Fiducial Reference Measurements for Ground-Based DOAS Air-Quality Observations

ESA Contract No. 4000135355/21/I-DT-lr

Deliverable D3.1:

Ancillary Data Availability Survey

Date: 20/03/2023

Version: 0

Contributing authors:

U. Frieß (IUP-HD)
T. Wagner, S. Ziegler and S. Beirle (MPIC)
F. Hendrick, M. Friedrich, and M. Van Roozendael (IASB-BIRA)
A. Piters (KNMI)
A. Bais and D. Karagkiozidis (AUTH)

Content

Acronyms and abbreviations

Acronyms and abbreviated terms that are specific for this document can be found below.

AOD	Aerosol optical depth
APS	Aerodynamical Particle Sizer
FRM_4DOAS	Fiducial Reference Measurements for Ground-Based DOAS Air-Quality Observations
LIDAR	Light Detection and Ranging
MAAP	Multi-Angle Absorption Photometer
MAX-DOAS	Multi-Axis Differential Optical Absorption Spectroscopy
SMPS	Scanning Mobility Particle Sizers
TIP	Technical implementation plan

1 Introduction

The objective of FRM$_4$DOAS WP3 is the development of a consolidated MAX-DOAS aerosol product and the documentation of the essential steps for the optimisation as a TIP. An important milestone to reach this goal is a validation of the FRM$_4$DOAS aerosol products (AOD and extinction profiles) with co-located independent aerosol measurements. As a first step, an assessment of co-located aerosol instrumentation was performed in order to select suitable validation sites as part of the FRM$_4$DOAS network. This was done by circulating a respective questionnaire among the PIs of the FRM$_4$DOAS network. This document summarises the results of this Ancillary Data Availability Survey and the validation sites selected by the FRM$_4$DOAS consortium.

2 Methods - The Ancillary Data Availability Survey Form

The Ancillary Data Availability Survey Form developed by UHEID includes a questionnaire on available remote and in situ instrumentation located in the vicinity of the FRM$_4$DOAS measurement sites, as well as on the MAX-DOAS instrument itself. For each instrument type, information on the manufacturer, the instrument PI, location and specific technical details was requested. The aerosol instrumentation and ancillary data included in the survey form was the following:

1. **Sun Photometer**
   These instruments determine the AOD by observation of attenuated direct sunlight at several wavelengths. An interpolation of the AOD to the FRM$_4$DOAS aerosol wavelengths (360 nm and 477 nm) can be done by interpolation using the Angström exponents retrieved from the sun photometer observations.
   In addition, sun photometer almucantar scans allow for retrieving the aerosol size distribution as well as optical and microphysical properties, such as the phase function and the complex refractive index of the aerosol particles [Dubovik and King, 2000].
   Together with the extinction profiles from ceilometer and LIDAR instruments, AOD measurements from sun photometers represent the most important parameter for the validation of FRM$_4$DOAS aerosol products.
2. **Ceilometer and LIDAR**
   LIDAR instruments detect the time-resolved backscatter signal of short laser pulses emitted vertically into the atmosphere. This allow for a qualitative reconstruction of the vertical distribution of aerosols and clouds. Ceilometer instruments use the same approach, but are optimised for the detection of aerosols and clouds in the lower troposphere [Münkel et al., 2007]. Raman LIDAR instruments are capable of directly retrieving the extinction profiles, but are difficult to perform during daylight owing to the comparably small Raman signal. Otherwise, the conversion of LIDAR and ceilometer backscatter profiles requires either an estimate for the backscatter–to–extinction ratio, or the profile can be scaled to the total AOD, e.g. using co-located sun-photometer or MAX-DOAS measurements. The vertical resolution of Ceilometer and LIDAR instruments is in the order of 30 m and 10 m, respectively. A disadvantage of Ceilometer and LIDAR instruments is the presence of a blind region near the surface (typically some tens of metres in case of ceilometers and between 300 m and 600 m for LIDARS), where MAX-DOAS instruments are most sensitive.
3. **SMPS/APS**
   SMPS and APS instruments measure the size distribution of aerosol particles [Sioutas, 1999]. Such

measurements represent useful constraints for the phase function of aerosols in the retrieval process, but this requires the implementation of a Mie model in the retrieval algorithms, which currently only assume a Henyey-Greenstein parametrisation for the phase function.

4. **Nephelometer**
   These instruments measure the extinction coefficient near the surface using optical in situ methods. This can be useful for the validation of the surface extinction retrieved by FRM$_4$DOAS. However, Nephelometers usually measure the extinction of dried aerosols, and the reconstruction of the extinction coefficient at ambient humidity is subject to significant uncertainties. Humidity controlled nephelometers are, to our knowledge, not operated at any of the FRM$_4$DOAS sites and showed only poor agreement for an intercomparison performed within the CINDI-1 campaign [Zieger et al., 2011].
5. **Transmissometer**
   Transmissometer instruments directly measure the extinction at the surface using the attenuation of radiation from an artificial light source. This represents a very useful quantity for the validation of the aerosol extinction at the surface retrieved by the FRM$_4$DOAS central processor, but is only available at one site (Cabauw).
6. **MAAP**
   MAAP instruments measure the aerosol absorption coefficient [Petzold and Schönlinner, 2004] by collecting particles on a filter substrate and can, together with nephelometer measurements, serve as a constraint for the single scattering albedo in the FRM$_4$DOAS aerosol retrieval.
7. **Particulate Matter analyser (or monitor)**
   Particulate matter (PM2.5 and PM10) is regularly observed at many sites for air quality monitoring purposes. Such measurements provide data for a qualitative comparison to the aerosol extinction at the surface retrieved by the FRM$_4$DOAS algorithms.
8. **Meteorological Parameters (Surface and Balloon Sounding)**
   Vertical profiles of temperature, pressure and humidity are important parameters for the radiative transfer modelling within the FRM$_4$DOAS retrieval algorithm. Direct observations of these meteorological parameters by balloon soundings potentially lead to an improvement of the retrieved extinction profiles. In addition, surface-based meteorological data provides constraints for pressure and temperature.

3 Results of the Ancillary Data Availability Survey and selection of validation sites

Table 1 summarises the results of the Ancillary Data Availability Survey as based on the feedback by the FRM$_4$DOAS partner institutes. The most comprehensive set of aerosol-related measurements is present at Cabauw. Sun Photometer and Ceilometer/Lidar instruments operate at Cabauw, Uccle, Mainz, Lauder and Thessaloniki. All sun photometer instruments are part of the Aeronet network, except for Lauder, whose instrument is part of Skynet.

Based on this assessment, the FRM$_4$DOAS consortium has selected Cabauw, Uccle, Mainz, Lauder and Thessaloniki as primary validation sites since these are equipped with the most comprehensive aerosol instrumentation, and cover a wide range of atmospheric conditions from remote (Lauder) over semi-polluted (Cabauw) to polluted urban and suburban sites (Thessaloniki, Uccle).

	Sun Photometer	Ceilometer	Lidar	SMPS/APS	Nephelometer	Transmissometer	MAAP	Particulate Matter	Meteorology	Ballon Soundings	Remarks	
Cabauw	■	■	■	■	■	■	■	■	■	■	Raman Lidar@355, 387, 407, 530, 532, 607, 1064 nm - 500 m overlap	Validation sites
Uccle	■	■	■		■		■	■	■	■		
Lauder	■	■	■	■					■	■	Not part of FRM4DOAS consortium	
Mainz	■	■							■			
Thessaloniki	■		■					■			Raman Lidar @ 355, 387, 532, 607, 1064 nm - 800 m overlap	
Neumayer		■							■	■		
Xianghe	■											
Bremen												
Ny-Alesund												
Arrival Heights												

Table 1: Aerosol-related ancillary measurements at the FRM4DOAS sites. The red frame indicates the sites selected for primary validation.

4 The Ancillary Data Availability Survey Form

FRM$_4$DOAS Ancillary Data Availability Survey

One of the objectives of the FRM4DOAS 2.0 project is the validation and improvement of the aerosol data products generated by the FRM4DOAS central processing system.
In order to identify suitable validation sites, we would appreciate if you could provide us with information on aerosol measurements co-located to your MAX-DOAS instrument by filling out the questionnaire below. Information on aerosol-related instrumentation in a distance of less than 20 km to your measurement site for which data is either publicly available or can be made accessible for the FRM4DOAS validation activites would be very valuable.

The questionnaire consists of different sections, with the first being on specifications of your MAX-DOAS instrument, and the following ones on different types of aerosol-related instrumentation. Please fill out the respective sections if aerosol-related measurements of one of the following types are available near your observation site:

- Sun Photometer (AOD)
- Ceilometer (backscatter profiles)
- LIDAR (backscatter/extinction profiles)
- SMPS or APS (size distribution)
- Transmissometer (visibility)
- Nephelometer (aerosol extinction)
- MAAP (black carbon)
- Particulate matter (PM2.5/PM10)
- Meteorological observations

Please return separate questionnaire files for each site in case you operate more than one instrument as part of the FRM4DOAS network.

Note that currently only MAX-DOAS instruments which are part of FMR4DOAS and regularly submit data to the operational processor can be considered in this validation study.

Please contact Udo Frieß (udo.friess@iup.uni-heidelberg.de) in case you have any questions.

FRM$_4$DOAS MAX-DOAS Instrument	
Name of PI:	
Affiliation:	

PI E-Mail:					
Instrument location:	Latitude:		Longitude:		
Channel 1 wavelength range [nm]:	From:		To:		
Channel 2 wavelength range [nm]:	From:		To:		
Almucantar measurements (y/n):					
Direct sunlight measurements (y/n):					
References:					
Comments/Remarks:					

Sun Photometer				
Type/Manufacturer:				
PI and affiliation: (if other than MAX-DOAS PI)				
PI E-Mail:				
URL (if available)**:**				
Instrument location:	Latitude:		Longitude:	
Instrument is part of AERONET (y/n):				
Inversions from Almucantar (y/n):				
Available wavelengths [nm]:				
References:				
Comments/Remarks:				

Ceilometer	
Type/Manufacturer:	
PI and affiliation: (if other than MAX-DOAS PI)	

PI E-Mail:				
URL (if available)**:**				
Instrument location:	Latitude:		Longitude:	
Ceilometer wavelength [nm]:				
References:				
Comments/Remarks:				

LIDAR				
Type/Manufacturer:				
PI and affiliation: (if other than MAX-DOAS PI)				
PI E-Mail:				
URL (if available)**:**				
Instrument location:	Latitude:		Longitude:	
LIDAR wavelength(s) [nm]:				
LIDAR type (Backscatter/Raman/...):				
Size of overlap region [m]:				
References:				
Comments/Remarks:				

SMPS/APS				
Type/Manufacturer:				
PI and affiliation: (if other than MAX-DOAS PI)				
PI E-Mail:				
URL (if available)**:**				
Instrument location:	Latitude:		Longitude:	

Particle size range [µm]:	From:		To:	
References:				
Comments/Remarks:				

Nephelometer				
Type/Manufacturer:				
PI and affiliation: (if other than MAX-DOAS PI)				
PI E-Mail:				
URL (if available)**:**				
Instrument location:	Latitude:		Longitude:	
References:				
Comments/Remarks:				

Transmissometer				
Type/Manufacturer:				
PI and affiliation: (if other than MAX-DOAS PI)				
PI E-Mail:				
URL (if available)**:**				
Instrument location:	Latitude:		Longitude:	
References:				
Comments/Remarks:				

MAAP				
Type/Manufacturer:				
PI and affiliation: (if other than MAX-DOAS PI)				
PI E-Mail:				
URL (if available)**:**				
Instrument location:	Latitude:		Longitude:	
References:				
Comments/Remarks:				

Particulate Matter				
Type/Manufacturer:				
PI and affiliation: (if other than MAX-DOAS PI)				
PI E-Mail:				
URL (if available)**:**				
Instrument location:	Latitude:		Longitude:	
Size range (PM2.5/PM10/…)**:**				
References:				
Comments/Remarks:				

Meteorology (temperature, pressure, humidity,…)	
PI and affiliation:	

(if other than MAX-DOAS PI)				
PI E-Mail:				
URL (if available)**:**				
Instrument location:	Latitude:		Longitude:	
References:				
Comments/Remarks:				

Meteorological Balloon Soundings				
Type/Manufacturer:				
PI and affiliation: (if other than MAX-DOAS PI)				
PI E-Mail:				
URL (if available)**:**				
Launch location:	Latitude:		Longitude:	
Launch frequency (days):				
References:				
Comments/Remarks:				

Other aerosol-related measurements				
PI and affiliation: (if other than MAX-DOAS PI)				
PI E-Mail:				
URL (if available)**:**				
Instrument location:	Latitude:		Longitude:	
References:				

Comments/Remarks:	

Other aerosol-related measurements				
PI and affiliation: (if other than MAX-DOAS PI)				
PI E-Mail:				
URL (if available)**:**				
Instrument location:	Latitude:		Longitude:	
References:				
Comments/Remarks:				

5 References

Dubovik, O. and King, M. D.: A flexible inversion algorithm for retrieval of aerosol optical properties from sun and sky radiance measurements, J. Geophys. Res., 105, 20673–20696, https://doi.org/10.1029/2000JD900282, 2000.

Münkel, C., Eresmaa, N., Räsänen, J., and Karppinen, A.: Retrieval of mixing height and dust concentration with lidar ceilometer, Boundary-Layer Meteorology, 124, 117–128, https://doi.org/10.1007/s10546-006-9103-3, 2007.

Petzold, A. and Schönlinner, M.: Multi-angle absorption photometry—a new method for the measurement of aerosol light absorption and atmospheric black carbon, Journal of Aerosol Science, 35, 421–441, https://doi.org/https://doi.org/10.1016/j.jaerosci.2003.09.005, 2004.

Sioutas, C.: Evaluation of the Measurement Performance of the Scanning Mobility Particle Sizer and Aerodynamic Particle Sizer, Aerosol Science and Technology, 30, 84–92, https://doi.org/10.1080/027868299304903, 1999.

Zieger, P., Weingartner, E., Henzing, J., Moerman, M., de Leeuw, G., Mikkilä, J., Ehn, M., Petäjä, T., Clémer, K., van Roozendael, M., Yilmaz, S., Frieß, U., Irie, H., Wagner, T., Shaiganfar, R., Beirle, S., Apituley, A., Wilson, K., and Baltensperger, U.: Comparison of ambient aerosol extinction coefficients obtained from in-situ, MAX-DOAS and LIDAR measurements at Cabauw, Atmos. Chem. Phys., 11, 2603–2624, https://doi.org/10.5194/acp-11-2603-2011, 2011.