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MOBILE OBSERVATIONS BY LIDAR, SUN PHOTOMETER AND IN SITU IN NORTH CHINA PLAIN

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ABSTRACT

A mobile laboratory integrating lidar, sun photometer and in situ instruments has been deployed to observe the aerosol spatial variability in North China Plain in May 2017. Results from the campaign are presented.

1. INTRODUCTION

MOABAI campaign (***M**obile **O**bservations of **A**tmosphere **B**y vehicle-borne **A**erosol measurement **I**nstruments*) has been carried out in the 5-23 May 2017 period in North China Plain (Fig. 1), one of the most populated and polluted regions of China, where long-standing heavy aerosol pollution episodes frequently occur. The campaign was purposed to elucidate and quantify the 4-D distribution of aerosols in a polluted region where few aerosol measurements are available, in order to get a comprehensive characterization of aerosol properties and their vertical distribution in variable atmospheric situations.

2. INSTRUMENTS AND METHODOLOGY

The mobile observations have been performed using a state-of-the-art instrumented van, which included both remote sensing and in situ instrumentation. The lidar and the mobile sun photometer from MAMS [1] (Mobile Aerosol Monitoring System) were transported and integrated on site in the existing van already equipped with in situ instruments.

2.1 Lidar

A commercial Cimel micropulse lidar (model CE370) has been integrated in the van. It is a one-wavelength elastic backscattering lidar operating at 532 nm with 20 µJ pulse energy and 4.7 kHz laser pulse repetition rate. The detection of backscattered light is done in photon counting mode using an APD. The lidar is a mono-axis system, consisting of a shared transmitter-receiver telescope connected to the control and acquisition unit through a 10 m optical fiber. The telescope has a diameter of 200 mm and a narrow field of view (55 µrad) in order to limit the background solar light. The lidar allows monitoring aerosols and clouds in the troposphere, typically up to 15 km with a vertical resolution of 15 m.

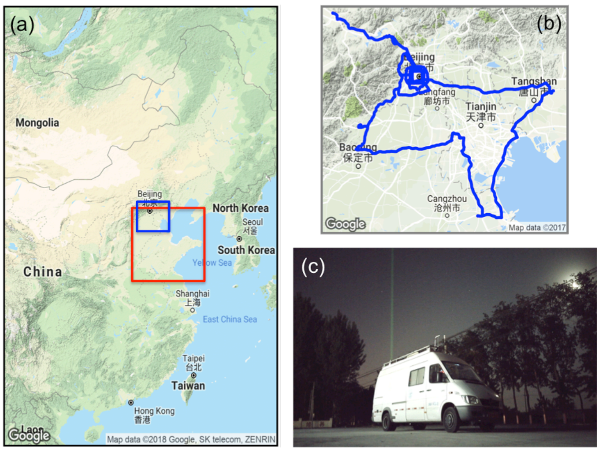

Figure 1. (a) North China Plain (red rectangle) and area investigated through mobile measurements (blue rectangle), (b) GPS track of all mobile transects during MOABAI and (c) IAP/LAGEO instrumented van used for mobile observations.

Vertical profiling of extinction coefficient is achieved using a Klett-based iterative inversion algorithm [2], constrained by coincident AOD from mobile sun photometer measurements. The mass concentration profiles are derived using an extinction-to-mass relationship, where additional information from in situ measurements at ground level and column-integrated volume size distribution are used in the calculations.

2.2 Sun photometer

The sun-tracking photometer PLASMA (*Photomètre Léger Aéroporté pour la Surveillance des Masses d'Air*) [3] is an instrument developed by LOA and SNO PHOTONS in Lille, France. Its unique features are the capability of performing direct solar radiation measurements during the vehicle motion and its light weight (~ 5 kg) and compactness (∅ 16 x H 23 cm). PLASMA has 9 spectral channels at same wavelengths as a standard Cimel CE318 photometer in AERONET. It is calibrated by SNO PHOTONS, French branch of AERONET, and undergoes the calibration protocol for the AERONET reference master instrument. Compared to CE318 sun photometer, the current PLASMA model performs only direct sun measurements.
PLASMA provides AOD measurements along the vehicle's track and column-integrated volume size distribution are derived from spectral AOD using GRASP-AOD algorithm [4].

2.3 In situ

The in situ instruments consisted of a polar nephelometer (Ecotech, model Aurora 4000), an aethalometer (Magee Scientific, model AE33), a Grimm Sky-OPC and trace gas analyzers for NO_2, SO_2 and O_3.

The measurements at ground level included particle number concentration, size distribution, particle scattering (450, 535 and 635 nm) and absorption (370, 470, 520, 590, 660, 880 and 950 nm) coefficients.

3. RESULTS

Ten days of mobile observations have been recorded during MOABAI campaign, six days in Beijing on the 4th, 5th and 6th ring-roads by daytime and nighttime and 4 days outside of Beijing, reaching Baoding, Tianjin and Tangshan. Four types of atmospheric situations were observed: two days of pollution and "background" (moderate pollution) situation in Beijing with a contribution of dust transported from Gobi desert (9 and 11 May), three heavy pollution days, when the air flow moved from south of China (18, 19 and 21 May), one day with moderate pollution (15 May) and one "clean" day, marked by lower aerosol loading (13 May), but with a contribution of long-range transported aerosols in altitude. In the case of pollution days, the height of the PBL extended up to 1 - 1.5 km altitude and the AOD at 440 nm was high (0.8 - 1.8), highest values being recorded when the air masses were moving from South direction. Angstrom Exponent (AE) values typical for fine mode particles predominance (1.2 – 1.6) were recorded for these days. For the "background" and "clean" situations, a contribution of both fine and coarse mode aerosols was evidenced, indicated by lower AE and by transported aerosol layers above 2 km. Three mobile observations were carried out outside Beijing (Fig. 2) : Beijing – Baoding - Tianjin (16 May), Tianjin - Tangshan (17 May) and Tangshan - Beijing (18 May). The AOD at 440 nm was in the range of 0.2 - 0.7, 0.3 - 0.79 and 0.43 - 1.35 for the transects on 16, 17 and 18 May, respectively. The values of AE were in the range of 0.38 - 1.5, 1.02 - 1.9 and 1.22 - 1.74 for 16, 17 and 18 May, respectively.

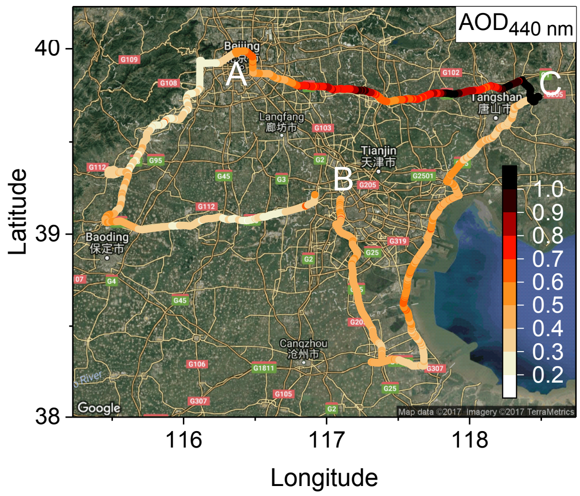

Figure 2. Spatial variability of AOD at 440 nm from PLASMA sun photometer measurements. The A, B and C denote the departure and arrival points for three transects: Beijing-Tianjin (AB) on 16 May 2017, Tianjin-Tangshan (BC) on 17 May 2017 and Tangshan-Beijing (CA) on 18 May 2017.

The lidar profiles showed higher particle concentrations when reaching polluted regions of Baoding, Tianjin, Binhai New Area and Tangshan and transport of desert dust from Inner Mongolia at about 2-3 km altitude.

Mapping of AOD, Angstrom Exponent and retrieved vertical profiles of aerosol extinction coefficients and column-integrated volume size distribution have been achieved. Results from some case studies in Beijing and along Tianjin coast will be presented.

3.1 Case study: 17 May 2017

The mobile observations on 17 May 2017 started from the city of Tianjin, along the Binhai New Area, on the coast of the Bohai Sea, and heading to Tangshan (Fig. 3). The weather was fair, with clear sky along the whole transect, with ambient temperatures in the 24° - 30° Celsius and RH in the 30 - 65 % range, with a noticeable increase along the coast of Bohai Sea, indicating the occurrence of a sea breeze event. Backward trajectories showed a flux from S-SE at ground level and up to 1 km and a flux from NW at 3 km, explaining the presence of fine dust layers transported from Inner Mongolia.

The Binhai New Area is a region marked by the presence of several industries, from machinery factories, petro-chemical manufacturing plants, automotive fitting factories and electronics facilities to sea salt production, shipbuilding and port activity. The area accounted 271 industrial enterprises in 2012, resulting in heavy pollution in the region [5, 6]. It is a region where the microphysical and optical properties of aerosols are not well characterized, much less at a fine scale. The situation is even more complex in spring season, as mineral dust transports frequently occur, adding to the local anthropogenic aerosols, which makes this region an interesting study area.

One previous study using mobile lidar measurements has been conducted in Tianjin, in different seasons in 2016 [7]. Nevertheless, this is the first time mobile observations with such rich instrumentation and methodology, combining remote sensing and in situ measurements, are conducted in Tianjin and in the Binhai New Area.

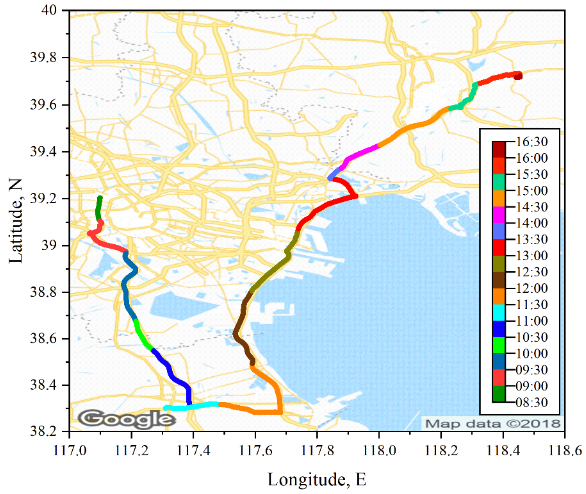

Figure 3. GPS track of the mobile transect from Tianjin to Tangshan on 17 May 2017, colour coded by 30 minutes time intervals (local time)

The spatial variability of the extinction coefficients profiles at 532 nm derived from the synergy of lidar and sun photometer measurements is presented in Figure 4. The mean extinction coefficient in the PBL, from the surface to about 2 km, was 0.14 ± 0.11 km^{-1} along the whole transect from Tianjin to Tangshan and a maximum of 0.57 km $^{-1}$ was recorded at 650 m height at Tianjin. Above the PBL, a lofted aerosol layer in the 2.2 – 3.5 km altitude range was observed all along the mobile transect. The backward trajectories indicated it is most likely desert dust, transported from Inner Mongolia. The mean extinction coefficient of the dust layer was 0.05 ± 0.03 km^{-1}, and the mean AOD at 532 nm was 0.06 ± 0.01, representing around 18-20% of the total measured AOD.

The highest values of extinction coefficient were found at Tianjin and along the Binhai New Area. This shows both the urban print of a metropolis (the 13^{th} world largest city) and the print of a coastal region with enhanced industrial activities and the presence of the port of Tianjin, the largest port in mainland China and one of the largest in the world.

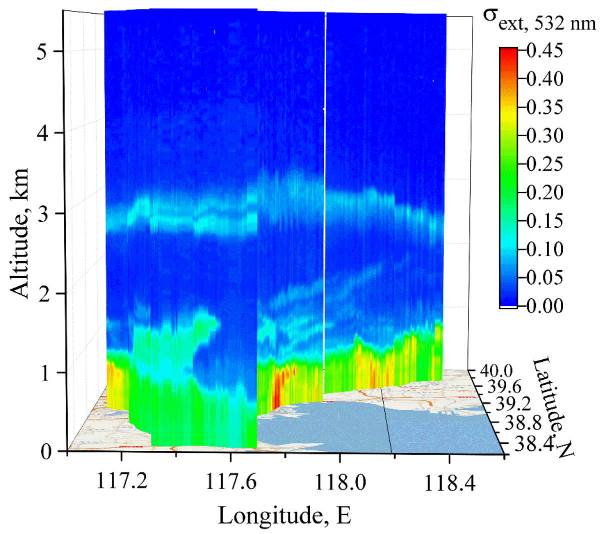

Figure 4. 3-D representation of the variability of lidar-derived extinction coefficients at 532 nm along the mobile transect from Tianjin to Tangshan

The profiles of aerosol mass concentration were estimated from the extinction coefficients profiles and using microphysical and optical properties of two defined aerosol models: an urban/industrial aerosol model in the PBL and a desert dust model for the elevated layer in the 2.2 – 3.5 km altitude range. The extinction profiles below 200 m are constrained by in situ extinction measurements at ground level.

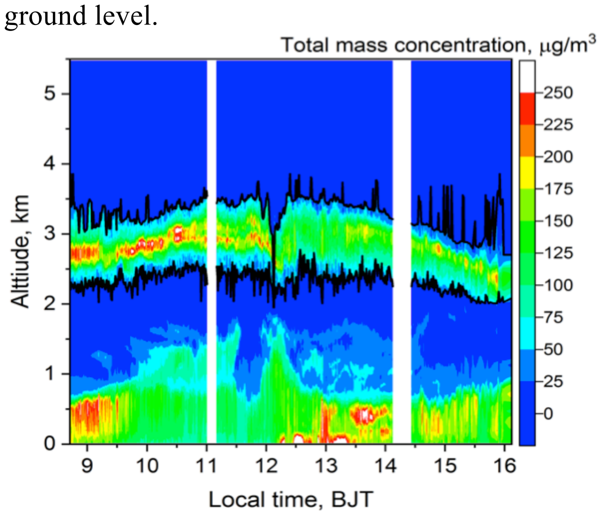

Figure 5. Particle mass concentration profiles derived from mobile lidar and sun photometer measurements on 17 May 2017 along the transect from Tianjin to Tangshan

The mean mass concentration in the dust layer was 95 ± 52 μg m^{-3} with a maximum of 284 μg m^{-3}. The mean mass concentration in the PBL was around 80 ± 62 μg m^{-3} for the whole transect. The standard deviations correspond to the variability along the transect. The highest particle mass concentrations were found near Tianjin, until 09:30, and when crossing the industrial coastal region, from 12:00 to 14:00 local time.

4. CONCLUSIONS

We have observed highly variable aerosol situations in North China Plain, proving the use of mobile observations for investigating the spatial variability of aerosol properties. The advantage of an instrumented van is that it can be easily deployed for the study of sudden aerosol events. The complementarity of in situ and remote sensing data is useful in the analysis of complex aerosol situations.

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