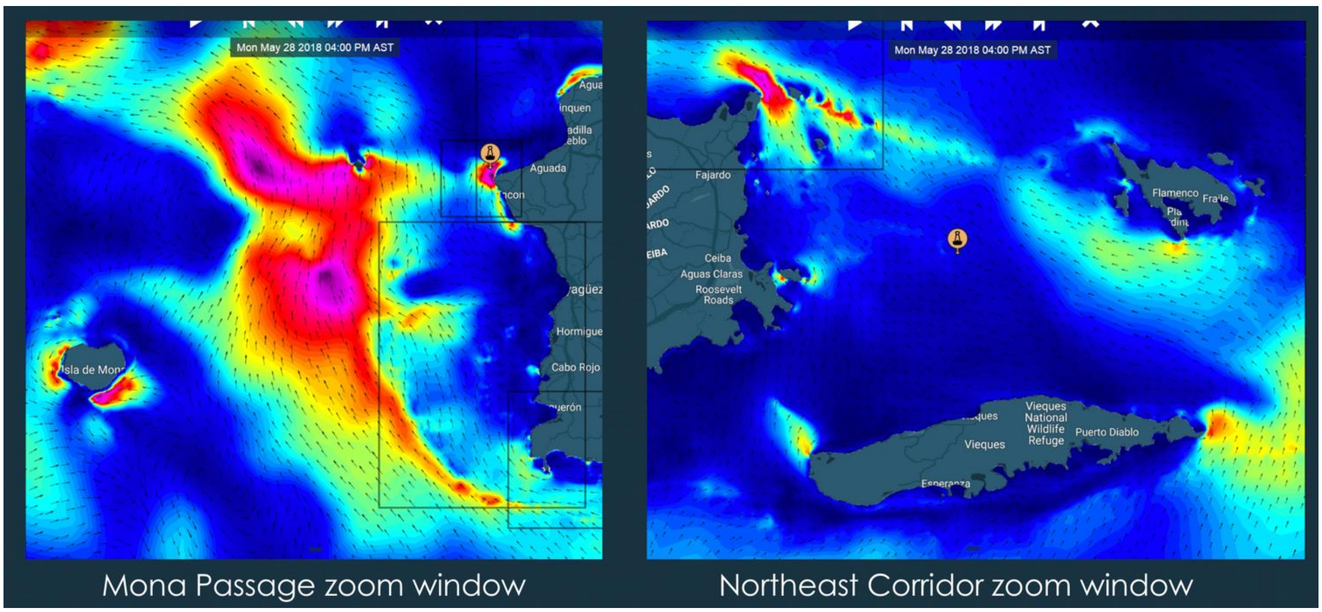

Figure 4: Example of FVCOM contour plots of circulation structure for the Mona Passage (left) and the Vieques n/ Fajardo area (right), as seen in the CARICOOS web page.

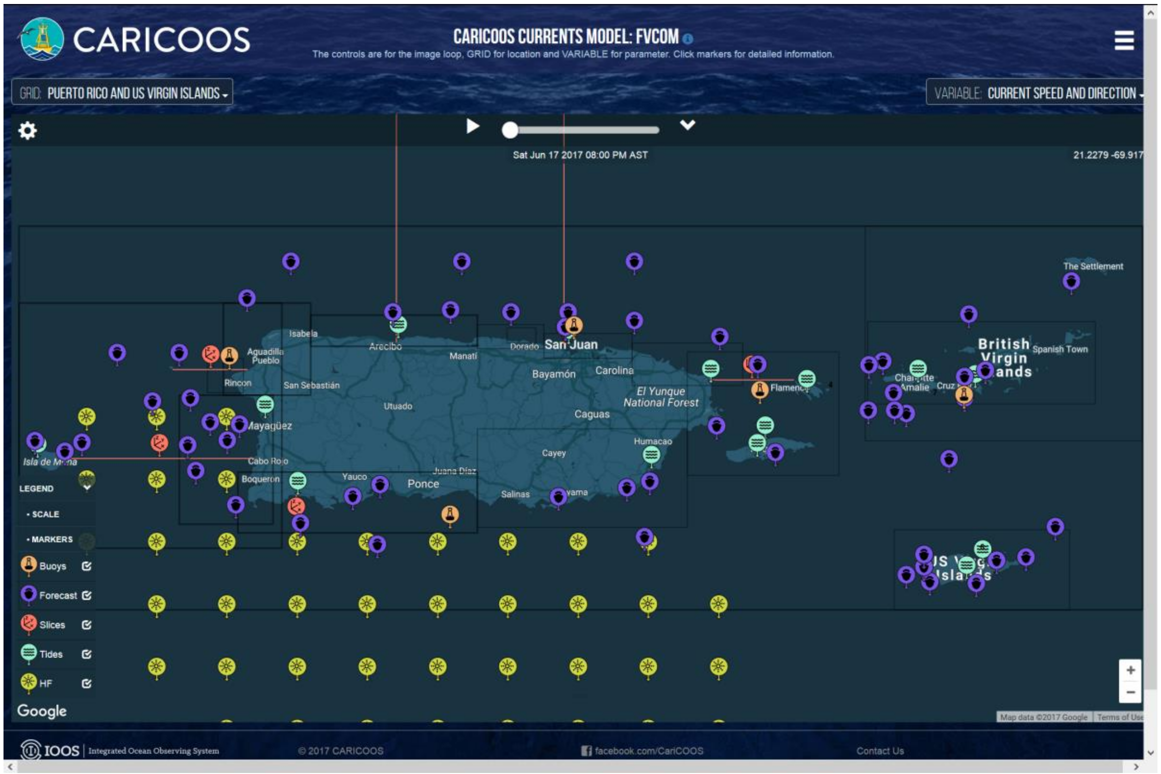

Figure 5: FVCOM validation and visualization tools in CARICOOS web page.

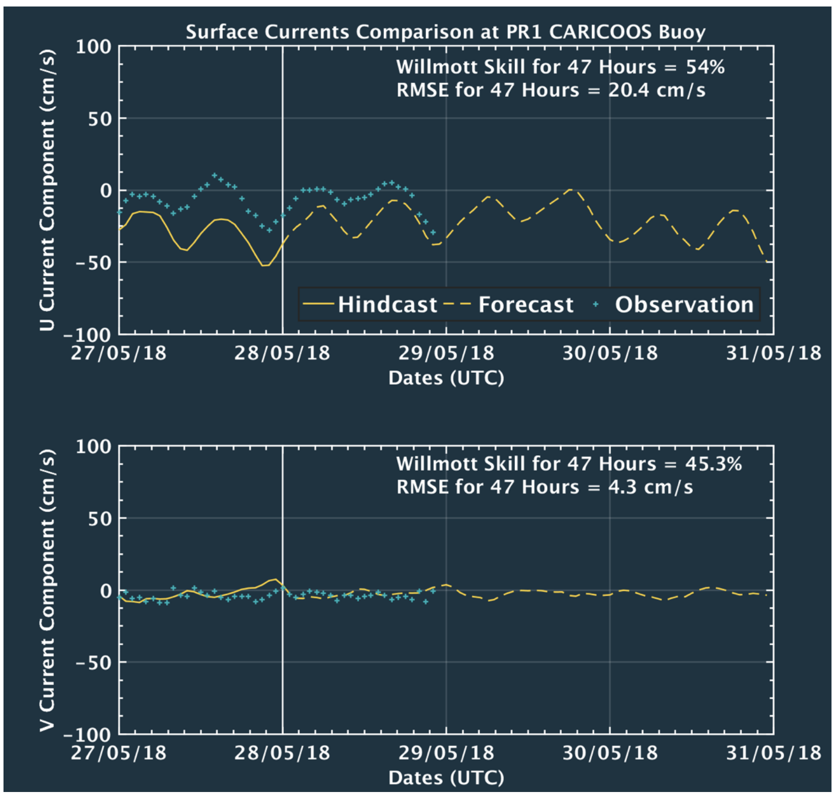

Figure 6: FVCOM real-time comparison with observed near surface currents at CARICOOS PR1 buoy in Ponce.

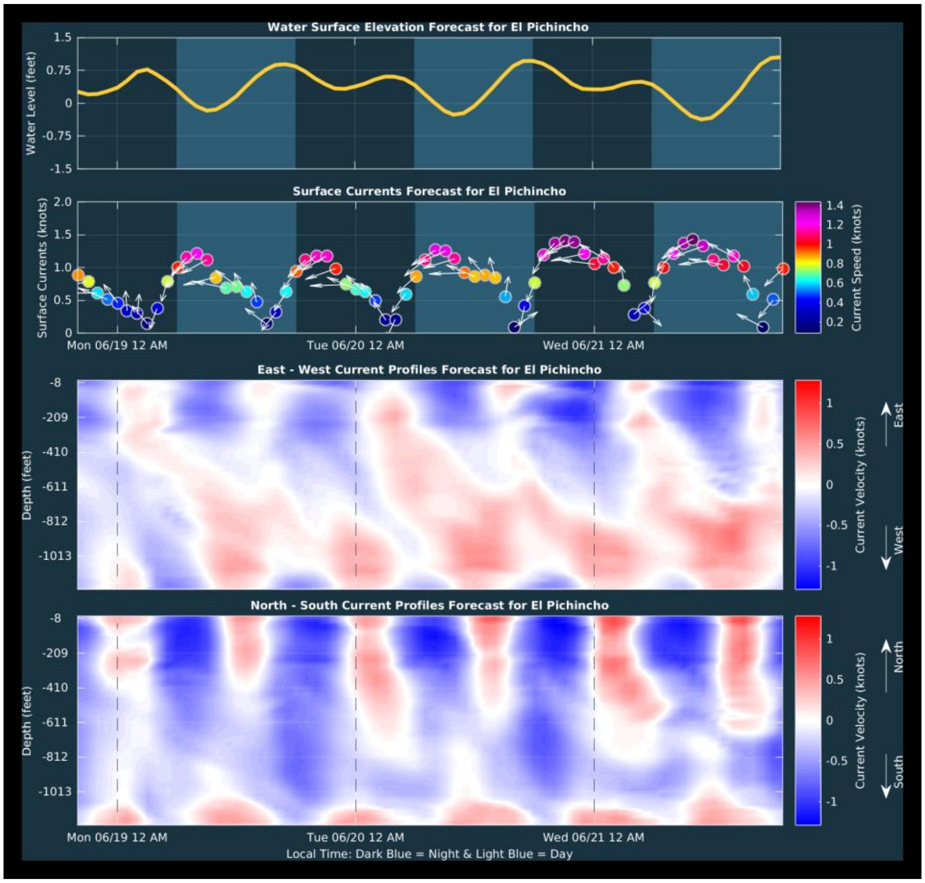

Figure7: Example of FVCOM point forecast at El Pichincho in the Mona passage.

WORK PLAN FOR UPCOMING PERFORMANCE PERIOD (June 1 2018 – Nov 30 2018)

An operational circulation model has been implemented, but significant work remains to further optimize the system, ensure continued uptime, and improve model performance through continuous R&D. Important tasks to be completed in FY2018 include:

- Restart operational FVCOM in AMAZON EC2 when funds become available
- Work with CARICOOS DMAC team to publish FVCOM results in NetCDF format
- Continue model validation, especially in critical nearshore areas
- Operational implementation of wave forcing from CARICOOS SWAN using offline coupling

PUBLICATIONS & PRODUCTS

FVCOM operational web-site:
http://www.caricoos.org/currents/forecast/FVCOM/PRVI/currents

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