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Comparison of measured and modeled shortwave radiation at the surface in the presence of an ice cloud

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Tropospheric ice clouds or cirrus are an important component in the Earth-atmosphere system through their role in the redistribution of radiative energy among others. These clouds are composed of non-spherical and often irregularly shaped ice crystals. The shapes, size distributions, and optical properties of ice crystals and therefore the radiative effects of cirrus are still poorly known. In this case study, shortwave radiative fluxes in the presence of a cirrus cloud are modeled using in-situ measured size-shape distributions of ice crystals. In particular, the sensitivity of the shortwave radiation to uncertainties in the concentrations and shapes of small ice crystals is quantified. Airborne microphysical data from a cloud particle imager, optical array probes, and forward scattering probes were collected during two flights of the University of North Dakota Citation aircraft over the Atmospheric Radiation Measurement program's Southern Great Plains site in Oklahoma on 13 March 2000. These data are used to construct vertical profiles of the size and shape distributions of ice crystals. Due to uncertainties associated with measuring the sizes and shapes of small ice crystals with maximum dimensions less than 120 μm, five alternate size-shape distributions are considered. The distributions are combined with existing databases of wavelength-dependent single-scattering properties of idealized ice crystals to obtain vertical profiles of the asymmetry parameter, single-scattering albedo, and extinction coefficient, which are input to the radiative transfer model libRadtran. The dependence of the surface as well as the top-of-the atmosphere fluxes on the uncertainties in the size-shape distributions is then simulated and the resulting surface fluxes (direct and diffuse) are compared against measurements at the surface. Before the comparison, the fluxes are corrected for the contribution of downward diffuse radiation within the angular range covered by the instrument measuring the direct radiation and lacking from the instrument measuring the diffuse radiation.

When the optical thickness is derived from the in-situ observations, the differences between the modeled and measured fluxes are too large to be explained by uncertainties in the shape and concentrations of small ice crystals. To further constrain the simulations, the optical thickness is adjusted so that the modeled and measured (corrected) direct fluxes match. These alternative optical thickness values are larger than those obtained from the in-situ measurements, and when used in the simulations the modeled total downward flux agreed well with the measurements (mean difference less than 19 Wm^{-2}). In addition, it is seen that reducing the asymmetry parameter slightly (less than 10%), would further improve the agreement with observations. The reduction in asymmetry parameter could be due to the presence of surface roughness, air bubble inclusions or other nonidealities in ice crystals.