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Belgian **R**esearch **A**ction through **I**nterdisciplinary **N**etworks - Phase 2

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ACRONYM: LEGO-BEL-AQ

Contract Number: B2/191/P1/LEGO-BEL-AQ

Title : Low-Earth and Geostationary Observations of Belgian Air Quality

Duration of the project : 15/12/2019 –15/03/2024

Budget : € 375 951

Context

Air Quality (AQ) in the European Low Countries is driven by complex processes covering a wide range of temporal and spatial scales, from point-like emissions of primary pollutants to intercontinental transport and the formation of secondary pollutants in a region with highly inhomogeneous land use. Consequently, the responsibility for AQ regulations is distributed among different levels of public authority, from international and federal to regional and local. In general, governmental AQ monitoring relies on in-situ measurements of near-surface concentrations, with geographical gaps between these (often sparse) observations filled in with interpolation techniques and numerical models incorporating meteorology and (proxies for) bottom-up emission estimates. However, a new constellation of Low-Earth Orbit (LEO) and geostationary (GEO) satellite sounders is becoming available, meant to support monitoring of AQ on the different relevant scales discussed above. Through its Copernicus programme, the European Commission is providing essential elements to this constellation, such as the Sentinel-5 Precursor (S5P, in LEO, launched in 2017 with the TROPOMI instrument on board), Sentinel-4 (GEO, to be launched in 2025), and Sentinel-5 (LEO, to be launched after 2025) suite of satellites. While offering near-contiguous observations of the entire European domain (cloud cover permitting), observations from space also imply substantial challenges that complicate the uptake by policy makers. First, in view of the size of the typical Low Emission Zones (LEZ) enforced in several (European) cities, there is a need to enhance the resolution of the satellite data. Second, there is a non-trivial relation between the column amount measured by a satellite and the near-surface concentrations actually leading to adverse health impacts. Third, the integration of observations from multiple LEO and GEO platforms into a synergistic system requires due care for their (relative) biases and for their different perception of atmospheric features.

Objectives

The overarching objective of the LEGO-BEL-AQ project was to facilitate the stakeholder uptake of satellite AQ data by advancing on the three challenges identified above, with applications specific to Belgium, its regions and cities. Essential to this was bringing together the expertise in satellite-based monitoring of tropospheric composition at BIRA-IASB with the in-situ and modelling expertise and the relation with key stakeholders and policy makers at IRCEL-CELINE. The first challenge was addressed by developing oversampling/superresolution tools for satellite data, based on selective aggregation and geostatistical techniques, effectively trading temporal for horizontal resolution (WP1 of the project), and by applying these on S5P observations of tropospheric NO_2 over Belgium, with a focus on key cities such as Brussels, Antwerp, Ghent, Liège, and Charleroi (WP2).

The second challenge was addressed by comparing the high-resolution S5P maps over Belgium with the in-situ measurements and the derived RIO interpolated data to assess under which conditions the high-resolution satellite maps of the NO_2 column can be considered as representative for the distribution of the NO_2 surface concentration (also in WP2); The third challenge was addressed (WP3) by running the OSSSMOSE observing system simulator at BIRA-IASB on the high-resolution maps produced in the 1st WP to quantify the impact of the particular viewing geometry of the geostationary sounders (located above the equator and observing our latitudes under very oblique angles) on the measurements and their consistency with the LEO platform data.
To advance on the uptake by key stakeholders, a separate work package (WP4) was dedicated to user interaction: collecting requirements, ensuring availability of outcomes, and designing a roadmap for the future to take this work to an operational level.

Conclusions & recommendations

From the work performed in LEGO-BEL-AQ, the following key messages could be distilled:

a. The approach to trade temporal for spatial resolution by aggregation and oversampling is successful for LEO sounders such as S5P-TROPOMI, in particular when the temporal averaging window is of the order of several months (Figure 1).

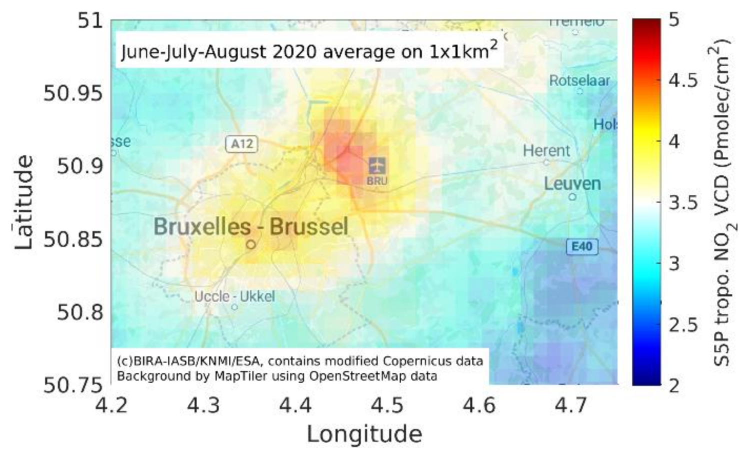

Figure 1: Oversampled average S5P-TROPOMI tropospheric NO_2 columns over Brussels for summer 2020.

b. Data sparseness, specifically due to cloud cover in winter, is an issue for smaller aggregation windows. Filling data gaps due to cloud cover is advised against as errors may be large.

c. The increased resolution obtained by oversampling S5P-TROPOMI tropospheric NO_2 data brings valuable information on the spatial distribution of NO_2 over Belgium, and on its medium to long-term temporal evolution

d. The spatial correlation between tropospheric NO_2 columns and corresponding near-surface concentrations as measured in-situ is (surprisingly) high for longer temporal averages (seasonal and annual). Correlation coefficients range from 0.8 to 0.9.

e. This high correlation implies that a pragmatic synergistic use of satellite and in-situ data, using Kriging Regression to derive near-surface concentrations for the entire Belgian domain, is meaningful. (Figure 2Figure 2).

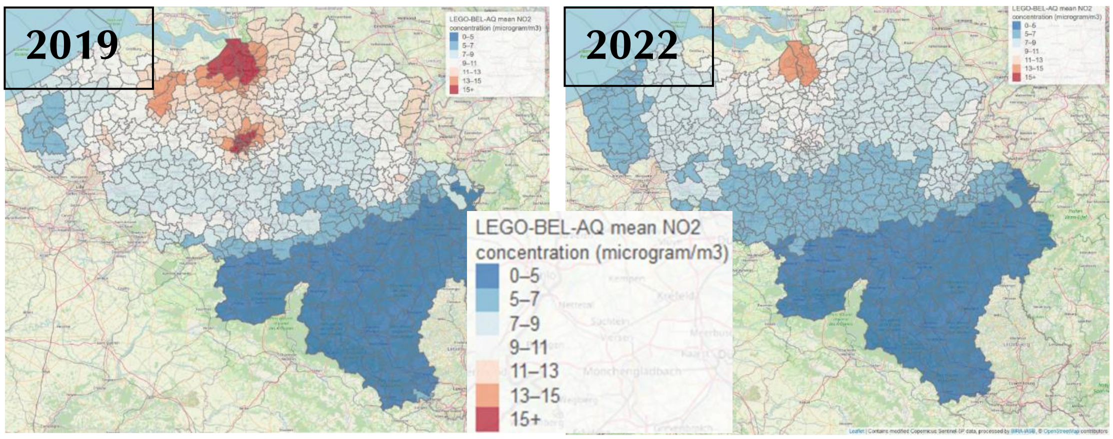

Figure 2: Maps of annual mean early afternoon NO_2 concentrations, averaged per municipality, for 2019 (left-hand panel) and 2022 (right-hand panel), as calculated with a synergistic use of both S5P TROPOMI NO_2 tropospheric vertical column densities and RIO near-surface concentration data. The color scale is chosen to reflect compliance with the WHO annual exposure limit guideline (10 µg/m3), although that refers to the full daily exposure, not just the early afternoon situation presented here.

f. To study long-term temporal evolution, care must be taken to start from a homogeneous level-2 satellite data set. For S5P-TROPOMI, ESA has just performed a full-mission reprocessing, which should be the starting point for any trend study. Cal/Val results must be taken into account.

g. Still, satellite and in-situ/model data show different long-term temporal behaviour; Satellite data shown no/little impact from LEZ (decline in NO_2 columns in line with previous years/decades), while in-situ and RIO show strong reductions in "urban" Belgium. Further analysis is needed.

h. Due to the fixed location of geostationary platforms, spatial resolution cannot be increased through aggregation + oversampling for these sounders. A synergistic use of LEO+GEO data is essential.

i. Spatial smearing biases due to large viewing and solar zenith angles may be substantial for GEO sounders such as the upcoming Sentinel-4.

j. Interest for these applications in the Earth Observation (EO) community is strong, worldwide.

k. However, awareness of the space component for AQ among environment specialists outside the EO community is limited and needs more exposure through channels other than those habitually used by EO scientists.

l. The collaboration between BIRA-IASB and IRCEL-CELINE is already very productive in making the bridge between EO and (in-situ) AQ monitoring (in Belgium).

Beyond the end of this project, recommended future research covers (1) further investigation into the discrepancy in temporal trends between satellite and in-situ measurements, (2) integration of the diurnal information to be obtained with Sentinel-4 when launched, (3) geographical extension to Europe and beyond, (4) inclusion of additional AQ components, such as PM2.5 estimates from aerosol optical depth data, (5) more advanced trend and exposure estimates including auxiliary data on e.g, population density, insolation, etc., (6) emission estimates, using for instance the flux divergence method, and comparison to bottom-up emission inventories, and finally, (7) further integration into the official monitoring systems.
Technical project outcomes are available through the website (http://lego-bel-aq.aeronomie.be) and/or by request to the project Principal Investigator.

Keywords

Air Quality trends - Nitrogen dioxide - Low Emission Zones - Remote sensing from space - Copernicus - ESA - Satellite observations – Sentinel-5P TROPOMI - Sentinel-4 - Superresolution