An Advanced Cloud Product for the Interpretation of Tropospheric Data from GOME and SCIAMACHY

A contribution to subproject TROPOSAT

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Introduction

This study focuses on the determination of cloud properties (e.g. effective cloud fraction and average cloud to height) from satellite observations and on the quantification of the corresponding cloud influence on tropospheric trace gas products derived from satellites. The investigations first concentrate on GOME and will later also be applied to SCIAMACHY on ENVISAT.

The most dominant effects of clouds are (a) that they shield the atmosphere below the cloud cover and (b) that their albedo is typically significantly larger compared to the earth's surface. Because of these effects the determination of quantitative tropospheric trace gas products depends strongly on the knowledge of cloud properties.

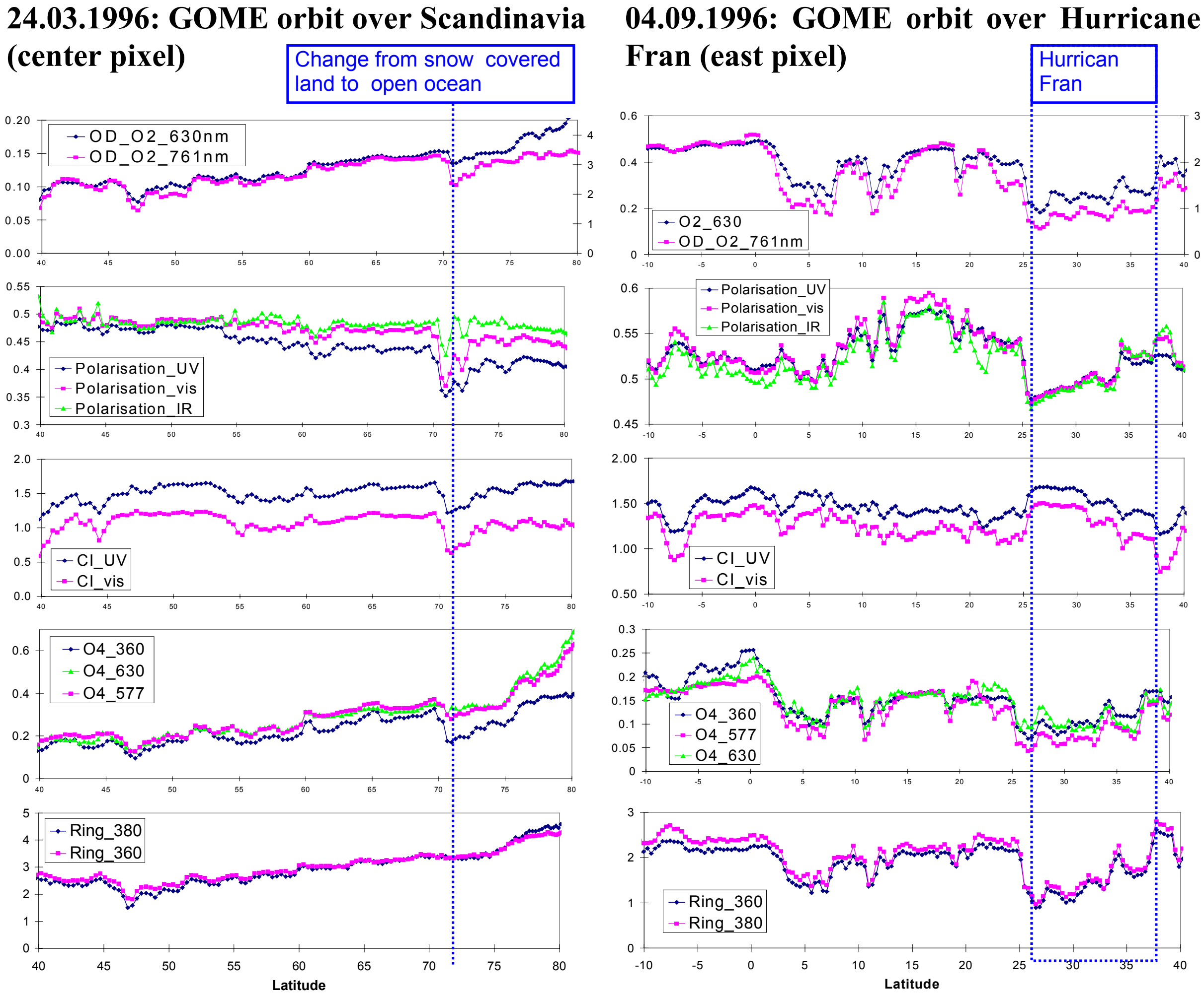
Already existing cloud algorithms are based on spatially resolved intensity measurements (Polarisation measurement devices, PMD, see ESA (1995)) as well as on the determination of the optical depth of the O_2-A-band (see e.g. Kuce and Chance (1994), Kjoelemeijer and Stammes, 1999). However, both quantities show important shortcomings, especially over snow and ice surfaces, which strongly limit their applicability.

A new set of cloud sensitive parameters

Already existing cloud algorithms (like ICFA, CRAG, PCRA, OCRA, FRESCO, etc., see ESA (2000) and references therein) are based on the analysis of the PMD measurements and the analysis of the O_2-A absorption (or a combination of both). However, these algorithms become insensitive over snow and ice surfaces. The O_2-A-band absorption is also affected by saturation effects. In this study we investigate a large variety of cloud sensitive parameters measured by GOME. Besides the 'traditional' cloud sensitive parameters mentioned above we also make use of the polarisation of the measured light and in particular of various absorption bands of the oxygen dimer O_4 (at 360, 380, 477, 577, and 630 nm (Greenblatt et al., 1990, Wagner et al., 2002)) as well as the filling-in of the solar Fraunhofer lines by inelastic Raman scattering (Ring effect (Grainger and Ring, 1962; Joiner and Barthia, 1995)). We demonstrate that several of these quantities are well suited for the characterisation of clouds, especially over snow and ice covered surfaces. One aim of our study was to investigate the principle suitability of different cloud sensitive parameters for the detection of clouds. For that purpose we selected GOME observations over the extended cloud cover of the hurricane Fran (Figure 1, right). The suitability of all selected parameters is expressly demonstrated by the synchronous changes of their values across the hurricane. In a second study we investigated the sensitivity of the selected measurements for changes of the ground albedo (Figure 1, left). It turned out that most of the measurements are very sensitive to changes of the ground albedo. However, in particular the Ring effect and the O_4 absorption at 630 nm show nearly no sensitivity to such changes. From these findings it seems to be possible to discriminate bright clouds from a bright ground surface using a suitable combination of different cloud sensitive parameters.

Table 1 Overview over cloud sensitive parameters and their dependencies on different scattering processes.

Cloud sensitive Parameter	Depending on
O_4-absorption 630 nm	Clear view down to the ground
O_4-absorption 360 nm	Clear view down to the ground ground albedo
Colour Index	Ratio of Rayleigh-scattered light to Mie-scattering and ground reflection
Polarisation	Ratio of single Rayleigh scattered light to total intensity
Ring effect	Ratio of Raman scattered light to total intensity
O_2-absorption 630 & 760 nm	Clear view down to the ground



24.03.1996: GOME orbit over Scandinavia (center pixel)

04.09.1996: GOME orbit over Hurricane Fran (east pixel)

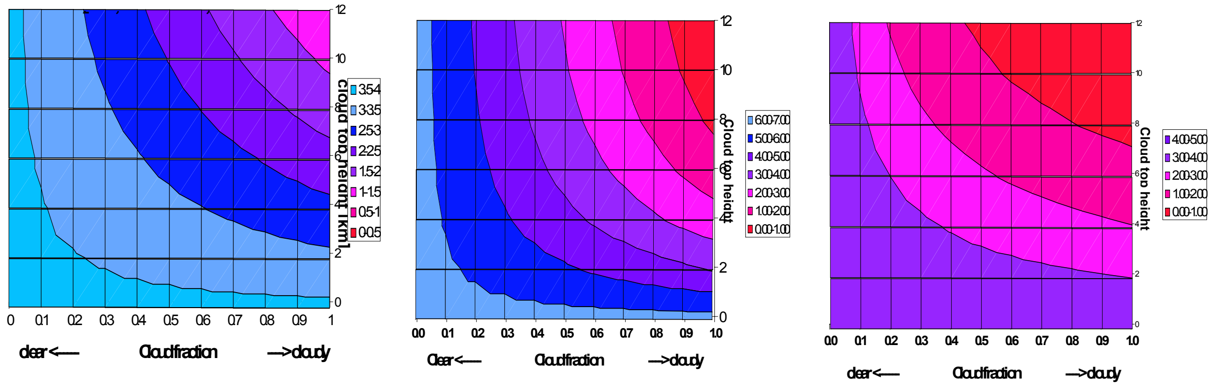
Figure 1 Dependence of different cloud sensitive quantities on the vertically extended cloud of the tropical hurricane Fran (right) and on the strong change of the ground albedo from open ocean to snow covered ground (left). All quantities show a strong sensitivity towards clouds. However, while several quantities are also sensitive to the ground albedo, in particular the Ring effect and the O_4 absorption at 630 nm show no or only a weak dependence on the ground albedo.

Case Study: Cloud fraction over snow and ice from combined O_2 and O_4 absorptions

In a first attempt we investigated in detail the different dependencies of O_4 and O_2 absorptions on cloud top height and cloud cover. The absorptions of O_2 and O_4 at the same wavelength (630 nm) show different dependencies on the cloud top height because of the different profile shapes of atmospheric O_2 and O_4. Also the O_4 absorptions at different wavelengths (360 and 630 nm) show different dependencies on the cloud top height because of the different strength of multiple scattering (strong wavelength dependence of Rayleigh scattering). From the simultaneous observations of the O_4 bands at 360 and 630 nm as well as the O_2 band at 630 it should thus be possible to separate the effects of varying cloud fraction and cloud top height.

We modelled the respective sensitivities on average cloud top height and effective cloud cover; the results (expressed as air mass factors, AMF) are shown in Figure 2.

For a given GOME measurement we then compared the O_4 absorptions at 360 and 630 nm as well as the O_2 absorption at 630 nm to the modeled values. The cloud fraction and top height of the model scene with the best agreement to the measurements was then regarded as the cloud properties of the measurement.



O_2, 630 nm **O_4, 630 nm** **O_4, 360 nm**

Figure 2 Dependence of the Air mass factors for O_2 and O_4 on the effective cloud fraction (x-axis) and average cloud top height (y-axis). The AMFs are calculated with the Mote Carlo radiative transport model AMFTRAN (Marquard et al., 2000) for a ground albedo of 80% and a solar zenith angle (SZA) of 80°.

For our first case study we selected GOME measurements north of Spitsbergen at 03.04.1998. For these observations the SZA was close to 80° and the earths surface was covered by snow and ice. For two selected measurements (marked in Figure 3) the differences between measurements and model results are plotted as function of cloud fraction and cloud top height (Figure 4). For case A a cloud fraction of about 60% and a top height of about 4 km were found; for case B a cloud fraction of about 90% and a cloud top height of about 2 km.

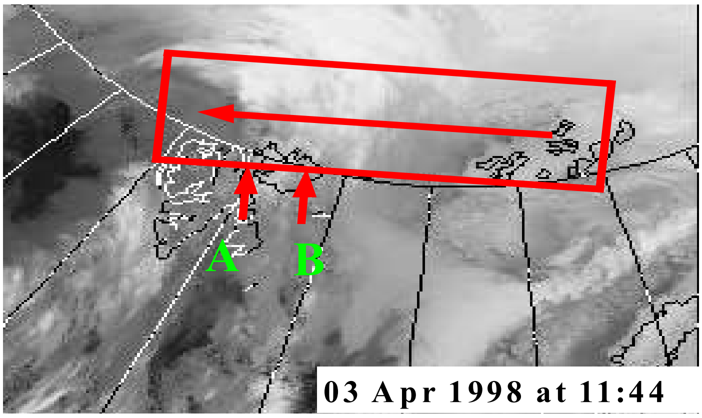


Figure 3 IR satellite image (11.5-12.5µm) for the region around Spitsbergen. The red Rectangle indicates the location of the GOME center pixels of Orbit 80403140. Arrows indicate the longitude of two selected observations.

The images are obtained via the Dundee Satellite Receiving Station, Dundee University, Scotland (http://www.sat.dundee.ac.uk/).

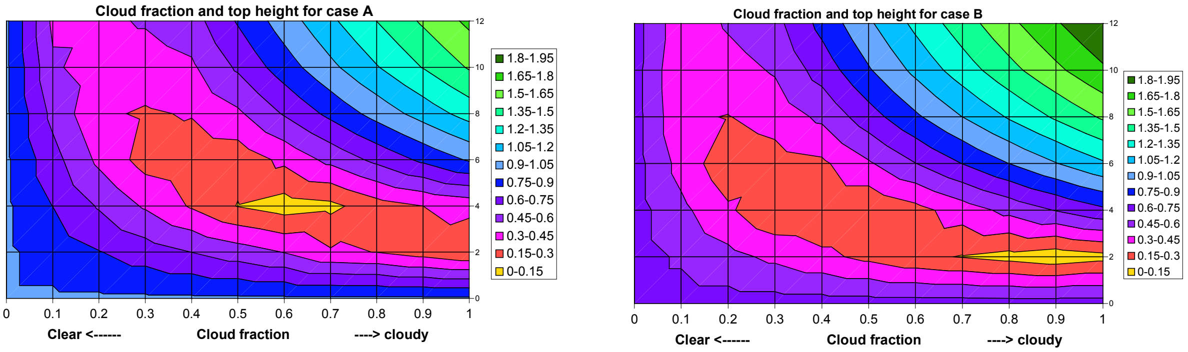


Figure 4 Dependence of the Air mass factors for O_2 and O_4 on the effective cloud fraction (x-axis) and average cloud top height (y-axis). The AMF are calculated

Conclusions

We investigated several cloud sensitive parameters for different atmospheric conditions and over different surface albedos. We found that in addition to the existing cloud algorithms a variety of cloud sensitive parameters can be used in order to derive more accurate cloud properties from satellite observations. More detailed information on cloud properties is highly desired for the determination of tropospheric trace gases from space.

We developed a prototype cloud algorithm for polar regions which utilizes different O_2 and O_4 absorptions in the GOME spectra. From our modeling results and a first case study we conclude that it should be possible to retrieve cloud fraction and cloud top height even over areas with high ground albedo. It will thus in the future be possible to analyse tropospheric trace gas measurements from satellite for polar regions in a quantitative way. This is of special importance for the interpretation of events of high boundary layer concentrations of BrO during polar spring. Future activities will include the validation of the new cloud algorithm and possible extension using measurements of the Ring effect. The algorithm can be easily adapted to nadir observations of SCIAMACHY on ENVISAT.

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