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Cloud thermodynamic phase discrimination over snow surfaces using passive solar remote sensing

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Despite mixed-phase clouds constitute the most common cloud type in Arctic regions, their contribution to the Arctic Amplification still remains unclear. The not-well-understood associated processes along with the lack of observations yield to serious uncertainties when estimating the mixed-phase clouds radiative forcing. The ice phase has been found to play an important role in this context, which makes a precise discrimination of the partitioning between ice and liquid water within the clouds crucial for a correct determination of such radiative forcing.
Traditional methods for phase discrimination rely on the different absorption of liquid water and ice in certain spectral regions. These differences imprint into the cloud top reflectivity as observed by airborne or satellite remote sensing. By different mathematical approaches, these spectral signatures between 1500 nm and 1800 nm have been used to extract parameters which serve as phase indices, e.g., the slope of a linear regression, the first component of a principal components analysis and the equivalent water thickness due to liquid water and ice derived by a spectrum fitting algorithm have been presented in literature. However, the performance of these methods has been demonstrated only for clouds over land or ocean, where surface albedo is low. In Arctic regions, snow and ice surfaces have similar spectral features compared to ice clouds and may bias the cloud phase indices. We have assessed the applicability of these phase indices over a series of simulated liquid, ice, and mixed-phase clouds with different microphysical and optical properties. The suitability of the phase indices has been tested not only over water surfaces (dark surfaces) but also over snow surfaces of different snow grain sizes (i.e. bright surfaces of variable albedo). In general, it was found, that all methods are able to discriminate the cloud phase also for clouds over snow surfaces if cloud optical thickness is high and the thresholds are adjusted. For clouds of low optical thickness, the surface reflection may dominate the reflected radiation above the clouds and bias the phase index to values representing ice clouds. This holds especially for snow with small grain sizes which have higher albedo values in the wavelength range of interest. Additionally, the feasibility of a quantitative estimation of the ice and liquid water path using the proposed phase indices is tested.