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Retrieval of high altitude cirrus from Odin sub-mm observations

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Introduction

Clouds in the upper troposphere, in short cirrus, have a central role for the Earth's radiation budget. Climate studies require global observations and this is today achieved by using IR and optical satellite data. Clouds are detected basically by their scattering properties, and this effect is strong at these short wavelengths. Sub-mm sounding is a promising alternative to perform cirrus measurements [*Evans et al.*, 2002]. Cirrus is also here detected through scattering, but this effect is at these longer wavelengths less pronounced and retrieved properties represent to a much larger extent the cloud bulk properties than IR/optical data, that are mainly sensitive to the cloud top layer. In addition, the scattering is dominated by particles larger than 100 μm, and this size fraction constitute a larger portion of the ice mass than the particles sensed by an IR instrument [*Rydberg*, 2004].

The first two satellite sub-mm instruments for atmospheric research are Odin-SMR and EOS-MLS, where both sensors are limb sounders. Odin was launched 2001 and carries two instruments, SMR (Sub-Mm Radiometer) and OSIRIS (Optical Spectrograph and InfraRed Imaging System). Cirrus retrievals using SMR data are here presented, but also OSIRIS provides cirrus information, in the form of occurrence frequency of sub-visual clouds above 14 km [*Bourassa et al.*, 2004]. EOS-MLS is part of the Aura satellite, launched 2004. Cirrus is listed as a standard retrieval product for EOS-MLS and first such results have just been presented [*Jiang et al.*, 2004].

Results

A basic requirement to retrieve cirrus properties from the measurements is to have

available a sufficient detailed simulation model for the radiative transfer problem of concern, a forward model. To make rigorous simulations of sub-mm limb sounding into the troposphere, simultaneous treatment of scattering of thermal radiation, 3D spherical geometry and full polarisation is required, and we have been involved in the development of the first forward model combining these features [*Emde et al.*, 2004; *Eriksson and Buehler*, 2005]. This forward model is denoted as ARTS, and is used as the base for the Odin-SMR cirrus retrievals. A second scattering module has been added to ARTS [*Davis et al.*, 2004], and this part is presently used to validate the simpler radiative transfer scheme used for the EOS-MLS processing. It will be demonstrated that ARTS is capable of reproducing the effects of scattering seen in Odin-SMR spectra.

Depending on tangent altitude and spectroscopic situation, scattering can either lead to an increase or decrease of observed radiances, compared to the clear sky case. Higher brightness temperatures are mainly obtained when the optical thickness along the line-of-sight is low. For low tangent altitudes, when the region around the tangent point acts as a blackbody background, scattering at higher altitudes results throughout in a radiance depression (RD), and this feature was used in a first study on Odin-SMR cirrus retrievals, using the 501.8 GHz band [*Rydberg*, 2004]. In short, the relationship between the column of ice water (CIW) above about 10 km and RDs was determined by ARTS simulations, which allowed that CIW could be retrieved from derived RDs. No clear saturation in RD for high CIWs was detected, which indicates a high dynamical range of the retrievals. In addition to the overall RD signal, detection of thinner clouds was made more robust by considering also a scattering induced change in shape of measured spectra. Obtained cirrus distributions exhibited expected features, such as high occurrence rate and high CIW for the western Pacific area, and were in reasonable agreement the parallel OSIRIS cirrus detection.

The retrieval of CIW must assume the validity of some parameterisation of the particle size distribution (PSD). Several PSDs have been compared and were found to deviate strongly, especially for the lower temperatures found in the upper troposphere. The PSD of *McFarquhar and Heymsfield* [1997] was assumed, and the validity of this PSD constitutes the largest error source for the CIW retrieval, and the size of this error will be more closely studied. However, this problem is even more problematic for IR observations. The detection limit is presently estimated to 5-10 g/m^2. This value will be improved by the activities discussed below, but the present selection of assumed PSD most likely gives an underestimation of CIW values.

The impact of particle shape and orientation has also been investigated. For an instrument measuring either vertical or horizontal polarisation, as EOS-MLS, both particle shape and orientation affect significantly measured radiances, and thus these unknown

parameters must be added to the error budget. This issue is much less problematic for Odin-SMR. This is the case as Odin-SMR measures effectively the mean of vertical and horizontal polarisation and no ARTS simulations have so far shown any larger impact of particle shape and orientation on the radiance intensity.

In *Rydberg* [2004] clear sky radiances were calculated using climatological data. Information from ECMWF and Odin-SMR retrievals for higher altitudes will now be incorporated to improve the accuracy in determination of RDs. This will also allow that the technique is applied globally, and not only for tropical latitudes. The processing will further be extended to the second Odin-SMR band around 544.5 GHz, which will give ice columns above about 13 km, and thus then the 10-13 km CIW can be estimated by comparison between 501.8 and 544.5 GHz results. The possibility to use low optical thickness data will be investigated, but that will give a along-track resolution of about 300 km, instead of 150 km when using the RD approach. Obtained cirrus distributions and CIW will be compared to external data coming from OSIRIS, EOS-MLS and geostationary satellites.

Conclusions

A 3D polarised forward model for spherical geometry has been developed (ARTS), and this model has made it possible to rigorously study the impact of clouds on submm limb sounding data. This development is here used to perform cirrus retrievals using Odin-SMR data. Both occurrence frequencies of cirrus clouds and partial columns of ice water can be derived. This for two adjacent layers, with limits at about 10 km, 13 km and the tropopause. The retrievals represent fairly well the bulk properties of the clouds, and put emphasis on thicker cirrus clouds ($> 10\,\mathrm{g/m^2}$ above 10 km). This in clear contrast to previously used techniques, and thus new information on cirrus clouds can be provided. Data can already be provided for more than three years.

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