TROLIX

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Arnoud Apituley (KNMI), Karin Kreher (BKS) Ankie Piters (KNMI), Tim Vlemmix (KNMI) and TROLIX team

Arnoud Apituley[1], Karin Kreher[2], Michael Van Roozendael[3], John Sullivan[4], Thomas J McGee[4], Marc Allaart[1], Ankie Piters[1], Deborah C Stein[1], Henk Eskes[1], J. S. Henzing[5], Tim Vlemmix[1], Bryan de Goeij[6], Bart Speet[6], Herman W.J. Russchenberg[7], Ronald W A Hutjes[8], Joris P Veefkind[1], Larry Twigg[4], Grant K. Sumnicht[4], Arnoud Frumau[9], Jan Vonk[10], Mirjam den Hoed[1] and Christine Unal[7], Eduardo Landulfo[11], Diego Alves[11], Alexandre Cacheffo[11], Alex Mendes[11], Fabio Lopes[11], Steffen Dörner[12], Dimitris Karagkiozidis[13], Alkis Bais[13], Elena Lind[14], Alexis Merlaud[3], Frederic Tack[3], Francois Hendrick[3], Richard Querel[15]

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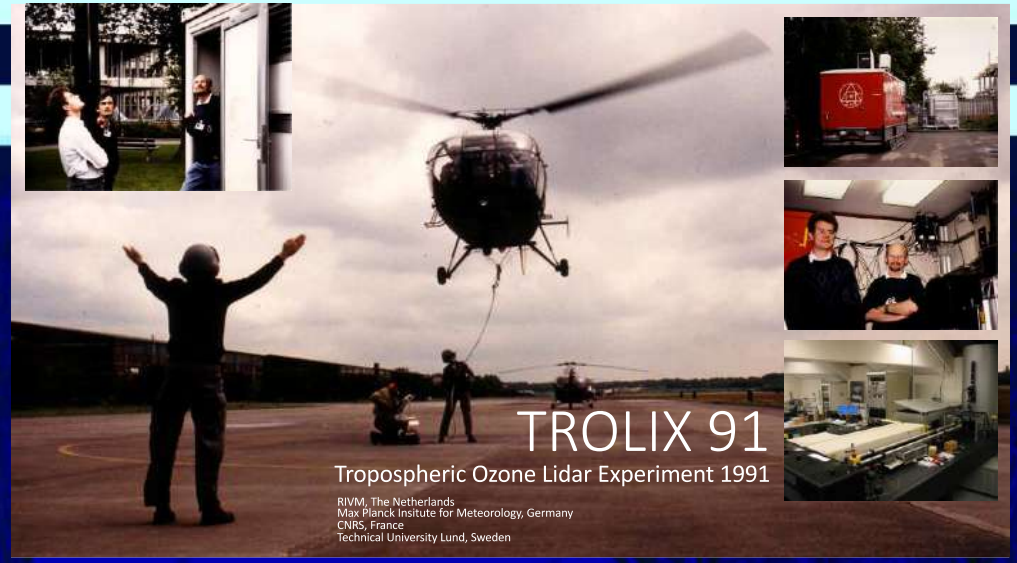
Netherlands Space Office

TROPOMI



- A Sentinel-5p/TROPOMI validation campaign was held in the Netherlands based at the Cabauw Experimental Site for Atmospheric Research during September/October 2019.
- The goal was to make intensive observations for the validation of TROPOMI L2 main data products (such as NO2, O3, HCHO, aerosol layer height, clouds and UVAI) under realistic, non-idealized conditions with varying cloud cover and a wide range of atmospheric conditions.
  - inhomogeneous sources of pollution
  - sub-pixel clouds
  - variations in ground albedo
- Observations were focused on the area around the Cabauw observatory & Rotterdam with the majority of observations carried out from the ground with mobile and airborne observations planned to be included during the later part of the campaign.

Cabauw Atmospheric Observatory

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Campaign heritage

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DANDELIONS 1
2005

DANDELIONS 2
2006

DANDELIONS (Dutch Aerosol and Nitrogen Dioxide Experiments for vaLIdation of OMI and SCIAMACHY) is a project that encompasses validation of NO2 measurements by the Ozone Monitoring Instrument (OMI) and SCIAMACHY (Scanning Imaging Absorption SpectroMeter for Atmospheric CartographY), and of aerosol measurements by OMI and the Advanced Along-Track Scanning Radiometer (AATSR), using an extensive set of groundbased and balloon measurements over the polluted area of the Netherlands.
The campaign organizers were KNMI and RIVM.
The first campaign was held at Cabauw from May 6 - June 30, 2005. The second campaign was held from Sep 1 - 30, 2006.
The data obtained during these campaigns has become publicly available through the AURA Validation Data Center of the Goddard Space Flight Center (NASA)

2009

From June to July 2009 more than thirty different in-situ and remote sensing instruments from all over the world participated in the Cabauw Intercomparison campaign for Nitrogen Dioxide measuring Instruments (CINDI).
Its main objectives were to determine the accuracy of state-of-the-art ground-based measurement techniques for the detection of atmospheric nitrogen dioxide (both in-situ and remote sensing), and to investigate their usability in satellite data validation.
The expected outcomes are recommendations regarding the operation and calibration of such instruments, retrieval settings, and observation strategies for the use in ground-based networks for air quality monitoring and satellite data validation.

2016

Second Cabauw Intercomparison of Nitrogen Dioxide Measuring Instruments

In September 2016, the Second Cabauw Intercomparison campaign for Nitrogen Dioxide measuring Instruments (CINDI-2)
The three major goals of CINDI-2 were to characterise and better understand the differences between a large number of Multi-AXis Differential Optical Absorption Spectroscopy (MAX-DOAS) and zenith-sky DOAS instruments and analysis methods, to discuss the performance of the various types of instruments and to contribute to a harmonisation of the measurement settings and retrieval methods.
This exercise is needed to be able to produce consistent, high-quality, long-term ground-based data sets, which are an essential requirement to generate reliable long-term measurement time series suitable for trend analysis and satellite data validation. With the launch of Sentinel-5 Precursor/TROPOMI and recent developments in MAXDOAS instruments there was a need for the CINDI-2 campaign to prepare for the global validation of TROPOMI.

2019

TROPOMI Validation Experiment 2019

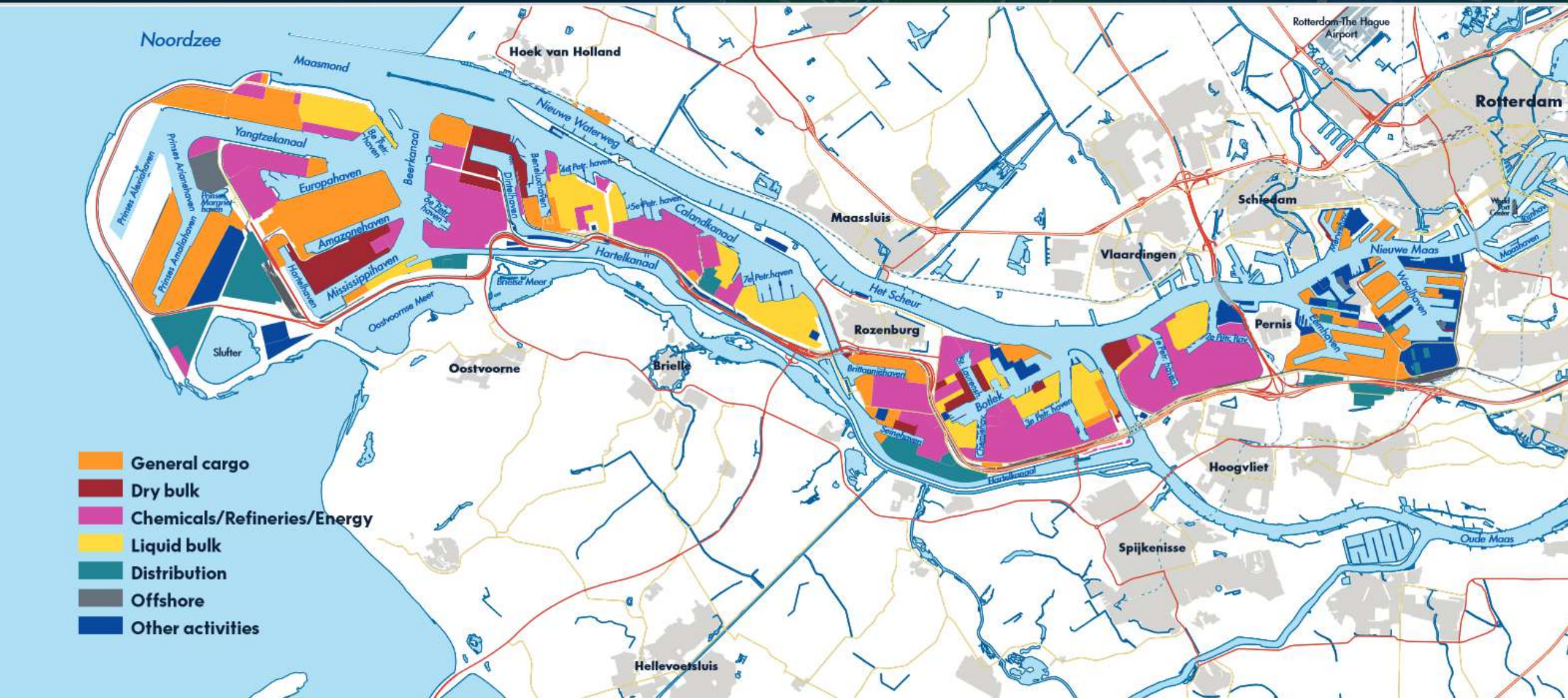
TROLIX

A Sentinel-5p/TROPOMI validation campaign was held in the Netherlands based at the Cabauw Experimental Site for Atmospheric Research during September 2019. The TROpomi vaLIdation eXperiment (TROLIX) consists of active and passive remote sensing platforms in conjunction with several balloon-borne, airborne and surface chemical measurements. The goal of this geophysical validation campaign is to make intensive observations to establish the quality of TROPOMI L2 main data products (UVAI, Aerosol Layer Height, NO2, O3, HCHO, Clouds) under realistic non-idealized conditions with varying cloud cover and a wide range of atmospheric conditions.

CINDI-3
(2023)

2023, the Third Cabauw Intercomparison campaign for Nitrogen Dioxide measuring Instruments (CINDI-3) is planned. This campaign will have the same objectives as CINDI-2 and is scheduled to prepare for the launch of Sentinel 4 and Sentinel 5
The CINDI campaign approach is now part of the ACTRIS Topical Center for Trace Gas Remote Sensing (CREGARS)

Rotterdam harbour sources



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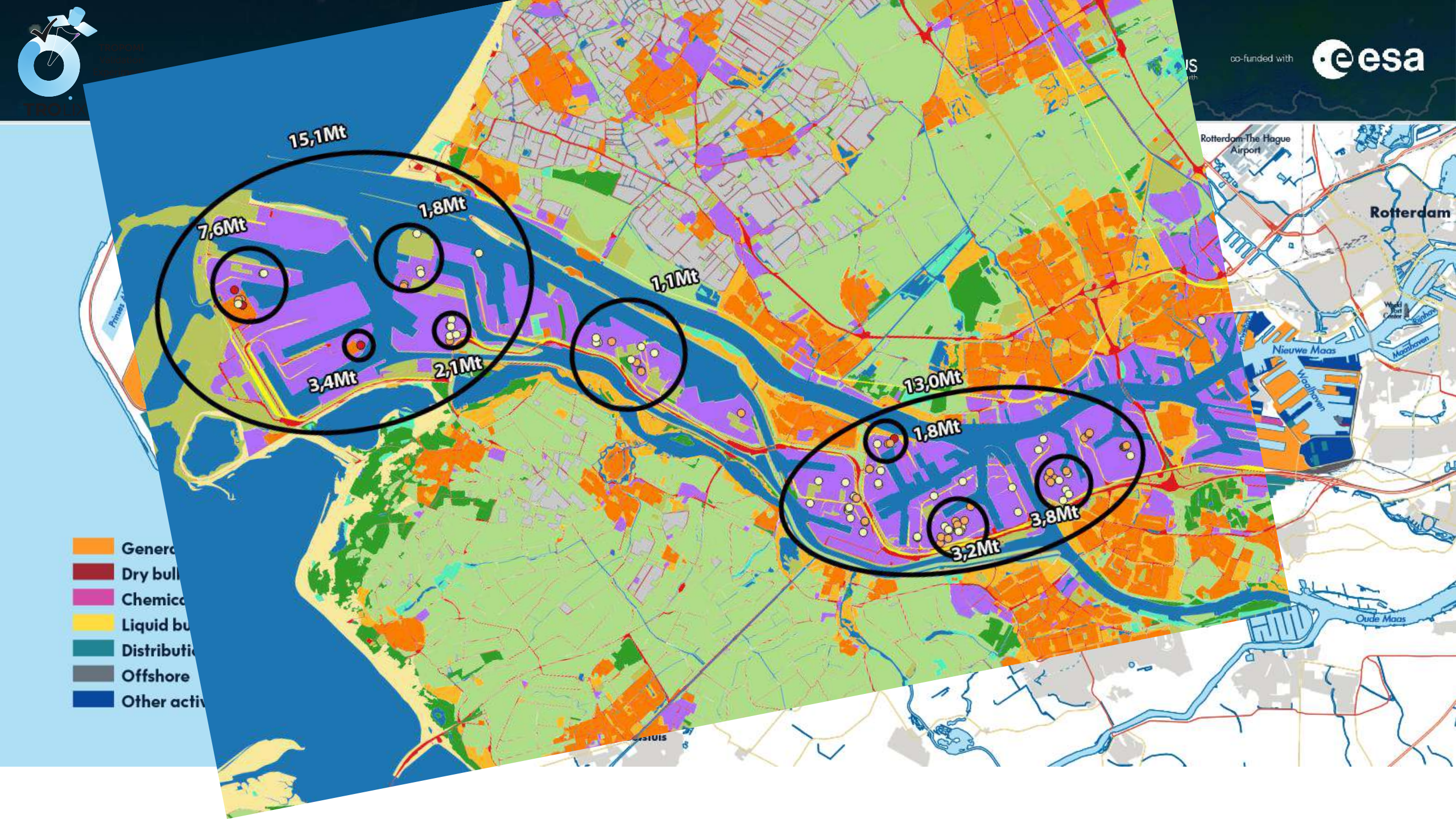

Measurement activities

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TROPOMI Validation Experiment 2019

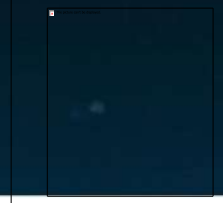
TROLIX

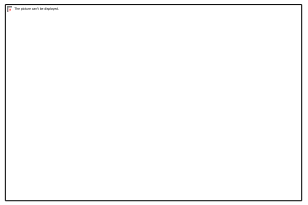
- Spatial information
  - MAXDOAS and Pandora network
  - Mobile DOAS
  - Airborne mapping
- Vertical profiling
  - NO2 sonde
  - Tropospheric ozone lidar
  - Stratospheric ozone lidar
  - Water Vapour, Aerosol and Cloud lidar
- In-situ observations
  - Chemical composition
  - Aerosols

TROLIX Campaign Schedule

Date	Activities
Mon 26 Aug through Fri 30 Aug	Instrument & Site Set Up
Mon 02 Sep through Fri 06 Sep	Warm-up, Instrument Testing phase
Mon 09 Sep through Fri 27 Sep	Intensive Observation Period
Mon 30 Sep through Sun 06 Oct	Possible Extension
Mon 07 Oct through Fri 11 Oct	Site break down

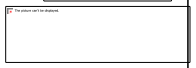
MaxDOAS/Pandora network



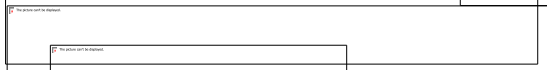


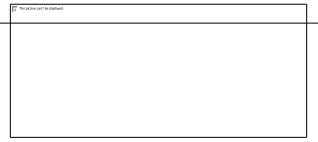
Tim Vlemmix. 2019

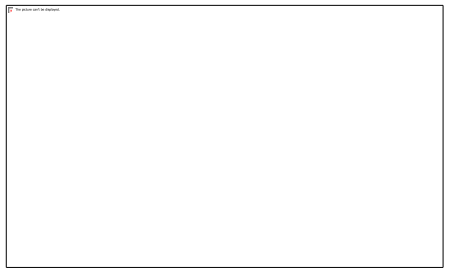
Karin Kreher, 2019



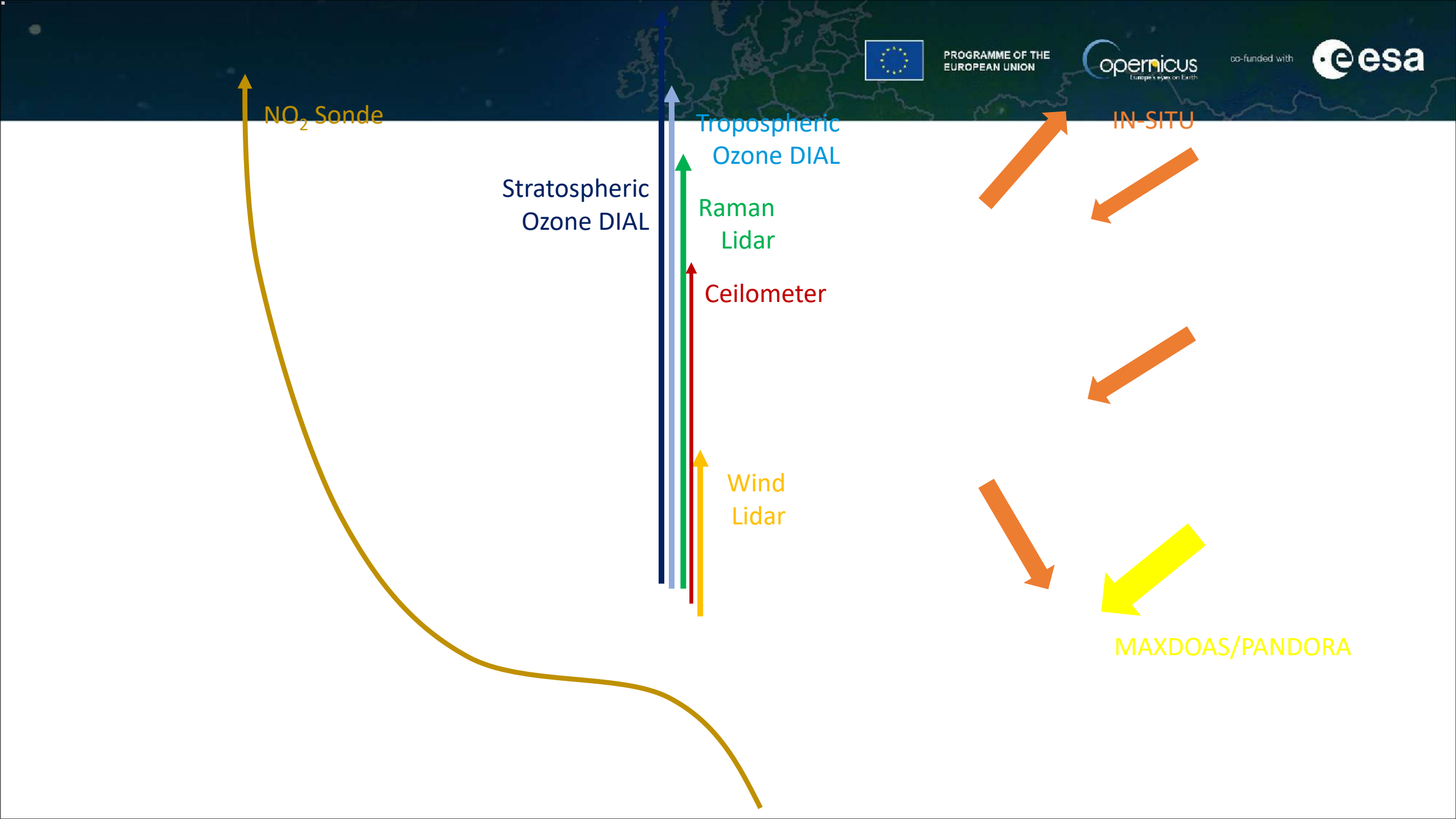
Ankie Piters, 2019







Michel van Roozendaal. 2019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NO_2 Sonde
Stratospheric Ozone DIAL
Tropospheric Ozone DIAL
Raman Lidar
Ceilometer
Wind Lidar
IN-SITU
MAXDOAS/PANDORA

Weather

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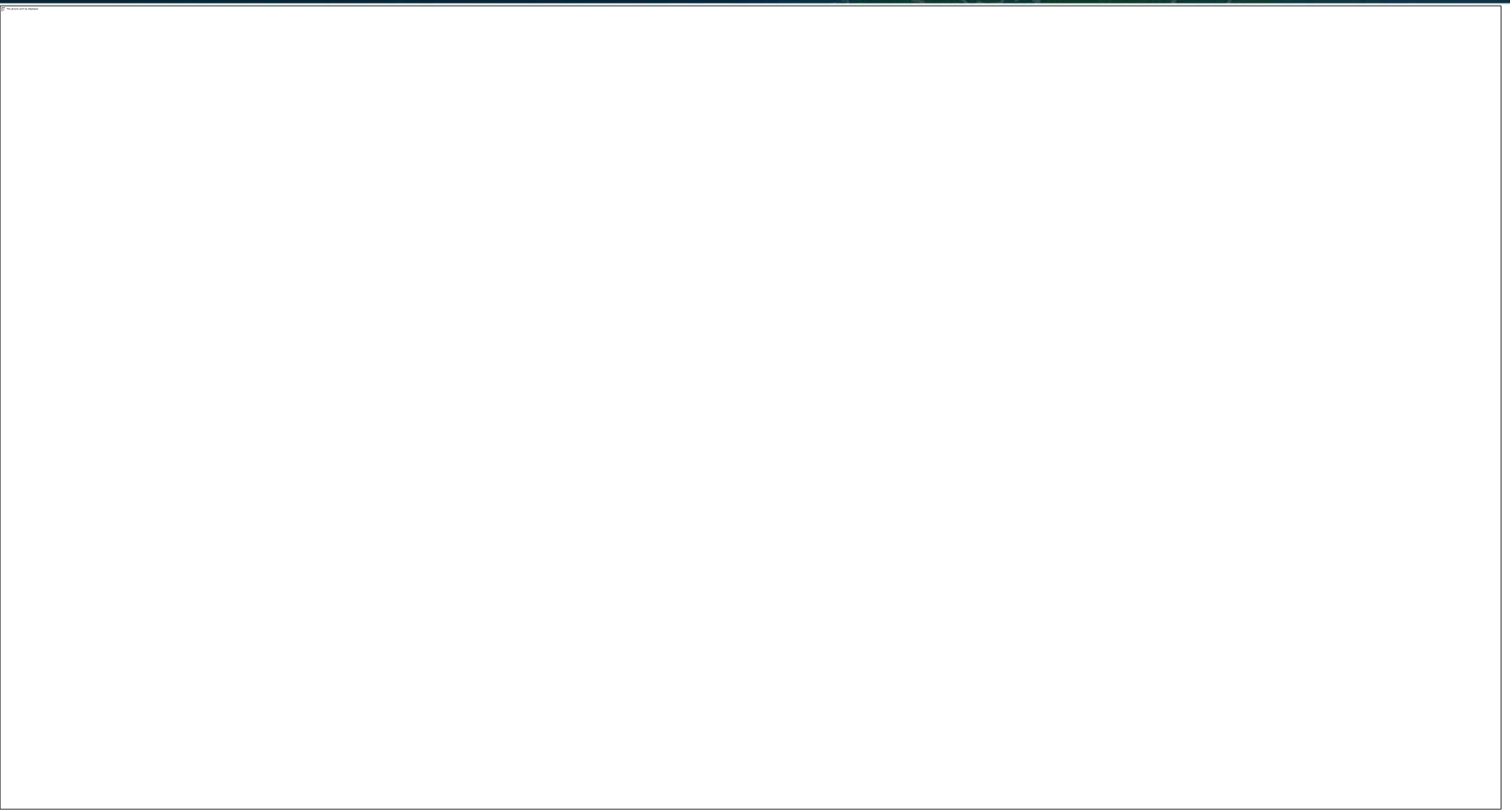


NO2 sonde launches

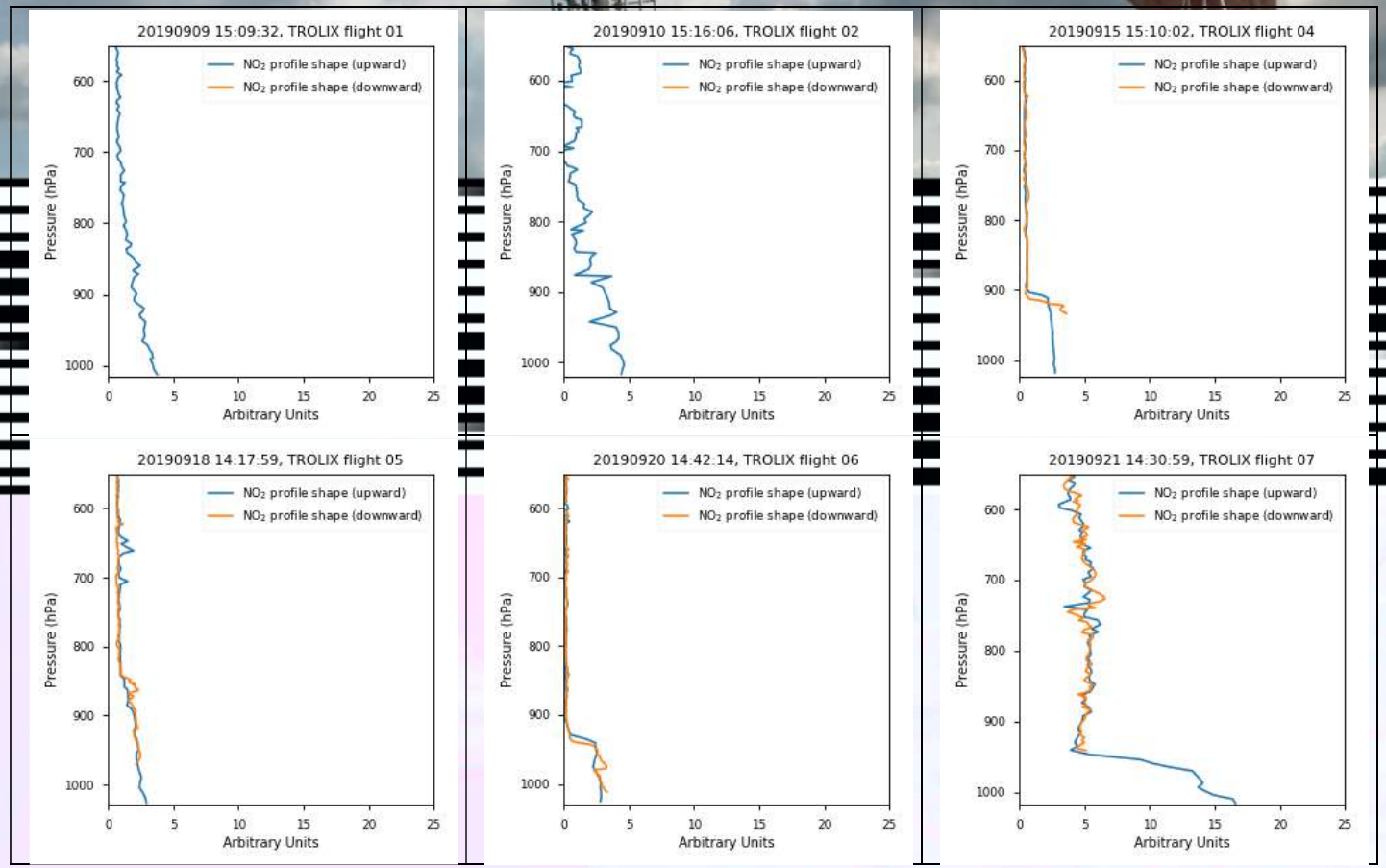
O3 sonde launches

Mo. 9 Sept.
Tue 10 Sept.
Sat. 14 Sept.
Sun. 15 Sept.
Wed. 18 Sept.
Fr. 20 Sept.
Sat. 21 Sept.
Wed. 2. Oct.

Thu. 12 Sept.
Thu. 19 Sept.
Thu. 26 Sept.
Thu. 3 Oct.
Thu. 10 Oct.

Sondes

Sondes



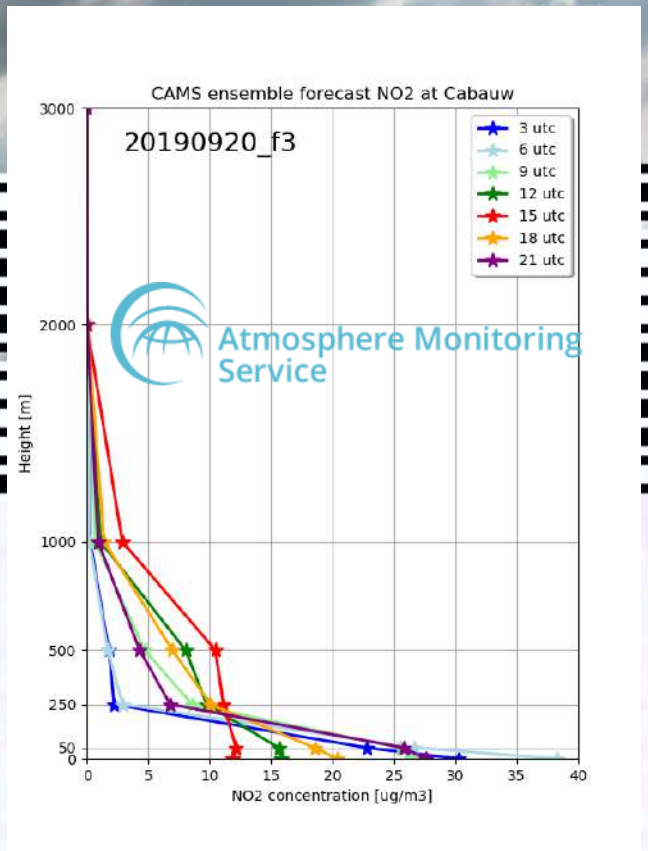
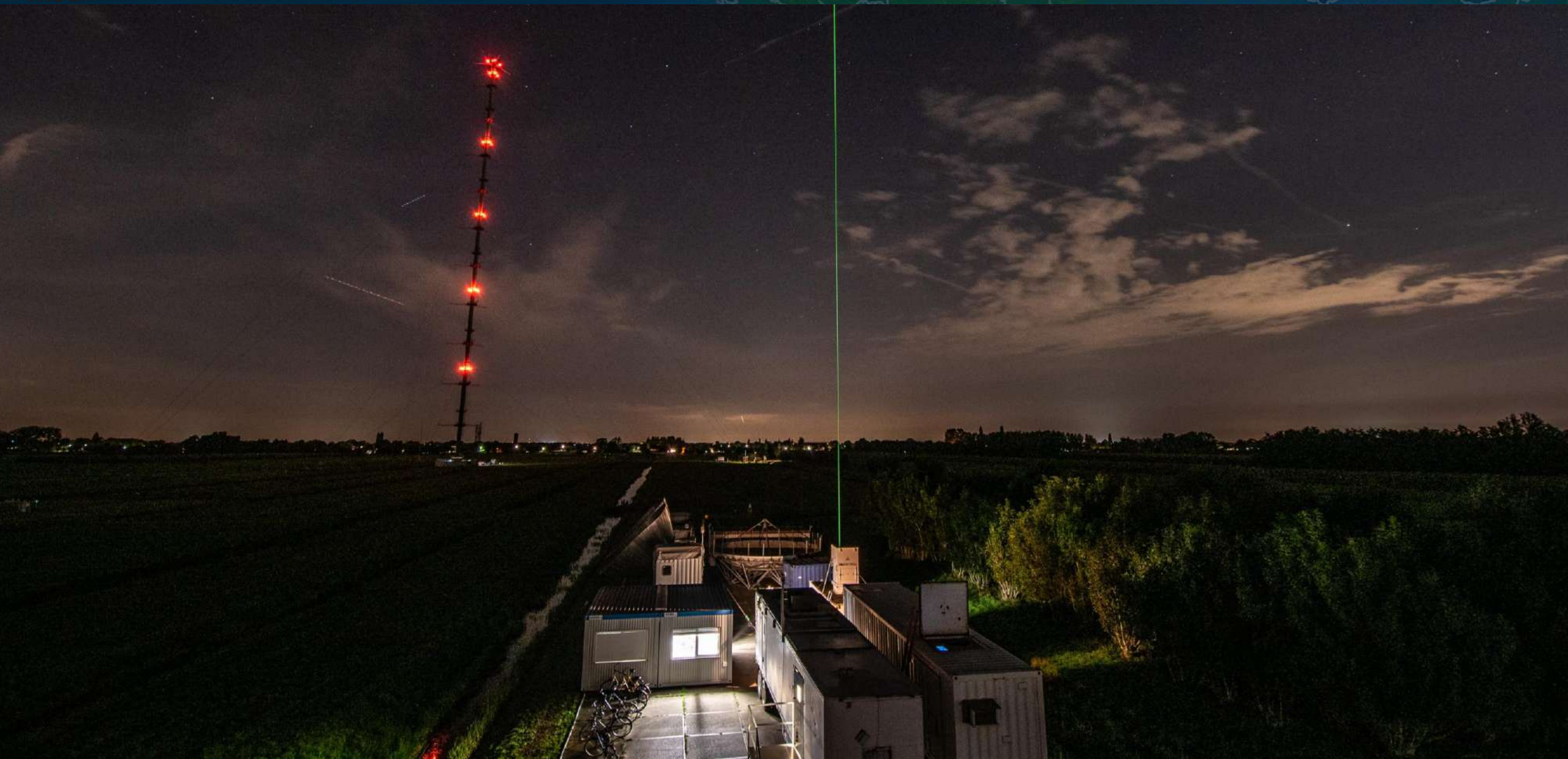


Figure 4: Quick looks of all the vertical NO_2 profiles measured with the KNMI NO_2-sonde during TROLIX'19 up to a pressure of 550 hPa.

Lidars



Lidars

TOLNET
Tropospheric Ozone LIDAR Network

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Sullivan, J. T., Apituley, A., Mettig, N., Kreher, K., Knowland, K. E., Allaart, M., Piters, A., Van Roozendael, M., Veefkind, P., Ziemke, J. R., Kramarova, N., Weber, M., Rozanov, A., Twigg, L., Sumnicht, G., and McGee, T. J.: Tropospheric and stratospheric ozone profiles during the 2019 TROpomi vaLidation eXperiment (TROLIX-19), Atmos. Chem. Phys., 22, 11137–11153, https://doi.org/10.5194/acp-22-11137-2022, 2022.

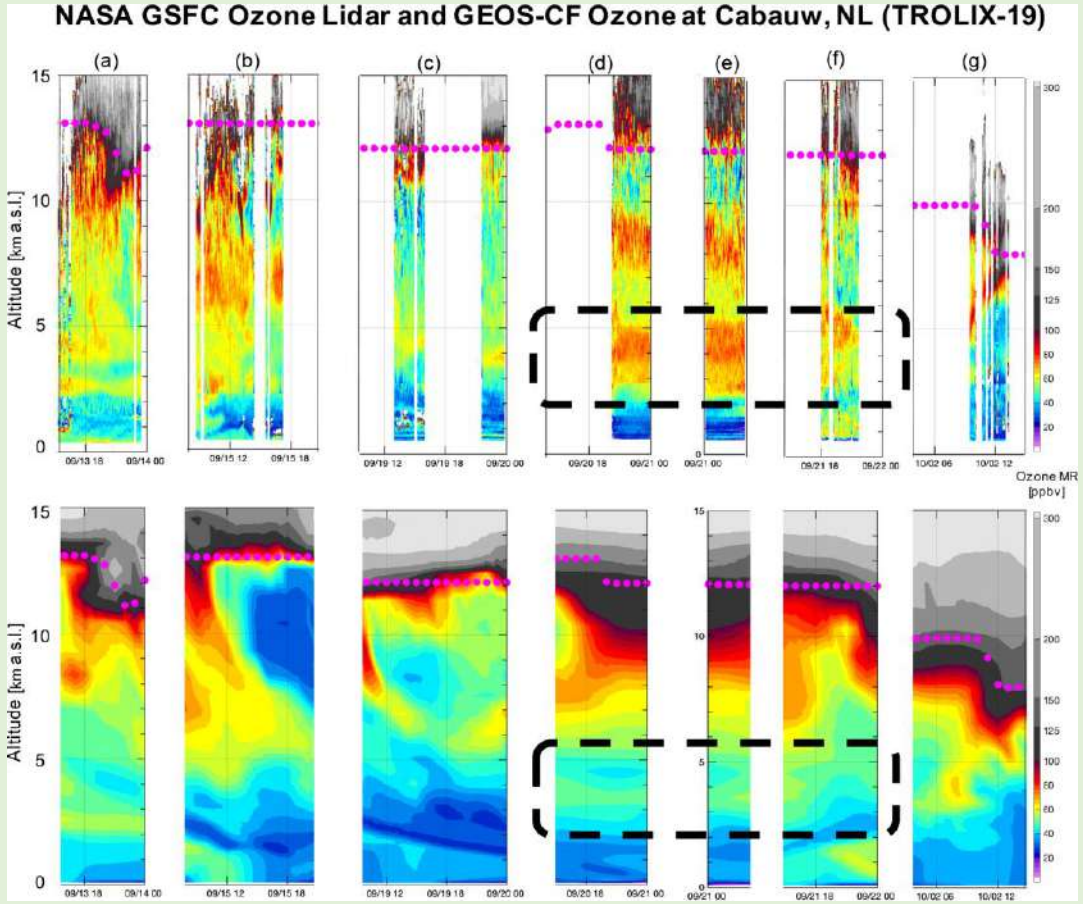


Figure 2. Cloud screened TROPOZ lidar retrievals (top panels) and the corresponding GEOS-CF model output (bottom panels) from the closest model grid cell to the CESAR observatory during TROLIX-19 for **(a)** 13 September at 14:00–00:00 UTC, **(b)** 15 September at 09:00–21:00 UTC, **(c)** 19 September at 10:00–00:00 UT, **(d)** 20 September at 16:00–00:00 UT, **(e)** 21 September at 00:00–03:00 UT, **(f)** 21 September at 16:00–00:00 UT and **(g)** 2 October at 04:00–14:00 UT. Pink dots are overlaid to indicate the simulated tropopause altitude based on a blended estimate (TROPPB).

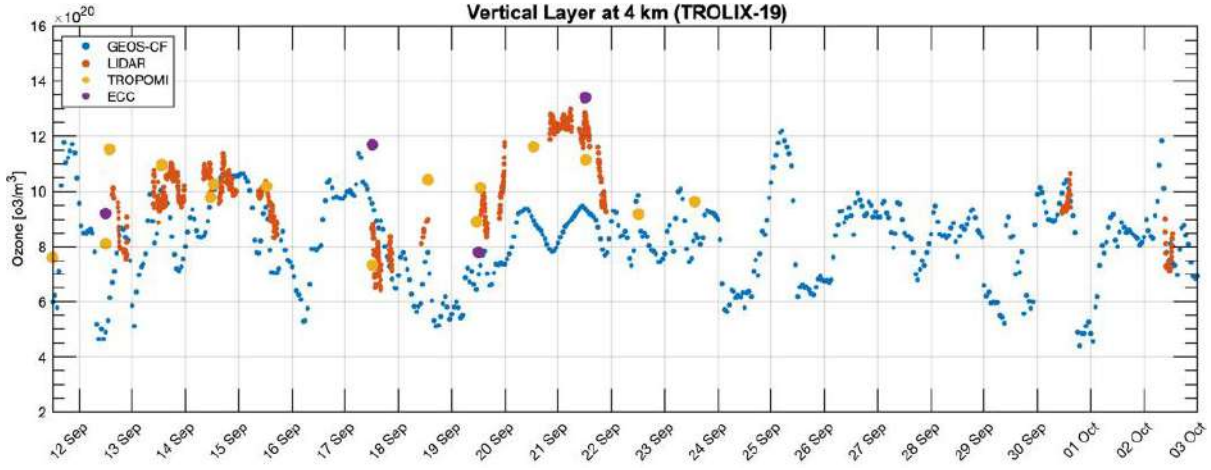


Figure 3. Ozone number density values for the TROPOZ lidar, GEOS-CF mode, TROPOMI and electro-chemical cell (ECC) ozonesondes at the 4 km layers. The layer was calculated to match the closest representative vertical layer of the GEOS-CF for consistent intercomparison. Data are averaged in a 500 m layer from 3.94 to 4.44 km a.g.l.

Sullivan, J. T., Apituley, A., Mettig, N., Kreher, K., Knowland, K. E., Allaart, M., Piters, A., Van Roozendael, M., Veefkind, P., Ziemke, J. R., Kramarova, N., Weber, M., Rozanov, A., Twigg, L., Sumnicht, G., and McGee, T. J.: Tropospheric and stratospheric ozone profiles during the 2019 TROpomi vaLIdation eXperiment (TROLIX-19), Atmos. Chem. Phys., 22, 11137–11153, https://doi.org/10.5194/acp-22-11137-2022, 2022.

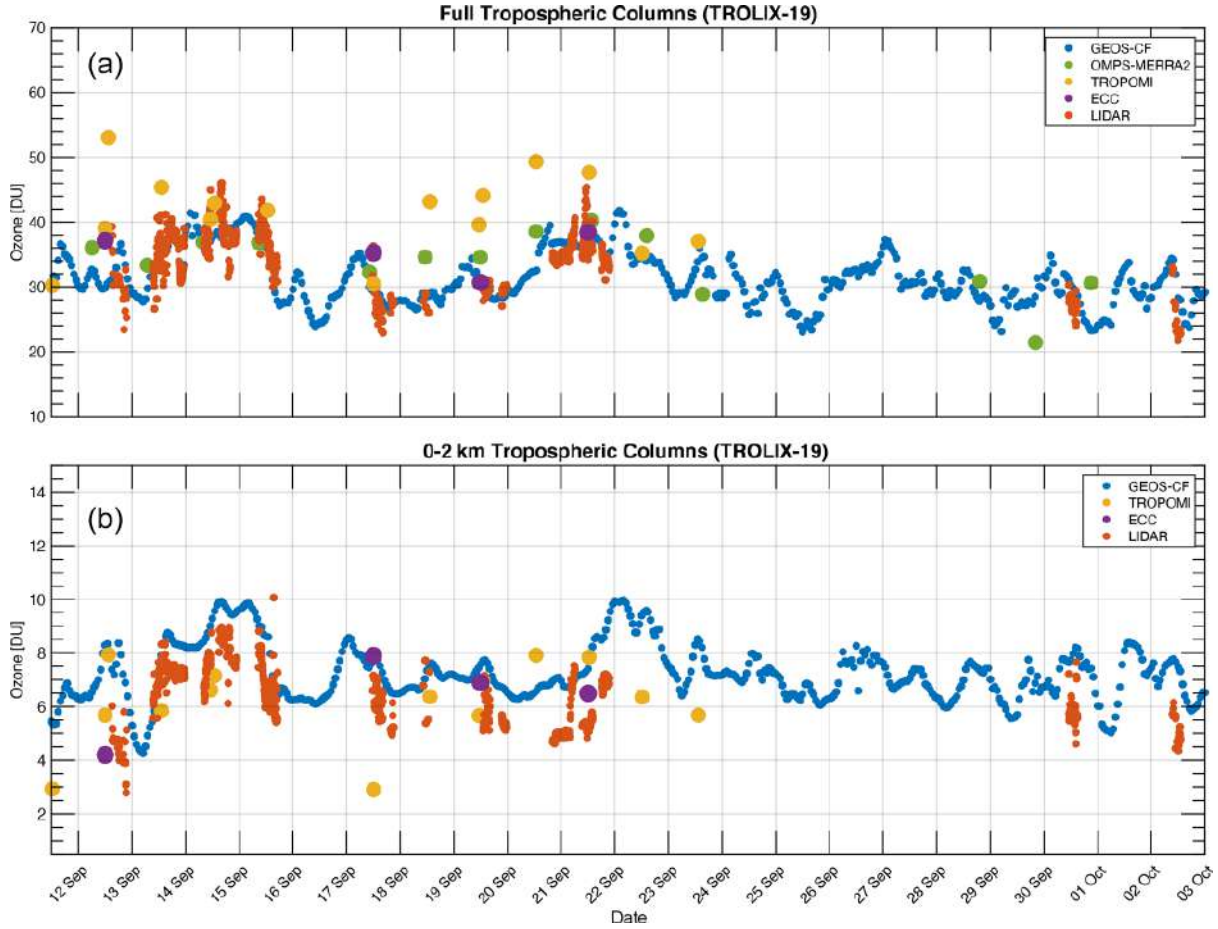


Figure 4. Full tropospheric columns **(a)** and 0–2 km tropospheric columns **(b)** calculated from GEOS-CF, OMPS-MERRA2 (full column only), TROPOMI, lidar and ECC. Data where reflectivity was greater than 0.6 were excluded to remove cloud interference.

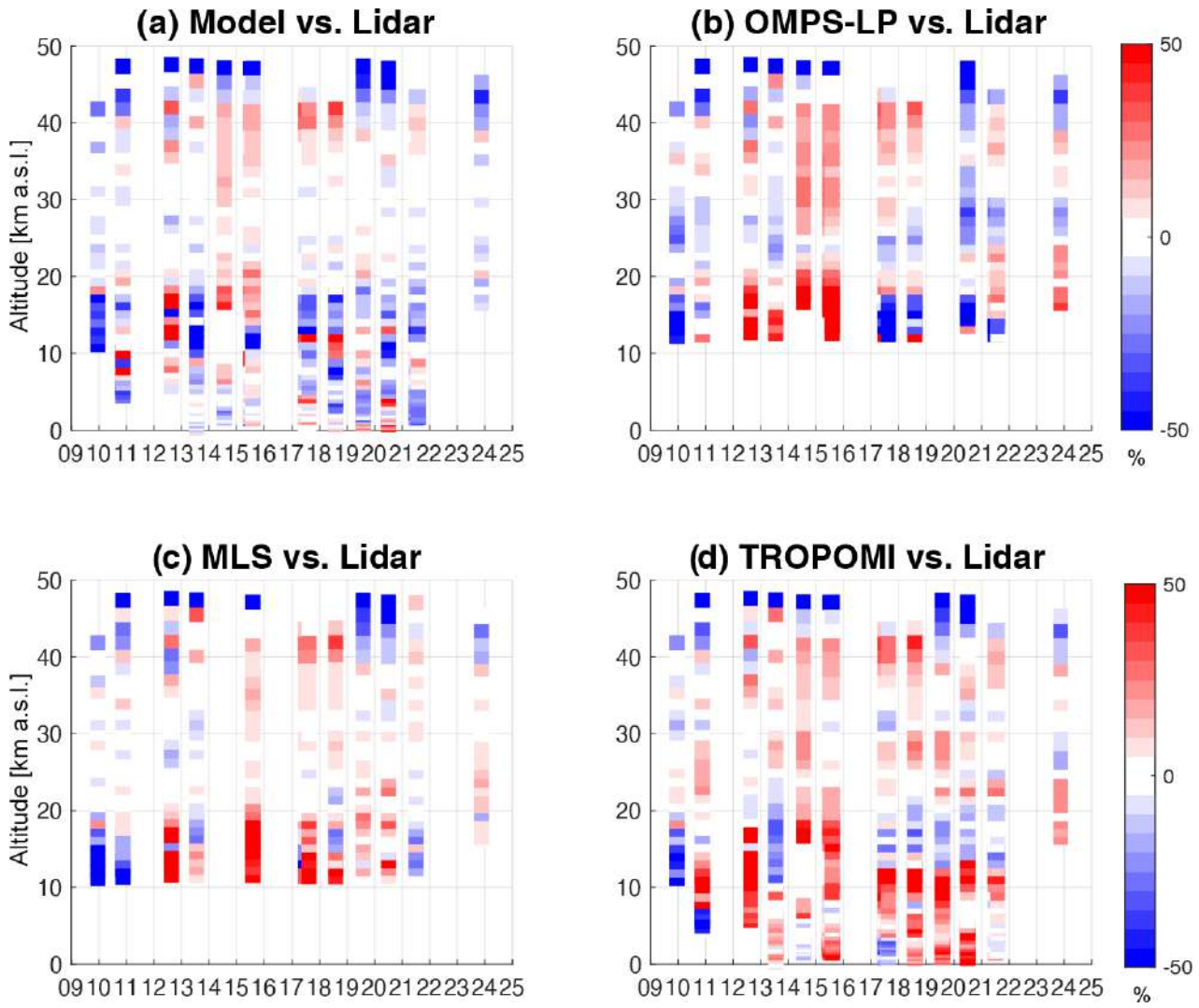


Figure 7. Differences in ozone number densities across all platforms for the TROLIX-19 time period for the model **(a)**, OMPS-LP **(b)**, MLS **(c)** and TROPOMI **(d)**. The x axis is the day of September 2019.

Sullivan, J. T., Apituley, A., Mettig, N., Kreher, K., Knowland, K. E., Allaart, M., Piters, A., Van Roozendael, M., Veefkind, P., Ziemke, J. R., Kramarova, N., Weber, M., Rozanov, A., Twigg, L., Sumnicht, G., and McGee, T. J.: Tropospheric and stratospheric ozone profiles during the 2019 TROpomi vaLIdation eXperiment (TROLIX-19), Atmos. Chem. Phys., 22, 11137–11153, https://doi.org/10.5194/acp-22-11137-2022, 2022.

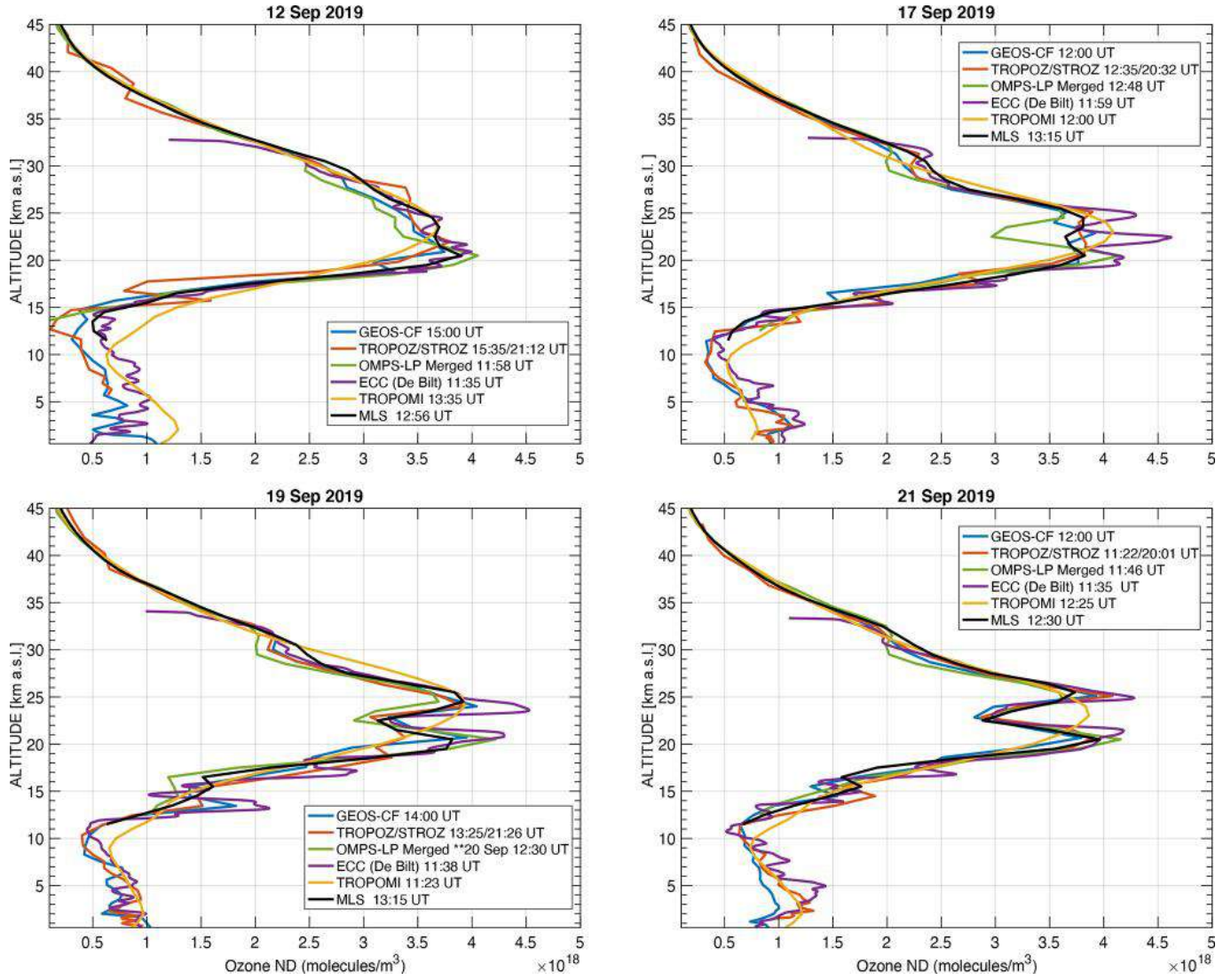
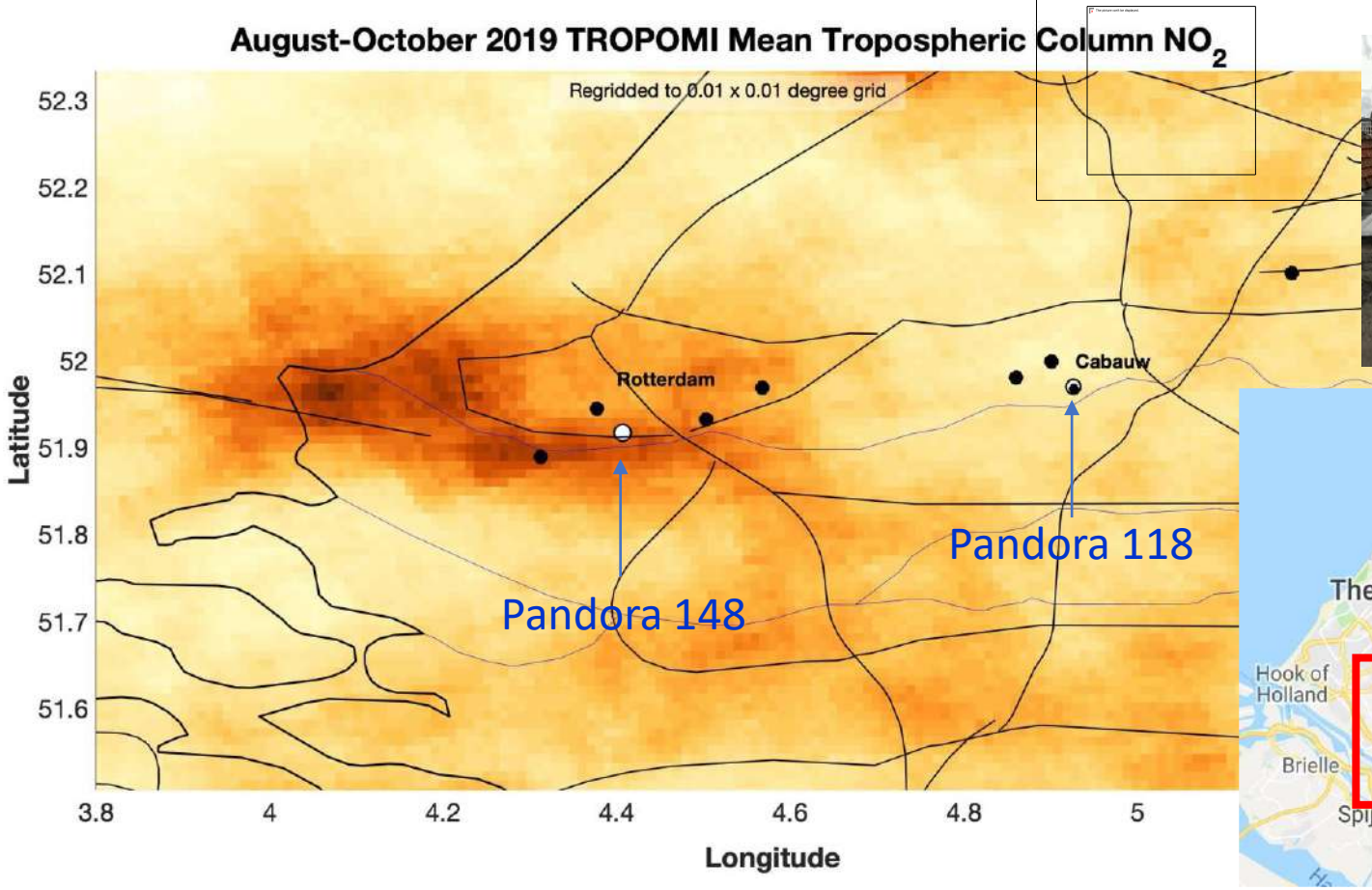
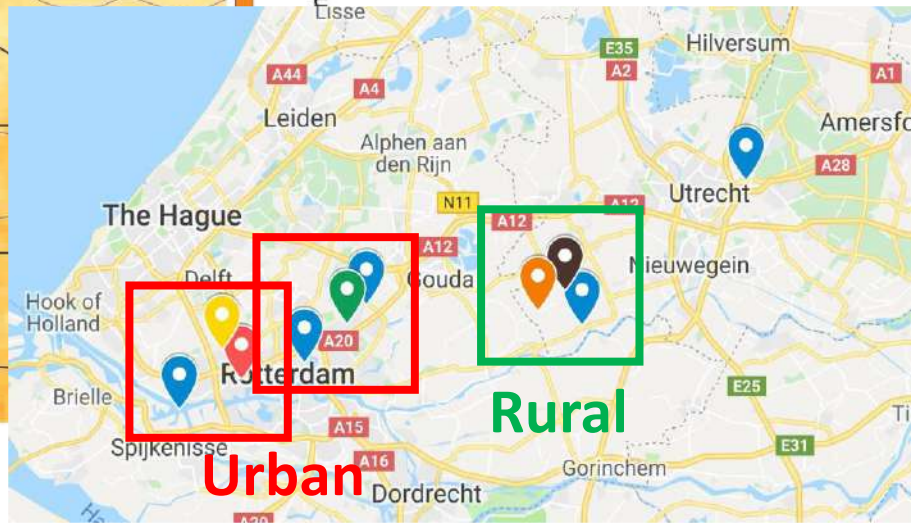


Figure 5. GEOS-CF, lidar, OMPS-LP, ECC, TROPOMI and MLS ozone profile comparisons for 12, 17, 19 and 21 September 2019. These days were selected as days within the campaign that had an ECC launch from De Bilt.

Sullivan, J. T., Apituley, A., Mettig, N., Kreher, K., Knowland, K. E., Allaart, M., Piters, A., Van Roozendael, M., Veefkind, P., Ziemke, J. R., Kramarova, N., Weber, M., Rozanov, A., Twigg, L., Sumnicht, G., and McGee, T. J.: Tropospheric and stratospheric ozone profiles during the 2019 TROpomi vaLIdation eXperiment (TROLIX-19), Atmos. Chem. Phys., 22, 11137–11153, https://doi.org/10.5194/acp-22-11137-2022, 2022.

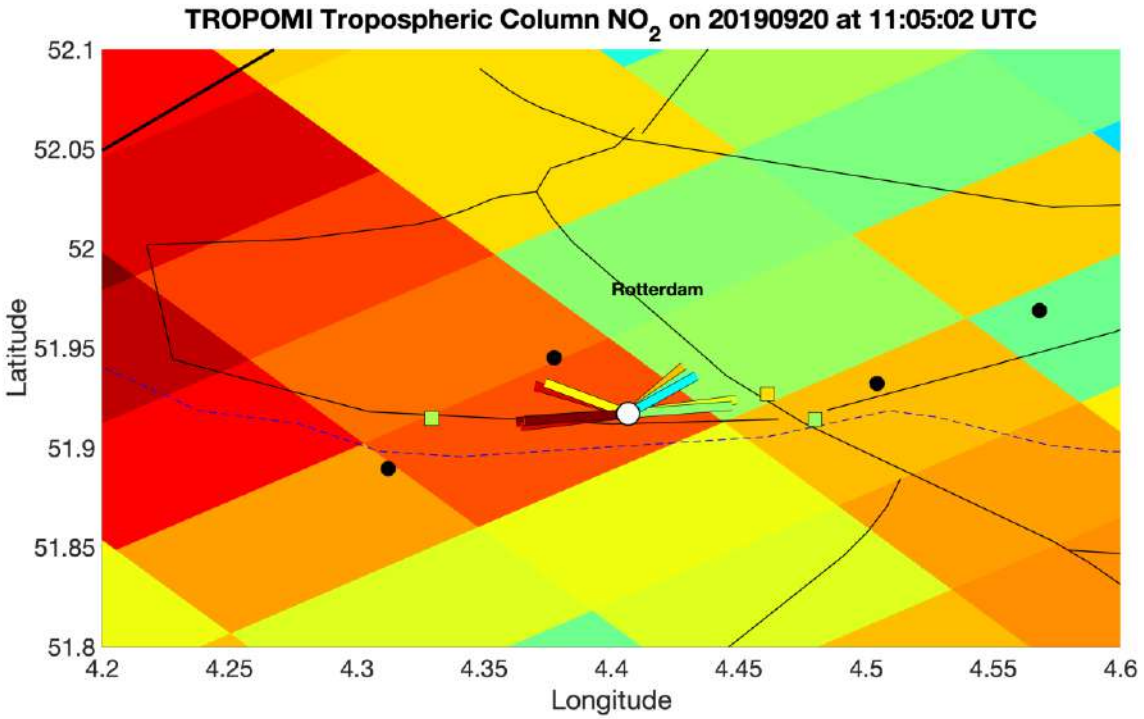
Spatial heterogeneity

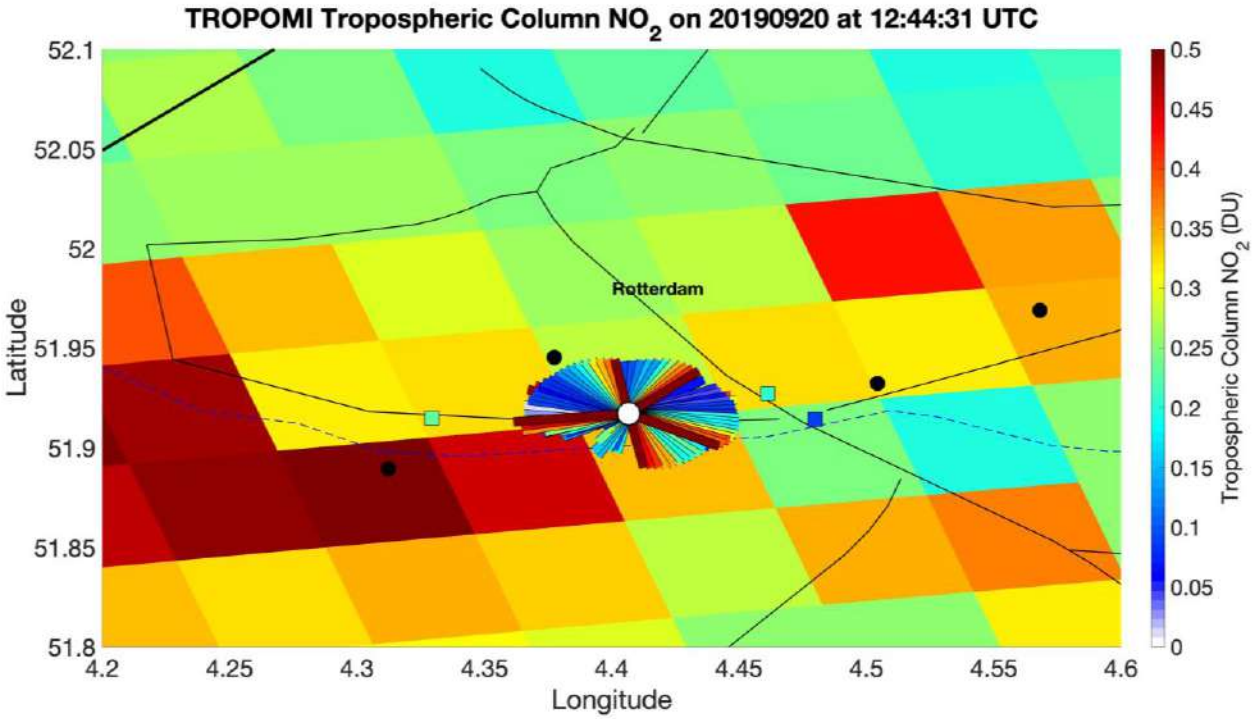




- KNMI R2
- VirTech R5
- KNMI R6
- MPIC R7
- BIRA R9
- KNMI K17
- KNMI K18
- KNMI K19
- AUTH C11
- NIWA C12

Spatial heterogeneity

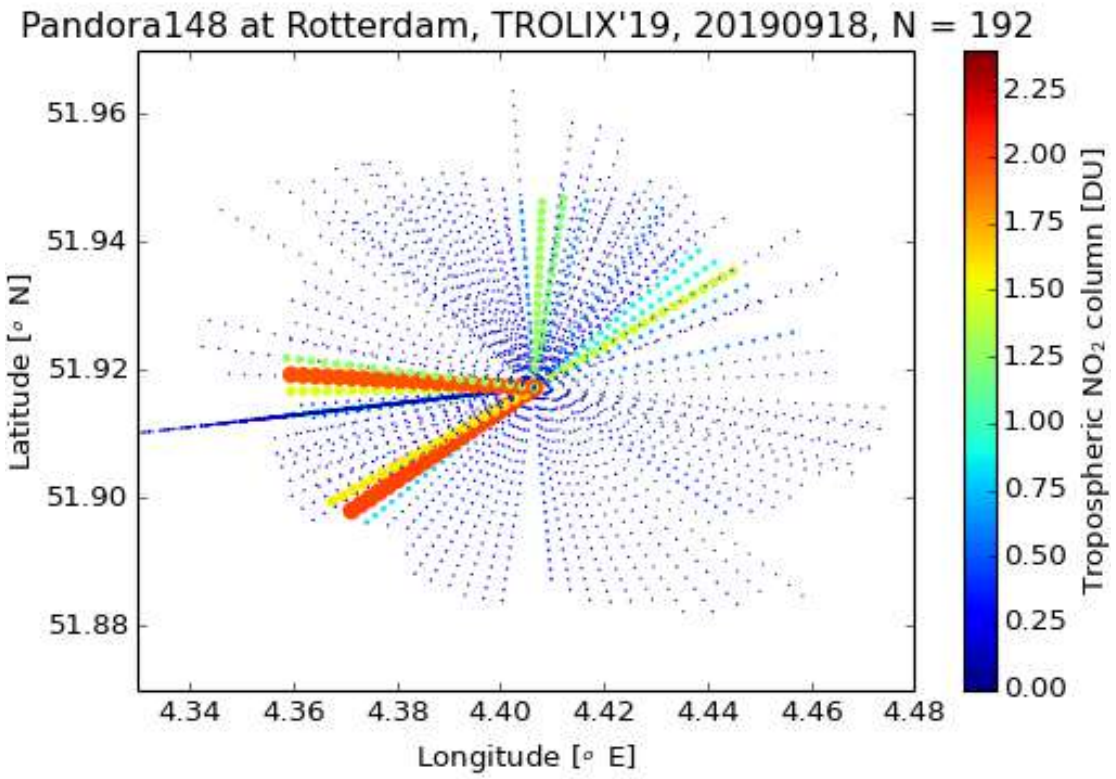


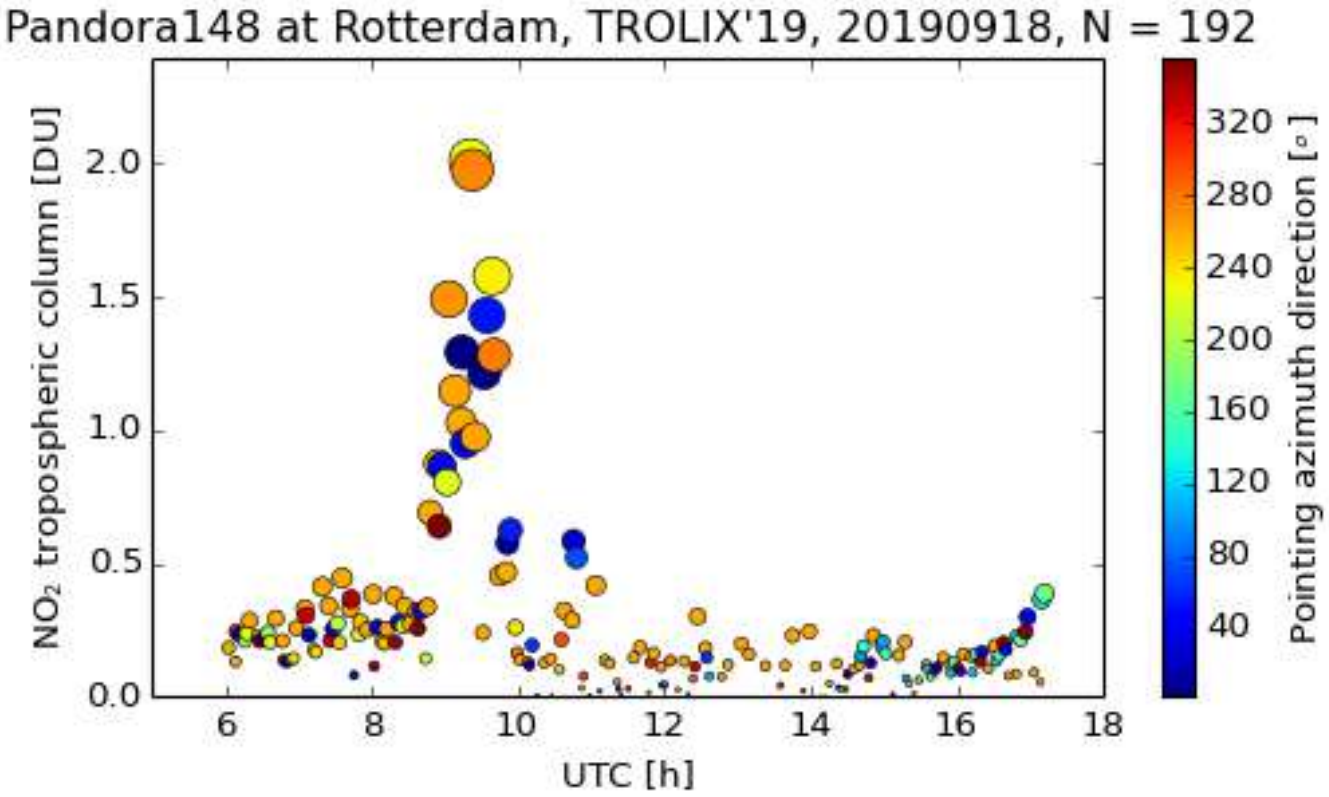


Can provide tropospheric column validation for various conditions, times and directions for current and future satellite missions including TEMPO

Elena Lind, Virginia Tech

Spatial heterogeneity



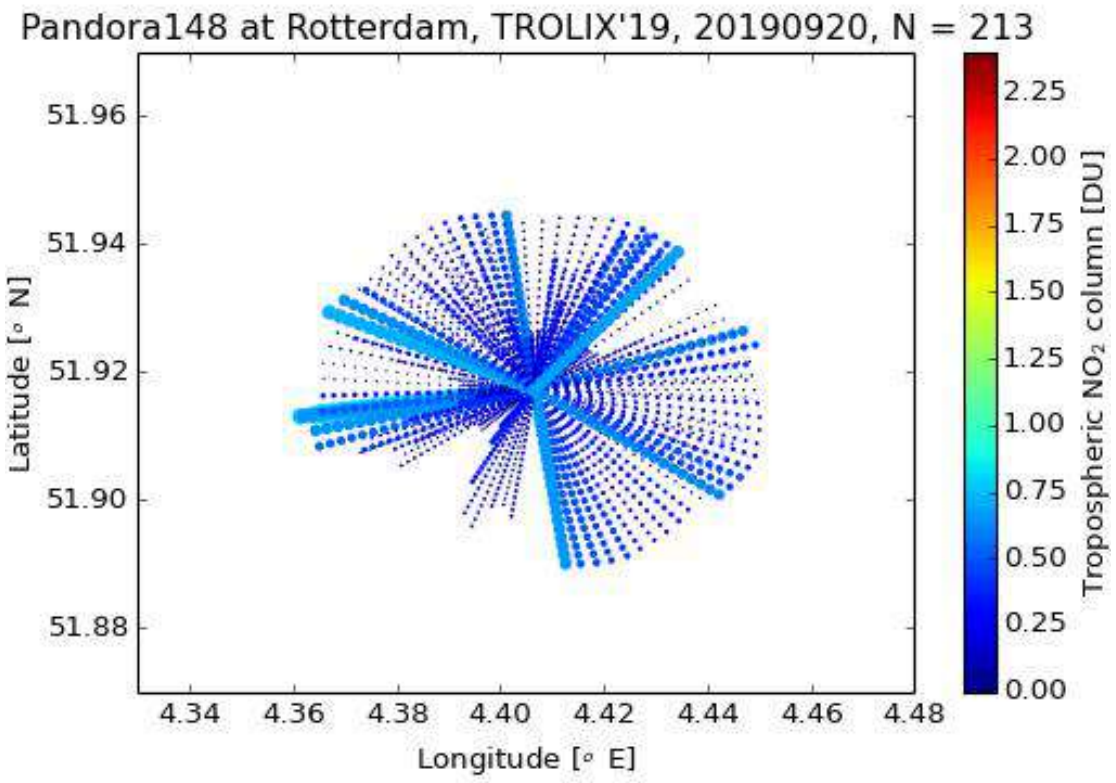


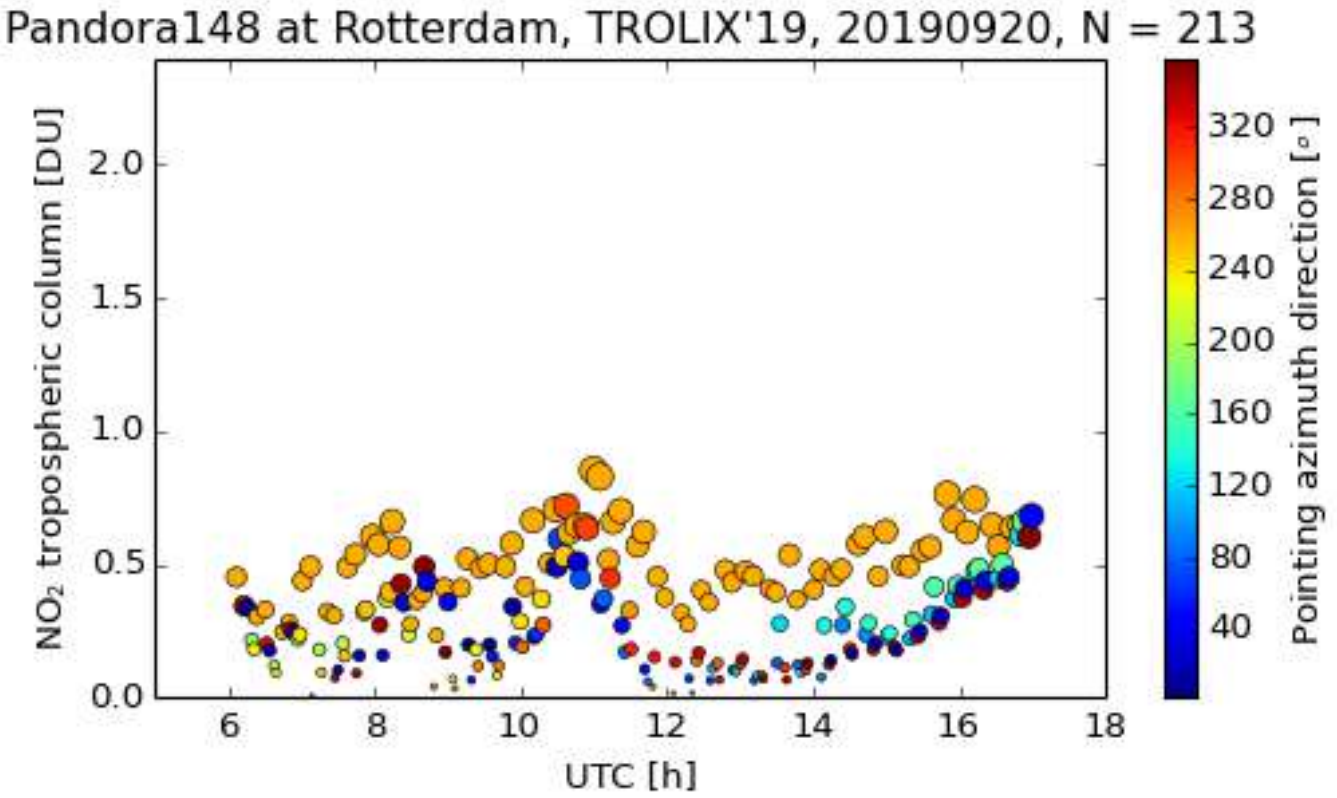
- Entire day data

Measurements are taken at:

- Direct sun for 1 min
- 4 directions relative to the sun position (15, 30, 90 elevation angles due to trees and buildings): + 90, + 135, -90, -135
- 1 or 2 fixed azimuth directions (full scan) => profiles, trop column, over the roof vmr

Spatial heterogeneity





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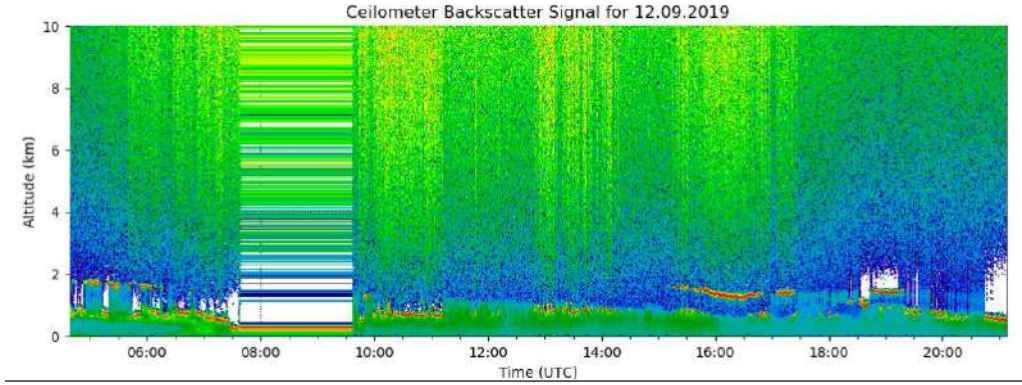
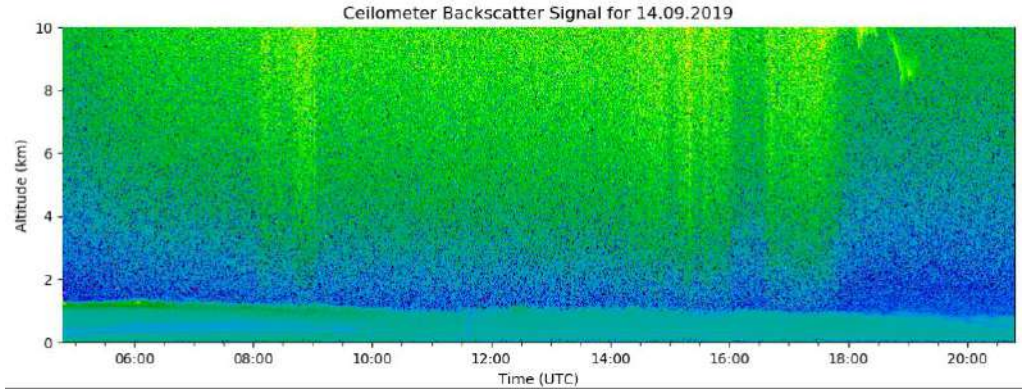
- 1 or 2 fixed azimuth directions (full scan) => profiles, trop column, over the roof vmr

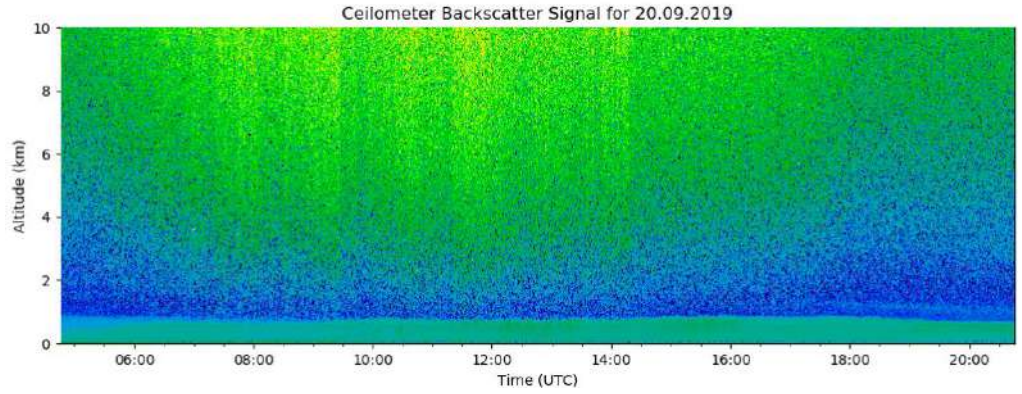
Elena Lind, Virginia Tech

Model comparison

- 12, 14 and 20 September 2019
  - TROPOMI needs optically thin clouds to measure NO_2
- MPIC ceilometer in Rotterdam center
  - Some clouds on 12 September
    - BIRA flagged large part of day with broken clouds
  - Other days almost cloud free



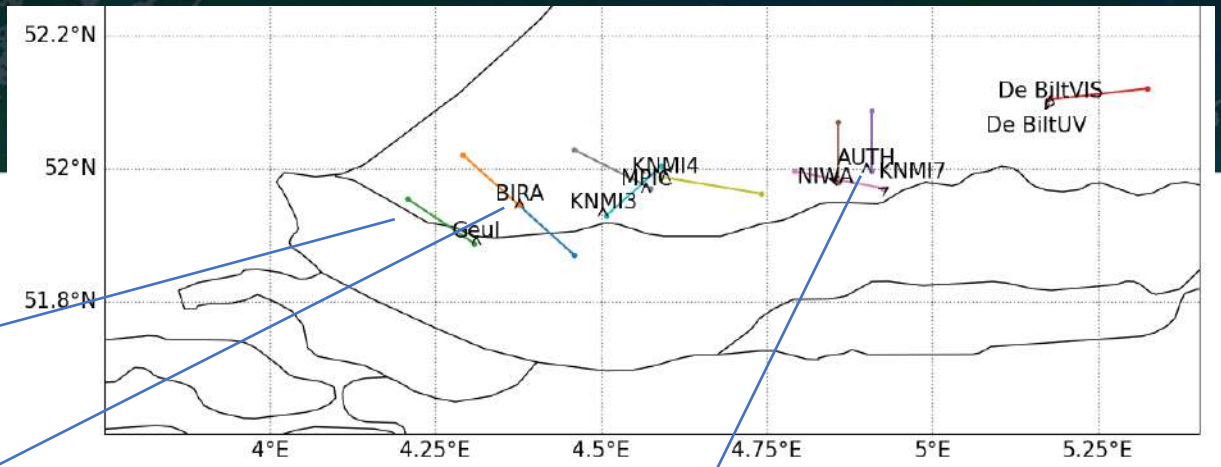


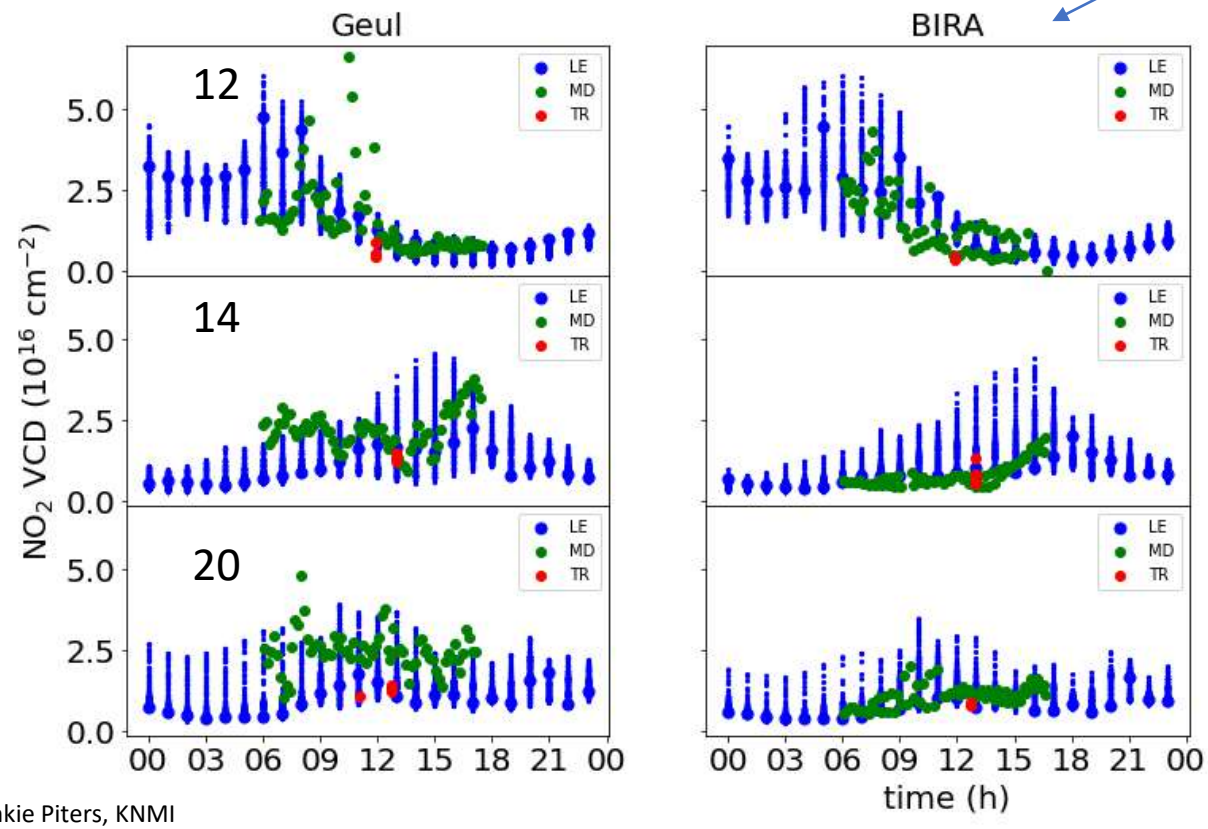


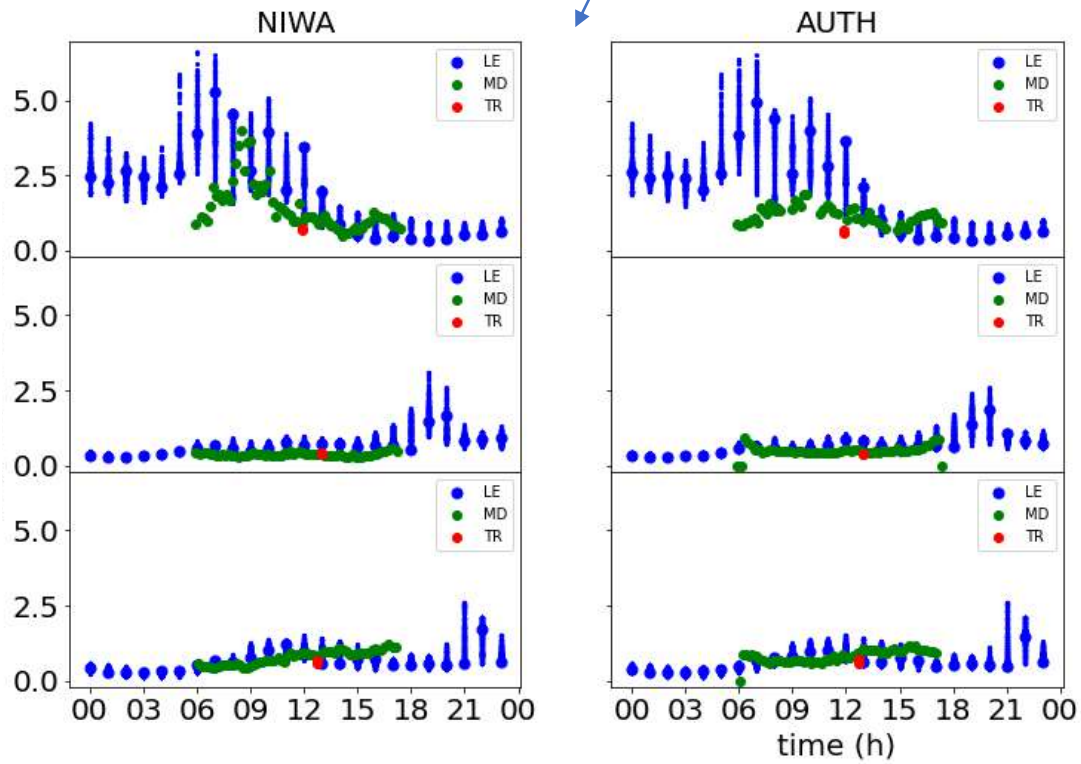
Ankie Piters, KNMI

Model comparison

VCD comparison



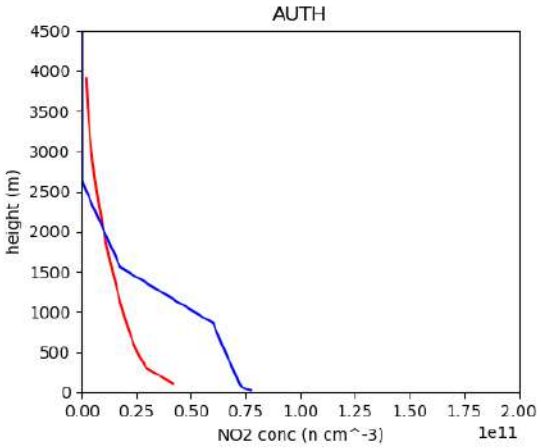


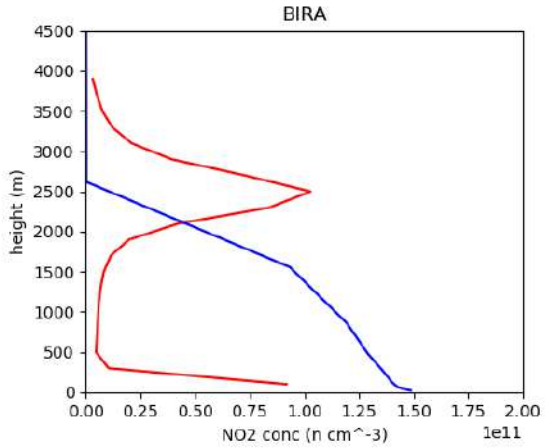


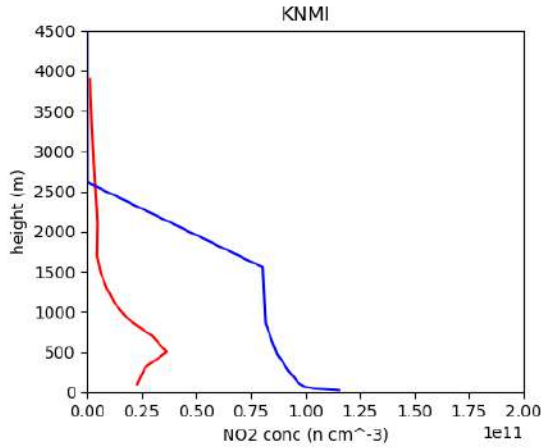
Ankie Piters, KNMI

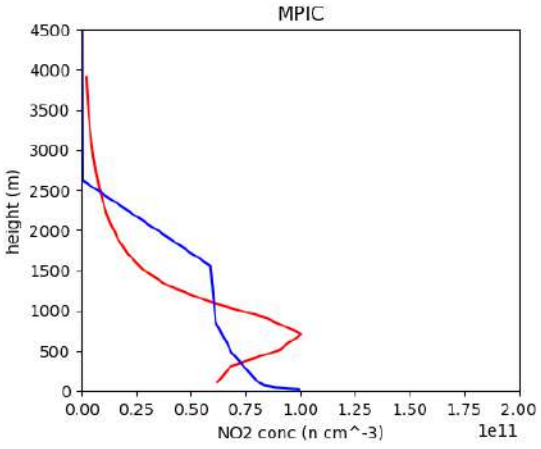
Model comparison

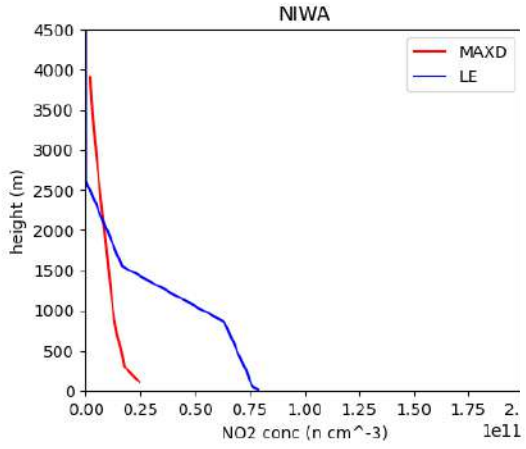
Comparison of MAX-DOAS and LOTOS-EUROS profiles for September 14th 12UTC

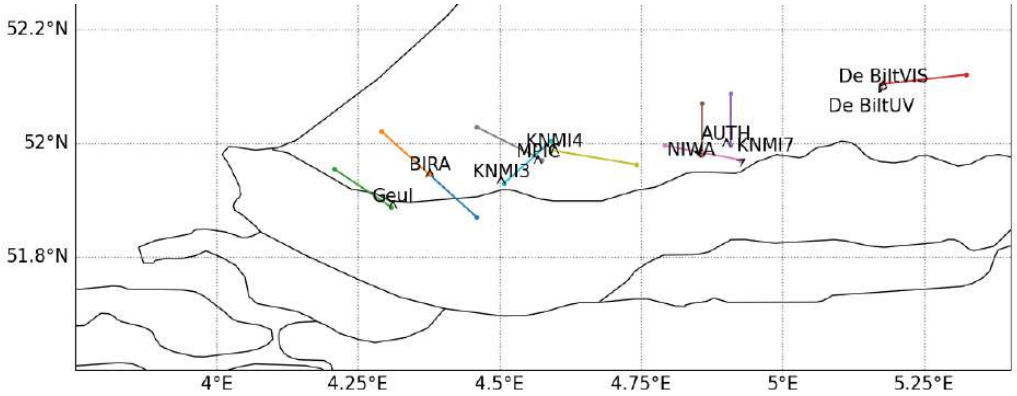












Ankie Piters, KNMI

Spectrolite/TROLIX flightplan

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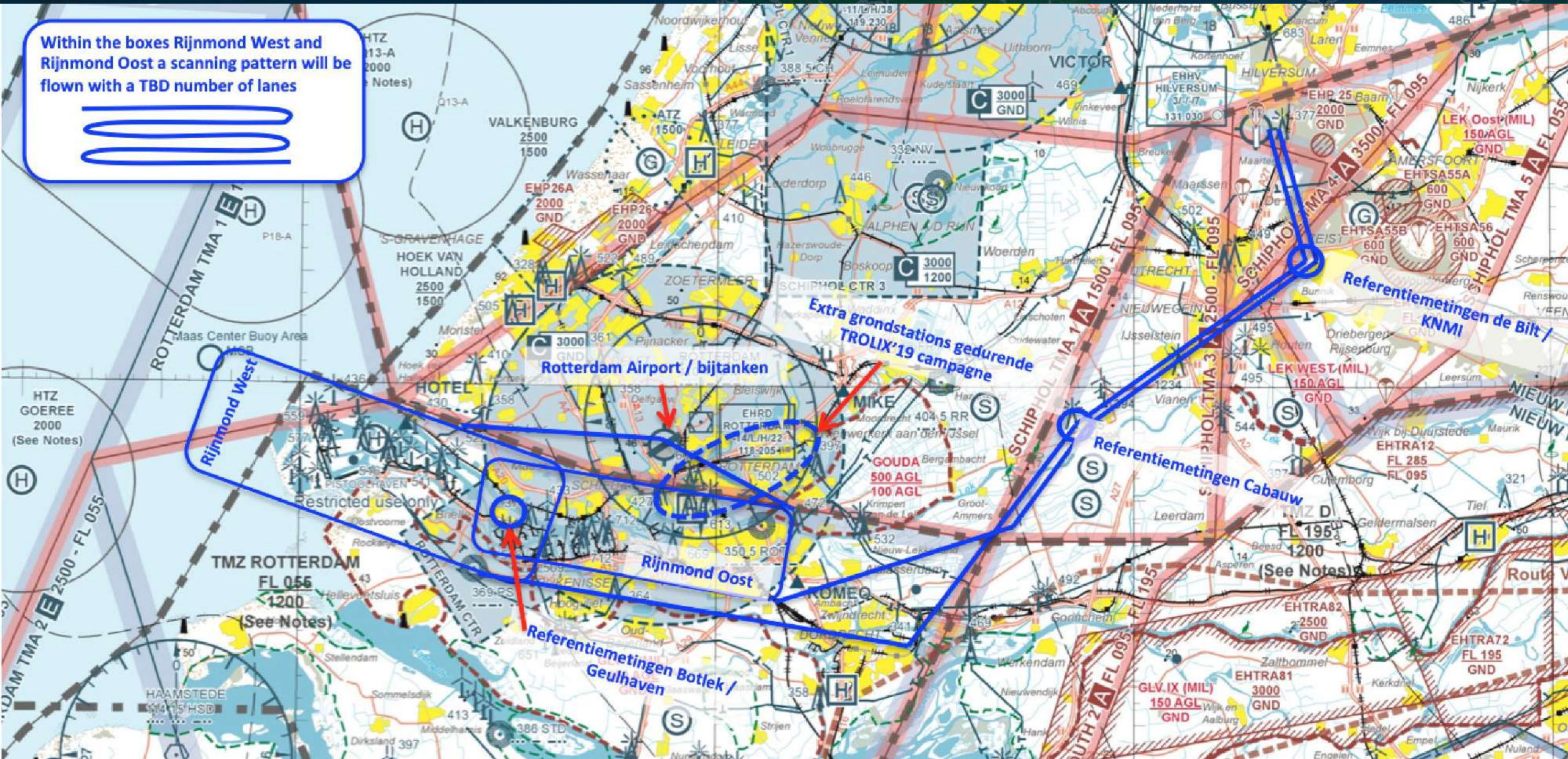

7 Oct. 2019 – test flight Spectrolite, Bart Speet (TNO), Tim Vlemmix (KNMI)

Flights

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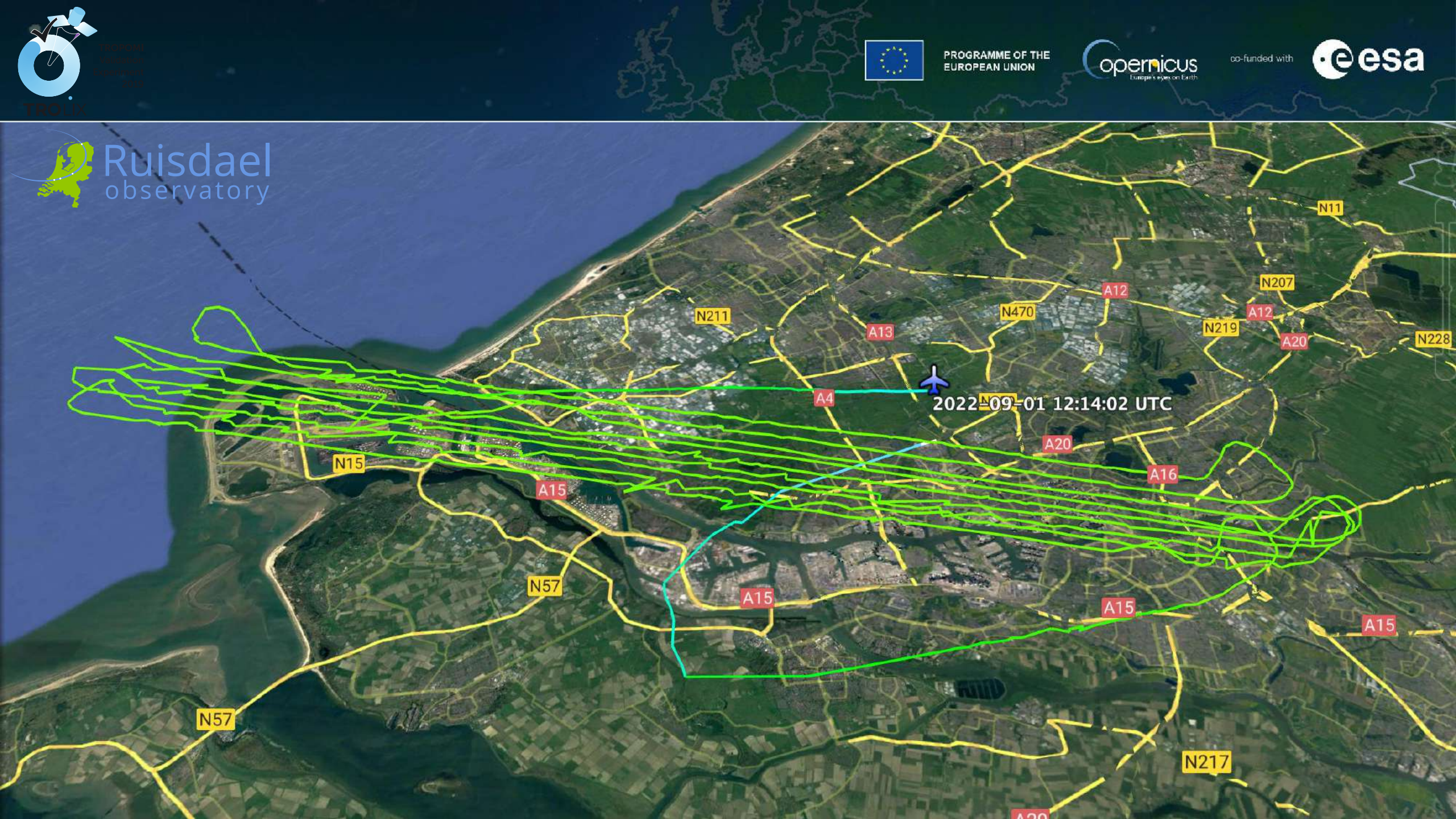
Ruisdael observatory


TROPOMI
Validation
Operations
2022
TROLIX
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Summary and Conclusions

- Ground based data set has been collected with emphasis on vertical structure and spatial heterogeneity
- National campaign with large international input and contributions
- Data analysis is still ongoing
- Concepts and lessons learned will be carried over in future studies and campaigns
- Preparations for a next maxdoas intercomparison campaign CINDI-(202)3 have started in preparation of Sentinel-4 and Sentinel-5 as part of the ACTRIS topical center for trace gas remote sensing (CREGARS)


Royal Netherlands
Meteorological Institute
Ministry of Infrastructure
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