Modeling the Impacts of Remote Forcing on Hurricane Storm Surge

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1. Introduction

On July 10, 2005, Hurricane Dennis made landfall just eastward of Pensacola, FL. About 275 km to the east, St. Marks, FL, and neighboring coastal communities of Apalachee Bay experienced a devastating storm surge estimated at 2.5 to 3 m, with even greater sea level maxima at some specific locations, making this the highest storm surge for the area since the 1920's. The surge caused extensive damage to private properties and local infrastructure, effectively isolating several communities. Official forecasts issued through public advisories from the National Hurricane Center (NHC) warned of a storm surge potential of only 4 to 6 feet (approximately 1.5 to 2 m) for this area. The extreme sea level rise is not obviously explained by the relatively weak (borderline tropical storm strength) winds measured along the coast and over the bay. This naturally leads to the question of the source of the additional 1 meter sea level rise in Apalachee Bay.

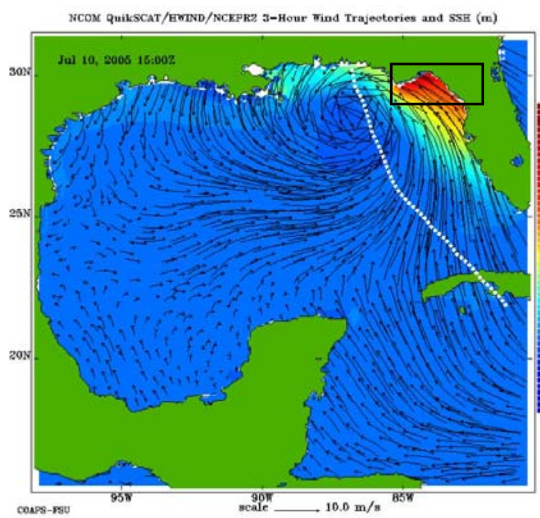

Figure 1. Modeled sea level anomaly with wind trajectories and schematic track of Hurricane Dennis overlaid with the dotted white line. The black box denotes the northeastern Gulf of Mexico nested model domain.

Storm surge models used to provide guidance for these official forecasts have a limited geographic domain, and thus do not include the effects of remotely generated sea level signals. Hurricane Dennis tracked northward, parallel to the West Florida Shelf (Figure 1), for several days. The hypothesis is that northward winds along the shelf generated a high sea level anomaly along the western coast of Florida, which then propagated northward as a topographically trapped wave. The wave was amplified by forcing from the storm, which traveled in the same direction as the shelf wave. This remotely generated wave could have increased the sea level in the northeastern Gulf (Apalachee Bay) by as much as one meter, adding to the local storm surge. This hypothesis is tested by running a series of experiments using nested models. The modeled wave nearly accounts for the excess sea level rise above the forecasts for this storm. The results from this exercise demonstrate the need for revising the modeling system currently used for predicting storm surge to account for remote influences, which can be important for storms the track parallel to coastlines.

2. The Experiments

The Navy Coastal Ocean Model [*Martin*, 2000] is configured for the Gulf of Mexico (GoM) domain (Figure 1) at 1/60° horizontal resolution and run in barotropic mode. A northeastern GoM subdomain is also defined (black box in Figure 1). Radiation open boundary conditions are applied along boundaries not on land. Wind fields are constructed by blending the NOAA AOML Hurricane Research Division H*Wind data [*Powell et al.* 1998] with NCEP Reanalysis II winds using the objective method described in *Morey et al.* [2005], where the H*Wind data are treated as "observations" in the objective method. The objectively gridded wind fields are computed at 1/8° resolution at time steps corresponding to the H*Wind fields (either every 3 or 6 hours) before interpolation to the model domain and model time step. Wind stresses are calculated using a quadratic drag coefficient formulation [*Morey et al.*, 2005].

The GoM barotropic model is integrated from rest applying the wind fields from July 8, 2005 0:00UTC to July 11, 2005 0:00UTC. Two additional experiments are conducted using the northeastern GoM domain. First, the limited-area model is integrated from rest with wind forcing. The radiation boundary condition is used along the western and southern open boundaries. Second, this northeastern GoM domain is nested within the GoM domain, so that open boundary conditions are obtained from the large scale model. No local wind forcing is applied to the northeastern GoM model in this case. These experiments are designed to isolate the impacts of local forcing (in the first case) and remote forcing (in the latter case).

3. Results and Conclusions

The GoM model produces a storm surge maximum in Apalachee Bay as was observed during the storm (Figures 2 and 3). The locally forced sea level response in the northeastern GoM model is very small compared to the sea level rise modeled in the full GoM simulation. In the experiment with the northeastern GoM model forced only at the boundaries by nesting within the GoM simulation, a maximum sea level anomaly on the order of 1m is found in the northern Apalachee Bay.

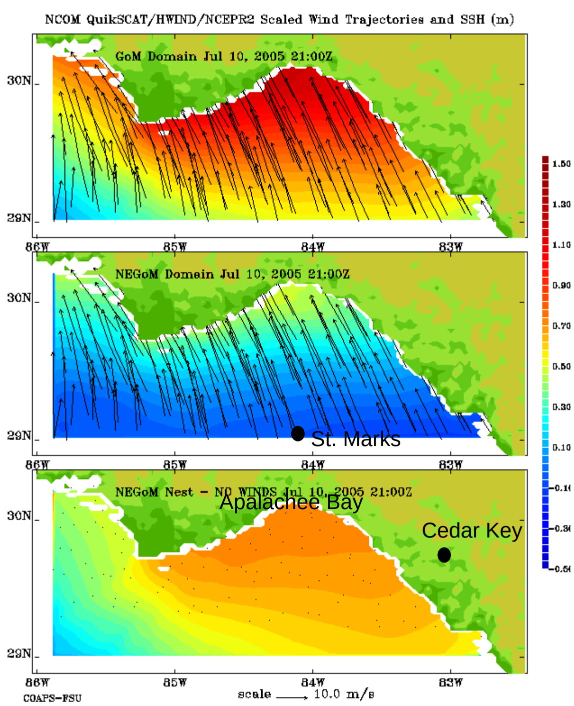

Figure 2. Modeled sea level anomaly with wind trajectories in Apalachee Bay for the northeastern region of the GoM model (top), the northeastern GoM model with local forcing (middle), and the northeastern GoM model with no local forcing nested inside the GoM model (bottom). Note that the experiments did not include the effects of atmospheric pressure, tides, wave setup, and small scale local bathymetric and coastline variations.

The unforced nested northeastern GoM model demonstrates the impacts of the remotely generated sea level signal on the sea level rise in Apalachee Bay. The signal propagated northward as a shelf wave (topographic Rossby Wave), and was reinforced by eastward Ekman transport toward the coast under the along-shore winds at the eastern side of the storm. Idealized shelf experiments have been used to validate this physical mechanism. Analysis of the sea level model fields shows that the sea level responds as a linear combination of the remotely generated sea level and the locally forced sea level (Figure 3).

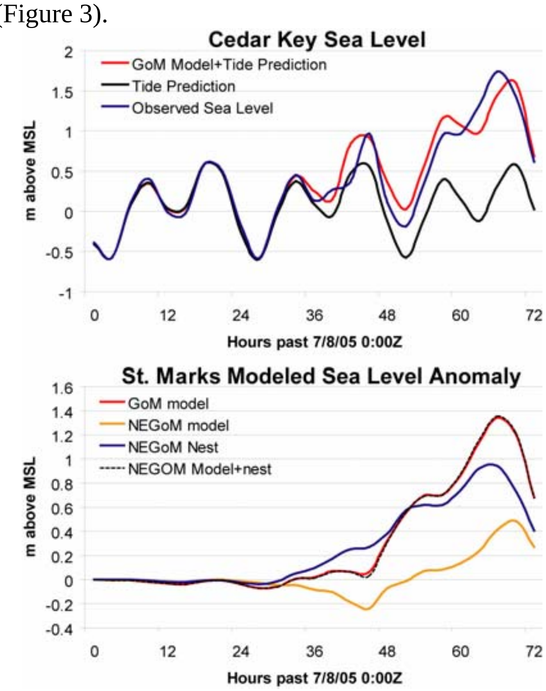

Figure 3. (Top) Modeled sea level anomaly plus tidal predictions plotted against observations at Cedar Key. (Bottom) Model sea level anomaly at St. Marks from the nested northeastern GoM model, locally forced northeastern GoM model, and the full GoM domain. The time series of the two northeastern GoM modeled sea level anomalies are added together and nearly match the full domain solution, demonstrating linearity of the sea level response to local and remote forcing.

Acknowledgements

This project was sponsored by NOAA as part of the Applied Research Center funding to COAPS. Thanks to Paul Martin and Alan Wallcraft at NRL for the NCOM development and their assistance with the model.

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