


City scale inversion of CO2 emissions: requirements for a cost effective monitoring of the sectorial budgets

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SOFIE, PKU-LSCE workshop
Oct 13, 2014

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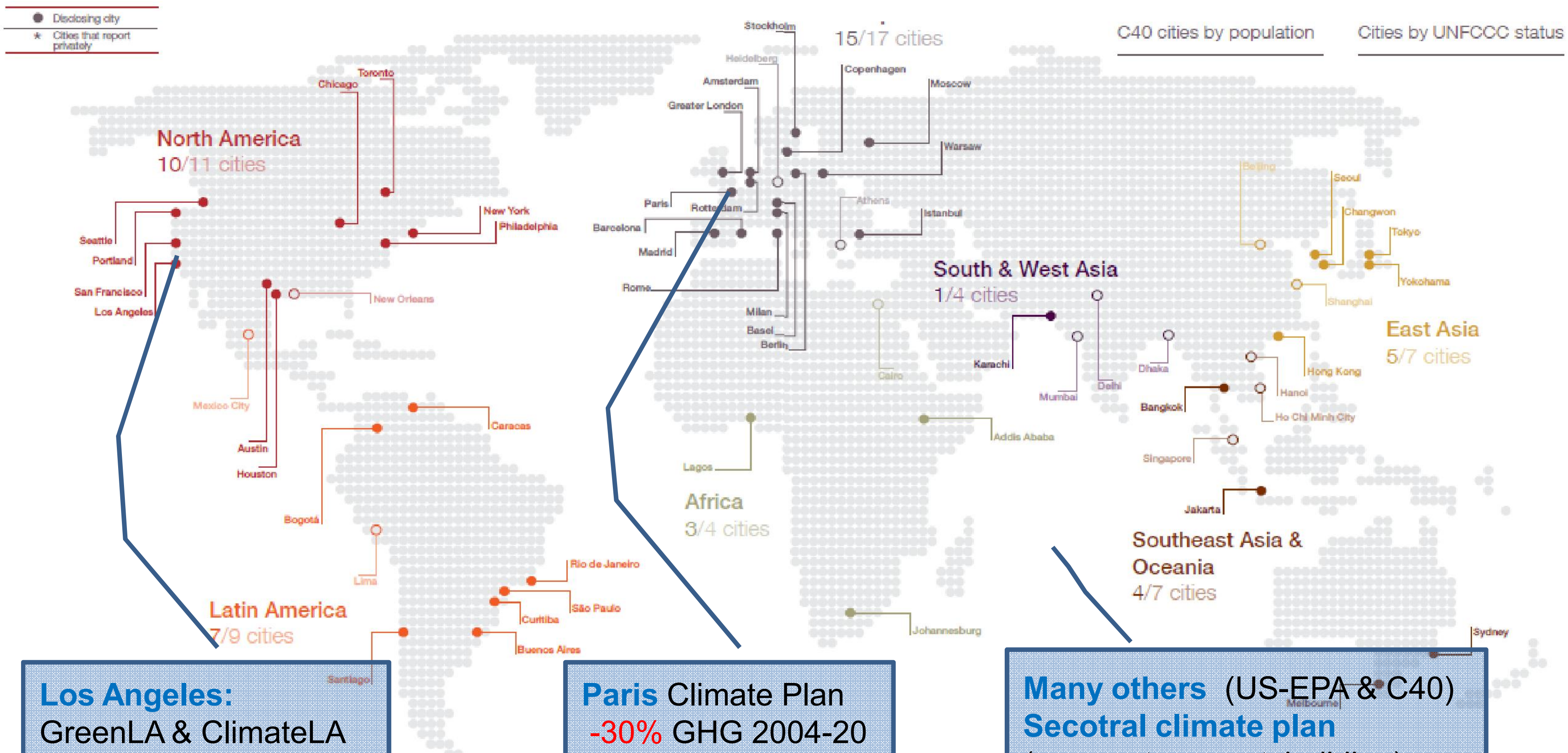
Cities in actions: political plans



Los Angeles:
GreenLA & ClimateLA
-35% GHG 1990-2030

Paris Climate Plan
-30% GHG 2004-20
-75% GHG 2004-50

Many others (US-EPA & C40)
Secotral climate plan
(energy, transport, building)

~70% energy-related emissions ~2% Earth surface
Challenge but also **chance**

MRV Sector: Regional & City Territorial Inventories

- ✓ Market and policy-based mitigations: carbon prices and taxes
  - ✓ European Union Emissions Trading Scheme (EU ETS, exchanges 50-80 B€/yr)
  - ✓ CDM (>300 B$ investments)
  - ✓ National inventories under UNFCCC (implying losses in business if inadequate)

- ✓ **Monitoring, Reporting, Verification (MRV):** core of climate actions; one of the fastest moving topics in international climate negotiations
  - ✓ Monitoring (scientific)
  - ✓ Reporting (administration)
  - ✓ Verification (police)

- ✓ MRV currently mostly based on inventories

- ✓ ~7% emissions have carbon price; city emissions not regulated

City Fossil fuel CO_2 emission inventories

	EDGAR10	AIRPARIF05	AIRPARIF08	IER05	Max - Min
Resolution	0.1° x 0.1°	1km x 1km	1km x 1km	1min x 1min	
Annual budget of Ile-de-France (TgC)					
Residential	6.75	5.65	7.80	5.36	31%
Road	8.50	3.63	3.37	6.03	60%
Industry	5.19	3.02	3.09	4.61	42%
Total	24.65	12.34	14.26	16.39	50%

50% difference at 25km when disaggregating into regions (*Duren and Miller 2012*)

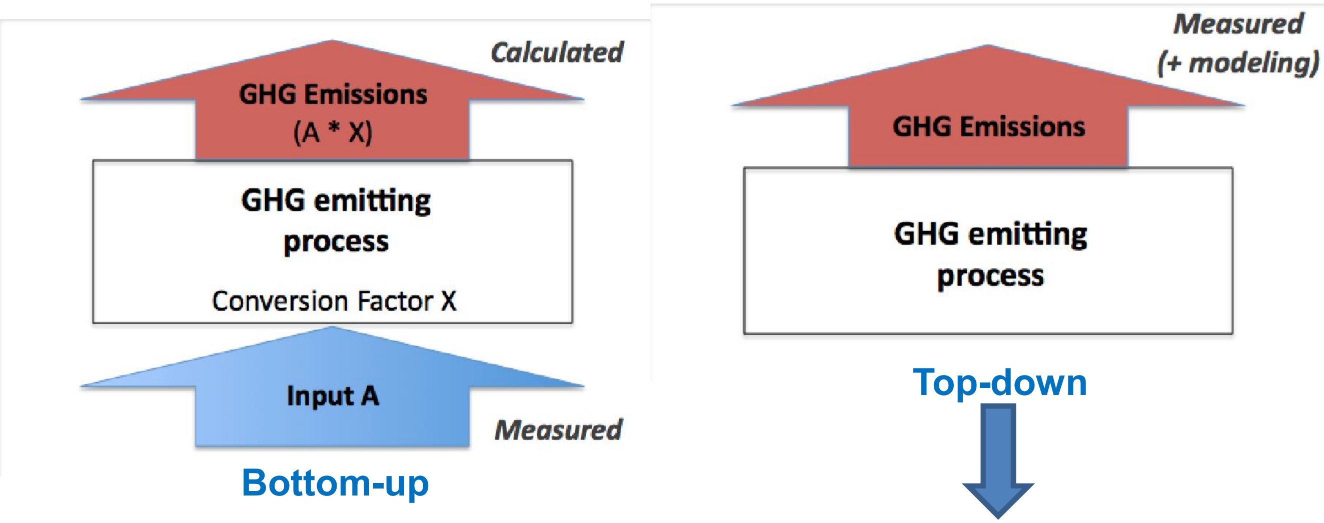
TYPE 1 Existing inventories

- **Research based tools** (EDGAR, IER, PKU): top-down, global coverage; uncertainty can be high
- Simple budget methods (low price, no assessment of the uncertainty)
- High quality inventories by local agencies (e.g. AIRPARIF) ~20% monthly uncertainty

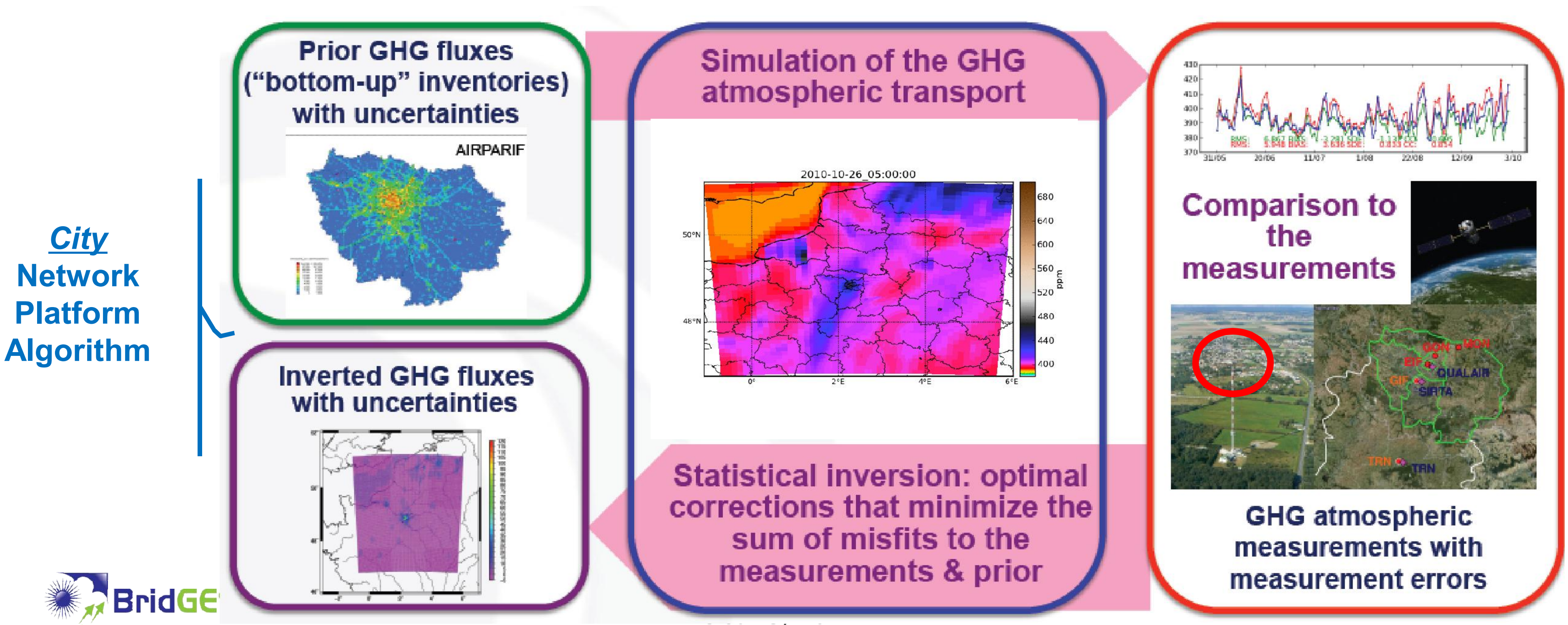
TYPE 2 Potential inventories if incentive in the future

- MRV practice (e.g.CITEPA); verified national uncertainty ~5%; following IPCC guideline

Innovative approach: atmospheric inversion (constraint from conc. observations)



- Observations linked with area emissions by numerical models
- Have been used for 15 years in scientific community to estimate natural fluxes at large scales
- Emergent regional/local applications: ability to estimate anthropogenic fluxes



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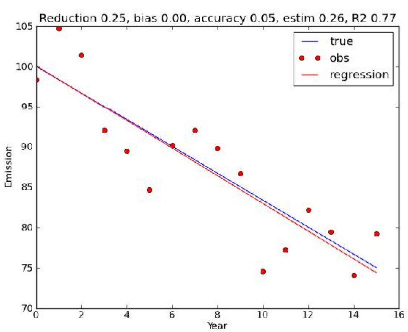
Objectives and accuracies targets

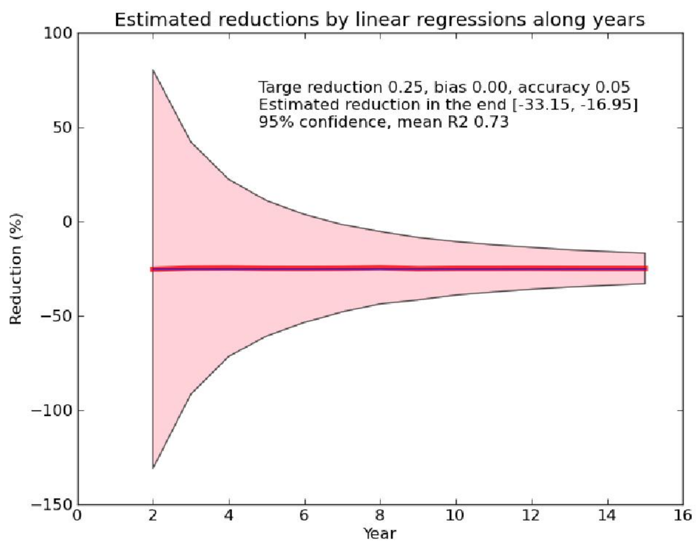
Inversion objective: 5% annual uncertainty

- Same as (national) inventories for MRV use; thus an alternative/verifying approach
- Ability to track gradually the 15-yr trend
- Sectorial verfications

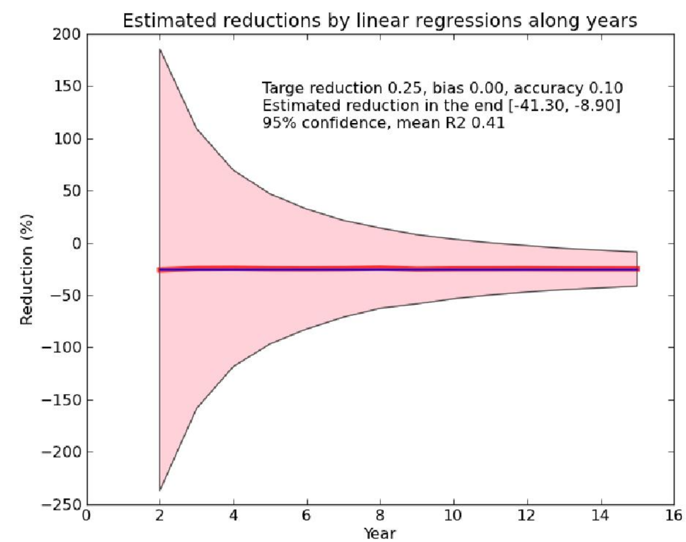
Monte-Carlo simulations of a linear trend model (5% annual accuracy in a 15-yr horizon)



5%



10%

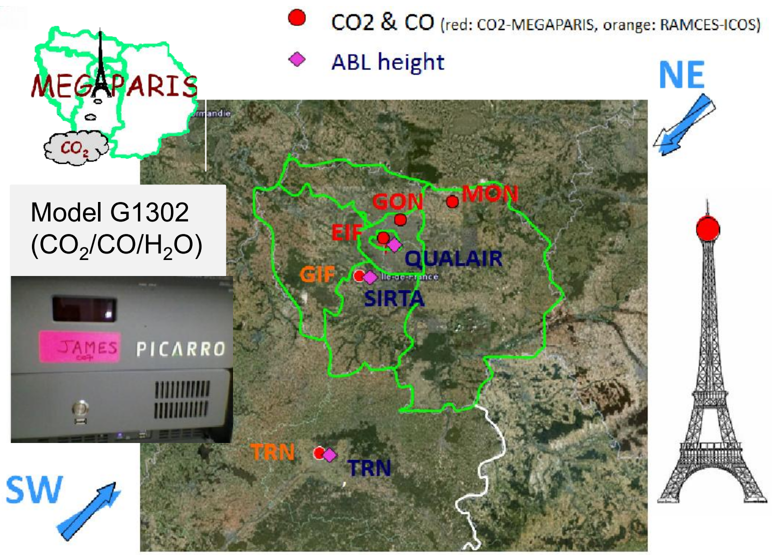


Aggregate **monthly** emissions **(prior 20%)** to **annual** emissions:

(1) 10% (50% reduction) ⟶ 5 %, **(2)** 15% (25% reduction) ⟶ limiting case

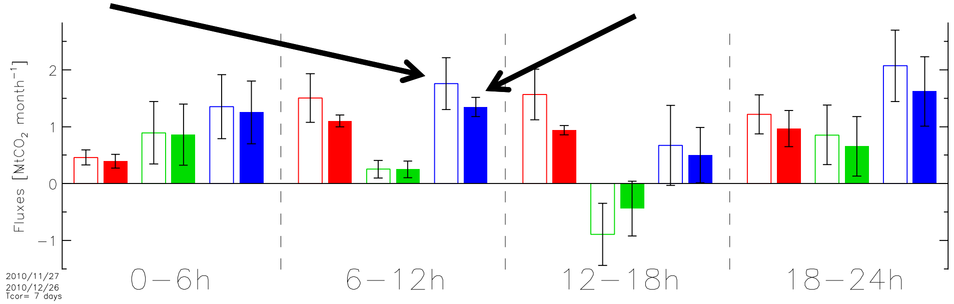
In-situ network of 5 stations for Paris CO_2 monitoring

Irène Xueref-Remy et al,
AGU 2013 & article in prep.



	CO2	CO
Accuracy	< 0.13 ppm	<11 ppb
Precision	< 0.1 ppm (0.38 ppm for EIF)	<10.2 ppb

- High-precision, multi-species observations
- Picarro(45k€)+ add cost: **1 M€ / ~10 Picarro**



Fossil Fuel (FF) + Bio = Total

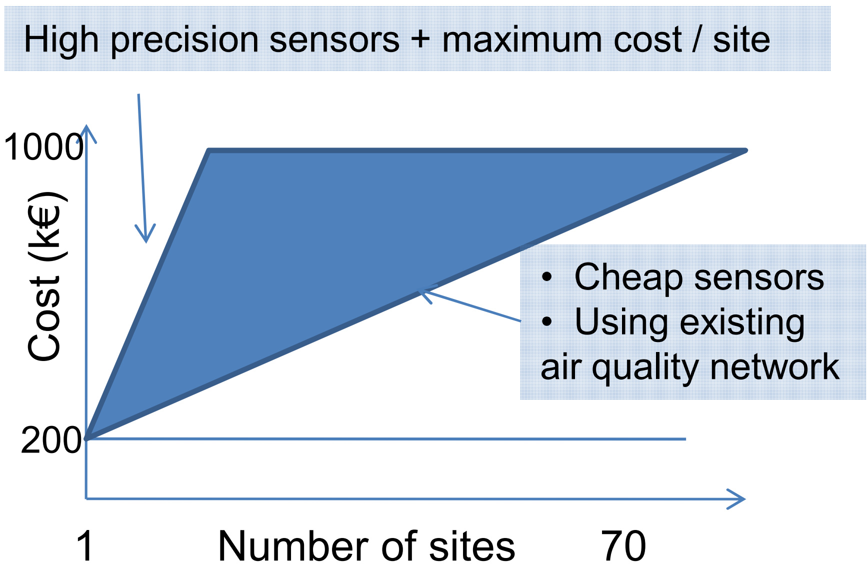
Inversion results, Breon et al. 2014

Data selection

- Afternoon data
- Wind > $3ms^{-1}$
- Obs gradient but not obs

Clipping out many data, but still have considerable uncertainty reductions

Extending network with cost effective sensors?



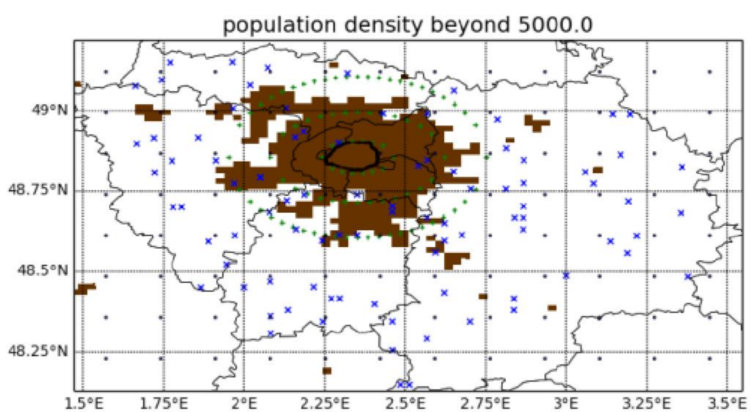
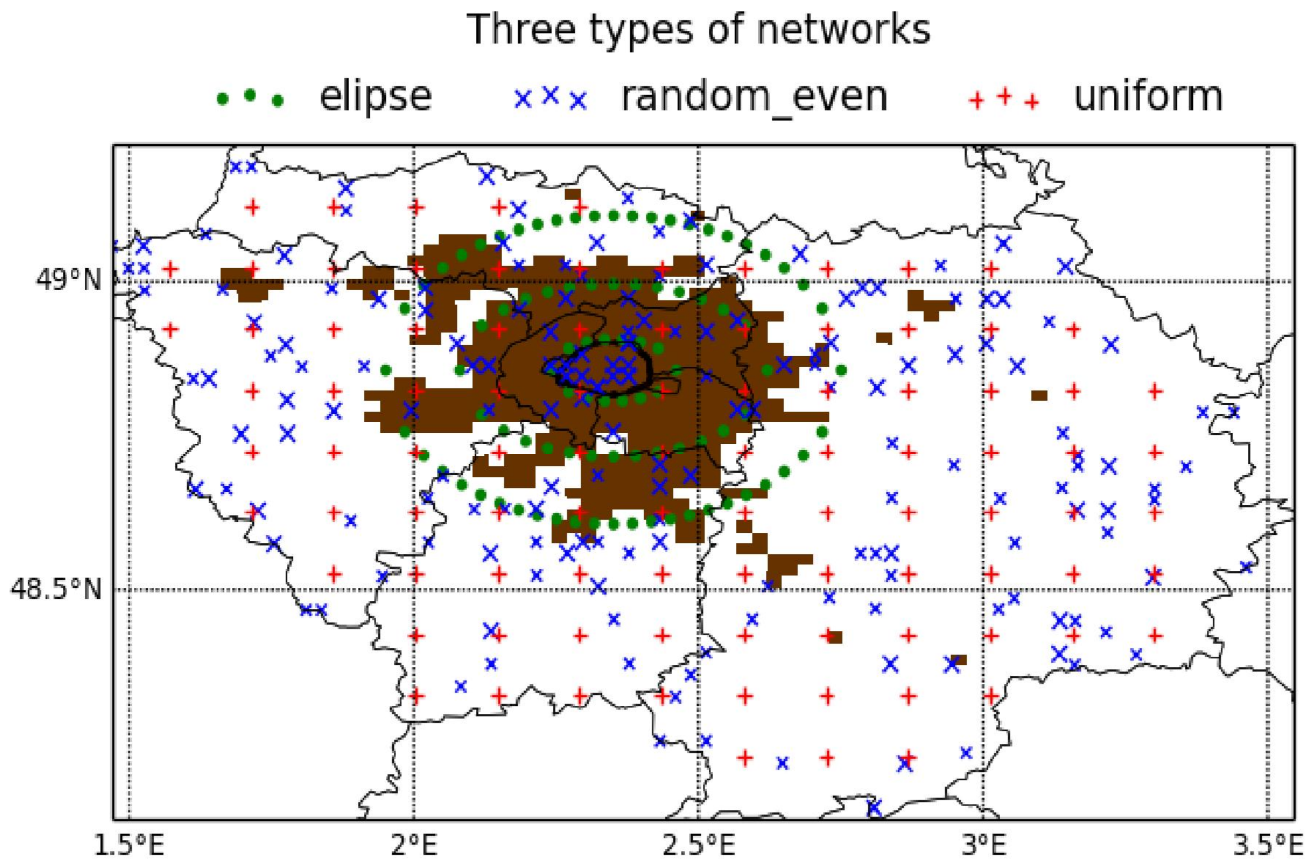


Table: detailed cost of monitoring network of high precision (**) and **cheap sensors** (*, **being tested at LSCE**)

	Cost		Comments
Sensors / site	*	**	* Low precision/ accuracy: 0.5-1 ppm/ 1ppm
	2 k€	45 k€	
Infrastructure / site	10-30 k€		Mininum: Inlet + calib = 10 k€
• Container	10 k€		
• Inlet + R-Box + drying	5 k€		
• Calibration	5 k€		
• Installation and others	5 k€		
Annual			
• Infrastructure / site	1-20 k€		Rent, electricity …
• 1 engineer: network	60 k€		
• 1 engineer: data	60 k€		
• 1 engineer: modeling	60 k€		

Different types of cheap sensor networks

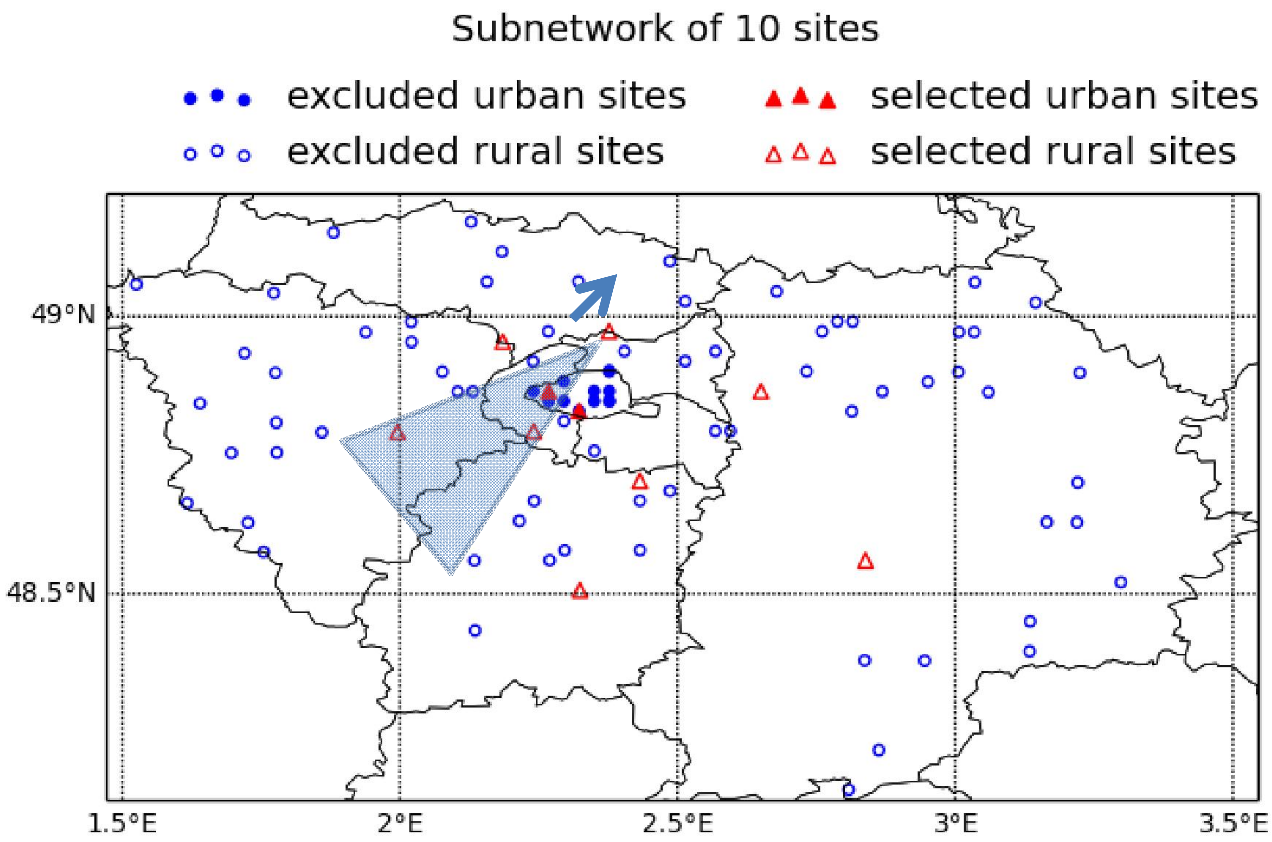


Eclipse network:
Urban area

Uniform network
Regular grid

random_even network
Balance between city center and surrounding areas

Assimiling observation gradients

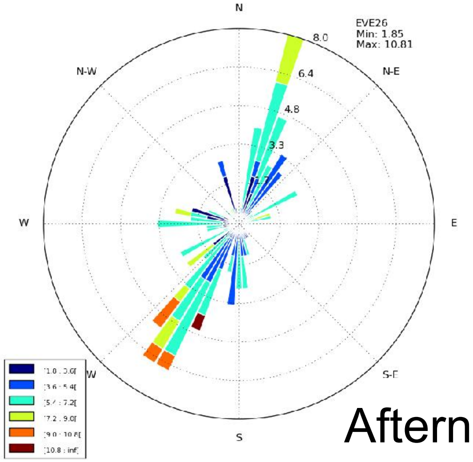


Data selection

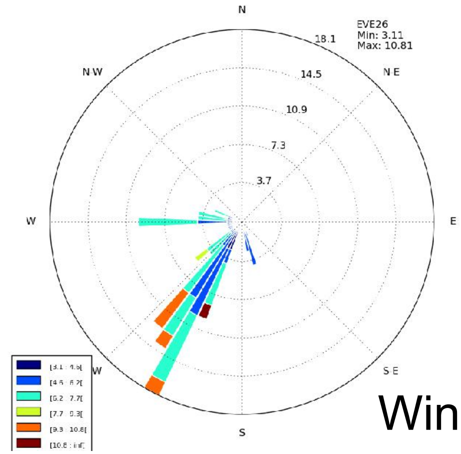
Afternoon data; Wind > 3ms^{-1};

choose one upwind station to compute the concentration gradients

Assimiling observation gradients



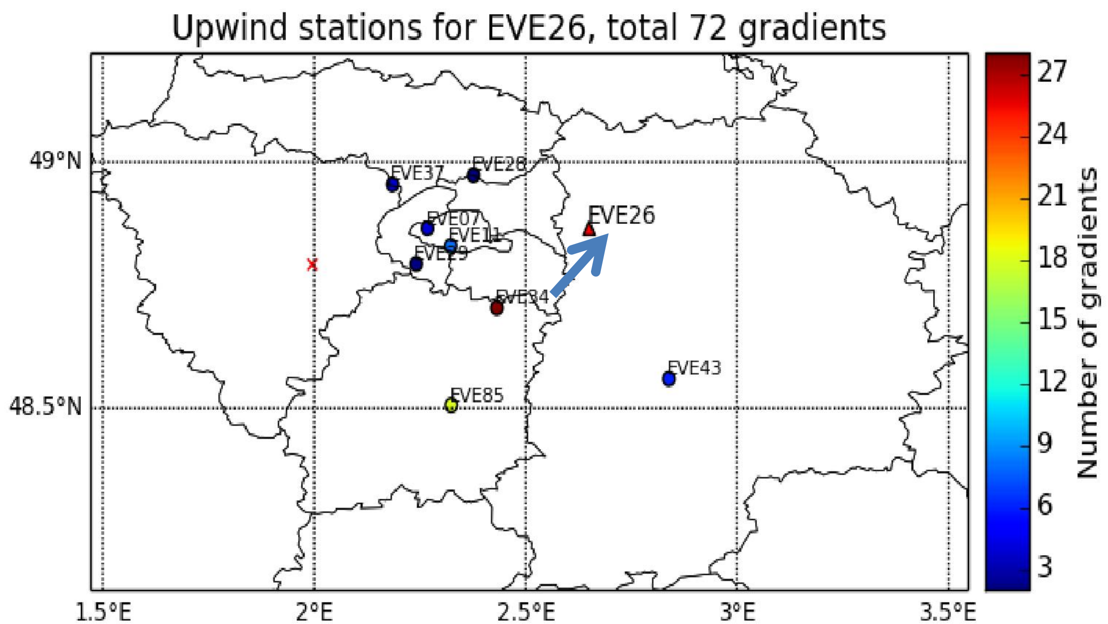
Afternoon winds



Winds after data selection

Counts of upwind stations selected for the calculations of concentration gradients

Selection rates: 7%-16%



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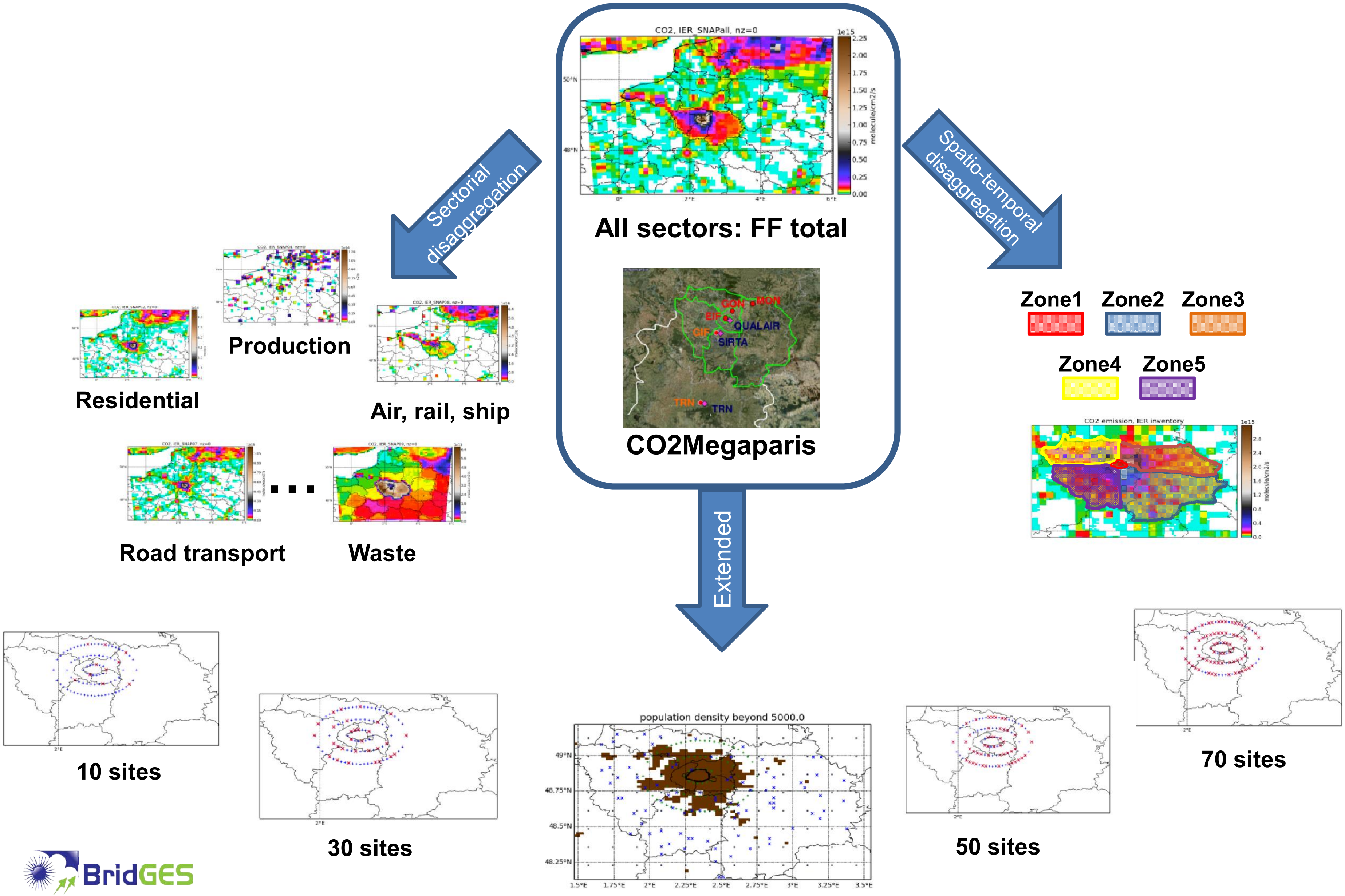
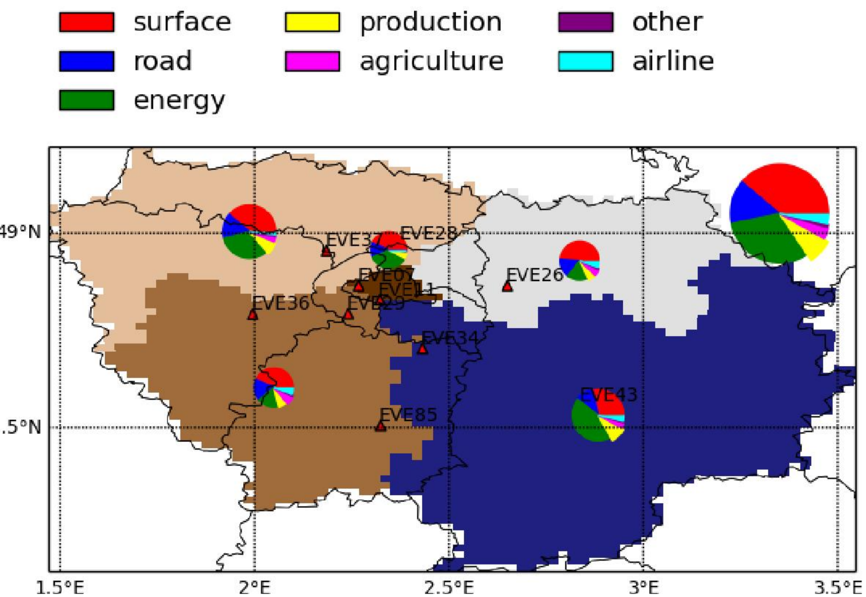
Sectorial Inversion of CO_2 fluxes using data from extended networks



Scaling factors

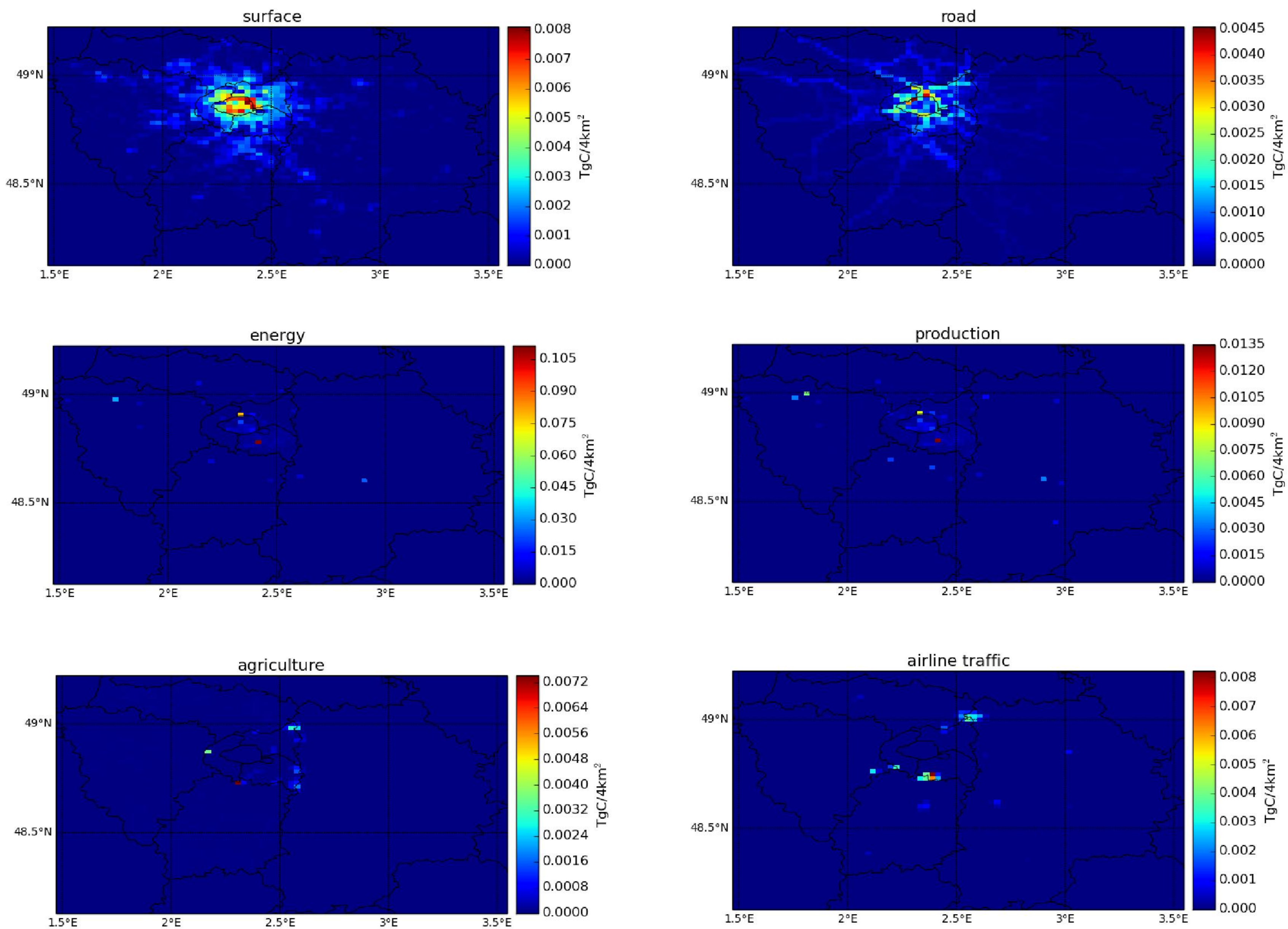


January 2011

Scaling factors applied to **IER inventory**

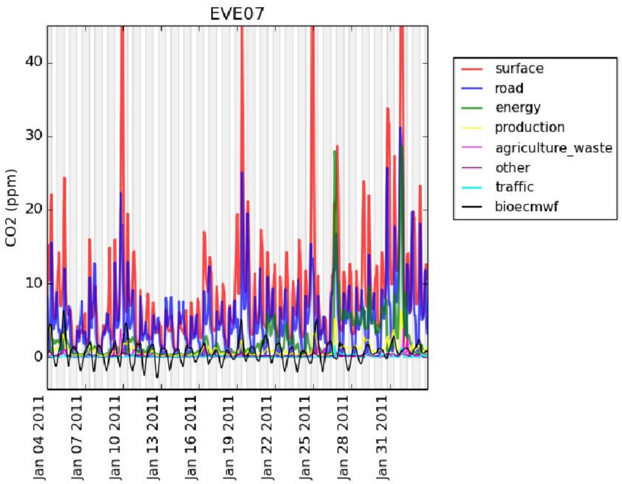
Control factors	Spatial resolution	Time resolution	Number of factors
Surface	5 zone	Daily daytime and night-time	300
Road	5 zones	Daily daytime and night-time	300
Energy	1 zone	Daily daytime and night-time	60
Production	1 zone	Daily daytime and night-time	60
Agriculture	1 zone	Daily	30
Other	1 zone	Daily	30
Airline traffic	1 zone	Daily	30
Biogenic	1 zone	5-day period with6-hour diurnal bins	24
Boundary/initial conditions	1 zone	Monthly	1
Total			**835**

Spatial distributions of sectorial IER inventory

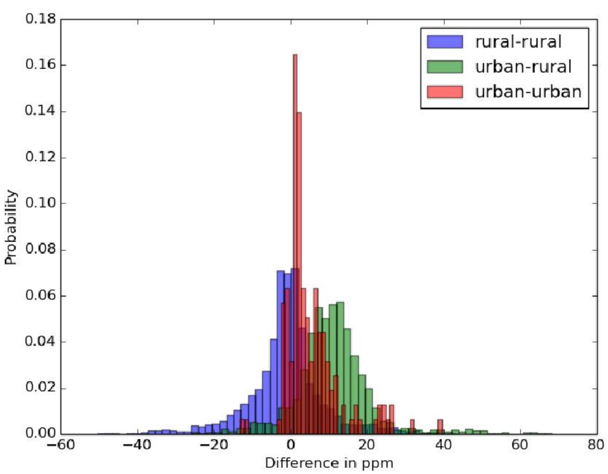


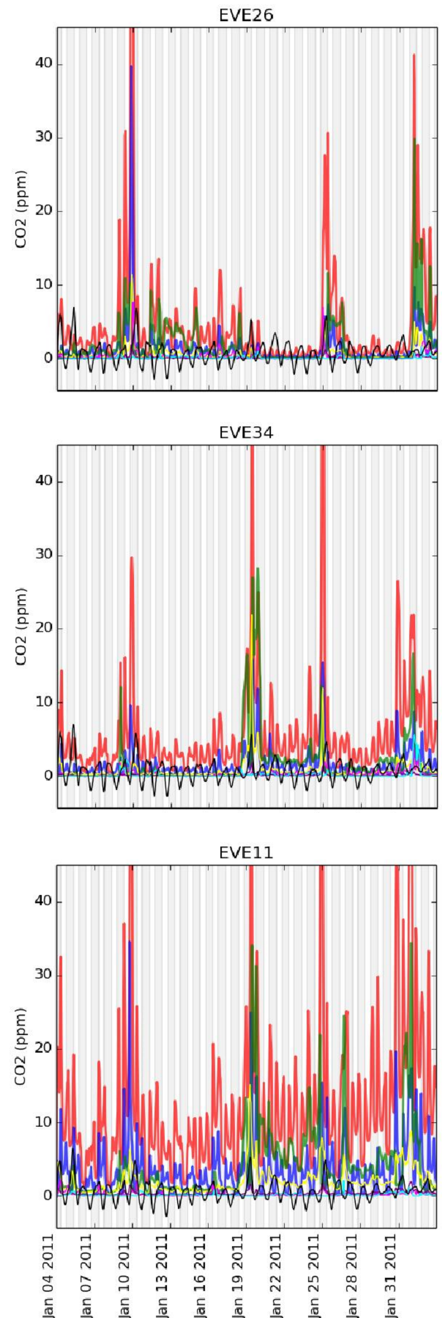
Sectorial simulation gradients between sites

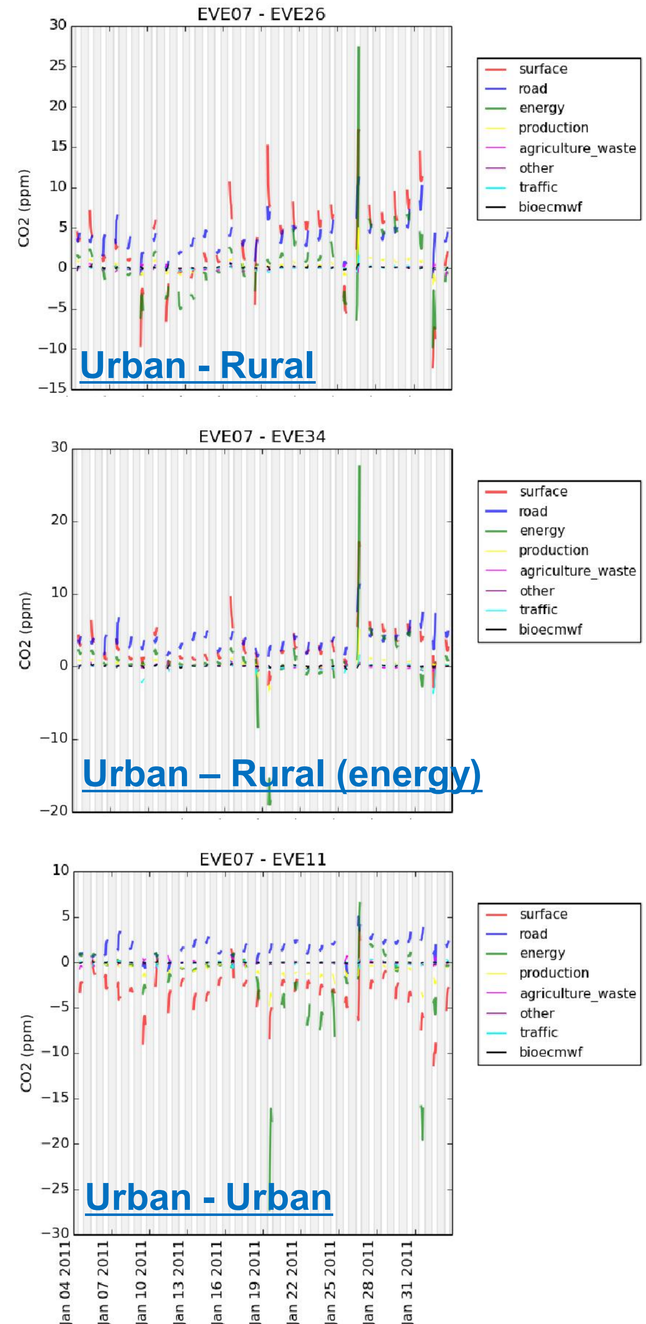
Ref. urban site



Histogram of gradients







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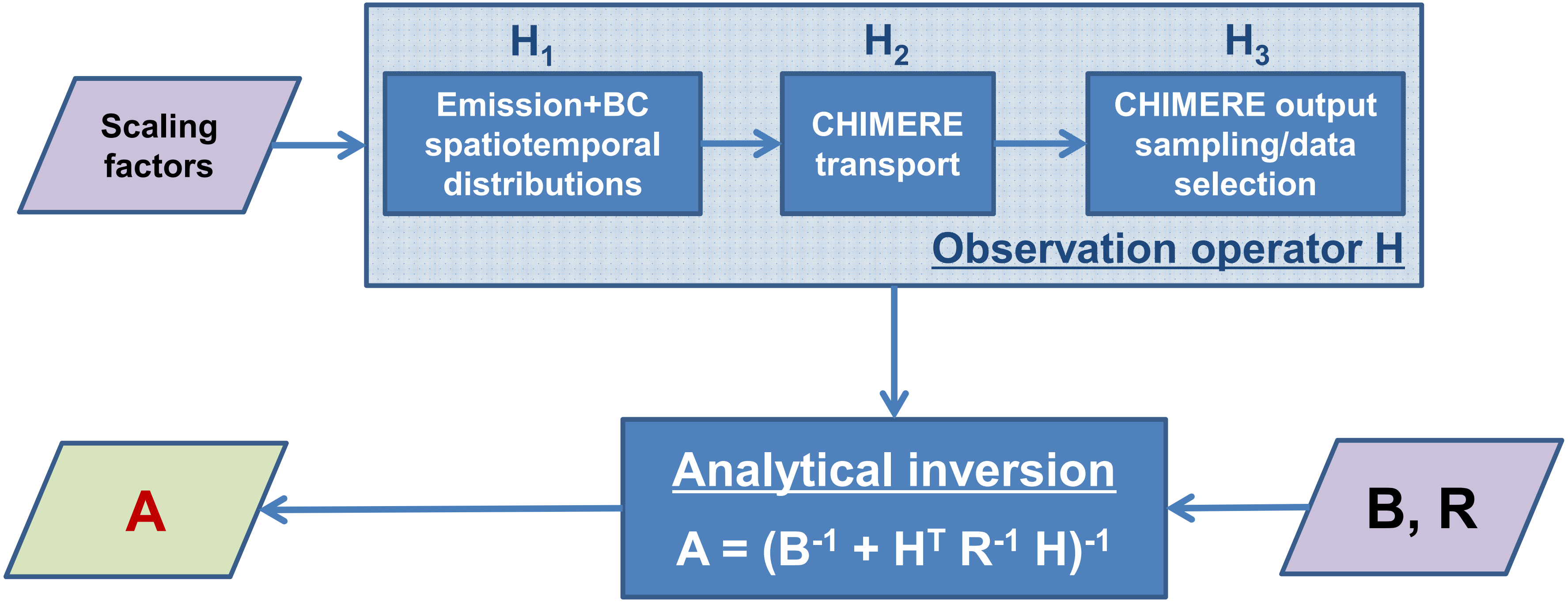
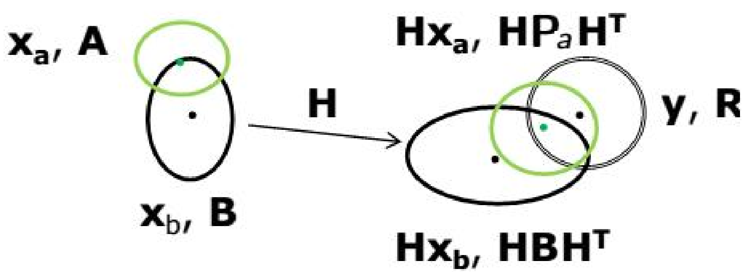
Uncertainty reduction for synthetic analytical inversion





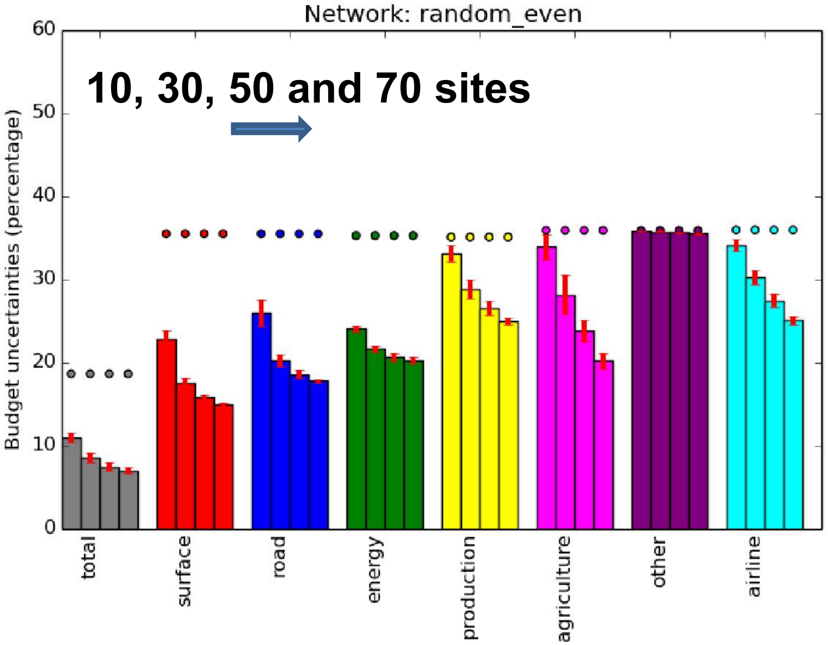
B: Temporal correlation [illegible] days, spatial correlations => Total error budget [illegible]0%

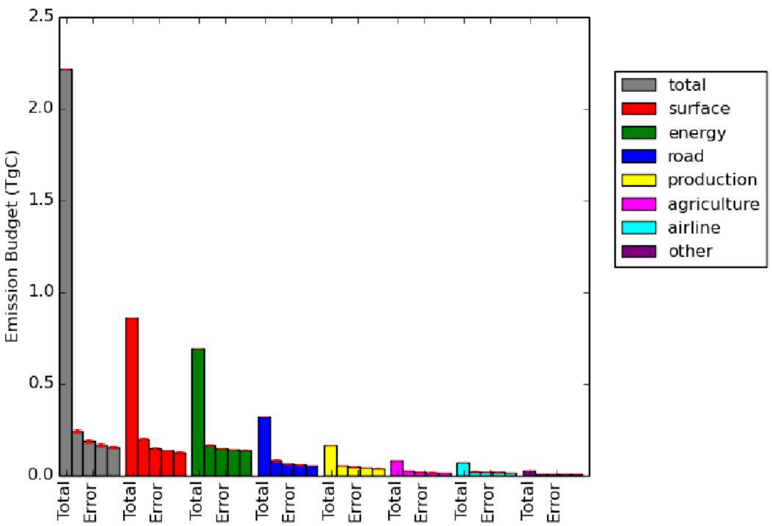
R: Urban sites ([illegible]ppm), rural sites ([illegible]ppm), gradients $\sqrt{\sigma_1^2+\sigma_2^2-2\sigma_1\sigma_2 corr}$

(0-10 ppm for rural site grad., Breon et al., 3 ppm thus **corr** = 0.82)

Our choice: 3.5 ppm

Uncertainty reductions



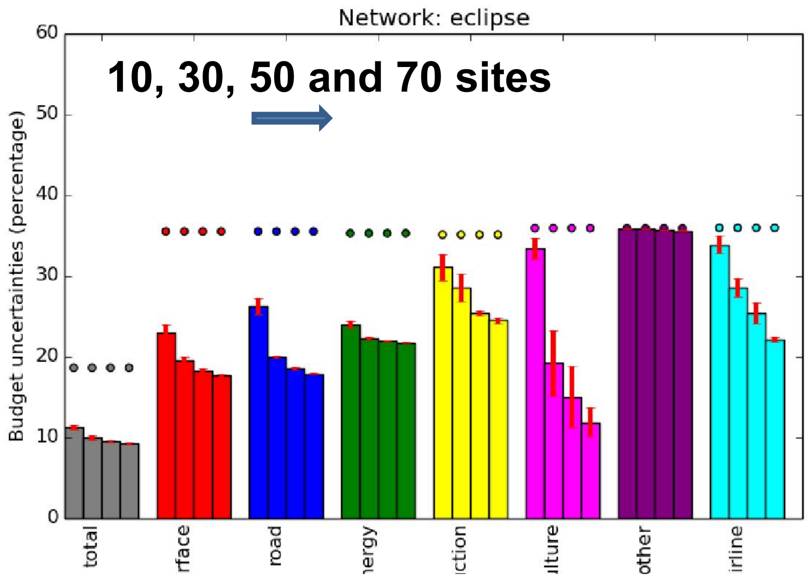


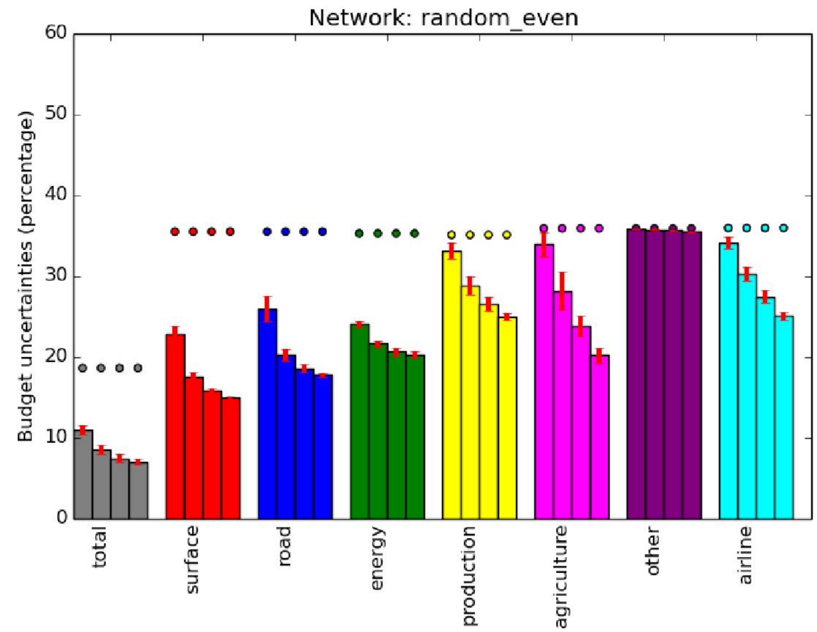
- Excellent reduction of uncertainties for total FF with very limited number of stations (~10 sites)

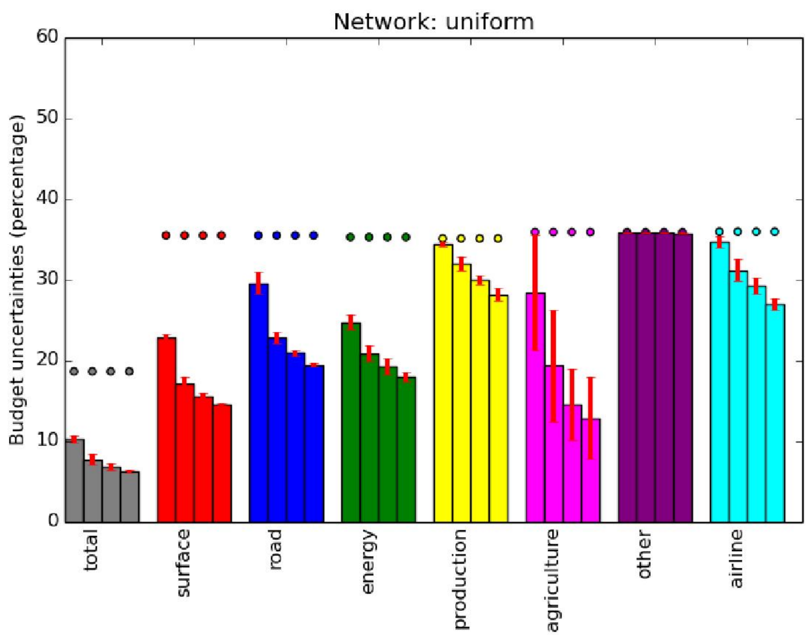
- More sites increase sectorial uncertainty reductions
  - Significant uncertainty reduction for surface (residential) emission (58%)
  - Less significant uncertainty reduction for energy and transport sectors
  - Small uncertainty reduction for minor sectors

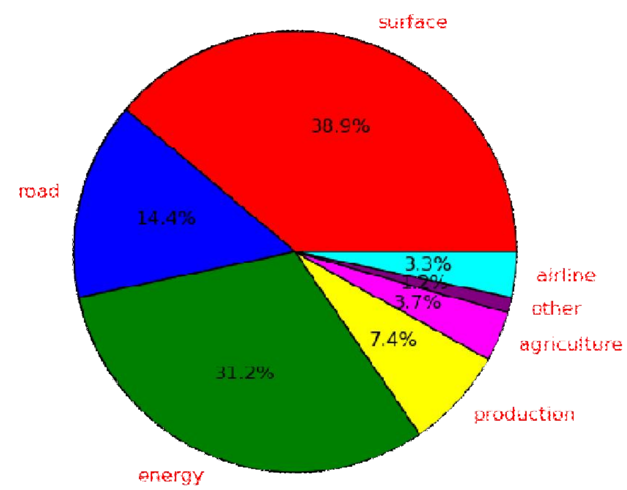
- Performance of different types of networks?

Performances of different networks



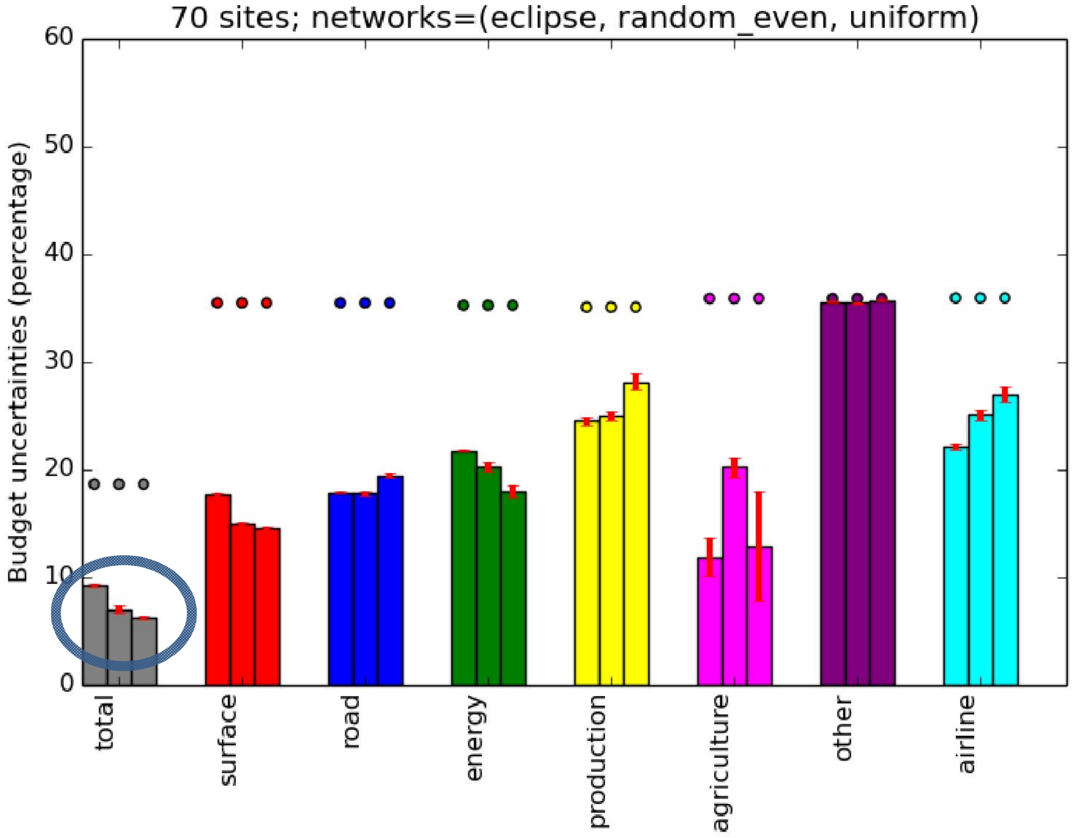






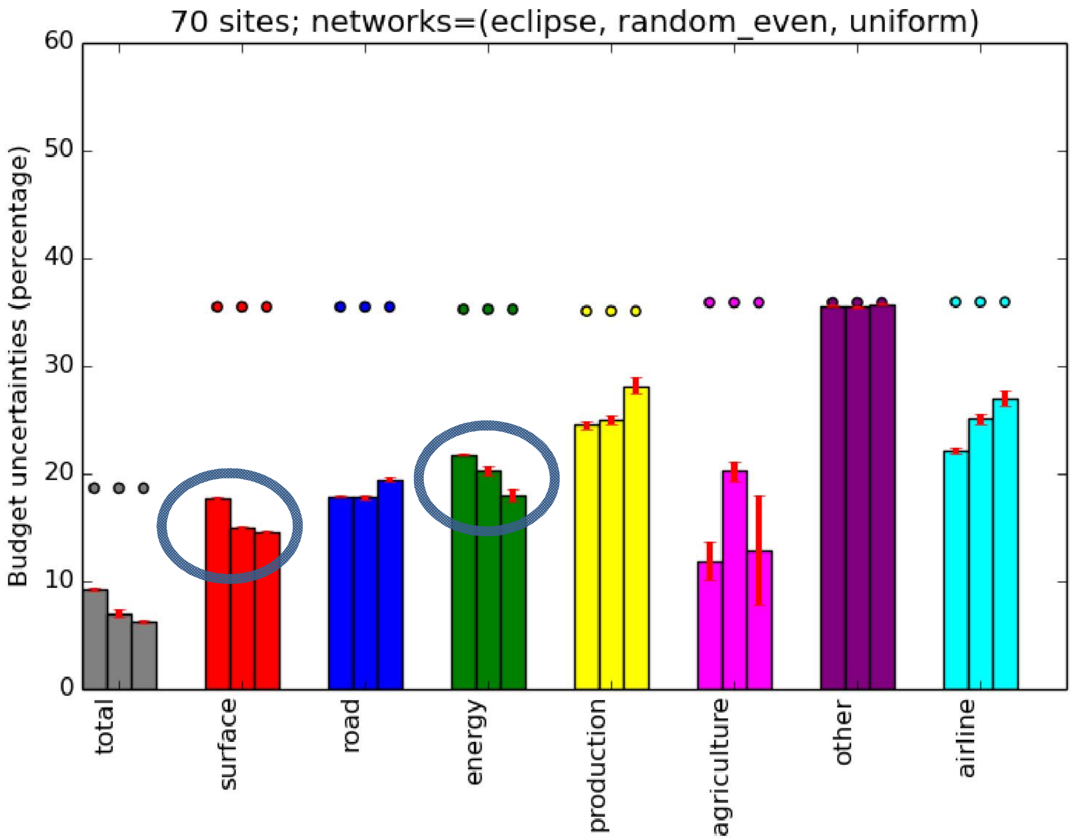
Surface + road + energy ~ 85%

Performances of different networks



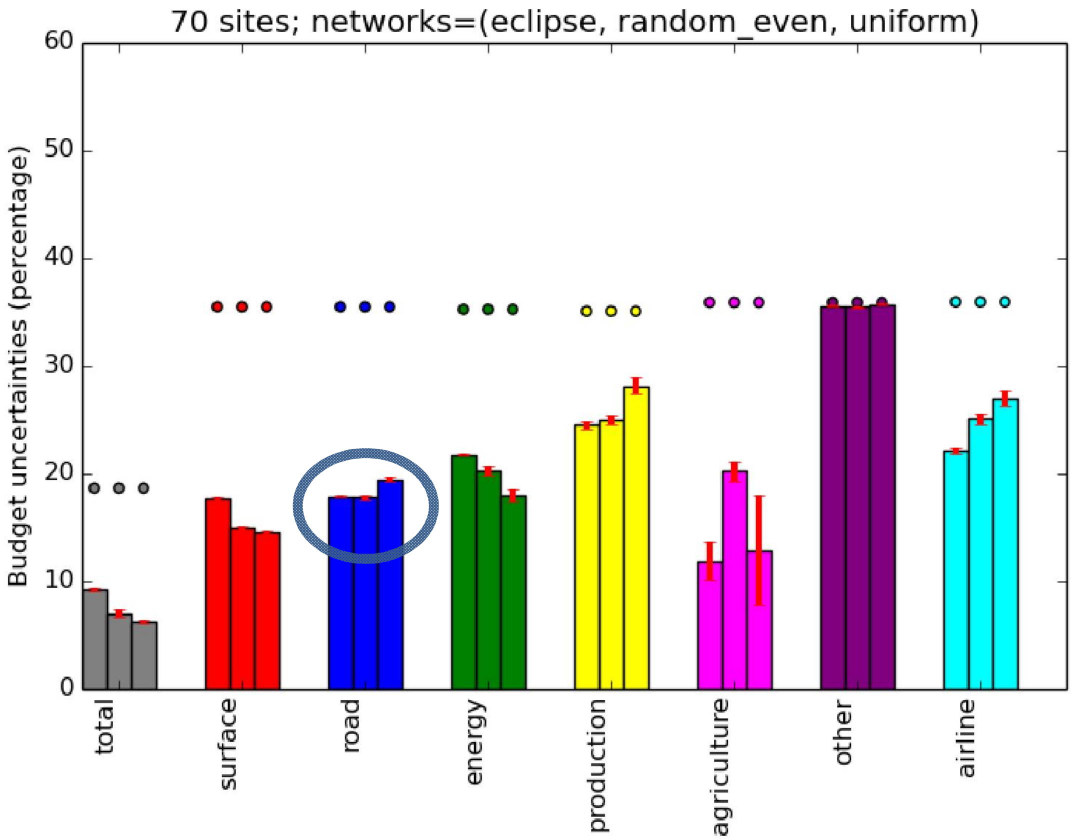
Saturation of uncertainty reduction of total emissions for eclipse network, since it covers only city center, while large point emissions could be located in rural areas (e.g. EDF Porcheville and TOTAL Grandpuits)

Performances of different networks



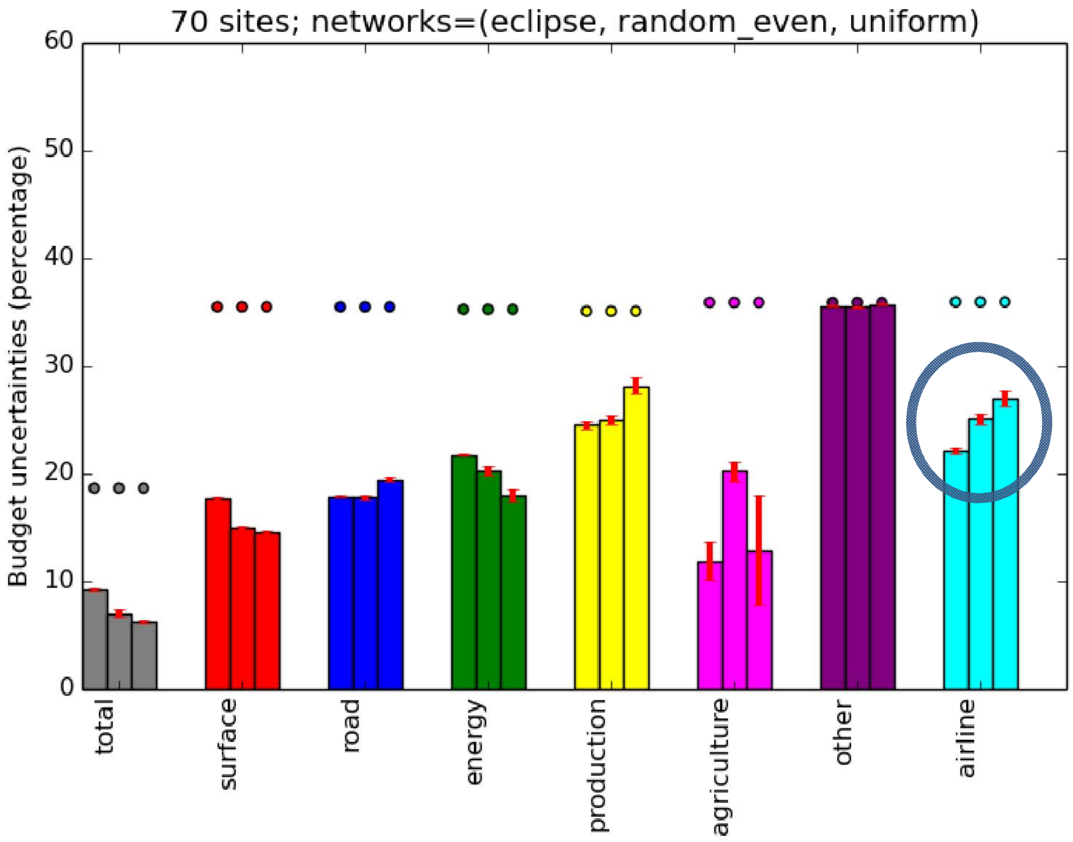
Worst performance of Eclipse network for surface and energy emissions since it the covers only the urban area.

Performances of different networks



Slightly better performance of eclipse network for road transport probably because the road network sprawls mainly at the urban area (e.g. peripherique).

Performances of different networks



Better performance of Eclipse network for air traffic since it the airports (Orly and CDG) overs only city center, are located between the two rings of the network

Summary

- Atmospheric inversion and MRV systems:
    - complementary to bottom-up approaches (Bayesian estimation)
    - a solution for a fully independent budget verification method
    - ability to monitor the city total emissions with high precision at a reasonable cost

- Synthetic sectorial analytical inversion conducted for great Paris region CO2 emissions
- Evaluated different types of networks with a large number (up to 70 sites) of cheap sensors.
- Significant reduction of uncertainties of total FF emissions with small networks (~10 sites)
- Significant reduction of uncertainties of surface residential emissions for larger networks (70 sites)
- Less significant reduction of uncertainties of energy and transport emissions for larger networks
- Further network design adapting to sectorial emissions may improve inversion performances
- More scaling parameters to be estimated