GREENLAND SURFACE MASS BALANCE USING A REGIONAL ATMOSPHERIC CLIMATE MODEL

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Introduction

As part of the RAPID Climate Change program we investigate the effects of rapid climate changes on the surface mass balance and freshwater contributions of the Greenland ice sheet. For this purpose we use the Regional Atmospheric Climate Model (RACMO2.1/GRN). The period September 1989 to December 2005 is simulated to validate the model output with other regional climate model studies and direct mass balance measurements along the K-transect in West-Greenland. This leads to an assessment of the spatial and temporal variability in the surface mass balance (SMB) and its subcomponents.

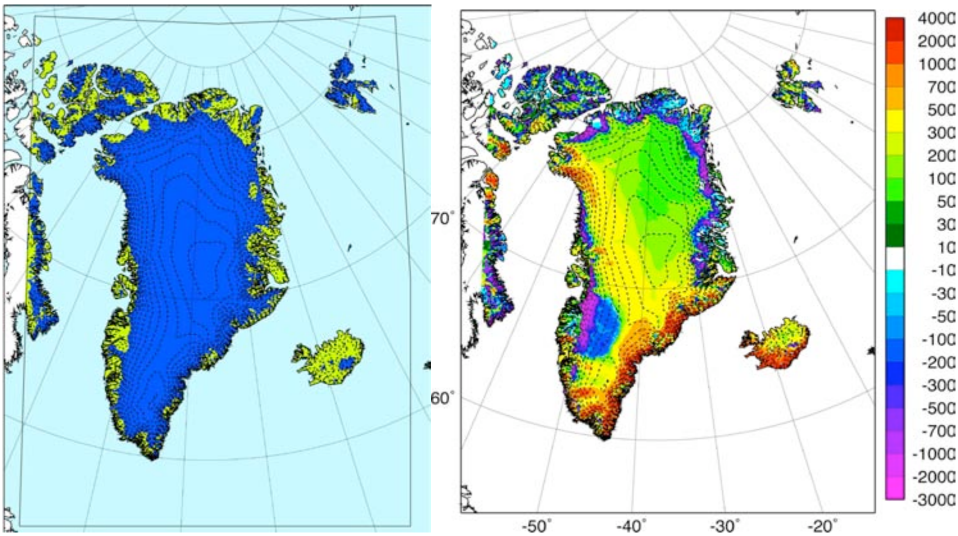

Figure 1. Left: RACMO2.1/GRN model domain for Greenland with dashed height contours every 250 m. Dark blue area is land ice, green tundra and light blue sea or sea ice. Right: annual surface mass balance for 2004 in mm w.e.; values have no meaning over land points.

Model setup

RACMO2.1/GRN is adapted from the second version of the Regional Atmospheric Climate Model (RACMO). It consists of the atmospheric dynamics of the High-Resolution Limited Area Model (HIRLAM) and the physical processes package from the European Centre for Medium-Range Weather Forecasts (ECMWF). To better represent the conditions on Greenland the multi-layer snow parameterization of Bougamont et al (2005) is implemented. This scheme computes subsurface and snow metamorphism processes like ice and snow melt, percolation and refreezing of meltwater, snow densification and ageing within the upper 25 meter of firn. Feedback between the snow surface and the overlying atmosphere is based on a skin temperature formulation and the surface albedo as function of the snow density of the first firn layer (Greuell and Konzelman, 1994).

The horizontal resolution of RACMO2.1/GRN is about 11 km. The model has 40 hybrid levels in the vertical, of which the lowest is about 10 m above the surface. ERA-40 fields force the model at lateral boundaries complemented with operational analyses until December 2005. Height data of the digital elevation model of Bamber et al. (2001) is used for an accurate topographic representation as shown in Figure 1a.

Model evaluation

The surface mass balance in the model is defined as the total precipitation (solid plus liquid) minus meltwater production and sublimation. The runoff component in the model is incorrectly parameterized, which makes this data unusable for explicit SMB calculation. Therefore, we assume that the meltwater production is an acceptable first order estimate of the runoff. This may lead to an overestimation of the mass loss since part of the meltwater will refreeze in the firn layer.

The pattern of the annual SMB of 2004 shown in Figure 1b agrees with other estimates based on observations (Zwally and Giovinetto, 2001) and models (Fettweis, 2007; Box et al., 2006). The simulated minimum and maximum values are more extreme than in previous estimates. Most mass is gained northeast of Baffin bay and the southeastern coastal area. These areas are associated with steep slopes that enhance solid precipitation rates. The regions with the most negative mass balance occur along the western margin south of Jacobshavn glacier and the northern ice margin where most melt occurs. Due to the low temperatures in the latter area, most of the meltwater will refreeze and actually not contribute to mass loss.

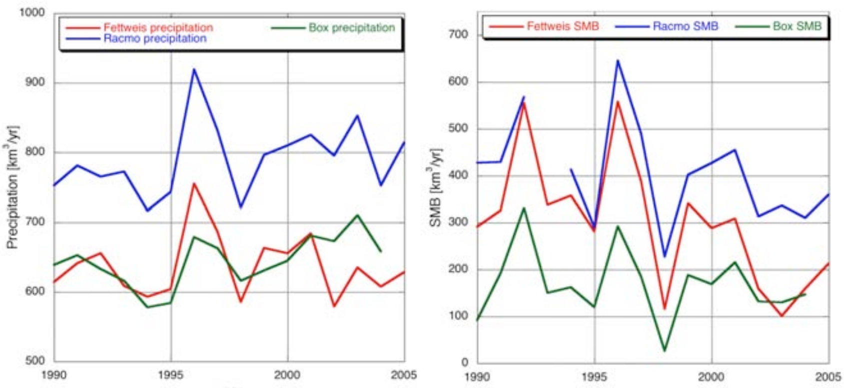

Figure 2. Left: Time series of the annual total precipitation for period 1990-2005. Right: the same plot as a for the annual surface mass balance

The RACMO2.1/GRN annual precipitation rates for the period 1990-2005 are plotted in Figure 2a, together with estimates based on the MAR (Fettweis, 2007) and the polar MM5 model (Box et al., 2006). RACMO2.1/GRN shows an enhanced precipitation rate mainly due to its horizontal resolution of 11 km, where the MAR model is running at 25 km and MM5 at 24 km resolution. The higher precipitation rates in RACMO2.1/GRN lead to a more positive SMB than the other models as seen in Figure 2b. The simulated interannual variability of the different SMB components is consistent with the other models.

In-situ data helps us to determine if the larger precipitation rates simulated are realistic or not. Figure 3 displays the simulated and observed (Van de Wal et al., 2005; complemented by pers. comm. Van de Wal) surface mass balance along the K-transect located at 67°N on the western margin in the ablation zone. For the year 2004, the simulated ablation is slightly weaker close to the ice margin due to an overestimation of winter snowfall, which prevents the darker glacier ice to surface early in the melt season. Overestimation further from the margin may be the result of the assumption that all meltwater produced runs off, while at these locations about half of the meltwater refreezes in the firn. Overall, the modeled values stay within the range of the measurements, which is promising for further validation of the model with other observational datasets.

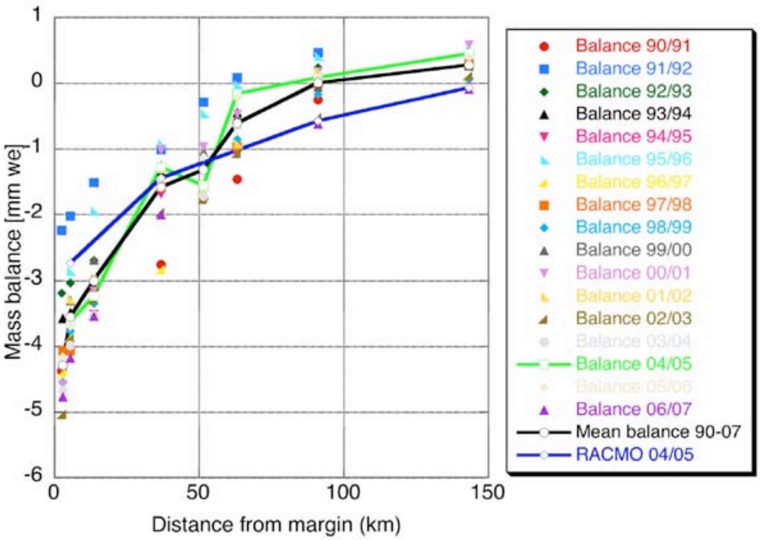

Figure 3. Surface mass balance as function of the distance to the ice margin. Dots are the measurements are for the period 1990-2007; black line is the mean over the entire period; the green line for the year 2004. The blue line is RACMO2.1/GRN for 2004.

Conclusions and outlook

RACMO2.1/GRN is able to simulate a realistic spatial and temporal SMB for the Greenland ice sheet. Compared to other model studies it simulates enhanced precipitation rates, mainly on the steep southeastern slopes. Even with the assumption made that all meltwater produces runs off, the total SMB is more positive than in other estimates.

The stake measurements show a steep gradient in SMB with distance from the margin, which is reasonably represented in RACMO2.1/GRN. Resolving the runoff problem by removing more efficiently the water from the ice surface and refreezing the meltwater in the firn pack will further improve the model agreement.

More validation of the model results is planned for the near future using available automatic weather stations data, ice core accumulation datasets and coastal precipitation gauge data.

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