How well does cloud correction of satellite NO_2 observations work?

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1 Introduction

- satellite derived tropospheric NO_2 columns are an important source of information on NOx pollution
- retrieval of tropospheric NO_2 is performed in the visible part of the spectrum and therefore clouds located above the boundary layer block pollution NO_2 from satellite view
- as clouds are much brighter than the surface, even a small cloud contamination of a satellite pixel can have a large blocking effect
- therefore two approaches are usually applied:
  - cloud screening (removal of scenes having more than a threshold fraction of clouds)
  - cloud correction using the independent pixel approximation (applied here)
- inputs to cloud correction are cloud fraction, cloud top height and a priori NO_2 vertical profile
- all of the inputs are uncertain

2 Observations

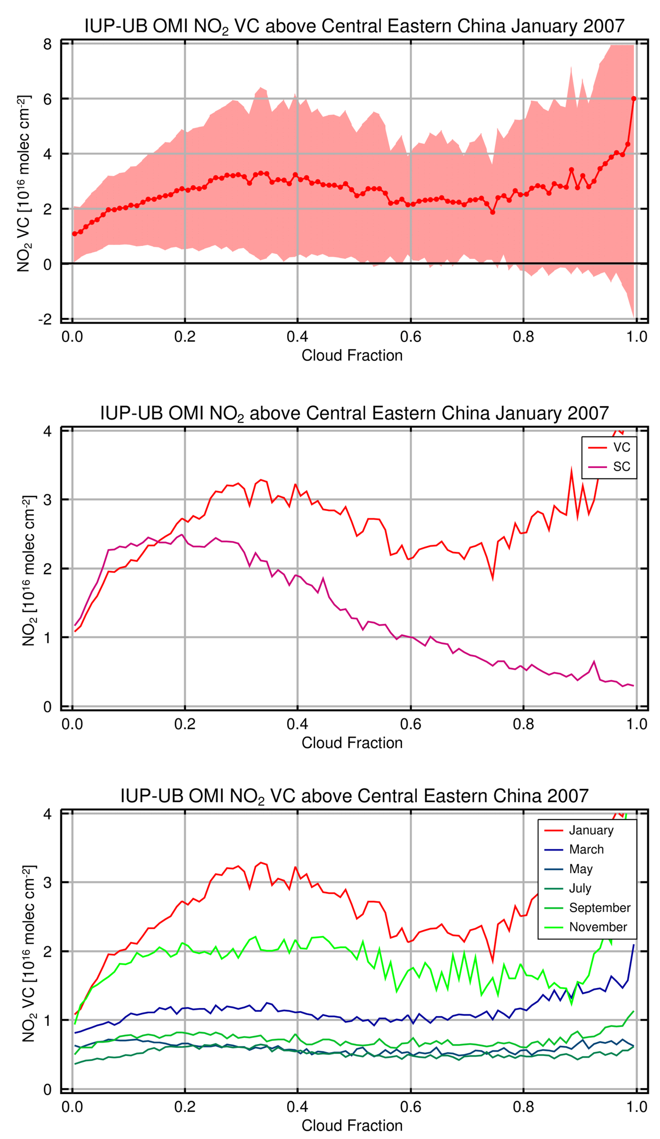

Figure 1: Cloud fraction dependence of OMI QA4ECV tropospheric NO_2 columns above Central Eastern China (CEC, 30 - 40°N, 110 - 123°E). Top: Tropospheric NO_2 vertical columns January 2007 and their standard deviation. Middle: Tropospheric slant and vertical columns. Bottom: Seasonality of vertical tropospheric columns.

Tropospheric Vertical Columns

- tropospheric vertical columns over Central Eastern China show an unexpected behaviour as function of cloud fraction
- assuming that pollution does not depend on cloud cover, constant values are expected
- a clear decrease in VC is observed to low cloud fractions
- the relative magnitude of the effect is large

Tropospheric Slant Columns

- analysis of tropospheric slant columns shows that already these do not show the largest values at smallest cloud fraction as expected
- cloud correction amplifies effect

Seasonality

- the effect is most pronounced in winter months but is observed throughout the year

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- SCIAMACHY lv1 data was provided by ESA through DLR
- OMI lv1 data was provided by NASA

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3 Detailed Evaluation

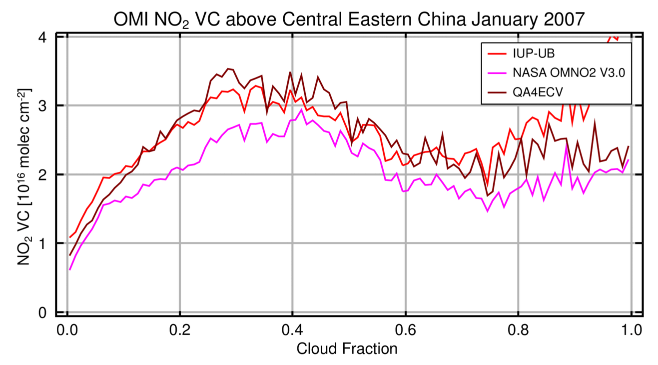

Figure 2: Comparison of three different OMI data sets over the CEC region in January 2007

Different OMI data sets

- comparison of three different OMI data sets using different fits, different a priori assumptions and different processing all show the same behaviour
- in detail, differences exist with the QA4ECV data set showing the largest increase at small cloud fractions

Different satellites

- comparison of OMI, GOME2-A and SCIAMACHY data show similar behaviour in spite of different overpass time, different cloud algorithms and different sampling
- SCIAMACHY data show large scatter because of limited number of measurements
- GOME2-A data show smallest effect

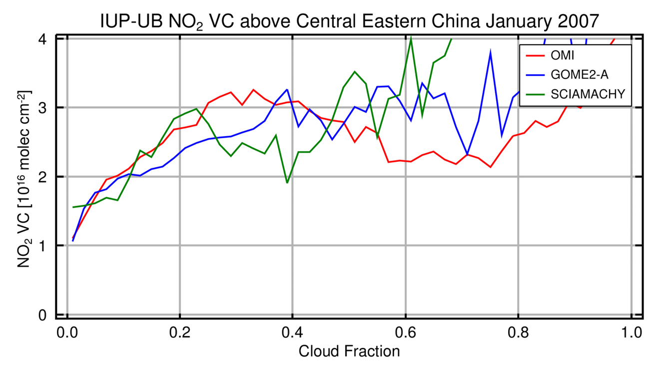

Figure 3: Comparison of NO_2 data from three different satellites over CEC in January 2007

Separation by cloud top height

- when separating data by cloud top height, the largest effect is seen if the lowest cloud top heights are included
- dependence of NO_2 columns on cloud top height is also unexpected and points at a problem with cloud treatment
- cloud top pressures at very small cloud fractions are unreliable and results cannot be trusted there

- looking at slant columns, the signal clearly decreases with increasing cloud top height as expected
- for none of the cloud top heights the expected increase of signal with decreasing cloud fraction is observed for cloud fractions below 20%
- the lowest cloud top heights behave differently from the other curves in that they have the steepest increase with cloud fraction and a plateau rather than a single maximum

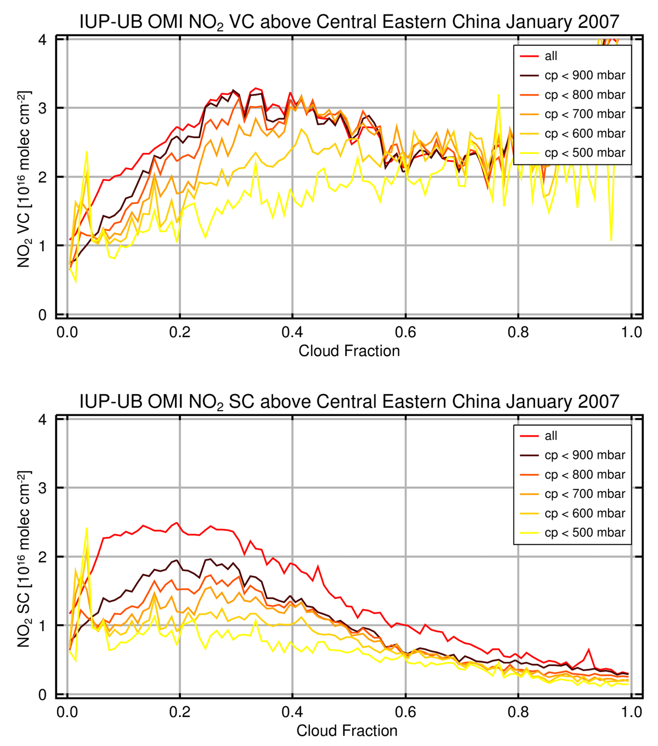

Figure 4: Cloud fraction dependence of OMI NO_2 columns over CEC in Janaury 2007, separated by cloud top pressure. Vertical columns are shown in the top panel, slant columns in the bottom panel.

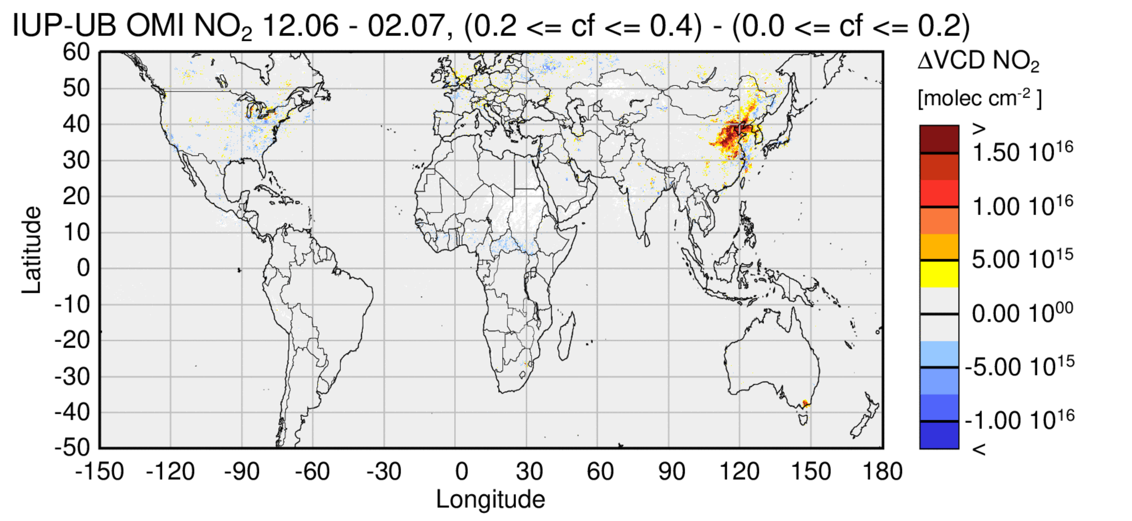

Figure 5: Difference between IUP-UB OMI NO_2 VC retrieved for cloud fractions between 20% and 40% and the columns retrieved for cloud fractions 0% - 20%. Larger columns at higher cloud fractions are found throughout central eastern China but rarely elsewhere.

4 Discussion

Different effects can contribute to the observed increase of NO_2 with cloud fraction:

Temporal sampling

- high NO_2 and high aerosol is probably strongly correlated
- high NO_2 conditions are therefore rarely found at clear sky

Scattering aerosols

- scattering aerosol increases the light path (multiple scattering, albedo effect)
- scattering aerosol increases the retrieved cloud fraction
- scattering aerosol in the presence of clouds leads to wrong cloud top height and cloud correction

Absorbing aerosols

- absorbing aerosols are not accounted for in the algorithm
- absorbing aerosols reduce retrieved cloud fraction
- absorbing aerosols reduce light path and decrease retrieved NO_2 columns

A priori NO_2 profile

- if the apriori NO_2 profile is to low in the atmosphere, the cloud albedo effect is underestimated, explaining the cloud top dependence of the retrieved NO_2 VC

A priori surface reflectance

- if the a priori surface reflectance is to low, NO_2 columns at low cloud fraction will be underestimated

5 Summary & Conclusions

- satellite retrieved tropospheric NO_2 columns over central eastern China show an unexpected increase with increasing cloud fraction
- the effect is seen by all instruments, in different data products and throughout the year, but most strongly in winter
- there are only few other places globally which show a similar behaviour
- possible reasons are a sampling effect because of the correlation between aerosol and NO_2 pollution, not properly corrected for aerosol effects on the retrieval or inappropriate a priori NO_2 profiles or surface reflectance
- this effect could have an important impact on many studies using satellite data as these are usually based on data having small cloud fraction
- validation with ground-based MAX-DOAS data is needed to decide if the observed increase in NO_2 with cloud fraction is real or a retrieval artefact

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