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The Effect of Ice Crystal Size and Orientation on Cirrus Cloud Solar Radiative Fluxes

A. Macke (1), I. Schlimme (2), S. Klotzsche (3)and J. Reichardt (4)

(1) Leibniz-Institute for Marine Sciences, IFM-GEOMAR, (2) Lufthansa, (3) Max-Planck-Institute for Meteorology, (4) Deutscher Wetterdienst DWD

The solar radiative properties of cirrus clouds depend on ice particle shape,size, and orientation, as well as on the spatial cloud structure. Radiation schemes in atmospheric circulation models rely on estimates of cloud optical thickness only. In the present work, a Monte-Carlo radiative transfer code is applied to various cirrus cloud scenarios to obtain the radiative response of uncertainties in the above mentioned microphysical and spatial cloud properties. The size induced variabilities in the solar radiative fluxes are in the order of few percents for the reflected and about 1 percent for the diffusely transmitted fluxes. Largest variabilities in the order of 10 to 30 percent are found for the solar broadband absorptance. For the reflected and transmitted fluxes, these variabilities are smaller than the flux differences due to the choice of ice particle geometries. The influence of cloud inhomogeneities on the radiative fluxes has been examined with the help of time series of Raman lidar extinction coefficient profiles. Significant differences between results for inhomogeneous and plane-parallel clouds were found. These differences are in the same order of magnitude as those arising from using extremely different crystal shapes for the radiative transfer calculations. Largest sensitivities of the solar broadband radiative fluxes of hexagonal ice columns to particle orientation have been found for the solar zenith angles $\Theta_0 = 40^\circ$ (scattering) and $\Theta_0 = 0^\circ$ (absorption), and for nearly horizontally oriented crystals. Provided that ice columns are horizontally oriented, the usual assumption of random orientation leads to an overestimation (underestimation) of the reflected (transmitted and absorbed) solar broadband radiation at high sun conditions and to an underestimation (overestimation) at middle solar zenith angles. The orientation effect is stronger pronounced for smaller ice crystals. For hexagonal plates $\Theta_0 = 90^\circ - 40^\circ = 50^\circ$ and $\Theta_0 = 90^\circ - 0^\circ = 90^\circ$ are the solar zenith angles with largest sensitivies to particle orientation.