GCM - Ice Model Coupling: Adventures in Energy Conservation

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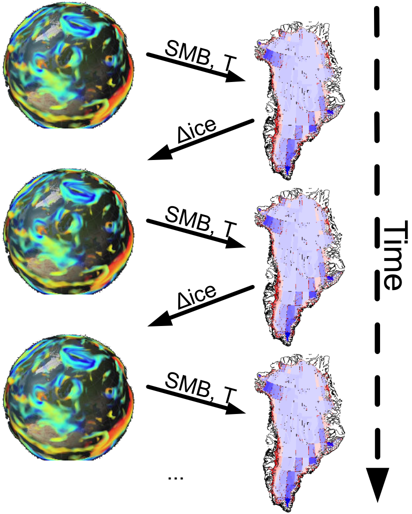
Synchronous Two-Way Coupling

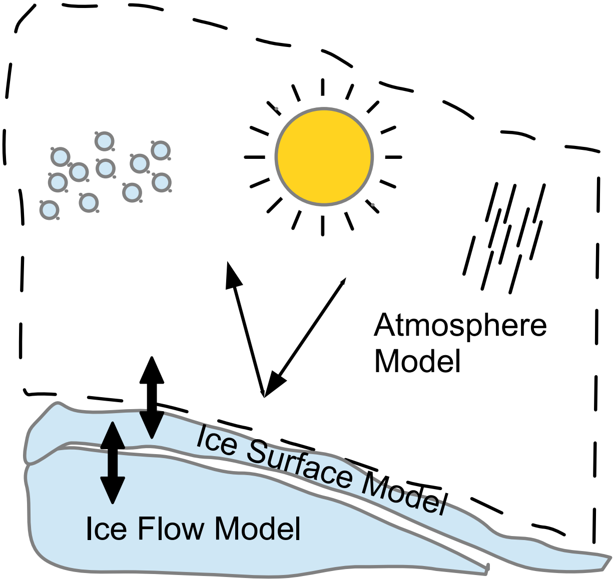
Important to resolve transients (human timescales).

Challenge:

- Balance mass and energy budget for (potentially) non-conservative ice model.
- Compute non-conservation; dump extra in ocean.

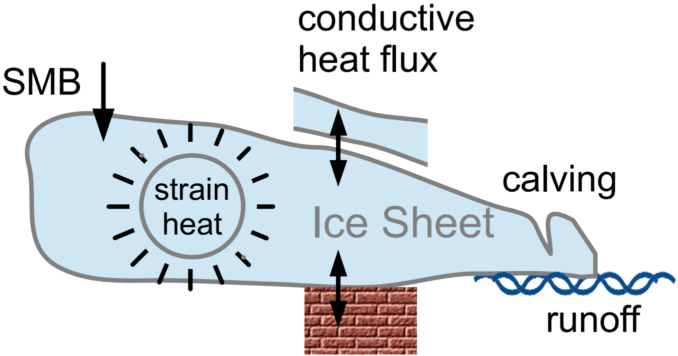


Three Models, Three Grids



Energy Budget

Account for energy flux in each 2D ice grid cell:



$$\psi(x, y, t) = \psi_0 + \int_{t_0}^{t} (e_s + e_b + e_c + h_s + h_b + h_i + \nabla \cdot \psi \mathbf{u} + \epsilon) dt$$

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ψ_0	=	Initial enthalpy state of ice sheet	J/m^2
ψ	=	Enthalpy of ice sheet	
$\mathbf{u}$	=	Ice velocity field	m/s
e_s	=	Enthalpy flux of SMB (from snow/firn)	W/m^2
e_b	=	Enthalpy flux of runoff	
e_c	=	Enthalpy flux of calving	
h_s	=	Conductive heat flux through top surface	W/m^2
h_b	=	Conductive basal heat flux	
h_i	=	Strain heating rate	
ϵ	=	Unaccounted energy flux	

- GCMs do not track gravitational potential.
- GCM must dispose of $h_i + \epsilon$ in non-physical way.

Coupling Fields

Initialization:
Ice Model → GCM

1. T, top of ice sheet
2. Depth of top layer
3. Elevation on ice grid

GCM Computes:

1. Conductive Heat Flux

GCM → Ice Model

1. Surface Mass Balance
2. Enthalpy of SMB
3. T at bottom of ice surface model

Ice Model → GCM

Mass and Enthalpy:

1. SMB
2. Internal Advection
3. Basal Runoff
4. Vertically-Integrated State
5. ϵ non-conservation (mass, energy)

Energy:

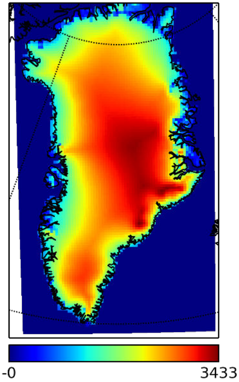
1. Strain Heating
2. Geothermal Flux

Other:

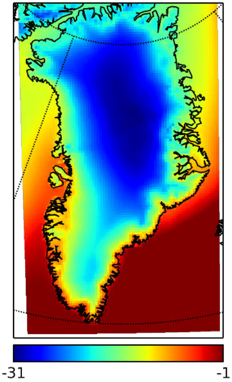
1. T, top of ice sheet
2. Depth of top layer
3. Elevation on ice grid

Step 1: Initialization

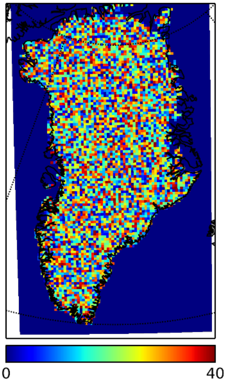
Elevation (m)



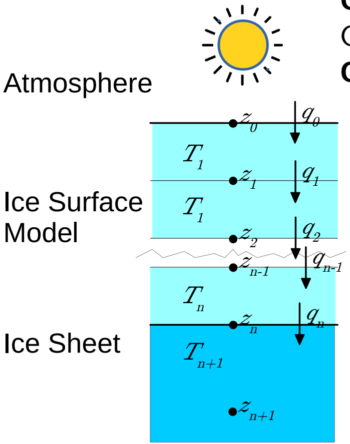
Surface T (°C)



Depth of Top Grid Point (m)



Step 2: GCM $\longleftrightarrow$ Ice Heat Flow



Goal:

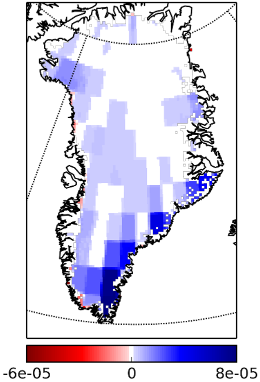
Compute q_n, heat flux between models

Challenges:

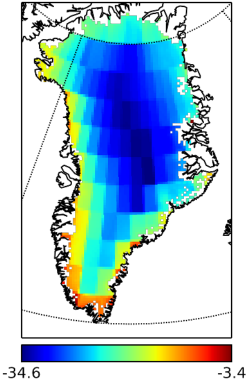
1. Differing Parameterizations
   - Solving heat equation between FD and non-FD model.
   - This FD ice model has no gridpoint at surfce.
2. Differing scales
   - Large Δz yields large ΔT, inappropriate for small scale of $z_1 \ldots z_n$.
   - T_{n+1} doesn't change over multiple timesteps for T_n

Step 3: GCM Outputs

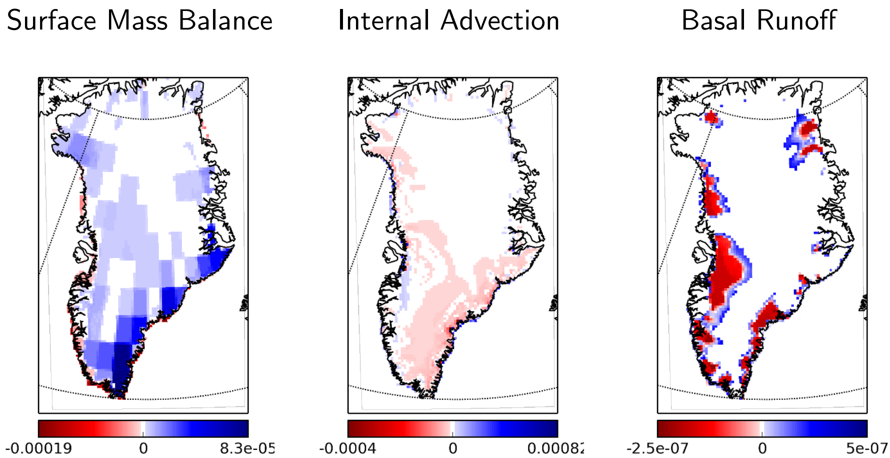
Surface Mass Balance
$(\mathrm{kg\,m^{-2}\,s^{-1}})$



Surface T (°C)

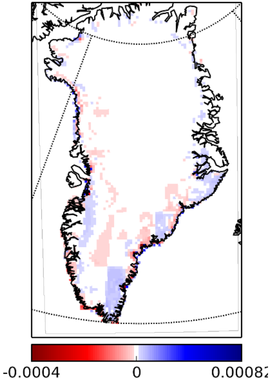


PISM Mass Budget ($kg\,m^{-2}\,s^{-1}$)

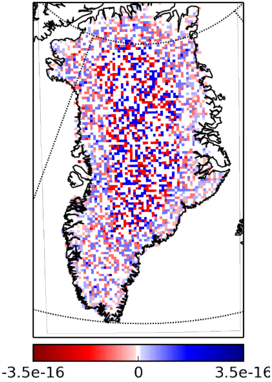


PISM Mass Budget ($kg\,m^{-2}\,s^{-1}$)

Total Mass Flux

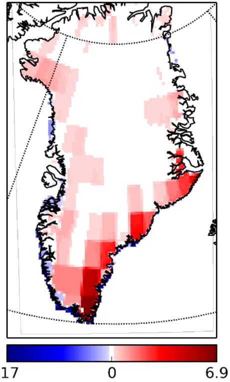


ϵ: mass

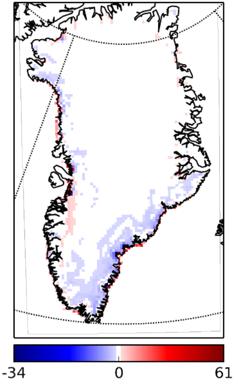


PISM Energy Budget: Enthalpy Flux (W/m^2)

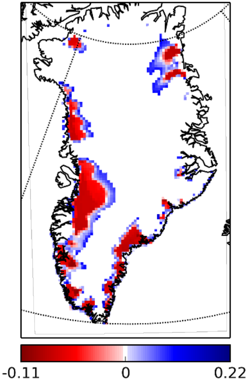
Surface Mass Balance



Internal Advection

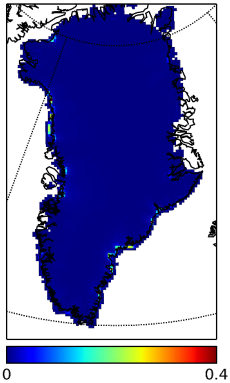


Basal Runoff

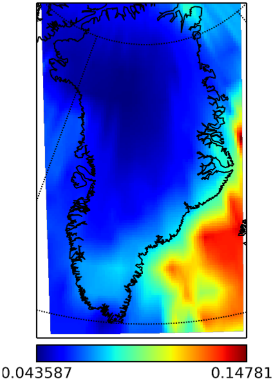


PISM Energy Budget: Heat Flux (W/m^2)

Strain Heating

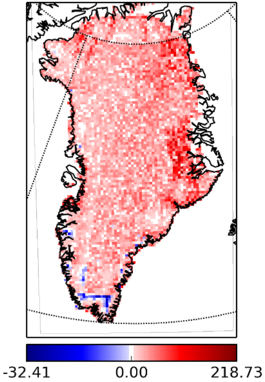


Geothermal Flux

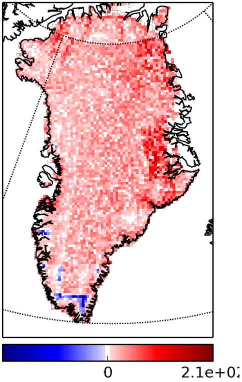


PISM Energy Budget: Results ($W\,m^{-2}$)

Total Enthalpy Flux



ϵ: enthalpy



Discussion

Why the enthalpy problem? Possibilities:

- No grid point at top of ice model? (Uncontrolled forcing when setting Dirichlet BC)
- Disparate time and space scales? (with explicit timestepping at model interface)
- Would Neumann BC for ice model help?
- Problematic parameterization in ice surface?
- Just a spin-up problem?
- We will find out with 1-D prototype.

Thanks to Ed Bueler, Constantine Khroulev, Andy Aschwanden and the PISM Team