Absolute calibration of sky radiances, colour indices and O_4 DSCDs obtained from MAX-DOAS measurements

T. Wagner, S. Beirle, S. Dörner, M. Penning de Vries, J. Remmers, R. Shaiganfar, Y. Wang

Max-Planck-Institute for Chemistry, Mainz, Germany

- Calibration of radiances (proportionality factor)
- Calibration of colour indices (proportionality factor)
- Calibration of the O_4 absoption (offset)

Why absolute radiometric calibration?

- Improved aerosol retrievals from MAX-DOAS: No normalisation by zenith sky observations needed. Possible separation of aerosol absorption and scattering.

- Improved cloud characterisation, e.g. quantitative comparison measured and simulated radiances from cloud sides.

- Estimation of actinic fluxes and UV doses at the surface, quantification of earth's radiation budget.

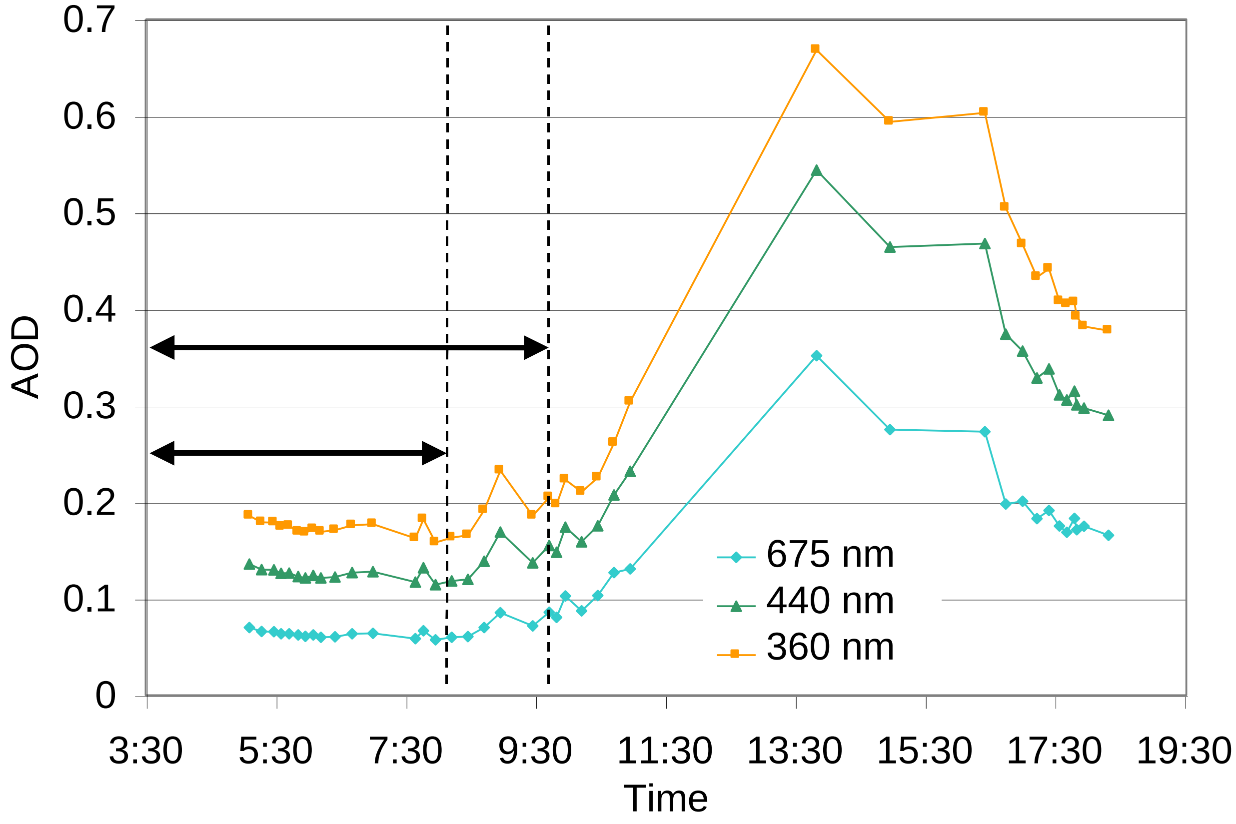
- Estimation of the energy yield of photovoltaic cells (including cells in the shadow).

Why calibration of CI and O_4?

- For cloud classification from MAX-DOAS.

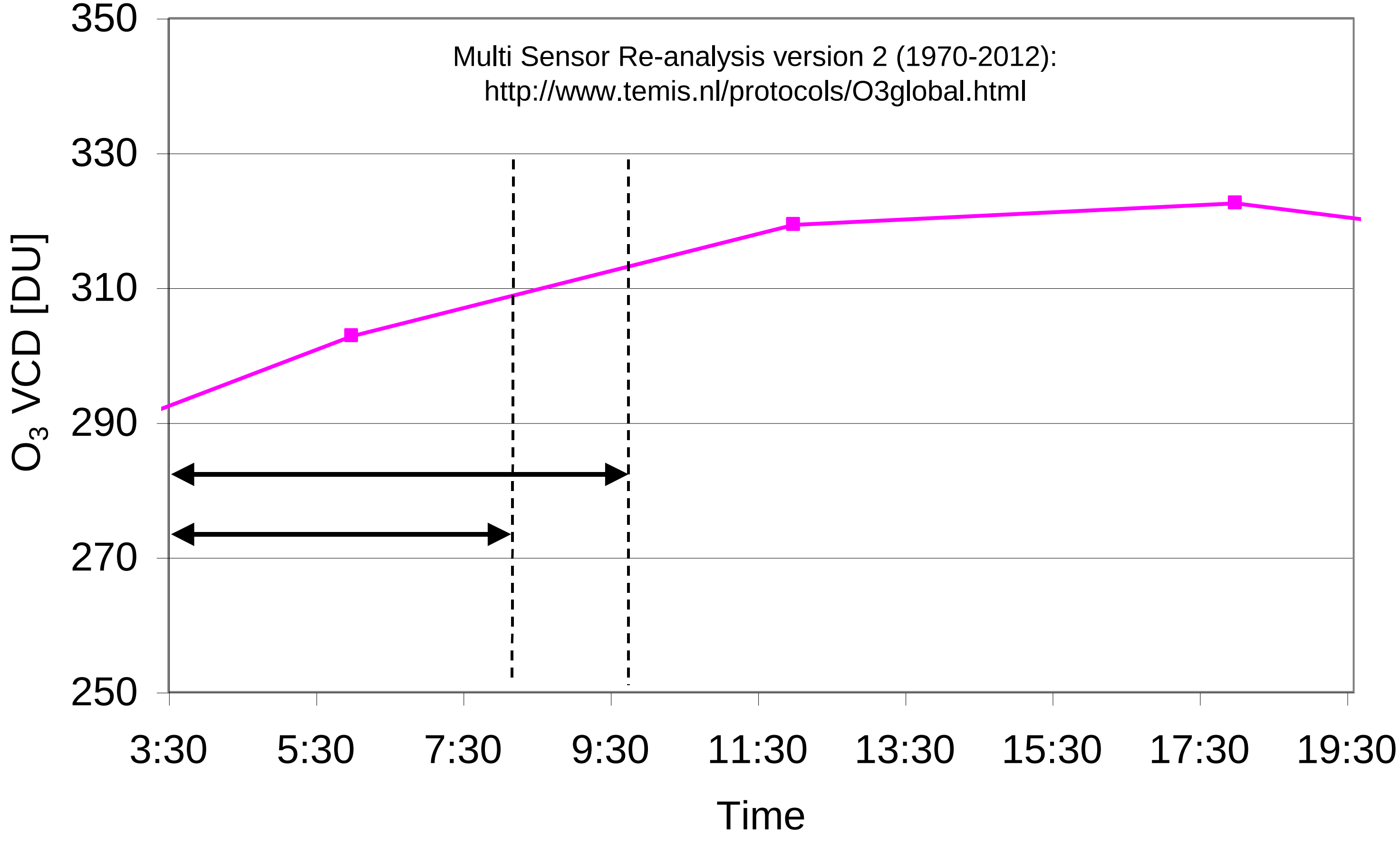
=> towards standardised cloud classification schemes (independent from instrument properties).

For the radiance calibration ‘stable’ measurement conditions are needed, e.g. constant AOD and O_3 VCD



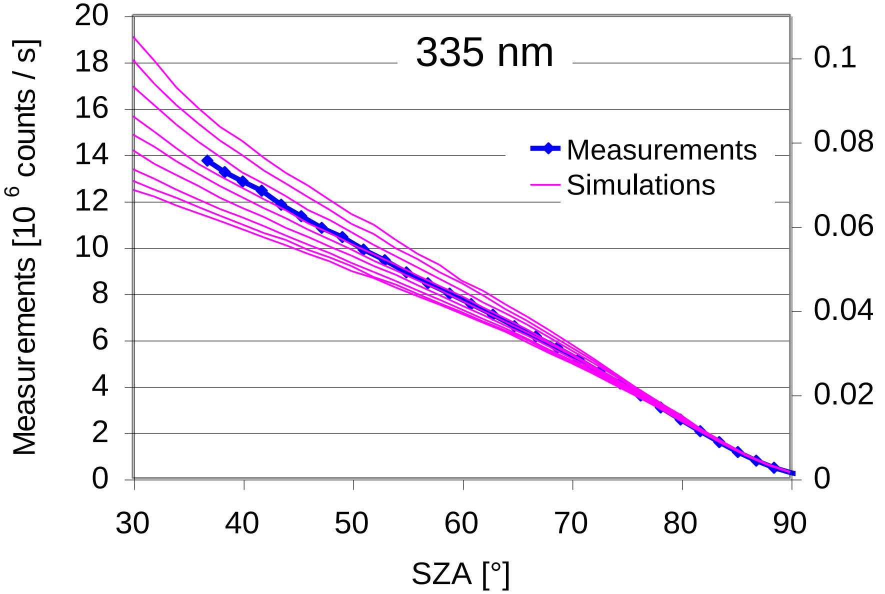
AERONET AOD at Cabauw at three wavelengths. The black arrows indicate the periods used in this study.(SZA: 37° - 90° or 50° - 90°)

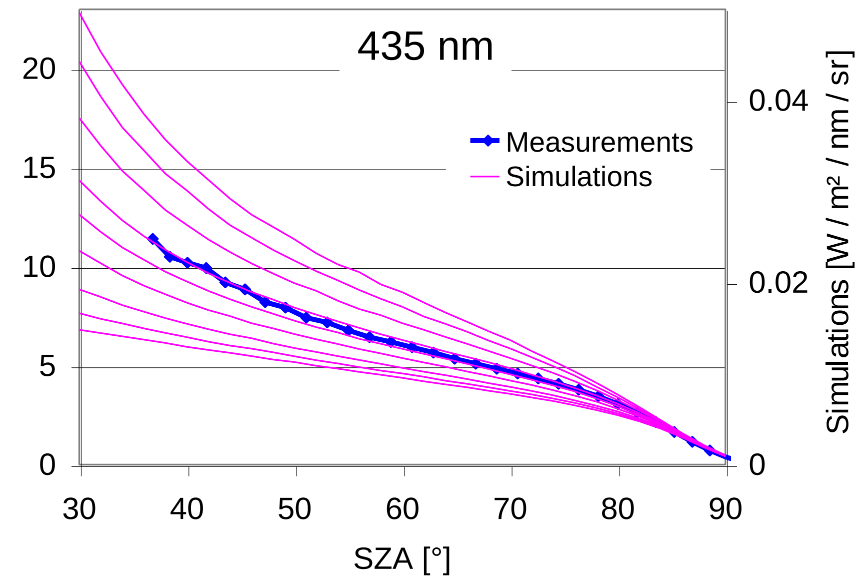
For the radiance calibration 'stable' measurement conditions are needed, e.g. constant AOD and O_3 VCD



O3 VCD above Cabauw

The method is based on the comparison of the SZA dependence of measured (blue, right axis) and simulated radiances (magenta lines, left axis).





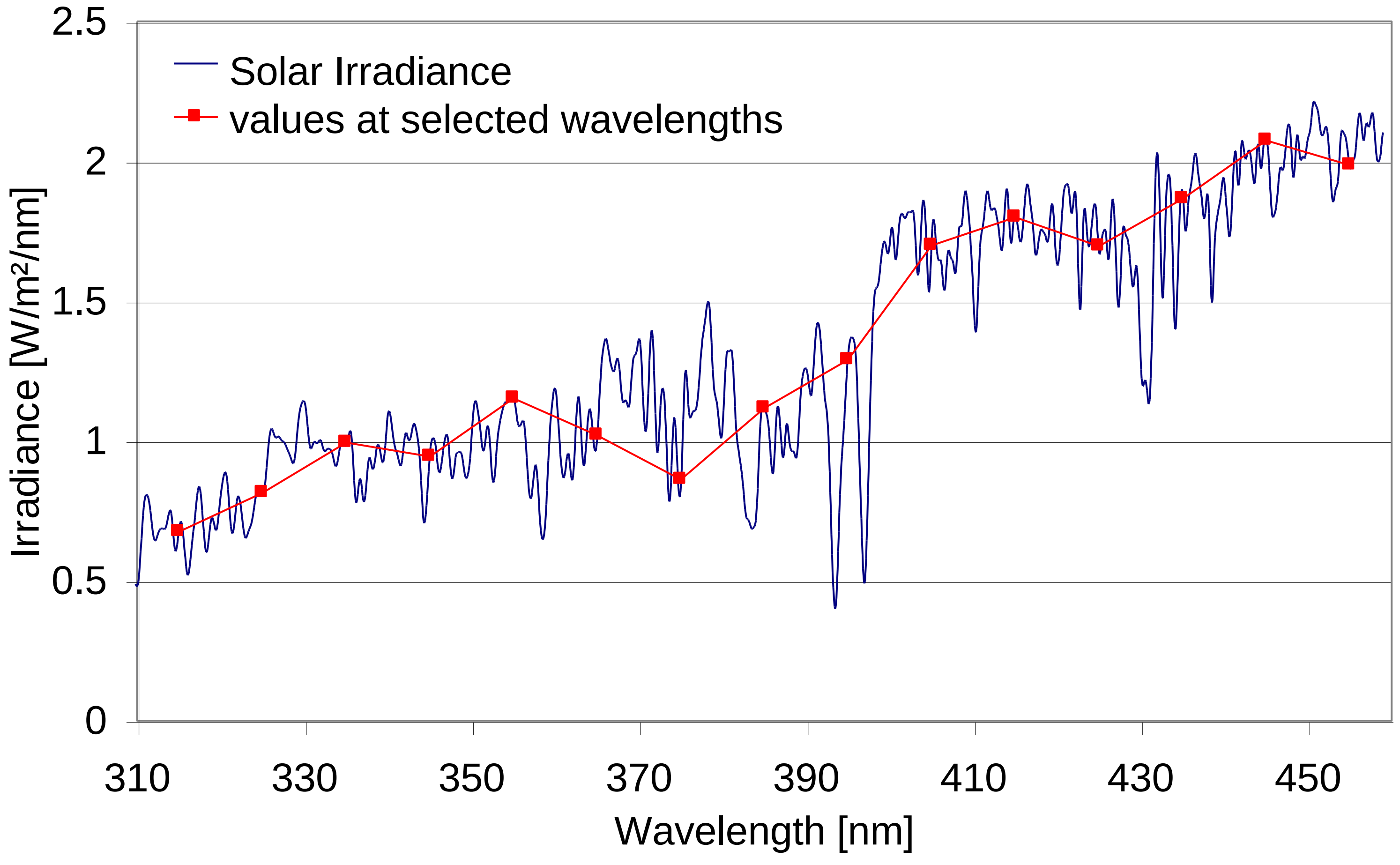
Here examples for two wavelengths are shown (the method is applied for the spectral range from 315 – 465 nm in intervals of 10 nm)

Care has to be taken that the radiance simulations exactly match the extraction of the measured radiance.

=> Exact wavelength calibration

=> Convolution of high resolution solar spectrum (blue line)

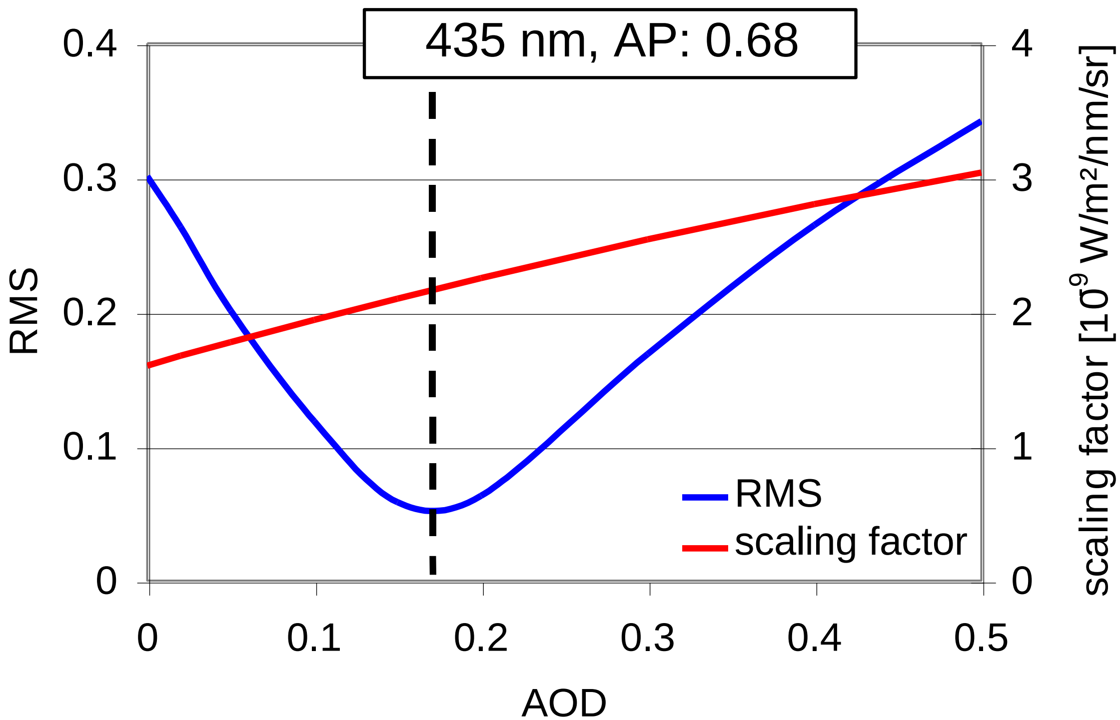
=> Same wavelength intervals (here ±3 detector pixels (red dots)



We fit the (SZA dependent) simulated radiances to the measured radiances:

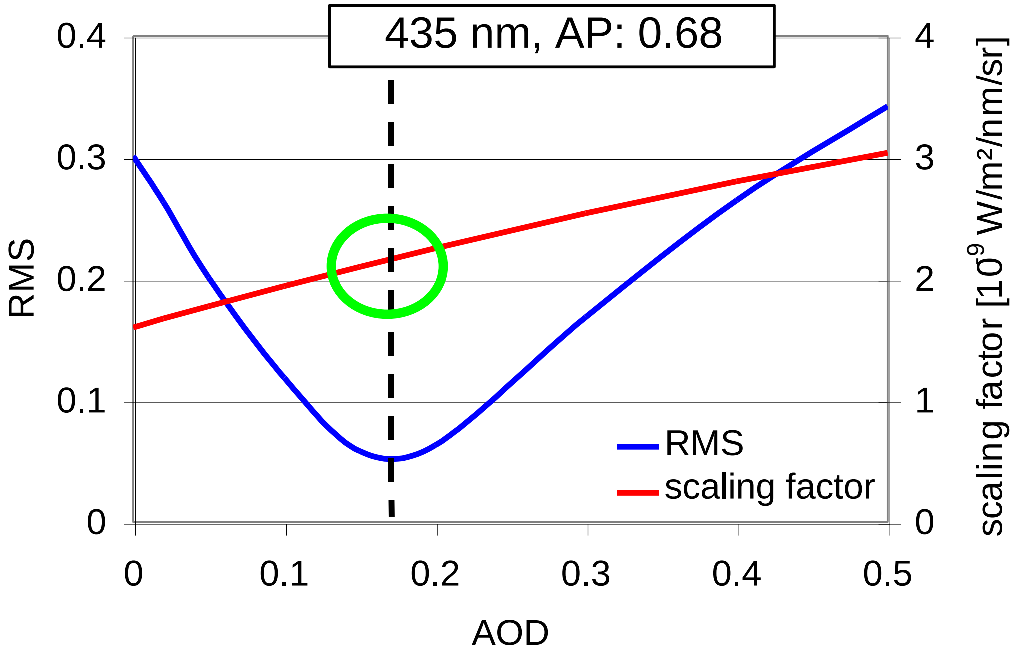
-The fit is performed individually for different scenarios and wavelengths
- different aerosol profiles, phase functions, single scattering albedo
- different surface albedo

-Simulations for different AOD are fitted; the respective RMS is determined.
-the fit coefficient for the minimum RMS represents the calibration factor



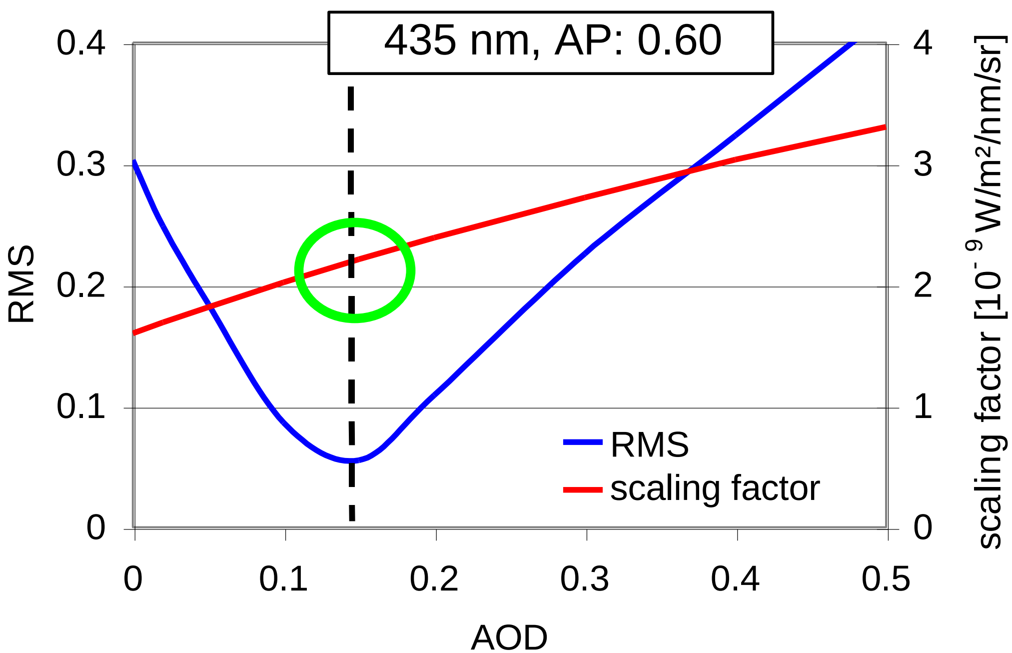
Example for 435 nm

(surface albedo: 5%, AP: 0.68, SCA: 0.95, layer height: 1 km)



Example for 435 nm

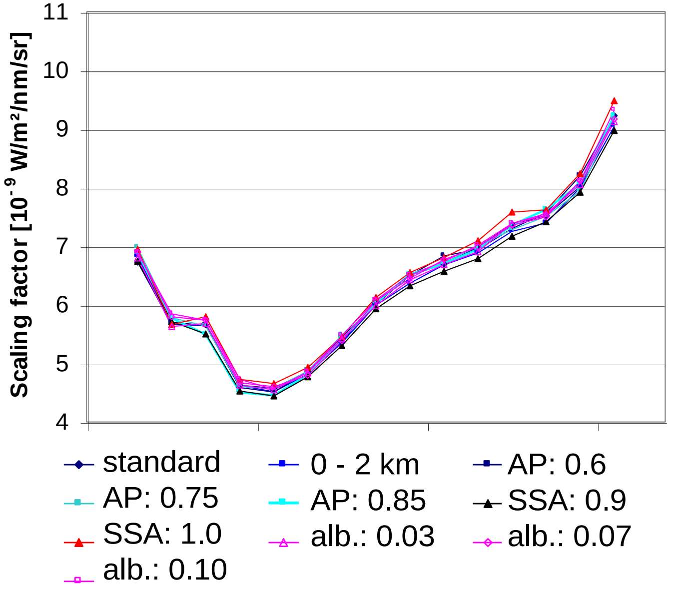
(surface albedo: 5%, AP: 0.68, SCA: 0.95, layer height: 1 km)



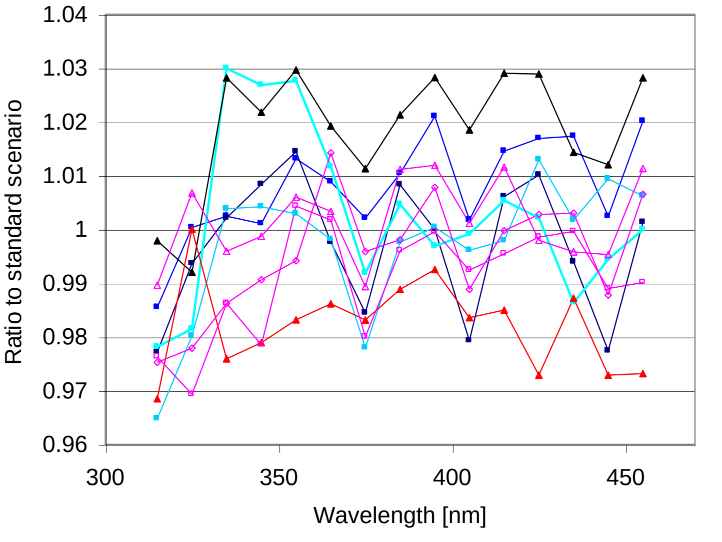
Fit results for simulation results with AP: 0.60

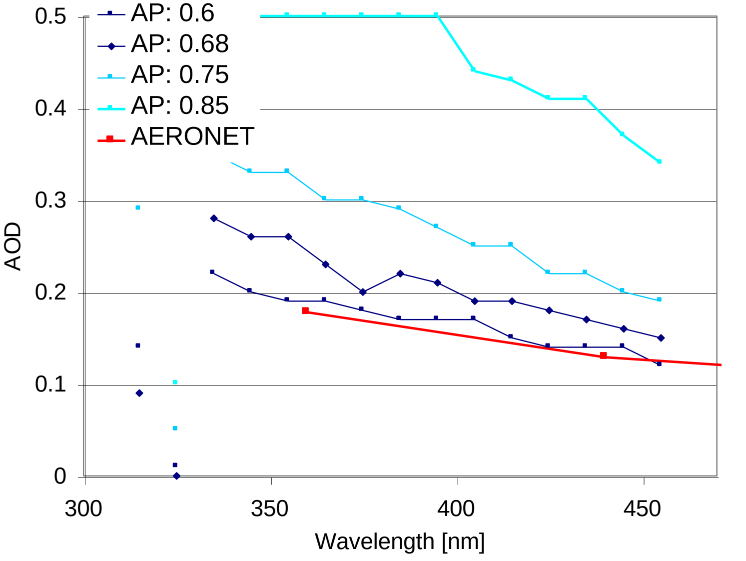
=> The scaling factor is almost independent from the aerosol phase function

Wavelength dependent scaling factors for the different scenarios



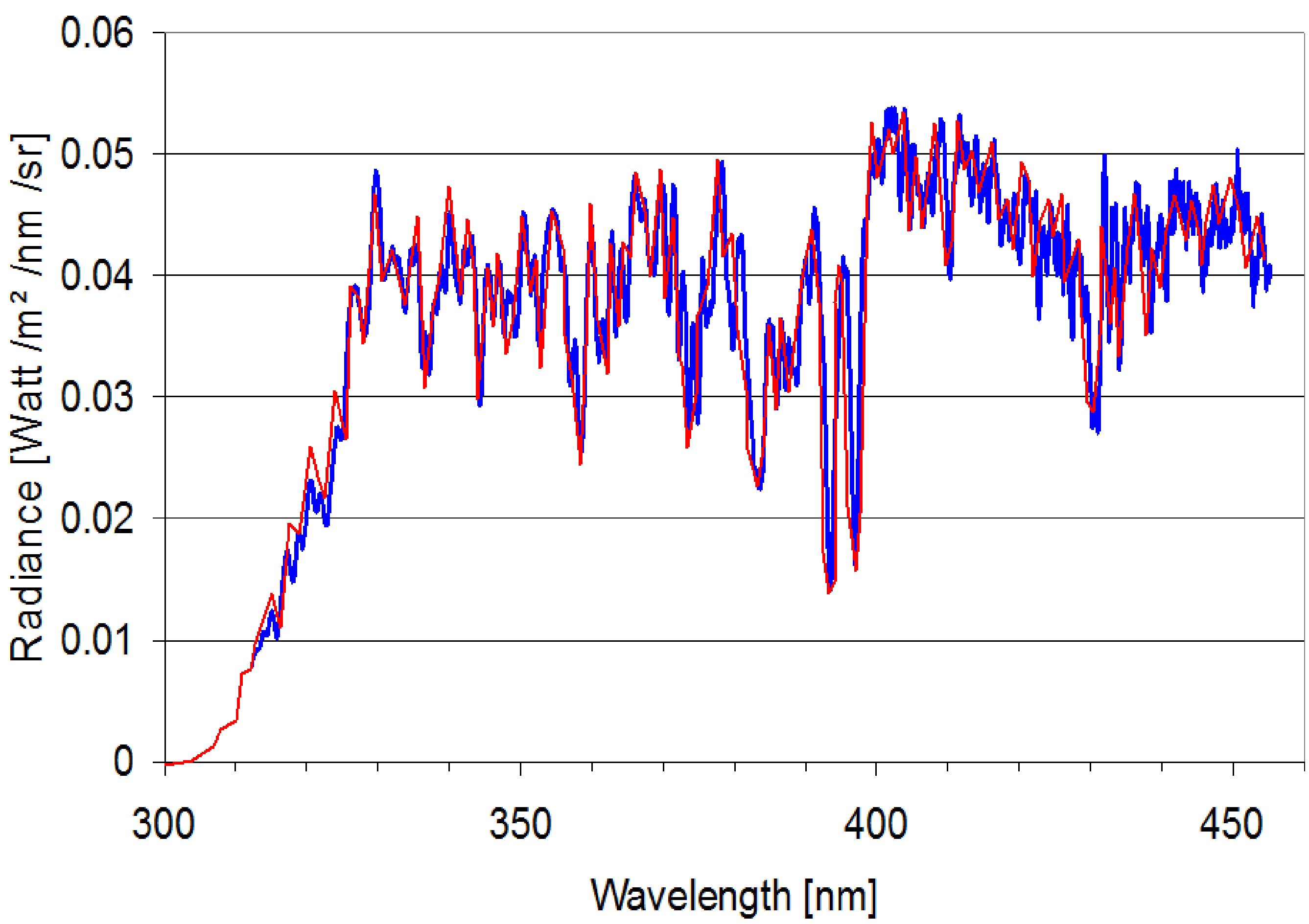
Relative differences





The simultaneous retrieved AOD depends strongly on the assumed AP

Comparison with independent measurement



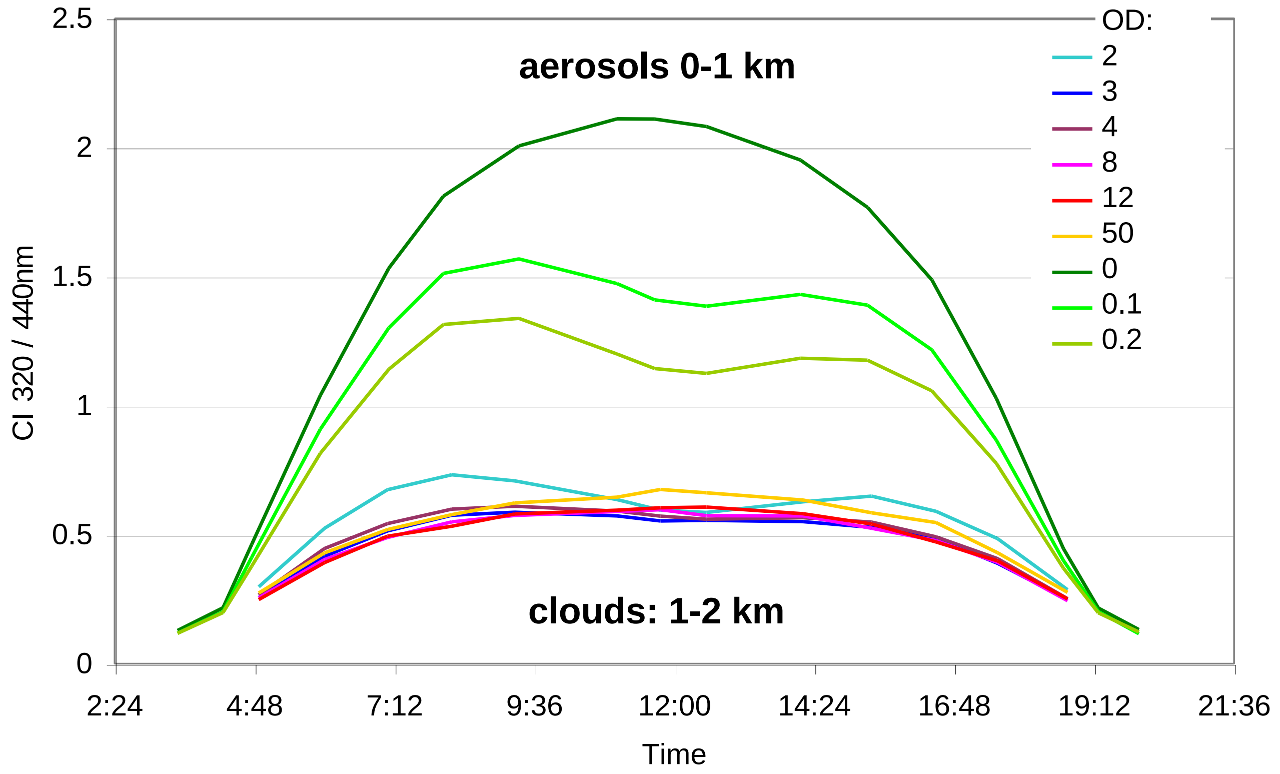
Good agreement with radiance measurement under similar conditions (red) in Hannover, Germany (SZA: 62°, Seckmeyer et al., 2009). Own measurement (blue): 24 June 2009, 6:54, SZA : 61°

Important aspects:

- Polarisation has to be considered in the simulations
- Because ozone VCD changes strongly during our measurements, calibration for wl < 330 nm has larger errors
- Variation of sun-earth-distance has to be corrected (here –3 %), maybe also solar cycle.
- Error caused by Ring effect is <1%
- Errors caused by other effects (stratospheric aerosol, BRDF, NO_2 absorption, pressure and temperture) are of the order of 1% or below

Calibration of the colour index (CI)

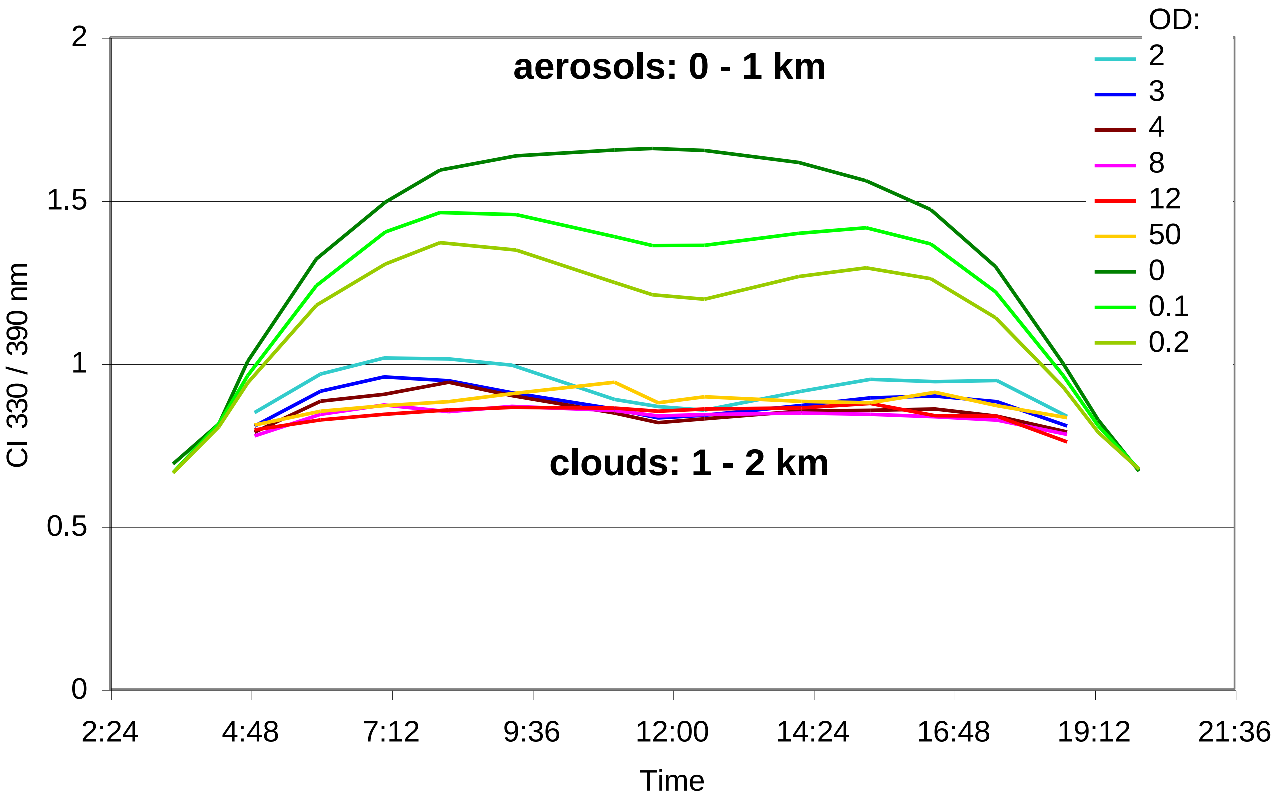
As shown in several studies (e.g. Gielen et al., 2014) the maximum CI depends critically on the AOD, especially for low AOD. Minimum CI are found for cloudy situations (but usually not for the highest optical depth)



The minimum CI is used for the calibration of the measured CI (here 320 nm and 440 nm are used)

Calibration of the colour index (CI)

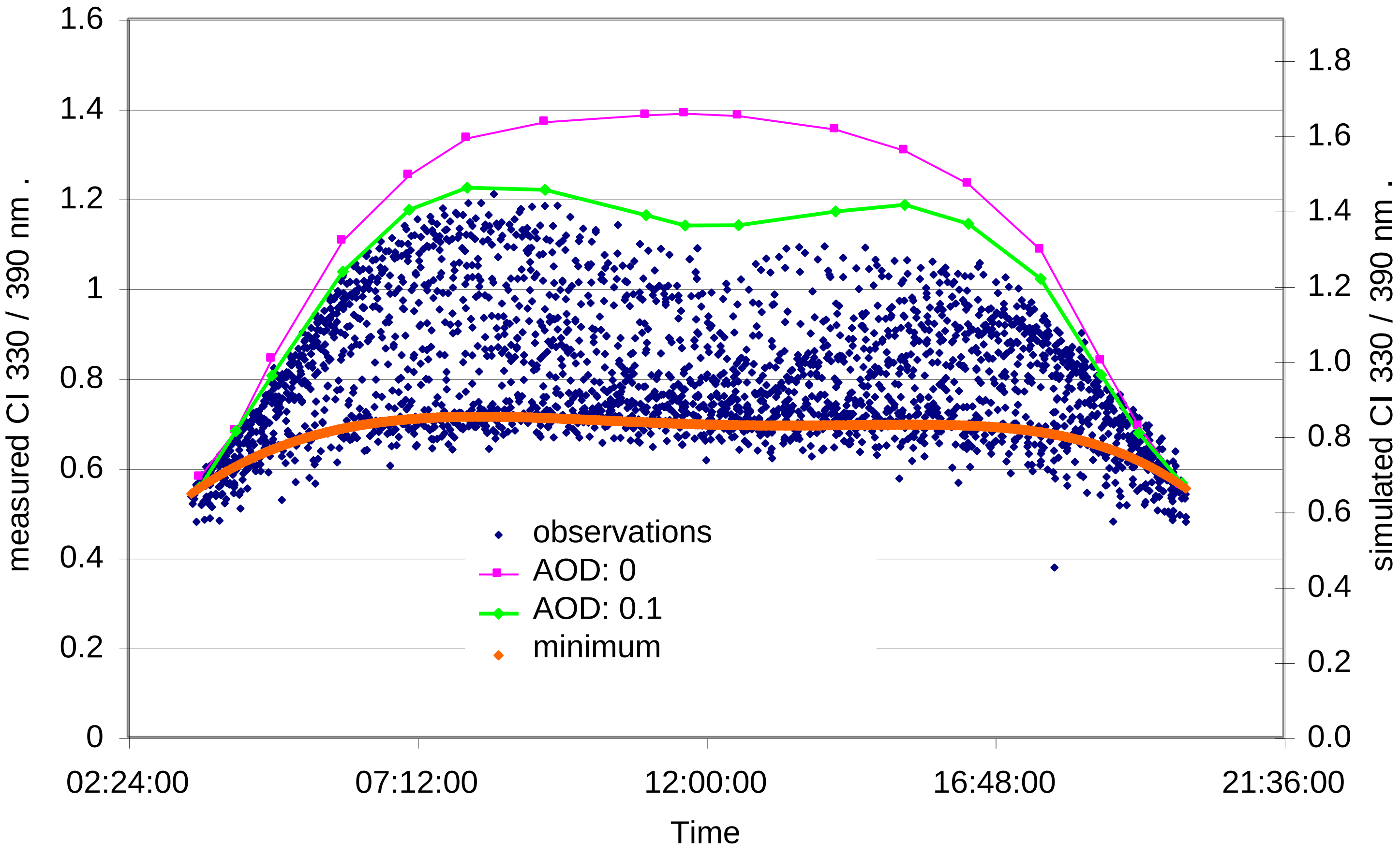
Similar results are found for other wavelength pairs (here 330 nm / 390 nm)



What is the reason for this choice?

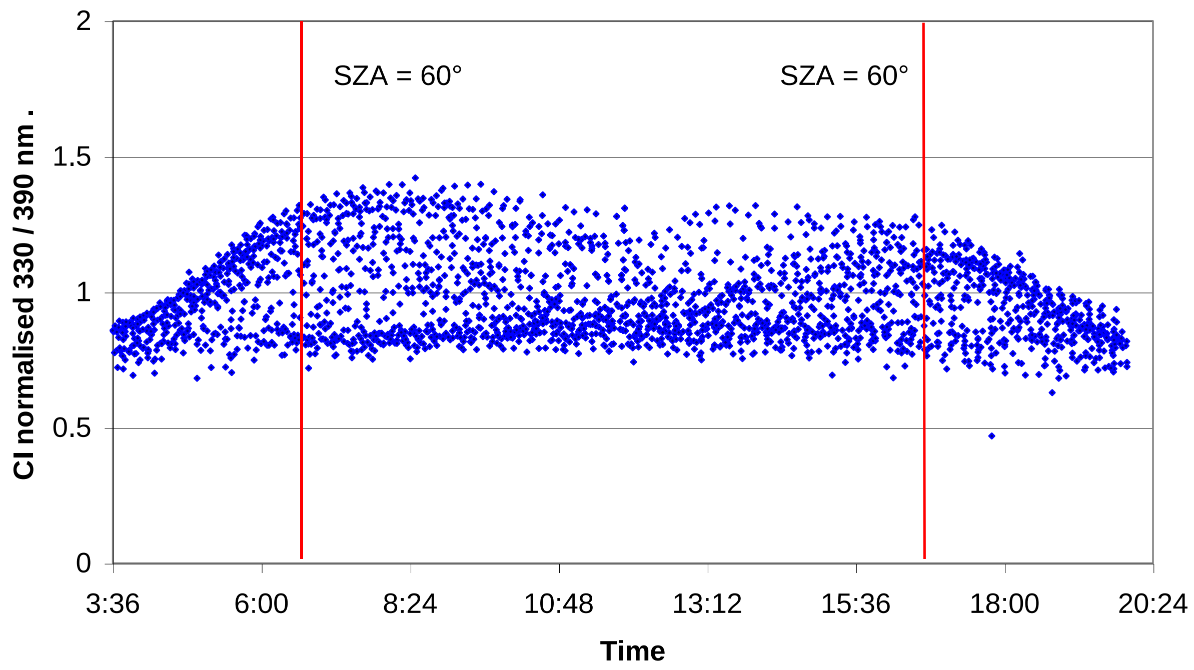
- 330 nm is outside the strongest ozone absorption
- 390 nm is covered by most UV DOAS instruments

Comparison of measured and simulated CI for the CINDI campaign



- The y-axes are chosen according ot the absolute radiane calibration.
- The measurements mostly fall between the simulation results.
- What causes the low values (and the scatter)? This can not be explained by measurement noise. Maybe 3D effects of broken clouds?

The measured CI are divided by the simulated minimum CI



The maxima of the frequency distributions represent the scaling factors for calibration.

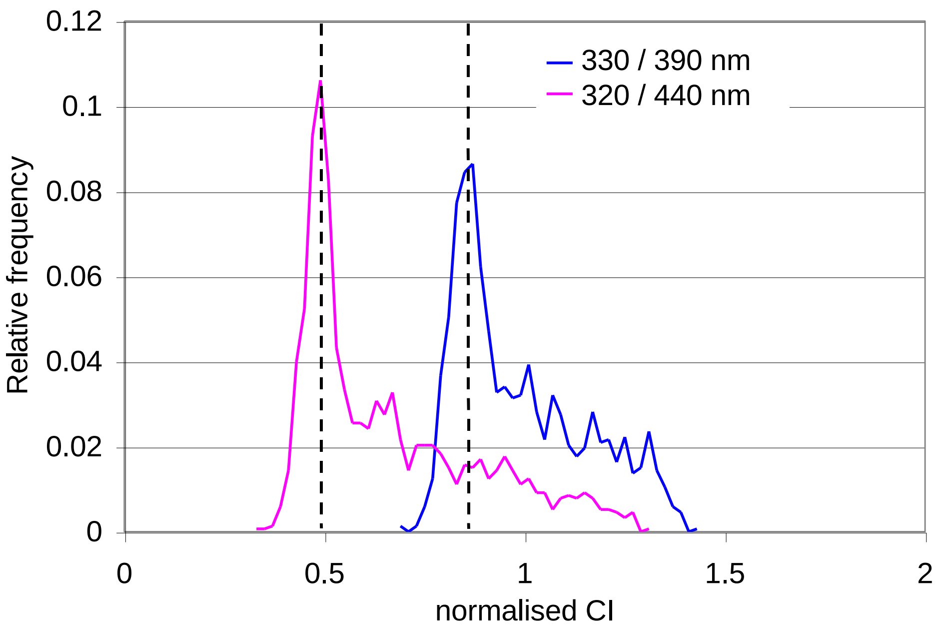
CI_{old}: 0.49±0.04

CI_{new}: 0.86±0.05

From radiance calibration:

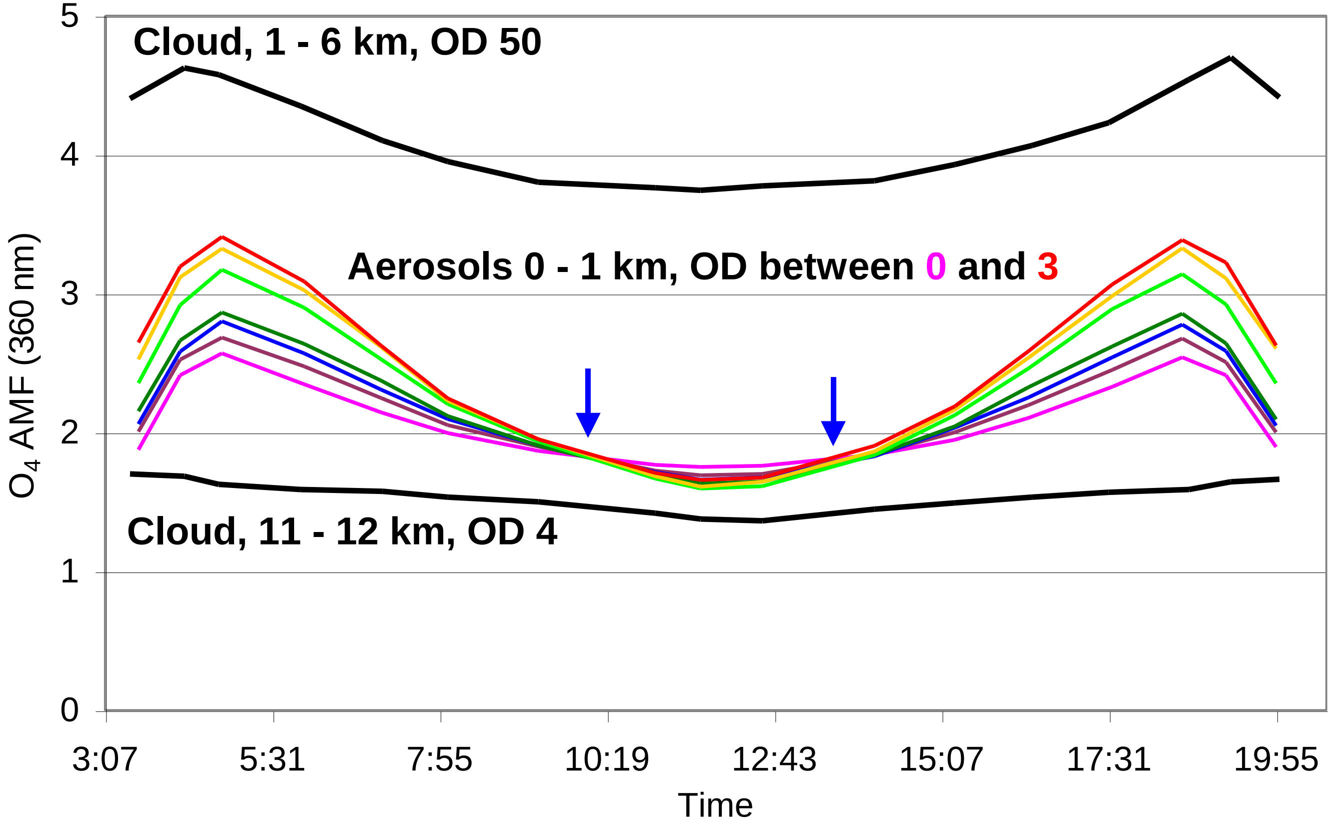
CI_{old}: 0.50

CI_{new}: 0.84



Calibration of the O_4 absorption (O_4 AMF)

For clear sky, the O_4 AMF becomes almost independent from the AOD for SZA around 36° (slightly dependent on aerosoll layer height)



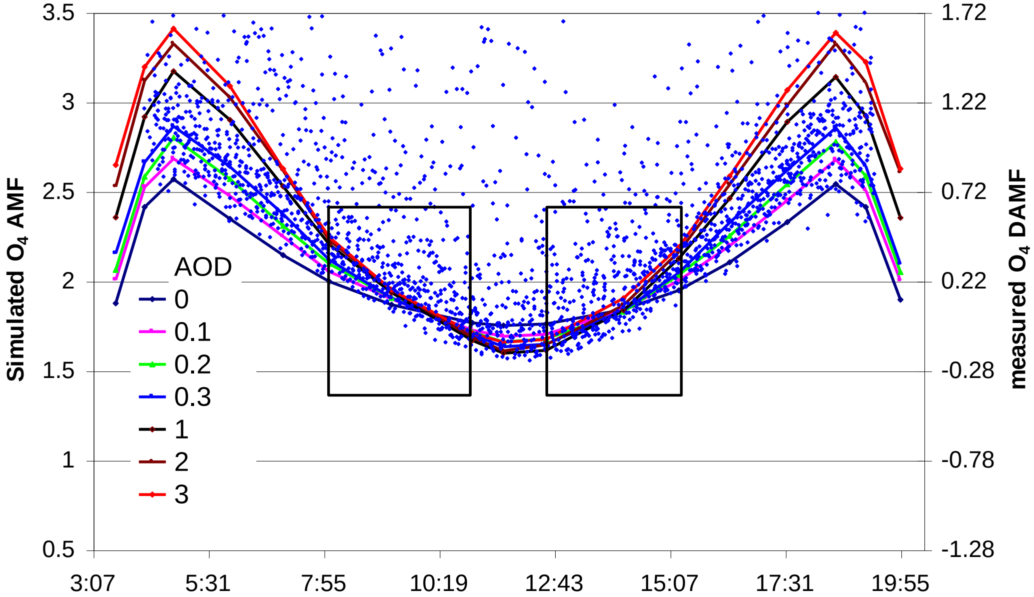
We compare the measured O_4 DAMF for clear sky with simulation results

Comparison of the measured O_4 DAMF with simulation results for different AOD

All measurements

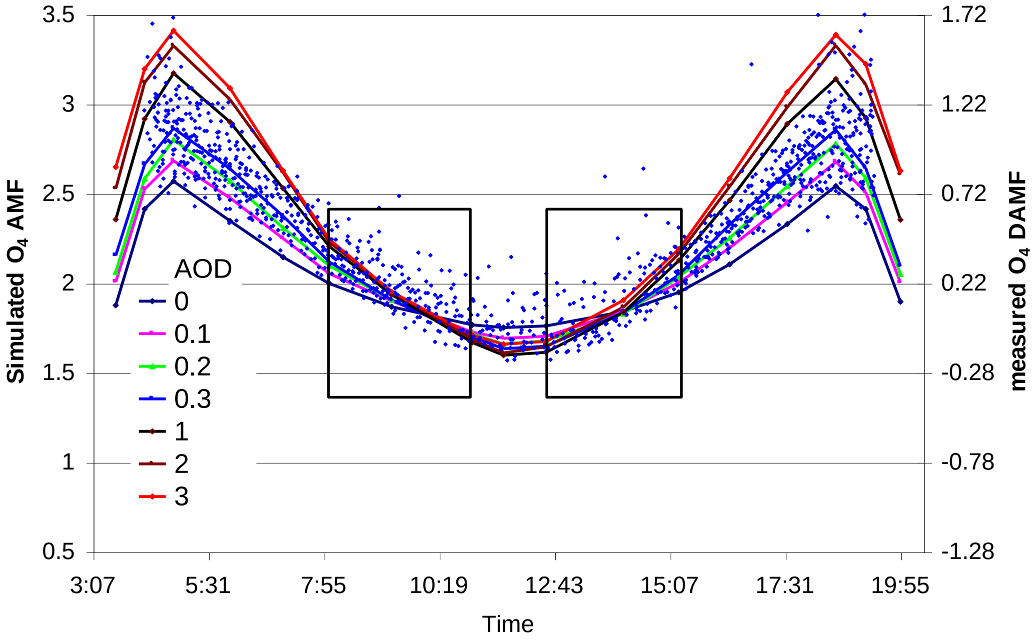
No measurements fall below simulations

=> No situations with only high clouds during CINDI?

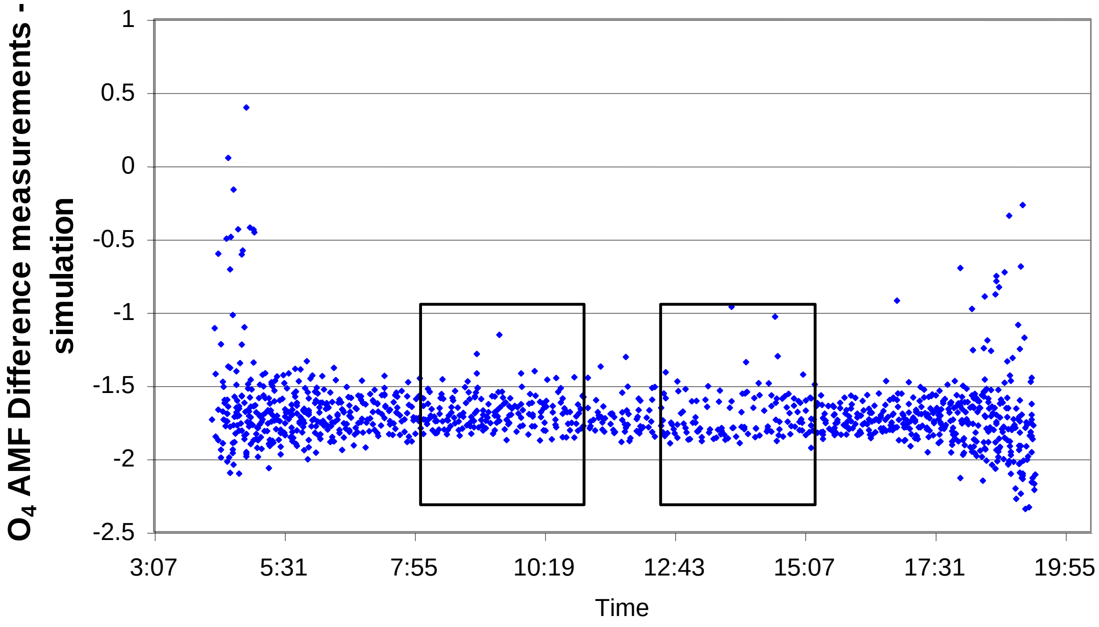


Clear sky measurements

Obviously some cloudy measurements passed the cloud filter



The simulated O_4 AMF (for AOD=0.2) are subtracted from the measurements



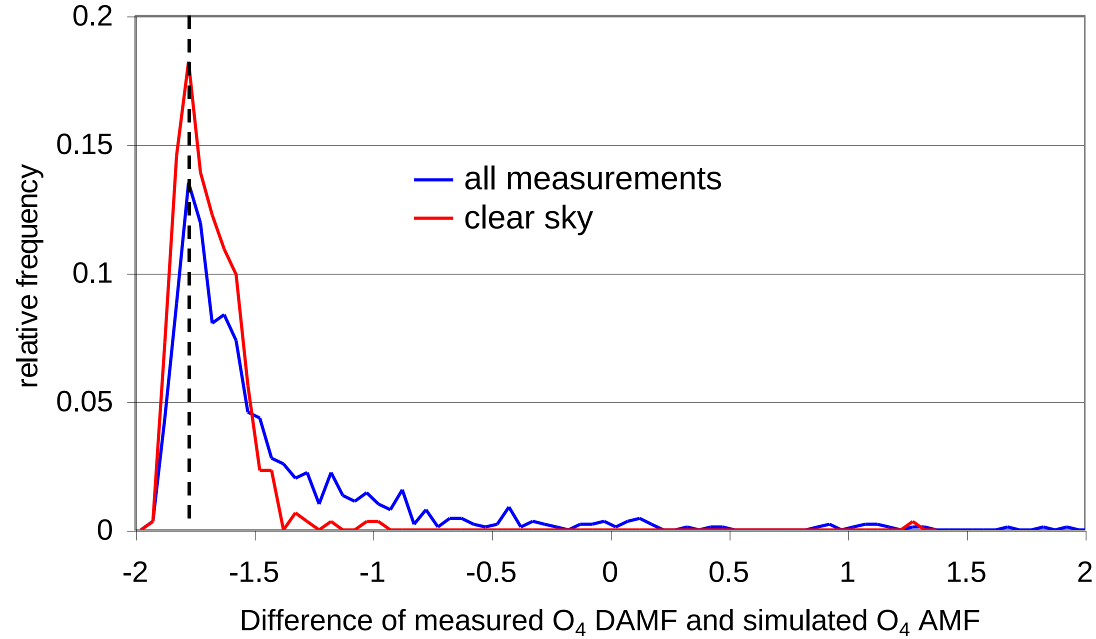
The maxima of the frequency distributions represent the calibration offsets (O_4 AMF of the FRS).

All measurements:

-1.78 (+0.26 / –0.05)

Clear measurements:

-1.78 (+0.28/ –0.05)



Summary

- The new method for absolute radiance calibration requires ‘stable’ atmospheric conditions (AOD, O_3 VCD), but is rather independent from aerosol phase function

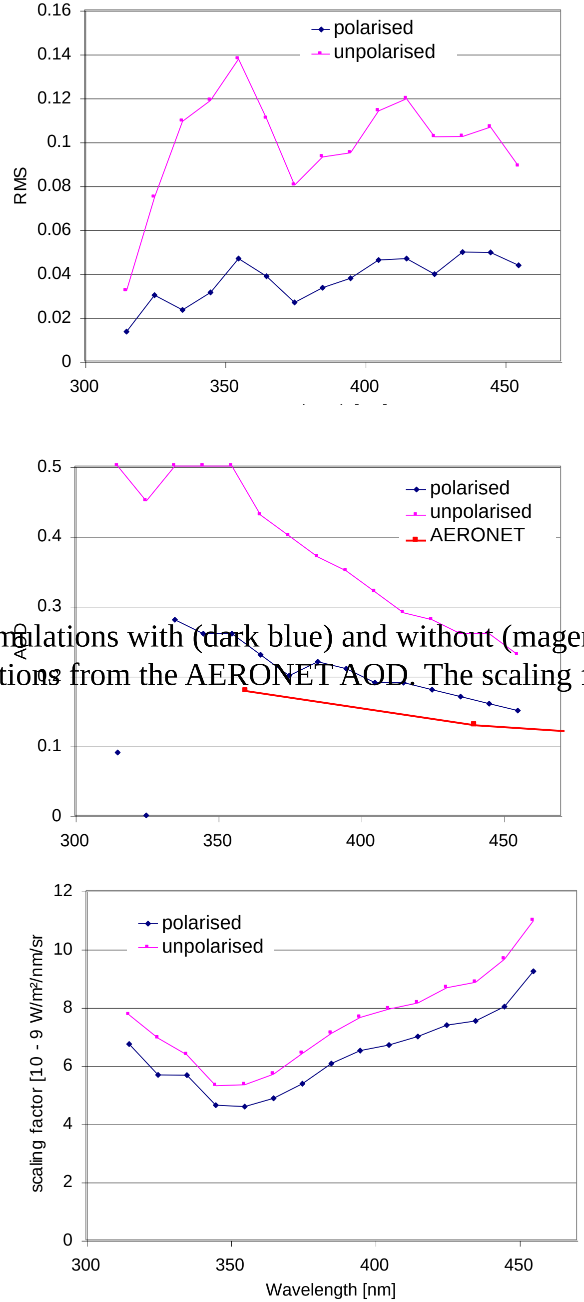
- Consideration of polarisation is essential, but errors caused by Ring effect, stratospheric aerosols, BRDF, temperature & pressure profiles, NO_2 absorption are negligible.

- Under ‘stable’ atmospheric conditions the accuracy is of the order of ~5 % (better than current laboratory calibrations for radiance measurements)

- The accuracy of the new CI calibrationis about 6% for the CI (330 nm / 390 nm)

- The accuracy of the new O_4 calibrationis about 0.05 (in O_4 AMF units)

- The new CI and O_4 calibrations could become the basis for universal cloud classification schemes (independent from instrumental properties)



Fit results for radiative transfer simulations with (dark blue) and without (magenta) considering polarisation. Ignoring polarisation leads to much larger RMS (top) and larger deviations from the AERONET AOD. The scaling factors for both cases differ only by about 10%.