A city to national-scale inverse modeling system to assess the potential of spaceborne CO_2 measurements for the monitoring of anthropogenic emissions

TRAcking Carbon Emissions

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1. The TRACE project

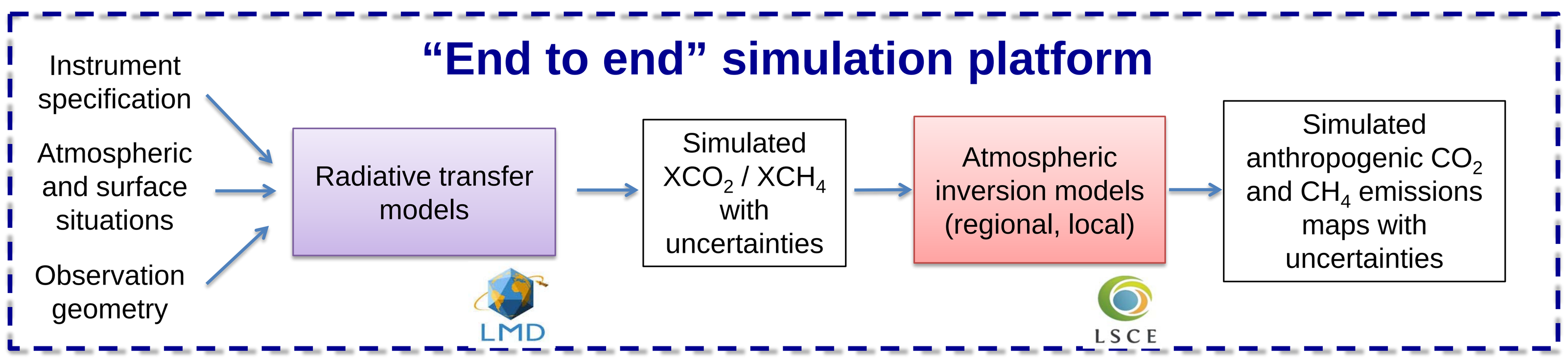
Comprehensive information about anthropogenic CO_2 emissions of power plants, cities, and countries up to the globe is needed to track the effectiveness of emission reduction policies in the context of the Paris Agreement on Climate and other voluntary emission reduction efforts. To answer that need, the TRAcking Carbon Emissions (**TRACE**) research project aims to analyze the potential of innovative space-based and in situ observing systems for the monitoring of greenhouse gas (GHG) emissions. The project addresses a broad range of spatial scales across which GHG emissions are distributed: ranging from local intense point sources like industrial sites to regional and national scales. It is hosted by the UVSQ university and gathers research laboratories (LSCE and LMD) with industry partners (ThalesAleniaSpace, Total and Suez).

2. An end-to-end performance simulation platform

The TRACE project will provide a complete forward and inverse modeling chain for the conversion of measurements from a SWIR instrument into GHG flux estimates.

The performance of new GHG space missions will be assessed:
- in terms of precision of the estimated fluxes
- with respect to the instrumental configurations

The inversion chain will control at high temporal resolution the emissions of 100-200 cities and power plants as well as regional budgets in western Europe.



3. Radiative transfer inverse scheme

The radiative transfer inverse scheme will provide XCO_2 data and errors from SWIR satellite measurements.

- Forward simulations of the radiances in SWIR by a radiative transfer model consistent with the observing instrument specifications and with the geometry of the orbits (Fig. 3.2.).
- Sensitivity of the simulated radiances to the atmospheric (CO_2, H_2O, aerosols, …) and surface (albedo, spatial sampling of the observations, …) parameters (Fig. 3.2).
- Computation of XCO_2 data and their errors by a radiative transfer inverse model following the instrument time-spatial sampling (Fig. 3.1.).
- The sensitivities of the inversion products to the instrumental specifications will be assessed.
- **XCO_2 error maps will be used by the flux inversion model (section 5) to compute the potential errors on the estimated CO_2 fluxes.**

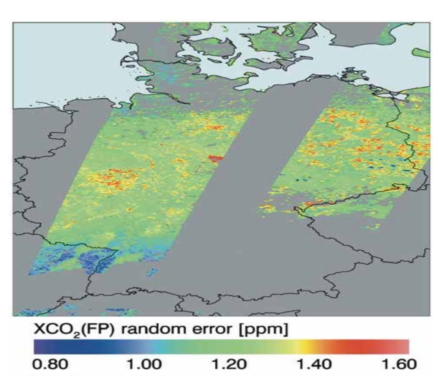


Fig 3.1. Example of simulation of XCO2 random errors along the spatial sampling of two Carbonsat tracks in Germany
Carbonsat report for mission selection – source IUP-Bremen

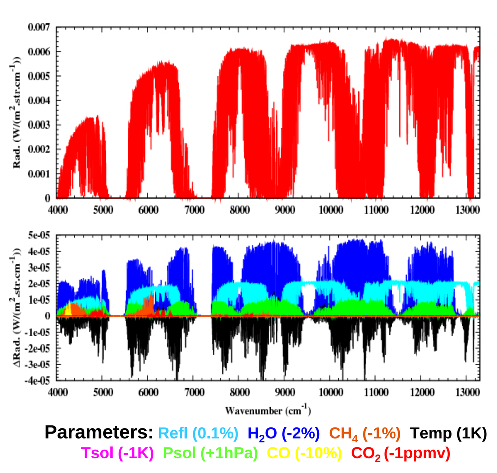


Fig 3.2.a Radiance spectrum in the SWIR range where absorption bands of CO_2 and CH_4 are located and from which dry-column concentrations of CO_2 and CH_4 can be derived.

Fig 3.2.a Sensitivities of the simulated radiances to atmospheric parameters or surface parameters (Surface temperature or reflectance)

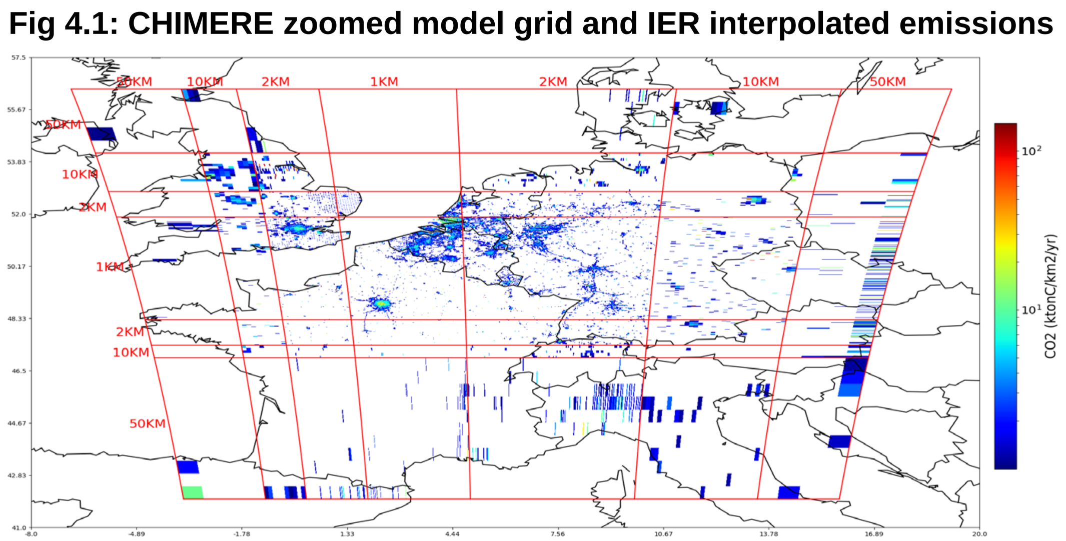
4. High resolution GHG transport model

Atmospheric transport configuration based on the regional CHIMERE model linking the local scales in Benelux-Northern France – SouthWest Germany.

- Zoomed model grid with resolutions ranging from 1km to 50km covering most of western Europe. Dense areas of anthropogenic emissions are finely covered by model resolutions of 1-2 km
- Anthropogenic emissions maps are extracted from the high-resolution data products of IER-Stuttgart (France 1mn, Germany 1mn, Benelux 1km, rest of Europe 5km)
- Biogenic CO_2 fluxes are derived from VPRM simulations at 8km resolution
- Anthropogenic and biogenic CO_2 fluxes have a temporal resolution of one hour
- Meteorological forcings and boundary concentration conditions are extracted from ECMWF products

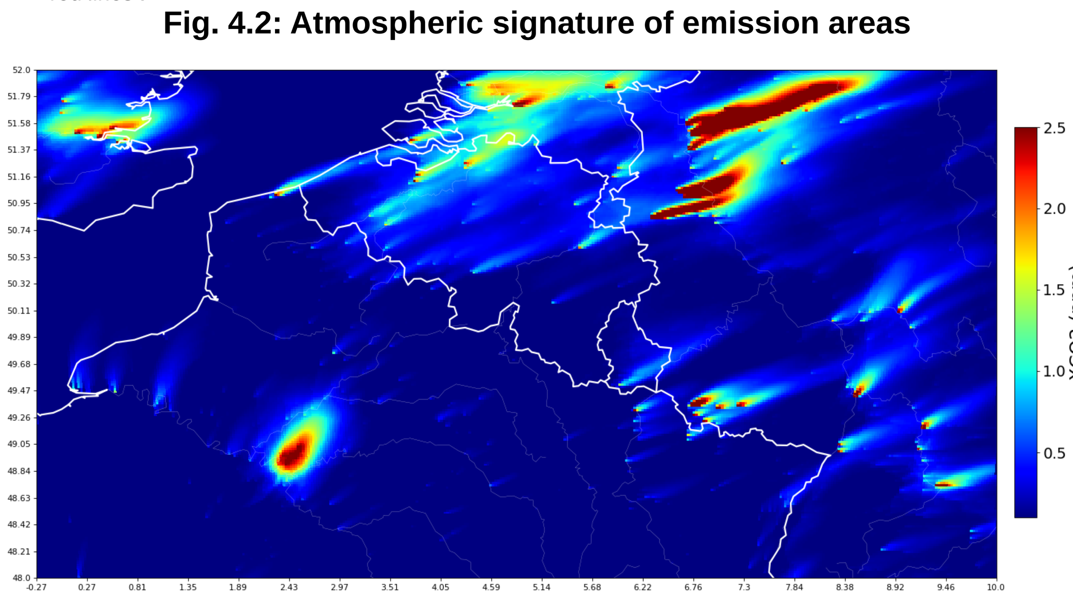
➢ Potential to simulate the atmospheric signatures of emission areas ranging from power plants (~1km²) to cities or countries at one hour time step.

Fig 4.1: CHIMERE zoomed model grid and IER interpolated emissions



IER annual emissions interpolated on the Grid of the CHIMERE model defined by different resolutions (50,10,2,1 km). Boundaries between areas of different resolutions are shown by the red lines .

Fig. 4.2: Atmospheric signature of emission areas



Simulation of the atmospheric signature of the anthropogenic emissions over northern France, Belgium and south-west Germany. The simulation covers 6 hours on july 05th, 2016. Are displayed the accumulated XCO2 over the 6 hours.

5. Flux inverse system

An analytical inversion sytem based on the bayesian formalism computes posterior uncertainties on CO_2 fluxes (**A** matrix, Fig. 5.1.)

- The inversion system will control the emissions of cities/power plants in the high resolution part of the domain and the regional budgets in the lower resolution part (Fig. 4.1.). This will enable the analysis of results at the city to national scales.
- In order to investigate the potential of satellites for the monitoring of CO_2 emissions, the inversion system can take into account a large range of specifications on the precision, the spatial resolution and swath of the satellite data.

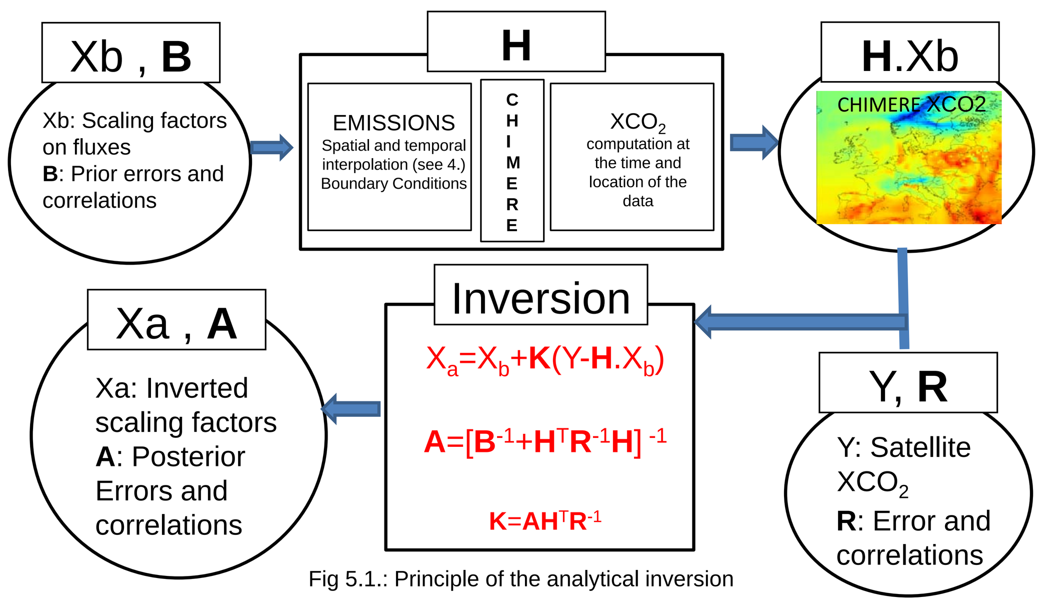


Fig 5.1.: Principle of the analytical inversion

Inversion of ~100 emitting areas
100-200 sources (cities and industrial sites in the target area, sectorial regional budgets in the lower resolution part of the domain) will be defined in order to be monitored individually by the inversion system.

A pattern recognition algorithm has been designed in order to define and select the high emitting areas that produce atmospheric XCO_2 signatures that could be detected from space (Figs 5.2 & 5.3.).

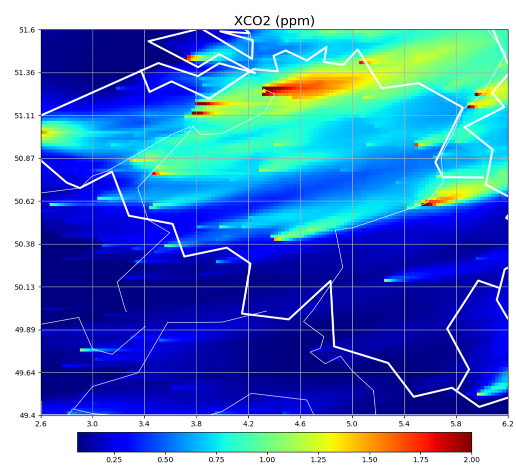


Fig 5.2.: Simulation of the atmospheric signature of anthropogenic emissions over Belgium (6H accumulated XCO_2)

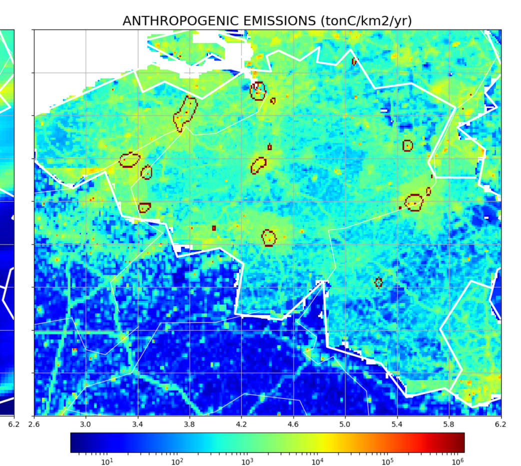


Fig 5.3.: Annual anthropogenic emissions extracted from IER products over Belgium (1km by 1 km resolution). High emitting areas detected by the pattern recognition algorithm are surrounded by a red countour.

6. Potential of CO_2 spaceborne spectro-imagers to constrain the hourly emissions of the Paris urban area

As a preliminary study, the inversion system is used to study the potential of a CO_2 spaceborne spectro-imager to constrain the hourly emissions of the Paris urban area.

- Inversion of the budgets of 1) the anthropogenic emissions for the Paris urban area, of 2) the anthropogenic emissions for the rest of the domain and of 3) the biogenic fluxes over the entire domain.
- For 10 days in march and may, the inversion system constrain hourly fluxes from 5 A.M to 11.AM (satellite overpass at 11 A.M.).
- The *a priori* errors on fluxes are set to 50% and no correlations are considered.
- Inversion results for the hourly fluxes (Fig. 5.1., 5.2., 5.3) and for the 6 hourly budgets (Fig. 5.3) of the Paris urban area are analyzed in terms of uncertainty reductions (UR) (Fig. 6.1., 6.2.) or in terms of *a priori* and *a posteriori* errors (Fig. 6.3.).
- **The inversion system allows to assess the sensitivity of the optimized emissions with respect to a large range of precisions (Figs 6.1, 6.2), of spatial resolutions (Fig 6.1.) and of swaths (Fig. 6.2.) of the satellite XCO_2 images. When considering several inversion days, it allows as well to assess the impact of the wind speed on the inversion of the hourly fluxes and 6H-budgets (Fig. 6.3).**

Impact of the precision

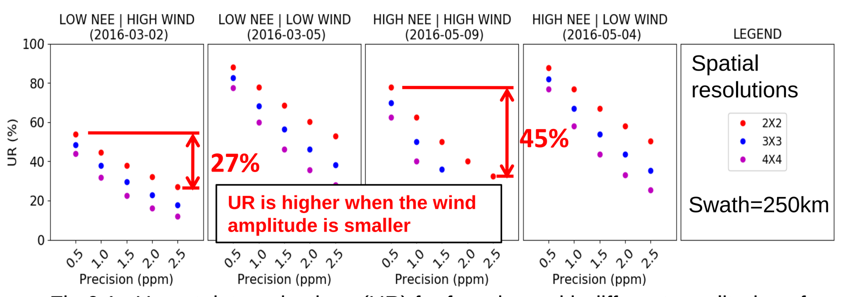


Fig 6.1.: Uncertainty reductions (UR) for four days with different amplitudes of biogenic CO2 fluxes (NEE) and different mean wind speeds. UR are computed for different precisions (x-axis) and spatial resolutions (colors) of the satellite data. Swath of the data is taken equal to 250km.

Swath impact

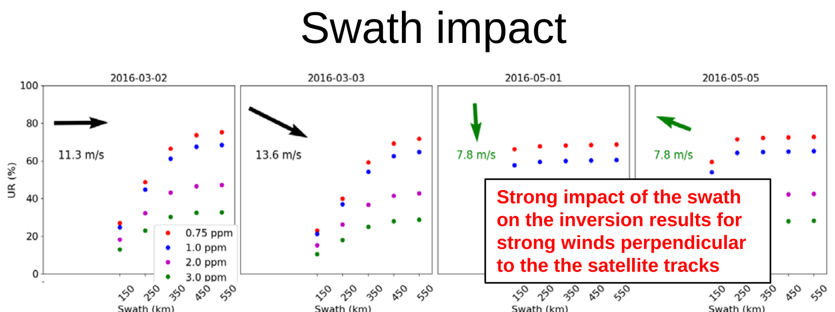


Fig 6.2.: Uncertainty reductions (UR) for four days with different mean wind speeds. UR are computed for different swaths (x-axis) and precisions (colors) of the satellite data. Spatial resolution of the data is taken equal to 2km by 2km.

Wind impact

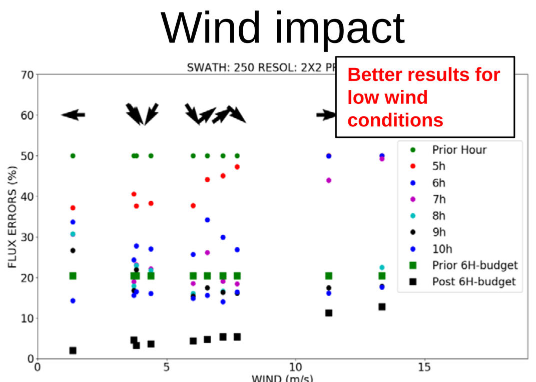


Fig 6.2.: A posteriori errors on hourly fluxes (dots) and on 6h-budgets (squares) for 10 days with different mean wind speeds (x-axis). The green dots stand for the *a piori* errors on hourly fluxes while the other dots represent the *a posteriori* errors for the hourly fluxes depending on the time of emission. The green and black squares represent respectively the *a piori* and *a posteriori* errors on the 6H-budgets for each day.

7. Conclusion & Perspectives

Benefits of the fine-scale information?
*W*hen targeting a large and isolated city such as Paris, increasing the spatial resolution of the imager by 2 does not appear to provide better results than if decreasing the measurement noise by 2 (Fig.6.1.) This indicates that the system does not really take advantage of the information on the fine scale patterns of the plume for such a city. **It should be different when considering more localized emitting areas.**

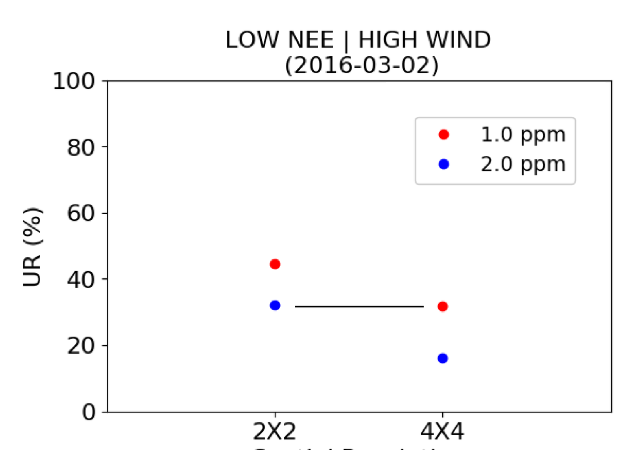


Fig 7.1: Uncertainty reductions on the anthropogenic emissions of the Paris urban area for different spatial resolutions (2km by 2km and 4km by 4km) and different precisions (1ppm and 2 ppm) of the satellite data. Results are shown for March the 2nd, 2016 characterized by a weak amplitude of the biogenic CO2 fluxes and high amplitude of the mean wind speed.

The inversion of an important number of different emission sources (section 5) will give, for a given measurement configuration, the precision of the estimated fluxes with respect to:
- The amplitude of the emission sources (temporal profiles)
- The extension of the emitting areas
- The impact of spatially closed emission sources whose atmospheric signatures may overlap