UV-Vis remote sensing of shipping emissions and atmospheric pollutants in the North Sea: the Zeebrugge campaign

G. Mettepenningen, M. Van Roozendael, C. Fayt, F. Tack, C. Van Doorne, L. Jacobs, S. Berkenbosch, A. Aubry, F. Desmet, M. De Mazière - BIRA-IASB

gytha.mettepenningen@aeronomie.be

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The SEMPAS project

The SEMPAS project develops an imaging UV-Vis spectrometer to measure NO_2 and SO_2 from shipping, and atmospheric pollutants in a marine environment. As regulations are strict for ship emissions in the North Sea [1], sensitive and regular compliance monitoring is needed. The instrument measures individual passing ships from a wind turbine platform. It applies the DOAS measurement principle to quantify trace gases [2]. The instrument is protected by a water- and weatherproof box. The optical fiber bundle is organized as a matrix, to create an image of the observed scene. When no ships are in the area, SEMPAS is used as a MAX-DOAS, measuring atmospheric composition. The next step will install the instrument offshore to verify compliance with emission regulations.

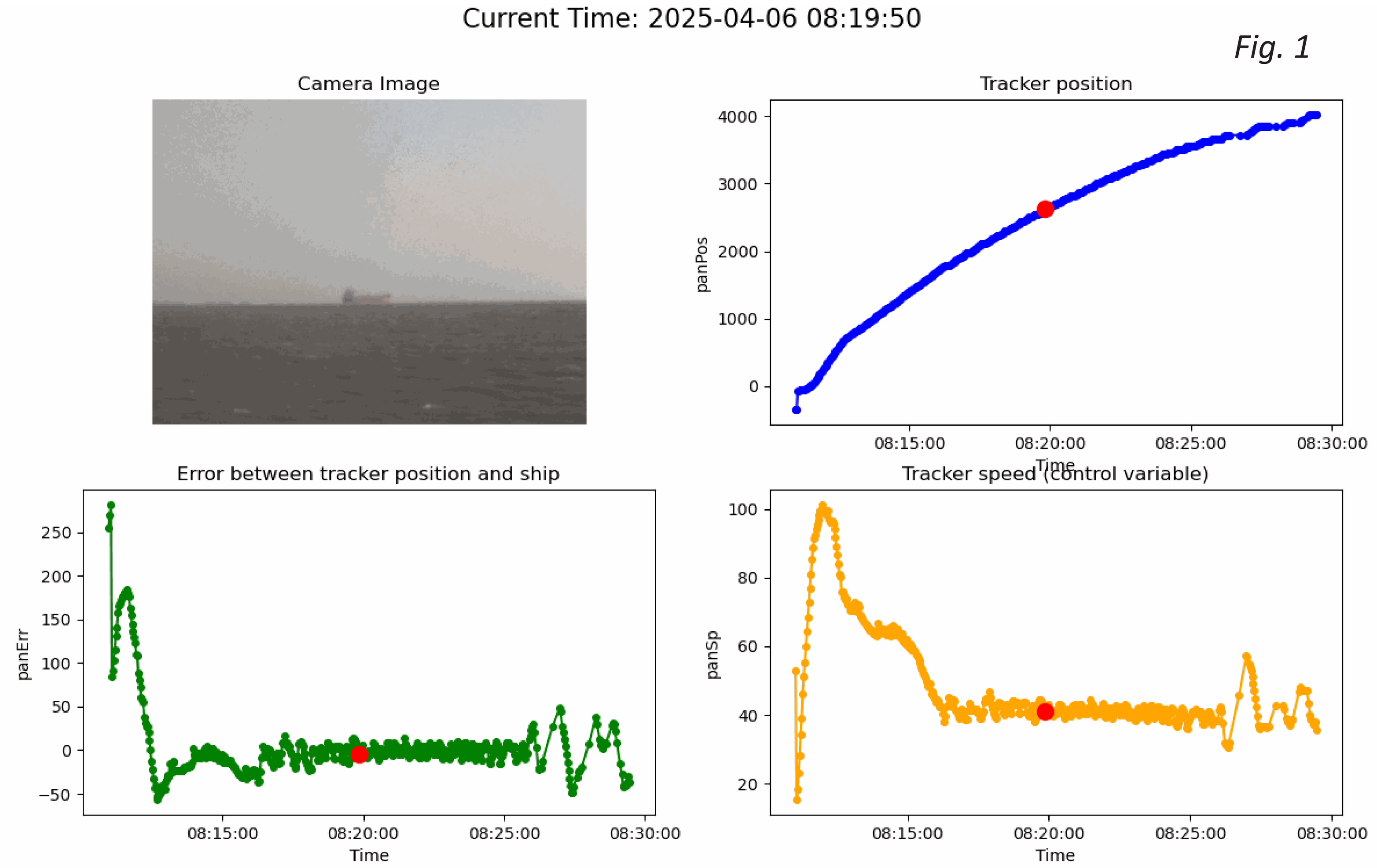


Fig. 1

The ship tracking algorithm

To increase measurement time, SEMPAS actively tracks ships in their movement. Based on a visual camera and image recognition software [4], the speed of the ship w.r.t. the instrument is estimated. With camera feedback, a PI-loop in velocity form is set up to constantly update this speed and smoothly track the ship.

$$v_n = v_{n-1} + K_p \bullet \Delta e + K_i \bullet e \bullet \Delta t$$

In Zeebrugge, ships can be tracked for up to 20 minutes, depending on visibility. An oscillation remains in the tracking, which cannot be reduced by tuning. This comes from the time delay of the system: the error is calculated based on an image of the camera, but the speed is not instantaneously corrected. Fortunately, this oscillation corresponds to the size of about one fiber, so the results are not influenced too much. The pointing of the system is refined to take into account current wind parameters and the location of the stack of the ship. Multiple checks are built in to prevent the system from disturbances if multiple ships are passing. Figure 1 shows the tracking of a ship in position, error and speed in step motor coordinates. Ask the presenter for the full video.

The Zeebrugge campaign

The instrument is currently installed in the port of Zeebrugge [3], indicated by the red cross in the overview map. It looks in between the breakwaters at ships passing by the port at 7 to 11km distance. Also for MAX-DOAS measurements, the instrument looks at the horizon away from the port.

Instrument specifications:

- UV grating 295-395nm, 0.5nm FWHM, U340 filter
- Imaging Field-of-View: 15x3 fibers, 1.44x0.29°, 276.4x55m at 11km distance

Measurement sequence:

- No ship → MAX-DOAS measurements
- Ship nearby → background measurements
- Ship in view → ship tracking measurements

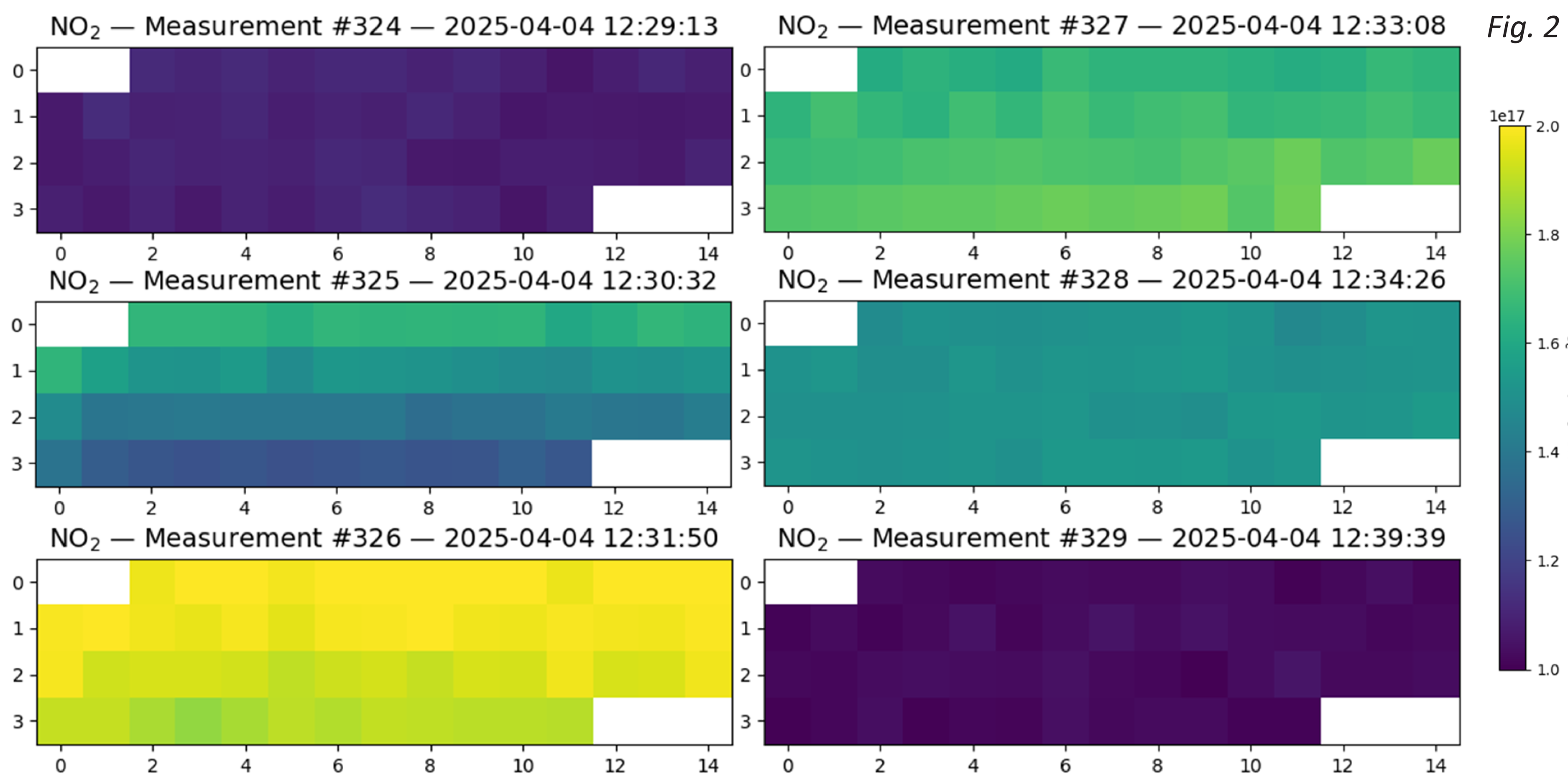


Fig. 2

Ship tracking results

Figure 2 shows six consecutive ship tracking measurements, creating a timeseries of a plume mapping. NO_2 is shown for its clear plume structure. In SO_2, enhancements can also be seen for the same ship, but without clear transition through the plume. The SO_2 is high or low, without spatial structure. SO_2 values measured are near the detection limit, while NO_2 is well above the sensitivity of the instrument. Note that one measurement is taken every minute, while the resolution of the tracking algorithm is 2 seconds. The expected behaviour is to see enhanced NO_2 and SO_2 signals over the entire tracking. This is not the case: sometimes we measure at the edge of the plume, switching between inside and outside. The dSCD's are very variable over measurements. Sometimes we see an enhancement in only one species: hotspots of NO_2 and SO_2 have different locations in the plume. This shows that the pointing of the system is very sensitive, depending on the accuracy and stability of the tracking algorithm, but also on wind and ship conditions. Secondly, the results depend on which zenith measurement is used. Sometimes negative values can be seen even on clear-sky days, meaning there was more NO_2 or SO_2 in the zenith than at the horizon. These are probably contaminations by port emissions. Overall many lessons learned from this campaign, but still improvements to go!

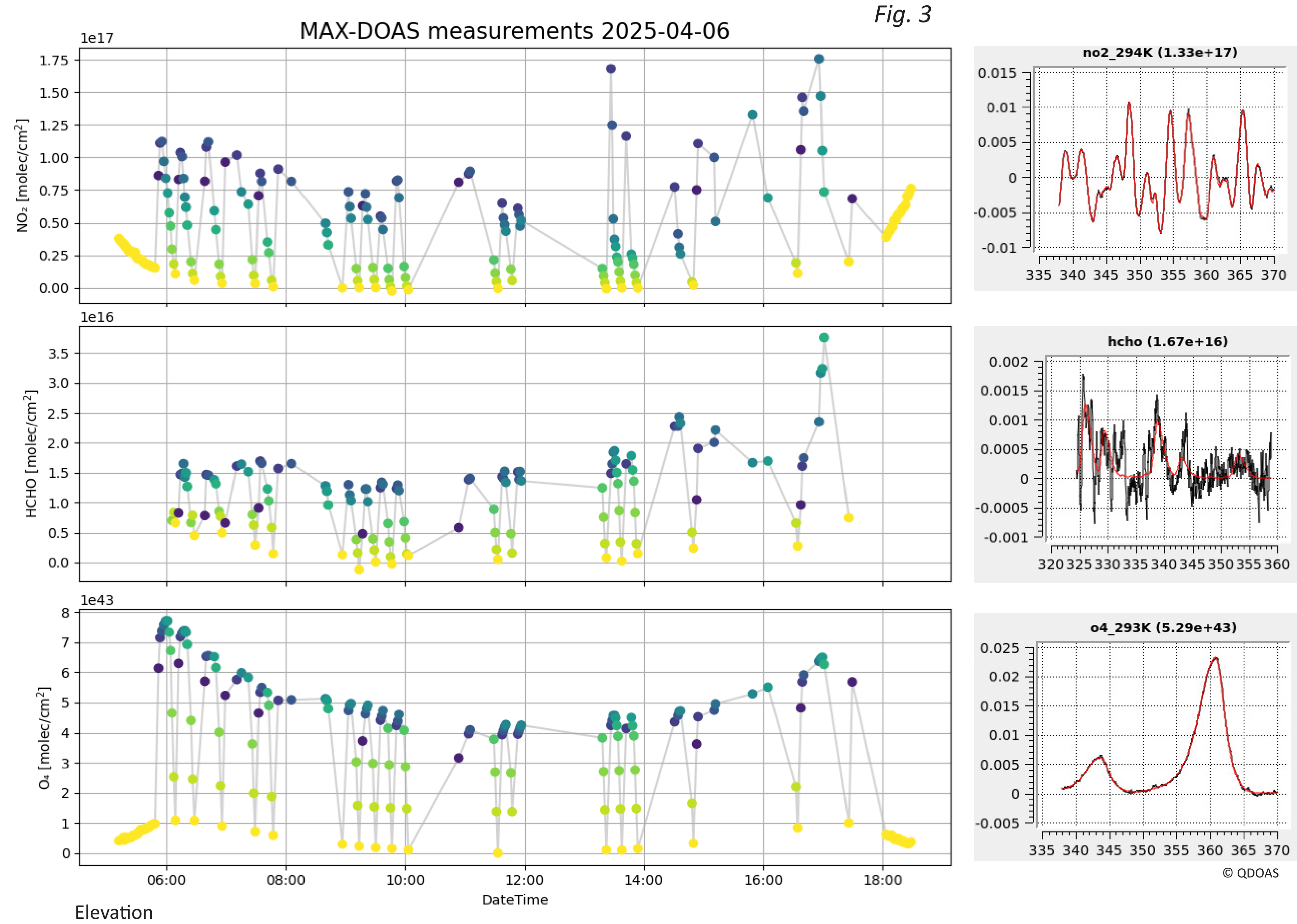
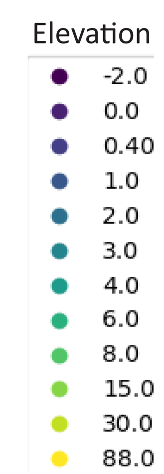


Fig. 3



MAX-DOAS results

As SO_2 is less relevant for atmospheric composition, the MAX-DOAS analysis focuses on NO_2 and HCHO. Figure 3 shows a one day timeseries, including O_4 and an indication of the fits at 16:50 UTC or SZA 66.3. The gaps in data are where the system was tracking a ship. Exploitation of this data remains limited at the moment, as current efforts focused primarily on ship tracking. The shown emissions can be from ship plumes remaining at the horizon, or transported portal and land emissions. The maximum layer of NO_2 is between 0 and 2° elevation.

References:

[1] IMO. *MARPOL Annex VI*, 2008

[2] Platt & Stutz, *Differential Optical Absorption Spectroscopy: Principles and Applications*, 2008

[3] https://mobilit.belgium.be/nl/news/nieuwe-sensor-moet-luchtkwaliteit-aan-de-kust-verbeteren

[4] https://github.com/ultralytics/yolov5

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