Comparison of NO_2 vertical columns from satellite measurements with those from ground based measurements over Xianghe, China

DPG 2017
UP 5.2
UP 67

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1 Motivation & Introduction

- NO_2 is one of the most important air pollutants
- catalyses ozone production, causes summer smog, acid rain, and adds to local radiative forcing
- due to its relatively short atmospheric life time, polluted areas can clearly be identified in global maps of satellite-derived NO_2 abundances
- for a better understanding of anthropogenic air pollution, there is constant need for validation of the satellite measurements using independent data sources
  ⇒ here, we compare two different versions of NO_2 vertical column (VC) retrievals from satellite measurements with ground based tropospheric NO_2 VCs

2 Method, Data & Instruments

- the analysis is based on the DOAS method: Differential Optical Absorption Spectroscopy
  - based on Lambert Beer's law: $\mathbf{I}(\lambda, \mathbf{s}) = \mathbf{I_0}\exp(-\sigma(\lambda)\rho\mathbf{s})$
    - λ: wavelength; σ: absorption cross-section; ρ: amount of absorbers
    - method to calculate the absorption of light travelling through the atmosphere
  - can be used for ultraviolet and visible light
  - amount of trace gases can be derived from the absorption

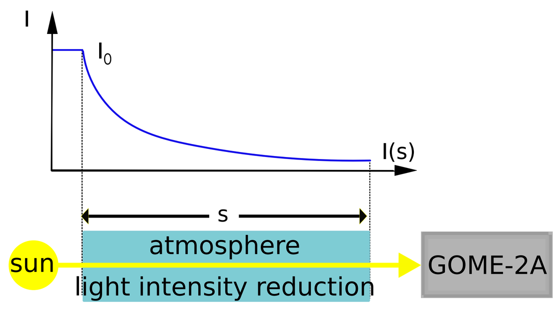

Figure 1: Ilustration of the DOAS method
I: intensity at the detector
I_0: intensity of the light directly from the sun
s: light path

- **ground based data**:
  - Multi-Axis Differential Absorption Spectrometer (MAX-DOAS) measurements
  - located at 39.75°N and 116.96°E (Xianghe, China)
  - March 2010 - December 2012, daily values, averaged overpass time
- **satellite data**:
  - *GOME2/A (Global Ozone Monitoring Experiment 2):*
    - installed on board of the MetOp-A satellite
    - measurements since January 2007
    - provides every day a nearly global coverage with a spatial resolution of 80x40 km^2
    - is in a sun-synchronous polar orbit with an equator crossing time of 9:30 local time
  - *OMI (Ozone Monitoring Instrument)*:
    - installed on board of NASA's EOS Aura satellite
    - measurements since October 2004
    - provides a nearly daily global coverage with a spatial resolution of up to 13x24 km^2
    - is in a sun-synchronous polar orbit with an equator crossing time of 13:45 local time
  - *SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY):*
    - installed on board of the ENVISAT satellite
    - measurements from August 2002 until April 2012
    - provides a nearly global coverage within 6 days with a spatial resolution of 60x30 km^2
    - was in a near-polar sun-synchronous orbit with an equator crossing time of 10:00 local time

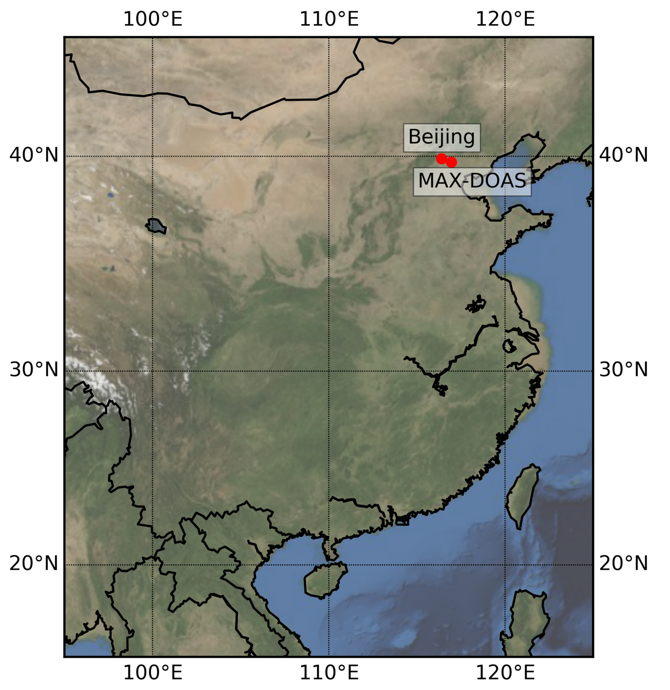

Figure 2: Location of the MAX-DOAS instrument
The MAX-DOAS instrument is located south-east of Beijing in Xianghe, a county of the province Hebei.

- **model data**:
  - to calculate VCs from the measurements, a-priori-model profiles are needed
  - here, two different models and assumptions are used to calculate NO_2 VCs:

1st version (V1):
- MOZART monthly climatology (2.8°x2.8°)
- no cloud correction
- aerosol effects are included
- stratospheric correction: reference sector
- surface of Lambertian Equivalent Reflectance: GOME climatology
- surface topography: MOZART

2nd version (V2):
- MACC Reanalysis daily NO_2 profiles (1.125°x1.125°)
- cloud correction via independent pixel approximation
- aerosols are implicitly corrected via cloud correction
- stratospheric correction: scaled daily MACC Reanalysis
- surface of Lambertian Equivalent Reflectance: MERIS climatology
- surface topograhy: GMTED2010

3 GOME2/A

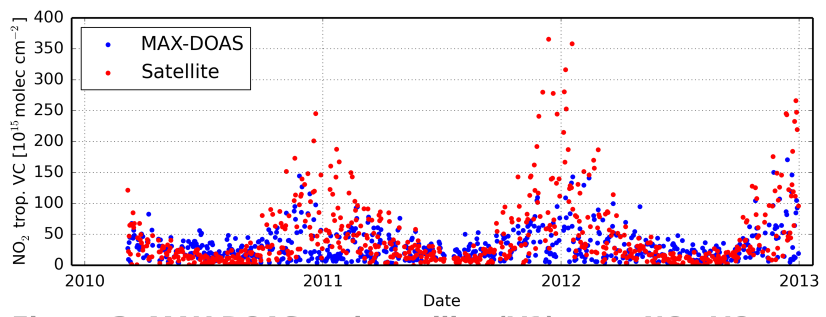

Figure 3: MAX-DOAS and satellite (V1) trop. NO_2 VCs
The NO_2 measurements are not filtered by cloud fraction.

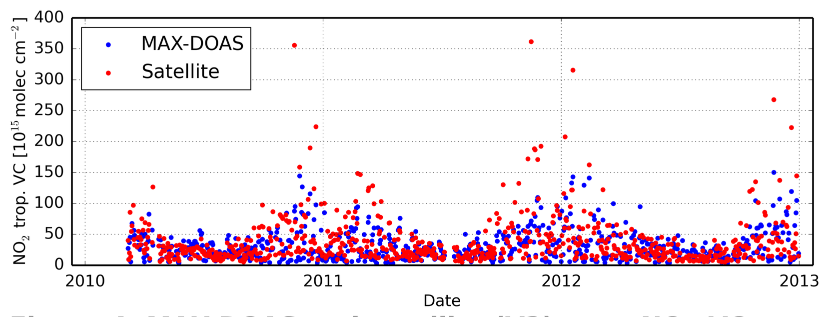

Figure 4: MAX-DOAS and satellite (V2) trop. NO_2 VCs
The NO_2 measurements are not filtered by cloud fraction.

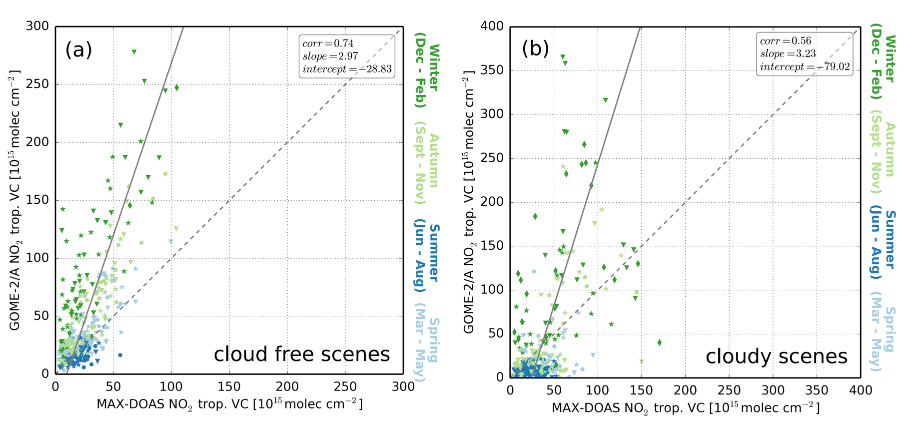

Figure 5: MAX-DOAS vs satellite (V1) trop. NO_2 VCs
Fig. 3 separated by seasons and in (a) cloud free (CF≤0.2) and (b) cloudy scenes (CF>0.2). Note the different axes.

Table 1: MAX-DOAS vs satellite (V1) trop. NO_2 VCs depending on cloud fraction
Correlation, slope and intercept (10^{15} molec cm^{-2}) for individual seasons shown in Fig. 5.

	cloud free scenes corr. / slope / interc.	cloudy scenes corr. / slope / interc.
spring	0.80 / 1.41 / -0.17	0.27 / 1.00 / -12.25
summer	0.46 / 0.48 / 5.96	0.16 / 0.08 / 5.71
autumn	0.88 / 1.97 / -4.40	0.63 / 2.10 / -43.64
winter	0.85 / 2.86 / 9.50	0.35 / 4.88 / -170.48

Table 2: MAX-DOAS vs satellite (V2) trop. NO_2 VCs depending on cloud fraction
Correlation, slope and intercept (10^{15} molec cm^{-2}) for individual seasons shown in Fig. 6.

	cloud free scenes corr. / slope / interc.	cloudy scenes corr. / slope / interc.
spring	0.75 / 1.23 / -1.39	0.65 / 1.72 / -21.33
summer	0.37 / 0.80 / 3.03	0.45 / 0.71 / 2.28
autumn	0.63 / 2.18 / -20.71	0.61 / 2.92 / -61.68
winter	0.77 / 1.41 / 3.21	0.68 / 1.98 / -39.42

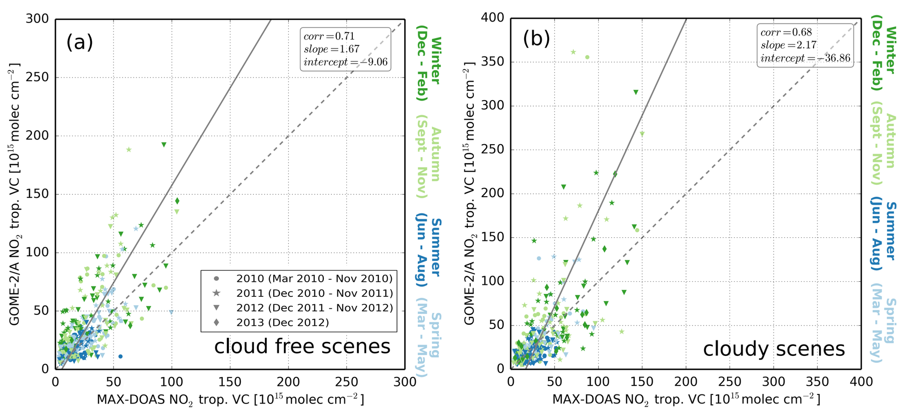

Figure 6: MAX-DOAS vs satellite (V2) trop. NO_2 VCs
Fig. 4 separated by seasons and in (a) cloud free (CF≤0.2) and (b) cloudy scenes (CF>0.2). Note the different axes.

1st version (V1):
- summer: the MAX-DOAS measurements are higher (Fig. 3)
- all other seasons: the satellite data are higher independent on cloud coverage (Tab. 1)
- the slope is strongly influenced by winter values (Fig. 5)
- Fig. 5b nearly no variation in satellite summer values

2nd version (V2):
- summer: the MAX-DOAS measurements are in a similar range as satellite measurements (Fig. 4)
- winter: the satellite data are higher with clear spikes (Fig. 4)
- Tab. 2 compared to Tab. 1 the slope is often close to 1
- in cloud free scenes the correlation is weaker for V2, whereas for cloudy scenes the correlation is higher compared to V1
- the slope also is strongly influenced by winter values (Fig. 6)
- Fig. 6 compared to Fig. 5, the slope is slightly smaller and the satellite summer values show a higher variation
- in cloud free scenes the correlation is weaker for V2, whereas for cloudy scenes the correlation is higher compared to V1

4 OMI

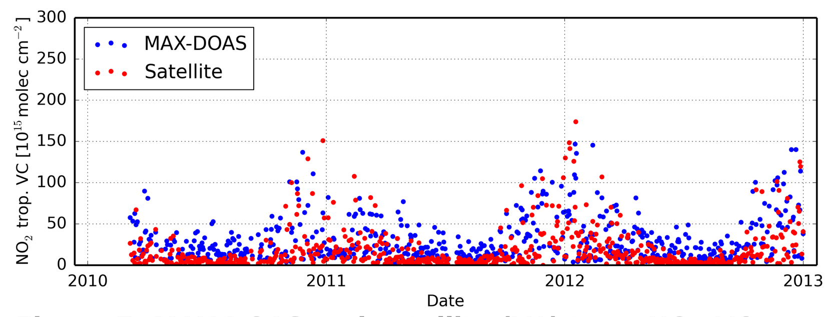

Figure 7: MAX-DOAS and satellite (V1) trop. NO_2 VCs
The NO_2 measurements are not filtered by cloud fraction.

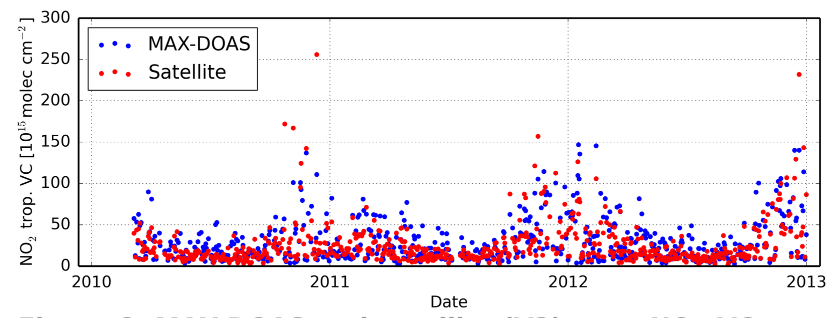

Figure 8: MAX-DOAS and satellite (V2) trop. NO_2 VCs
The NO_2 measurements are not filtered by cloud fraction.

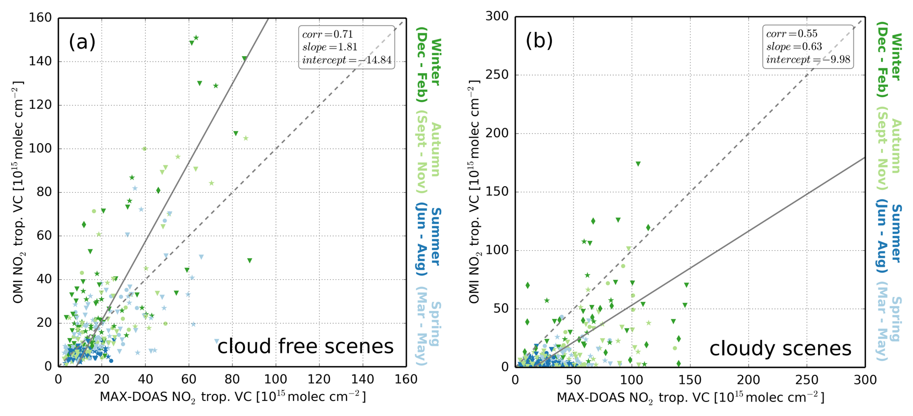

Figure 9: MAX-DOAS vs satellite (V1) trop. NO_2 VCs
Fig. 7 separated by seasons and in (a) cloud free (CF≤0.2) and (b) cloudy scenes (CF>0.2). Note the different axes.

Table 3: MAX-DOAS vs satellite (V1) trop. NO_2 VCs depending on cloud fraction
Correlation, slope and intercept (10^{15} molec cm^{-2}) for individual seasons shown in Fig. 9.

	cloud free scenes corr. / slope / interc.	cloudy scenes corr. / slope / interc.
spring	0.56 / 1.06 / -4.32	0.34 / 0.18 / 1.67
summer	0.31 / 0.16 / 4.11	0.15 / 0.05 / 2.45
autumn	0.80 / 1.73 / -12.81	0.55 / 0.47 / -6.78
winter	0.76 / 2.03 / -12.49	0.25 / 0.96 / -21.46

Table 4: MAX-DOAS vs satellite (V2) trop. NO_2 VCs depending on cloud fraction
Correlation, slope and intercept (10^{15} molec cm^{-2}) for individual seasons shown in Fig. 10.

	cloud free scenes corr. / slope / interc.	cloudy scenes corr. / slope / interc.
spring	0.69 / 0.68 / 4.13	0.72 / 0.57 / 1.81
summer	0.50 / 0.41 / 5.83	0.31 / 0.26 / 7.56
autumn	0.89 / 0.88 / 3.59	0.72 / 1.32 / -18.11
winter	0.88 / 0.67 / 8.71	0.68 / 1.44 / -32.05

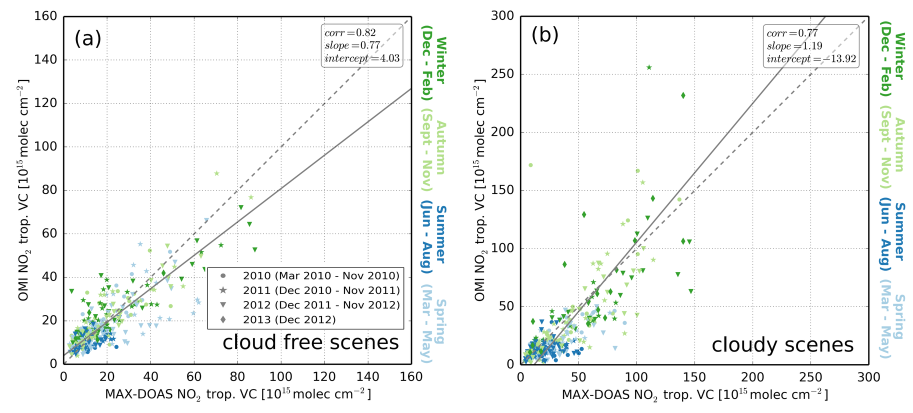

Figure 10: MAX-DOAS vs satellite (V2) trop. NO_2 VCs
Fig. 8 separated by seasons and in (a) cloud free (CF≤0.2) and (b) cloudy scenes (CF>0.2). Note the different axes.

1st version (V1):
- here for cloud free scenes (except summer), the satellite data are higher (Fig. 9)
- all other cases: the MAX-DOAS data are higher (Fig. 7, Fig. 9)
- the slope for cloud free scenes is strongly influenced by winter values (Fig. 9)
- no influence is visible for cloudy scenes and no variation is visible in satellite summer values (Fig. 9)

2nd version (V2):
- summer: the MAX-DOAS measurements are slightly smaller (Fig. 8)
- winter: the satellite data are higher again with some spikes
- Tab. 4 compared to Tab. 3: slope and correlation are higher
- generally, the slope is close to 1
- the slope also is strongly influenced by winter values
- Fig. 10b: the influence of the spikes observed in Fig. 8 is visible

5 SCIAMACHY

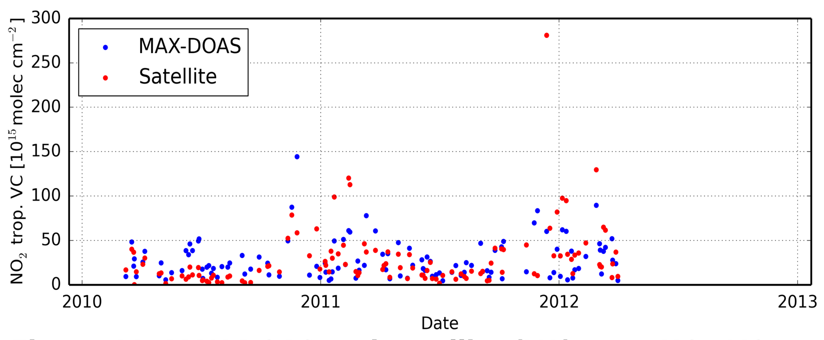

Figure 11: MAX-DOAS and satellite (V1) trop. NO_2 VCs
The NO_2 measurements are not filtered by cloud fraction.

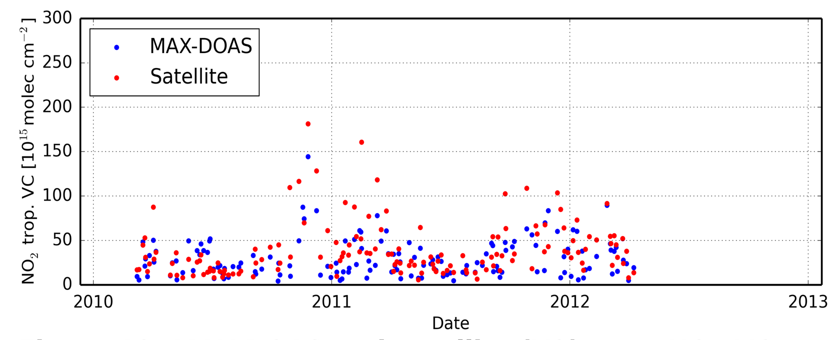

Figure 12: MAX-DOAS and satellite (V2) trop. NO_2 VCs
The NO_2 measurements are not filtered by cloud fraction.

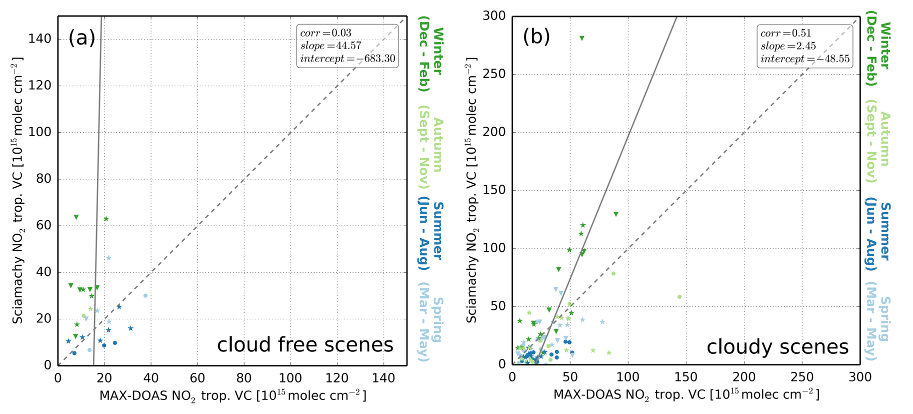

Figure 13: MAX-DOAS vs satellite (V1) trop. NO_2 VCs
Fig. 11 separated by seasons and in (a) cloud free (CF≤0.2) and (b) cloudy scenes (CF>0.2). Note the different axes.

Table 5: MAX-DOAS vs satellite (V1) trop. NO_2 VCs depending on cloud fraction
Correlation, slope and intercept (10^{15} molec cm^{-2}) for individual seasons from Fig. 13.

	cloud free scenes corr. / slope / interc.	cloudy scenes corr. / slope / interc.
spring	0.46 / 2.06 / -18.36	0.55 / 0.77 / 1.62
summer	0.59 / 0.47 / 4.04	0.59 / 0.24 / 2.62
autumn	-	0.58 / 0.47 / 5.51
winter	0.39 / 8.14 / -58.72	0.71 / 3.59 / -66.03

Table 6: MAX-DOAS vs satellite (V2) trop. NO_2 VCs depending on cloud fraction
Correlation, slope and intercept (10^{15} molec cm^{-2}) for individual seasons from Fig. 14.

	cloud free scenes corr. / slope / interc.	cloudy scenes corr. / slope / interc.
spring	0.85 / 2.00 / -13.65	0.81 / 1.35 / -4.81
summer	0.74 / 0.82 / 4.07	0.27 / 0.23 / 11.94
autumn	0.79 / 3.26 / -8.29	0.64 / 2.80 / -57.82
winter	0.25 / 15.80 / -142.89	0.57 / 1.93 / -12.75

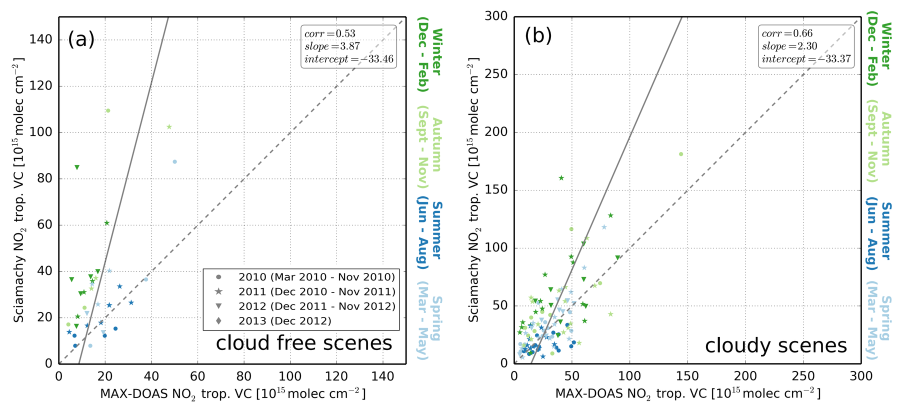

Figure 14: MAX-DOAS vs satellite (V2) trop. NO_2 VCs
Fig. 12 separated by seasons and in (a) cloud free (CF≤0.2) and (b) cloudy scenes (CF>0.2). Note the different axes.

1st version (V1):
- summer: the MAX-DOAS measurements are slightly higher
- winter: the satellite data are partly higher (Fig. 11)
- only a few measurements are available for cloud free scenes
- the satellite data are often higher than MAX-DOAS measurements (Fig. 11, Fig. 13)
- the slope is strongly influenced by winter values

2nd version (V2):
- summer: the MAX-DOAS measurements are in a similar range compared to satellite measurements (Fig. 12)
- winter: the satellite data are higher (Fig. 12)
- Tab. 6: for the individual seasons, the slope is higher or in a similar range as for V1
- the slope also is strongly influenced by winter values (Fig. 14)

6 Conclusion & Summary

- *GOME2/A:*
  - for V1 the ground based summer data are higher compared to satellite data, for all other seasons the satellite data are higher
  - for V2 the slope is mostly closer to 1
  - in general, for this satellite the agreement between V2 and the ground based data is higher
- *OMI:*
  - for cloud free scenes, the trop. NO_2 VCs of the V2 satellite retrieved data are always smaller than the ground based data
  - for V2 correlations are higher than for V1 and the slope is closer to 1
  - V2 shows a better agreement with ground based data
- *SCIAMACHY:*
  - no real conclusion can be drawn for this satellite, which is related to the reduced number of mearements, caused by the different measurement modes
- the differences between the annual slope of V1 and V2 are mostly driven by winter values
- for cloud free scenes, the differences between V1 and V2 are strongest in winter
- the differences between V1 and V2 are partly related to the two different a-pripori-model assumptions
- the differences between the three satellites could be partly related to the differences in spatial sampling and to the differences in overpass time
- in summer clouds mostly cover the NO_2, and therefore, the satellite values are always lower than MAX-DOAS trop. NO_2 VCs; this is corrected by cloud filtering
- in V1 strong a strong aerosol forcing is included which leads to the higher NO_2 values in winter compared to V2, and therefore, V2 is more realistic
- further investigations are needed to explain the reason for the remaining very high winter values observed in V2

References & Acknowledgements

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- This study has been funded by the EU FP7 project Patnership with ChiNa on space DAta (PANDA, grant no. 606719), by the University of Bremen, and by the DFG-Research Center / Cluster of Excellence "The Ocean in the Earth System".
- GOME-2 lv1 data were provided by EUMETSAT, OMI lv1 data were provided by NASA, SCIAMACHY lv1 data were provided by ESA

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