**Title**

Sticky Snow: Combining Snow and Radiative Transfer Models in the Percolation Area of the Greenland Ice Sheet

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**Abstract**

Subsurface firn processes play a crucial role in ice sheet mass loss mechanisms. On Greenland surface meltwater percolates to deeper layers where porous firn retains it, directly inhibiting runoff. However, secondary effects such as the formation of impermeable ice slabs may indirectly and irreversibly accelerate runoff and with it global sea level rise. Microwave remote sensing offers opportunities to monitor these processes, but due to the simplicity of their underlying snow models retrieval methods fail over areas subject to melt and refreezing - areas where the firn's (in)ability to buffer meltwater is critical. This study presents a new forward model which given initial conditions and atmospheric forcing first solves for the firn state through a full-complexity snow model (SNOWPACK) and then simulates multifrequency brightness temperature (Tb) time series (using radiative transfer model SMRT). As part of a comprehensive sensitivity analysis three ensembles of multi-decade Tb time series (19 and 37 GHz) were modelled for the DYE-2 site in the percolation area of the Greenland Ice Sheet. Model performance based on RMSE w.r.t. independent Tb satellite observations was found to be sensitive to biases introduced in the atmospheric forcing record (with air temperature, precipitation and relative humidity controlling variance) and snow model settings (new snow grain size and albedo settings) and not to initial profile conditions. However, computed RMSEs were high (min. 17.8 K at 37V and 19.4 K at 19V) due to trends in modelled Tb consistently underestimating observed trends when taken over an accumulation season. It is shown that this can only be explained by the constant-with-time stickiness assumption used to link the snow model’s microstructure representation to the sticky hard sphere model employed for the radiative transfer scheme. A seasonal stickiness signal is made evident for the conditions at DYE-2 and linked to its yearly melt-refreeze-accumulation cycle. These results demonstrate that earlier approaches to forward model microwave satellite observations based on a constant-with-time stickiness assumption (or that lack a third snow microstructure parameter altogether) are not valid for ice sheet areas prone to melt. This study is expected to be the starting point for a more sophisticated implementation that estimates a snow layer's stickiness from microstructure information already available in the snow model. If successful it would be the first of its kind and open the door to satellite-based retrieval of subsurface firn properties and processes from areas where observations are currently lacking, greatly reducing uncertainty in ice sheet mass loss and global sea level rise projections.