Geophysical Research Abstracts
Vol. 19, EGU2017-18220, 2017
EGU General Assembly 2017

The liquid water balance of the Greenland ice sheet

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Mass loss from the Greenland Ice Sheet (GrIS) is an increasingly important contributor to global sea level rise. During the last decade, the mass loss was dominated by meltwater runoff. Linking actual runoff from the ice sheet to melt and other forms of liquid water input at the surface (rainfall and condensation) is however complex, as liquid water may be retained within the ice sheet due to refreezing and/or (perennial) storage. In the ablation zone on bare ice, liquid water runs of laterally at the surface, accumulates in supraglacial lakes or enters the ice sheet's en- or subglacial hydraulic system via moulins and crevasses. In the higher elevated accumulation zone, liquid water percolates into the porous firn layer and part of it may be retained due to refreezing and/or perennial storage in so called firn aquifers.
In this study, we investigate the liquid water balance of the GrIS focussing on the role of the firn layer. For this purpose, we ran SNOWPACK, a relatively complex one-dimensional snow model, on a horizontal resolution of $\sim 11\,km$ and for the transient period of 1960 to 2015. At the snow-atmosphere-interface, the model was forced by output of the regional atmospheric climate model RACMO2.3. A comparison of SNOWPACK with in-situ observations (firn density profiles) and remote sensing data (firn aquifer locations inferred from radar measurements) indicated a good agreement for most climatic conditions. On a GrIS-wide scale, the modelled surface mass balance of SNOWPACK exhibits, in combination with ice-discharge data for ocean-terminating glaciers, an excellent agreement with GRACE data for the period 2003 - 2012.
GrIS-integrated amounts of surface melt reveal a significant positive trend ($+11.6\,Gt\,a^{-2}$) in the second half of the simulation period. Within this interval, the trend in runoff is larger ($+8.3\,Gt\,a^{-2}$) than the one in refreezing ($+3.6\,Gt\,a^{-2}$), which results in an overall decrease of the refreezing fraction. This decrease is for instance less pronounced in the south-eastern area of the GrIS, where the refreezing fraction is comparably high (~ 0.75) due to large amounts of available pore space. This area also indicates the highest increase in the modelled areal firn aquifer extent ($+343\,km^2\,a^{-1}$). Generally, many components of the liquid water balance reveal distinctively different magnitudes and temporal patterns on a local, basin-wide scale.