The influence of polarization on box air mass factors for UV/vis DOAS observations

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sentinel-5p

Motivation

- DOAS retrievals of atmospheric trace gases yield *slant column densities*.
- Radiative transfer simulations are needed to convert these into easily interpretable *vertical column densities*, via an *air mass factor*.
- The incoming solar irradiation is unpolarized; the radiation becomes polarized by the various scattering processes in the atmosphere before it is being measured by the instrument.
- These scattering processes exhibit a scattering angle polarization dependence.
- Often, polarization effects are not considered in the radiative transfer

Aim

- To quantify the effect of polarization on box air mass factors (BAMF) of NO_2.
- To give a recommendation if polarization effects should be taken into account in operational and scientific data analysis.

Method

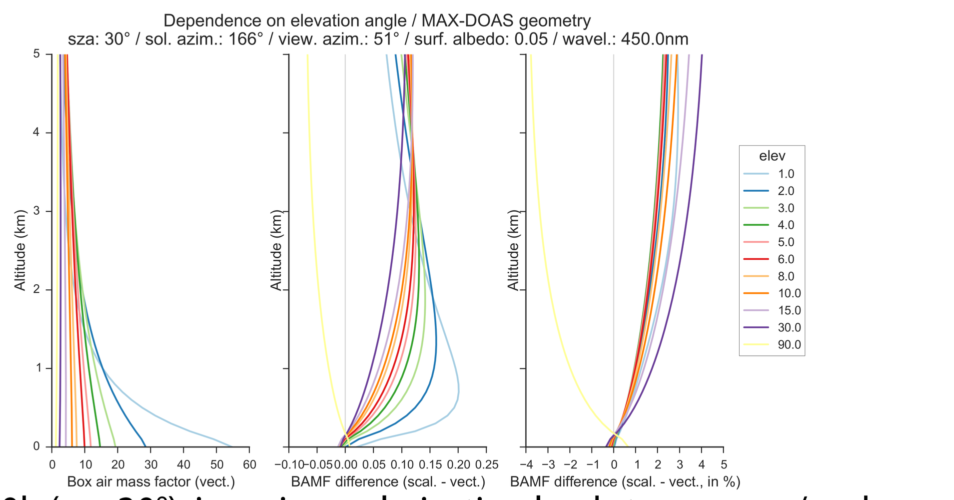
- NO_2 Box air mass factors (BAMF; indicative of vertical measurement sensitivity) at different wavelengths in the UV/vis are calculated with *SCIATRAN 3.5.6* for both vector (with polarization effects) and scalar (no polarization effects) radiative transfer in spher. geometry.
- From these calcuations, lookup-tables for satellite and MAX-DOAS geometry are generated.

Study setup / MAX-DOAS geometry

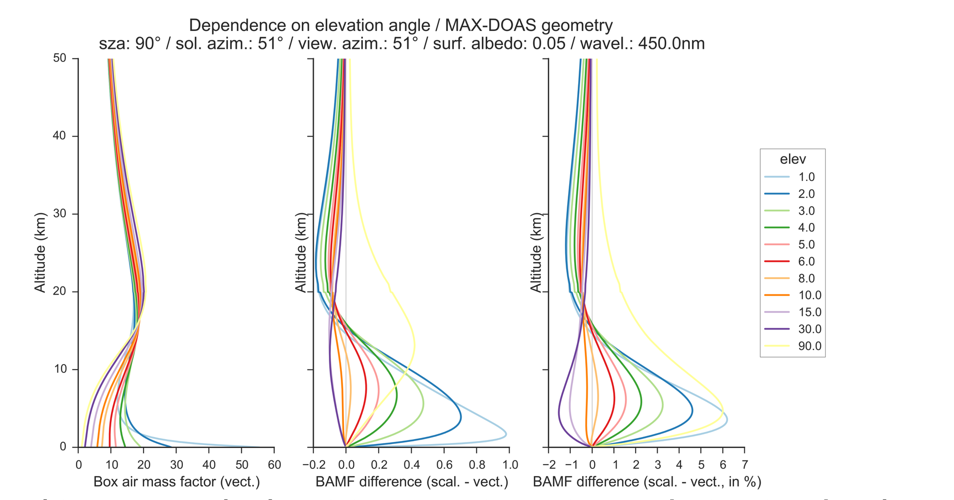
- Simulated one summer day in Mainz/Germany (51°N)
- constant viewing azimuth (towards rising sun)
- sza and rel. azimuth vary together

solar zen. angle:	30°, 40°, 50°, 60°, 70°, 80°, 85°, 88°, 90°
elev. angle:	1°, 2°, 3°, 4°, 5°, 6°, 8°, 10°, 15°, 30°, 90°
altitude:	0..10km (100m), 10..60km (1km), 60..100km (2km)
aerosols:	none

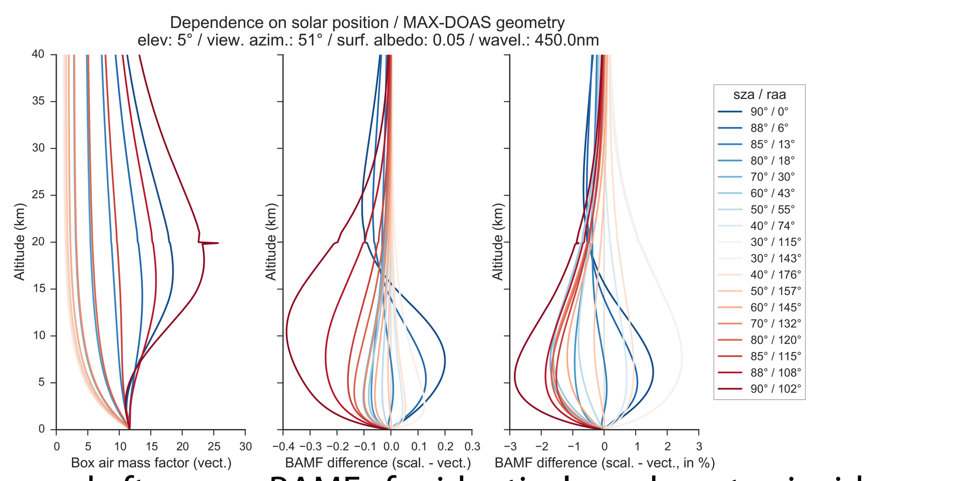
Sensitivity Study / MAX-DOAS Geometry



- At 11:00h (sza 30°), ignoring polarization leads to an over-/under-estimation of the BAMF of up to 4% for elevation angles <30°, and zenith measurements, respectively (error adds up for dSCD).
- The effect on NO_2 in the boundary layer is low.



- When looking towards the rising sun, ignoring polarization leads to an over-estimation for small elevation angles and in zenith, and to an under-estimation for larger elevation angles.
- Effects mostly in troposphere; only zenith measurement shows significant sensitivity in UT/LS.

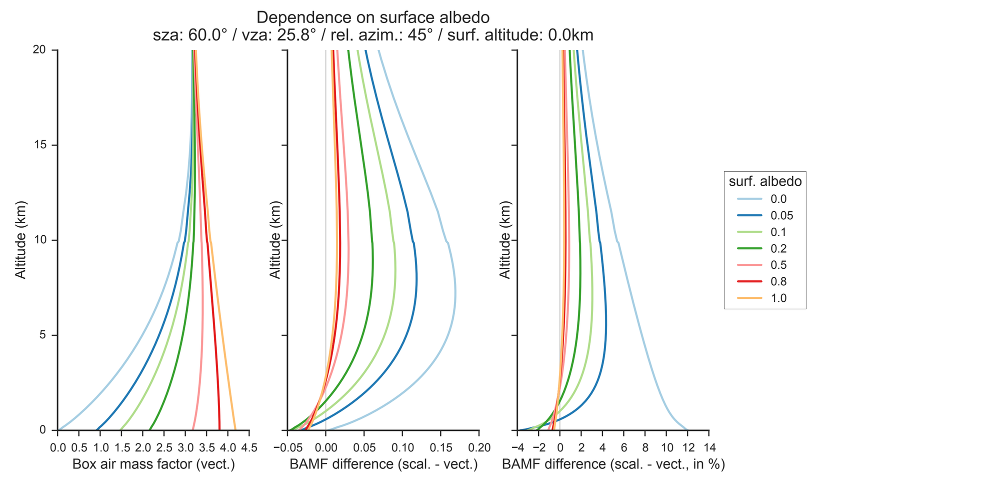


- Morning and afternoon BAMFs for identical sza do not coincide, showing the influence of the relative azimuth angle
- At 5° elev., ignoring polarization leads to an error of up to +/- 3%

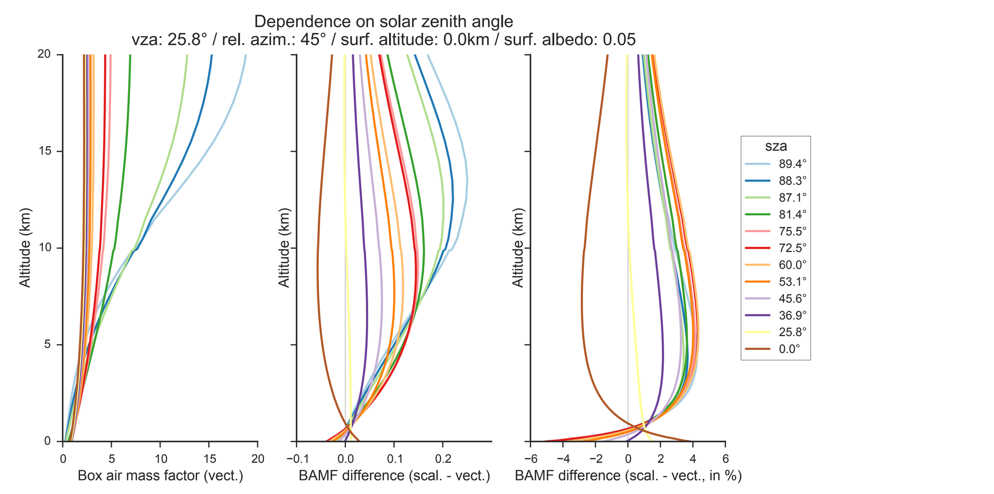
Study setup / Satellite geometry

cos(sza):	0.01, 0.03, 0.05, 0.15, 0.25, 0.3, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0
cos(vza):	0.3, 0.5, 0.7, 0.8, 1.0
rel. azim. angle:	0°, 15°, 30°, 45°, 60°, 75°, 90°, 105°, 120°, 135°, 150°, 165°, 180°
surface albedo:	0.0, 0.05, 0.1, 0.2, 0.5, 0.8, 1.0
surface altitude:	0, 1, 2, 5, 10 km
altitude:	0..10km (100m), 10..60km (1km), 60..100km (2km)
aerosols:	none

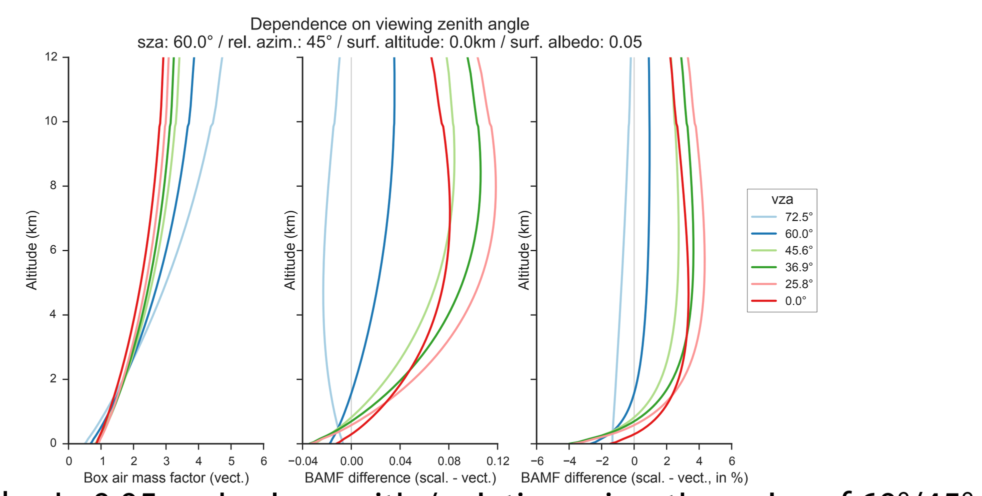
Sensitivity Study / Satellite Geometry



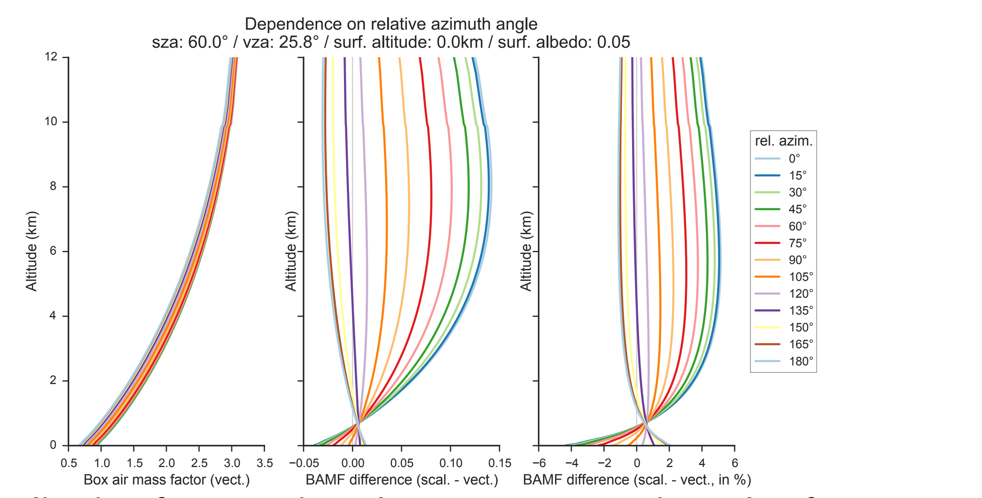
- For a typical GOME-2 scene (sza=60°, vza~26°), not accounting for polarization effects leads to a systematic error having a high-bias in the BAMF for all surface albedos.
- For dark surfaces, systematic error can reach >10% at the surface.
- For more realistic albedos of, e.g., 0.05, the systematic error is highest at ~5km and is less than 4% everywhere.
- For bright surfaces, the systematic error is less than 1% everywhere (under-/over-estimation below/above ~3km, respectively).



- For an albedo of 0.05 and a line-of-sight / relative azimuth of ~26°/45°, not accounting for polarization effects leads to an under-/over-estimation of the sensitivity below/above ~1.5km, respectively, for all solar zenith angles >0°.
- For solar zenith angles >0°, the over-estimation is highest at ~4-5km; its max varies between ~2% (sza~26°) and ~4.5% (sza~89°).
- For these scenarios, the under-estimationclose to the surface varies between 0% (sza~37°) and ~5% (sza~89°).



- For albedo 0.05 and solar zenith / relative azimuth angles of 60°/45°, not accounting for polarization leads to an over-/under-estimation of the BAMF above/below ~1-2km, depending on the line-of-sight.
- The over-estimation is highest at ~4-6km; its maximum varies between ~3-4%, for viewing zenith angles <60°.
- In all cases, the under-estimation close to the surface is below ~4%.



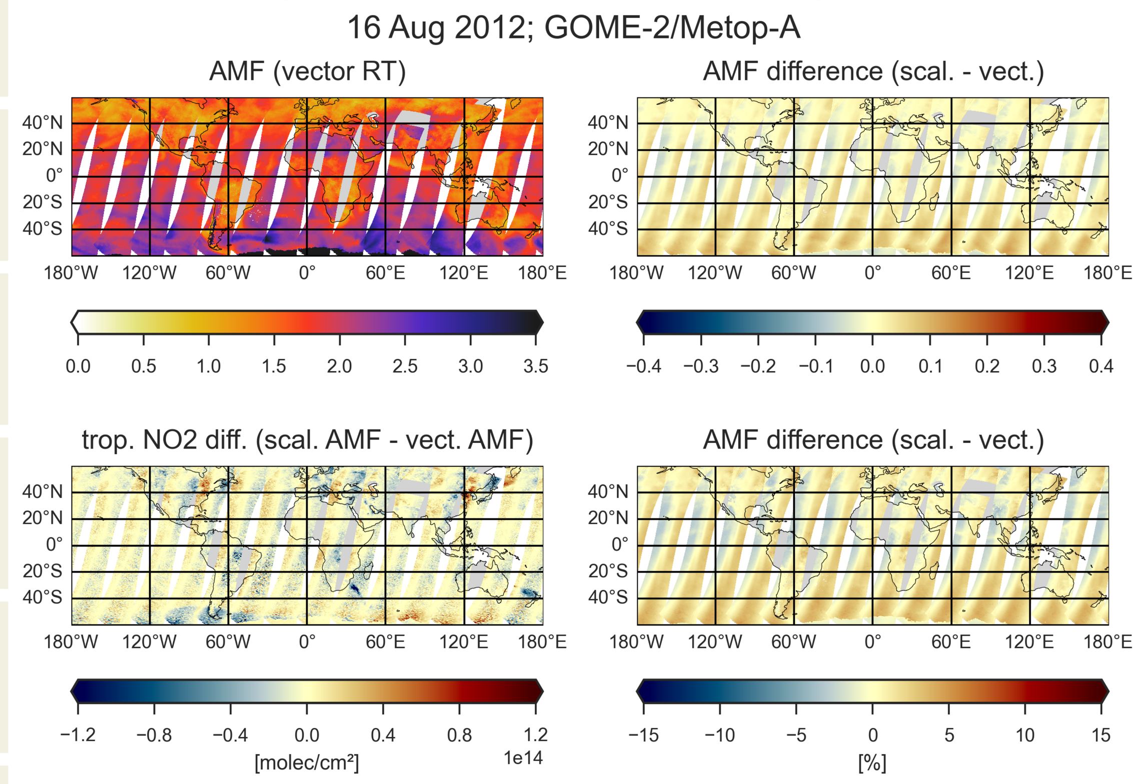
- For an albedo of 0.05 and a solar / viewing zenith angle of 60°/~26°, ignoring polarization effects leads to an over-/under- estimation of the measurement sensitivity above/below ~1-2km, respectively.
- Over-estimation largest (~5%) towards the sun and peaks ~6km.
- Error becomes smaller with larger rel. azim., until ~-1% for raa=180°.
- Near surface, lines-of-sight towards the sun under-estimate up to 4%, and large relative azimuth angles over-estimate up to 2%.

Case Study: GOME-2/Metop-A, Aug. 2012

Study Setup

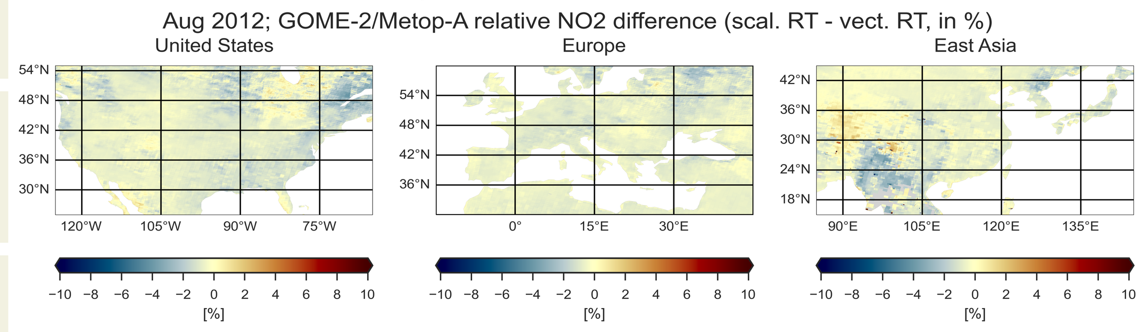
- NO_2 profiles from MACC-II MOZART reanalysis (fbov)
- Surface albedo from OMI climatology (OMLERV003)
- Surface altitude fom Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010)
- Tropopause heights from ECMWF ERA-Interim
- No aerosols

Single day comparison: 16 Aug 2012



- AMF data show signatures of anthropogenic pollution (U.S., EU, China, shipping lanes).
- Clear dependence of polarization effect on viewing geometry (vza/raa).
- This dependence propagates into a systematic error of ±1E14 molec/cm² in the NO_2 trop. VCD over unpolluted regions.

Influence on monthly mean trop. NO_2 vert. column fields



- Under- and overestimations resulting from viewing geometry cancel in monthly aggregates/composites.
- Not accounting for polarization effects in the AMF calculation leads to systematic under-estimation of trop. NO_2 vertical column averages from 1-2% (Europe, China) up to 2-4% (United States).

Conclusions

- Polarization effects have significant impact on NO_2 BAMFs.
- The impact depends on the measurement scene in a complex way and cannot be easily predicted.

- In ***MAX-DOAS geometry***, polarization effects are highest in the free troposphere (up to 7%)
- The zenith view behaves different from 'regular' measurements, often leading to a cumulation of polarization effects when calculating the dSCD.
- The impact of polarization also depends on the relative azimuth.

- In ***satellite geometry***, sensitivity to NO_2 located near the surface / in the free troposphere can be under-/over-estimated by up to 5% if polarization is not taken into account, depending on scenario.
- In single orbits of GOME-2 measurements, the bias introduced by not accounting for polarization effects is mostly dependent on the line-of-sight.
- In monthly averages, these geometry-dependent biases mostly cancel out; a systematic low-bias of the tropospheric NO_2 fields of up to 4% remains.
- In realistic scenarios (including aerosols), the effect of polarization is expected to be less pronounced.

- While the impact of other quantities (surface reflectance, aerosols, ...) on the BAMF is certainly higher than that of polarization, polarization effects can be as large as 10% and should be accounted for, if not in the BAMF calculation then in the error budget.

References

- Danielson, J.J., and Gesch, D.B.: Global multi-resolution terrain elevation data 2010 (GMTED2010). *U.S. Geological Survey Open-File Report* 2011–1073, 2011.
- Dee, D. P., et al.: The ERA-Interim Reanalysis: Configuration and Performance of the Data Assimilation System. *Q. J. R. Meteorol. Soc.*, 137(656): 553–97, doi:10.1002/qj.828, 2011.
- Hilboll, A., et al.: Long-term changes of tropospheric NO2 over megacities derived from multiple satellite instruments. *Atmos. Chem. Phys.*, 13(8): 4145–4169, doi:10.5194/acp-13-4145-2013, 2013.
- Inness, A., et al.: The MACC Reanalysis: An 8 Yr Data Set of Atmospheric Composition. *Atmos. Chem. Phys.*, 13(8): 4073–4109, doi:10.5194/acp-13-4073-2013, 2013.
- Kleipool, Q. L., et al.: Earth Surface Reflectance Climatology from 3 Years of OMI Data. *J. Geophys. Res.*, 113: D18308, doi:10.1029/2008JD010290, 2008.
- Rozanov, V., et al.: Radiative Transfer through Terrestrial Atmosphere and Ocean: Software Package SCIATRAN. *J. Quant. Spectrosc. Rad. Transfer*, 133, 13–71, doi:10.1016/j.jqsrt.2013.07.004, 2014.

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