Detection of PSC types in limb infra-red emission spectra from remote sensing satellite instruments

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ABSTRACT: Differentiation of polar stratospheric cloud (PSC) types is in principle possible based on their characteristic infra-red spectral features but this has until recently proved to be a challenging task. A new analysis of observations by the CRISTA instrument during the Antarctic winter of 1997 has shown evidence for characteristic spectral features of PSCs in spectra of the atmosphere measured between 5 and 15 µm. Comparisons with radiative transfer calculations using a compiled database of refractive indices for PSC particles, in conjunction with trace gas measurements by CRISTA and microphysical models, show that the classification of different PSC type spectra (NAT, STS and Ice) could be possible. The features are clear enough to facilitate a fast and simple detection of cloud types on a global basis. Results are shown here for the CRISTA 1997 measurements. A preliminary identification of the same PSC signature is also shown in a spectrum for MIPAS on ENVISAT.

Key Questions

For the Antarctic/Arctic PSCs the following items are still not completely understood [e.g.: *Tolbert and Toon*, 2001] :

- Formation mechanism of NAT
- Denitrification by large NAT particles and in particular the occurrence and formation of NAT rocks
- Existence of a polar freezing belt

Therefore differentiation of PSC types from space is quite important. In addition the monitoring of the cloud coverage is essential for better understanding and quantification of the denitrification in both polar vortices as well as its effect on ozone recovery [*Tabazadeh et al.*, 2000].

Toon and Tolbert [1995] have shown that it is possible to detect PSCs spectroscopically and inferred the presence of non-NAT particles from infra-red spectral observations. However the data had large errors whereas CRISTA offer an excellent signal-to-noise ratio.

Investigation using CRISTA, which measures infra-red spectra with a resolution of 2 cm^{-1}, are restricted to the southern hemisphere (SH) only, but the intention was to develop a robust cloud detection and classification methods for CRISTA and future instruments like MIPAS on ENVISAT or TES and HIRDLS on EOS-Aura.

CRISTA cloud detection

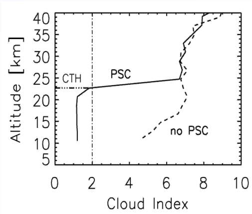
Spang et al. [2001, 2002] have verified a simple and robust approach for cloud detection by using the ratio of radiances in the 788–796 cm^{-1} range, dominated by CO_2, and the 832–834 cm^{-1} regions, dominated by aerosol and cloud emissions.

Fig.1 shows examples of this so-called Cloud Index (**CR-CI**) profiles. A threshold value defines cloud detection height:

Cloud:

$CI<2 \Leftrightarrow \varepsilon = 0.2–5 \cdot 10^{-2}\ km^{-1}$

Very thin cloud: 2 < CI < 4



A characteristic spectral PSC feature

Model line-by-line calculations in conjunction with Mie-calculations using a database of all currently published refractive indices give no indication for strong spectral feature characteristics of PSC types. In contrast we found a relative sharp spectral feature in the atmospheric spectrum around 820 cm^{-1}. Figure 2 shows the two typical classes: with radiance enhancement (**RE**) and without enhancement (**NRE**).

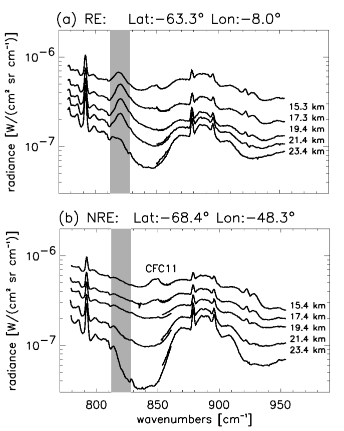


Fig. 2: CRISTA spectra in the the south polar vortex at subsequent heights steps (23 km to 15 km) with and without the obvious spectral signature around 820 cm^{-1} (shaded area).

Laboratory and modelled data

The refractive indices (imaginary part) in figure 3 shows that a number of possible Type 1 particles have spectral absorption signatures around 820 cm^{-1} due to the ν_2 band of NO_3^- (STS, binary solutions of HNO_3 and H_2O, the meta-stable α-NAT, β-NAT, and nitric acid di- and mono-hydrate abbreviated NAD and NAM respectively). The signature is definitively not related to ice (not shown).

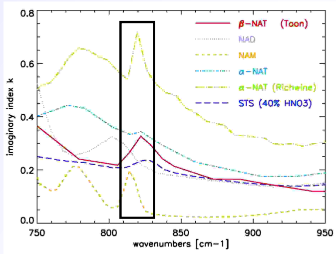


Figure 3: Refractive indices from the MAPSCORE database (see references)

Mie-calculation over a wide range of possible size distribution parameter show, that only β-NAT and STS with high HNO_3 concentration (weight percentages > 40%) were able to produce a significant enhancement in the investigated wavelength region.

Definition of an cloud type indicator

To quantify the percentage of spectra with enhanced radiation, an additional radiance ratio was developed to identify the new PSC spectral feature in a more sensitive way. The ratio of the mean radiances around the strong CO_2 emission used in CR-CI divided by the radiances in the 819-821 cm^{-1} range is a simple and effective indicator for the enhancement. This is illustrated by the obvious separation in the scatter-plot in Figure 4.

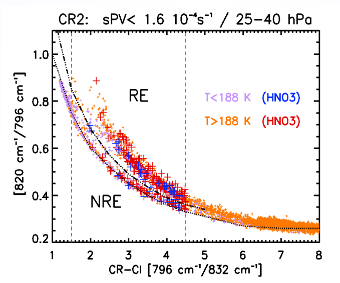


Fig. 4: CRISTA cloud index (CR-CI) versus the radiance ratio indicating the the spectral feature at 820 cm^{-1}. Only inner vortex observations are taken into account. The separation is highlighted by the thick black dash-dotted curve. The grey dashed vertical lines represents cloudy but not optical thick conditions. The colouring relates to temperature and if HNO_3 is retrieved.

Horizontal distribution of cloud types

The classification in different types of spectra (RE, NRE and optically thick), which corresponds to different PSC types, allows one to monitor the evolution of the PSC coverage during the CRISTA period (Fig.5). The two areas of optically thick clouds (green), whereby one dissolves during the mission, are surrounded by the RE (red) and NRE (blue). The RE clouds are especially located downstream of the thick clouds. The location of the thick clouds corresponds to the minima in temperature field (T<190 K),

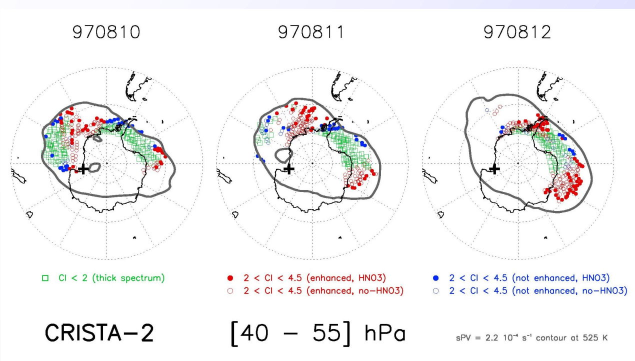


Fig. 5: SH projection from 40°S to the pole of different cloud types (RE, NRE, optically thick). CRISTA observations are restricted north of 74°S. Cloud events with corresponding retrieved HNO3 values are marked by filled circles.

Differentiation between NAT and STS

The HNO_3-temperature relation is strongly related to the PSC composition. The results in Fig. 6 show a strong preference that RE events corresponds to NAT and NRE events to STS. Uncertainties of the input parameter for the thermodynamical model are taken into account (T, H_2O, and HNO_3).

The model predicts a significant amount of volume densities (which corresponds to an enhancement in the spectra) for NAT at higher temperatures than for STS. In conclusion NAT should be traceable and is observed at higher temperatures.

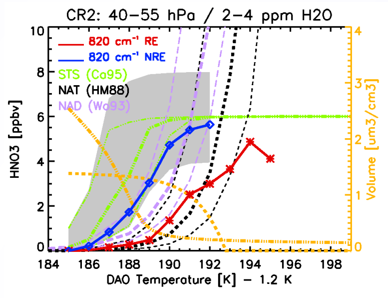


Fig. 6: Mean CRISTA HNO3 mixing ratios with/without enhancement (red/blue see also Figure 5) as a function of GSFC Data Assimilation Office (DAO) temperature. Temperatures are reduced by a 1.2 K warm bias of the meteorological analysis [*Spang et al.*, 2001]. Model curves are plotted for a range in H_2O, for STS also for a range in HNO_3 (grey). Volume densities for NAT (dashed) and STS (dash-dotted) are superimposed.

PSC spectra from MIPAS on Envisat

The MIPAS instrument, a Michelson interferometer with a spectral resolution of 0.025 cm^{-1}, was successfully launched on ENVISAT on the 1st of March 2002. First 4 orbits of preliminary spectra are available to ESA expert teams. The cloud detection method works successfully for MIPAS. Some of the profiles in the Antarctic vortex show clear but relatively weak indications for RE type spectra (Figure 7).

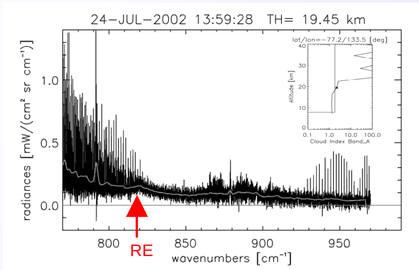


Fig. 7: Part of MIPAS band A spectrum in south polar vortex. The same spectrum with a reduced spectral resolution similar to CRISTA (~2 cm^{-1}) is shown in grey. The corresponding cloud index profile is also superimposed.

Conclusions

- CRISTA IR-spectra allow an easy (fast) cloud detection on an excellent statistical basis.
- A very pronounced spectral feature at 820 cm^{-1} (NAT or STS) is found in atmospheric spectra of Antarctic PSCs.
- Separation in cloud indices suggests a separation in two cloud types.
- Thermodynamical model results in conjunction with HNO_3 measurements give strong evidence for NAT than STS (for particles r < 1 µm).
- MIPAS cloud detection is working in a similar manner to CRISTA. Cloud type differentiation will be possible.
- Near real time information on clouds would be valuable for campaign activities like Vintersol and could be easy to establish.

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References:

Refractive index database compiled for MAPSCORE: www.msf.rl.ac.uk/eumaps/internal/mapscore_data.htm (see references).

Spang, R., et al. CRISTA-2 observations of the south polar vortex in winter 1997: A new dataset for polar process studies, *Geophys. Res. Lett., 28*, 3159-3162, 2001.

Spang, R., et al., CRISTA observations of cirrus clouds around the tropopause, in press, *J. Geophys. Res.*, 2002.

Tabazadeh, A., et al., Quantifying denitrification and its effect on ozone recovery, *Science, 288*, 1407-1411, 2000.

Toon, O.B., and M.A. Tolbert, Spectroscopic evidence against nitric acid trihydrate in polar stratospheric clouds, Nature, 365, 218-221, 1995.

Tolbert, M.A., and Toon, O.B., Solving the PSC Mystery, Science, 292, 61-63, 2001.

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