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Numerical simulation of spectral albedos of glacier surfaces covered with glacial microbes in northwestern Greenland

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Snow and ice in the Arctic are presently undergoing drastic changes. The mass balance loss from the Greenland Ice Sheet increased significantly after the mid-1990s. One of the possible reasons of snow/ice surface melting is due to the increases of light absorbing impurities in snow/ice and snow grain size. This is because the surface albedo of snow (ice) is strongly controlled by mass concentration of light absorbing impurities including glacial microbes and snow (ice) grain size. To clarify this we carried out the spectral albedo measurements on ablation area in Qaanaaq Glacier in northwestern Greenland in July 2011. The almost glacier surfaces in the ablation area were covered with cryoconite (biogenic dust) on ice grain layer with the size of 1 to 2 centimeters and the several-centimeter depth above bare ice. There were also cryoconite holes (a water filled cylindrical melt-holes with cryoconite on the bottom), red snow (snow algae) and rivulets in some parts of the glacier surfaces. We measured the spectral albedos of the glacier surfaces using a spectrometer FieldSpecrPro (ASD Inc., USA) for a spectral range from 0.35 to 2.5 μm.

The measured spectral albedos had a remarkable contrast between red snow surface and ice surface covered with cryoconite mainly for the ultraviolet to visible regions (0.35-0.75 μm), where red snow albedo increased rapidly with the wavelength, while cryoconite surface albedo was relatively flat. The spectral albedos of cryoconite surface in the spectral domain from 1.0 to 1.4 μm were higher than that for the underlying bare ice. This is due to light scattering by ice grains, on which the cryoconite covers, above the bare ice. The relative high albedo in the near-infrared spectral domain is important for the melting process of glacier surface as well as those in the visible region affected by glacier microbes. Since the spectral albedo in the spectral region beyond 1.0 μm is theoretically not so sensitive to snow impurities, we can retrieve the ice grain size by satellite remote sensing.

We simulated the spectral albedos of cryoconite surface and red snow surface with a radiative transfer model for the atmosphere-snow system. The single scattering properties of snow grains are calculated with Mie theory assuming the snow gains to be spherical particles with the size of several millimeters. The ice grains are assumed to be non-spherical particles of Voronoi aggregates with the size of several tens millimeters and the single scattering properties are calculated with geometric optics. Those grain sizes are based on in-situ measured values. For the effects of snow impurities of cryoconite and snow algae (red snow), we simply assumed the optical properties of mineral dust of in-situ measured mass concentrations with external mixtures. For both cases of cryoconite and red snow, the theoretically calculated spectral albedos at the wavelengths beyond 0.75 μm agreed with the measurements, while those for the spectral region less than 0.75 μm were higher than the measurements. The differences are due to the effects of glacial microbes. It is important to determine to the absorption properties of glacial microbes in the visible region for simulating the dark glacier surface albedos.