Progress in coupling Land Ice and Ocean Models in the MPAS Framework

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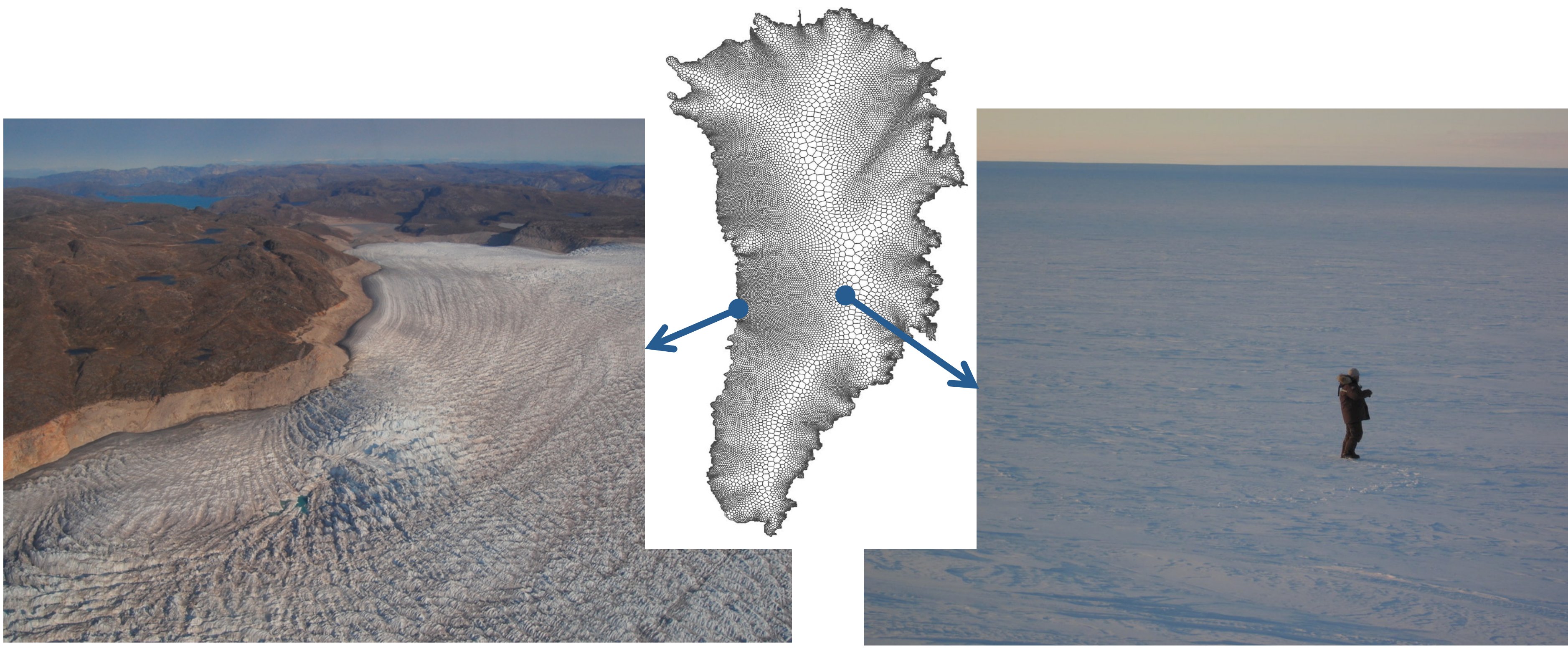
MPAS: Variable-resolution grids

- **MPAS** - **M**odel for **P**rediction **A**cross **S**cales: A climate modeling framework that supports dynamical cores on unstructured Voronoi (SCVT) meshes (existing MPAS Atmosphere, Ocean, Land Ice cores)
- Allows high resolution in regions of interest, reducing necessary number of grid cells by ~10x



Interface MPAS-LIFEV

MPAS

- Grid
- Evolution (thickness, tracers)
- Physics

Land ice component

MPAS
<u>Framework</u>
I/O
MPI
Grid management
Timekeeping
Shared operators
…

2D CVT mesh
(Stereographic projection)

thickness/elevation/layers

temperature/ice flow factor

bedrock sliding coefficient

Solver options:
model (FO, L1L2, SSA, SIA)
nonlinear solver (Newton, Picard, JFNK)
Boundary condition (free-slip, no-slip, robin, coulomb)

→

←

velocity

heat dissipation

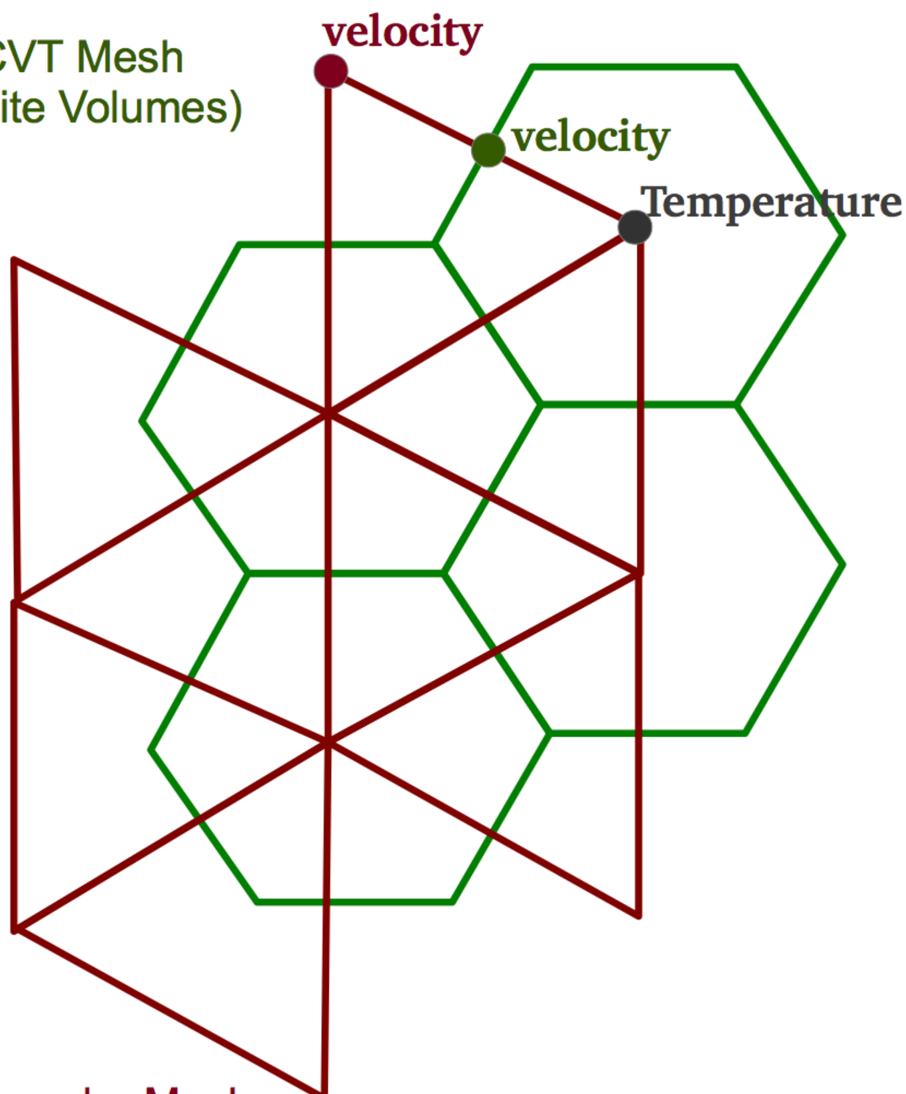
viscosity

LIFEV

ice-sheets component

Slide modified from Mauro Perego

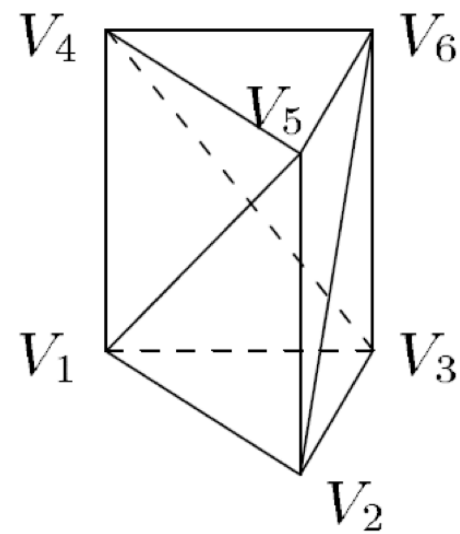
MPAS CVT Mesh
(OK for Finite Volumes)



Lifev Dual triangular Mesh
(OK for Finite Elements)

Based on 2D grid and thickness and layers build vertically structured **3D grid.**

Build prisms with triangular base and split them in tetrahedra.



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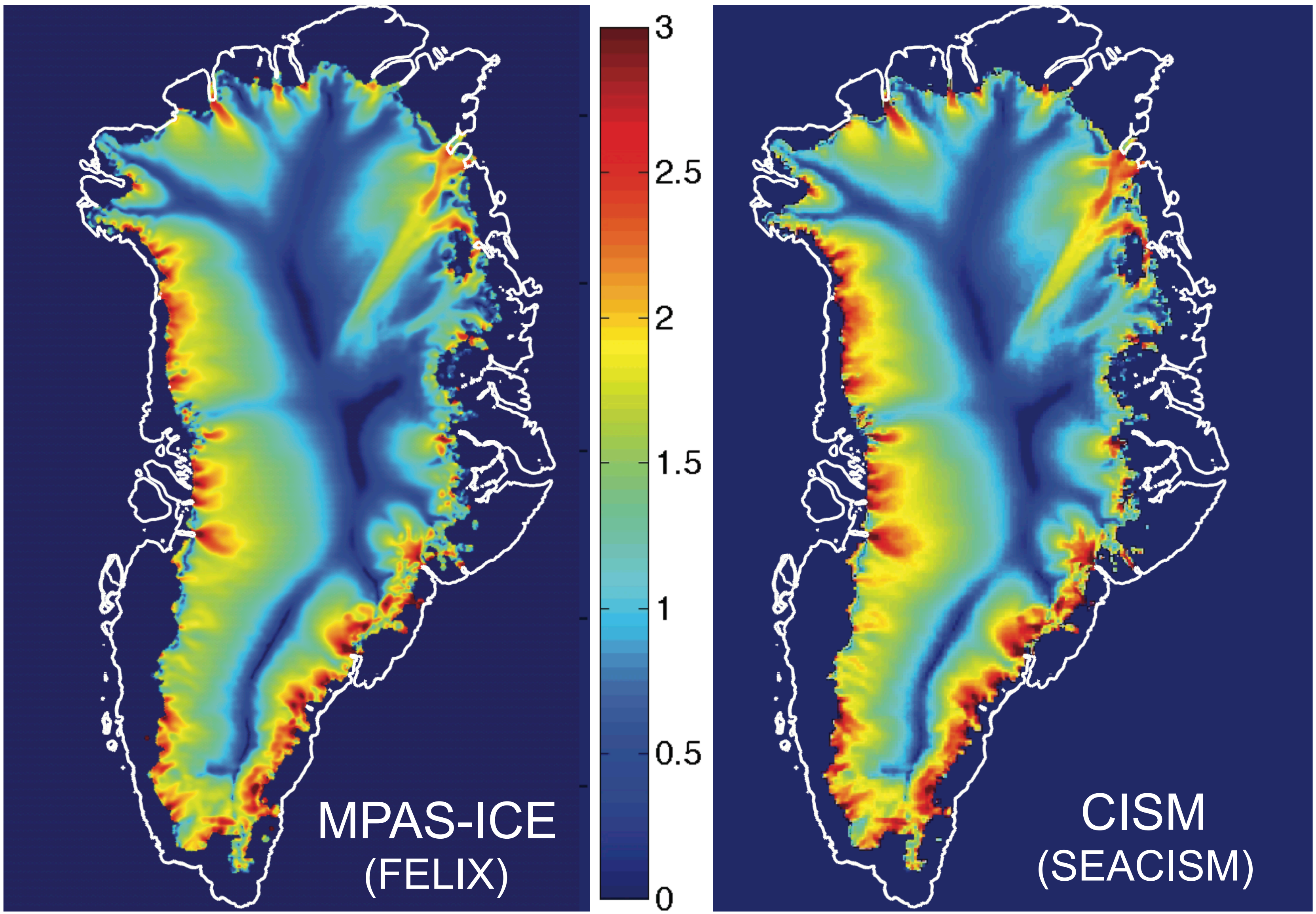
MPAS-Land Ice Status

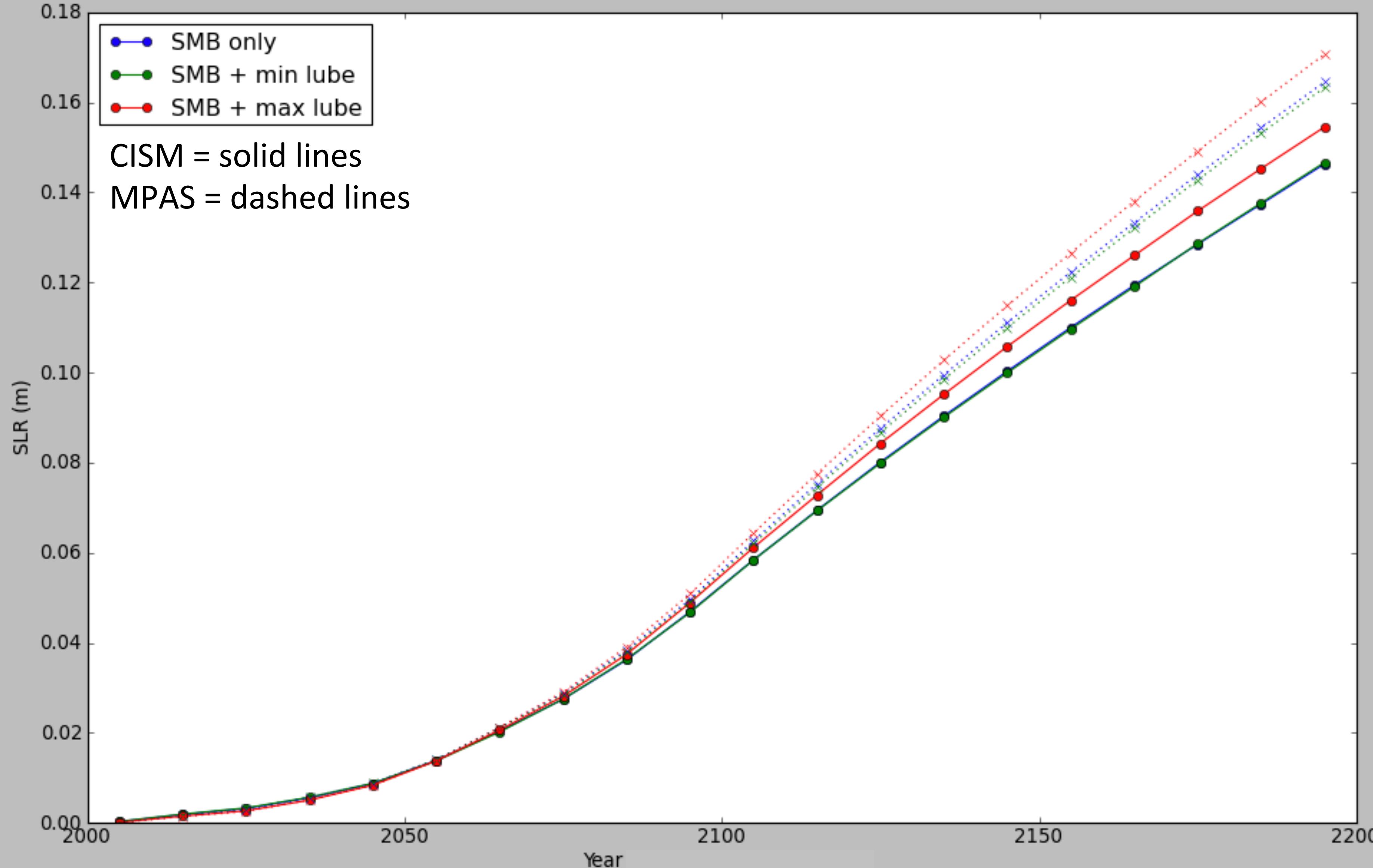
- Interface to LifeV (FO, L1L2, Stokes)
- Native SIA velocity solver
- Forward Euler Time Integration scheme
- FO Upwind thickness advection
  - Margin advance & retreat
  - Surface Mass Balance
- Ability to apply time-varying forcings (SMB, beta, Tsfc, G)
- Tools external to MPAS (written in python)
  - Setup land ice grids on regular planar hex mesh
  - Ability to setup dome test case,
    copy CISM datasets to MPAS grids
  - Visualization tools (not many off-the-shelf options)
- Performed 2 ice2sea Greenland SLR experiments (3 publications)

5km Greenland, Diagnostic Velocity

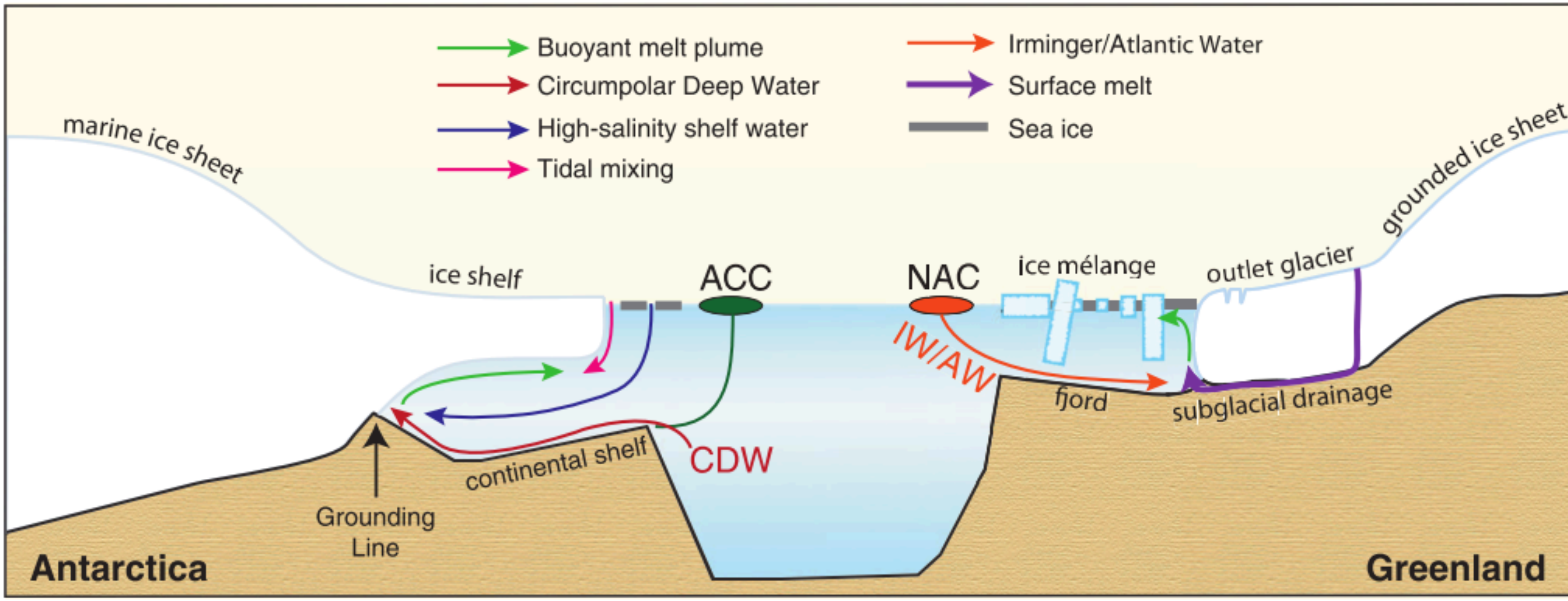
Run successfully on up to 2048 procs, timings comparable to CISM - CISM is doing more work (e.g. temperature solve), but most of the cost is the velocity solve, so encouraging.



Greenland Ice Sheet sea level rise
ice2sea basal lubrication experiments



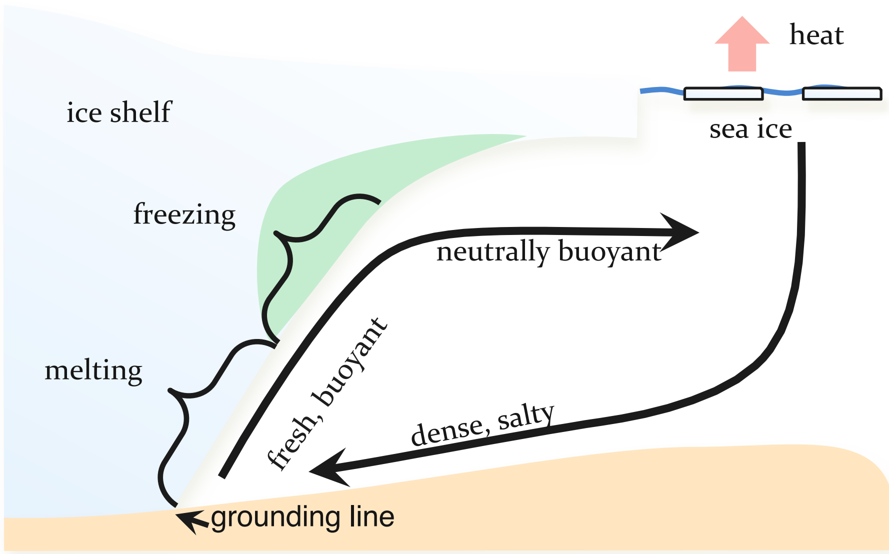
Ice-Ocean Processes

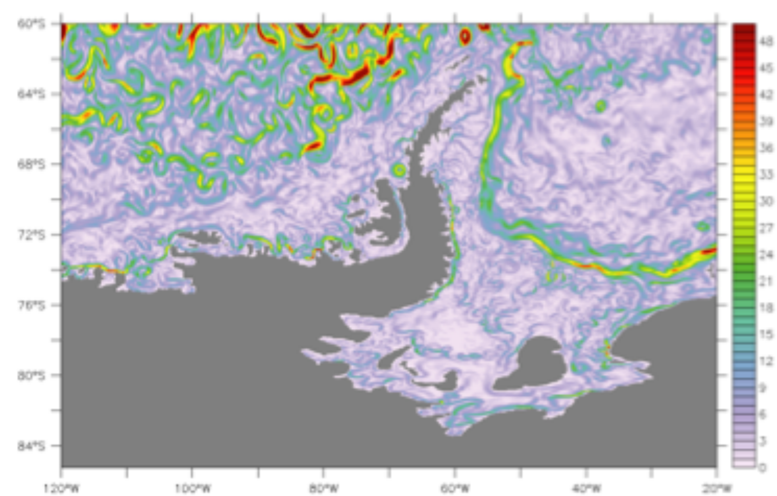


Joughin et al. 2012

Ice-shelf Processes

- Ice-shelf melt/freezing drives an overturning circulation: Melt water is colder but less salty than ocean water
- Coriolis force induces counterclockwise flow: Inflow in the west, outflow in the east





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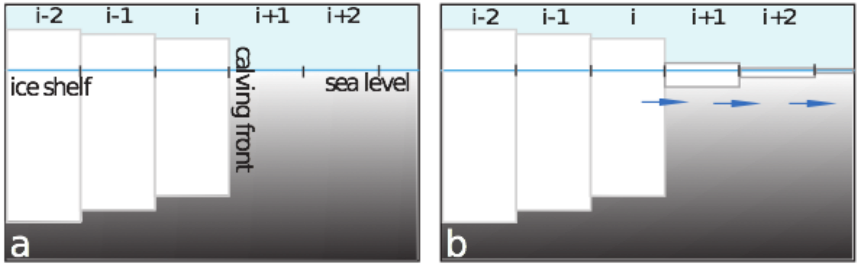
Land Ice Model features needed for ice shelf simulations

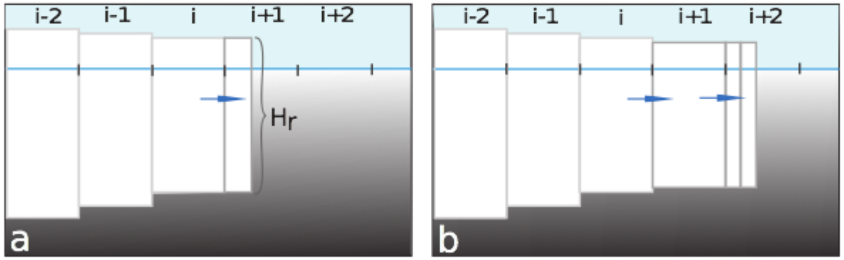
- Ice shelf basal (free-slip) and lateral (hydrostatic pressure) boundary conditions
- Advance of floating ice
- Calving 'laws'
- Basal Mass Balance
- Grounding line migration (floatation, subgrid)

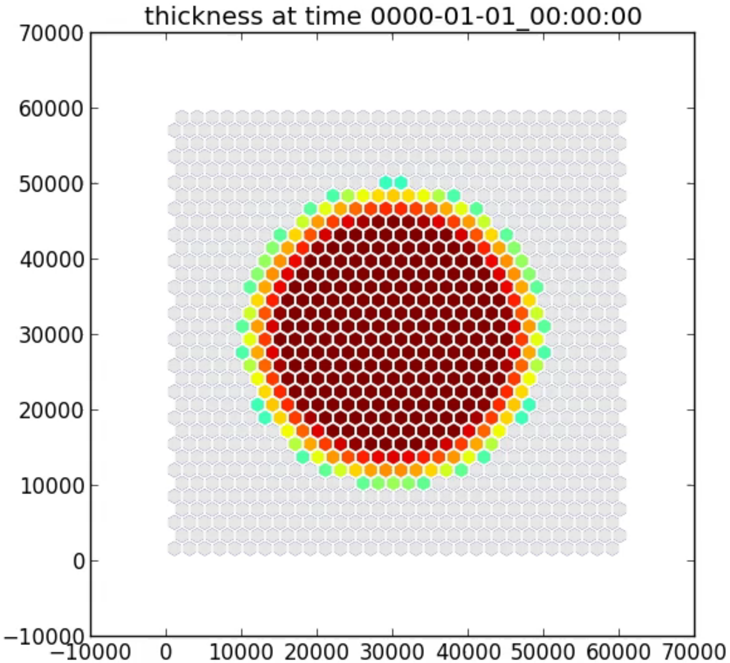
- Subglacial discharge
- Tracer advection (FO, FCT, vertical temperature diffusion)

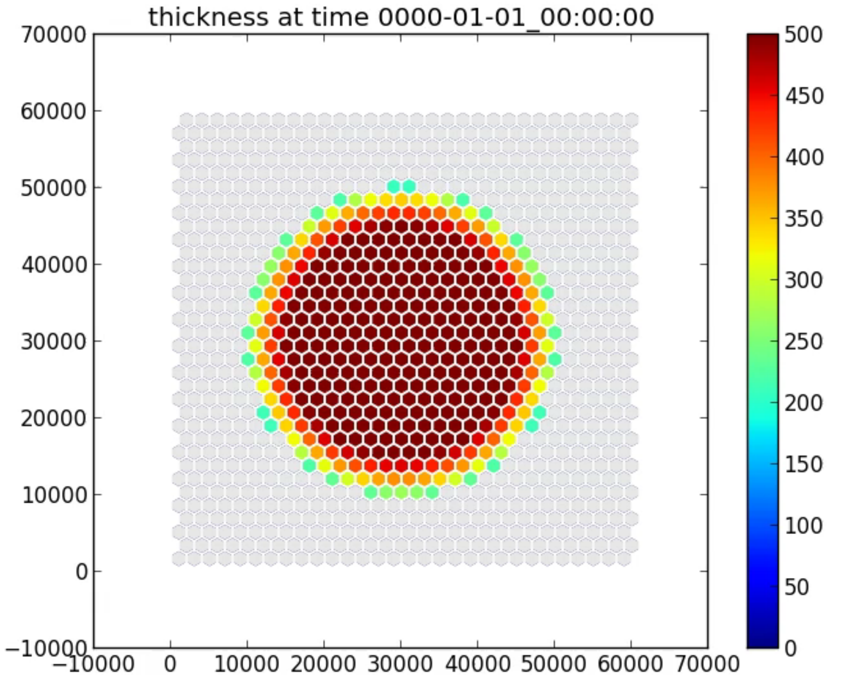
Advance of floating ice

Sub-grid parameterization of ice shelf advance (Albrecht, et al. 2011)









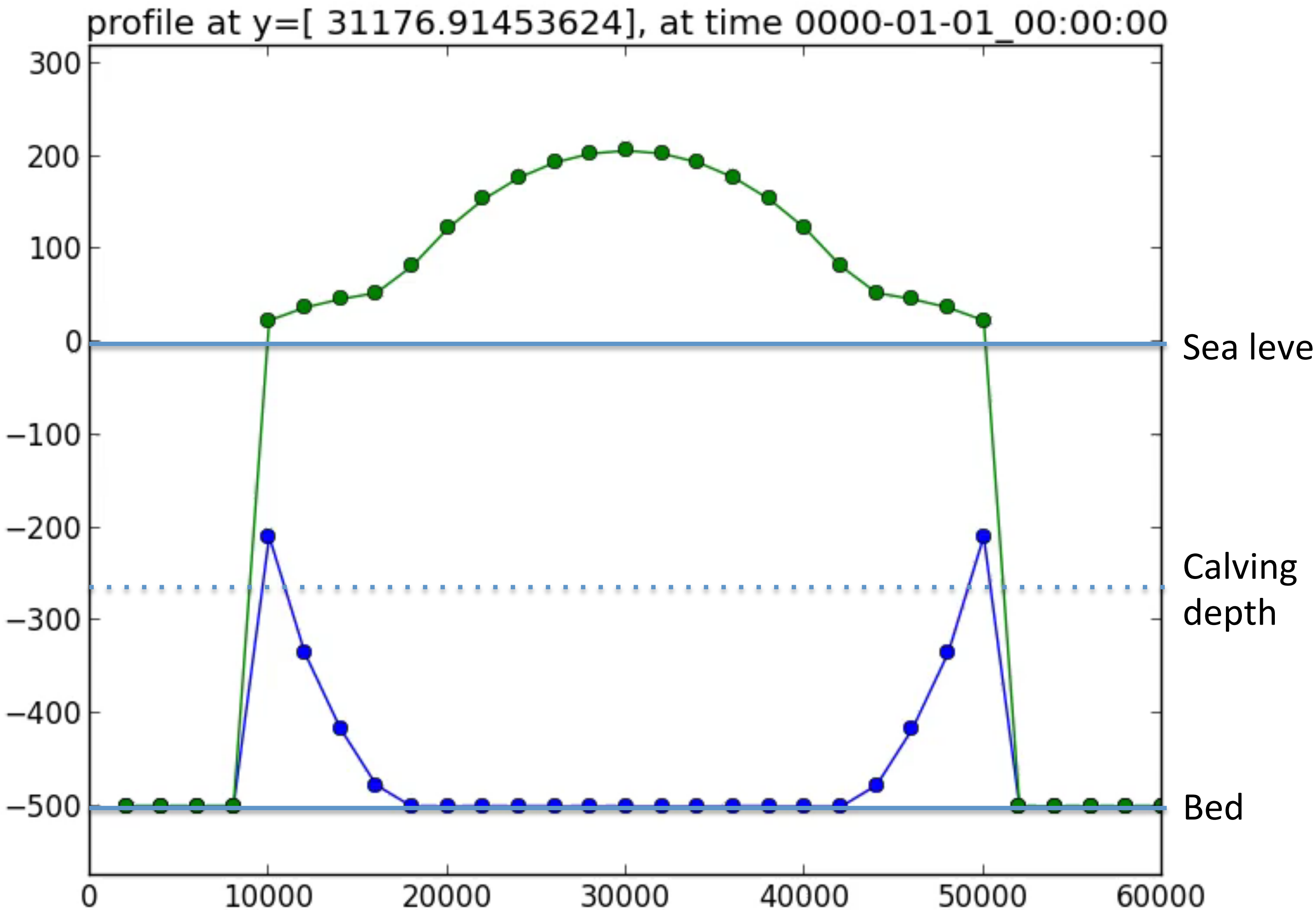
Calving "Laws"

- Ocean kill
- Constant calving front position ($v_{calving} = v_{front}$)
- Specified calving flux
- Critical ocean depth
- Critical thickness
- Crevasse depth = water line; $f(H, R_{xx})$ (Nick et al. 2010)
- Eigencalving; $f(\varepsilon)$ (Levermann et al. 2010)
- Damage (Borstad et al. 2012)

Note: most of these require physically realistic marine advance.

Critical thickness calving law

(with sub-grid parameterization of ice shelf advance)



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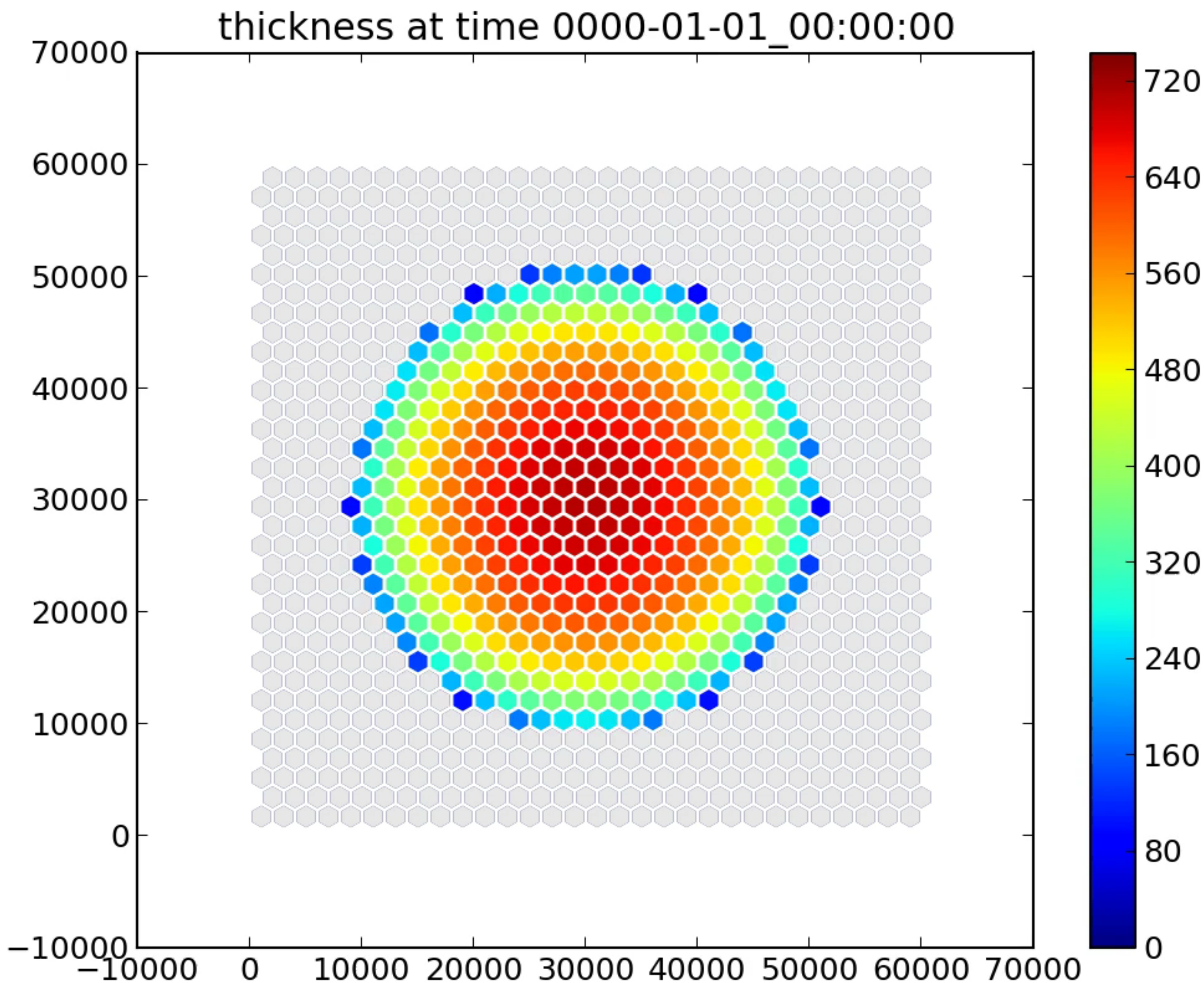
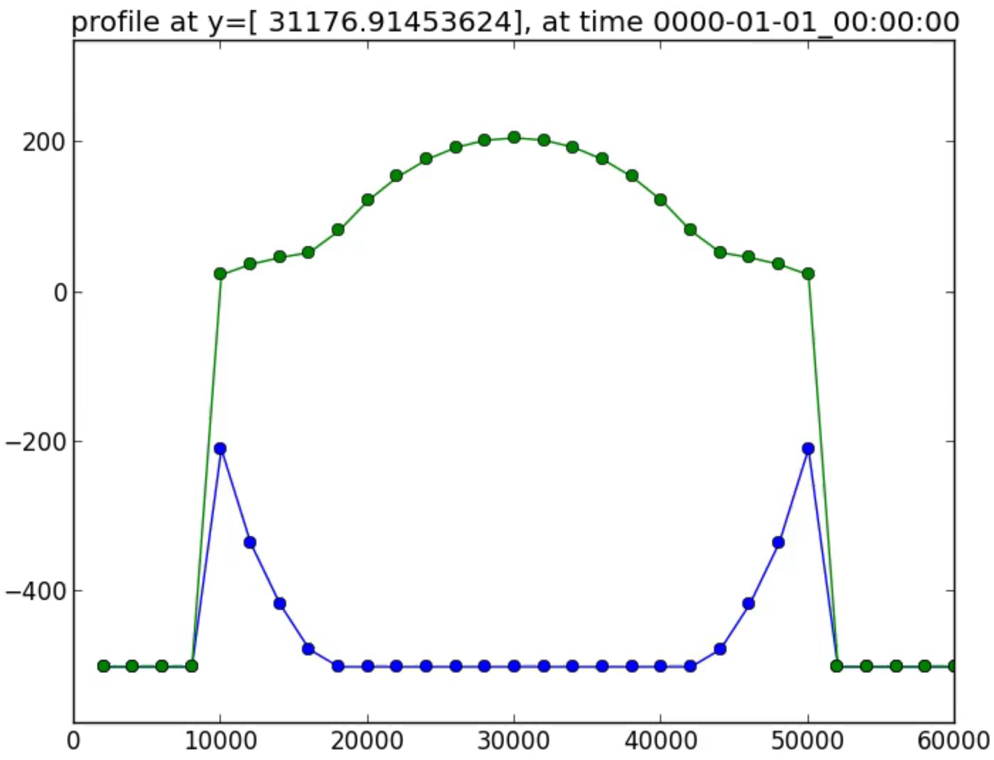


Basal Mass Balance

- Source term in thickness evolution
- Todo:
  - Couple to ocean model
  - Parameterize f(bed slope) (Little et al. 2012)



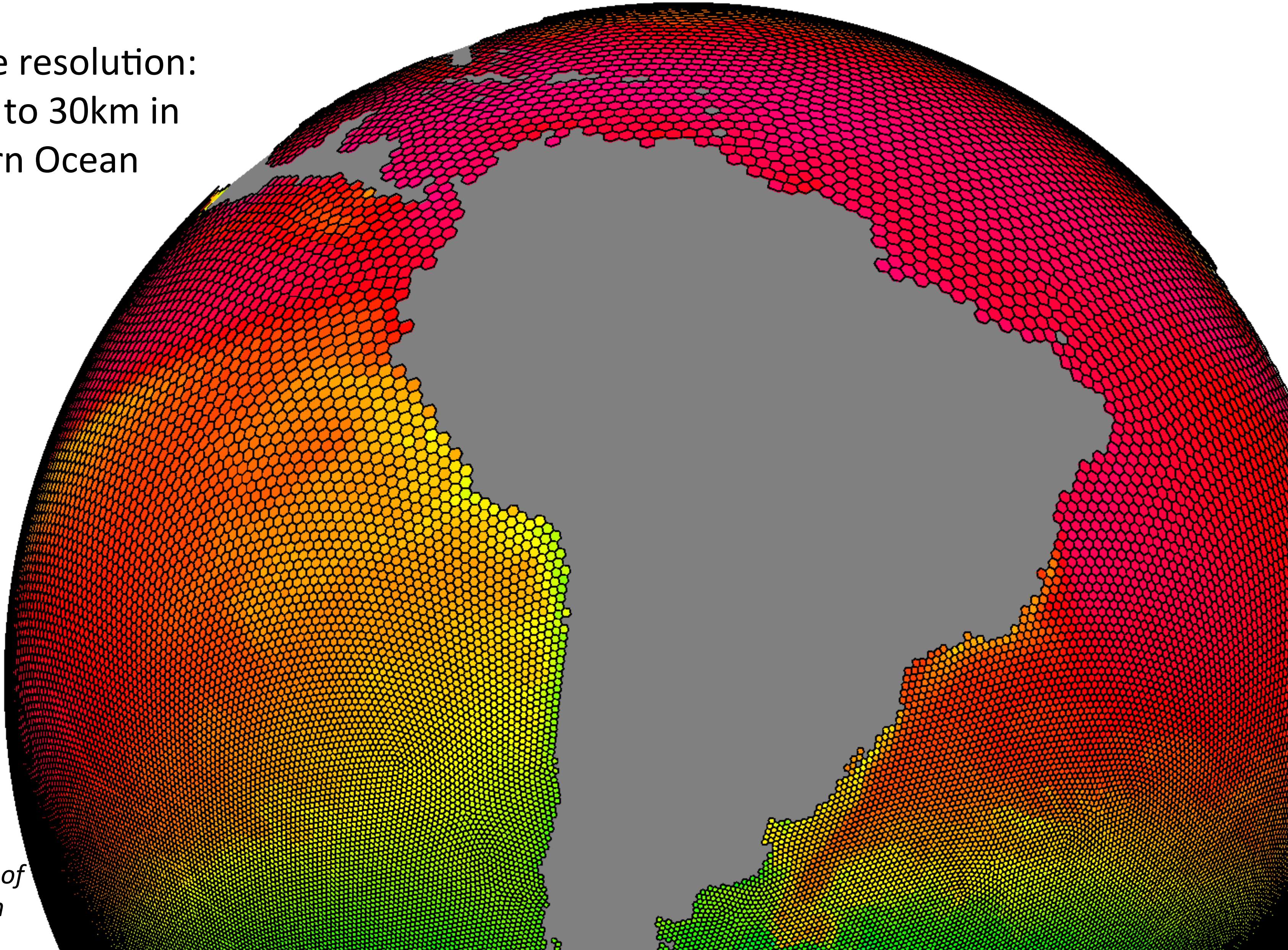
Ocean Model features needed for ice shelf simulations

- Sub-shelf circulation
  - Ocean surface is not sea level
  - Vertical walls
  - Changing upper surface elevation
- Mass and tracer fluxes at ice-ocean interface
- Boundary-layer physics (working in POP)
- Sea ice model (in early stages of development)

- Coupling to Land Ice Model

MPAS-Ocean Horizontally Unstructured Grids

Variable resolution:
120 km to 30km in
Southern Ocean



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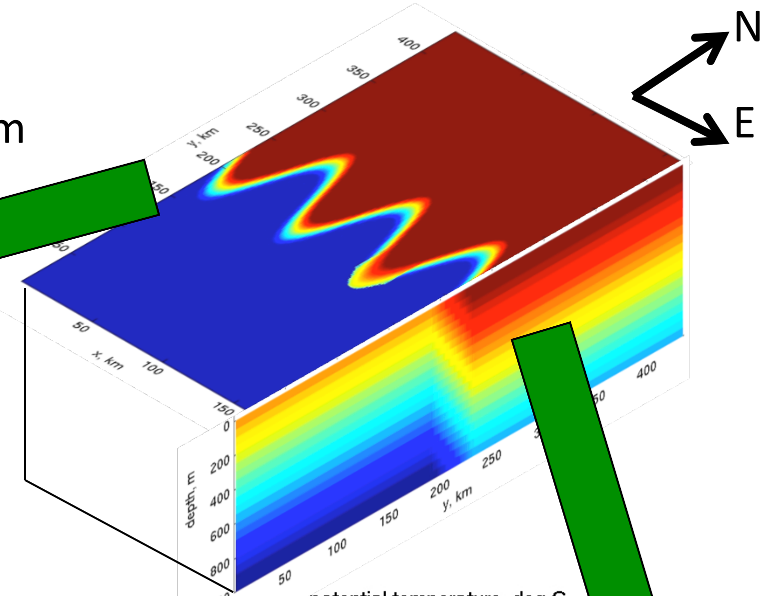
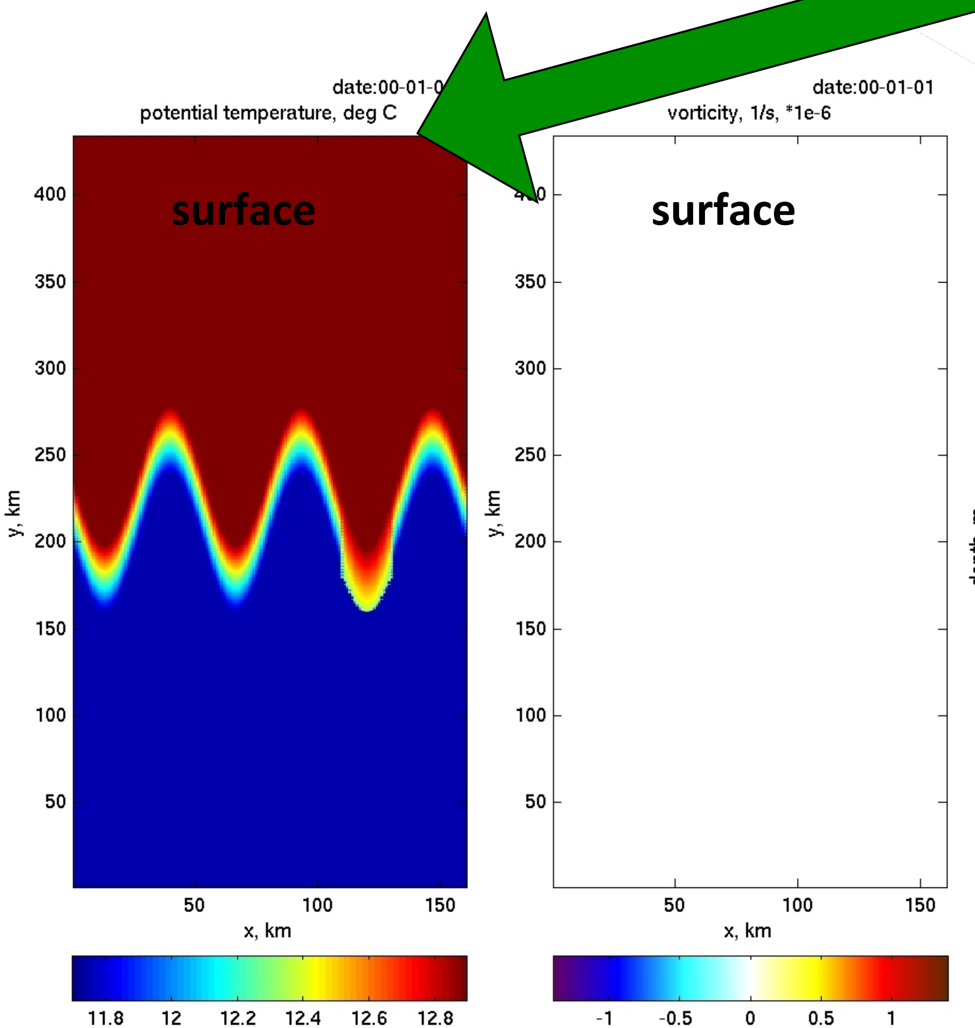
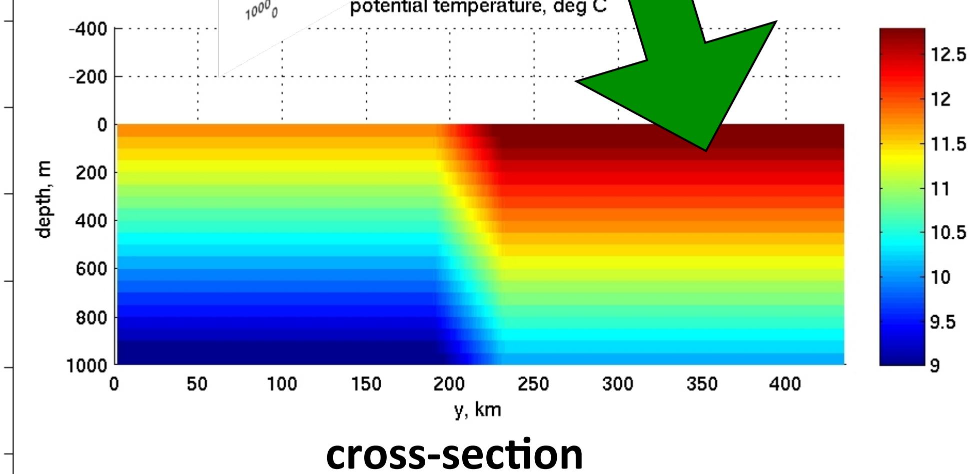
Mark Petersen

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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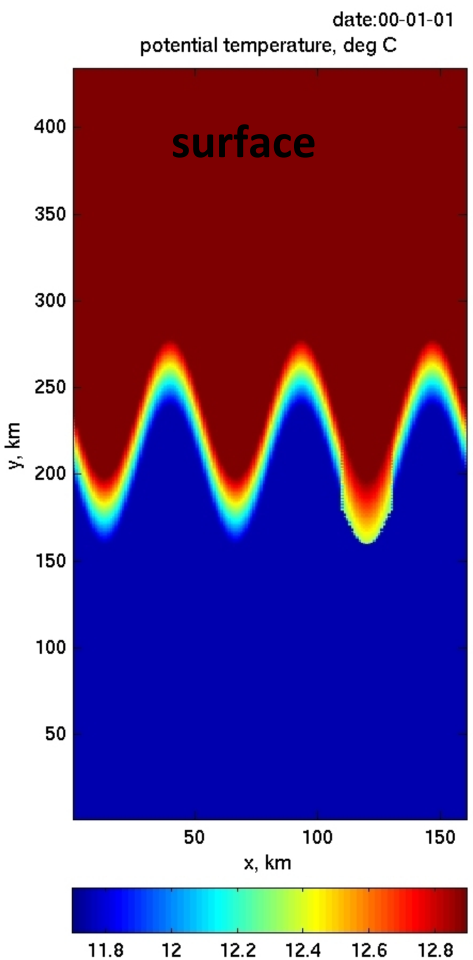
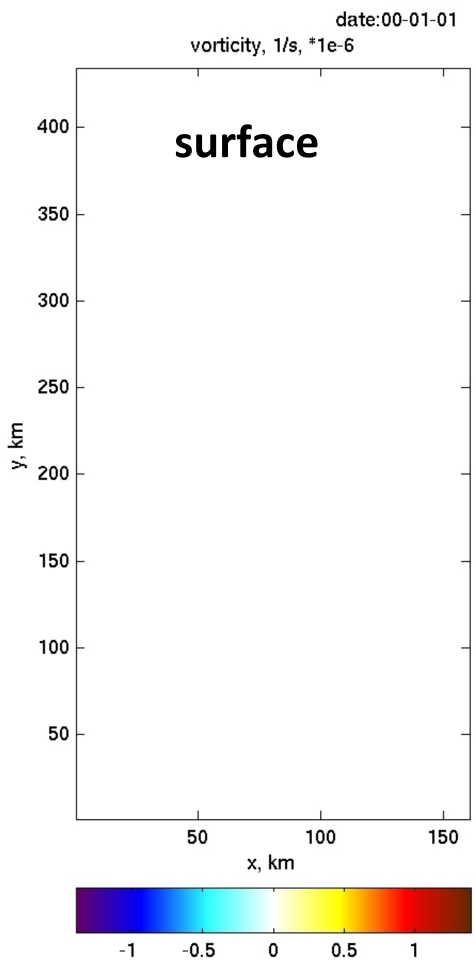
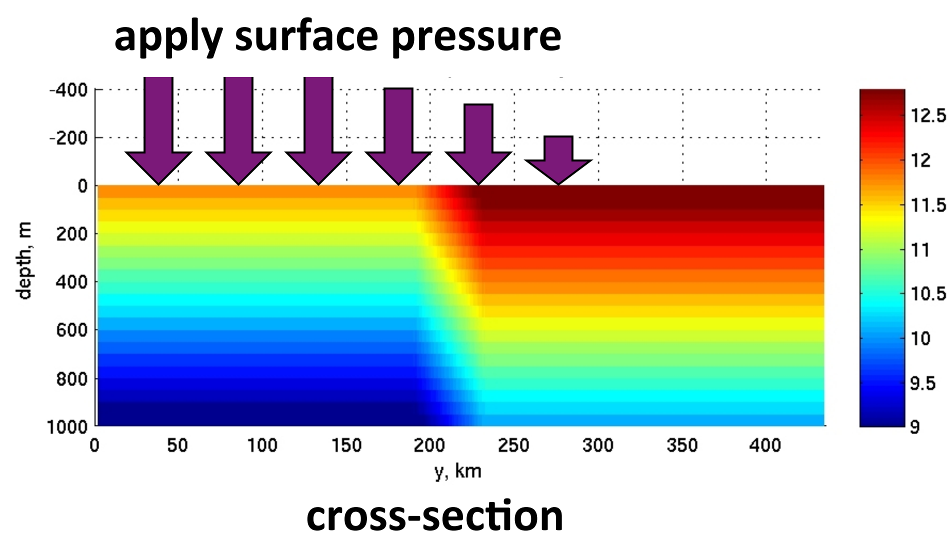
MPAS-Ocean: Ice Shelf Above Ocean Surface

- 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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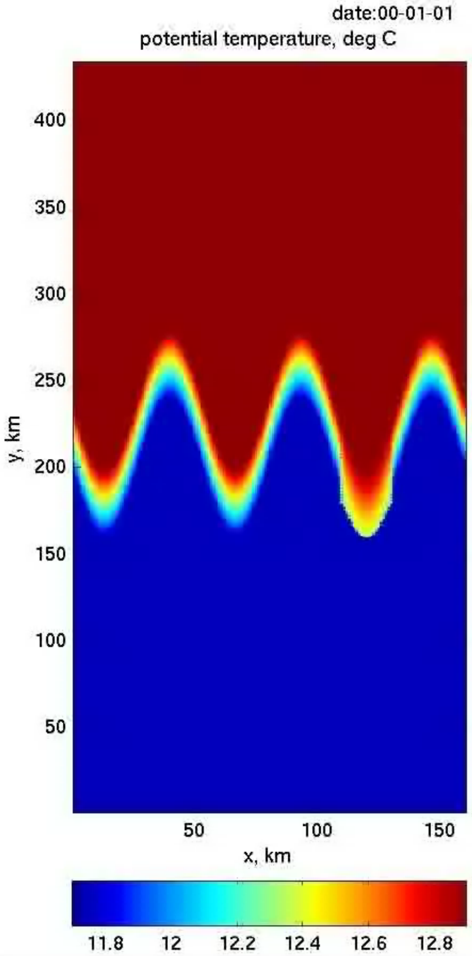

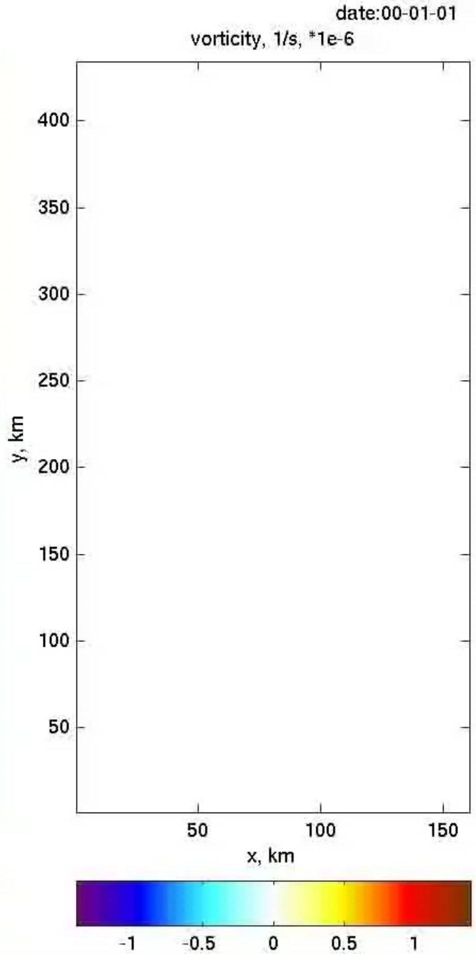

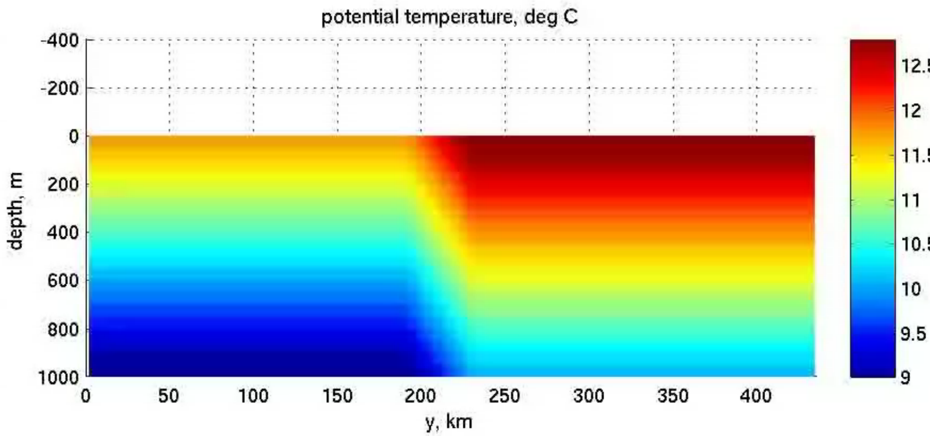

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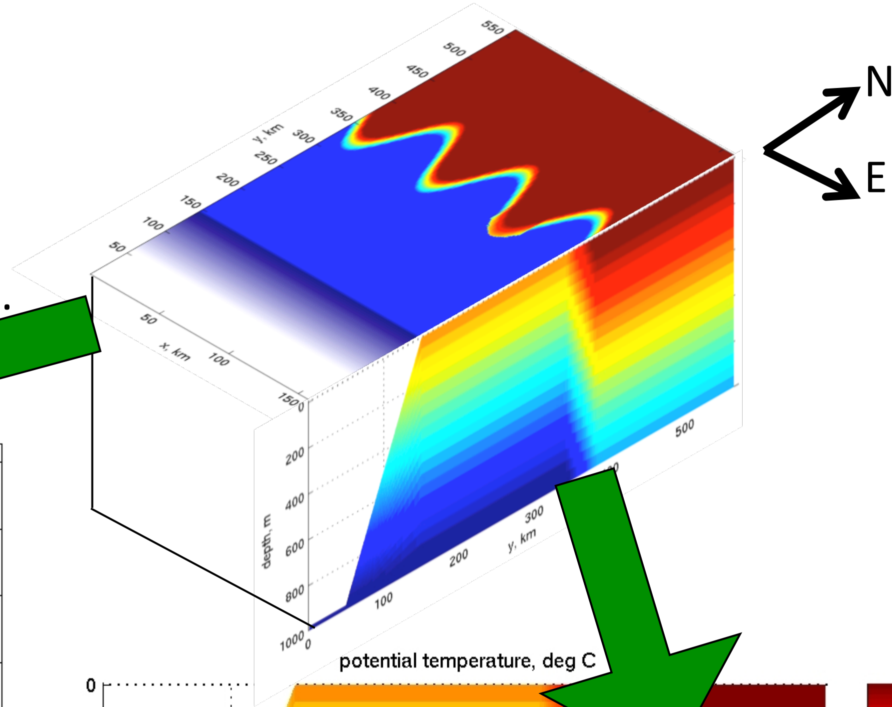
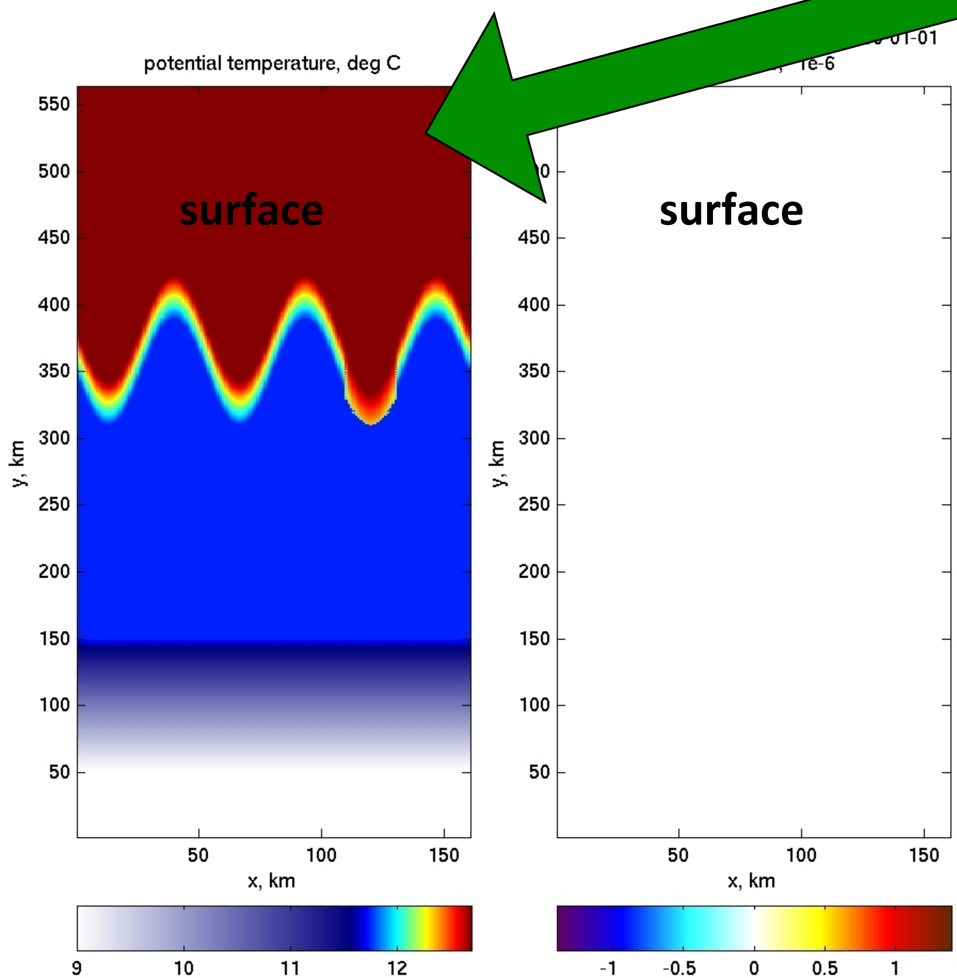
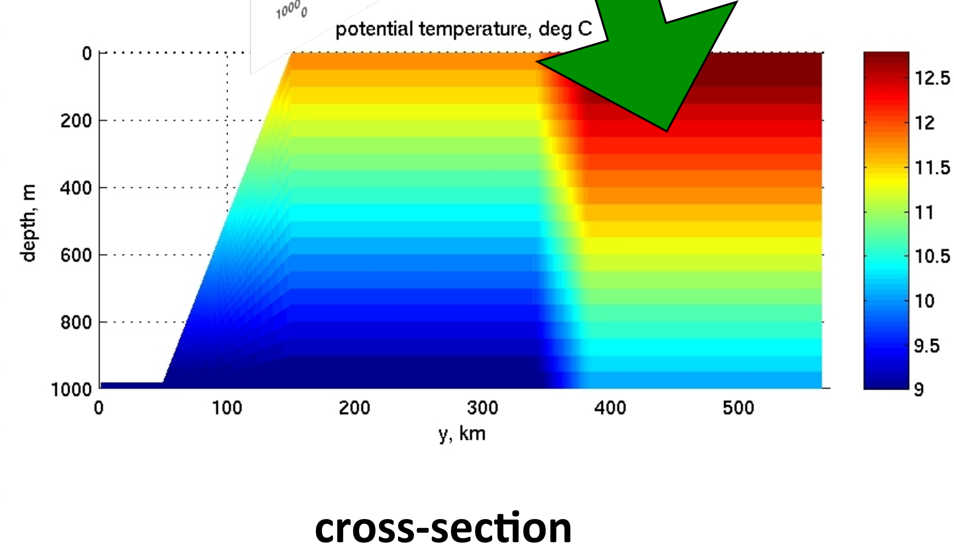
- Surface pressure applied to southern 150km, constant in time.
- Baroclinic instability in northern portion.







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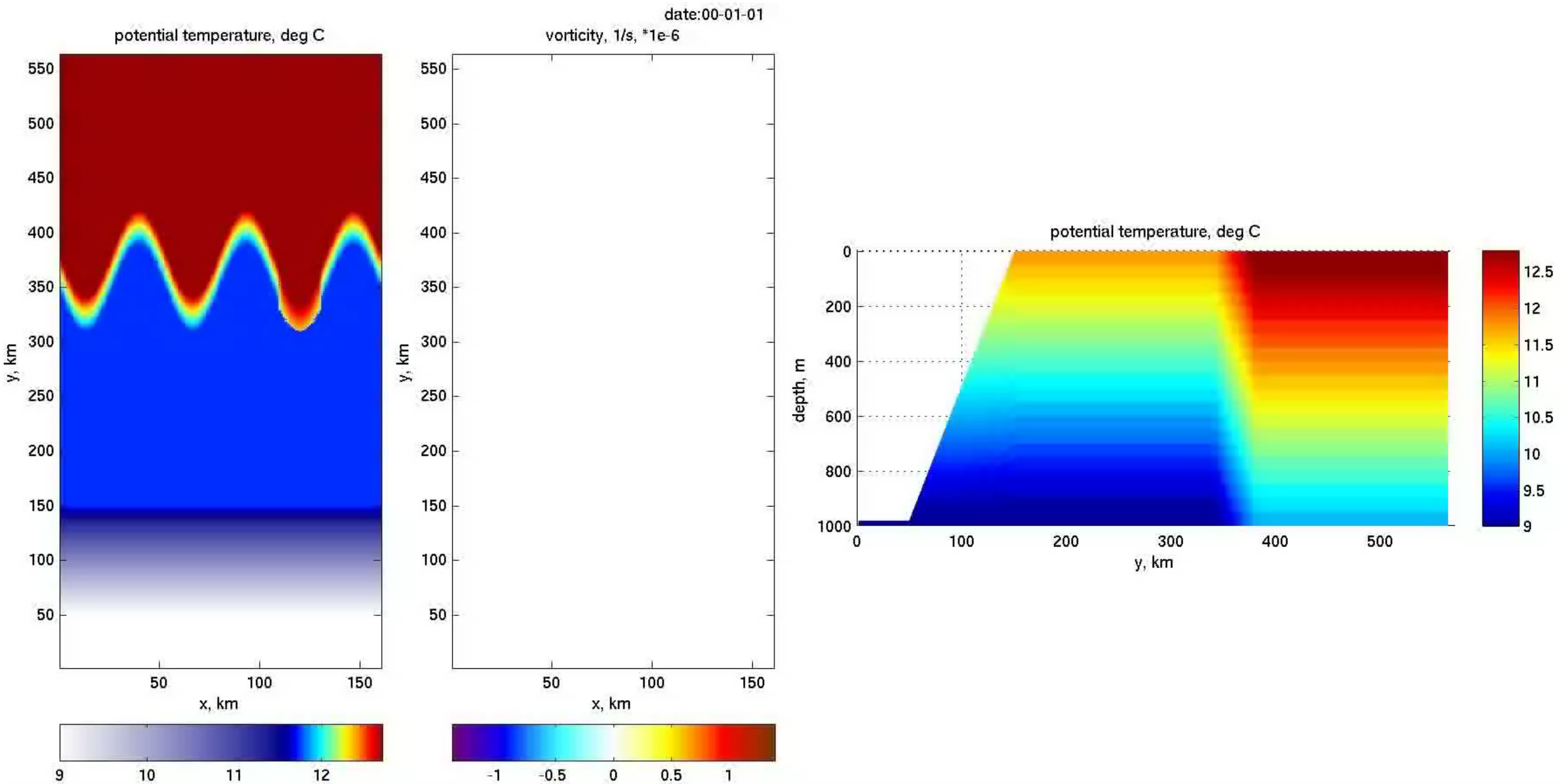
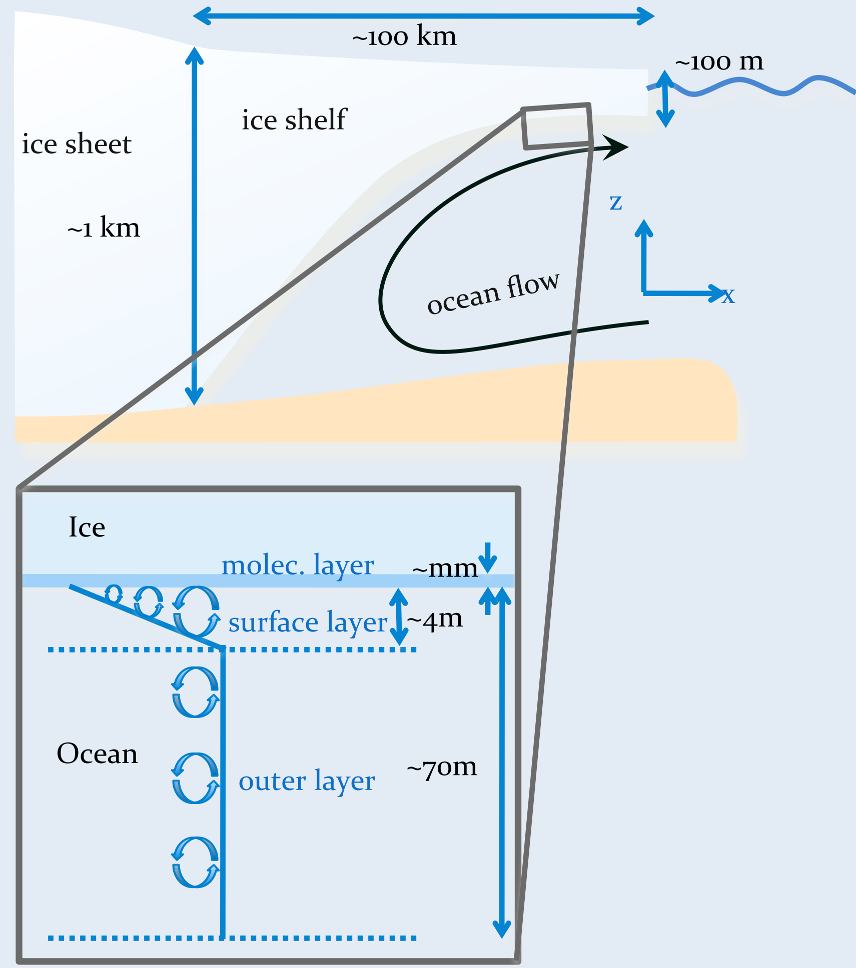


Boundary Layer Physics
heat, salt, momentum and mass transport

- *Very few* observations under ice shelves:
- So, using boundary layer theory validated under **sea ice** (McPhee 2008)
- Includes stabilizing effect of **stratification**, very important for rapid melting



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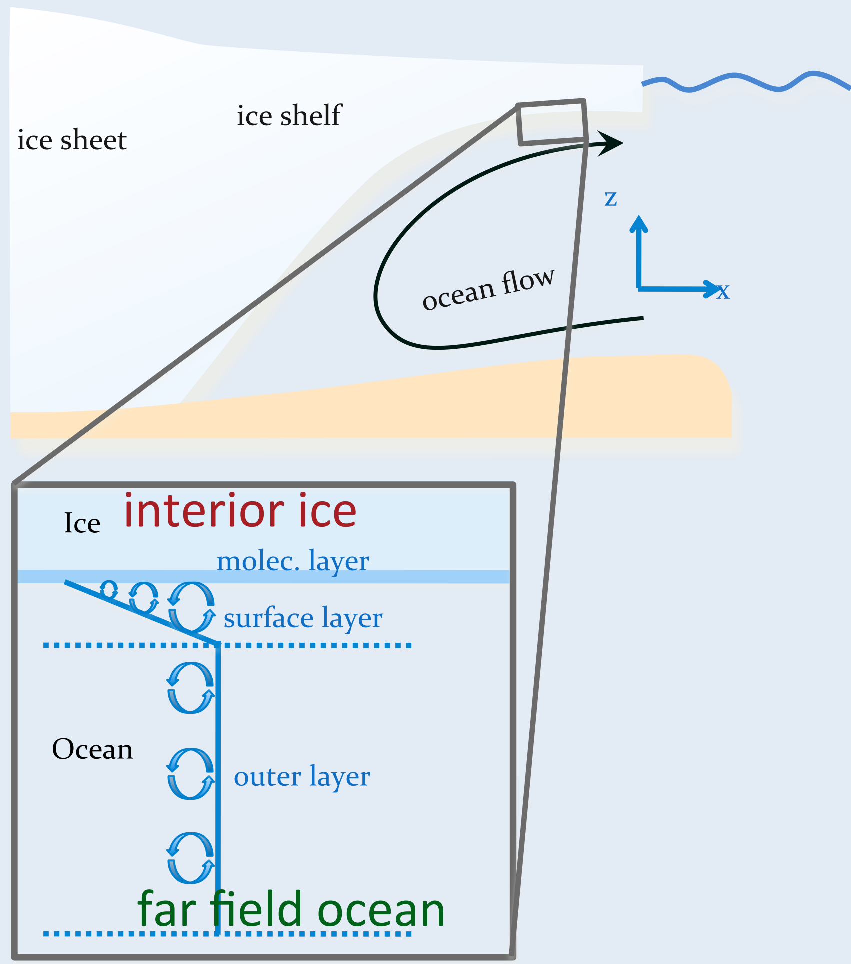
Boundary Layer Physics
heat, salt, momentum and mass transport

- Requires:
  - far field ocean temp., velocity, salinity
  - interior ice temperature
  - 2 parameters (z0, C)
- Gives at interface:
  - heat flux
  - salt flux
  - momentum flux
  - mass flux



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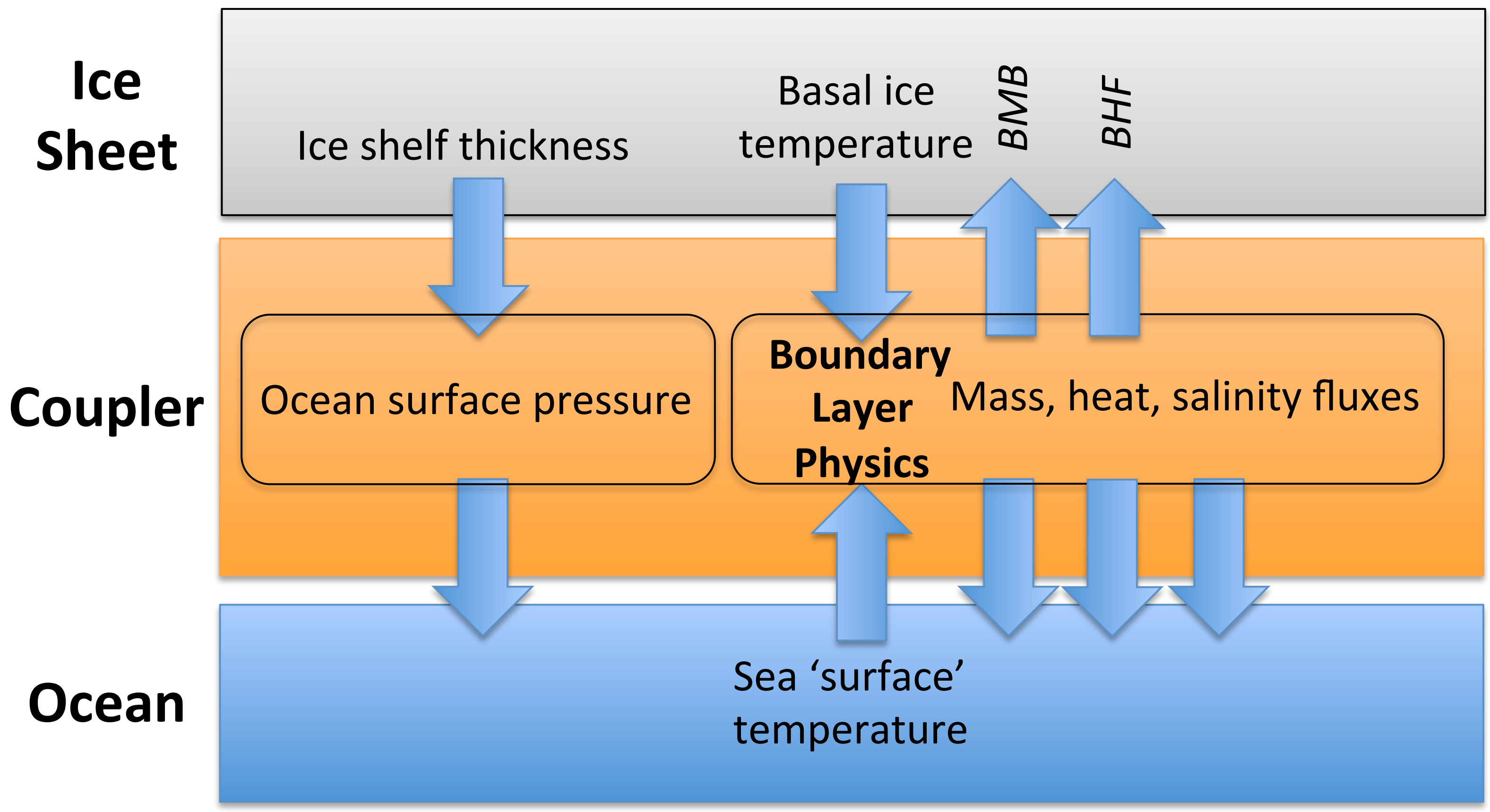
Coupling Land Ice/Ocean Models



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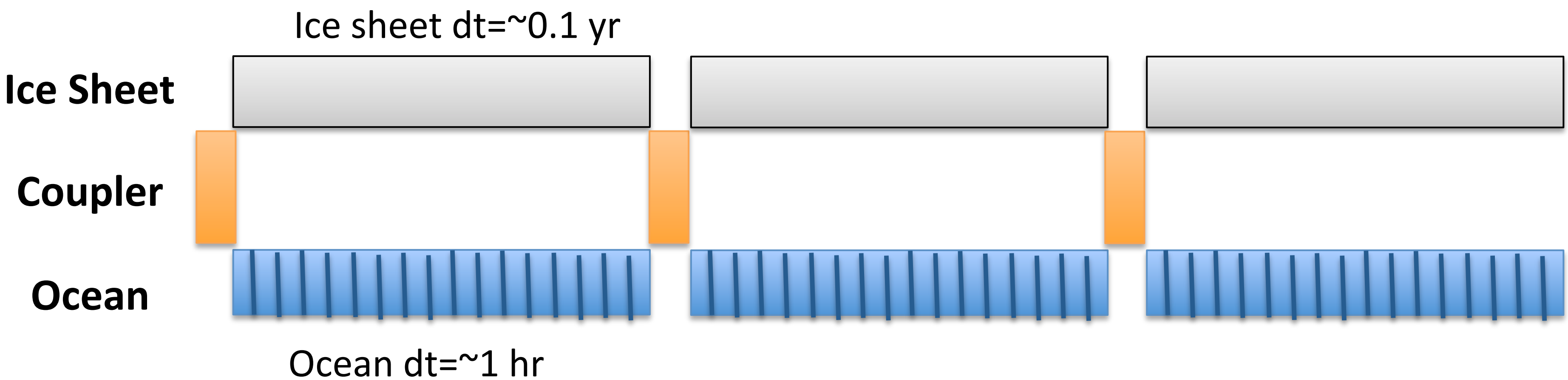
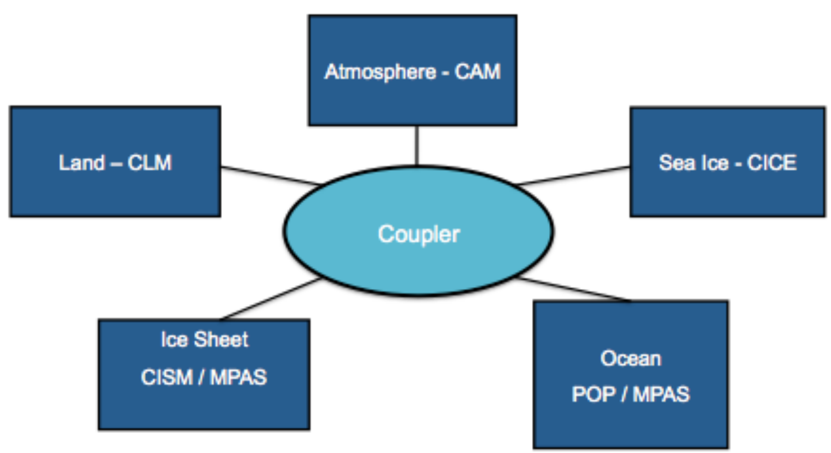


Near-term: Python-based coupling using MPAS' restart capability
Run Ice Sheet and Ocean on same MPAS grid.

Long-term: CESM



Future work priorities

- More realistic calving laws (e.g. crevasse penetration depth)
- Subgrid grounding line migration

- Build coupler, add boundary layer physics

- Variable resolution planar, spherical hex meshes
- Finish temperature implementation (vertical diffusion)
- MPAS trunk merge (get PIO, multiple blocks; "get in the game")

Greenland Model Results