Linking coastal flooding impacts and climate change within the Energy Exascale Earth System Model (E3SM)

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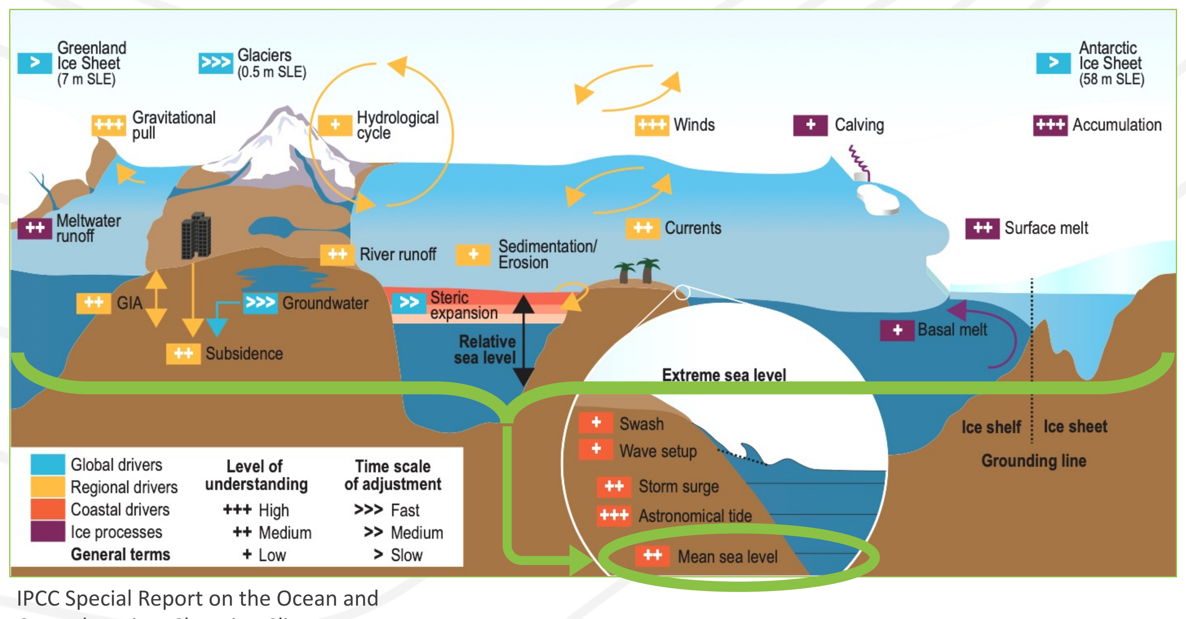
1. Multiscale Barotropic/Baroclinic Coupling

❑ MOTIVATION

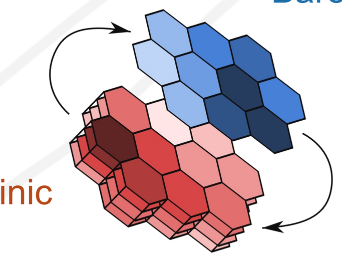
- Coastal water levels are influenced by a number of regional and global processes.
- Due to the disparate scales involved, these processes have traditionally been modeled separately.
- This has limited our understanding of how coastal water level processes interact in a changing climate.



IPCC Special Report on the Ocean and Cryosphere in a Changing Climate

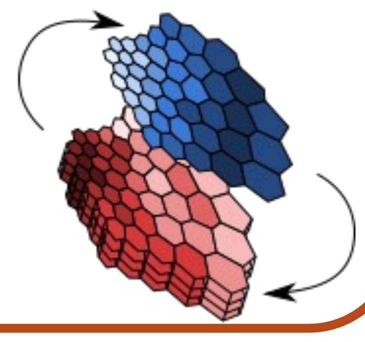
- Coastal-urban flooding affects large portions of the global population.
- Understanding risks from both extreme and "nuisance" flooding is essential to adaptation strategies.
- High resolution models (O(10-100m)) are critical to accurately predicting coastal water levels at relevant scales.

Standard resolution OGCM
Grid resolution is too coarse

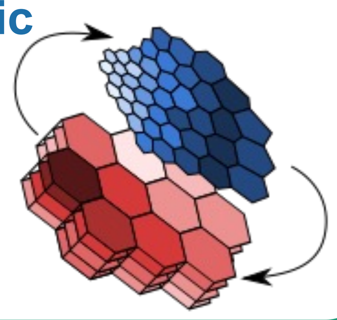


Coastal barotropic model
Not appropriate for use within ESMs

High resolution OGCM
Prohibitively expensive

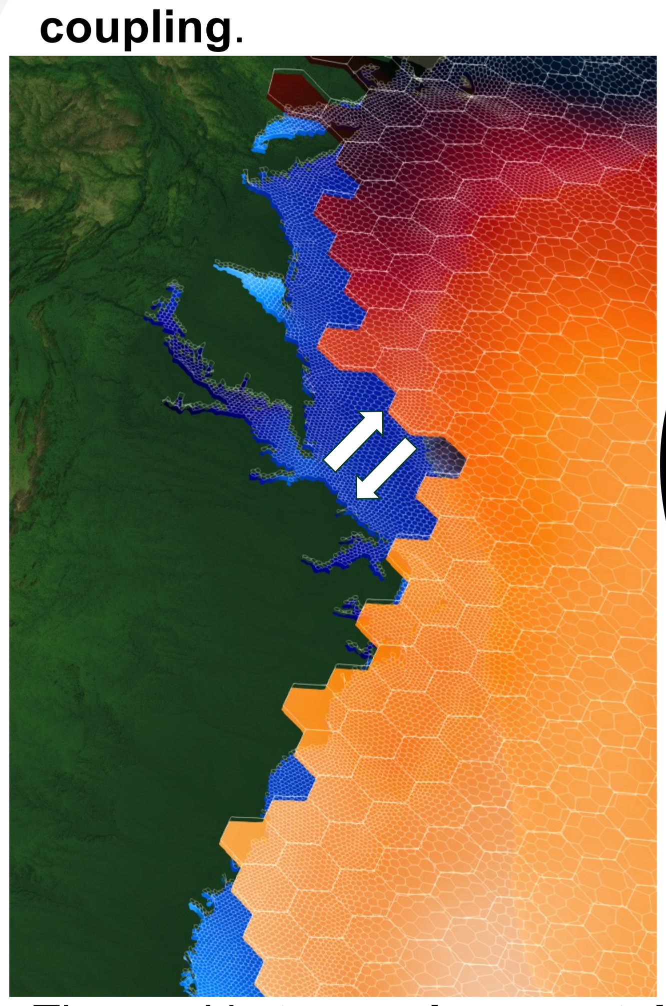


Coupled, high resolution barotropic/standard resolution baroclinic
Capture coastal water levels with connections to global circulation



❑ APPROACH

Extend the temporal mode splitting methods, which are commonly used in OGCMs to separate fast barotropic and slow baroclinic modes, with a **multiscale spatial coupling**.



The goal is **to resolve coastal water level variability** with connections to the larger scale dynamic sea level

Primitive equations:

$$\nabla \cdot \mathbf{u} + \frac{\partial w}{\partial z} = 0$$

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\cdot\nabla)\mathbf{u} + w\frac{\partial \mathbf{u}}{\partial z} + f\mathbf{k}\times\mathbf{u} = -g\nabla\left(\eta + \int_z^{\eta}\left(\frac{\rho(\Theta,S)-\rho_0}{\rho_0}\right)dz'\right) + D$$

Velocity Separation:

$$\mathbf{u}' = \mathbf{u} - \bar{\mathbf{u}}$$

Baroclinic Barotropic

Mode Split Equations:

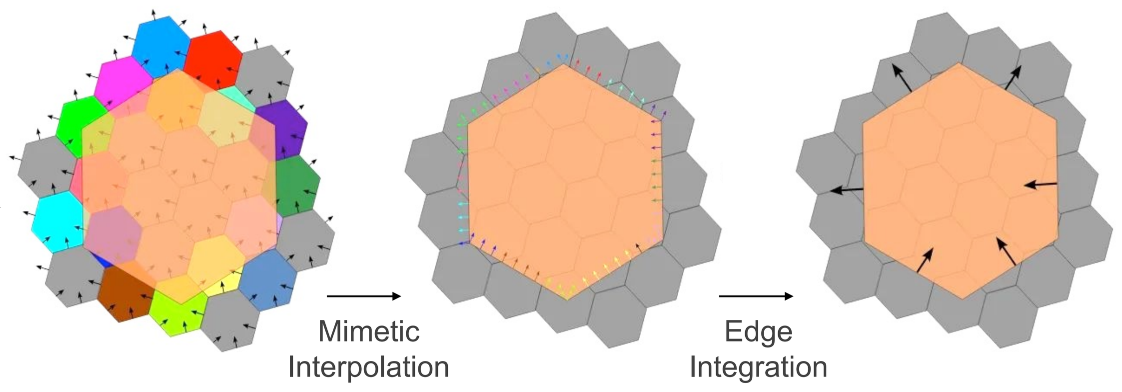
Remap from high resolution to standard resolution $\bar{\mathbf{u}}H$

$$\frac{\partial \eta}{\partial t} + \nabla\cdot(\bar{\mathbf{u}}H) = 0$$

$$\frac{\partial \bar{\mathbf{u}}}{\partial t} + f\mathbf{k}\times\bar{\mathbf{u}} = -g\nabla\eta + G$$

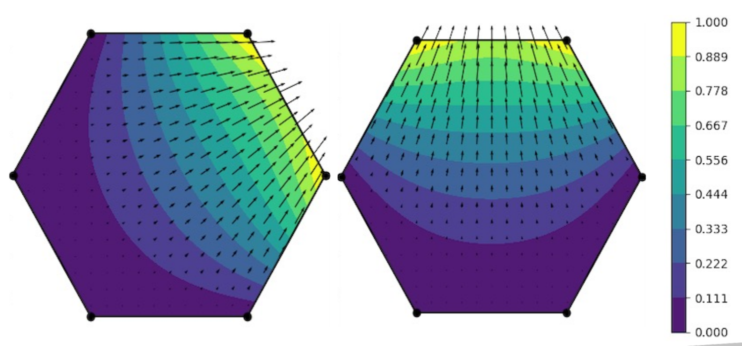
G Remap from standard resolution to high resolution

$$\frac{\partial \mathbf{u}'}{\partial t} + (\mathbf{u}\cdot\nabla)\mathbf{u} + w\frac{\partial \mathbf{u}}{\partial z} + f\mathbf{k}\times\mathbf{u}' = -g\nabla\int_{-z}^{\eta}\left(\frac{\rho(\Theta,S)-\rho_0}{\rho_0}\right)dz' + D - G$$



Basis functions satisfy:

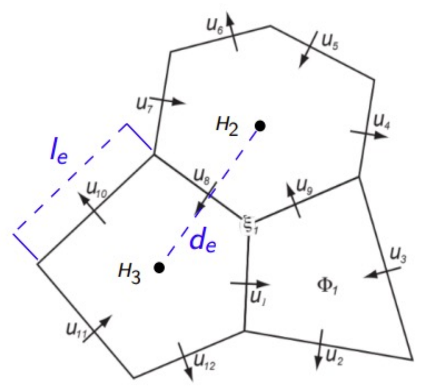
$$\int_{e'} \phi_e \cdot d\mathbf{x} = \delta_{e',e}$$



2. Subgrid Scale Approaches for Inundation

❑ APPROACH

Single layer MPAS-Ocean semi-discrete scheme:



$$\frac{dH_i}{dt} = -\frac{1}{A_i}\sum_{e\in EC(i)} u_{n,e}H_e l_e$$

$$\frac{du_{n,e}}{dt} = \frac{1}{d_e}\sum_{i\in CE(e)} -n_{e,i}\eta_i - \frac{C_f}{H_e}|\mathbf{u}_e|u_{n,e} + \frac{1}{H_e}F_{n,e} + \text{TRSK\_adv\_scheme} + \cdots$$

In MPAS-O, as usual:

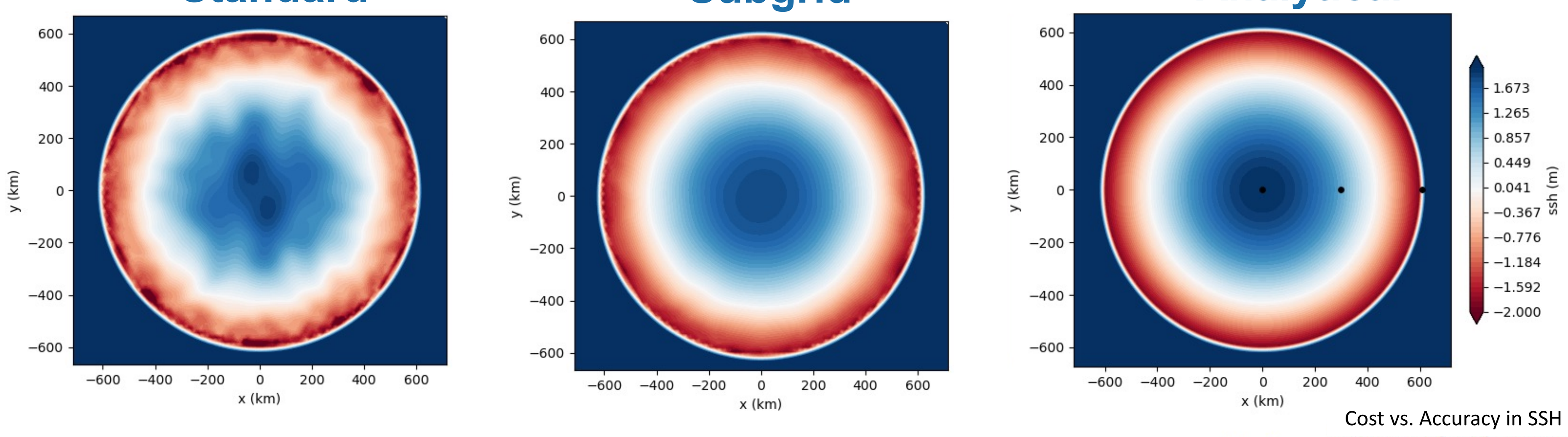
$$H_i = \eta_i + b_i$$

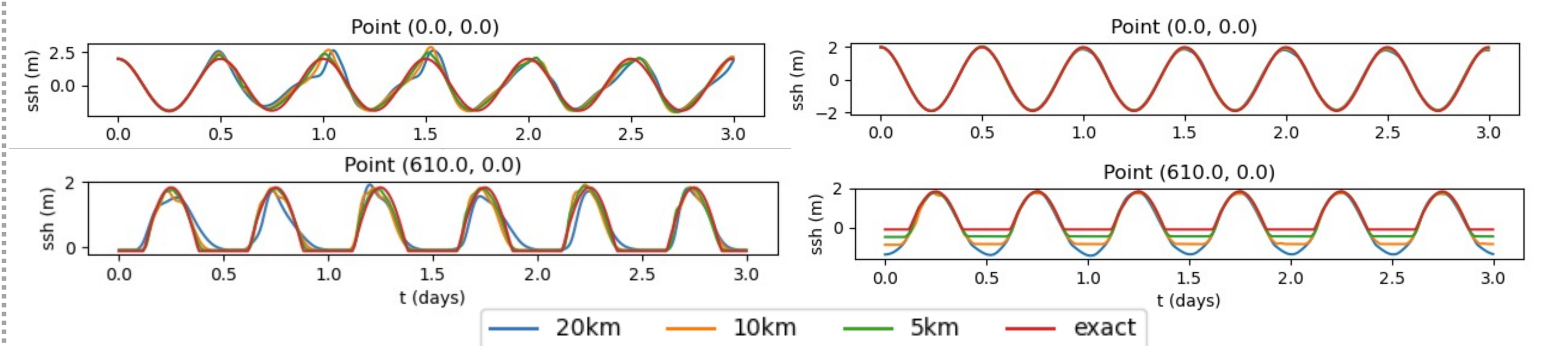
Subgrid scale correction for mass (precomputed lookup table):

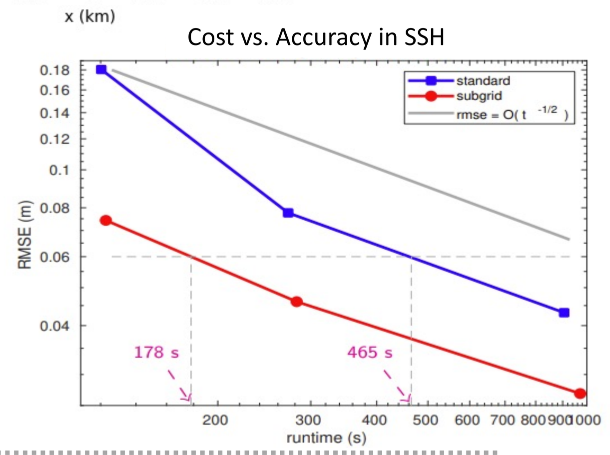
$$H_i(\eta_i) = \frac{1}{A_i}\int_{A_i} \max(\eta_i + b(\mathbf{x}), 0)\,d\mathbf{x}$$

Bathymetry data from high resolution DEM

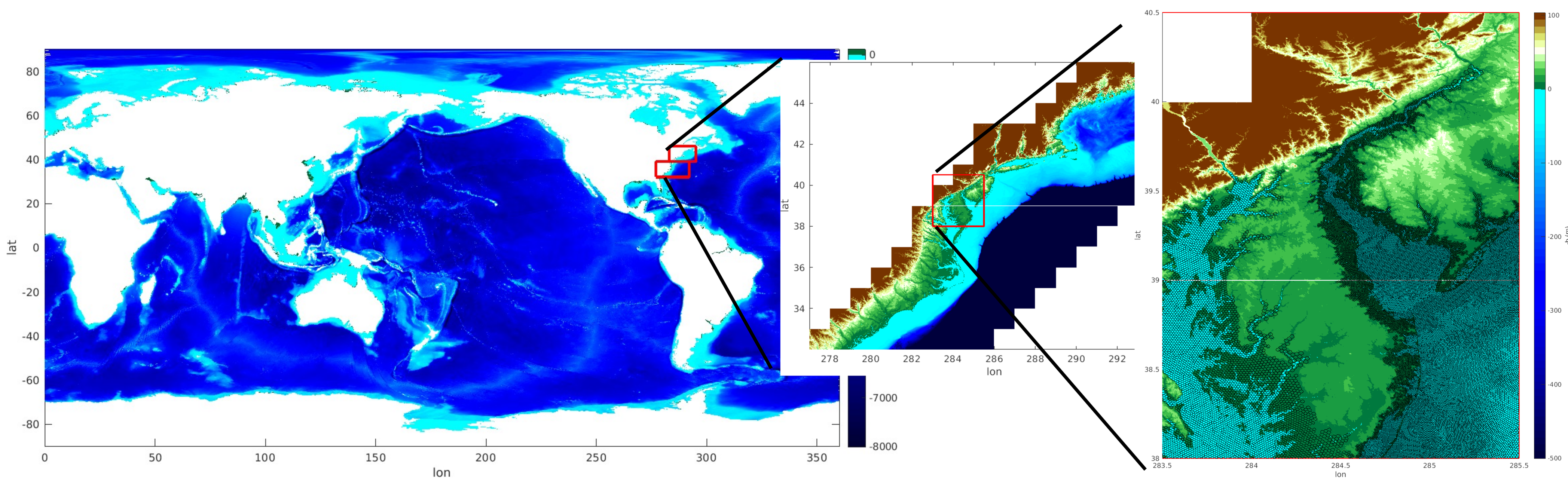
❑ VERIFICATION





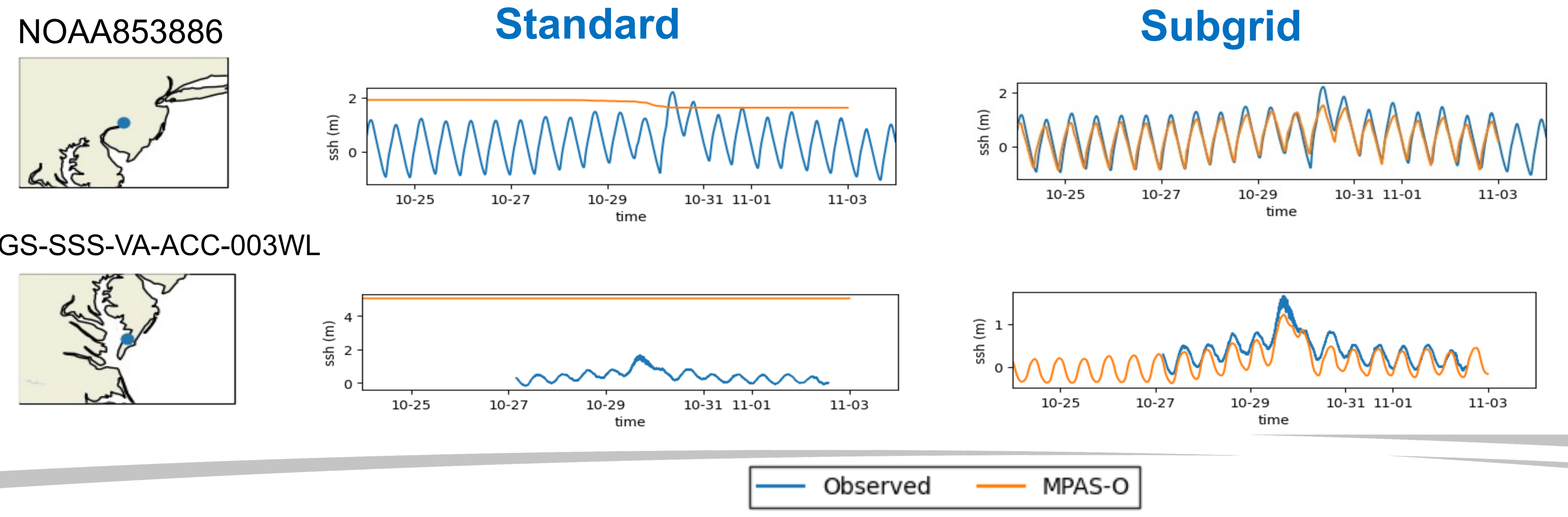


❑ SIMULATION OF STORM TIDE DURING HURRICANE SANDY (2012)



- Global domain with 1km resolution in Delaware Bay
- Apply subgrid corrections in the US East coast from the coast of SC to ME
- Employ Coastal Relief Model (3 arc-seconds) for the high resolution subgrid bathymetry

❑ VALIDTDATION OF SEA SURFACE HEIGHT: HURRICANE SANDY



E3SM Energy Exascale Earth System Model
e3sm.org

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ICoM

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