Geophysical Research Abstracts
Vol. 20, EGU2018-16873-1, 2018
EGU General Assembly 2018

Remote sensing of vertical profiles of cirrus optical and microphysical properties using optimal estimation and information content theory

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Common cloud retrieval algorithms simultaneously retrieve the total cloud optical thickness τ_c and particle effective radius r_e using a pair of solar reflectance/radiance measurements, one at a scattering and one at an absorbing wavelength, and assume a plane-parallel and vertically homogeneous cloud geometry. This conventional technique only provides information on the particle sizes at cloud top because the retrieved r_e represents a vertically weighted value which is dominated by the absorption at cloud top. Using near-infrared wavelengths with different absorption characteristics, this retrieval algorithm can be extended to provide r_e representative for different cloud altitudes. An extended retrieval technique based on Bayesian optimal estimation is employed to simultaneously retrieve the τ_c and particle effective radius at cloud top and cloud base ($r_\mathrm{e,t}$, $r_\mathrm{e,b}$). By assuming that r_e decreases with altitude, the profile of effective radius as a function of optical thickness in the cloud can be inferred. Additionally, the Shannon information content of spectral measurements is analyzed to characterize the wavelengths which adds the most information on the individual retrieval properties. Further, the optimal wavelength pair to be applied in the optimal estimation retrieval can be defined. The applicability of this method is tested for cirrus clouds above ocean measured during the ML-CIRRUS campaign. Solar radiation reflected by cirrus was measured by the Spectral Modular Airborne Radiation Measurement System (SMART) installed on board of the German HALO research aircraft. The comparison of the retrieved profile with the corresponding in situ measurements yields a deviation of about $4\,\%$ at cloud top and about $9\,\%$ at cloud base. This illustrates, that this technique can add information on the vertical cloud profiles which is needed to investigate microphysical processes in cirrus on larger scales by remote sensing.