The SWING activities and developments within the RAMOS project

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Abstract

The Small Whiskbroom Imager for atmospheric compositioN monitorinG (SWING) is a compact payload developed for trace gas mapping. It was initially designed to measure the atmospheric composition from an Unmanned Aerial Vehicle (UAV) platform. SWING is based on a compact UV-Visible spectrometer and a scanning mirror to collect scattered sunlight under the aircraft and in zenith. The spectra recorded on flight are analyzed with the Differential Optical Absorption Spectroscopy (DOAS) method. SWING was successfully demonstrated onboard a UAV during the AROMAT-1 campaign (Romania, 2014). The instrument was later mounted on a Cessna during AROMAT-2 (Romania, 2015) and AROMAPEX (Germany, 2016) campaigns. The weight, size, and power consumption of SWING are respectively 1100 g, 33x12x8 cm^3, and 15 W.

In the context of the ESA RAMOS (Romanian Atmospheric Observation System) activity, BIRA has built two new SWING-type instruments. These instruments will be operated by INCAS and installed on two different INCAS airborne platforms: an octocopter UAV and a Britten-Norman 2 (BN-2) manned aircraft. A complete redesign was necessary for the integration in the BN-2. This new instrument (SWING+) is 3.8 kg. We present these SWING/SWING+ instruments and the associated characterization work in the lab. We also present the campaign plans for the first test flights in Romania in 2018. Applications of these new SWING/SWING+ observations systems include validation of air quality satellites such as TROPOMI/S5p, urban air quality studies, quantification of NO_2 or SO_2 emissions, and ship emissions monitoring.

SWING-UAV

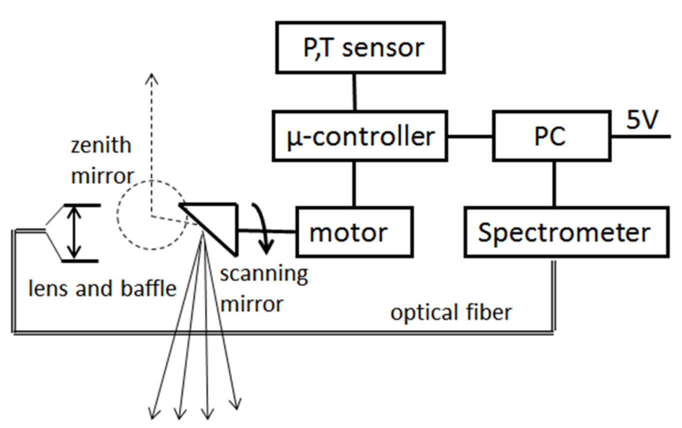


Figure 1 Schematic diagram of the SWING instrument.

Figure 2 SWING UAV onboard the INCAS octocopter during a test flight (August 2017)

SWING+

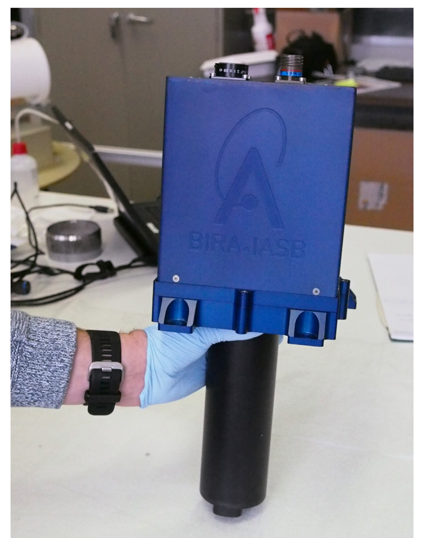


Figure 3 The SWING + Instrument .

Figure 4 The INCAS BN-2 aircraft. SWING+ will be (semi) permanently installed on this platform.

Lab characterization of the SWING instruments

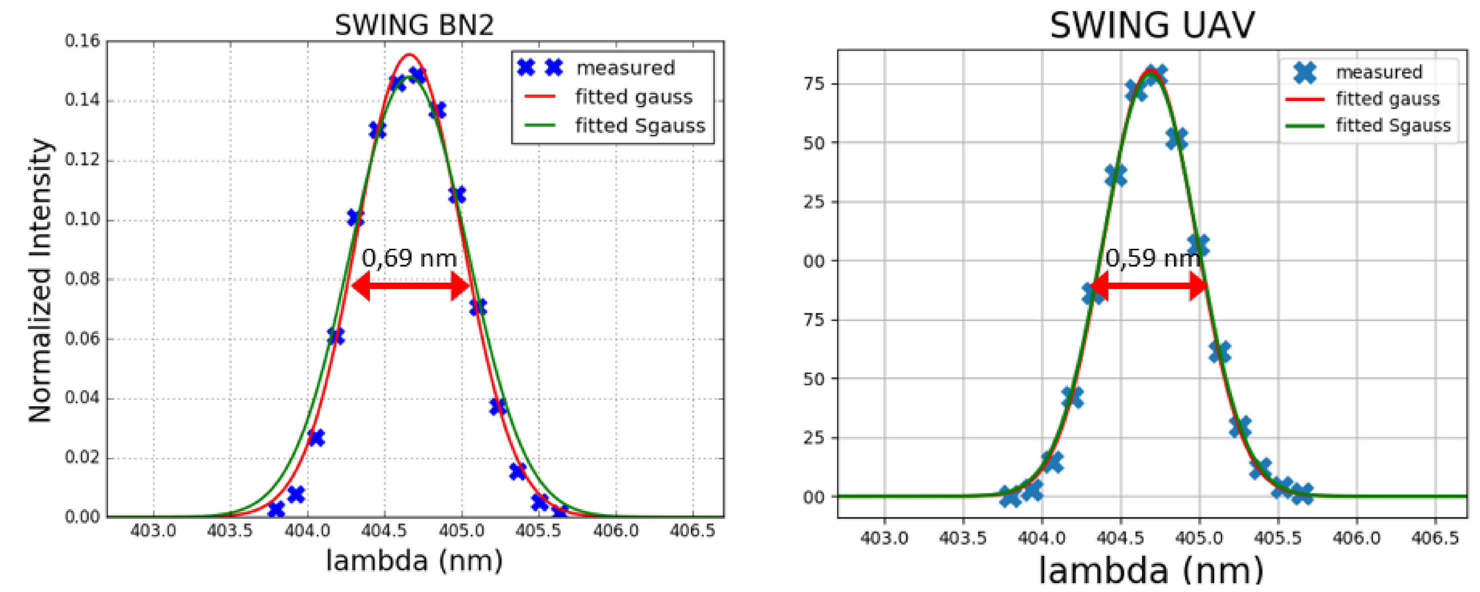


Figure 5 Slit function of the two spectrometers used in the SWING+ (left) and SWING-UAV instruments

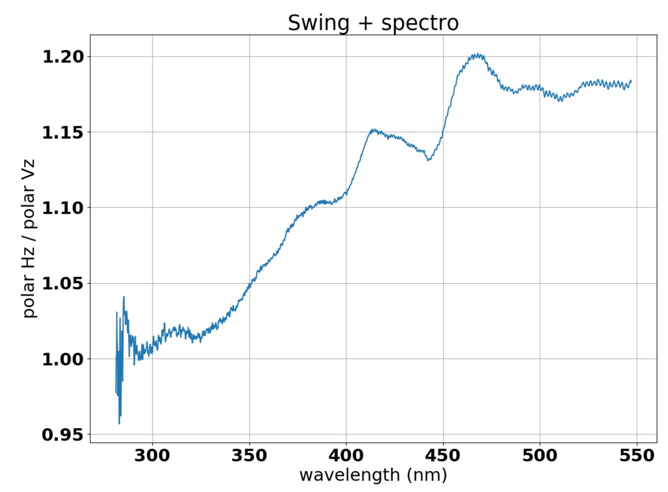


Figure 6 Sensitivity to polarization. A structure appears in the NO_2 fitting window, more visible in the UAV version due to the smaller op-

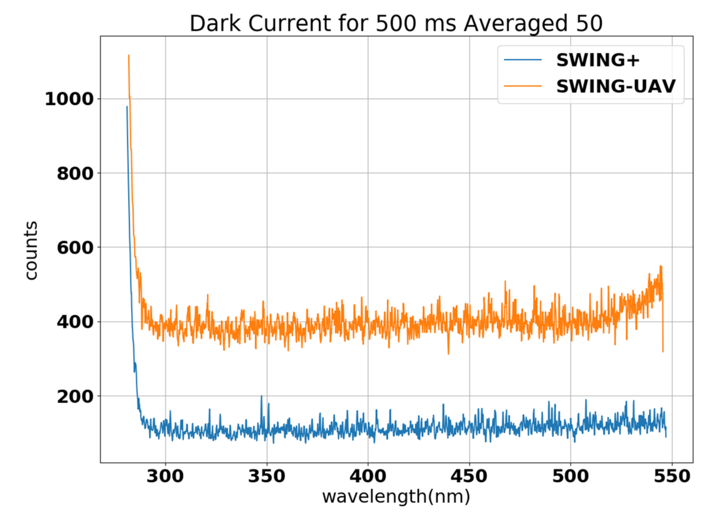


Figure 7 Dark currents of the two spectrometers. It is smaller in SWING+ due to the new Avantes electronics (EVO).

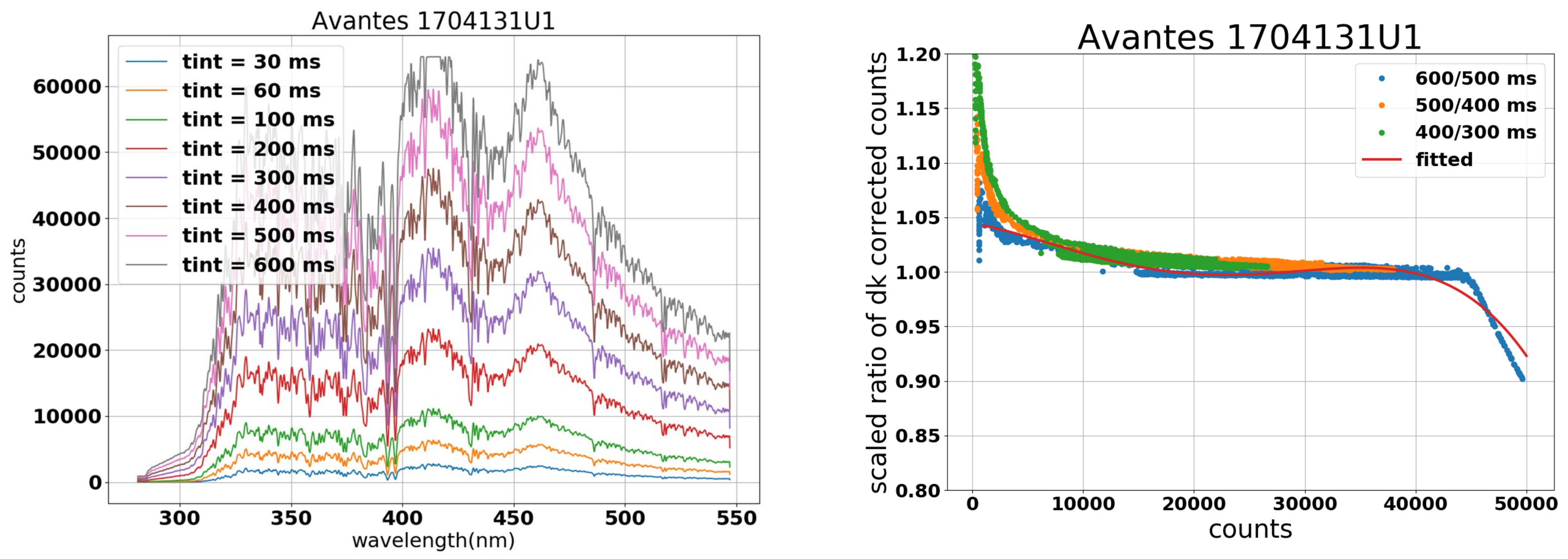


Figure 8 Characterization of the linearity from sky spectra recorded at different integration times

	Swing UAV	Swing+
Weight	1.2 kg	3.8 kg
Size	8 cm X 12 cm x 33 cm	45 cm X 19 cm x 15 cm
NO_2 DSCD detection limit (nadir at 3 km, 0.5s)	ca. $1.8e^{15}$ molec.cm^{-2}	ca. $1.7e^{15}$ molec.cm^{-2}
SO_2 DSCD detection limit (nadir at 3 km, 0.5s)	ca. $2e^{16}$ molec.cm^{-2}	ca. $1.4e^{16}$ molec.cm^{-2}

Table 1 Some characteristics of the SWING –UAV and SWING+ instruments

Examples of SWING measurements

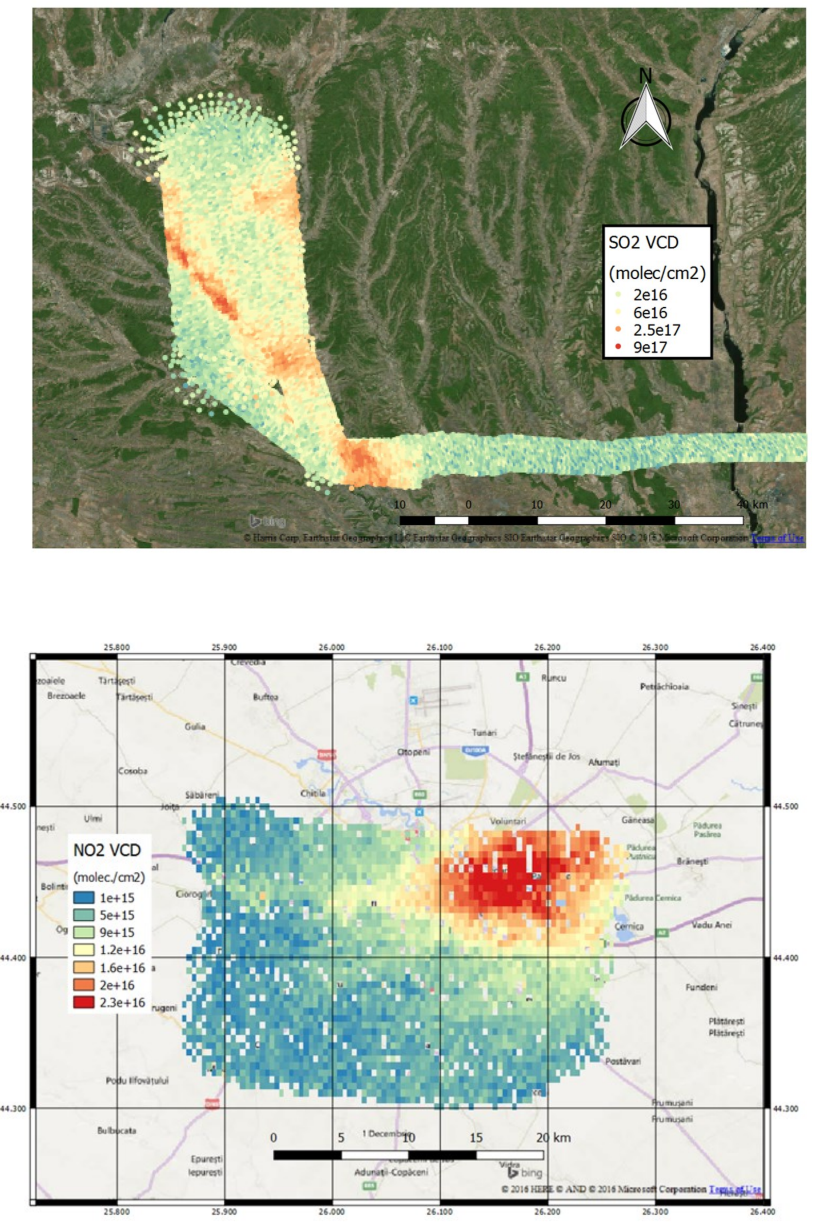


Figure 9 Measurements of SO_2 and NO_2 during the AROMAT-2 campaign (August 2015, Romania)

Previous version of the SWING instrument were tested from a fixed wing UAV and from the Free University of Berlin Cessna during the ESA-funded AROMAT (Romania, 2014 and 2015) and AROMAPEX (2016) campaigns

SWING mapped the exhaust plume (NO_2 and SO_2) of thermal power plants and the NO_2 above the city of Bucharest and Berlin.

During AROMAT/AROMAPEX, SWING was operated in parallel with larger instruments which lead to several intercomparisons (see references below).

References in Atmos. Meas. Tech.:

Merlaud et al., 2018, SWING, Tack et al, 2018, AROMAPEX, submitted to AMT, Merlaud et al, 2018, AROMAT, to be submitted to AMT

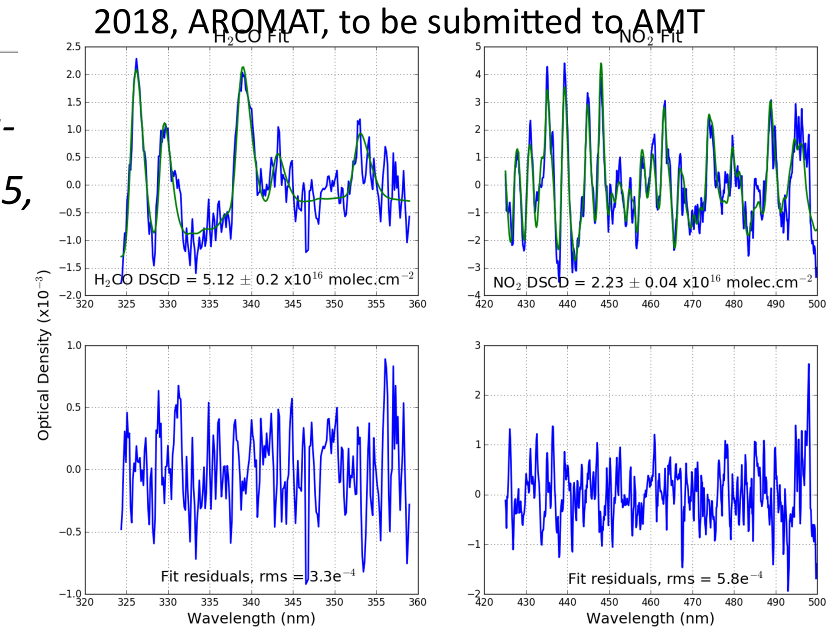


Figure 10 DOAS fits of NO_2 and H_2CO recorded with SWING from the ground in MAX-DOAS set-up. The integration time is 25 s.

SWING as a MAXDOAS

Within the ESA RAMOS project, SWING was operated from the ground as a MAX-DOAS in July 2017, from the roof of INOE (Magurele, close to Bucharest, Romania). SWING could detect a clear signal of H_2CO beside NO_2.

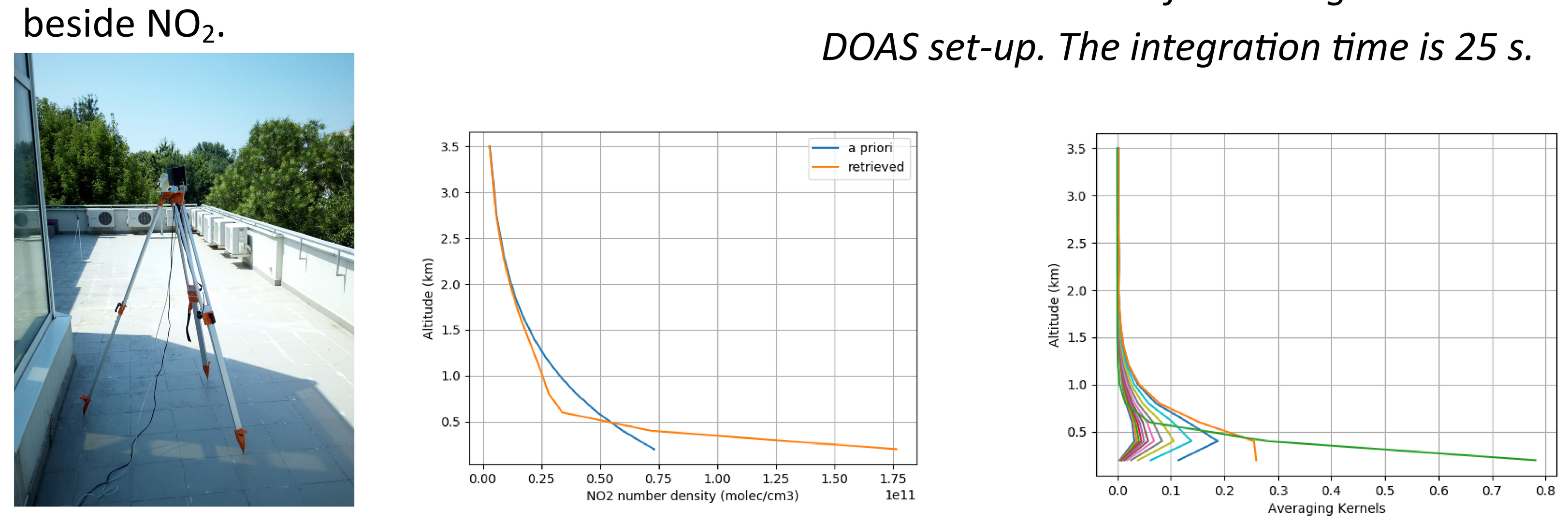


Figure 11 SWING as a MAX-DOAS during the RAMOS campaign in July 2017, and exemple of retrieved profile of NO2 with the associated averaging kernels. The DOFS is around 1.3

Future plans

The maiden flight with SWING+ on the INCAS BN-2 is planned in September 2018, above Bucharest. Within RAMOS, we will also fly over the power plants of the Jiu Valley. In 2019, these observation systems will take part in the ESA S5P validation campaigns.

Synergetic use of the Mobile-DOAS measurements during Cindi-2

A.Merlaud, F. Tack, M. Van Roozendael (BIRA) D. Constantin, A. Rosu (UGAL) K. Riffel , S. Donner, T. Wagner (MPIC), S. Schreier (BOKU), A. Richter, F. Wittrock, A. Hilboll, M. Vrekoussis (IUP-Bremen), H. Eskes, J. Douros, (KNMI)

Background

Five Mobile-DOAS systems were operated during the CINDI-2 campaign. These instruments are all based on compact UV-Vis grating spectrometers and primarily focused on the measurement of NO_2 in the visible range. BIRA-IASB operated a double channels (zenith and 30° above horizon) instrument (Merlaud, 2013) permanently integrated in a car (namely the Aeromobil system), together with a compact zenith-only instrument mounted on a bike. MPIC operated a Mini-MAX-DOAS (Wagner, 2010, Shaiganfar,2017) on the roof of a van. Two more zenith-only DOAS systems, both of them based on compact UV-Vis Avantes spectrometers, were operated from cars by UGAL (constantin,2013) and BOKU (Schreier,2016). Finally, the IUP-Bremen movable MAX-DOAS instrument, which is mounted on a truck, was installed at the remote sensing site close to the other static instruments during the campaign.

Contrary to the static ground-based measurements, the DOAS analysis was not harmonized for the Mobile-DOAS dataset. Preliminary studies involving some of the aforementioned Mobile-DOAS instruments during the MADCAT (2013) and AROMAT (2014) campaigns indicated that it was difficult to define common DOAS settings leading to realistic SCDs for all the instruments, considering in particular their different spectral ranges. Similarly, the VCD retrieval was optimized independently for each instrument, making best use of its characteristics and limitations (e.g. multi-angle or zenith-only). Note however that two intercomparison exercises were performed to check the consistency of the mobile NO2 DSCDs, on 10 September 2016 (BOKU and MPIC) and on 25 September 2016 (BOKU, MPIC, BIRA Aeromobil and Bike DOAS). Both led to good agreements. Regarding the mobile NO2 VCD products, they were checked through comparisons with the BIRA MAX-DOAS data at the Remote Sensing Site (see below).

ID	Platorm	PI	Geometry	Spectral range (nm)	Spectral resolution (nm)	Temperature
CINDI-2.45	Car	A. Merlaud	Zenith and 30°	200-750	1.2	Ambient
CINDI-2.46	Car	T. Wagner	1D Scanning	299-454	0.6-0.9	-5°
CINDI-2.47	Car	D. Constantin	Zenith-only	280-550	0.7	Ambient
CINDI-2.48	Truck (static)	F. Wittrock	2D Scanning	286-419/413-524	0.55/0.65	-35°
n.a.	Car	S. Schreier	Zenith-only	300-550 nm	0.7	Ambient
n.a.	Bike	F. Tack	Zenith-only	280-550 nm	0.7	Ambient

The table above summarizes the main characteristics of the Mobile-DOAS instruments. Theywere operated around Cabauw, and between Rotterdam and Utrecht. On 13, 14, and 15 September 2016, the mobile measurements were coordinated to optimize the spatial coverage and the time coincidence. The five mobile instruments were operated along four loops of different lengths (BIRA and BOKU driving along the same loop in opposite direction). This led to a particularly interesting dataset thanks to clear-sky conditions on these days.

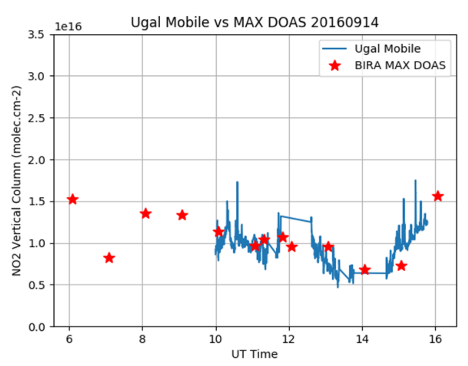
	5-sept	6-sept	7-sept	8-sept	9-sept	10-sept	11-sept
BOKU							
BIRA_car							
BIRA_bike							
MPIC							
UGAL							

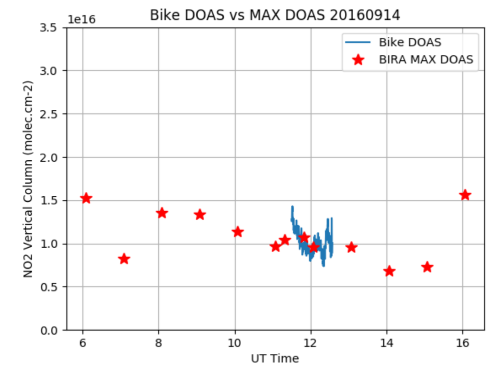
	12-sept	13-sept	14-sept	15-sept	16-sept	17-sept	18-sept
BOKU							
BIRA_car							
BIRA_bike							
MPIC							
UGAL							

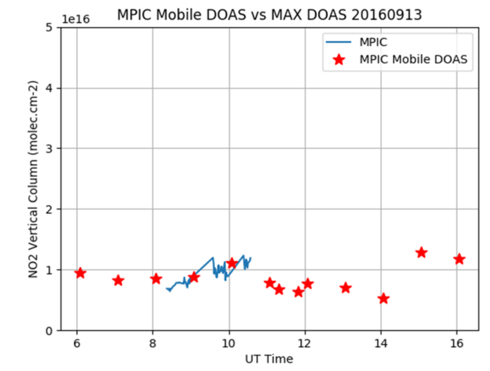
	19-sept	20-sept	21-sept	22-sept	23-sept	24-sept	25-sept
BOKU							
BIRA_car							
BIRA_bike							
MPIC							
UGAL							

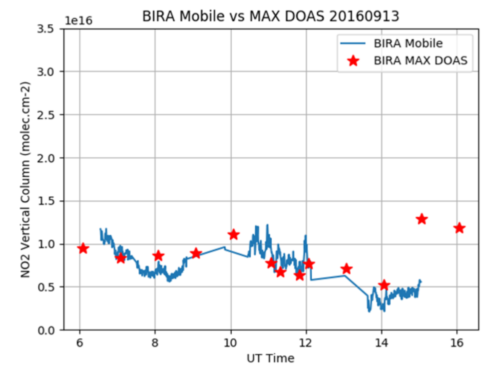
Schedule of the Mobile-DOAS measurements

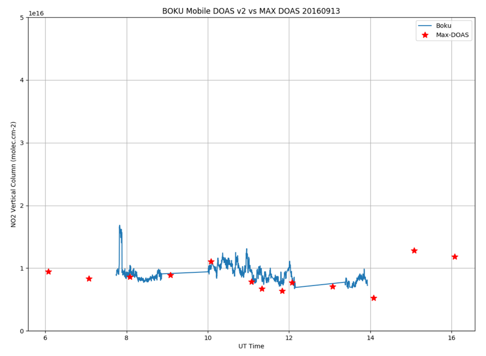
Mobile-DOAS systems and comparisons of the VCDs with the BIRA static MAX-DOAS







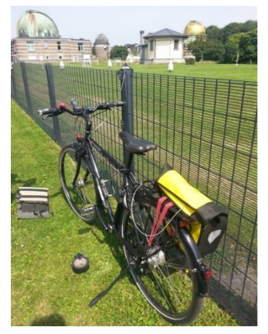




The VCDs of each instrument were derived independently and checked with the BIRA static MaxDOAS instrument.

The Mobile-DOAS VCDs for are available on the CINDI-2 FTP.

UGAL Zenith only system



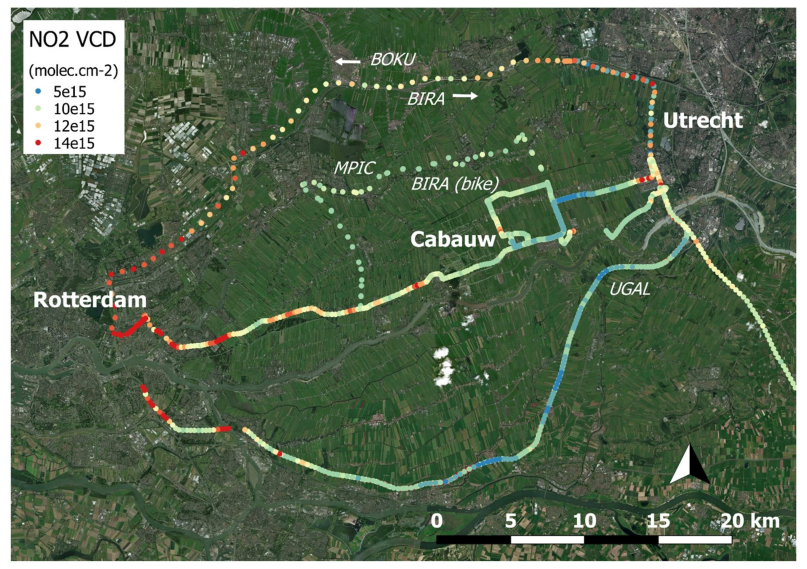
BIRA Bike DOAS

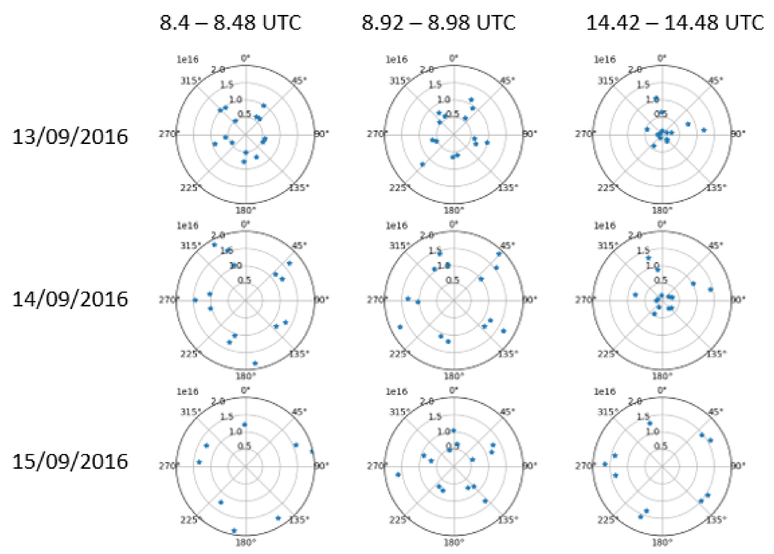
MPIC miniMaxDOAS

BIRA Aeromobil

BOKU Zenith-only system

Coordinated measurements on 13-14-15/09/2016





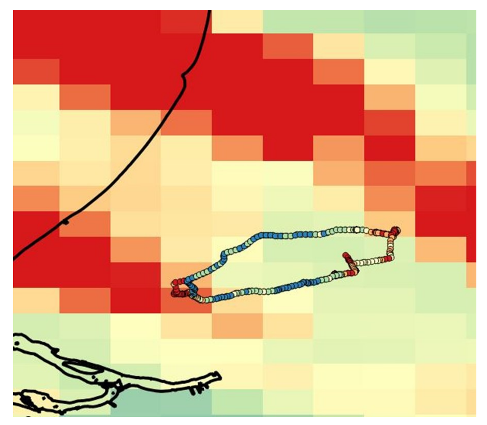
On 13, 14, and 15 September 2016, the mobile measurements were coordinated to optimize the spatial coverage and the time coincidence. The five mobile instruments were operated along four loops of different lengths (BIRA and BOKU driving along the same loop in opposite direction). This led to a particularly interesting dataset thanks to clear-sky conditions on these days.

The map below presents this set-up of coordinated measurement and shows some of the mobile NO2 VCDs measurements collected on 13 and 14 September 2016. The NO2 VCDs vary between 5 and 14 x 10^{15} molec cm^{-2}, the extrema are located respectively in the large rural area around Cabauw and close to Rotterdam. The NO_2 is also clearly enhanced around Utrecht. The NO_2 field around the Remote Sensing Site appears relatively smooth, despite a few hotspots of local origin. Note that this map only presents a sample of the mobile measurements and that the observed NO_2 horizontal distribution varied during the campaign. Nevertheless, its pattern is consistent with the low azimutal variability observed with the MAX-DOAS on these three golden days (see uper figure, right).

Ongoing work

The Mobile DOAS VCDs database will also be compared with high resolution (up to 1x1 km2) of WRF-Chem.

Comparisons with the Lottos Euros model



The Mobile DOAS VCDs on 13,14, and 15 September 2016 were compared with the Lotos Euros model outputs.

The horizontal patterns observed with the cars are in general reproduced in the model.

Differences between models and measurements are consistent for the différent instruments, and are found positive or negative depending on the considered time.

13/09

14/09

15/09