SWING-UAV: Small Whiskbroom Imager for atmospheric compositioN monitorinG from an UAV

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We describe the Small Whiskbroom Imager for atmospheric compositioN monitorinG (SWING), and its first test flight on a dedicated Unmanned Aerial Vehicle (UAV). One objective is the mapping of NO_2 columns at high spatial resolution allowing to subsample satellite measurements within the extent of a typical ground pixel. Simulations show that tropospheric NO_2 columns can possibly be monitored at a ground resolution of 200x200 m^2 in polluted zones. The instrument is based on a compact ultra-violet visible spectrometer and a scanner to achieve whiskbroom imaging of the trace gases fields. Including housing and electronics, the weight, size, and power consumption of SWING are respectively 920 g, 27x12x12 cm^3, and 6 W. The custom-built UAV wingspan is 2.5 m and can reach an altitude of 3 km during 2 hours, flying at 100 km/h in preprogrammed tracks. Considering the 120° swath of the instrument, it is able to cover an area of 20x20 km^2 in less than one hour. The spectra are analyzed using Differential Optical Absorption Spectroscopy (DOAS). Several atmospheric species are detectable in the spectral range covered by the spectrometer (250-750 nm). Water vapor, ozone, and O_4 have been identified in the spectra recorded during the test flight, which took place on 11 May 2013 near Galati, Romania. From this experiment, the detection limit of SWING-UAV for NO_2 is estimated to lie around 2 ppb. Beside the validation of air quality satellite or local chemistry and transport models, other potential applications include monitoring NO_2 and/or SO_2 emissions from power plants, industries, ships, or volcanoes.

Scientific rationale and simulations

Several DOAS imagers have already been operated from planes to map the distribution of trace gases (1,2,3). These measurements offer a ground resolution enabling to study the fine structures of the NO_2 field close to the sources, which is not possible from satellite. A whiskbroom imager, the ACAM (5), has been operated from a UAV, the NASA Global Hawk. The instrument presented here, SWING, uses a whisbroom set-up for spatial mapping, similarly to ACAM. However, it is designed for a smaller UAV and is therefore more compact.

To estimate a realistic ground resolution achievable with a compact spectrometer from 3 km altitude, we performed simulations using a local high resolution air quality model (IFDM, http://promote.vito.be/webtool/). The noise level was scaled according to the different geometry and integration time from a previous airborne experiment (4) with the same spectrometer. Results for different ground resolution (and thus integration times) are shown in Fig. 1.

(1) Heue et al. ACP, 2008, (2) Schönardt et al., Proc. DOAS workshop 2011, (3) Popp et al., AMT, 2012
(4) Merlaud et al., AMT, 2012, (5) Kowalewski and Janz., Proc. SPIE 7452, 2009

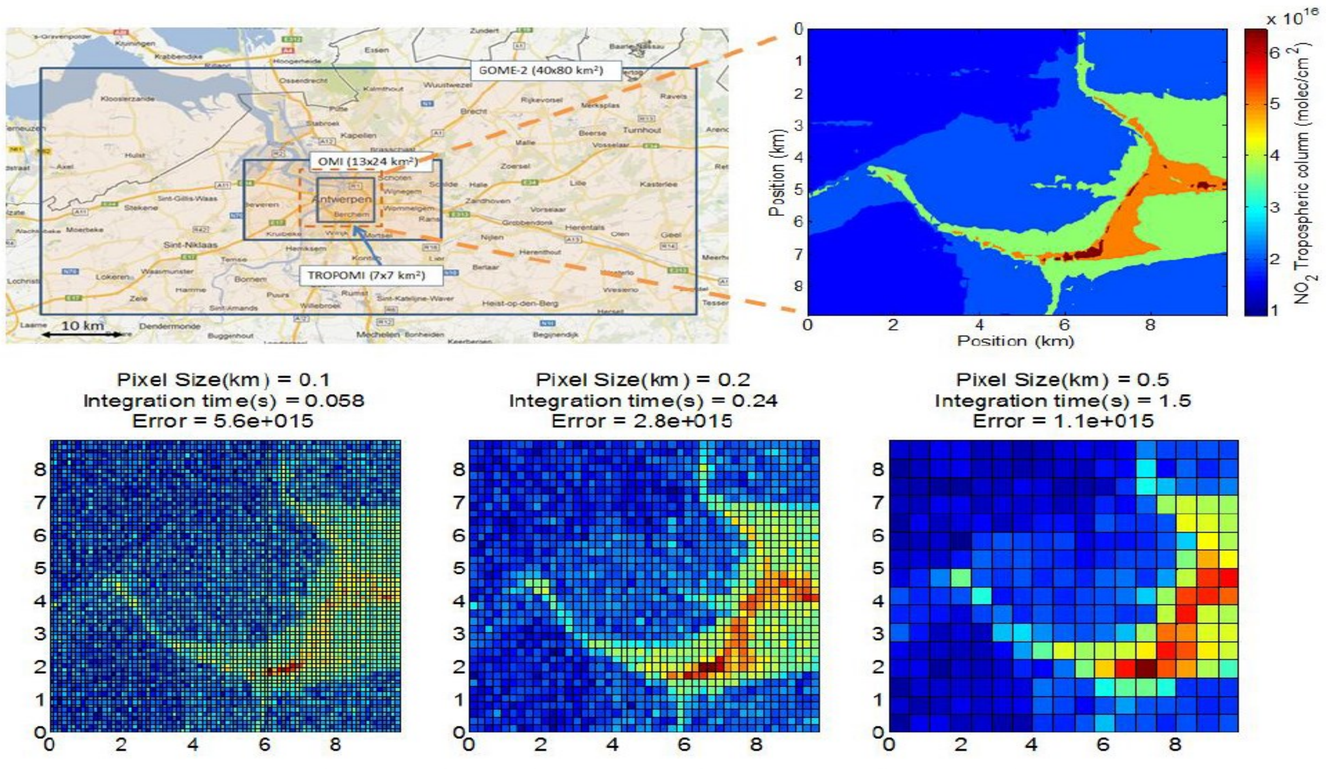

Figure 1. Simulations of NO_2 observations from an UAV flying at 3 km.

Instrument and platform description

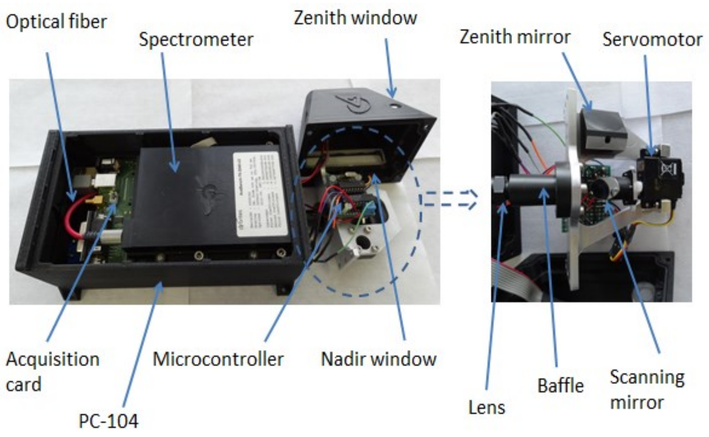

Figure 2. The SWING instrument.

SWING is based on a compact grating spectrometer (AvaSpec 2048 from AVANTES). The scanning mirror is driven by a servomotor around the nadir direction. A zenith channel enables to record reference spectra. The spectra are saved on the PC during the flight.

Figure 3. The custom built UAV.

The UAV was customly built by ReevRiver Aerospace. It is an electrically propelled 2.5 m flying wing, which can fly in preprogrammed tracks for 2 hours at 3 km altitude.

Table 1. Main characteristics of the SWING-UAV observation system.

SWING	Size	27x12x12 cm^3
	Weight	920 g
	Power consumption	6 W
	Angular FOV	120°
	Instantaneous FOV	2.5°
UAV	Ceiling	3 km
	Wingspan	2.5 m
	Speed	60-130 km/h
	Autonomy	2 h
SWING-UAV	Pixel size	200 m
	Detection limit (NO_2)	2 ppb

Results of the first test flight (May 2013)

Figure 4. Flight tracks of the UAV flight.

On 11 May 2013, we perfomed the first test flight with SWING on the UAV, 15 km NW of Galati, Romania (45.53°N, 27.9°E). The flight pattern consisted of loops at 420 to 450 m.a.s.l, around predefined waypoints (Fig. 4). The wind was blowing from NE and thus few NO2 was expected to be detected, but the weather was clear.

Fig. 5 presents the geometry of the measurements for an excerpt of the flight time series: the scan angle, the attitude, and their effect on the air mass factor (AMF) for two ground albedos, calculated with a radiative transfer model (DISORT). Noticeably, the AMF are relatively stable under 70° of viewing angle.

Fig.6 presents DOAS fits of 4 absorbers from spectra recorded during the flight. Note that the reference spectrum was recorded afterwards in Bruxelles, which explains the negative fitted columns. From the rms, the detection limit lies around 2 ppbv.

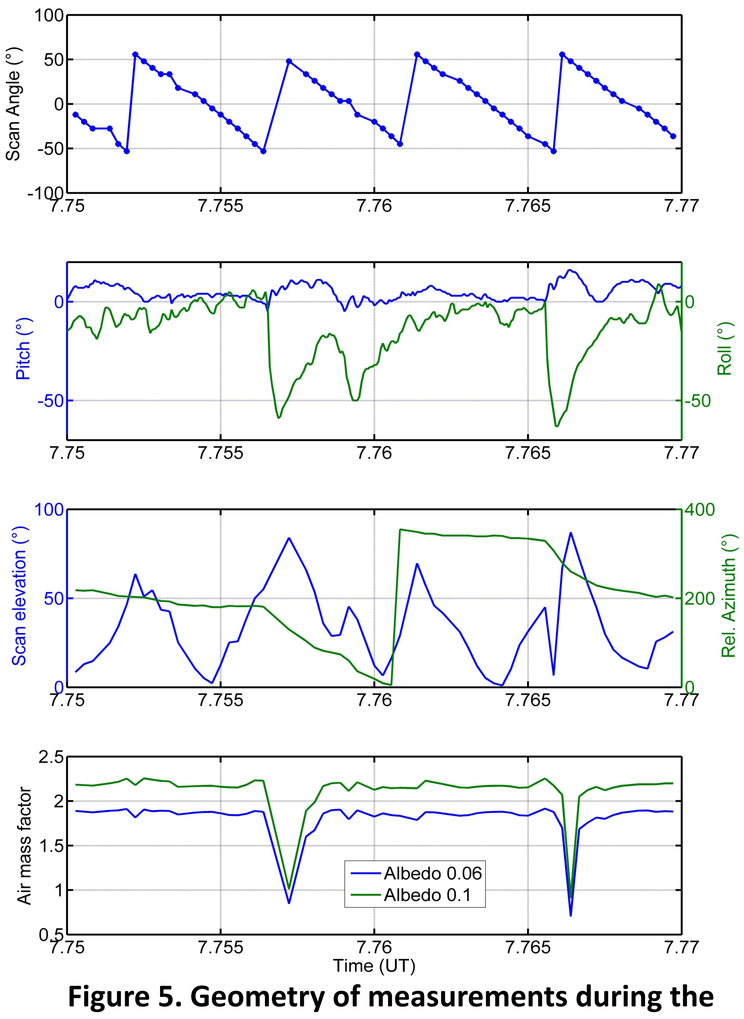

Figure 5. Geometry of measurements during the flight and its effect on the air mass factor.

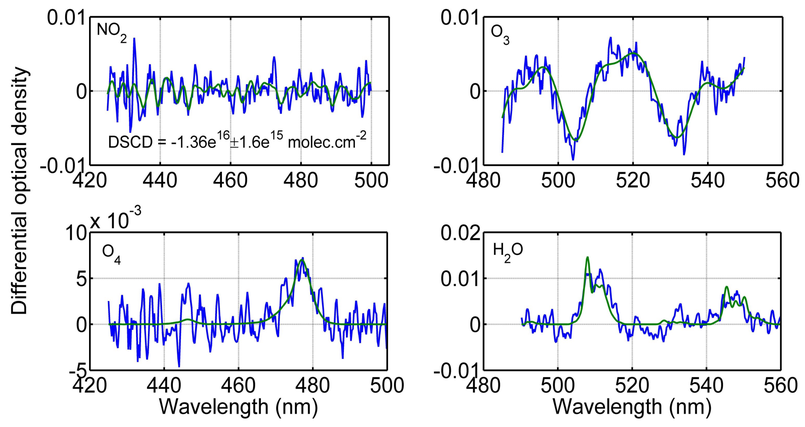

Figure 6. DOAS fits from spectra of the test flight.

Near-future perspectives

Figure 7. Targets of future SWING-UAV flights in Romania.

SWING-UAV is currently being optimized from the experience gained with the first succesful test flight. In Sept.-Oct. 2013, we will perform more UAV flights around NOx sources in Romania, such as around steel (Fig. 7, a) or fertilizer (Fig. 7, b) factories.

More Technical details about SWING-UAV:

-Merlaud A., Development and use of compact instruments for tropospheric investigations based on optical spectroscopy from mobile platforms, Phd Thesis, 2013
-Merlaud et al., Small Whiskbroom Imager for atmospheric compositioN monitorinG (SWING) from an Unmanned Aerial Vehicle (UAV) , Proc. 2013 ESA conference on Rockets and Balloons

Acknowledgements: Belgian Science Policy, European Space Agency. We thank Dirk Schuettemeyer and Frederik Tack for useful discussions.

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