Quantifying CO_2 emissions in (a few) urban areas

Lecturer: F. R. Vogel

Special thanks to:

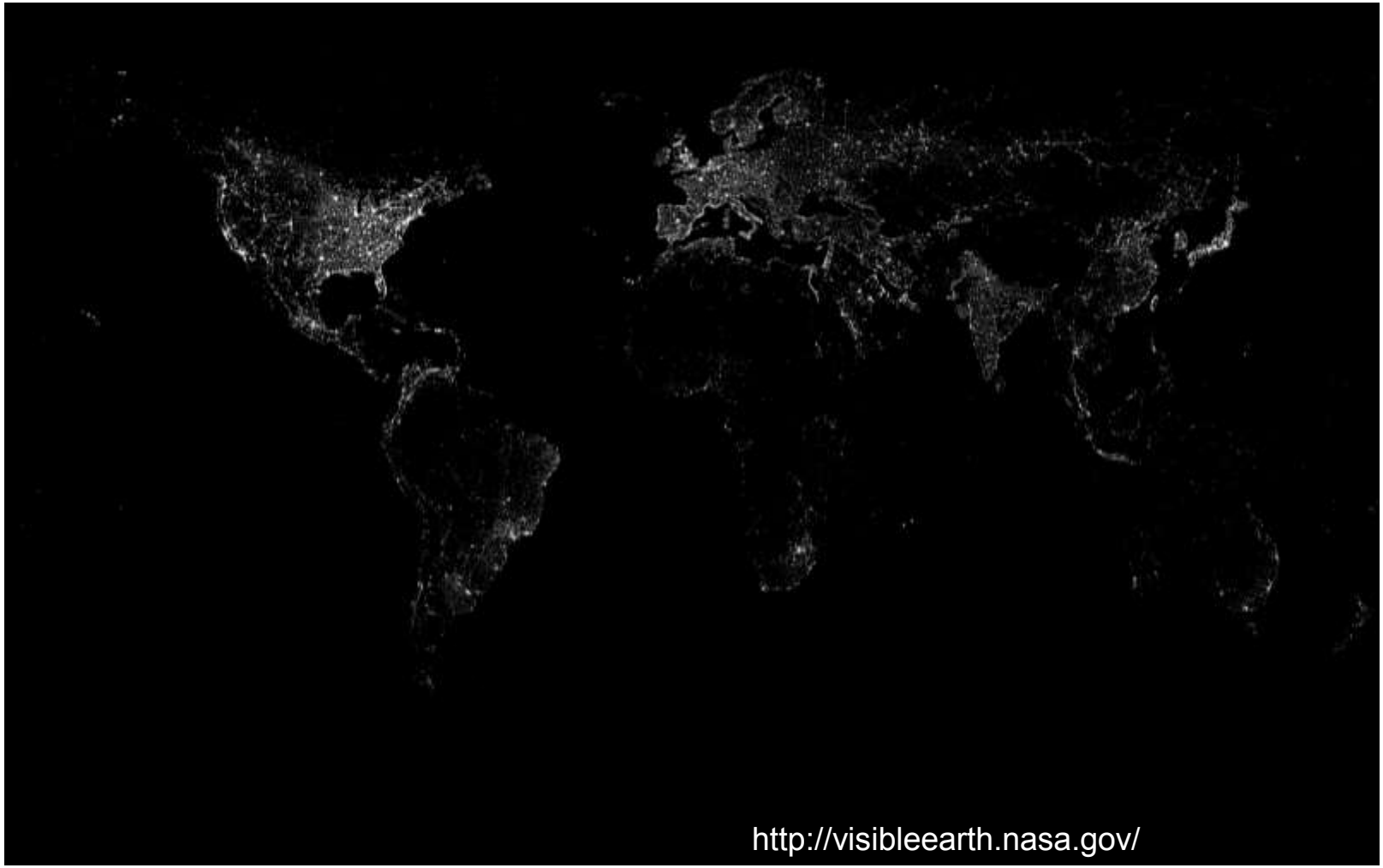
L. Wu, G. Broquet, J. Staufer, F. Hase, M. Frey, I. Xueref-Remy, F. Chevallier and P. Ciais

ICOS-RAMCES/ATC, SATINV, ARIA tech. and the teams of the COCCON Paris campaign
see http://www.chasing-greenhouse-gases.org

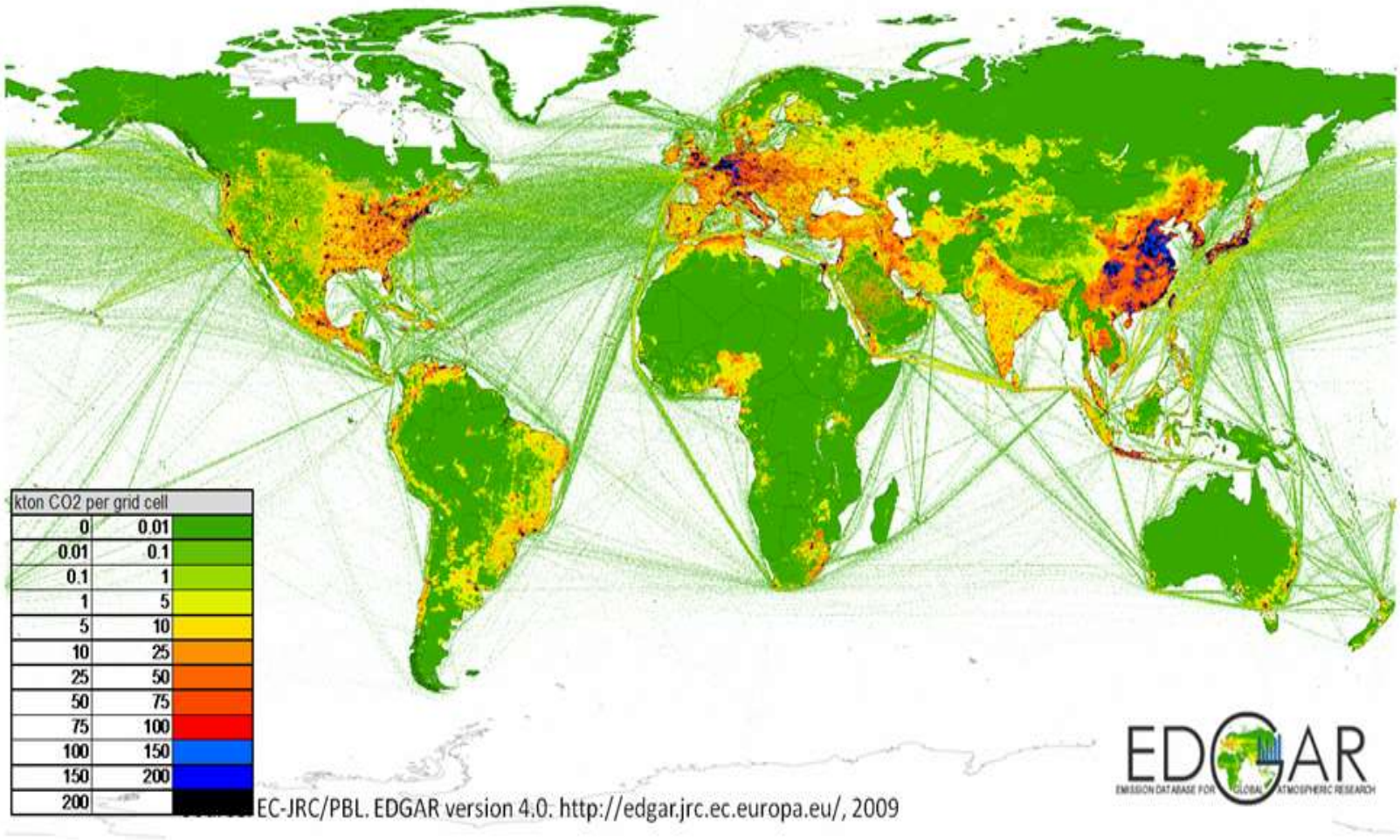
Outline

- Introduction
- Urban emission inventories
- New atmospheric observation techniques

Earth seen from space

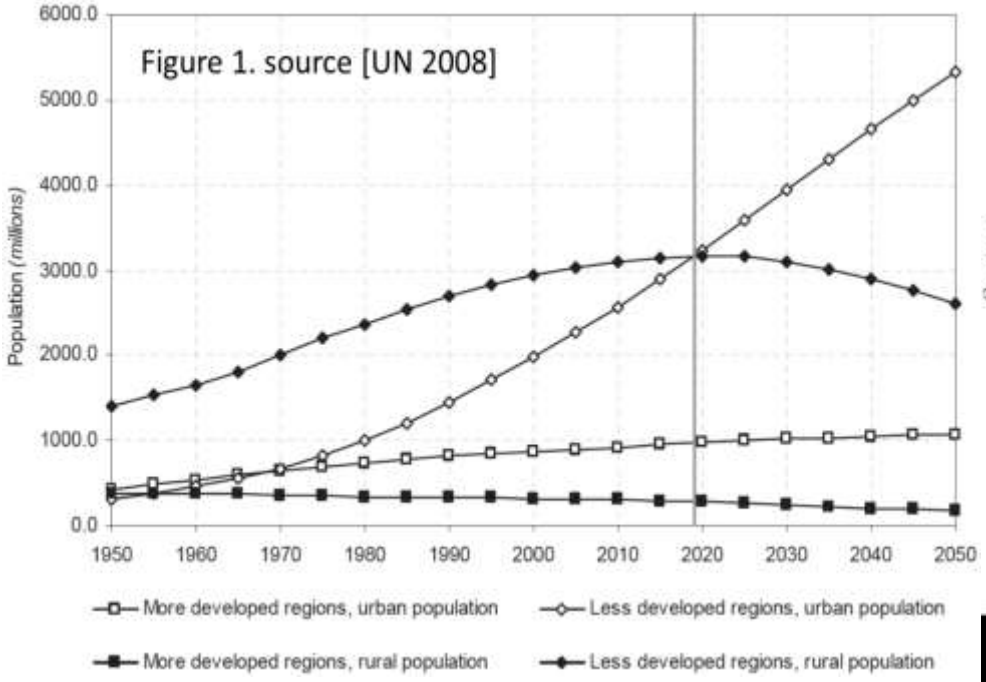


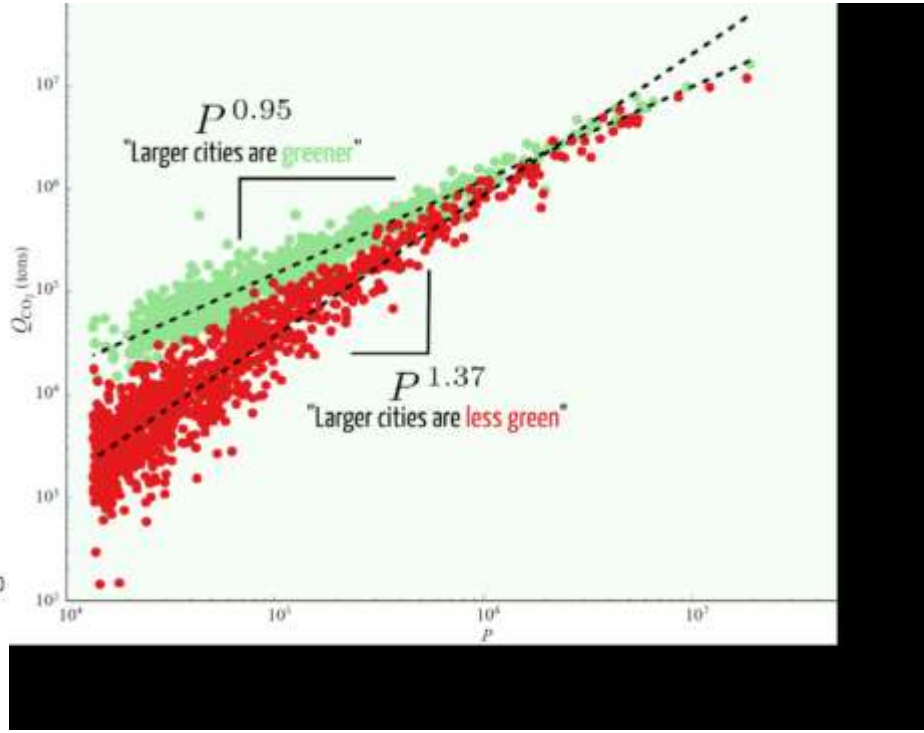
CO_2 emissions from fuel use and cement



53%-87% of CO_2 from energy use come from urban areas [IPCC, 2014]

The future of urban emissions



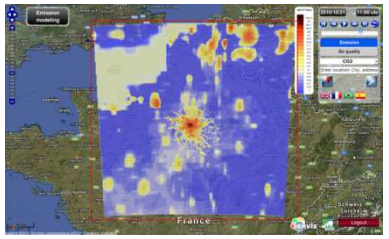


The urban population will rise…

… but will the per capita emissions rise – stagnate – decrease?

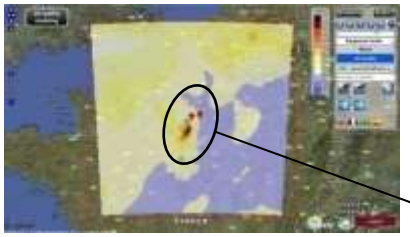
Data assimilation framework

Prior CO_2 emission



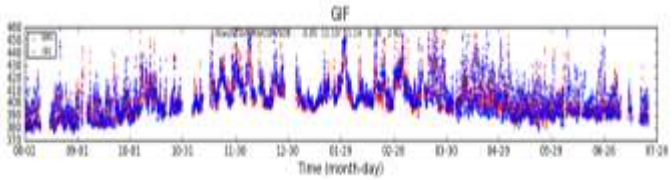
Atmospheric Chemistry Transport Model CHIMERE

CO_2 concentration fields

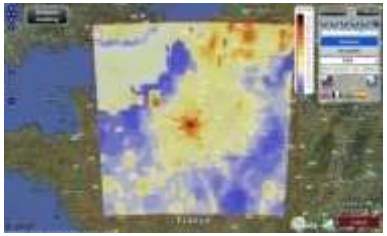


Comparison of simulated CO_2 concentration with *in situ* measurements

In situ observations network around Paris



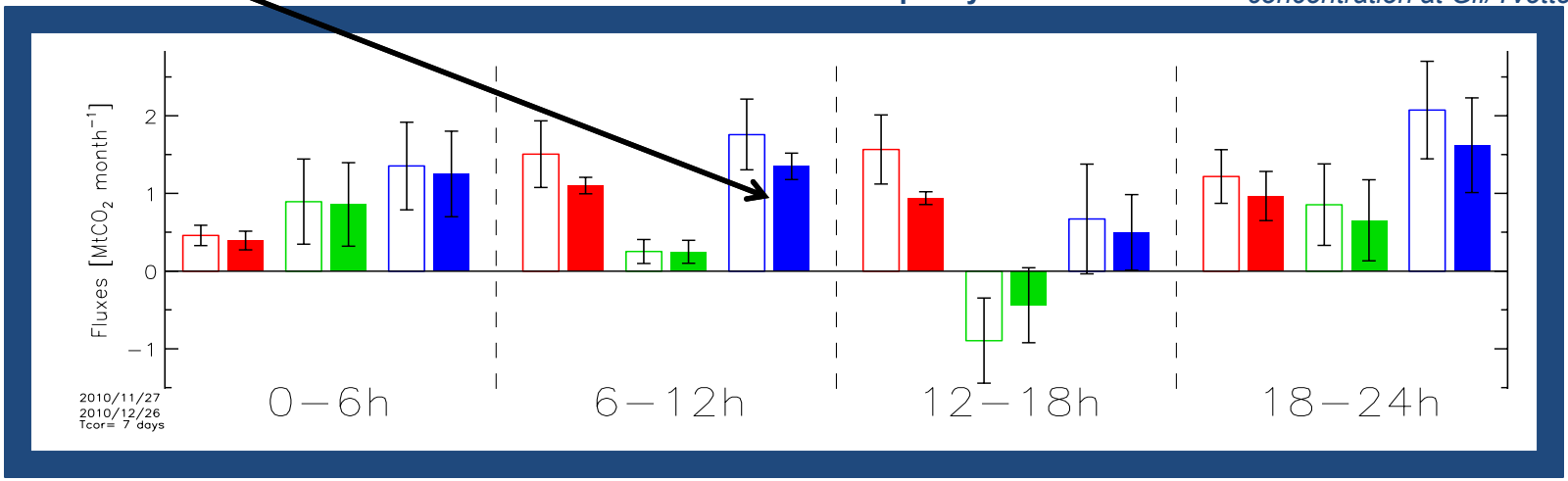
Inverse Modeling Technique



***Posterior* CO_2 emission**

Probabilistic tools to compute the best CO_2 emission estimate that reduces the observations/simulation discrepancy

Time evolution of simulated and observed CO_2 concentration at Gif/Yvette



[Breon et al. 2014]

Fossil fuel + Bio = Total

Data assimilation framework

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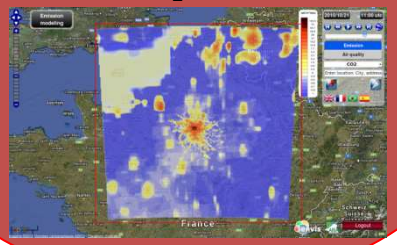

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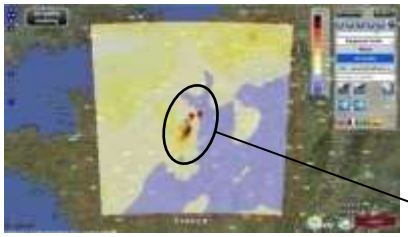

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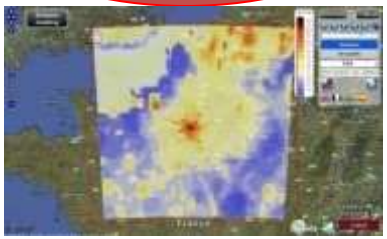

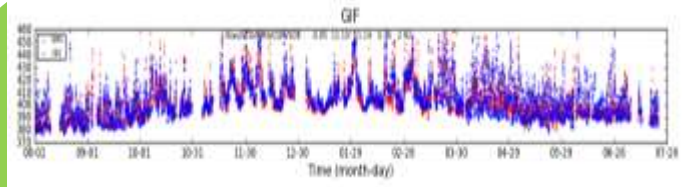

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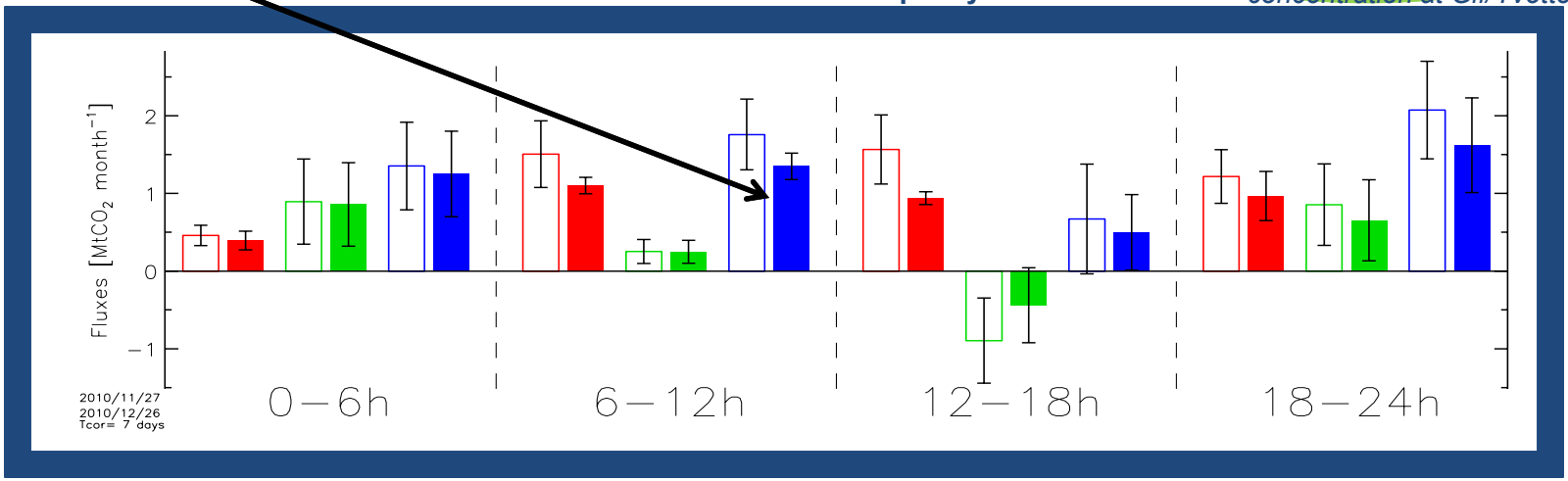
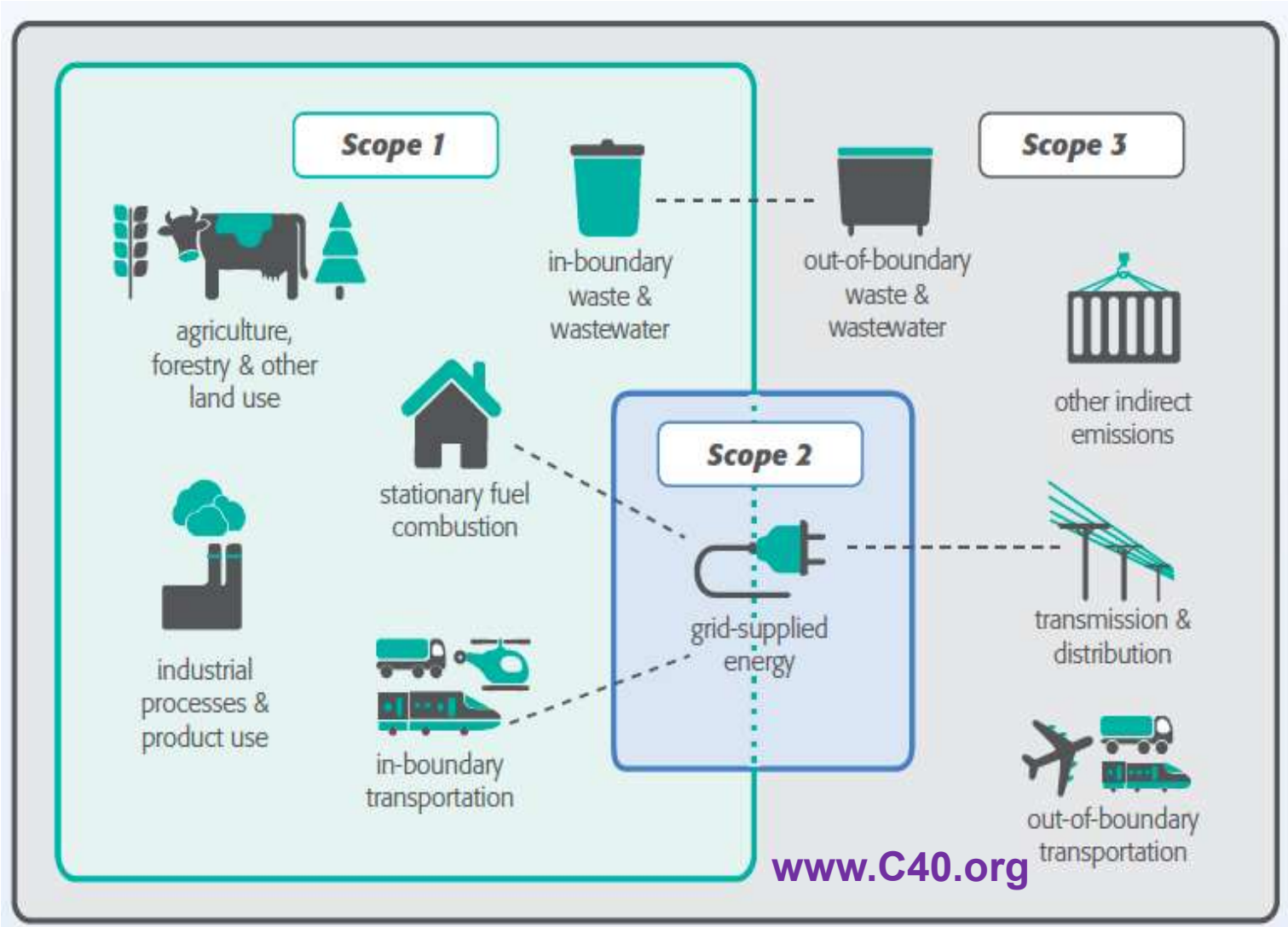


[Breon et al. 2014]

Fossil fuel + Bio = Total

Definition of “boundaries“ of urban emissions



Bottom-up inventories based on IPCC

Energy sector:

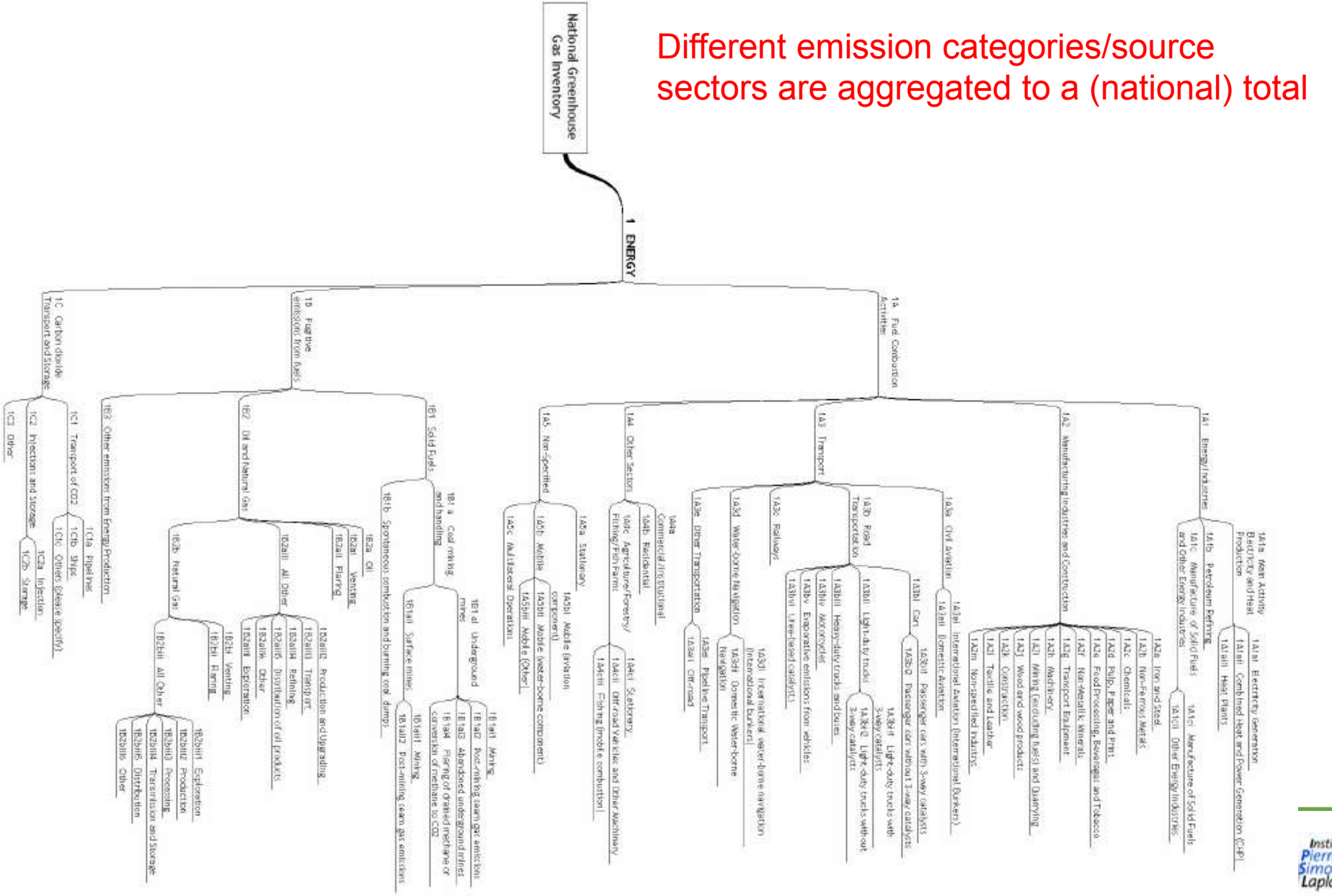
- Exploration and exploitation of primary energy sources
- Conversion of primary energy in refineries and power plants
- Transmission and distribution of fuels
- Use of fuels in stationary and mobile applications

Intergovernmental Panel on Climate Change

2006 IPCC Guidelines for National Greenhouse Gas Inventories

Bottom-up inventories based on IPCC

Different emission categories/source sectors are aggregated to a (national) total



Bottom-up inventories based on IPCC

Definition of Tiers:

- Tier 1 - fuel-based approach using emission factors per industry/process
- Tier 2 - fuel-based approach using emission factors per industry/process but country specific
- Tier 3 – emission model specific for individual sites or measurements

Bottom-up inventories based on IPCC

Definition of Tiers:

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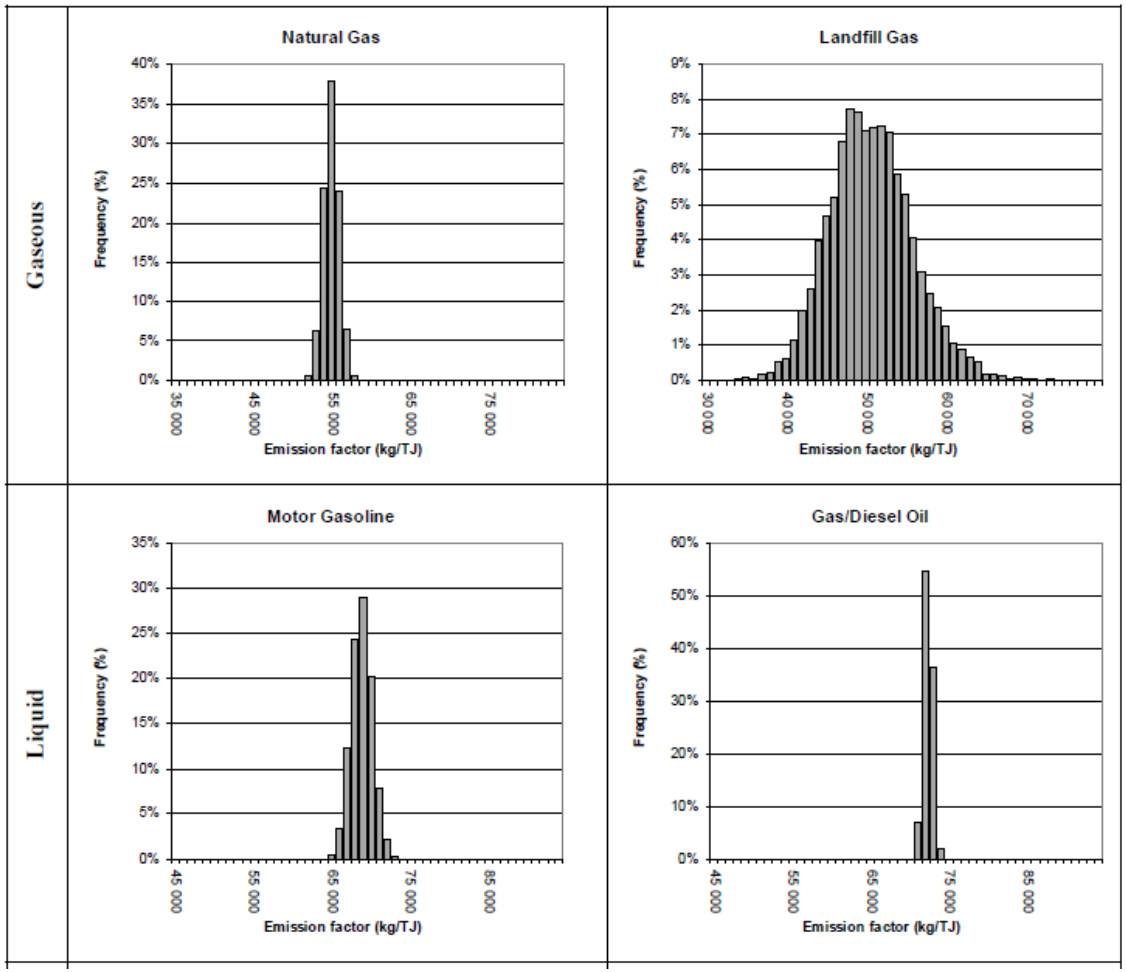
- Tier 2 - fuel-based a
  but country specific
- Tier 3 – emission mo

Figure 1.3 Some typical examples of probability distribution functions (PDFs) for the effective CO_2 emission factors for the combustion of fuels.



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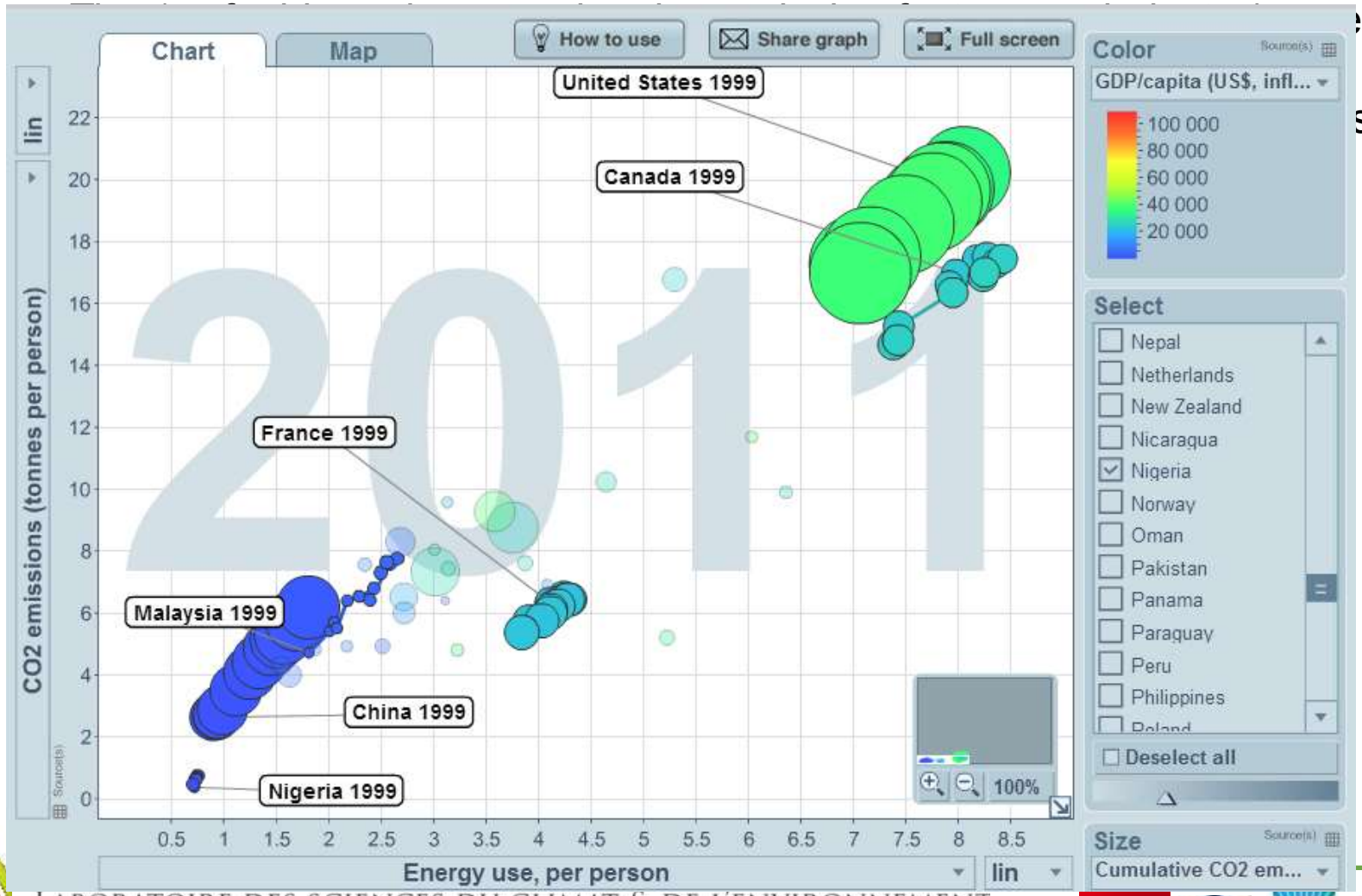
Definition of Tiers:

Gapminder online tool



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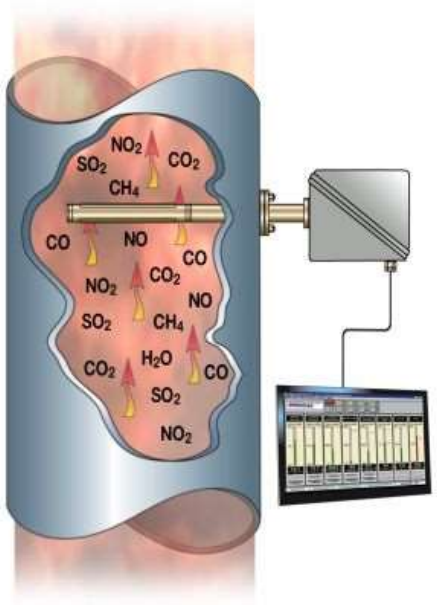
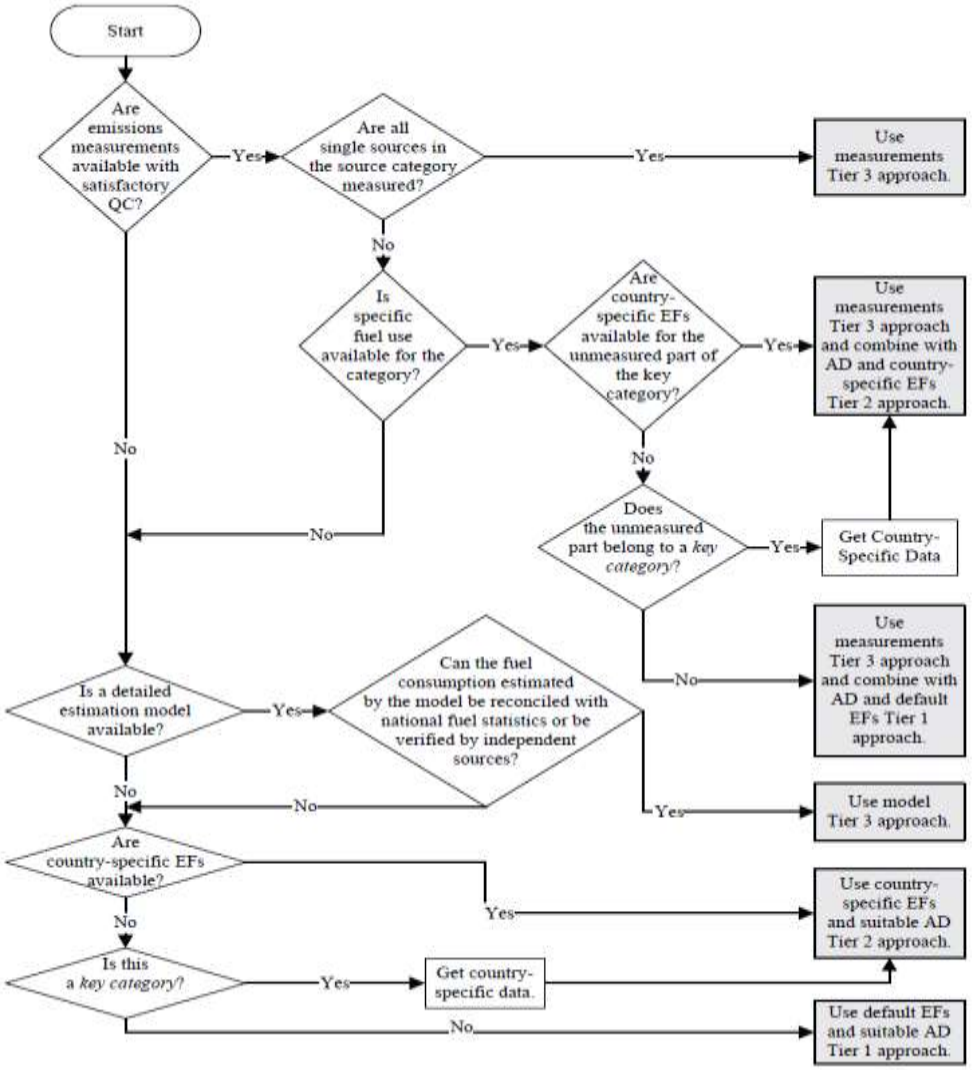


Bottom-up inventories based on IPCC



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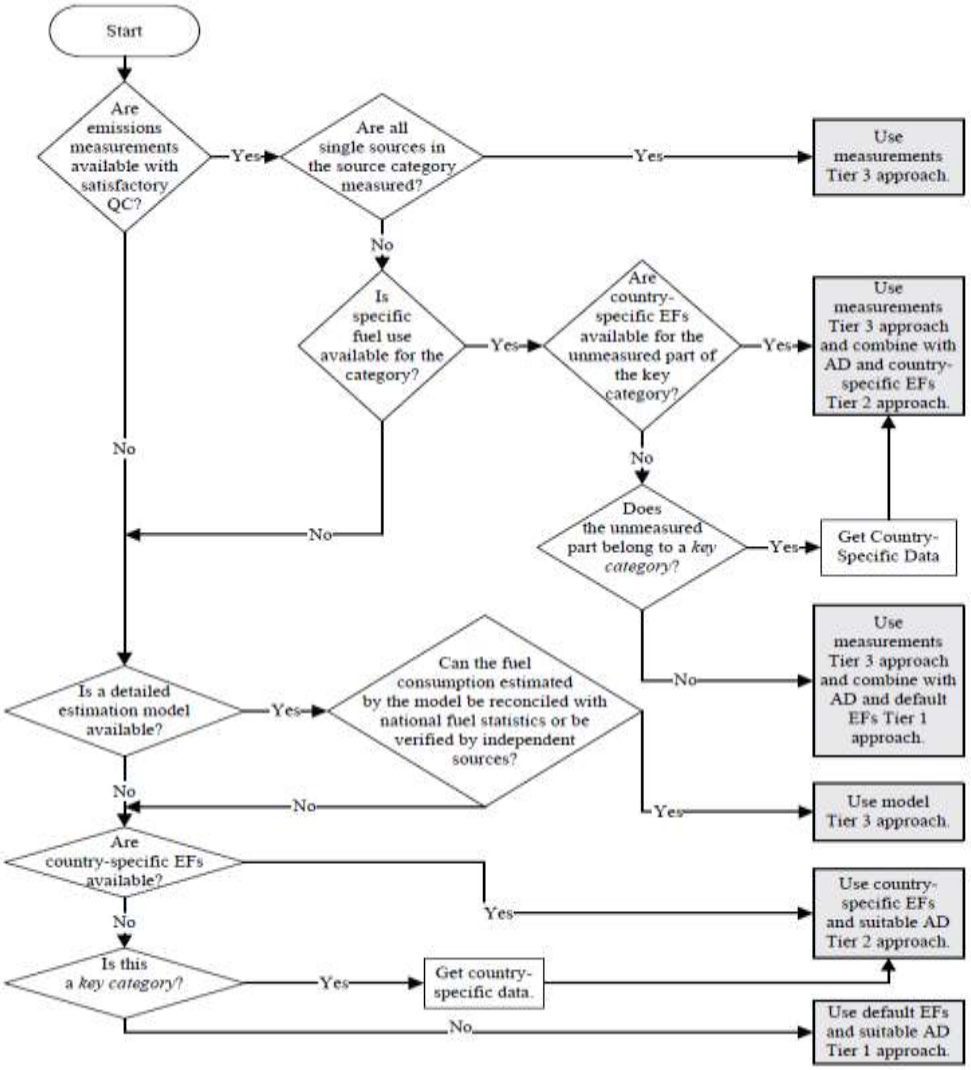


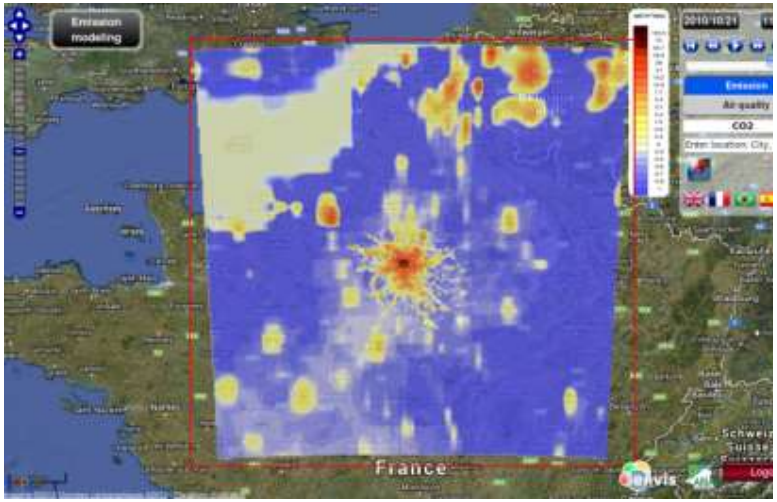
Combination with top-down?

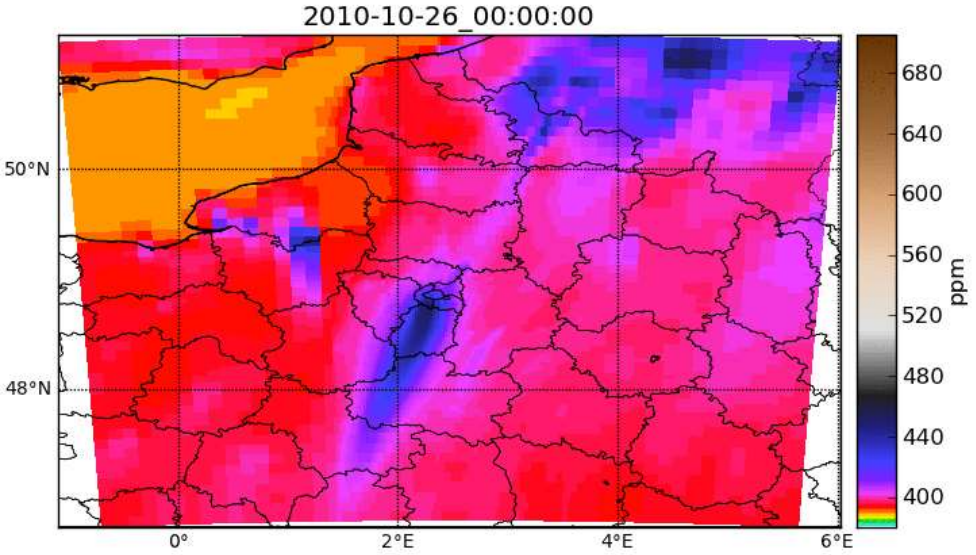
CARBONCOUNT CITY RECIFE PROJECT

ESTABLISHING THE INVENTORY OF CO_2 EMISSIONS IN RECIFE CITY AND THE SPATIAL DISTRIBUTION OF THESE EMISSIONS

CARBOCOUNT CITY

What kind of data is needed for urban applications?

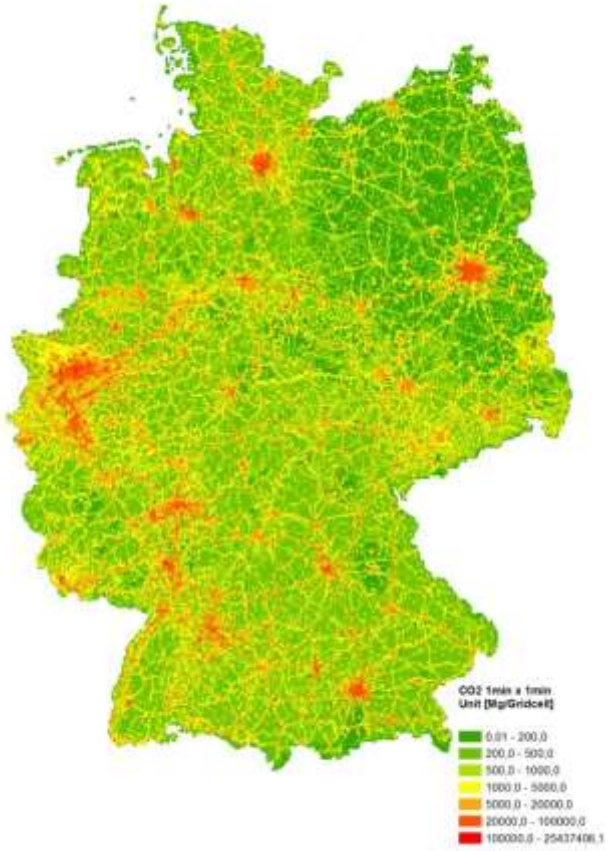




- We need spatially and temporally resolved emission data!

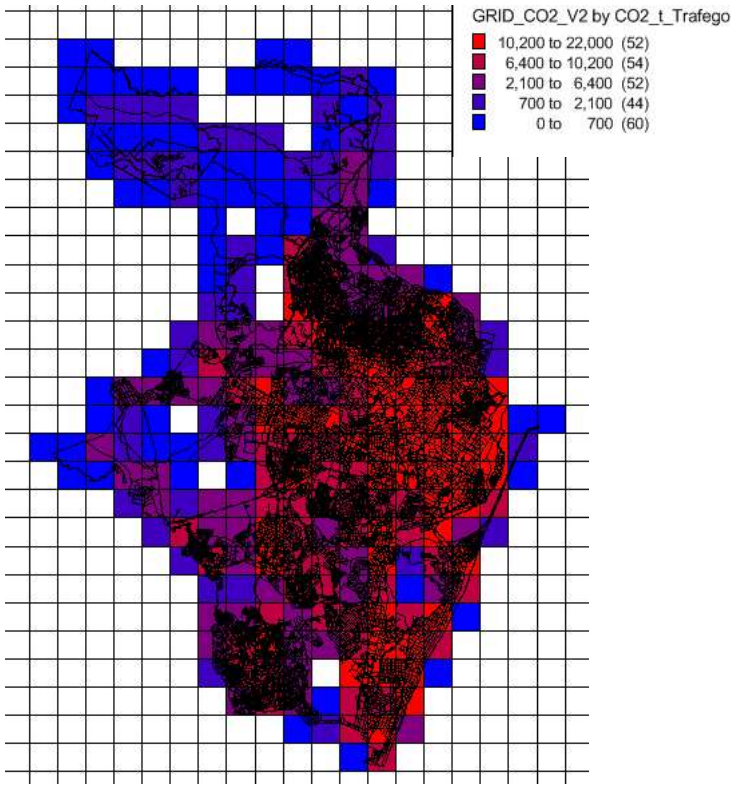
Spatialised emission inventories

Germany, national total



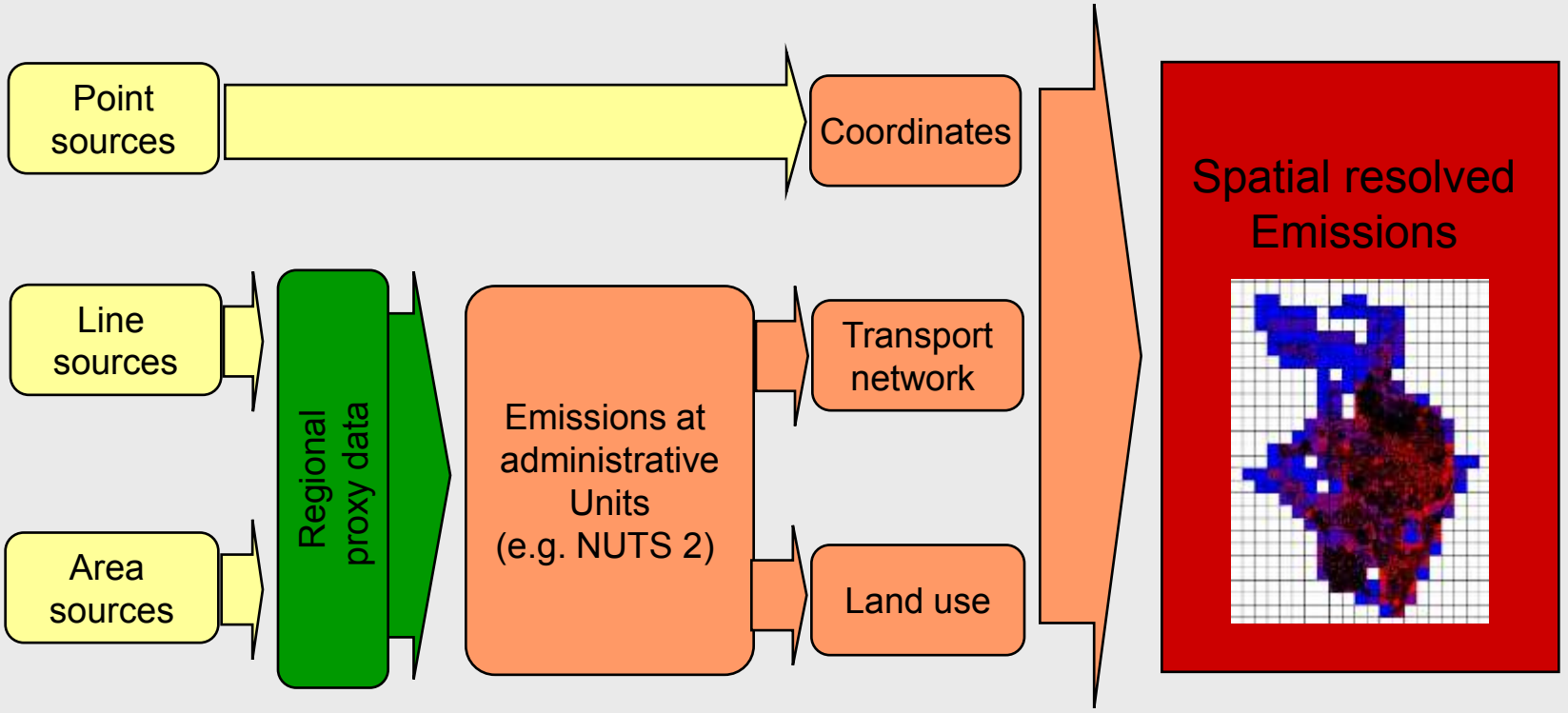
750km

City of Recife, Brazil



20km

Methodology for spatial disaggregation



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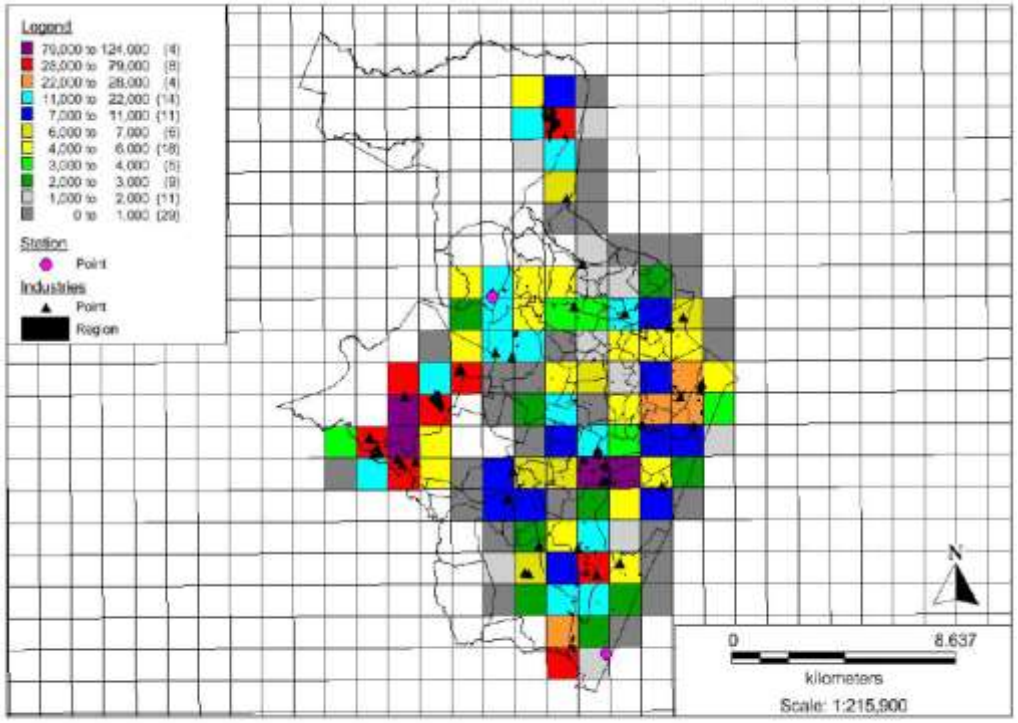


Figure 2-7: Industrial Emissions Spatialized

Potential data sources

- Reported emissions of CO2
- Emission ratios (CO2/CO)
- Carbon intensity of industry (CO2/$)
- Emissions per employee (CO2/p.P.)
- …

Methodology for spatial disaggregation

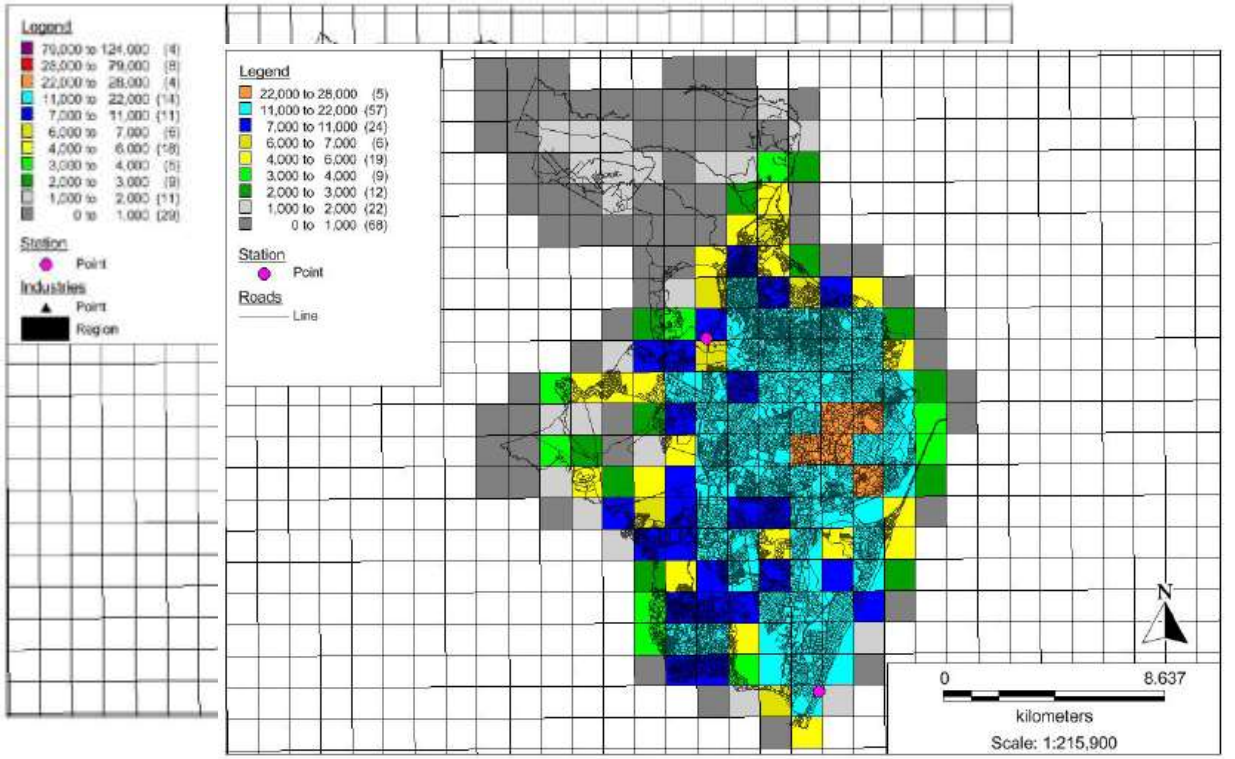
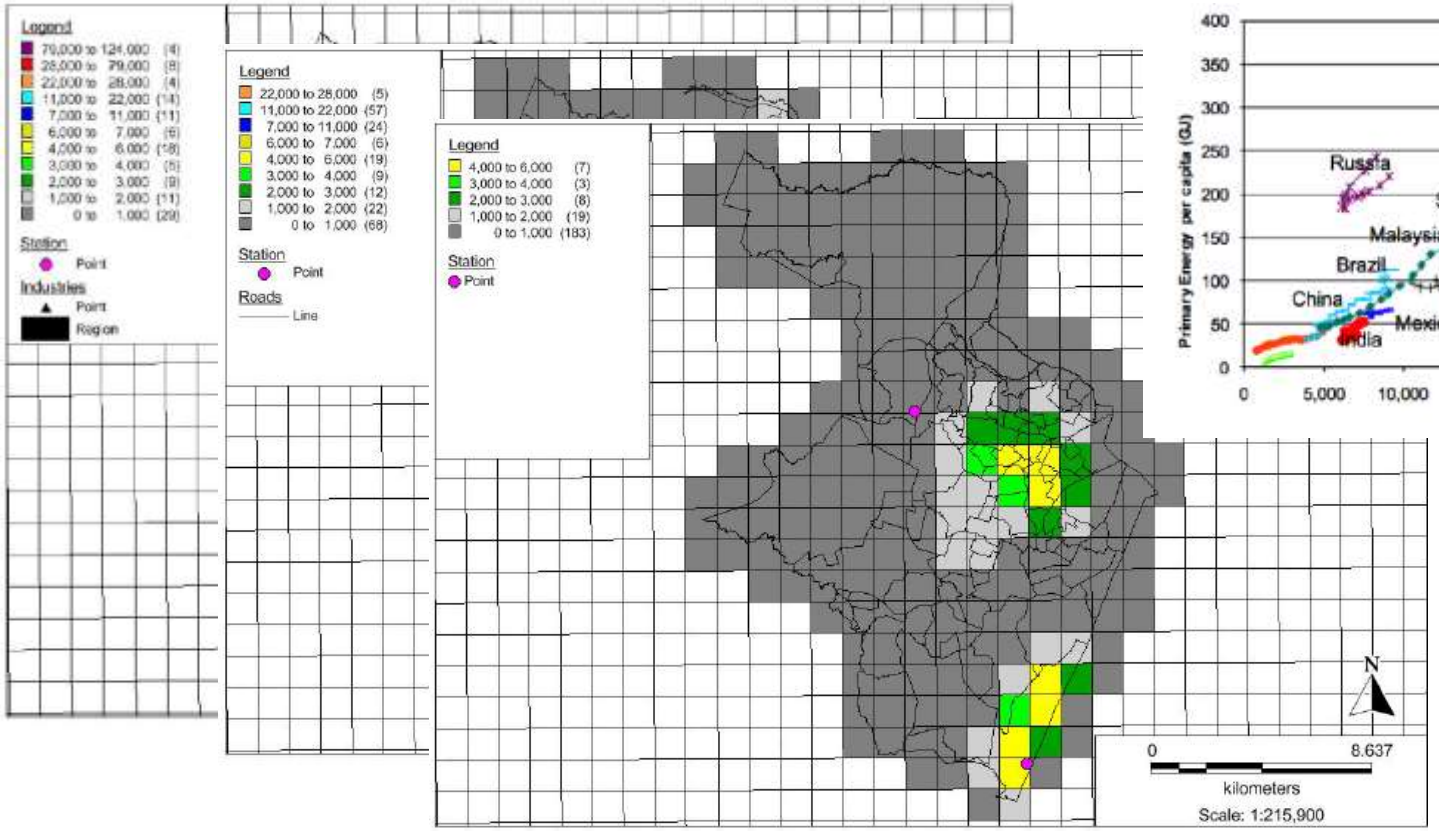


Figure 2-10: Traffic Emissions Spatialized.

Potential data sources

- Traffic counts
- Road categories
- Fuel sales by county
- …

Methodology for spatial disaggregation



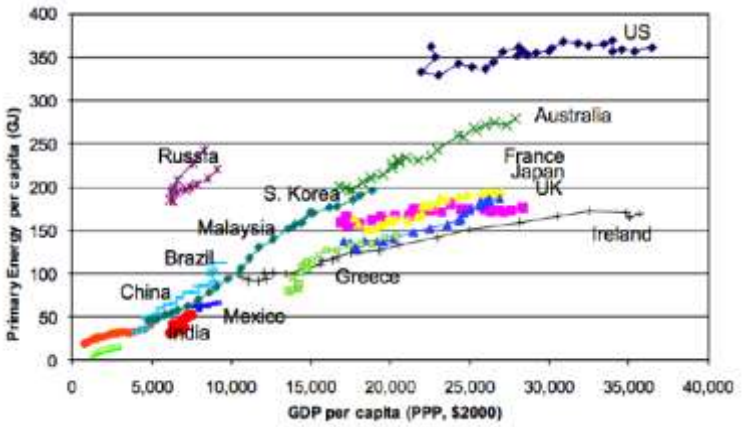
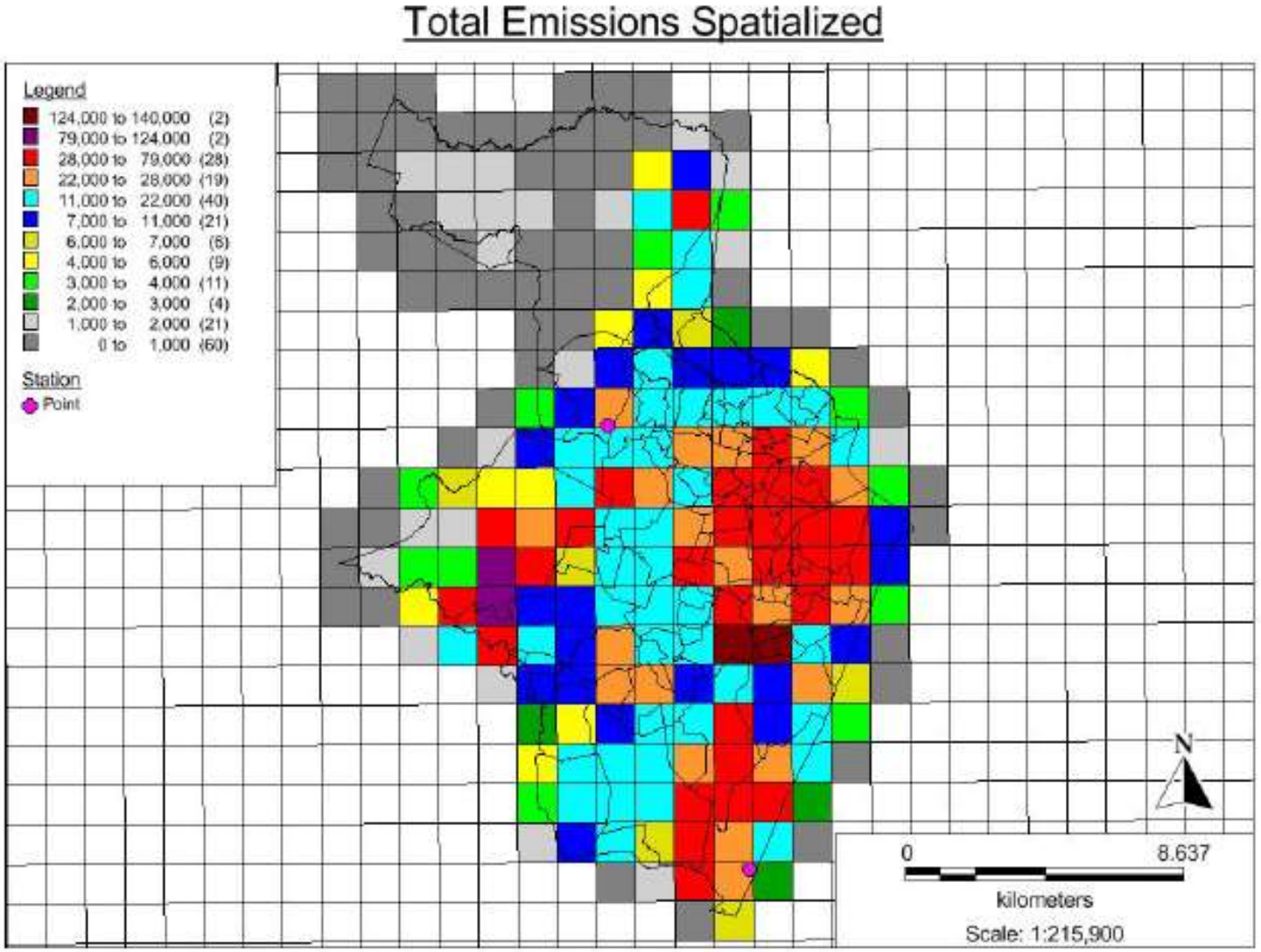


Figure 2-5: Residential Emissions Spatialized.

Income (R$)	Average Income	Variation	Total Population	Income Factor
500-1000	750	1.00	593 436	0.14
1000-2000	1500	2.00	631 064	0.29
2000-4500	3250	4.33	109 543	0.11
4500-10000	7250	9.67	203 661	0.46

Methodology for spatial disaggregation



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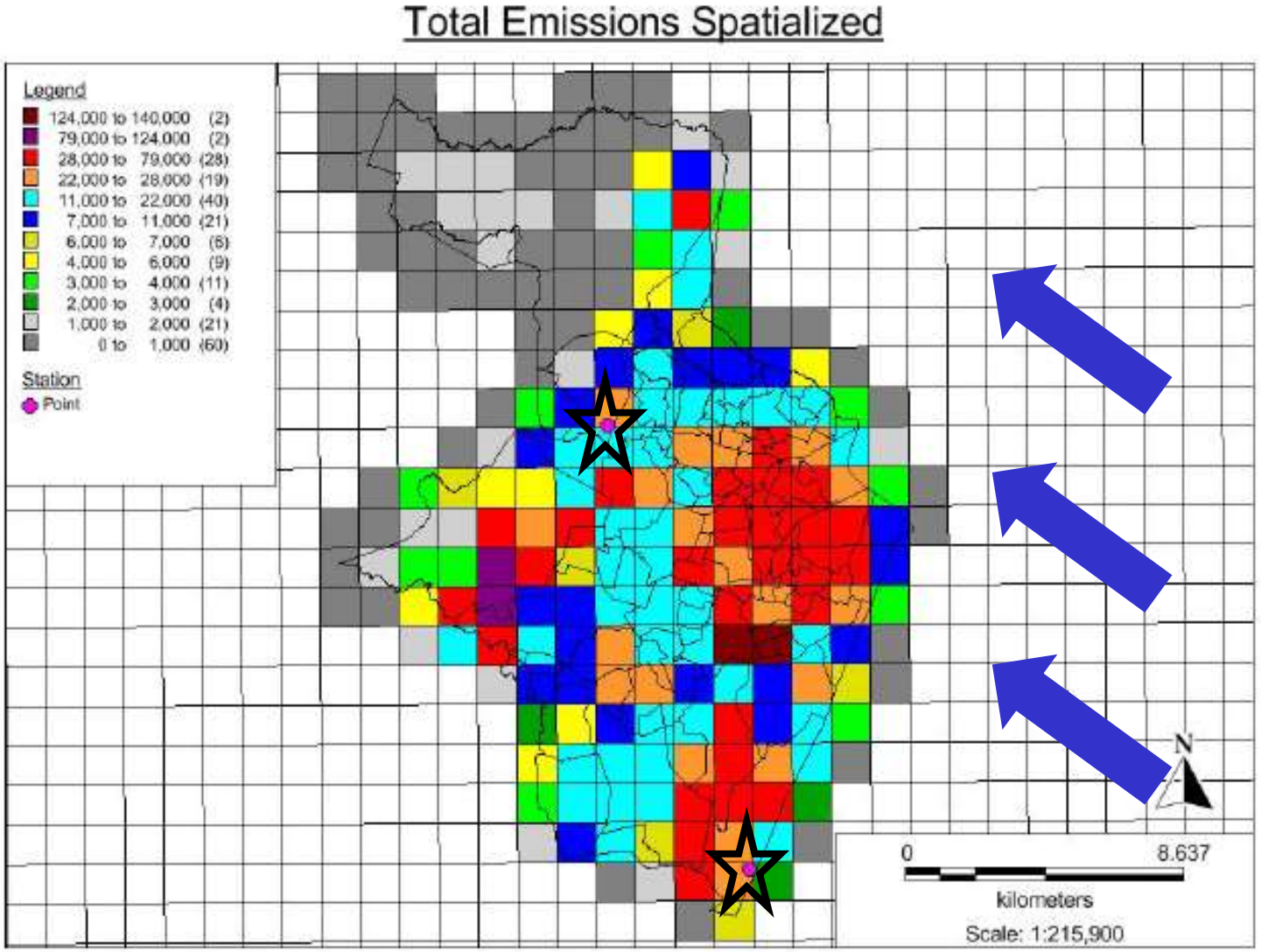

Data assimilation framework

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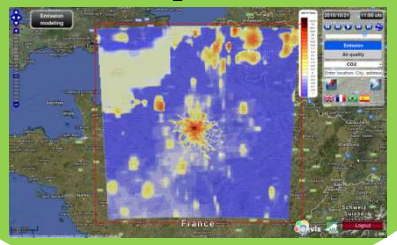

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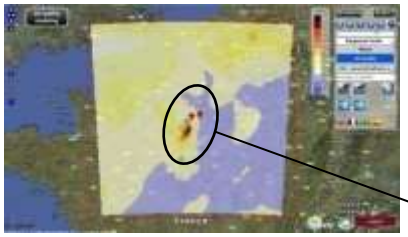
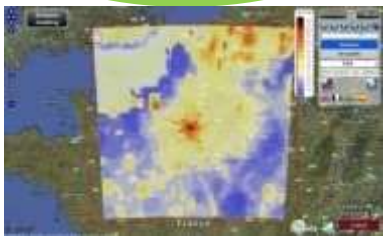
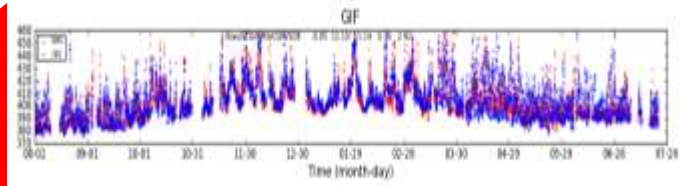


Comparison of simulated CO_2 concentration with *in situ* measurements

In situ observations network around Paris

Inverse Modeling Technique





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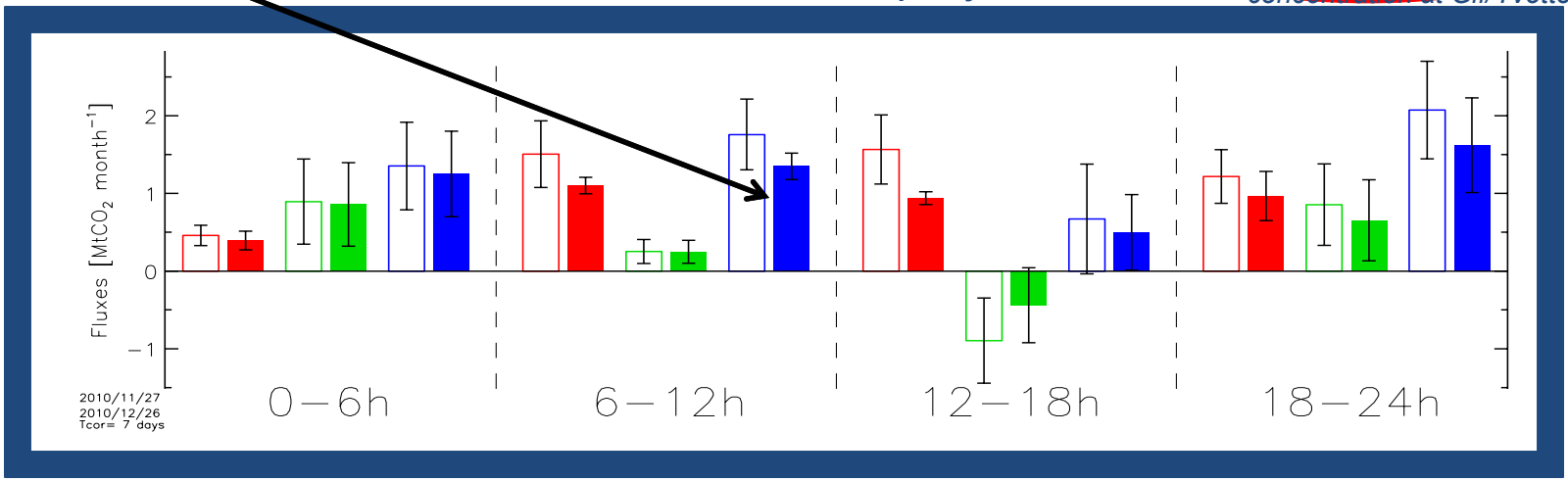


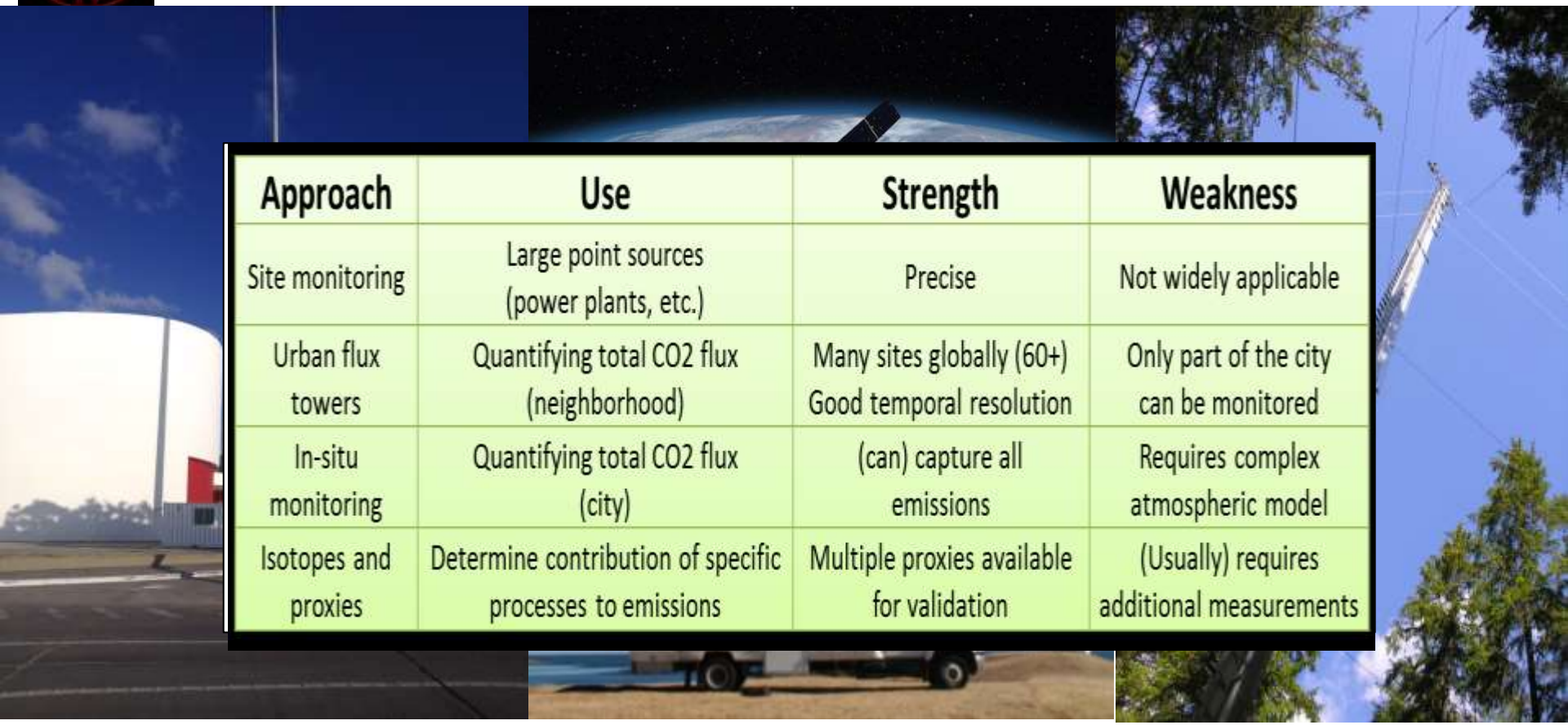
[Breon et al. 2014]

Fossil fuel + Bio = Total

Atmospheric observation studies

Total column – airborne – in-situ monitoring – mobile campaigns

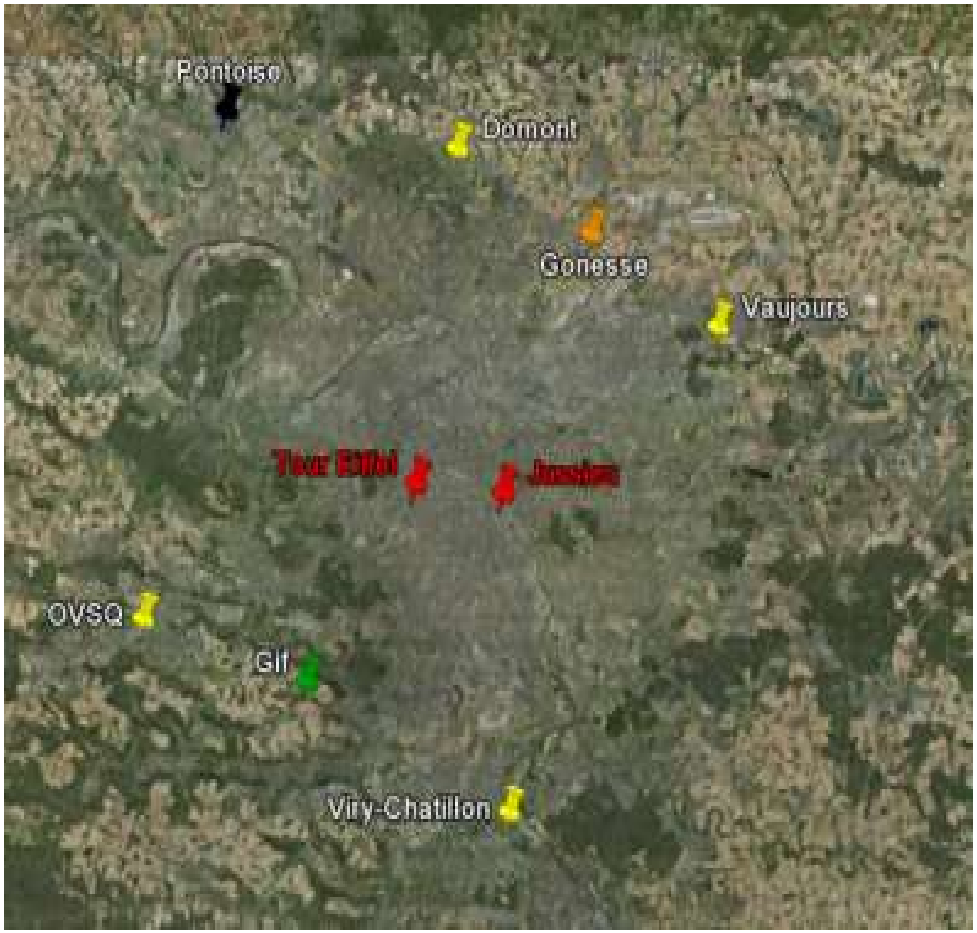
Atmospheric observation studies



Approach	Use	Strength	Weakness
Site monitoring	Large point sources (power plants, etc.)	Precise	Not widely applicable
Urban flux towers	Quantifying total CO2 flux (neighborhood)	Many sites globally (60+) Good temporal resolution	Only part of the city can be monitored
In-situ monitoring	Quantifying total CO2 flux (city)	(can) capture all emissions	Requires complex atmospheric model
Isotopes and proxies	Determine contribution of specific processes to emissions	Multiple proxies available for validation	(Usually) requires additional measurements

Total column – airborne – in-situ monitoring – mobile campaigns

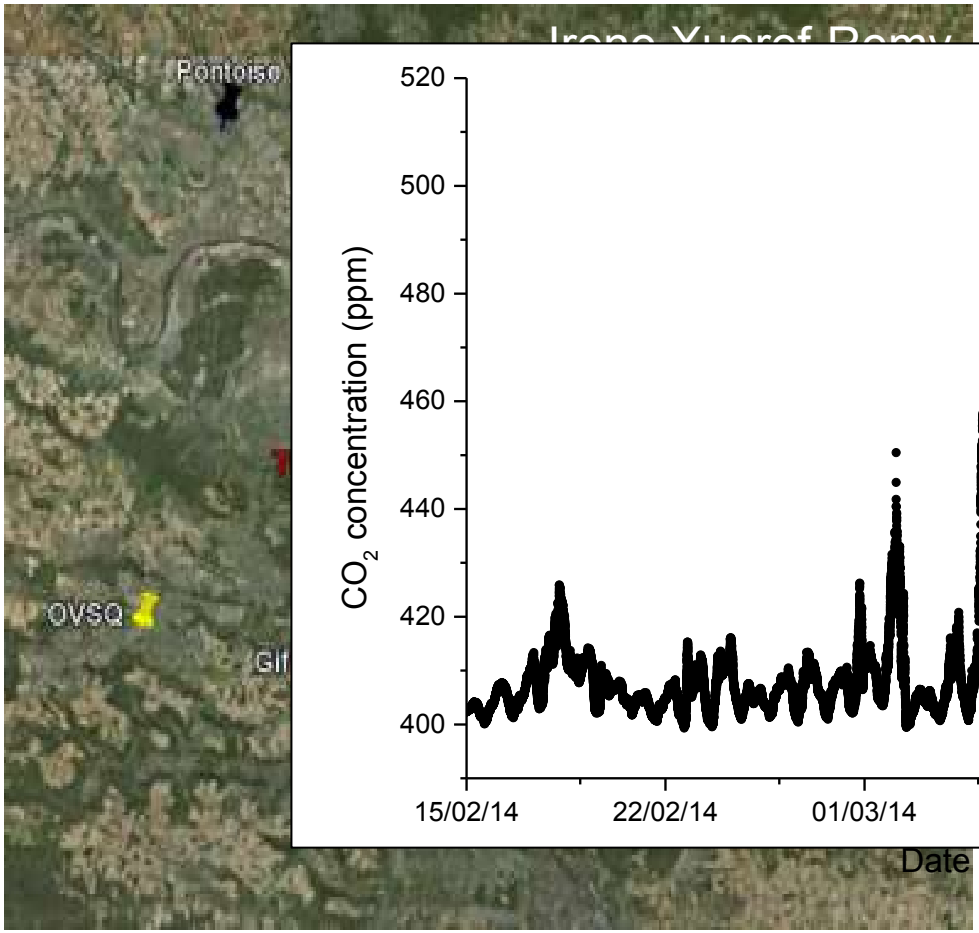
In-situ observations



Concentration monitoring network

Laser spectrometers

In-situ observations



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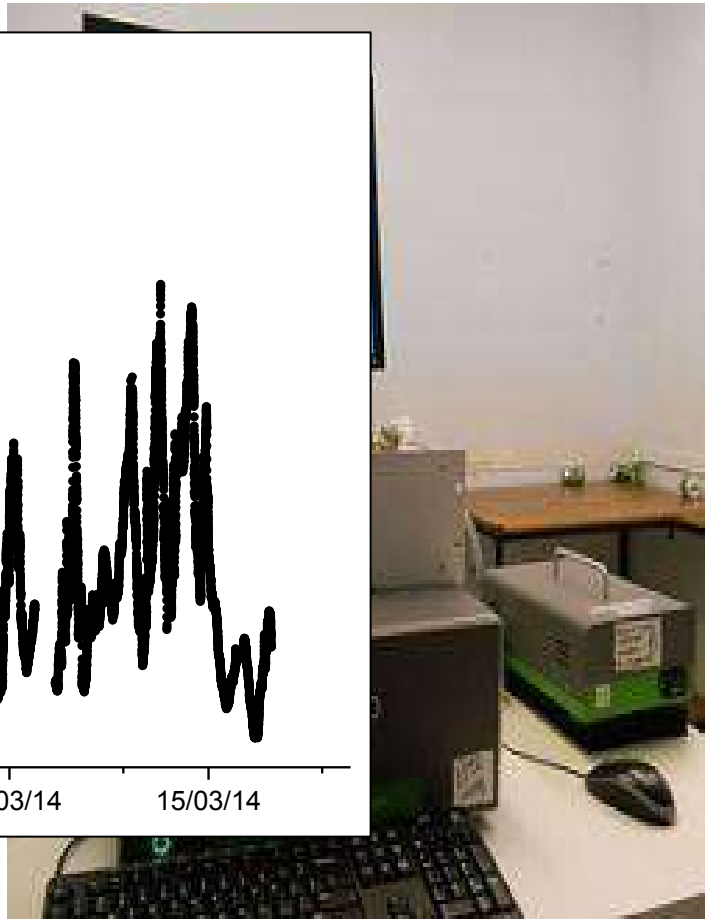
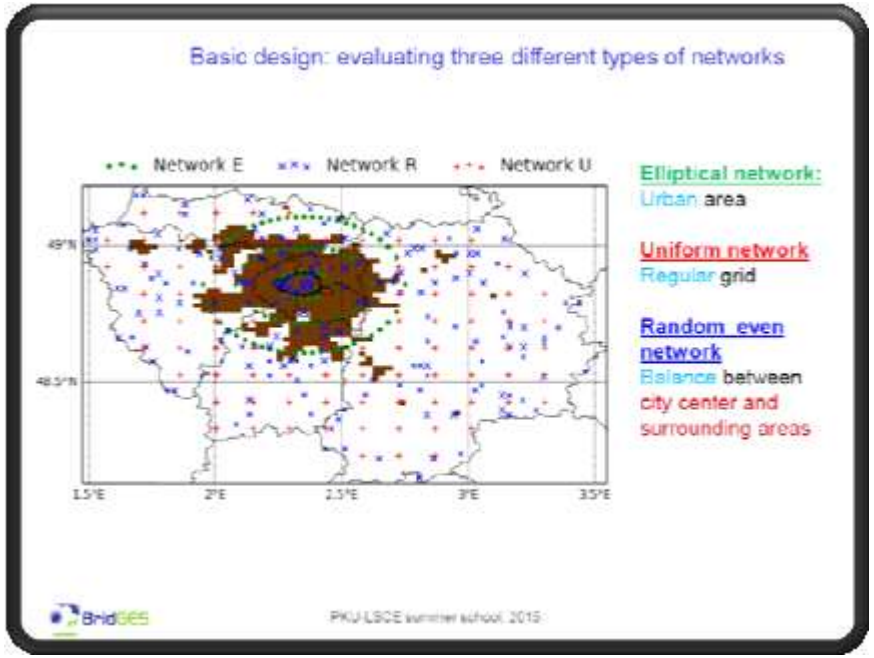
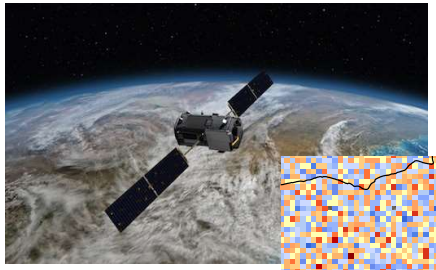


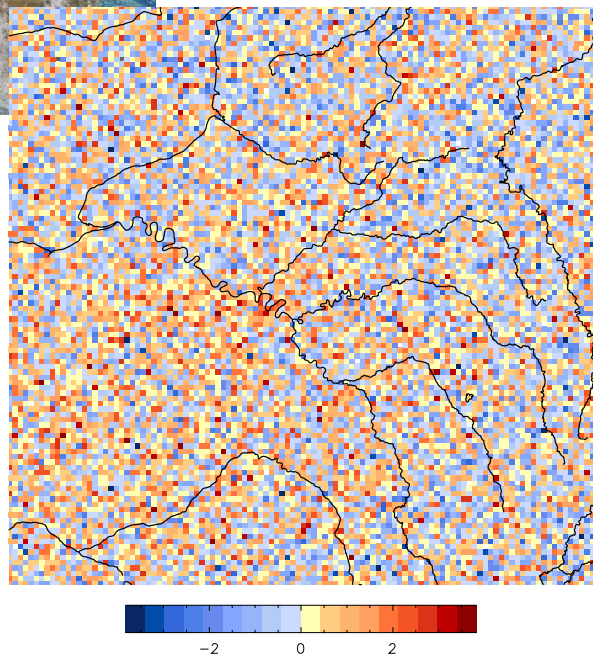
Laser spectrometers

Novel observational data/designs

Lin Wu – network design study







4km imagery with 1.2 ppm measurement noise (Note : Sentinel 5 ≈ 8 km)

F. Chevallier on satellite-based data

Novel observational techniques

CO_2 CCON
Collaborative Carbon Column Observing Network

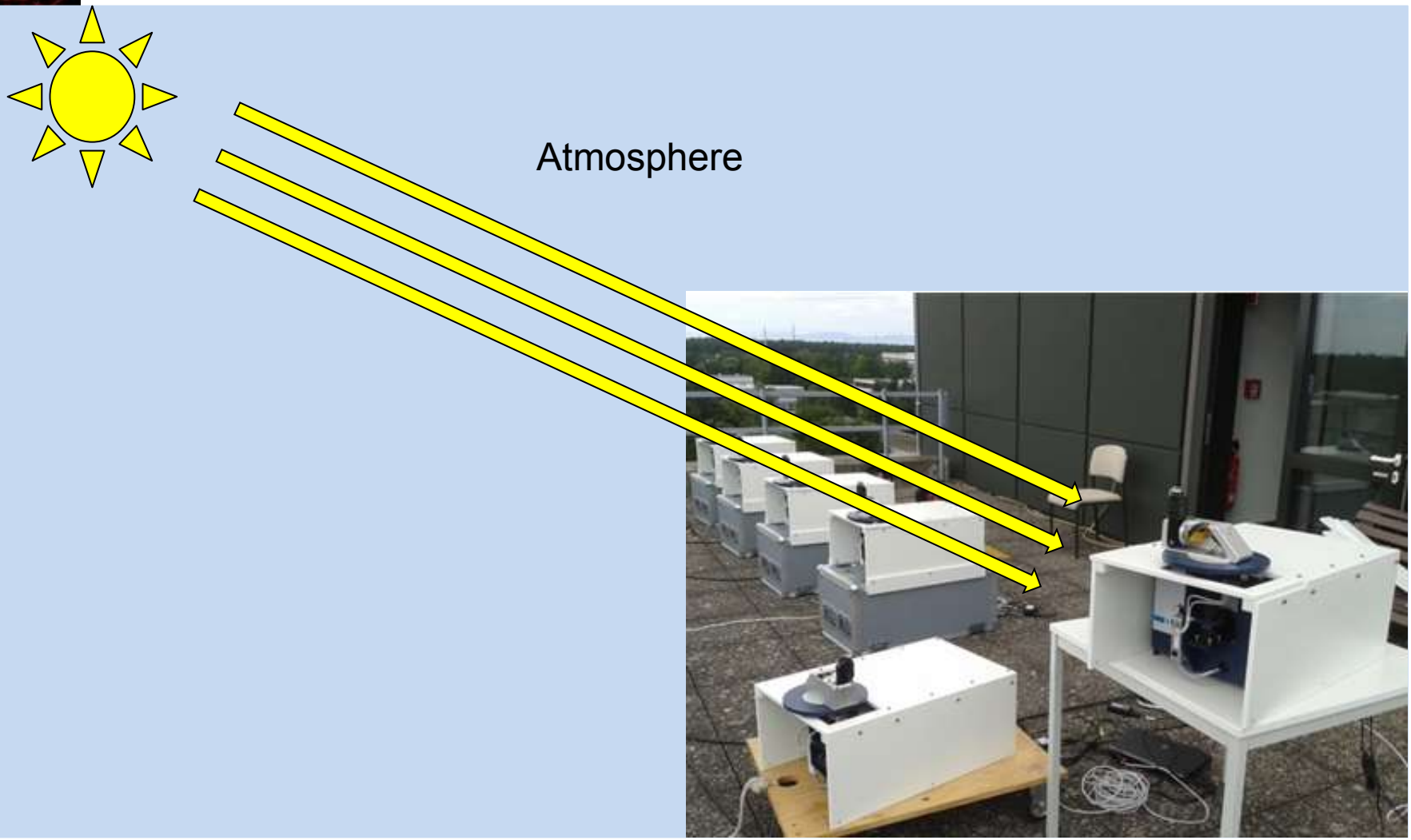
Karlsruhe Institute of Technology

l'Observatoire de Paris | LERMA

LSCE
Laboratoire des Sciences du Climat & de l'Environnement

lisa | Laboratoire Inter-universitaire des Systèmes Atmosphériques

Novel observational techniques



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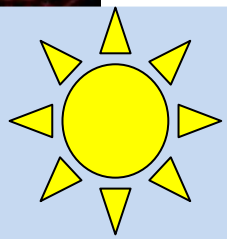
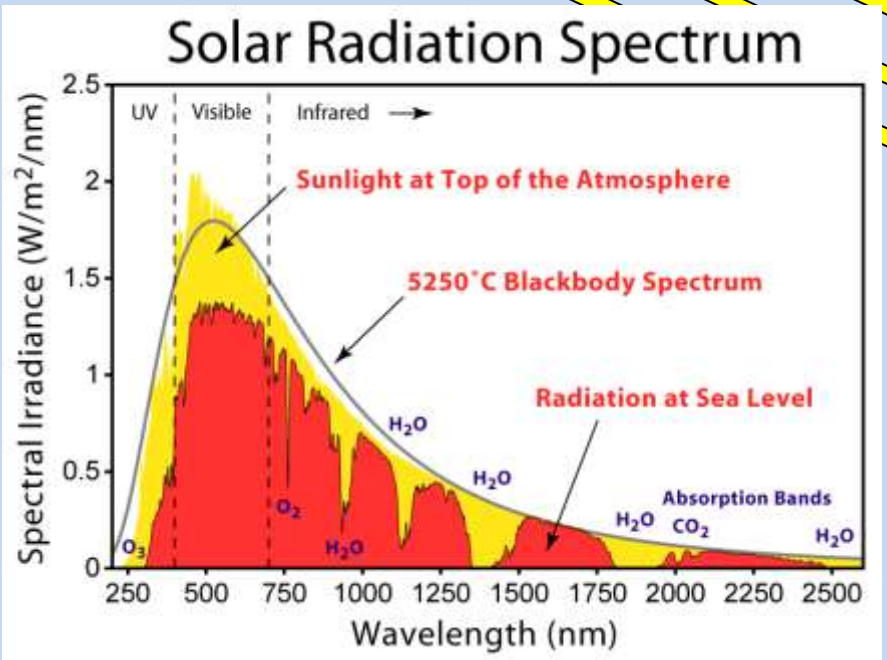
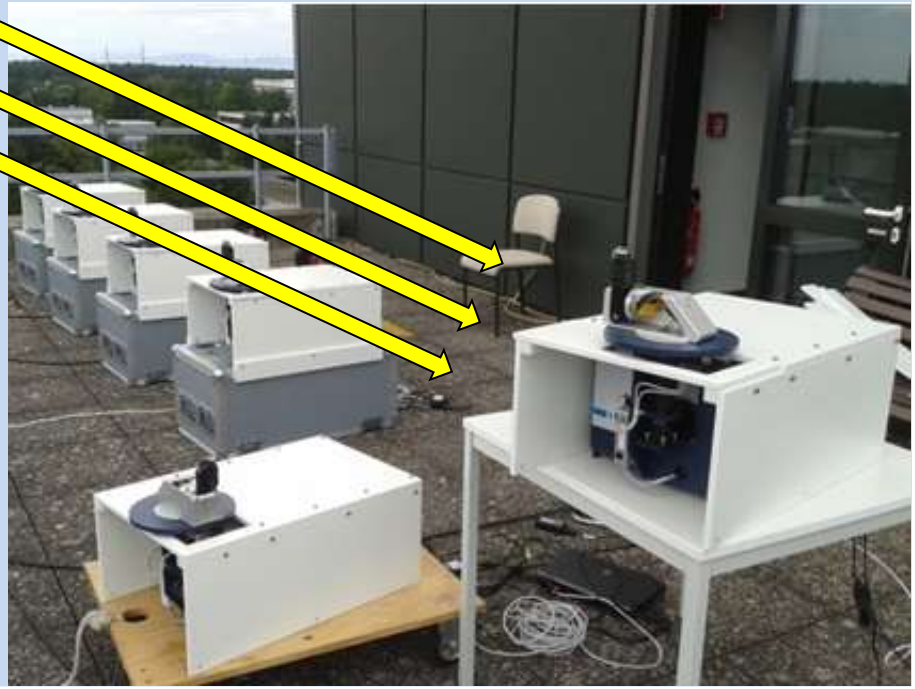


Atmosphere



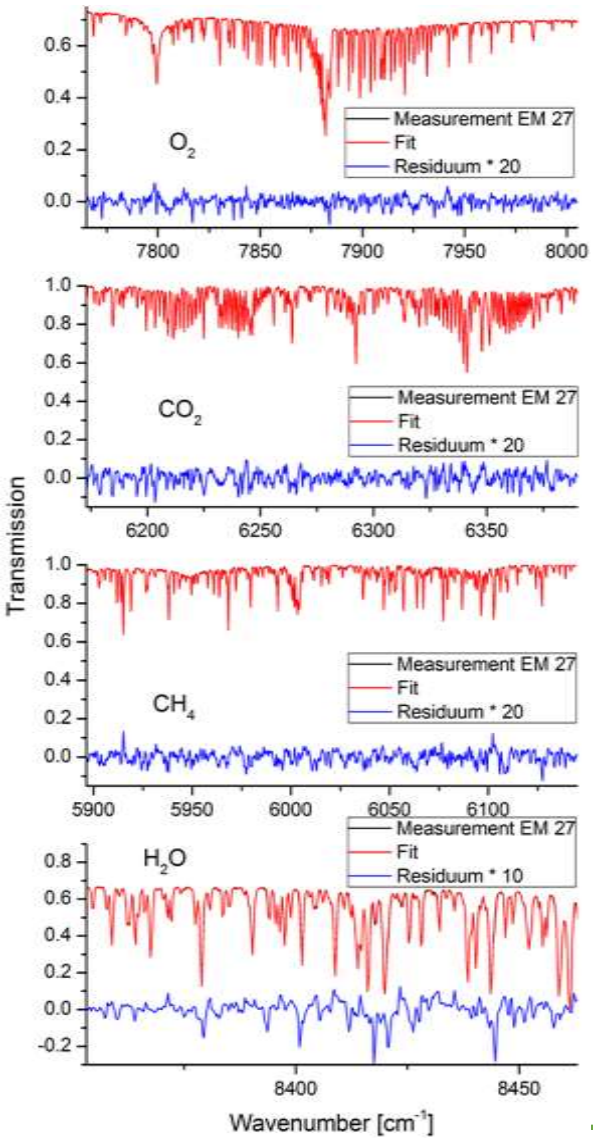


EM27sun technical core data

- Requirement: Calibration of instruments to common scale
- Calibration measurements performed before and after campaign at IMK-ASF office building
  - 0.5 cm^{-1} resolution
  - 10 scans
  - 10 khz scanner velocity
  - ~ 1 min
- GPS receiver for precise time recording
- Additional pressure and temperature on site from tall tower measurements

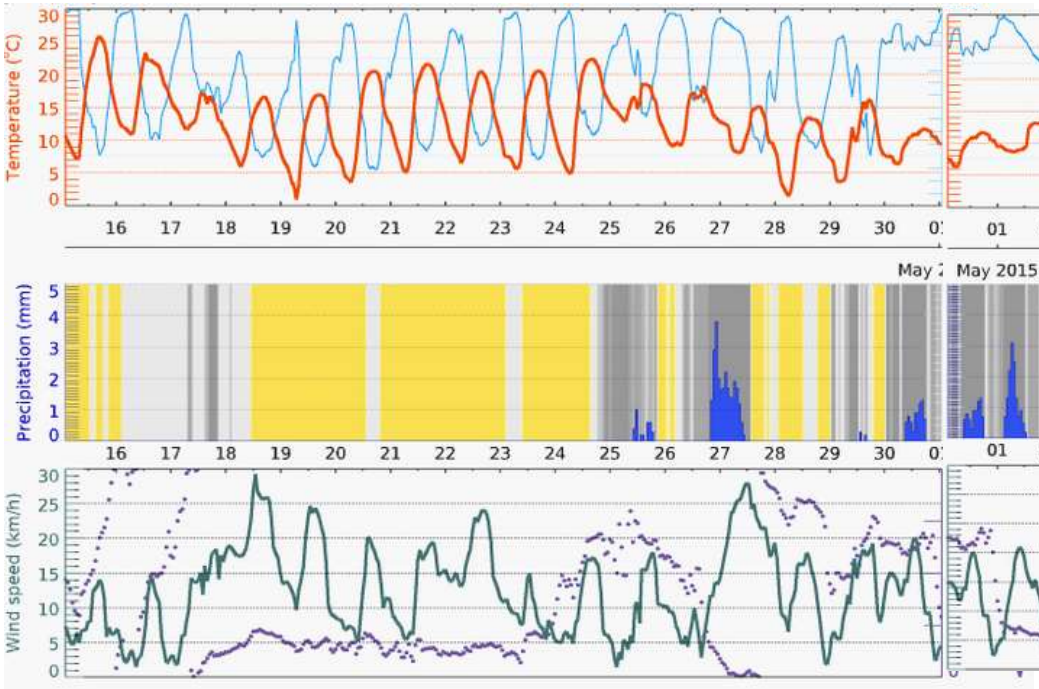
EM27sun technical core data

- Preprocessing: Python tool (DC-correction, quality filter, generate PROFFIT spectrum format) maintained by M. Kiel
- P&T profiles including intraday variability from ECMWF/CHIMERE
- Linelists
  - HITRAN 2008 O_2, CO_2, CH_4 linelist + adjustments
  - HIT09mod H_2O linelist



COCCON campaign in Paris 2015

Weather/measurement conditions

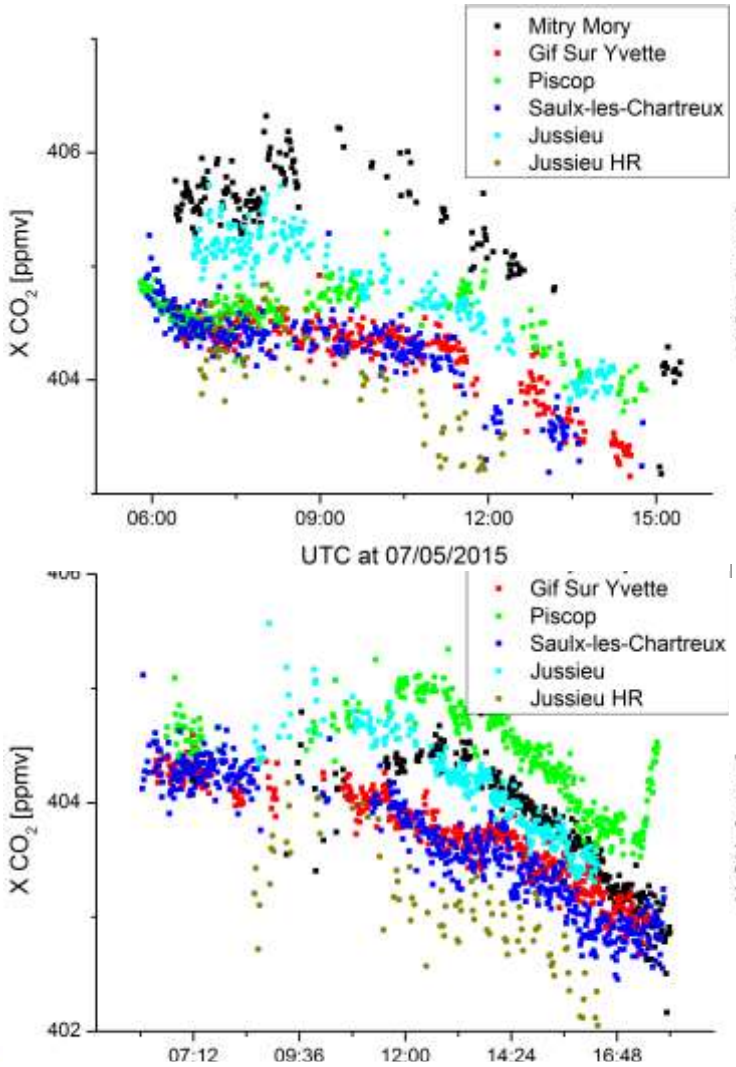


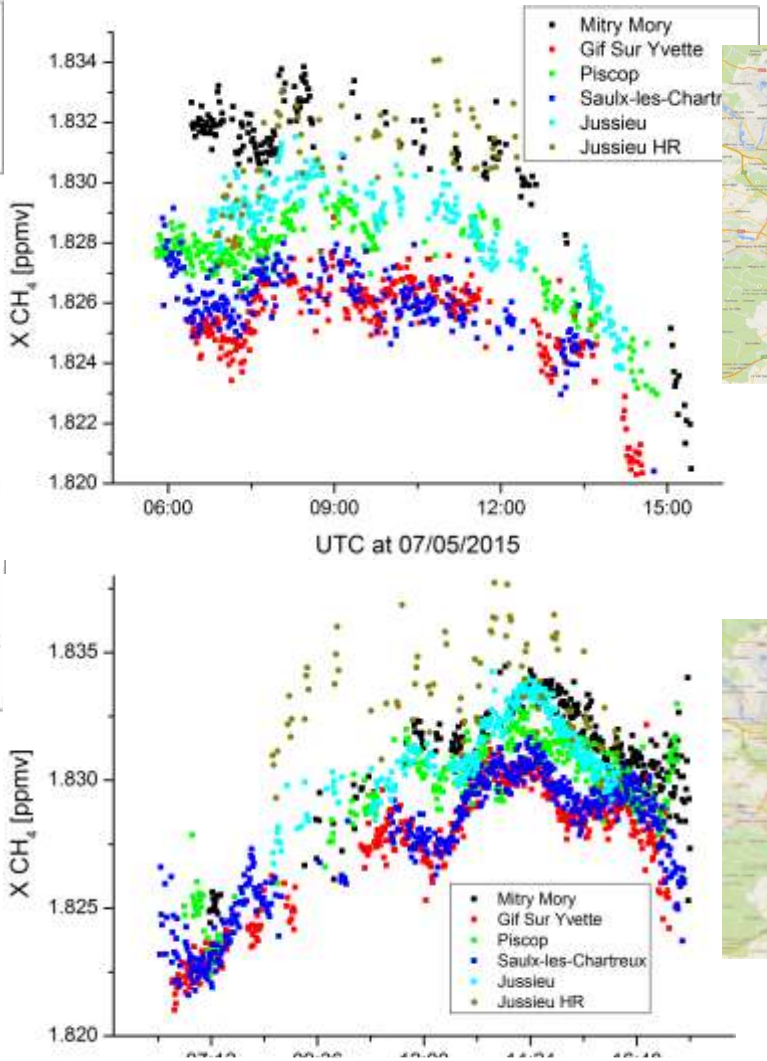
Source: meteoblue.com

Difficult weather conditions!!!

Nevertheless: approx. 10000 spectra recorded during campaign

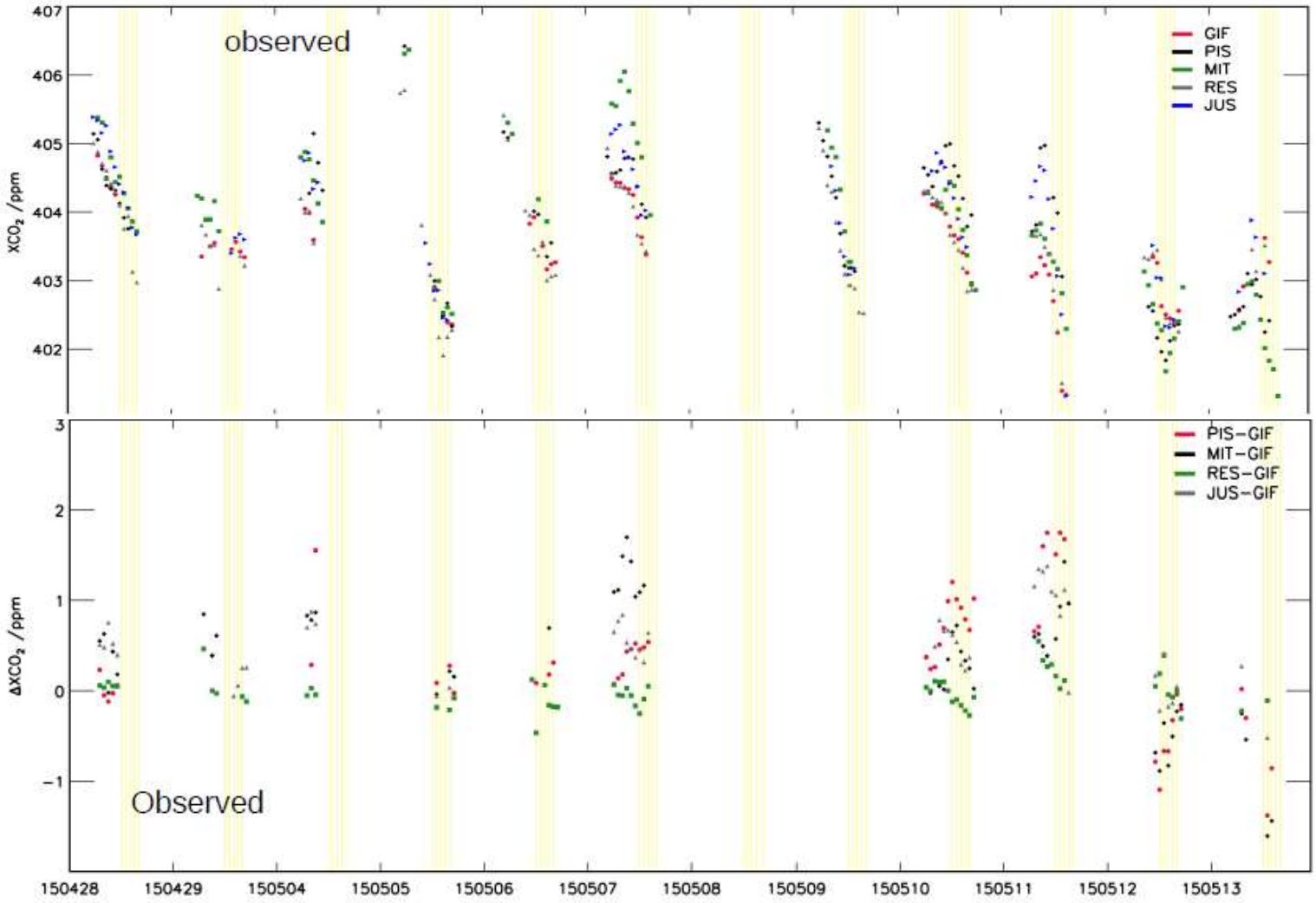
XCO_2 and XCH_4 for individual days



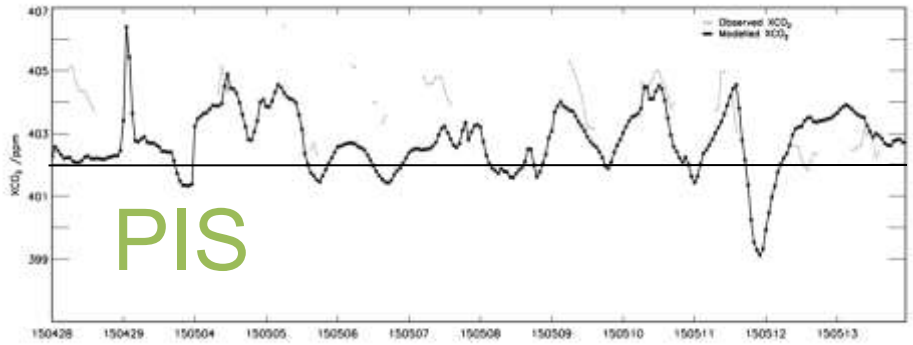


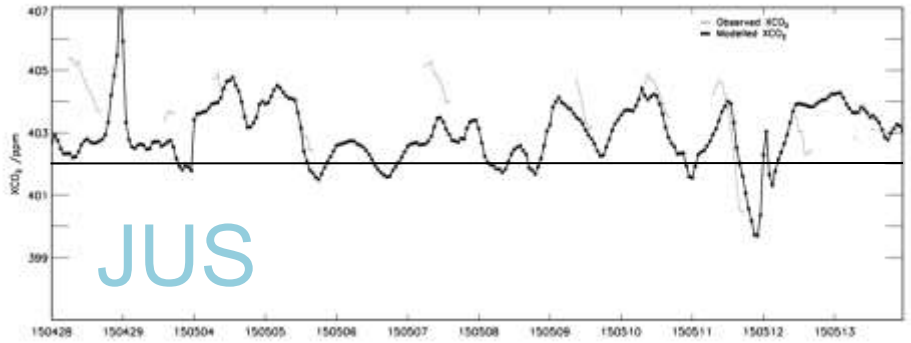
M. Frey, Detection of CO2 and CH4 in Paris

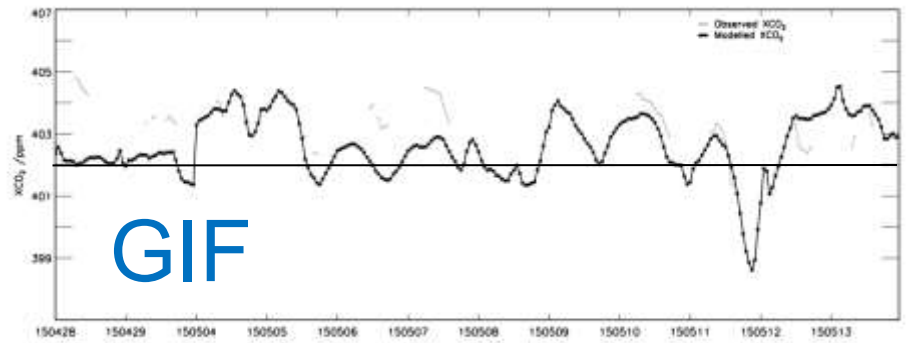
XCO_2 and urban XCO_2 gradients

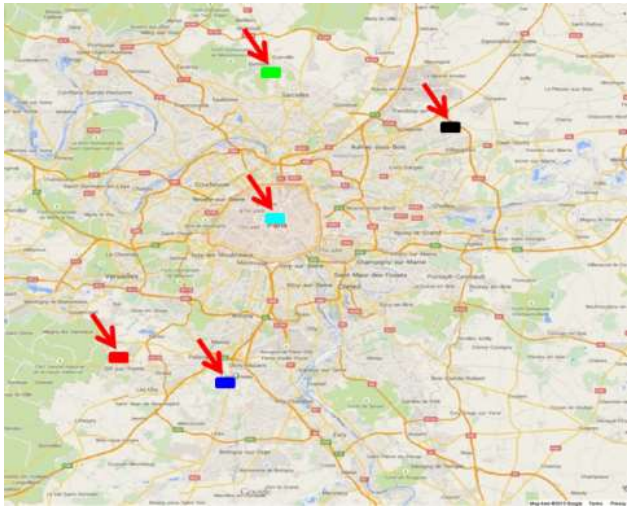


XCO_2 measurement vs model



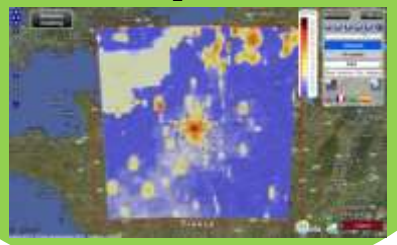






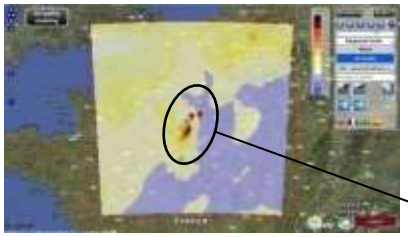
Data assimilation framework

Prior CO_2 emission



Atmospheric Chemistry Transport Model CHIMERE

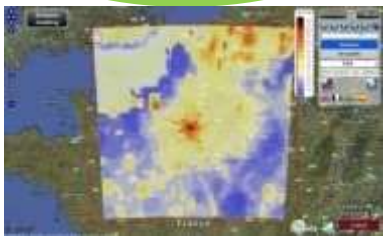
CO_2 concentration fields

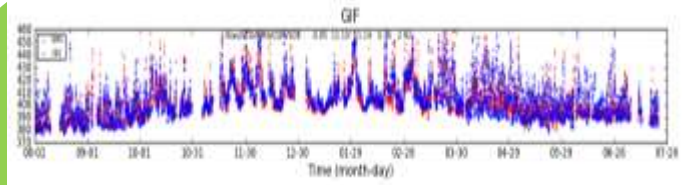


Comparison of simulated CO_2 concentration with *in situ* measurements

In situ observations network around Paris

Inverse Modeling Technique

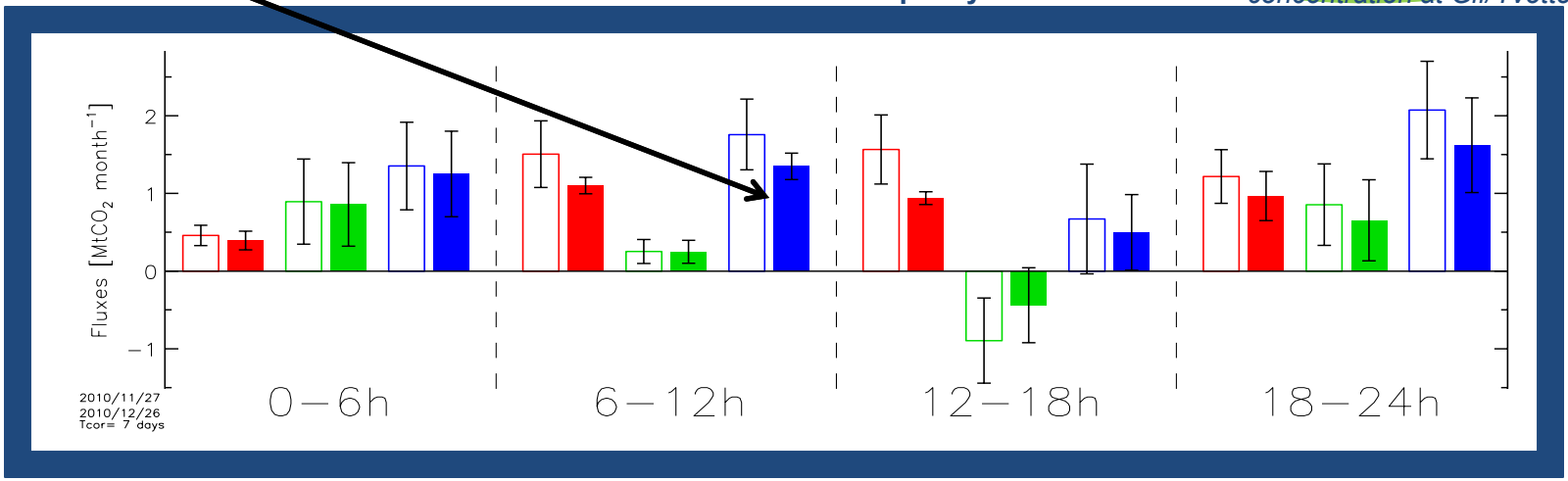




Time evolution of simulated and observed CO_2 concentration at Gif/Yvette

***Posterior* CO_2 emission**

Probabilistic tools to compute the best CO_2 emission estimate that reduces the observations/simulation discrepancy



[Breon et al. 2014]

Fossil fuel + Bio = Total

Summary and take home message

- Different methods can be used to estimate emissions bottom-up and create a temporally and spatially resolved emission model
- Good inventory or local activity data is important to build a high-quality inversion framework
- A broad suite of measurement techniques exist for urban monitoring (in-situ, total column, flux towers, isotopes,…)
- Novel “low resolution“ total column FTS instruments are a potentially useful new datastream