Earth & Environmental Systems Modeling

ESMD Coastal Overview

LeAnn Conlon, Gautam Bisht, Steven Brus, Rich Fiorella, Nicole Jeffery, Luke Van Roekel

U.S. DEPARTMENT OF ENERGY | Office of Science

2024 EESM PI Meeting
August 6–9, 2024

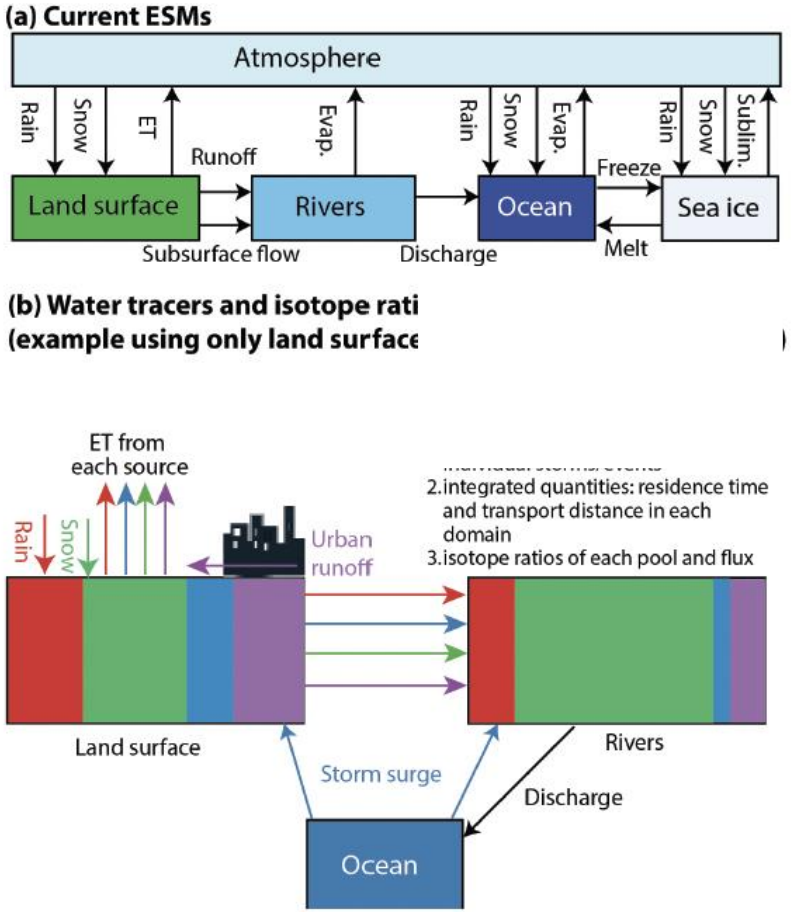
ESMD Coastal efforts are very broad

- E3SM, ICoM, InteRFACE, SciDAC, COMPASS-GLM, ECR
  - No time to cover them all!
- Highlight a few important efforts and topics in the coastal space
  - Tracking water in the coupled system
  - Tides
  - Coastal inundation
  - Coastal BGC
  - Arctic watersheds
  - Rivers
  - Great Lakes

Coastal Water Cycle

Probing water-cycle processes and extremes in coastal and urban environments using water isotope ratio tracers and numerical tags

- This project will add water tracers/isotopes to EAMxx, ELM (in collaboration), and MOSART, and work toward coupling these systems
- The new tracer infrastructure will increase capability to understand coastal-urban change, the impacts of urbanization on coasts and extreme events, and the efficacy of urban-coastal resilience strategies



PI: Rich Fiorella

Ocean and Sea ice

Tides in MPAS-Ocean

- MPAS-Ocean is capable of accurately simulating tides
  - Computationally efficient inline self attraction and loading (Barton et al. 2022, Brus et al. 2023)
  - Ice shelf cavities (Pal et al. 2022)
  - Topographic wave drag parameterization
- Variable resolution meshes are required to resolve coasts, shelf-breaks, mid-ocean ridges.
- Tides are dynamically changing: SLR, ocean stratification, ice shelf geometry (Barton et al. in prep).

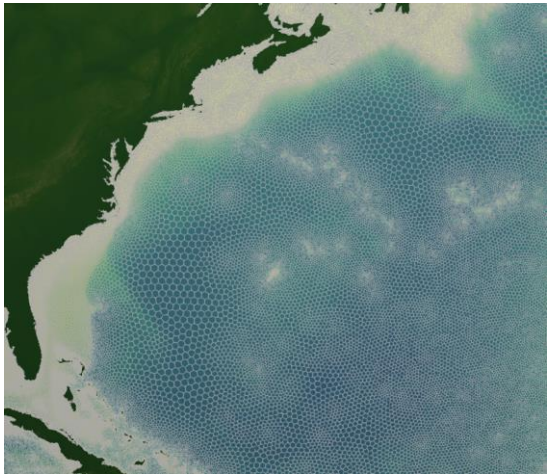
Tidal Potential

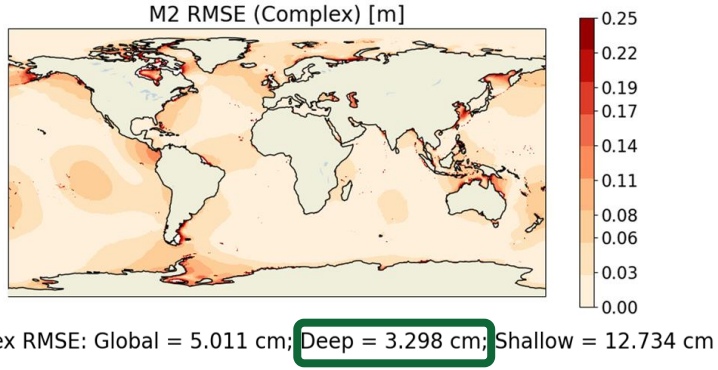
$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\cdot\nabla)\mathbf{u} + f\mathbf{k}\times\mathbf{u} = -g\nabla(\zeta - \zeta_{EQ} - \zeta_{SAL}) + F$$

Inline SAL

$$\zeta_{SAL}(\theta,\phi) = \sum_{n=0}^{N}\sum_{m=-n}^{n} \frac{3\rho_w(1+k'_n+h'_n)}{\rho_e(2n+1)}\zeta^{(n,m)}Y^{(n,m)}(\theta,\phi)$$

Variable resolution mesh: 45 to 5 km

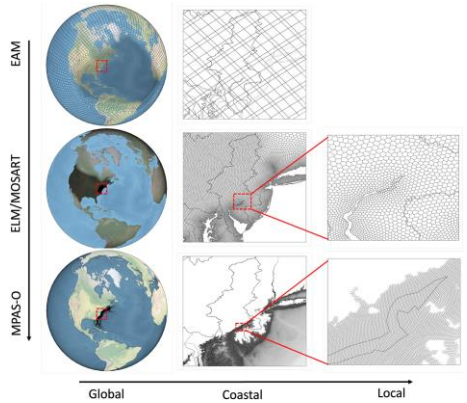




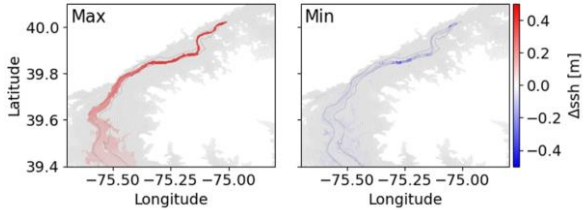
Complex RMSE: Global = 5.011 cm; Deep = 3.298 cm; Shallow = 12.734 cm

Coastal Inundation in E3SM

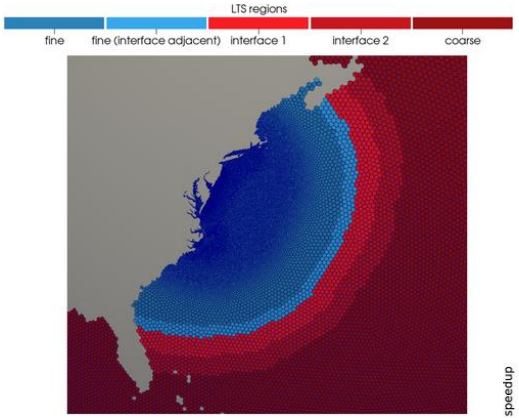
- Unified framework for two-way land/river/ocean coupling allows for assessment of compound flooding effects



Differences between 1-way and 2-way coupling

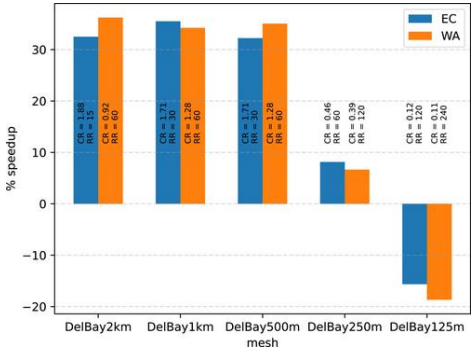


- Local time-stepping (LTS) is a promising approach for increasing the efficiency of high coastal resolution



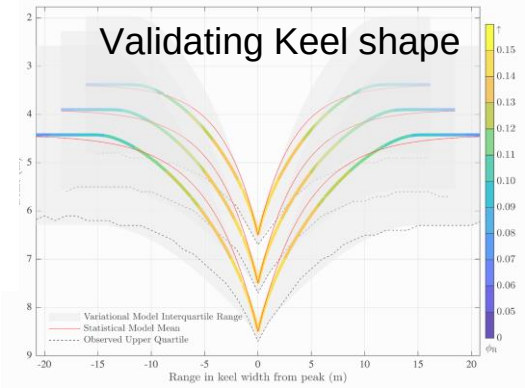
Lilly et al. 2023

LTS speedup



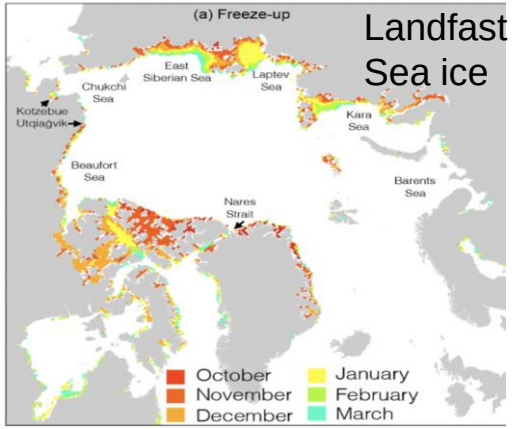
Feng et al. 2024

MPAS-Seaice: Improving the shape of Sea ice ridges for coastal sea ice model

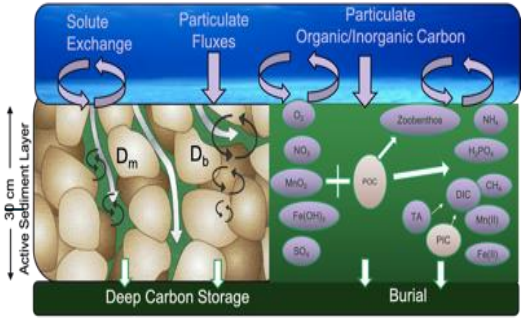


Metzger et al. 2021

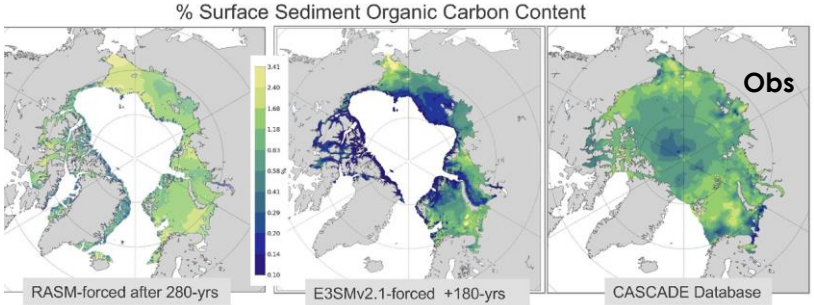
Future efforts – Improving Multi-phase coupling in E3SM in the littoral zone for landfast sea ice modeling



MPAS-Ocean: New Seafloor (benthic) BGC submodule for Arctic coastal and shelf waters dynamic modeling of sediment diagenesis



Equilibrium % Organic Carbon in Surface Sediments



RASM-forced E3SMv2-forced

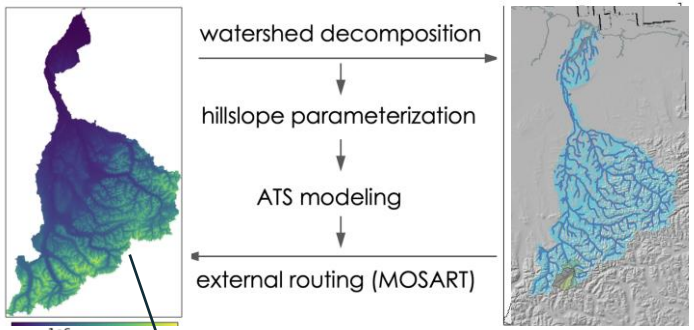
Jeffery

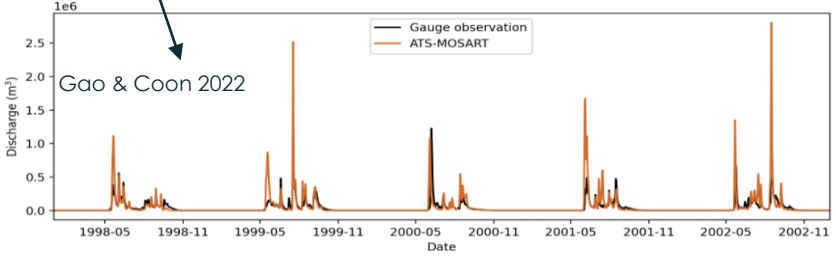
Future efforts 2-way coupling with MarBL for evaluating ocean biogeochemical feedbacks with the seafloor

Rivers, Lakes, and Watersheds

Arctic Watersheds

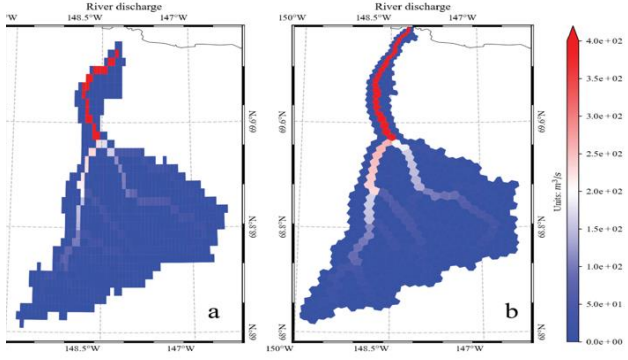
Multi-scale methods for Arctic watershed modeling – Coupling process-rich models (ATS) to understand the impacts of lateral flow on Arctic river outflow (MOSART) **with RGMA**





Future efforts use ML approaches to reduce the hillslope number by an order of magnitude to enable ***multiple watersheds*** and ***century*** simulations

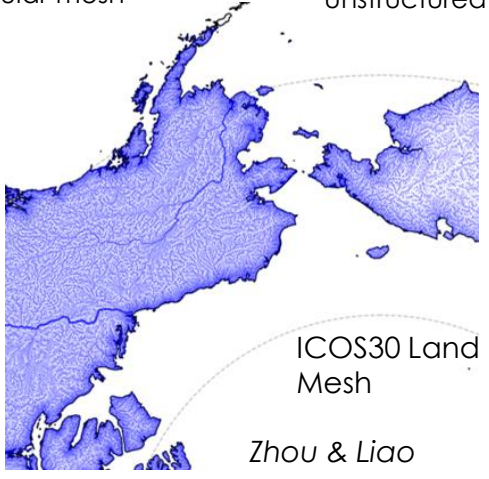
MOSART: A novel approach to construct mesh-independent river networks (with ICoM) Sagavanirktok River Basin, AK



Regular mesh

Unstructured Mesh

Future efforts - Towards a **Land-River-Marine Unified** Mesh for the Arctic

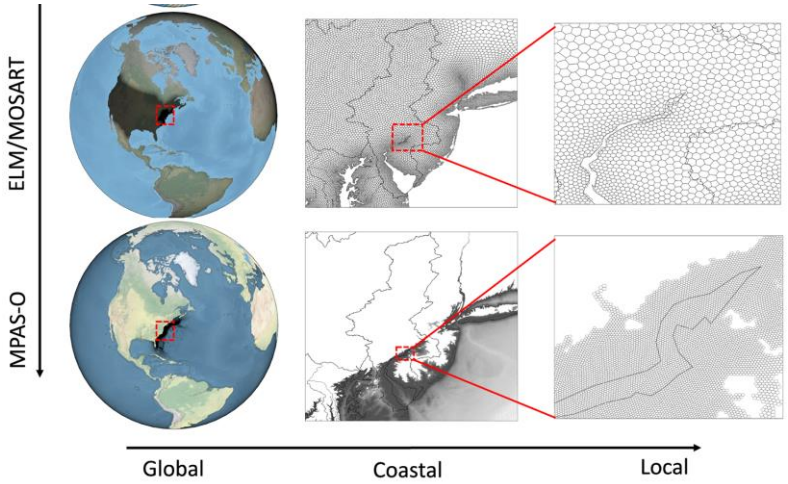


ICOS30 Land Mesh

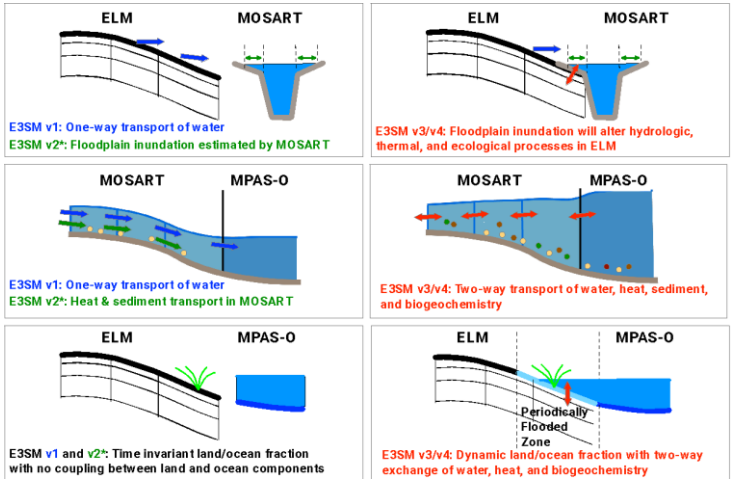
Zhou & Liao

New & Upcoming Modeling Capabilities across the land-river-ocean interface in E3SM

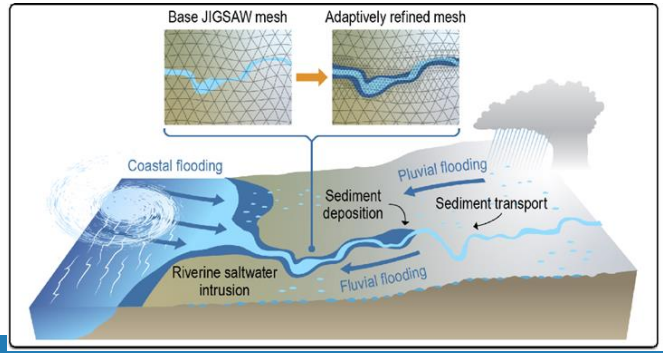
Unified Surface Mesh: ICoM

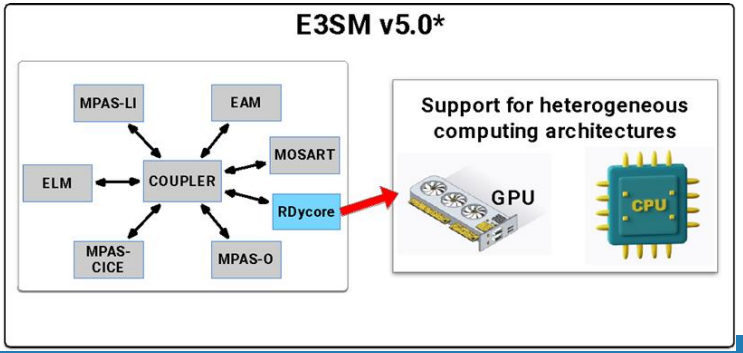


Two-way transport of water, nutrients, and sediments between land, river, and ocean: ICoM & E3SM



A River Dynamical Core (RDycore) is being developed to model compound flooding, sediment dynamics, and saltwater intrusion: SciDAC5

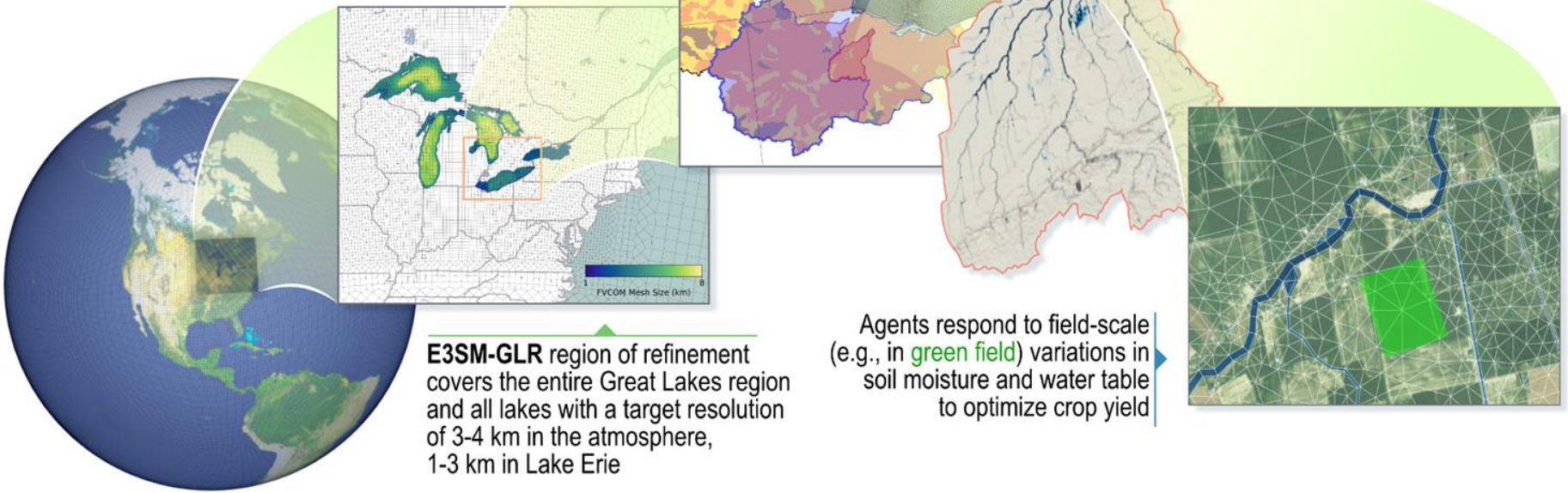




COMPASS-GLM brings together a hierarchy of models with a broad range of resolution

CHANGE-ABM and **ELM-ATS** target domain (in blue) focuses on intensive Ag chem. fert. region (in orange) to capture event scale nutrient export

High-res agricultural watershed model (e.g., Portage and Maumee Rivers, left) resolves key nutrient transport processes, like artificial drainage



E3SM-GLR region of refinement covers the entire Great Lakes region and all lakes with a target resolution of 3-4 km in the atmosphere, 1-3 km in Lake Erie

Agents respond to field-scale (e.g., in green field) variations in soil moisture and water table to optimize crop yield

Outstanding Questions and Grand Challenges

- E3SM and ESMs more broadly are likely not the right tools for all coastal questions
  - Time steps
  - Missing couplings and physics
  - Model assumptions
  - Feedback from coast to large scale may be small
- How can the full range of models/tools be interfaced to answer important science questions?
  - Data formats? In situ vs. offline coupling?
- What key model developments are needed for coastal zones?
  - A few ideas: Regional complexity for BGC, scale aware physics, coupling capability to MSD ‘use case’ models, improved wave physics. Computational improvements (performance, stability, etc…)