Validation of cloud and aerosol classification results based on three years MAX-DOAS observations in Wuxi (China) using independent data sets

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Abstract

Multi-Axis-Differential Optical Absorption Spectroscopy (MAX-DOAS) observations of trace gases can be strongly influenced by clouds and aerosols. Thus it is important to identify clouds and characterise their properties. In the former work (Wagner et al. 2013) we found the colour index, radiance and O4 absorption from MAX-DOAS measurements are sensitive to the properties of cloud and aerosol and built a sophisticated classification scheme. In this work we further improved the identification of clouds and aerosol for each elevation sequence of MAX-DOAS based on three years of measurements (2011 to 2013) in Wuxi, China (31.57°N, 120.31°E). The cloud classification results were verified by comparing with other cloud or aerosol data sets such as the aerosol optical depth (AOD) from the AERONET Taihu monitoring site (31.42° N, 120.22° E), MODIS Level 2 cloud products and cloud parameters in level 2b productions of OMI and GOME-2 from TEMIS. We find good agreement with the MAX-DOAS cloud classification using statistical analyses. Based on the results of MAX-DOAS cloud classification, we investigate the validation of tropospheric NO_2 VCD from OMI with the clouds tropospheric NO_2 VCD from MAX-DOAS. The flags of sky conditions provide more information on the validation of satellite productions by MAX-DOAS observations.

Motivation

- The effects of sky conditions (clear sky, continuous clouds, broken clouds and high aerosol load) on MAX-DOAS measurements are quite different.
- It is necessary for processing or interpolation of MAX-DOAS data to flag the sky conditions for each measurement.
- It is helpful to precisely validate the tropospheric vertical column density from satellite products in different sky conditions.

We want to build a convincing scheme to derive cloud and aerosol information (sky conditions) from the individual MAX-DOAS observations

Cloud classification scheme of MAX-DOAS

The classification scheme is based on seven quantities deduced from the radiance, CI and O_4 absorption observed by MAX-DOAS. The seven quantities are shown in the table 1. Based on the quantities, we built this scheme in figure 1. Its left column show the determinations and the right blue column show the deduced sky conditions. We identify the sky conditions by comparing the quantities from individual MAX-DOAS observations with their corresponding reference values in clear sky. The scheme include two kinds of classifications. One is primary classifications indicated by the black arrows and another one is additional classifications indicated by the blue arrows. Note that The sky condition for each MAX-DOAS measurement should belong to one primary classification. In addition to the primary classification additional secondary classifications can be assigned.

Quantity for cloud classification	abbreviation	threshold
Normalized CI (340nm/420nm) for zenith view	CI_z^n	0.9
Normalized temporal smoothness indicator of CI for zenith view	TSI_z^n	8×10^{-8} s^{-2}
Sum of normalized temporal smoothness indicator of CI for non-zenith view	TSI_L^n	2.5×10^{-7}
spread of the CI	$Spread_{CI}$	0.3
Normalized O_4 AMF	AMF_{O4}^n	0.8
Normalized radiance at 380 nm	$Radiance_n$	0.9
spread of the O_4 dAMF	$Spread_{O4}$	0.4

Table. 1. The quantities derived from MAX-DOAS for cloud classification, their abbreviations and thresholds.

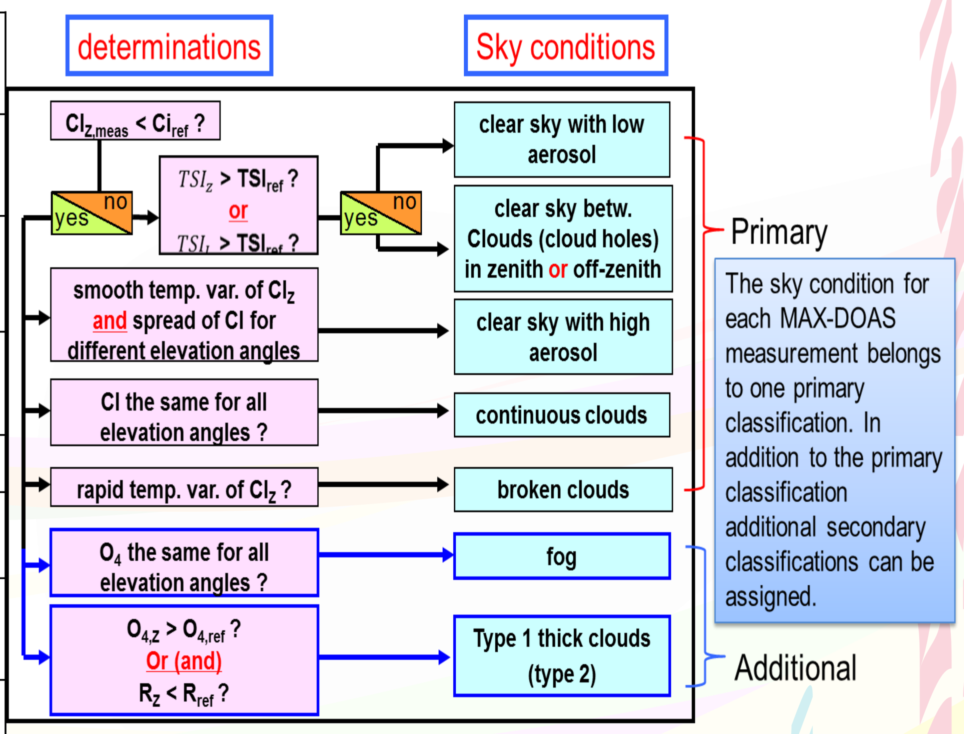

Fig. 1. the cloud classification scheme of MAX-DOAS .

Validation of the scheme based on MAX-DOAS Measurements in Wuxi, China

MAX-DOAS: The measurements are operated from 1 May 2011 to 29 Nov 2013 with 5 elevation angles (5°, 10°, 20°, 30° and 90°), azimuth angle is 0 °(north)

Other techniques for comparisons with MAX-DOAS:

1.Visibilitymeter: the visibility at 550 nm

2.Aeronet: The AOD is available from sun photometer operated at Taihu about 18 km west-south away from the Wuxi MAX-DOAS site.

3.effective cloud fraction form OMI, GOME-2

4.geometrical CF from MODIS

5.cloud optical thickness from MODIS

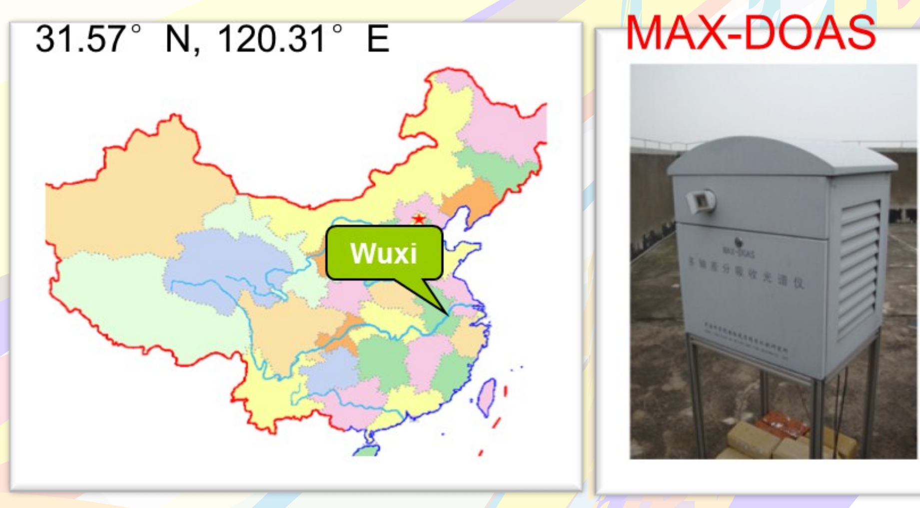

Fig. 2. the location of Wuxi city in China and MAX-DOAS instrument .

Validation of the scheme based on MAX-DOAS Measurements in Wuxi, China

Each MAX-DOAS measurement (elevation sequence) is assigned by one sky conditions identified by the scheme in figure 1 in the period from 1 May 2011 to 29 Nov 2013. The identified sky conditions in the sample days are shown in Fig. 3. Overall the deduced sky conditions are consistent to the one identified by MODIS images and Aeronet. In detail the variation of sky condition on one day is rapid.

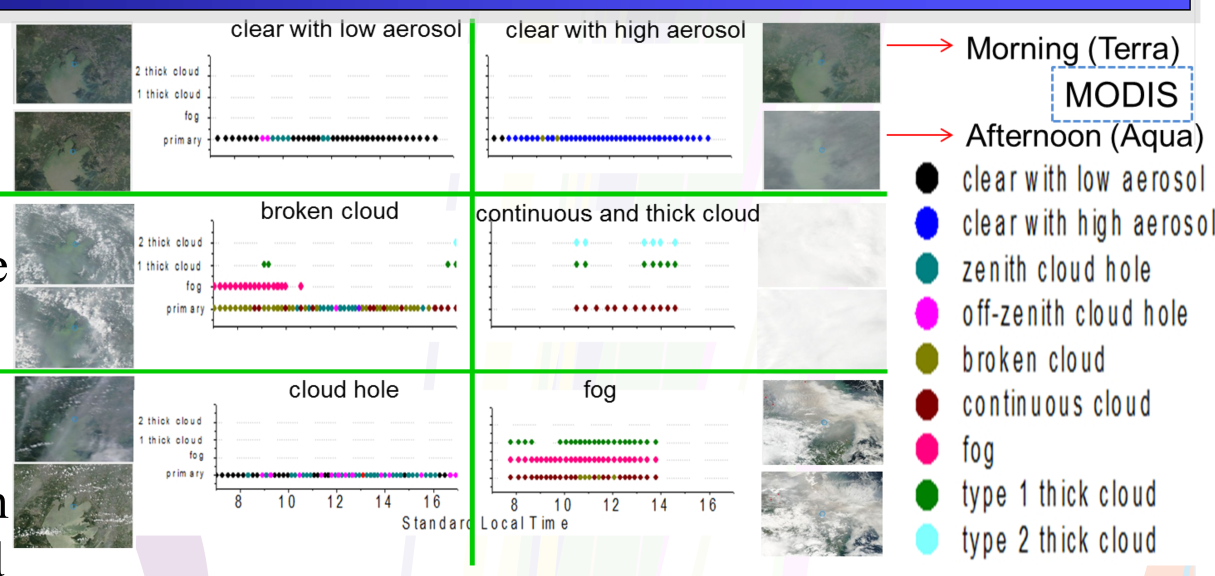

Fig. 3. the comparison of the identified sky conditions and visual images from MODIS.

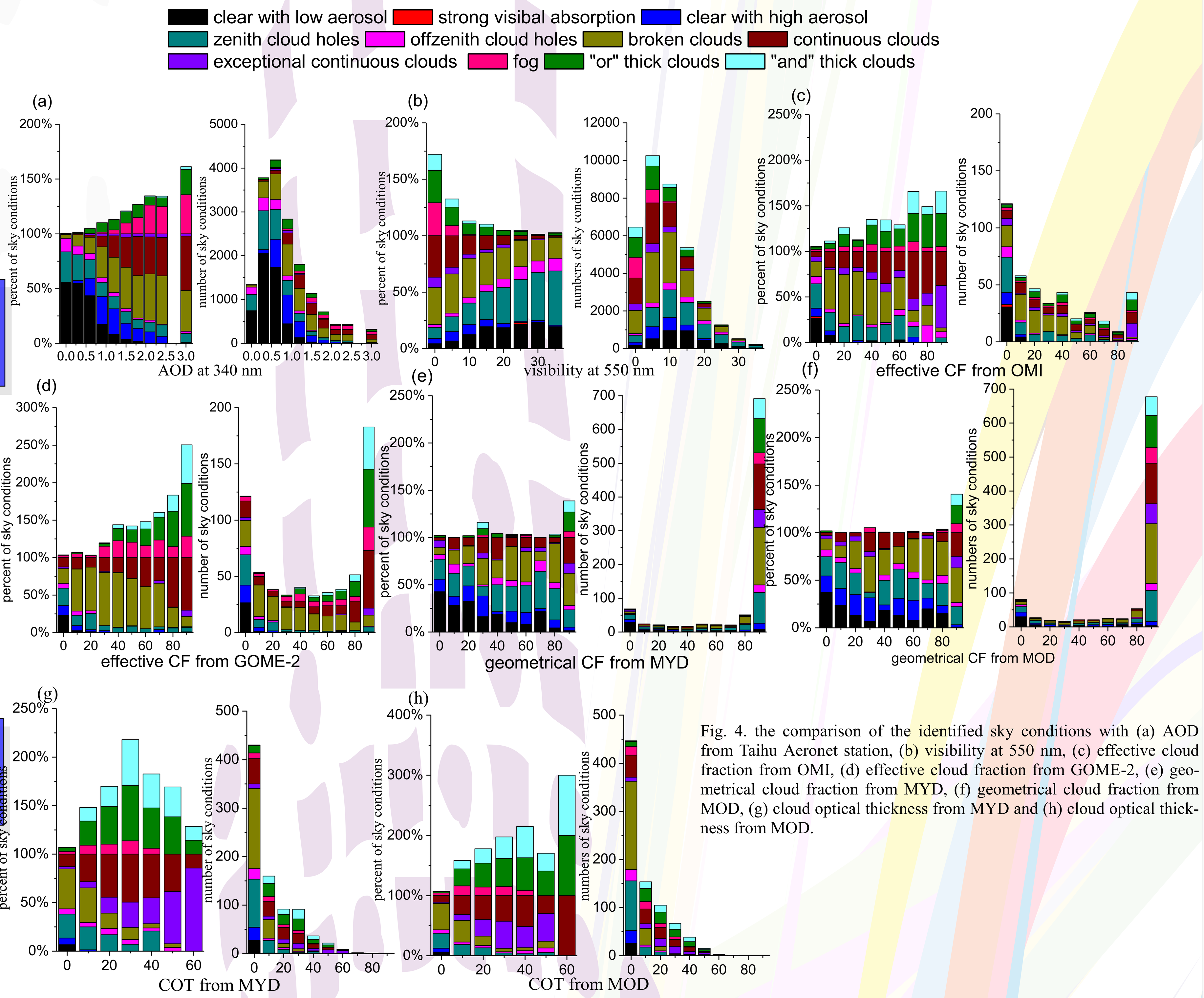

Fig. 4. the comparison of the identified sky conditions with (a) AOD from Taihu Aeronet station, (b) visibility at 550 nm, (c) effective cloud fraction from OMI, (d) effective cloud fraction from GOME-2, (e) geometrical cloud fraction from MYD, (f) geometrical cloud fraction from MOD, (g) cloud optical thickness from MYD and (h) cloud optical thickness from MOD.

The comparison of the sky conditions identified by MAX-DOAS with the AOD from Aeronet, the visibility from visibility meter and cloud productions from MODIS, OMI and GOME-2 confirm believability of the classification scheme in Figure 4. The identified sky conditions are in good agreement with the AOD from Aeronet, visibility from visibilitymeter and the effective CF from OMI and GOME-2, but inconsistent with the geometrical CF from MODIS and CRF from GOME-2. This feature implies this scheme can reasonably identify the sky condition and its sensitivity is depended on the cloud optical thickness. This dependence is further proved by the comparison with COT from MODIS.

The tropospheric NO_2 VCDs are retrieved using geometrical method and using profile retrieval process from MAX-DOAS observations, respectively. Then the two kinds of VCDs from MAX-DOAS are compared with the NO_2 tropospheric VCD from TEMIS of OMI in different scenarios of cloud fraction or sky conditions (see table 2). Profile retrieval process makes the slopes (MAX-DOAS VCD against satellite VCD) much more close to one than geometrical method, especially in the condition of clear with high aerosol.

Table. 2. The linear relationship of tropospheric NO2 VCDs from OMI and VCDs from MAX-DOAS using geometrical method and profile retrieval process, respectively.

	VCD from geometrical method of MAX-DOAS measurements			VCD from profile retrieval process of MAX-DOAS measurements		
statement	R^2	slope	Point number	R^2	slope	Point number
All points	0.6585	1.3717	203	0.578	1.213	142
CF<0.3	0.7095	1.401	115	0.567	1.074	92
CF<0.2	0.754	1.34	98	0.763	1.050	86
CF<0.1	0.842	1.298	72	0.834	1.033	68
Clear with low aerosol	0.839	1.202	30	0.821	1.048	28
Clear with high aerosol	0.8111	1.4427	9	0.909	1.057	9
Cloud holes	0.82842	1.3031	46	0.639	1.295	61
Broken clouds	0.7012	1.237	67	0.685	1.166	38
Continuous clouds	0.5424	1.790	58	0.7868	2.098	11

Summary

1.The sky conditions can be automatically detected and classified for each measurement sequence of MAX-DOAS only using the quantities (CI, O4 absorption and radiance) observed by MAX-DOAS.

2.The good agreements of MAX-DOAS cloud classifications with other techniques verified our scheme.

3.The flags of sky conditions provide more information on the validation of satellite productions by MAX-DOAS observations.