Chapter 7

Summary

The aim of the work presented here has been the development of a consistent radiative transfer model, which is able to consider emitted and scattered radiation from solar and terrestrial sources. To our knowledge, it is the first model, that is capable of limb modeling in ultraviolet, visible, near to far infrared, and microwave spectral region. The structure and principles of the radiative transfer model SARTre have been described.

The model calculates monochromatic intensity spectra for arbitrary observation geometries in a spherical shell atmosphere using the source function integration technique. Molecular optical properties are derived by a line-by-line algorithm for the calculation of high resolution molecular absorption cross sections, that has been adapted from the radiative transfer package MIRART. Optical properties of aerosols and clouds are taken from external databases. The modeling of multiple scattering is based on the assumption of a locally plane-parallel atmosphere. The incident radiation field is derived from DISORT.

SARTre has been verified by model intercomparisons to MIRART, KOPRA and ARTS in the mid-IR and to McSCIA in the ultraviolet spectral region. The verification of terrestrial radiative transfer has included the calculation and comparison of limb spectra under clear-sky and cloudy conditions. For the evaluation of the validity of the local planarity assumption concerning multiple scattering, radiance fields in and around the cloud, calculated by SARTre and ARTS, have been compared. SARTre has been found to yield accurate results for clouds with optical thickness $\tau \geq 0.1$. Solutions for subvisible ice clouds deviated by up to 10 % to the full spherical model ARTS.

For the verification of solar radiative transfer, UV limb scattering radiances have been compared. In general, single scattering contributions were found to agree within some tenth of a percent. When multiple scattering has been considered, deviations of up to several percent were observed. SARTre has performed well for simulations where ozone absorption dominates as well as for tangent altitudes below 25 km in case of conservative scattering. The pseudo-spherical approach reaches its limit at high tangent altitudes in strongly scattering atmospheres, when deviations of up to 6 % occur.

Regarding the use of a linear-in-τ approximation for the parameterization of the source function, which basically corresponds to a Trapez-Laguerre quadrature, the importance of linearity of individual quantities affecting the source terms became evident. Solar transmission as well as layer optical properties, that are essentially determined by both, molecular and particulate matter properties, were found to be prone to nonlinear behavior, when the optical path length of individual path segments is not small enough.

However, SARTre was found to be able to model limb emission and scattering measurements with sufficient accuracy for most of the examined cases and to be a reasonable fast model for simulations in the infrared and microwave spectral region. It is the first model, that allows to consistently investigate shortwave and longwave measurements, e.g. from MIPAS and SCIAMACHY on ENVISAT, with respect to advantages of concurrent multispectral data analysis on retrieval of atmospheric parameters.

SARTre has been used to study effects of cirrus clouds on infrared limb emission spectra. Sensitivity concerning a number of cloud parameters, e.g. cloud optical and geometrical thickness, cloud altitude, ice water path, particle size and shape, has been evaluated. Furthermore, the influence of uncertainty in tangent altitude as well as surface properties has been examined. It has been demonstrated, that the determination of cloud properties from a single spectral microwindow in the mid-IR is highly ambiguous. However, the use of several microwindows placed over a wider spectral range, e.g. the ice absorption band around 12 μm, has been proved to allow for the separation of effects from cloud optical thickness and particle size, that can hardly be separated in a narrow spectral interval. By deriving information about cloud optical thickness and particle size, it becomes possible to retrieve ice water path, that can not be measured directly in the infrared.

Based on the sensitivity study, cirrus cloud properties have been derived from a single MIPAS limb sequence taken over the Arabian peninsula. Spectra modeled by SARTre have been fitted to MIPAS spectra simultaneously for two subsequent limb measurements over three microwindows between $825\,\mathrm{cm}^{-1}$ and $1230\,\mathrm{cm}^{-1}$. Even without a sophisticated retrieval algorithm, it was possible to fit simulation and measurement close to measurement accuracy in the continuum signal as well as for the molecular absorption lines, e.g. of H_2O.

The ice water path of the cloud, observed by the examined MIPAS measurement, was found to be extremely low ($0.1\,\mathrm{g/m}^2$). With an optical thickness of 0.008 in the mid-IR, the cirrus cloud causes a significant enhancement of the continuum signal in limb spectra, but can hardly be detected from infrared nadir or slant measurements. Although the optical thickness of the cloud is higher in the visible spectral region ($\tau \simeq 0.02$), it is still too thin to be observed by nadir looking instruments. This conclusion matches with MODIS and MERIS data, that did not detect cirrus clouds over that area.

A validation of SARTre retrieved cloud properties was not possible due to the lack of proper in-situ data. Cirrus cloud properties have not been acquired yet by in-situ measurements, neither in parallel to MIPAS overpasses, nor to MIPAS-B flights or TES measurements.

A joint ballone-borne mission of MIPAS-B and TELIS, a platform of three sub-millimeter and Terahertz instruments, is planned for near future. Analyzing data from cirrus cloud observations of this mission will be an interesting and challenging task, that can be addressed by SARTre. It will provide the opportunity to simultaneously study cirrus effects in the infrared and microwave spectral region. Retrieving cloud properties separately from MIPAS-B and TELIS measurements will allow for cross-validation of the results. Consistency in derived cloud properties may greatly support confidence in SARTre modeling results. In addition to that, MIPAS-B and TELIS data may be used for examining synergy effects from microwave and infrared cloud measurements.

In conclusion, SARTre has been shown to be an appropriate tool for the remote sensing of ice clouds from infrared limb measurements.