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

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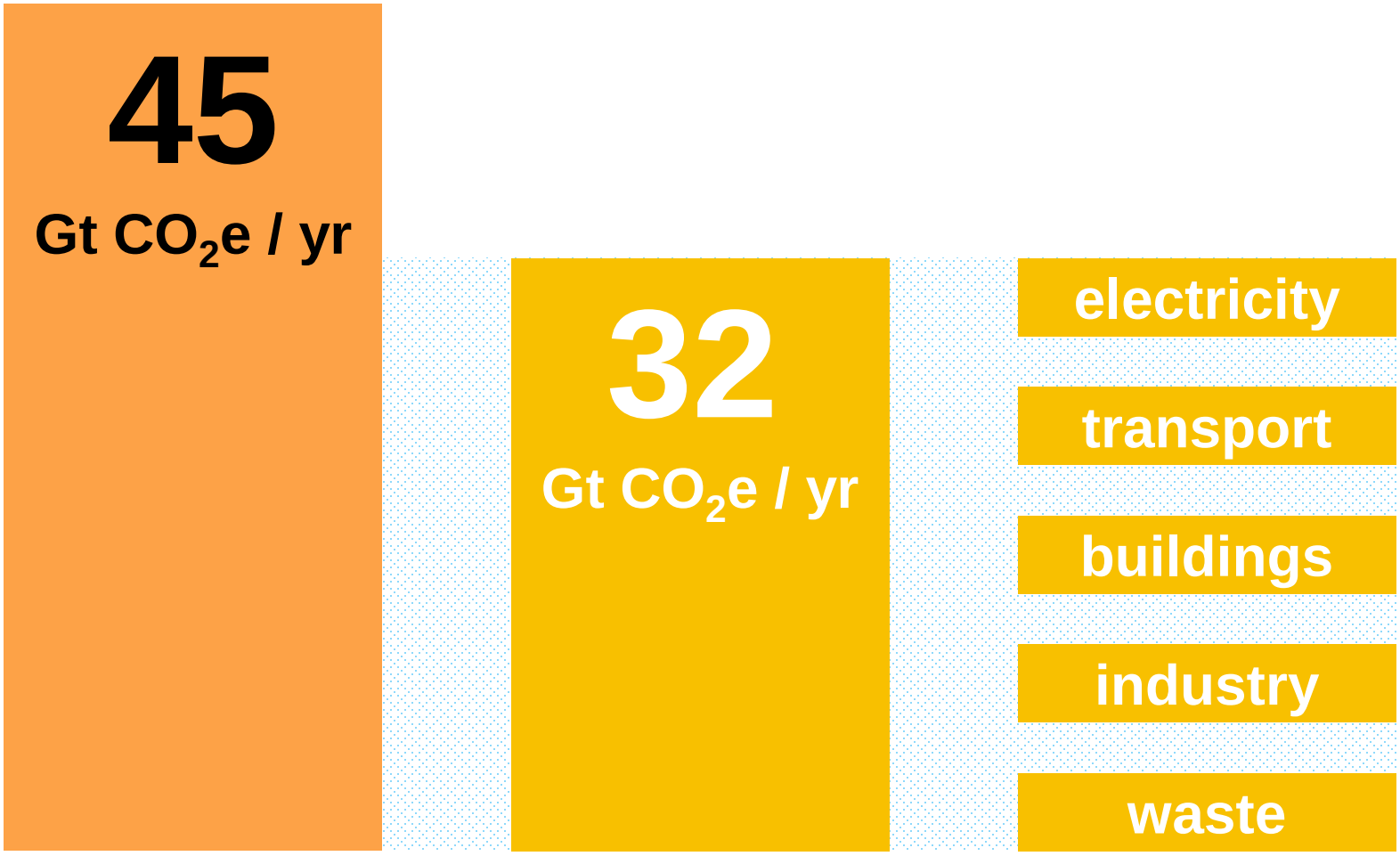
Why knowledge of cities CO_2 emissions is needed ?
Cities account for 70% of global emissions



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

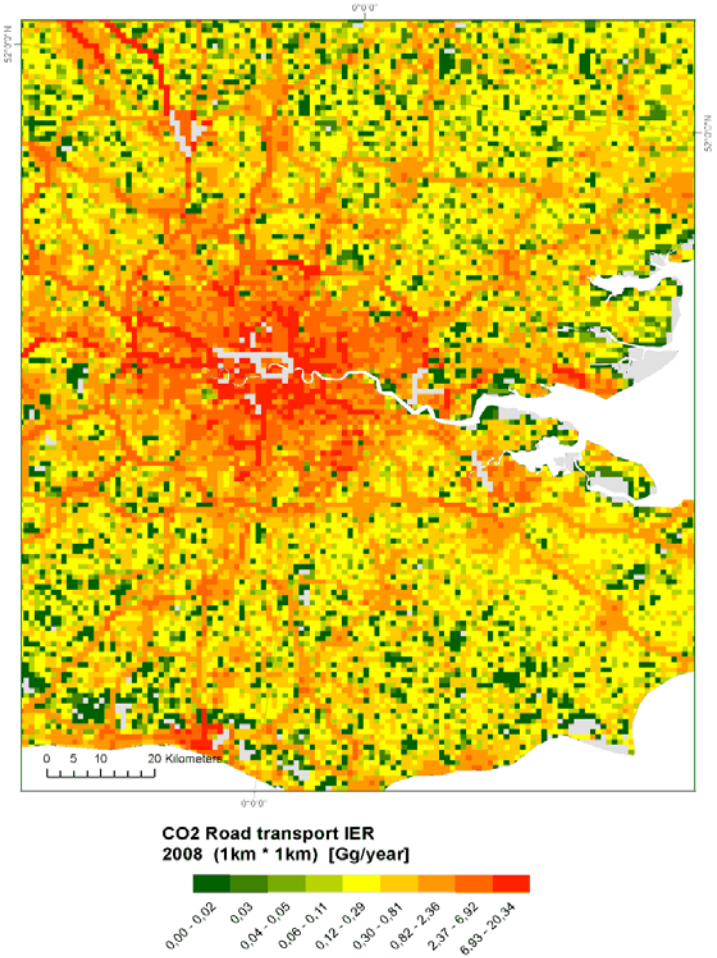
- **Cities are open systems, exchanging fuel and energy**
- **High spatial, temporal & sectorial variability of emissions**
- **Lack of knowledge limits the effectiveness of emission reductions**

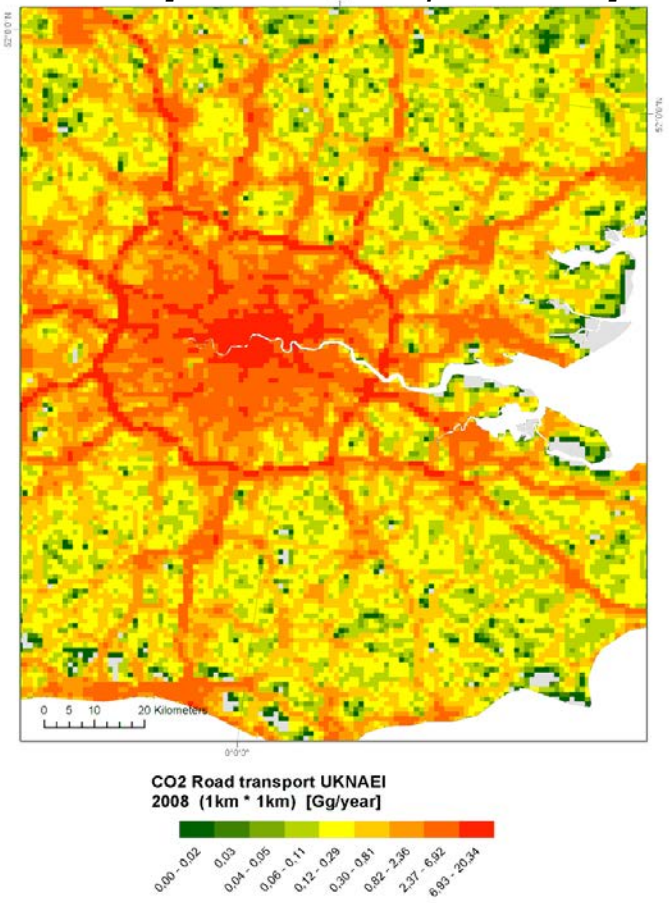
CO_2 emission inventories from Ile de France (Paris region)

	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

[B. Thiruchittampalam, IER]

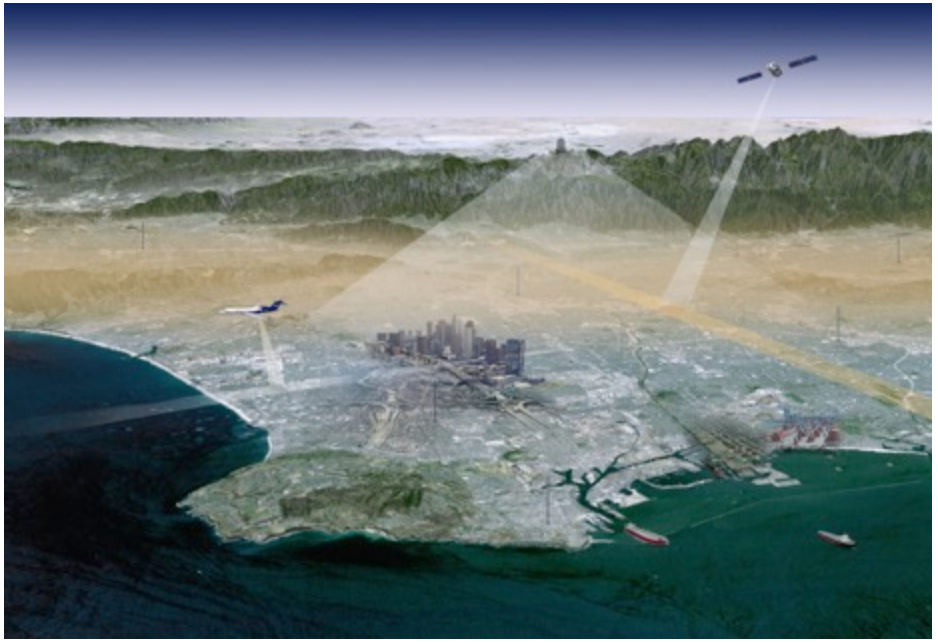




Monitoring city scale emissions from the atmosphere

- **Cities: the major part of CO_2 emissions over < 2% of land area**
- **Inventories either non existent or infrequently 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**

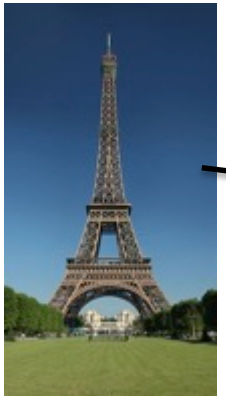
Measurement towers in Indianapolis (NIST/ INFLUX project)

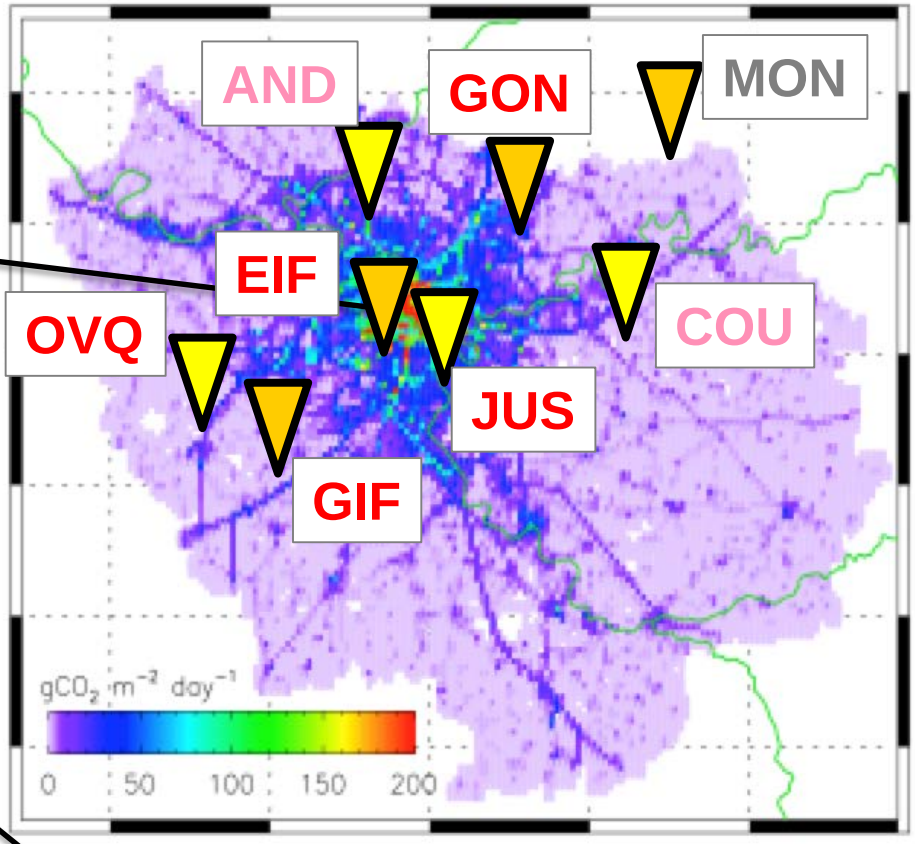


CO_2 Megacities project in L.A. (JPL/NASA)
See D Riley presentation

The Paris in-situ measurement network

Developed since 2009 from research projects





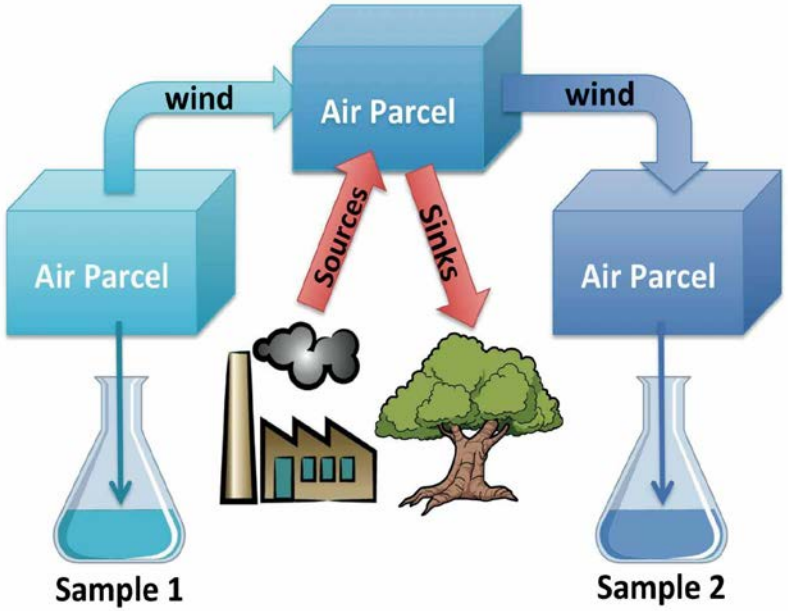
dominant wind directions

Bréon et al. 2015, ACP

An urban station

Inverse modeling of emissions

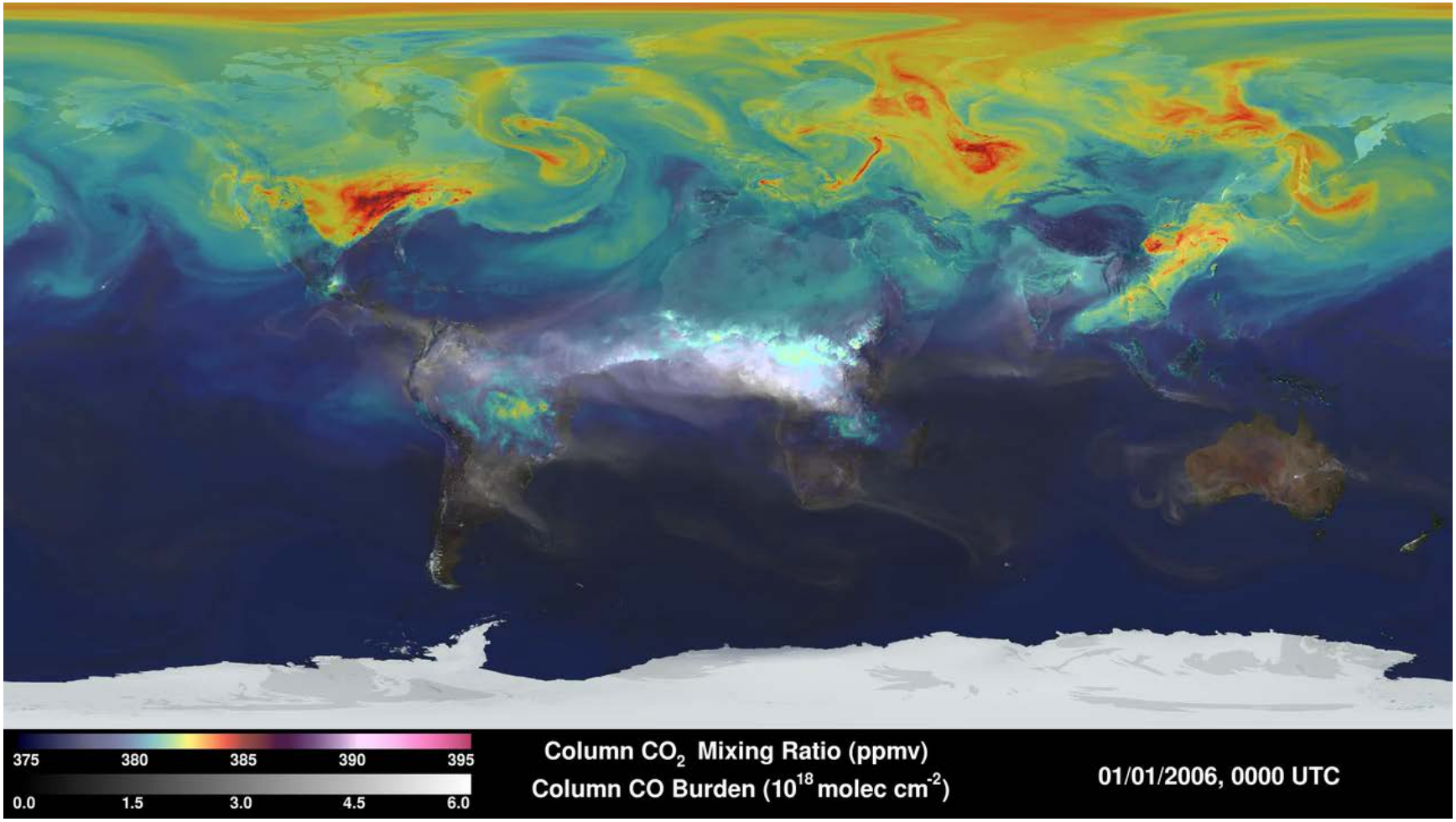
The atmosphere is a powerful integrator of surface fluxes



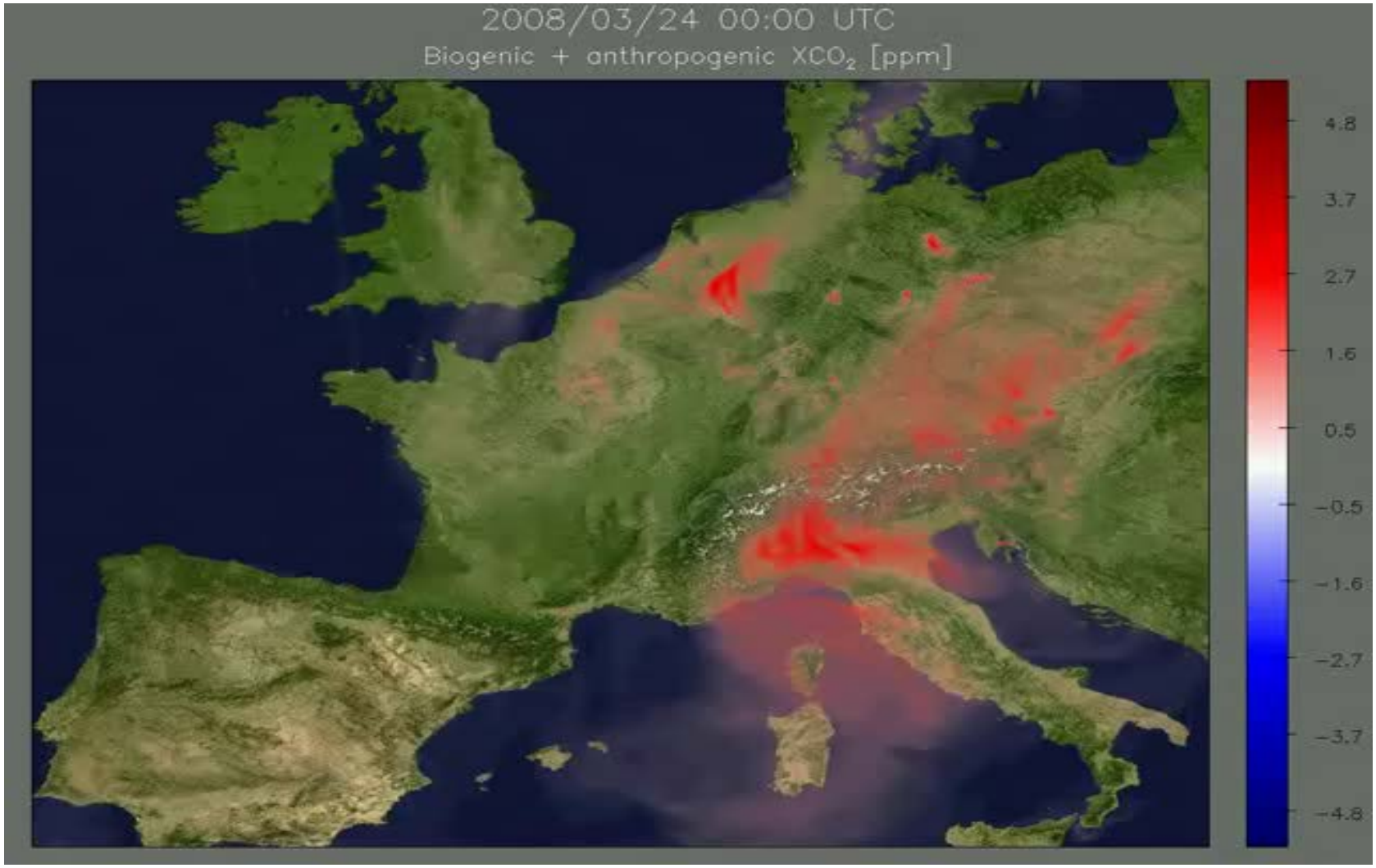
… but to unleash its power, dense sampling is needed

- **Atmospheric measurements** were already proven to be effective to quantify regional CO_2 and CH_4 fluxes at all scales : global, continental, regional, country, local.
- But we do not have a **dense sampling of the atmosphere in space and in time to elucidate the spatial details of fluxes beyond continental scales**

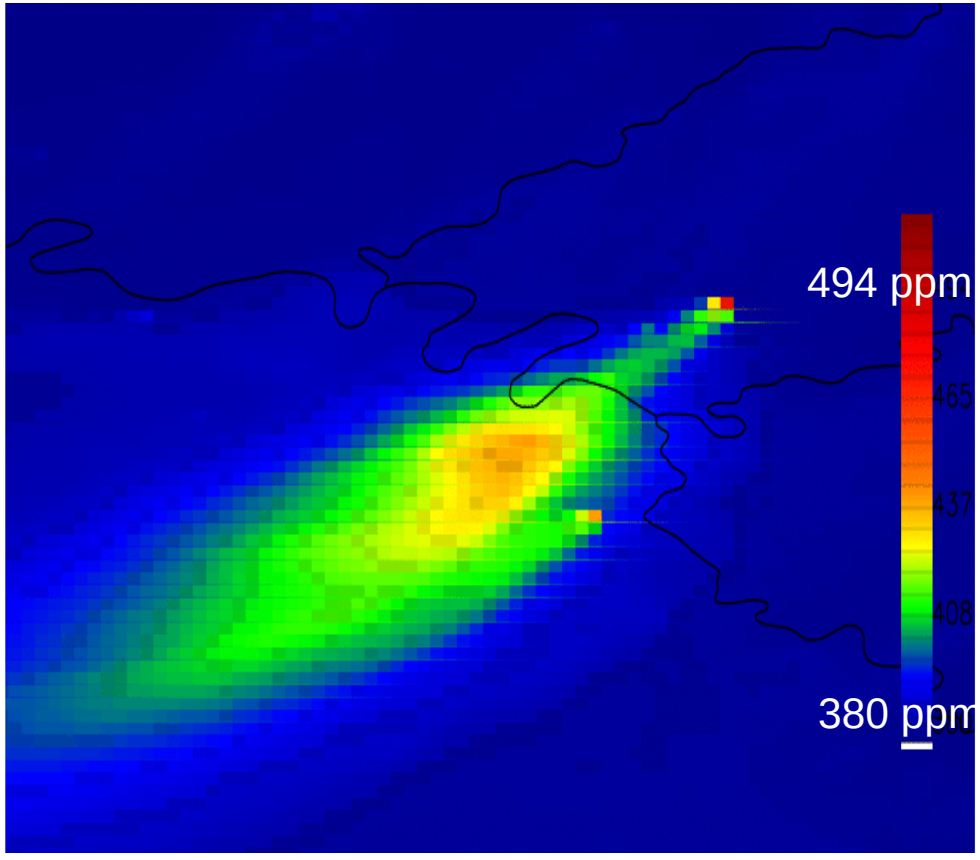
Transport of CO_2 in the atmosphere



Plumes of emissions

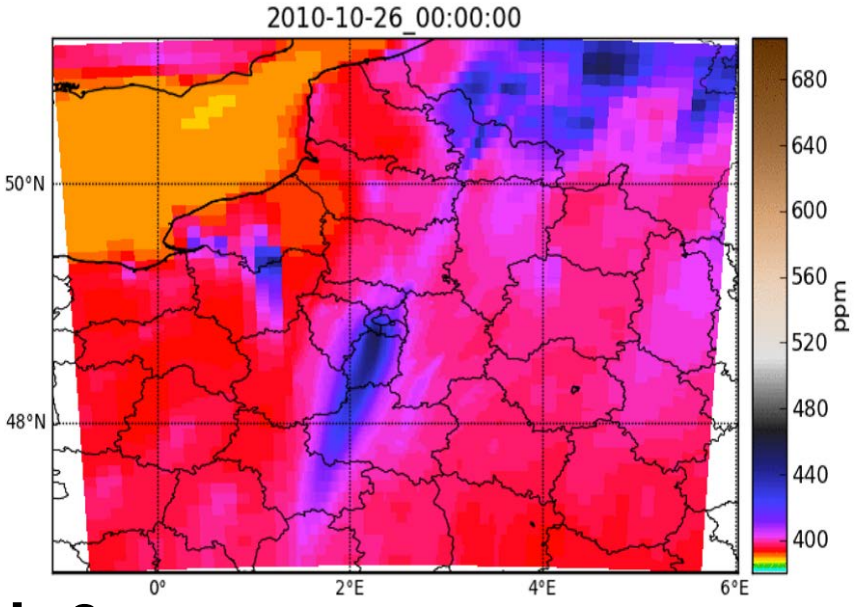


CO_2 plume of Paris City



Atmospheric transport modeling system

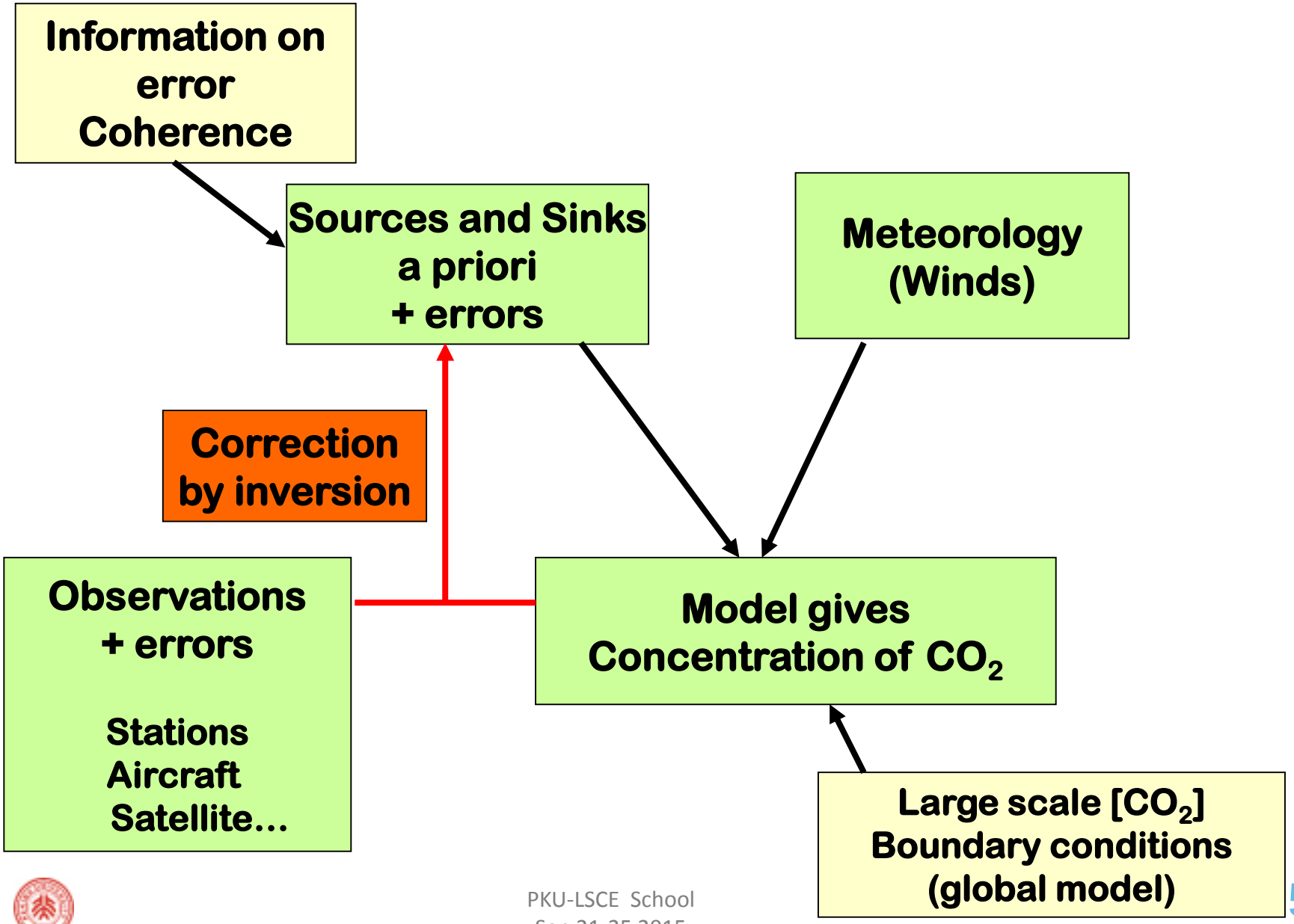
- **Eulerian transport model CHIMERE**
- **Resolution 2 km (interpolated 15 km ECMWF winds) + numerical diffusion**
- **Emissions : AIRPARIF in Paris + EDGAR in the domain outside Paris region**
- **Surrounding vegetation and soils CO2 sources and sinks hourly from CTESSEL model**
- **Atmospheric CO_2 lateral boundary conditions hourly from MACC v10.2 global transport model with optimized fluxes**



Domain of high resolution CO_2 simulation

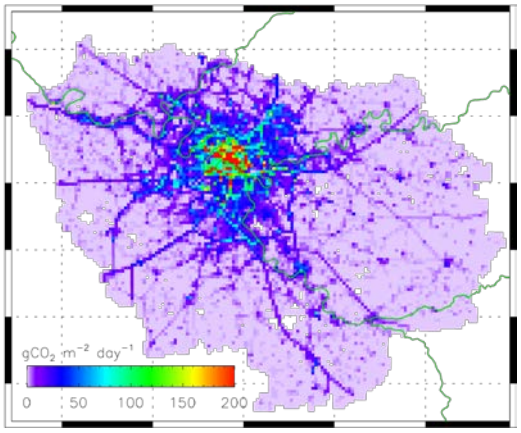
Goal : invert CO_2 emissions each 6 hour with 4 stations and vegetation fluxes each week for year 2010

Inversion of sources and sinks of GHG

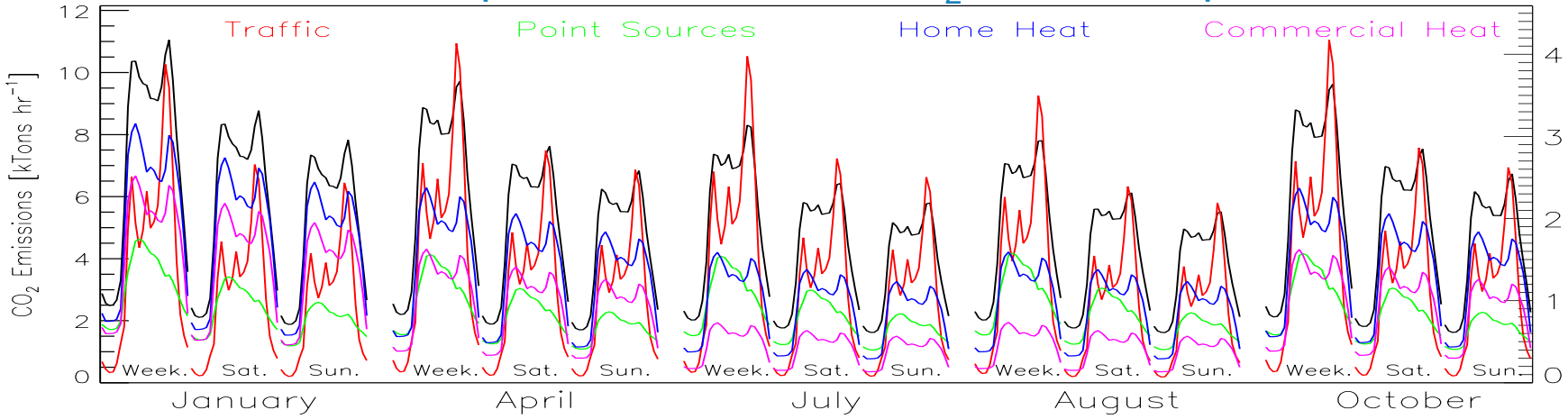


Starting point : inventory released in 2008

- **Data compiled by local air quality agency AIRPARIF**
- **Developed for pollutants, but contains CO_2**
- **Resolution 1 km / hourly**
- **Simplified sectorial time profiles**
- **Version used here: 2008 – updated since**



Assumed temporal variations of CO_2 emissions per sector



Comparison of measured vs. simulated concentrations

Hourly and afternoon CO_2

In Dec 2010

Red : Measurements

Green : Model

Thin black : CO_2 from boundaries and from emissions outside Paris

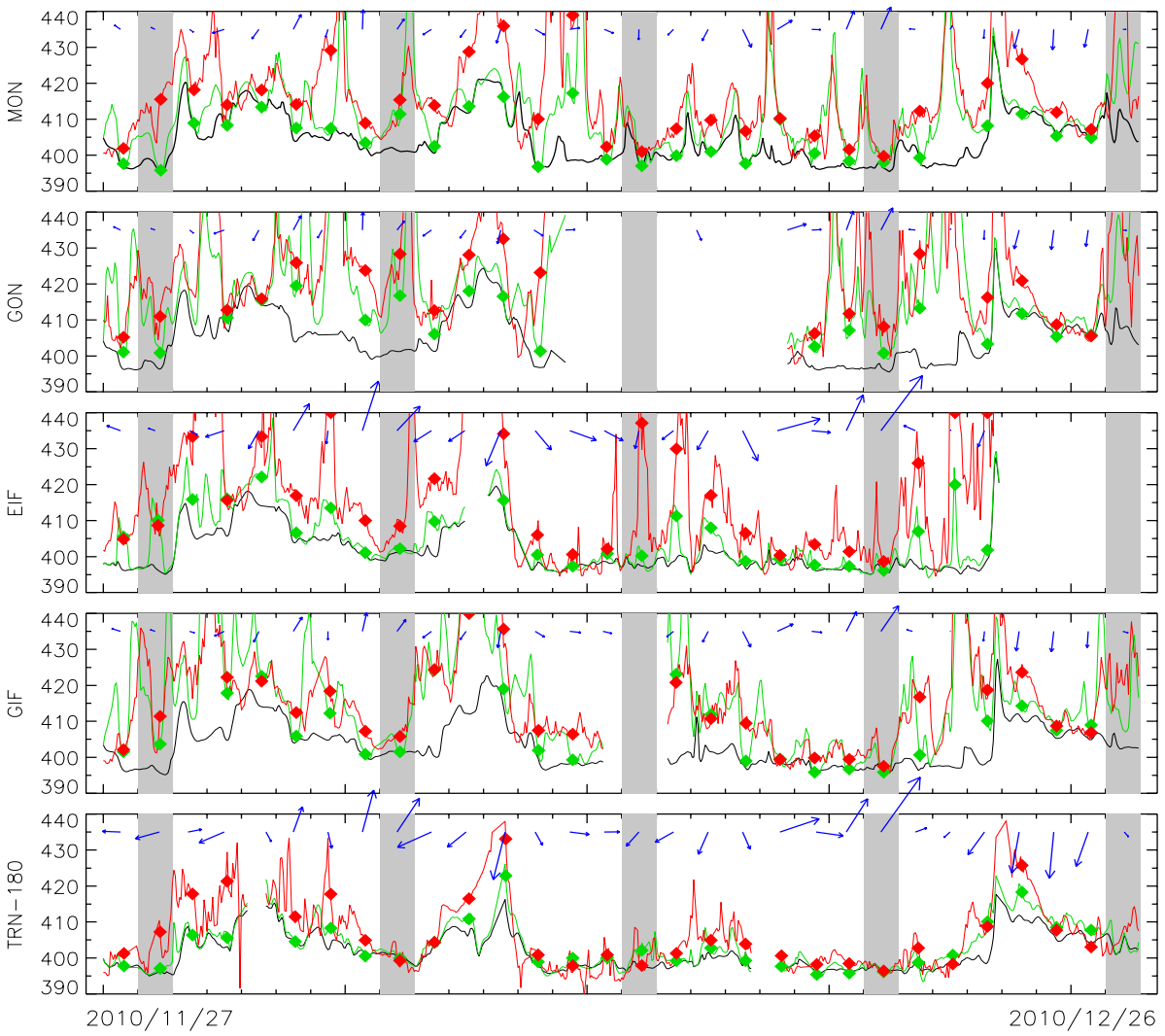
Blue arrows : daily wind

Ignored CO_2 error time correlations

Select CO_2 data

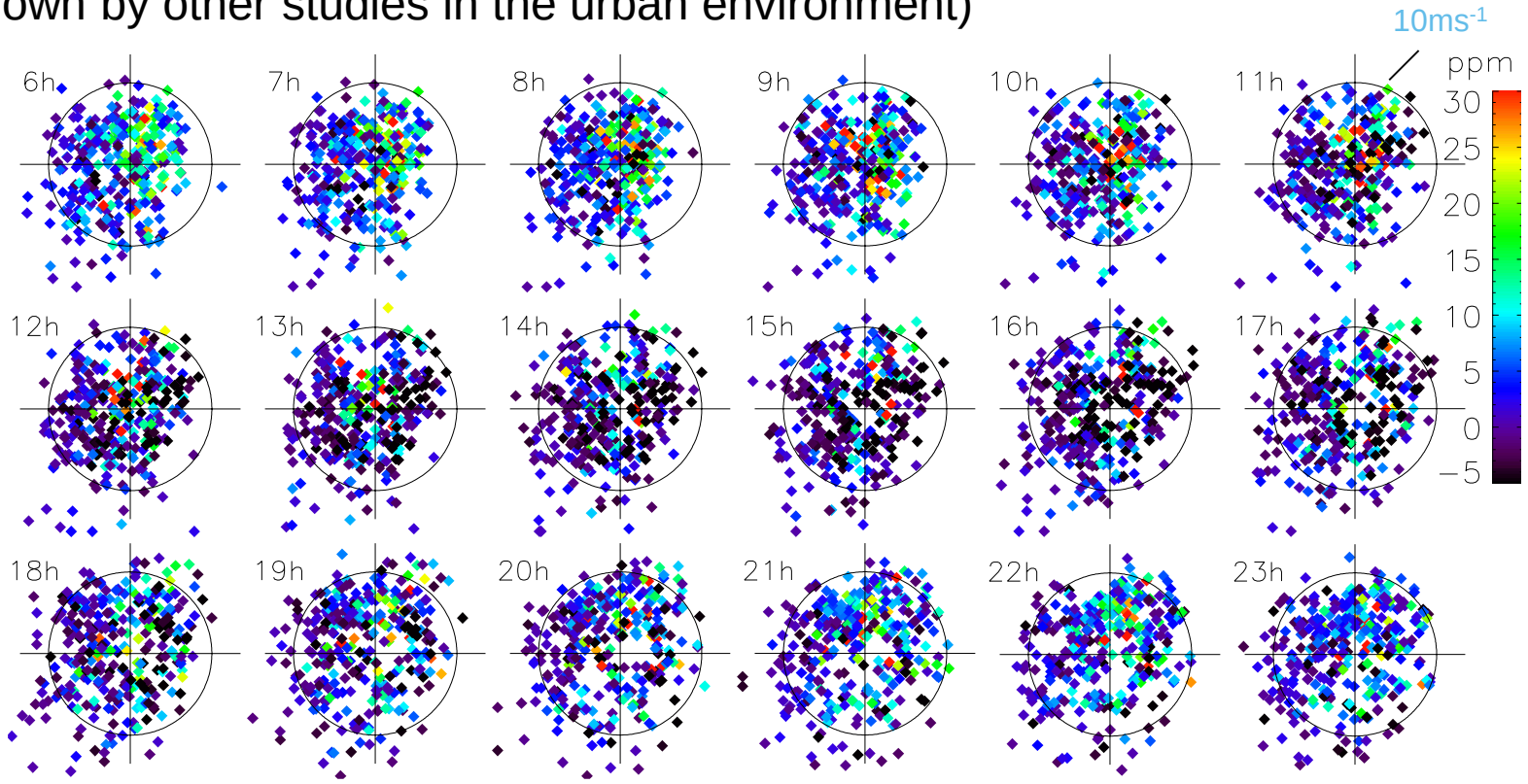
Mid afternoon

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)

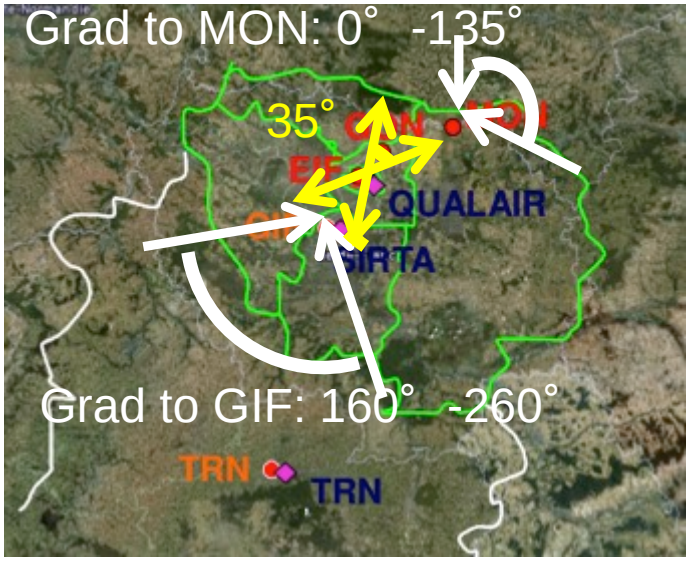


Wind roses of the model-data misfits at EIF for the full year of simulation

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

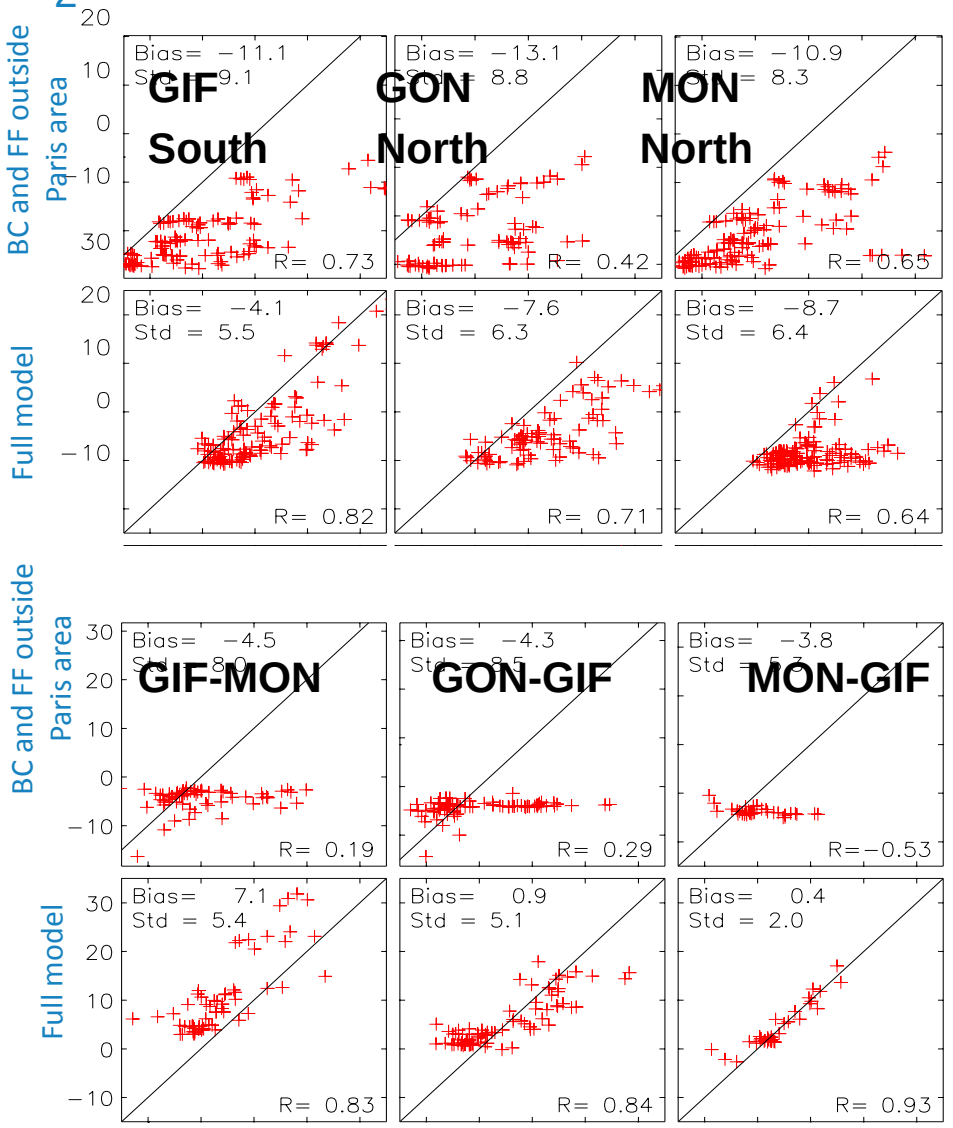
Using city upwind – downwind gradients

Modeled 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**

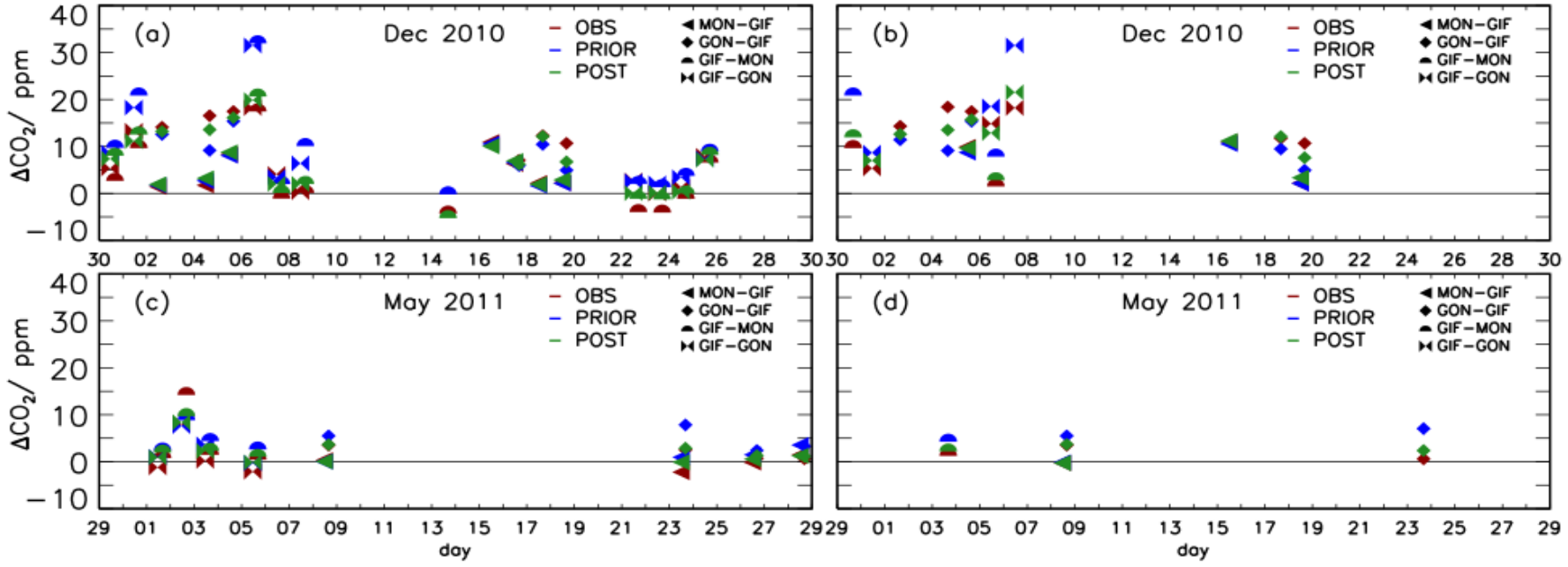
Negative gradients with the looser selection

(high potential for aggregation errors)

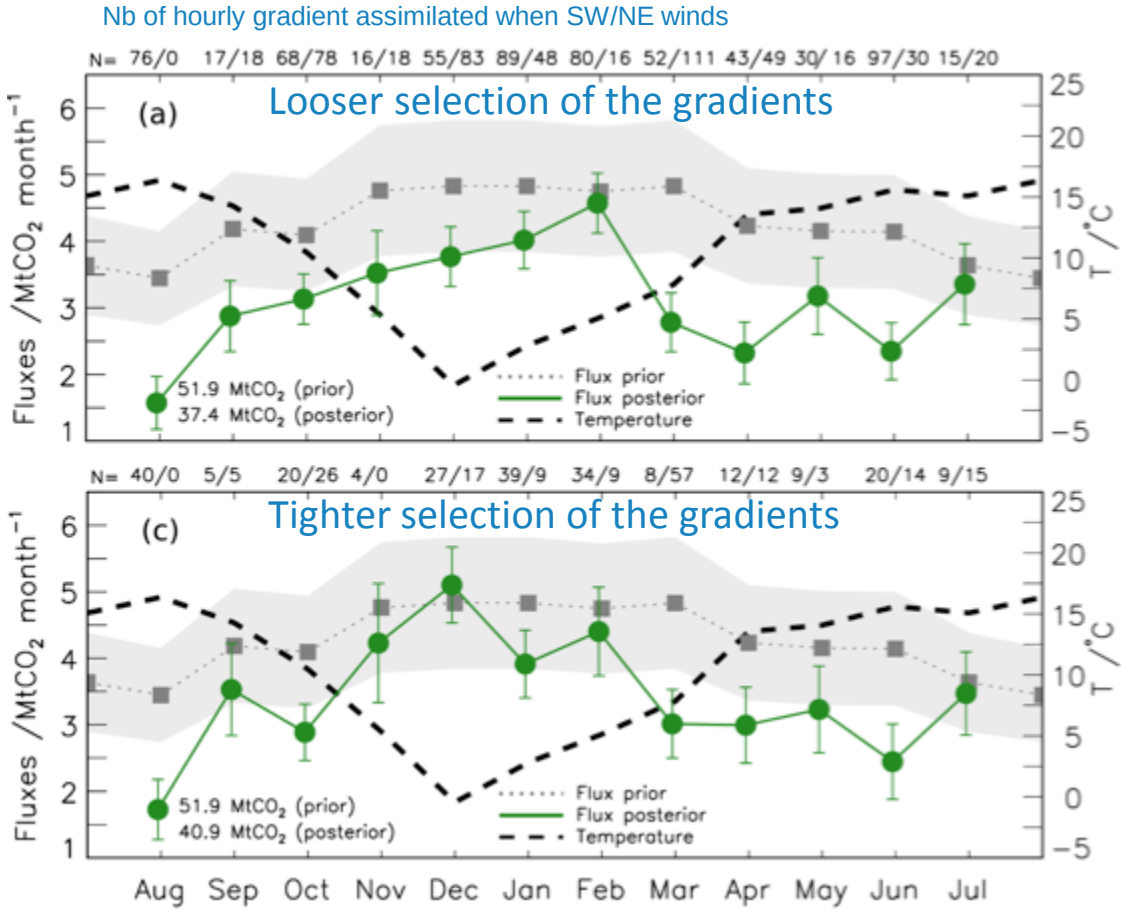
Mid afternoon gradients used by the inversion

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

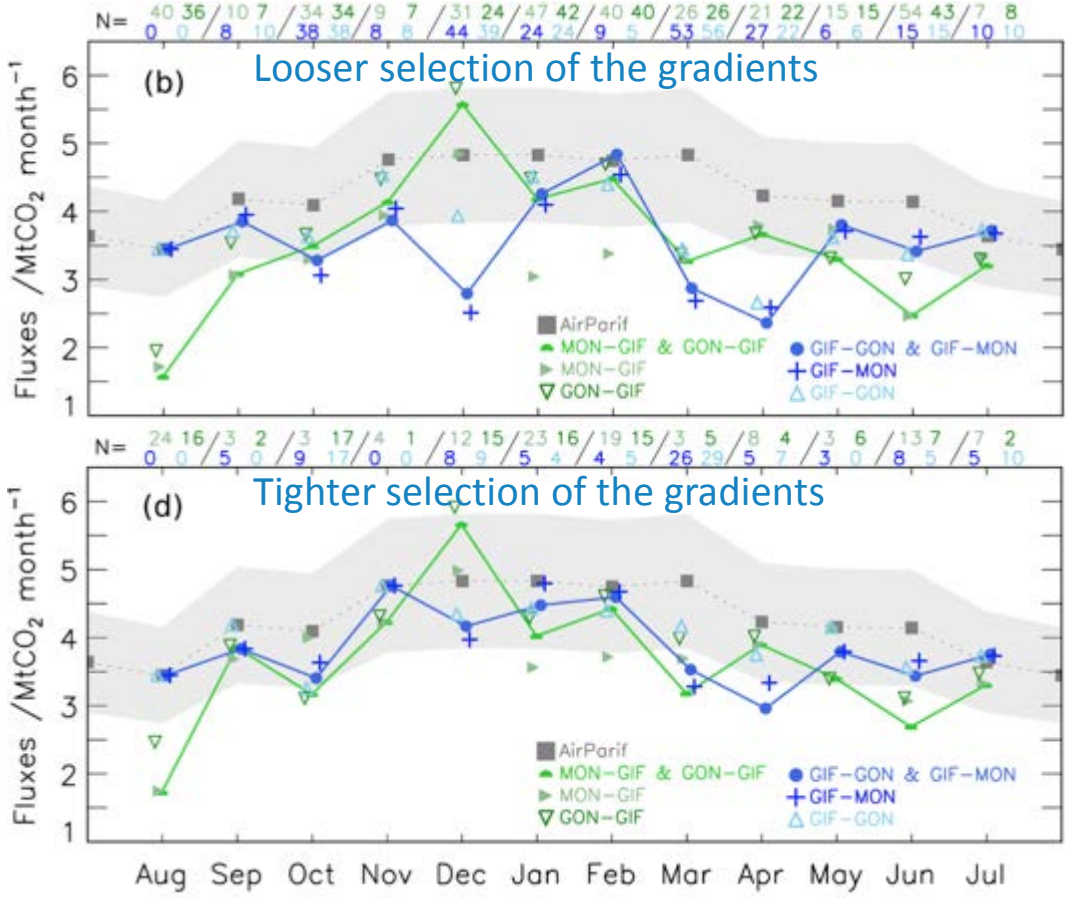
Annual budget = 40.9 MtCO2

Close to that of AIRPARIF 2010 ≈ 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

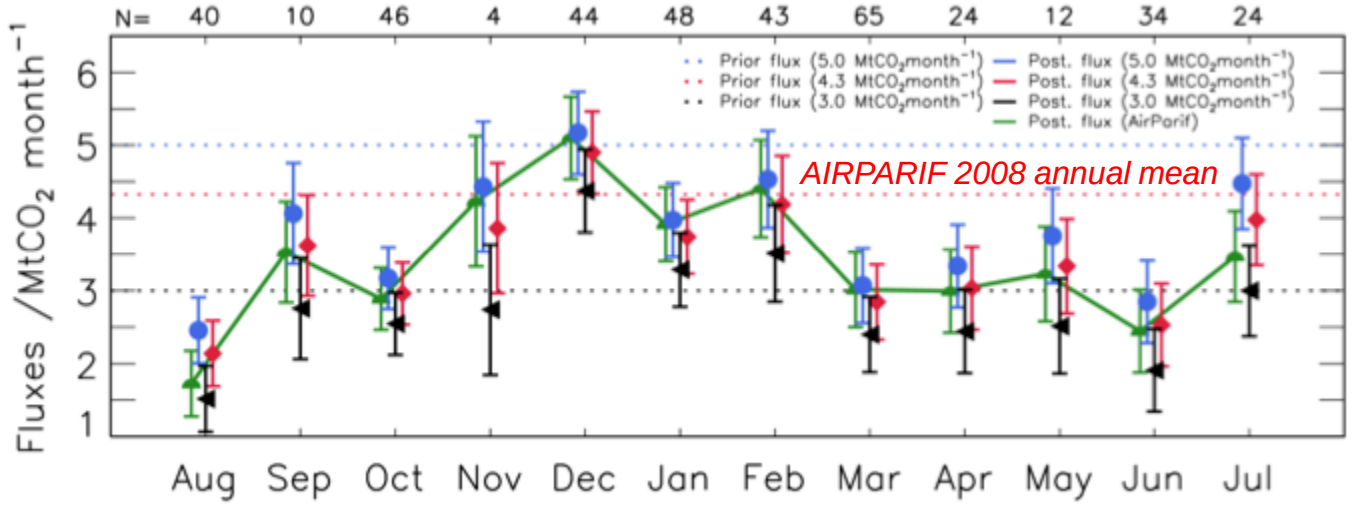


Discrepancies between results using gradients when NE vs. SW winds: impact from remote fluxes (emissions from NE France, Benelux, Germany) or a difference in time sampling ?

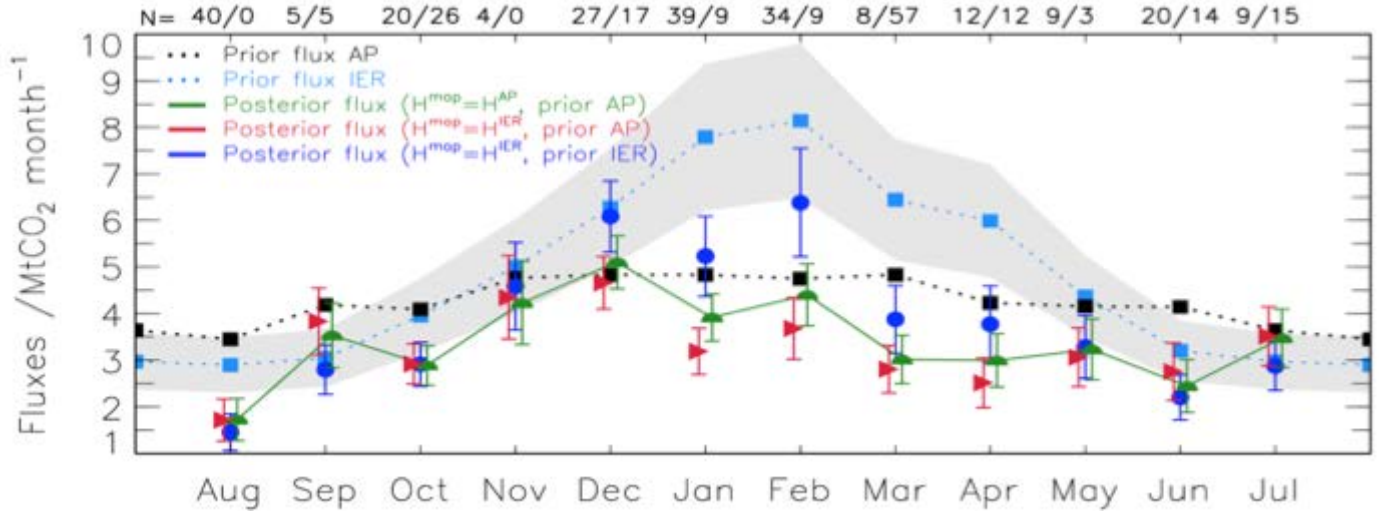
The problem is far less critical when using the tight gradient selection

Tests of robustness with the tight gradient selection

Tests using different emission first guess

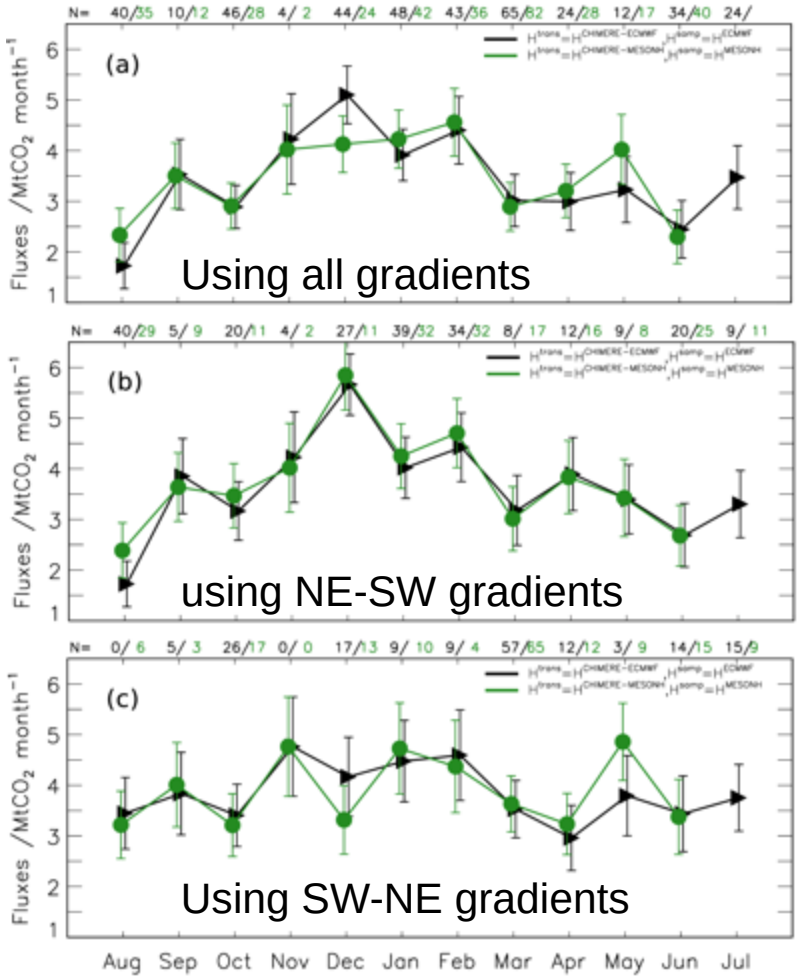


Tests using AIRPARIF2008 or IER prior total / patterns of emissions



Tests of robustness with the tight gradient selection

Using ECMWF (15 km) or Meso-NH winds
2km res, urban scheme; from Meteo-France)



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

Some differences when NE winds

Need for better characterizing the uncertainties related to transport

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

Micro-scale modelling

Ground concentration of CO2 near the Jussieu station – MSS model (Micro-SWIFT-SPRAY)

Inheritage of the AIRCITY system

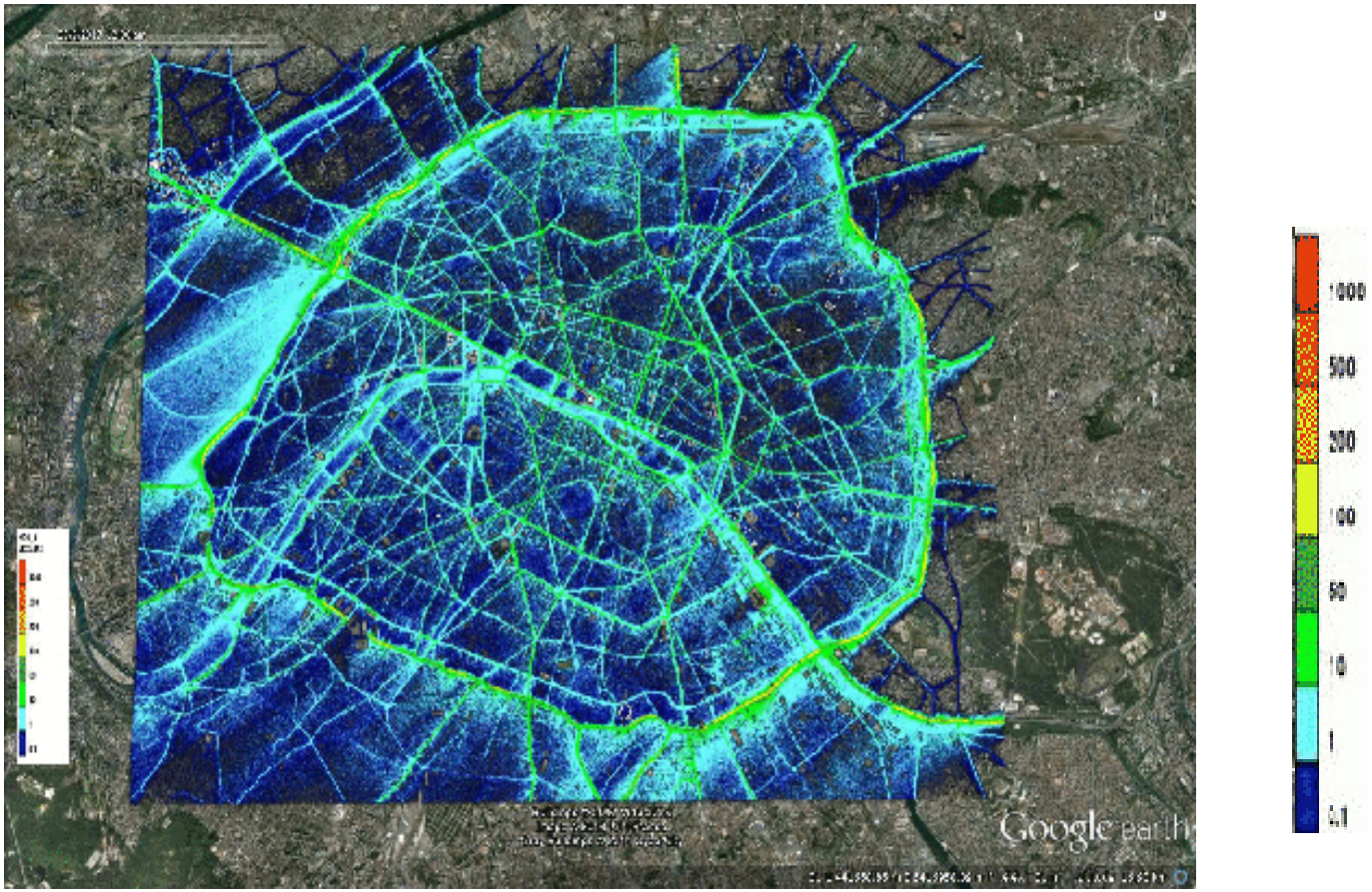
Full high-resolution 3D model of urban air quality

AIRCITY is a high resolution 3D simulation system of air quality in a city, allowing both analysis and forecast. The Paris simulation system covers a **14x11.5 km domain with 3m resolution**.

25/03/2013

NOx

No background

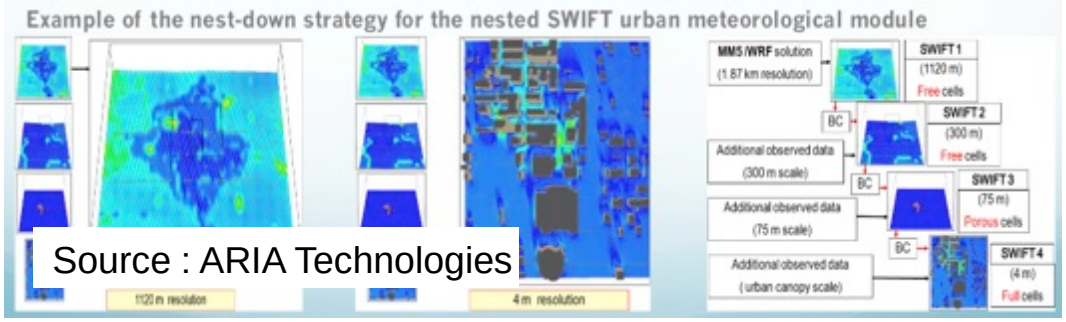


Thank you for your attention

Next objectives

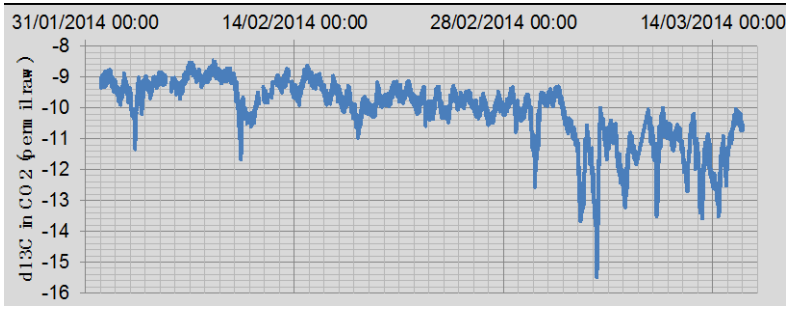
- **For the European CO2 natural flux inversion:** use of **satellite data; inversion of anthropogenic emissions** (use of co-emitted species, C-isotopes); **stronger links with land carbon models;** nesting with national systems
- **For the Paris scale CO2 flux inversion**: increasing the network, **exploiting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



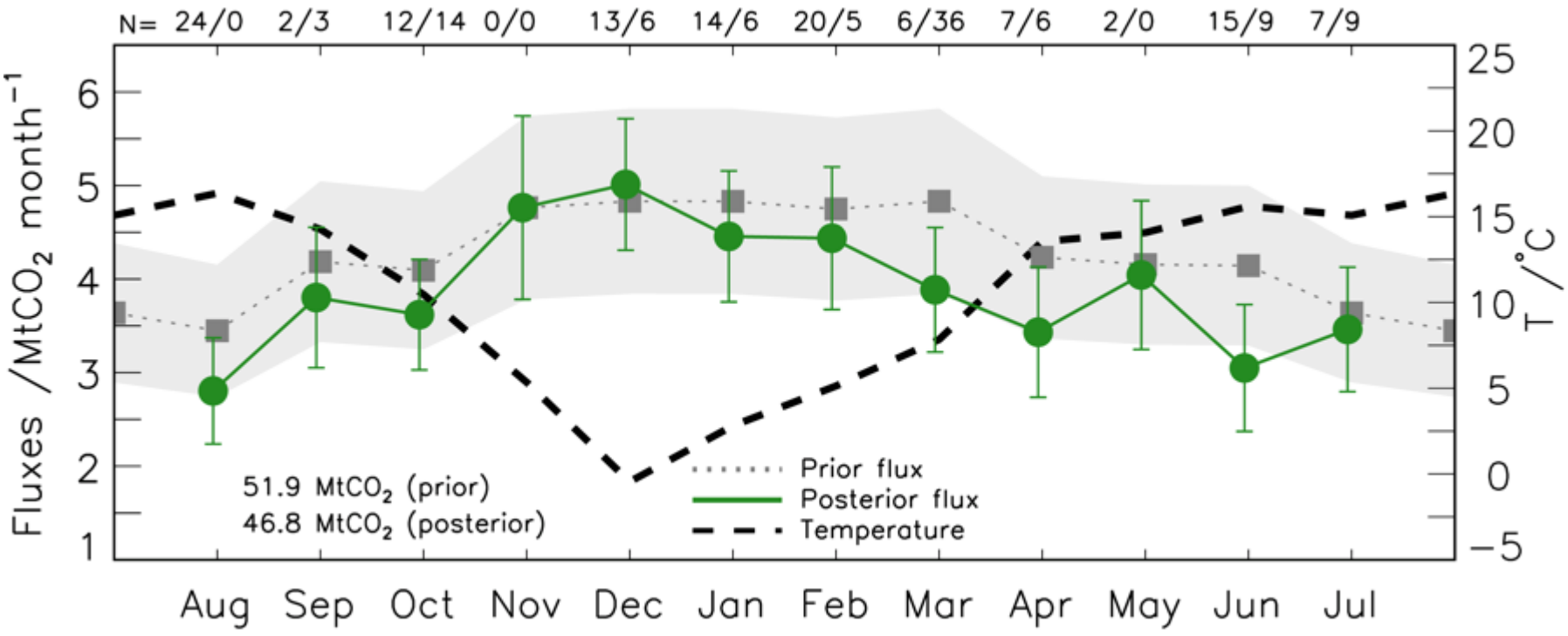
Source : ARIA Technologies

13CO2 measurements at GIF



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)

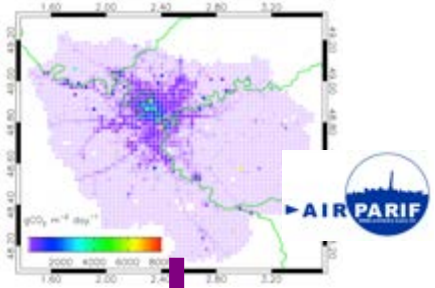
The city inversion framework: sequence of 1 month inversions

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

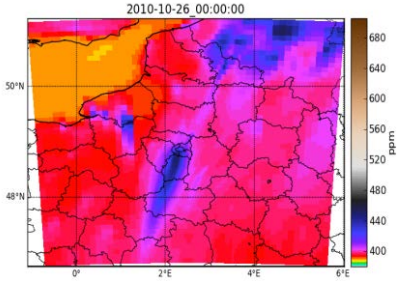
PRIOR FF: AIRPARIF
PRIOR NEE: C-TESSEL
Uncertainty in FF: 20% in monthly FF
Correl length ~1 week
for a given 6-hour window

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



POSTERIOR FLUXES and uncertainties

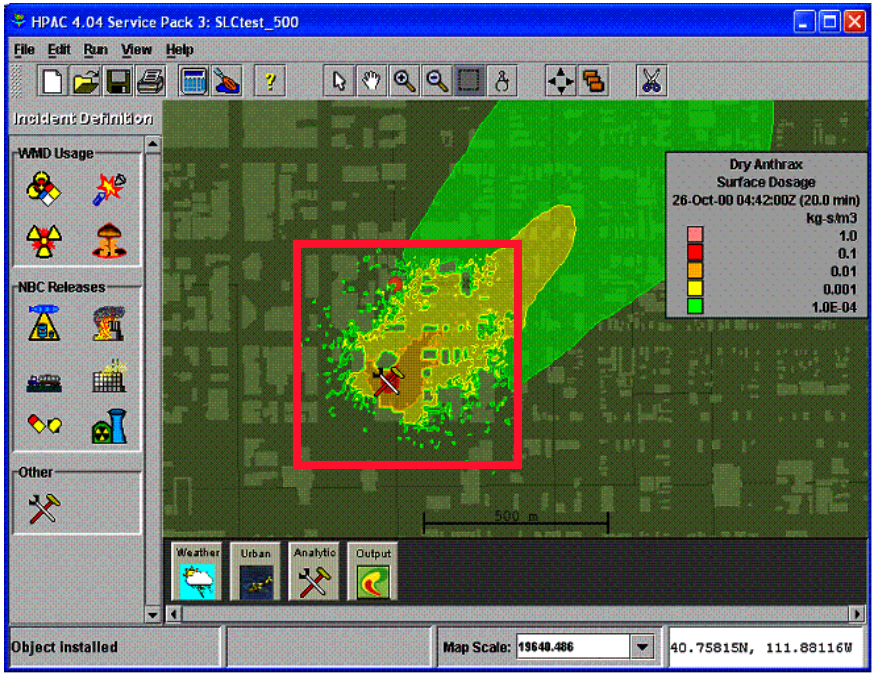
CO2-MP / ICOS hourly city upwind-downwind gradients
12:00-16:00
when wind > 3ms^{-1}

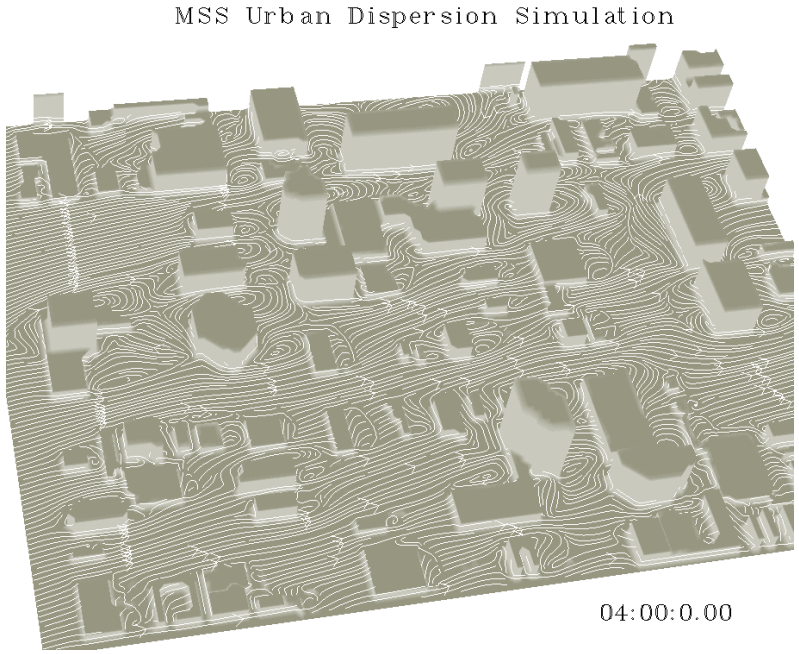
(Grad MON and GON to GIF when SW winds and grad GIF to MON and GON when NE winds)

Model error (1h scale): 3 ppm

Origin of PMSS code: emergency response

PMSS in inserted into the HPAC system



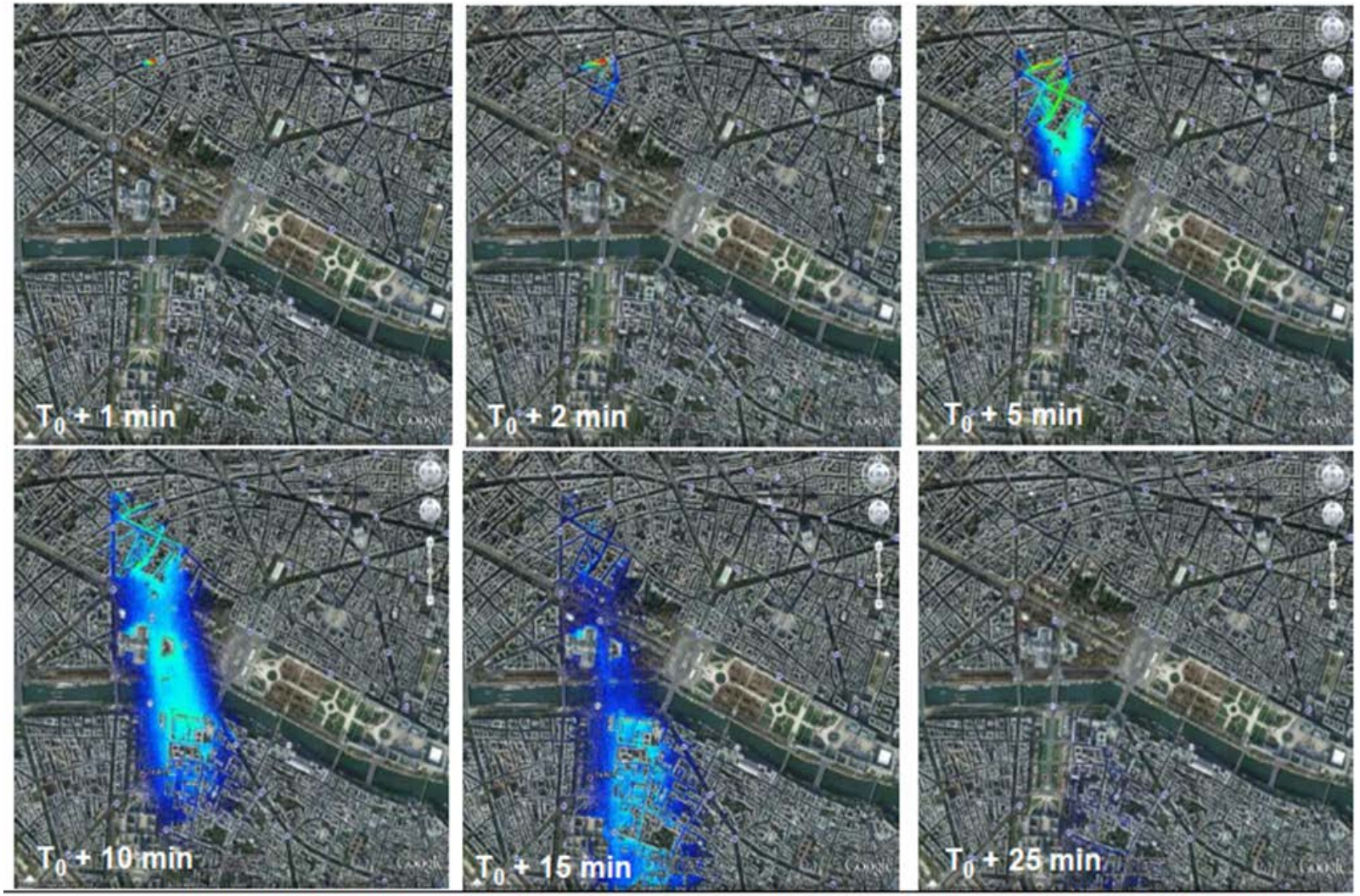


MSS is included into the HPAC 5 suite of models by DTRA (US-DOD)

- Coupled to SWIFT meteorological assimilation model
- Coupled to SCIPUFF (Particle to Puff conversion and handoff)

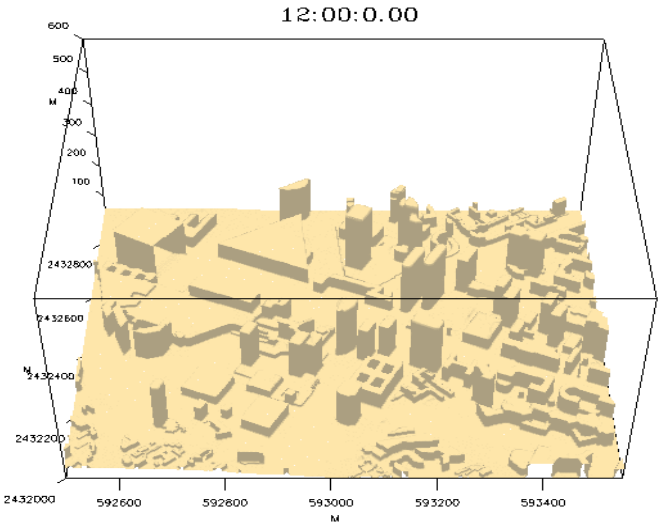
Operational resolution in HPAC for MSS Urban subdomain: 3 to 5 m

AIRCITY is the air quality application of a civil defence born modeling system

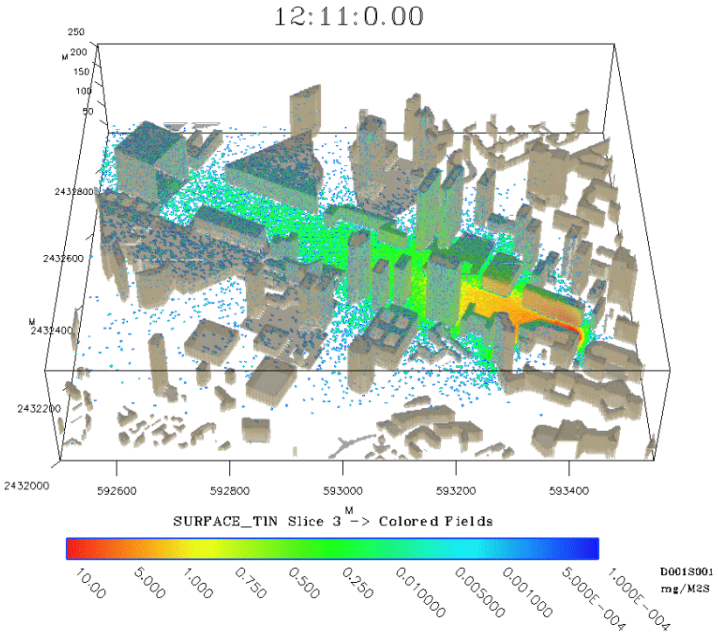


Parallel version of MSS

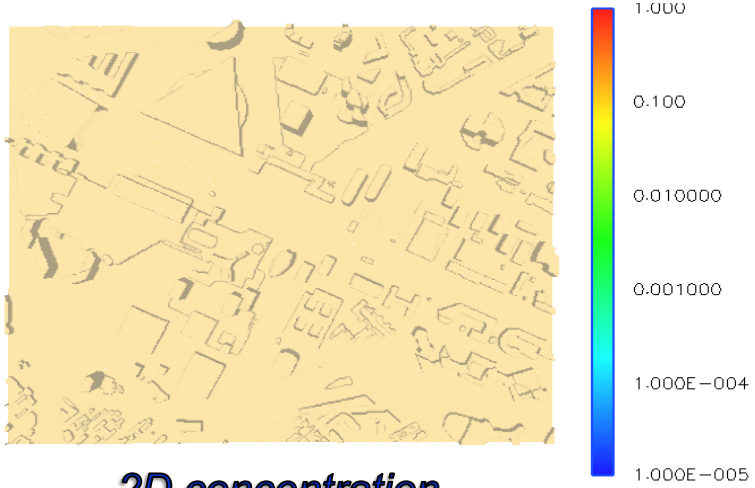
Examples of CEA applications: Paris case



3D plume



3D deposition on ground buildings frontages, roofs



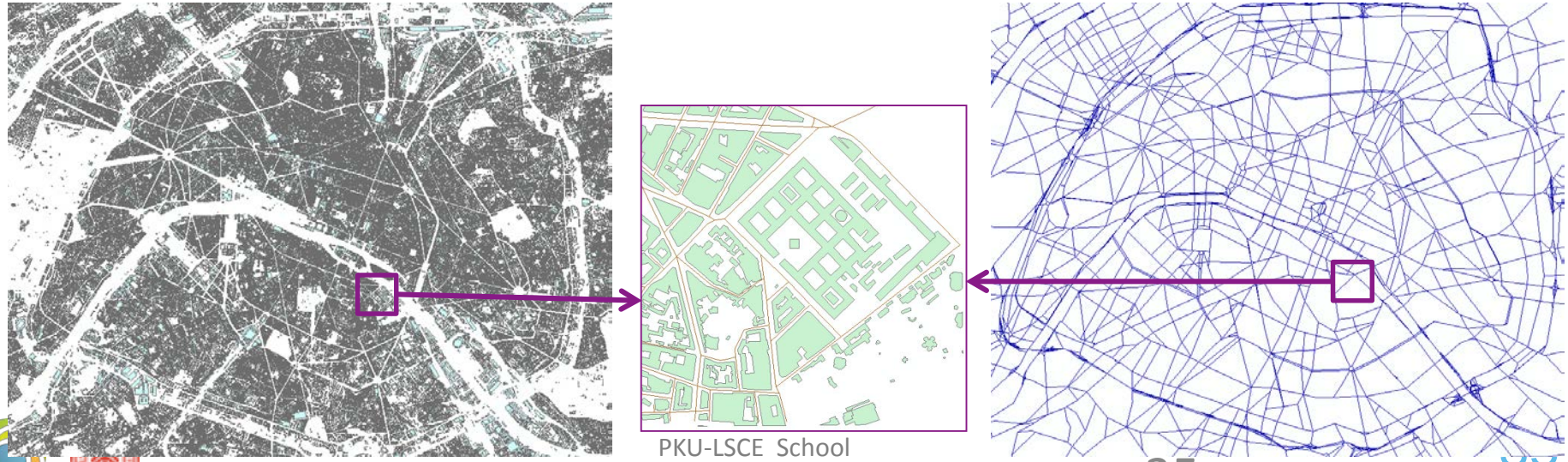
2D concentration near ground

..6 - Micro-scale modelling

In WP4, micro-scale flow and GHG dispersion modelling are performed in the area surrounding the static GHG stations (Gif, Gonesse and Jussieu at least). Vector data describing buildings and emission are created or extracted from existing database. Here is the example of Jussieu GHG station.

GHG concentrations are computed at a resolution of 3m. The concentration computed near station will be compared to the 2km-spatial average concentration. Then the spatial representativeness of the station output could be quantify before being used in the inverse regional dispersion model.

Without AIRPARIF inventory, ARIA is trying to get data from Ville de Paris.



Building and traffic emission extracted for Jussieu micro-scale modelling domain