Dynamic land units and energy conservation for coupled climate / ice models

Elizabeth Fischer, Sophie Nowicki, Gavin Schmidt

Columbia University
NASA Goddard Institute of Space Studies
New York City

January 10, 2018

Energy-Conserving Coupling

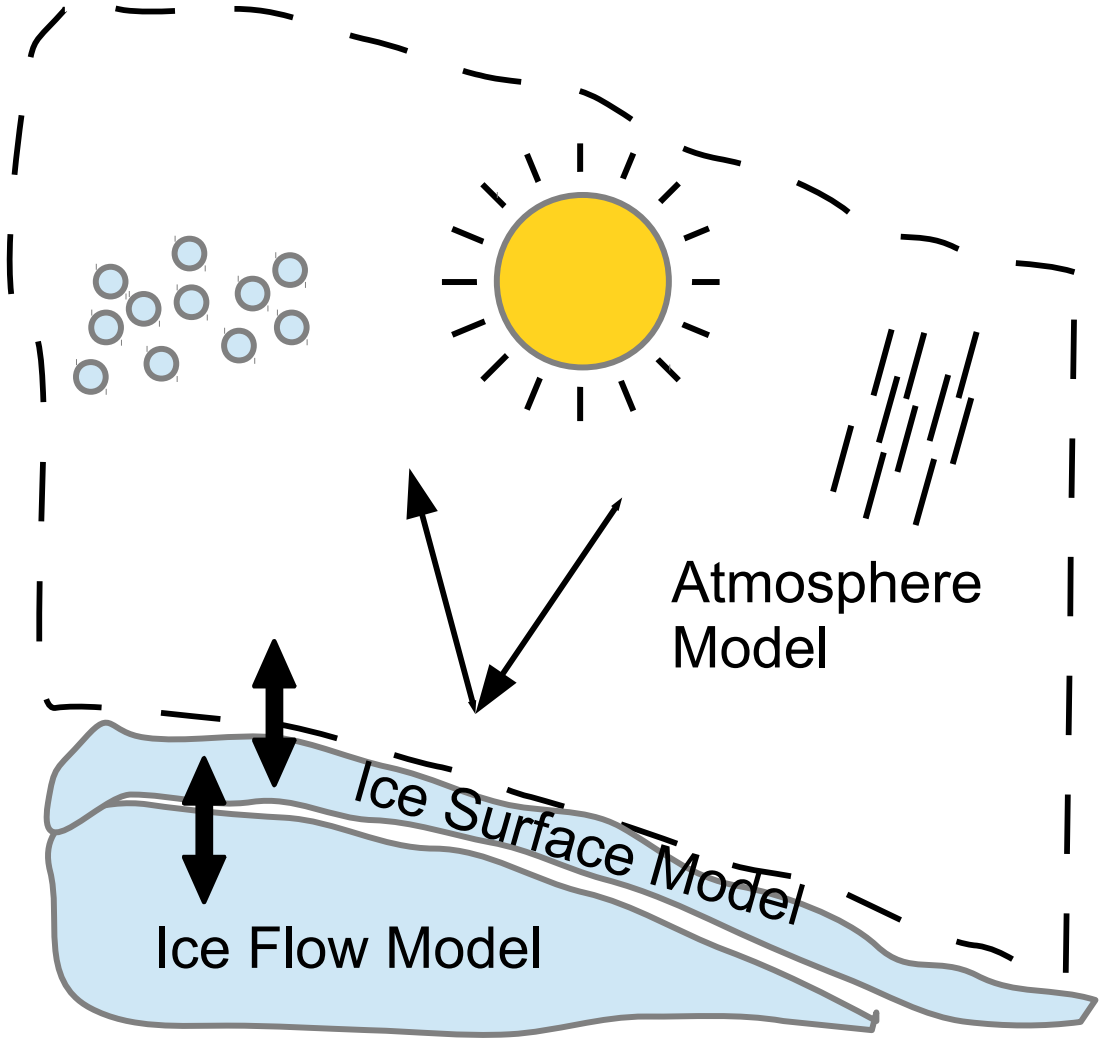
Coupling GISS ModelE with PISM. Why conserve energy?

- Avoid unknown climate forcings due to non-conservation.
- Quantify, evaluate and quantify effects from non-conservative ice models and couplers.

Essential to model long-range evolution of ice sheets.

Flux-Based Coupling

Cannot just pass average T and SMB from GCM to ice sheet.



Three grids: Atmosphere Grid, Elevation Grid, Ice Grid

Generalized Conservative Regridding (REGRID)

All conservative regridders use the same linear algebra:

$$g_i^Q(x, y) = \text{Basis function for cell i of grid Q}$$

$$f_i^Q = \text{Vector describing a value on grid Q } (kg/m^2)$$

then...

$$f_i^B = \frac{< g_i^B, g_j^A > f_j^A}{\sum_j < g_i^B, g_j^A >}$$

Projection Scaling (PROJ)

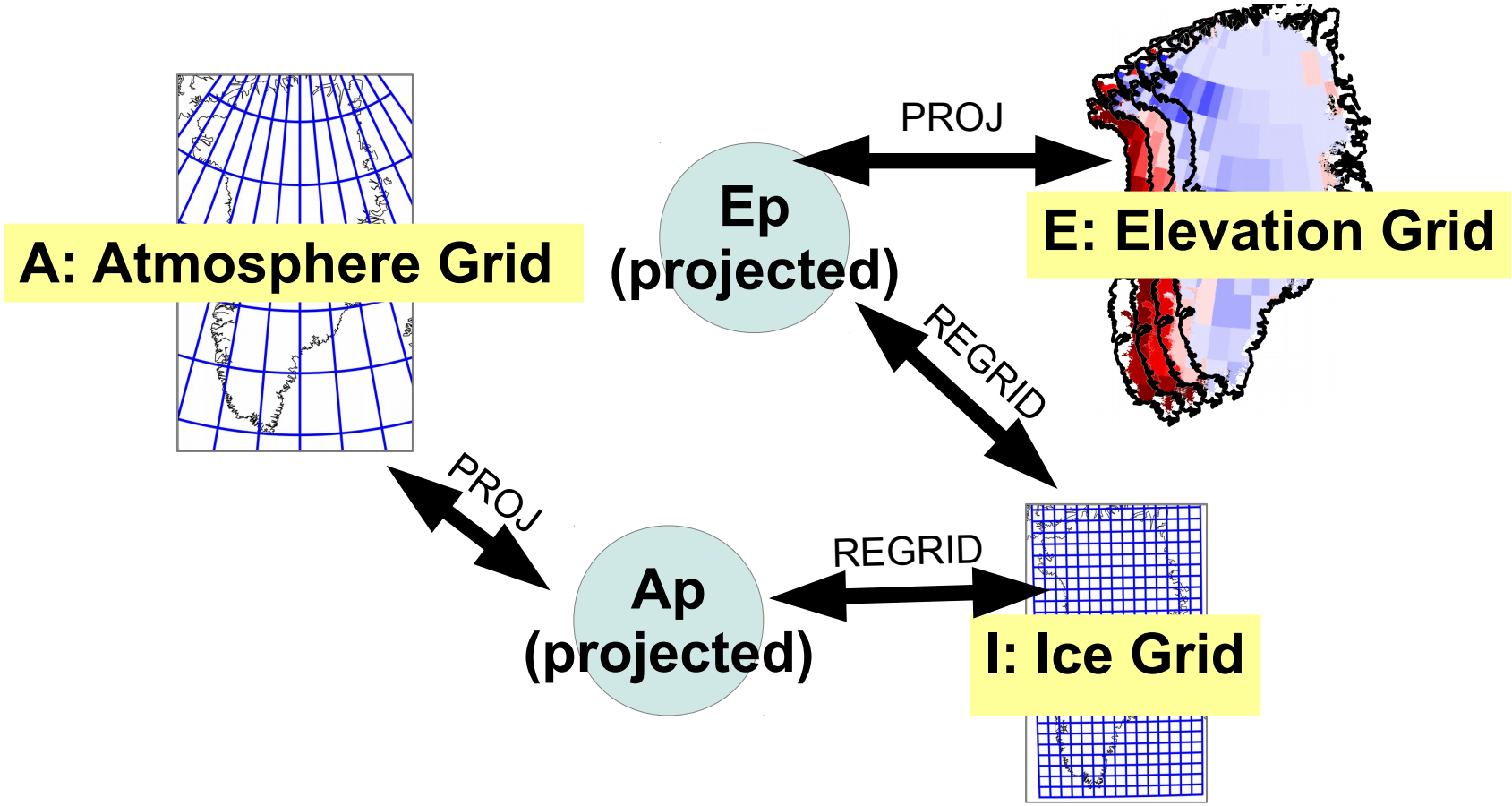
If A is a grid on the sphere and Ap is its projection on a plane, then:

$$f_i^{Ap} = \frac{|g_i^A|}{|g_i^{Ap}|} f^A$$

- Necessary because ice models run on a flat earth!

Constructing Regrid Matrices

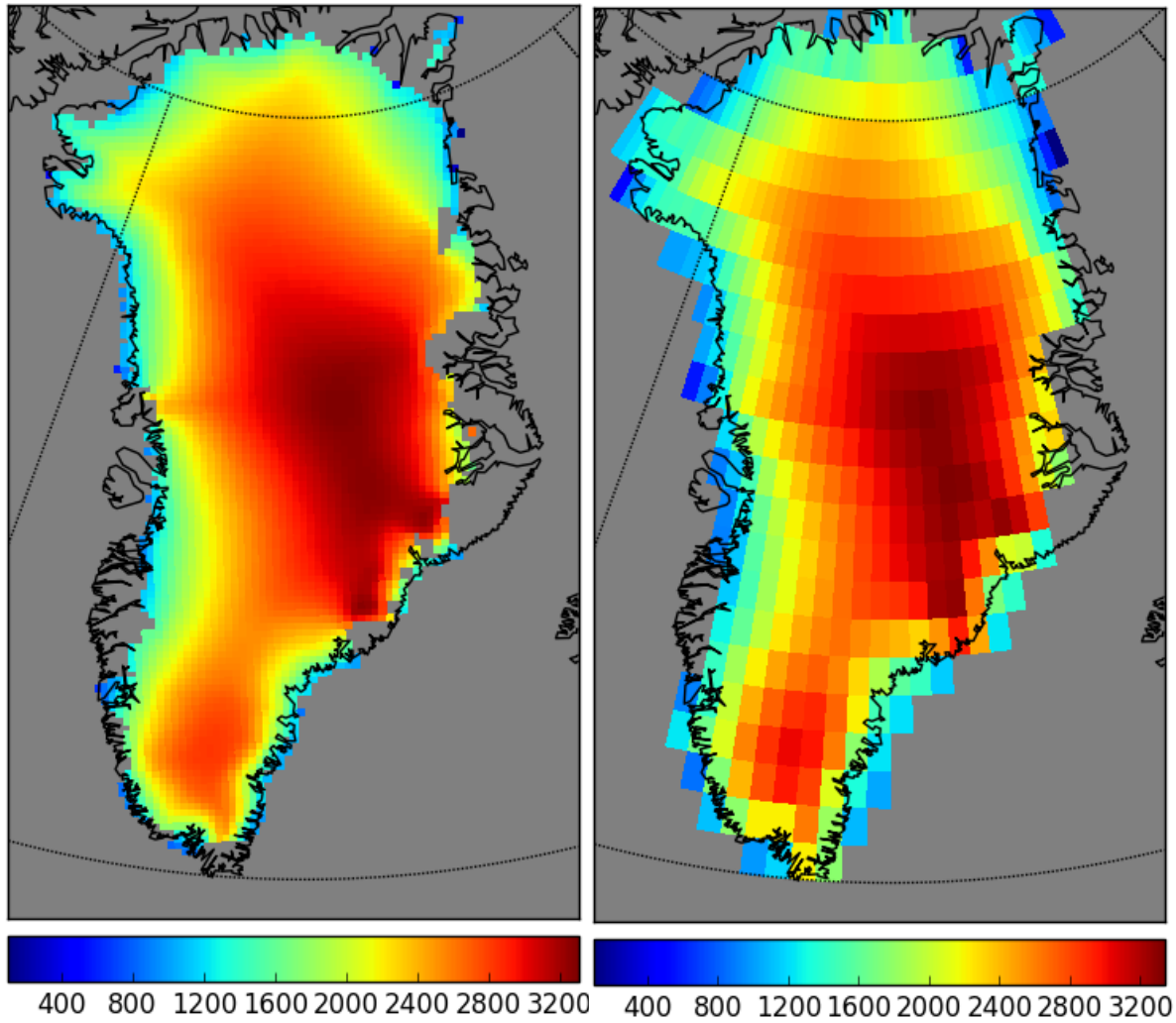
Multiply consecutive matrices for desired result.



GCM Ocean: Grid-Cell Rounding

GCM Ocean cannot do partial grid cells

$\longrightarrow$ GCM and Ice Model see different ice sheets!!



Reinterpretation (REINTERPRET; not conservative)

Bridge between GCM and Ice Model view of an ice sheet.

Let:

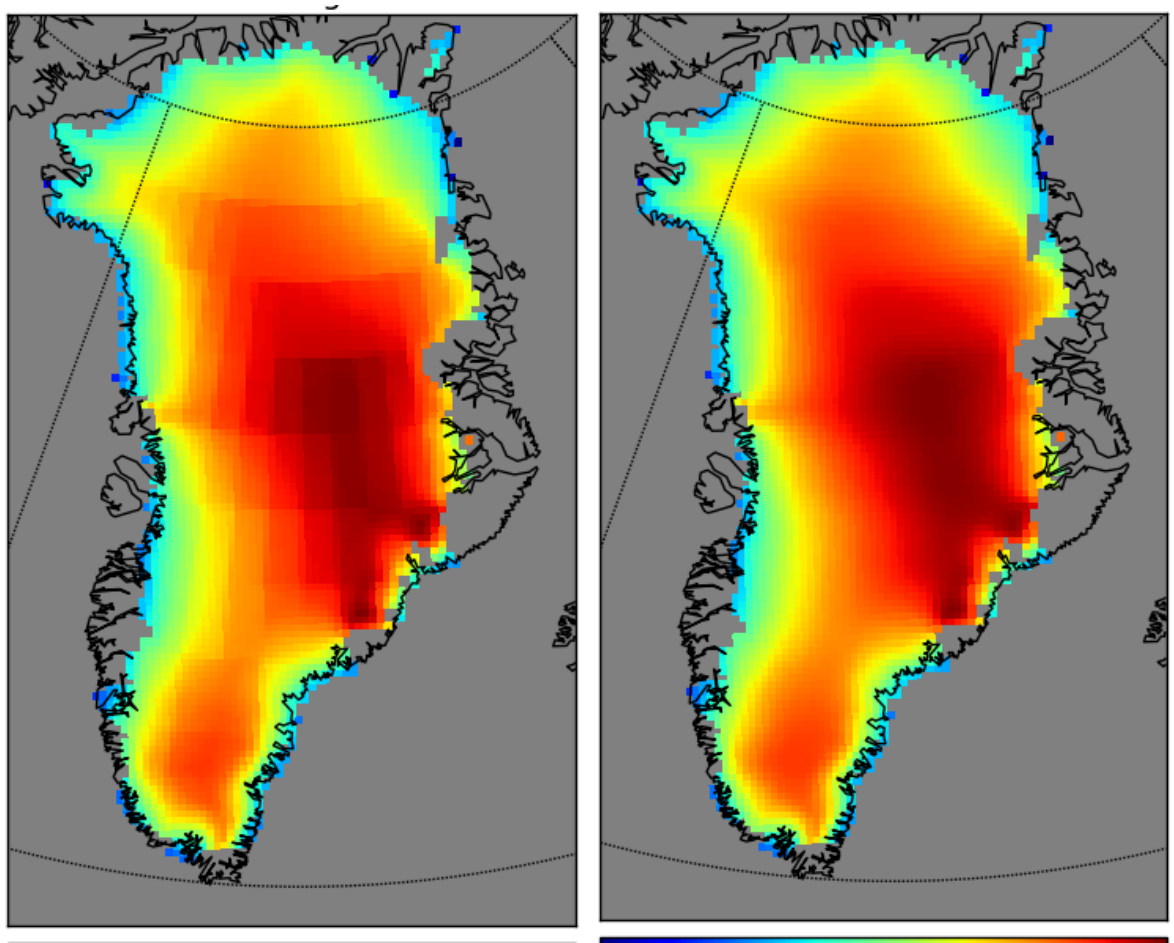
- Qm = Grid Q as seen by GCM.
- Qp = Grid Q as seen by ice model.

Then let $f^{Qm} = f^{Qp}$.

3D Gaussian Smoothing (SMOOTH; not conservative)

Convolve a 3D Guassian on the 2D ice grid.

- Let $\vec{x}_i = (x_i, y_i, z_i)$ be position and elevation of grid cell i.
- Let $\vec{\sigma} = (\sigma_x, \sigma_y, \sigma_z)$ be the standard deviation of our 3D Guassian function.
- Smoothing not conservative: edge effects.



Conservation Correction (CONSERVE; non-linear)

Suppose we have an almost-conservative regridding matrix M_{ij} such that:

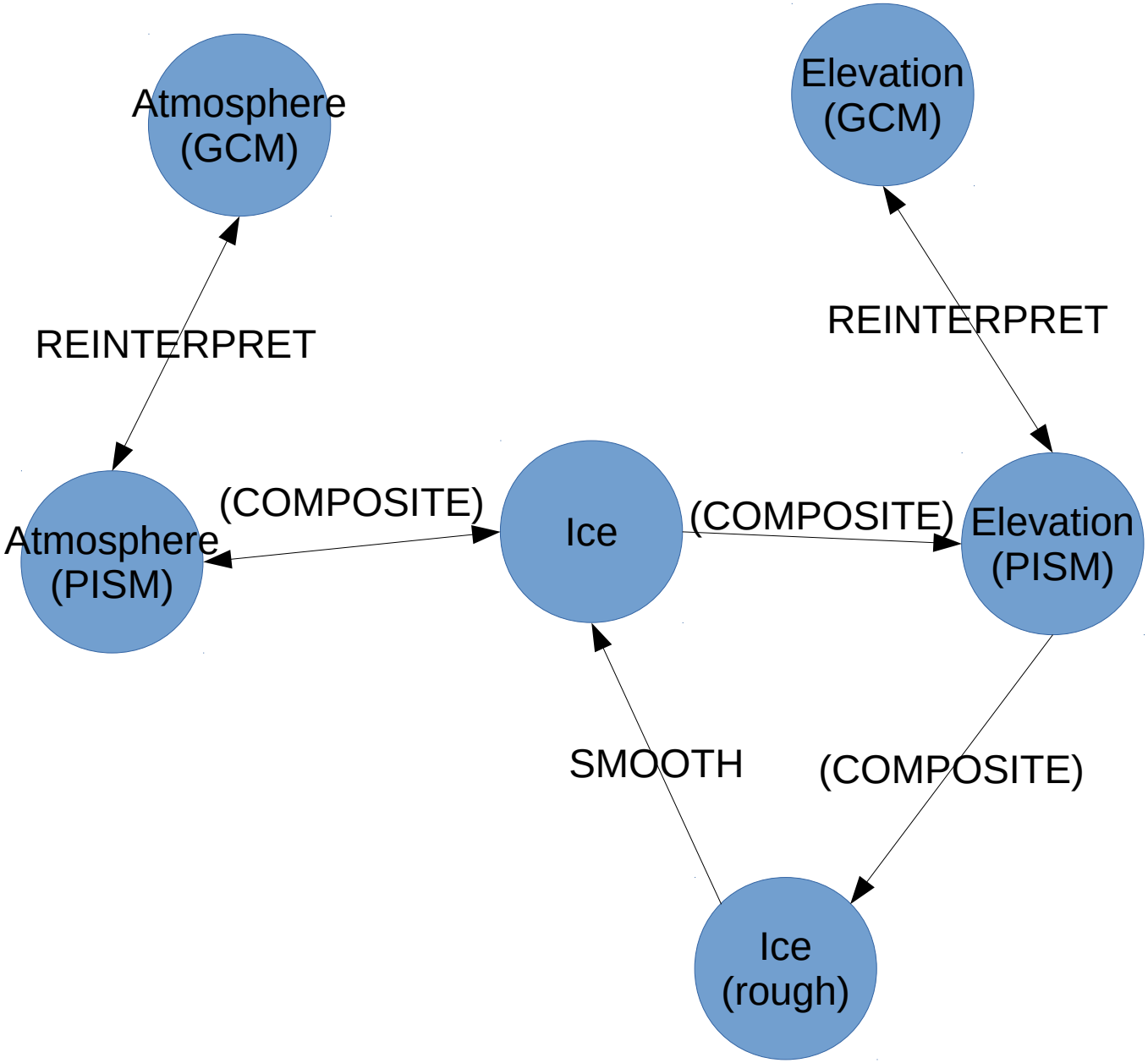
$$\tilde{f_i^B} = M_{ij} f_j^A$$

Then apply a global conservation correction with:

$$f_i^B = \frac{f_j^A |g_j^A|}{\tilde{f_i^B} |g_i^B|} M_{ij} f_j^A$$

- Conservation correction is the last step in an otherwise non-conservative series of transformations.
- So far, corrections are small ($<<$ 1%).

Mismatched Regridding



Growing Ice Sheet

Modelled ice sheets often grow during coupled spinup.

Snow/Firn Model:

- Run in "ghost" grid cells close to used grid cells — in X/Y and elevation.
- Turn off grid cells as ice sheet moves out of elevation classes.
- Ghost grid cells must be close to real cells; model crashes if too far off.

GCM/Ice Model Mismatch:

- Ice sheet could move into some ocean grid cells, but GCM ocean is unable to adapt.
- Difference between GCM and Ice Model would increase.

Shrinking Ice Sheet

Snow/Firn Model:

- Ghost grid cells still needed, as ice sheet deflates.

GCM/Ice Model Mismatch:

- At first a problem: new ocean opens up (but is made to be land)
- Later, not a problem: ice sheet retreats entirely on land.

ModelE Capabilities: Update

Current

- Elevation classes for SMB on Greenland.
- Energy-conserving two-way coupling of Greenland for 3 months.

Future

- Elevation classes for SMB over all ice-covered regions.
- Energy-conserving two-way coupling of Greenland for long runs.
- Ocean coupling for Antarctica.