# Retrieval of Cloud Fraction and Pressure from the Ozone Monitoring Instrument

Johan F. de Haan, Pepijn Veefkind,
Maarten Sneep, and Pieternel Levelt
KNMI, de Bilt, The Netherlands

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- OMI cloud algorithms: Raman and $O_2$-$O_2$
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- Current and future algorithms

# OMI Data Products

- Ozone
  - Total column
  - Profile
  - Tropospheric
- $NO_2$
  - total column
  - Tropospheric
- Aerosols
- Clouds
  - coverage
  - pressure
- $SO_2$
- BrO
- HCHO
- OClO
- Surface UV Irradiance

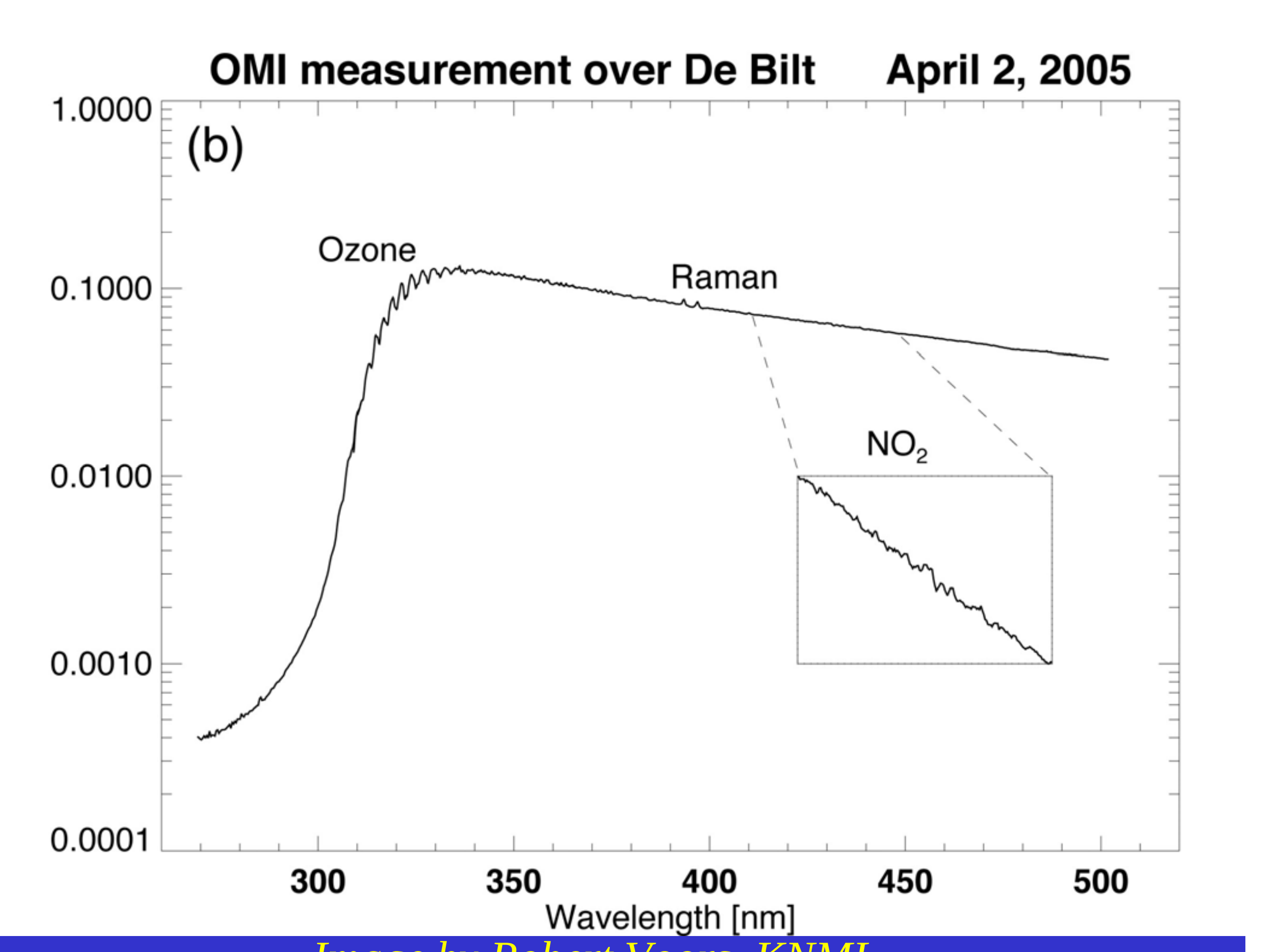
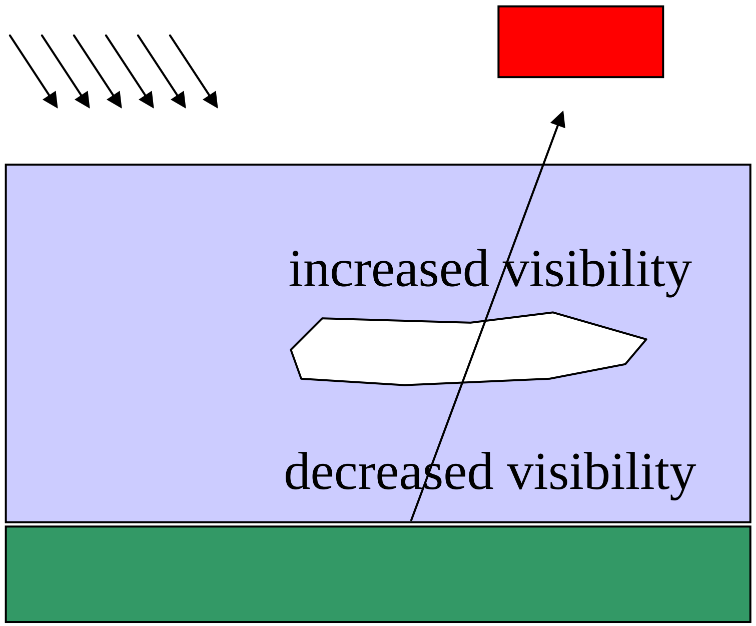
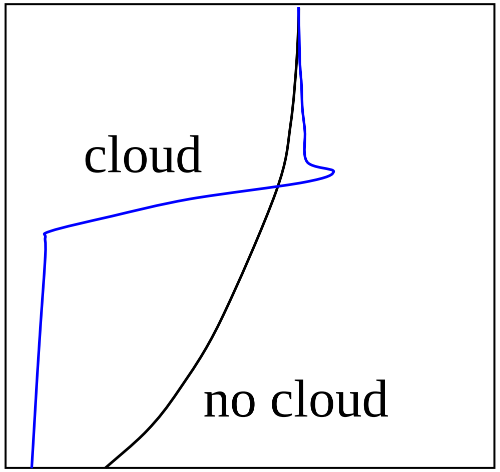



*Image by Robert Voors, KNMI*

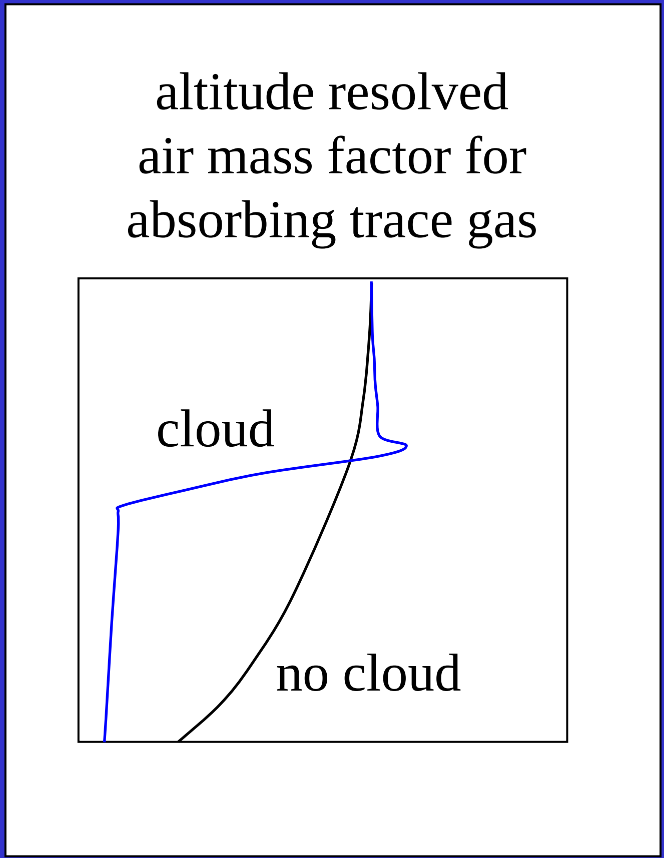
# Clouds and the retrieval of trace gases -1




altitude resolved
air mass factor for
absorbing trace gas



# Clouds and the retrieval of trace gases -2




Full correction for cloud effects
requires knowledge of trace gas profile and:

- (radiance) cloud fraction
- altitude (pressure) cloud
- optical thickness (albedo) cloud
- surface albedo
- geometrical extend of cloud system (multi-layered clouds)

Difficult to retrieve all these parameters from the measured spectrum:
- use climatologies: e.g. surface albedo
- use geometrically thin, optically thick cloud (Lambertian surface)

# OMI cloud algorithms - 1

Simplification used for OMI algorithms:

- model cloud as Lambertian surface with fixed albedo ($A_c$ =0.8)
- use climatology (LUT) for surface albedo

Determine from measured spectrum:

- radiance (effective) cloud fraction
- cloud pressure

# OMI cloud algorithms - 2

Effective cloud fraction: use measured reflectance of pixel

$c = (R_{meas} - R_{clear}) / (R_{cloud} - R_{clear})$

Cloud pressure: use spectral features of $N_2$ or $O_2$ or both

=> column of air above the cloud

Candidates:

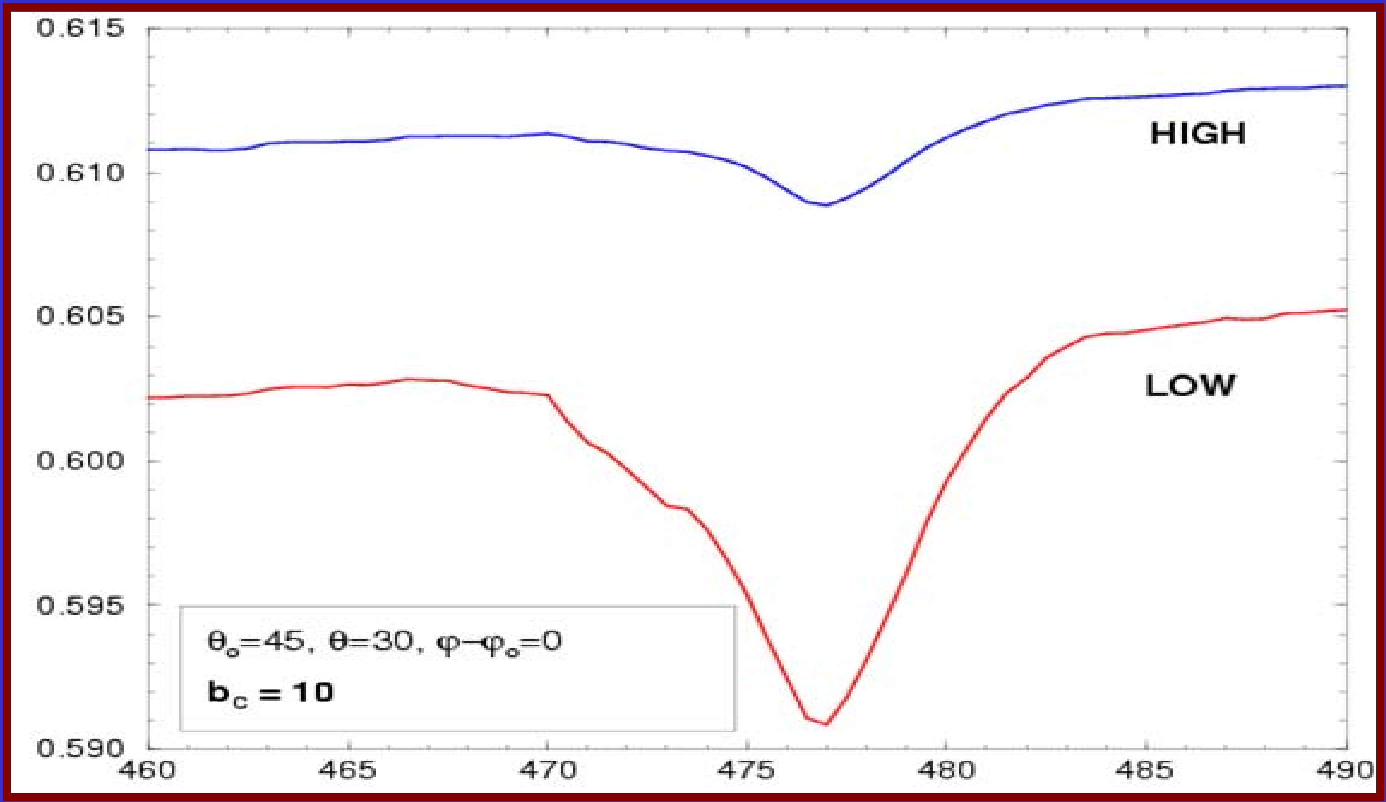
$O_2$-A, $O_2$-B, $O_2$-$\gamma$, (none seen by OMI)

bands of collision complex $O_2$-$O_2$, (477 nm band)

rotational Raman scattering (RRS) by $N_2$ and $O_2$

(deep solar Ca II lines near 395 nm show RRS best)

# $O_2$-$O_2$ algorithm - 1



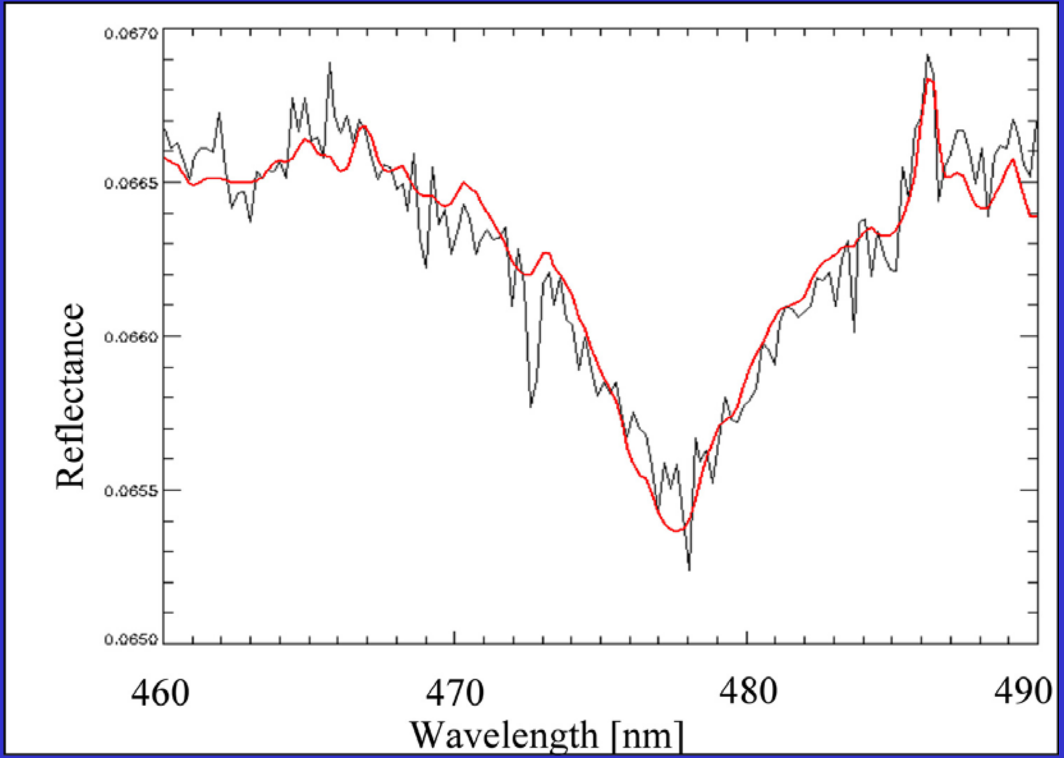

Simulated reflectance for high and low cloud

# $O_2$-$O_2$ algorithm - 2

Use DOAS fit on (460,490) nm with $O_2$-$O_2$, $O_3$, and Ring

=> continuum reflectance

=> slant column $O_2$-$O_2$




Use LUTs based on radiative transfer calculations

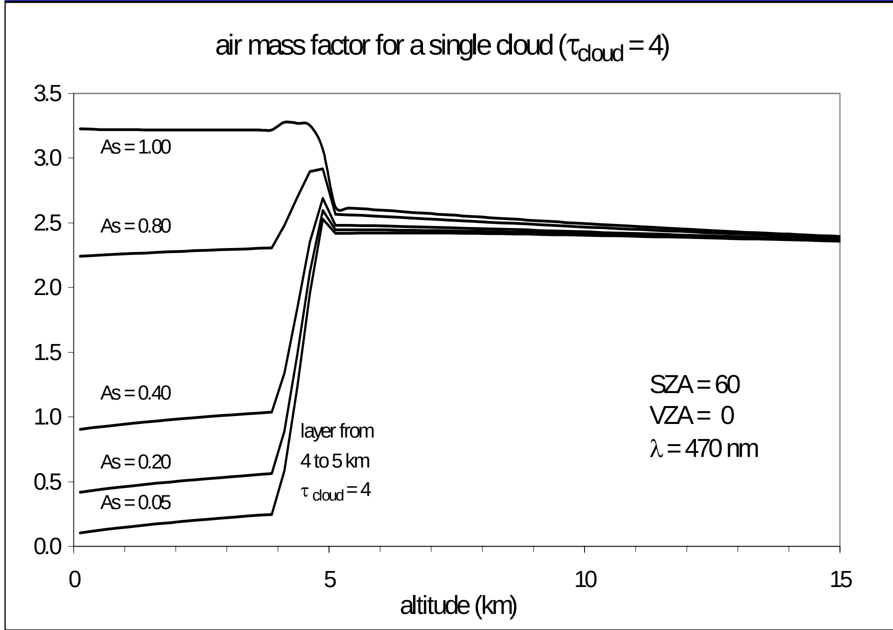
=> effective cloud fraction

=> vertical column of $O_2$-$O_2$ above/in the cloud => cloud pressure

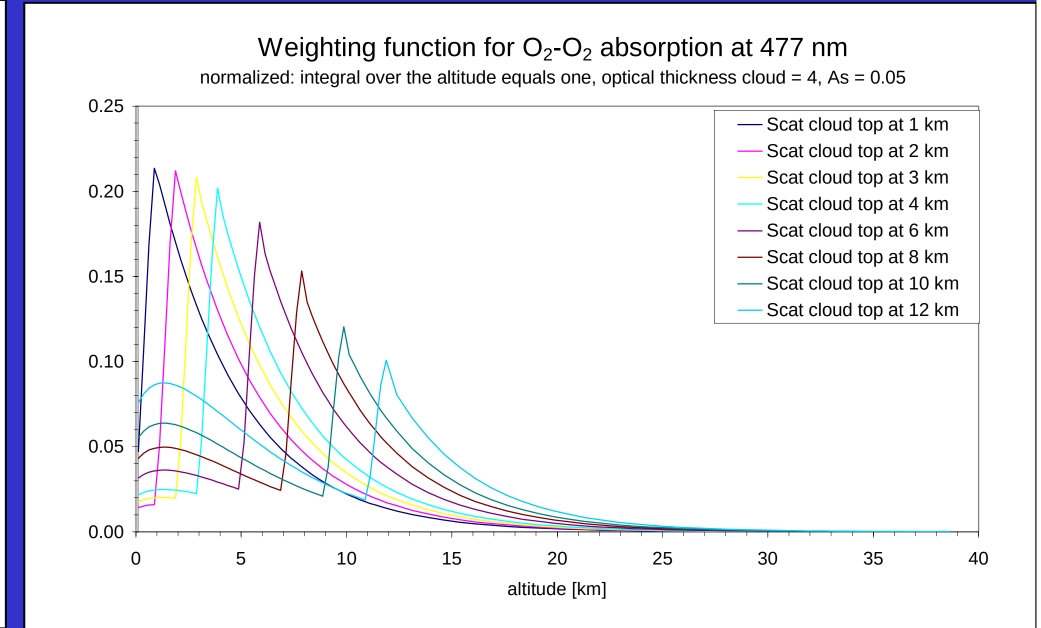
# $O_2$-$O_2$ algorithm - 3

What cloud altitude (pressure) do we retrieve?

AMF

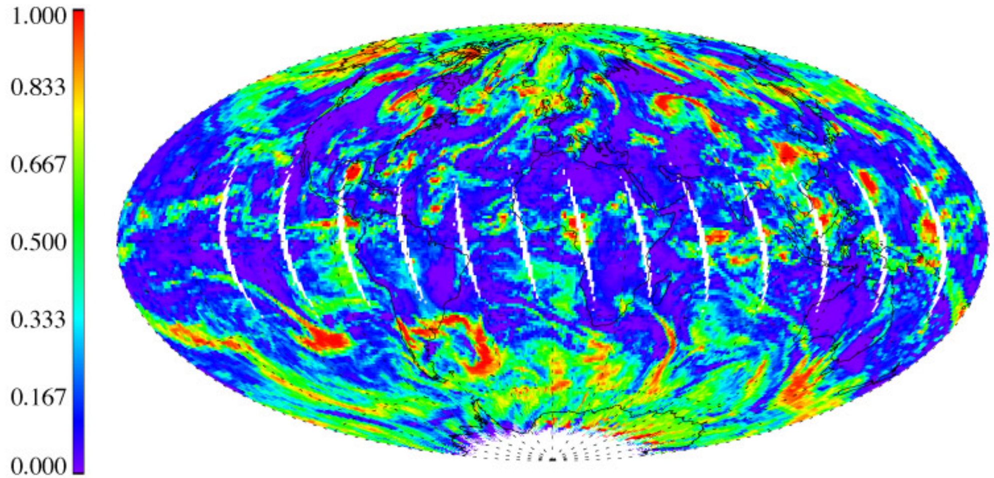



AMF x number density $O_2$-$O_2$ (normalized)

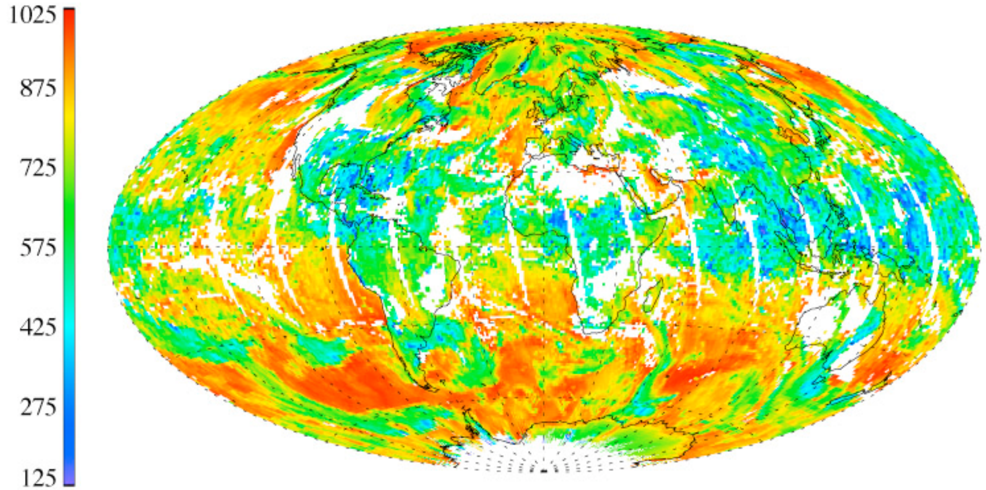



For high surface albedos and high clouds bias can be expected

Cloud Fraction for $A_c = 0.8$




Cloud Pressure




## OMI $O_2$-$O_2$ cloud product for August 28, 2005

Retrieved cloud fraction and cloud pressure as expected

Low cloud pressures occur mainly in the tropics

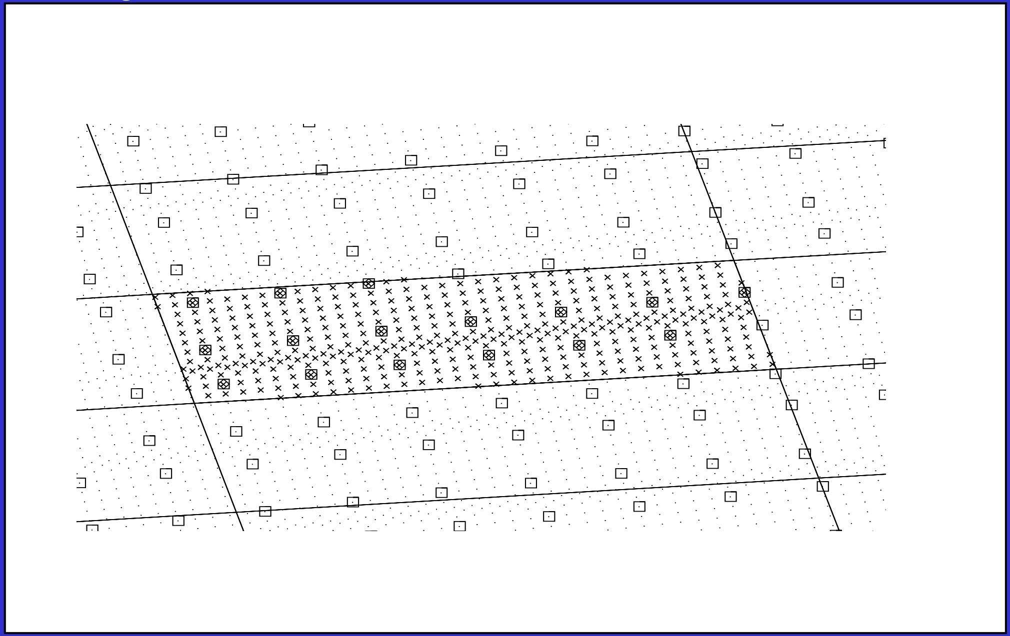
Accuracy???

- compare with MODIS data
- compare with OMI RRS product
- compare with radar/lidar

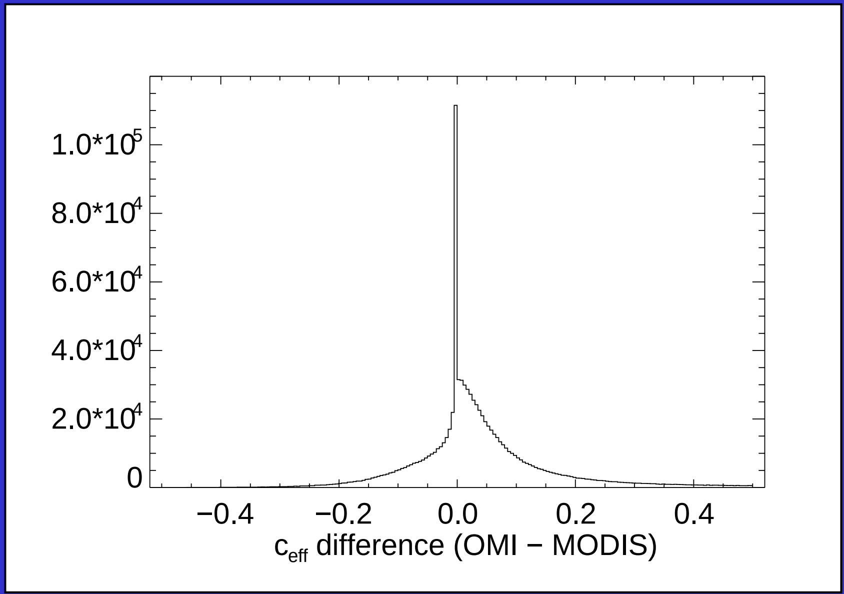
# Comparison with MODIS

Translate the geometrical cloud fraction and cloud optical thickness given by MODIS
into an effective (radiometric) cloud fraction
(radiative transfer for optical thick cloud, $\tau_c = 30$)

Use MODIS cloud pressure from thermal infrared as comparison



Re-grid MODIS cloud data to OMI grid
MODIS cloud product on 5 km x 5 km grid

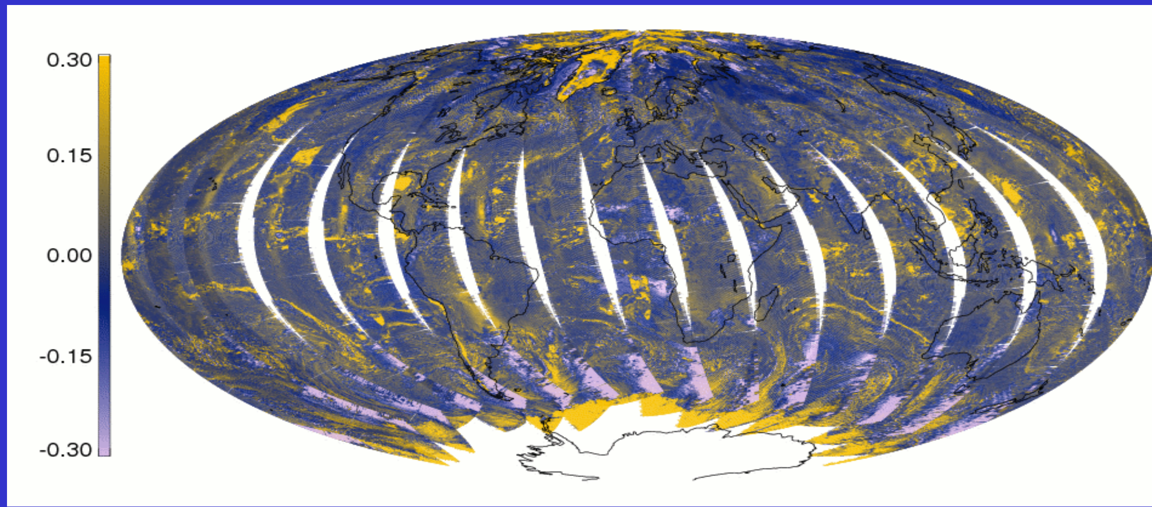


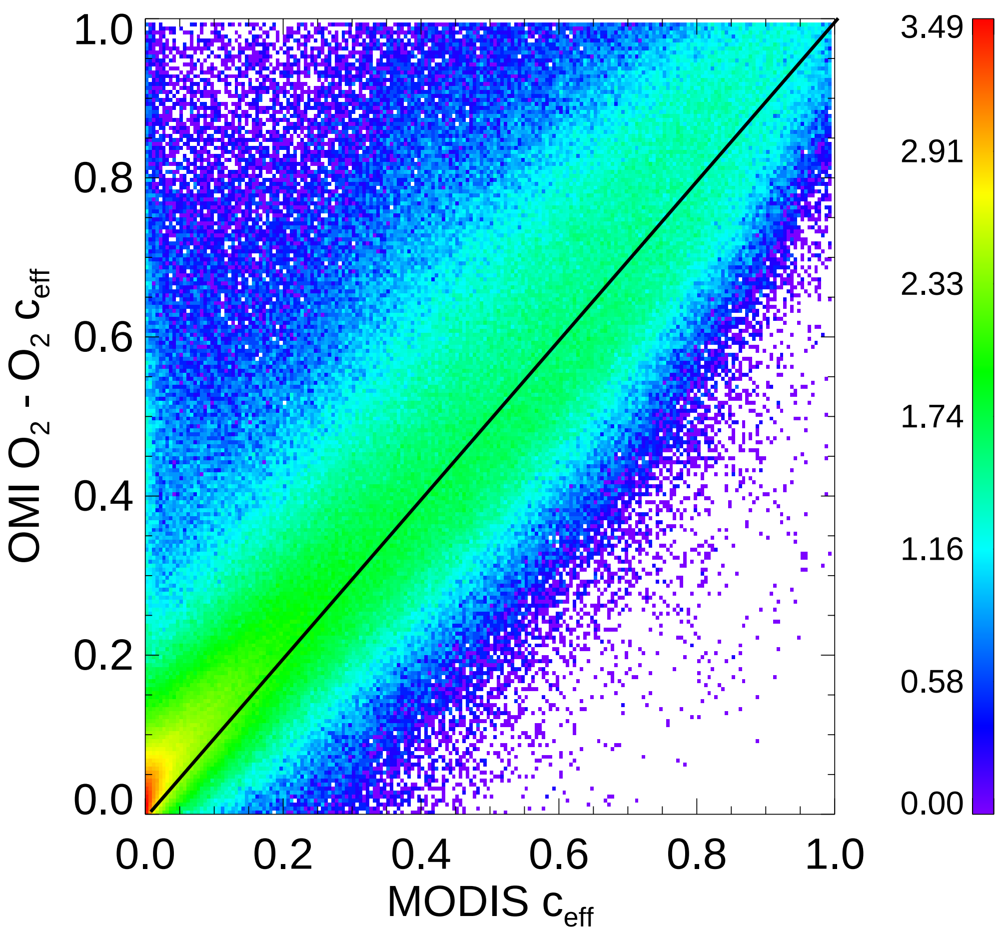

# Comparison cloud fraction - 1

Difference in effective cloud fraction for MODIS and OMI August, 28, 2005

Overall good agreement, but
- Greenland
- some clouds
- ice cover

significant differences



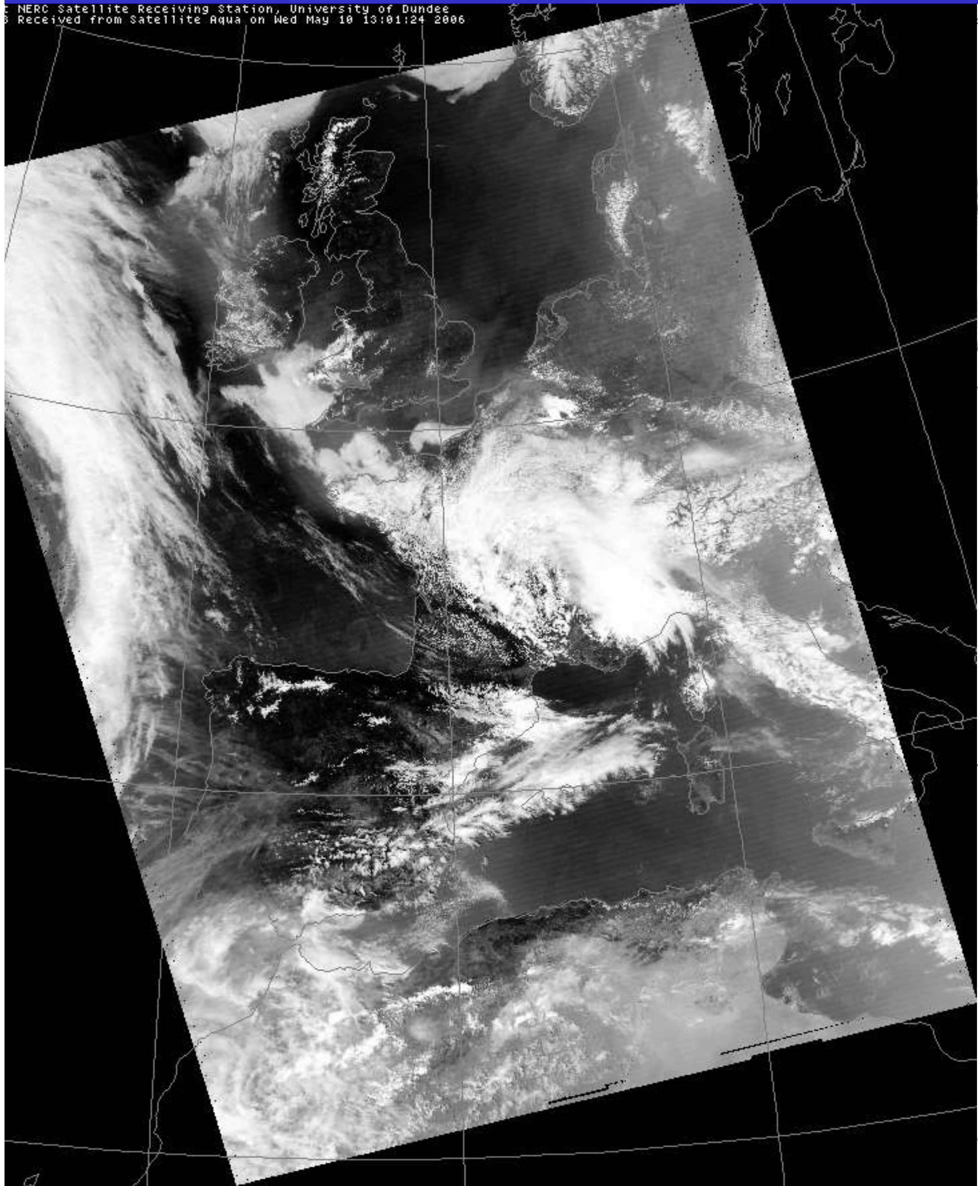



# Comparison cloud fraction - 2

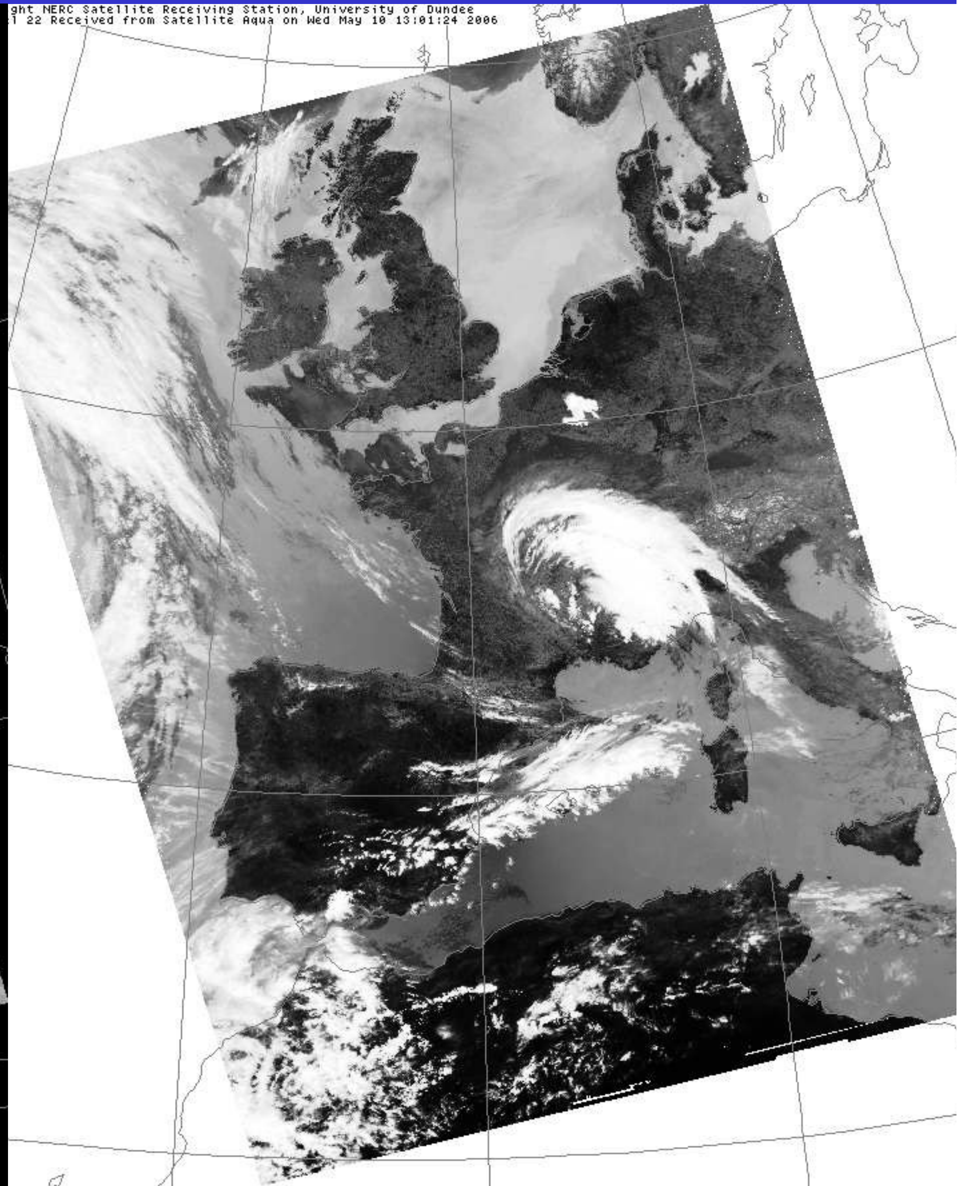
Scatter diagram
OMI $O_2$-$O_2$
effective cloud fraction
and MODIS effective
cloud fraction
(log color scale)

- nearly 1-1 relationship
- some bias (differences in cloud model, surface albedo?)

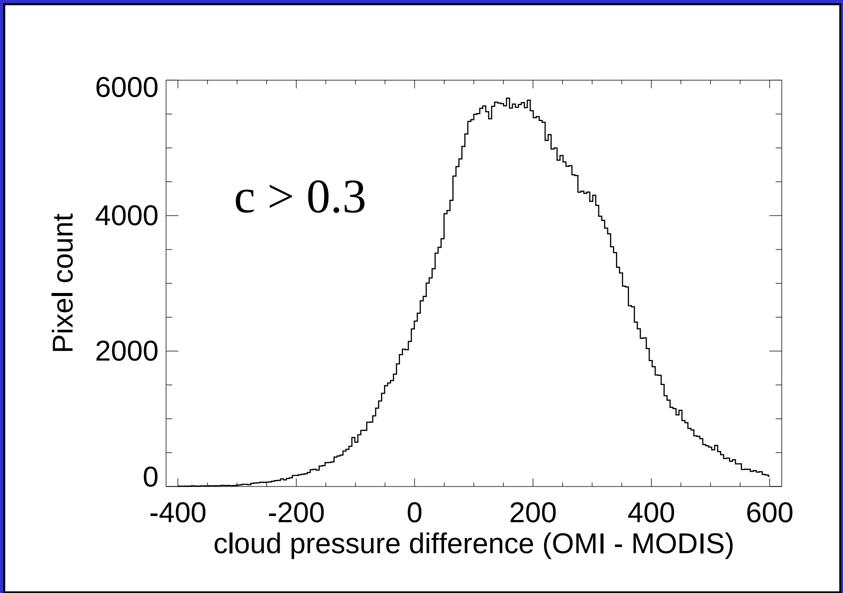
## Visible




## Infrared

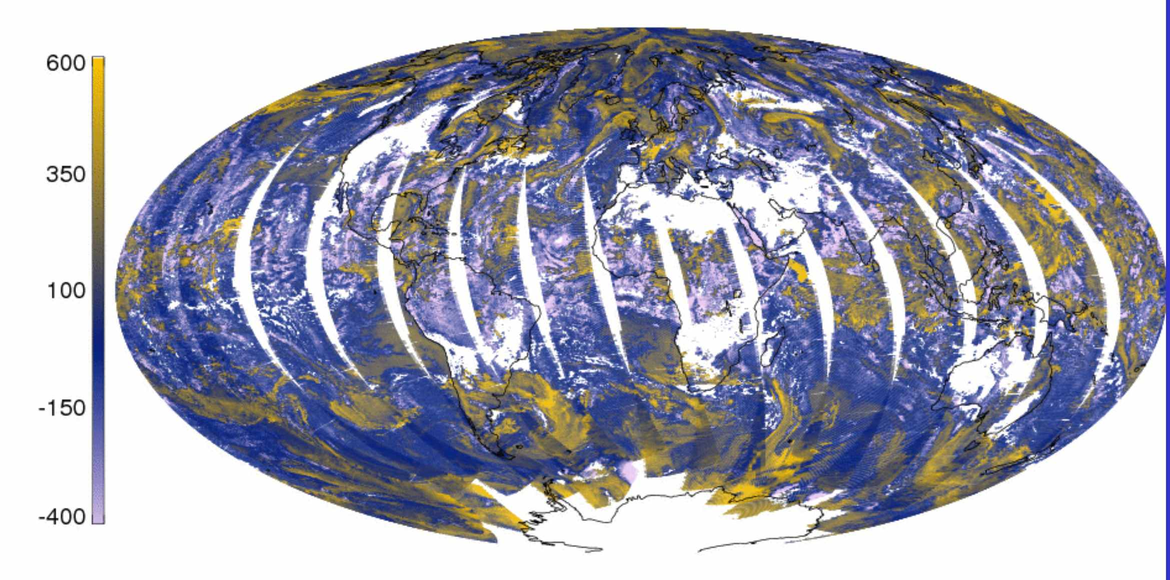


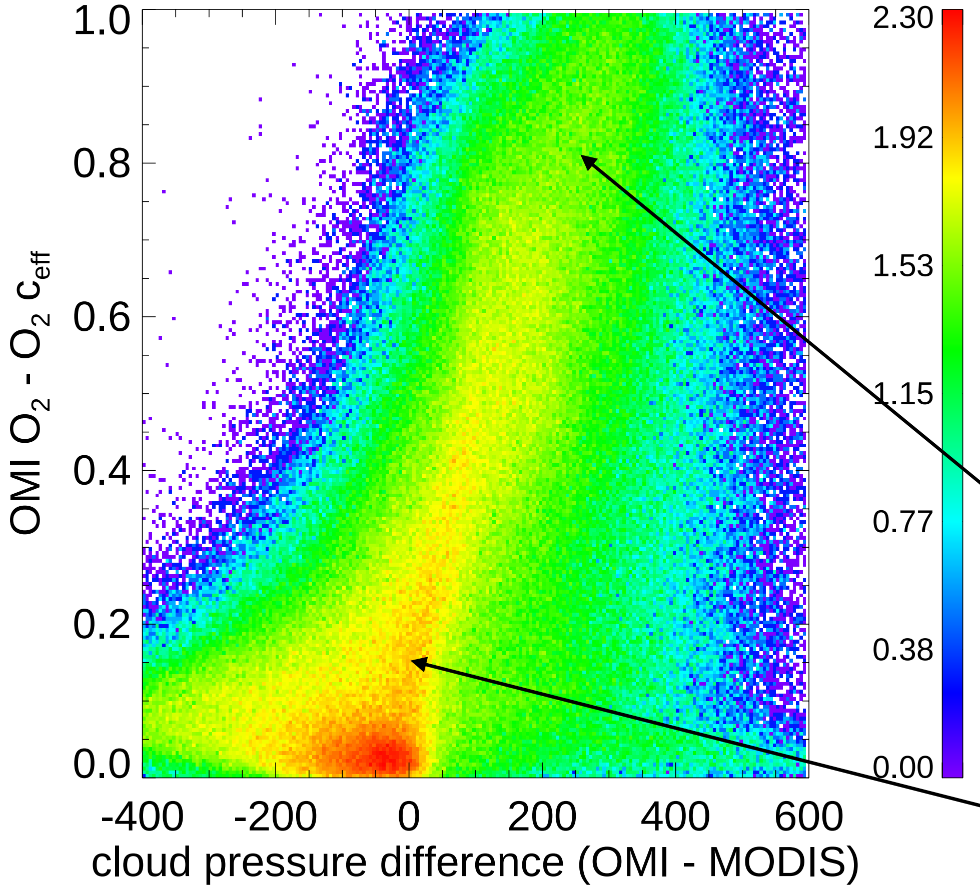
# Comparison cloud pressure - 1




Cloud pressure OMI - MODIS
August, 28, 2005
MODIS uses thermal infrared
OMI uses VIS (477 nm)

Average cloud pressure for OMI larger
- MODIS more sensitive to high clouds
- sometimes MODIS pressure larger (unexpected)






# Comparison cloud pressure - 2

Scatter diagram difference cloud pressure OMI – MODIS as function of the OMI effective cloud fraction

(log color scale)

Thick clouds

Thin clouds

# Comparison MODIS

- Effective cloud fractions agree well
  some bias due to different cloud models, surface albedo, …

- Cloud pressure:
  - thick clouds: $O_2$-$O_2$ algorithm gives larger pressures ~ 150 hPa
  reason: thermal IR more sensitive to high clouds (cirrus)
  - thin clouds (small cloud fractions) : large scatter in differences
  reason: ?????

# Cloud correction for trace gas retrieval current algorithms

The most important effects of clouds are probably captured with current algorithms (Lambertian surface - thick cloud)

- needs to be demonstrated more clearly for thin clouds

radiative transfer using scattering clouds (poster Ping Wang $NO_2$)

altitude resolved air mass factor gives more insight

- for small cloud fractions (tropospheric trace gases)

a more accurate surface albedo LUT seems to be needed

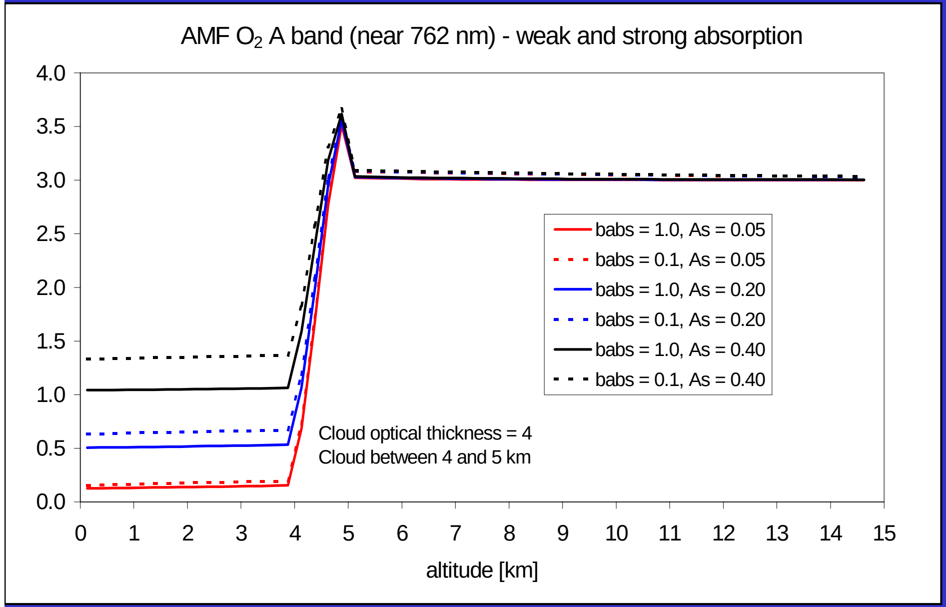
# Cloud correction for trace gas retrieval future algorithms - 1

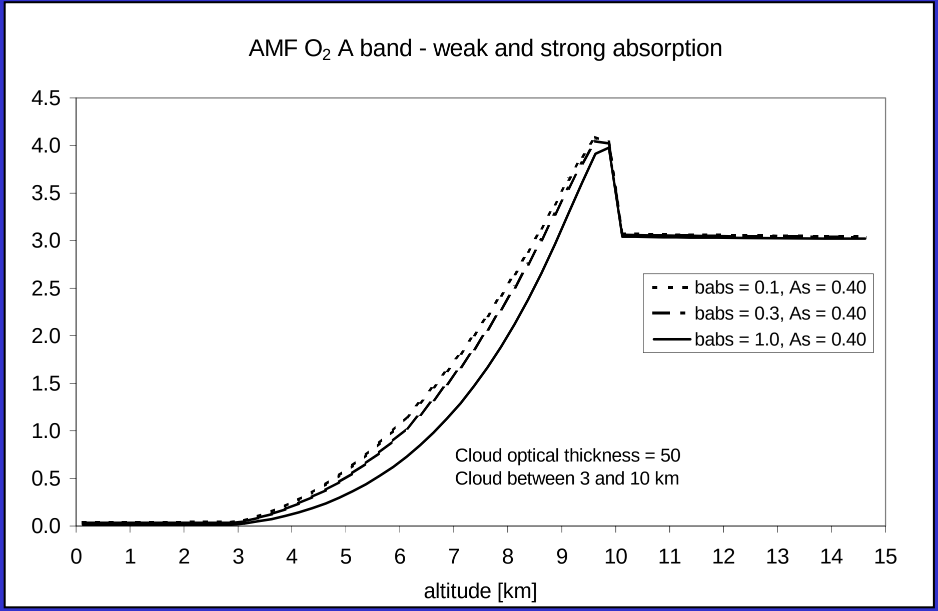
Improvements in cloud algorithms:

- use scattering clouds instead of Lambertian surfaces
- employ weak and strong absorption in the $O_2$A band
- combine $O_2$-$O_2$ with Raman and/or $O_2$A –band
- combine UV/VIS and thermal IR algorithms
- use wavelength dependence of continuum reflectance
  (small) difference for Rayleigh scattering and cloud

# Cloud correction for trace gas retrieval future algorithms - 2

Use weak and strong absorption in the $O_2$A band to get more cloud information



# Conclusions

- The $O_2$-$O_2$ cloud product is operational.
- The cloud fraction shows good comparison to MODIS Aqua.
- The cloud pressure shows a bias with the MODIS IR cloud pressure.
  - This bias is expected, but more validation is needed.
- The use of weak and strong absorption in the $O_2$-A has the potential to retrieve more cloud parameters.

# Back-up slides

# Required S/N estimates for a simple atmospheric model

Atmospheric model without scattering => analytic solution

Sufficient to estimate required signal to noise

Lambertian reflector for cloud ($A_c$ = 0.60) and ground surface ($A_s$ = 0.05)

Trace gas number density has scale height of 2 km and cloud fraction = 0.1

Calculated: Error in retrieved trace gas column for different S/N ratios (single point)