Airborne remote sensing in support of atmospheric satellite missions

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BIRA-IASB

International Conference on Air Quality, Thessaloniki, 29-06-2022

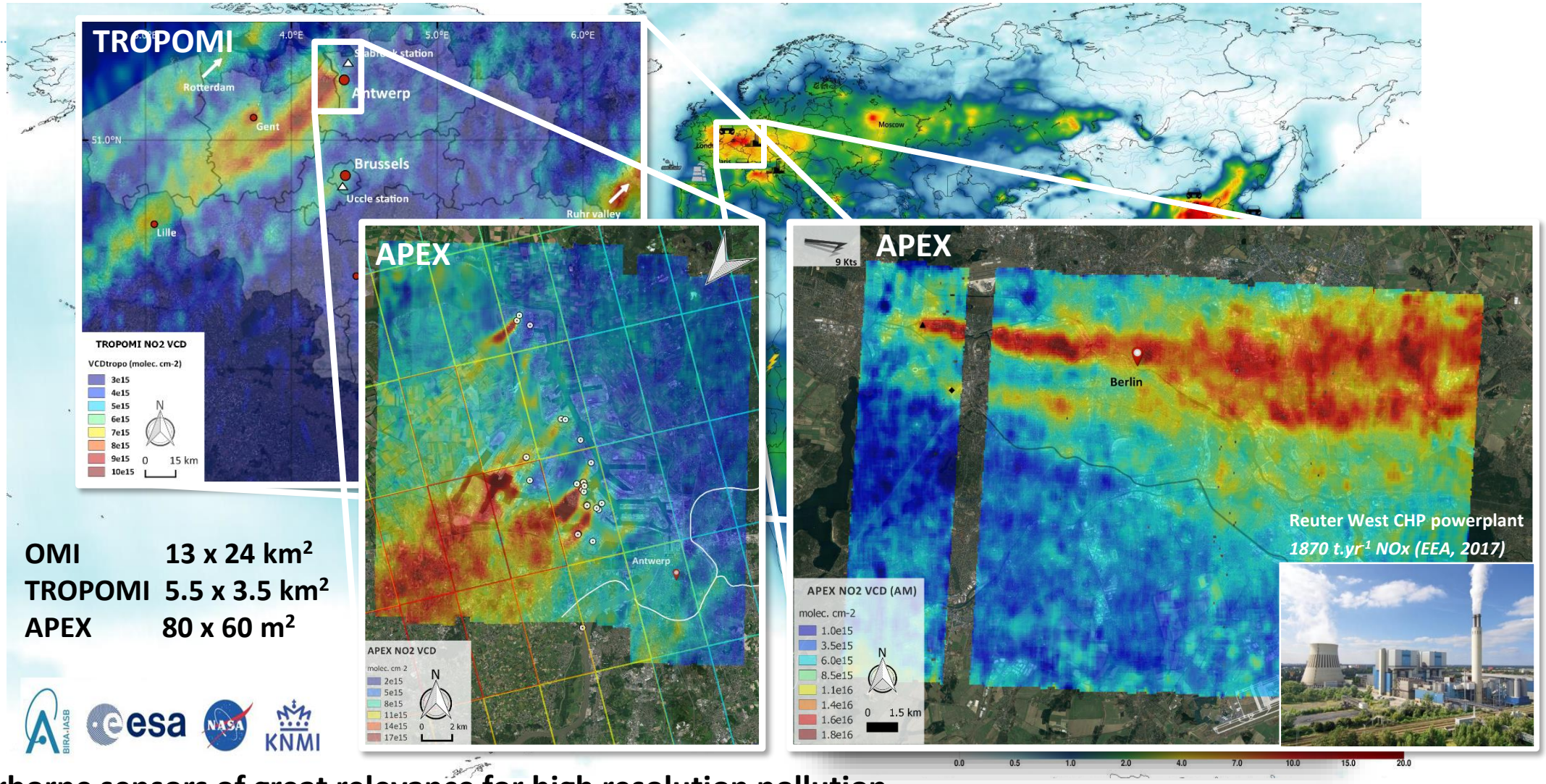
Outline

- **Introduction to airborne imaging**
  - Motivation
  - Airborne Imaging Differential Optical Absorption Spectroscopy (**I-DOAS**)
  - Key applications

- **Airborne imaging in support of atmospheric satellite missions**
  - Validation of satellite missions, dedicated to AQ and climate (ESA SVANTE/QA4EO project → S5P)
  - Support to future satellite mission design (ESA NITROCAM project → NITROSAT)
- **Conclusion & perspectives**

→ **Focus on hyperspectral imaging/mapping of UV-VIS products (mainly tropospheric NO_2)**

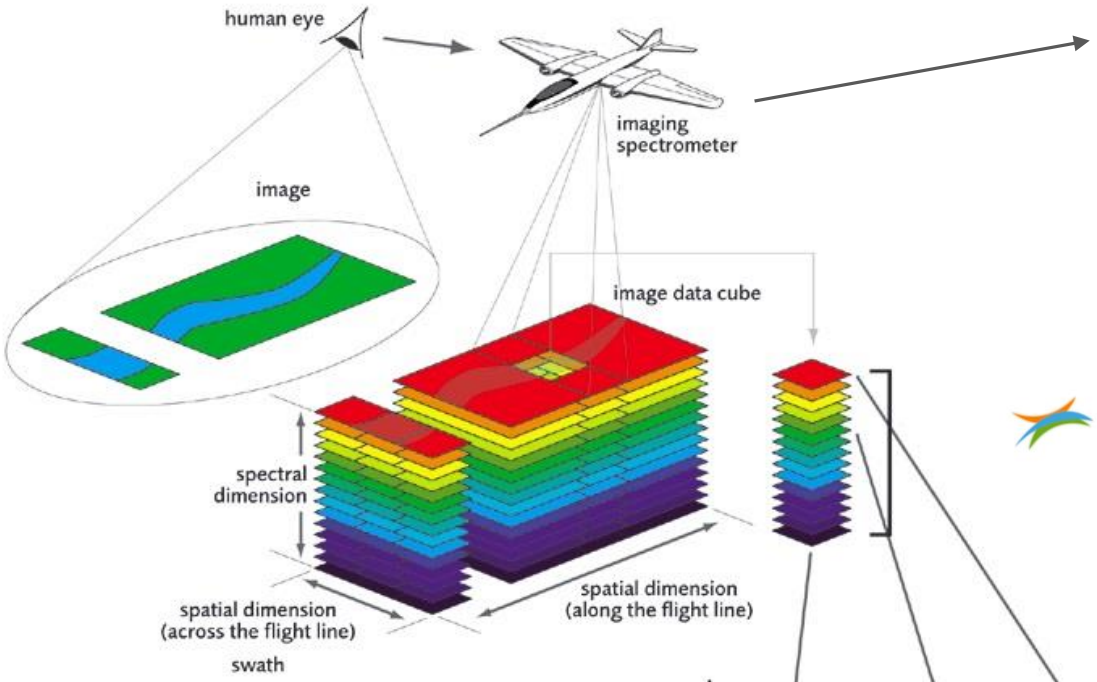
Motivation



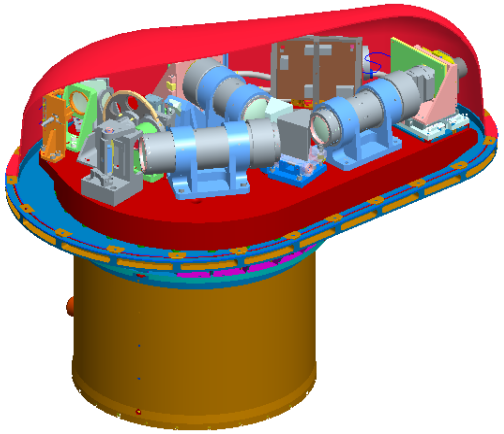
OMI 13 x 24 km^2
TROPOMI 5.5 x 3.5 km^2
APEX 80 x 60 m^2

Airborne sensors of great relevance for high resolution pollution mapping at scale of cities → complementary to spaceborne instruments

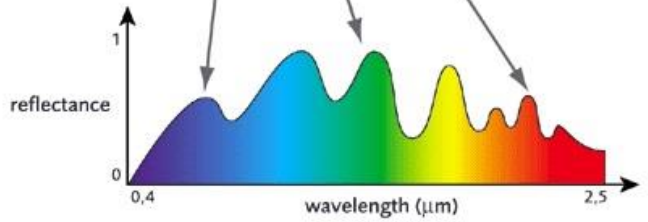
Airborne imaging spectroscopy

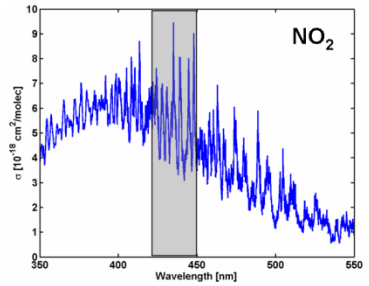


APEX



I-DOAS (**I**maging **D**ifferential **O**ptical **A**bsorption **S**pectroscopy)

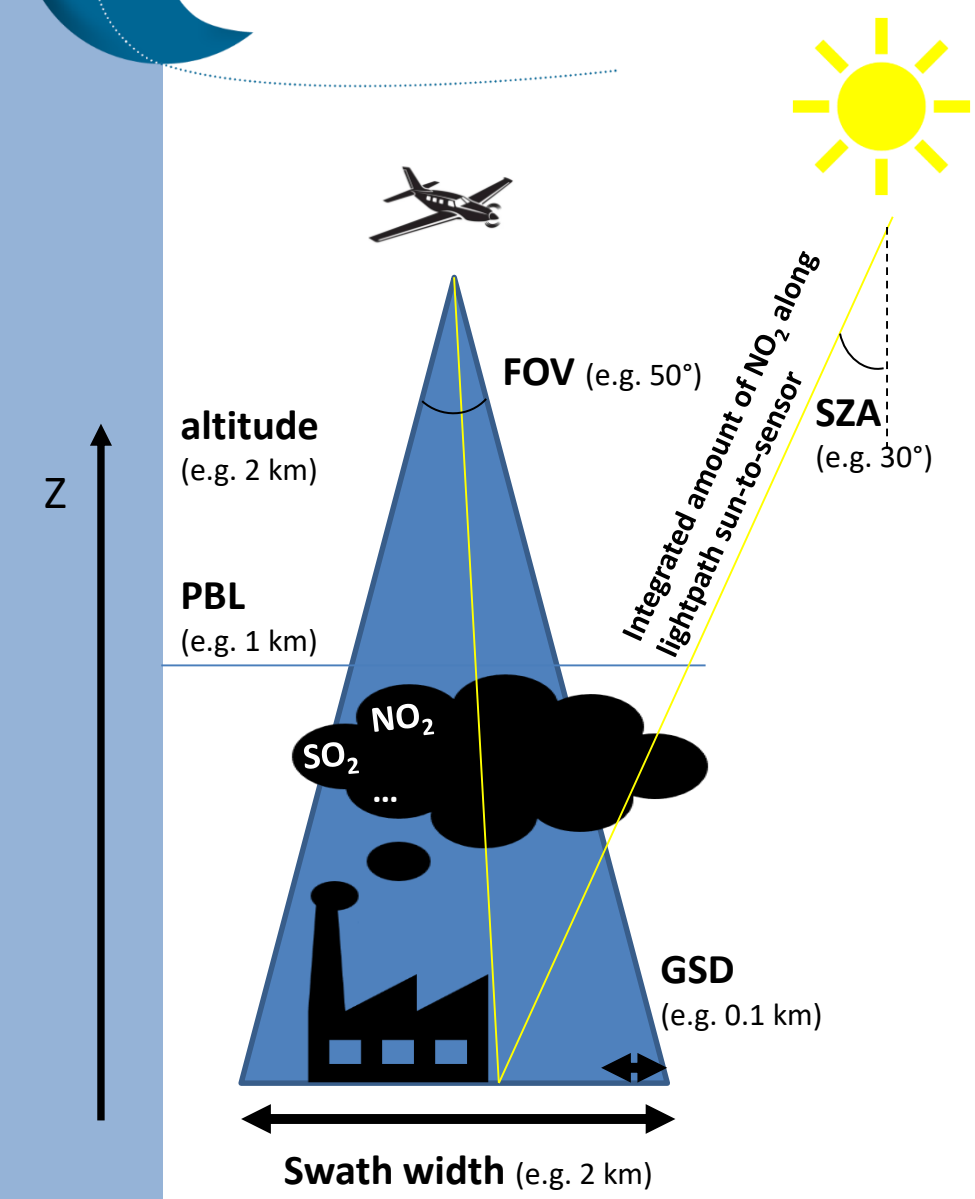


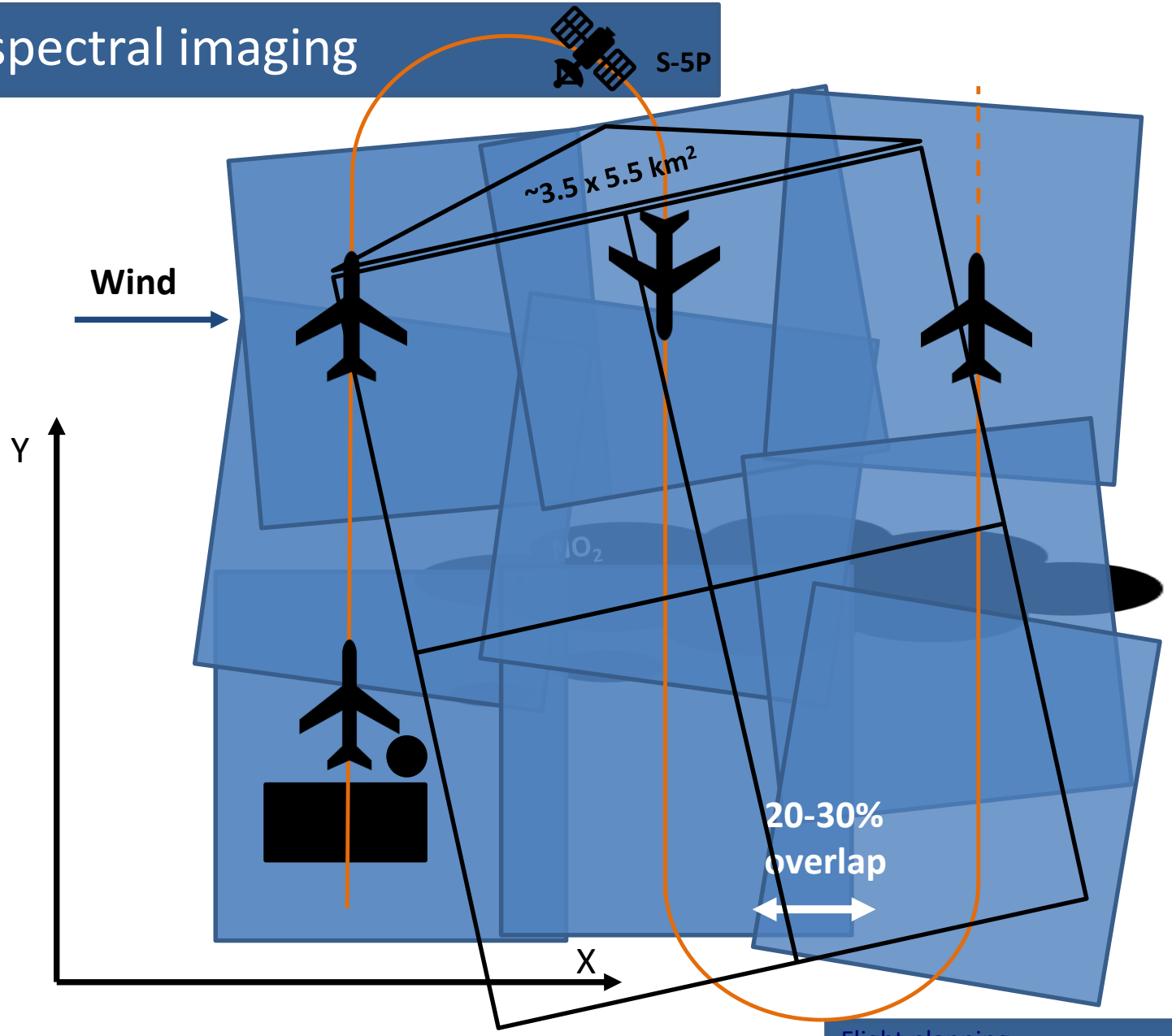


Spectral fit between ~400-500 nm for NO_2

Product: Slant column densities (SCD): integrated amount of molecules along the lightpath, expressed as molec. cm^{-2}

Flight strategy for hyperspectral imaging



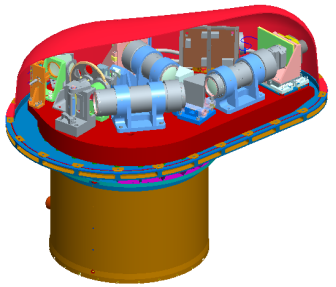


Motivation + key applications

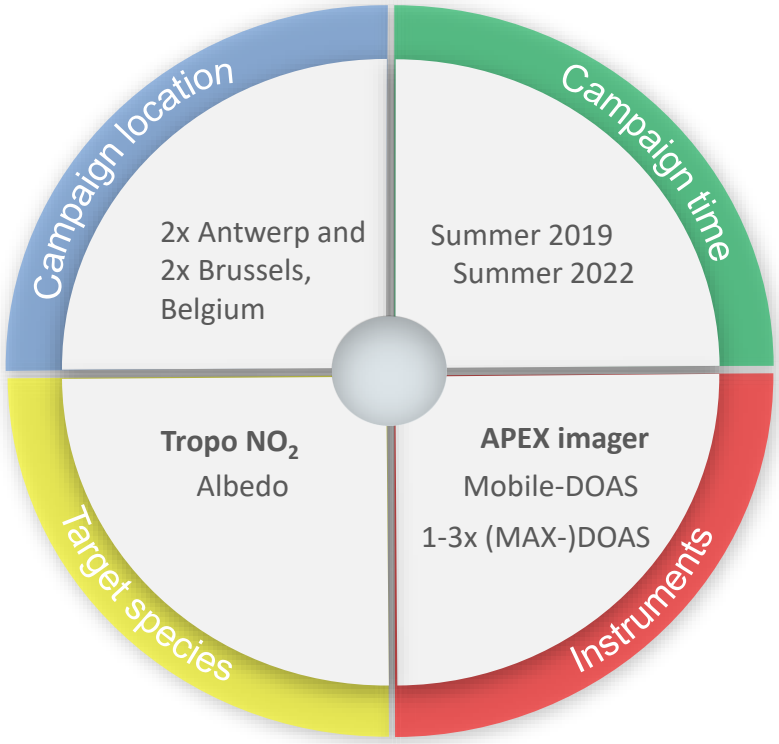
- **Air quality monitoring** (BUMBA and AROMAPEX project)
  - Mapping of the **spatial distribution of pollutants** (e.g. NO_2, SO_2, HCHO) at high resolution (~100 m) over cities/industrialised areas
  - Top-down HR **source identification** and **emission rate estimation**
  - **Gapfiller** between spaceborne and ground-based observations
- **Trend monitoring**
- **Enforcement of (inter)national agreements and policymaking**, e.g. Paris Agreement (COP26, 2016), Green Deal, LEZ and ECA, etc.
- Chemistry transport **model input** or **validation** (BUMBA project)
- **Satellite validation** → case study over Belgium (SVANTE/QA4EO project)
- Support to future **satellite mission design** (NITROCAM project)
- …

S5PVAL-BE

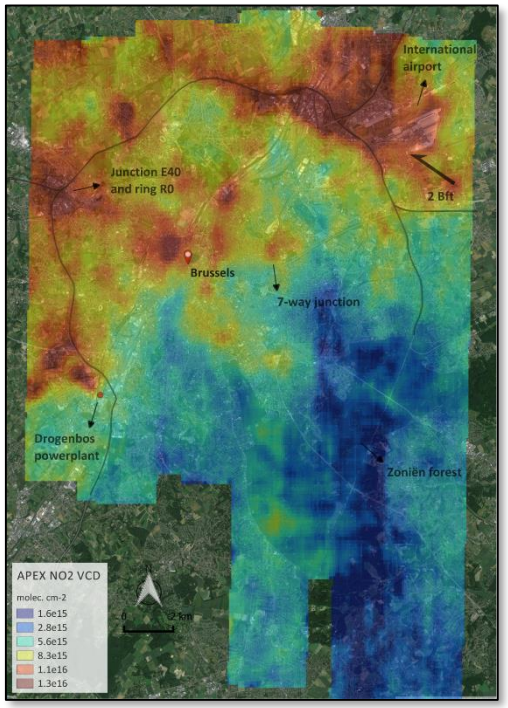
APEX

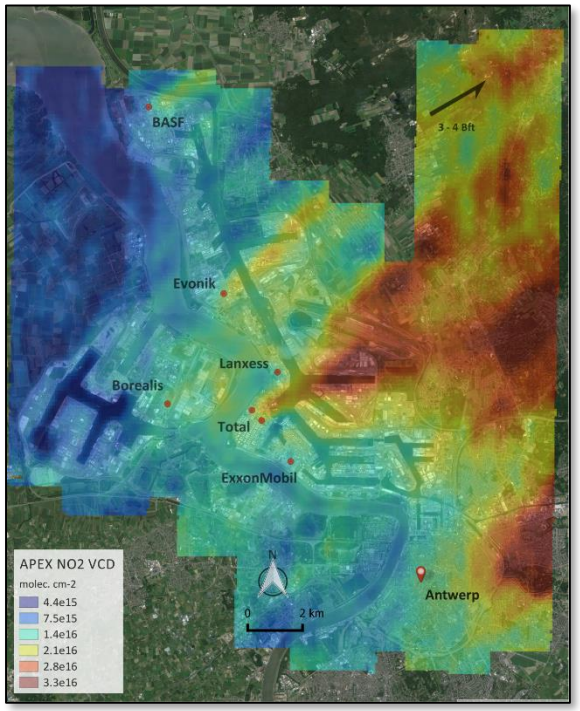


- Airborne mapping of tropospheric NO_2 with **APEX imager** (VIS - 80 m x 60 m)
- Antwerp one of largest petrochemical clusters in Europe + urban emissions
- 4th APEX flight campaign over these sites (BUMBA project) and 2nd for S-5p validation

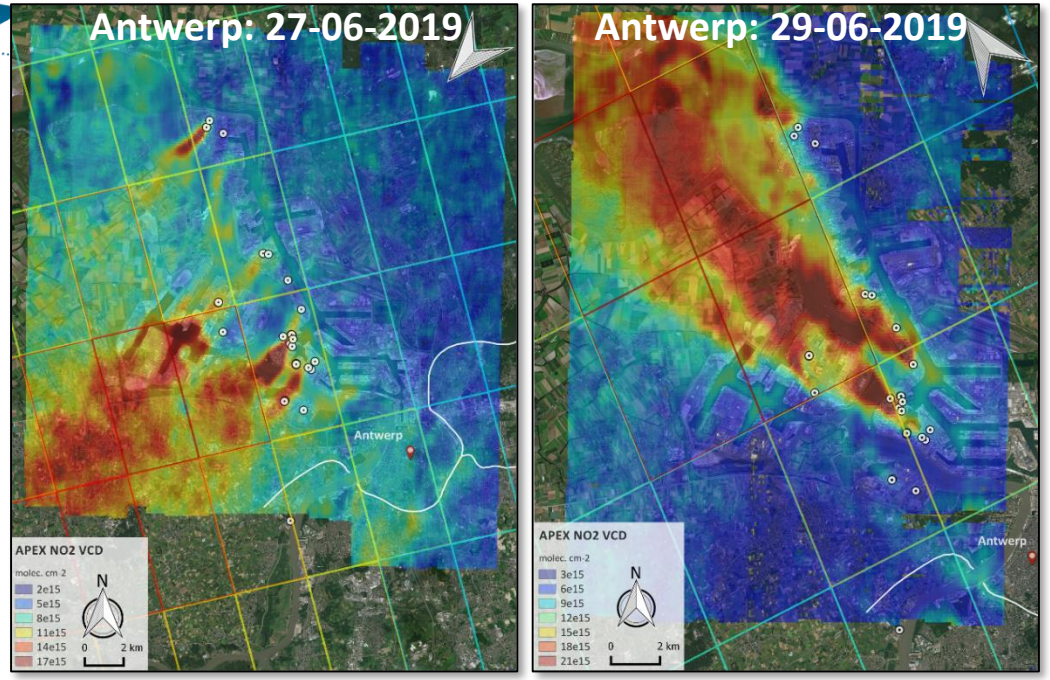


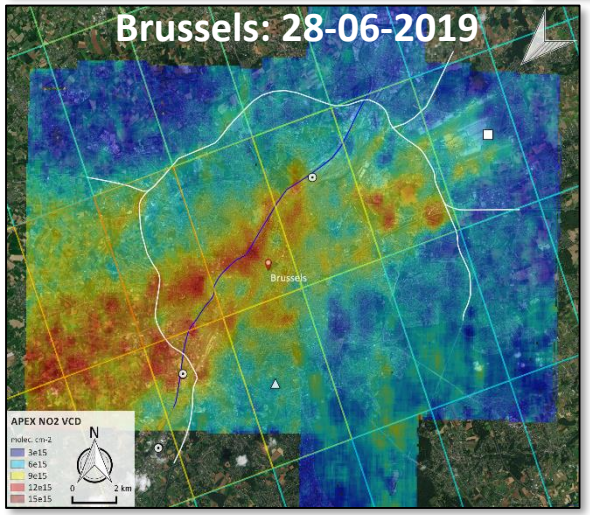
BUMBA campaign (2015)

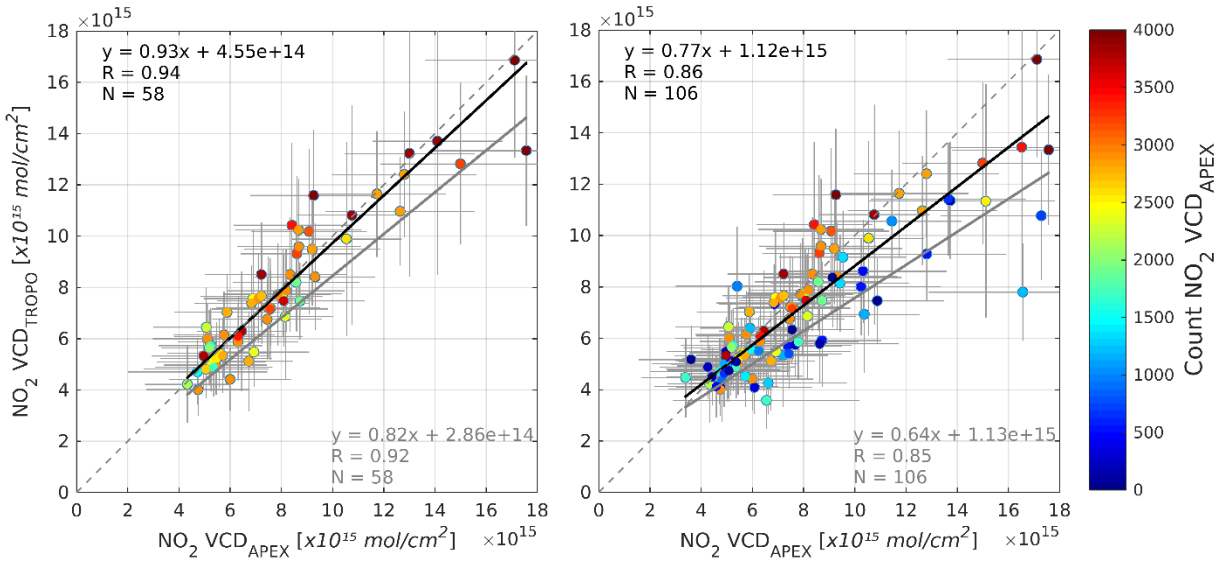


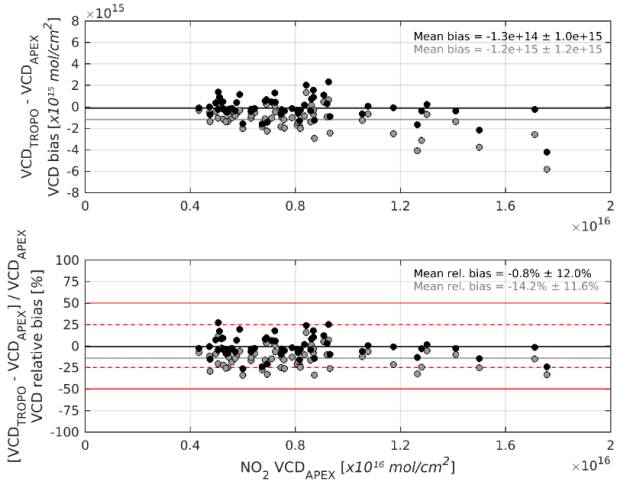


S5PVAL-BE - APEX NO_2 VCD retrievals









Scatterplots and linear regression analyses of co-located TROPOMI and averaged APEX NO_2 VCD retrievals for the data sets acquired on 26-29 June 2019 + **NO_2 VCD bias** ($VCD_{TROPO(-CRE)} - VCD_{APEX}$)

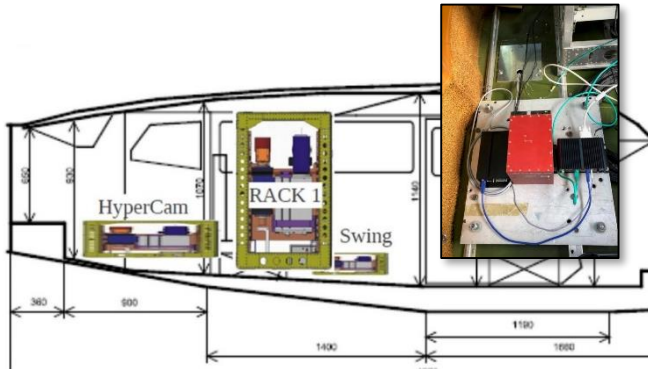
Full analysis available in AMT (Tack et al., 2021)

ESA NITROCAM campaign in support of NITROSAT

- **NITROSAT**
  - NITROSAT is an **EE11 candidate** (potential launch 2032?)
  - Satellite mission proposed to **simultaneously observe NO_2 (VIS) and NH_3 (TIR)** → Key reactive species of the global nitrogen cycle
  - Globally at a **spatial resolution of at least 500 m** (current satellite missions, e.g. IASI, 12 km and S5P, 3.5x5.5 km^2)
  - Main motivation:
    - NO_2 and NH_3 have a strong impact on human health, environment and climate
    - While NO_2 emissions are decreasing, NH_3 emissions are rising in Europe and developing countries
- **NITROCAM**
  - **ESA airborne campaign** in support of the NITROSAT EE11 candidate (phase 0)
  - BIRA (NO_2 retrievals, coordination), ULB (NH_3 retrievals), FUB (flight planning and instrument operations)
  - Main objectives:
    - Simultaneous retrieval of NO_2 and NH_3 from various sources based on **airborne demonstrator**: agricultural, industrial, domestic, transportation
    - downsampling airborne to satellite resolution, study sensitivity + detection limit, emission rate retrieval, etc.

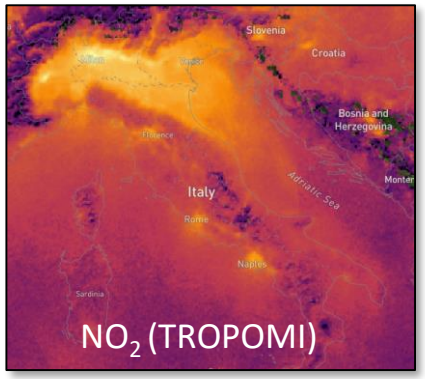
ESA NITROCAM campaign in support of NITROSAT

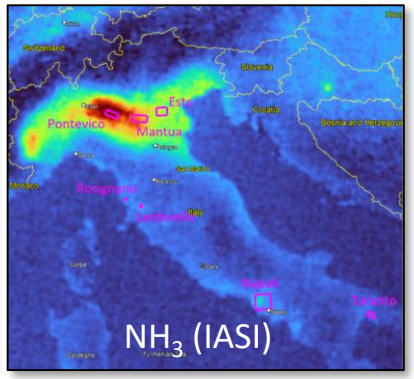
- **Airborne demonstrator: SWING (BIRA) and TELOPS Hyper-CAM LW (GFZ) in Cessna 207T (FUB)**

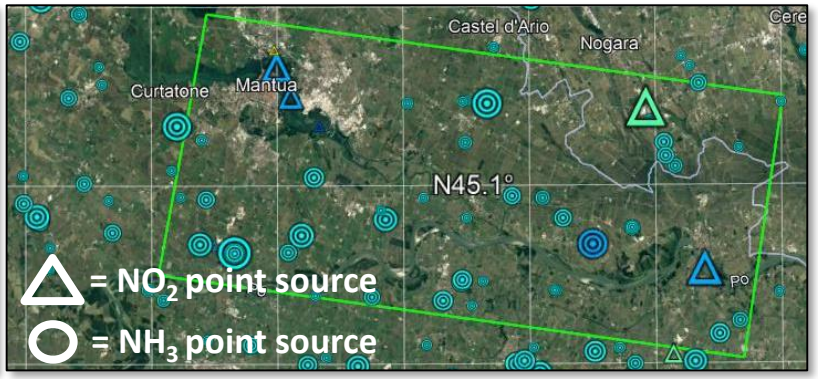


	SWING+	TELOPS Hyper-Cam LW
Wavelength range	280-550 nm	848-1288 cm^{-1}
Spectral resolution (FWHM)	0.7 nm	1.45 cm^{-1}
FOV across-track	100°	25.7° max
IFOV across track	3°	0.08°
Swath width	2900 m	1350 m
Ground speed	60 m/s	51 m/s
Exposure time	0.5 s	2.29 s
Spatial resolution	170 m	5 m
Weight	3 kg	140 kg
Size (LxWxH)	20 x 20 x 30 cm^3	100 x 60 x 50 cm^3
Scanning	Whiskbroom	Imaging Fourier interferometer
Target platform	UAV/aircraft	Aircraft

- **Airborne campaigns**
  - **Focusing on variety of sources** (agricultural, industrial, domestic, transportation)
  - **NITROCAM-DE**: 2021 – rural and urban/industrial sites close to **Berlin** (+ Bremen area in 2023?)
  - **NITROCAM-IT**: May-July 2022 – **Po Valley, Tuscany** – in collaboration with KCL, BAS, and NASA/JPL (HyTES)





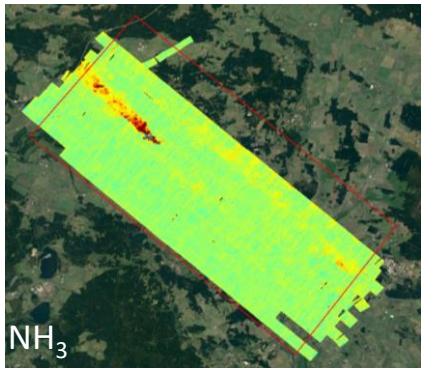


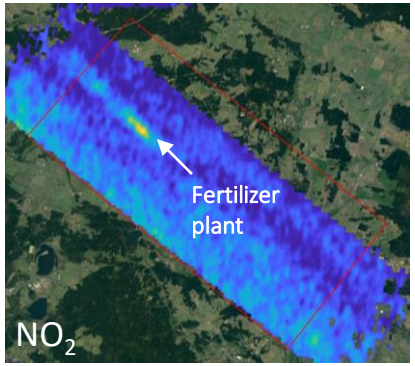

HyTES


BAS Twin Otter

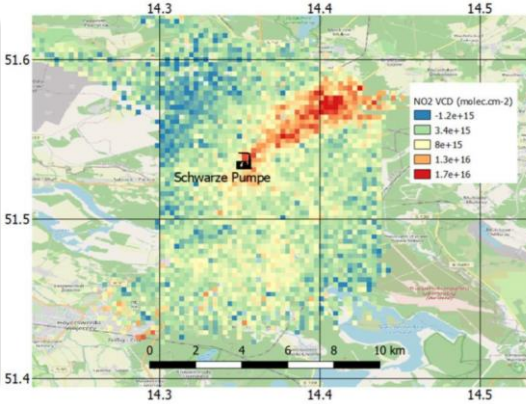
NITROCAM-DE

NH_3 and NO_2 over Piesteritz – 28/04/2021 – first simultaneous retrieval

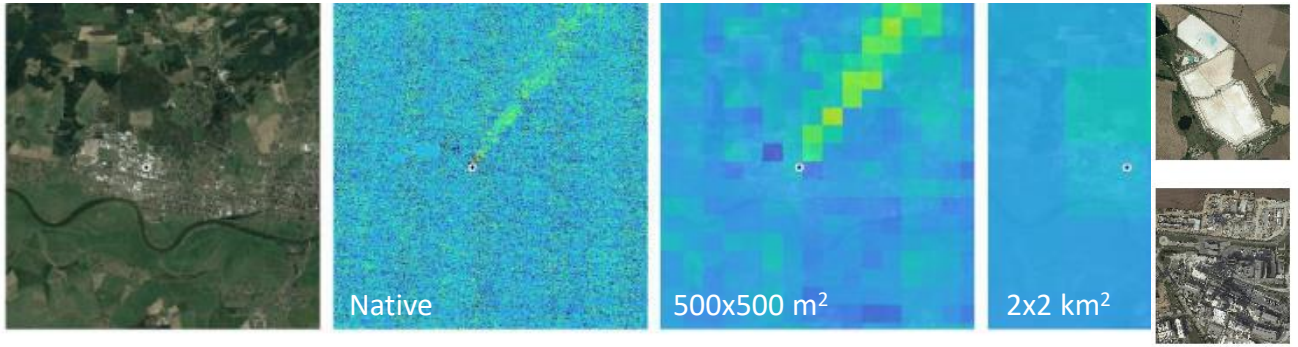




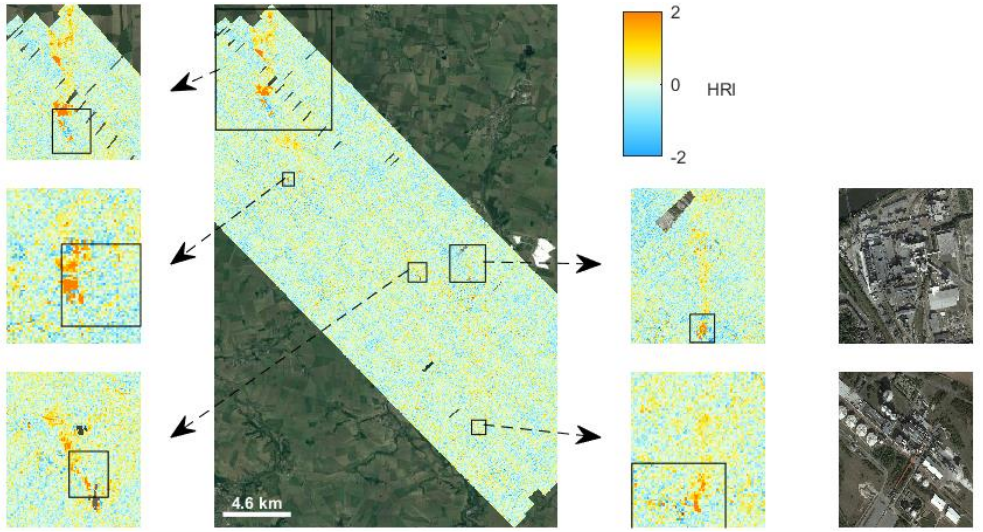
NO_2 over Schwarze Pumpe – 14/11/2020



NH_3 over Piesteritz – 08/10/2020 – downsampling to pseudo-satellite resolution



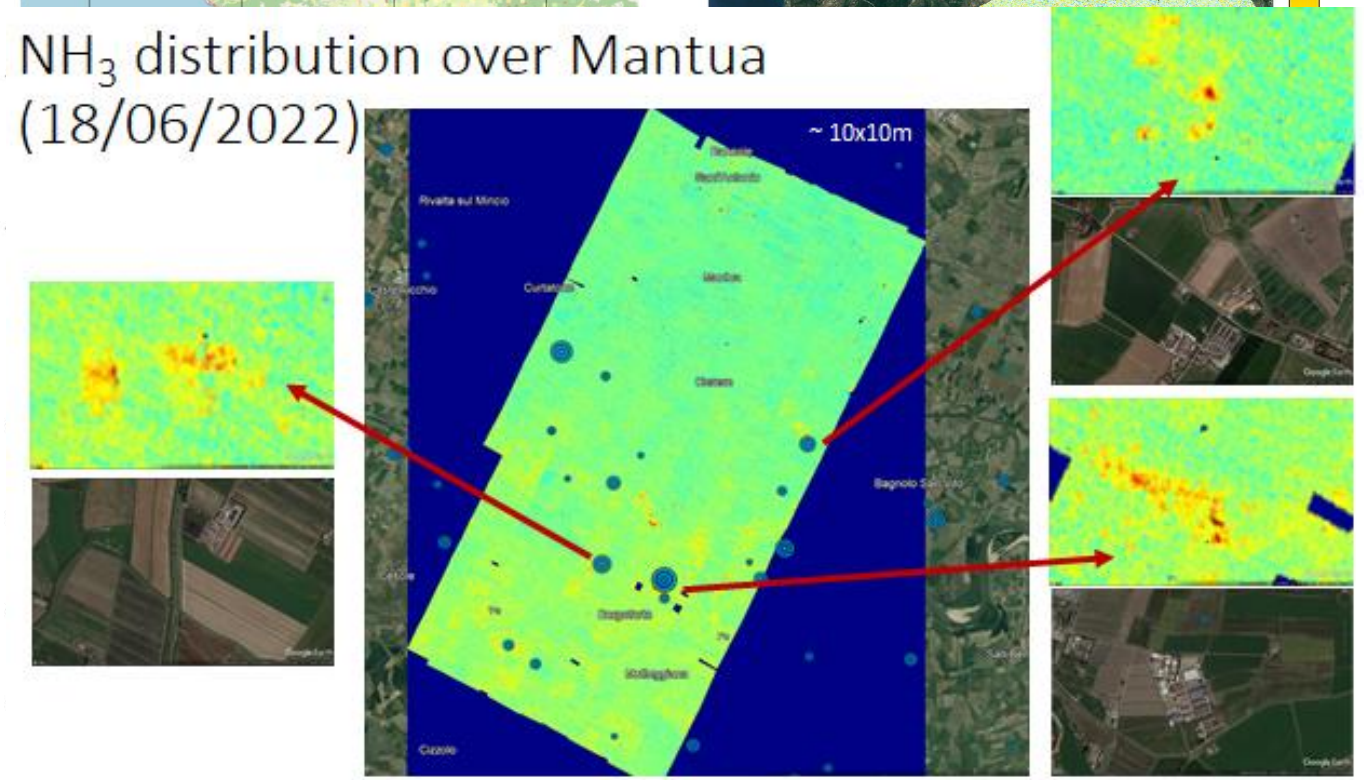
NH_3 over Stassfurt/Bernburg – 09/05/2021 – signal from many sources



Contributions from Lieven Clarisse, Lara Noppen (ULB), Alexis Merlaud (BIRA), Thomas Ruhtz (FUB)

NITROCAM-IT

Preliminary quicklooks



Contributions from Lieven Clarisse, Lara Noppen (ULB), Alexis Merlaud (BIRA), Thomas Ruhtz (FUB)

Conclusion and perspectives

- **Several studies demonstrate that clear NO_2 (and NH_3) signals can be retrieved and individual NO_2 plumes can be identified and linked to their sources over urban/industrialised areas based on airborne imaging data**
  - High spatial resolution (~100 m^2)
  - High spatial coverage (~350 km^2 within 90 minutes)
  - NO_2 VCD error approximately 20%
- **High potential for**
  - Local air quality studies → gap filler between satellites and ground-based networks
  - Input for emission inventories and CTMs
  - Trend monitoring and policymaking
  - Validation of satellite measurements and AQ models
  - Airborne precursor - support to future satellite mission design
- **But… Need for more best practice documents, joint standards, harmonization, protocols for data acquisition and processing → through EUFAR at European level?**

Conclusion and perspectives

- **Needs and perspectives for air quality applicatio**
  - Need for **high spatial and temporal resolution to monito** spatiotemporal variability

	✈	
Spatial resolution	•Spatial resolution (< 100 m^2) close to the naturally smoothed signal of the dispersed NO_2 field	•Curren km^2 (S5
Temporal resolution	•Restricted to campaigns – need for more systematic flights for near-continuous monitoring	•Daily (•Hourly

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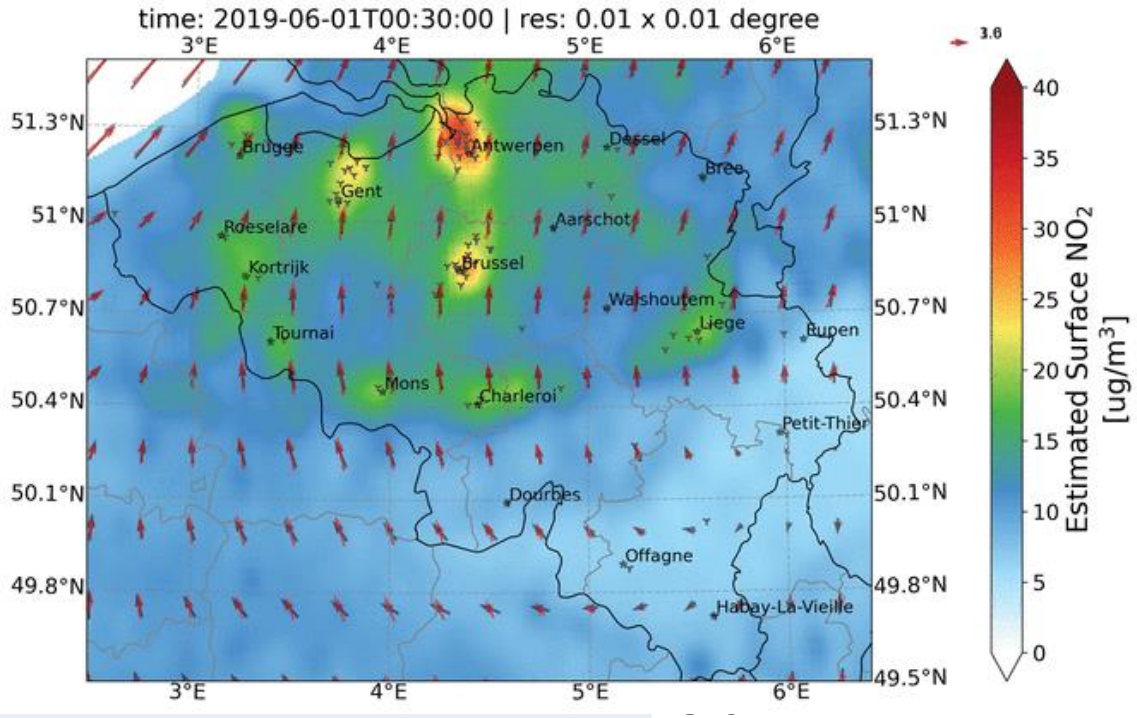


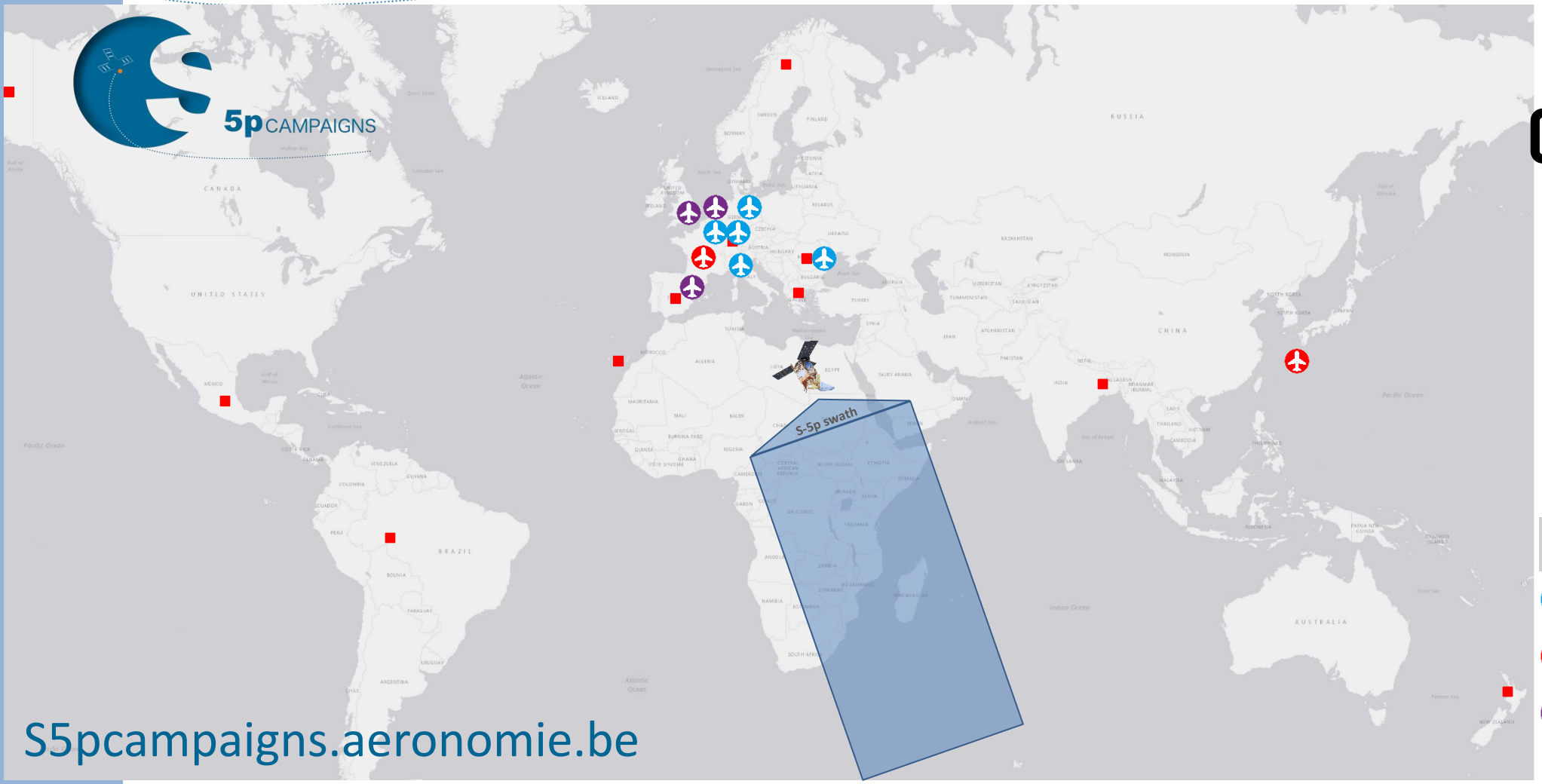
- Current airborne imaging systems as **precursors** for future (low-cost) stratospheric and spaceborne missions, complementing flagship missions like S5P, S5, S4, Nitrosat, etc
  - e.g. deploy on **HAPS/drone**s (20-30 km altitude) hovering over certain ROI or geostationary
  - e.g. deploy on large constellation of orbiting compact, **low-cost CubeSats** (400 km)
- Need to convert retrieved atmospheric columns (VCD) to **surface concentrations** (VMR)

...Thank you!

uv-vis.aeronomie.be/airborne
S5pcampaigns.aeronomie.be

Contact: frederik.tack@aeronomie.be

ESA SVANTE and QA4EO campaigns – S5P validation



S5PVAL-DE-RUHR
S5PVAL-DE-BERLIN
S5PVAL-RO
S5PVAL-BE
S5PVAL-TRANS
NET-Sense
MAGIC
ACCLIP
S5PVAL-KOLKATA
COCCON

NO_2
SO_2
HCHO
CO
CH_4

Legend

- Airborne UV-VIS
- Airborne IR
- Airborne UV-VIS & IR
- Ground-based IR