ON THE USE OF THE MAXDOAS TECHNIQUE FOR THE VALIDATION OF TROPOSPHERIC NO_2 COLUMNS MEASUREMENTS FROM SATELLITE

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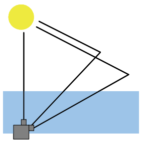
Abstract

The MultiAxis DOAS (MAXDOAS) technique has been recently developed as a new remote sensing tool for the monitoring of tropospheric pollutants by means of the differential optical absorption spectroscopy (DOAS) method (Heckel et al., 2005, Honninger et al., 2004). In contrast to zenith-sky DOAS instruments which have been commonly used over the last decade for stratospheric monitoring and satellite validation, e.g. as part of the Network for the Detection of Atmospheric Composition Change (NDACC), MAXDOAS instruments are designed to allow the quasi simultaneous observation of the scattered sun light in a range of different line-of-sight (LOS) directions from the horizon to the zenith, which leads to increased sensitivity towards atmospheric absorbers present close to the surface. Through adequate retrieval process, the near-surface concentration of atmospheric pollutants like NO_2 can be determined, as well as their integrated tropospheric and stratospheric column abundances. Owing to these capabilities, the MAXDOAS technique represents a very promising technique for the validation of tropospheric NO_2 column measurements that have been retrieved from UV-Visible nadir sounders such as GOME, SCIAMACHY, OMI and more recently GOME-2 on-board MetOp. In this work, we summarize the experience acquired at BIRA-IASB with tropospheric NO_2 validation using the MAXDOAS technique. Results from the DANDELIONS (Dutch Aerosol and Nitrogen Dioxide Experiments for validation of OMI and SCIAMACHY) campaign, from recent observations performed in China nearby Beijing as well as from longer-term measurements performed at the Observatoire de Haute Provence (OHP), in Southern France (44°N, 5.7°E) are discussed. Strengths and limitations of the MAXDOAS technique for satellite validation are highlighted and illustrations of achievements recently obtained are given with particular emphasis on the GOME-2 instrument.

1. The geometrical approximation applied to MAXDOAS data



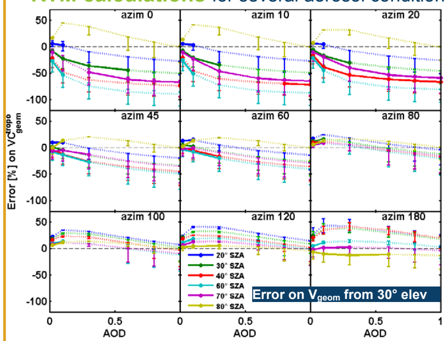
Assumptions:
- NO_2 layer located below the scattering altitude
- similar stratospheric contribution

$$VC_{geom} = \frac{SCD_{off} - SCD_{zen}}{\sin^{-1}(LOS) - 1} = \frac{DSCD_{tropo}}{AMF_{tropo}}$$

Check:
- compare results from 30° and 15° elevations
- retain only measurements where the tropospheric VCD agrees within 20%

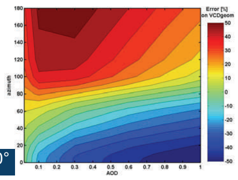
Error estimation: on the tropospheric NO_2 VCD retrieval with the geometrical approximation

RTM calculations for several aerosol conditions, geometries, albedo and NO_2 profiles.



$$Error = \frac{VC_{geom} - VC_{RTM}}{VC_{RTM}} = \frac{AMF^{tropo}_{RTM}}{AMF^{tropo}_{geom}} - 1$$

Over-estimation at every azimuth and SZA for column retrieved from 15° elevation (not showed). Over-estimation or under-estimation depending on the geometry for 30° elevation.



Basic simulations (and additional tests)

λ: 440nm
Geometry: SZA: 20 to 80, azimuths: 0 to 180
Albedo: 5% - 10%
NO_2 profile: cst concentration within 0-1km and 0 above
- additional stratospheric and free tropospheric content
Aerosols: cst extinction within 0-1km and 0 above, asymmetry factor = 0.68, very small absorption (single scattering albedo ~ 1) - cst up to 0.5km and to 2km, asymmetry = 0.73

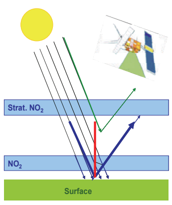
Changing the **albedo** increases the 30° over-estimation (-> multiple scattering). Changing the **NO_2 profile**, do not change the general findings.

Large errors occur for small azimuth angles, but the check between data retrieved at 15° and 30° allows the elimination of most of the critical situations.

2. Tropospheric NO_2 retrieval from satellites

SCIAMACHY on Envisat, OMI on Aura, GOME-2 on MetOp-A
- UV/Vis grating spectrometers, collecting retro-reflected light by the surface and the atmosphere; spectra analyzed with DOAS technique, in same wavelength range
- Sun-synchronous orbits, with a nadir viewing geometry
- Time and spatial resolution:

Overpass:	10h	13h30	9h30
Global coverage:	every 6 days	every day	every day
Resolution:	60x30km²	13x24km²	80x40km²



Tropospheric NO_2 retrieval: 3-step procedure
- obtain slant column
- separate stratosphere
- convert to vertical column

$$VC_{trop} = \frac{SCD - SCD_{strato}}{AMF_{trop}}$$

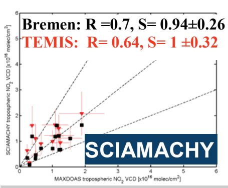
	GOME-2 DLR	OMI Standard Product	OMI TEMIS	SCIAMACHY TEMIS	SCIAMACHY IUP Bremen
SCD retrieval	DOAS within 425-450nm (GDP 4.2)	DOAS within 405-465nm		DOAS retrieval within: 426.3-451.3nm	425-450nm
Stratospheric correction	Spatial masking/ smoothing of the polluted NO_2 fields	Spatial masking/ smoothing of the polluted NO_2 fields	Assimilated NO_2 stratospheric slant columns with the TM4 chemistry-transport model		Stratospheric reference sector over Pacific
AMF calculation	LIDORT	TOMRAD	DAK		SCIATRAN
- NO_2 a-priori profile	Monthly mean profiles (MOZART-2)	Polluted/unpolluted scenarios (GEOS-CHEM)	Daily profiles (TM4)		Monthly mean profiles (MOZART-2)
- Cloud treatment	Correction based on OCRA/ROCCIN cloud retrieval scheme	Correction based on OMI operational O_2-O_2 cloud retrieval scheme		Correction based on FRESCO cloud retrieval scheme	Screening based on cloud fraction
- Aerosols	Implicitly corrected by cloud treatment				Scenarios (LOWTRAN)
- Albedo	GOME/TOMS database	GOME	GOME/TOMS database		

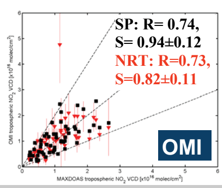
3. Tropospheric NO_2 validation examples

Cabauw (52°N, 5°E)

DANDELIONS project - 2 campaigns 5-7/2005 and 9/2006, BIRA, Bremen, Heidelberg MAXDOAS (Brinksma et al., 2008)
http://www.knmi.nl/omi/research/validation/dandelions

Ground-based data averaged around ±1h of satellite overpass time. Closest point of **cloud free data** (CF<20%) within 50km for OMI and 200km for SCIAMACHY



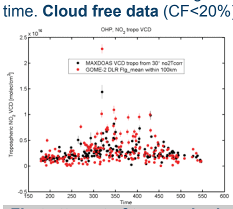


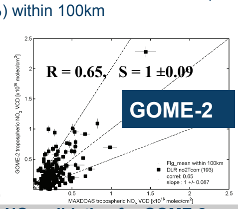
Large dispersion: Difference in the NO_2 field sampled by the satellite and ground-based instruments. Local pollution is averaged within the satellite pixels.

O.H.P (44°N, 5.7°E)

O3MSAF CDOP project - BIRA MAXDOAS since June 2007 (Pinardi et al, O3M-SAF technical note, 2008)
http://o3msaf.fmi.fi/

Ground-based data averaged around ±2h of satellite overpass time. **Cloud free data** (CF<20%) within 100km



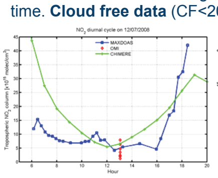


First attempt of tropospheric NO_2 validation for GOME-2: very encouraging! Pollution episodes are reproduced and good quantitative comparisons are obtained. Large scatter also found for other satellites products (ex: OMI SP).

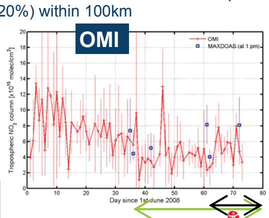
Beijing (40°N, 116.3°E)

AMFIC project - BIRA MAXDOAS in Beijing centre since June 2008
http://www.amfic.eu/index.php

Ground-based data averaged around ±1h of satellite overpass time. **Cloud free data** (CF<20%) within 100km



Diurnal cycle of NO_2 from CHIMERE model and MAXDOAS data. Help for the emissions estimation included in the model.



Measurements before, during and after the Olympic games

Beijing 2008 Olympic Games Aug. 08-24 2008

4. Conclusions and future work

- The **geometrical approximation** has been used to infer tropospheric NO_2 VCD from MAXDOAS measurements. Radiative transfer calculations have been performed for several geometrical settings, aerosols loads and NO_2 distributions, in order to **asses the errors** related to the use of this approximation.
- Examples of **tropospheric NO_2 validation** have been presented for three locations and several satellites (encompassing different satellite products), including validation of **one year of GOME-2** tropospheric data over the OHP, a primary NDACC station.
  A large scatter due to the different NO_2 field sampled (including spatial inhomogeneities and temporal variations of the ground-based NO_2 field) is pointed out. Efforts are needed to improve the spatial co-location (multi-azimuth instruments and/or spatial array of (mini) MAXDOAS instruments)
- Future: Apply the BIRA aerosol/NO_2 profile retrieval tool (currently under development) to DANDELIONS data, revise comparisons and compare with satellite a-priori profiles
  Use of trajectory analysis and local AQ modelling to analyse the impact of NO_2 field gradients on the comparisons (do we understand the scatter?)

Selected References

Brinksma et al., 2008: NO_2 and aerosols validation during the 2005 and 2006 DANDELIONS campaigns, JGR, VOL. 113, D16S46, doi:10.1029/2007JD008808
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