A first estimate of CO_2 emissions from the Paris city using an array of atmospheric measurement sensors

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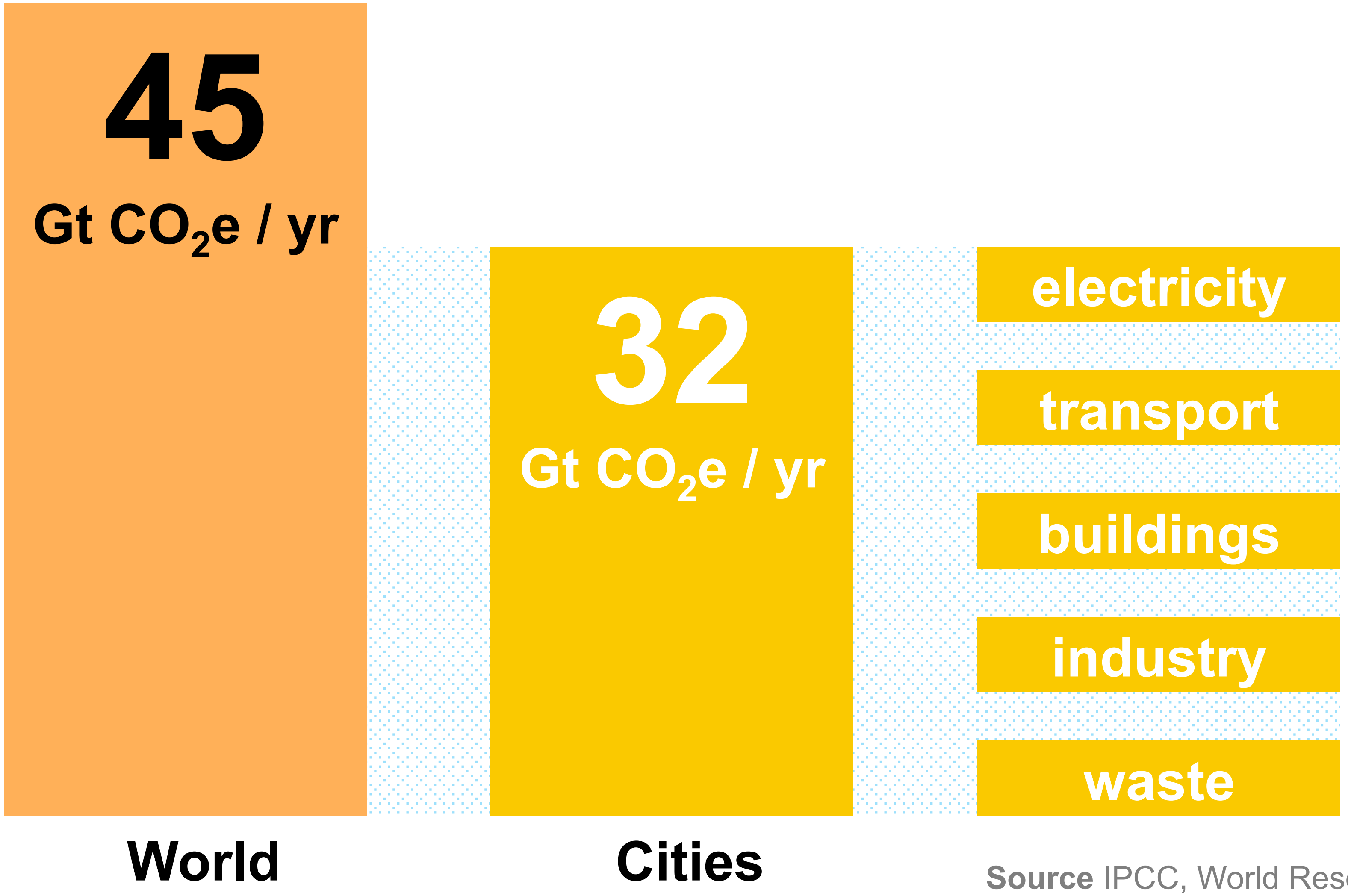
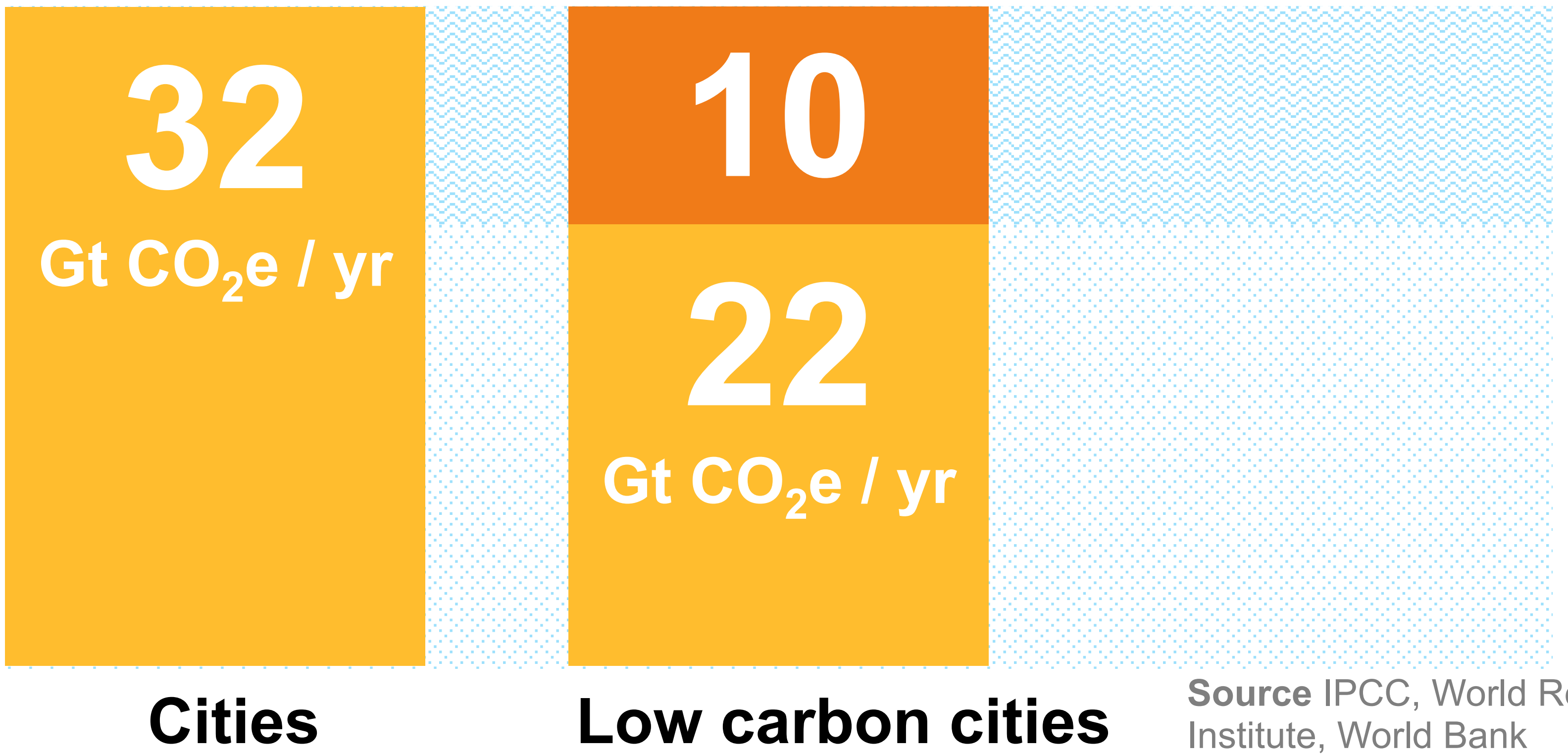
Why knowledge of cities CO_2 emissions is needed ?
Cities account for 70% of global emissions



Source IPCC, World Resources Institute, World Bank

Cities have a gigantic potential to reduce GHG



Source IPCC, World Resources Institute, World Bank

Cities in action…

>488

Source ICLEI, carbon Registry

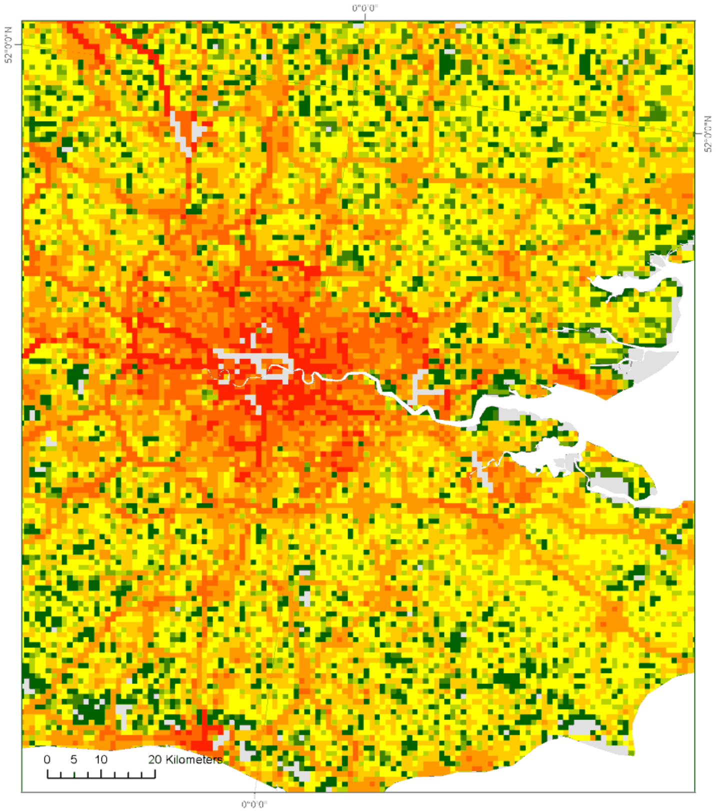
Uncertainties of city-scale emission inventories are large

- **Cities are open systems, exchanging fuel and energy**
- **High spatial, temporal & sectorial variability of emissions**
- **Lack of knowledge limits the effectiveness of emission reductions**

CO_2 emission inventories from Ile de France (Paris region)

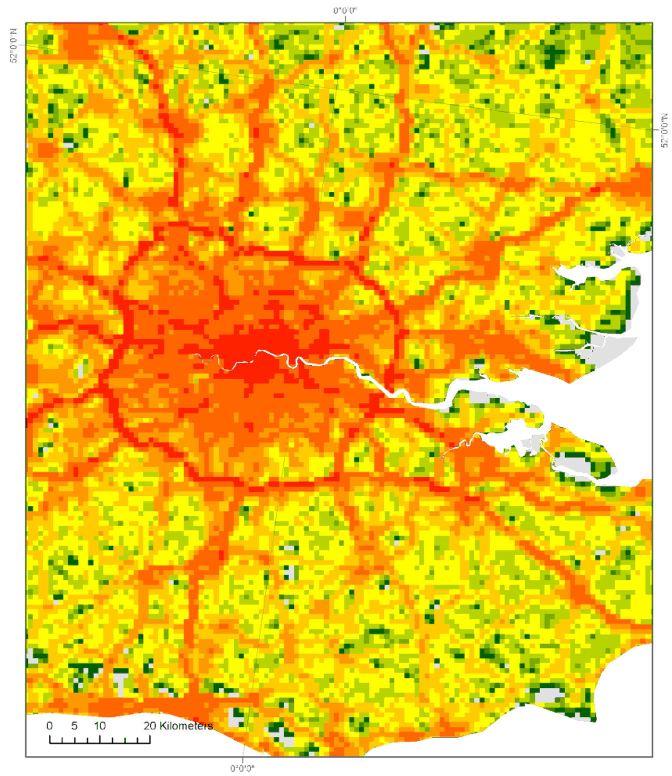
	EDGAR V4	IER 2005	AIRPARIF2005	AIRPARIF2008	Max – Min
Resolution	0.1° x 0.1°	1min x 1min	1km x 1km	1km x 1km	
Annual budget of Paris Urban Area (TgC per year)					
Residential	6.75	5.36	5.65	7.80	**31%**
Road	8.50	6.03	3.63	3.37	**60%**
Industry	5.19	4.61	3.02	3.09	**42%**
Total	24.65	16.39	12.34	14.26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

Two emission maps for London
IER and UKNAEI



CO2 Road transport IER
2008 (1km * 1km) [Gg/year]

0,00 - 0,02
0,03
0,04 - 0,05
0,06 - 0,11
0,12 - 0,29
0,30 - 0,81
0,82 - 2,36
2,37 - 6,92
6,93 - 20,34



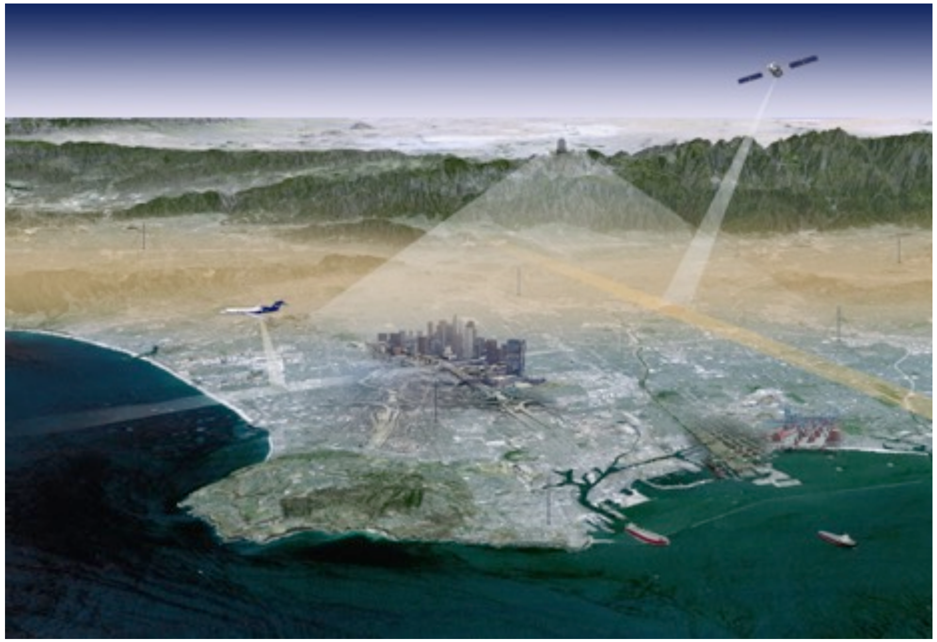
CO2 Road transport UKNAEI
2008 (1km * 1km) [Gg/year]

0,00 - 0,02
0,03
0,04 - 0,05
0,06 - 0,11
0,12 - 0,29
0,30 - 0,81
0,82 - 2,36
2,37 - 6,92
6,93 - 20,34

Monitoring city scale emissions from the atmosphere

- **Cities: the major part of CO_2 emissions over < 2% of land area**
- **Inventories either non existent or un-frequently updated**
- **Political need for improving / verifying emissions and emission trends**
- **Few pilot city scale in situ CO_2 measurement networks**
- **Space borne data in the future**

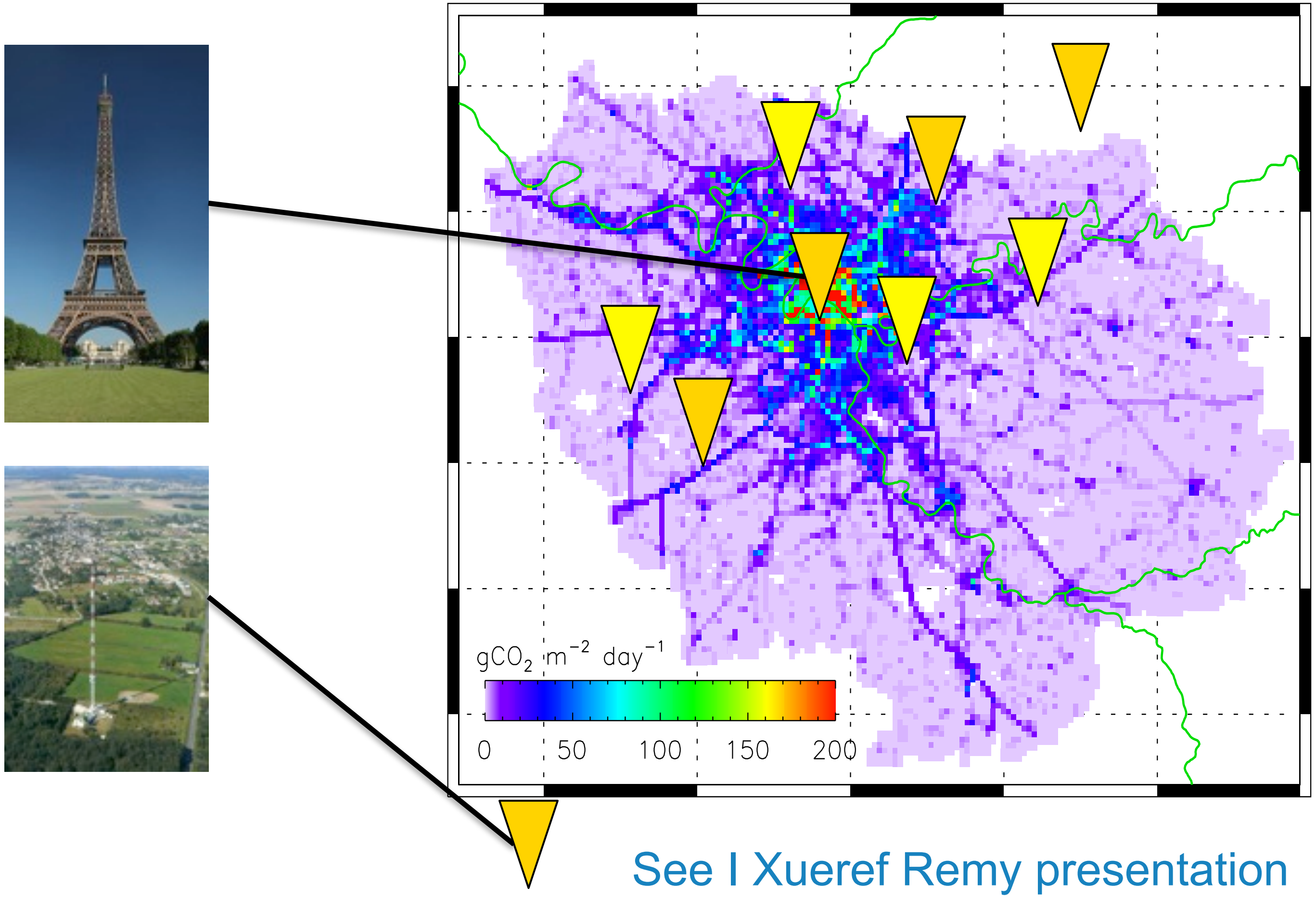
Measurement towers in Indianapolis
(NIST/ INFLUX project)



CO_2 Megacities project in L.A. (JPL/NASA)
See D Riley presentation

The Paris in-situ measurement network

Developed since 2009 from research projects

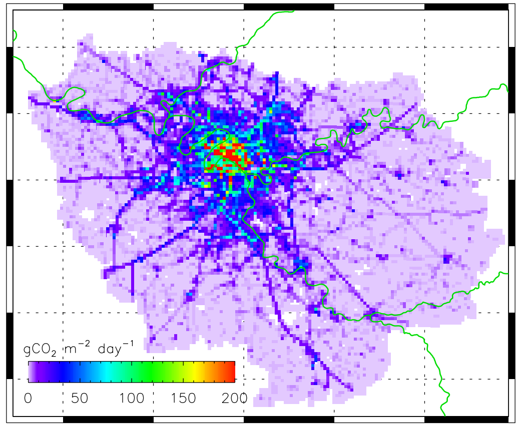


See I Xueref Remy presentation
Bréon et al. 2015, ACP

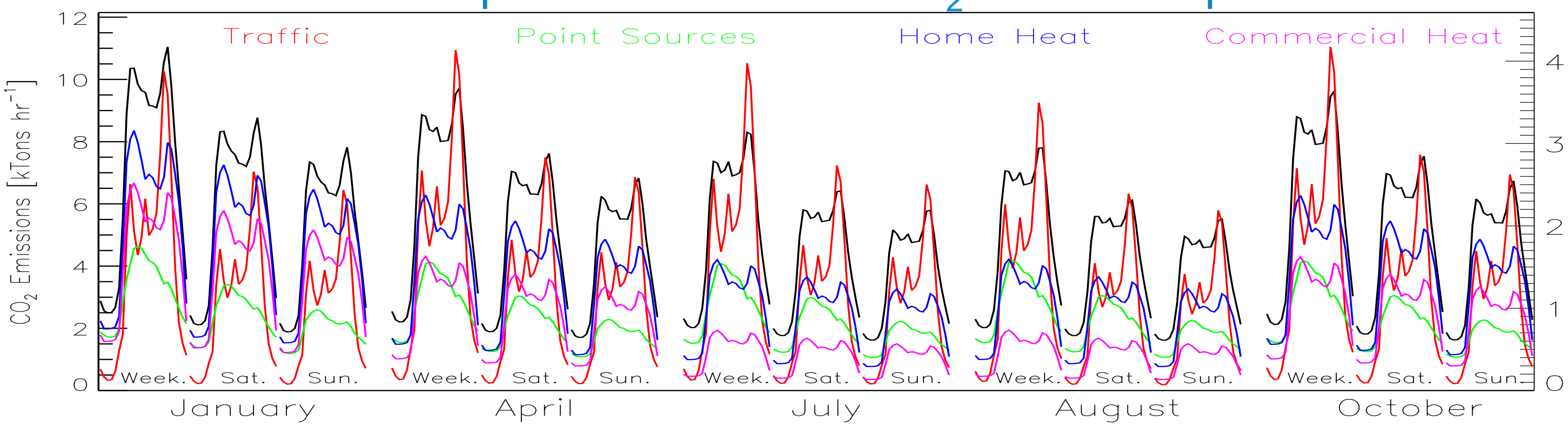
An urban CO_2 and CH_4 station

Starting point : inventory released in 2008

- Data compiled by local air quality agency AIRPARIF
- Covers GHG and pollutants
- Spatial resolution 1 km
- Simplified sectorial time profiles
- Last update 2008

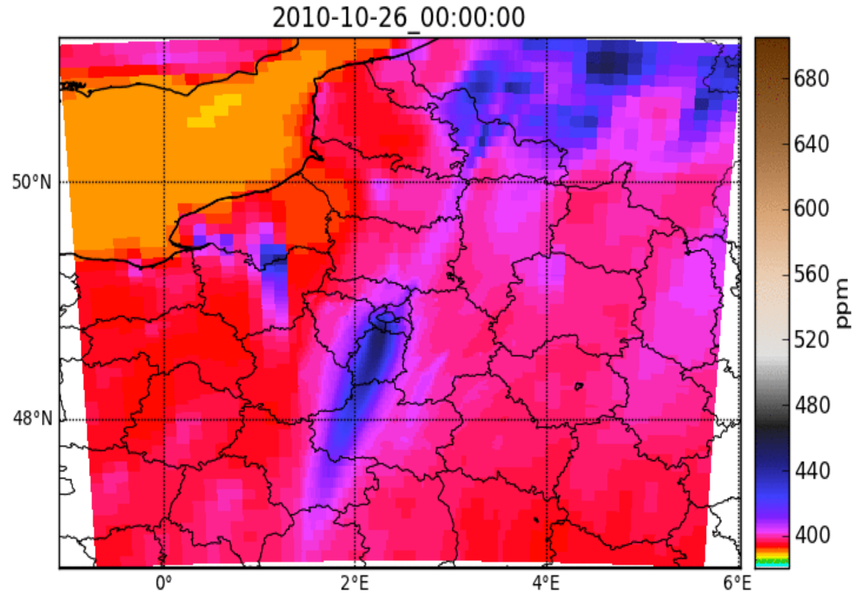


Assumed temporal variations of CO_2 emissions per sector



Atmospheric transport modeling system

- **Eulerian transport model CHIMERE**
- **Resolution 2 km (interpolated 15 km ECMWF winds) + numerical diffusion**
- **Emissions : AIRPARIF hourly + EDGAR in the domain outside Paris region**
- **Surrounding vegetation and soils CO2 sources and sinks hourly from CTESSEL model**
- **Atmospheric CO2 lateral boundary conditions hourly from MACC v10.2 global transport model with optimized fluxes**



Domain of high resolution CO_2 simulation

Goal : invert emissions each 6 hour with 4 stations in 2010 and vegetation fluxes each week

Comparison of measured vs. simulated concentrations

Hourly (lines) and afternoon CO2
In Dec 2010

Red : Measurements

Green : Model

Thin black : CO_2 from boundaries and from emissions outside Paris

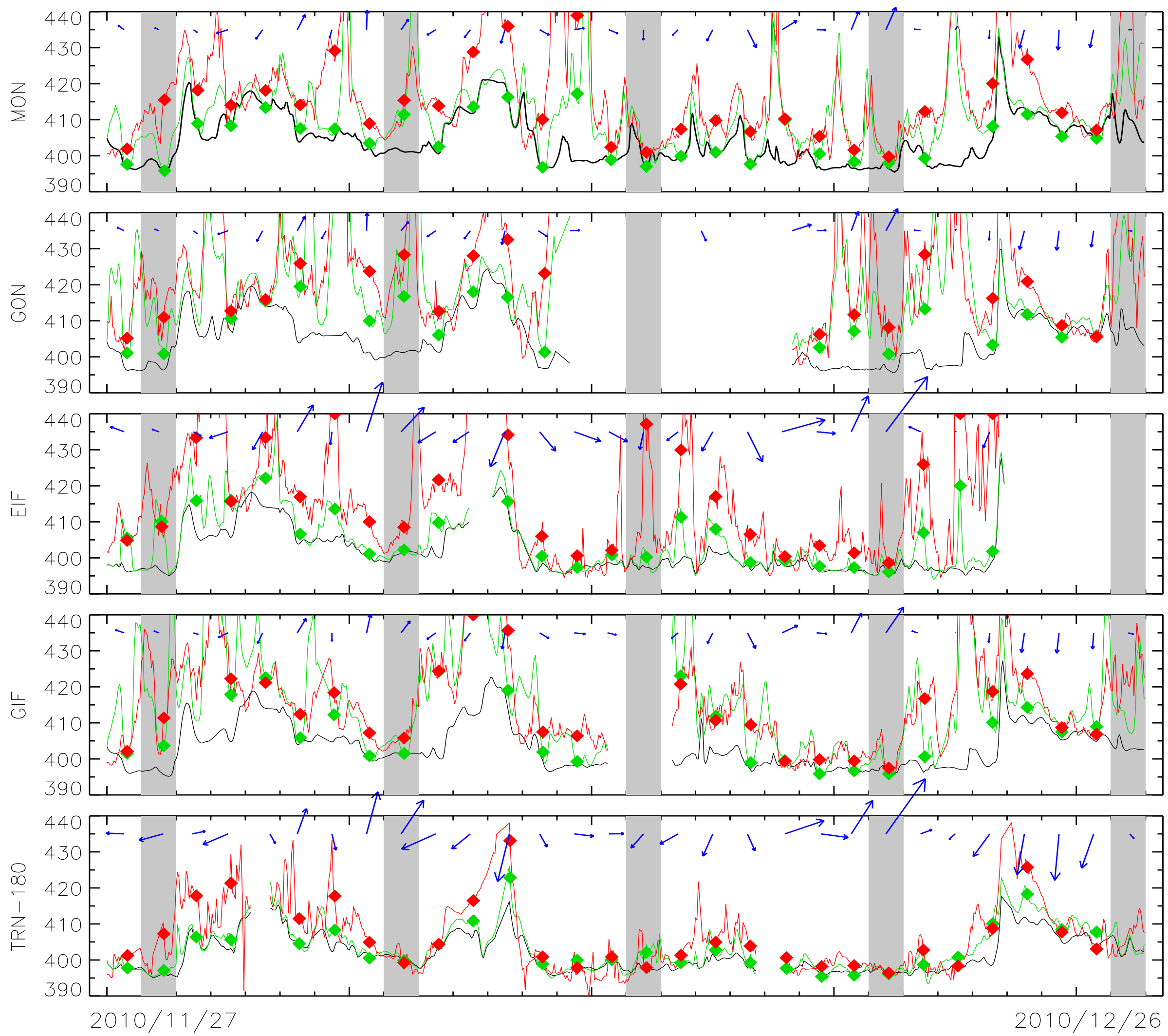
Blue arrows : daily wind

Ignored CO_2 error time correlations

Select CO_2 data

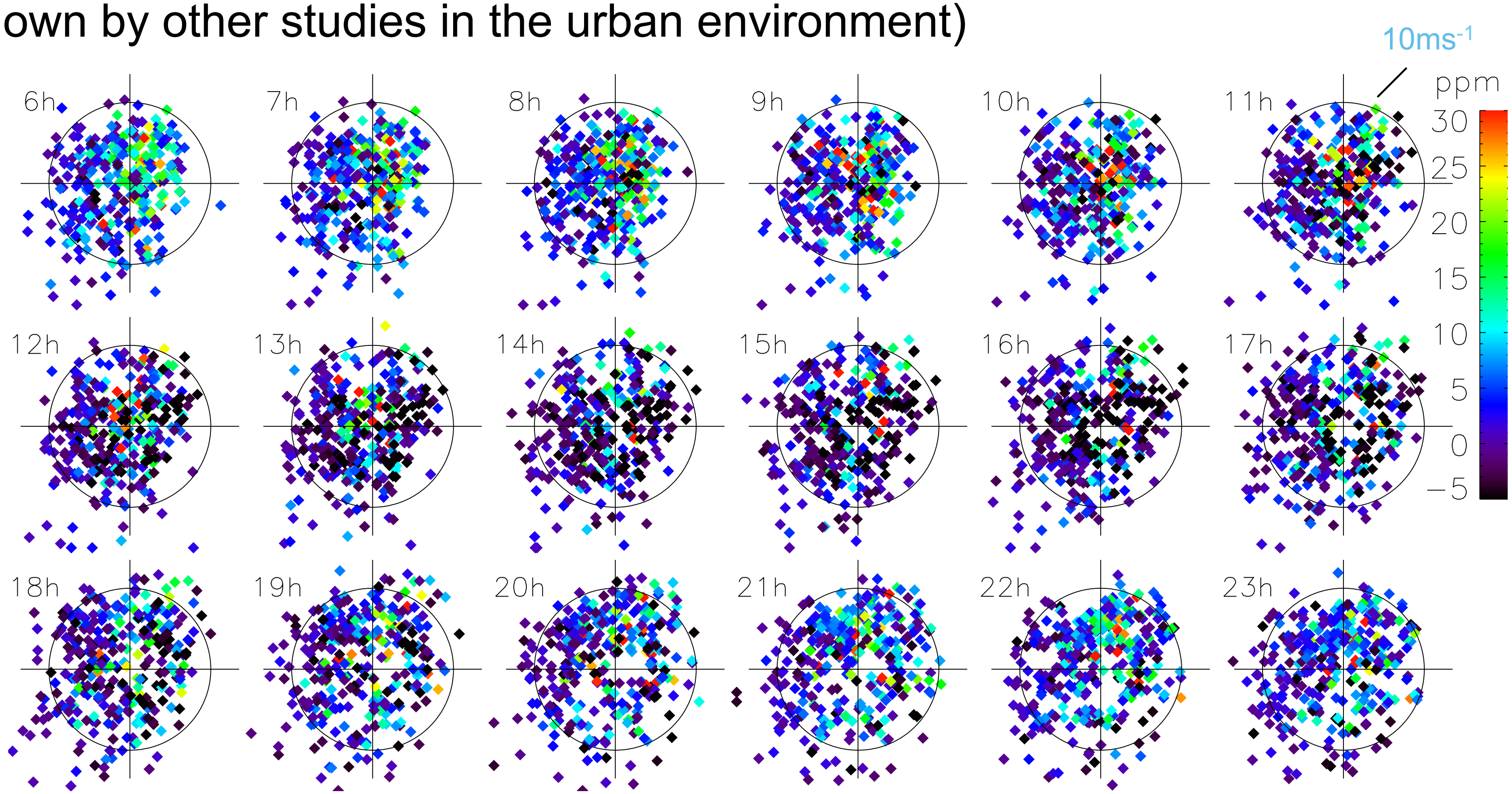
Mid afternoon

Wind > 2 to 3 ms^{-1}



Difficulties in simulating urban CO_2

Large misfits unusual for inverse modeling applications (similar misfits shown by other studies in the urban environment)

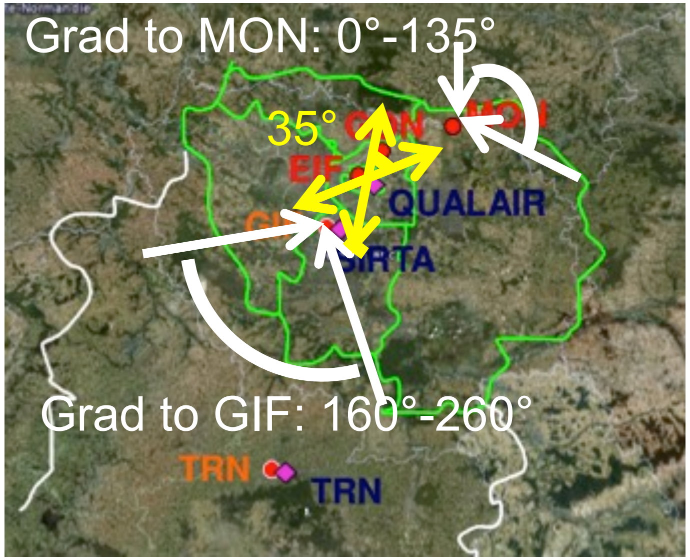


Wind roses of the model-data misfits at EIF for the full year of simulation

Lack of understanding of misfits at Eiffel tower: the site is ignored for the inversion, use of semi-urban sites only

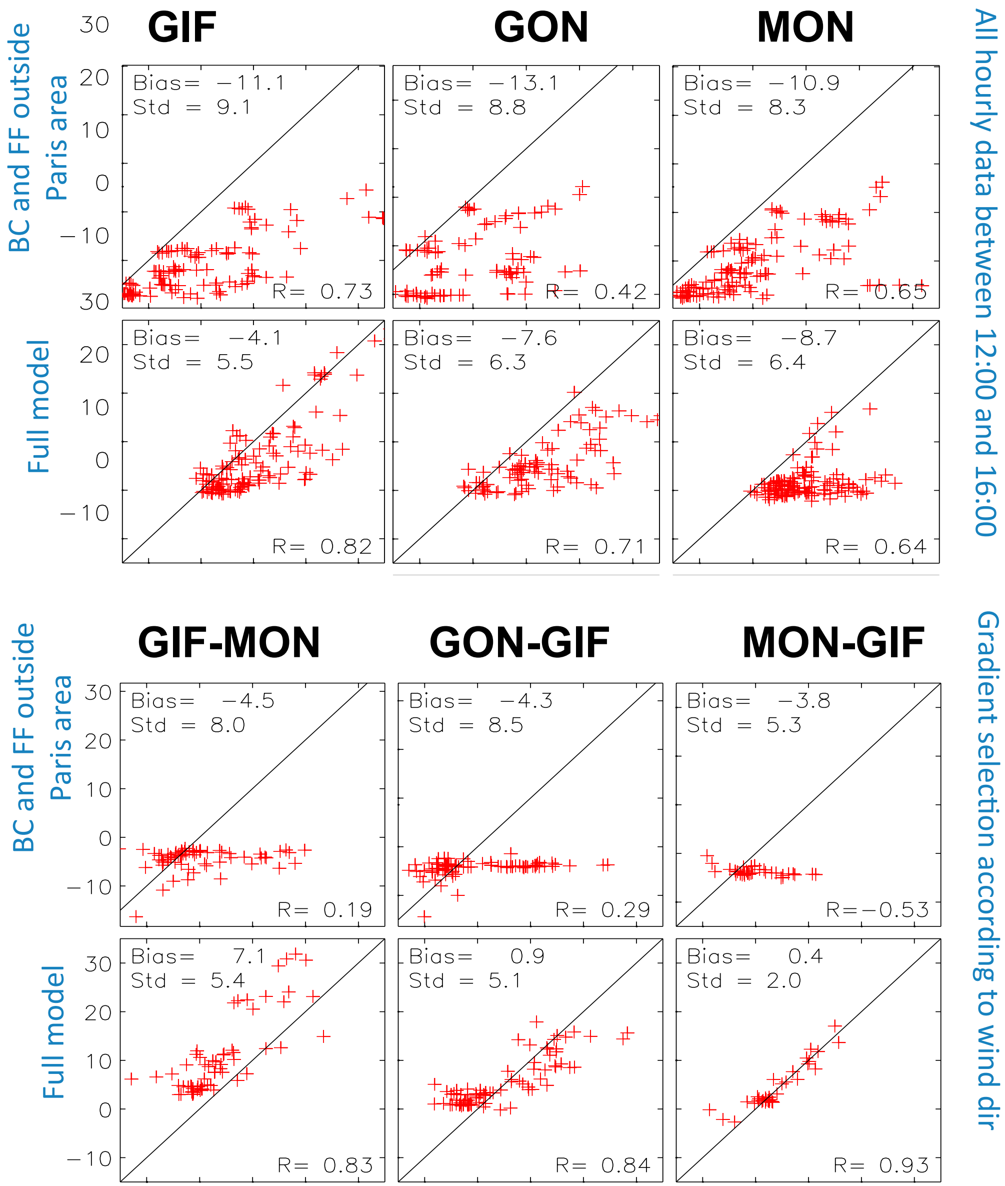
Using city upwind – downwind gradients

Model vs. observed CO_2 after wind and time selection



Two options for selecting gradients between semi-urban sites as a function of the wind direction

CO_2 gradients between sites better captured than individual time series



Results: data filtering and model-data misfits

☺ **Good fit to the data after inversion**

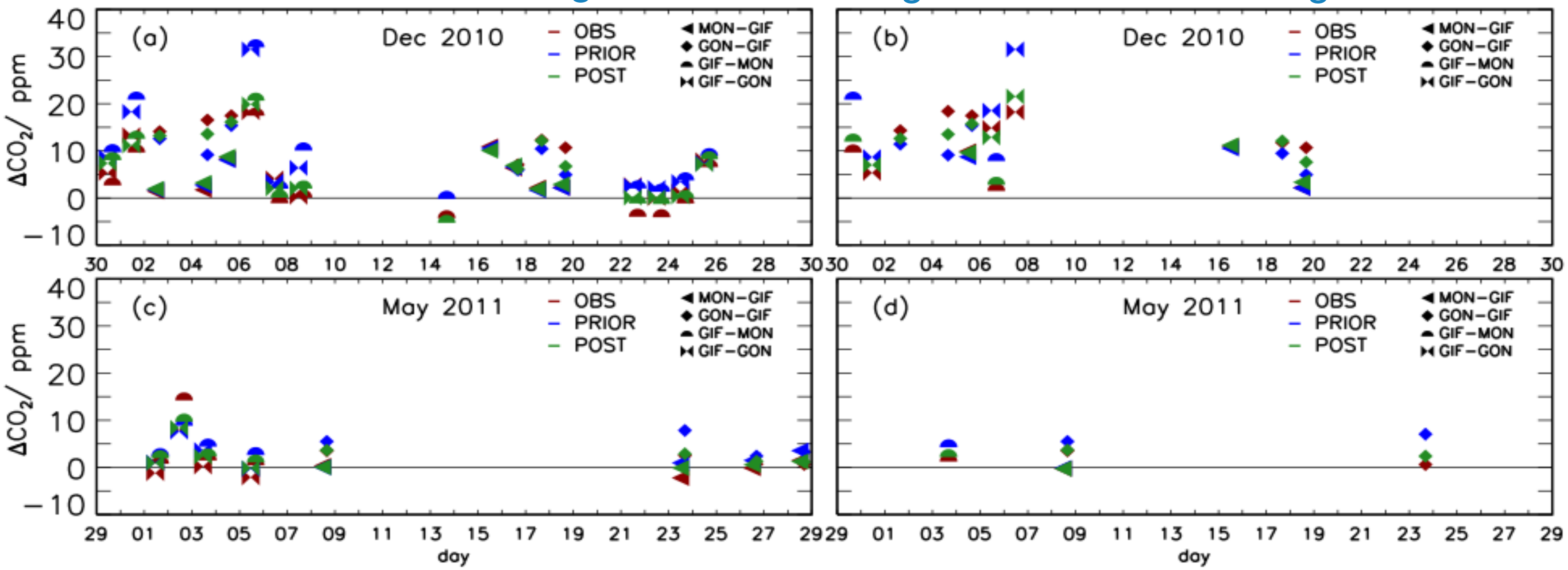
☹ **Significant loss of data**

Negative gradients with the looser selection

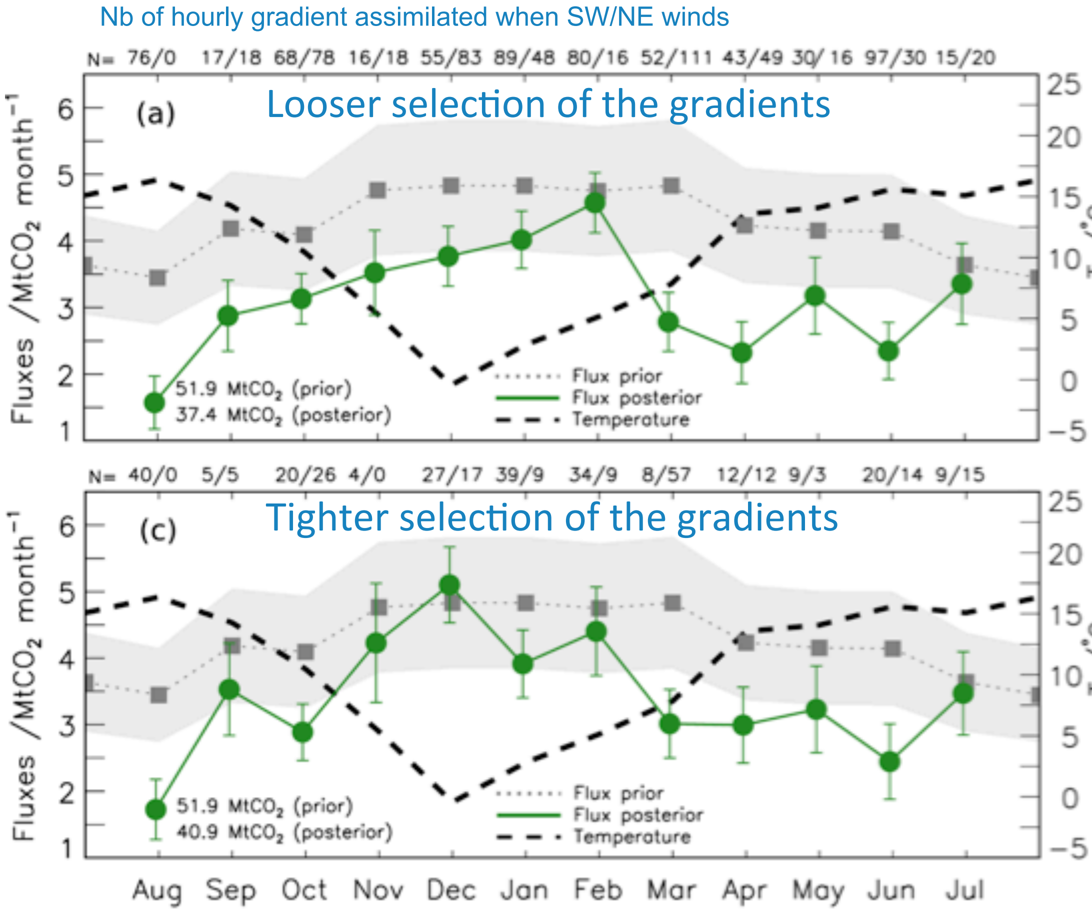
(high potential for aggregation errors)

Mid afternoon gradients used by the inversion

Looser selection of the gradients | Tighter selection of the gradients



1 year of emissions from the atmosphere



Results improved with the tight gradient selection

Good agreement with temperature, better seasonal variations

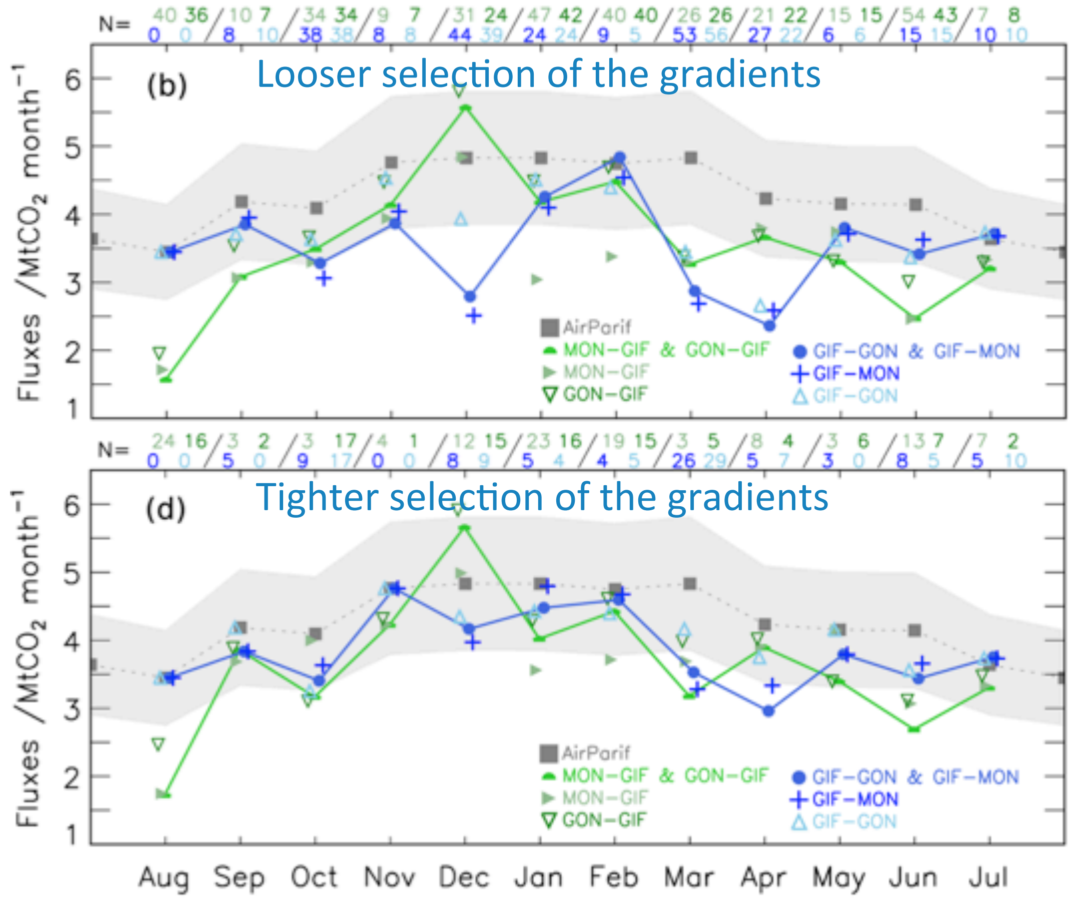
Despite strict data selection, the model predicts high uncertainty reductions

Annual budget close to that of AIRPARIF 2010 (approx. 41.8 MtCO2)

An independent check of the performance of the system

1 year of emissions from the atmosphere

Sensitivity of monthly budgets when using subsets of gradients

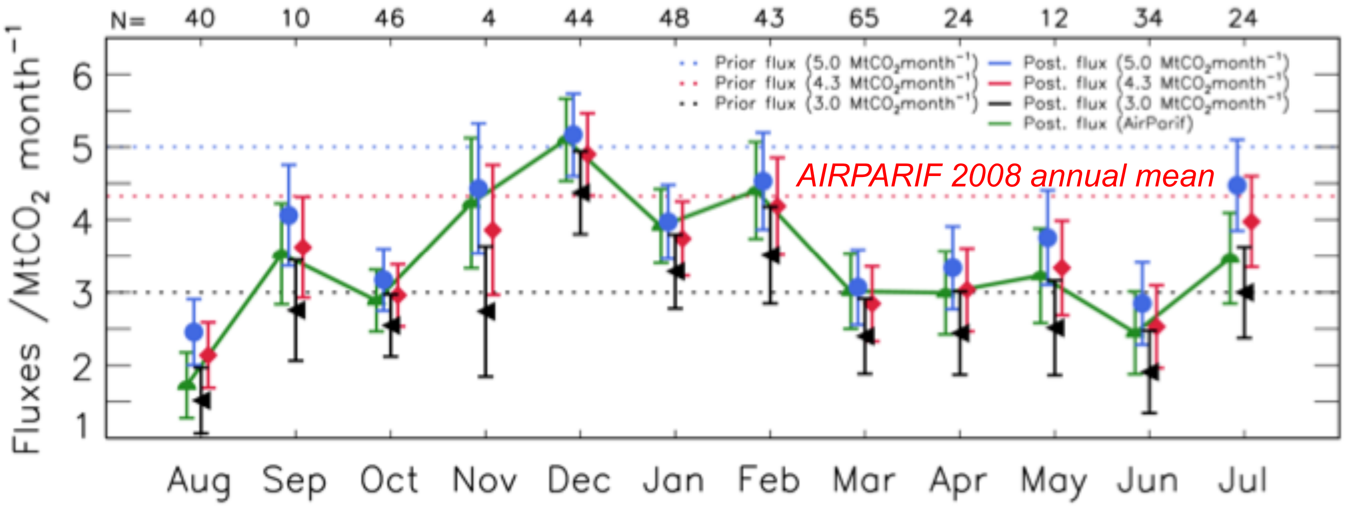


Discrepancies between results using gradients when NE vs. SW winds: impact from remote fluxes (emissions from NE France, Benelux, Germany) or a difference in time sampling ?

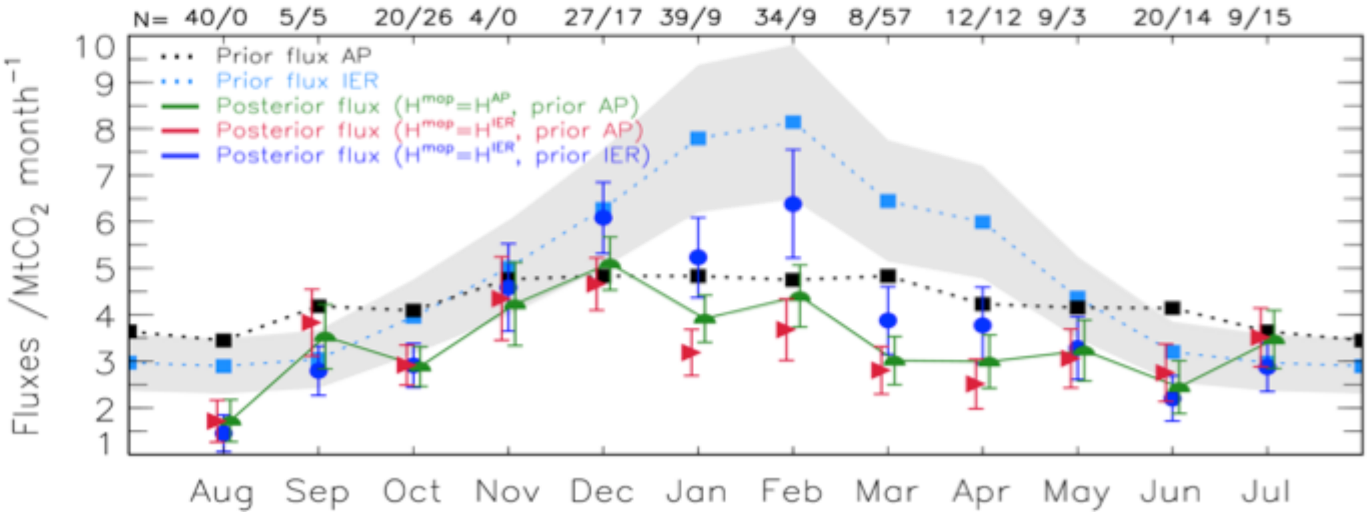
The problem is far less critical when using the tight gradient selection

Tests of robustness with the tight gradient selection

Results using AIRPARIF2008 emission pattern (red) or flat priors

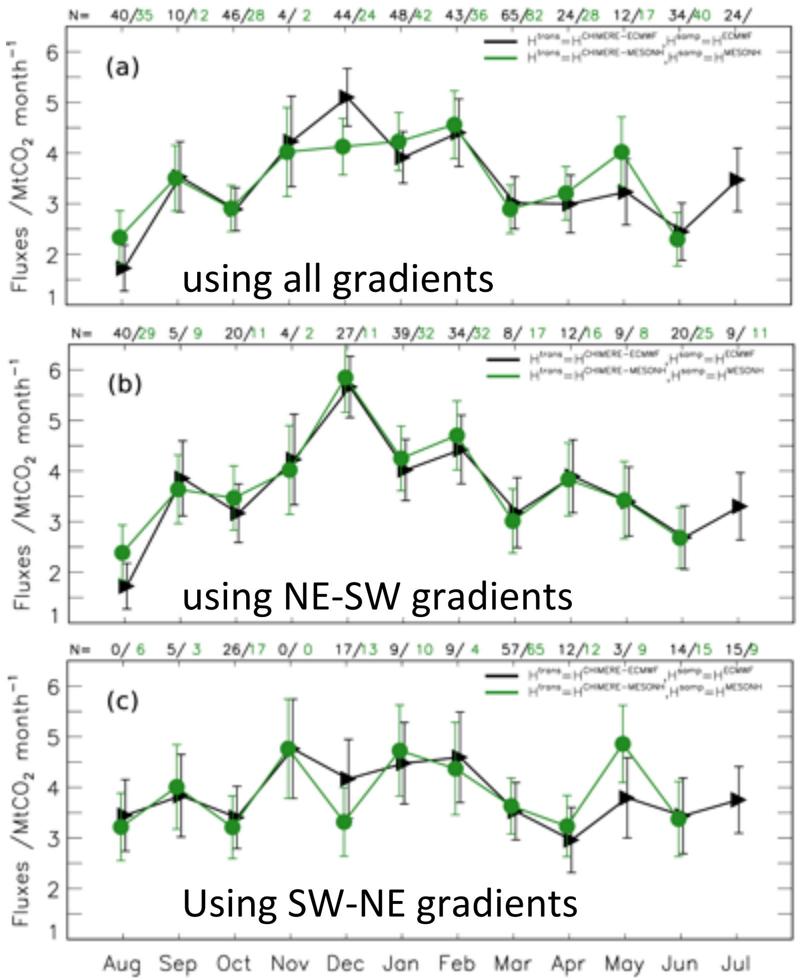


Results when using AIRPARIF2008 or IER as a prior for total / patterns of emissions



Tests of robustness with the tight gradient selection

Using ECMWF or Meso-NH winds (2km res, urban schemes; from Meteo-France)



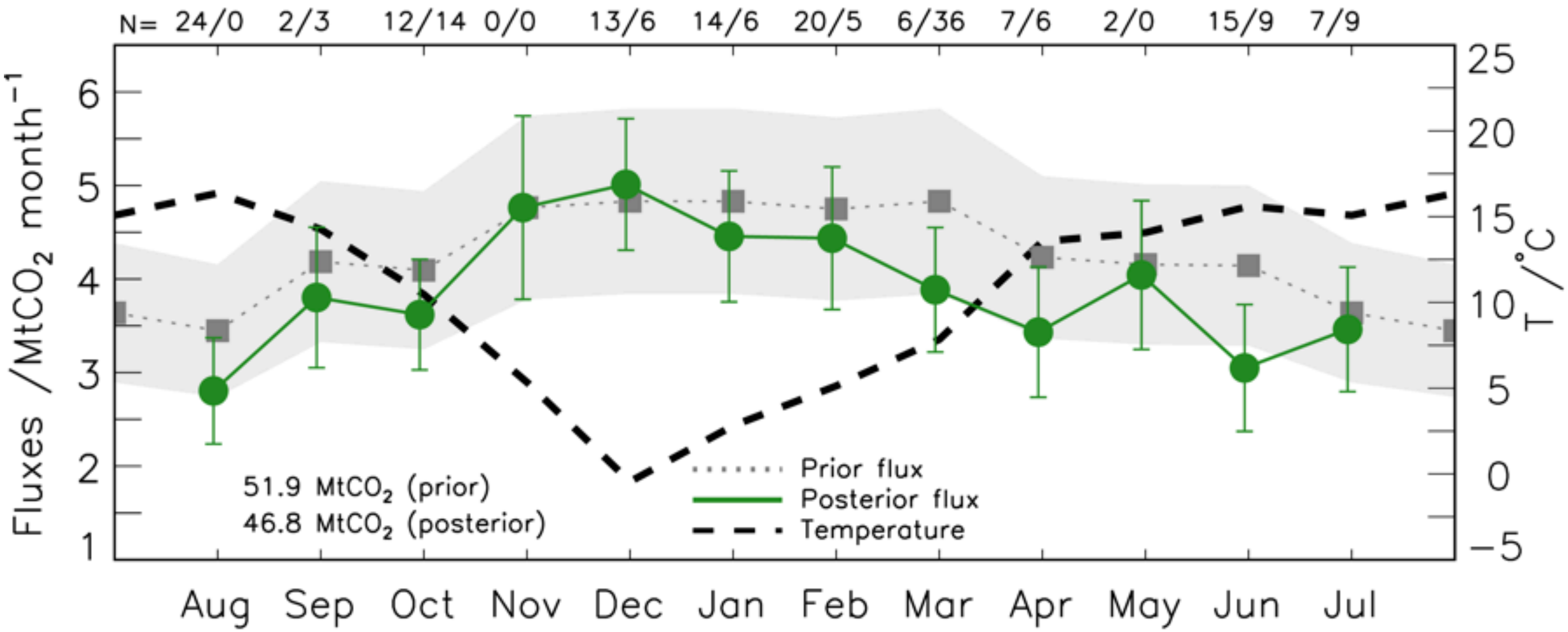
Robust results when using gradients for SW winds . In general, monthly budgets strongly controlled by the data

Some differences using gradients when NE winds

Need for better characterizing the uncertainties

From spatial to spatio-temporal gradients ?

Estimate of monthly budgets of CO2 emissions when using gradients between downwind concentrations at 14:00 to 16:00 and upwind concentrations at 12:00 to 14:00 (2-hour lag time)



- Number of data assimilated approximately divided by 2: results nudge back to prior (the inversion predicts weak uncertainty reduction)

Results

- First city CO_2 emission inversion for one year
- Promising results but at the cost of stringent data selection (to ensure the citywide representativity of the gradients)

Perspectives

- Need more stations to surround the city for a continuous monitoring of the emissions.
- Co-emitted species
- Use of satellite data
- Improved atmospheric transport

The city inversion framework:
sequence of 1 month inversions

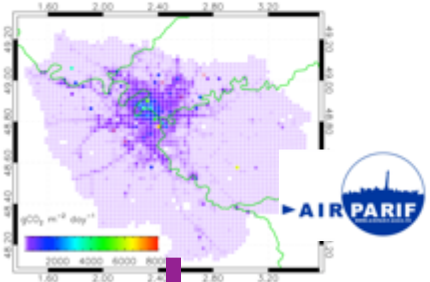
Control vector:
6-hour budgets of FF in IdF & NEE

PRIOR FF:
AIRPARIF
PRIOR NEE:
C-TESSEL
Uncertainty in FF:
20% in monthly FF
Correl length ~1 week for a given 6-hour window

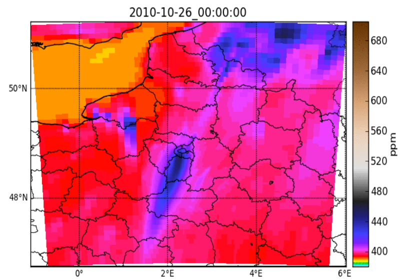
POSTERIOR FLUXES
and uncertainties

Analytical inversion

Spatial mapping from AIRPARIF (FF in Idf) and C-TESSEL (NEE)



CHIMERE-ECMWF IdF config
2km resolution
BC: INV-LMDZ
FF outside IdF: EDGAR



CO2-MP / ICOS hourly city upwind-downwind gradients
12:00-16:00
when wind > 3ms^{-1}

(Grad MON and GON to GIF when SW winds and grad GIF to MON and GON when NE winds)

Model error (1h scale): 3 ppm

Next objectives

- **For the European CO2 natural flux inversion:** use of **satellite data; inversion of anthropogenic emissions** (use of co-emitted species, C-isotopes); **stronger links with land carbon models;** nesting with national systems

- **For the Paris scale CO2 flux inversion**: increasing the network, **exploiting urban data** (use of urban meteorology, high res simulations), **use of co-emitted species: joint measurement and assimilation of GHG and AG data**, **C-isotopes**, complementarity with satellite data; **increasing the spatial / sectorial resolution**

- **Better filtering the information from the CO2 measurements (rejecting less data) that can be exploited for the inversion of target quantities despite model errors: better definition of the control and observation vectors through more complex mathematical operators ?**

Model used for the sub-km simulations

13CO2 measurements at GIF