# Results of the imaging DOAS instrument IMPACT at CINDI-2 and comparison to MAX-DOAS-observations

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CINDI-2 Second Cabauw Intercomparison of Nitrogen Dioxide Measuring Instruments

## Introduction

**Measurement principle: Differential Optical Absorption Spectroscopy (DOAS)**

- Based on Lambert-Beer's law
- High-frequency part of (known) absorption structures σ are fitted to optical depth τ
- DOAS equation (I and are $I_0$ are measured):

$$\tau_{\text{meas}} = \ln\left(\frac{I_0}{I}\right) = \sum_i \sigma_i(\lambda)\cdot SC_i + polynomial + residual$$

- Result: Slant columns $SC_i = \int \rho_i \cdot ds$ (absorber concentration ρ integrated over light path s)
- $I_0$ measured usually in zenith direction
- Current Multi-Axis (MAX-DOAS) instruments are able to point in any direction allowing several elevation and azimuth directions

**Limitations of current MAX-DOAS instruments:**

- Only one measurement in a certain pointing direction per time
- Full hemispheric coverage not possible as being too time-consuming

→ Vertical scans (sequence of different elevations) performed in limited azimuthal directions only, or horizontal scan (sequence of different azimuths) performed in limited elevations

**Aim of the new imaging DOAS instrument IMPACT:**

- Using an imaging spectrometer to perform measurements in multiple viewing directions simultaneously
- In addition: Mounting the entrance optics on a pan-tilt-head

→ Full hemispheric coverage on the time scale of minutes

## Instrument

**Instrument characteristics:**

- Outdoor parts: Entrance optic (Camera objective, ~50° FOV) mounted on commercial ENEO VPT-501 pan-tilt-head, 100°/s)
- Optical fiber bundle consisting of 69 single glass fibers vertically aligned in the same sequence at both ends (50 mapped on CCD)

→ allows optical imaging and flexible positioning of the instrument

- Indoor parts: Andor Shamrock SR303i-A imaging spectrograph (temperature stabilized to 35°C, 400-525 nm, 0.7-1.0 nm resolution) coupled with a full-frame CCD (Andor Newton DU940P-BU) camera (cooled), electronics, computers

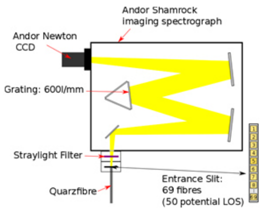



Fig 1: Sketch of the instrument's spectrometer.

**Advantage of the instrument:**

- Due to the combination of special fiber bundle and imaging spectrometer the spatial information of the radiance is retained

→ 50 equally spaced vertical viewing directions (elevation angles)

- Pan-tilt-head allows azimuthal changes while 50 elevations are measured simultaneously

→ Full hemispheric coverage each 15 minutes (during CINDI-2)

- Installed at the CINDI-2 campaign from September to October 2016

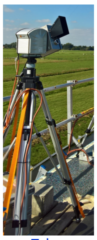


Fig 2: Telescope unit mounted on pan-tilt-head for azimuthal movement.

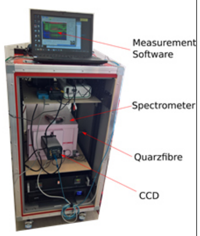



Fig 3: Rack containing indoor parts.

## Hemispheric Scans

Fig 6: Panorama view of IMPACT during CINDI-2.


- Obstructions by a single tree **(A)**,
- high trees **(B)** and other telescopes **(C)**
- Few local sources: mostly agriculture
- But: local street from Utrecht to Rotterdam
- Within a radius of <40km: the four largest cities of the Netherlands

→ **$NO_2$ amounts depend on wind speed and direction**

- Differences in distribution of $NO_2$ :

→ Amount of $NO_2$
  - Sundays (e.g. 18.09.16) very little $NO_2$
  - $NO_2$ depends on traffic

→ Vertical extent
  - different profiles

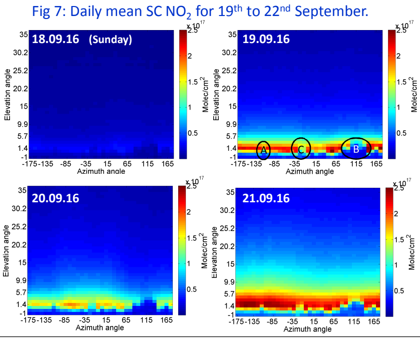
- Outlook:

→ Comparison with wind measurements

→ Comparison with car measurements around the measurement site

→ Retrieving VC profiles for $NO_2$

Fig 7: Daily mean SC $NO_2$ for 19th to 22nd September.




## CINDI-2 Campaign

**Introduction**

- Located in Cabauw, the Netherlands
- Semi-blind intercomparison took place 12th September – 28th September
- 33 DOAS-instruments installed including IMPACT

**Measurement Routine**

- Partly following official intercomparison protocol:
  - First 15 minutes, every hour, from 6 to 16 UTC
  - Azimuth angle: 287°, elevation angles: 1°, 2°, 3°, 4°, 5°, 6°, 8°, 15°, 30°, 90°
    (Could not be adjusted exactly by IMPACT due to imaging-elevation characteristics)
- Hemispheric scans in between sequences:
  - Azimuth angles: full coverage in 10° steps
  - Elevation angles from -5.1° to 35.8° simultaneously

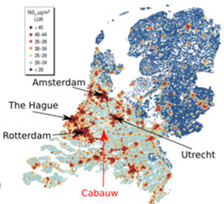



Fig 4: $NO_2$ distribution in the Netherlands for the year 2001. [1]


Fig 5: Set-up of all instruments on container at the remote sensing site.
Ground-floor: 1D MAX-DOAS
Top-level: 2D MAX-DOAS and IMPACT

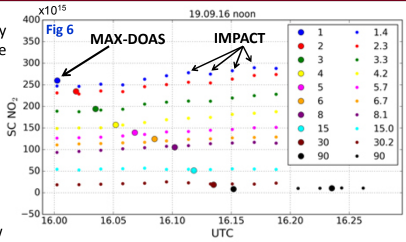
## Comparison to MAX-DOAS-observations

**Fig 6: One sequence of official intercomparison protocol.**

- IMPACT measures elevations up to 30° simultaneously contrary to MAX-DOAS that needs to scan each angle individually
- Fixed elevation angles due to set-up characteristics

→ Elevation angles not corresponding exactly to MAX-DOAS

- IMPACT catches increasing $NO_2$, while not visible in MAX-DOAS measurements




**Comparison of SC $NO_2$ for the 19th September 2016**

- Very good agreement
- Differences due to elevation angles and different field of view

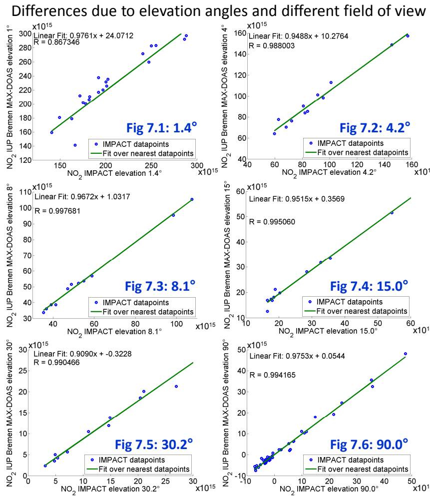



Fig 7.1 - 7.6: Regression plots of selected elevations for 19.09.2016.

- Only comparing time nearest measurements of IMPACT to single MAX-DOAS measurements
- Slope: between 0.91-0.98

→ Good agreement

→ IMPACT underestimating probably is due to higher elevation angles and larger field of view

- Correlation coefficients: between 0.867-0.998

→ Very good correlation between MAX-DOAS and IMPACT

→ 1.4° elevation has the worst correlation and a lot of scattering (Fig 7.1)
  - most sensitive to misalignment (comparing 1.4° to 1°)
  - possible ground features in large field of view

→ Other elevation angles show better correlation and little scattering

**Correlation coefficient over whole campaign**

- Mean correlation coefficient similar to 19th September.
- 2°,4°,6°,8°,15°,30°,90° very good for the whole campaign

→Only 1°, 3°, 5° not as good, due to misalignment, larger field of view and exchanged fibres

| **Elevation** | 1.4° | 2.3° | 3.3° | 4.2° | 5.7° | 6.7° | 8.1° | 15.0° | 30.2° | 90° | mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***R* (19.09.16)** | 0.867 | 0.981 | 0.927 | 0.988 | 0.952 | 0.995 | 0.998 | 0.995 | 0.991 | 0.994 | 0.969 |
| ***R (mean ,all days)*** | 0.908 | 0.993 | 0.924 | 0.993 | 0.940 | 0.996 | 0.995 | 0.986 | 0.979 | 0.987 | 0.970 |

Tab 1: Correlation coefficient for the 19.09.16 and mean over whole campaign.

## Conclusions

- ***Successful first application of the new ground-based imaging DOAS instrument IMPACT*** at the CINDI-2 campaign, including participation in the semi-blind intercomparison.
- ***Elevation angles not fully adjustable*** due to imaging characteristics, resulting in small differences with MAX-DOAS elevation angles.
- ***Good correlation between the Bremen MAX-DOAS and IMPACT*** for all campaign days for nearly all elevation angles.
- **Hemispheric scans with full azimuthal coverage are possible:**
  - ***Good vertical and horizontal coverage achieved*** at high speed (15minutes) overcoming the limitation of current ground-based MAX-DOAS instruments.
  - ***Full hemispheric detection***, i.e. vertical as well as azimuthal distribution, ***of tropospheric $NO_2$*** over Cabauw.
- ***Temporal evolution of $NO_2$ pollution can be monitored***.
- ***Outlook: Analysis of the complete hemispheric scans***
- **See also accompanying talk by E. Peters (UP 10.3)**

## Acknowledgements

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