A-band retrievals of cloud height: a brief overview

Alexander Marshak (GSFC)

Concept

from Stephens et al. (2005)

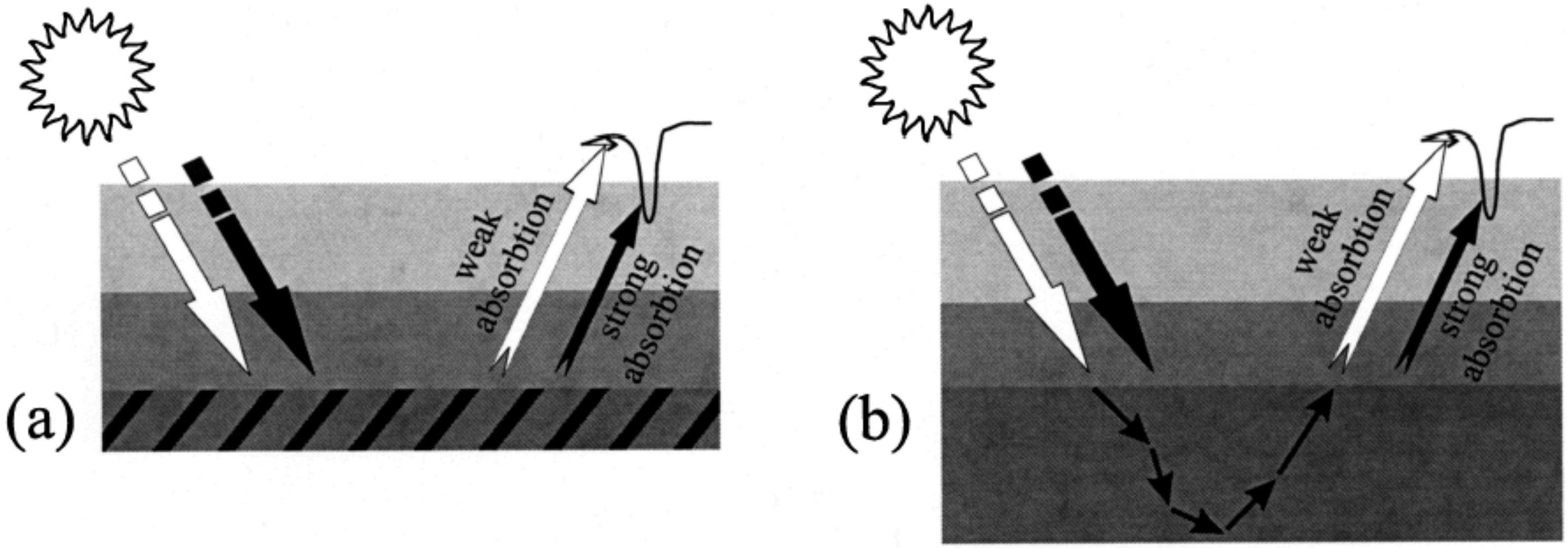


Fig. 13.3. (**a**) Geometry for the problem of absorption by a gaseous atmosphere overlying a reflecting surface; (**b**) as in (a) but for the case of a gaseous atmosphere overlaying and imbedded in a scattering layer

The depth of O2 absorption depends on the amount of absorber above the cloud; hence, the cloud-top pressure can be retrieved

POLDER

from Ferlay et al. (2010)

- spatial resolution of about 20 km;

- A-band: 10 nm (narrow) band centered at 763 nm and 40 nm (wide) centered at 765 nm);

- uses ratio I_{narrow}/I_{wide};

- gets apparent pressure;

- corrects it for surface;

- doesn't account for absorption inside the cloud layer.

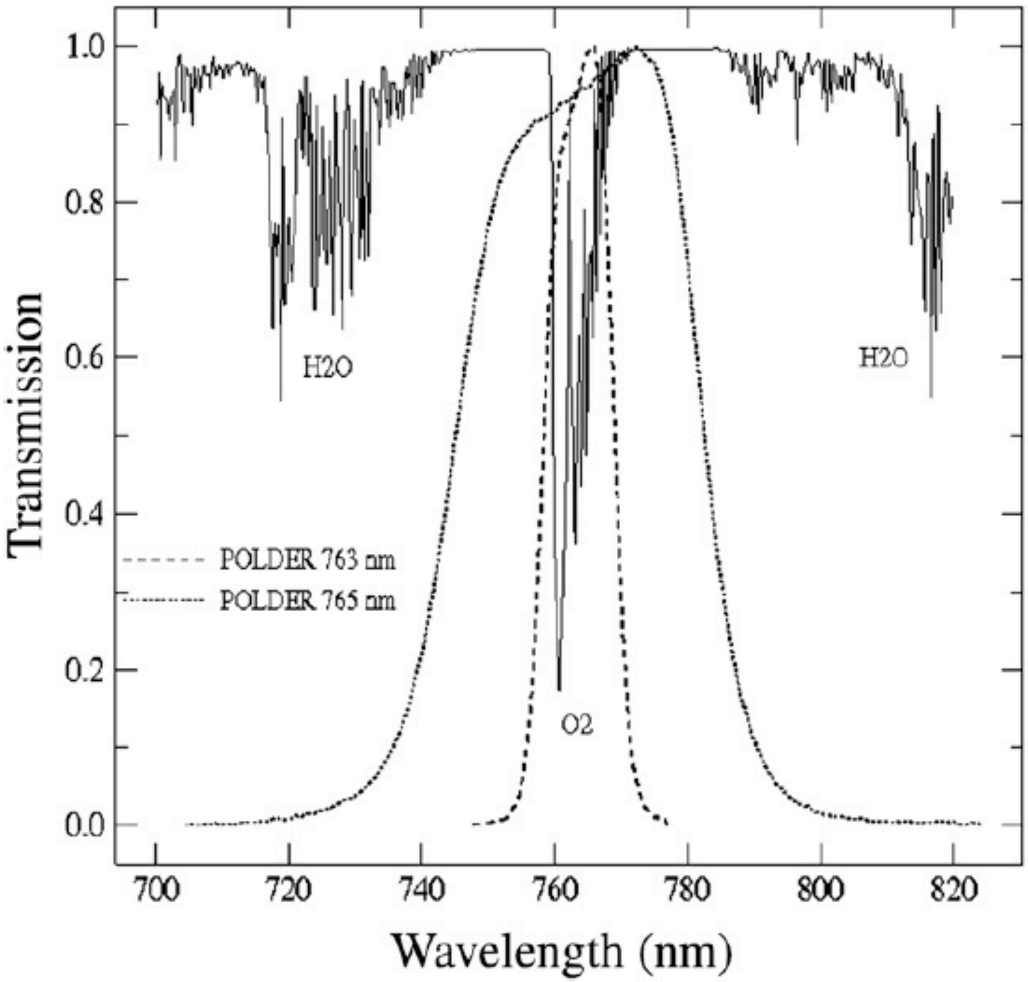


FIG. 1. Atmospheric transmission in the region of the oxygen A band at a resolution of 5 cm^{-1} ($\simeq$0.3 nm) and filter transmission in the narrow (10 nm) and wide (40 nm) POLDER bands centered at 763 and 765 nm, respectively.

POLDER

from Sneep et al. (2008)

- because of photon penetration inside cloud before reflection back into space, POLDER P_{O2} overestimate cloud top pressure (CTP).

- Vanbause et al. (2003) and Sneep et al. (2008) showed that CTP to be close to the middle-of-cloud pressure;

Some numbers from Sneep et al. (2008):
- the average differences in the CP is between 2 and 45 hPa, with an RMS of 65 to 93 hPa.
- this falls within the science requirement for the OMI CP (an accuracy of 100 hPa).

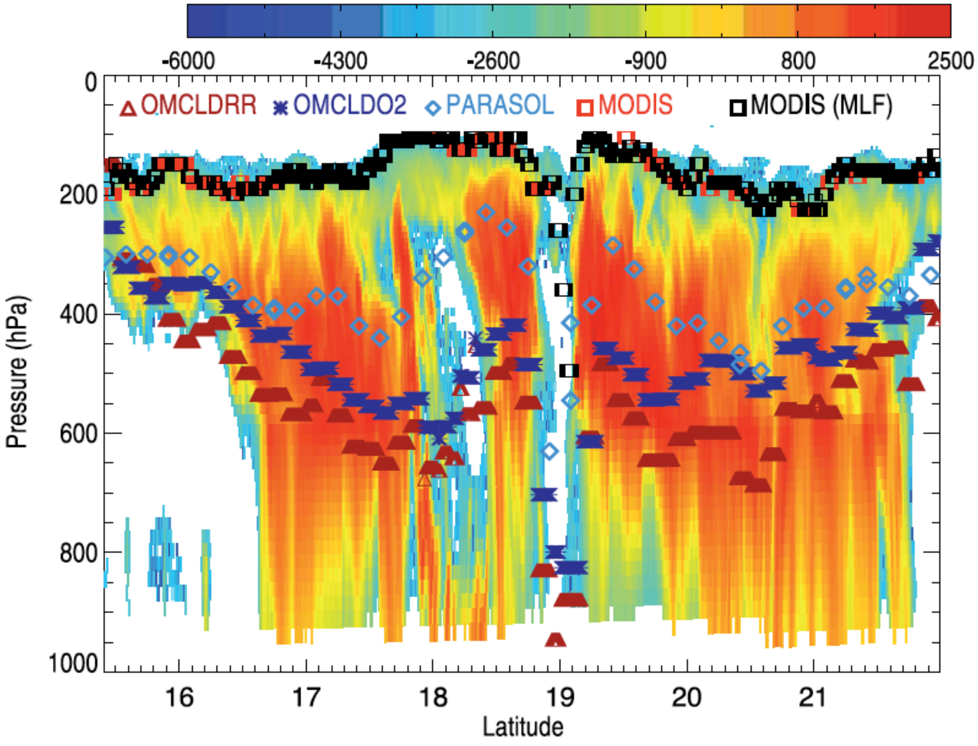


Figure 1. CloudSat profiles through hurricane Ileana, with the cloud pressures from OMCLDO2, OMCLDRR, PARASOL, and MODIS (with and without Multi-Layer-Flag, MLF) plotted on top of them. The CloudSat radar reflectivity is indicated by the color bar, in arbitrary units.

Differences between retrievals from OMCLDRR, OMCLDO2, and PARASOL

POLDER

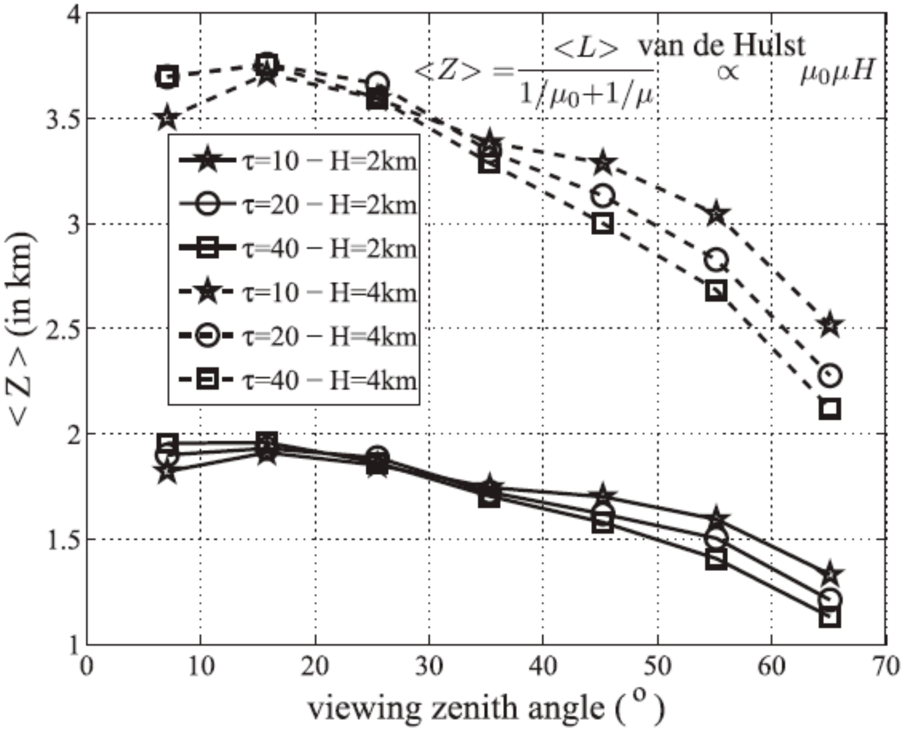
from Ferlay et al. (2010)

- Ferlay et al. (2010) states that in addition to the middle-of-cloud pressure, cloud geometrical thickness may be inferred using different viewing angles.

For large COT (van de Hulst, 1980): $\langle L \rangle \sim H(\mu+\mu_0)$

- the equivalent vertical penetration *<Z>* depends weakly on τ but predominantly on *H* (*<Z>* increases with H linearly;

- the amplitude of the angular variability of *<Z>* also depends strongly on *H*:



POLDER

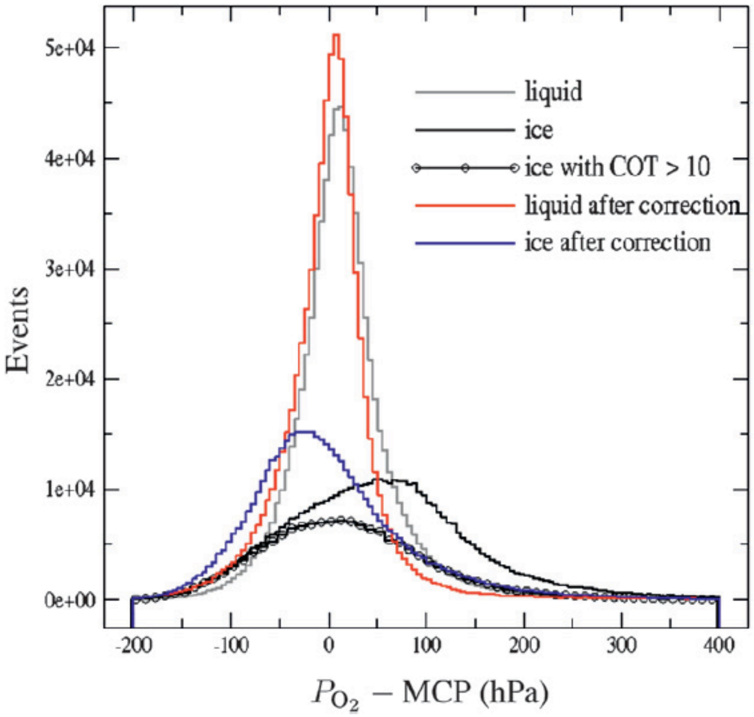
from Ferlay et al. (2010)

the difference P_{O2} - MCP is unbiased for liquid clouds as well as for ice clouds with high-enough optical thickness.

Some numbers from Ferlay et al. (2010):

- for liquid clouds (gray curve), the histogram of P_{O2} - MCP is quasi symmetric and almost centered: P_{O2} - MCP ~ 20 hPa with a standard deviation 75 hPa.
- for ice clouds (black curve), the peak is wider and significantly off center: P_{O2} - MCP ~ 54 hPa, with sd ~ 99 hPa.

For liquid clouds of COT>10, cloud thickness *H* is almost linear with σ_{PO2} and can be estimated from σ_{PO2}

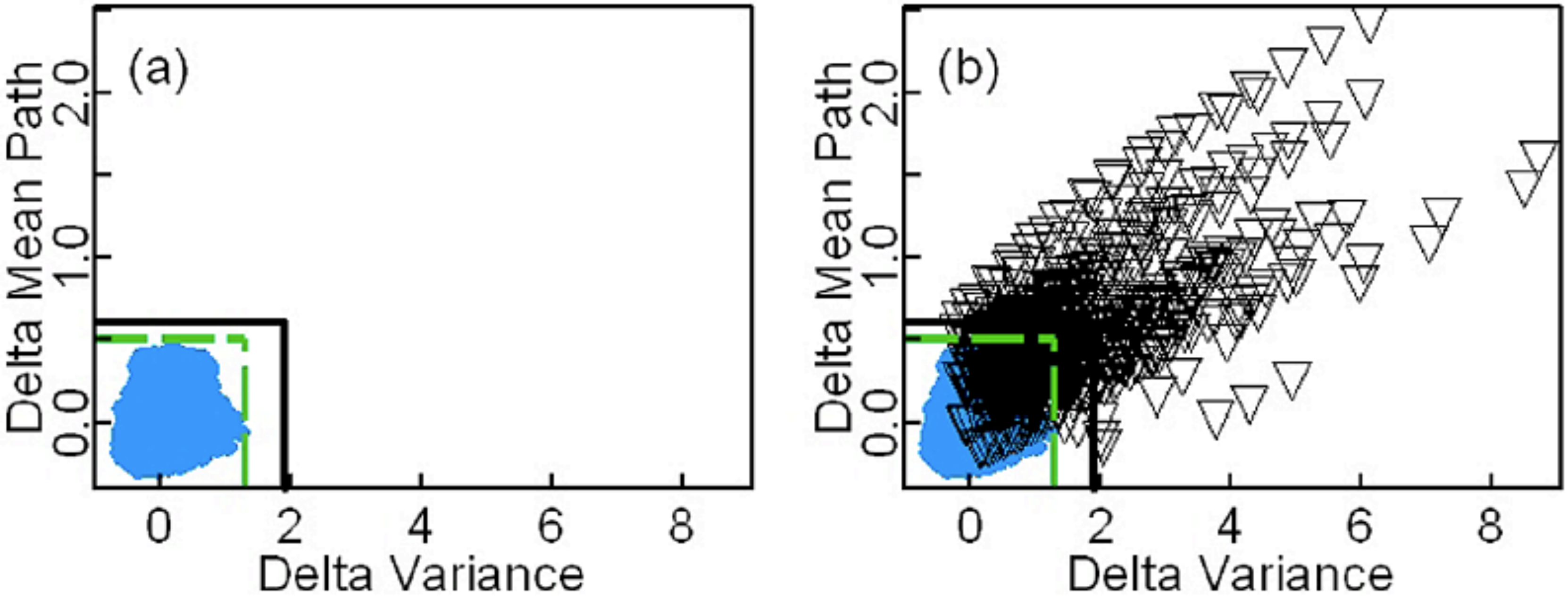


The whole year 2008: Comparison between POLDER and CALIPSO/CloudSat

Detecting Multilayer Clouds

(from the ground)

from Li and Min (2010)



Δ-Mean and Δ-Variance of Photon Path for single-layer cloud and multilayer cloud:

(a) single-layer clouds (blue dots);

(b) single-layer clouds (blue dots) and multilayer clouds (black triangles).

MERIS

from Preusker and Lindstrot (2009)

- spatial resolution of 270 m;
- A-band at 761.9 nm with 3.75 nm width;
- uses ratio L11/L10;
- gets COD from L10

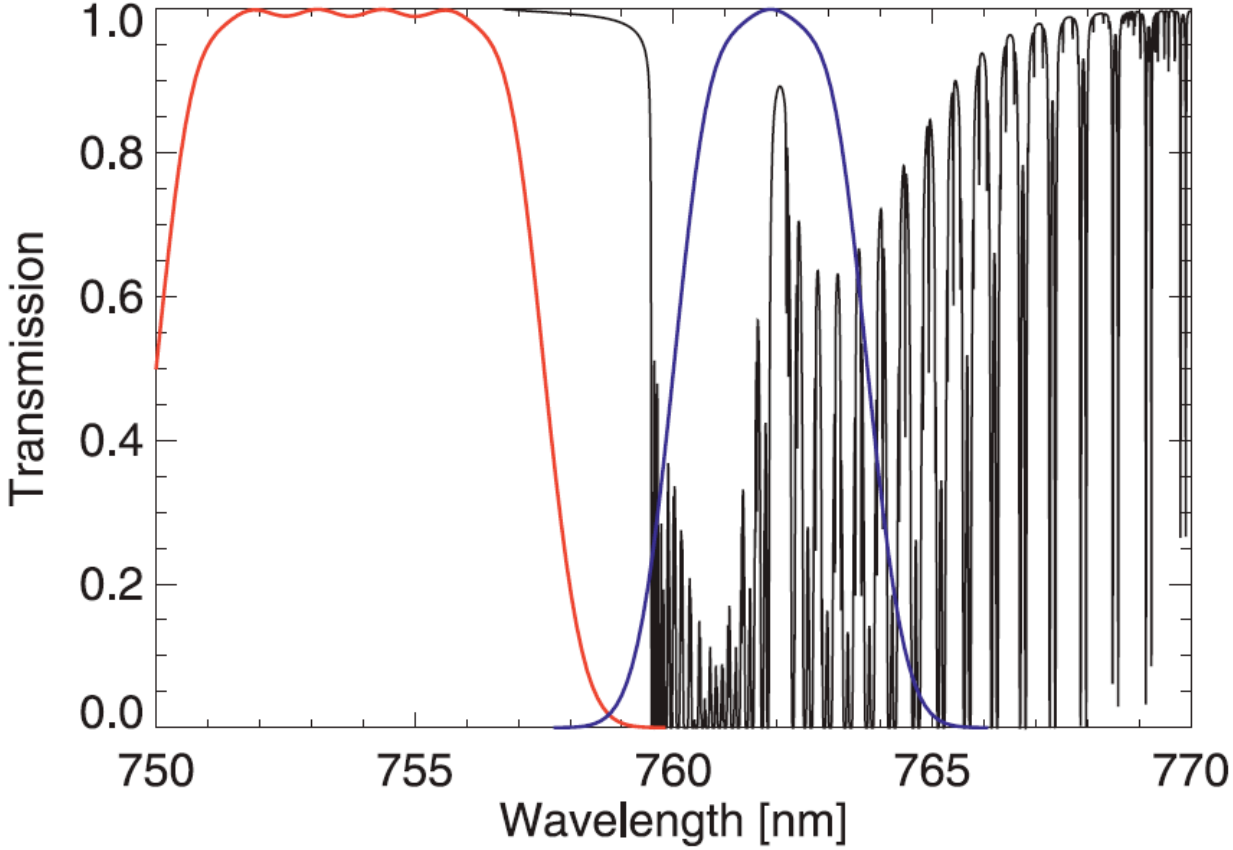


FIG. 1. Response functions of MERIS channels 10 (red) and 11 (blue) and transmission of molecular oxygen at 760 nm.

MERIS
Sensitivity Analysis; Single Layer

from Preusker and Lindstrot (2009)

- 10 hPa change in cloud height causes the same change of signal as a change of the geometrical thickness of 13 hPa. *E.g., 130 m uncertainties in cloud thickness lead to 100m uncertainties in cloud high for low clouds and 200m for high clouds.*

- 10% change of cloud fraction (CF) has a similar effect as a 10% change of cloud optical thickness (COT).

- 10% change of COT or CF causes a change in signal comparable to a CTP change of 10 hPa. *E.g., if for high clouds tau is found to be 2.2 instead of 2 then we expect 200m error in cloud hight for high clouds.*

- In the case of thin clouds above bright surfaces, the signal is dominated by the surface brightness and the surface pressure, **precluding cloud retrievals.**

MERIS
Sensitivity Analysis; Multiple Layer

from Preusker and Lindstrot (2009)

- A thin cloud above the lower cloud only slightly changes the effective CTP ; *e.g., an upper cloud optical thickness of 2 increases the CTP by 25 hPa.*

- A low-level cloud changes the effective CTP significantly, even in cases in which the upper layer is thick; *e.g., a lower-COT of 10 beneath an upper-COT of 40 leads to an increase of the effective CTP by 40 hPa.*

- The average accuracy of the retrieved CTP is worse for high clouds, since the probability of multilayer systems is higher. Supplementary information on the vertical profile of extinction from additional channels in the oxygen A band is possible to some degree.

MERIS
Sensitivity Analysis
Multiple Layer (cont.)

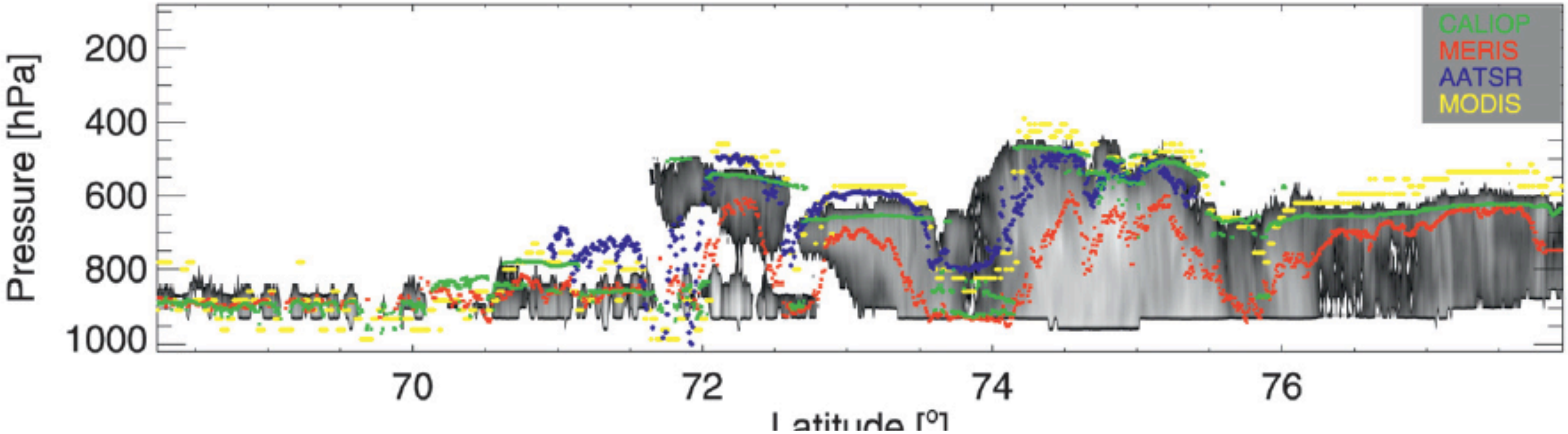
from Preusker and Lindstrot (2009)

- However, because of high correlation, additional moderately resolving channels within the oxygen A band provide a limited increase of information about the vertical structure of clouds as compared with a single-channel retrieval.

- A moderate increase of spectral resolution to a value of 0.5 nm does NOT significantly improve the retrieval.

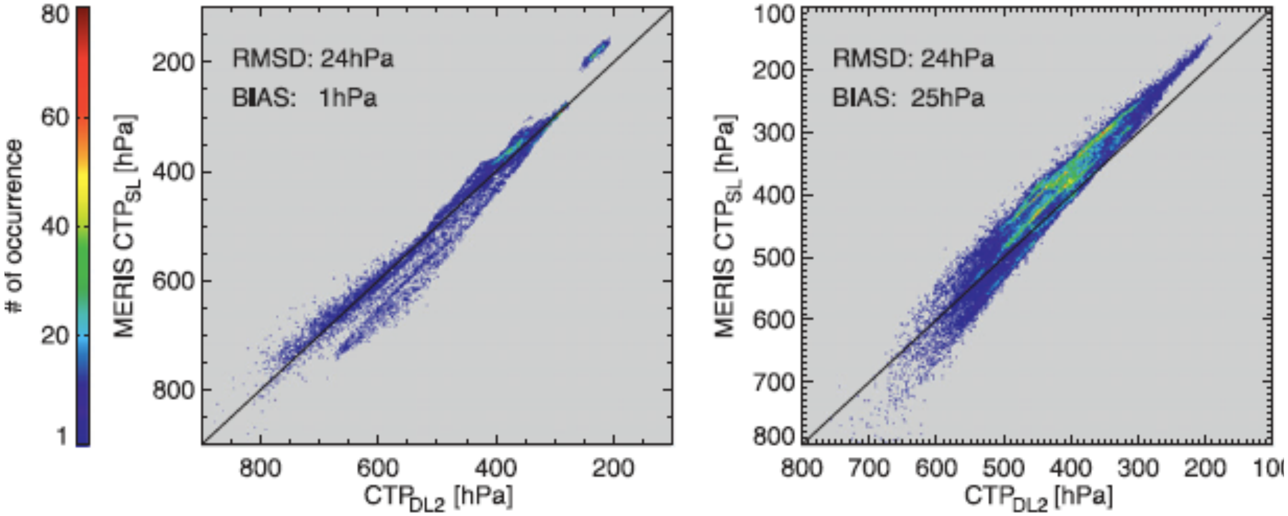
MERIS Accuracy

From Lindstrot et al. (2010)



-Some numbers: 24 hPa in the case of low-level Cu and St clouds with a bias of ~ 22 hPa.

- A max bias of 24 hPa with an rms deviation of 50 hPa is found when a cirrus optical depth of 4 is assumed.



Cloud geometrical thickness

Here, cloud optical depth is proportional to cloud thickness;
Surface albedo: 0.15
Retrieval method: OMI RRS

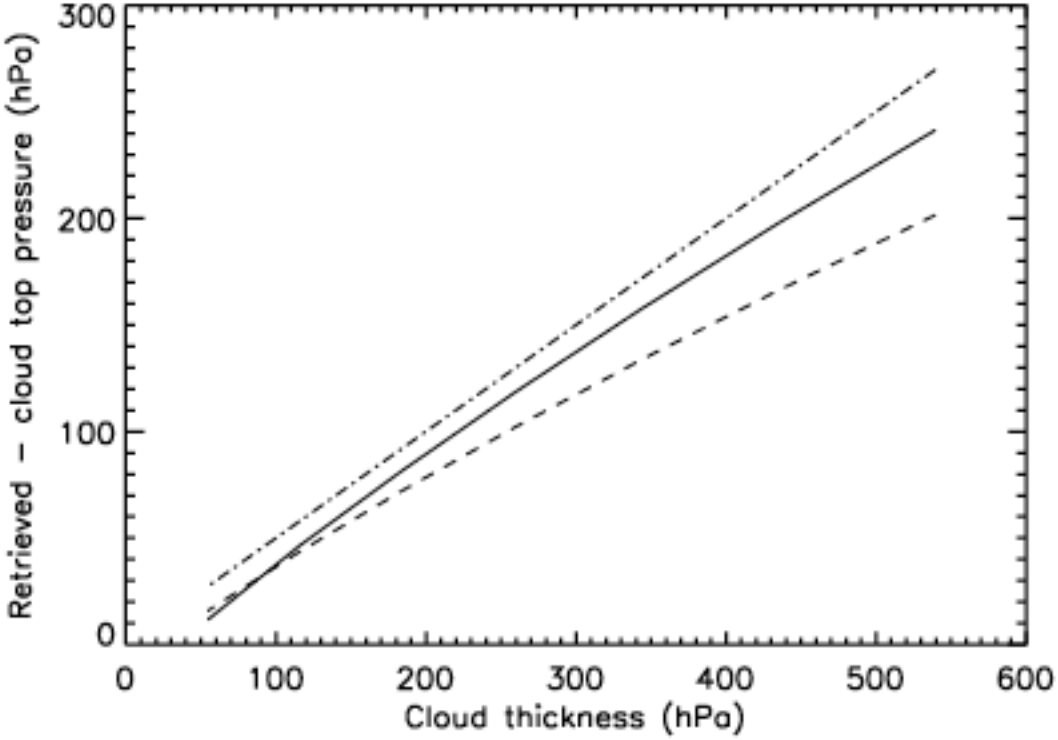


Figure 8. The simulated sensitivity of the retrieved cloud pressure (as measured from the top of the cloud) to the cloud geometrical thickness. (solid line) VZA = 0°; (dashed line) VZA = 40°, azimuth angle = 40°. Dash-dot line represents the cloud pressure midpoint.

from Vasilkov et al. (2008)

GOME

from Koelemeijet et al. (2001)

- 320 x 40 km2 in standard mode and 80 x 40 km2 for the narrow swath;

- very high spectral res.;

- uses the FRESCO model: clouds are represented by a Lamb. surface with albedo 0.8;

- uses 3 channels:
Reference: 758-759 nm
Strong abs.: 760-761 nm
Medium abs.: 765-766 nm
Solution is found by the least squares minimization.

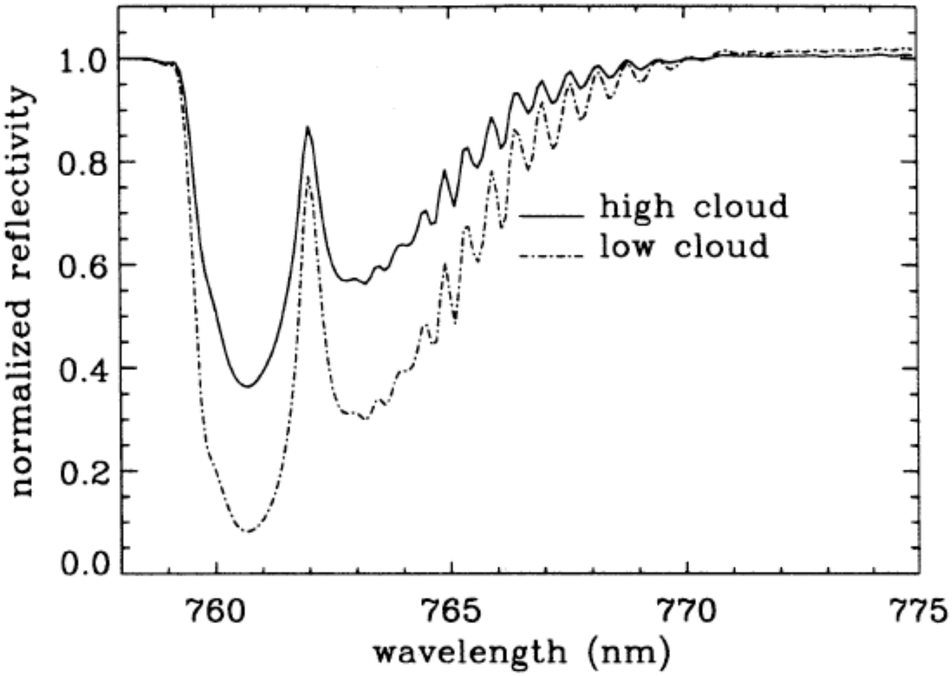


Figure 1. Example of GOME measurements of the oxygen A band. The reflectivity spectra are normalized to unity at 758 nm. The high-cloud and low-cloud pixels have comparable illumination and viewing directions. The spectral resolution of GOME at these wavelengths is ~0.36 nm; the spectral sampling is ~0.207 nm.

FRESCO algorithm

from Koelemeijet et al. (2001)

R_{obs}: observed radiance
A_c: cloud fraction
α_s: surface albedo
α_c: cloud albedo
T : transmittance

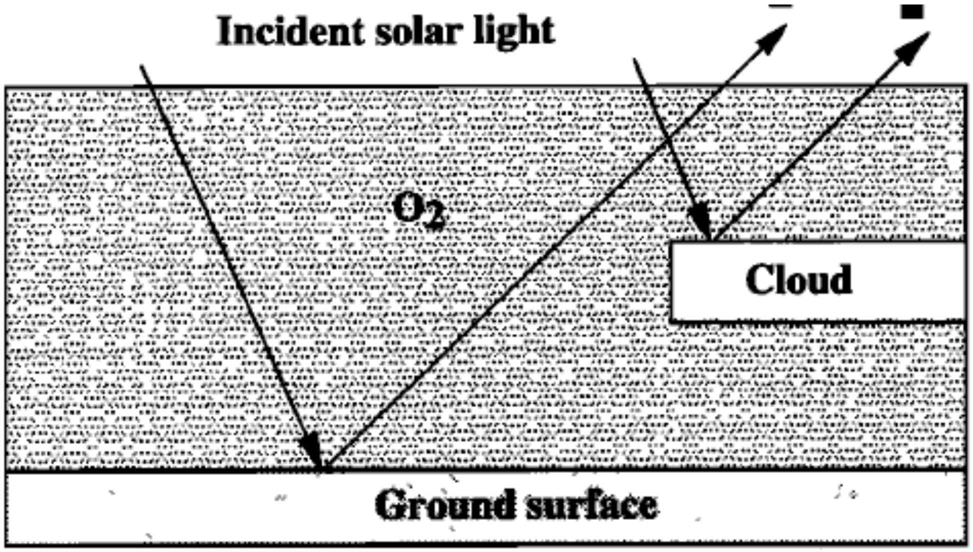


Figure 2. The two types of photon paths used in the FRESCO retrieval algorithm to simulate the spectrum of a partly cloudy pixel.

$$R_{obs-abs} = (1 - A_c)\alpha_s T_{abs}(\lambda, P_s, \theta, \theta_0) + A_c \alpha_c T_{abs}(\lambda, P_c, \theta, \theta_0) \qquad (1)$$

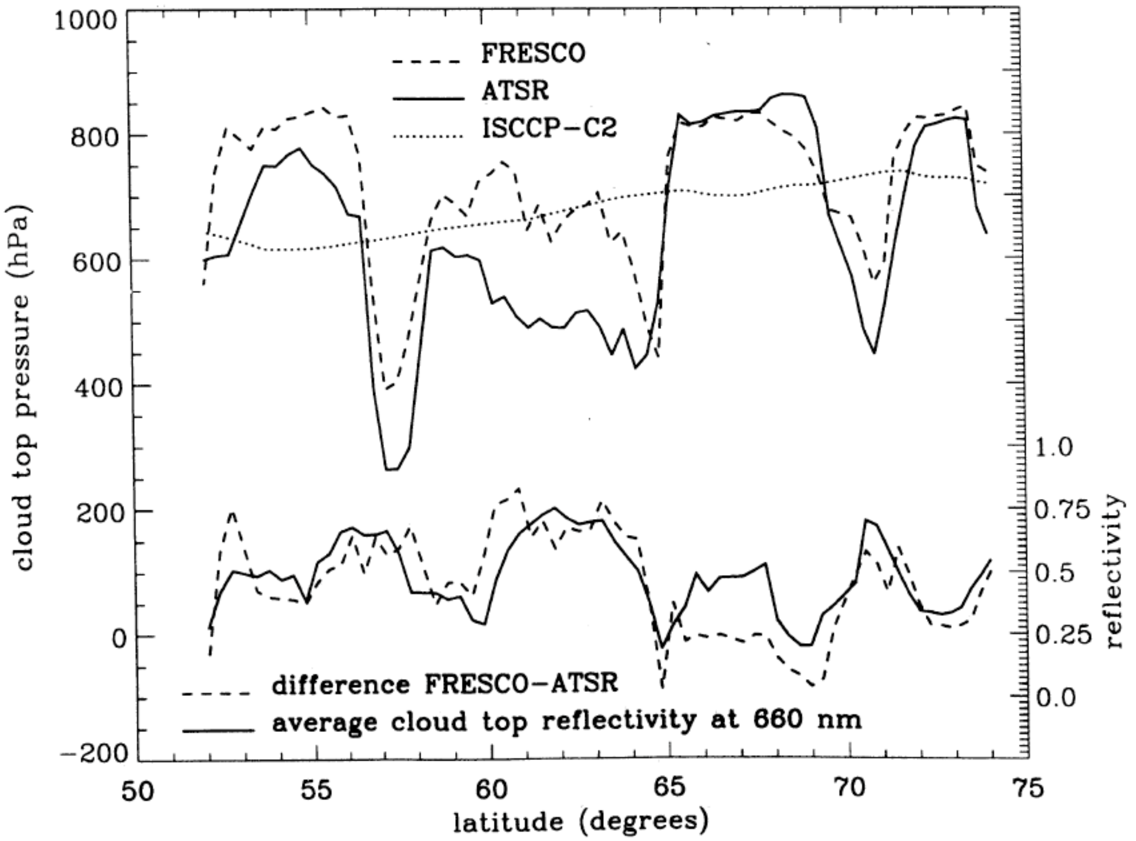
$$R_{obs-ref} = (1 - A_c)\alpha_s T_{ref}(\lambda, P_s, \theta, \theta_0) + A_c \alpha_c T_{ref}(\lambda, P_c, \theta, \theta_0) \qquad (2)$$

Accuracy of FRESCO

from Koelemeijet et al. (2001)

Some numbers from Koelemeijet et al. (2001):
- the average dif. is 65 hPa
- std. 92 hPa

- they state that the systematic difference is due to neglecting absorption inside the cloud layer (50-100 hPa).



SCIAMACHY

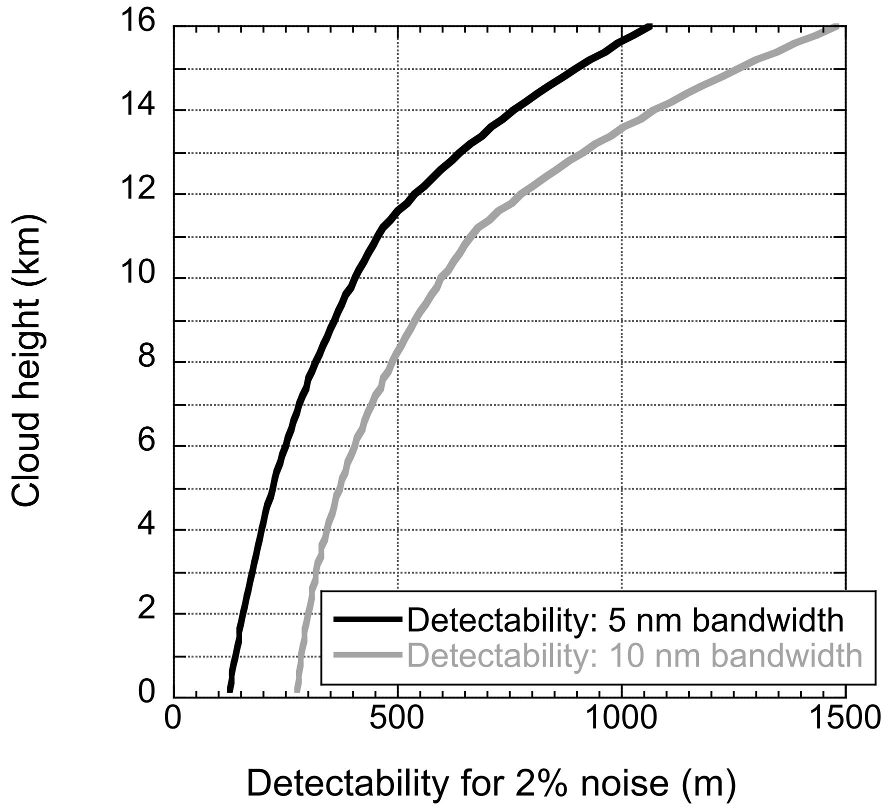
SCIAMACHY: (SCanning Imaging Absorption SpectroMeter for Atmospheric CartograpHY)
Satellite: ENVISAT
Spectral range: 240 to 2380 nm
Spectral res.: 0.2 nm - 1.5 nm
Spatial res.: 30 km (along track) x 60 km (across track)

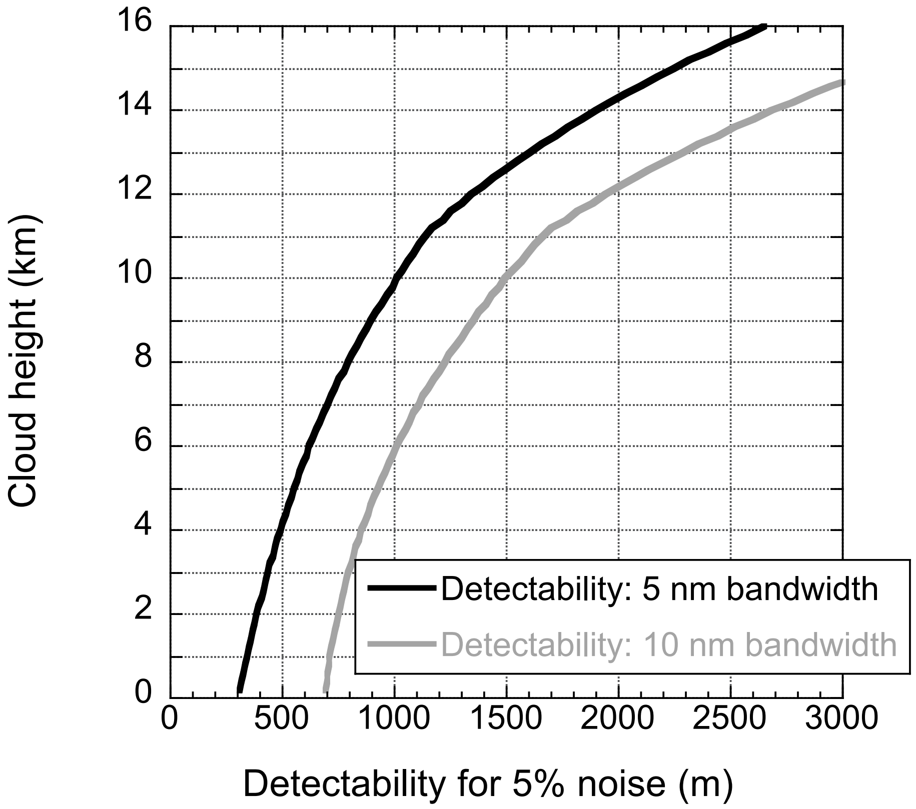
SCURA cloud product derived from SCIAMACHY (Kokhanovsky)

SACURA: Semi-Analytical CloUd Retrieval Algorithm;
Restricted to optically thick clouds ($\tau \geq 5$);
14 orbits per day in a zipped file

Two uncoupled algorithms:
- SACURA-A is for the determination of the cloud droplet radius and liquid water path and
- SACURA-A is for the determination of the COT *and the cloud geometrical characteristics like cloud top* height *and cloud geometrical thickness (SACURA-B).*

A-band: cloud height detectability 5 nm vs. 10 nm width





Summary

from section 2.4 clouds

In summary, *the O_2 A-band pressure height: (a) may be of limited use for high thin clouds but can carry potential information on cloud geometrical thickness, (b) is expected to be very useful for low cloud pressure retrievals esp. in regions of temperature inversion and where the geometrical thickness is limited or well known* .

For Phase-A cloud studies is recommended to study "*Cloud height and vertical information content, including multilayer detection, from a combination of A-band (two adjacent 5 nm channels and/or a broader 10 nm channel) and 940 nm water vapor channel* and, perhaps, with other O2 channels."

Concept

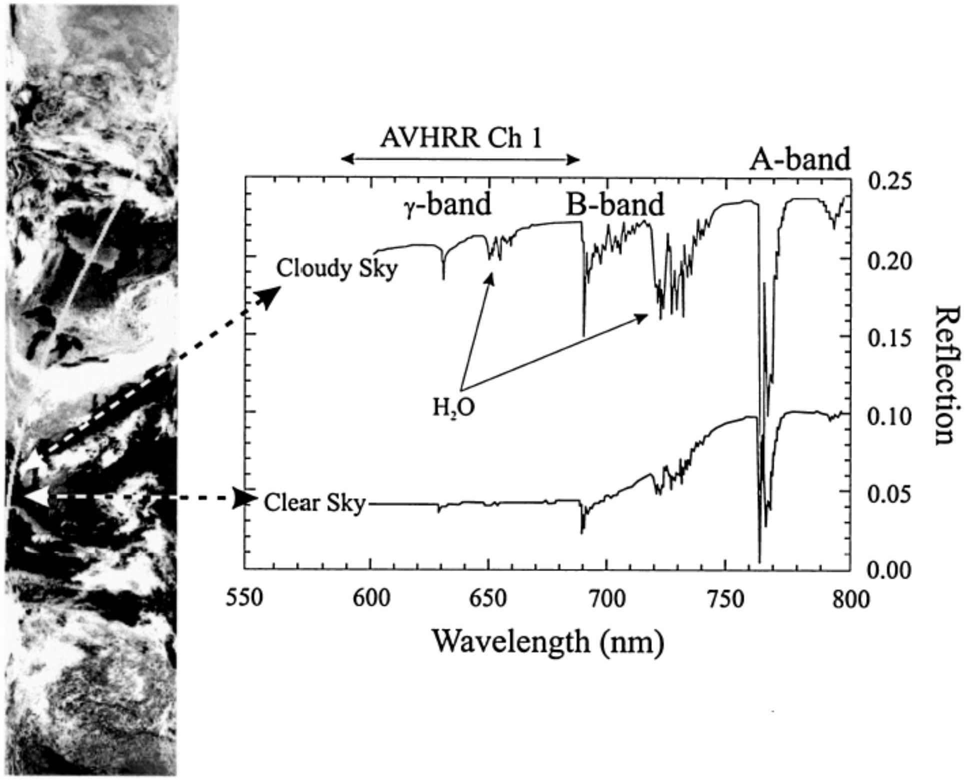
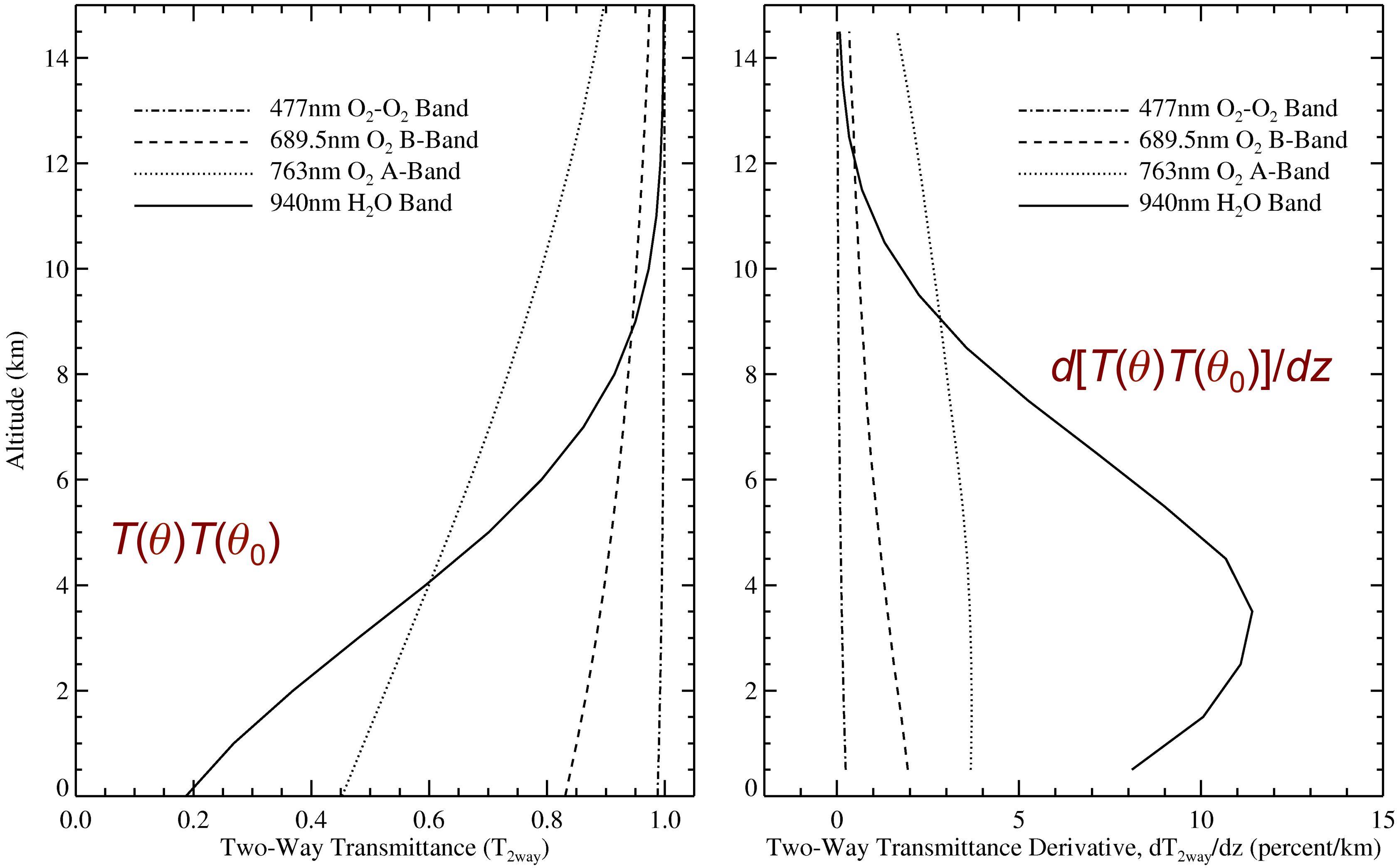


Fig. 13.1. Two spectra measured by GOME over the regions indicated from the overlay of the orbit path of GOME on a near-coincident AVHRR visible (channel 1) image of the atmosphere and surface below. The spectral width of the AVHRR channel 1 is shown for reference

from Stephens et al. (2005)

Absorption Properties in OES O_2 and OES+ H_2O 940 nm Bands

(overhead sun & nadir view, MLS, without Raleigh scattering, *K. Meyer et al.)*



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