KNMI

Can we use the O_2 A band for cloud and surface characterization and improve retrieval algorithms?

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Introduction

ESA project CAMELOT
Instrument Requirements for Sentinels 4/5

- International Team – agreement on instrument requirements
- KNMI: UV-VIS-NIR part of the spectrum
  - build upon knowledge obtained during OMI project (UV-VIS)
  - extension with O_2 A band near 760 nm for clouds (NIR)
- CAMELOT ends this summer
- KNMI responsible to specify instrument requirements for the NIR channel, i.e. the O_2 A band (S/N, offsets, spectral knowledge). However, no requirements are specified for cloud properties. Therefore, derive instrument requirements indirectly using requirements on NO_2 in the boundary layer

Calculate Instrument Requirements - 1

Calculating instrument requirements from level 2 requirements

- Define atmospheric model containing trace gas
- Simulate radiance spectrum using radiative transfer
- Simulate a measurement using a (simple) instrument model using noise, spectral slit function, offsets, spectral shifts
- Perform retrieval of the column/profile of the trace gas using a retrieval algorithm
- Compare the retrieved column/profile with the simulated column/profile
- When the retrieved column has an error equal to the requirement e.g. due to an offset, then this offset is the level 1b requirement
- Repeat this for all relevant instrument parameters, for different viewing geometries, SZA, surface albedo values, columns, cloud fractions, cloud altitudes.

Calculate Instrument Requirements - 2

For cloud retrieval no requirements specified

- Use combined retrieval of cloud properties and NO_2
- First retrieve cloud parameters + error covariance matrix using optimal estimation (large a-priori errors) from O_2 A band
- Use these cloud parameters in a second retrieval for boundary layer NO_2, using the previously obtained cloud parameters as a-priori.
  Parameters for this second fit are
  - cloud fraction
  - cloud optical thickness
  - cloud altitude
  - surface albedo in NO_2 window
  - NO_2 column density
- Evaluate the error in the NO_2 column when Level 1b in NIR changes (e.g. offsets, S/N, etc.)

Software development - 1

Started developing DISAMAR code nearly 1.5 years ago for the CAMELOT project.
DISAMAR = Deriving Instrument Specifications and Analyzing Methods for Atmospheric Retrievals

- Developed for simulation studies, not only for retrieval
- Radiative transfer based on Doubling + LABOS
- Fully implemented optimal estimation algorithm
- Fit parameters can be:
  - trace gas column, trace gas profile
  - altitude of a cloud / aerosol layer
  - optical thickness of cloud /aerosol layer or Lambertian albedo
  - geometric cloud fraction
  - polynomial coefficients for spectral surface albedo
  - stray light parameters
- Code is still under development

Sofware development - 2

Some limitations

- Only one trace gas can presently be used (not NO_2 and O_2 A band)
- Polarization is ignored (can read polarization correction table)
- Rotational Raman scattering currently ignored
- Cloud models:
  - Lambertian cloud model
  - Scattering cloud model with Henyey-Greenstein phase function
  - clouds can cover a part of the pixel

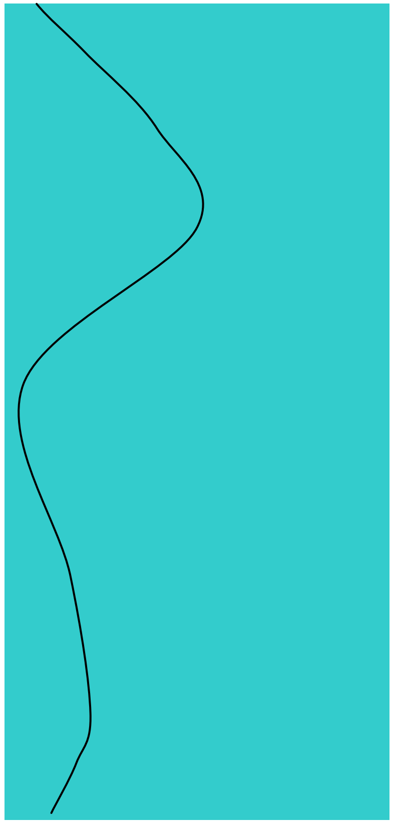
  Not yet Mie scattering or scattering by ice crystals
- Ground surface is a Lambertian surface (no BRDF)
- Partial correction for spherical effects (no different axes)
- Retrieval only for reflected light (not for measurements at the surface)

Software development - 3

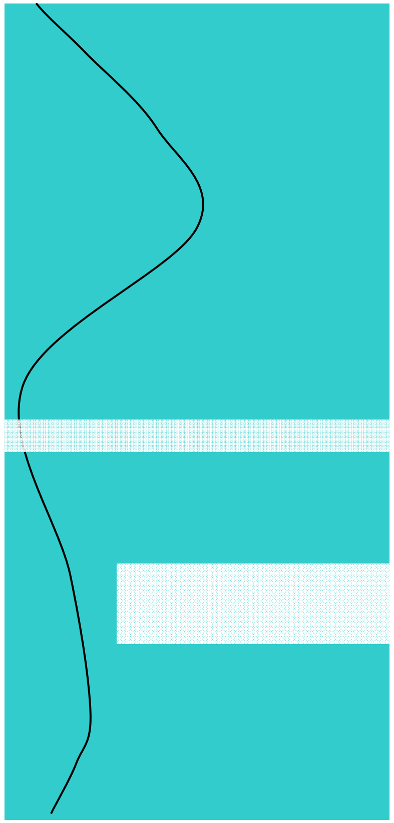
Some details

- Profile defined by spline interpolation on ln(vmr) on *n* nodes not related to layers used by radiative transfer model. For profile ln(vmr) at the values at *n* nodes are fit parameters.
- Line absorbers (e.g. H_2O, CH_4, O_2) can be used. HITRAN 2004 files can be read and a wavelength grid is defined using the strongest lines (Gaussian division points between line positions).
- Calculation of derivatives based on reciprocity (equivalent to approach used by Landgraf – SRON – adjoint solution). More efficient than the linearization used by Spurr for LIDORT.
- Full diagnostic output: averaging kernels – a-priori and a-posteriori covariance matrices – gain matrix – DFS

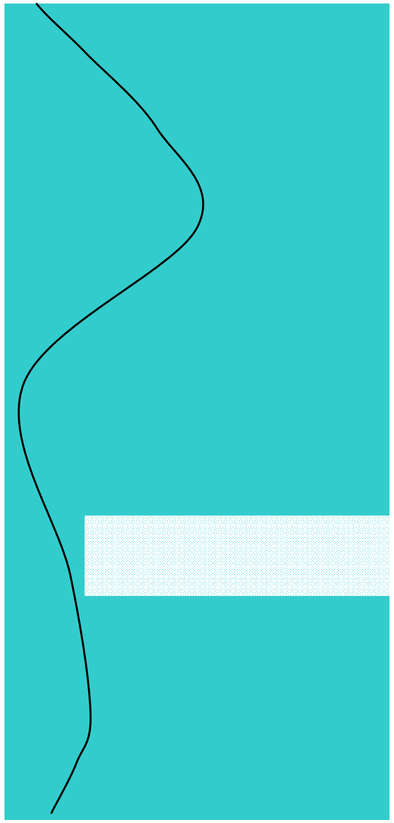
Cloud and aerosol – altitude grid



absorbing gas
spline interpolation

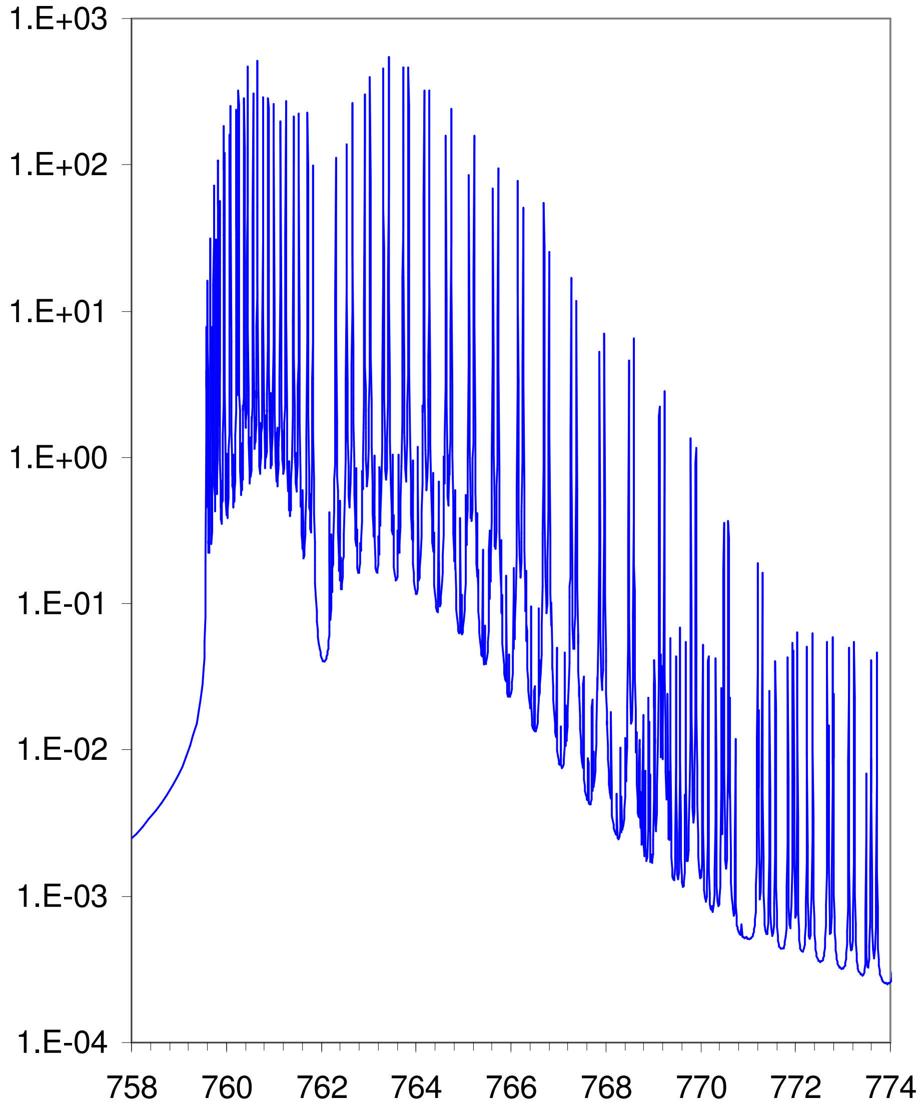


Simulation multiple
cloud layers



Retrieval one
cloud layer

O_2 A band



O_2 A band used for cloud characterization:

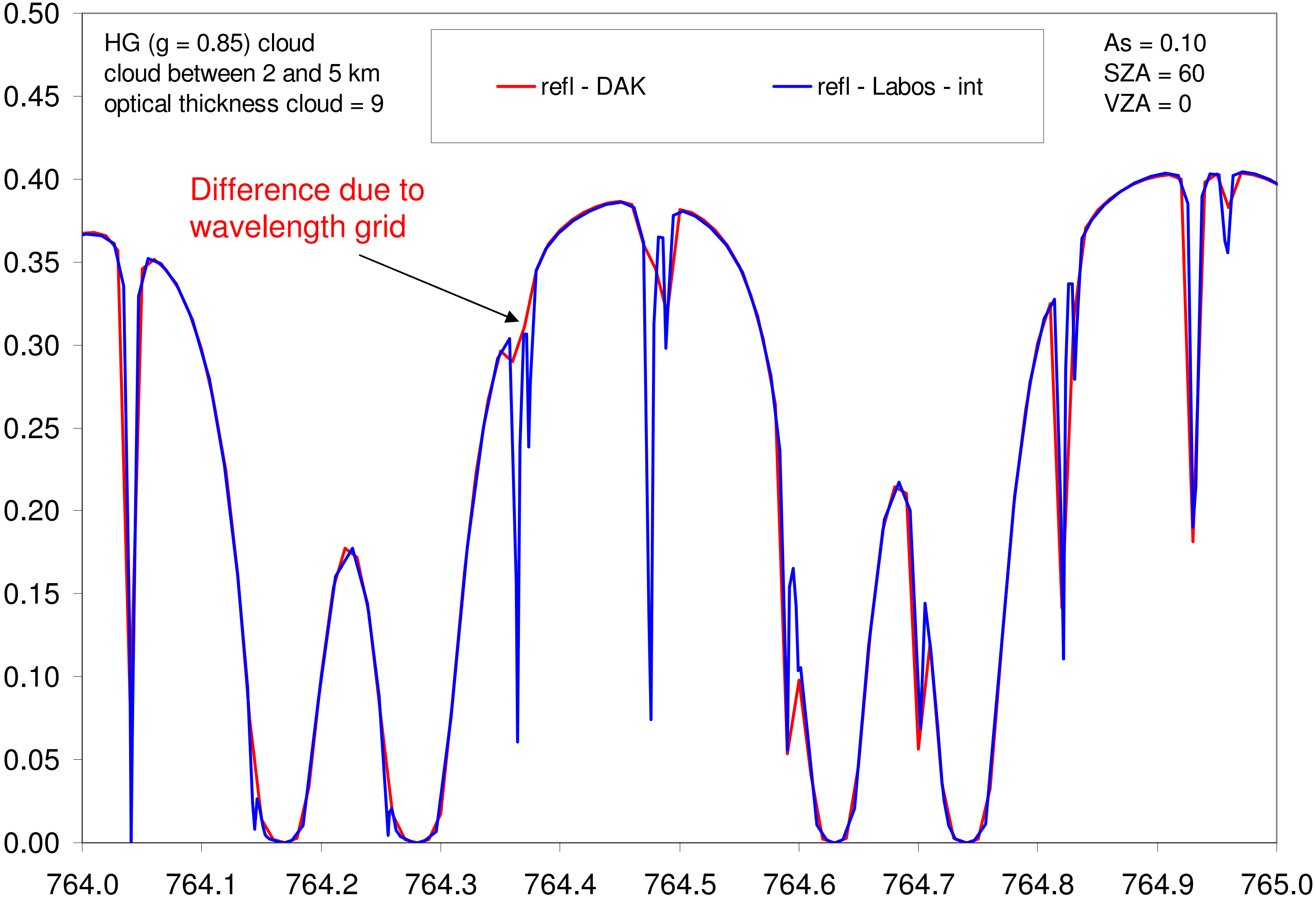
- Cloud optical thickness
- Cloud fraction
- Cloud altitude

Currently FRESCO is used which is based on a few spectral regions in the band
and a fixed cloud albedo

Earlier work by
Van Diedenhoven (SRON) fit also part of the UV to separate cloud fraction and cloud albedo / cloud optical thickness

Here look at the information content O_2 A band.

Comparison with DAK for O_2 A band



O2 A band

Cloud between 2.1 and 2.6 km

Cloud optical thickness = 5

Solar zenith angle = 60, Nadir viewing

Surface albedo (760 nm) = 0.15, cloud fraction = 0.2

O_2 A band without UV-VIS yields high correlations for the error covariance => large errors in cloud fraction and cloud optical thickness

	fraction	thickness	altitude
fraction	1.000000	– 0.999945	0.979800
thickness	– 0.999945	1.000000	– 0.981831
altitude	0.979800	– 0.981831	1.000000

O_2 A band

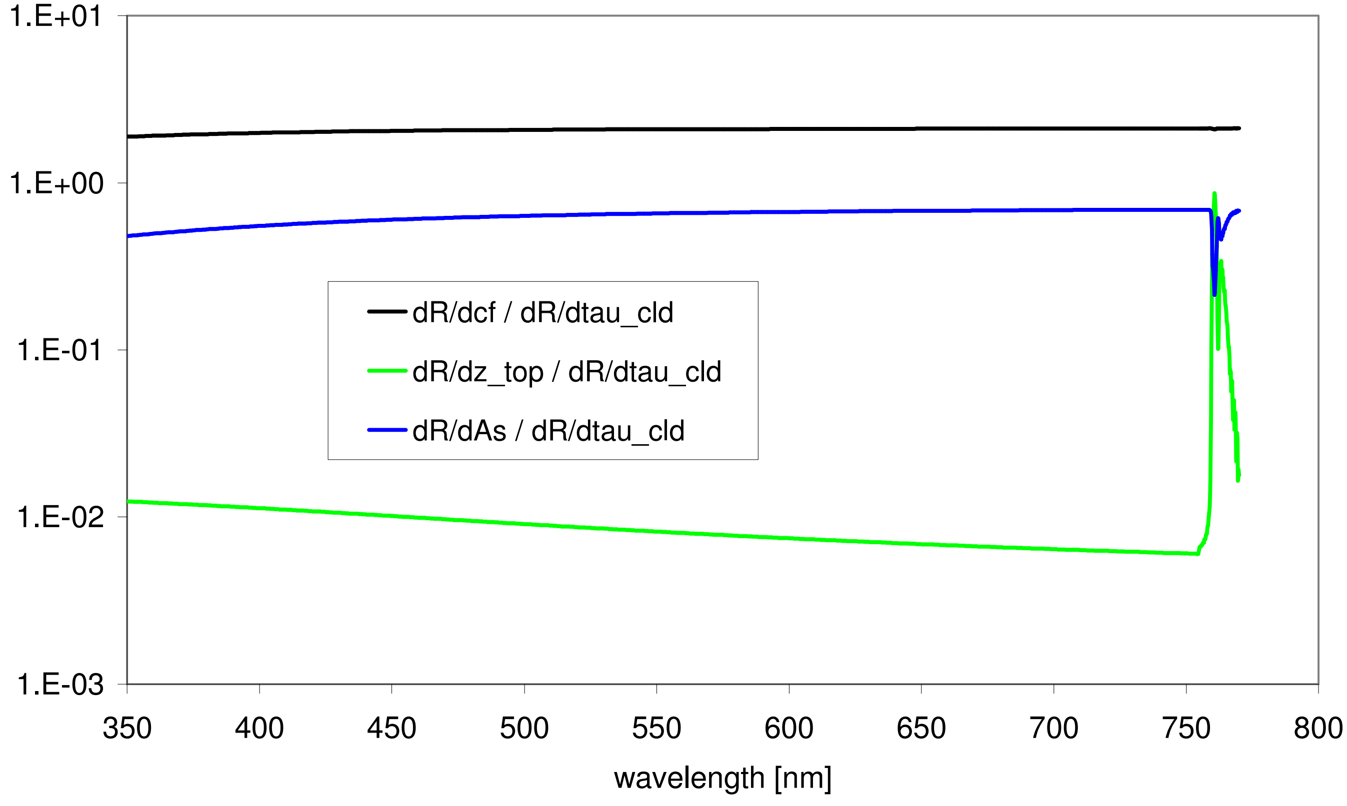
$$\frac{R_{meas}(\lambda) - R_{model}(\lambda)}{\partial R(\lambda)/\partial \tau_c} = \Delta\tau_c + \frac{\partial R(\lambda)/\partial c_f}{\partial R(\lambda)/\partial \tau_c}\Delta c_f + \frac{\partial R(\lambda)/\partial z_{top}}{\partial R(\lambda)/\partial \tau_c}\Delta z_{top} + \frac{\partial R(\lambda)/\partial A_s}{\partial R(\lambda)/\partial \tau_c}\Delta A_s$$

spectral fit of the reflectance => parameters can be distinguished if the spectral shape of the derivatives are different

Example:
SZA = 60 VZA = 0
cloud optical thickness (tau_cld) = 10
cloud fraction (cf) = 0.2
cloud top altitude (z_top) = 2.6 km (2.1 – 2.6 km)
surface albedo (As) = 0.04

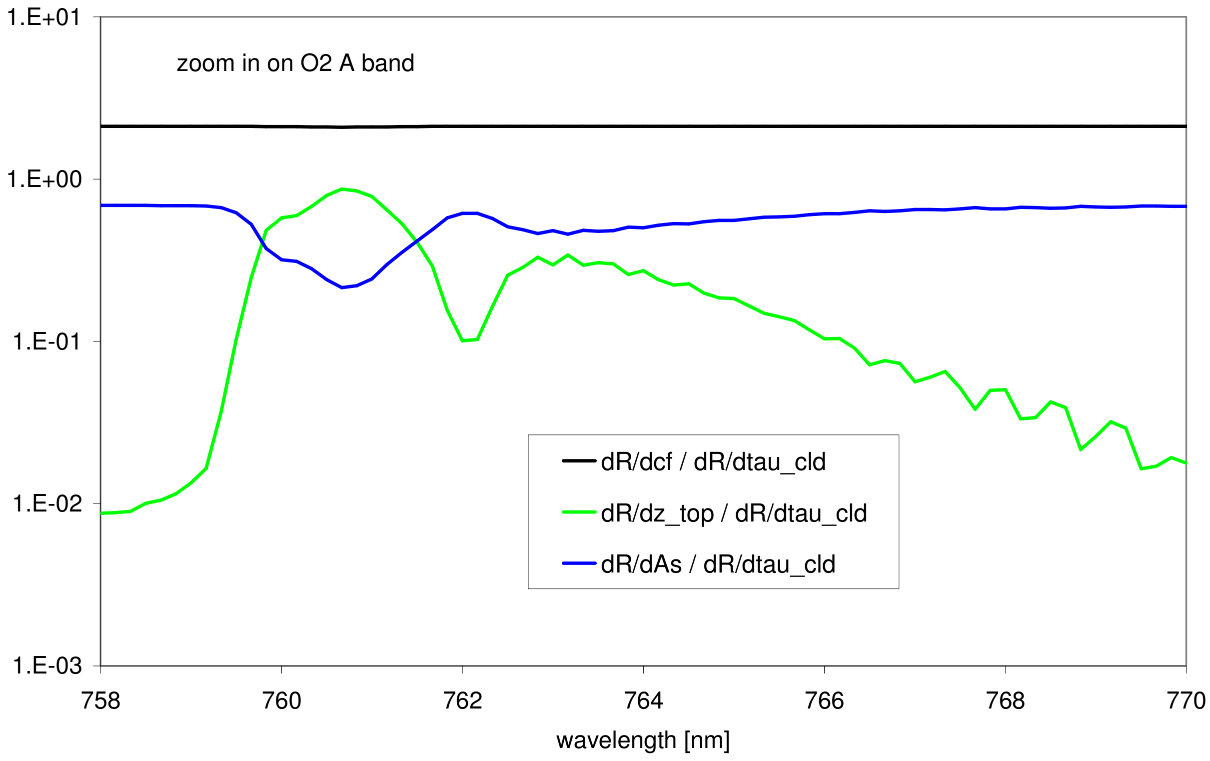
Derivatives - 1

$$\frac{R_{meas}(\lambda) - R_{\mathrm{mod}el}(\lambda)}{\partial R(\lambda)/\partial \tau_c} = \Delta\tau_c + \frac{\partial R(\lambda)/\partial c_f}{\partial R(\lambda)/\partial \tau_c}\Delta c_f + \frac{\partial R(\lambda)/\partial z_{top}}{\partial R(\lambda)/\partial \tau_c}\Delta z_{top} + \frac{\partial R(\lambda)/\partial A_s}{\partial R(\lambda)/\partial \tau_c}\Delta A_s$$



Derivatives - 2

$$\frac{R_{meas}(\lambda) - R_{model}(\lambda)}{\partial R(\lambda)/\partial \tau_c} = \Delta \tau_c + \frac{\partial R(\lambda)/\partial c_f}{\partial R(\lambda)/\partial \tau_c} \Delta c_f + \frac{\partial R(\lambda)/\partial z_{top}}{\partial R(\lambda)/\partial \tau_c} \Delta z_{top} + \frac{\partial R(\lambda)/\partial A_s}{\partial R(\lambda)/\partial \tau_c} \Delta A_s$$

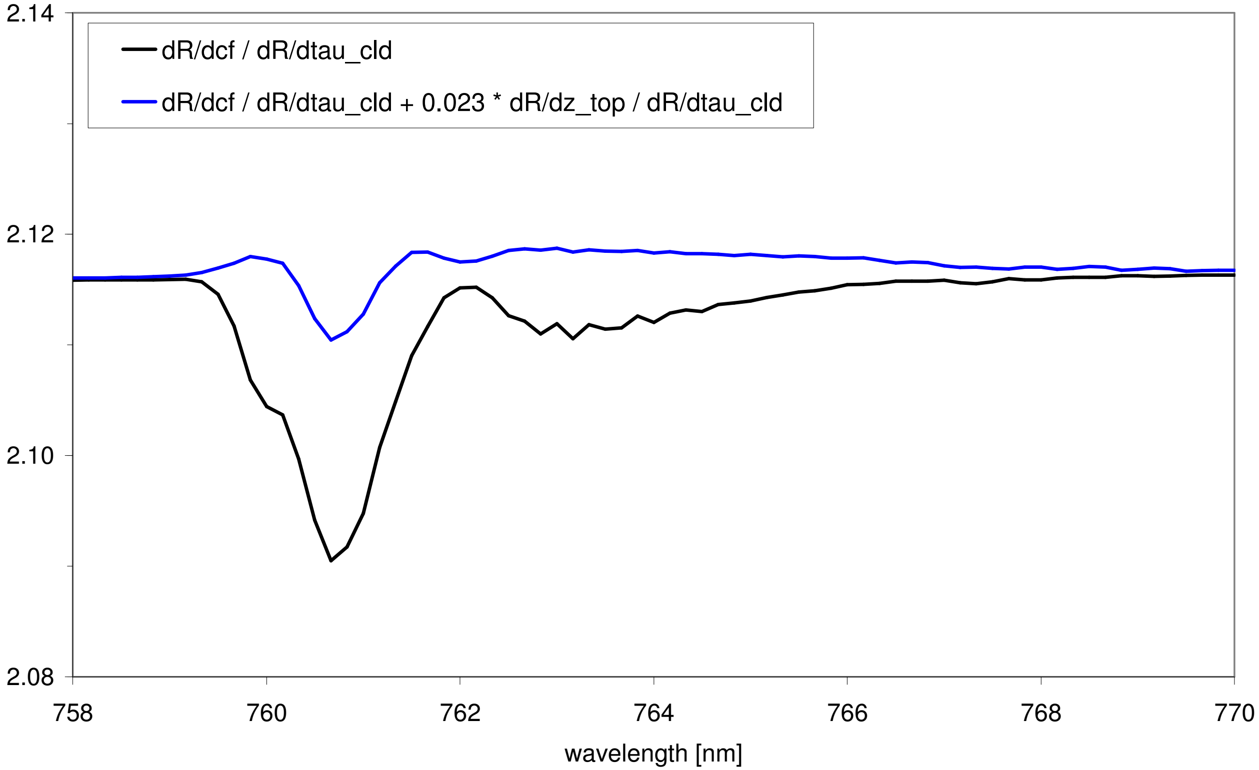


Deriving the cloud top and the surface albedo (O_2A band) is no problem (green and blue)

Difficult to discrimate between cloud fraction and cloud optical thickness (black line nearly constant)

Derivatives - 3

$$\frac{R_{meas}(\lambda) - R_{model}(\lambda)}{\partial R(\lambda)/\partial\tau_c} = \Delta\tau_c + \frac{\partial R(\lambda)/\partial c_f}{\partial R(\lambda)/\partial\tau_c}\Delta c_f + \frac{\partial R(\lambda)/\partial z_{top}}{\partial R(\lambda)/\partial\tau_c}\Delta z_{top} + \frac{\partial R(\lambda)/\partial A_s}{\partial R(\lambda)/\partial\tau_c}\Delta A_s$$

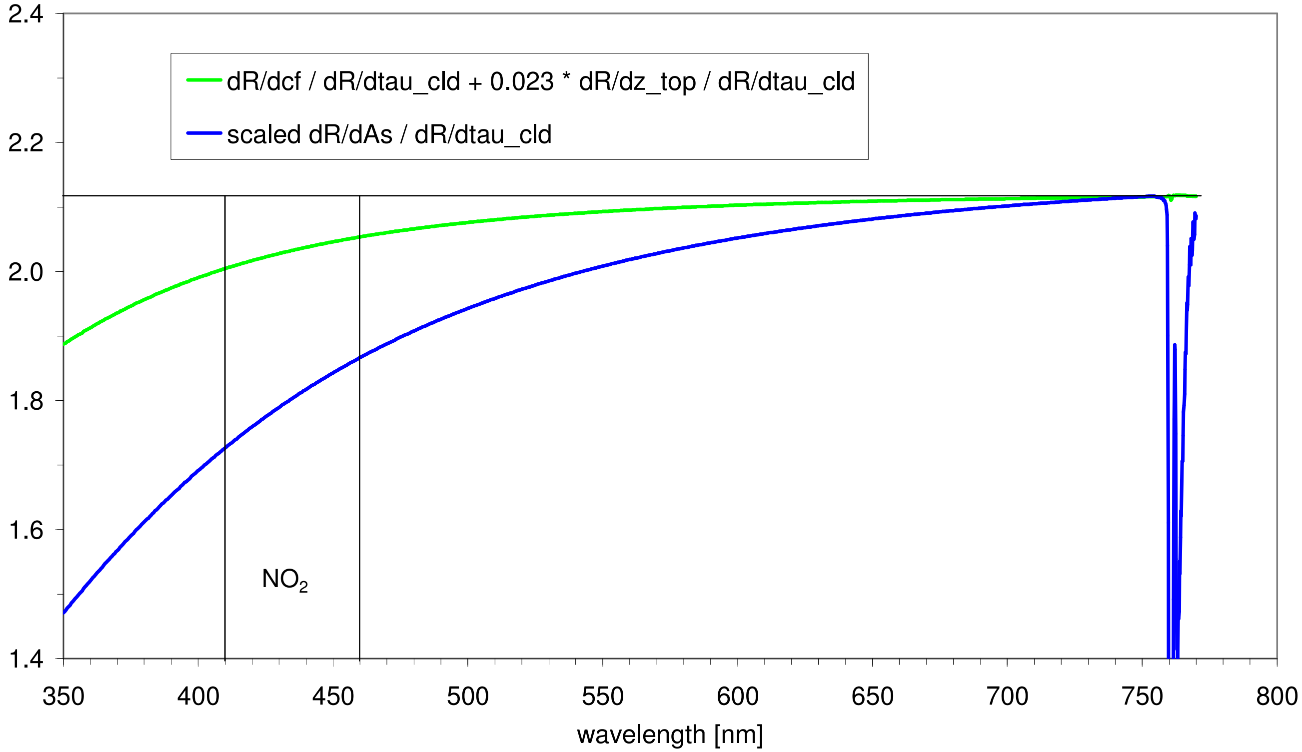


Blue line:
linear combination
nearly constant

S/N > 10000
needed to
distinguish cloud
fraction and cloud
optical thickness
from O_2 A band
alone

Derivatives - 4

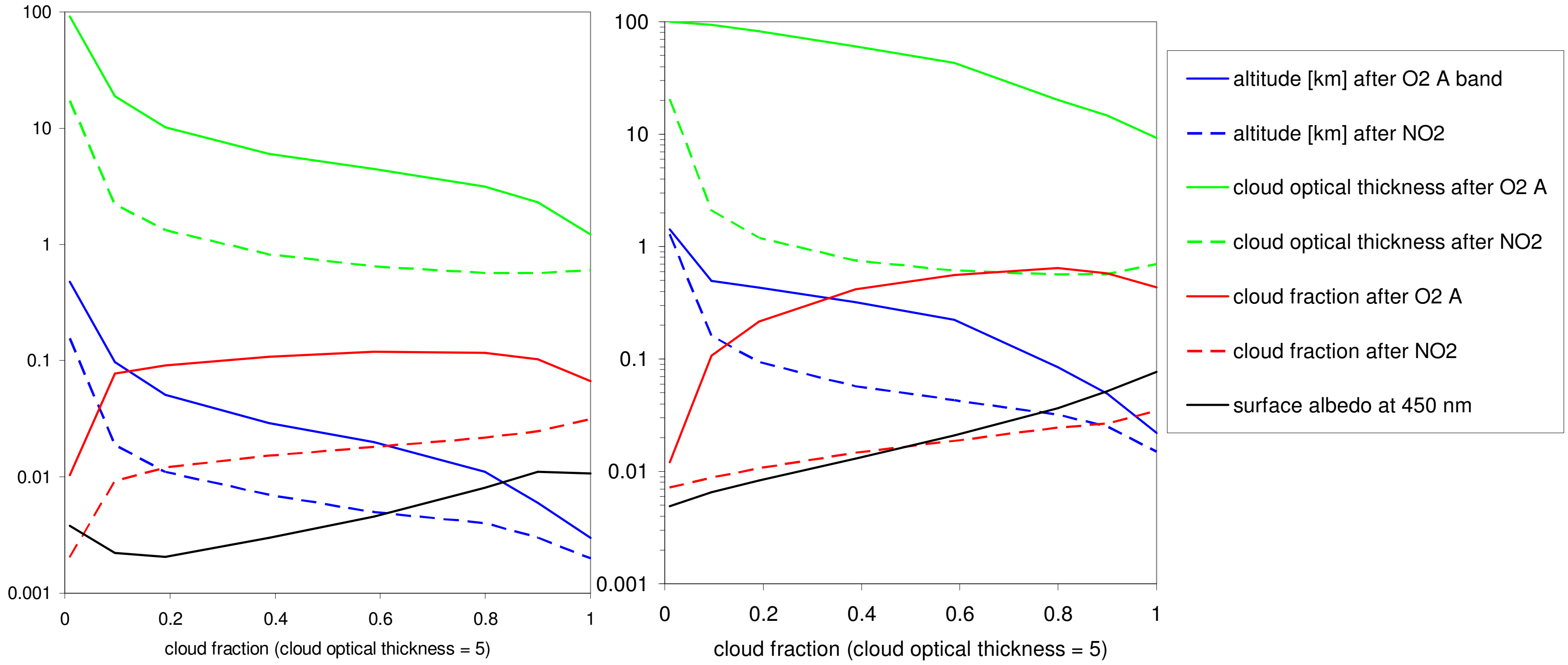
$$\frac{R_{meas}(\lambda) - R_{model}(\lambda)}{\partial R(\lambda)/\partial \tau_c} = \Delta\tau_c + \frac{\partial R(\lambda)/\partial c_f}{\partial R(\lambda)/\partial \tau_c}\Delta c_f + \frac{\partial R(\lambda)/\partial z_{top}}{\partial R(\lambda)/\partial \tau_c}\Delta z_{top} + \frac{\partial R(\lambda)/\partial A_s}{\partial R(\lambda)/\partial \tau_c}\Delta A_s$$



In UV/VIS green and blue line differ from a horizontal line and differ from each other
=>
possible to fit
surface albedo (NO_2)
surface albedo (O_2A)
cloud fraction
cloud optical thickn
cloud altitude
separately for combined retrieval

Different S/N values O_2 A band

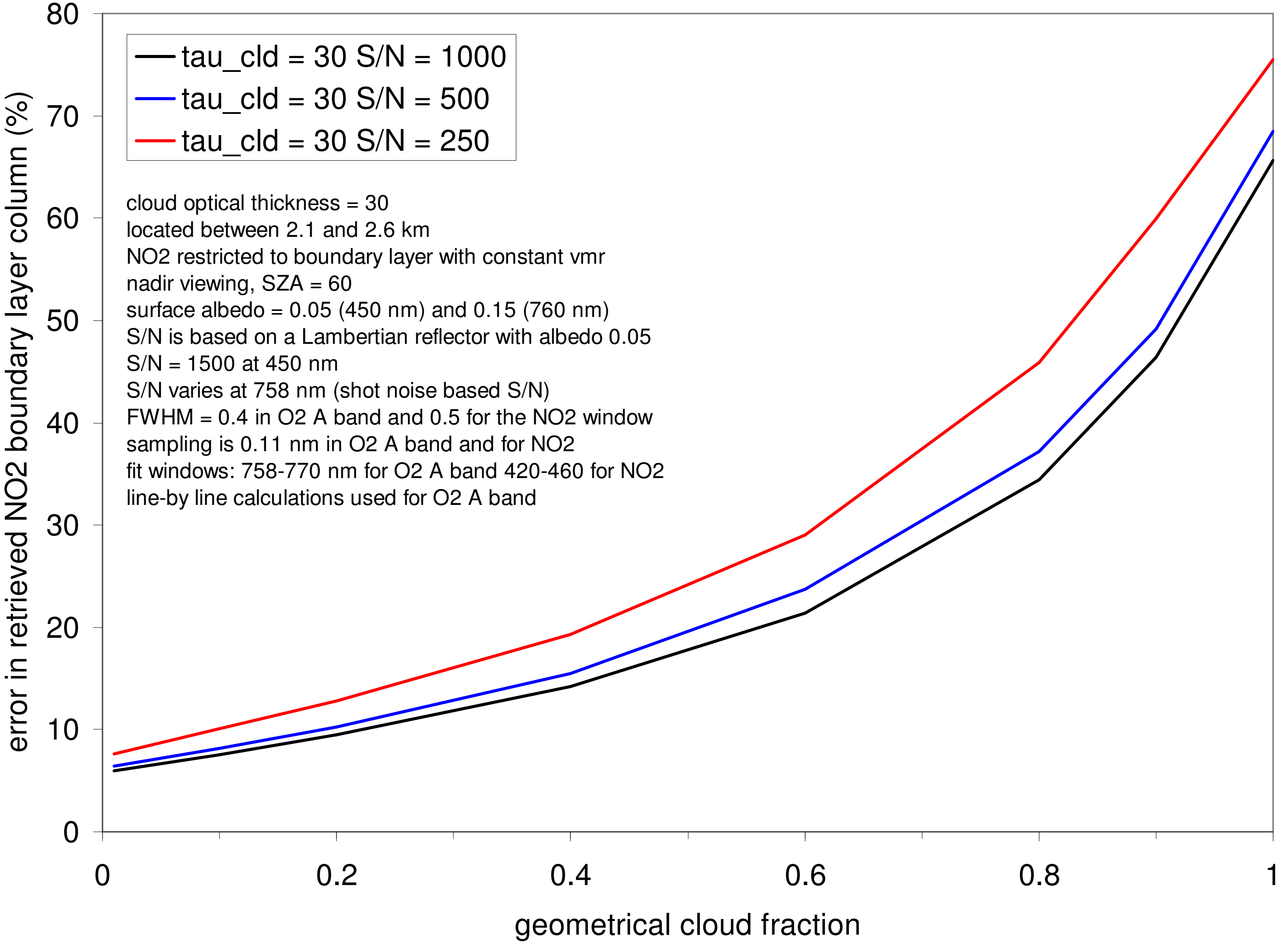
S/N = 2000   S/N = 200



Combined retrieval O2 A band and NO2

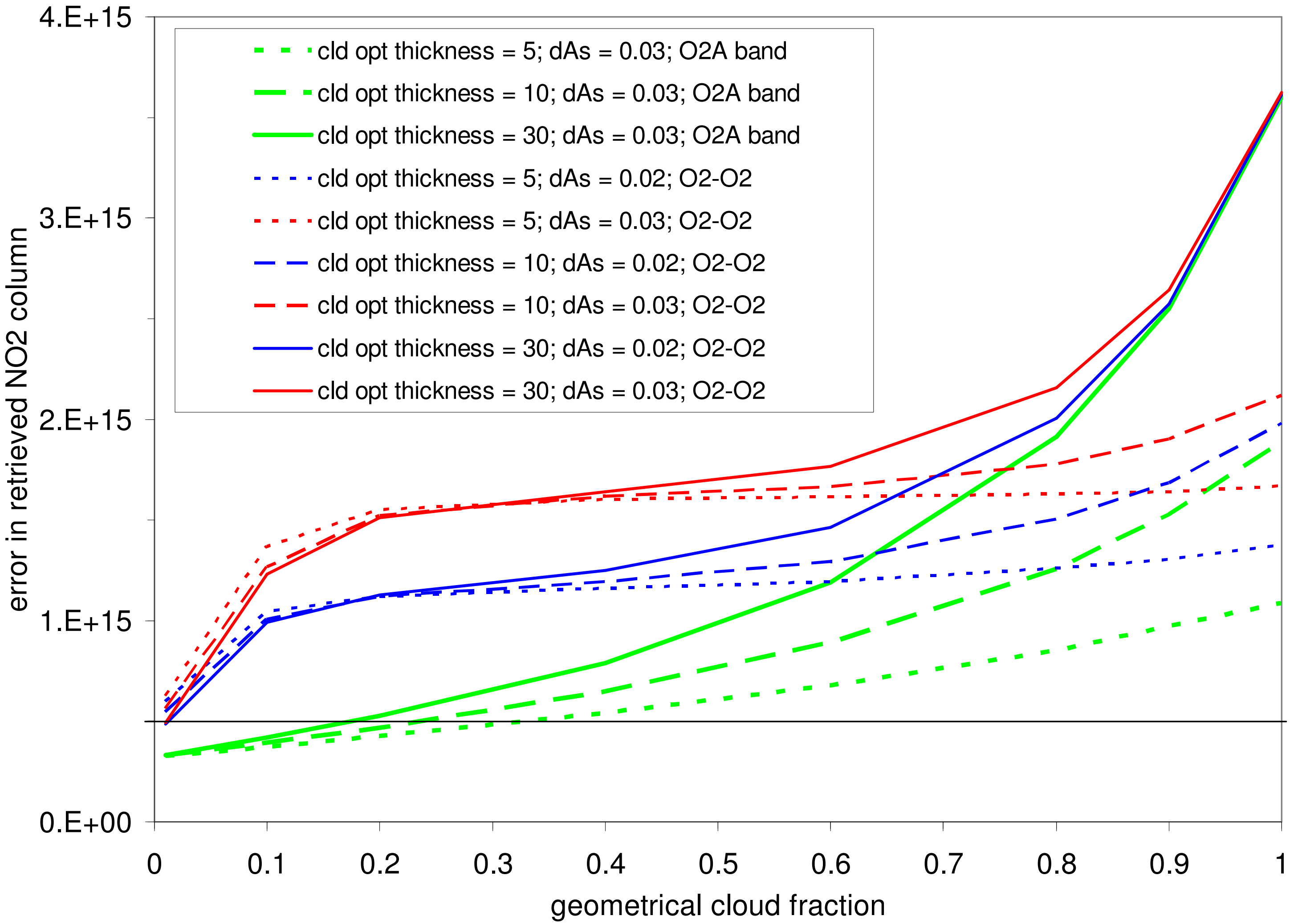
SZA = 60, nadir view, cloud above PBL (2.1-2.6 km), tau_cld = 5

Different S/N values O_2 A band



O_2-O_2 at 477 vs O_2 A band

small error in surface albedo data base is essential for O_2-O_2



As = 0.05

SZA = 60

nadir view

410-460 nm

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Conclusions / Outlook

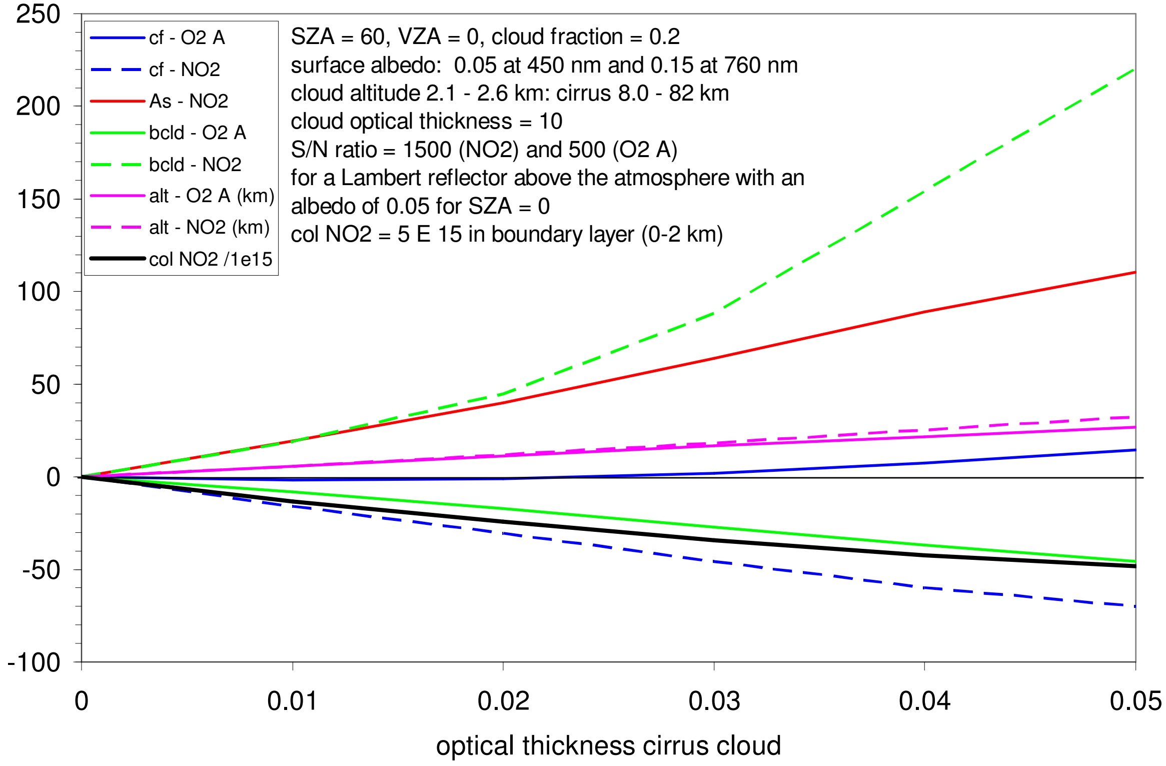
- Able to derive NIR instrument requirements using a combined NO_2 and O_2 A band retrieval.
- Confirmed that O_2 A band alone can not give cloud fraction and cloud optical thickness, unless S/N > 10000.
- Combined O_2 A band and NO_2 retrieval can provide accurate values for surface albedo (450 nm), cloud fraction, cloud optical thickness, and cloud altitude => reduction error in NO_2 column and makes retrieval possible for larger cloud fractions.
- All this is based on simulations.
  Perhaps SCIAMACHY measurements can be used to test this (outside the scope of CAMELOT project).
  Plan to use this (or a similar) approach for TROPOMI

Back-up slides

Complication: cirrus clouds

Spectral variation due to Rayleigh scattering is used to distinguish between cloud fraction, cloud optical thickness, and surface albedo.
Cirrus clouds distort this mechanism => large errors in NO_2.

error in retrieved values in percent due to thin cirrus clouds

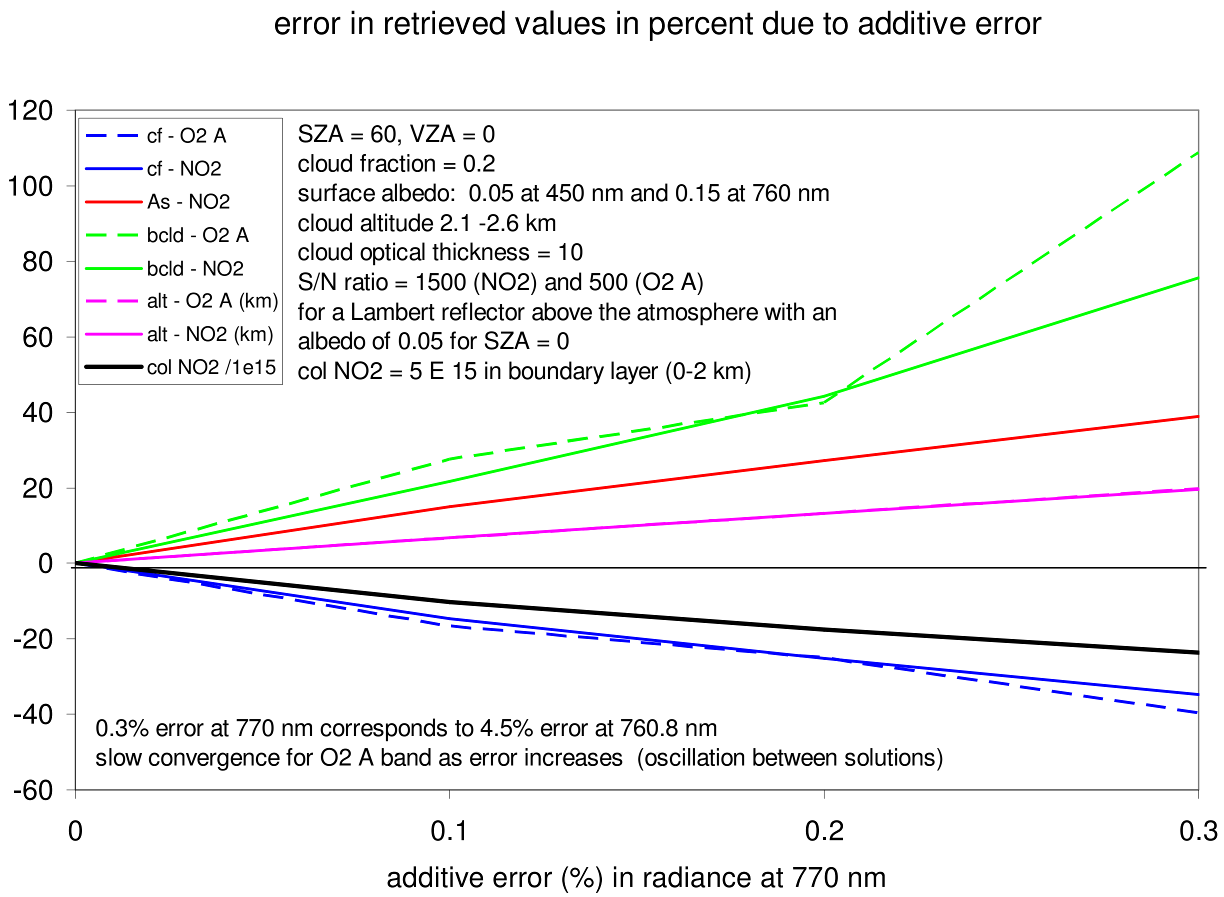


Possible solution:
Use cirrus also in the retrieval
- fixed altitude
- fully covering the pixel
- fit its optical thickness.

Current software can only fit cloud properties for one cloud layer.
Extensions needed.

Additive offsets radiance

Case considered: SZA = 60, nadir view,
cloud optical thickness = 10, cloud fraction = 0.2



Additive offset less than 0.1% at 770 nm or 1.5% at 760.7 nm is needed for an error in the NO_2 column < 10%.