Ground-based MAX-DOAS observations of tropospheric aerosols, NO_2, SO_2 and HCHO in Wuxi, China, from 2011 to 2014

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1. Purpose, Highlight and Method

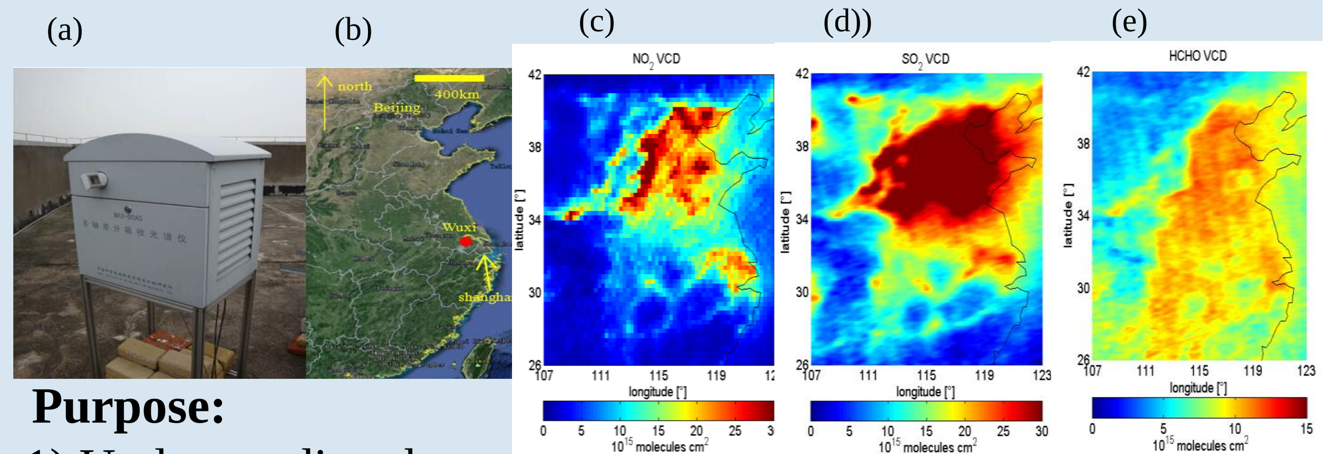


Fig. 1. The MAX-DOAS instrument (a) is operated in Wuxi city (b) marked by the red dot. The mean maps of tropospheric VCDs of NO2 (from DOMINO) (c), SO2 (from BIRA) (d) and HCHO (from BIRA) (e) derived from OMI observations in the period of 2011 to 2014 are shown

Purpose:

1) Understanding the temporal variation and spatial distribution of the abundances of NO_2, SO_2, HCHO and aerosols in an urban region.

2) Validate satellite and model tropospheric products of trace gases.

Highlights:

1) Two important aspects of the MAX-DOAS retrievals: a) effect of systematic seasonal variation of temperature and pressure on the O4 VCD, b) differences of VCDs from either the geometric approximation (GA) or by the integration of the retrieved profiles (IoP)

2) Evaluation of cloud effects on MAX-DOAS results by comparisons with independent techniques

3) Characterization of the seasonal, diurnal, and weekly variations of column densities, near-surface concentrations and vertical profiles of the species

4) Comparisons of bi-monthly mean satellite and model products with MAX-DOAS results

Method:

1) a MAX-DOAS (see Fig. 1a) instrument operated from May 2011 to Nov 2014 in Wuxi, China (see Fig. 1b).

2) We determine the tropospheric VCDs, near surface concentrations and vertical profiles of aerosols and trace gases from the MAX-DOAS observations using DOAS method and optimal estimation based inverse algorithm (referred to as "PriAM") (Wang et al., 2013a,b) (see Fig. 2).

3) We verified the results by comparing them with other independent techniques in different cloud conditions acquired from MAX-DOAS observations by the cloud classification scheme (Wagner, et al., 2014 and Wang, et al., 2015).

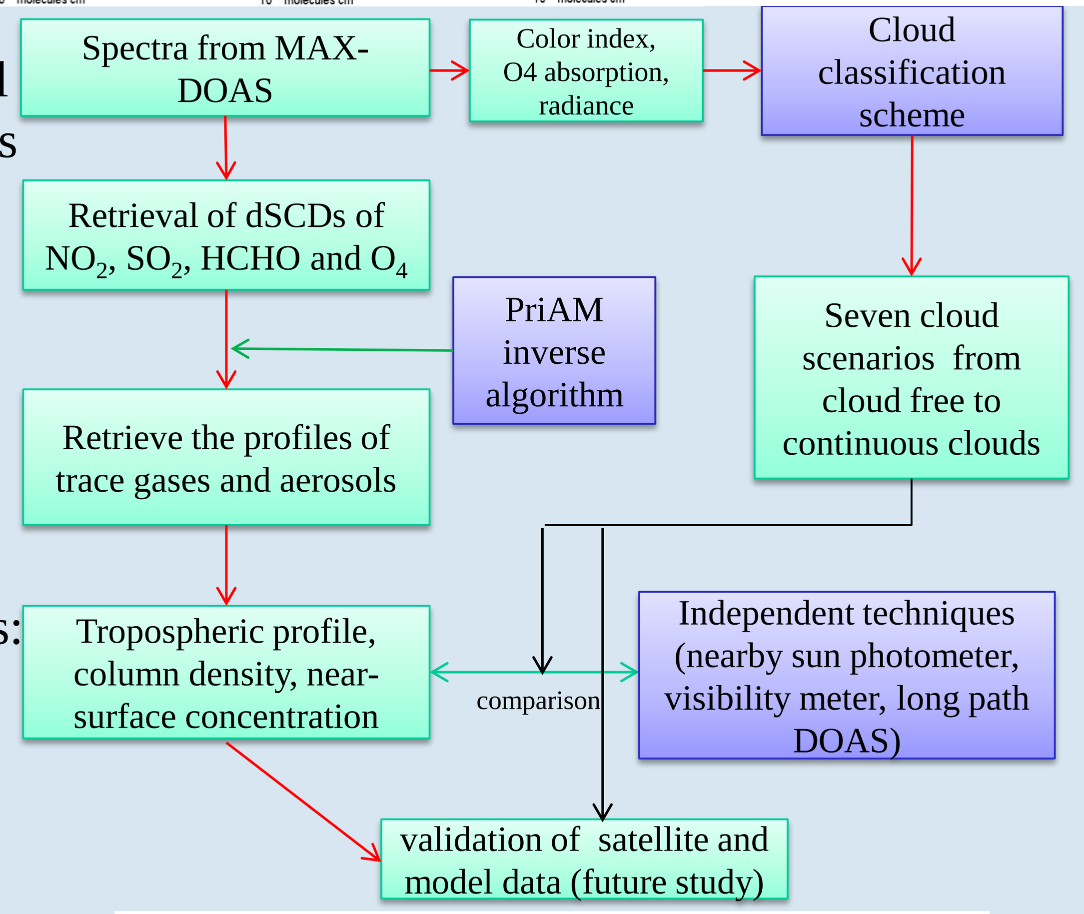


Fig. 2. The scheme of the data processing from MAX-DOAS

2. Two important aspects in MAX-DOAS retrievals

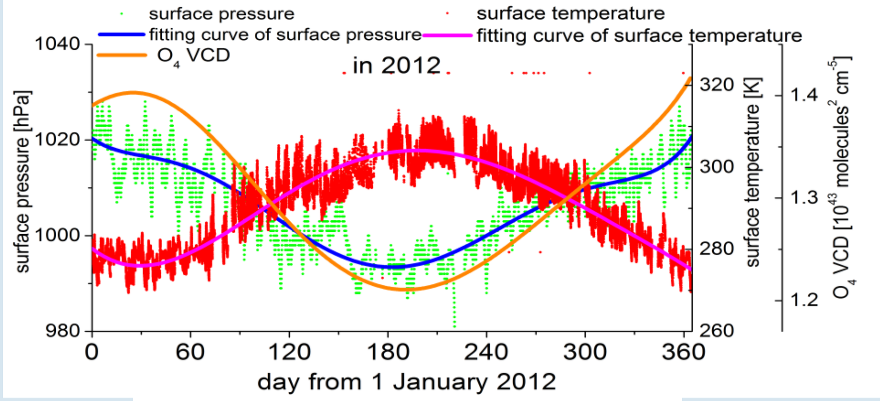
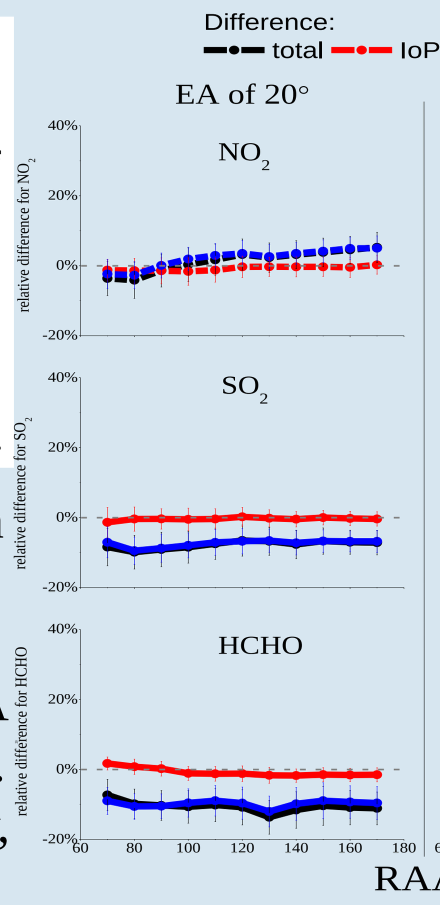


Fig. 3. seasonal variation of temperature, pressure and O4 VCD

Fig. 4. Relative differences of the VCDs derived by GA and IoP as function of the relative azimuth angle for elevation angles of 20° and 30°. The differences caused by the IoP (red dots) and GA (blue dots) are shown.



1. Without correction of the systematic seasonal variation of the O4 VCD of about 15% (Fig. 3), AOD is biased up to 20%. It is corrected in this study.

2. Fig. 4 shows that the differences of VCDs between GA and IoP are mainly caused by the geometric approximation. The bias of GA depended on sun and meas. geometry, aerosol load and trace gas profiles.

3. Cloud effect on MAX-DOAS results

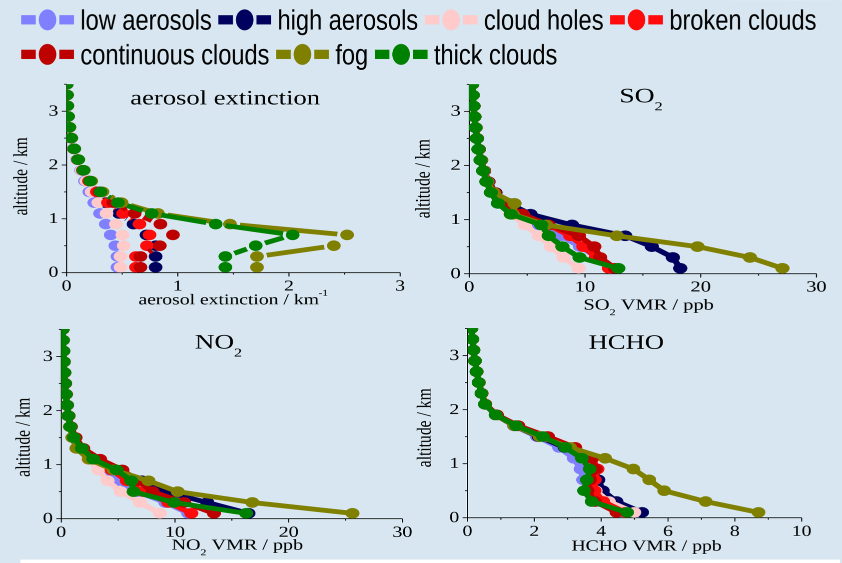


Fig. 5 profiles of the trace gases and aerosols in different sky conditions

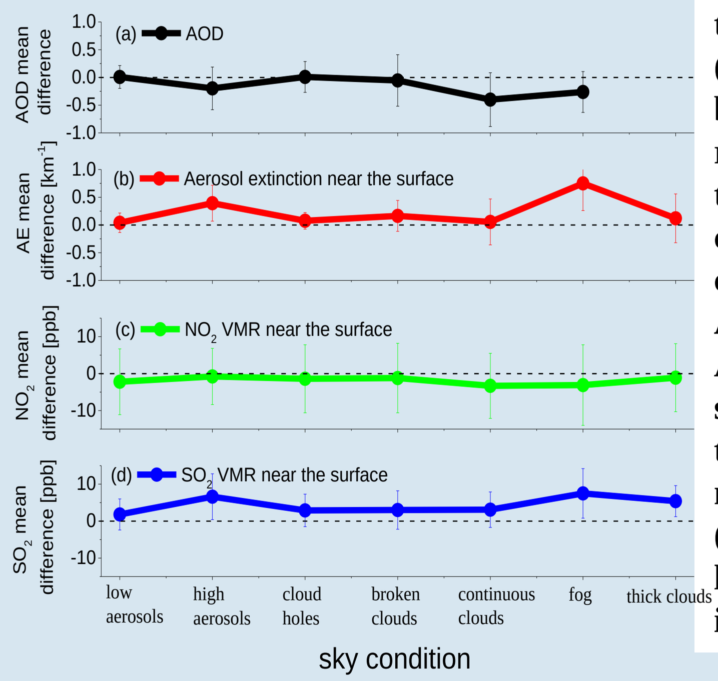


Fig. 6 Mean differences and the standard deviation (shown as the error bar) between MAX-DOAS results and independent techniques for different sky conditions. Different colours denote the values of AOD (compared with Taihu AERONET level 1.5 data sets), AE (compared with the visibility meter located nearby) and NO2 and SO2 (compared with the nearby long path DOAS instrument).

Fig.5 and 6 show that the trace gases results (VCD and profiles) and near-surface aerosol extinctions for clear and cloudy sky conditions (except fog and optically thick clouds) are credible, but AOD and aerosol profiles are only credible for clear sky conditions.

4. Seasonal, weakly, diurnal variation of trace gases and aerosols

Seasonal variations: Fig. 7 shows that the prominent seasonality of trace gases is similar in different years. Aerosols show different seasonality in different years.

Yearly trend: see Fig. 8, from 2011 to 2014, only SO2 shows a clear decreasing trend, while NO2, HCHO and aerosol levels stay almost constant.

Weekly cycle: see Fig.9, similar cycles are found for the species, indicating anthropogenic sources.

Diurnal cycle::see Fig. 10, depends on the interplay of sources and depositions.

Seasonality of the profiles: see Fig. 11, NO2 and SO2 (HCHO and aerosols) are more close to the surface (lifted) in summer. Transport is found to be probably an important effect for SO2 and aerosols.

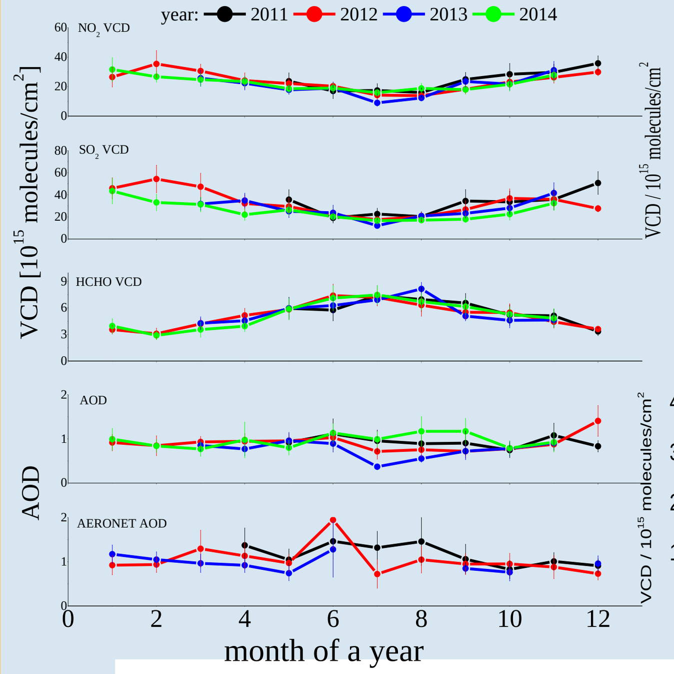


Fig. 7 monthly mean results

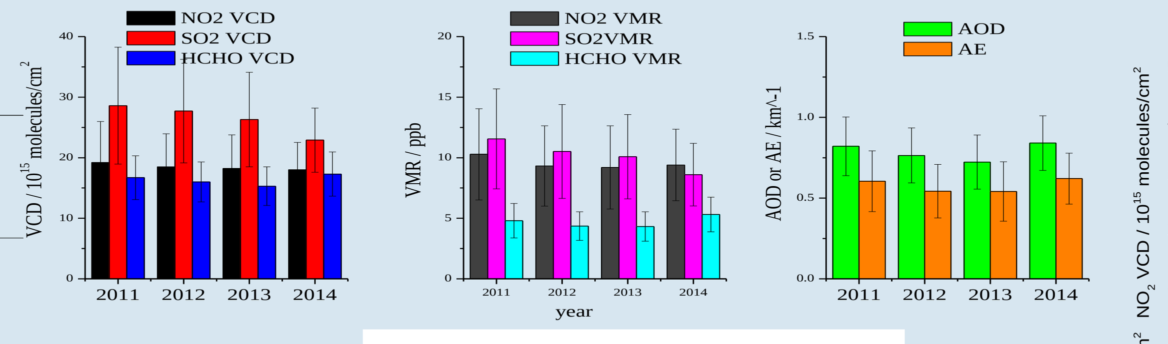


Fig. 8 yearly mean results

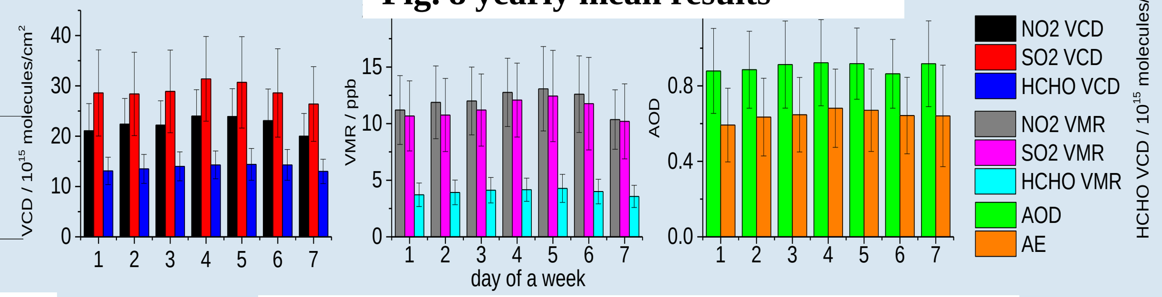


Fig. 9 mean values in different days of a weak.

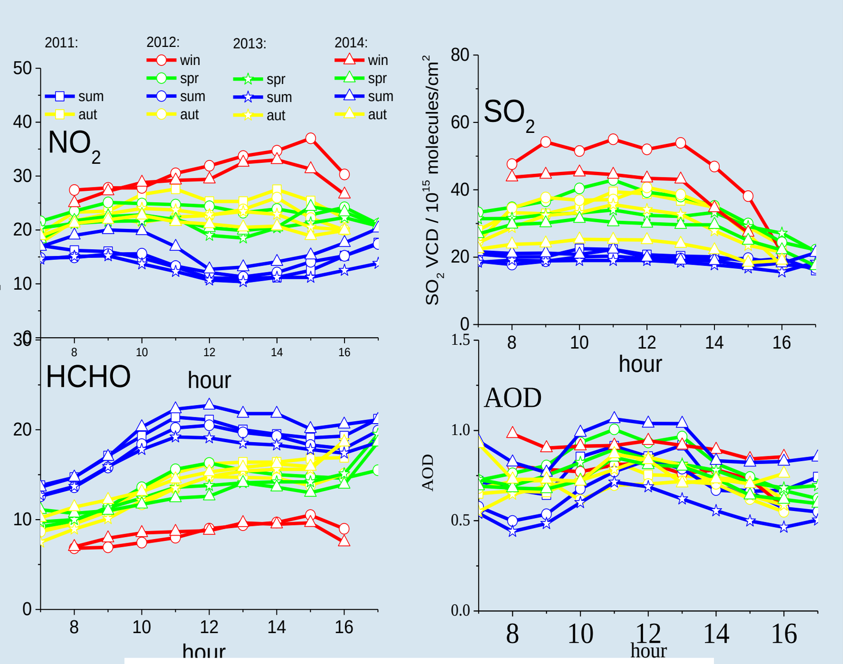


Fig. 10 diurnal cycle of the species

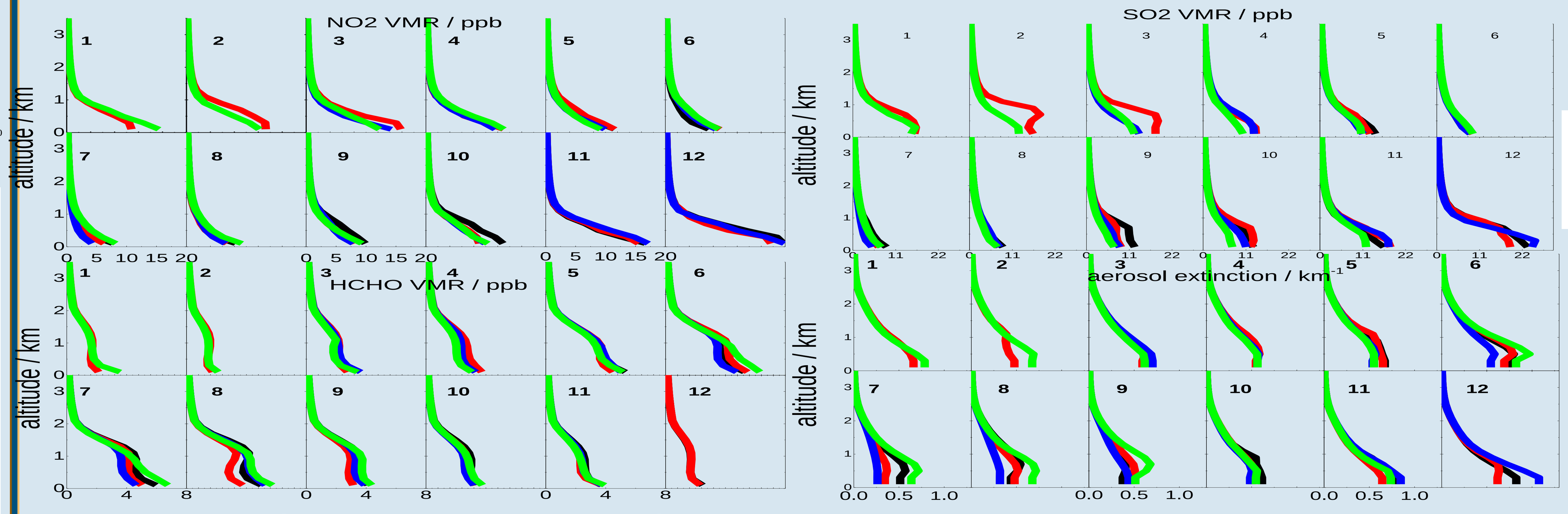


Fig. 11 monthly mean profiles

5. Validation of tropospheric VCDs of OMI, GOME-2A\B by comparisons with MAX-DOAS

Satellite data sets: OMI DOMINO version 2 NO_2 product, GOME-2A/B TM4NO2A version 2.3 NO_2 products; OMI NASA OMSO2 PBL SO_2 product, OMI and GOME-2A BIRA SO_2 products ; OMI, GOME-2A/B BIRA HCHO products.

Coincident criteria: pixel centre distance of 20km for OMI NO2 and SO2; 50km for OMI HCHO and all GOME-2 data.

Main conclusion: 1) OMI DOMINO NO2 product is consistent, only slightly lower in winter. GOME-2A/B NO_2 products are systematically higher; 2) significant systematic underestimations of all SO2 and HCHO products; 3) seasonality is well represented by all the satellite products, except GOME-2A HCHO; 4) replacing a-priori profiles from CTM by those from MAX-DOAS can improve the agreement, and significantly increases VCDs when VCDs are large.

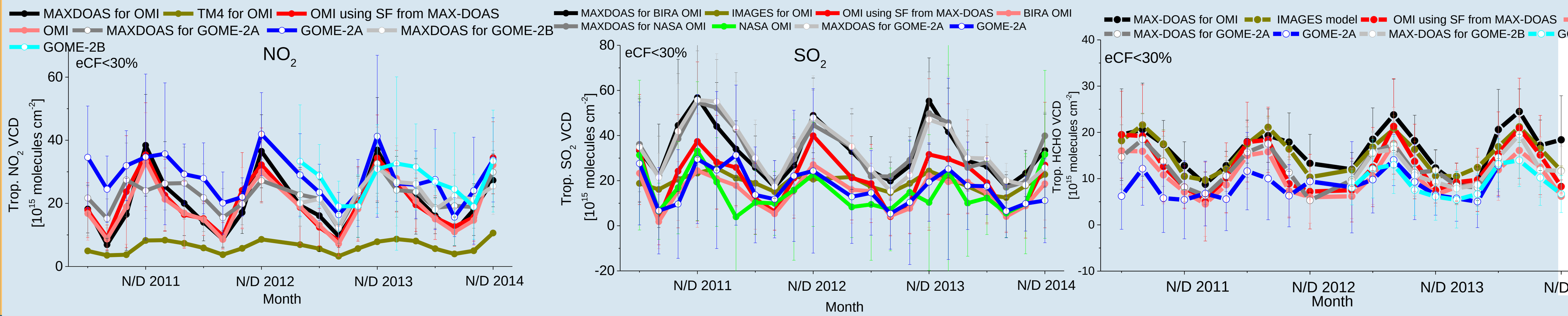


Fig. 12 bi-monthly mean VCDs from satellite, model and MAX-DOAS

(1) Thomas Wagner, et. al.: Cloud detection and classification based on MAX-DOAS observations, AMT, 7, 1289-1320, 2014. (2) Yang Wang, et al.: Cloud and aerosol classification for 2.5 years of MAX-DOAS observations in Wuxi (China) and comparison to independent data sets, AMT, 8, 5133-5156, doi:10.5194/amt-8-5133-2015, 2015.. (3) Yang Wang, et al.: Retrieving vertical profile of aerosol extinction by multi-axis differential optical absorption spectroscopy, Acta Phys. Sin., 16, doi: 10.7498/aps.62.180705, 2013. 4) Yang Wang. et al.:Measuring tropospheric vertical distribution and vertical column density of NO2 by multi-axis differential optical absorption spectroscopy, Acta Phys. Sin., 16, DOI:10.7498/aps.62.200705