# BROADBAND_CLOUDS: A TOOL FOR 2D REPRESENTATION OF CLOUDS IN MIPAS/ENVISAT SCENARIO, DESCRIPTION AND APPLICATIONS.

E. Castelli[1], B.M. Dinelli[1], M. Carlotti[2], M. Ridolfi[2], E. Arnone[2] and E. Papandrea[2]

[1] ISAC-CNR Istituto di Scienze dell'Atmosfera e del Clima – CNR, Bologna, Italy
[2] DCFI - Dipartimento di Chimica Fisica ed Inorganica, Bologna, Italy

*mail to : e.castelli@isac.cnr.it*

**Abstract.** The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS), operating on-board ENVISAT, is a limb sounding Fourier Transform spectrometer for the measurement of high-resolution gaseous emission spectra. Studies on MIPAS data have demonstrated its sensitivity to the radiation emitted from the clouds.
The GMTR forward model has been used to create a self-standing Broad Band (BB) forward model (capable to simulate extended spectral regions). We have introduced into the BB forward model the capability to model the effects of cloud contamination into MIPAS spectra (BB_Clouds). Exploiting the 2D approach, the cloud is no longer represented as an infinite cloudy shell, but it is characterized by both a vertical and a horizontal extension. BB_Clouds has been used to assess the possibility to retrieve cloud extension and other parameters from MIPAS spectra. The developed algorithm and the results of the tests performed are presented and discussed.

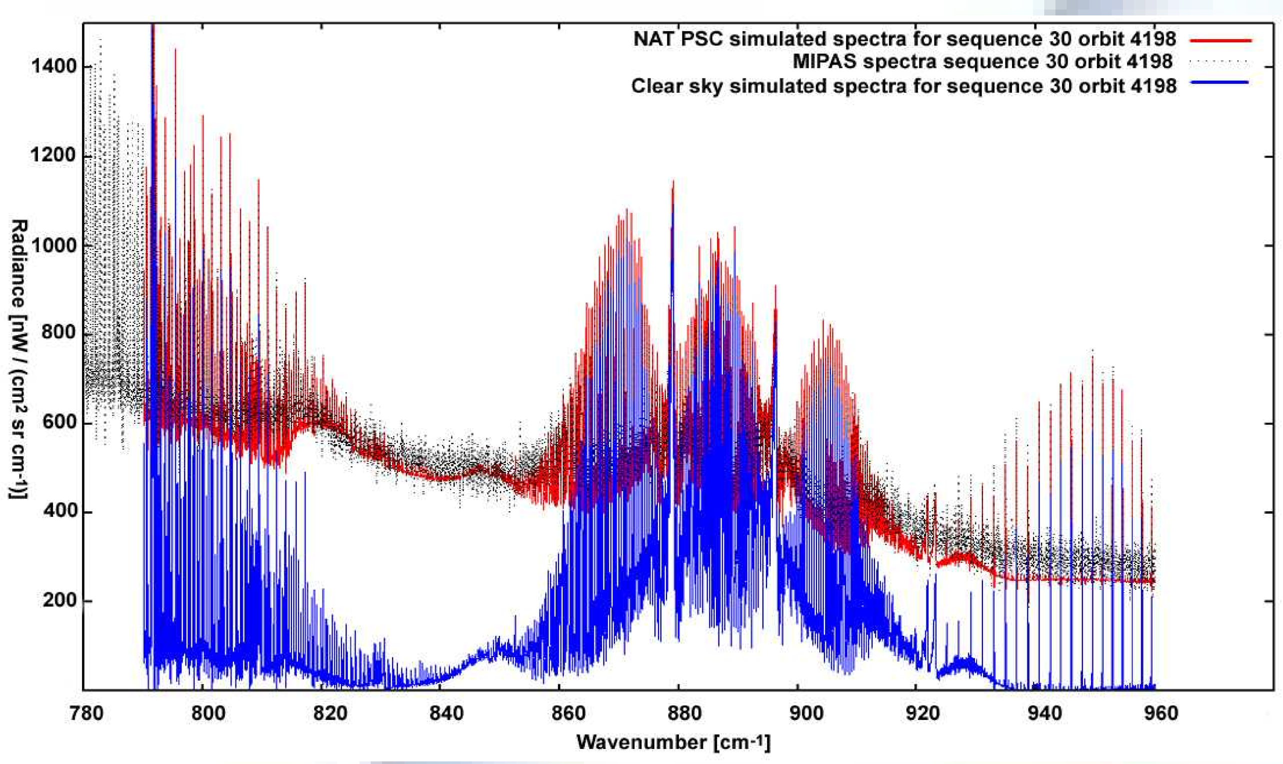
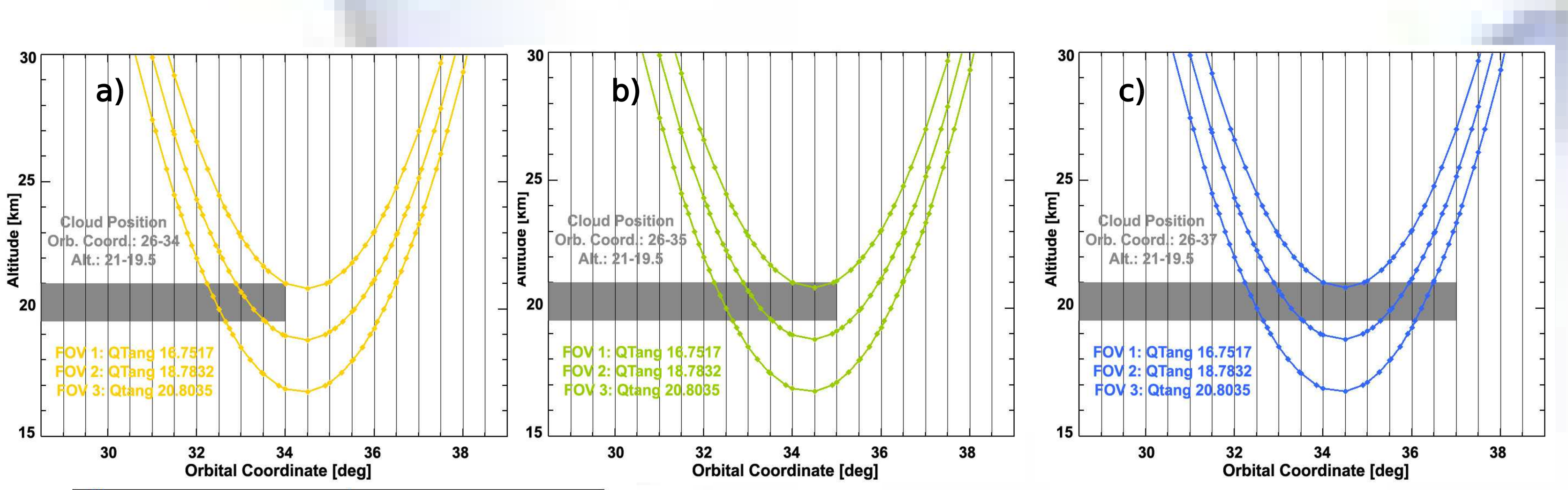
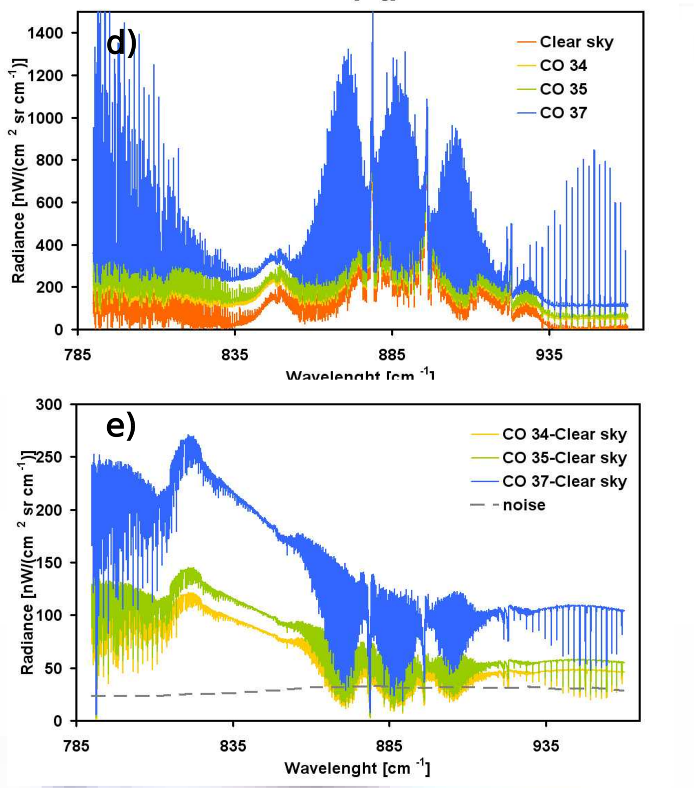



***Figure 1: Cloud contaminated MIPAS measurement (dotted) versus clear sky simulated spectra (blue) and BB_Clouds simulation of PSC cloud (red) at 18.5 km tangent altitude, scan 30 orbit 4198 (2002/12/19).***

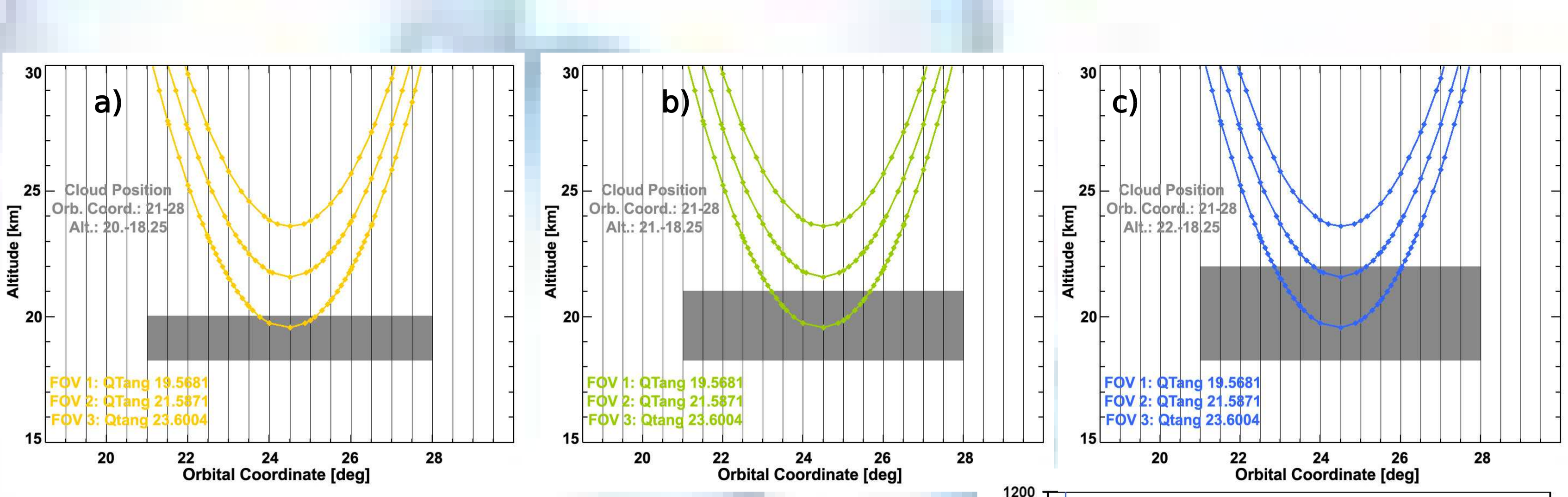
**1. Algorithm description.** The GMTR retrieval system [Carlotti et al., 2006] is an open source code specifically designed for MIPAS measurements. The GMTR adopts a 2-D discretization of the atmosphere, dividing the atmosphere into "cloves", i. e. sectors of atmosphere that are delimited by consecutive altitude levels and extensions of the earth radius at constant latitude step, enabling to model horizontal atmospheric inhomogeneities. The BB_Clouds forward model has been created, using as starting point the GMTR internal forward model, in order to simulate cloud contamination into MIPAS/ENVISAT spectra. In a cloudy atmosphere, BB_Clouds represents the cloud as an ensemble of cloudy cloves.
Cloud scattering and absorption parameters (namely absorption, scattering and extinction coefficients and the Phase Function) are calculated by the Fortran subroutine for Mie scattering calculation proposed by Mishchenko [2002] starting from input parameters like particle radius, distribution, number density, real and imaginary part of refraction index, frequency.
These parameters are used to model the cloud into the scalar radiative transfer equation that is used in single scattering approximation for unpolarized light. The contribution given by the Scattering Source Function (SSF) is computed using the incoming radiances calculated in a 1D spherical shell atmosphere neglecting SSF as in Höpfner and Emde [2004].
The assessment of single scattering performances versus multiple scattering in a limb view-IR forward model has been extensively examined in Höpfner and Emde [2004]. The article highlights that for optically thin (in limb direction) clouds, such as Polar Stratospheric Clouds (PSC) or subvisible cirrus, the single scattering approach differs by only few percent from the multiple scattering.

The BB_Clouds forward model has been validated using results from Höpfner and Emde [2004] in a 1D atmosphere.
An example of BB_Clouds performances is presented in figure 1 where cloud contaminated measurements versus clear sky spectra and BB_Clouds simulation of PSC cloud are reported.




**2. Sensitivity to cloud horizontal extension and to Cloud Top Height (CTH).** In real MIPAS measurement scenario, clouds often only a fraction of the entire FOV.
The BB_Clouds algorithm, exploiting the GMTR approach that divides the atmosphere into cloves, allows the treatment of horizontally partially cloud filled FOVs. The calculation of scattering and absorption properties can be properly performed only for cloves marked as cloudy. Spectra simulated with horizontally cloud filled FOVs as in figures 2a to 2c are reported in figure 2d. It can be noticed that simulated spectra show high sensitivity (difference between cloudy and clear sky spectra higher than the corresponding measurement noise as in figure 2e) to variations of the cloud horizontal position; actually radiance values increasing with the FOV fraction occupied by the cloud.
For the MIPAS instrument, the angular distribution reproducing the vertical FOV, can be modelled with a trapezium centred around the tangent altitude of the geometry. In order to model the effect of a partially vertically filled FOV (e.g. with the upper pencil beam looking above the cloud as in figure 3) the convolution of the FOV angular distribution with cloudy and clear sky spectra has been exploited. Spectra simulated with a vertically cloud-filled FOV as in figures 3a to 3c are reported in figure 3d. Also in this case, simulated spectra show high sensitivity to variation of CTH. The difference between cloudy and clear sky spectra, reported in figure 3e, is higher than the corresponding measurement noise for cases 3b and 3c. Only for case 3a, where only a minor fraction of FOV is occupied by the cloud, the difference between cloudy and clear sky spectra shows no sensitivity to cloud with respect to the corresponding noise .
The possibility of modelling a partially filled FOV not only improves the forward model accuracy, but can also be used to obtain information about the CTH.



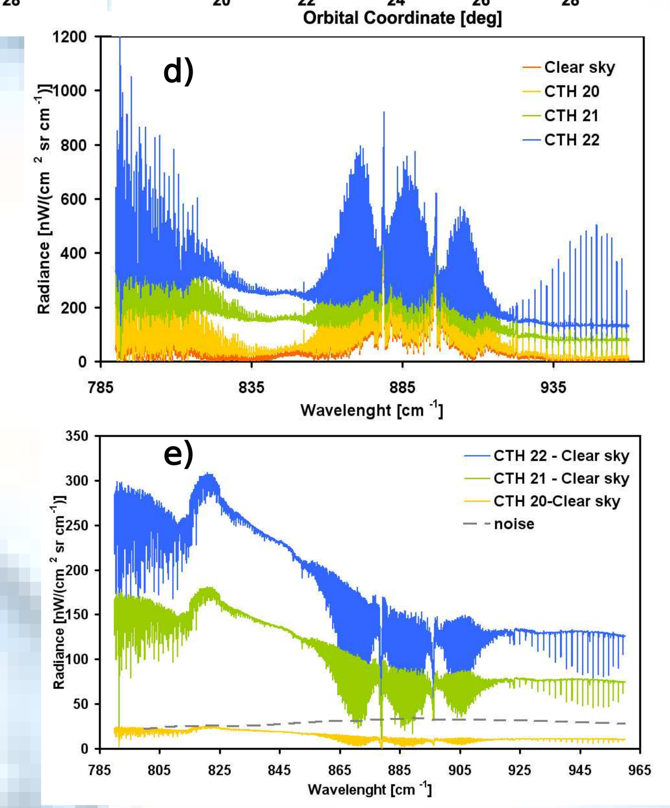




***Figure 2: Panels a)-c) Different horizontal cloud positions and BB_Clouds ray tracing (for tangent altitude 18.7 km) in the altitude/latitude domain. Simulated spectra in panel d) are obtained through the convolution of MIPAS FOV function with spectra calculated for the three pencil beams (named FOV 1, FOV 2, FOV 3 in panels a)-c)). Panel d) BB_Clouds simulated spectrum for different cloud (same PSC used for figure 1) horizontal positions. Panel e) Differences between simulated spectrum in cloudy and clear sky conditions. The noise level for MIPAS sweep 13 scan 31 orbit 4198 is also reported with a dashed line.***

***Figure 3: Panels a)-c) Different cloud top positions and BB_Clouds ray tracing in the altitude/latitude domain for tangent altitude 21.6 km. Simulated spectra in panel d) are obtained through the convolution of MIPAS FOV function with spectra calculated for the three pencil beams (named FOV 1, FOV 2, FOV 3 in panels a)-c)). Panel d) BB_Clouds simulated spectra for different cloud (same PSC used for figure 1) top height positions. Panel e) Differences between simulated spectrum in cloudy and clear sky conditions. The noise level for MIPAS sweep 12 scan 29 orbit 4198 is also reported with a dashed line.***

**3. Applications.** Tests performed with our analysis system have shown that the highest cloudy measurement into a MIPAS limb scanning sequence (detected using the Cloud Index (CI) method, [Remedios and Spang, 2002]) can be used for CTH retrievals. Three spectral intervals (called MircroWindows (MWs)) are used for the retrieval depending on cloud composition (water/ice clouds or PSCs). Such MWs are chosen in order to minimize the interference of cloud composition into CTH retrieval. The atmospheric fields used in the retrieval should be as close as possible to the real ones. Therefore MIPAS2D database data, obtained through the application of GMTR retrieval system to the whole MIPAS mission (see poster by Papandrea et al.: ANALYSIS OF REDUCED RESOLUTION MIPAS MEASUREMENTS WITH THE 2D TOMOGRAPHIC GMTR SYSTEM - MIPAS2D), are integrated with the IG2 atmosphere used into the MIPAS level 2 operational analyses for molecules not present in the MIPAS2D database, and with temperature and pressure extracted from ECMWF operational data.
The CTH is found through a Gauss-Newton iterative procedure where the solution is found using the least square method.
Self consistency tests as well as comparison with the POAM instrument [Bevilacqua et al., 2002] have provided an indication of a general correct behaviour of CTH retrievals using BB_Clouds. As an example of application we consider the retrieved CTH and the nearby located POAM extinction profile in the case of the PSC event presented in Figure 4b (time delay 3 h, distance 500 km as in Figure 4a).

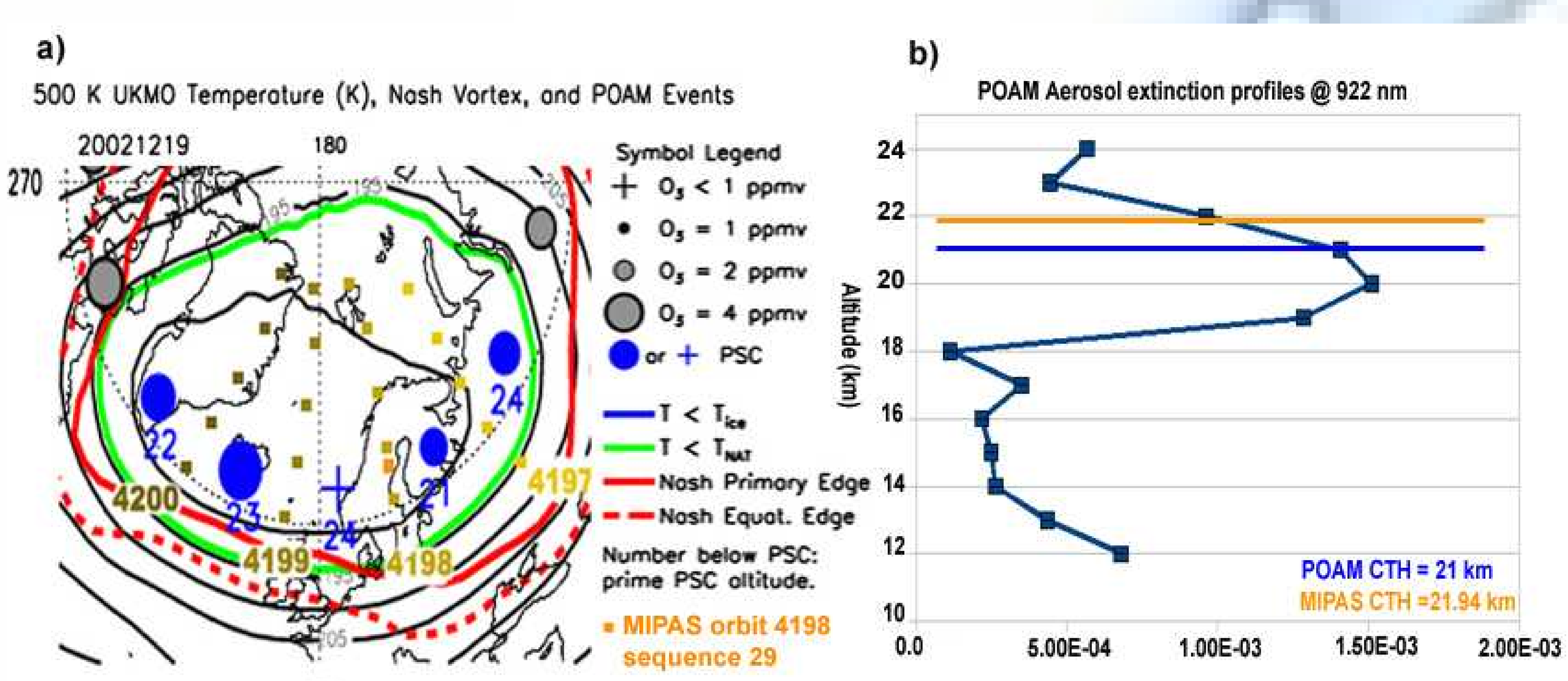



***Figure 4: Panel a) Position of POAM measurements and MIPAS scan 29 orbit 4198 (2002/12/19). Time delay is 3 h, and displacement distance 500 km. Panel b) Aerosol extinction profile at 922 nm from POAM measurements, CTH position from POAM and MIPAS measurements retrieved by BB_Clouds.***
***BB_Clouds retrieval is performed using the 3 MWs: 832-834 $cm^{-1}$, 940-950 $cm^{-1}$, 1295-1300 $cm^{-1}$. In order to minimize errors on CTH, some tests over a broad range (790-960 $cm^{-1}$) have been conducted in order to determine cloud phase and particle radius that best match the real cloud characteristics.***

**4. Conclusions and Future work.**
The BB_Clouds forward model, exploiting the 2D-GMTR approach, allows finite cloud modelling: the cloud is no longer represented as an infinite cloudy shell, but it is characterized by both a vertical and a horizontal extension, therefore with a more realistic description.
Tests performed with the forward model have highlighted a sensitivity to both cloud horizontal and vertical extension. The sensitivity to vertical cloud extension has been exploited to perform CTH retrievals both on simulated and real data.
Further tests using coincident products from Terra MODIS, MSG SEVIRI and AVHRR will be carried on in order to validate BB_Clouds CTH retrievals and to analyse the forward model potentialities due to system sensitivity to horizontal cloud extension.

**5. References.**
Bevilacqua , R. M., Fromm, M. D., Alfred, J. M., et al., 2002: Observations and analysis of polar stratospheric clouds detected by POAM III during the 1999/2000 Northern Hemisphere winter, J. Geophys. Res., 107(D20), 8281, doi:10.1029/2001JD000477.
Carlotti M., G. Brizzi, E. Papandrea, M. Prevedelli, M. Ridolfi, B. M. Dinelli, and L. Magnani, 2006:GMTR:Two-dimensional geo-fit multitarget retrieval model for Michelson Interferometer for Passive Atmospheric Sounding/Environmental Satellite observations; Appl. Opt.45, 716-727.
Höpfner,M. and Emde, C., 2004: Comparison of single and multiple scattering approaches for the simulation of limb–emission observations in the mid–IR, J. Quant. Spectrosc. Radiat. Transfer, 91, 275–285.
Mishchenko, M. I., Travis L. D., and Lacis A. A., 2002: Scattering, Absorption, and Emission of Light by Small Particles, Cambridge Univ. Press.
Remedios J.J. And Spang R.,2002: Detection of cloud effects in MIPAS spectral data and implications for the MIPAS operational processor,Proceedings of the ENVISAT calibration review, 9-13 September 2002, ESA-ESTEC, Noordwijk, the Netherlands.