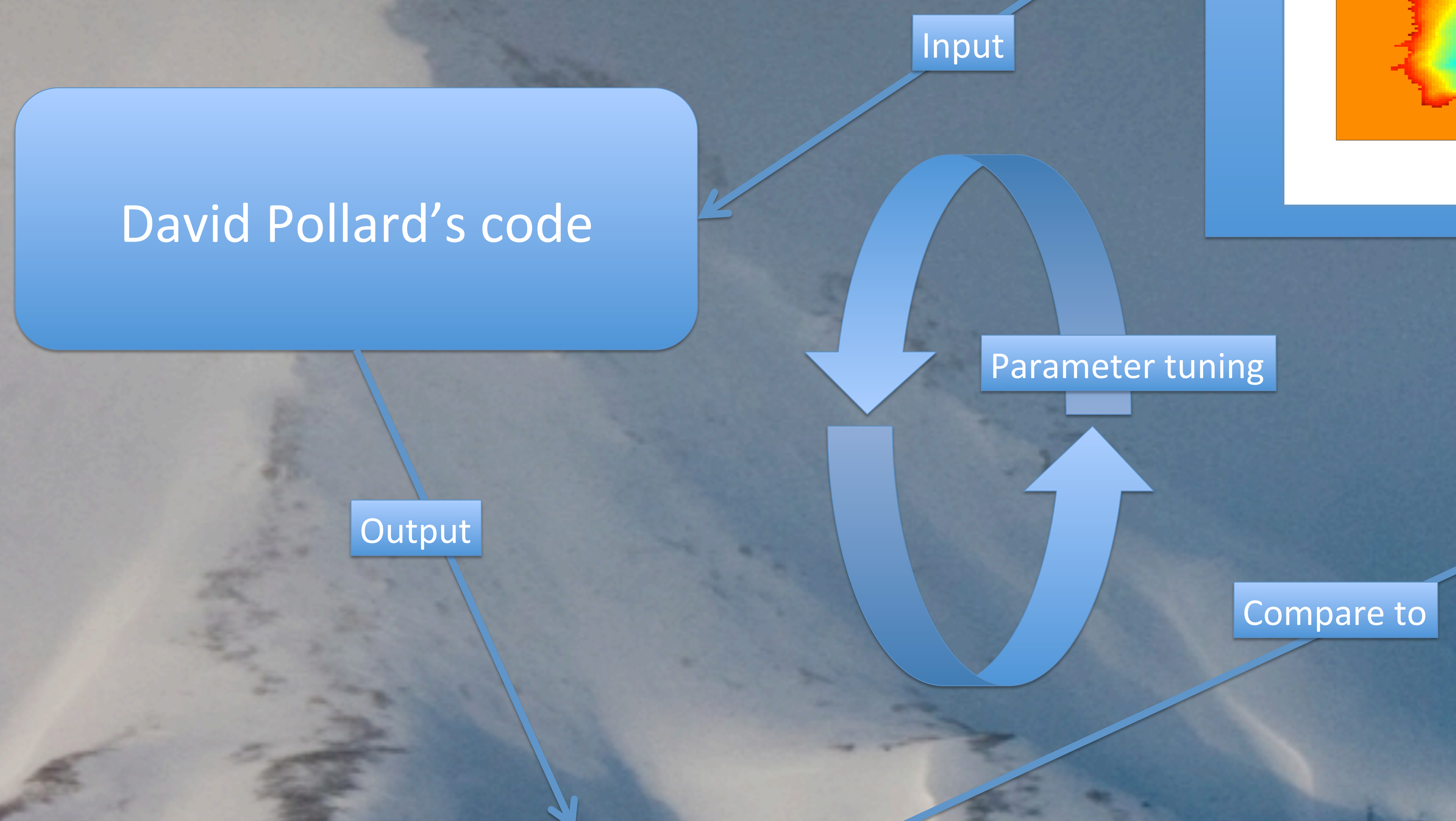
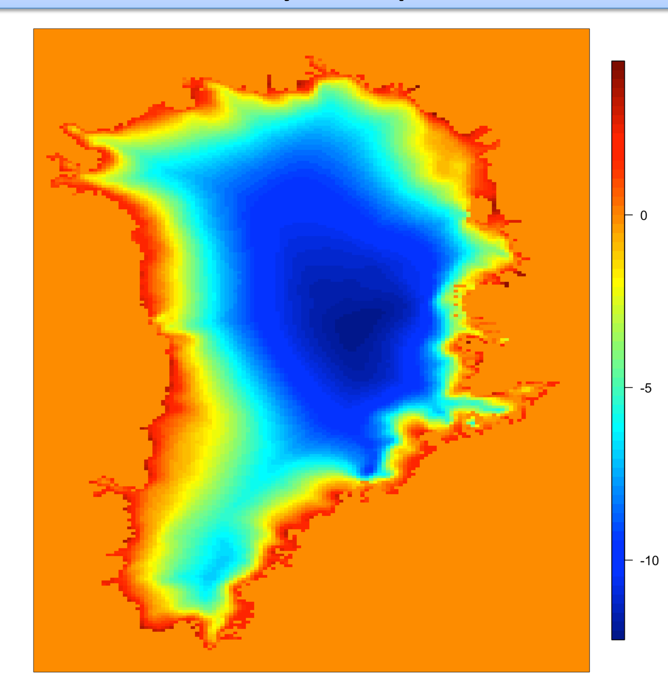
Testing ablation schemes for ice sheet model simulations of the Greenland Ice Sheet

Taisiya Postnikova, Patrick J. Applegate, David Pollard

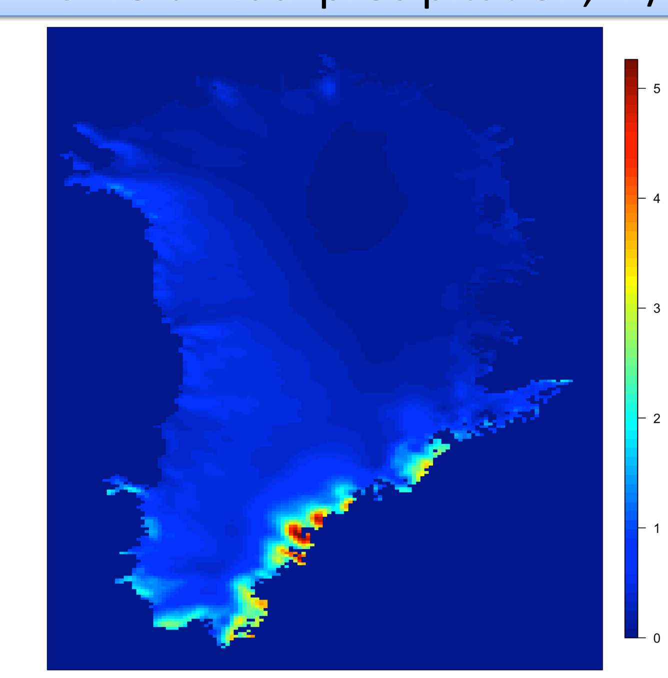
Background. The Penn State 3D ice sheet model is a computationally efficient ice sheet model with "hybrid" ice sheet dynamics. It was originally developed by David Pollard for simulation of the Antarctic Ice Sheet over long time scales, and includes the Schoof grounding line treatment and other features that are needed for careful simulation of the marine West Antarctic Ice Sheet. In contrast to the Antarctic Ice Sheet, which is in contact with the ocean essentially everywhere around its margin, the Greenland Ice Sheet's behavior is largely controlled by its surface mass balance (the sum of mass addition from snowfall and mass loss from melting and sublimation). Here, we propose to test different melt calculation schemes for possible inclusion in the Penn State 3D model. The best of these melt calculation schemes will be added to the model to improve its ability to simulate the behavior of the Greenland Ice Sheet.



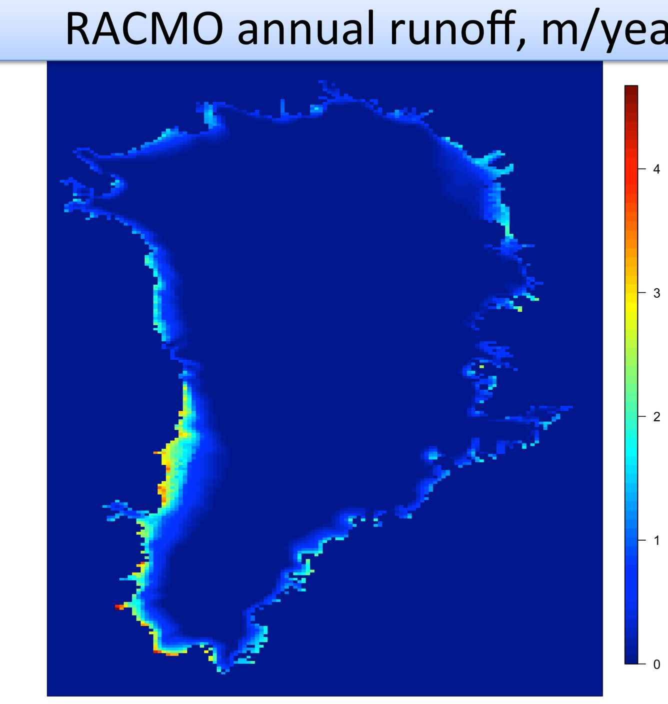
RACMO July temperatures, ° C



RACMO annual precipitation, m/year



RACMO annual runoff, m/year



Model 1

One-step model: annual cycle with explicit snow and ice, based on refreezing fraction. Similar to **Robinson et al**. (2010).

Model 2

One-step model: annual cycle with explicit solid snow and embedded liquid amounts in pore space. Runoff escapes from snowpack only when the snowpack is saturated with embedded liquid (no air), and further melting occurs.

PDD scheme

Positive degree-day scheme. Based on an empirical formulation that relates snow and ice melt rates (through degree-day factors) to the sum of the excess of temperatures above 0◦C.

Insolation scheme

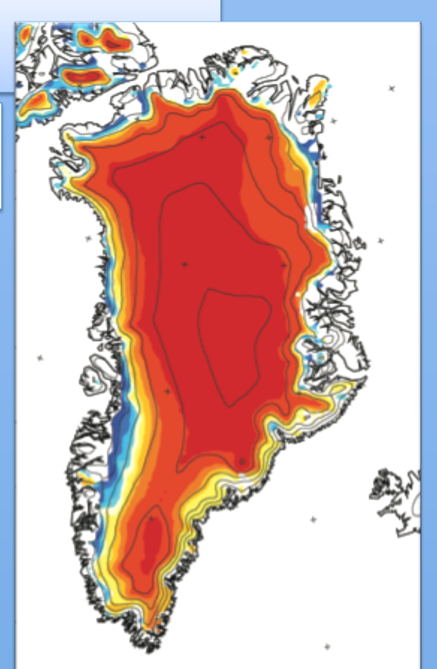
- Physically based
- Albedo and elevation effects

$$M_s = \frac{\Delta t}{\rho_w L_m}[\tau_a(1-\alpha_s)S + c + \lambda T]$$

Melt rate; Transmissivity; Surface albedo; Insolation; Temperature

$$\tau_a = 0.46 + 0.00006 z_s$$

Elevation



July albedo (van de Berg, 2009)

Other parameters

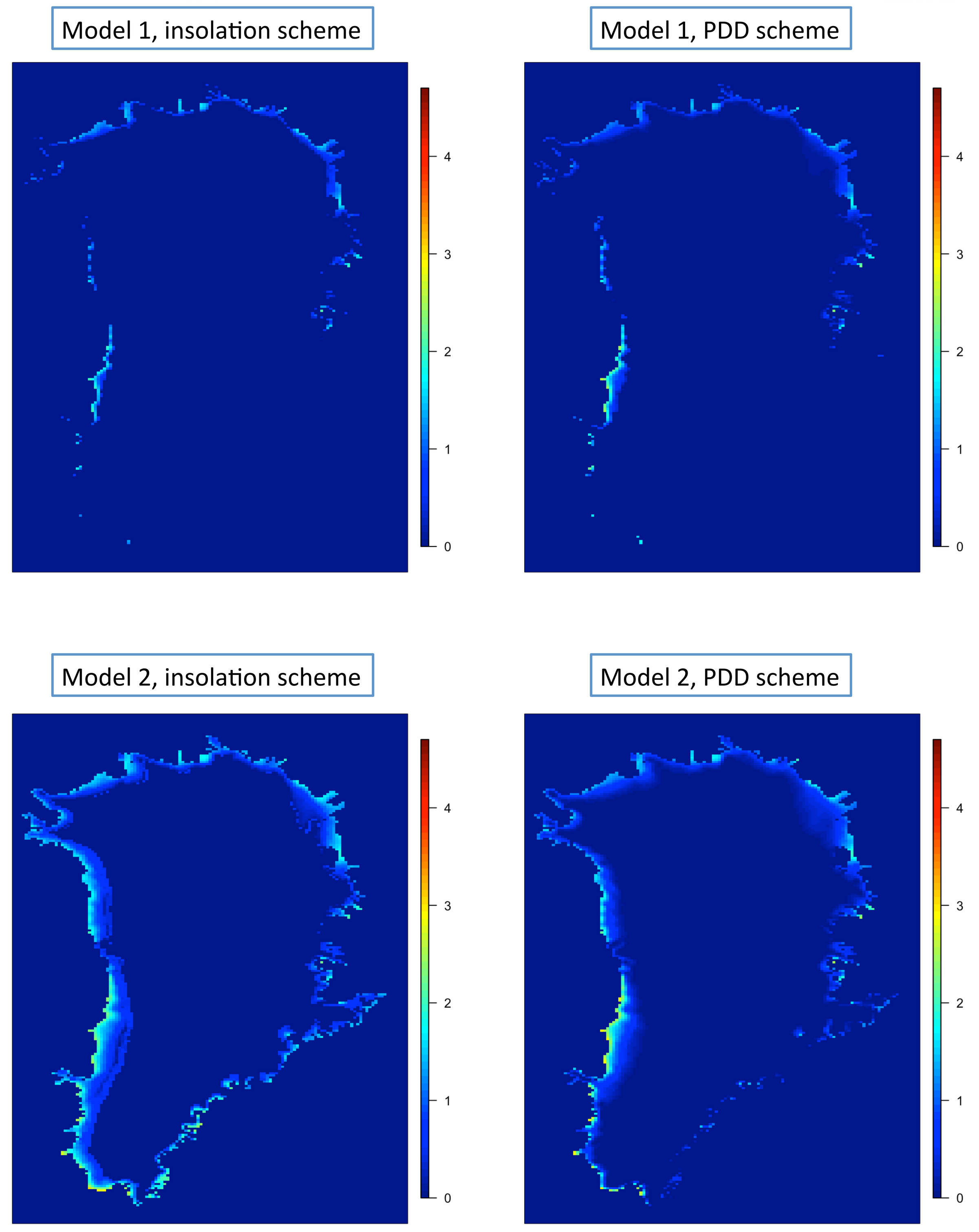
- Snow density
- Snow albedo
- Time step (1 hour or 5 days)
- Coefficient *c* for longwave radiation
- Refreezing of embedded liquid in model 2

1 hour time step allows the model to catch diurnal variations both in temperature and insolation.

Methods. Each melt model accepts climatological input variables (particularly air temperatures at 2 m above the ice sheet surface, precipitation, and, in some models, insolation) and produces an estimate of melting. However, these models include tunable parameters whose "correct" values are not known a priori (for example, the positive degree-day coefficients for ice and snow).

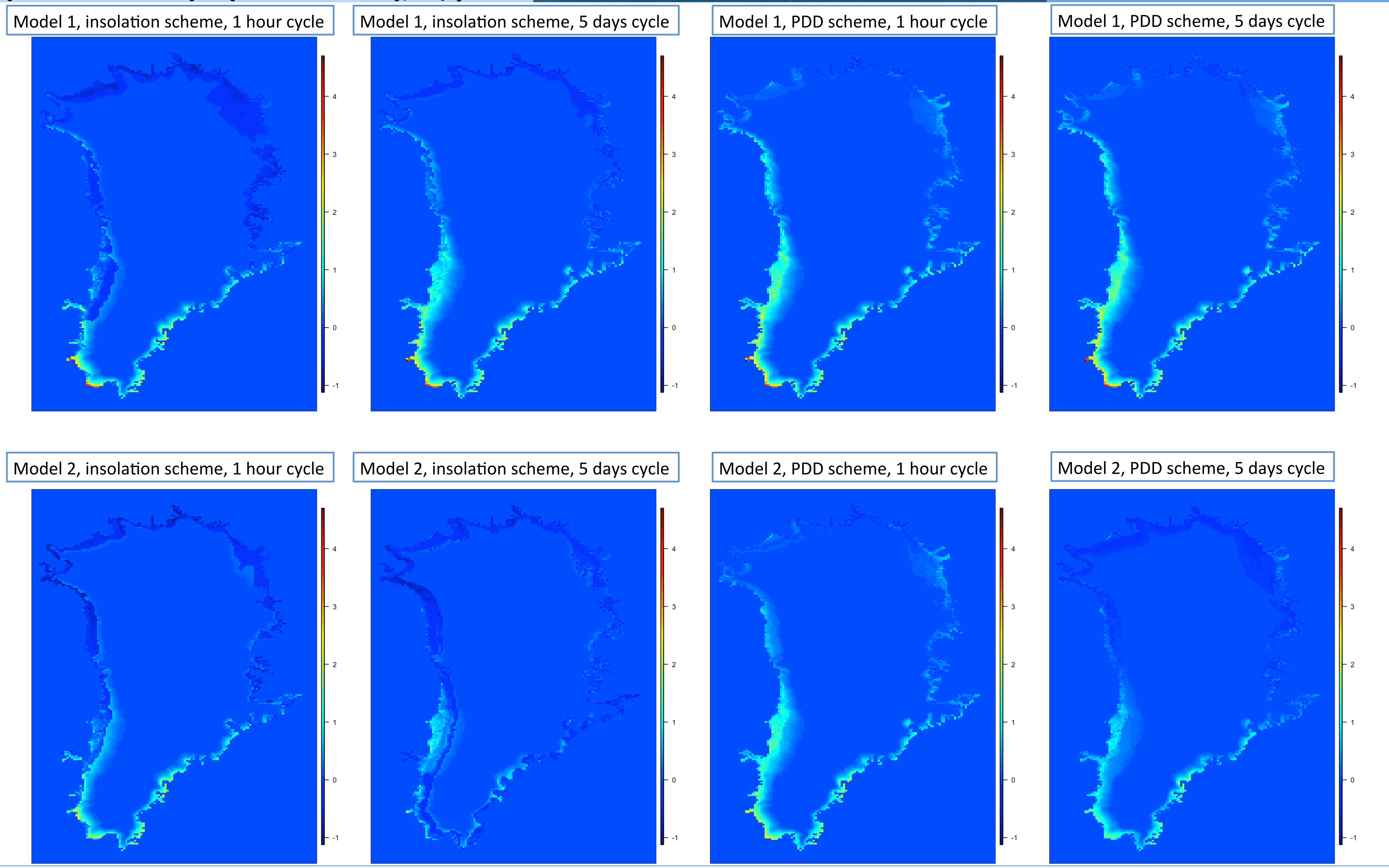
To determine the optimal values for each melt scheme, we use output from the RACMO2 regional climate model (Ettema et al., 2010a, b). This output is available as netCDF files at http://www.staff.science.uu.nl/~broek112/Data/. Relevant output variables include temperature at 2 m above the ice sheet surface, snowfall and runoff (Figure 1). We systematically adjust the parameters of each melt model to minimize the root mean squared error between the modeled and RACMO2-estimated melt values in each ice-covered grid cell.

Runoff from models, m/year



Runoff on the Greenland ice sheet calculated by models 1 and 2 using PDD and insolation scheme. Density of snow is equal to 550 kg/m3 here and the free parameter *c* is equal to -30 W/m2. The time step is equal to 5 days. It can be seen that model 1 by Robinson underestimates the runoff if to compare with RACMO results.

{RACMO runoff} – {model runoff}, m/year



An example of maps of the residuals between RACMO and models 1 and 2 using PDD and insolation scheme with 5 days or 1 hour time step. Density of snow is equal to 550 kg/m3 here (except the case of insolation scheme, 1 hour time step, where for model 2 (including refreezing of embedded liquid) it equals to 400 kg/m3, and for model 1 it equals to 500 kg/m3), the free parameter *c* is equal to -30 W/m2, the snow albedo is 0.8 and the time step is 5 days. As expected, PDD schemes overestimate the runoff in higher latitudes and underestimate it in lower latitudes.

Conclusions.

For the parameter combinations we investigated,

- Model 2 by David Pollard represents the total runoff better than Robinson's. Robinson's model underestimates the runoff.
- Insolation scheme works better than positive degree- day scheme.
- 1 hour time step doesn't improve the estimate of melt, and it is computationally expensive, so there is no need to include it to the Penn State 3D model.

Acknowledgements.

This work was supported by the National Science Foundation through the Network for Sustainable Climate Risk Management (SCRiM) under NSF cooperative agreement GEO-1240507.

I am particularly grateful for the assistance given by Patrick J. Applegate and David Pollard.

References.

Berg, W.J. van de, M.R. van den Broeke, J. Ettema, F. Kaspar and E. van Meijgaard, *Greenland Ice Sheet Surface Mass Balance during the Eemian,* Poster: AGU 2009 Fall Meeting, 14/12/2009-18/12/2009, San Francisco, USA, American Geophysical Union.

Ettema, J., et al. "Climate of the Greenland ice sheet using a high-resolution climate model–Part 1: Evaluation." *The Cryosphere* 4.4 (2010): 511-527.

Pollard, D., and R. M. DeConto. "Description of a hybrid ice sheet-shelf model, and application to Antarctica." *Geoscientific Model Development* 5 (2012): 1273-1295.

Robinson, A., R. Calov, and A. Ganopolski. "An efficient regional energy-moisture balance model for simulation of the Greenland Ice Sheet response to climate change." *The Cryosphere* 4.2 (2010): 129-144.