Ben Hills
ESS 533 – Ice Dynamics
Class Summary for 5/21/18

On Monday, May 21, 2018, we discussed a snow model intercomparison project (Essery et al., 2013). Several such model intercomparison projects (MIPs) had been done for snow prior to 2013 (i.e. PILPS2d, PILPS2e, Rhône-AGG, SnowMIP and SnowMIP2) each comparing a long list of snow models (i.e. Crocus, SNOBAL, SNOWPACK, etc.). Taking the idea of a MIP a step further, Essery et al. (2013) standardize the different snow models into one model framework, the JULES Investigation Model (JIM).

While JIM consistently uses the same numerical methodology, the parameterizations for physical processes are changed between runs. This way the differences between physical processes in snow models can be shown without the interference of numerical effects. Seven separate parameterizations are changed between runs, and each run is classified by a base-3 number,

$$m = n_c n_s n_a n_e n_f n_h n_t$$

with numbers, n's, being parameterizations with the options of 0 being physically-based, 1 being empirical, or 2 being constant or simply neglected. Parameterizations are compaction (n_c), fresh snow density (n_s), albedo (n_a), turbulent exchange (n_e), snow cover fraction (n_f), snow hydrology (n_h) and thermal conductivity (n_t).

Encouragingly, the results from Essery et al. (2013) are similar to those from SnowMIP (Etchevers et al., 2004) and other snow MIPs. A large spread in the models is seen particularly when melting initiates (Fig. 1). The consistency between JIM model spread and that from other MIPs points out that it is the parameterizations of the physical processes that leads to model discrepancy, *not* differences in the numerical methods implemented in separate models.

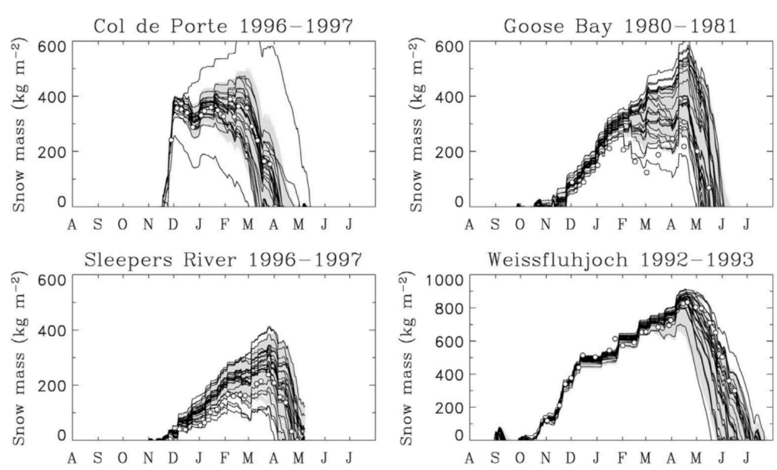

Figure 1. Snow mass through time four field sites. Open circles are measured data. Black lines are the 23 separate models that participated in SnowMIP. The shaded gray region is the model spread for the 1701 parameterizations done with JIM.

Although there are more physical parameterizations used in JIM (Essery et al., 2013) than we discussed in class, those that we got to were:

Energy Balance. In order to properly calculate the accumulation/ablation of snow, a model must conserve energy by balancing all energy inputs and outputs.

$$SW\downarrow + SW\uparrow + LW\downarrow + LW\uparrow + H + L + G + R = M$$

where SW and LW are short and longwave radiation in and out of the surface, H is the sensible heat flux, L is the latent heat flux, G is the geothermal flux, R is the water flux through precipitation, and M is the resulting melt of snow (negative meaning freezing).

Albedo. JIM parameterizes albedo through: 0) a physical parameterization with a spectral dependency based on Wiscombe and Warren (1980); 1) an empirical parameterization that decays in time either linearly for cold snow or exponentially for melting snow; and 2) a linear parameterization using simulated snow temperature.

Compaction. JIM parameterizes the compaction, or change in density, of the snowpack through: 0) rapid settling of fresh, low density snow followed by slower densification under load resisted by a compactive viscosity; 1) an empirical parameterization with snow density increasing at a rate proportional to the difference between the current density and a maximum attainable density; and 2) constant snow density.

Hydrology. Finally, JIM simulates the movement of water through the snowpack with a conservation equation

$$\frac{\partial U}{\partial z} + \phi \frac{(\partial S_w)}{\partial t} = \frac{m}{\rho_w}$$

where U is the water velocity, S_w is water saturation, m is meltwater input, and ρ_w is the water density. This conservation equation is implemented in two different ways, both of which have a maximum liquid water mass fraction over which any additional water moves downward to the next unfull cell. The second implementation also uses a fixed irreducible water saturation. The final parameterization for snow hydrology is to ignore it completely and say that any meltwater or rainfall simply moves to the base of the snow.

References

Etchevers, P., Martin, E., Brown, R., Fierz, C., Lejeune, Y., Bazile, E., . . . Yang, Z. (2004). Validation of the energy budget of an alpine snowpack simulated by several snow models (Snow MIP project). *Annals of Glaciology*, 38, 150-158. doi:10.3189/172756404781814825

Essery, R., Morin, S., Lejeune, Y., & Ménard, C. B. (2013). Advances in Water Resources A comparison of 1701 snow models using observations from an alpine site. *Advances in Water Resources*, *55*, 131–148. https://doi.org/10.1016/j.advwatres.2012.07.013

Wiscombe WJ, Warren SG, 1980. A model for the spectral albedo of snow. I: pure snow. *Journal of Atmospheric Science*. 37, 2712–2733.