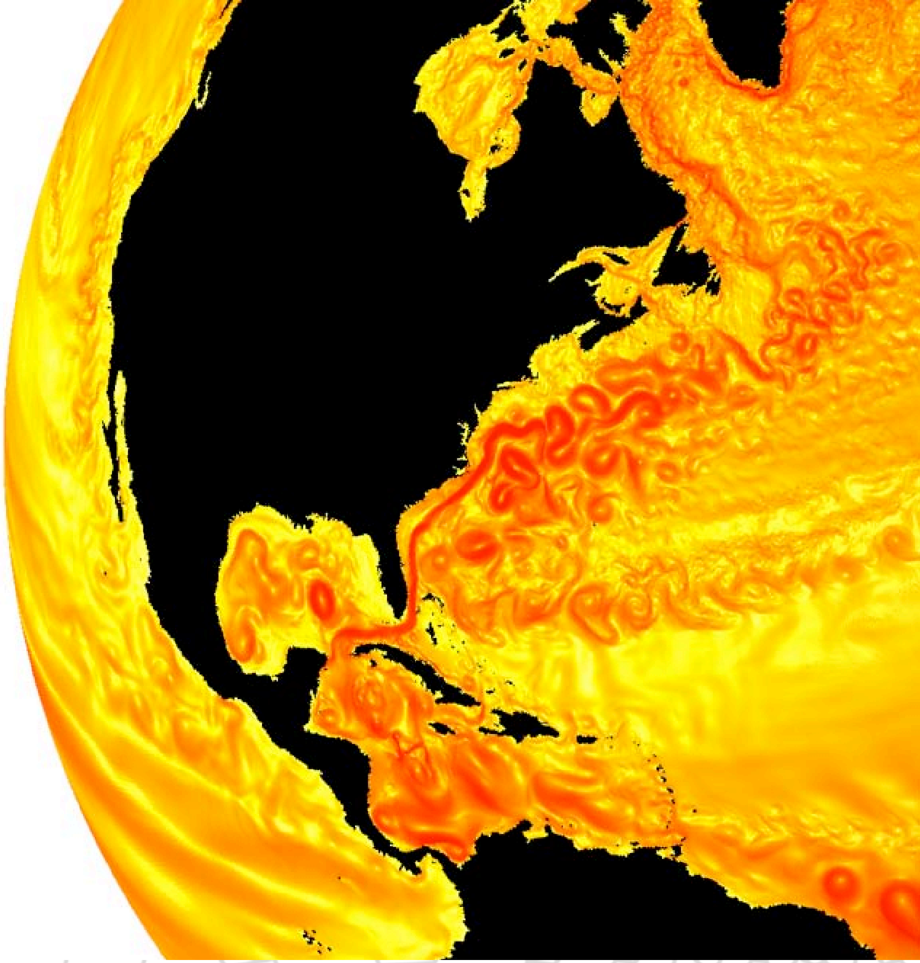
MPAS-Ocean
A Variable-Resolution Global Ocean Model



Mark Petersen

and the MPAS-Ocean development team:

Todd Ringler, Doug Jacobsen, Mathew Maltrud, Phil Jones, Qingshan Chen
Los Alamos National Laboratory

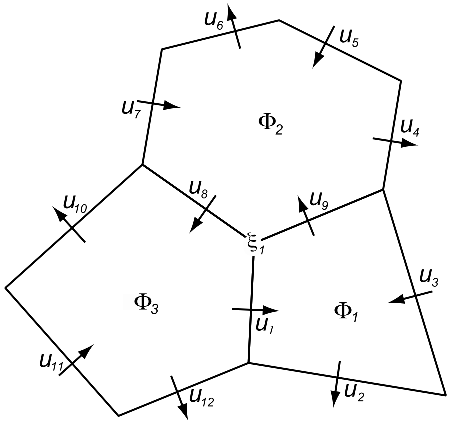
MPAS
Model for Prediction Across Scales

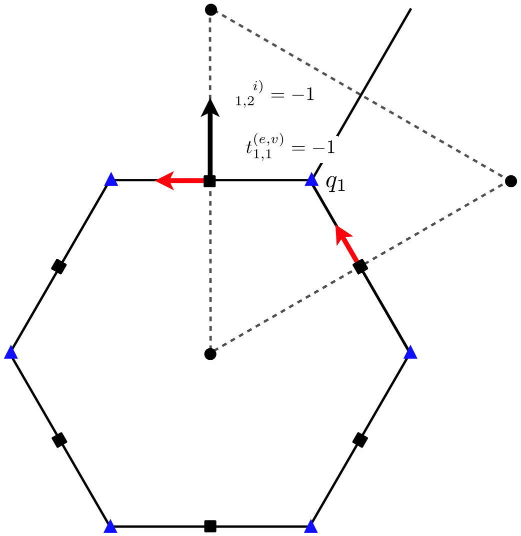
MPAS-Ocean: Highlights

- Development began January 2010
- Primitive equation, Hydrostatic, Boussinesq
- **Horizontal grid:** unstructured, based on Voronoi Tesselations, C-grid
- **Vertical grid:** Arbitrary Lagrangian-Eulerian (ALE): z-level, z-star, sigma, idealized isopycnal. With full bathymetry and partial bottom cells.
- **Time stepping:** Split explicit, 12-13 times speed-up over RK4
- **Tracer advection:** high order, monotonic Flux-Corrected Transport (FCT)
- **Statistics and Visualization:** Many tools under development
- **Performance:** Scales well to millions of grid cells, typically on 3000-6000 processors. 15km global same throughput as 0.1 degree POP. (Doug)
- **First Paper** on MPAS-Ocean under review in Ocean Modelling
- **CESM Coupling** underway, successfully runs with data atmosphere. (Doug)

MPAS Numerics

- The numerical scheme developed by Thuburn et al. (2009) and Ringler et al. (2010) conserves mass, total energy and potential vorticity on these variable-resolution meshes.
- May run on grids with polygons with arbitrary number of edges.
- C-grid staggering: velocity normals at cell edges
- Mass, geopotential, and kinetic energy are defined at cell centers.
- Vorticity and potential vorticity are defined at cell vertices.
- Code is “mesh-unaware”. That is, code is identical for Voronoi Tessellation, quad meshes, or any other grid configuration.



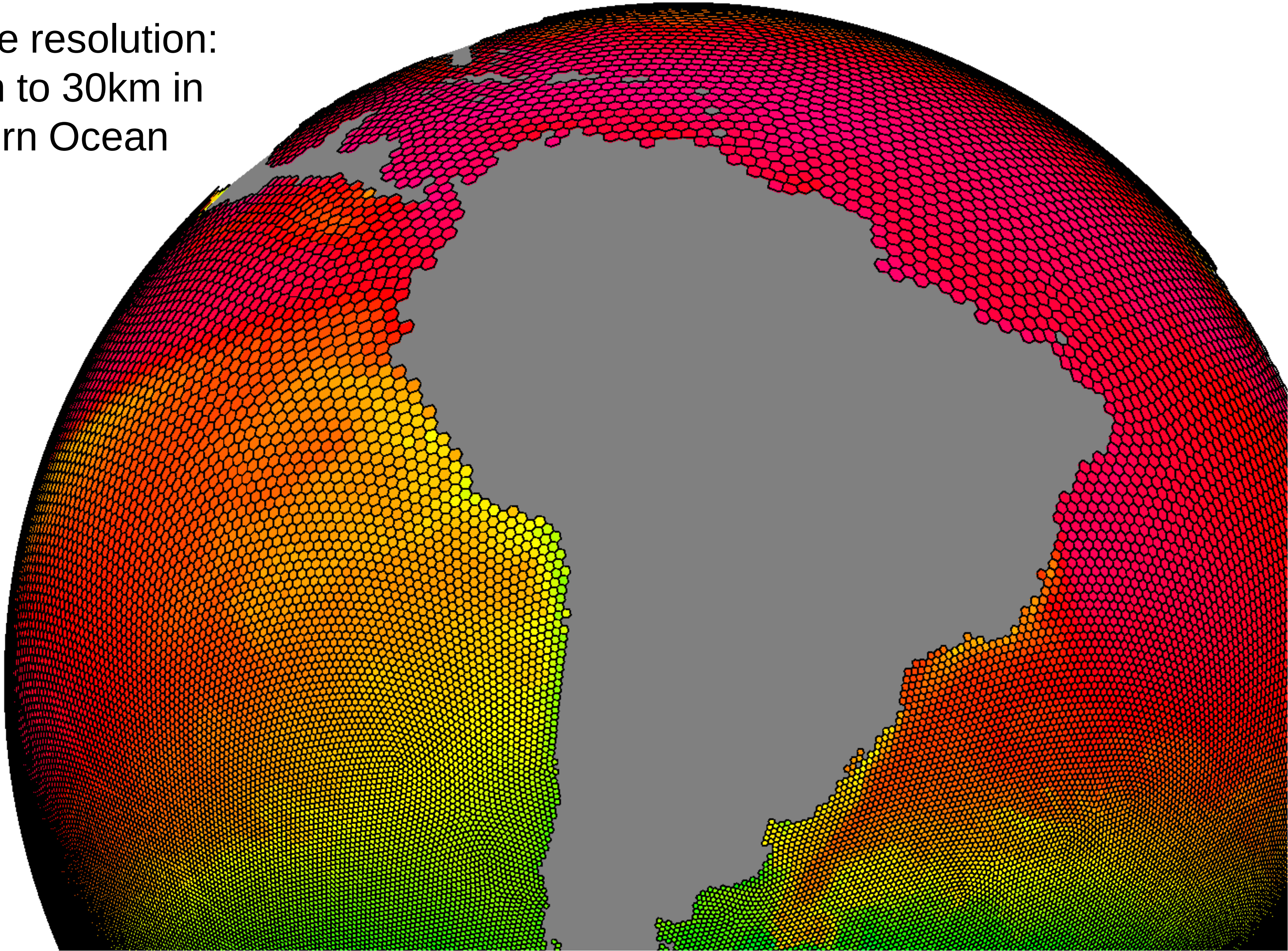


Ringler, T., J. Thuburn, J. Klemp and W. Skamarock, 2010: A unified approach to energy conservation and potential vorticity dynamics on arbitrarily structured C-grids, J. Comp. Physics, 229 3065–3090.

Thuburn, J., T. Ringler, J. Klemp and W. Skamarock, 2009: Numerical representation of geostrophic modes on arbitrarily structured C-grids, J. Comp. Phys, 228 (22), 8321-8335

MPAS Horizontally Unstructured Grids

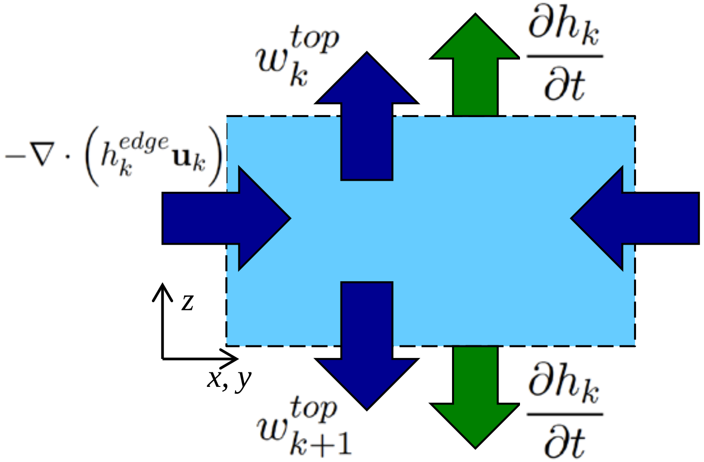
Variable resolution:
120 km to 30km in
Southern Ocean



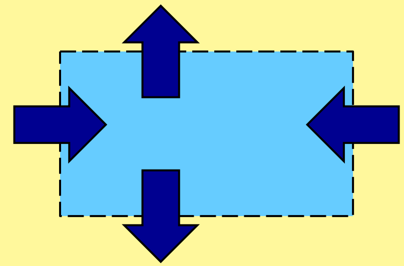
Arbitrary Lagrangian-Eulerian (ALE) Vertical Coordinate

Thickness equation: $$\frac{\partial h_k}{\partial t} = -\nabla \cdot \left(h_k^{edge} \mathbf{u}_k \right) + w_{k+1}^{top} - w_k^{top}$$

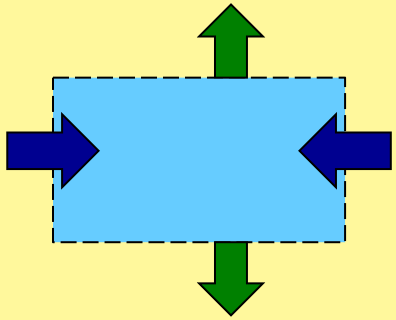
w is transport *through* interface



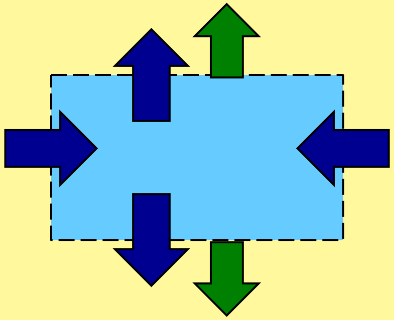
z-level $\frac{\partial h_k}{\partial t} = 0$, except layer 1



isopycnal (for adiabatic, idealized studies) w=0



z-star Layer thickness changes in proportion to SSH

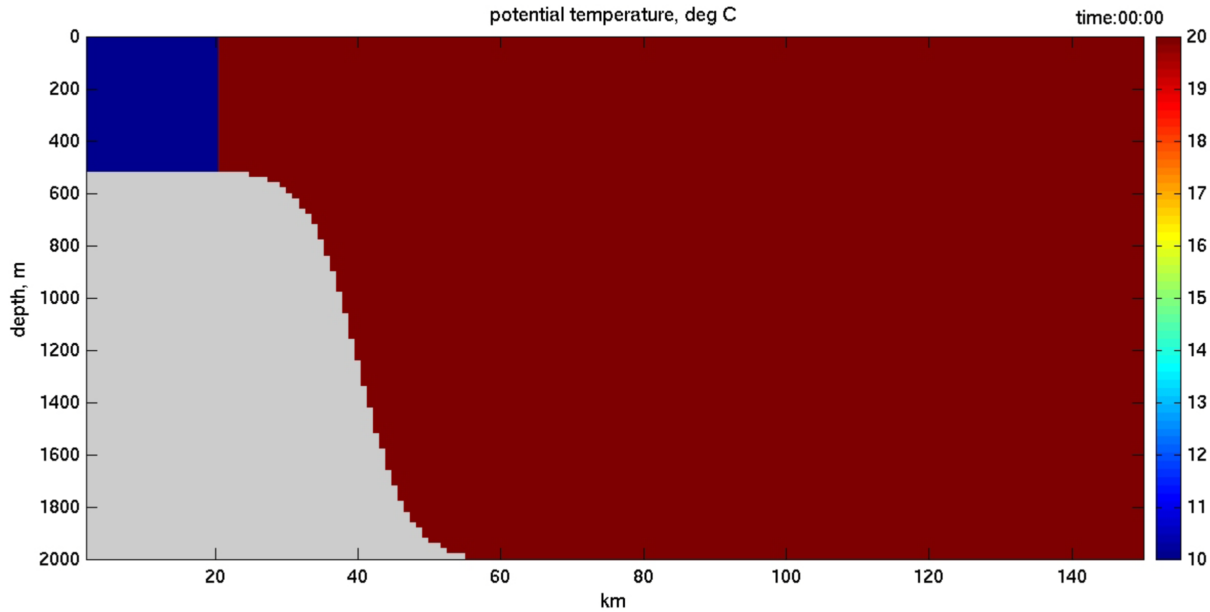


$$\frac{\partial h_k}{\partial t} = \frac{c_k}{\sum_k c_k} \frac{\partial \eta}{\partial t}$$

Evaluation of Vertical Coordinate

2D overflow test from Ilicak et al 2012.

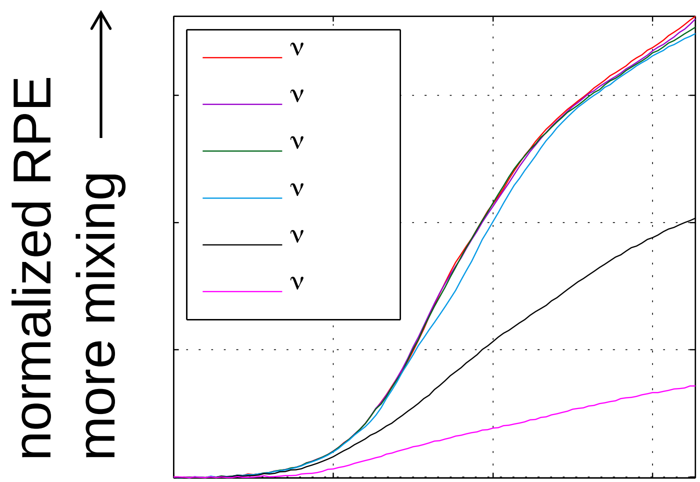
- Zero tracer diffusion
- 100 layers,
- 1km grid,
- hor. viscosity = $10^3 m^2/s$
- vert. viscosity = $10^{-4} m^2/s$



Resting Potential Energy (RPE), a measure of mixing

$$RPE = g \int \rho^* z \, dV$$

where ρ* is the sorted density for a resting fluid.



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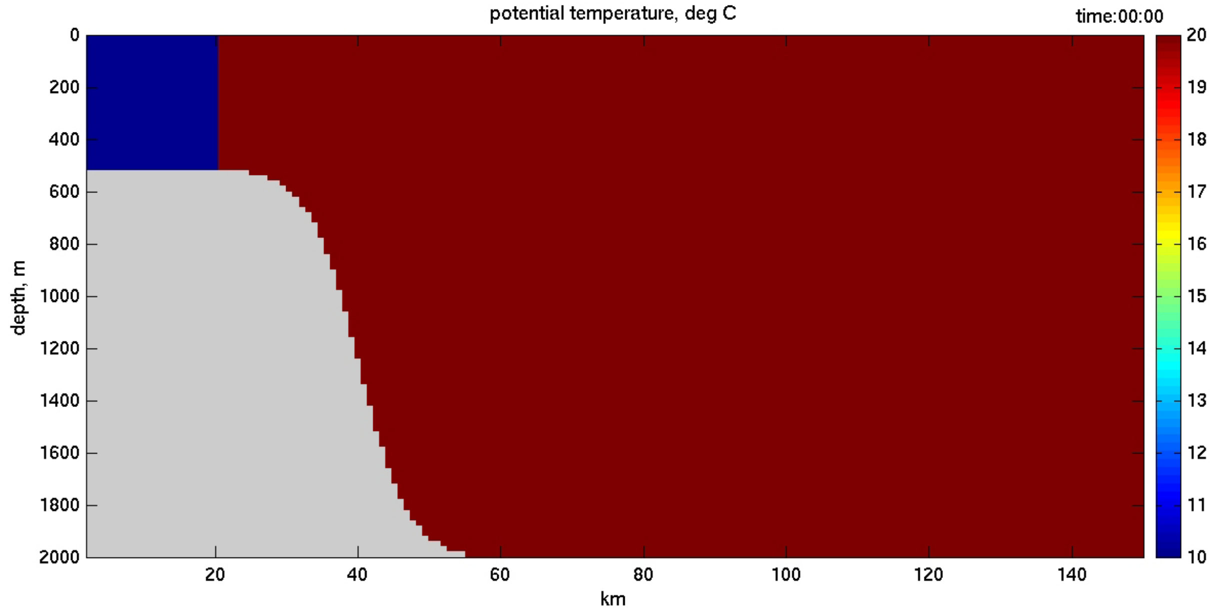

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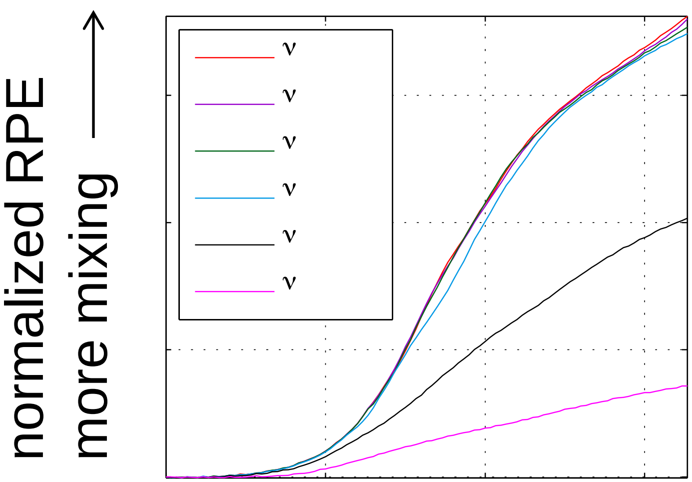
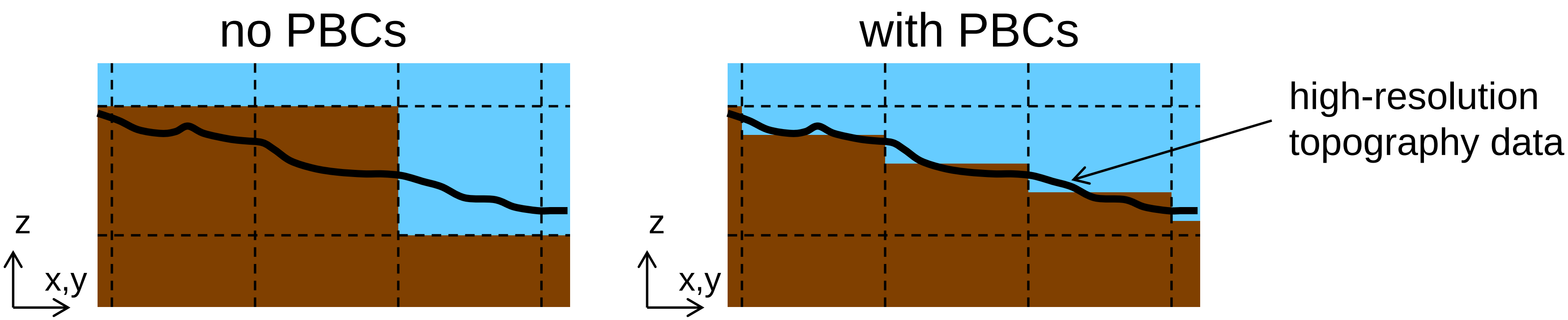
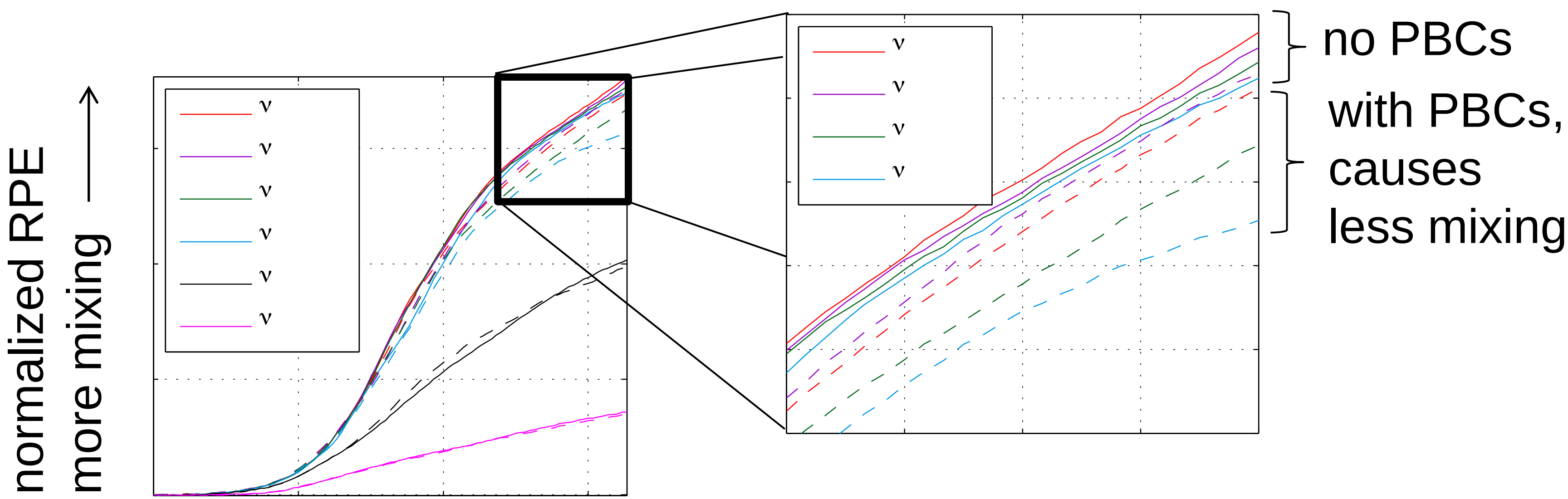


Evaluation of Vertical Coordinate

- These tests let us compare vertical coordinates.
- Effects of Partial Bottoms Cells (PBCs):

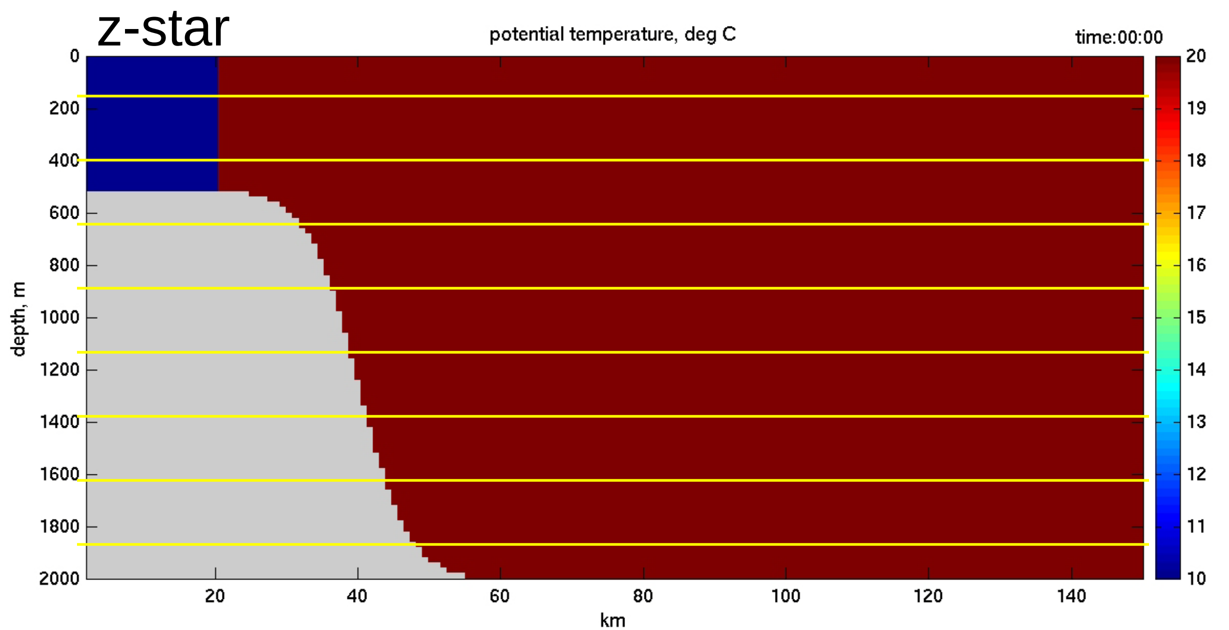




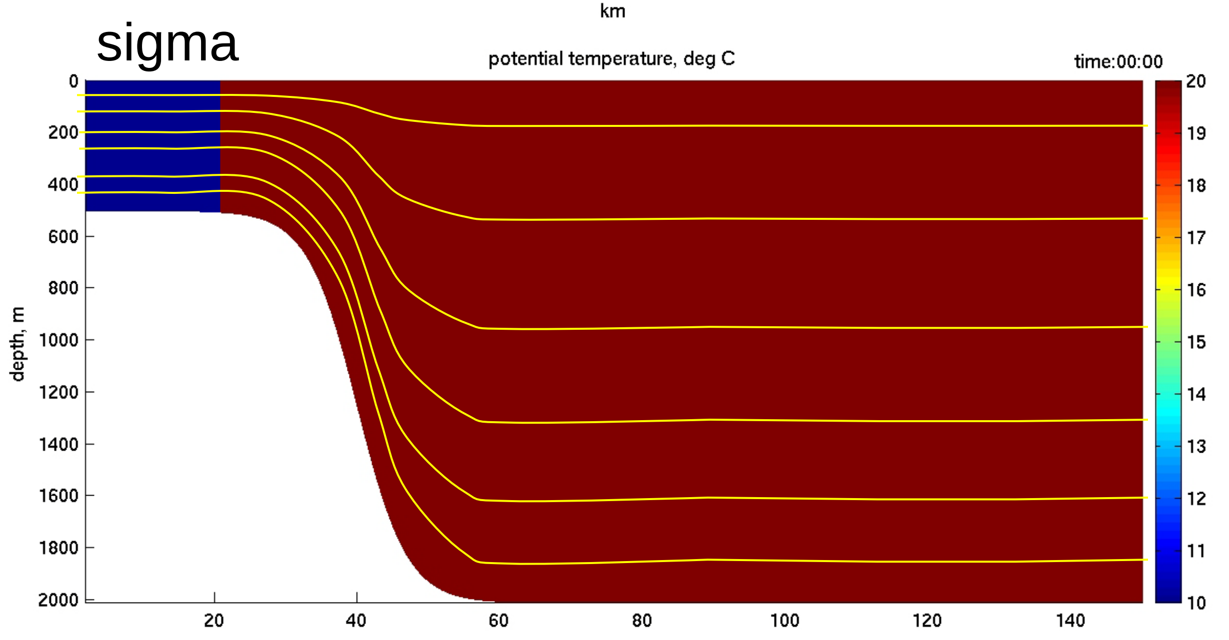
Sigma Vertical Coordinate

Initial layer thicknesses may be set to be:

- equal thickness (like z-level or z-star) where land cells are inactive



- variable thickness, i.e. terrain-following (sigma) coordinates, where all cells are active.



2D overflow test from Ilicak et al 2012. Zero tracer diffusion, 100 layers, 1km grid, $\nu_h = 10^3 m^2/s$

$\nu_v = 10^{-4} m^2/s$

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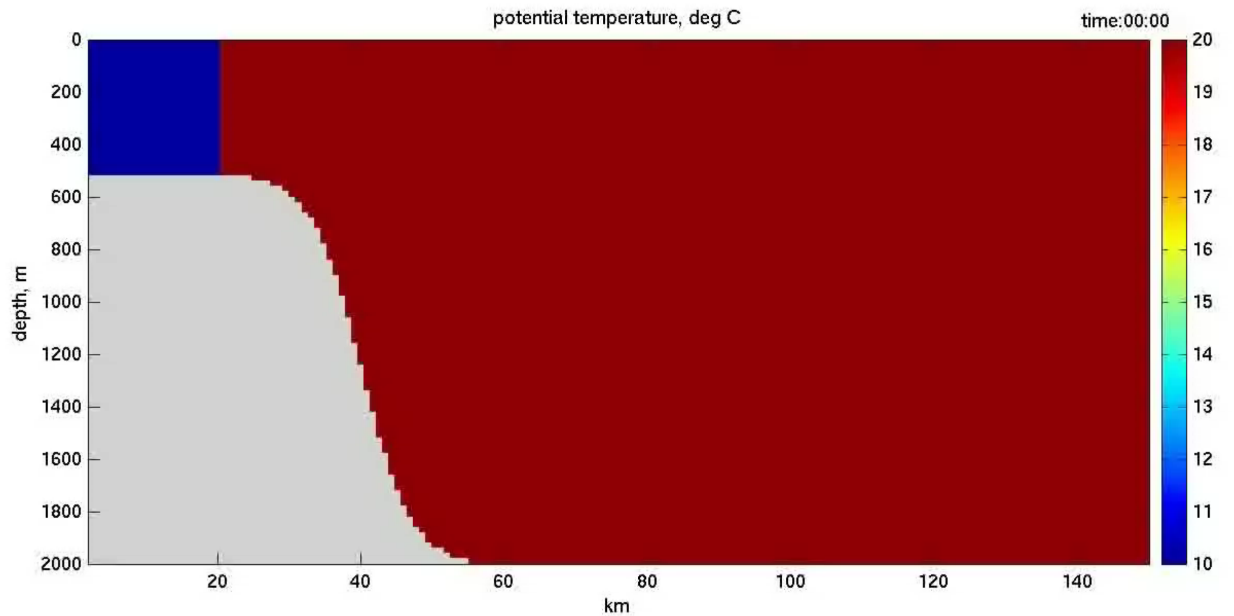

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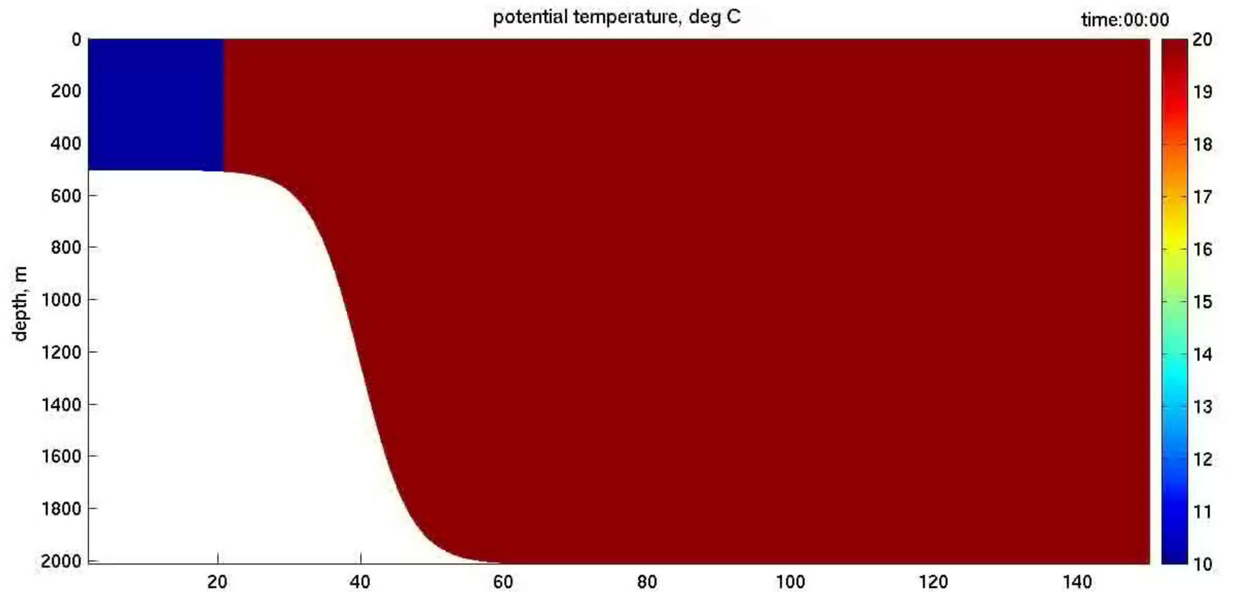

2D overflow test from Ilicak et al 2011. Zero tracer diffusion, 100 layers, 1km grid, ν_h=$10^3 m^2/s$

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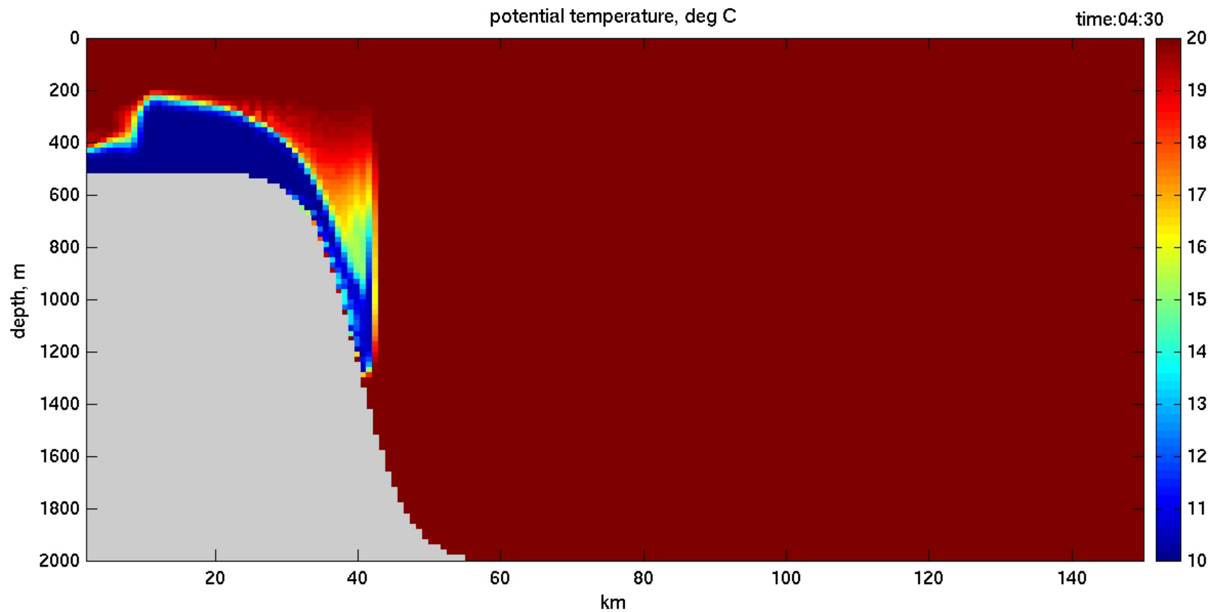

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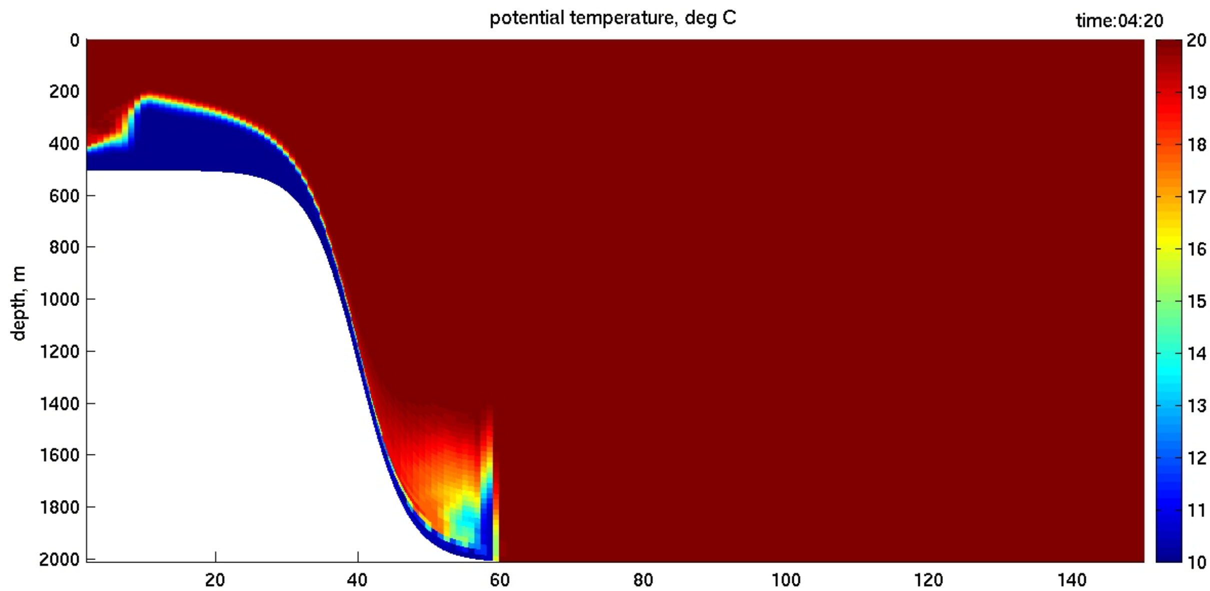


2D overflow test from Ilicak et al 2011. Zero tracer diffusion, 100 layers, 1km grid, ν_h=10^{3}m^2/s

ν_v=10^{-4}m^2/s

MPAS-Ocean: Ice Shelf Above Ocean Surface

- For coupled ocean-ice shelf modeling, we need to depress the ocean surface with the weight of the ice shelf.

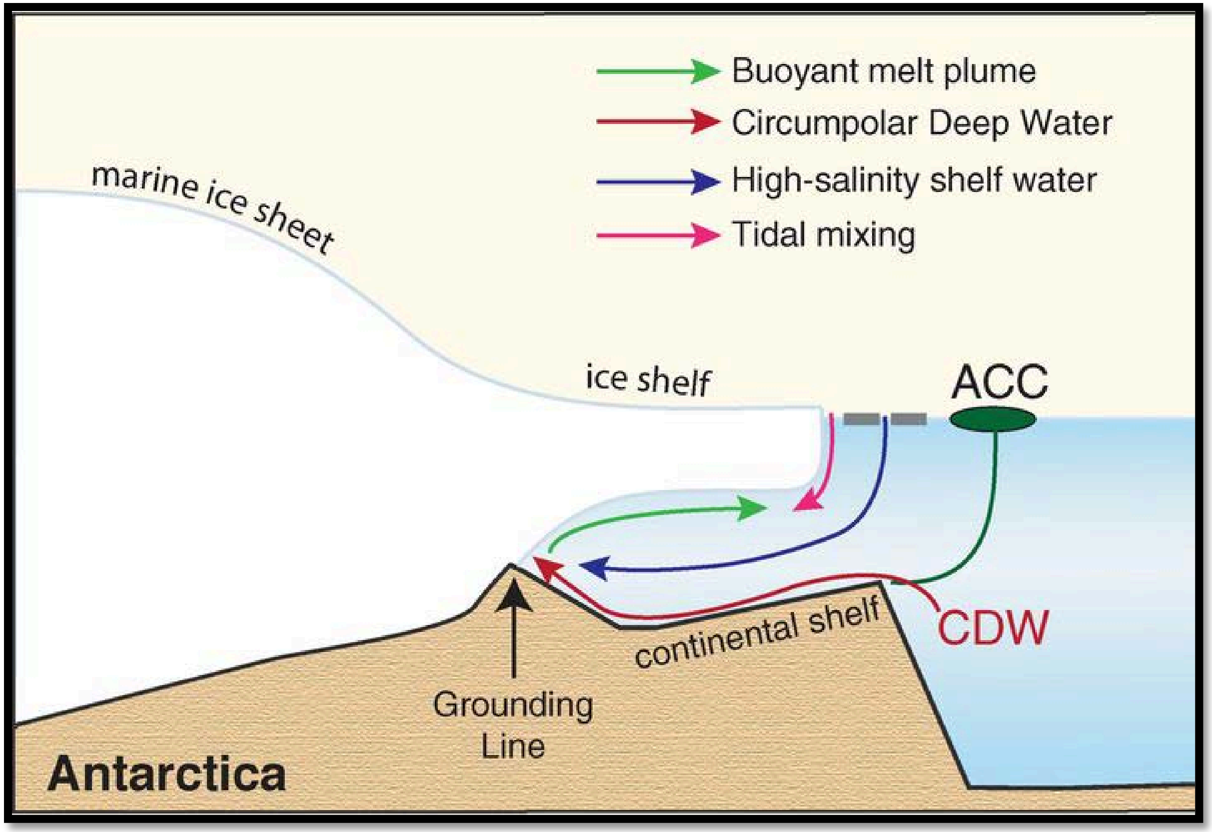
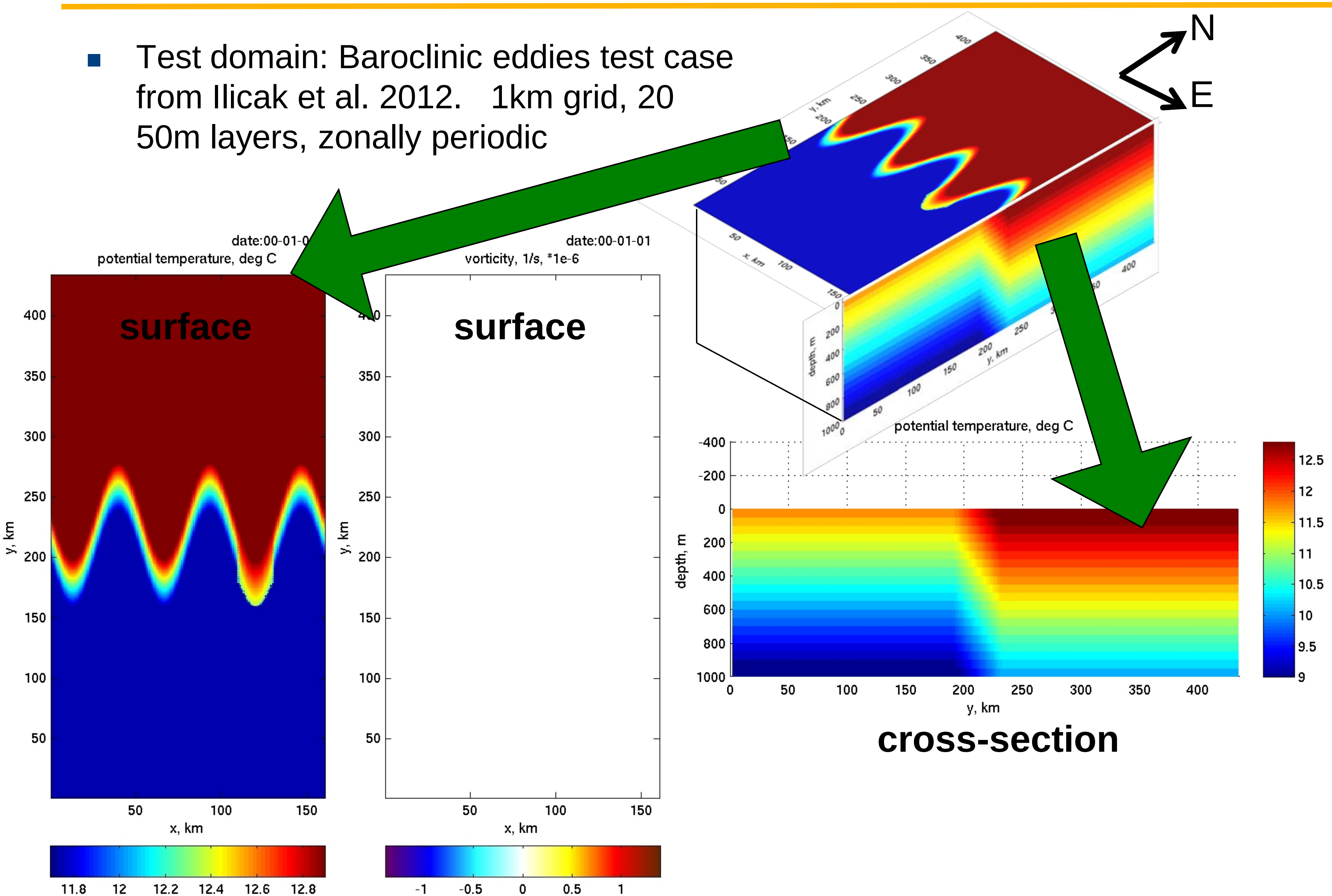


image from Joughin ea. Science, 2012

MPAS-Ocean: Ice Shelf Above Ocean Surface

- Test domain: Baroclinic eddies test case from Ilicak et al. 2012. 1km grid, 20 50m layers, zonally periodic



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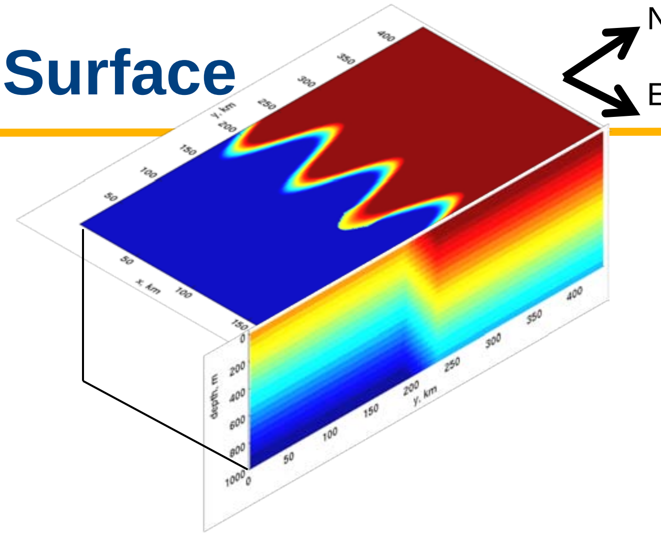
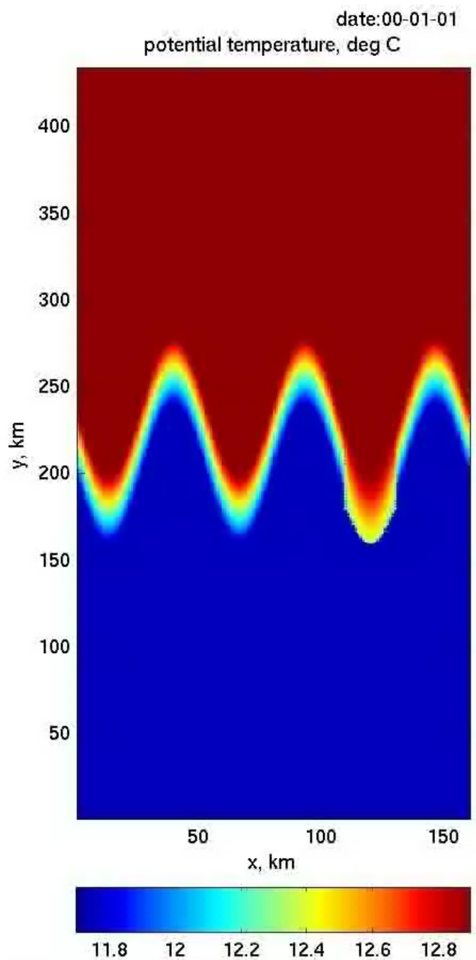
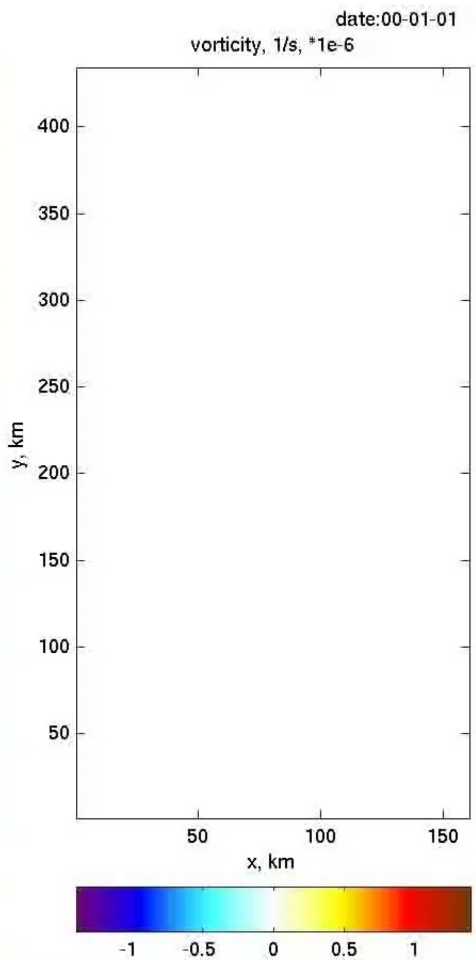
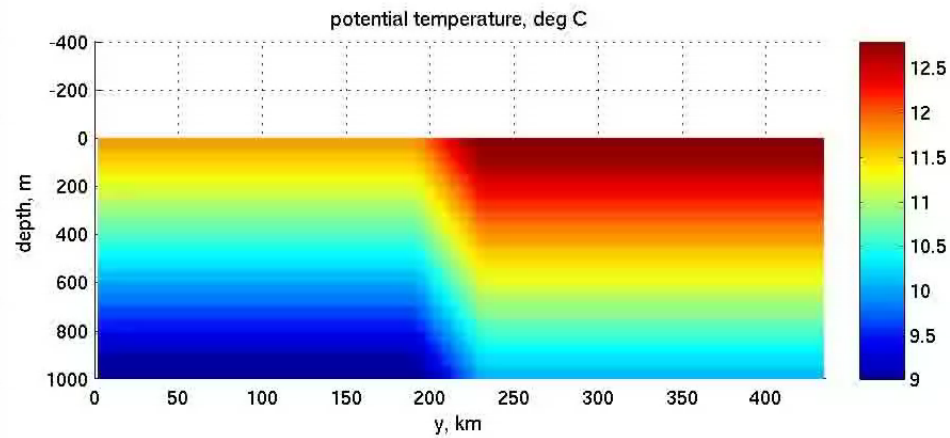


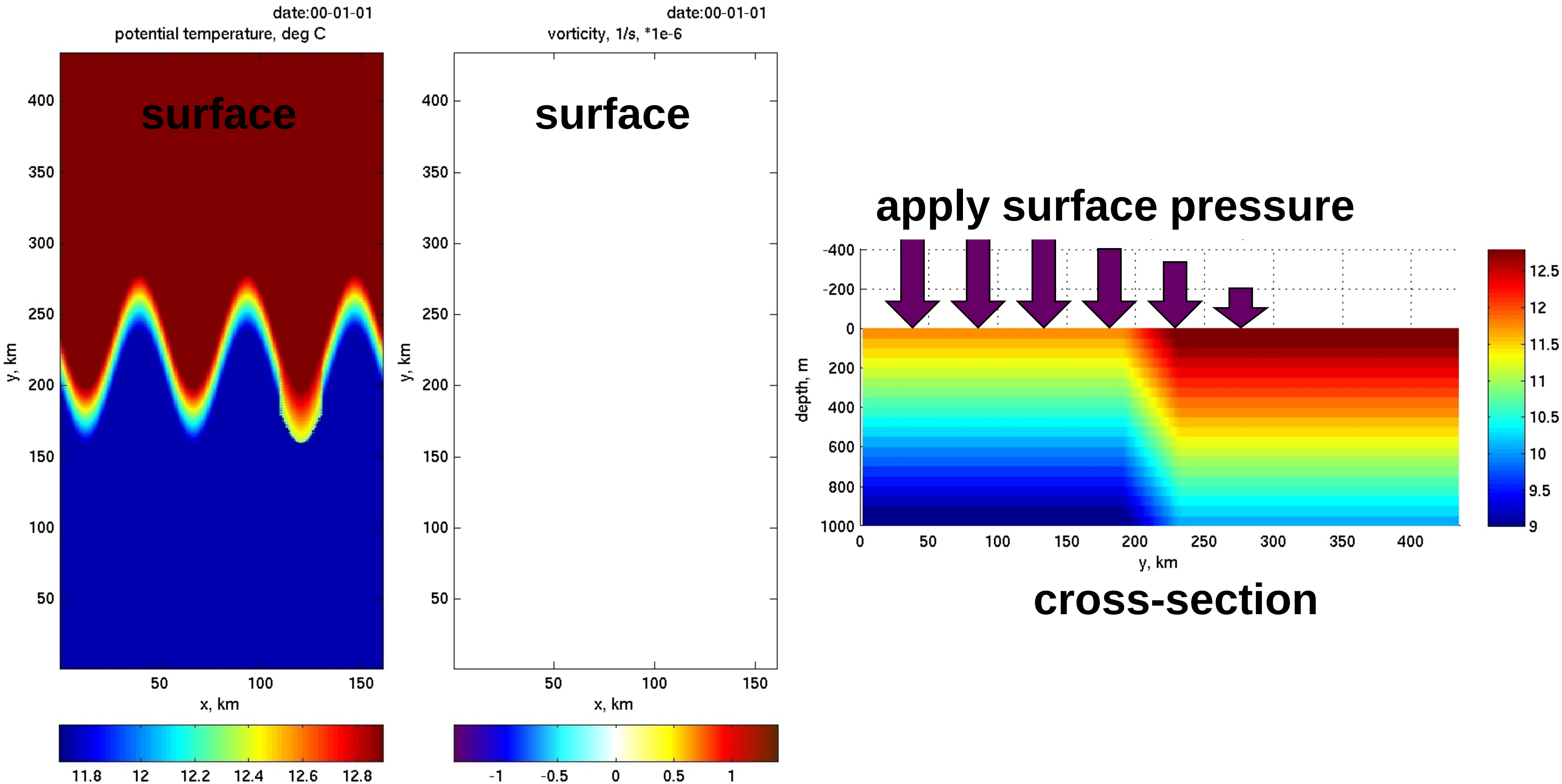






MPAS-Ocean: Ice Shelf Above Ocean Surface

- Apply surface pressure, increasing in time, to southern portion.
- Vertical coordinate is z-star, so all layers compress proportionally.
- This is meant as a proof of concept to test robustness of the vertical coordinate, and not as a realistic land ice test.



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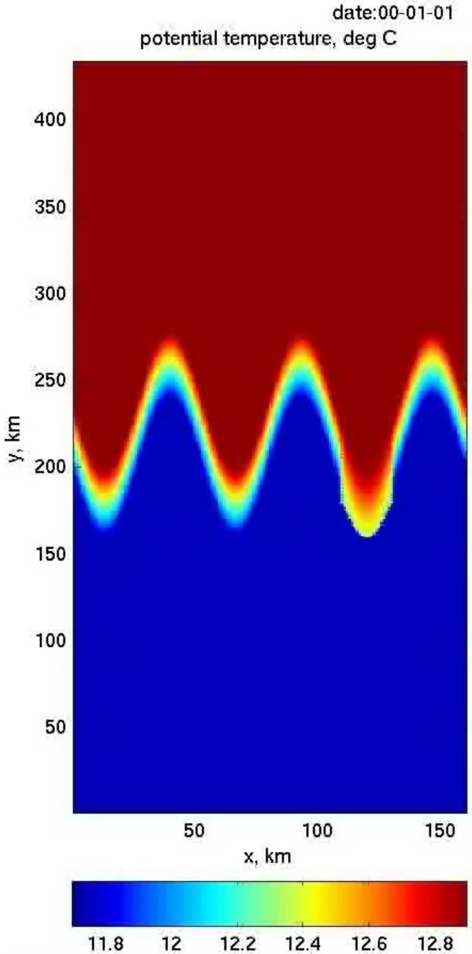
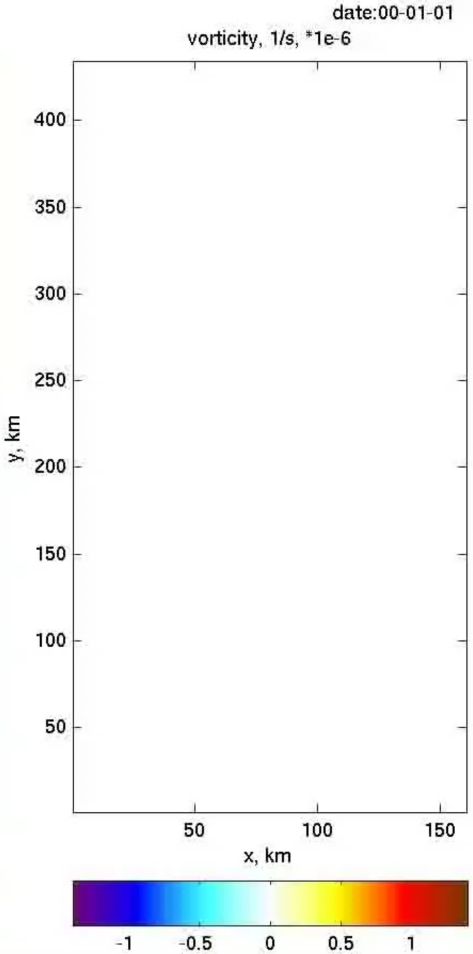
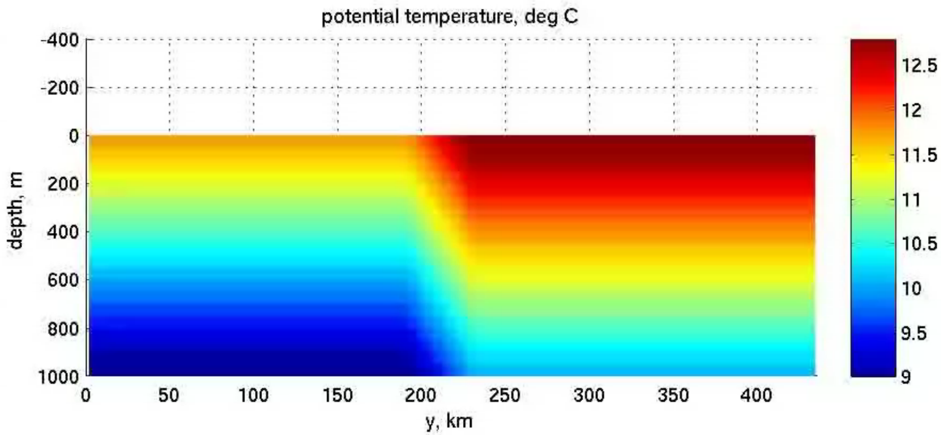
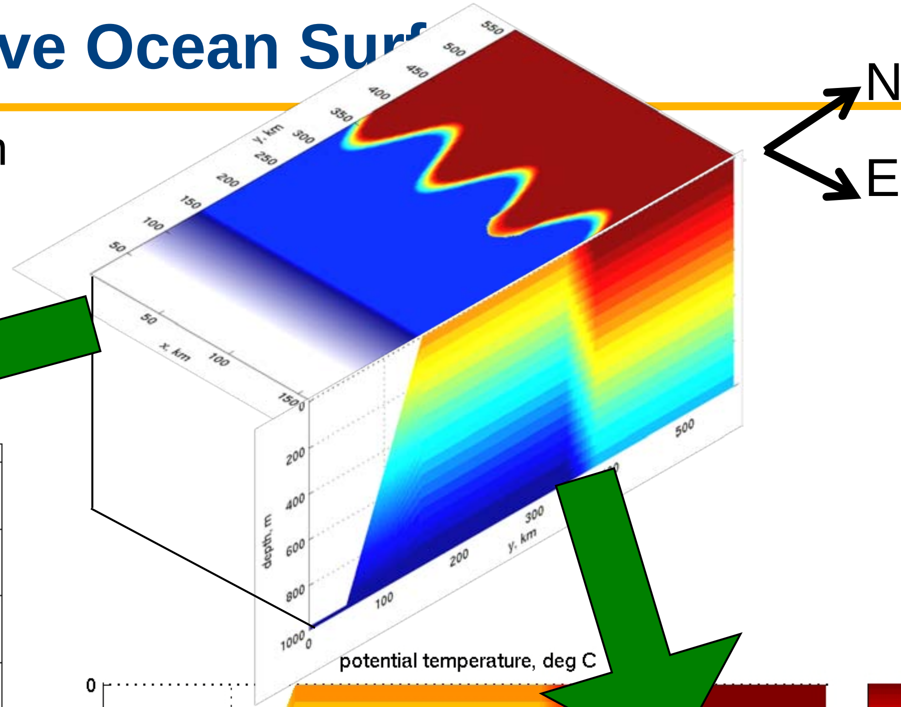


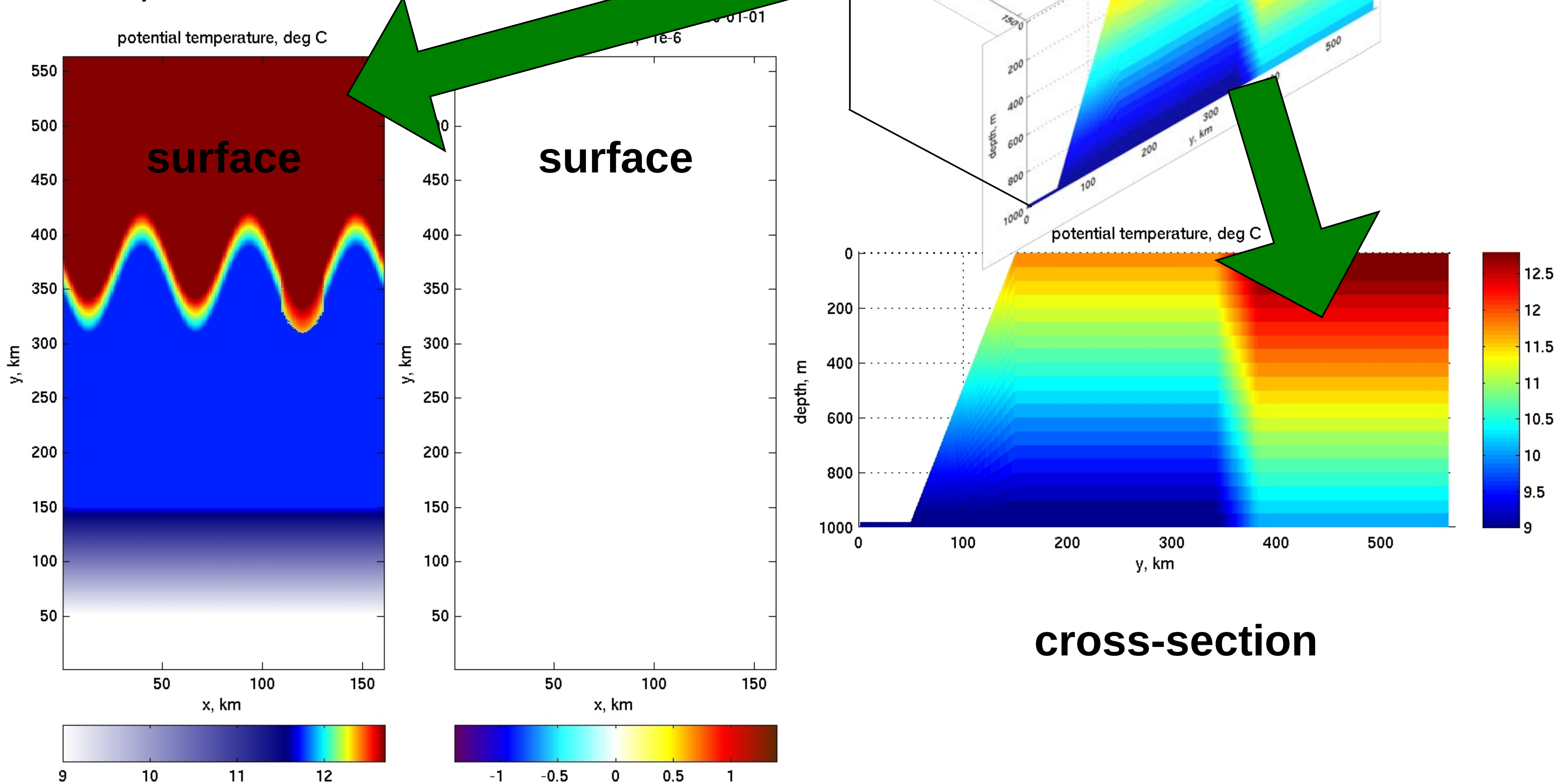




MPAS-Ocean: Ice Shelf Above Ocean Surf

- Surface pressure applied to southern 150km, constant in time.
- Baroclinic instability in northern portion.





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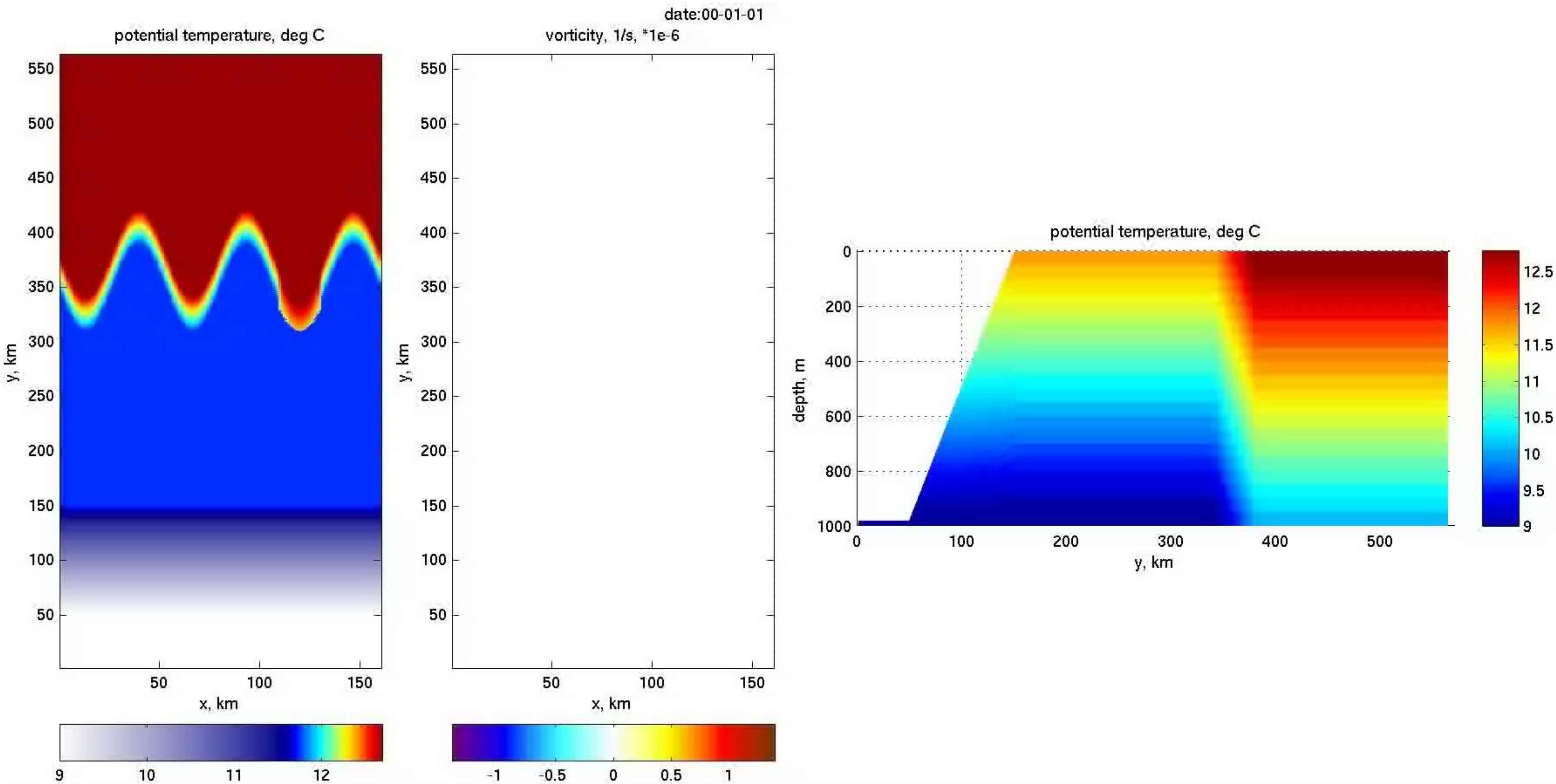
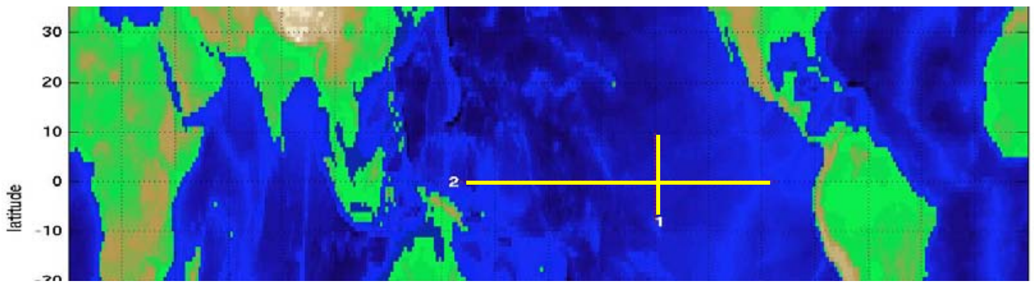


Visualization and Statistics

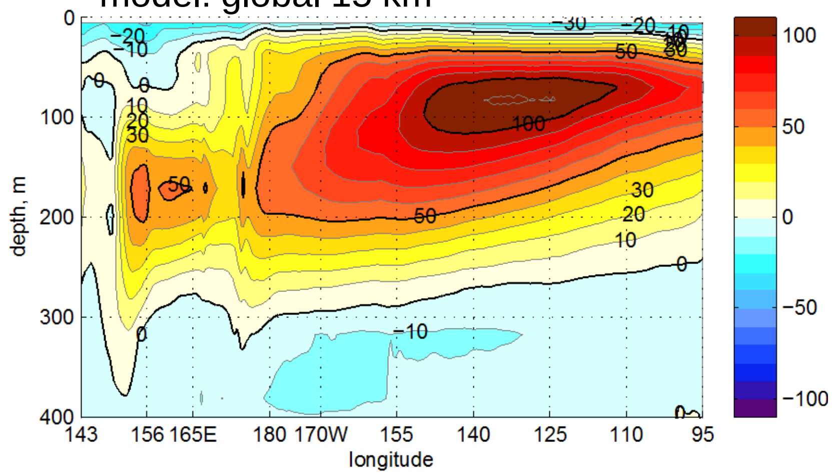
- New tools visualize cross-sections and compute transports through arbitrary sections.
- Visualization scripts are currently in Matlab.



Equatorial Undercurrent: mean zonal velocity

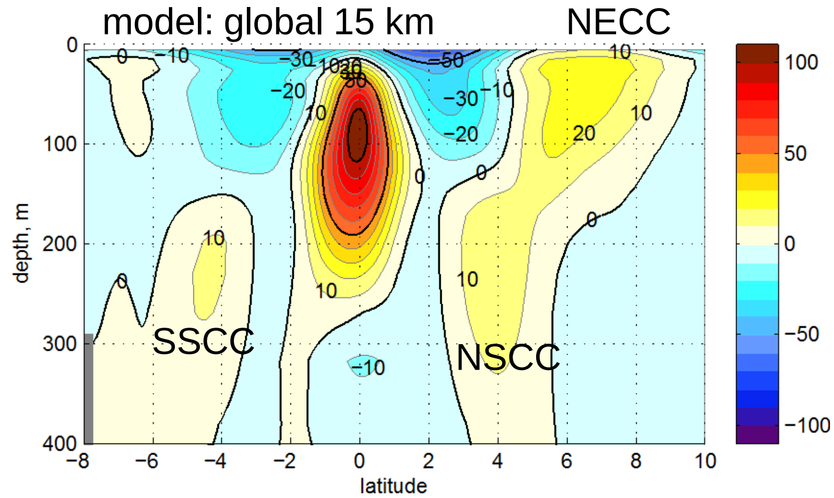
Pacific equatorial cross-section

model: global 15 km



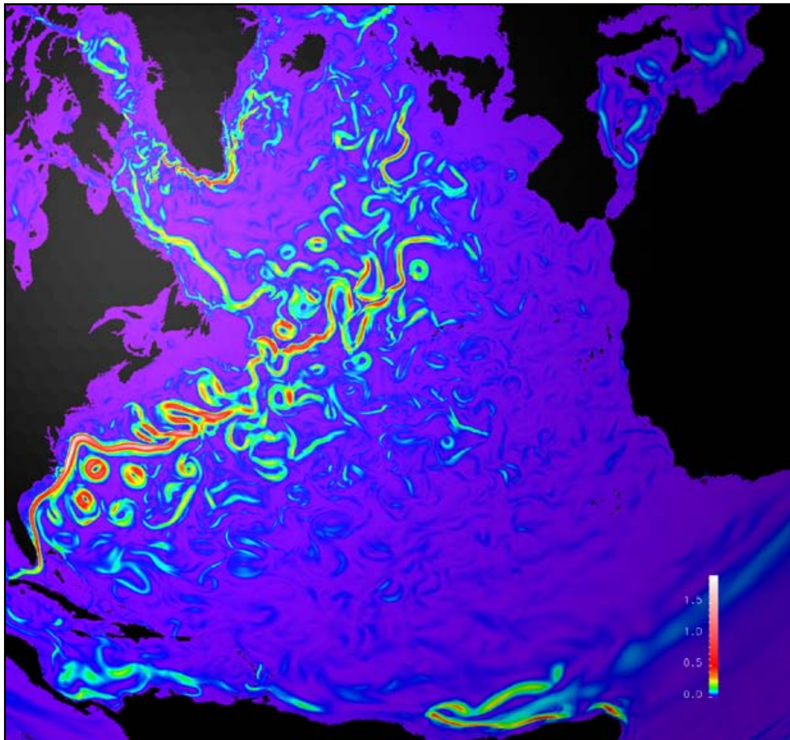
cross-section at 140 W

model: global 15 km



MPAS-Ocean: Documentation

- Appendix of first paper on MPAS-Ocean describes equations, discretization, and time-stepping methods.
- Requirements and design documents include details of each stage of development.
- These will be combined to create a User's Guide and Reference Manual for the public release.



Center for Nonlinear Studies

Ocean Turbulence

June 3-7, 2013 Santa Fe, NM

www.cnls.lanl.gov/oceanturbulence

The world's oceans exhibit phenomena at multiple length and time scales whose effects accumulate to produce the large scale circulation responsible for the heat and tracer transport that so greatly affects global climate, as well as the more local ocean currents that affect such things as fishing, regional climate and energy. Two very different examples of seemingly turbulent phenomena are:

1. Baroclinic instability and mesoscale eddies. Baroclinic instability creates eddies at the scale of the deformation radius that not only have many of the characteristics of turbulent flow (chaos, multiple scales) but that lead to important changes in the stratification, especially at high latitudes in the Southern Ocean.

2. Mixing at small scales. When dense water spills over oceanic ridges Kelvin-Helmholtz instability leads to strong, perhaps explosive, turbulent mixing, and when tides and mesoscale eddies force water over topography gravity waves are generated and break, again giving rise to mixing. Recent results further suggest that turbulent mixing can arise when internal waves propagate through the strain generated by mesoscale eddies or through a geostrophic instabilities that develop close to topographic corrugations. Not only does such mixing help set the stratification locally, but it greatly affects the meridional overturning circulation and hence the flow at global scales. Evidently, small-scale turbulence is not just a passive consequence of the larger scales: rather, the feedbacks on the large-scale flow are of first-order importance.

This conference will address the inter-relation of these and other phenomena through theory, modeling, and observation. Mixing seems to play a central role, but is this a consequence of turbulence, a definition, or what? And is mixing truly important, or is the ocean interior adiabatic at first order? Is the concept of an 'eddy diffusivity' still useful? How does energy pass through the system from the large scales to the Kolmogorov scale? Are mesoscale eddies genuinely turbulent, and what is their relation to mixing and to the small scales, if any? Finally, what can we learn from looking at the

Speakers Include:

Stephen Belcher
UK Met Office
Oliver Buhler
New York University
Claudia Cenedese
Woods Hole Oceanographic Institution
Eric D'Asaro
University of Washington
Charlie Doering
University of Michigan
Raffaele Ferrari
Massachusetts Institute of Technology
Baylor Fox-Kemper
Brown University
Peter Gent
Nat'l Center for Atmospheric Research
John Gibbon
Imperial College, London
Peter Haynes
University of Cambridge
Keith Julien
University of Colorado, Boulder
Patrice Klein
Laboratoire de Physique des Oceans
John Marshall
Massachusetts Institute of Technology
Jen McKinnon
Scripps Institute of Oceanography
James McWilliams
University of California Los Angeles
Peter Rhines
University of Washington

James Riley
University of Washington
Harry Swinney
University of Texas at Austin
K. Shafer Smith
New York University
Harry Swinney
University of Texas at Austin
Lief Thomas
Stanford University
Edriss Titi
University of California Irvine
Jacques Vanneste
University of Edinburgh
Carl Wunsch
Massachusetts Institute of Technology
William Young
Scripps Institute of Oceanography

Center for Nonlinear Studies

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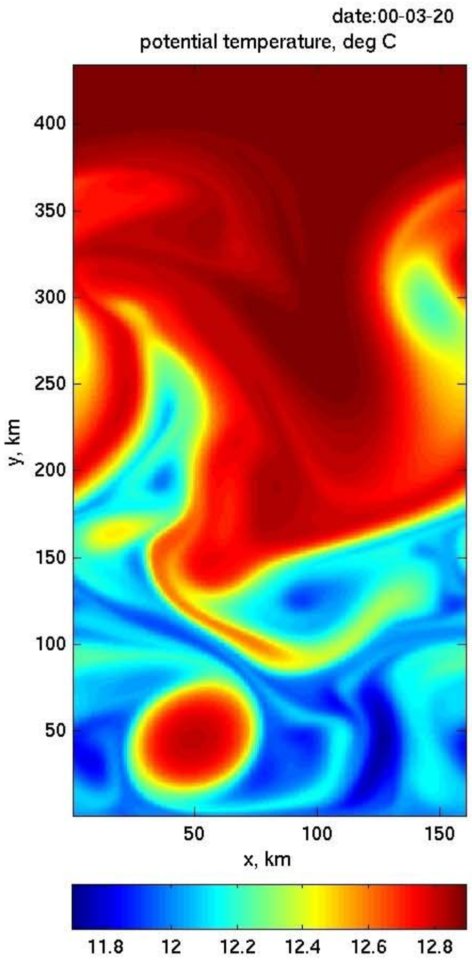

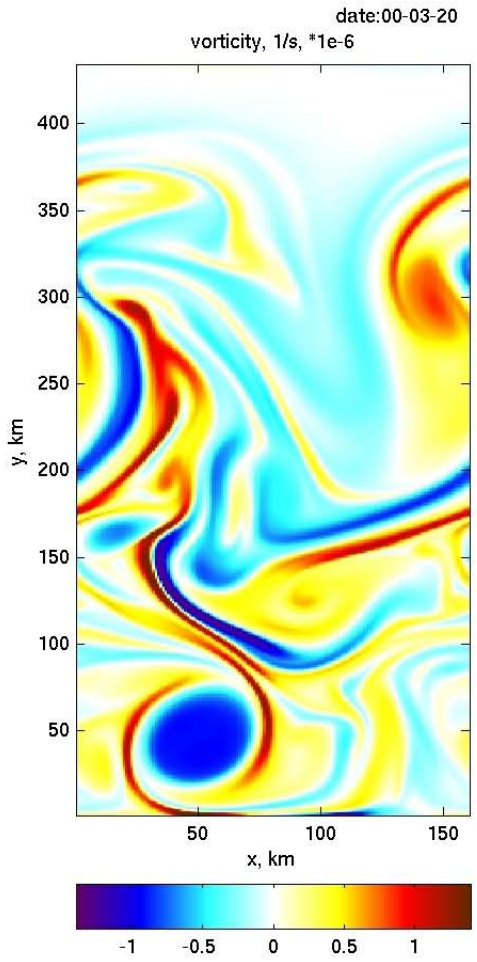

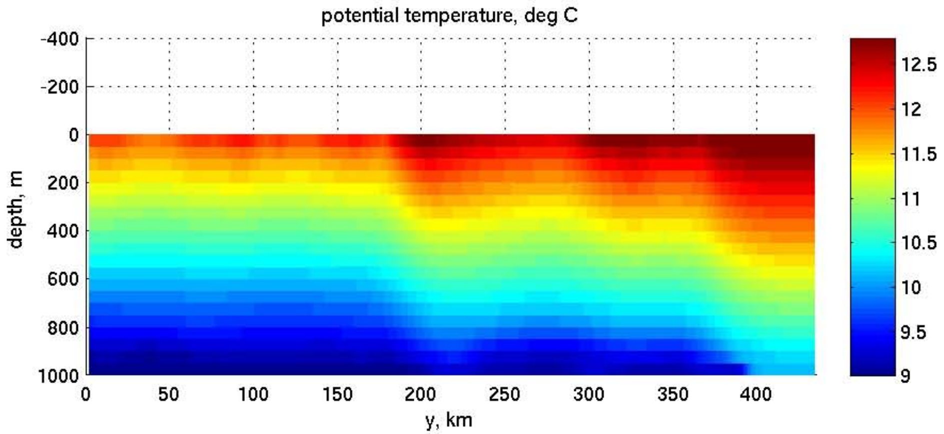

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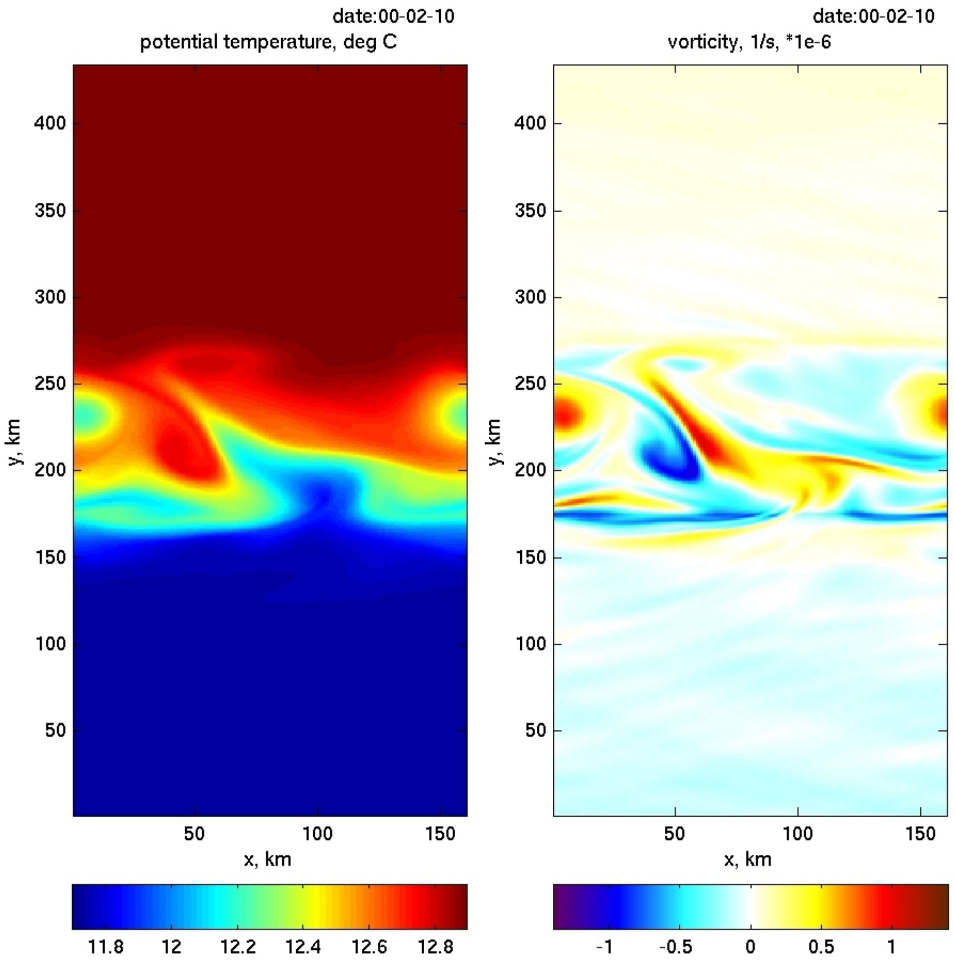

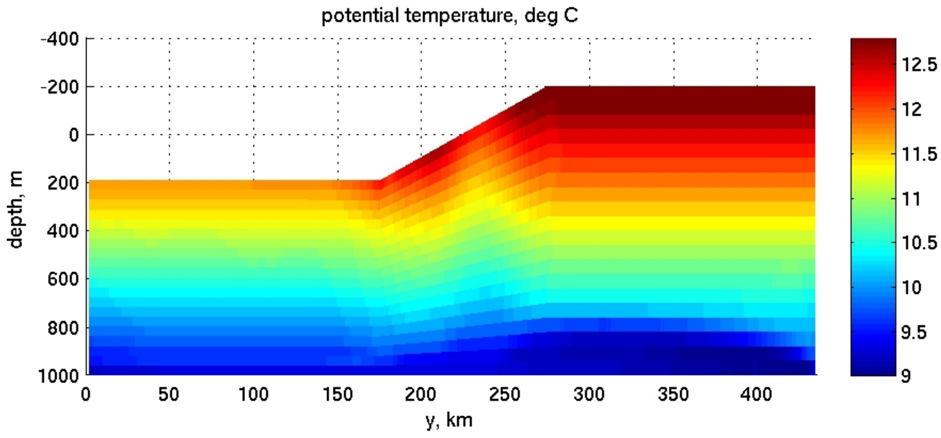

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