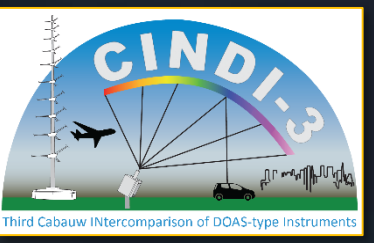
Airborne component during CINDI-3 - Preliminary results



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and the CINDI-3 consortium

BIRA-IASB

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CINDI-3 workshop 18/03/2025

Overview

- **Objectives**
- **Campaign plan**
- **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

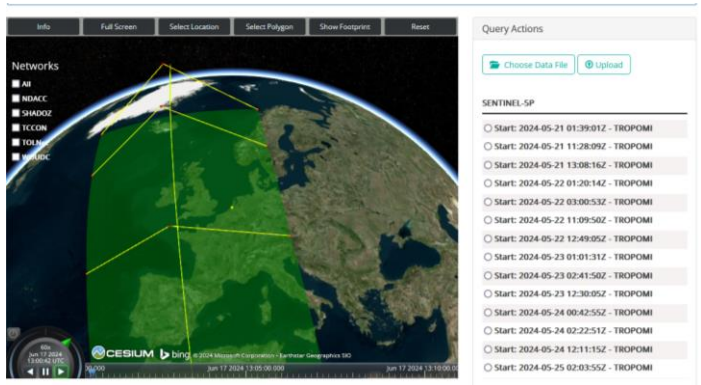
- **Mapping horizontal NO_2 distribution with airborne imaging instrument (SWING+) and sampling vertical NO_2 and O_3 distribution with in-situ (ICAD NO_2 and POM O_3)**

- **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 → 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
    - Forecast provided by Uni Bremen based on WRF and Flexpart (GFS data)
    - Tools such as windy.com
  - Flights synced with TROPOMI overpass based on ESA OPOT tool
  - Coordinated with GB and mobile operations → foreseen for Cabauw and Rotterdam only



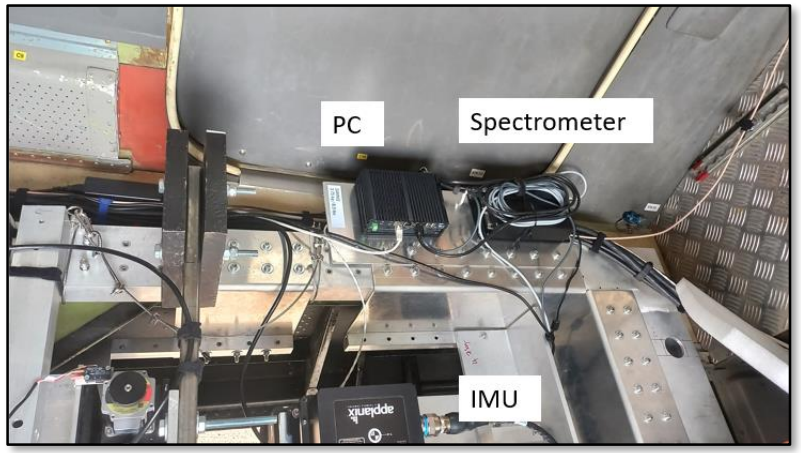
Aircraft → BN-2 coastguard plane

- **MUMM BN-2 Belgian Coast Guard plane (Management of the Marine Environment)**
  - Department at Belgian Institute for Natural Science (contact person: Dr. Ward van Roy)
- **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)**
- **Strengths**
  - Belgian Scientific team → operations from base airport
  - Experience integrating SWING+
  - TROPOMI cal/val (AMT – Riess et all., 2022)
- **Weaknesses**
  - Payload space is limited due to standard equipment on board, e.g. no space for AirMAP or IR imaging system like TELOPS
  - Coast guard plane – accidents at sea have priority

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



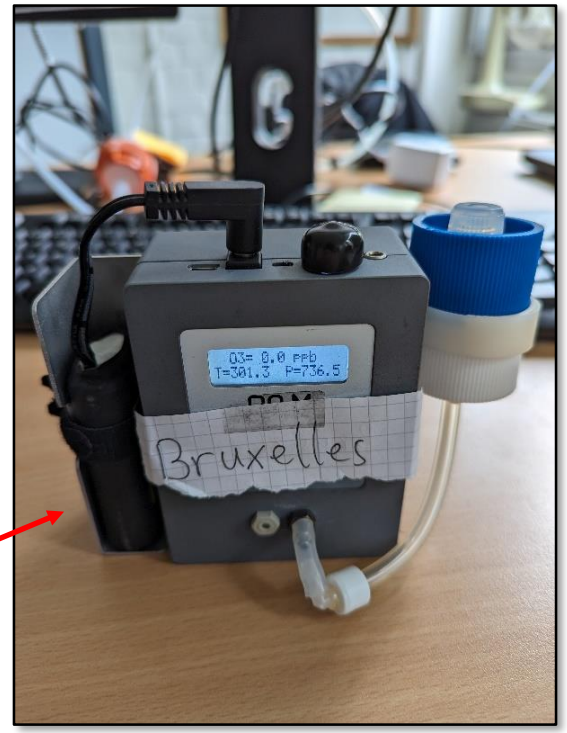
Instruments → AIRYX NO_2 ICAD and POM O_3

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

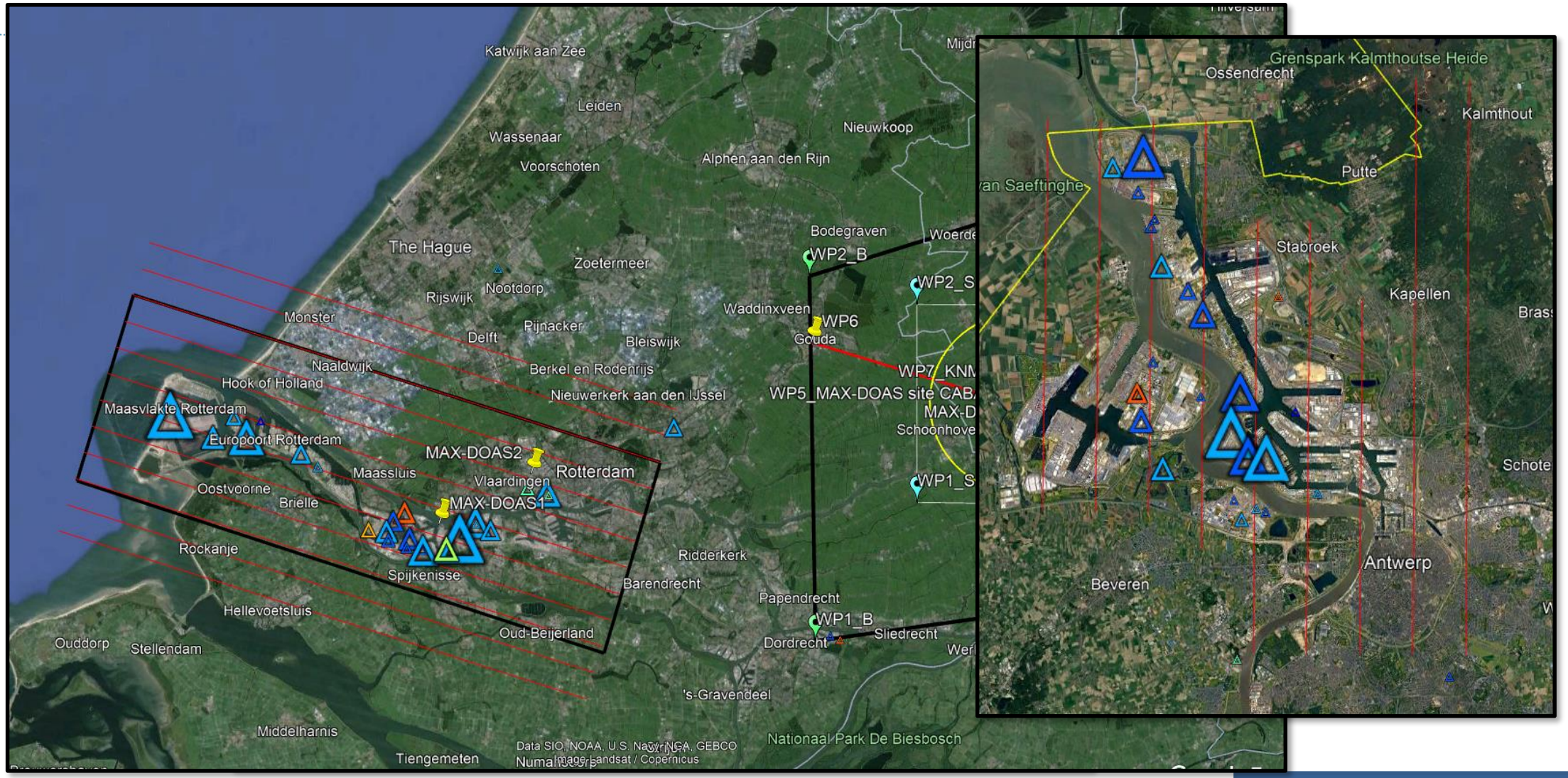
SWING (BIRA)

Airyx ICAD (BIRA)

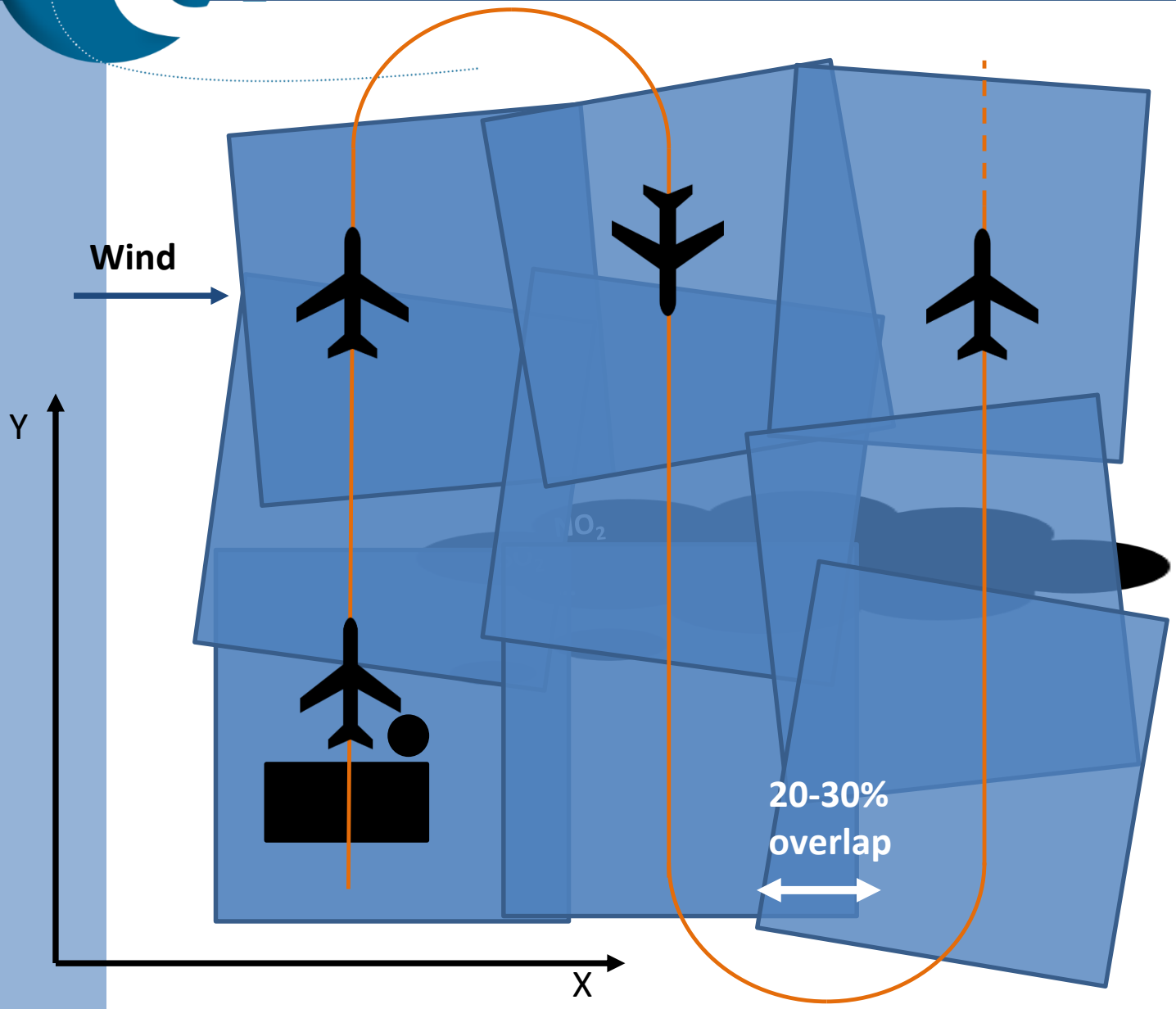
POM (MPIC – T. Wagner)

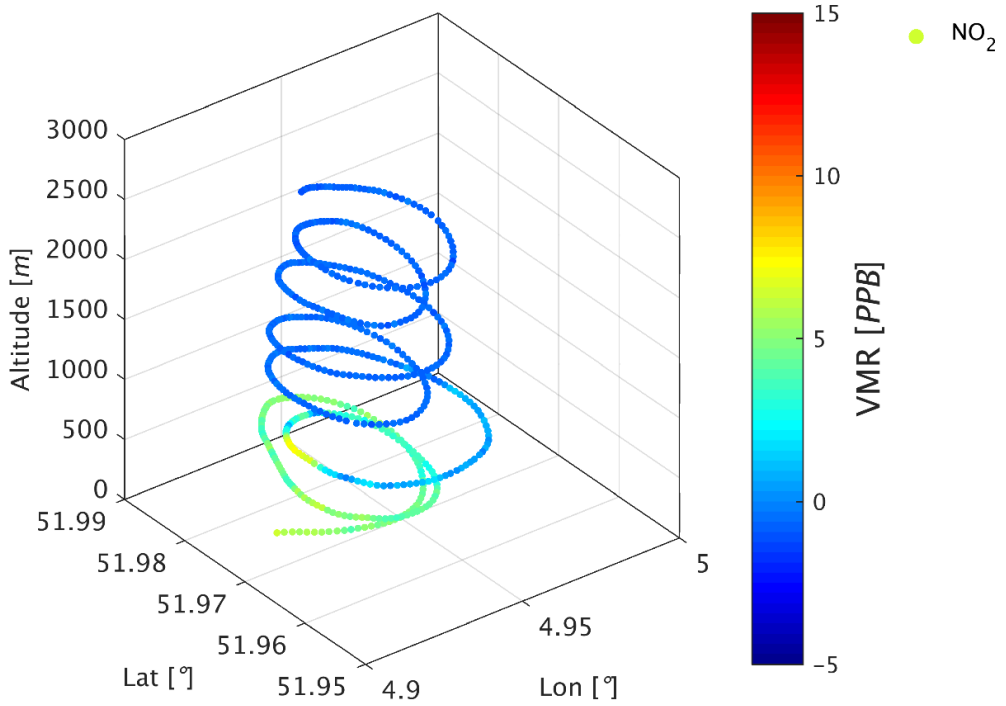


ROI and flight planning



Flight planning - Mapping + Profiling



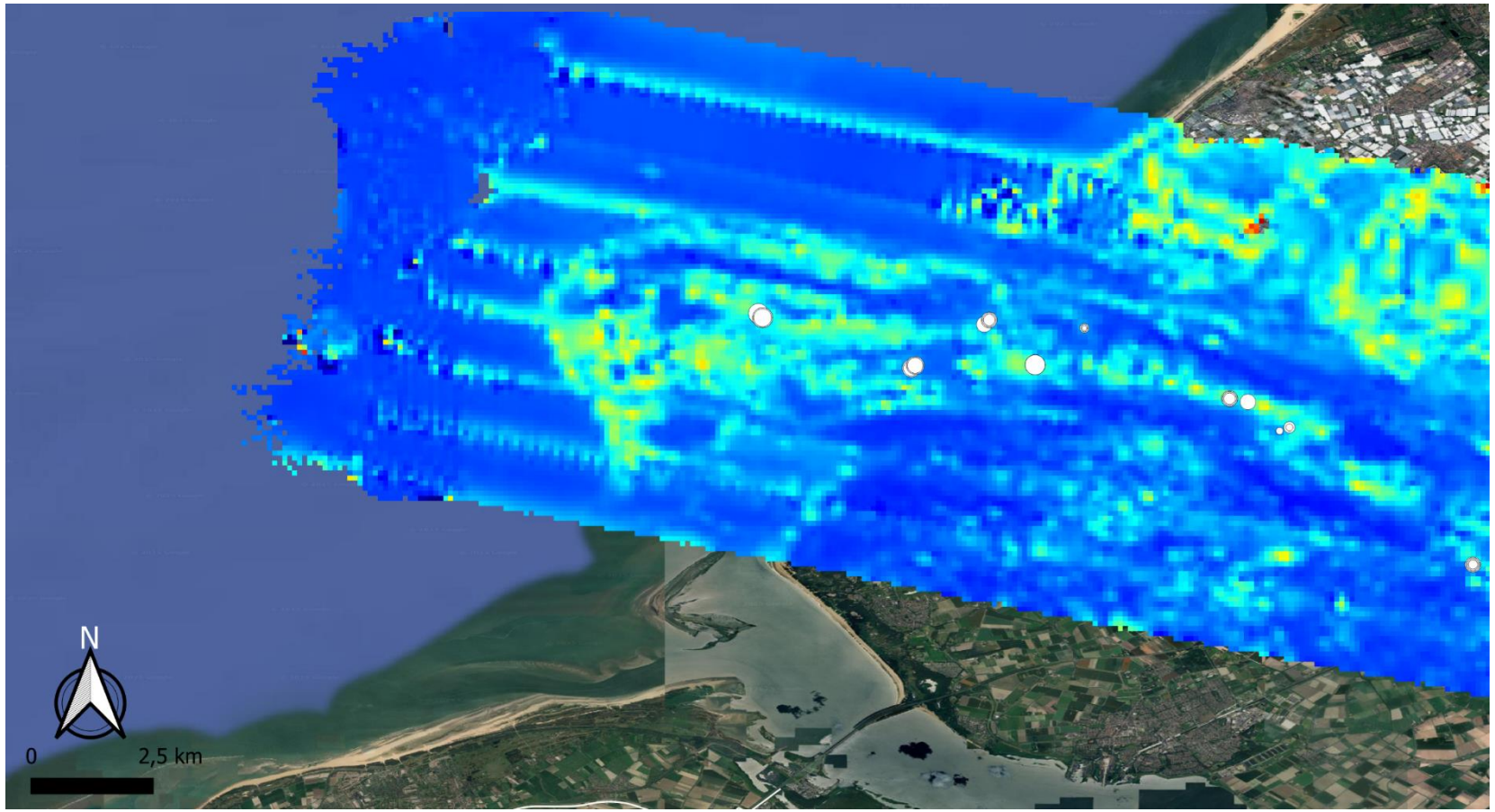


Overview airborne data acquisition

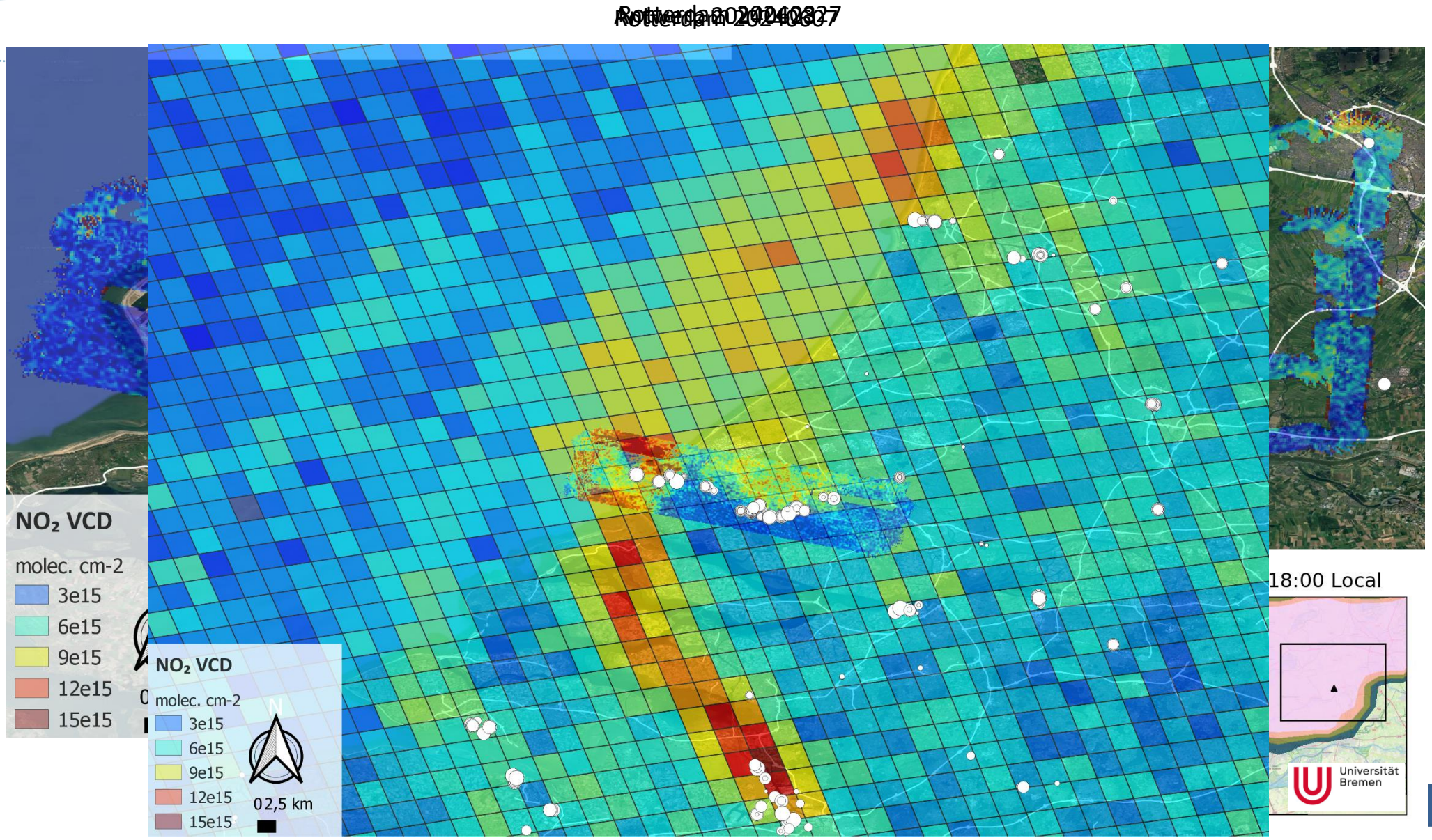
Date	ROI	Type of flight			Technical comments	Conclusion from quicklooks
		Spiral up	Mapping	Spiral down		
20240602	Antwerp				Test flight over Antwerp / Only a few lines acquired due to cloud cover / ICAD did not work properly due to GPS failure	SWING data will be excluded from further processing
20240605	Rotterdam				Not all flight lines could be acquired due to restrictions from ATC	NO_2 plumes were in the area where flightlines were acquired so can be used for satellite validation
20240607a	Cabauw				POM logging issues	Flight over Cabauw consist of 1 flight line in main MAX-DOAS direction + 2 boxes around site + spiral focused on the tower
20240607b	Rotterdam				POM logging issues	
20240623	Antwerp					Only 3 overlapping TROPOMi pixels: many filtere out due to QA value (clouds) + edge of the swath
20240624	Antwerp				IMU data corrupted and cannot be used. Use OPTIMARE data?	Maps and profiles can be analysed but will be excluded from TROPOMI validation
20240625	Antwerp					
20240626	Antwerp					
20240821	Rotterdam				High amount of data filtered out due to presence of clouds	Will be excluded from further processing
20240827	Rotterdam				No IMU. Use OPTIMARE data?	
20240828	Antwerp				No IMU. Use OPTIMARE data?	

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

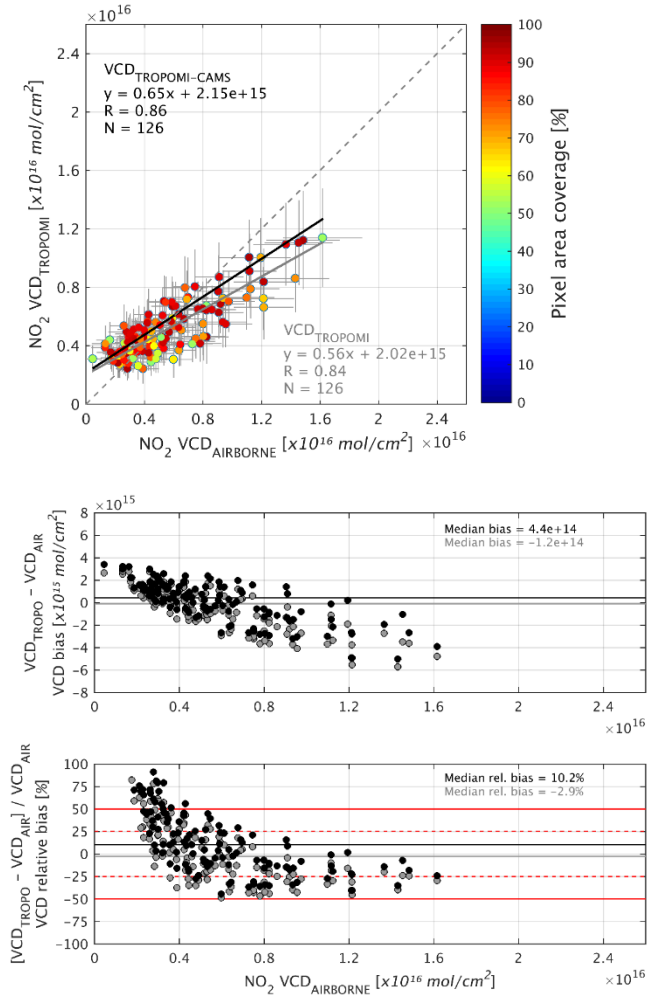
- **Central airborne data processor v1.1**
  - **Airborne imaging NetCDF data format**, following CF metadata conventions
  - **Consistent** a priori assumptions (albedo, NO_2 profile, aerosol scenario, SCD_{ref}) in processing of data from different campaigns/instruments
  - **Process in a harmonized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

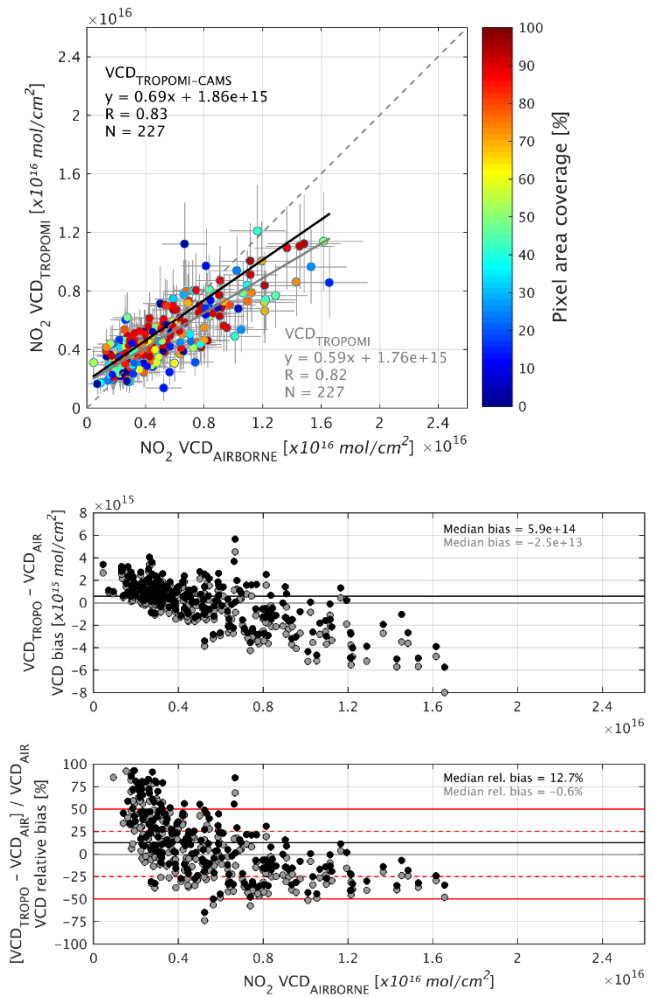
sun/viewing geometry, etc.

Preliminary results: S5P NO_2 validation

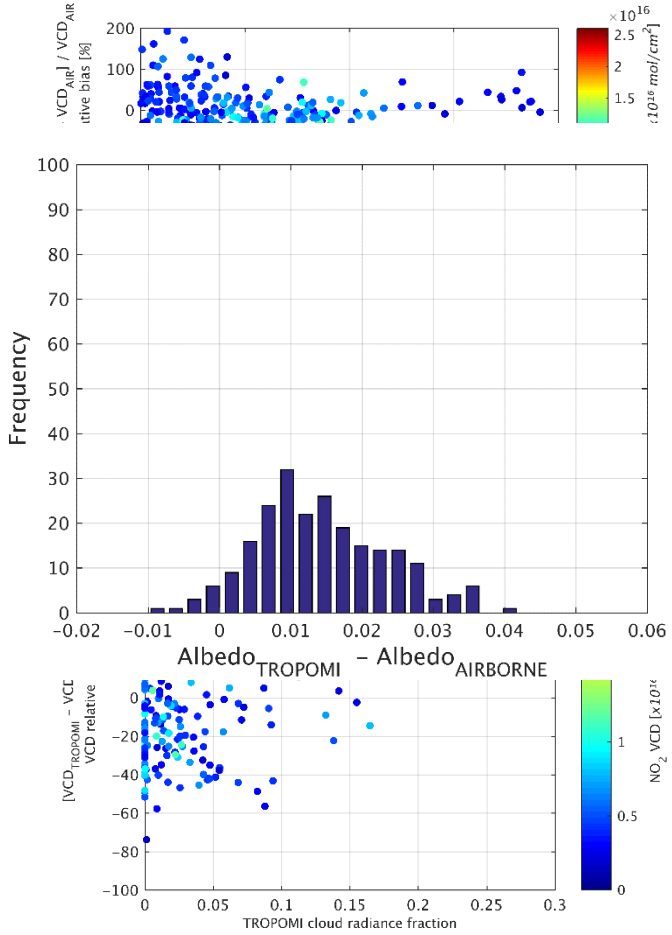
Ensemble 7 flights
OFFL(-CAMS) v2.6 - 50% overlap - <=1 hour)



Ensemble 7 flights
OFFL(-CAMS) v2.6 - No spatiotemp. constraints)



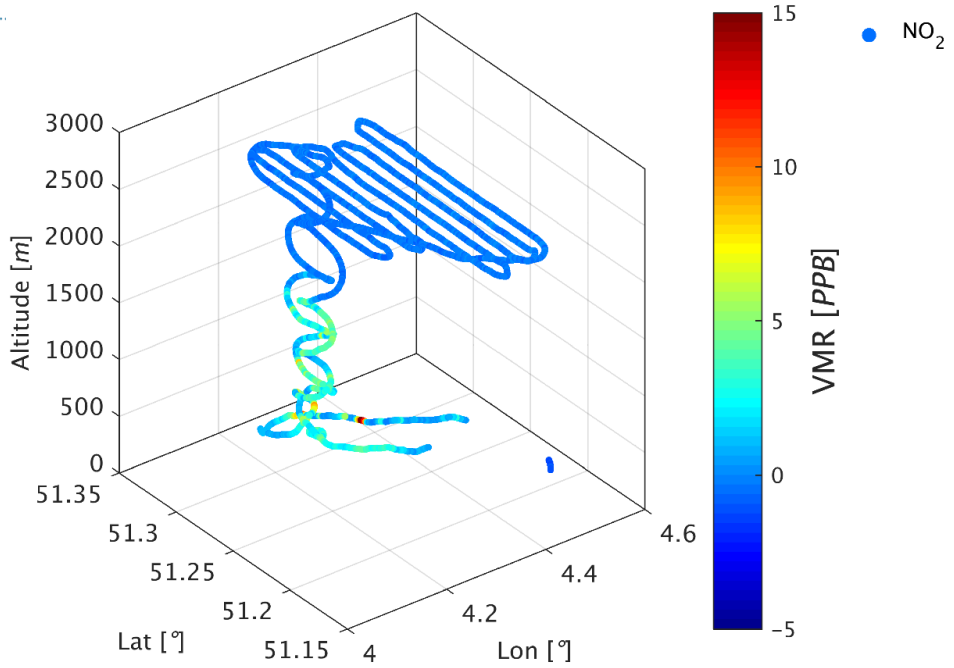
Ensemble 7 flights – Impact spatiotemporal variability and CRF

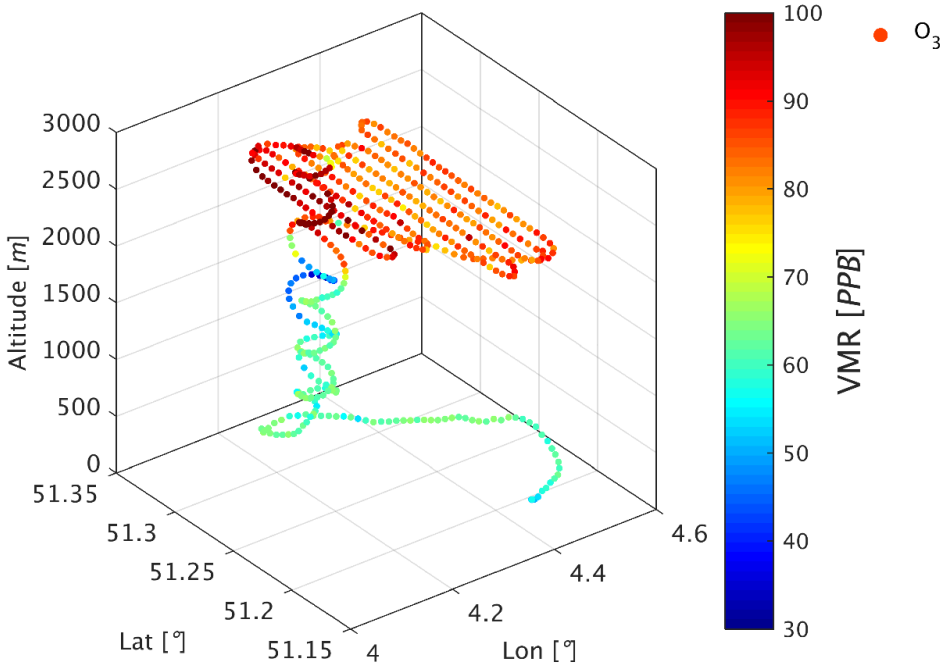


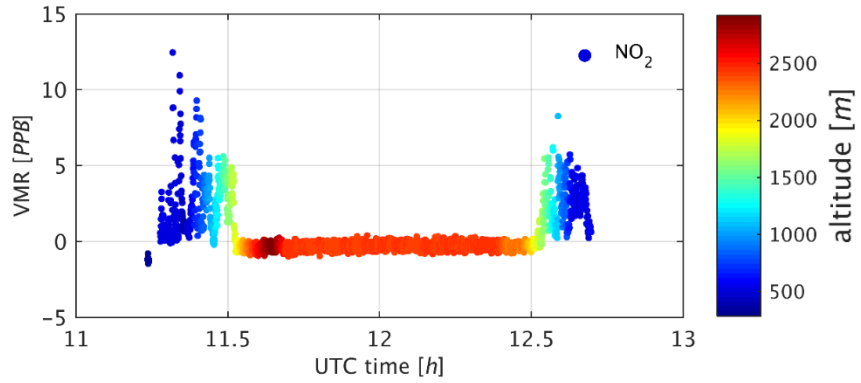
Preliminary results: S5P NO_2 validation

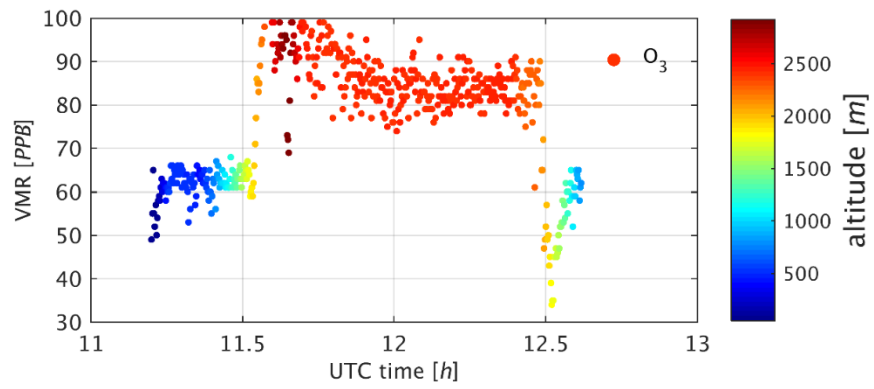
- **Issues with TROPOMI v2.6 version (feedback H. Eskes – KNMI)**
- **FRESCO**
  - "In version 2.6.0 a **bug was fixed** in the FRESCO processor, specifically in the calculation of the error on the reflectance. This turned out to lead to **unintended side effects on the cloud pressure and on the NO2 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**. On average, the histogram of this albedo dataset is similar to the OMI LER. albedo is biased high by approximately 0.01
  - In v2.7.1 we introduced the S5P DLER v2.1 which is computed from L1B v2. As shown in the attached figure this lowers the albedo by almost 0.01, increasing VCD by about 9%

2024-06-25 in-situ mapping - Antwerp

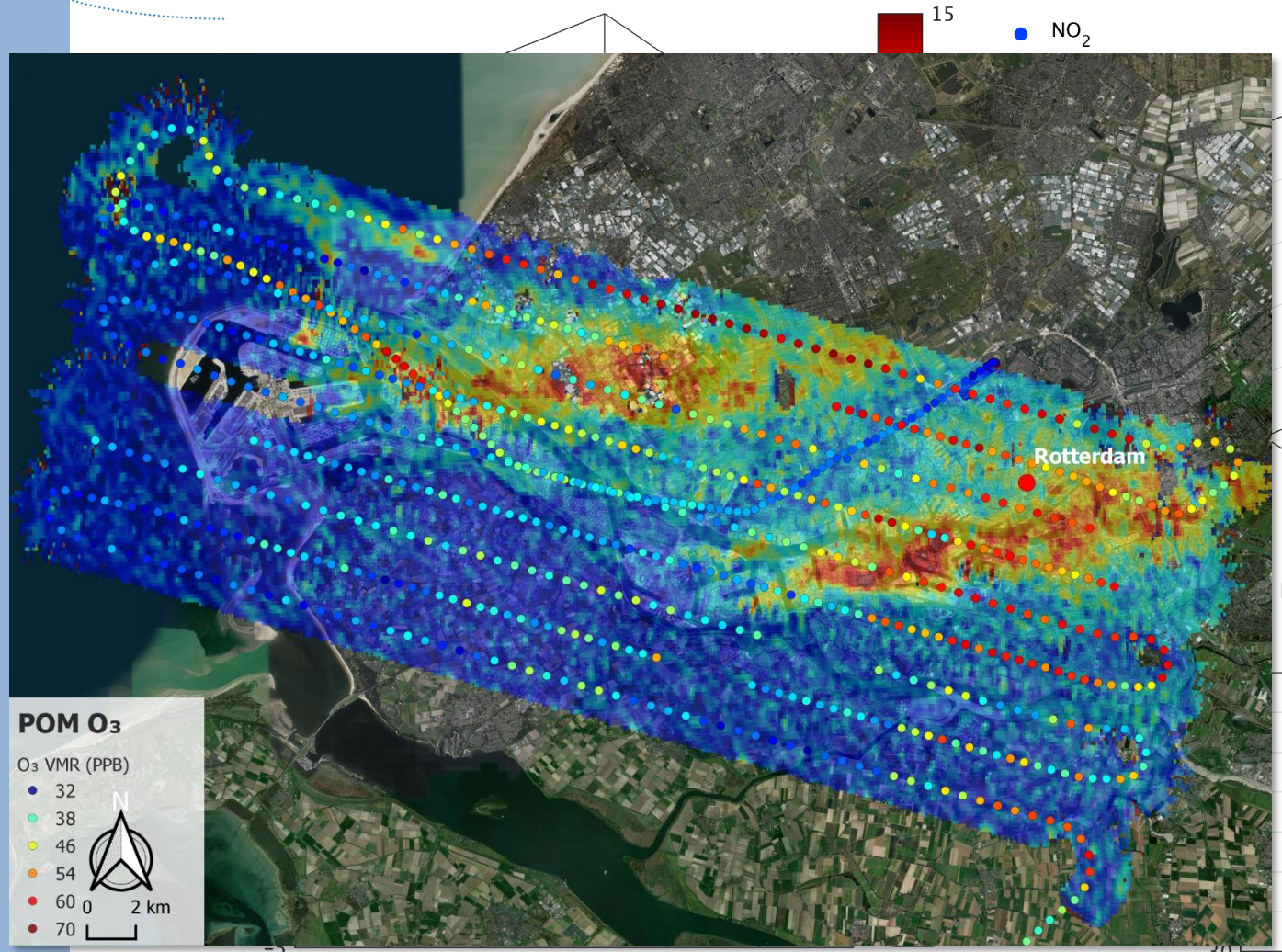


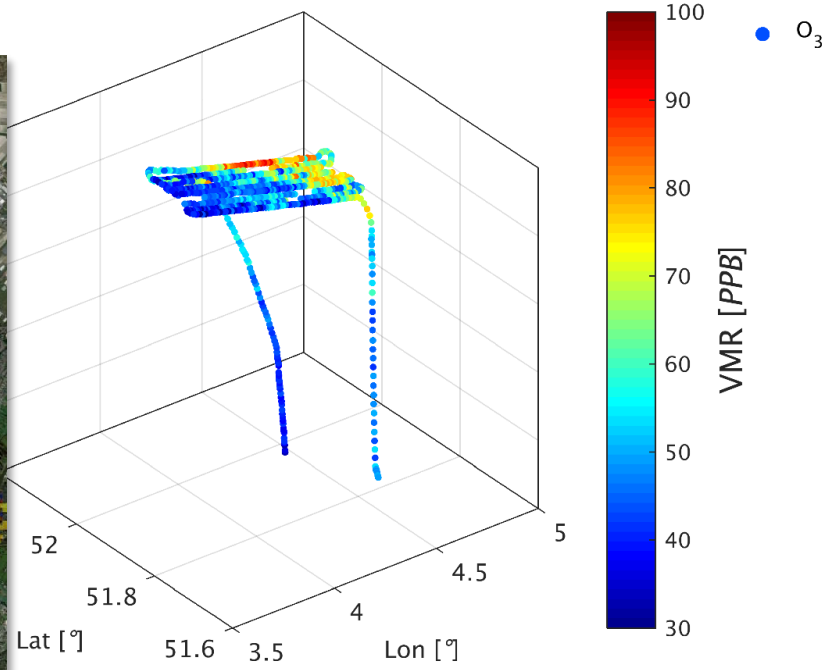




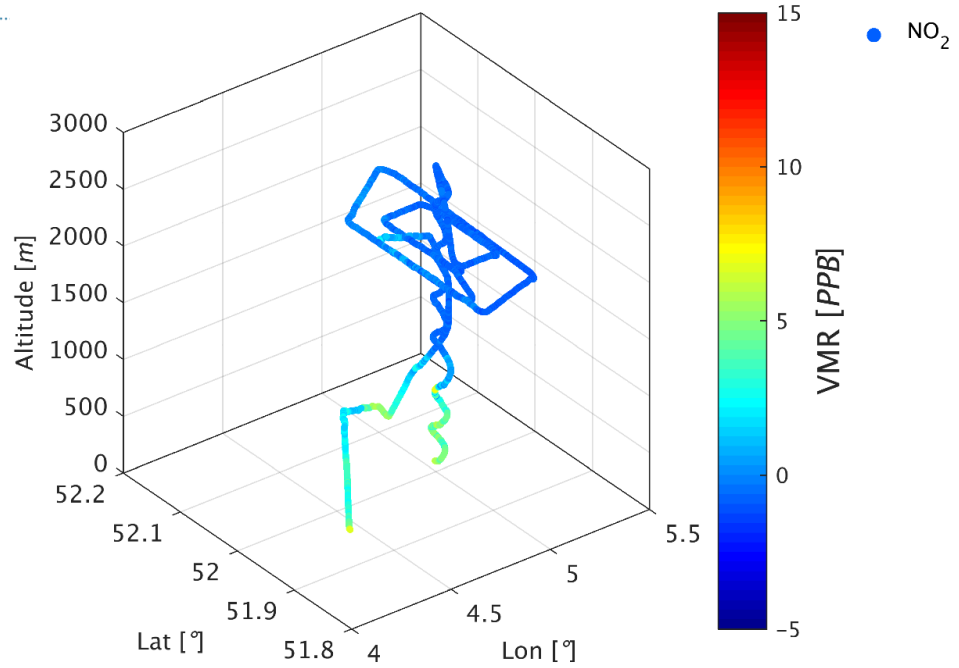


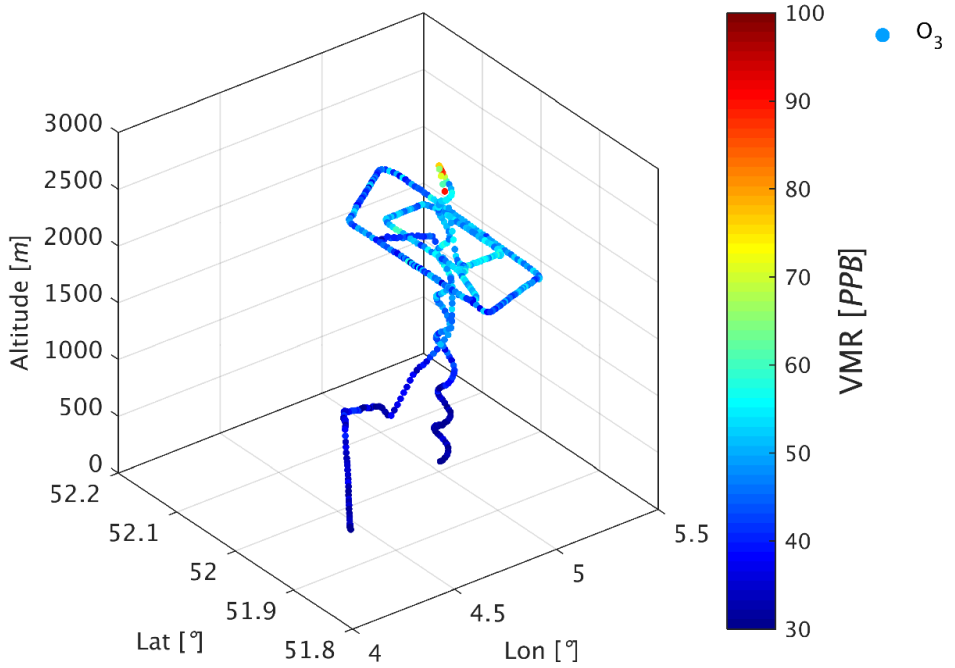
2024-06-07 in-situ mapping - Rotterdam

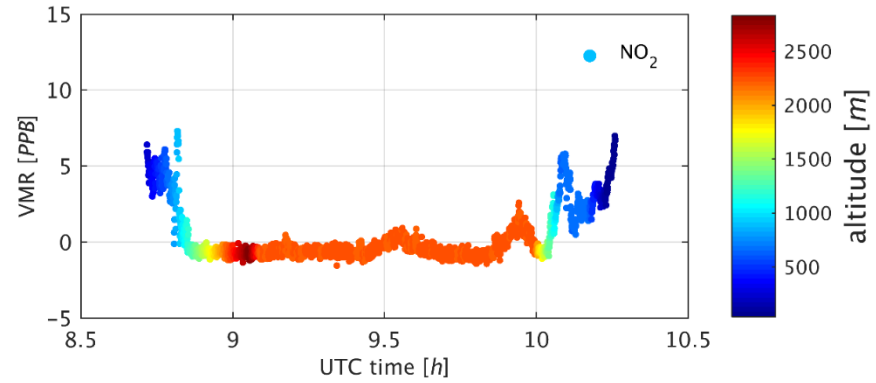


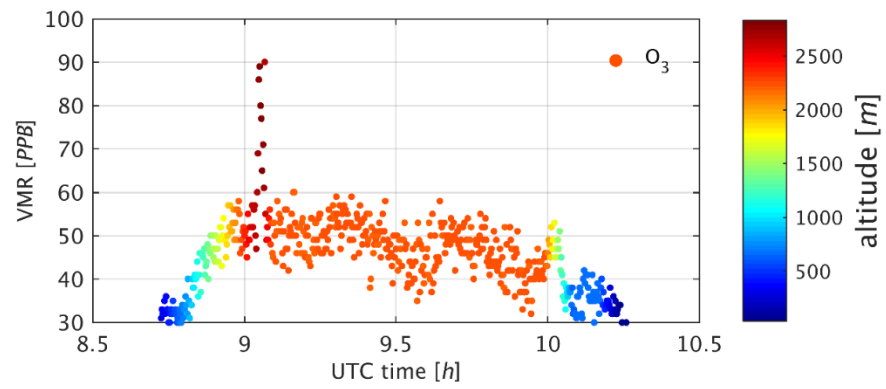


2024-06-07 in-situ mapping - Cabauw









NO_2 vertical profiles - Antwerp

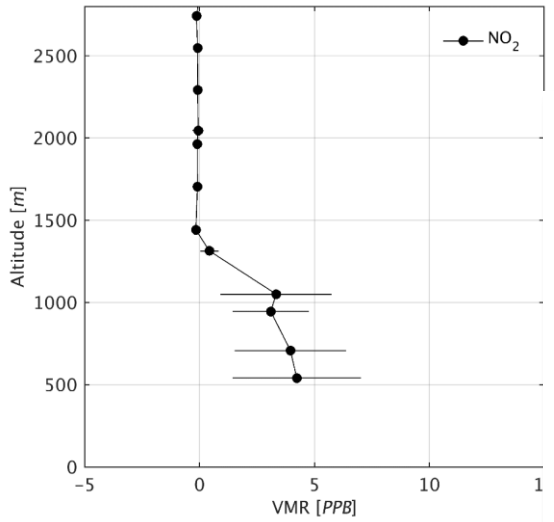
20240602 (test flight)

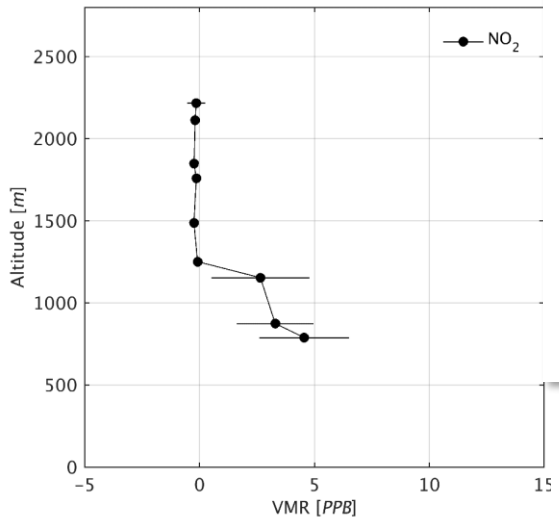
20240623

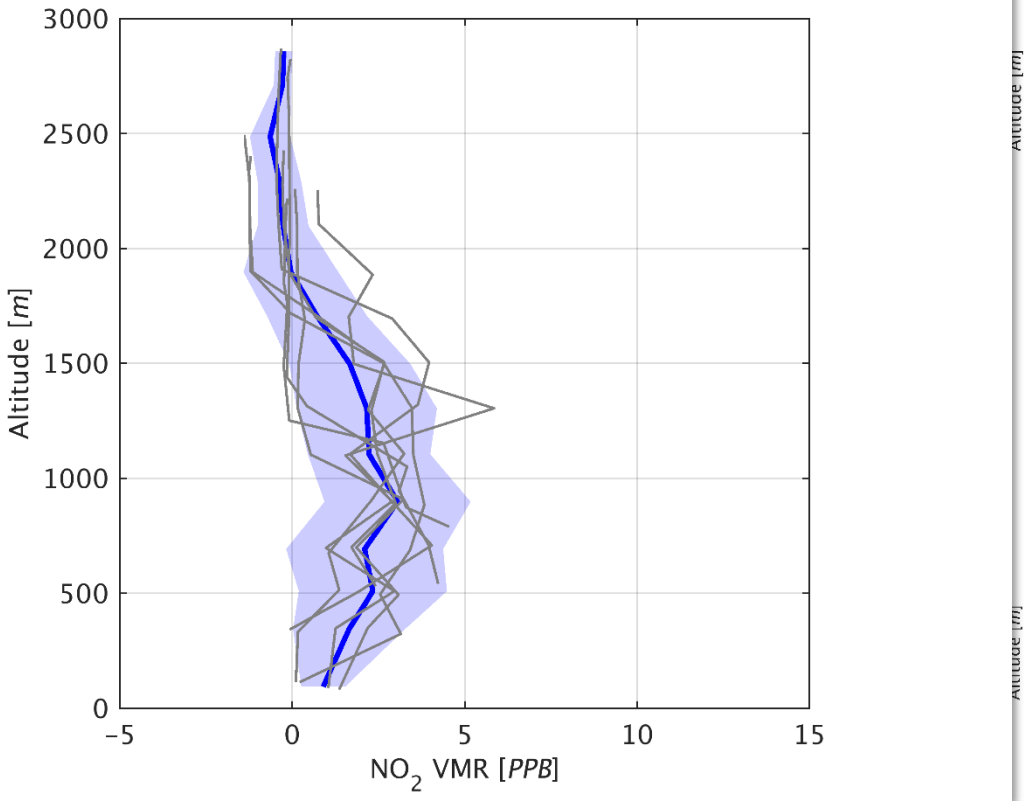
20240625

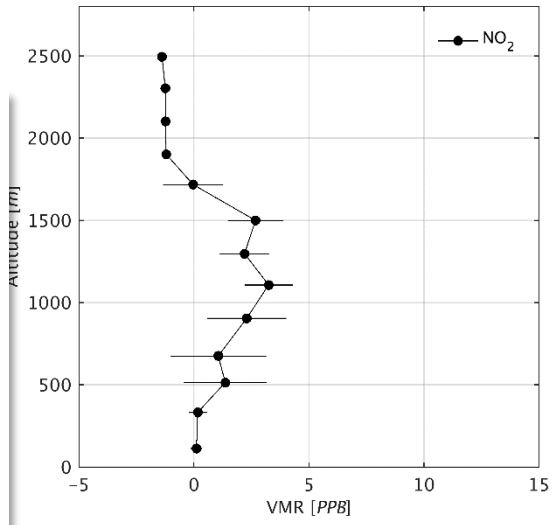
20240626

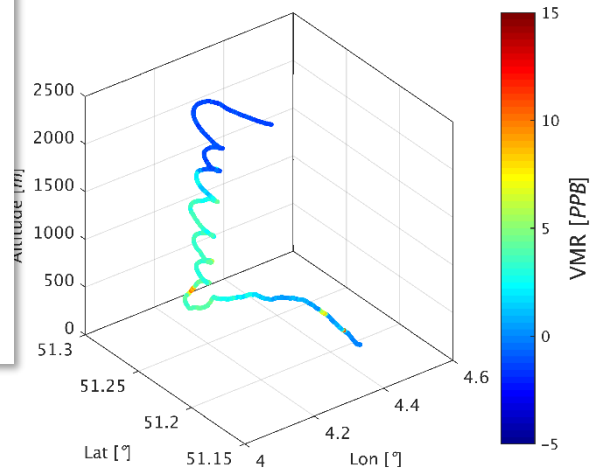
Rise of PBL?
Spiral up: 11
Spiral down:







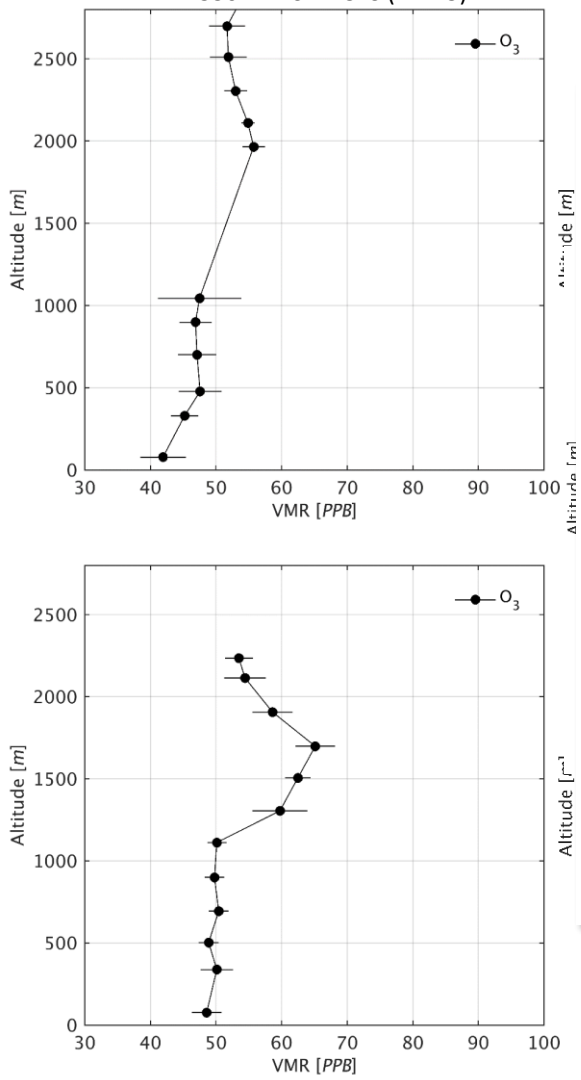




O_3 vertical profiles - Antwerp

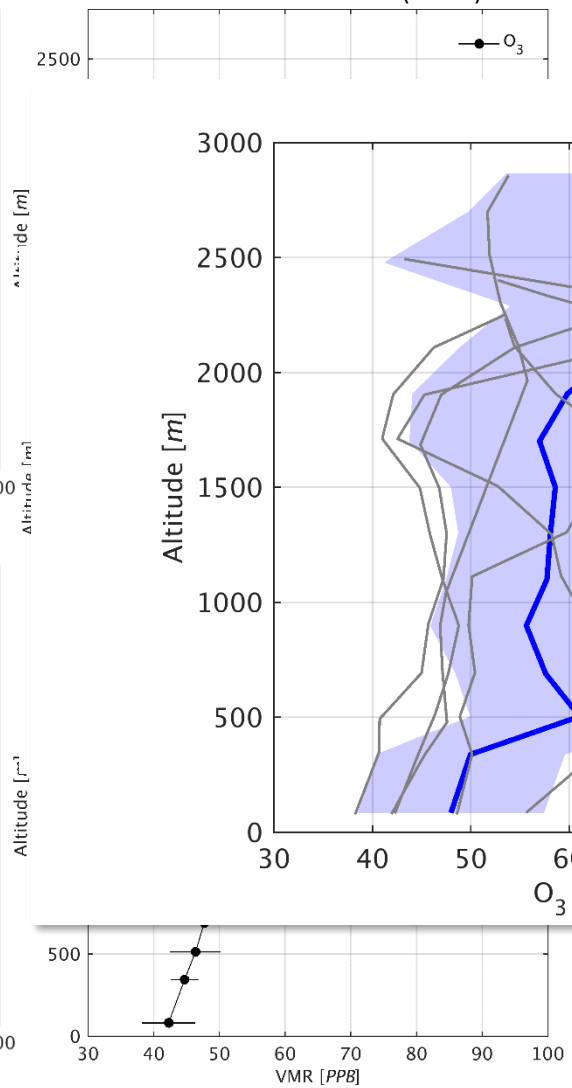
20240602 (test flight)

PBL: 550 m – ST: 15°C (ERA-5)



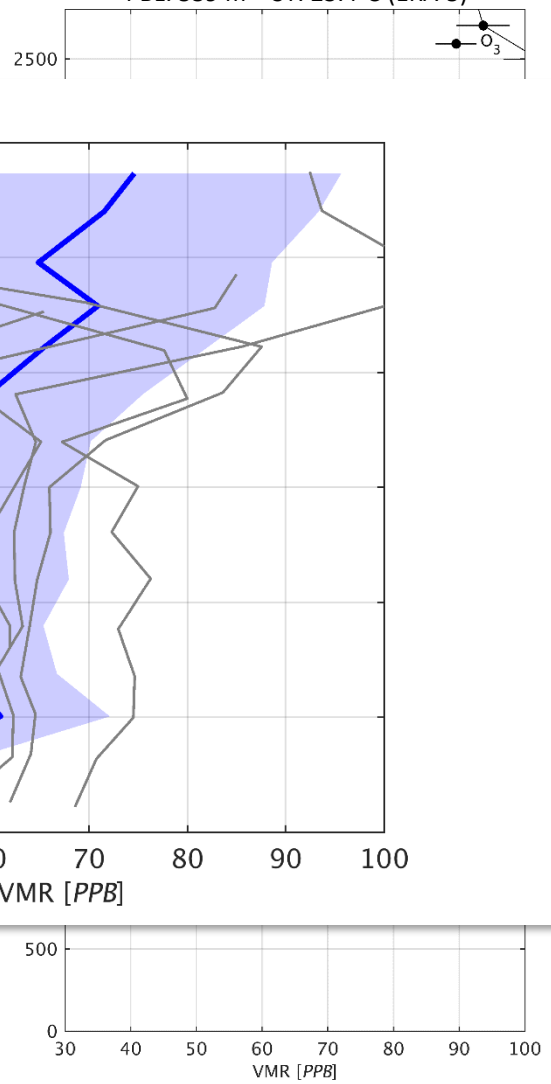
20240623

PBL: 503 m – ST: 18°C (ERA-5)



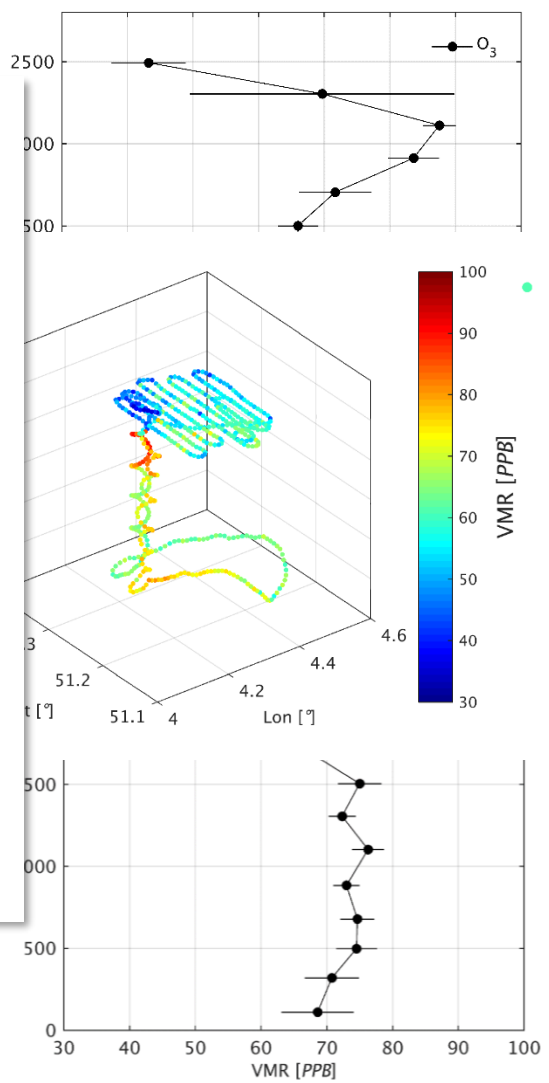
20240625

PBL: 559 m – ST: 23.4°C (ERA-5)



20240626

PBL: 837 m – ST: 25°C (ERA-5)

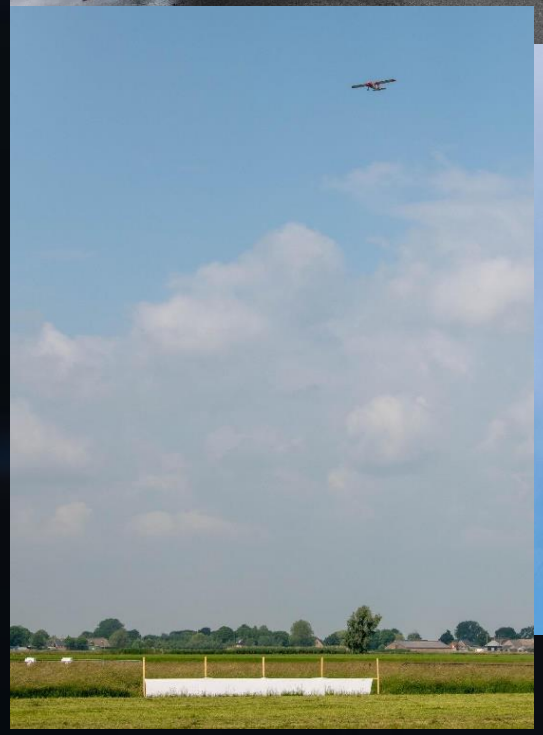


Outlook and Next steps

- **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)?
    - Calibration of ICAD NO_2 data at flight altitude
    - Better understand relation NO_2/O_3
- **Validation of coinciding TROPOMI tropospheric NO_2 product**
- **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!

Contact: frederik.tack@aeronomie.be