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Uncertainties in the present-day and future surface mass balance of the Greenland ice Sheet

J Bamber (1), M Bougamont (1), E Hanna (2), W Greuell (3), R Gladstone (1), T Payne (1), I Rutt (1), J Ridley (4)

(1) Bristol Glaciology Centre, University Bristol, UK, (j.bamber@bristol.ac.uk), (2) Dept of Geography, University Sheffield, UK, (3) IMAU, Utrecht University, Netherlands, (4), Hadley Centre, Met Office, UK.

The surface mass balance of the Greenland ice sheet has, in the past, been determined most commonly with the aid of a positive degree day model (PDDM) to estimate ablation. This is a reduced form of an energy balance model (EBM) where temperature is the sole variable that determines melt. Less empirical EBMs exist that, for example, take account of radiative, turbulent and sensible heat fluxes explicitly but the data needed to drive them, until now, has been inadequate. Consistent global climate re-analysis data have recently been generated that show considerable skill in reproducing the observed temporal and spatial trends in key variables such as radiative fluxes and precipitation, and which are starting to be used to force EBMs of the ice sheet.

EBMs and PDDMs have different sensitivities to climate forcings. For example, an EBM is sensitive to changes in cloud cover as this affects both long and shortwave radiative fluxes, while a PDDM is only indirectly affected through any changes in surface temperature that may result from the different cloud cover. To investigate these differences quantitatively for a future climate warming scenario we forced an EBM and PDDM for the Greenland ice sheet with the output of a coupled atmosphere-ocean GCM, HadCM3, which was run from the present-day forward in time for 110 years assuming a 4 x C02 forcing trend. The EBM comprises two components: one that determines the energy balance and a second snow diagenesis part that models the evolution of the snowpack and its thermal energy. The PDDM, by contrast, uses a simple parameterization for determining the proportion of melt that refreezes within the snowpack. The HadCM3 data were used to force the two models forward in time for 300 years with constant climate from year 110. As expected, the two models produced markedly different melt volumes (by up to a factor 2) but, more surprisingly, differences in the amount of refreezing were as large as differences in total melt.

It is the case that there are tuneable parameters in both models and that some of the difference could be reduced by changing these values. However, here we used relatively "standard" values for the PDDM and the EBM was tuned to provide agreement with in-situ observations of mass balance along the K-transect in southwest Greenland. There is, therefore, limited scope for tuning without moving one or other model away from observations. Our results highlight the large uncertainty in estimates of the future surface mass balance response of the ice sheet. They also highlight the importance of refreezing as well as the method for estimating the amount of melt. To date, most emphasis has perhaps been placed on the latter compared with the former possibly because of the difficulty in acquiring direct measurements of refreezing.