REGIONAL CLIMATE MODELLING OF THE GREENLAND ICE SHEET

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Introduction

The results presented here are part of the RAPID-project “Mass balance and freshwater contribution of the Greenland ice sheet: a combined modelling and observational approach” that aims to study rapid climate changes in the North Atlantic and its effects on the surface mass balance and freshwater contributions of Greenland ice sheet using an atmospheric limited area model. We use the Regional Atmospheric Climate Model version 2.1 (RACMO2.1) of the Royal Netherlands Meteorological Institute (KNMI). This model has been successfully applied in Antarctic climate studies (Van de Berg *et al.*, 2004, Reijmer *et al.*, 2005). The strong seasonal melting in the well-defined ablation zone of the Greenland ice sheet is important for its mass balance. Simulations with two different snow schemes in the single column model version of RACMO2.1 over a location in the ablation zone shows that processes like retention and refreezing of melt water are important for realistically representing snow under melting conditions.

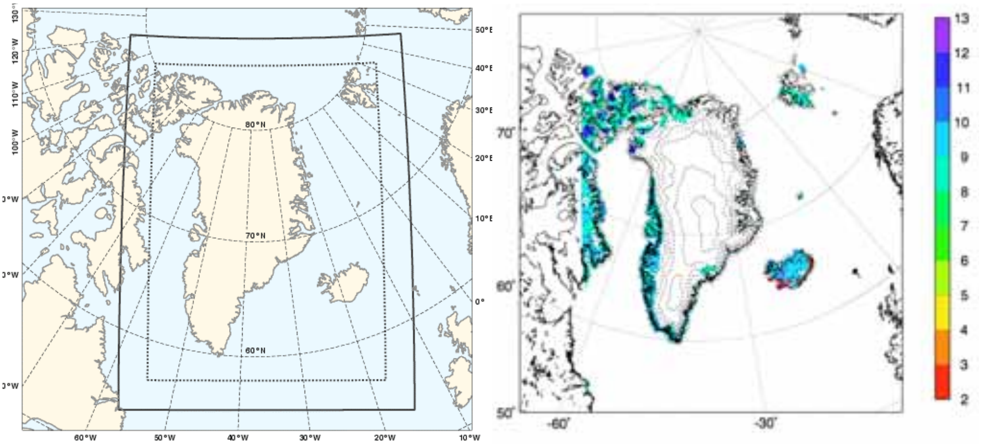

Figure 1. Left: RACMO2.1 model grid for Greenland. Right: low vegetation map RACMO2.1. Numbers refer to low vegetation type (2: short grass, 7: tall grass, 8: desert, 9: tundra, 11: semi desert, 13: bogs and marshes). Contour lines indicate surface height on 500 m intervals from US Navy dataset.

Model Setup

The atmospheric dynamics in RACMO2.1 originates from the High Resolution Limited Area Model (HIRLAM, version 5.0.6). The description of the physical processes is adopted from the European Centre for Medium-Range Weather

Forecasts (ECMWF, cycle 23r4). The horizontal resolution of RACMO2.1 over Greenland will be ~18 km (figure 1). The model has 40 atmospheric hybrid-layers in the vertical, of which the lowest is ~10 m above the surface. The hybrid-layers follow the topography close to the surface and pressure levels at higher altitudes. ECMWF Re-Analysis (ERA-40) fields force the model at lateral boundaries, while the interior of the domain is allowed to evolve freely. Sea surface temperature and sea ice fraction are prescribed from ERA-40.

For an accurate topographic representation of the Greenland ice sheet, height data of the digital elevation model of Bamber *et al.* (2001) will be used. The global U.S. Navy data is used as standard height dataset in RACMO2.1, but it gives non-smooth height contours as shown in Figure 1. Other adjustments are needed to the vegetation map underlying RACMO, which exposes too little tundra along the east coast (Figure 1).

Here, two snow schemes are tested for their ability to simulate melting snow. The original description of snow in RACMO2.1 describes the Greenland ice sheet as a single layer of snow with a climatological depth of 10 m w.e. Because a single layer of 10 m w.e. has a too large thermal inertia, the depth of the thermal calculations is limited to 1 m of snow. There is no melt or refreezing in this snow scheme. The second snow scheme tested is the englacial module of a surface mass balance model (Bougamont *et al.*, 2005) including subsurface processes in snow such as water percolation, retention and refreezing. These processes are modelled for 25 m w.e. of firn/snow/ice, composed of a maximum of 100 layers. Initially the thickness of each individual layer increases linearly with depth with an upper layer thickness of 0.09 m. Layer thickness varies due to melting, freezing or accumulation. An infinitely thin skin layer is used to calculate the surface energy fluxes and the surface temperature as input to both schemes. For testing and comparing both snow schemes they were imbedded in the single column version of RACMO2.1, which is essentially an isolated column of air over a snow surface located in the ablation zone.

Results

A number of experiments was performed with the single column model to test both schemes, the original snow scheme as reference (ref) and the new multilayer snow approach (smb). The experiments presented here are driven by prescribed initial atmospheric profiles of temperature, humidity and wind speed taken from ERA-40. Due to the initially cold atmosphere there is no melt at the surface. The single snow layer in the original scheme is initialized as 10 m w.e. snow with the same properties as the upper 5 m snow in the new scheme that is lying on top of 20 m of colder ice. The single column model is allowed to evolve freely over the full period of 6.5 days starting at 12 UTC. In two subsequent melting experiments (ref-melt and smb-melt) the temperature profile is increased such that the lower atmosphere is warmer than the melting point. No precipitation is simulated in the experiments.

Figure 2 shows surface albedo and snow temperature and density of the single layer for the original snow scheme and of the first snow layer in case the new scheme is used. The single layer of snow is rather insensitive to the increase of atmospheric temperature (ref and ref-melt). Its snow temperature, density and surface albedo are very similar under these very different atmospheric conditions due its large volumetric heat capacity. Splitting the snow pack into multiple layers, like done in the new snow scheme, does not largely affect the snow properties of the top layer under non-melting conditions (Figure 2, smb). Differences in surface albedo and snow density between the schemes are due to different parameterizations used. Under warmer atmospheric conditions the upper snow layer quickly reaches the melting point and starts to melt. At day 4 the upper snow layer is fused with the underlying layer causing a jump in snow density and surface albedo.

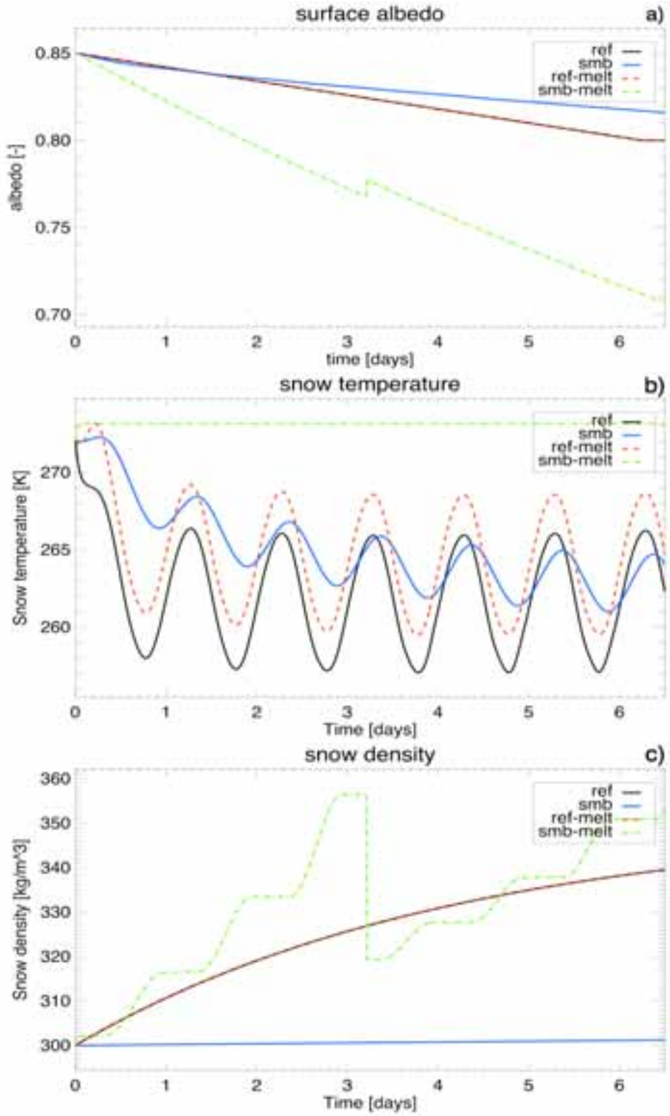

Figure 2. Time series of surface albedo (a), snow temperature (b) and density (c)of the top layer simulated with the original (ref) and new (smb) snow scheme imbedded in single column model version of RACMO2.1 under non-melting and potential melting (melt) atmospheric conditions.

Snow temperature, density and water content of the upper 5 m of fresh snow under melting conditions are presented in Figure 3. The warm atmosphere persistence in time allows underlying snow layers to warm up and an isothermal layer is formed. Melt water is present and percolates further downward if the maximum retention capacity is exceeded. Due to high temperatures at the surface no refreezing of melt water in the snow pack is occurring.

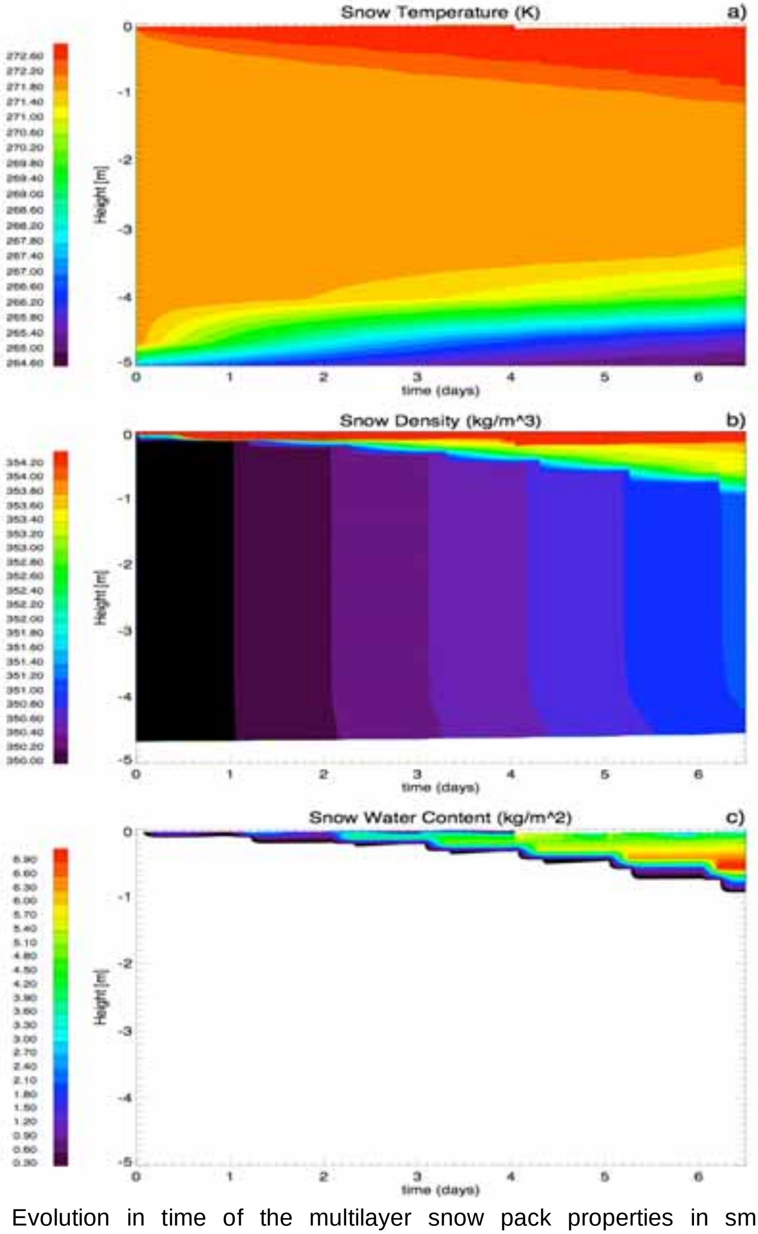

Figure 3. Evolution in time of the multilayer snow pack properties in smb-melt for temperature (a), density (b) and water content (c) under melting conditions.

Conclusions and outlook

To accurately estimate the surface mass balance of the Greenland ice sheet it is important to simulate the widespread seasonal melt in time and space. Two different snow schemes are tested under melting and non-melting atmospheric conditions with a single column model version of RACMO2.1. For non-melting conditions both schemes perform very similar. Under melting conditions the new snow scheme is able to melt a thin layer of snow, where as the warming of the single snow layer in the original scheme is much slower due to its thickness. In this study we have seen that a single layer approach of the Greenland ice sheet is not capable to deal with melt. Instead the new snow scheme of Bougamont *et al.* (2005) will be used in RACMO2.1.

References

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