

living planet symposium | BONN 23-27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE



Monitoring Belgian Air Quality from space through the synergistic use of the Sentinel constellation

Tijl Verhoelst, Steven Compernelle, Jean-Christopher Lambert (BIRA-IASB, Brussels, Belgium)
Frans Fierens, Charlotte Vanpoucke (IRCEL-CELINE, Brussels, Belgium)

23 May 2022

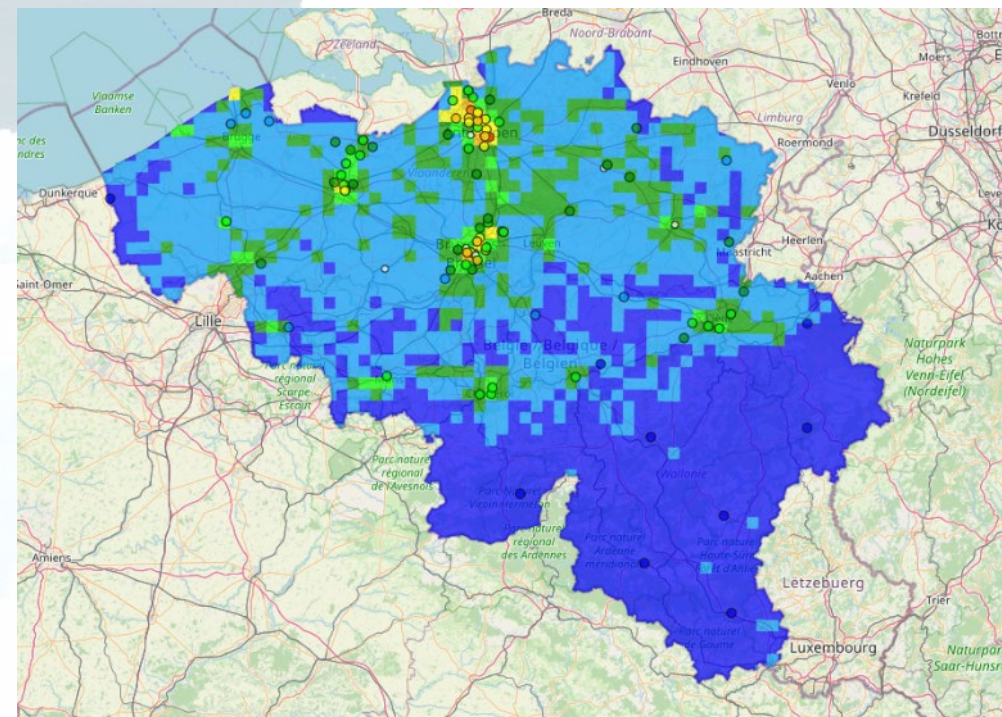
Context: space-based Air Quality monitoring at various scales

International Air Quality framework: EU Ambient Air Quality Directives, EU National Emission Reduction Commitments Directive (NEC), UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP)...

Increasing number of local regulations put into place to improve AQ, often on a city scale. E.g., the gradually tightening LEZ in Antwerp (2017), Brussels (2018), Ghent (2020), and entire Wallonia (2023).

SARS-CoV-2 related reduction of human activities offers a low emissions test case (especially in summer).

In-situ measurements of NO_x, O₃, PM₁₀, PM_{2.5} and BC are the standard for AQ monitoring ⇒ sparse data sets, made contiguous by (model-based) interpolation.



Annual mean (2019) NO₂ concentration, in-situ data interpolated (4x4km²) (RIO model, IRCEL-CELINE)



AQ monitoring from space



The LEO+GEO Satellite Constellation for Air Quality



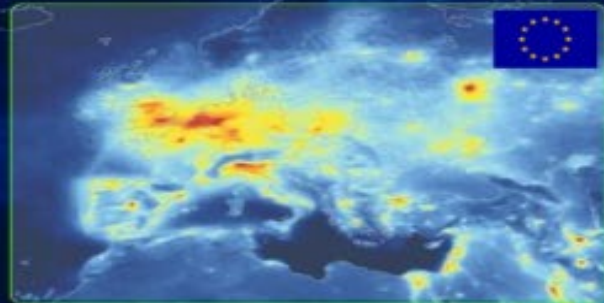
2023-2029

TEMPO (hourly)



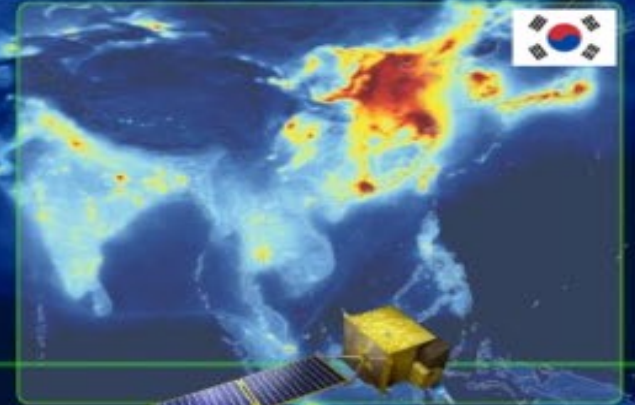
2024-2042

Sentinel-4 (hourly)



2020-2031

GEMS (hourly)

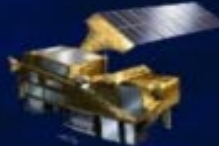


+ Sentinel-3 (AOD)
+ CO2M (NO2)



Sentinel-5P
(once per day)

2017-2027



Sentinel-5
(once per day)

2024-2044



OMPS
(once per day)

2011-2038



EMI GaoFen-5
(once per day)

2018-2028



Equator

Challenges for the uptake of satellite Air Quality data by policy makers and other stakeholders

- ❖ In spite of large investment in the Copernicus programme, uptake of satellite data by Air Quality stakeholders remains limited (in Belgium).
- ❖ Challenges are technical, communicational, and legislative:
 - Spatio-temporal resolution lower than classical methods combining near-surface network data and modelling
 - Relation to near-surface concentrations not straightforward
 - Cloud cover
 - Accuracy
 - Multiple platforms with different properties: LEO+GEO; S5P, S4, S5, CO2M, S3...
 - Data and metadata format
 - Legal requirements
- ❖ BRAIN-be 2.0 project LEGO-BEL-AQ (BIRA-IASB + IRCEL-CELINE): aims at a ***synergistic application of Air Quality EO satellites (R&D) to bring EO data closer to Belgian stakeholders (service).***

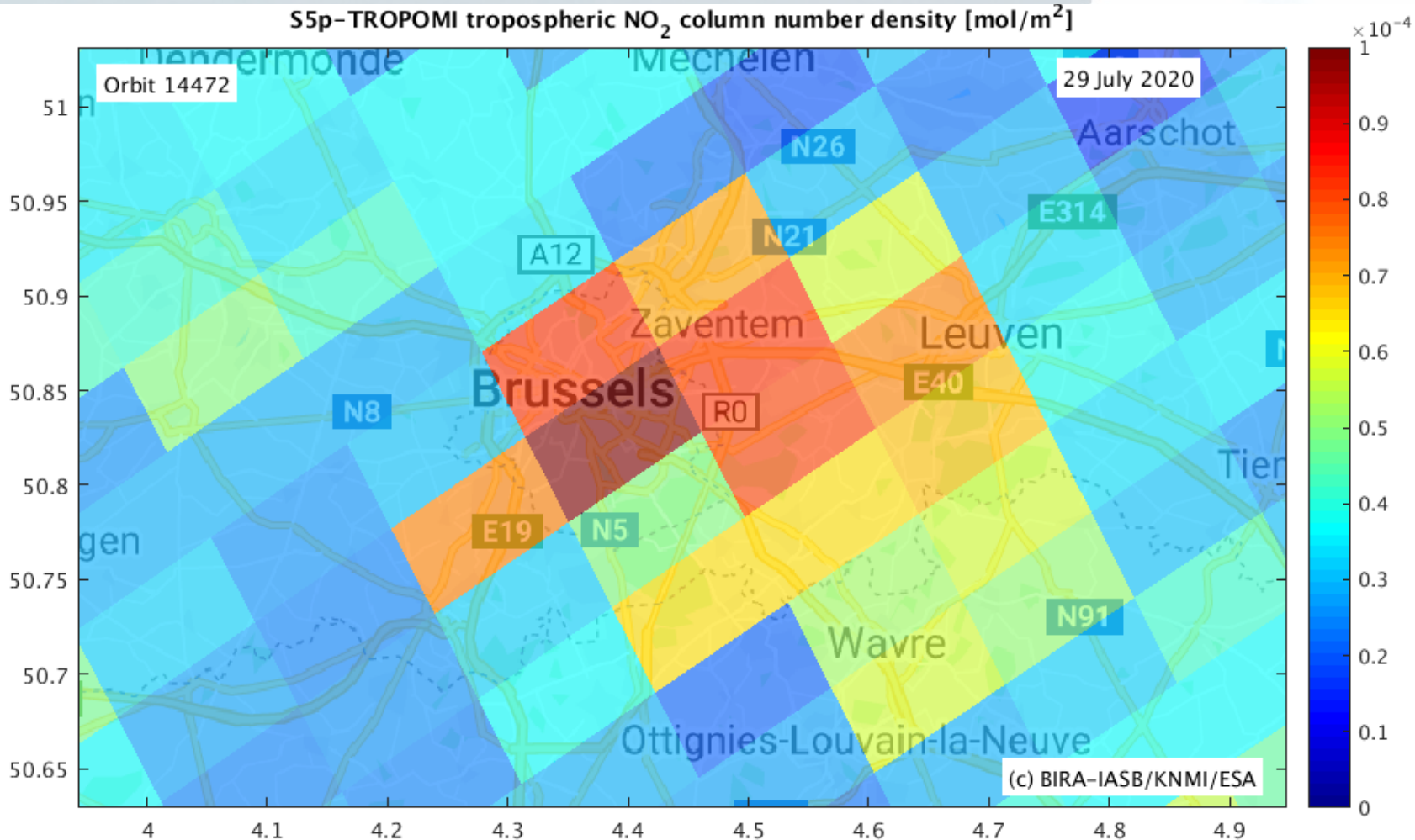
LEGO-BEL-AQ: a Belgian project for synergistic use of Copernicus AQ satellites

- I. Spatio-temporal mapping and downscaling toolbox for (Copernicus AQ) satellite data sets
QA/QC, aggregation, interpolation, uncertainty propagation
- II. Application to S5P TROPOMI data over Belgium and comparison to in-situ data
City-level maps and time series; comparison to in-situ and RIO-modelled surface concentrations
- III. Developments for the specific viewing geometry of the geostationary sounders (S4):
3D LEO and GEO observation operators to assess spatial smearing and potential obscuration effects along the measured optical path + impact on perceived diurnal cycle
- IV. Outreach and valorisation
Liaison with identified stakeholders, both in AQ policy and in the data retrieval communities

Balancing spatial and temporal resolution (S5P NO₂)

A single Sentinel-5p
overpass over
Belgium

Nominal ground
resolution at nadir:
3.5 x 5.5 km²



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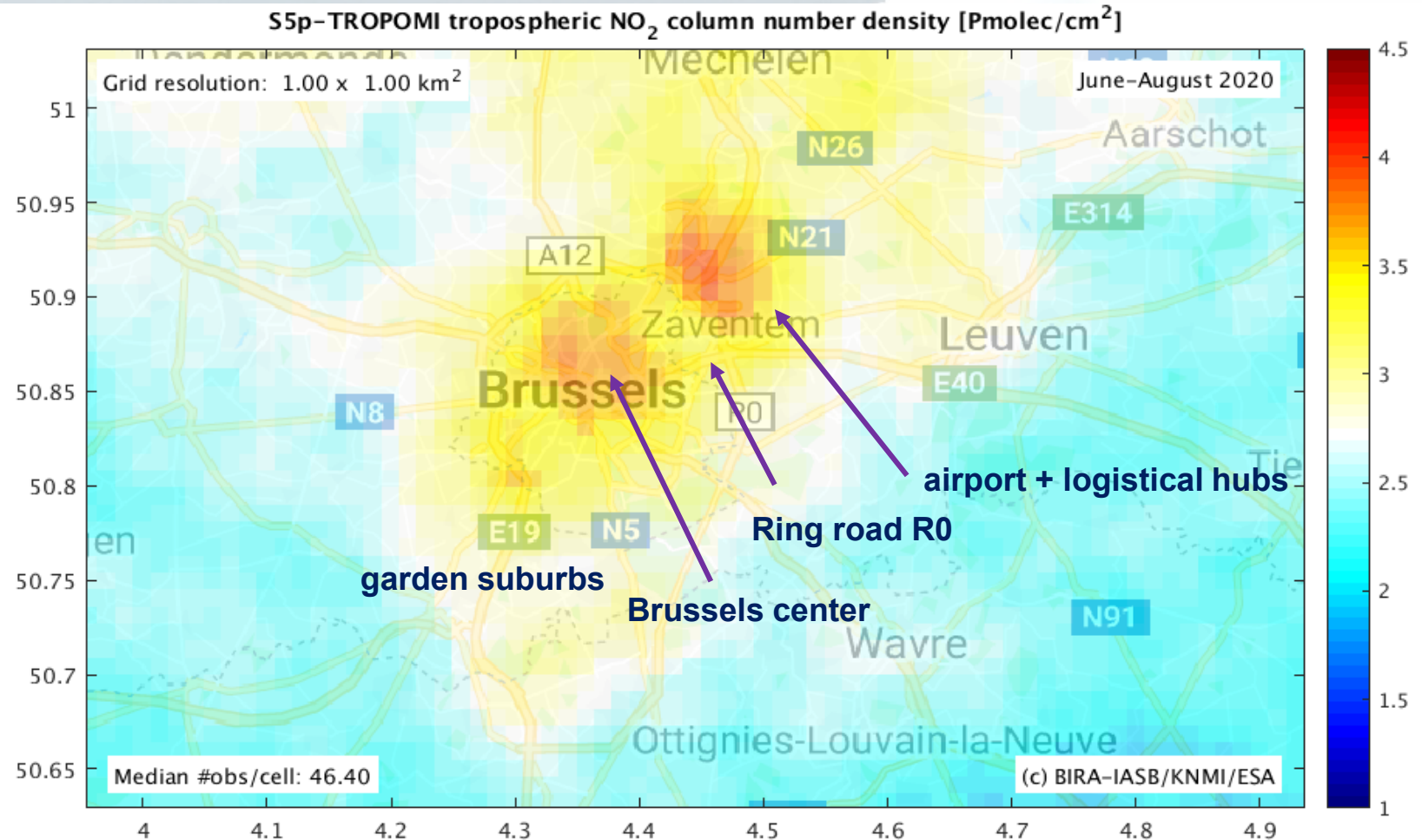
Balancing spatial and temporal resolution (S5P NO2)

- **Temporal aggregation** (from days to months, here: 3 months)
- **Filtering** (on quality, SZA, and winds)
- **Spatial oversampling** with area-overlap weighting

$$VCD_{L3,j} = \frac{\sum_i w_i VCD_{L2,i}}{\sum_i w_i}$$

$$w_i = \frac{Area_{L2,i \cap L3,j}}{Area_{L3,j}}$$

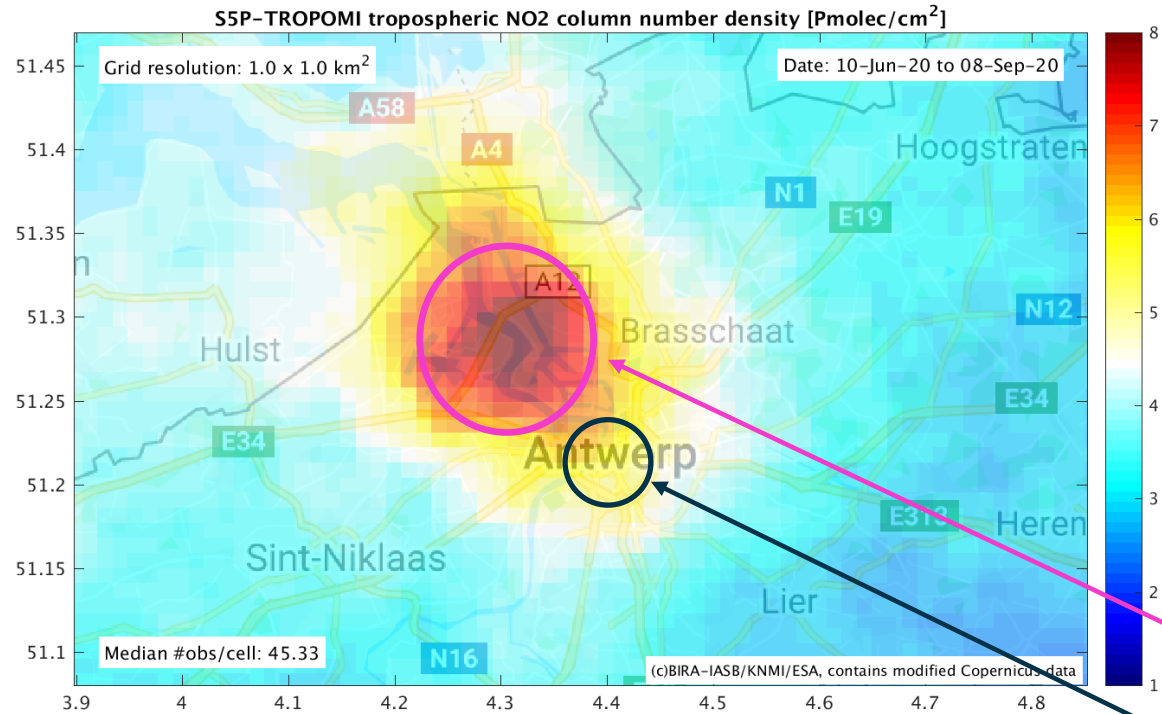
- **Uncertainty propagation**
- **Optional: gap filling (clouds) with Kriging**



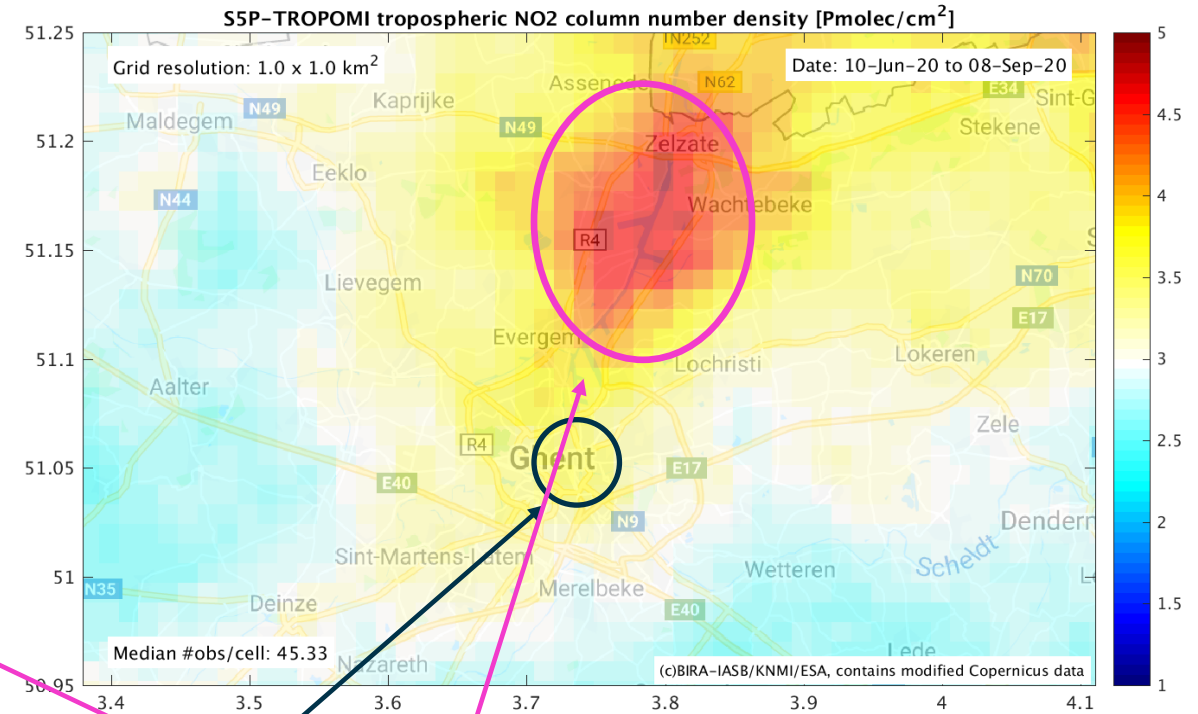
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Balancing spatial and temporal resolution (S5P NO2)

Antwerp



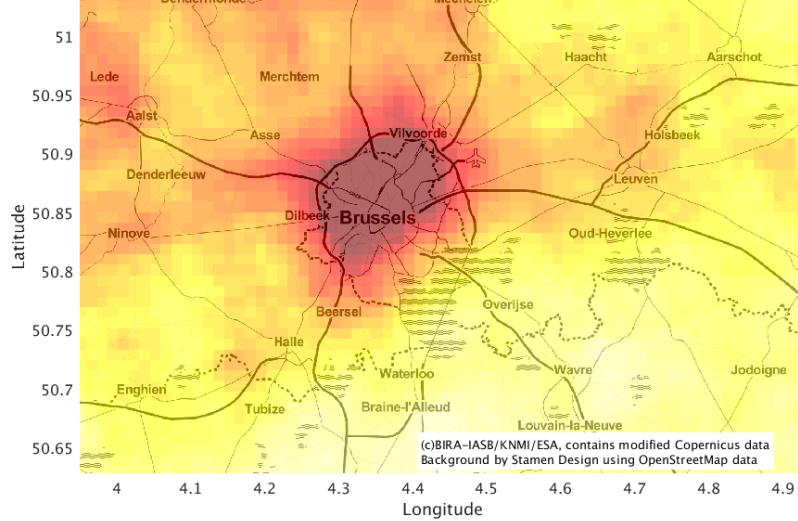
Ghent



Two cities with enforced “Low Emission Zones” in their centre but also with harbour to their North.

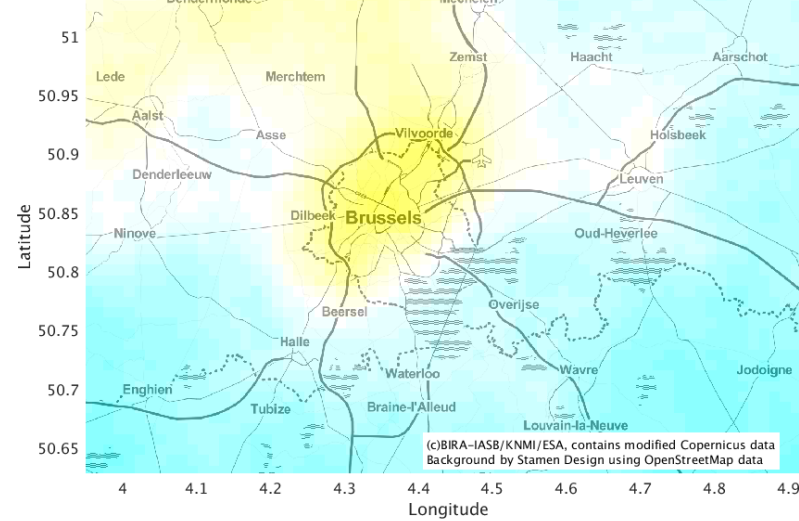
Impact of CoViD-19 related reduced activity (S5P NO2)

LEGO-BEL-AQ S5P-TROPOMI tropospheric NO2 VCD MAM 2019 [Pmolec/cm²]



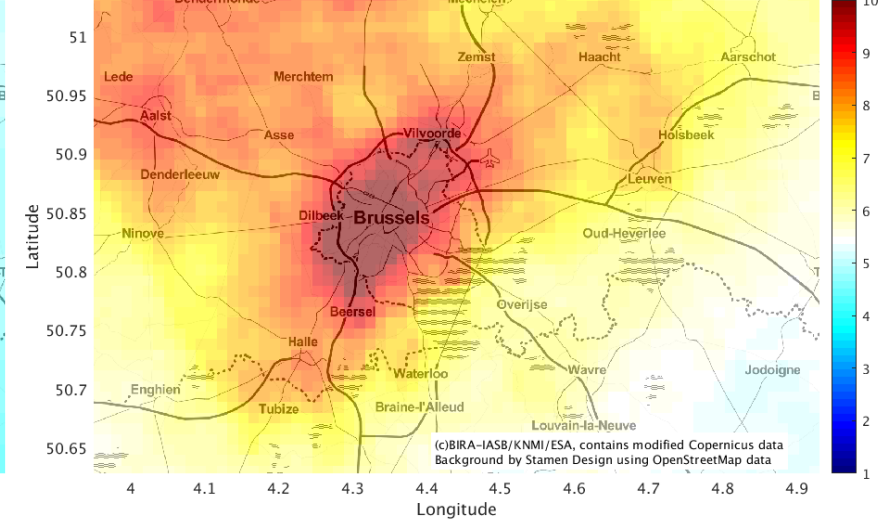
Spring 2019

LEGO-BEL-AQ S5P-TROPOMI tropospheric NO2 VCD MAM 2020 [Pmolec/cm²]



Spring 2020

LEGO-BEL-AQ S5P-TROPOMI tropospheric NO2 VCD MAM 2021 [Pmolec/cm²]



Spring 2021

To evaluate (long-term) trends, accuracy and stability are critical.

- ❖ PAL reprocessing (V2.3.1) + OFFL (Beware of RPRO + OFFL, see poster by Compernelle et al.).
- ❖ CAMS-regional prior substitution
- ❖ Ground-based validation (ESA/Copernicus ATM-MPC + BELSPO TROVA-2)

QA/QC of these S5P NO2 data sets

Operational validation of S5P NO2 nominal data product by ATM-MPC, see Lambert *et al.*, Monday 2pm in A1.02.1:

“Latest Results of the Operational Validation of Sentinel-5p TROPOMI”

Evaluation of NO2 data evolution by ATM-MPC and BELSPO/ProDEx TROVA-E2, see Compennolle *et al.*, Poster Session on Tuesday:

“Evolution of Sentinel-5P NO2 data product and implications for air quality applications”

Evaluation of LEGO-BEL-AQ oversampled NO2 datasets vs. in-situ and RIO-modelled surface data

Home Search VDAF Server

TROPOMI BIRA-IASB

VALIDATION FACILITY

SENTINEL-5 PRECURSOR MISSION PERFORMANCE CENTRE

Total Ozone Tropospheric Ozone Ozone Profile Nitrogen Dioxide Formaldehyde Sulphur Dioxide Carbon Monoxide Methane Clouds Aerosols

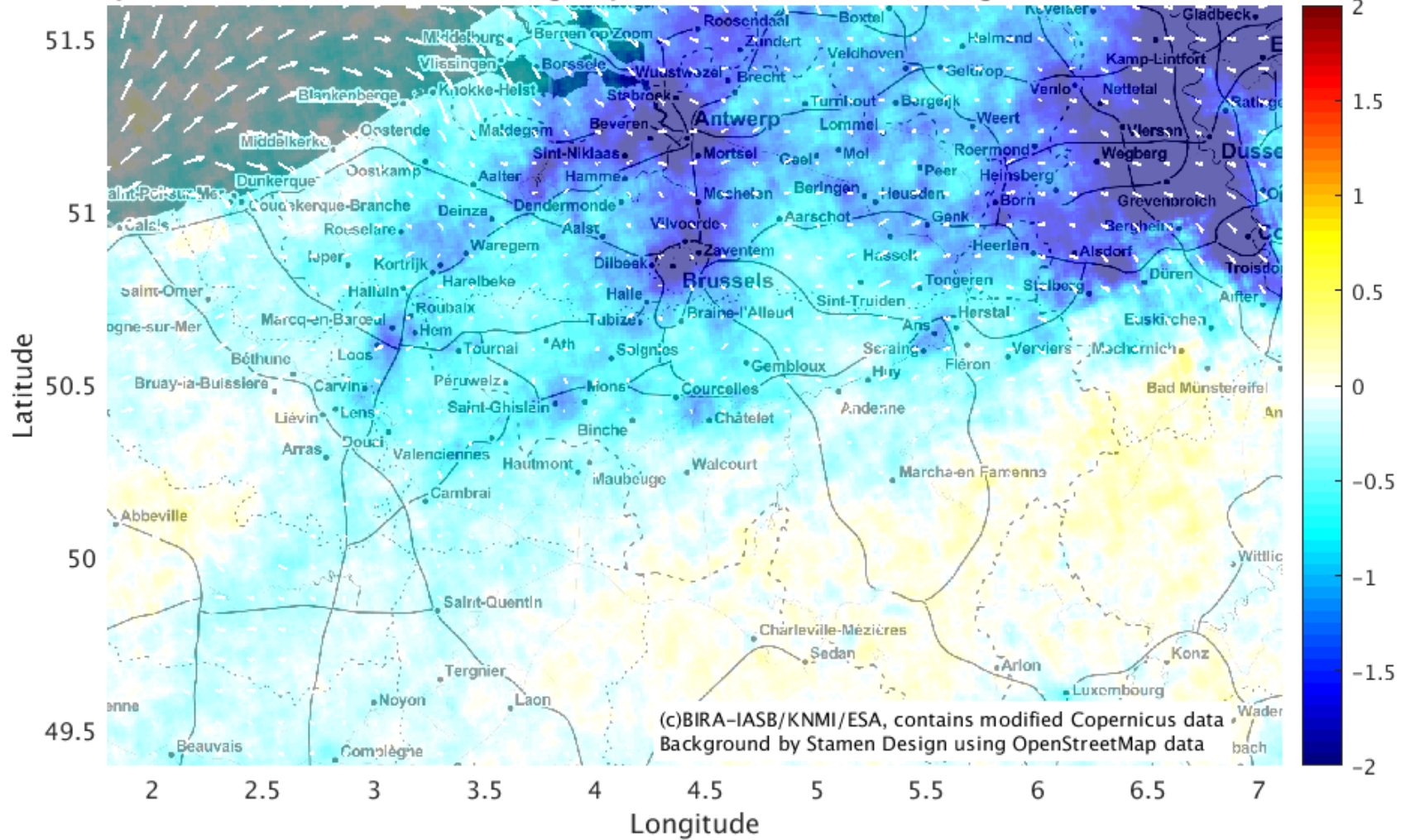
The Sentinel-5P Validation Data Analysis Facility (VDAF) portal is the public entry point to the Routine Operations Validation Service for TROPOMI.

Launched on 13 October 2017 on board of the ESA/Copernicus Sentinel-5 Precursor satellite, TROPOMI measures each day the global distribution of atmospheric trace gases and aerosols for a better understanding of air quality, the ozone layer, atmospheric chemistry and transport, ultraviolet radiation, and climate change.

<https://mpc-vdaf.tropomi.eu/>

Week-end effect (derived from Sentinel-5p NO2)

S5P tropo. NO2 VCD: weekend-working days (multi-annual JJA average, PAL-OFFL) [Pmolec/cm²]



Information at the level of administrative entities

Support policy making, monitoring and assessment by tailoring information to the different administrative levels, i.e.:

- i. Federal
- ii. Region
- iii. Province
- iv. Municipality

Note: This requires technical interfaces with the administrative-geographical framework (e.g., projections and file formats)



Main Menu

[Home](#)
[Nitrogen dioxide maps](#)
[By municipality](#)
[Data access](#)
[Project description](#)
[Team](#)
[Contact us](#)

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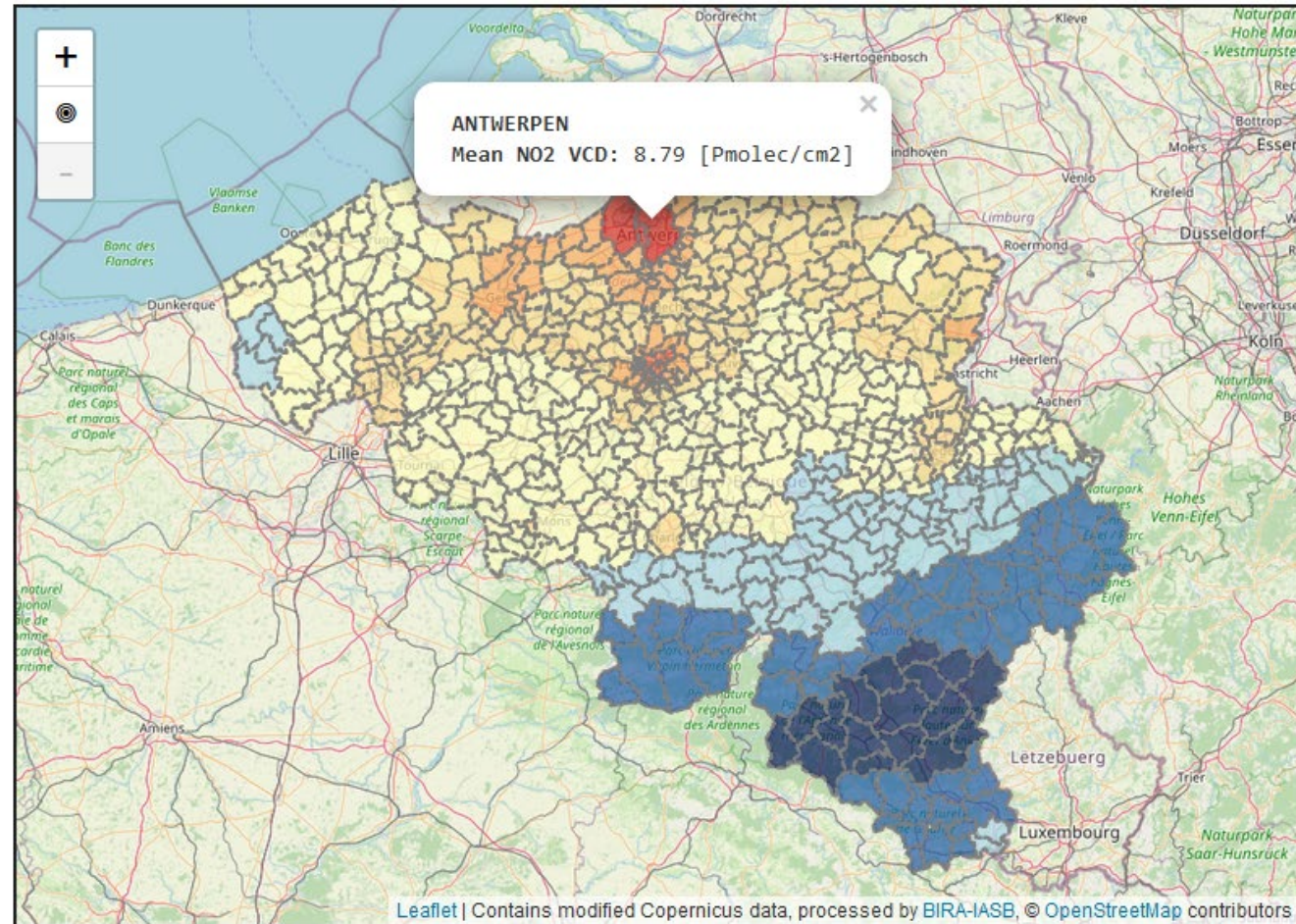


Acknowledgments



By municipality

The interactive map below presents long-term average tropospheric NO₂ column values per Belgian municipality. These results are based on the LEGO-BEL-AQ oversampled (1km by 1km) S5P-TROPOMI data (PAL reprocessing + OFFL processing).



Beyond Sentinel-5p NO2

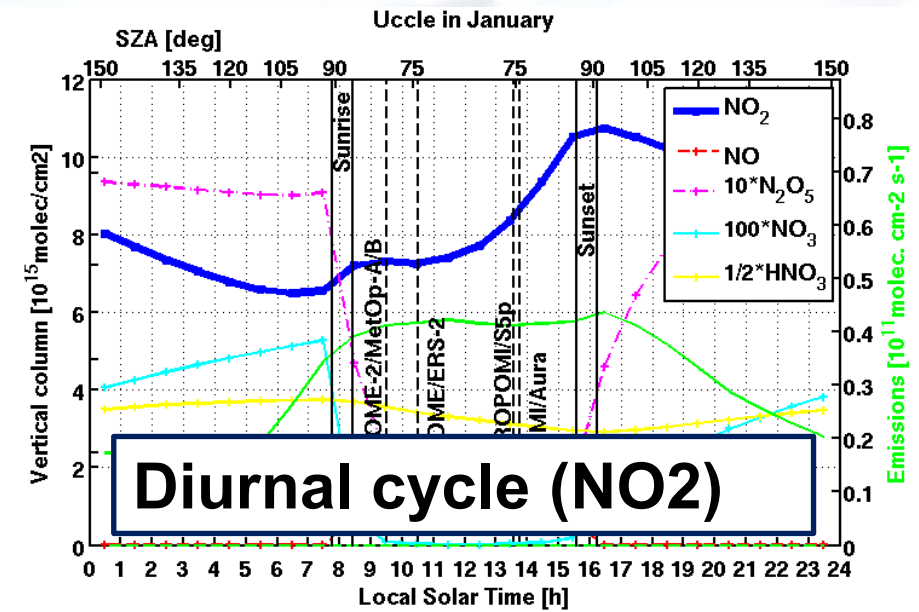
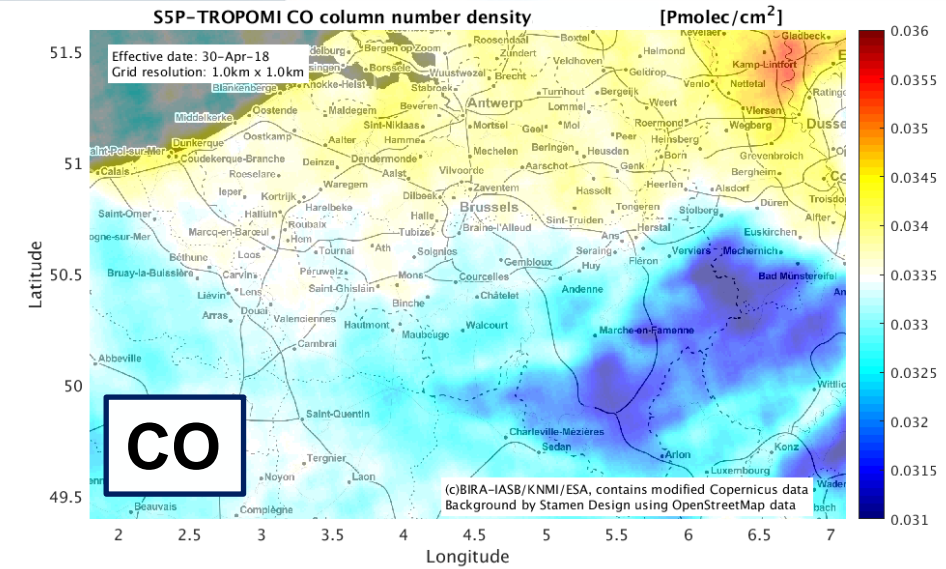
Synergistic use of the constellation

Through creation of an ARD data cube of:

- ❖ Specifically tailored Sentinel-5(P) NO₂, CO, CH₄, HCHO, and aux. data (e.g. AAI).
- ❖ Sentinel-4 diurnal data (+R&D on impact of GEO vantage point)
- ❖ Sentinel-3 AOD data

And intercomparison to in-situ

Facilitate use of satellite AQ data in Belgium



Interaction with stakeholders

- ❖ Website:
<https://lego-bel-aq.aeronomie.be>
- ❖ Our network (IRCEL-CELINE)
- ❖ Our follow-up committee includes EC “Clean Air Unit” representative
- ❖ Publications in specialized literature (e.g., magazine “Lucht”)
- ❖ Lessons learned from the SAT AQ team at FMI (I. Ialongo & H. Virtanen)



LEGO-BEL-AQ

a BELSPO BRAIN-be 2.0 project (12/2019 - 3/2024)

Main Menu

[Home](#)
[Nitrogen dioxide maps](#)
[By municipality](#)
[Data access](#)
[Project description](#)
[Team](#)
[Contact us](#)

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Acknowledgments



Belgian air quality as seen from LEO and GEO

Low-Earth and Geostationary Observations of Belgian Air Quality (LEGO-BEL-AQ) is a project funded by BELSPO under the BRAIN-be 2.0 programme. Its objective is to exploit the full spatio-temporal resolving power of the LEO and GEO Copernicus Atmospheric Sentinel missions to support air quality policies in Belgium.

This includes the production of high spatial resolution maps of NO₂ based on S5p-TROPOMI data over Belgium, and R&D on the complementarity and synergies within the (future) LEO+GEO constellation.

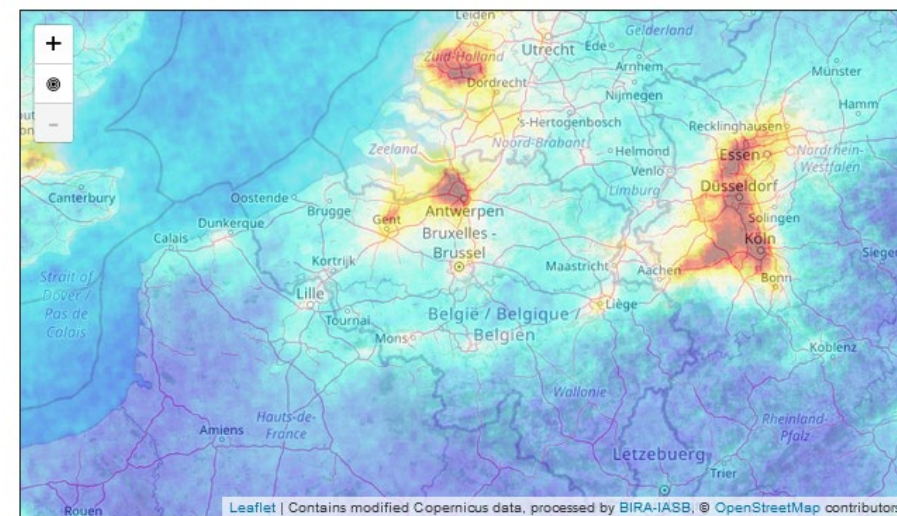
Example maps

City-specific results can be found [here](#).

S5P-TROPOMI tropospheric NO₂ column number density [Pmolec/cm²]

Grid resolution: 1.0 x 1.0 km²

Date: June-July-August 2021



You are here: Home

