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Motivation & Introduction

- NO₂ is one of the most important air pollutants
- catalyses ozone production, causes summer smog, acid rain, and adds local radiative forcing
- NO_x emission sources and their horizontal distribution are well known from satellite measurements
- knowledge of the vertical NO₂ distribution is only limited
- DOAS: Differential Optical Absorption Spectroscopy
- based on Lambert Beer's law: $\mathbf{I}(\lambda, \mathbf{s}) = \mathbf{I_0} \mathbf{exp}(-\sigma(\lambda)\rho\mathbf{s})$
- λ: wavelength; σ: absorption cross-section; ρ: amount of absorbers
- method to calculate the absoprtion of light travelling through the atmosphere
- can be used for ultra violet (UV) and visible (vis) light
- amount of trace gases can be derived from the absorption => slant columns (SCs) can be calculated
- Rayleigh scattering in the atmosphere depends on the wavelength
- larger wavelength: larger penetration depth than smaller wavelength
- => vertical sensitivity of NO₂ measurements
- NO₂ SCs derived from the visible are mostly higher than from the UV spectral range
- vertical sensitivities, expressed as box air mass factors (BAMFs) can be calculated with the radiative transfer model SCIATRAN to investigate the differences between the UV and visible spectral ranges
- above 9km, the sensitivity is slightly higher in the UV, while below 9km, the sensitivity is considerably higher in the vis

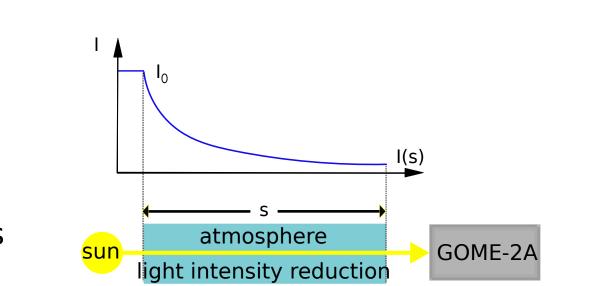


Figure 1: Ilustration of the DOAS method

- I: intensity at the detector
- I_o: intensity of the light directly from the sun
- s: light path

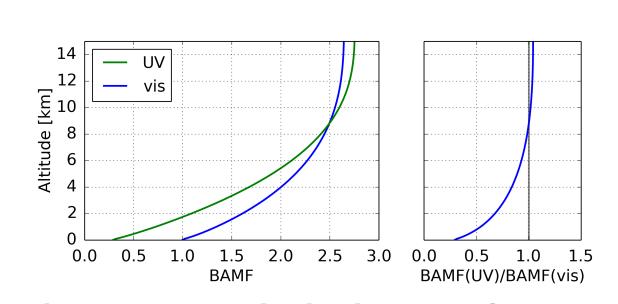


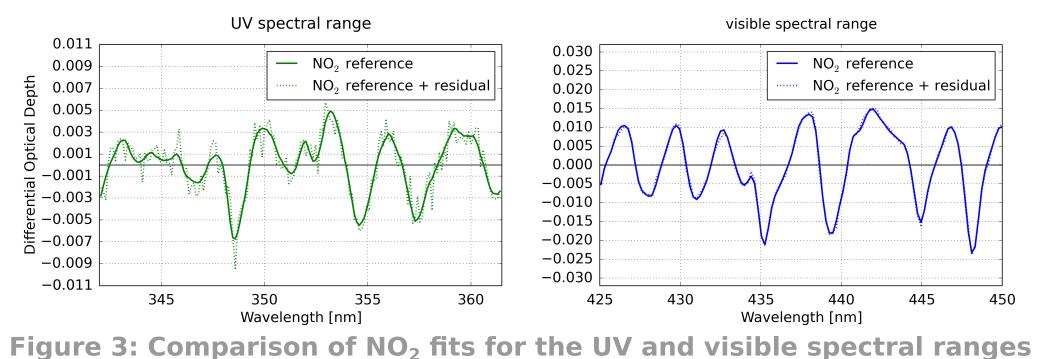
Figure 2: BAMF for both spectral ranges BAMF for 352 nm (UV) and 438 nm (vis) with a solar zenith angle of 50°, a surface spectral reflectance of 0.04 (UV) and 0.06 (vis) and a US standard atmosphere profile.

=> to get additional knowledge about NO₂ vertical distribution: develop new NO₂ retrieval for UV spectral range based on satellite observations from GOME-2 on board of EUMETSAT's MetOp-A

2 The NO₂ DOAS retrievals and datasets

• fit settings of NO₂ retrievals:

	UV NO ₂ fit	vis NO ₂ fit
fitting window	342 – 361.5nm	425 – 450nm
polynomial degree	5	3
cross sections	O ₃ , NO ₂ , O ₄ , BrO, HCHO, Ring	O ₃ , NO ₂ , O ₄ , H ₂ O, Ring
instrumental function	Zeta	_



The NO₂ reference and reference plus residual for the UV (left) and visible (right) spectral ranges for one pixel of an orbit above Teheran (35.38°N, 51.47°E) on January 22, 2008. The retrieved SC for this pixel for the UV spectral range is 6.31×10^{16} molec cm⁻² with a fit error of 4.3%. The SC for this pixel for the visible spectral range is 9.33×10^{16} molec cm⁻² with a fit error of NO₂ VCs. The curves are normalised and 0.8%. Note the different y-axes.

- the dataset is from 2007 to 2015
- UV NO₂ VCs have a larger spread $(7.4 \times 10^{14} \text{ molec cm}^{-2})$ compared with vis NO_2 VCs (2.1×10¹⁴ molec cm⁻²)

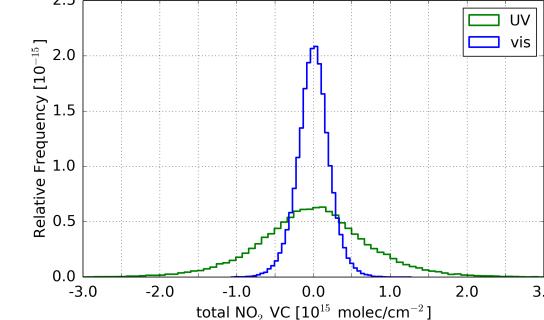


Figure 4: Scatter of NO₂ retrievals istribution of NO₂ VCs (January 2008) over a clean area (located over the Pacific: 5°S - 5° N, 150° - 210°E). It is assumed that there is no NO₂ in the troposhere. Therefore, a stratospheric AMF was applied to calculate centred on zero.

Comparison of global NO₂ SCs

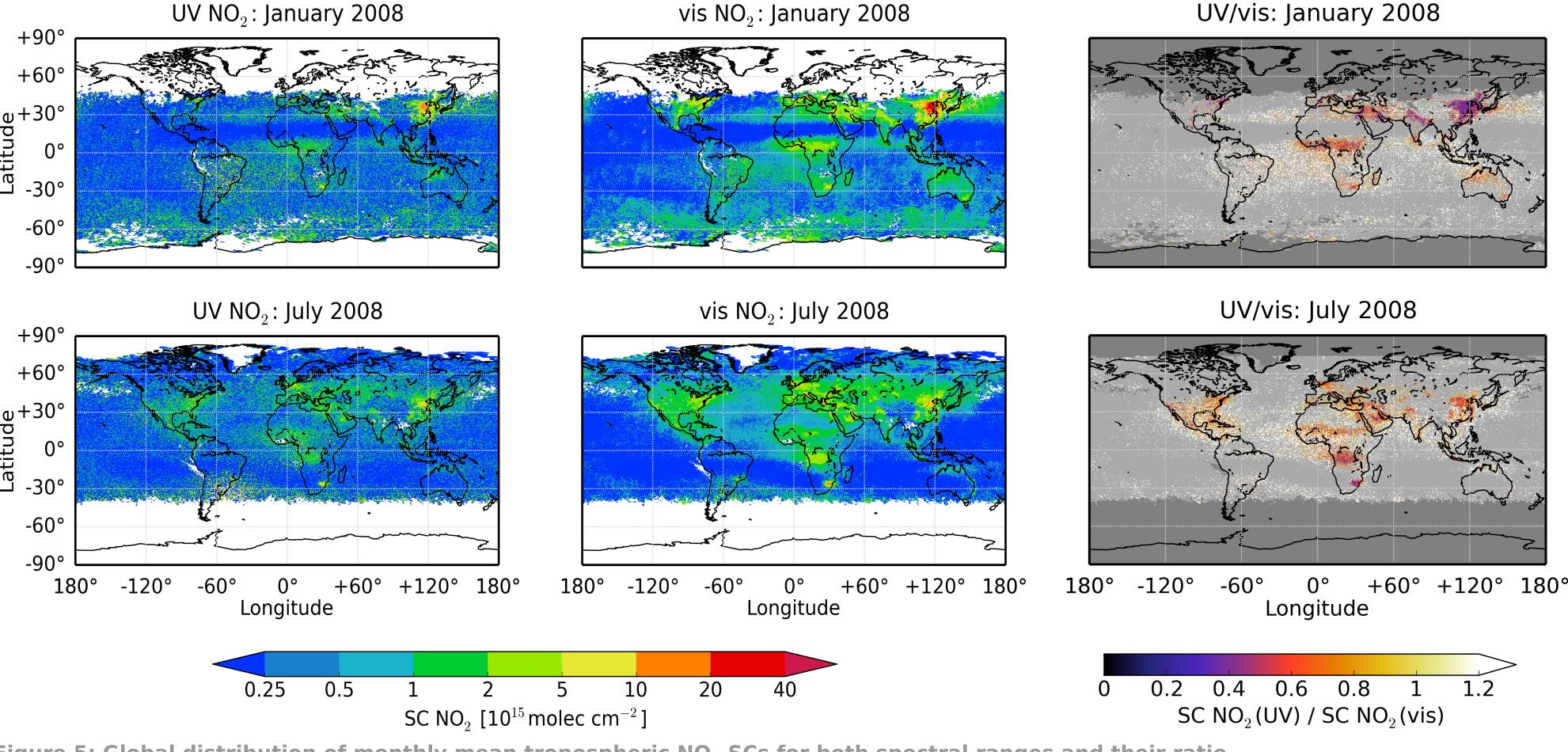


Figure 5: Global distribution of monthly mean tropospheric NO₂ SCs for both spectral ranges and their ratio SCs (left and center columns): Simliar patterns in UV and visible spectral ranges can be found. Also in the UV spectral range, well known NO2 signals above highly polluted areas can be observed. Ratio (right column): Dark gray shaded areas indicate that there are no NO₂ values available. Lighter gray

shaded areas indicate that the NO₂ values are below one standard deviation of a smoothed latitude-dependent threshold over the reference sector.

- only pixels with cloud fraction < 0.2 are used (FRESCO+ version 6)
- for stratospheric correction: reference sector (180° – 210°E) method

NO₂ SCs:

- with the UV NO₂ retrieval both anthropogenic and natural air pollution can be detected
- anthropogenic: e.g., China and Highveld Plateau region in South Africa
- natural: biomass burning regions, e.g., Africa south of the Equator
- NO₂ signals in the UV spectral range are lower than the NO₂ signal in the visible spectral range
- larger differences between NO₂ retrievals above highly polluted areas, especially in the winter hemisphere

Ratio of SCs:

- to assess vertical sensitivity of NO₂, the ratio of two NO₂ retrievals is calculated
- in the winter hemisphere the values of the NO₂ ratio are smaller
- highly polluted areas are clearly visible as local minima of the SC ratio

4 Comparison of time series of NO₂ SCs

5 Summary & Outlook

values are smaller than vis NO₂ values

=> possibility to assess vertical distribution of NO₂

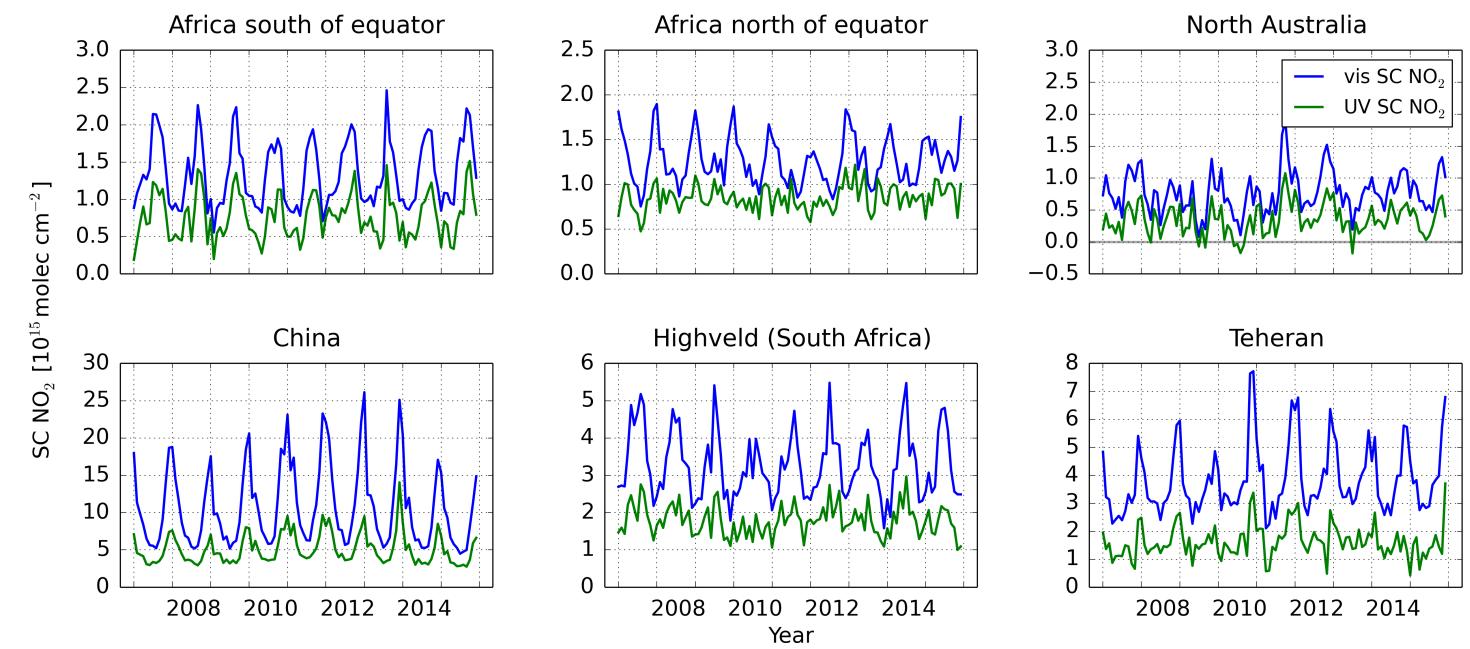


Figure 7: Time series of tropospheric NO₂ SCs for the visible (blue) and UV (green) spectral ranges Time series from 2007 to 2015 for different regions. The upper three plots are for biomass burning regions and the lower plots are regions with high anthropogenic air pollution. Note the different y-axes of the individual subplots.

• we provide a NO₂ DOAS fit in the UV spectral range for GOME-2/MetOp-A satellite data

• NO₂ retrieval in the visible spectral range is more sensitive to the lower troposphere

• large differences are mostly located in areas with high anthropogenic air pollution

• the patterns of SCs derived from vis and UV spectral ranges agree well, however UV NO₂

• next step: comparison of NO₂ VCs, we can get additional information about height dependency

there should be no differences in NO₂ vertical columns for the two wavelength ranges

=> if the a priori model simulates the air pollution profile with correct height dependency,

Natural air pollution:

- seasonal cycles of the three biomass burning areas differ, because of the shift in the intertropical convergence zone
- Africa south of Equator and north Austraila: similar seasonal cycle for UV and visible spectral range
- Africa north of Equator: clear seasonal cycle in vis, but no intra-annual variability in UV
- possible reasons:
- the NO₂ values are to small to be detected
- the NO₂ is close to the ground, i.e., difficult to detect in UV
- introduced due to stratospheric correction or cloud filter artefacts
- slightly negative values in north Australia are due to stratospheric correction, which introduces an offset

Anthropogenic air pollution:

- higher values in the respective winter season
- stronger differences between UV and vis NO₂ values in anthropogenically polluted areas compared to naturally polluted areas
- stronger seasonal cycle in the visible spectral range than in UV

References & Acknowledgement

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