Tides and Storm-Surge Modeling Using MPAS-Ocean

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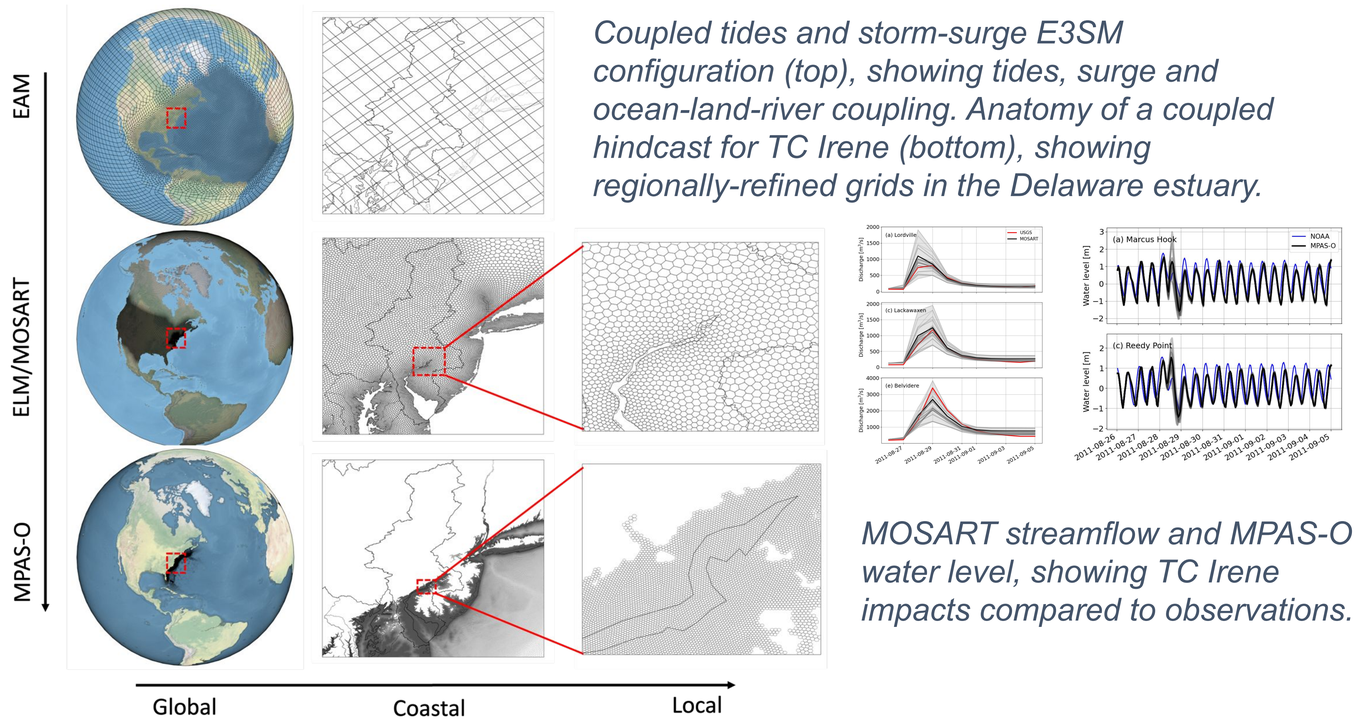
Tides and storm-surge dynamics are important contributions to extreme events and global climate processes, responsible for significant sea surface height fluctuations in nearshore regions as well as mixing processes in deep oceans and coastal estuaries. The action of the tidal cycle and storm-driven surge impacts can combine to generate substantial flooding and inundation in low lying coastal regions, posing significant risk to communities and infrastructure. Using a newly developed barotropic configuration of MPAS-Ocean, in which depth-averaged dynamics are solved using a simplified, single-layer approach, the Integrated Coastal Modeling (ICoM) team are extending E3SM capabilities to capture these events by:

- Understanding the impact of future sea-level rise and changes to polar sea-ice and land-ice forcing on global tides, assessing changes in the amplitude and phase of tides due to climate change, with a focus on shallow shelf and coastal regions.

- Developing new parameterizations of internal tide dynamics to represent barotropic-to-baroclinic transfers that occur near rapid changes in the ocean's bathymetry and/or stratification. This new formulation improves the accuracy of the tides model reducing the RMS error from 5cm to 3cm.

- Developing new subgrid parameterizations of inundation and drag to capture the effect of unresolved fine scale interactions within the ocean bottom boundary layer and due to wetting & drying processes. A very high resolution subgrid representation of bathymetry is used within each MPAS-Ocean mesh cell, allowing a high fidelity representation of these processes at relatively coarse model resolutions.

- Developing novel 'Local' Time-Stepping (LTS) methods for time integration, that tailor the length of the model's time-step to the local resolution of the mesh — focusing computational resources in the highly resolved regions of a simulation. These improvements have been found to make the model as much as four times faster to run, enabling the solution of storm-surge problems at resolutions as low as 125m.



Coupled tides and storm-surge E3SM configuration (top), showing tides, surge and ocean-land-river coupling. Anatomy of a coupled hindcast for TC Irene (bottom), showing regionally-refined grids in the Delaware estuary.

MOSART streamflow and MPAS-O water level, showing TC Irene impacts compared to observations.

- Barton, K.N., Pal, N., Brus, S.R., Petersen, M.R., Arbic, B.K., Engwirda, D., Roberts, A.F., Westerink, J.J., Wirasaet, D. and Schindelegger, M., 2022. Global Barotropic Tide Modeling Using Inline Self-Attraction and Loading in MPAS-Ocean. Journal of Advances in Modeling Earth Systems, 14(11), p.e2022MS003207.

- Lilly, J.R., Capodaglio, G., Petersen, M.R., Brus, S.R., Engwirda, D. and Higdon, R.L., 2023. Storm Surge Modeling as an Application of Local Time-Stepping in MPAS-Ocean. Journal of Advances in Modeling Earth Systems, 15(1), p.e2022MS003327.

- Brus, S.R., Barton, K.N., Pal, N., Roberts, A.F., Engwirda, D., Petersen, M.R., Arbic, B.K., Wirasaet, D., Westerink, J.J. and Schindelegger, M., 2023. Scalable self attraction and loading calculations for unstructured ocean tide models. Ocean Modelling, p.102160.

E3SM Energy Exascale Earth System Model

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