THE DISTRIBUTION OF SHEAR STRESS AND NUTRIENTS IN A TIDALLY ENERGETIC ESTUARY: THE ROLE OF NUMERICAL RESOLUTION AND VEGETATION

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EXECUTIVE SUMMARY

Ocean tides represent a major forcing mechanism in many coastal environments, responsible for the transport of salt, temperature, sediment, nutrients, and pollutants. Increases in population density and associated anthropogenic impacts have altered the productivity of estuarine environments, resulting in increased nutrient loading and amplified suspended sediment that reduces water quality. To accurately predict sediment transport, a good understanding of the bed shear stress that drives the sediment erosion, suspension, and deposition is essential. In this work, a high-resolution three-dimensional coupled hydrodynamic–wave–sediment transport numerical model (COAWST) was implemented and verified in a tidally dominated estuary located in the Gulf of Maine. The model was used in conjunction with available observational data sets to predict the shear stress distribution from the tidal channels across the mudflat.

RESEARCH CHALLENGE

The coastal ocean includes diverse ecosystems encompasing both terrestrial and marine habitats that support approximately a third of the world's population [1]. We are only beginning to understand the economic and environmental value of these resources and how to protect them in the face of climate change, sea level rise, extreme storm events, and increased human impact and pollution associated with population growth. These highly nonlinear systems are difficult to observe; however, the advent of numerical models and increased computational resources has made predicting the dynamics of these systems more accessible.

Coastal managers and decision-makers rely on data to understand how to protect them for future generations. Coastal currents and waves and their interactions with vegetation are complex and until recently, researchers have relied on sparse observations and theory alone. With the increase in numerical modeling formulations and computing power, the predictive capability of managers to help create more resilient coastal communities has increased. Better management of human impact and better understanding of the complex biogeochemical interactions and physical properties of these systems can help us sustainably interact and rely on them.

An open question this research addressed is the resolution required to capture the shallow water dynamics and how to couple these higher-resolution models to coarser regional and global models. In this work, the PI employed a validated high-resolution numerical model of a New Hampshire estuary (Fig. 1) to estimate the nutrient loading from sediments in the estuary to the coastal ocean.

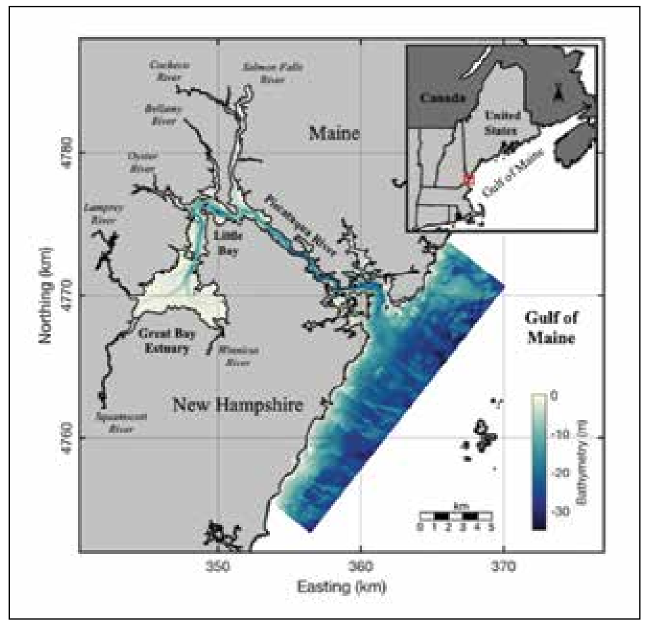

Figure 1: The Great Bay estuary and model bathymetry within the Gulf of Maine.

METHODS & CODES

This research was unique in that it relied on both collecting observational data in the estuary and the use of numerical model data sets. The observations were used to validate the model for currents and estimated shear stress in several locations. This provided fidelity in the overall distribution of shear stress in currents temporally and spatially within the estuary. The numerical model used was the COAWST modeling system. The 10-meter and 30-meter grid models were forced on the ocean side with five tidal constituents, three semidiurnal (M2, S2, N2) and two diurnal (O1, K1), using the Oregon State University Tidal Prediction Software package with the United States East Coast Regional Tidal Solution. River flow is generally low in the summer months, and since this modeling effort was representing those conditions, river flow was not considered. Shear stress was determined using a logarithmic bottom boundary layer assumption that is common in modeling shallow coastal environments.

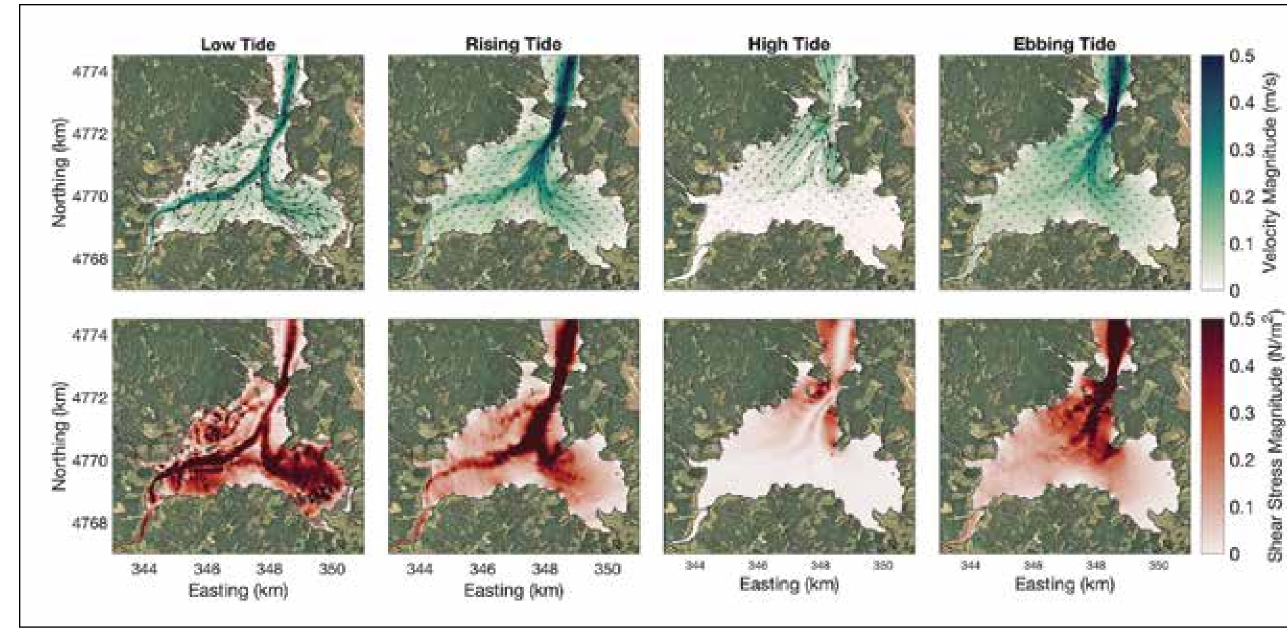

Figure 2: Spatial variability in velocity and shear stress for low (a), rising (b), high (c), and ebbing (d) tide. Velocity arrow resolution is decimated by a factor of 3.

RESULTS & IMPACT

The results of this study present an estimate of spatial distribution of shear stress in a tidally dominant estuary using a verified numerical model and compared with stress estimates from observed currents at several locations. The spatial distribution of depth averaged velocities and shear stress are presented in Fig. 2 for four stages of the tide. The model runs (not shown) included the effects of vegetation and resolution and found that incorporating vegetation was an important improvement to the model, whereas the higher-resolution 10-meter model vs. the coarser-resolution 30-meter model had little effect on estimates. This provides a significant savings in computational resources when considering this issue. Future work looking at the distribution of waves or sediment types might require the higher-resolution model.

The distributions of shear stress were then used to estimate internal nutrient loading from sediments for a typical tidal cycle, spring, and neap cycle, and averaged over a month. When compared with rivers, model results suggest that internal sources of nutrient loads from sediment are on the same order as rivers for at least half of the year. These results indicate that when eelgrass populations are healthy and abundant, they lower the availability of sediment for resuspension and subsequent release of nutrients. This study demonstrates that a coupled hydrodynamic–vegetation model is capable of estimating the distribution of shear stress for a tidally dominant estuary.

Although nutrient loading from sediments is considered an internal load to the system, estuarine managers do not incorporate it into current nutrient loading estimates. This is not a process that can be mitigated; therefore, greater attention must be placed on those processes that can be controlled in terms of impervious surface cover, fertilizer use in residential and agricultural lands, industrial outputs of nitrogen and phosphorus, and wastewater treatment plants.

WHY BLUE WATERS

The Blue Waters system and associated project staff were incredibly reliable and provided a powerful tool that was integral for this research, whereas the other machines the PI has used were incapable. The professionalism and efficient nature of the project staff were and are simply unparalleled, and have created a new standard in high-performance computing scientific support.

PUBLICATIONS & DATA SETS

S. Cook, T. C. Lippmann, and J. D. Irish, "Modeling nonlinear tidal evolution in an energetic estuary," *Ocean Model.*, vol. 136; pp. 13–27, Apr. 2019.

Salme Cook received a Ph.D. in oceanography from the University of New Hampshire in May 2019, having worked under the direction of Tom Lippmann.