Can snow impurities be detected on Greenland ice sheet by satellite remote sensing?

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Warren (2013) pointed out that attempts to use satellite remote sensing to estimate the black carbon (BC) content of snow are unlikely to be successful, except in highly polluted industrial regions, with the reasons as follows. The possible albedo reductions for the shortwave and visible wavelengths due to the typical concentration of BC (3–30 ppbw) in remote areas of the Northern Hemisphere are 0-1 % and 0-2 %, respectively for cold fine-grained snow, and 0–3% and 1–6%, respectively for melting snow. Compareing to these small albedo reductions typical errors in surface albedo inferred from satellite measurements are comparable (a few percent), which are attributed to uncertainties of undetected thin clouds, atmospheric aerosols, vertical profile of snow grain size, surface roughness, and subpixel heterogeneity of the thin and patchy snow cover as well as satellite sensor calibaration and bidirectional reflectance distribution function (BRDF) model of snow surface used in the retrieval algorithm.
We are challenging to develop the satellite remote sensing algorithm to retrieve snow impurities on Greenland ice sheet (GrIS) to estimate the possible contribution to the recent albedo reduction. The algorithm is based on look-up table method in which BRDFs are tabled as functions of solar and satellite zenith angles and relative azimuth angle, snow impurity concentration and snow grain size. Our algorithm employed a two-snow layer model by which the effect of vertical inhomogeneity of the snow parameters is taken into account. To examin the possibility of satellite remote sensing of snow impurities with our algorithm on GrIS, we estimated the albedo reduction due to BC on GrIS with physically based snow albedo model (Aoki et al., 2011). The albedo reduction for melting snow for the BC concentration range previously measured (0.55-20 ppbw) on GrIS is 0.02-2.6% and 0.03-4.8% for the shortwave and visible wavelengths, respectively. On GrIS there are no uncertainties of subpixel heterogeneity of the thin and patchy snow cover. The surface roughness is also very small in summer season over acculuration area on the ice sheet. The atmospheric aerosols effect are generally small. Hence, the major uncertainties are satellite sensor calibaration, thin cloud effect, and BRDF model used in the algorithm. These issues were improved by employing the latest MODIS C6 data set, new cloud detection algorithm (Chen et al., 2014), and Voronoi snow shape model for BRDF calculation in our algorithm. The retrieval results of monthly mean BC-equivalent concentration of snow impurities from 2000 to 2015 on GrIS in summer season were 8-34 ppbw which are same or somewhat higher than the previous in-situ measurements (0.55-20 ppbw). However, those in spring reason were too high (29-383 ppbw) compared to the in-situ measurements. The inter-annual trend of the concentration in summer was small increase of 10-30%/decade. From this result, there is a possibility to detect snow impurity on GrIS in summer season by satellite remote sensing.
References
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