Title:

Regional and urban flux inversions: focus on the estimates of the European CO2 natural fluxes and of the CO2 anthropogenic emissions from Paris

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Abstract :

Regional atmospheric inversions using mesoscale atmospheric transport models have been developed in view to derive robust estimates of natural greenhouse gas fluxes at the continental to local scales. They are now also expected to support the monitoring of anthropogenic emissions at the city scale. We illustrate some of their achievements and critical remaining challenges through the description of some of the regional activities led at LSCE: the estimation of natural CO2 fluxes in Europe at 0.5° / 6-hour resolution and the estimation of the CO2 emissions from the Paris area at 6-hour resolution using ground based networks of CO2 mixing ratio measurements. We also give insights on the study of the potential of future high resolution satellite imagery of CO2 for the monitoring of city emissions.

Regional and urban flux inversions

Focus on the estimates of the European CO2 natural fluxes and of the CO2 anthropogenic emissions from Paris

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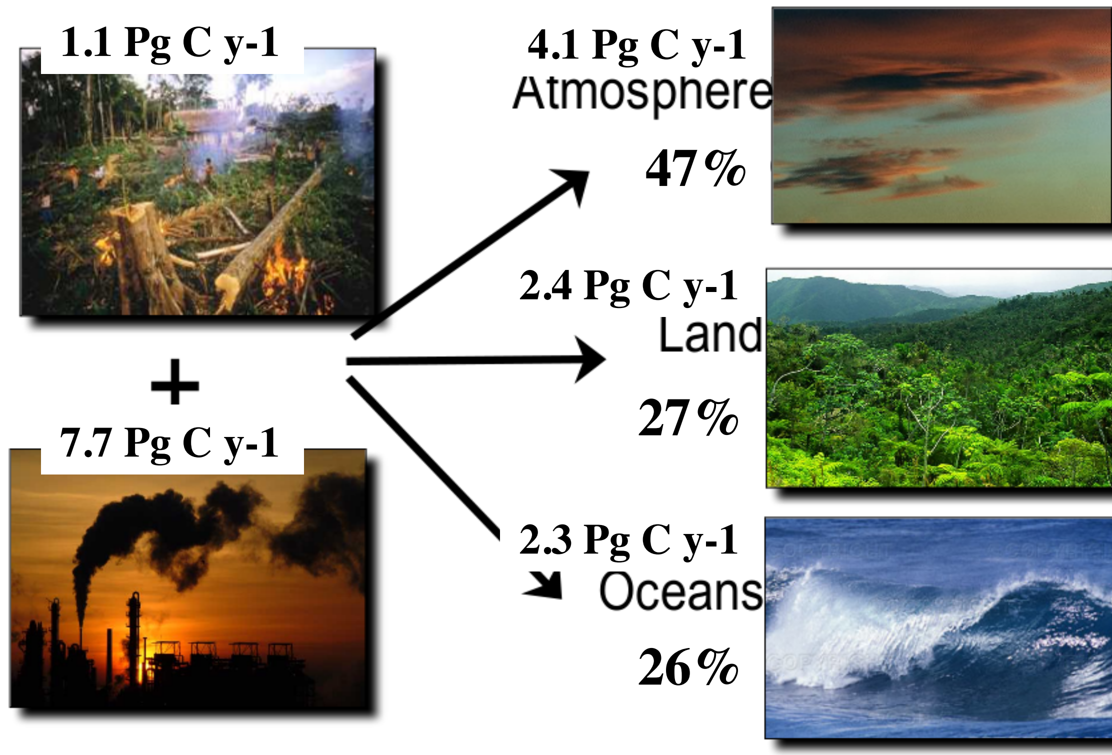
and other CarboEurope-IP, ICOS, AIRPARIF, CO2-Megaparis, Carbocount-city, LOGOFLUX, BridGES partners

The need for characterizing the spatial and temporal distribution of the carbon fluxes

Global estimates: CO2 anthropogenic emissions and natural sinks/sources for 2000-2009



- **Local, frequent and sectorial information on C-fluxes supports climate plans (verification, strategies for mitigation)**
- **Understanding the processes underlying C-fluxes based on high resolution information → ability to forecast their evolution / impact**

Uncertainties in traditional inventories of Carbon fluxes

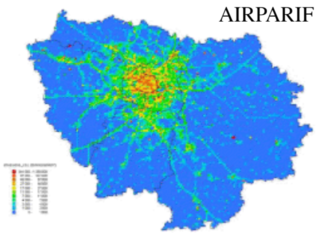
- **Large uncertainties especially at high spatial, temporal & sectorial resolution**
- **Need for an objective / independent quantification**
- **The atmospheric inversion developed by the scientific community can be used to improve / verify the inventories**

Emission inventory data for Paris – for different emission data sets

	EDGAR V4	IER 2005	AIRPARIF2005	AIRPARIF2008	Max – Min
Resolution	0.1° x 0.1°	1min x 1min	1km x 1km	1km x 1km	
Annual budget of Ile-de-France (TgC)					
Residential	6.75	5.36	5.65	7.80	**31%**
Road	8.50	6.03	3.63	3.37	**60%**
Industry	5.19	4.61	3.02	3.09	**42%**
Total	24.65	16.39	12.34	14.26	**50%**

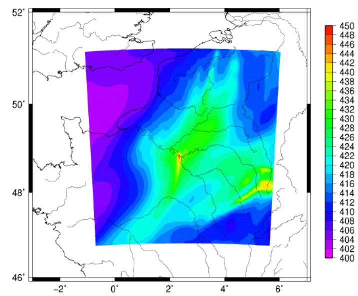
GHG atmospheric inversions from the global to local scales

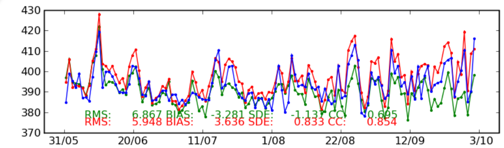
Prior GHG fluxes (“bottom-up” inventories) with uncertainties



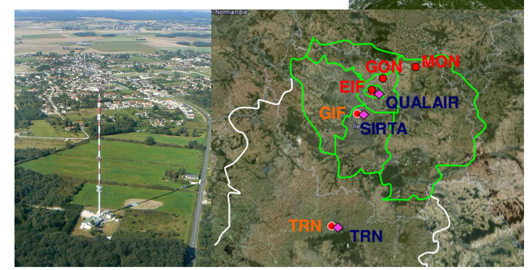
Simulation of the GHG atmospheric transport

Transport models bearing “model errors”





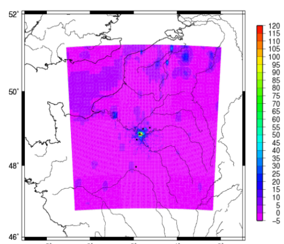
Comparison to the measurements



GHG atmospheric measurements with measurement errors

Statistical inversion: optimal corrections that minimize the sum of misfits to the measurements & prior

Inverted GHG fluxes with uncertainties

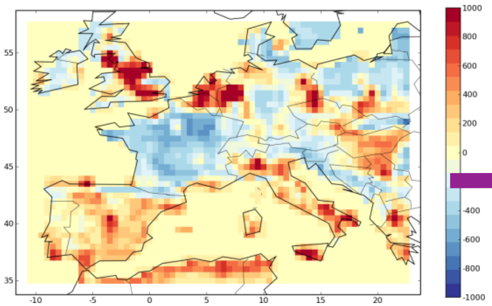


- **Used for more than 10-years to estimate natural fluxes at global scale**
- **Emergence of regional systems: ability to derive more robust local estimates and to track anthropogenic emissions**

Regional inversion of CO2 Net Ecosystem Exchange (NEE) in Europe using a mesoscale model

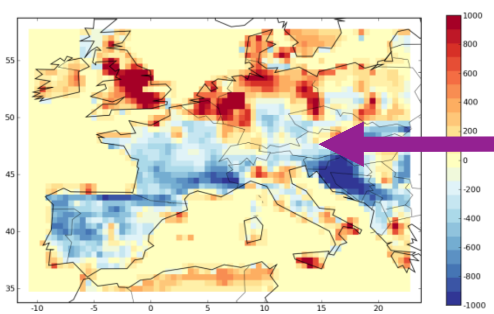
Broquet et al. 2011, JGR

PRIOR NEE: ORCHIDEE

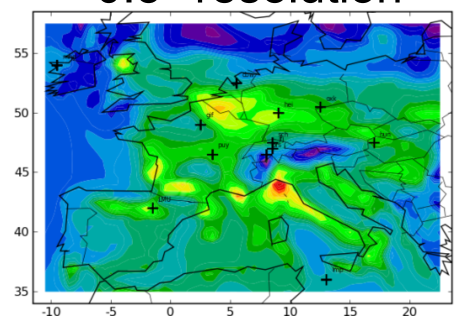


Uncertainty in NEE:
~1.5-2.5gCm^{-2}day^{-1}
Corr len ~250km/1 mth
for a given 6-hour window

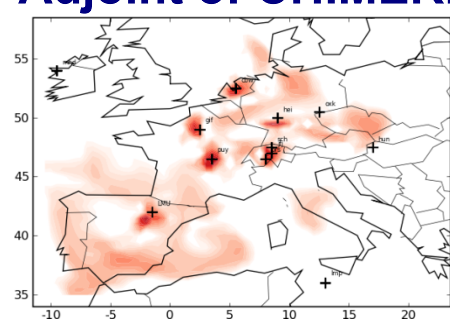
OPTIMIZED FLUXES
and uncertainties



CHIMERE Europe config
0.5° resolution

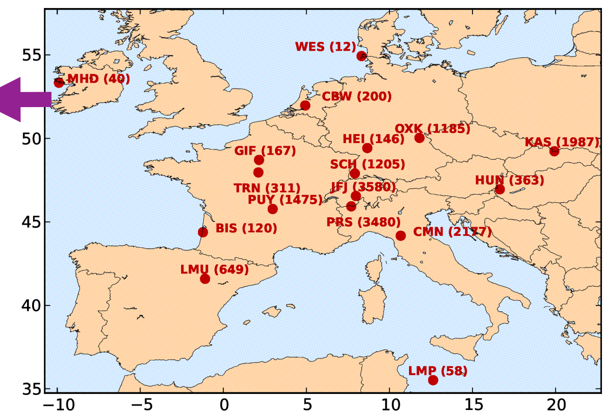


Adjoint of CHIMERE



corrections to NEE at 6-hour / 0.5° resolution

CarboEurope IP / ICOS hourly data
low alt.: 12:00-20:00
high alt.: 0:00-6:00
model error: ~4-15 ppm

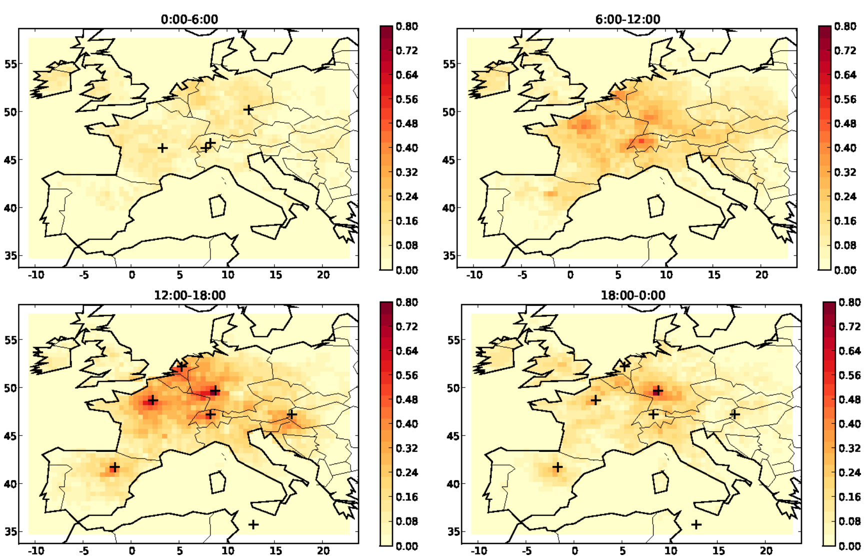


Variational inverse modeling with Monte Carlo estimates of uncertainties (*Chevallier et al. 2007*)

Estimate of Uncertainty Reduction (UR) for NEE

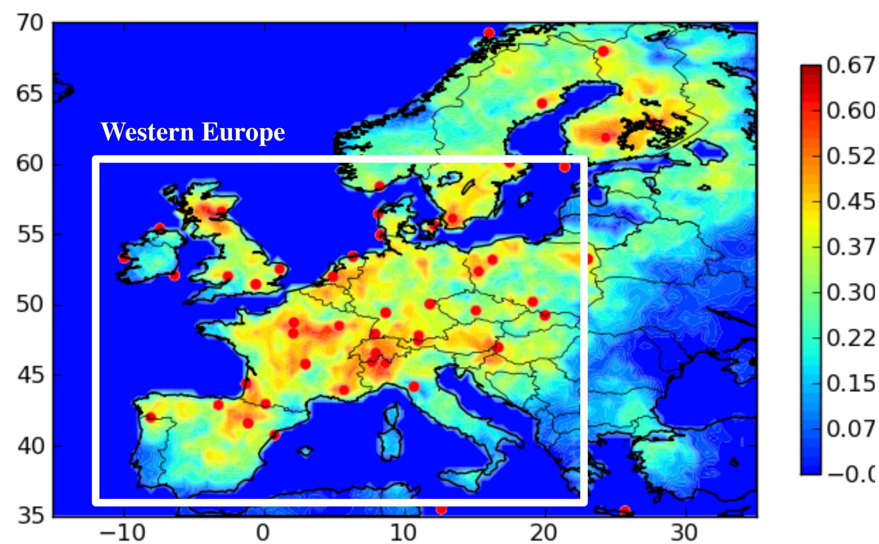
- **UR= 1 - (std uncert a posteriori / std uncert a priori)**
- UR for 1-month / West. Europe with existing network: **~60% throughout 2002-2007**
- High UR estimated vs high prior uncertainty from a biosphere model (potential improvement of prior at low resolution using bottom-up inventories)

UR for 30-day avg NEE for each 6-hour window of the day (summer 2006; use of CE-IP stations)



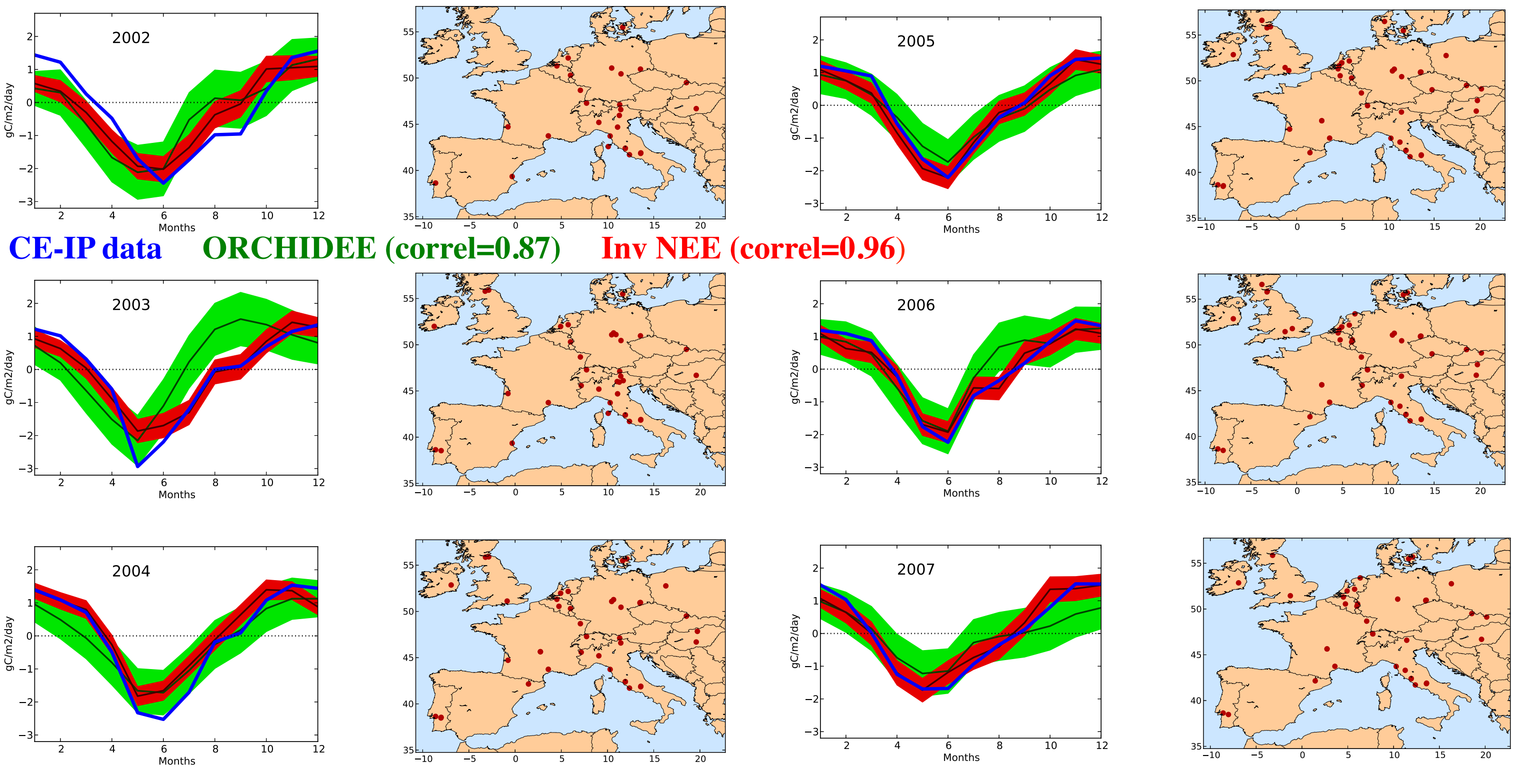
Broquet et al. 2011, JGR

UR for 14-day avg NEE (July 2007; use of 50 ICOS near term stations)



Kadygrov et al. 2013, in prep

Inversion of CO_2 NEE in Europe for 2002-2007: comparison to the eddy covariance flux data



Broquet et al. 2013, ACP

30-day avg NEE ($gCm^{-2}day^{-1}$) at CE-IP eddy covariance flux measurement sites.

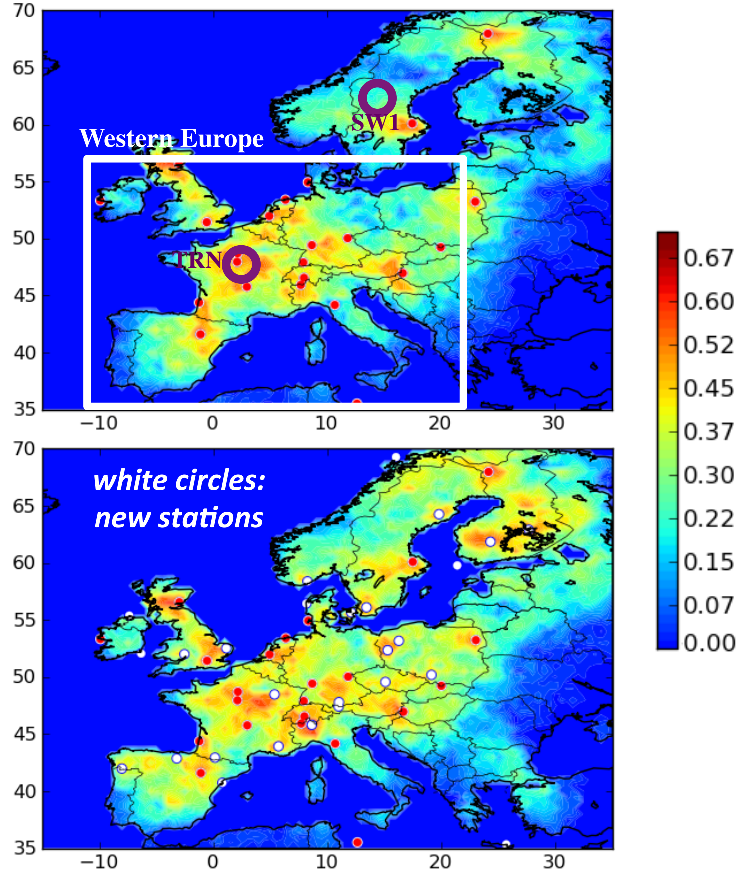
Shadded areas: +/- std of model uncertainty

Statistics on 30-day mean NEE at EC sites	a priori	a posteriori	UR
RMS of the uncertainty STD	0.69 $gCm^{-2}d^{-1}$	0.33 $gCm^{-2}d^{-1}$	53%
STD of the misfits to EC data	0.64 $gCm^{-2}d^{-1}$	0.4 $gCm^{-2}d^{-1}$	38%

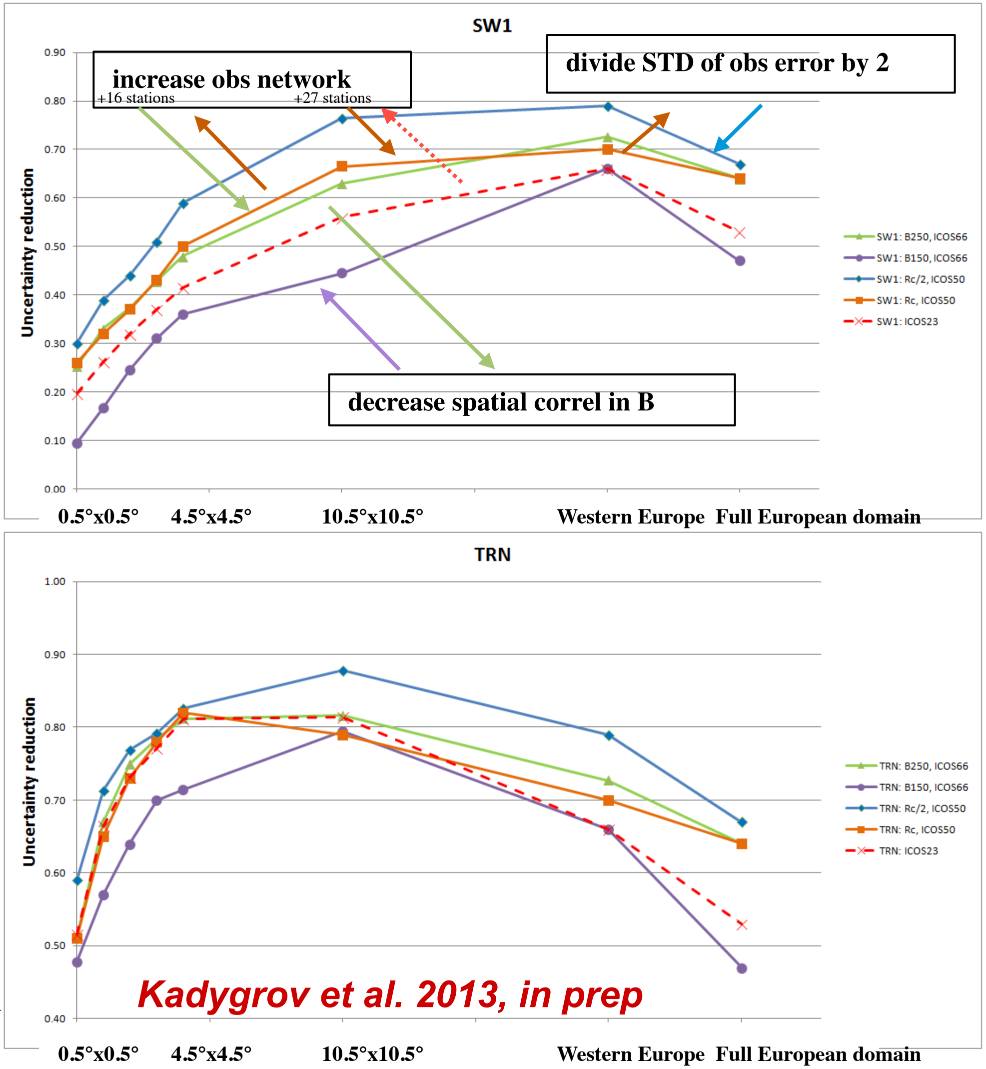
- Misfits to EC data include **repr error** and **eddy covariance meas errors**
- ➢ Fair consistency: **high confidence in the results at the European / monthly scale**

The uncertainty reduction as a function of the spatial scale, network density and model / prior uncertainties

UR for 14-day avg / 0.5° res NEE (July 2007) when using 23 and 50 ICOS stations



Uncert. red. for areas centered on SW1 and TRN

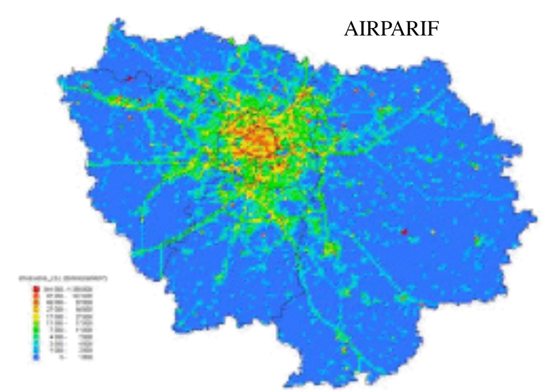


- **Highest sensitivity = to prior uncertainty**

Atmospheric monitoring of city CO_2 emissions

- Cities: more than 75% of GHG emissions on less than 2% of land surface
- Political need for **improving / verifying** the estimate of **emissions from cities**
- Increasing number of **city scale in situ CO_2 measurement networks**:
  - ➢ difficulties to deal with **local signals**, to get integrated views of city plumes
  - ➢ **political issues** for setting-up in situ networks dedicated to verification
- Future satellite **high res imagery of XCO_2 (2 to 4-10 km / ~1 to 5 days)**
  - ➢ **Cannot monitor a city continuously**
  - ➢ Issues: **high meas errors, lower signal, linking fluxes to column integrated mixing ratios**

➢ Study of the potential of **in situ** and **satellite** atmospheric data for quantifying city emissions using **the Paris area**

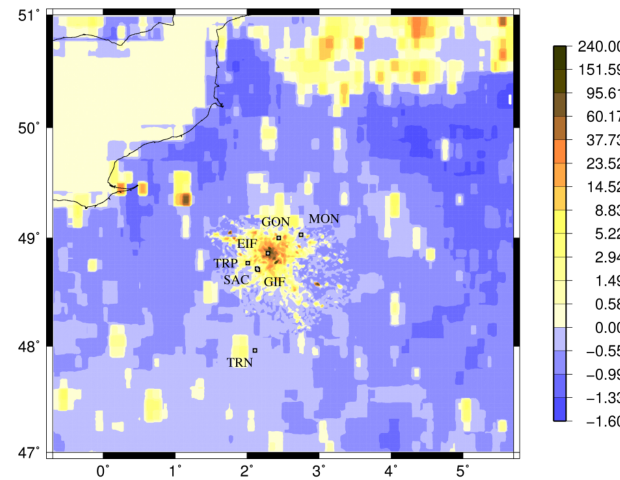


Inversion of CO2 emissions from Ile de France using ground based measurements: "ingredients"

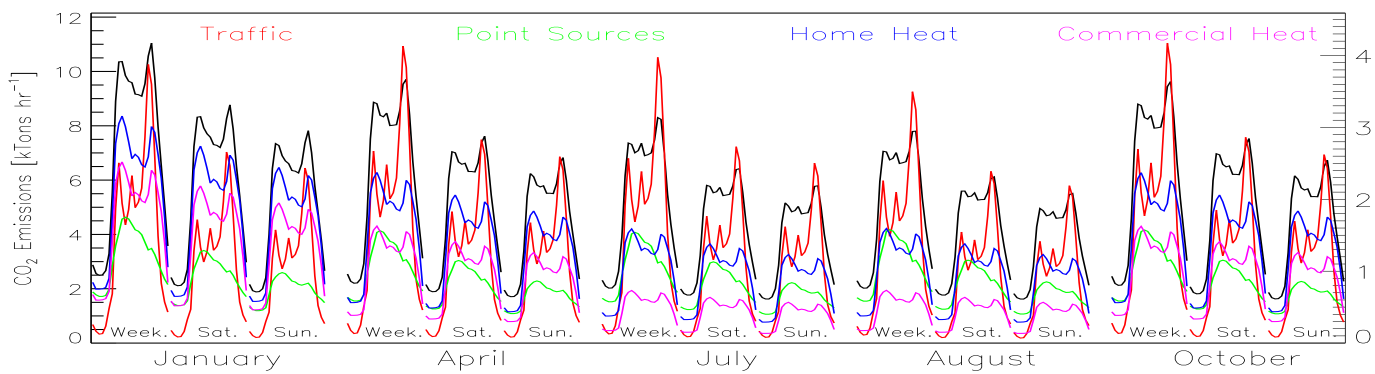
- An inventory with a **good spatial distribution & annual mean** but a lot of assumptions of **homogeneity for the temporal profiles**
- Existing ground network = 1 site in Paris + **3 sites close to the urban core** + 1 site outside IdF
- **Transport model at 2km res with too much diffusion** (difficulties to model urban sites)

➤ Objectives: **improving the inventory regarding the monthly IdF emissions and their temporal variations (daily resolution)** without solving the spatial distribution

Annual mean CO2 surface flux in the CHIMERE configuration ($gCm^{-2}d^{-1}$) and the CO2-MEGAPARIS and ICOS sites

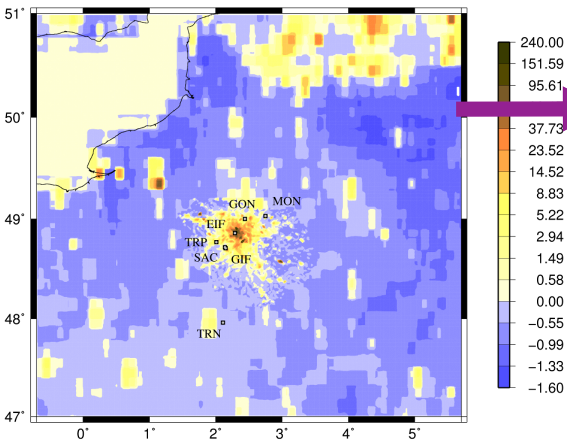


Temporal variations of the CO2 emissions per main sector in the AIRPARIF inventory



Inversion framework

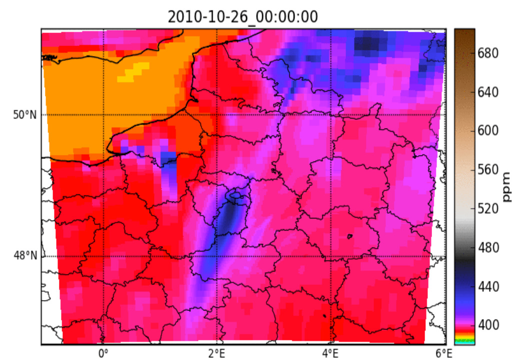
PRIOR FF: AIRPARIF
PRIOR NEE: C-TESSEL



Uncertainty in FF:
20% in monthly fluxes
Correl length ~1 week
for a given 6-hour window

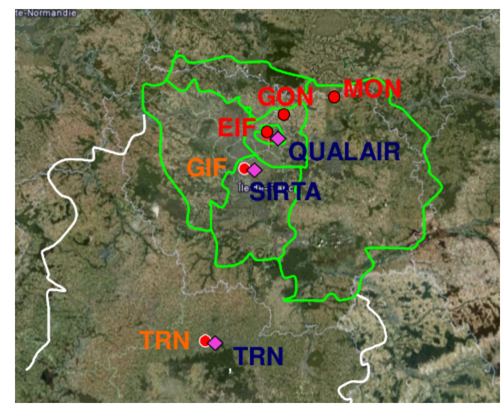
Analytical inversion
(transport matrix built with response functions to individual flux components)

CHIMERE IdF config
2km resolution



corrections to total NEE and FF in IdF at 6-hour resolution

CO2-MP / ICOS hourly gradients to ref site
12:00-16:00
when wind > 3ms^{-1}
no urban site (EIF)
Grad to GIF when SW winds and **grad to MON when NE winds**



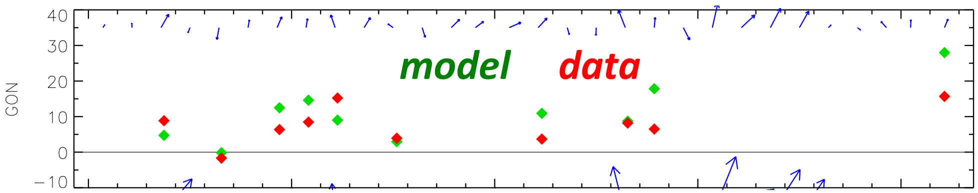
Model error ~5 ppm

OPTIMIZED FLUXES
and uncertainties

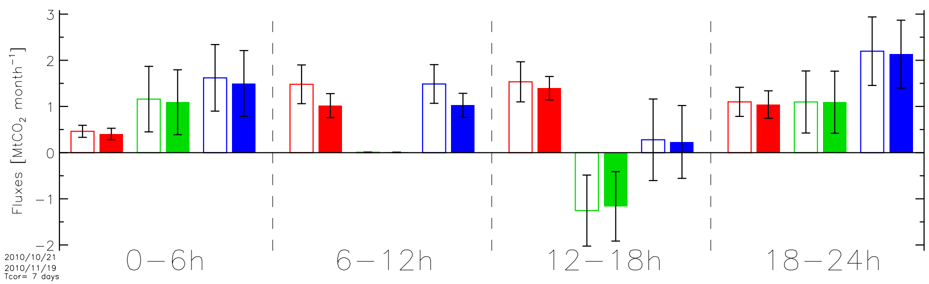
Puygrenier et al. 2013, in prep
Bréon et al. 2013, in prep

Results for Oct 21 – Nov 19 2010

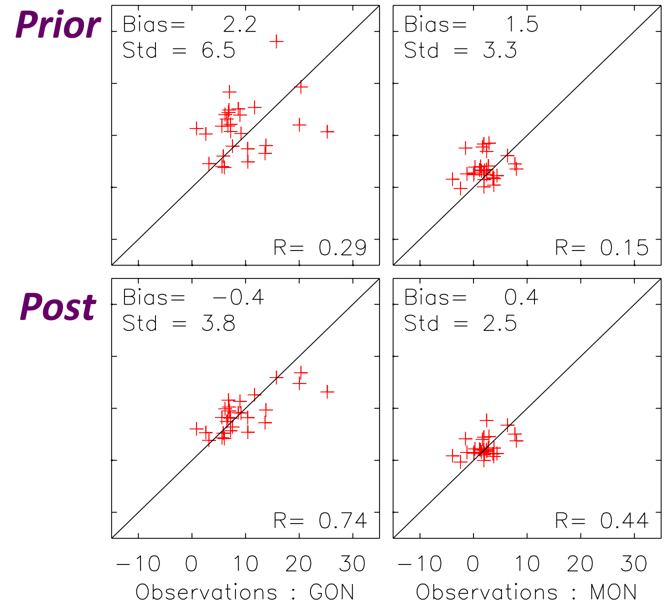
12:00-16:00 mean gradients to GIF and MON at GON when the wind blows from SW and NE respectively



30-day budget of CO2 fluxes in the IDF "region" defined by the control vector FF NEE Total



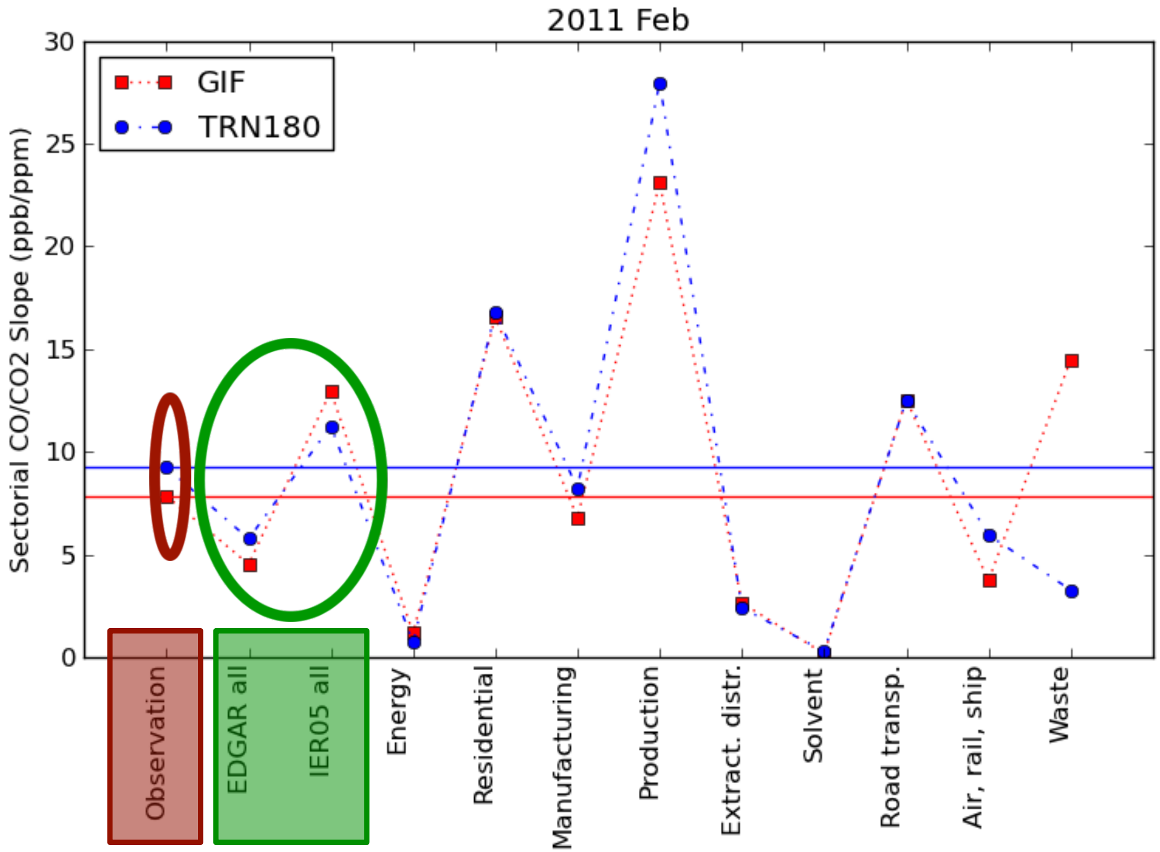
Hourly model vs meas gradient to GIF



- **The data selection leaves relatively few data for assimilation but the system diagnoses some significant uncertainty reduction**
- Need for validation data or **longer experiments (to assess the agreement with indexes such as cold/warm events):** on-going analysis of 1-year inversions
- The use of gradients requires a site upwind: limits the ability to monitor continuously the emissions (unless having a "ring" of station around the city)

Use of other data-streams to constrain the CO2 inversion

Analysis of CO/CO2 ratios at GIF and TRN



Analysis from L. Wu

- **Monitoring pollutants co-emitted with CO2 (CO, NOx…) and C-isotopes (^{14}C, ^{13}C) helps constrain CO2 emissions, their separation from natural fluxes and their resolution by type of fuel (~sector), by sector and in space / time**

➤ Development of a multi data stream system for the city scale inversion (FFDAS) in collaboration with the air quality community

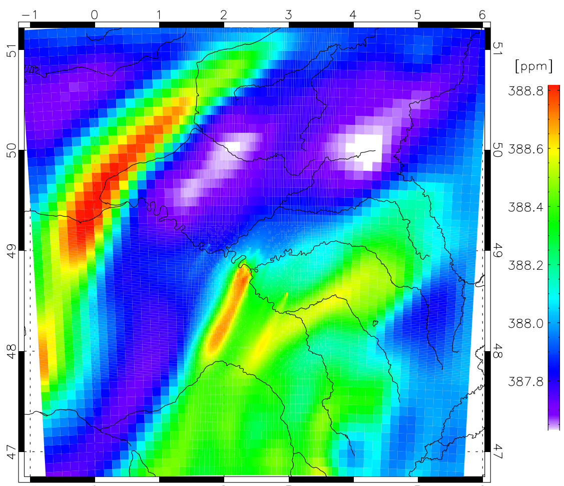
Evaluation of the potential of future satellite imagery for city scale inversions

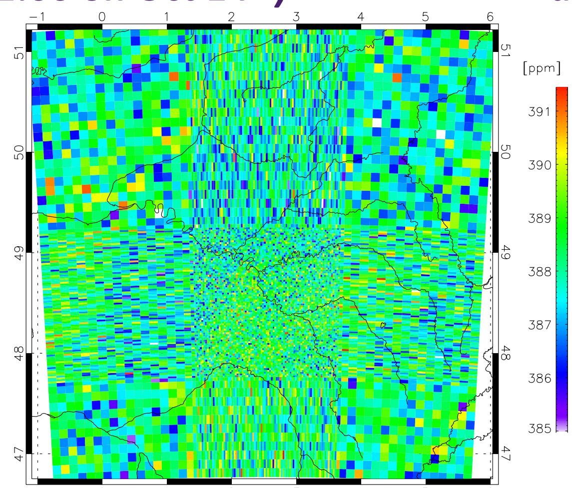
- Inversions of 5-hour emissions using individual satellite images
- **Uncertainty could be increased by the assimilation of satellite data** due to source of biased & non-Gaussian errors

➤ **high res sun-synchronous imagery could not be used to resolve city-scale fluxes** with sufficient accuracy **based on state of the art inversion methods**

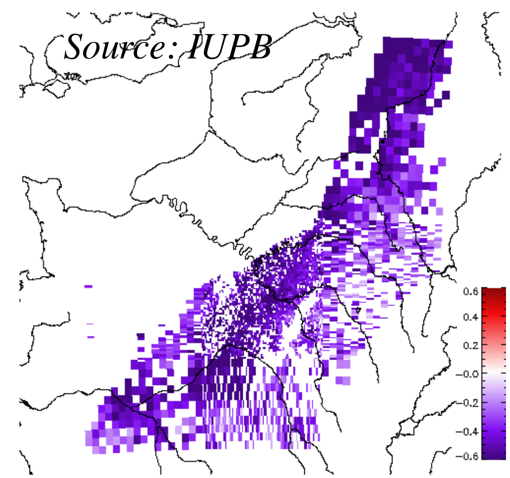
- For Carbonsat, only 20 cases of cloud free images of the plume per year
  - ➤ **Need for knowledge on temporal profiles to derive daily to annual FF**

An unfavourable case: "true" and "observed" XCO2 at 2km res. (11:00 on Oct 14th)





A realistic distribution of cloud cover and systematic errors for Carbonsat



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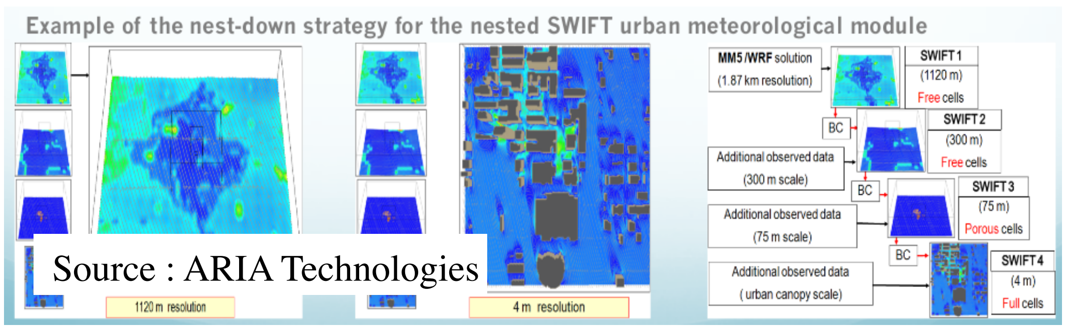
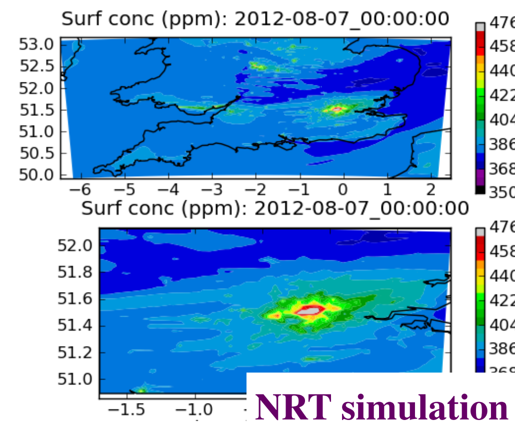
Conclusions (1): some insights for the improvement of the results

- **Need for methodological improvement of inversions to fully exploit the data** (reject less in situ CO2 data, decrease the impact of model / measurement errors)
  - ➢ cannot overcome all issues due to model / measurement errors
  - ➢ but could lead to critical improvements as long as there is no breakthrough improvement of the models and measurement: relevance for the long term ?
- The **complementarity with in situ data** seems critical for satellite data (at least due to the need for gap-filling)
- City scale inversion: **stronger links with air quality community**
- The concept of monitoring the city emissions based on ground based network is not "validated" yet but a stronger assessment of feasibility may require a larger number of stations

Conclusions (2): objectives

- Next targets
  - **For the European CO2 flux inversion**: use of **satellite data; inversion of anthropogenic emissions**
  - **For the Paris scale CO2 flux inversion**: use of urban meteorology, subgrid scale simulations (Carbocount-city), use of co-emitted species, C-isotopes, test of geostationary missions (chaire industrielle BridGES); **attempt at increasing the spatial / sectorial resolution**





NRT simulation of CO2 over London

- **Other regional inversions of GHG fluxes at LSCE**:
  - biogenic and anthropogenic CO2/CH4/N2O in Europe
  - biogenic and anthropogenic CO2/CH4/N2O in France (coupling with Europe)
  - biogenic CO2 in South America
  - biogenic and anthropogenic CH4 in Siberia
  - CO2 City-scale inversions for London