The potential of the XCO_2 high resolution imagery for the monitoring of CO_2 emissions from large cities and industrial plants

An overview of the studies at LSCE

Presentation: G. Broquet

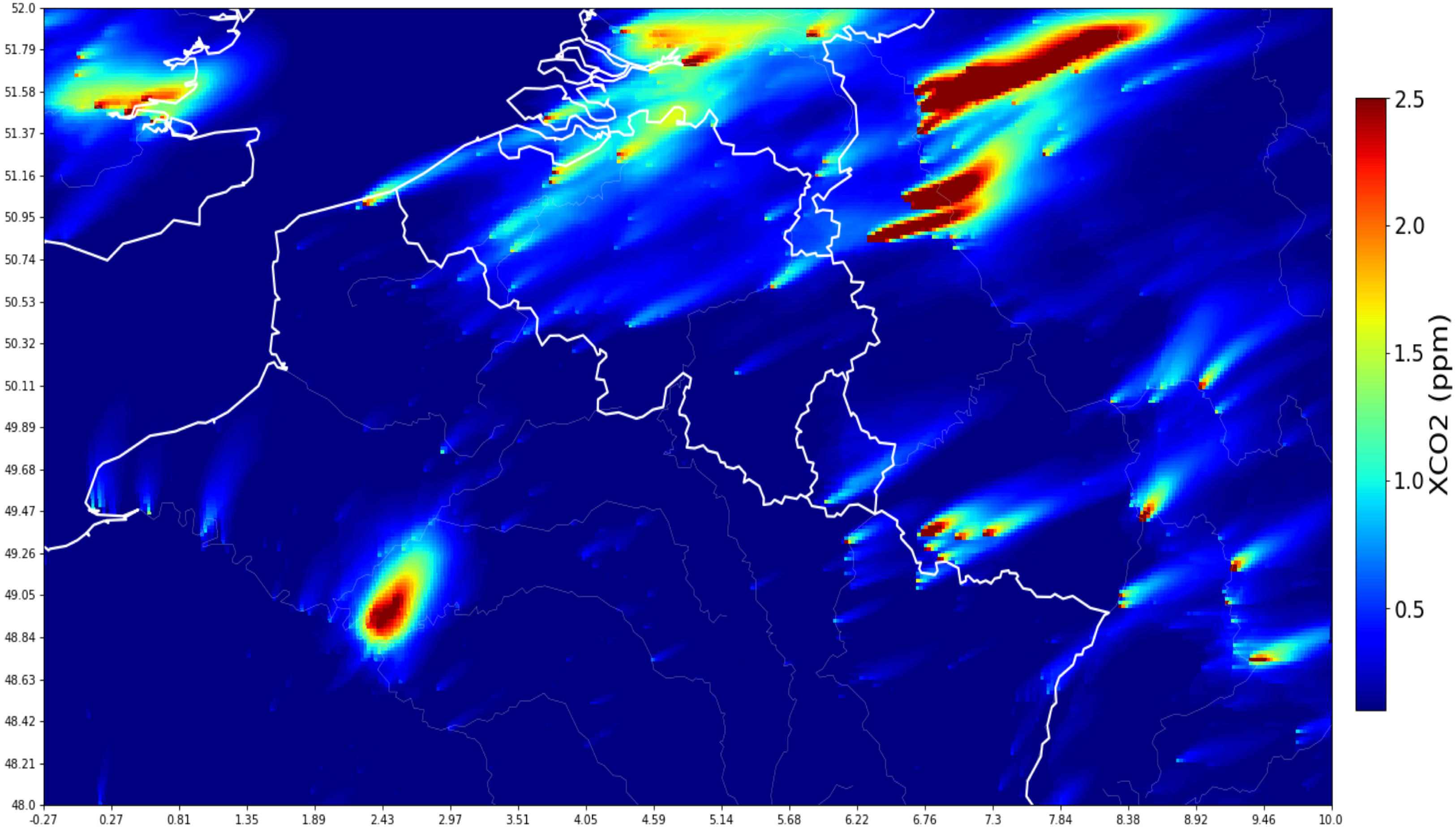
Contributions, collaborations

LSCE, Gif-sur-Yvette, France: D. Santaren, Y. Wang, F. Lespinas, A. Prokaieva, E. Potier, F.-M. Bréon, F. Chevallier, P. Ciais
IUP, Univ Bremen, Germany: M. Buchwitz, M. Reuter, H. Bovensmann
LMD, Palaiseau, France: C. Crevoisier, V. Cassé
JRC, Ispra, Italy: G. Maenhout
GMAO-NASA/GESTAR-USRA, Maryland, USA: T. Oda
Thales Alenia Space, Cannes, France: D. Simeoni
ESA, Noordwijk, Netherlands: Y. Meijer, A. Loescher

and partners and financial support from: **ESA LOGOFLUX** and **PMIF**, chaires **BridGES** & **TRACE** (with **Thales Alenia Space**), **EU/H2020 CHE**, **CNES-Geocarb-Fr** (incl. **SPASCIA**), **SPACEOBS** (**Univ. Paris-Saclay**)

Observing the atmospheric signature of CO_2 emissions from space

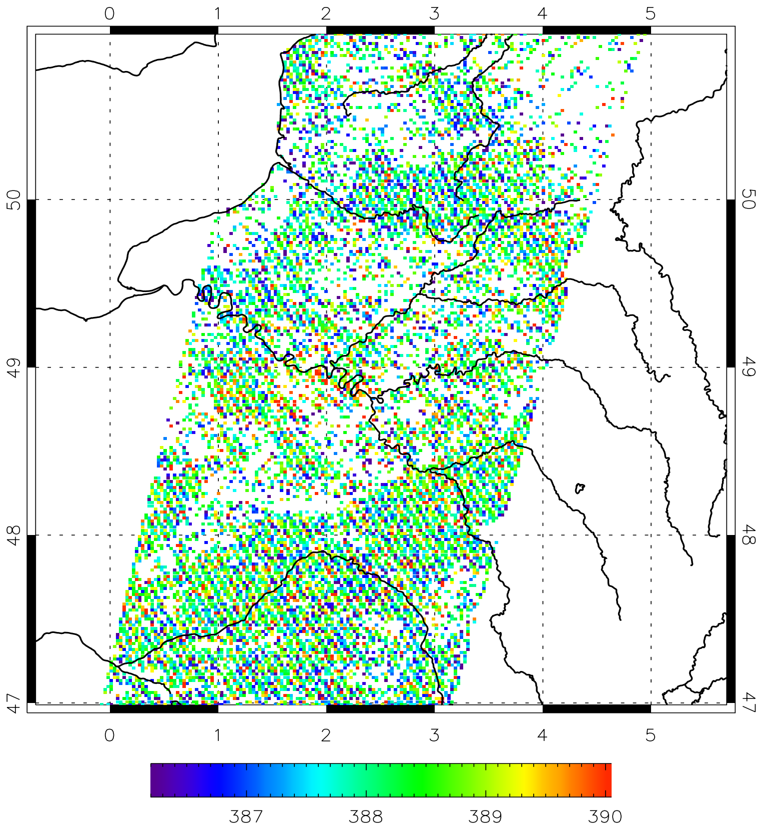
Simulation of a 1-h avg XCO_2 signature of anthropogenic CO_2 emissions in Europe at 2 km res (TRACE, Santaren et al.)



Local scale strategy for the inversion of the emissions

Targeting individual cities and power plants with images of their XCO_2 plumes

- **Individual images to invert emissions few hours before**
- **Challenges** for the analysis of plumes:
  - ➤ Detection, accuracy: large measurement errors and large background variations
  - ➤ Fitting the plumes despite model errors
- Studies often **focused on single (large) cities/plants: need to generalize results**
- **Number / temporal coverage of images limited: need for extrapolation to assess 1-day to 1-year budgets**:
  - ➤ Need for knowledge on the temporal variations of emissions, for constellations and complementary observation systems



XCO_2 obs in the Paris area by CarbonSat simulated with CHIMERE at 2 km res, the AIRPARIF inventory (Paris ~14 MtC.y^{-1}) and obs sampling & errors from IUPB (LOGOFLUX, Broquet et al. 2018, AMT)

OSSEs with local scale inversion at LSCE

For Paris & single images (LOGOFLUX, PhD theses)

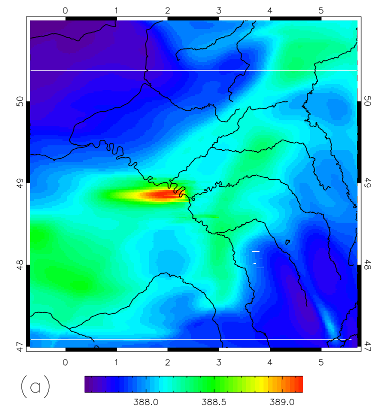
- Full analysis of impact from random and syst. obs errors
- Methods to address uncertainties in the plume modeling

For West Europe and few weeks (TRACE, CHE)

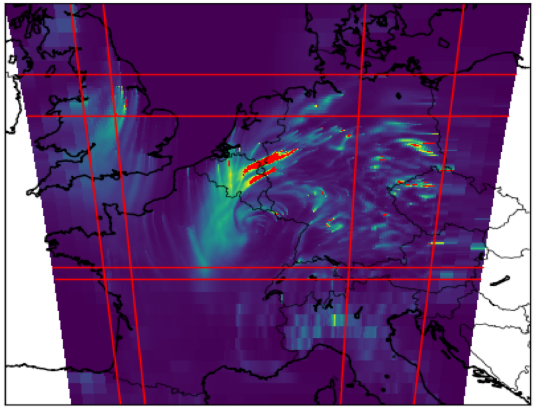
- Generalization to a wide range of sources, estimate of few-day and/or regional budgets
- Keeping Eulerien model, natural / diffuse fluxes
- Account for overlapping of plumes from nearby sources
- Ability to exploit synoptic / remote patterns (mix between local and large scale approaches)

World-wide system covering a full year (PMIF)

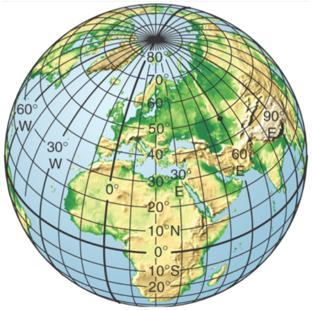
- Generalization to all sources / situations, estimate of few hour to 1-year, point source to national budgets
- Gaussian transport model, ignoring sources of errors



2 km res CHIMERE

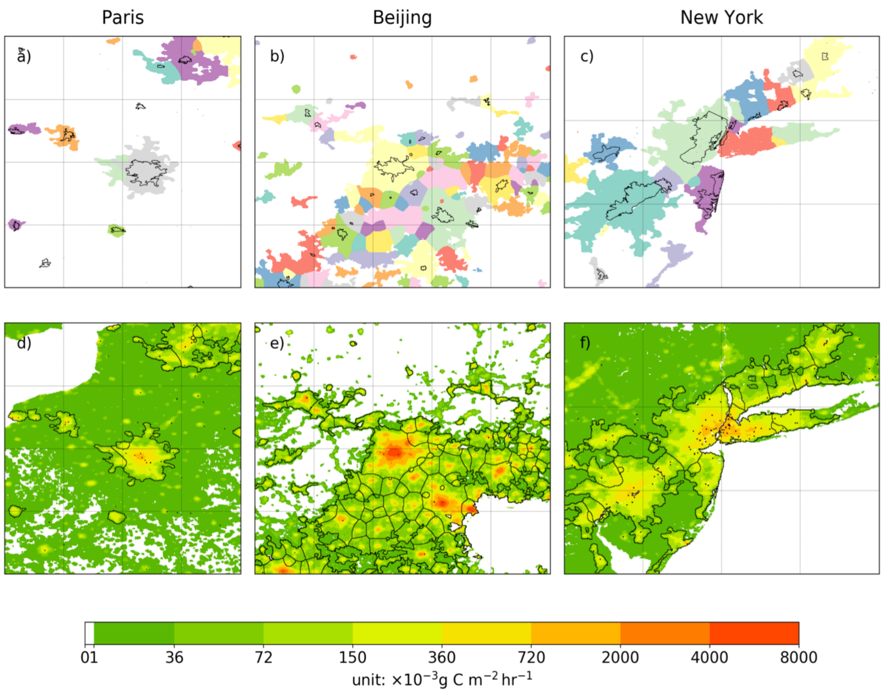

50 to 2 km res CHIMERE

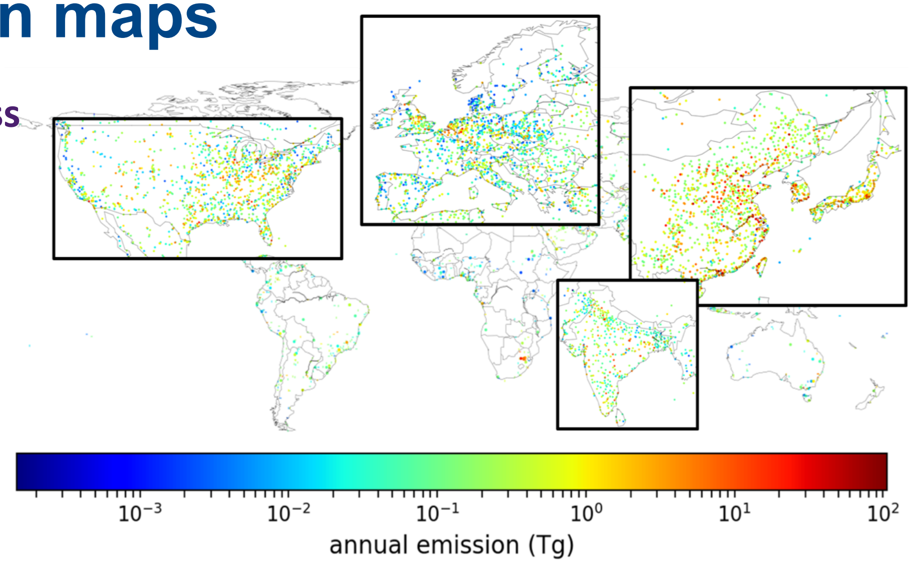
10° x 10° overlapping inversion windows



Decomposition of the emission maps

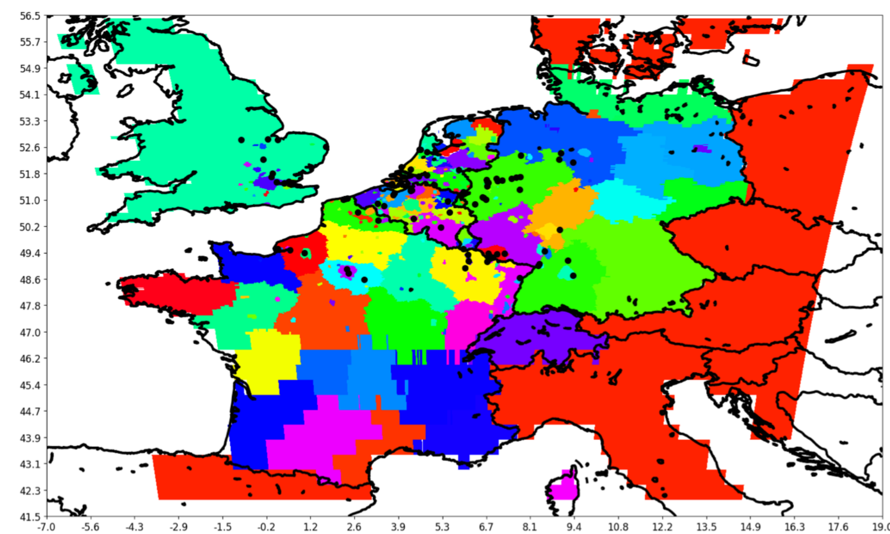
~11000 clumps (~70% of emissions) extracted across the globe from the ODIAC 1km res inventory
(PMIF, Wang et al. 2019, ESSD)





- Thresholds on emissions at 1-4 km^2 res
- Pattern recognition
- Large plants locations
- Analysis of XCO_2 fields
- Administrative boundaries

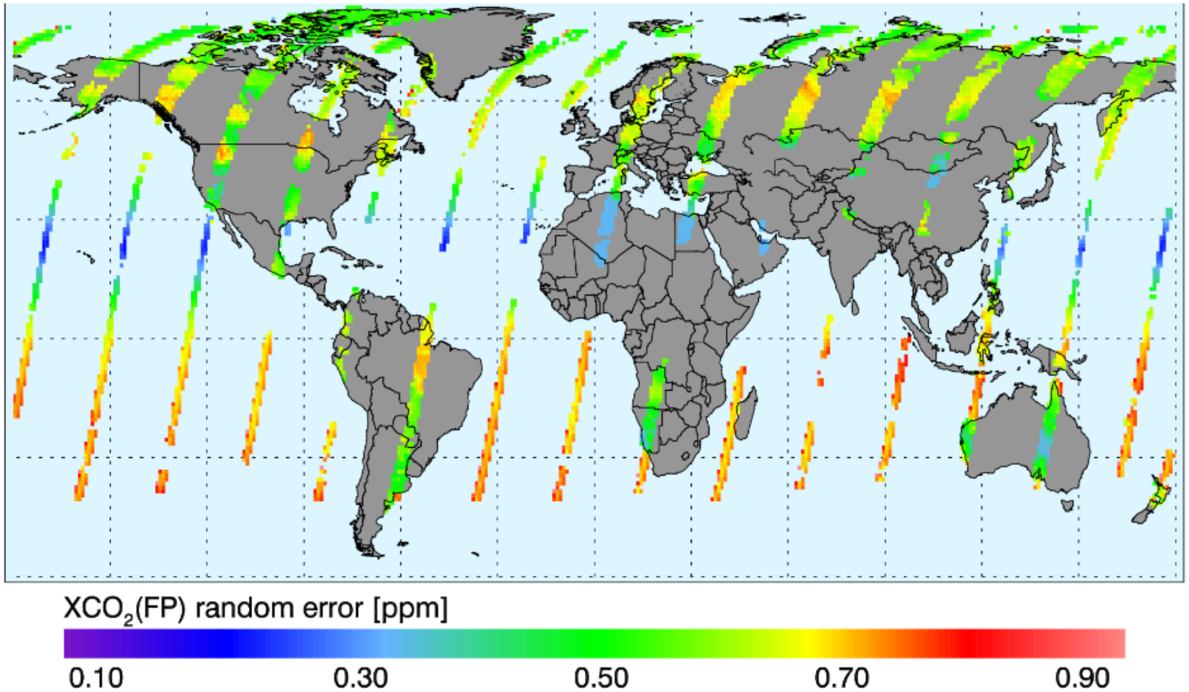
Clusters of emission in Western Europe
(TRACE, Santaren et al., in prep)



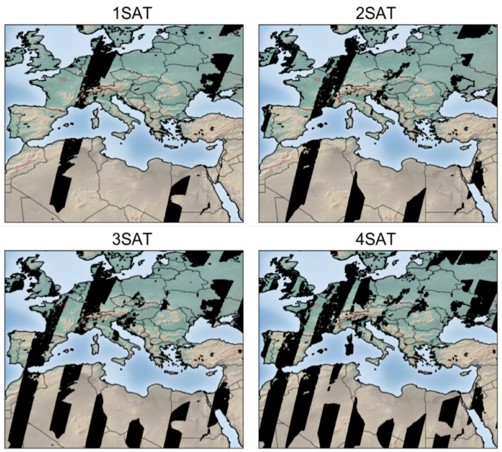
Observation sampling and errors

From idealized observations (with coverage at 2km res & 1 ppm precision) to realistic L2 data for **1 to 4 CO2M satellites** from IUPB (PMIF) and LMD (TRACE)

- **systematic errors ignored in the results presented here**



Simulation of random errors on data over 1-day from 1 CO2M satellite with 290-km swath by IUPB (PMIF, source IUPB)



Sampling of 1 to 4 CO2M satellites with 300-km swath during a day in April simulated by IUPB (PMIF, Lespinas et al. in prep)

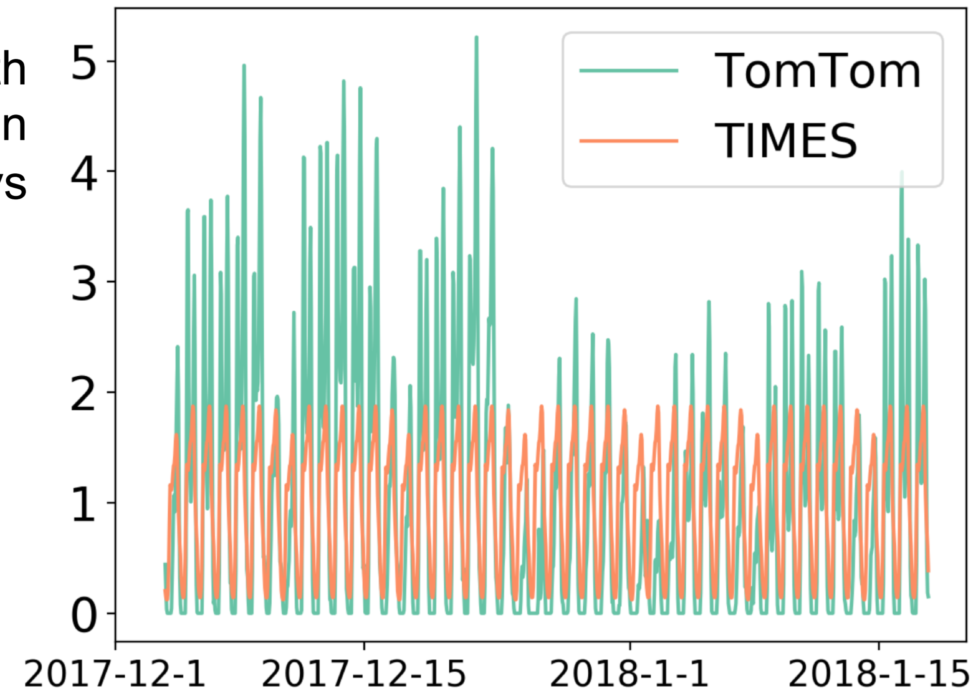
Temporal and spatial smoothing / extrapolation

- **New analysis of the spatial and temporal scales of the correlations of uncertainties in the inventories (used as prior of the inversions)**

➤ Monte Carlo generation of EDGAR maps by JRC, comparisons between EDGAR V4.3.2, ODIAC, FFDAS, PKU-CO2 v2

➤ Analysis of the real daily data for traffic and electric consumption, comparisons to the typical periodic profiles applied to inventories

➤ Different sets of inversions with different options for the correlation temporal scales within/between days including:
  - → Intermediate: 12h / 7d
  - → Strong: full / 20d



Comparison between daily traffic indices from TOMTOM and TIMES periodic profiles for traffic emissions
(PMIF, Wang et al., in prep)

Results at the 3/6-h scale (ignoring temporal correlations)

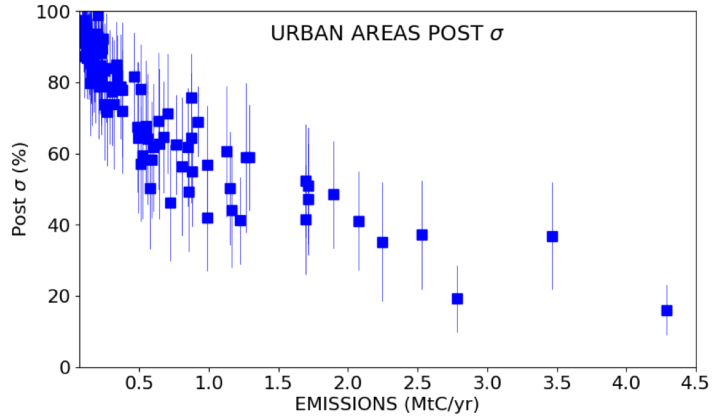
→ OSSEs ignoring systematic errors in XCO_2 retrievals and transport errors

Uncertainty in 6-h emissions of cities in W. Europe before satellite images for 15 different days in March

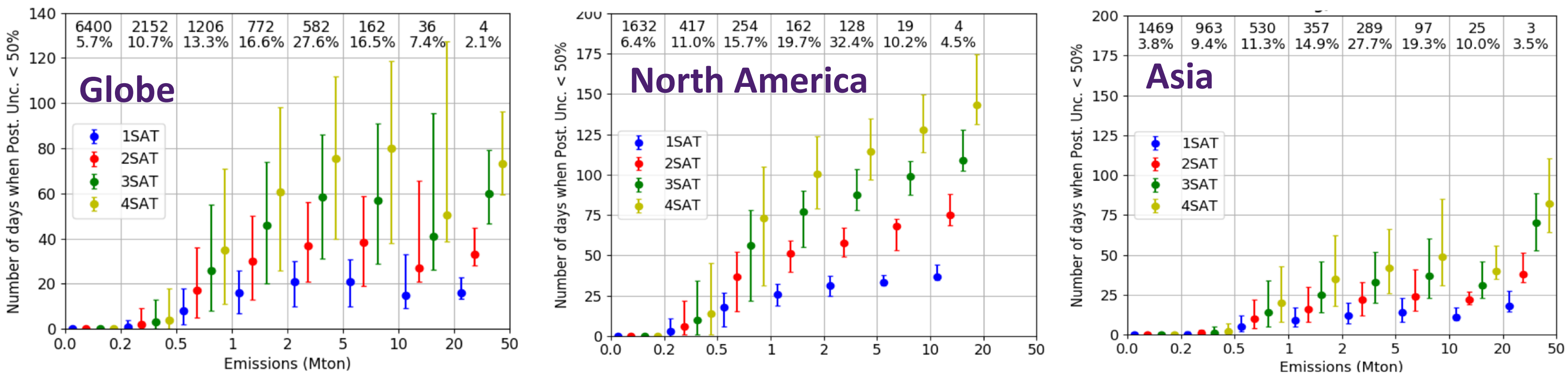
Spread: mainly due to wind

prior uncertainty: 100%

(TRACE, Santaren et al., in prep)



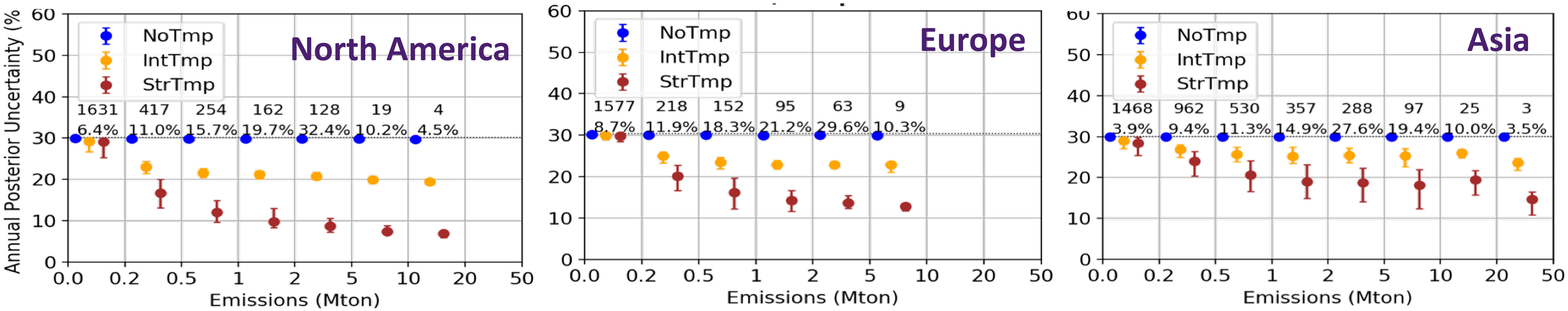
Number of days in the year with uncertainty in 8:30-11:30 emissions < 50% using CO2M images (at 11:30) (PMIF, Lespinas et al., in prep)



- Number of days with post uncert < 50% ~proportional to number of satellites
- Variations across regions & seasons driven by avg & seasonal clear sky fractions

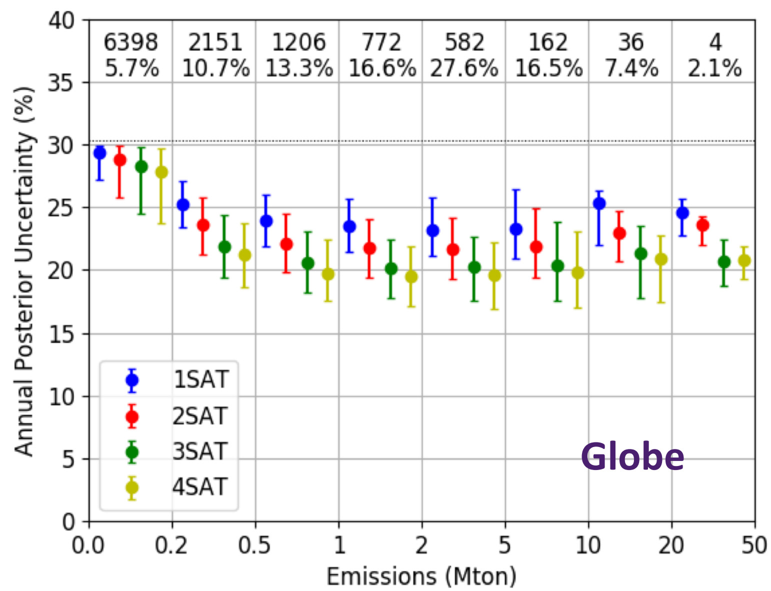
Results at the annual scale

Uncertainty in the annual budget of emissions of clumps with 1 CO2M satellite and with 3 scenarii of temporal correl in prior errors (PMIF, Wang et al., in prep)



Using 1 to 4 CO2M sat and 12-h/7-d temporal correlations in prior uncertainties

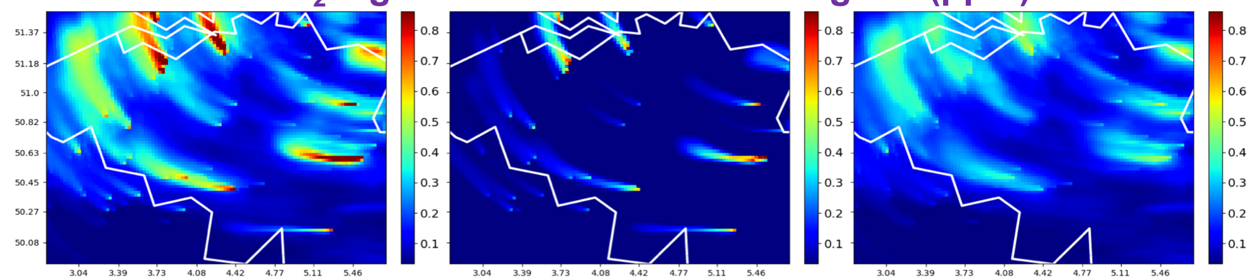
(PMIF, Lespinas et al., in prep)



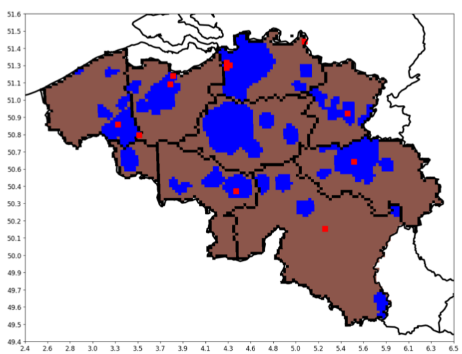
Ability to separate sources

Strong separation and ability to invert diffuse sources due to the good knowledge of transport ?

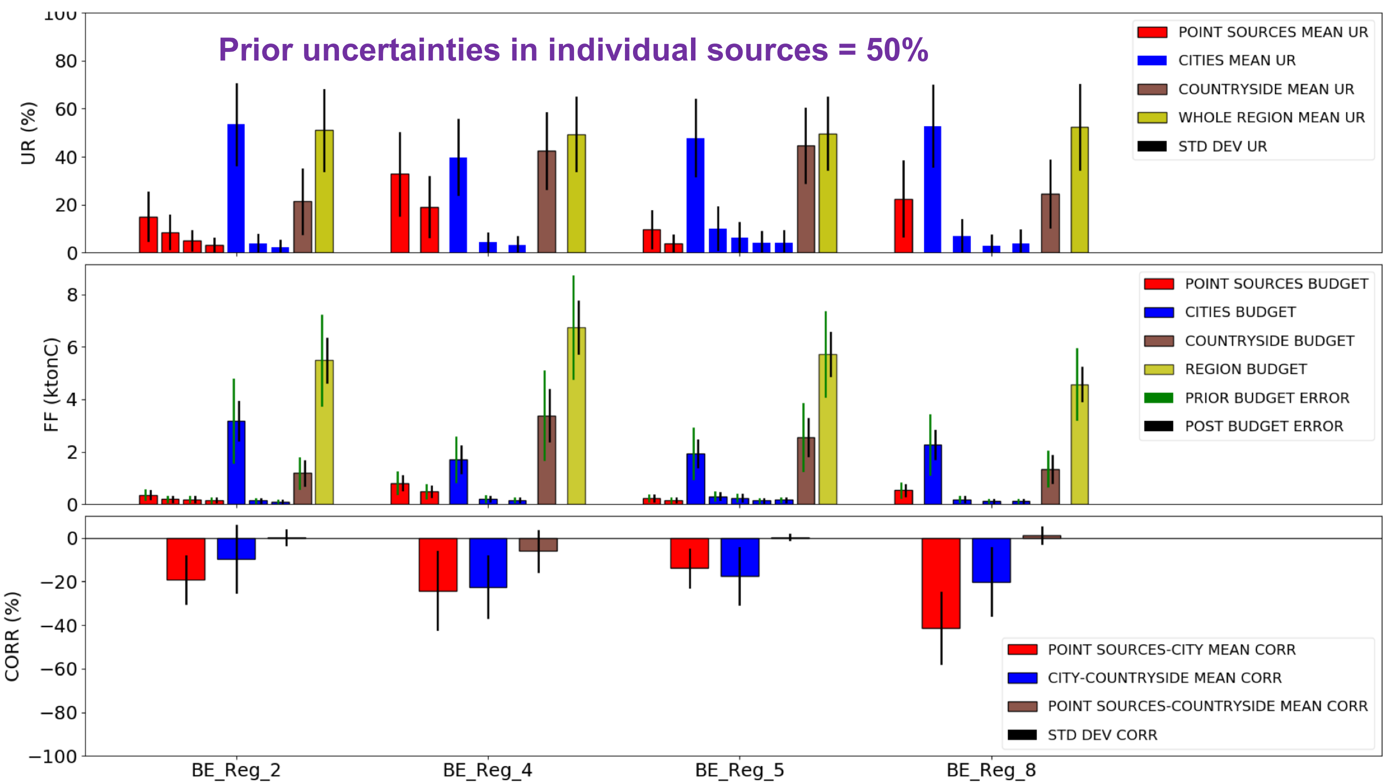
XCO$_2$ signature for sources in Belgium (ppm)



All sources **Large plants > 0.1 MtC/yr** **Other sources**

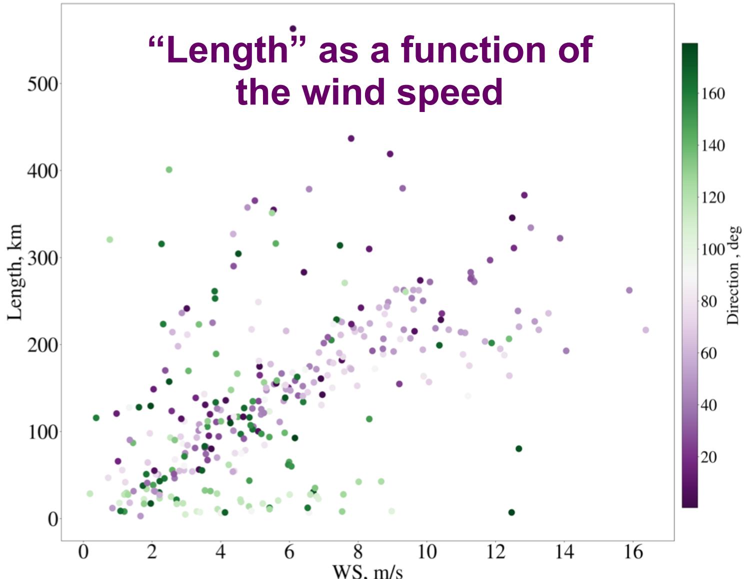


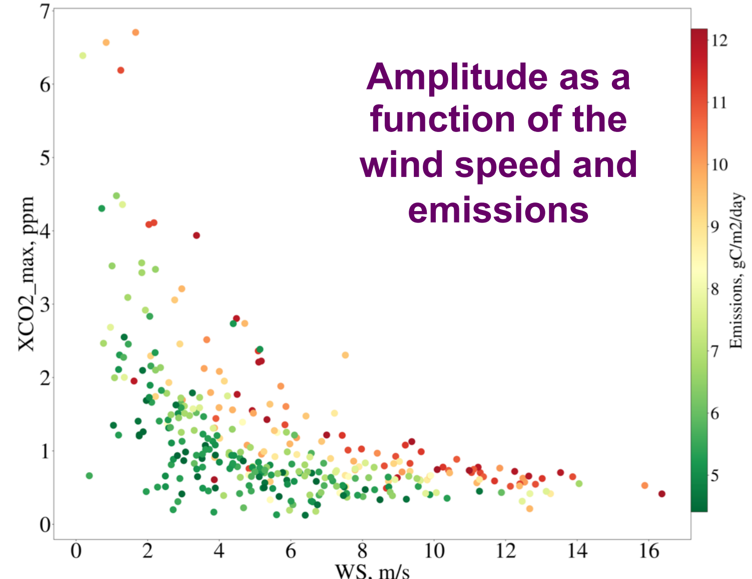
Statistics of uncertainties in 6-hour emissions from sources in Belgium (before satellite images) from 15 days in March (TRACE, Santaren et al., in prep)



Development of new methods to tackle realistic transport uncertainties

- **Characterizing the patterns of the plume from Paris**
  (CNES PhD thesis, Prokaieva et al., in prep)



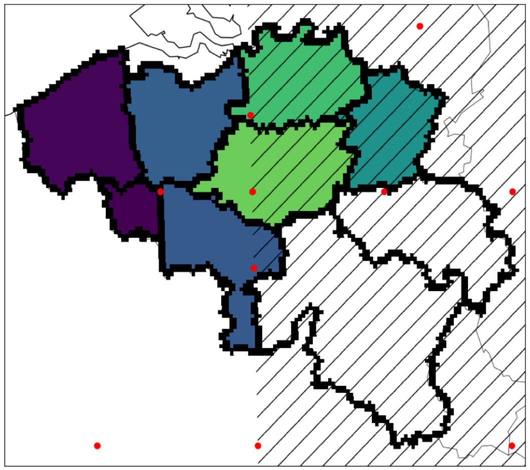


Simulations: 2 km res CHIMERE

- Collaboration with SPASCIA: fitting the XCO_2 images with Gaussian plume models ➞ see the talk by C. Camy-Peyret
- PhD thesis on the analysis of OCO-3 data (supervisors: T. Lauvaux, G. Broquet)
- Plans for analyzing plumes from TROPOMI

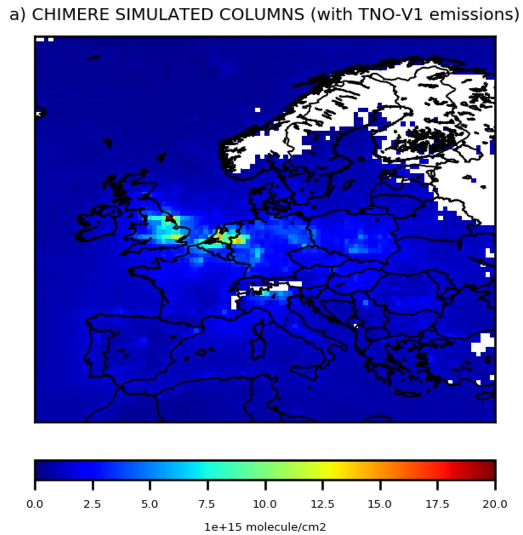
Complementary studies

Combination with ground based CO2, $^{14}CO_2$, APO and AQ networks, and with CO and NO_2 satellite data, coupling with large scale approaches

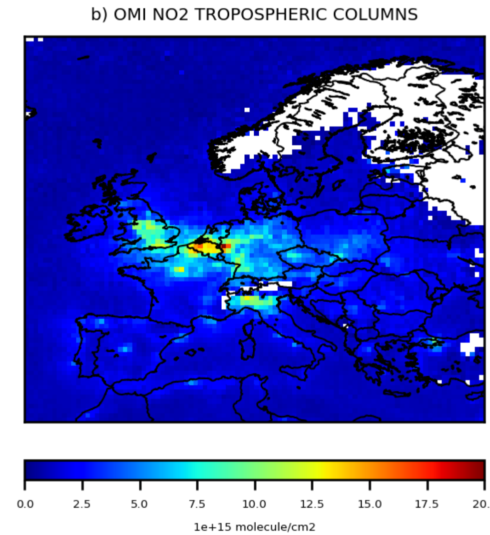


Joint assimilation of satellite XCO2 and in situ CO2 data to constrain regional budgets in Belgium
(H2020-CHE, study by E. Potier)

CHIMERE - TNO



OMI



Monthly mean of NO_2 tropospheric columns for the month of March 2012, in 1^e15 molec.cm^{-2}
(H2020-VERIFY, study by A. Fortems-Cheiney)

- Temporal and spatial complementarity between satellite and in situ data
- Tracers to strengthen the detection of $FFCO_2$ and the sectoral inversions
- ➤ Need for strategies for optimal co-assimilation

Some general comments

- The problem of separation of individual sources from other sources/sinks not critical when assuming that transport errors ~random noise ?

→ results from the global system quite consistent (slight overestimate of the inversion precision) with those from systems more complex locally

- Here, analysis of the limitations from the satellite and XCO_2 retrievals only (sampling & errors) ➞ optimistic regarding what will be achieved in practice
- However, modest levels of precision from inversion for a major part of the cities and plants

→ satellite CO_2 imagers should not be seen as stand alone obs systems, even if the starting point may be to design them as such ?

- Proper account for transport modelling uncertainties: critical need for new techniques to exploit satellite XCO_2 images