**Brief model description**

The model used is the Community Firn Model (CFM).

The densification process in the model is based on the formulation of Kuipers Munneke et al. (2015) or on the formulation of the CROCUS model (Vionnet et al., 2012). The files containing results of the simulations using the Kuipers Munneke densification scheme are labelled CFM-KM and the files containing results of the simulations using the Crocus densification scheme are labelled CFM-Cr.

An advanced liquid water scheme is implemented in the model. We use a dual domain approach to separate matrix flow and preferential flow. The scheme is based on the one implemented in SNOWPACK and described in Wever et al. (2016). Both matrix and preferential flow are governed by the Richards Equation with water transfers between the domains and refreezing applied every 15 minutes in accordance with the original flow scheme. Layers with density superior to the pore close-off density are impermeable to matrix flow but not to preferential flow. There are a few modifications with respect to the model described in Wever et al. (2016):

(i) We don’t use their equation (1) for the calculation of but use a constant value.

(ii) We apply the runoff formulation of Zuo and Oerlemans (1996) in layers containing liquid water. However, runoff is not applied in saturated layers building up at the end of the domain, thus allowing for the formation and the persistence of firn aquifers.

(iii) We make saturated layers in the matrix flow domain impermeable to incoming flow.

There are two tuning parameters in the flow scheme of Wever et al. (2016): Θ (threshold preferential flow domain saturation for back flow to matrix flow domain) and N (number of preferential flow paths per m2). For the RETMIP experiments, we used the value Θ = 0.1 as Wever et al. (2016) and we used the smallest non-zero value tested for N and thus N = 0.2.

Note that the temporal resolution of the liquid water scheme itself is different from the 3 hourly temporal resolution of the model. The flow scheme uses an adaptive time step required for the solving of the Richards Equation. When 3 hours have passed, the flow scheme stops and the other routines of the Community Firn Model take place (densification, heat diffusion, etc.).

The model requires the grain size property. For the initial grain size at the surface, we use the equation (11) of Linow et al. (2012). Grain size growth is in accordance with equations (16) and (17) of Katsushima et al. (2009)and thus similar to equation (18) of Langen et al. (2017):

**Initialisation of the model**

To initialise the grain size, we use an analytical profile derived from equation (B3) in Arthern et al. (2010) where the grain size depends on the surface grain size, the annual mean surface temperature and the age of the layer.

For the initial age of every layer, we start by calculating a proxy of the age of the oldest initial layer by using the 1950-1999 average annual accumulation:

From there, we calculate a proxy of the age of each individual layer according to the part of the total mass above it:

At the bottom of the firn column, the model uses a Neumann temperature boundary condition. Thus, we add several high density layers initialised at the temperature provided in the protocol as the “Observed deep firn temperature” to account for the thermal mass of the ice sheet. These layers are not taken into account in our calculations of the outputs (e.g. for the total firn air content) and no water is allowed to flow in these layers.

**Contacts:**

Max Stevens, [maxstev@uw.edu](mailto:maxstev@uw.edu)

Vincent Verjans, [v.verjans@lancaster.ac.uk](mailto:v.verjans@lancaster.ac.uk)

**References:**

Arthern, R. J., Vaughan, D. G., Rankin, A. M., Mulvaney, R. and Thomas, E. R.: In situ measurements of Antarctic snow compaction compared with predictions of models, J. Geophys. Res. Earth Surf., 115(3), 1–12, doi:10.1029/2009JF001306, 2010.

Katsushima, T., Kumakura, T. and Takeuchi, Y.: A multiple snow layer model including a parameterization of vertical water channel process in snowpack, Cold Reg. Sci. Technol., 59(2–3), 143–151, doi:10.1016/j.coldregions.2009.09.002, 2009.

Kuipers Munneke, P., Ligtenberg, S. R. M., Noël, B. P. Y., Howat, I. M., Box, J. E., Mosley-Thompson, E., McConnell, J. R., Steffen, K., Harper, J. T., Das, S. B. and Van Den Broeke, M. R.: Elevation change of the Greenland ice sheet due to surface mass balance and firn processes, 1960-2013, Cryosph., 9(3), 3541–3580, doi:10.5194/tcd-9-3541-2015, 2015.

Langen, P. L., Fausto, R. S., Vandecrux, B., Mottram, R. H. and Box, J. E.: Liquid Water Flow and Retention on the Greenland Ice Sheet in the Regional Climate Model HIRHAM5: Local and Large-Scale Impacts, Front. Earth Sci., 4, doi:10.3389/feart.2016.00110, 2017.

Linow, S., Hörhold, M. W. and Freitag, J.: Grain-size evolution of polar firn: A new empirical grain growth parameterization based on X-ray microcomputer tomography measurements, J. Glaciol., 58(212), 1245–1252, doi:10.3189/2012JoG11J256, 2012.

Vionnet, V., Brun, E., Morin, S., Boone, A., Faroux, S., Le Moigne, P., Martin, E. and Willemet, J. M.: The detailed snowpack scheme Crocus and its implementation in SURFEX v7.2, Geosci. Model Dev., 5(3), 773–791, doi:10.5194/gmd-5-773-2012, 2012.

Wever, N., Würzer, S., Fierz, C. and Lehning, M.: Simulating ice layer formation under the presence of preferential flow in layered snowpacks, Cryosphere, 10(6), 2731–2744, doi:10.5194/tc-10-2731-2016, 2016.

Zuo, Z. and Oerlemans, J.: Modelling albedo and specific balance of the Greenland ice sheet: Calculations for the Søndre Stromfjord transect, J. Glaciol., 42(141), 305–316, doi:10.3198/1996JoG42-141-305-317, 1996.