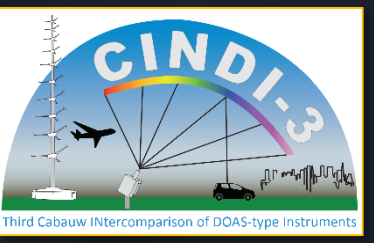
Airborne Mapping of Tropospheric NO_2 Distribution during CINDI-3



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and the CINDI-3 consortium

BIRA-IASB

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DOAS workshop 10/07/2025

Overview

- **Objectives**
  - What do we want to achieve?
- **Campaign plan**
  - Key phases, location and timing
- **Instruments and ROI**
- **Preliminary (!) v1 results**
  - SWING NO_2 maps and TROPOMI NO_2 validation
  - ICAD NO_2 + POM O_3 maps and vertical profiles
- **Outlook and next steps**

Objectives - Planned + Executed

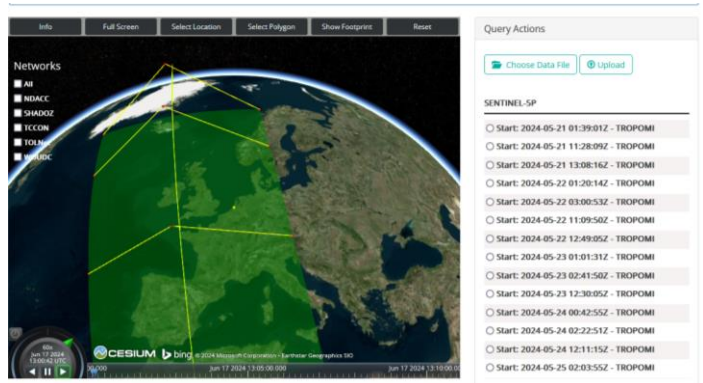
- **In a nutshell…during the CINDI-3 campaign**
  - Mapping **horizontal NO_2 distribution** with airborne imaging (SWING+)
  - Sampling **vertical NO_2 and O_3 distribution** with in-situ (ICAD NO_2 and POM O_3)

- **Main objectives**
  - **Validation of TROPOMI NO_2** over Rotterdam + Antwerp (city + harbour) ✓
  - Evaluate airborne a priori VCD retrieval assumptions with focus on **assessment of aerosol and NO_2 profile assumptions** based on CINDI-3 observations ✓ but small data set due to restricted flights over NL
  - Vice versa **provide support to MAX-DOAS measurements**, e.g. horizontal distribution of NO_2 around Cabauw site ✓ but small data set due to restricted flights over NL
  - **Mapping key emissions** over the Rotterdam + Antwerp (harbor) region for **AQ purposes** ✓

- **Funded by ESA SVANTE-II project (focus on S5P validation)**

Campaign plan - Planned + Executed

- **6-7 flights, assuming per flight:**
  - Mapping over Rotterdam (harbour)
  - Few flightlines over Cabauw, e,g. 1 flightline in MAX-DOAS main direction
  - Profile over Cabauw site (9000 to 500 ft)
  - **→ 10 flights in total (6 Antwerp, 3 Rotterdam, 1 Rotterdam + Cabauw)**
- **Timeframe: 27 May - 21 June 2024 → Extended to end of August**
- **Flights require a lot of planning and coordination**
  - Air traffic control (submit plans ahead and confirm morning of flight)
  - Weather forecasts –> clear-sky conditions required
  - Flights synced with TROPOMI overpass based on ESA OPOT tool
  - Coordinated with GB and mobile operations



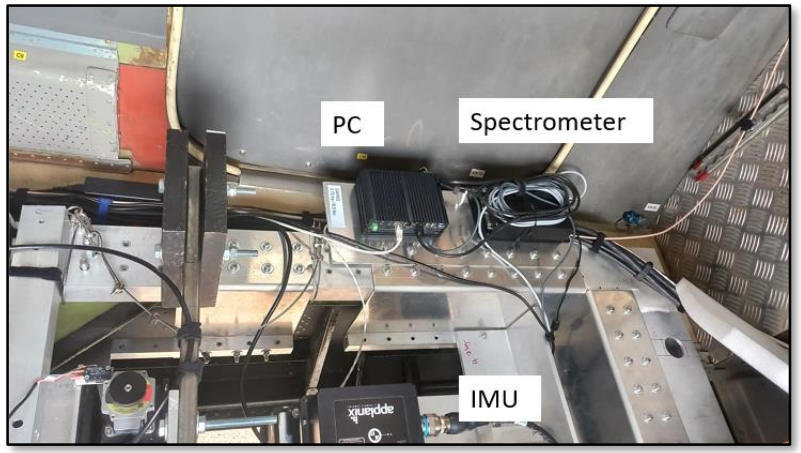
Aircraft → BN-2 coastguard plane

- **MUMM BN-2 Belgian Coast Guard plane**
  - Department at Belgian Institute for Natural Science
- **Maritime surveillance**
  - Air pollution from ships (check compliance with SECA, NECA)
  - Marine pollution (e.g. oil discharge)
  - Fishing control
  - Marine environmental management
  - Scientific observations (e.g. see mammal monitoring)
- **Payload**
  - Standard: NOX / NO / SO_2 / CO_2 “sniffers” or in-situ instruments
  - **Additional: SWING+ / NO_2 ICAD / 0_3 POM**
  - **Applanix IMU (APX-15)**

Instruments → SWING+

- **BIRA SWING+: Airborne whiskbroom imaging system for mapping of UV-VIS trace gases**

	SWING+
Wavelength range	280-550 nm
Spectral resolution (FWHM)	0.7 nm
FOV across-track	100°
IFOV across track	3°
Swath width	2900 m
Ground speed	60 m/s
Exposure time	0.5 s
Spatial resolution	170 m
Weight	3 kg
Size (LxWxH)	20 x 20 x 30 cm^3
Scanning	Whiskbroom
Target platform	UAV/aircraft



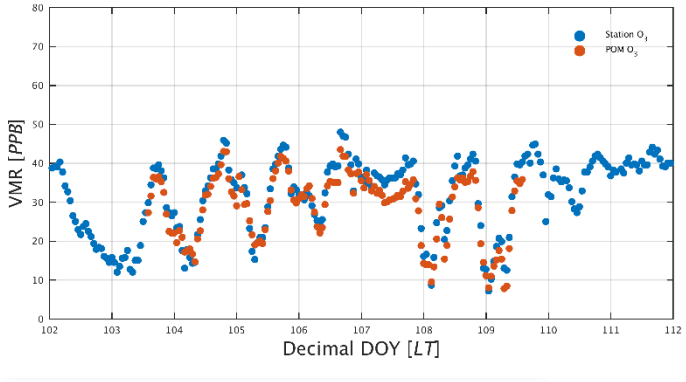
Instruments → AIRYX NO_2 ICAD and POM O_3

- **AIRYX NO_2 ICAD and POM O_3 in-situ**
- **Instrument integration finished and test flight performed on 25/04/2024**

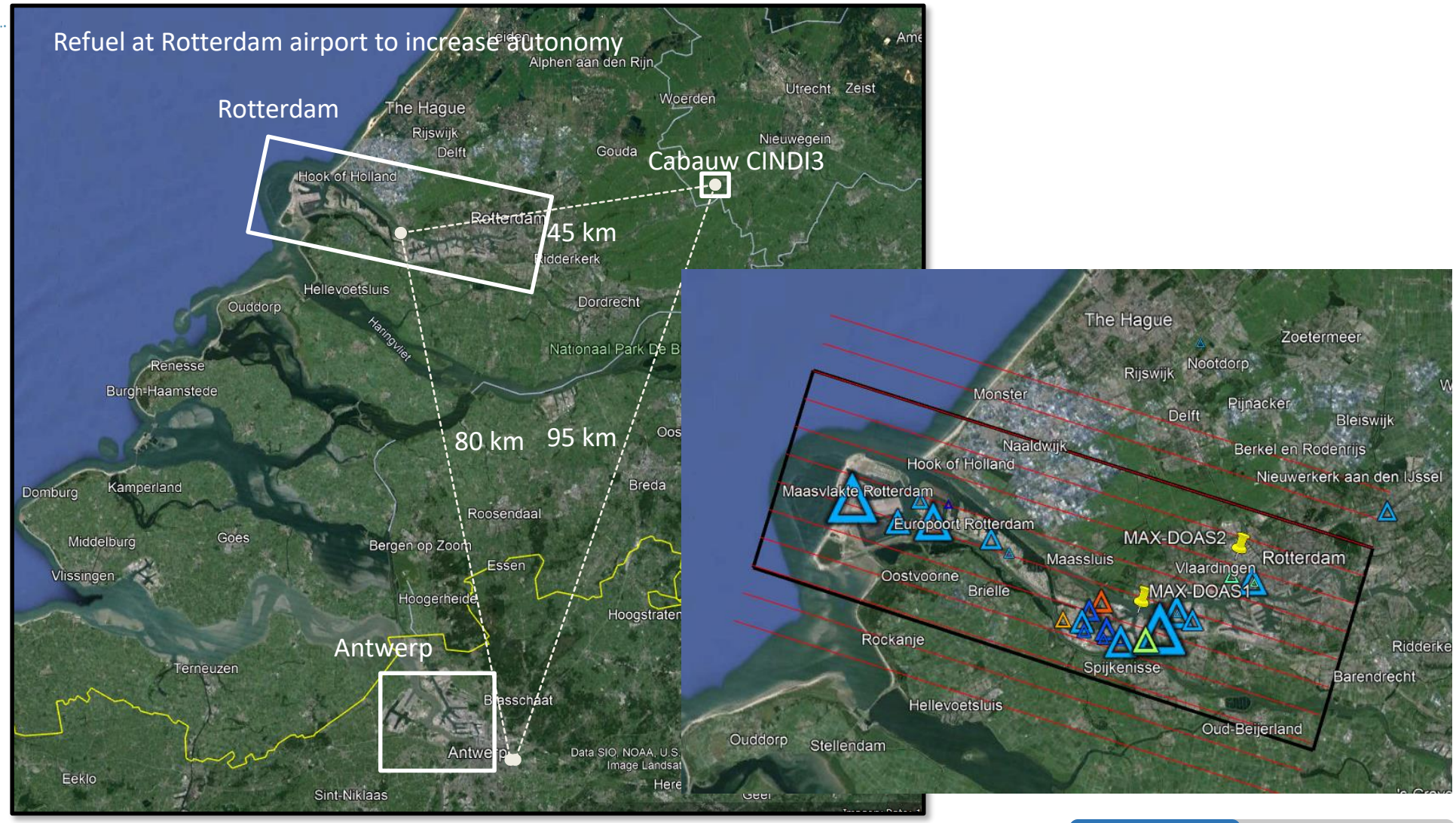
SWING (BIRA)

Airyx ICAD (BIRA)

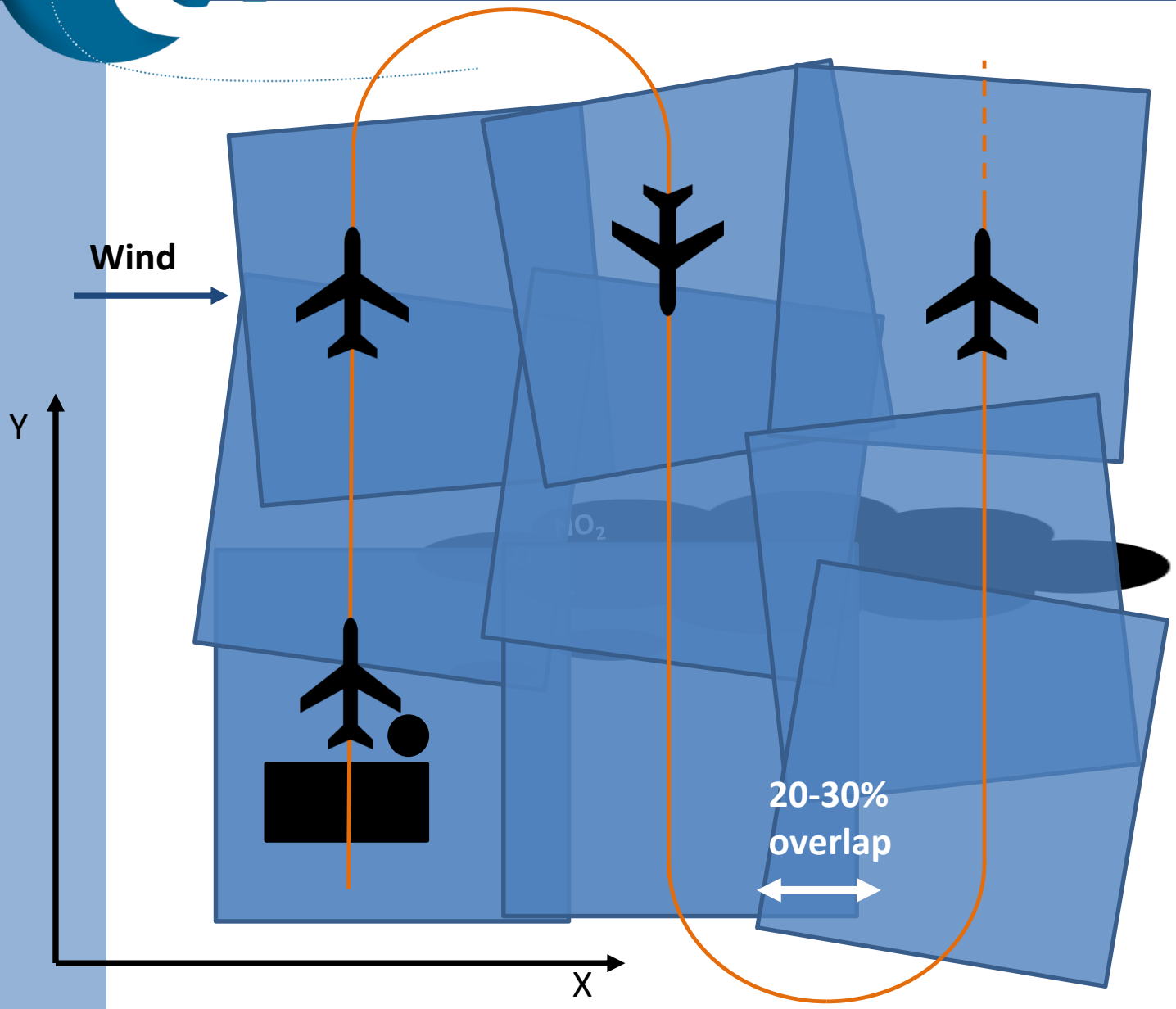
TB Tech POM (MPIC)

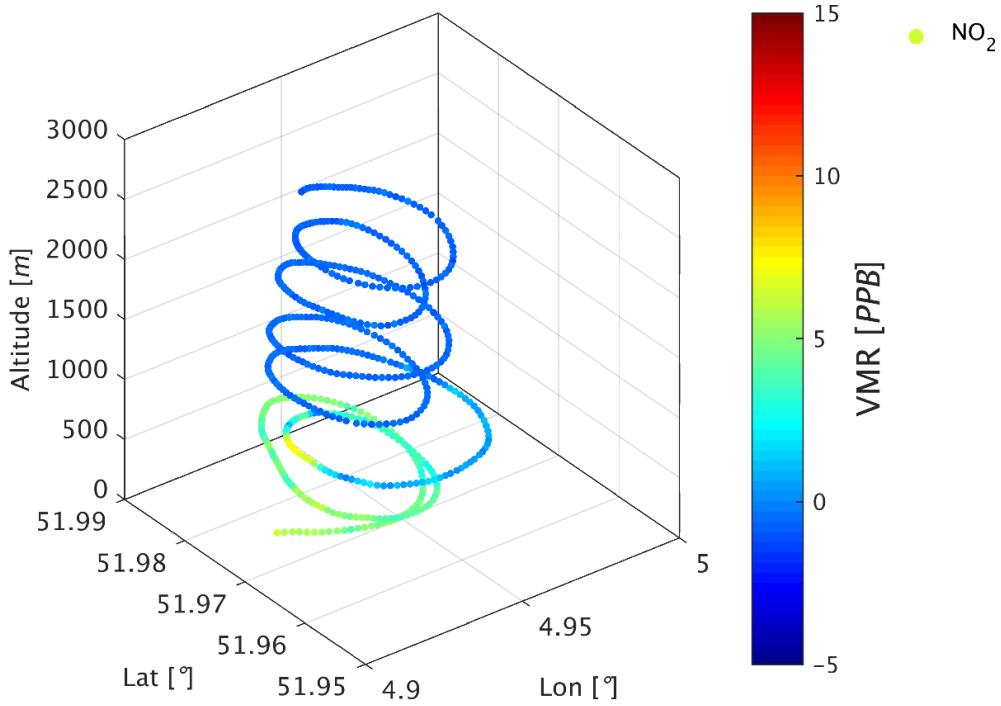


ROI and flight planning



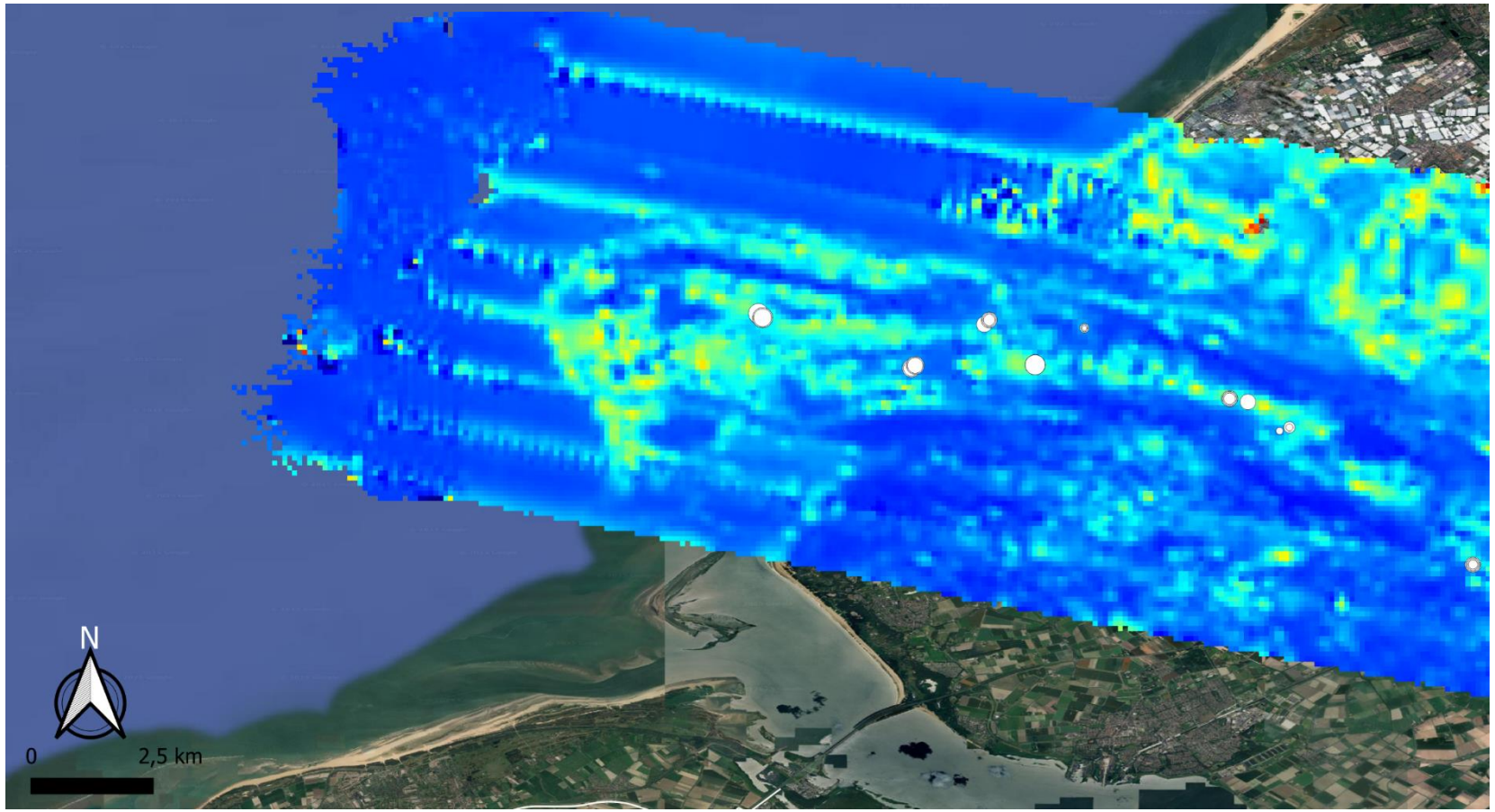
Flight planning - Mapping + Profiling



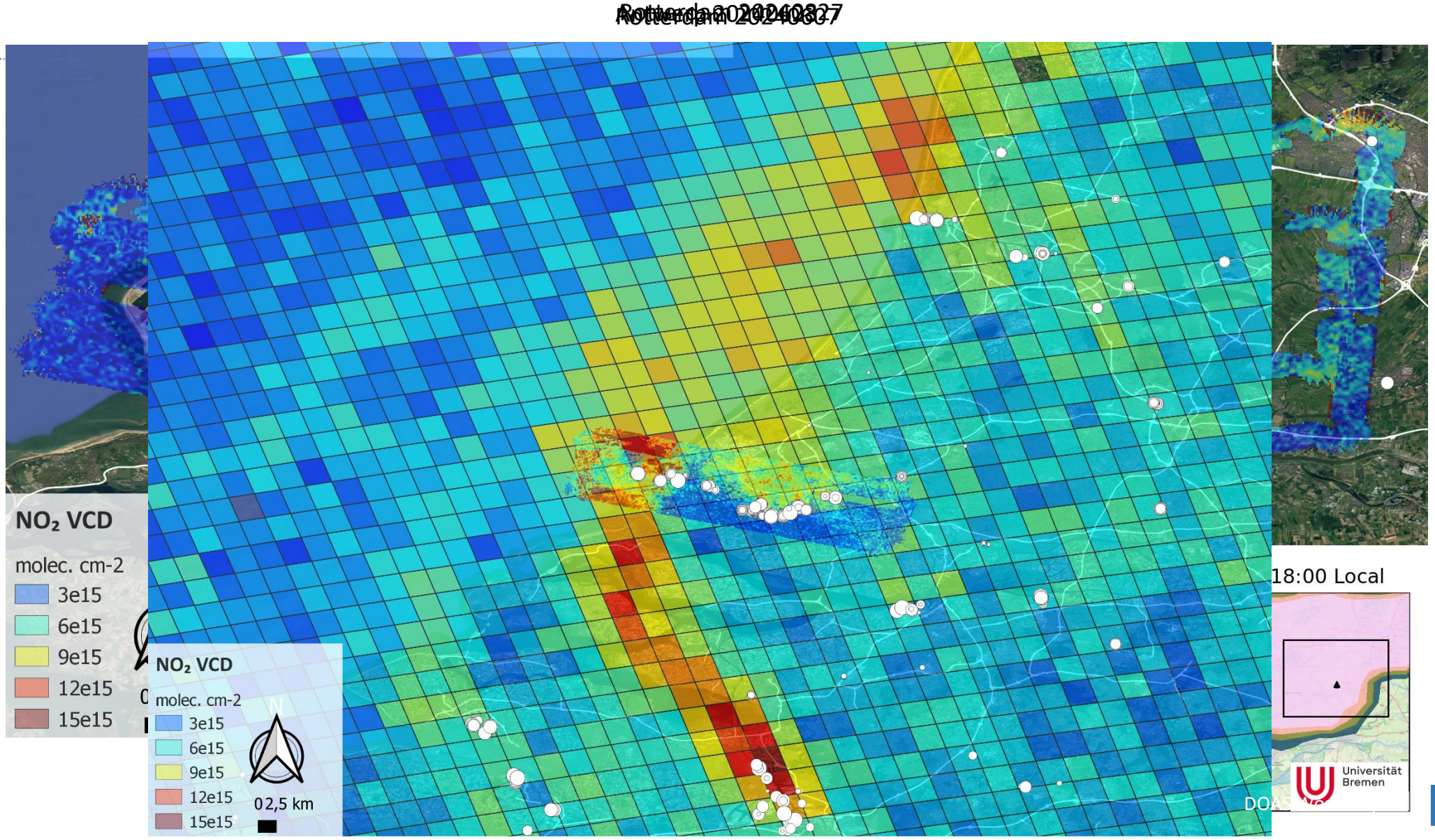


Preliminary results: SWING+ NO_2 VCD maps

Rotterdam 20240827 – SWING intensity



Preliminary results: SWING+ NO_2 VCD maps



SVANTE central processing and S5P NO_2 validation

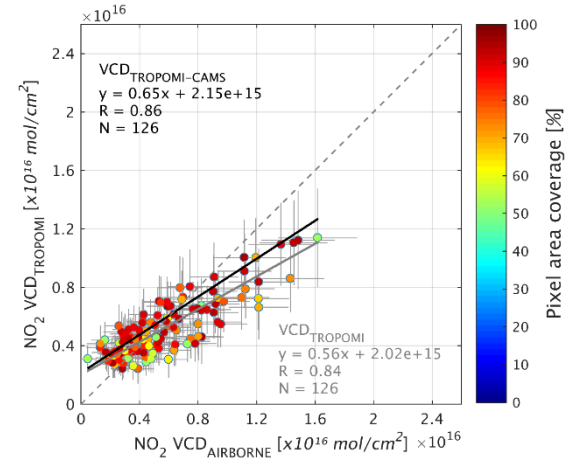
- **Central airborne data processor v1.1**
  - **Airborne imaging NetCDF data format**, following CF metadata conventions
  - **Consistent** a priori assumptions (albedo, NO_2 profile, aerosol scenario, SCD_{ref}) in processing of data from different campaigns/instruments
  - **Process in a harmonized way** in order to obtain **independent reference data sets** to compare with TROPOMI

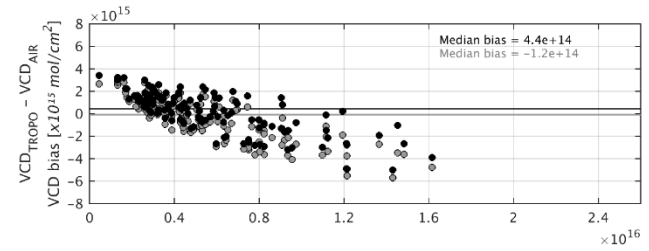
	SWING-TROPOMI intercomparison
	Averaging airborne pixels (~ 0.17 x 0.17 km²) within each TROPOMI pixel (~3.5 x 5.5 km²)
Constraints	
- Data quality	-TROPOMI **QA value >= 0.75** -SWING slant error <= 3 x detection limit (~7e15 molec. cm^{-2})
- Spatial	TROPOMI pixel **covered at least 50%** by airborne data
- Temporal	**ΔT < 1 hour** (difference between airborne vs spaceborne overpass)
- Weather	Clear-sky conditions
Flights	
- Rotterdam	3 flights
- Antwerp	4 flights + 1
TROPOMI product	Comparisons done with OFFL(-CAMS) v2.6 tropospheric NO_2 product

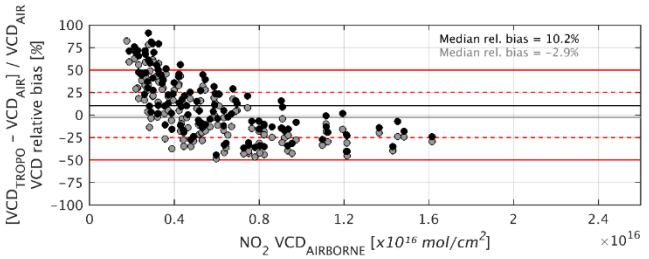
sun/viewing geometry, etc.

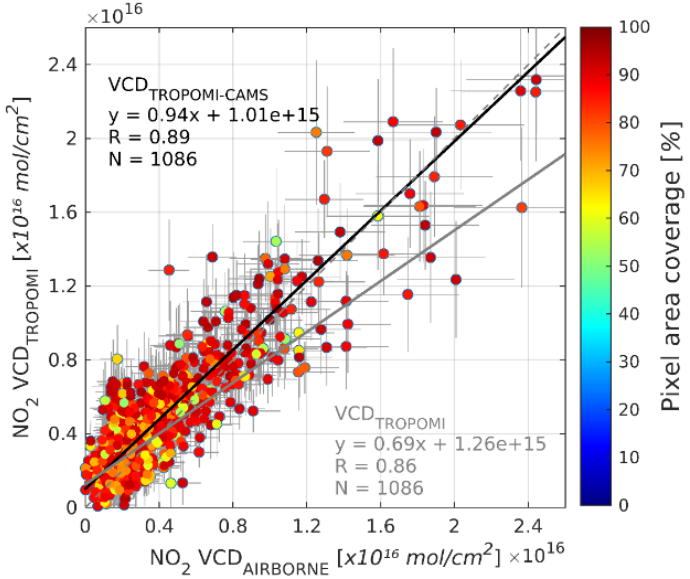
Preliminary results: S5P NO_2 validation

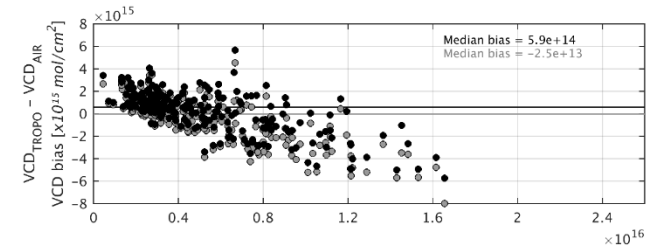
Ensemble 7 flights
OFFL(-CAMS) v2.6 - 50% overlap - <=1 hour)

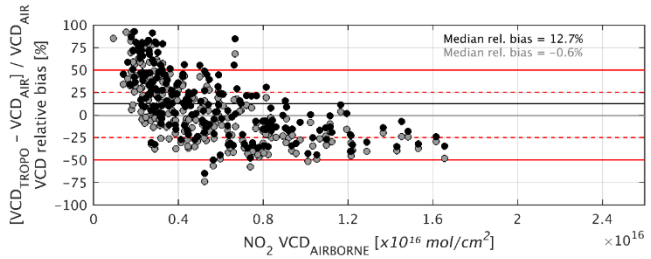




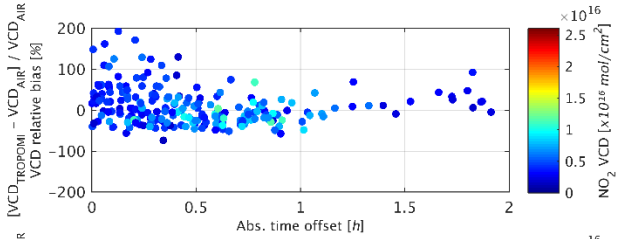


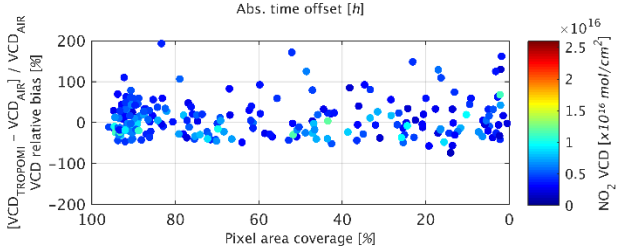


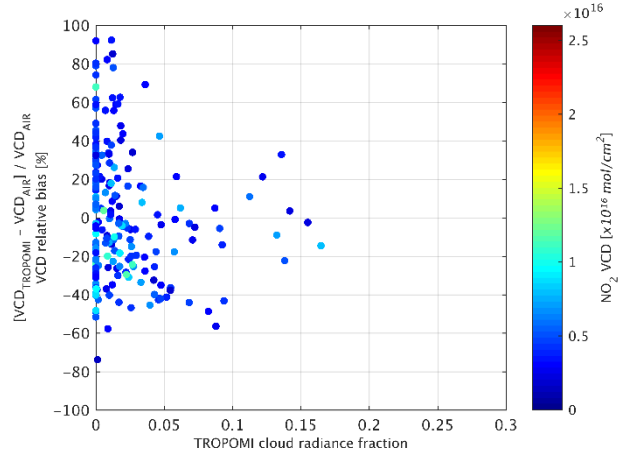




Ensemble 7 flights – Impact spatiotemporal variability and CRF

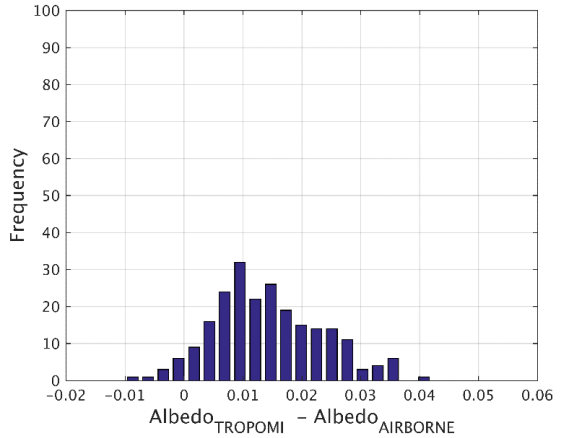




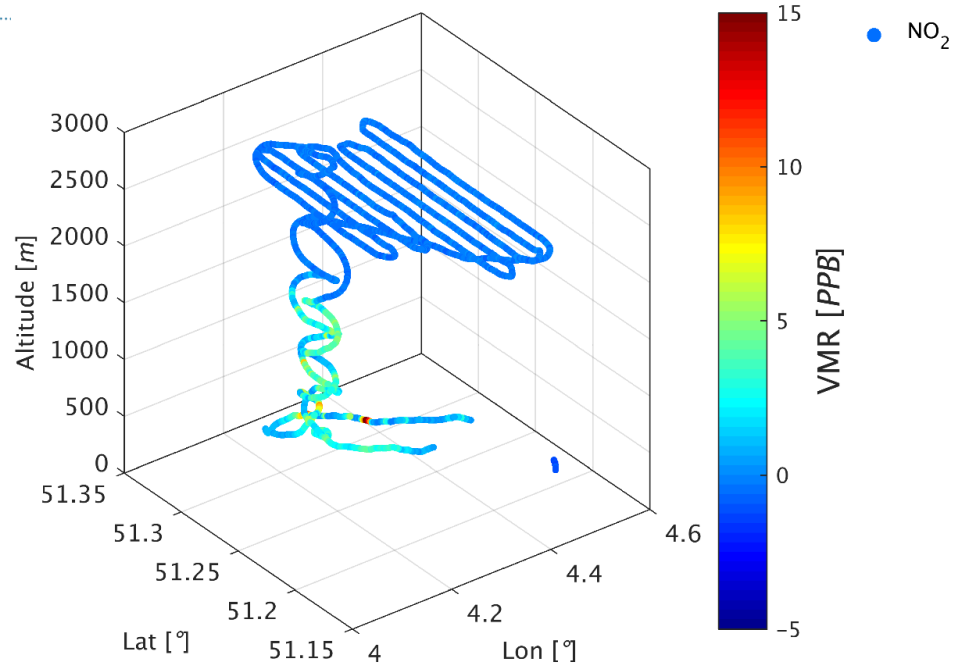


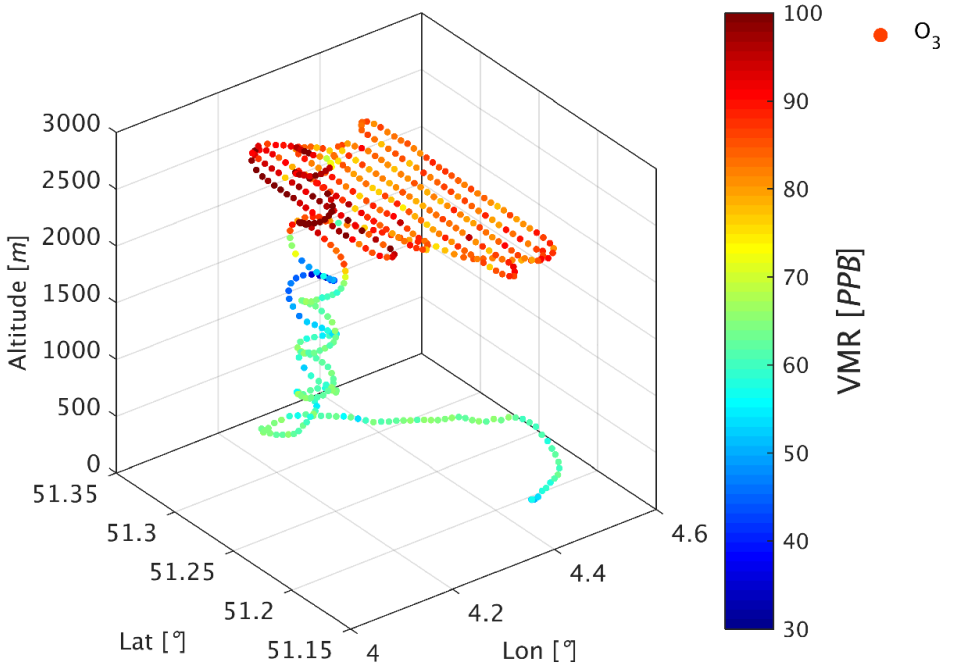
Preliminary results: S5P NO_2 validation

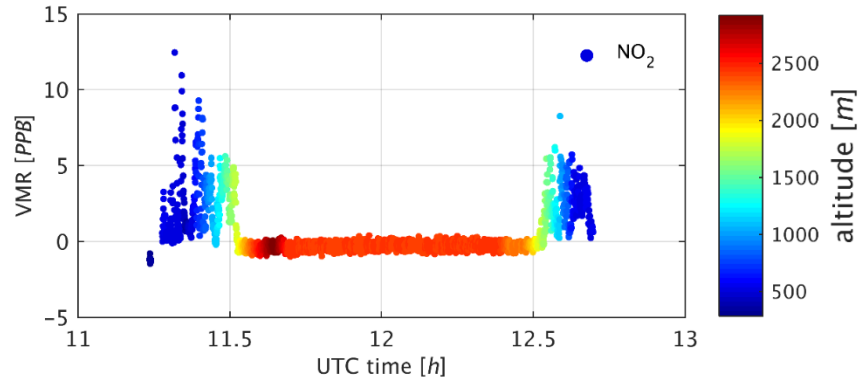
- **Major issues with TROPOMI v2.6 version (feedback H. Eskes – KNMI)**
- **FRESCO**
  - "In version 2.6.0 a **bug was fixed** in the FRESCO processor, specifically in the calculation of the error on the reflectance. This turned out to lead to **unintended side effects on the cloud pressure and on the NO2 tropospheric column, lowering the columns significantly**, especially in winter.
    Users are advised to use NO_2 data from version 2.6.0 with care, especially when combined with versions 2.4.0 and 2.5.0."
  - Version 2.8.0 has a major upgrade leading to a much better agreement of the FRESCO scene pressure and surface pressure in the case of cloud free pixels.
- **Albedo**
  - v2.6 uses the **S5P DLER v1 based on the L1B v1 product**. Albedo is biased high by approximately 0.01
  - v2.7.1 introduced the S5P DLER v2.1 which is computed from L1B v2. this lowers the albedo by almost 0.01, increasing VCD by about 9%

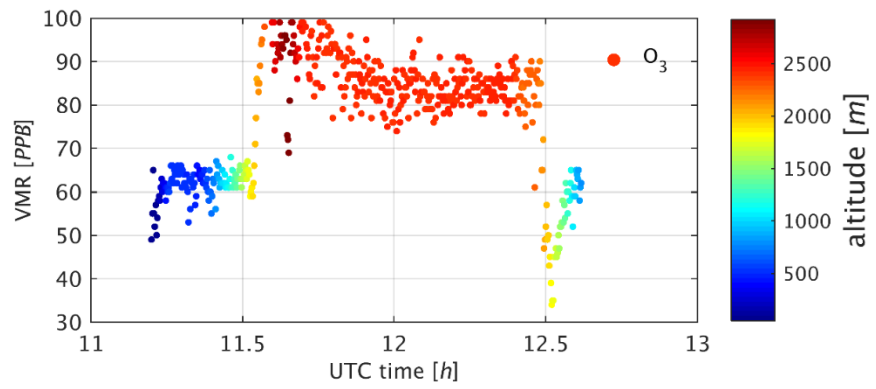


2024-06-25 in-situ mapping - Antwerp

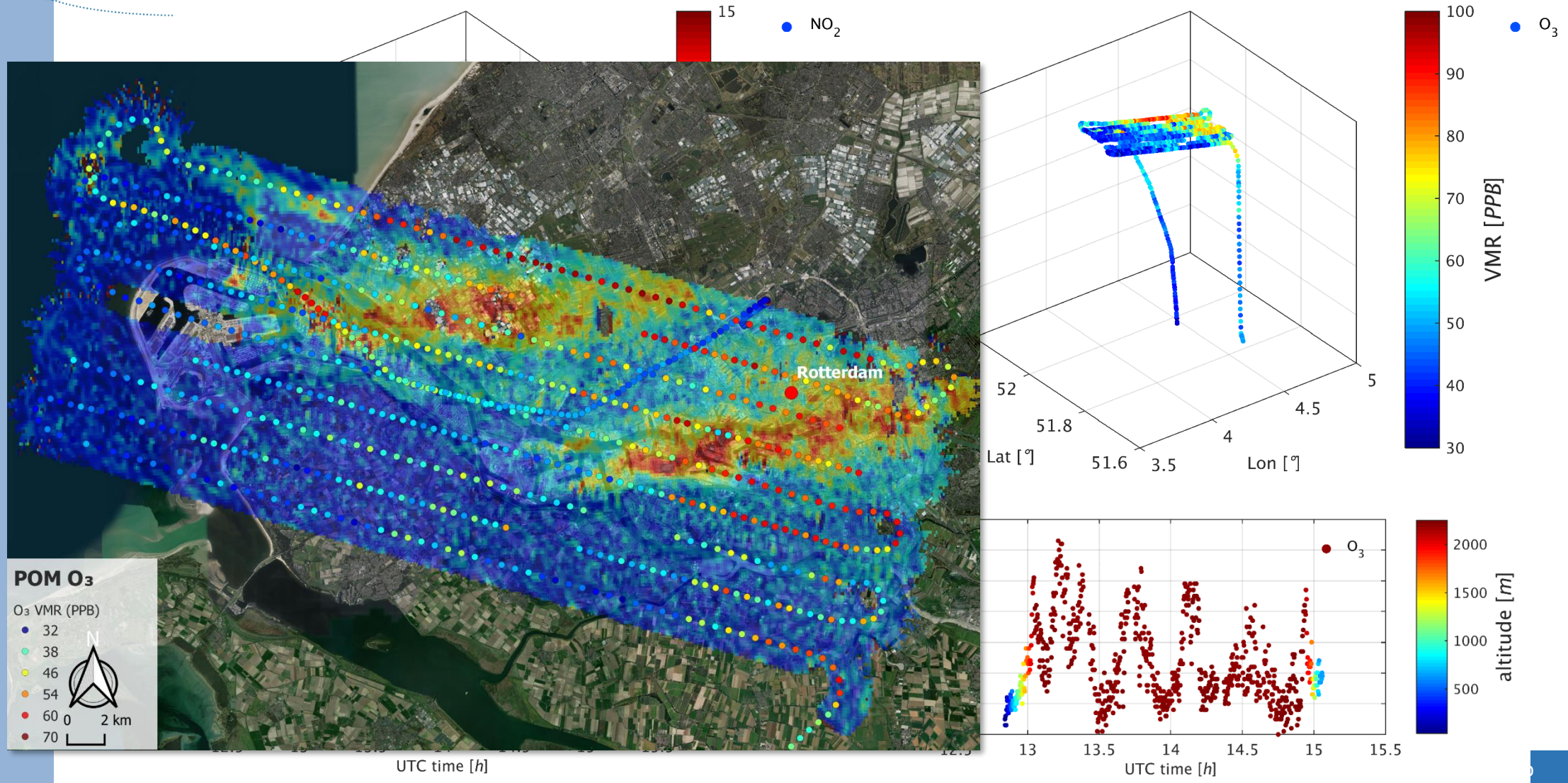








2024-06-07 in-situ mapping - Rotterdam

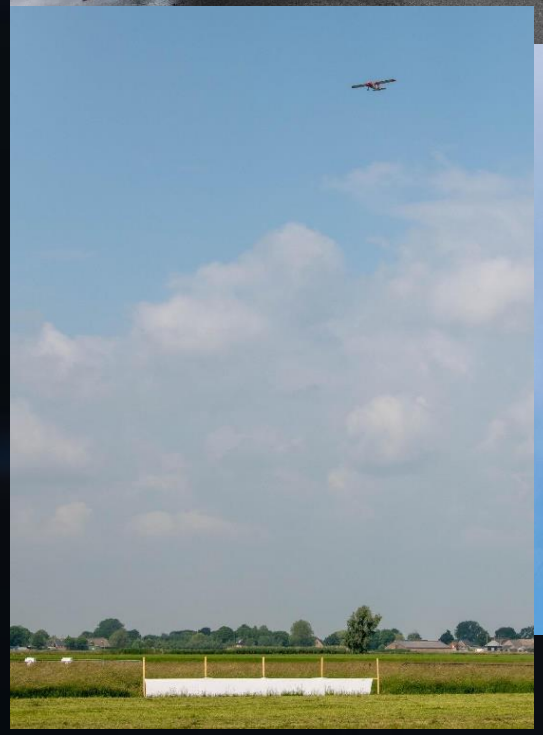


Outlook and Next steps

- **Lessons learned**
  - Weather → Need for clear-sky conditions
  - ATC → Hard to fly in proximity of Schiphol airport. Better contacts with ATC management needed
  - Many technical issues with all key instruments
    - → Problem of interferences, turbulence, pressure and temperature changes?
- **Further data exploitation and interpretation of v1 key dataset**
  - In-depth analysis of SWING+ data
    - Are the signals over sea real? Exploit AIS data.
  - In-depth analysis of ICAD NO_2 and POM O_3 data (discuss with experts)
    - T-profile (ERA-5 or measurements)?
    - Better understand relation NO_2/O_3
- **Continue validation of coinciding TROPOMI NO_2 product (improved version?)**
- **Collection of relevant ground-based data (e.g. mobile DOAS data, MEMS, PANDORA, MAX-DOAS, NO_2 sonde, tower in-situ, etc.) and evaluate a priori retrieval assumptions**







...Thank you!

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