SEDIMENT TRANSPORT IN ESTUARIES: ESTIMATING BED SHEAR STRESS DISTRIBUTION FROM NUMERICALLY MODELED TIDES IN AN ENERGETIC ESTUARY

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EXECUTIVE SUMMARY

Ocean tides constitute a significant forcing mechanism and are responsible for the transport of salt, sediment, nutrients, and pollutants in most coastal environments. Estuaries are the areas where rivers flow into the ocean and an increase in human population density in their vicinity has a significant anthropogenic impact on them. This impact, in turn, alters the productivity of estuarine environments and results in increased nutrient loading and amplified suspended sediment that reduces water quality. To accurately predict sediment transport, a detailed understanding of the bed shear stress that drives sediment erosion, suspension, and deposition is essential. In this work, we implemented and verified a high-resolution three-dimensional coupled hydrodynamic–wave–sediment transport numerical model for a tidally dominated estuary located in the U.S. Gulf of Maine. When paired with observational data sets, the model successfully predicted the shear stress distribution from the tidal channels across the mudflat.

RESEARCH CHALLENGE

More than half of the world's population lives within 50 miles of a coast, and two-thirds of the world's largest cities are located near estuaries [1]. Estuaries are fertile ecosystems that provide both invaluable ecosystem services and considerable economic benefits to society. The rise in land development and associated increases in impervious surface cover have led to a decline in water quality and estuarine health by depositing higher loads of sediment, nutrients, and pollutants. In order to guide legislative policies and conservation efforts, scientists and environmental managers are relying increasingly on computer models that represent the hydrodynamics, sediment transport, and associated biogeochemical fluxes within these systems. Numerical modeling is a cost-effective way to predict the impact of sediments on estuary-wide nutrient loads, a potentially significant but so far largely neglected source of nutrients.

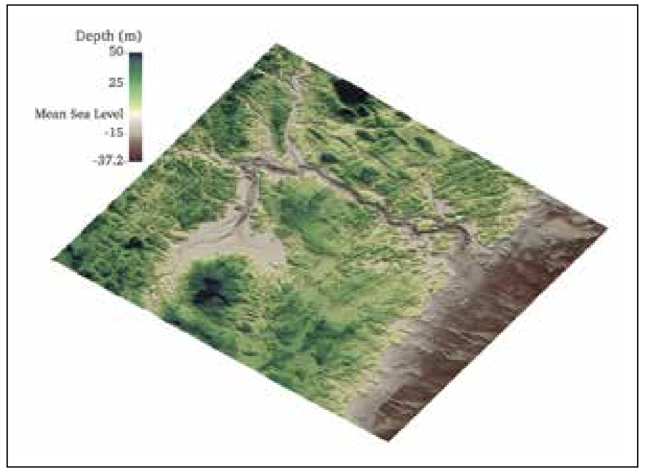

Figure 1: The bathymetry and topography of the Piscataqua River–Great Bay estuary for the 30-meter grid.

In this project, we applied a coupled ocean-sediment transport model to a New England estuary to resolve the importance of tidally induced sediment transport of fine-grained sediment, specifically in estuarine mudflats. Both the suspension and resuspension of fine-grained material are driven by the critical shear stress that is strong enough to overcome the cohesive forces at the bed. Tidal currents are a relatively well-understood forcing mechanism. However, in combination with wind-driven circulation and the wetting and drying of mudflats during a tidal cycle, tidal currents create spatial and temporal variabilities that are hard to sample in the field.

METHODS & CODES

In this work, we used the Regional Ocean Modeling System (ROMS) [2] within the Coupled–Ocean–Atmosphere–Wave–Sediment Transport coupled model framework [3,4]. What makes the estuary we simulated unique is the high-resolution bathymetry and topography used to create the model grid (Fig. 1) as well as extensive observational data sets (1972–present) available for verification of modeled flows. Our first goal was to verify the 30-meter model grid for tides and meteorological forcing using different bottom boundary conditions that directly affect the estimates of shear stress and, thereby, sediment transport. We tested four different bottom boundary conditions for purely tidal and for tidal plus meteorological forcing. We ran each model for 30 days, saving model state data at five-minute intervals. Using time series and statistical analyses, we determined the best-fit bottom boundary condition for the next model runs. Differences between simulations using models with and without meteorological oscillations were found to be negligible, suggesting that interactions among the tides and other low-frequency (weather-forced) mean flows are weak and can be ignored when considering tidal dynamics. This result directly informs the next set of models that will include wind-driven circulation that might have an episodic but nonetheless significant effect on the shear stress distribution within tidally modulated estuaries.

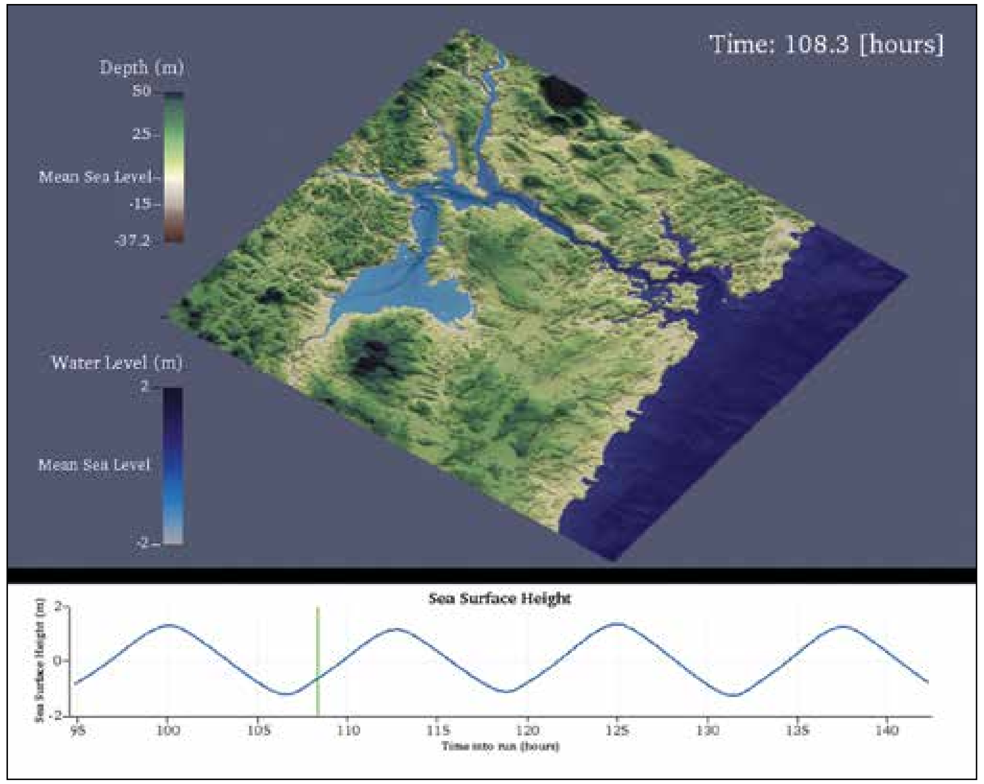

Figure 2: The Piscataqua River-Great Bay estuary at mid-tide—108.3 hours into the model run. Darker blue colors indicate higher water levels than lighter blue colors. The differences in the tidal level from the Atlantic Ocean to the estuary drive large tidal currents that are important for sediment transport.

RESULTS & IMPACT

Comparison of simulation results to experimental observations suggests that the model reproduces the nonlinear tidal behavior and accurately describes the sea surface elevations and velocity throughout the estuary. This result supports the estimates of shear stress distribution, sediment transport, and nutrient fluxes caused by the tidal forcing. Our results suggest that nutrient fluxes form sediment during a typical tidal cycle that are significant and should not be neglected when estimating nutrient loads in estuaries with strong currents and tidal mudflats. Scientists, land managers, and legislators should be aware of this finding when funding projects and determining best practices for estuarine management.

Modeled currents have also aided in the planning of several field studies, particularly the timing and location of deploying instrumentation, which in the past have been difficult to plan efficiently. Future work will include a comparison of a coarse (30-meter) and fine (10-meter) grid to determine how grid resolution affects estimated shear stress distributions. Since grid resolution is directly proportional to computational needs, this is important for estimating computational requirements for such projects. This could potentially lead to better estimates of shear stress, sediment transport, and nutrient loading, particularly for estuaries with small-scale bathymetric features like the tidal channels in this estuary.

With the assistance of the NCSA Visualization Group, the modeled tidal currents and shear stress have been visualized in new and exciting ways (see Figs. 1 and 2). These figures and movies have captured the interest of groups around campus, local scientists, and government agencies.

WHY BLUE WATERS

The major limitations to this research project in the past have been the accessibility of computational resources to resolve these processes at the necessary temporal and spatial scales, and availability of observational data to verify model results. The Blue Waters system provided the required computational power to test models using a higher-resolution 10-meter grid, which was previously infeasible. Further, the project support staff were an invaluable asset in getting this project up and running on Blue Waters.

PUBLICATIONS & DATA SETS

Cook, S., T.C. Lippmann, and J.D. Irish, Modeling nonlinear tidal evolution in an energetic estuary. *Ocean Modeling*, under review (2018).

Salme Cook is a sixth-year PhD student in oceanography at the University of New Hampshire. She is working under the supervision of Tom Lippmann and expects to graduate in May 2019.