VERBE: towards a greenhouse gas emission monitoring and verification system for Belgium - current status

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VERBE project and objectives

In the context of the Paris Agreement, the VERBE project aims to build a dedicated observation infrastructure accompanied by a dedicated inversion framework for Belgium, to establish a sustainable Belgian observation- and model-based Emission Monitoring and Verification System (MVS) for emissions of greenhouse gases (GHG).

- Focus on **CH_4, CO_2 and N_2O**
- 4-year project, funded by Belgian Science Policy Office (BELSPO), End of project: Dec 2026
- Related long-term project (10 years): BE-MVS, structural collaboration between BIRA-IASB and UAntwerp

- **New** additional atmospheric ICOS- and TCCON-type **observations of GHG in Belgium**
- An inverse modelling **framework** for GHG for Belgium, based on WRF-Chem
- A **demonstration of the added-value** of providing top-down information about GHG emissions for Belgium
- **An indication of the potential** to reduce uncertainties in the bottom-up inventories and of the potential of the initiated system to become a key decision support tool for stakeholders and policymakers
- Provide **spatially resolved** feedback of the bottom-up emission inventories
- A **roadmap** to further improve and sustain the MVS capacity in Belgium

Observation infrastructure (BIRA-IASB, UAntwerp, ULiège)

Atmospheric observations

Based on an ensemble of existing observations, including the integrated Carbon Observing System (ICOS) atmospheric and existing satellite data, to be complemented with new local observations: Campaign-based initialization of the proposed infrastructure for ground- and tall-tower based in situ and remote sensing observations of the target GHGs in Belgium.

FTIR campaign, focus on the city and port of Antwerp

- Mobile FTIR remote sensing instruments up- and downwind of Antwerp
- First campaign between April 25 - May 5 2024. Two EM27/SUN instruments were provided by Karlsruhe Institute for Technology (KIT), one by Vrije Universiteit Amsterdam. The fourth instrument was the BIRA-IASB Invenio instrument enclosure.

- Despite technical and meteorological challenges, a good intercomparison was found, gaining additional experience and insights into the instruments.
- Second campaign planned for 2026.

Figure 1. Left: FTIR instrument locations around Antwerp during the campaign.
Right: Intercomparison of four mobile instruments at BIRA-IASB, Uccle, before the campaign.

New ICOS atmospheric site in Belgium

- With support from Michel Ramonet at LSCE a Picarro analyzer will be placed at a communications tower in the Meerdaal forest in Oud-Heverlee (7 km South of the city of Leuven).
- Two platforms at 58 meters above ground level (magl) and 81 magl.
- Currently being implemented, ready by end of 2025
- To be labelled ICOS class 2 site (with support of Belspo).

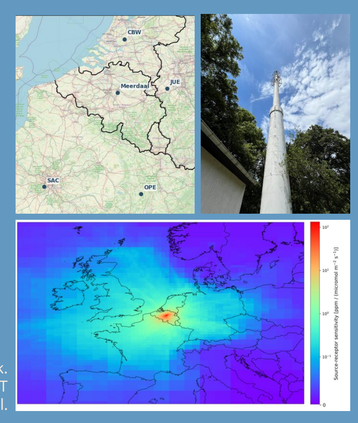


Figure 2. Left: Location of Meerdaal site compared to existing ICOS network.
Right: The communications tower with two platforms. Bottom: Integrated STILT surface sensitivity for the year 2022 at the 81m tower level in Meerdaal.

Ecosystem observations

- UAntwerp and the ULiège operate 7 ICOS ecosystem stations in Belgium. They bring the knowledge of their ecosystem sites and associated datasets, and their experience in the modelling of biogenic GHG exchanges, ensuring an appropriate use of the ICOS flux data.
- The available flux data will for example be used to validate the derived emissions.

Inversion framework

Combine ground- and space-based **observations** of atmospheric GHG concentrations with **atmospheric transport models** in a Bayesian inversion framework. The observations are used to **constrain prior emission inventories** and to yield top-down emission estimated for the target GHGs

➔Application of **CTDAS-WRF** (currently being implemented at BIRA-IASB)
The CarbonTracker Data Assimilation Shell (CTDAS) applies an Ensemble Kalman Filter approach for optimizing GHG fluxes using observations of their atmospheric mole fractions (van der Laan-Luijkx et al., 2017). Recently, it was coupled with the atmospheric transport model WRF-Chem, called CTDAS-WRF (Reum et al, in prep.).

Prior fluxes (UAntwerp, ULiège)

Improve precision of regionally upscaled biogenic GHG fluxes specifically adapted to the Belgian domain:

- Limit estimations to landcovers/ecosystems regionally present while fine-scaling these (e.g. Croplands)
- Integrate high-resolution Sentinel remote sensing data
- Based on the Vegetation Photosynthesis Respiration Model (VPRM) and/or FLUXCOM-X machine learning system

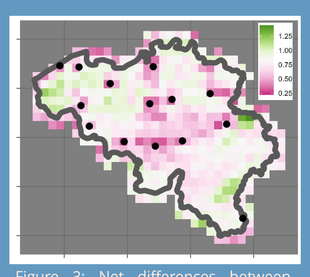


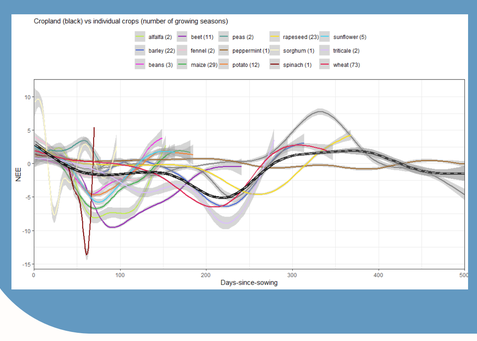
Figure 3: Net differences between monthly global VPRM and FLUXCOM-X net ecosystem exchange (NEE) emission predictions across the Belgian domain from 2012 – 2021 (without 2019).

VPRM vs. FLUXCOM-X vs. ICOS

- VPRM generally predicts more extreme fluxes
- Most agreement in predictions in urban areas and summer/winter and highest disagreement in rural areas and spring
- By far the highest divergence to actual fluxes on cropland which is at the same time the largest landcover class in Belgium

Landcover (LC)	BEL LC (%)	Dif. VPRM	Dif. FC-X
Cropland	**39.3**	**1 ±2.7**	**0.9 ±2.8**
Closed mixed forest	8.4	-0.3 ±0.9	0.2 ±0.8
Herbal Vegetation	8.4	0.1 ±2.1	0.2 ±1.4
Evergreen needle forest	6	-0.3 ±1.1	0.1 ±1.3
Shrubs	0.1	-0.3 ±1	0.1 ±0.5

Table 1: The five ecosystem/landcover classes represented by ICOS towers within Belgium (Landcover), their respective percentage share of landcover across Belgium overall (BEL LC) and the average divergence in monthly average NEE fluxes to the estimates from global VPRM (Dif. VPRM) and FLUXCOM-X (Dif. FC-X) estimates.



Integration of crop type

- Different crops show very different NEE emission profiles after sowing (left figure)
- Sentinel resolution RS data and crop-type identification allows field level characterization

➔ Does the inclusion of crop type improve regional GHG estimation and/or biogenic prior uncertainty estimation for the atmospheric inversion?

Atmospheric transport model (BIRA-IASB)

Evaluation of WRF-GHG forward simulations over Belgium and neighboring countries by comparing with local meteo observations (RMI), ICOS and TCCON data.
Sensitivity tests of anthropogenic inventories and vertical emission profiles.
Publication in prep. (Wang et al.)

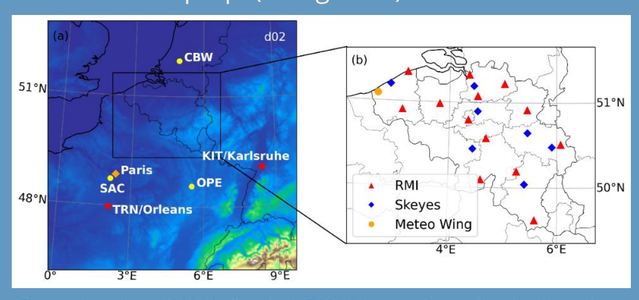


Figure 4: Locations of ICOS (yellow dots), TCCON (orange diamond) and co-located (red stars) sites within domain 2 (a), and synoptic stations in Belgium for which meteorological data are available for our study period (b). The background color in (a) represents surface altitude.

WRF-GHG configuration

- Nested domains: 9 km – 3 km
- Simulation from June 2018 to August 2018
- Boundary conditions: ERA5, CAMS EGG4
- Online VPRM fluxes using MODIS, Copernicus Dynamic Land Cover and parameters by Glauch et al. (2025)

Anthropogenic emissions

- CAMS-REG-ANT (0.1° x 0.05°)
- EDGAR v2024 (0.1° x 0.1°)
- TNO2018 (~ 1km x 1km)

Applying sector-specific sectoral profiles from Brunner et al. (2019)

➔ Largest impact of anthropogenic emissions at Karlsruhe (KIT), where many sources are nearby. There, using vertical emission profiles significantly improves the model simulations. The other sites are more rural.

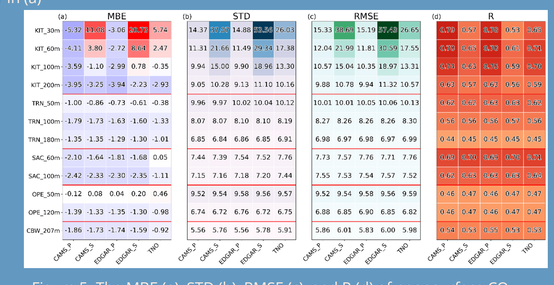


Figure 5. The MBE (a), STD (b), RMSE (c), and R (d) of near surface CO_2 concentrations between observations and five different simulations at different heights at various ICOS stations.

We thank the work of the PIs of the ICOS and TCCON sites for providing their data.

Partners

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National partners

International partners from Germany, France and the Netherlands are involved in the VERBE project or are member of the project's follow-up committee.