Seahorçe overview

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U.S. DEPARTMENT OF ENERGY | Office of Science

SEAHORÇE

Integrated Coastal Modeling (ICoM)

https://icom.pnnl.gov/

Impacts of extreme events and climate change attribution along the US east coast

Great Lakes Modeling (COMPASS-GLM)

https://compass.pnnl.gov/glm/

Understanding feedbacks in a coupled, regional earth system model for improved regional climate projections

U.S. DEPARTMENT OF ENERGY | Office of Science

ICOM

COMPASS | GREAT LAKES MODELING

Coastal Observations, Mechanisms, and Predictions Across Systems and Scales

Seahorçe objectives

The **Study for Exascale Advances in a High-resolution Ocean using ROMS Coupled to E3SM** (SEAHORÇE) SciDAC5 project will:

Focus on *improved representations of small-scale coastal and open-ocean processes* — such as river plumes, coastal fronts, and meso- and submesoscale eddy processes — in the context of global ESMs

Design a scientific and technical *framework for two-way coupling* between ROMS and MPAS-O for optional, flexible, efficient, and robust dynamical up- and downscaling

Create and evaluate ROMS-X a GPU-enabled port of ROMS that exploits the latest HPC architectures

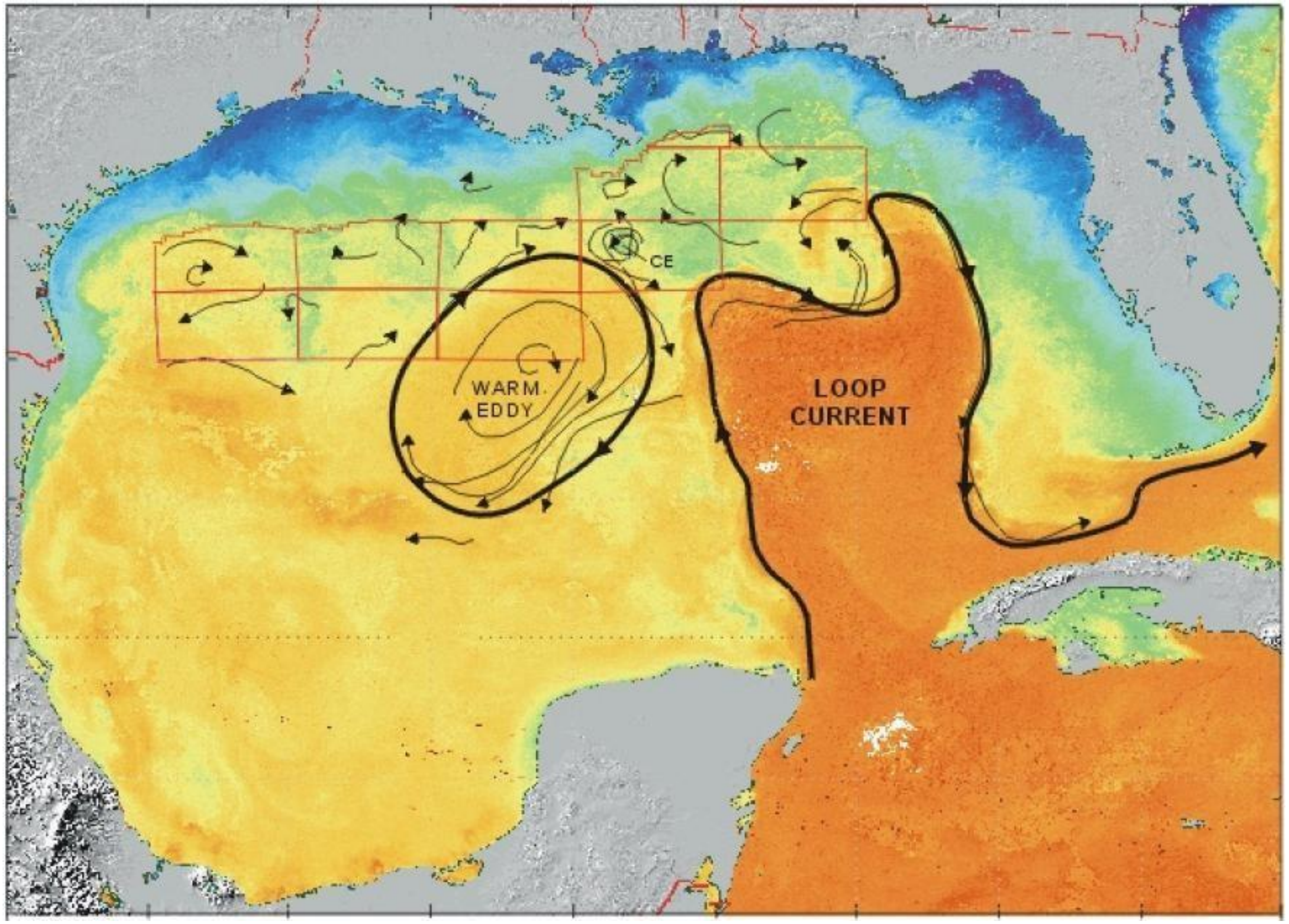
Dynamics Across Scales with MPAS-O

- Developing a hierarchy of regionally-refined MPAS-O configurations centered on US Gulf + East coast/shelf regions to **assess how MPAS-O captures detail across model resolution**.

- Using O(30km), O(10km) and O(2km) span from *mesoscale-permitting* to *mesoscale-resolving* to *submesoscale-permitting* configurations.

- O(30km) config. consistent with E3SM-LR.
- O(10km) config. consistent with E3SM-HR.
- O(2km) config. “ultra-high resolution” (for a global ocean model).

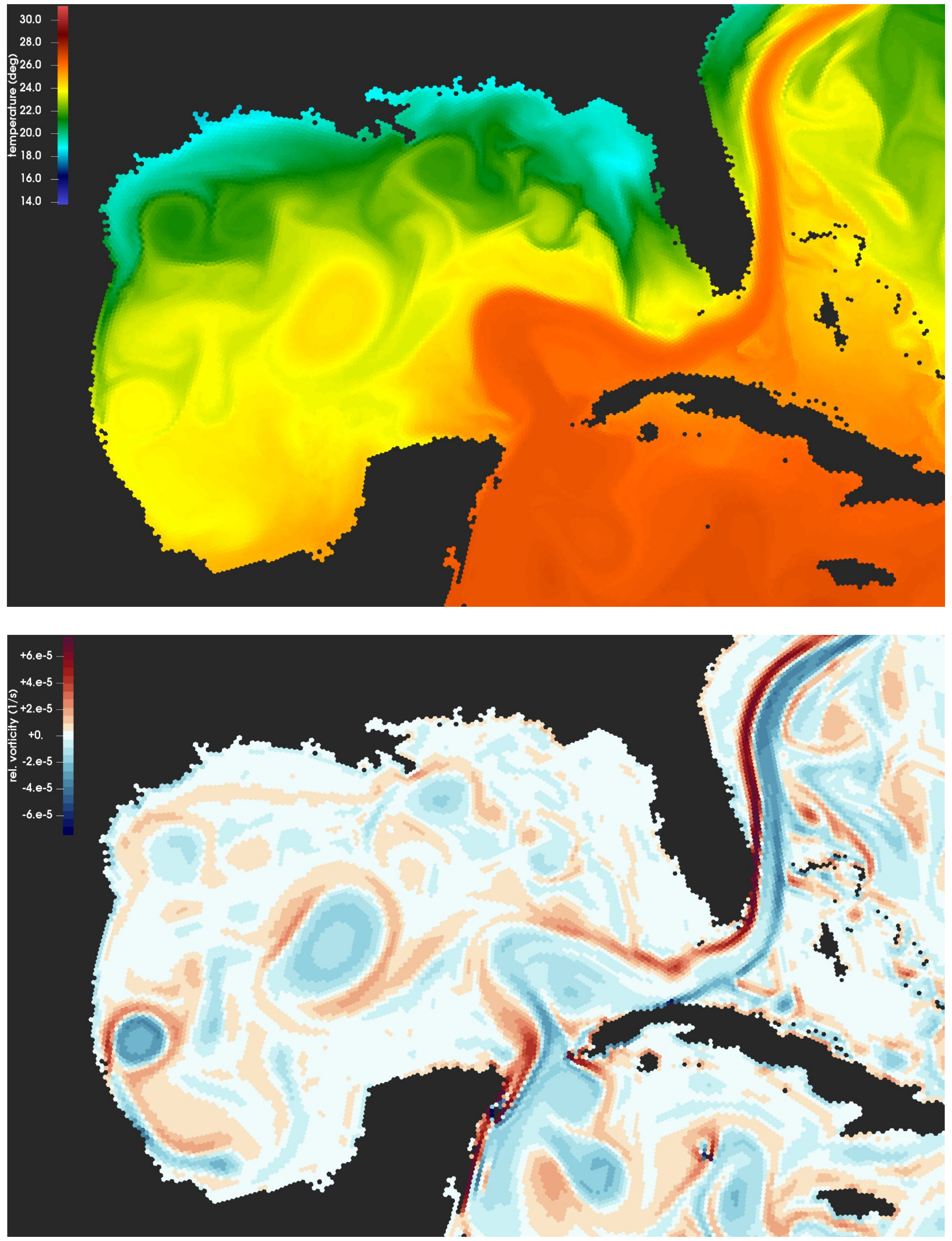
- Consider computational scaling with resolution.



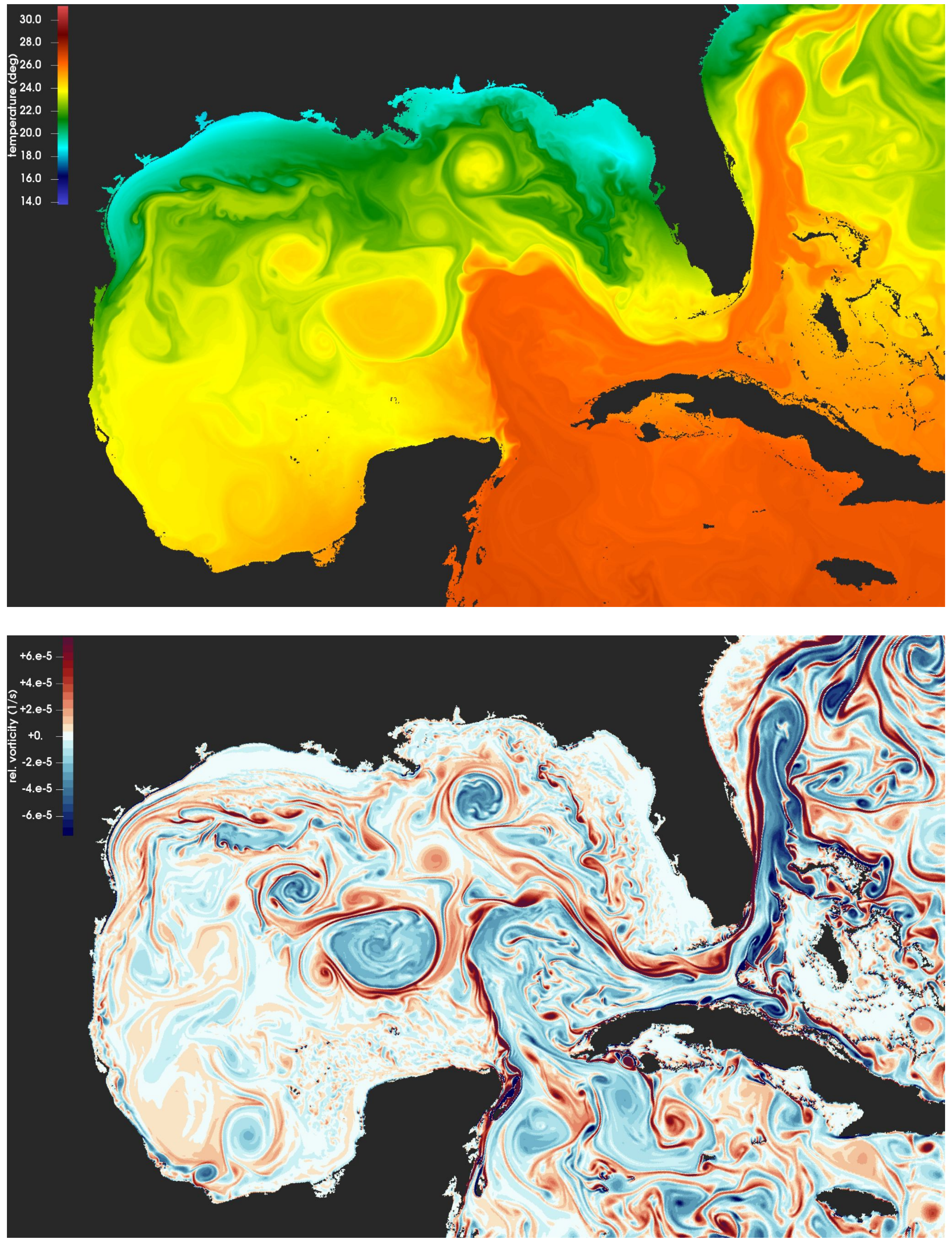
Sea surface circulation and temperature, courtesy of Horizon Marine

Dynamics Across Scales with MPAS-O

- O(30km) ‘ESM-LR’ config. (not shown) gives lower quality representation of temperature + vorticity dynamics, **missing dynamic evolution of loop current/eddies.**
- O(10km) ‘E3SM-HR’ config. captures broad mesoscale dynamics, though **eddy features are relatively weak** (lower vorticity magnitude) and diffuse (numerical mixing + diffusion at grid-scale is dominant).
- O(2km) config. captures not only sharp mesoscale dynamics, but **entirely new classes of eddies and fronts at the submesoscale**.
  Fine-scale ocean circulation consistent with satellite obs., and dominates mixing of surface constituents in practice.



O(10km) a’la E3SM-HR



O(2km) submesoscale permitting

Dynamics Across Scales with MPAS-O

- Exciting to achieve submesoscale-permitting simulations with MPAS-Ocean — positions us at forefront of current O(1-5km) 'very high-resolution' ocean modeling efforts worldwide — but…

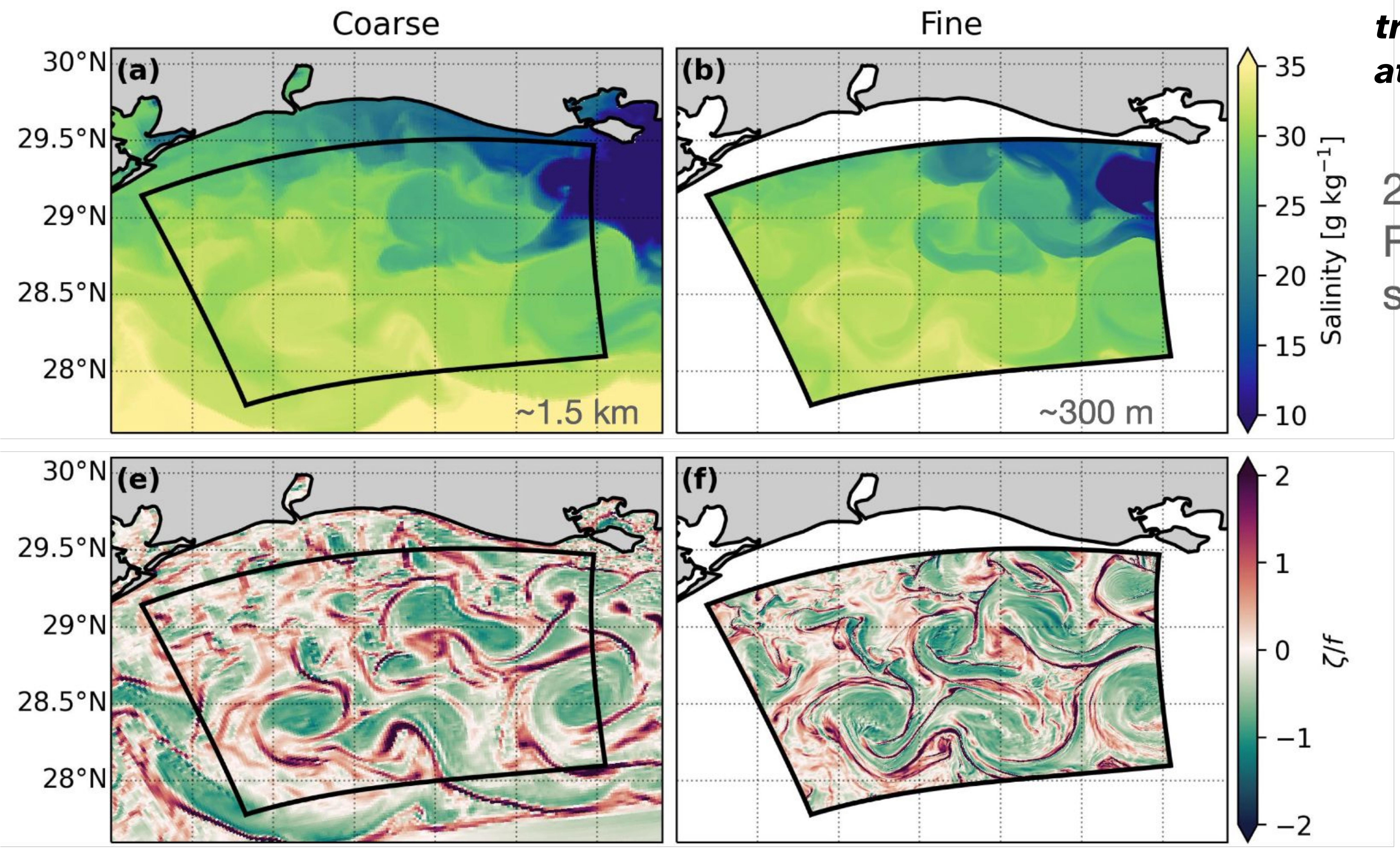
  …these simulations are expensive!

- Highest resolution (baroclinic) MPAS-O simulation to-date.
- Current throughput: 96 simulated-days-per-day using 12,000 cores (using NERSC HPC).
- Short, 5 year model spin-up requires 3 weeks wall clock.
- Are submesoscale dynamics 'well-enough' resolved at O(2km) resolution? No…
- Expect **x4-x8 slowdown** to achieve O(1km) resolution.
- Typical ROMS applications employ O(100m) resolution to capture submesoscale effects.

- In practice, there are limits to how far we can refine resolution with MPAS-O — at 'small-enough' scales it is more efficient to embed a local, ultra high-resolution model (ROMS-X) than run a global model.

- We do achieve a lot using MPAS-O's regional refinement — efficiently spanning the O(30km) ⇔ O(5km) mesoscale-permitting space for climate modeling. **Simulating small scale processes (submesoscale eddies, fronts, etc) better achieved using our ROMS-X coupling approach.**

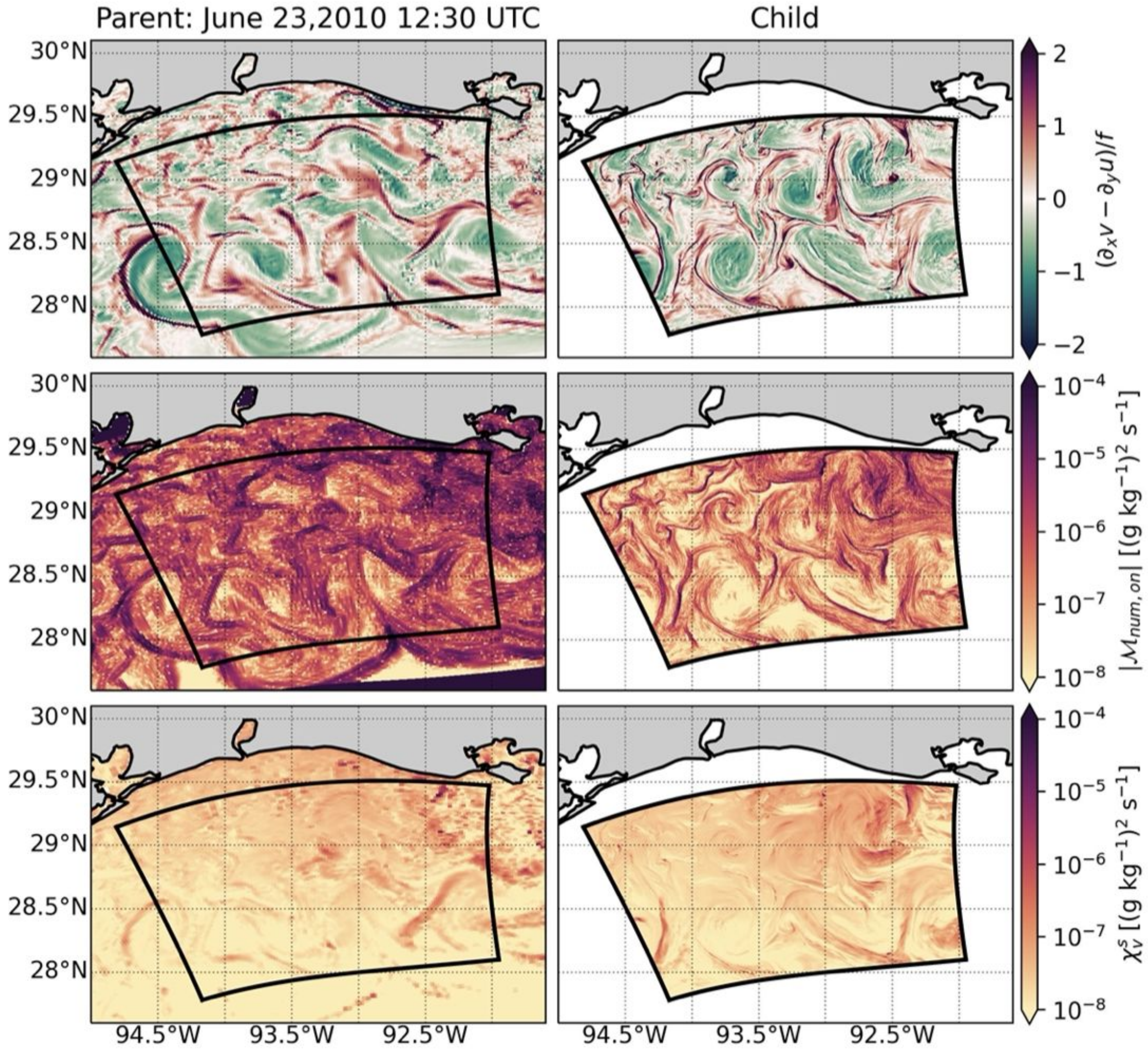
Similar dynamical transitions also occur at smaller scales



2-way nested ROMS simulations

Energetic: $\zeta/f = \mathrm{Ro} \sim 3$ at fronts

Schlichting et al., (*JAMES*, submitted)



Relative vorticity

Numerical mixing

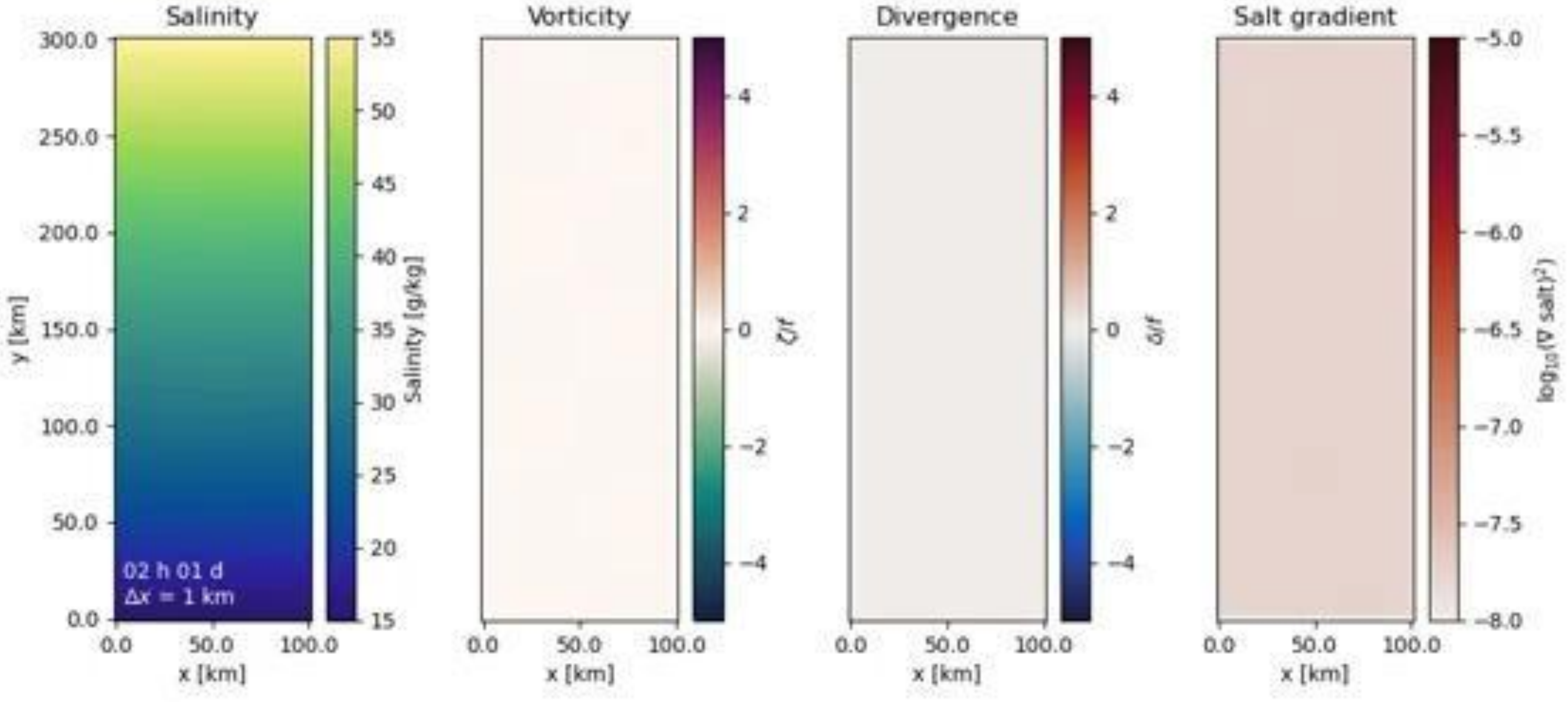
Burchard & Rennau (*OMOD*, 2008)

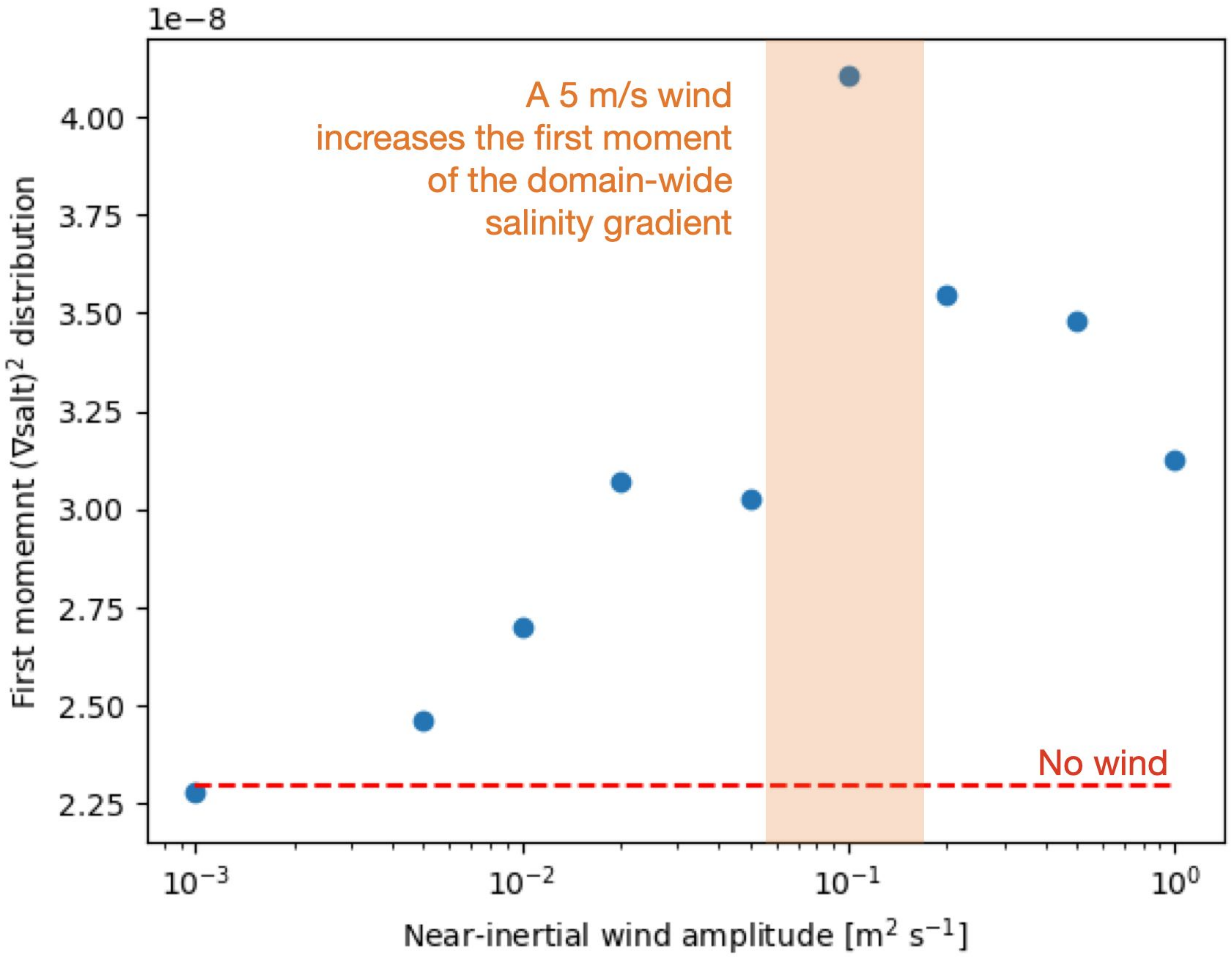
Explicit vertical mixing

Representation of fronts impacts model fidelity

- Numerical mixing is about ⅓ of the total (prescribed through closure + spurious numerical) mixing.
- Increased (5x) resolution decreases numerical mixing by ~⅓
- Numerical mixing is associated with fronts, though not exactly.

A test case of baroclinic instability in a flat-bottomed channel, forced with weak near-inertial winds will be used to compare and contrast ROMS with MPAS-O to assess, e.g., equivalent effective resolution of each model.

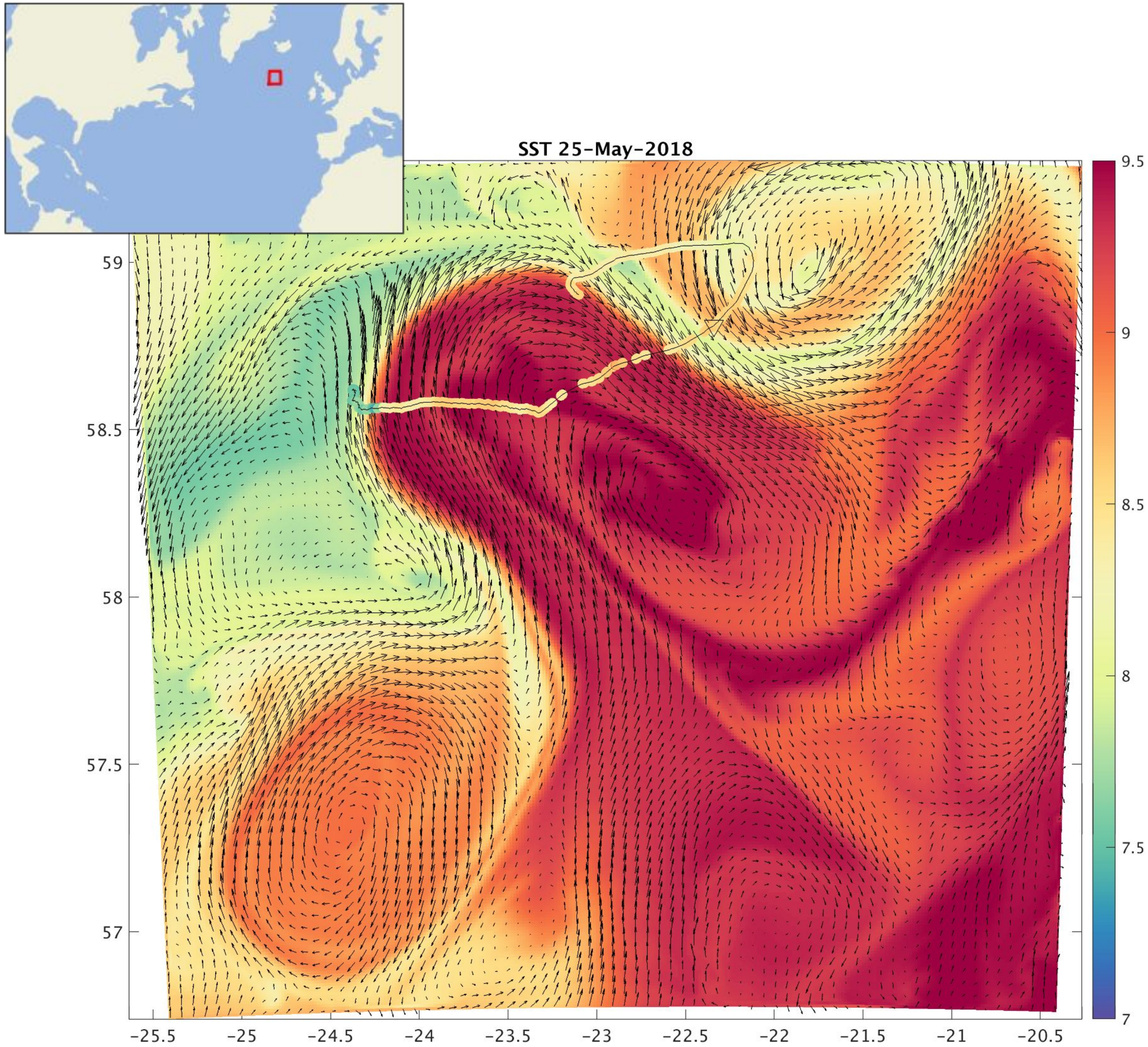




A small, near-inertial wind enhances gradients within the eddies, strengthening fronts, resulting in a more challenging regime for the model comparison test bed.

ROMS/MPAS-O Test Case Configuration

- Re-entrant channel, flat bottomed, spatially uniform wind case is a simple configuration for both ROMS and MPAS-O
- Parameter space with strong buoyancy forcing, similar to northern Gulf of Mexico
- Existing observations (e.g., MCH, SUNRISE) and idealized studies (‘shelfstrat’ test case, ~5 papers by Hetland & students) provide a good foundation.
- Focus on frontal processes, as these are the most numerically challenging dynamical features



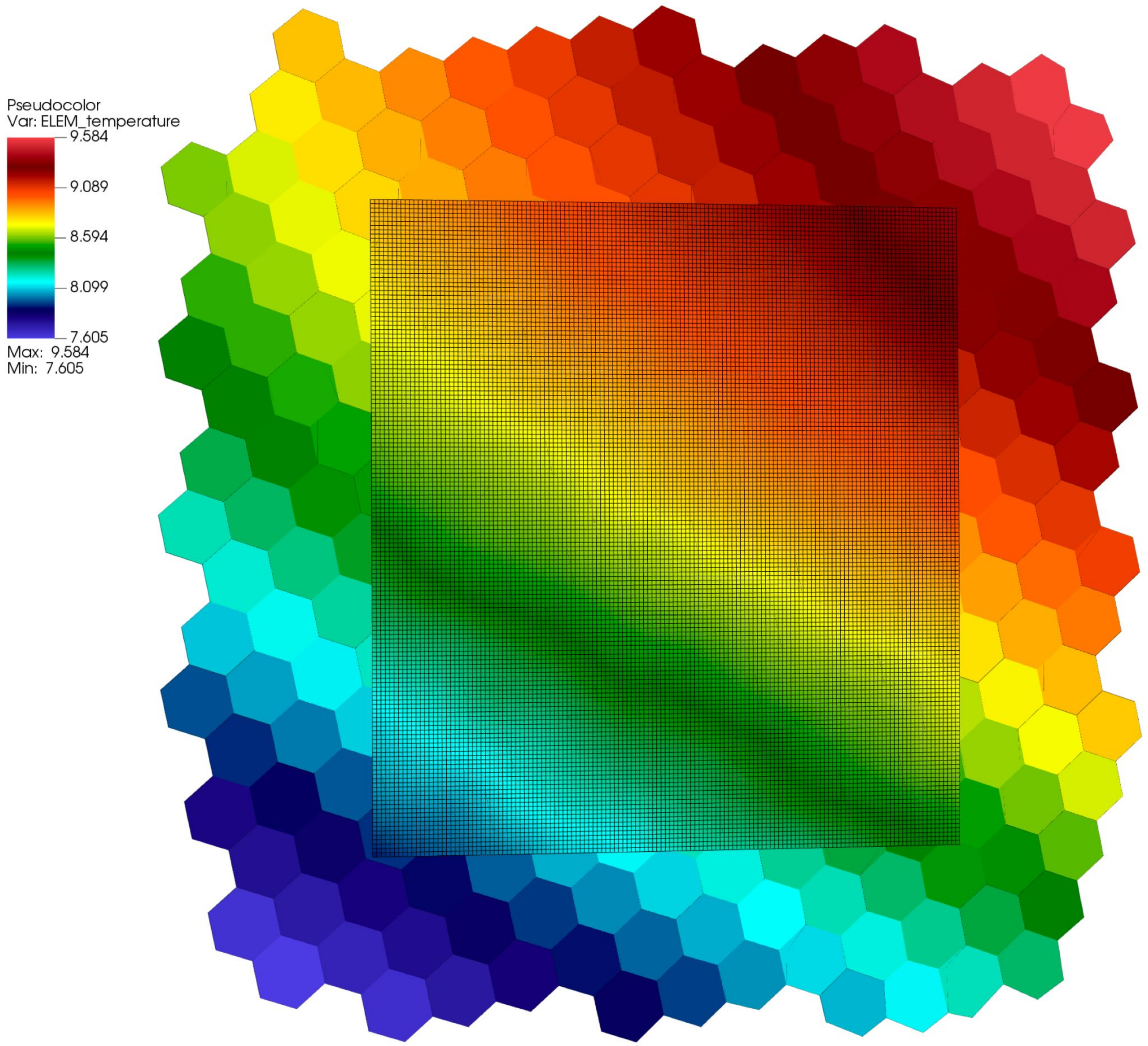
North atlantic limited domain ROMS simulation by Harper Simmons (UW-APL)

Realistic North Atlantic ROMS Domain

- Initial domain chosen to simple, with no strong bathymetric gradients, and no coastlines.
- Scientific motivation eddy/internal wave interaction
- Leverage ONR NiSKINE modeling and observations

E3SM coupler interface

(Vijay Mahadevan & Iulian Grindaenu, ANL)



MPAS-O surface temperature interpolated to the ROMS North Atlantic grid within the MOAB offline coupler.

- MOAB coupler interface to MPAS and ROMS models (*done*)
- Offline 2D remap of data from MPAS to ROMS (1st order locally conservative or bi-cubic globally conservative *done*)
- Offline 3D remap with a 2Dx1D decomposition (in progress)
- Test offline MPAS to ROMS downscaling workflow with the 3D remapper (*Q3*)
- Integrate offline remapper to coupler and run representative downscaling tests (*Q4*)

ROMS-X (led by Ann Almgren & Jean Sexton, LBNL)

- ROMS-X is a new code built on the AMReX software framework. AMReX provides a software layer to enable performance portability, i.e. the same ROMS-X code will run with MPI + X, where X can be OpenMP for multicore architectures or CUDA/HIP/SYCL for NVIDIA/AMD/Intel GPUs.

- The functionality of ROMS-X will initially be that of ROMS – by the end of FY23, ROMS-X will be able to run the same idealized configurations as ROMS but exploiting GPU-based architectures.

- ROMS-X will also be able to exploit the fast parallel I/O provided by AMReX, with options to also write directly to netcdf files or to post-process directly into python-based tools.

- Current status: ROMS-X is able to initialize the data for an idealized simulation and export the solution in native or netcdf format. Implementation of the time-stepping algorithm is in progress.