Atmospheric inversion of city CO2 emissions: first lessons from the Paris experiment

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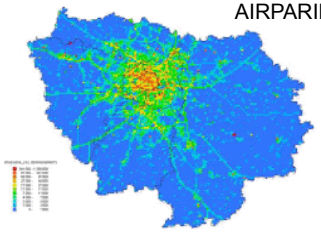
Results from: Bréon et al. 2014, ACPD
Staufer et al., in prep

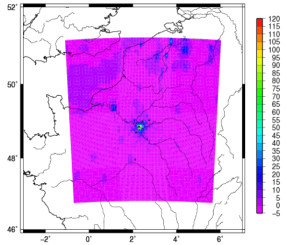
Long-lived GHG atmospheric inversions

Prior GHG fluxes ("bottom-up" inventories) with uncertainties

AIRPARIF

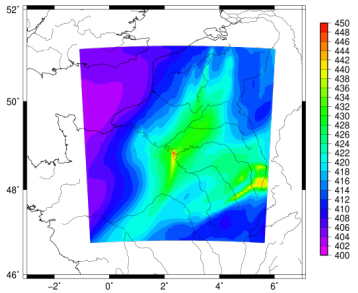


Inverted GHG fluxes with uncertainties

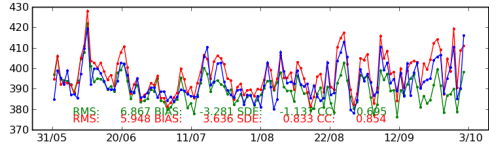


Simulation of the GHG atmospheric transport

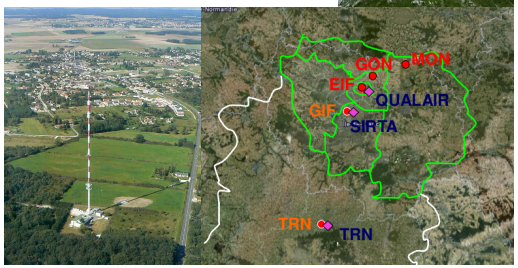
Transport proxy/models bearing "model errors"



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



Comparison to the measurements

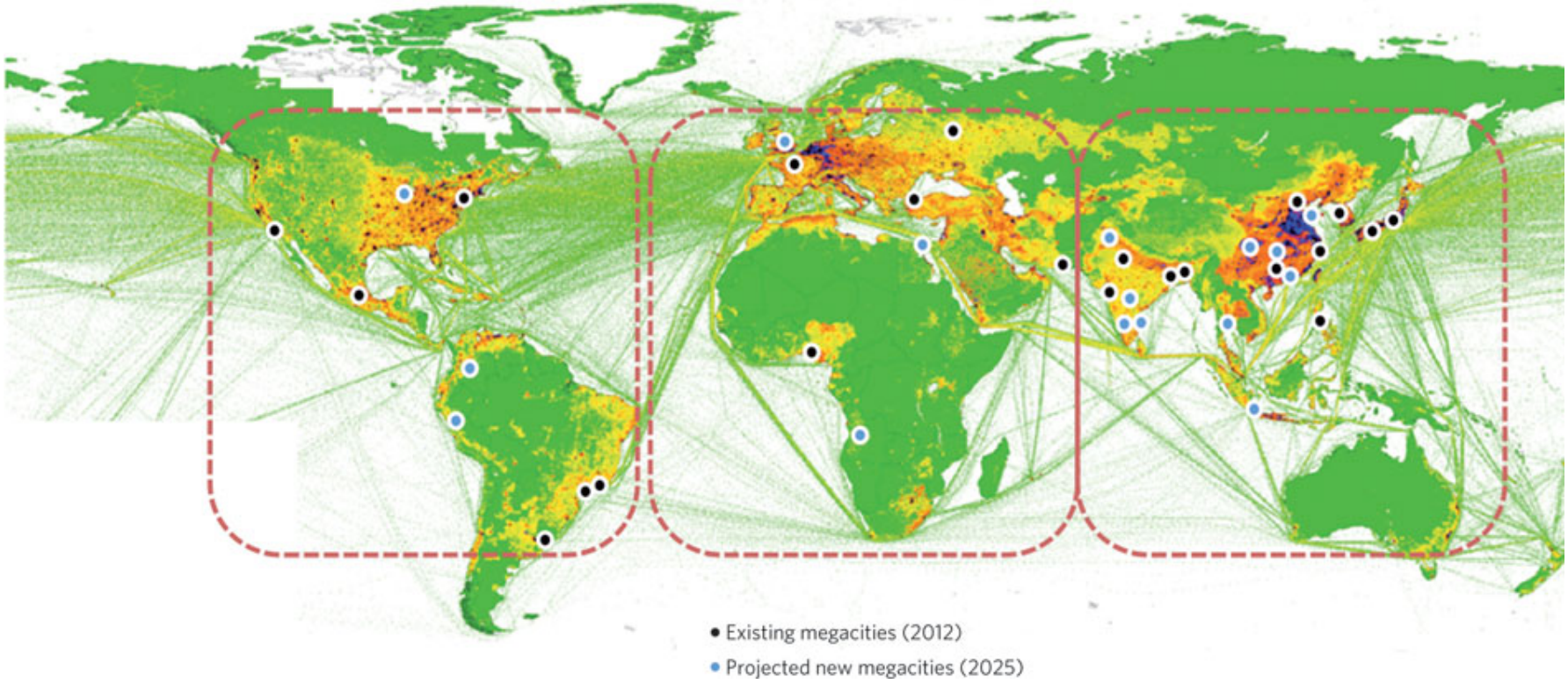


GHG atmospheric measurements with measurement errors

- **Used for more than 10-years to estimate CO2 natural fluxes at global scale**
- **Emergence of regional systems: ability to derive more robust local estimates and to track anthropogenic emissions**

Expectations for the monitoring of city scale emissions

- Cities: more than 75% of CO2 emissions on less than 2% of land surface



Duren and Miller, Nature CC 2012 (map of emissions from EDGAR)

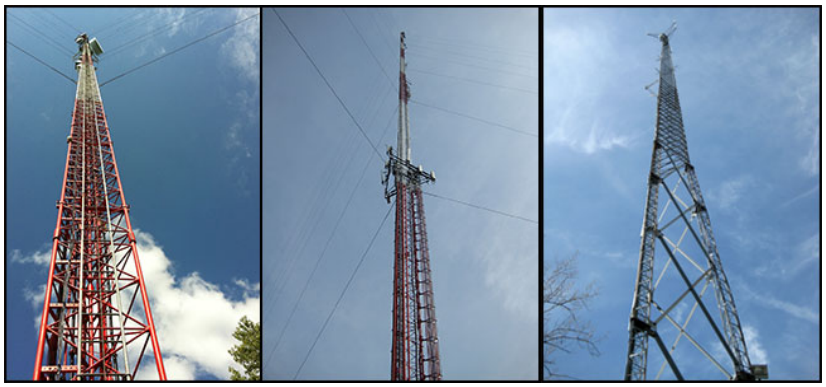
Expectations for the monitoring of city scale emissions

- Cities: more than 75% of CO2 emissions on less than 2% of land surface
- Political need for **improving / verifying** the estimate of **emissions from cities**

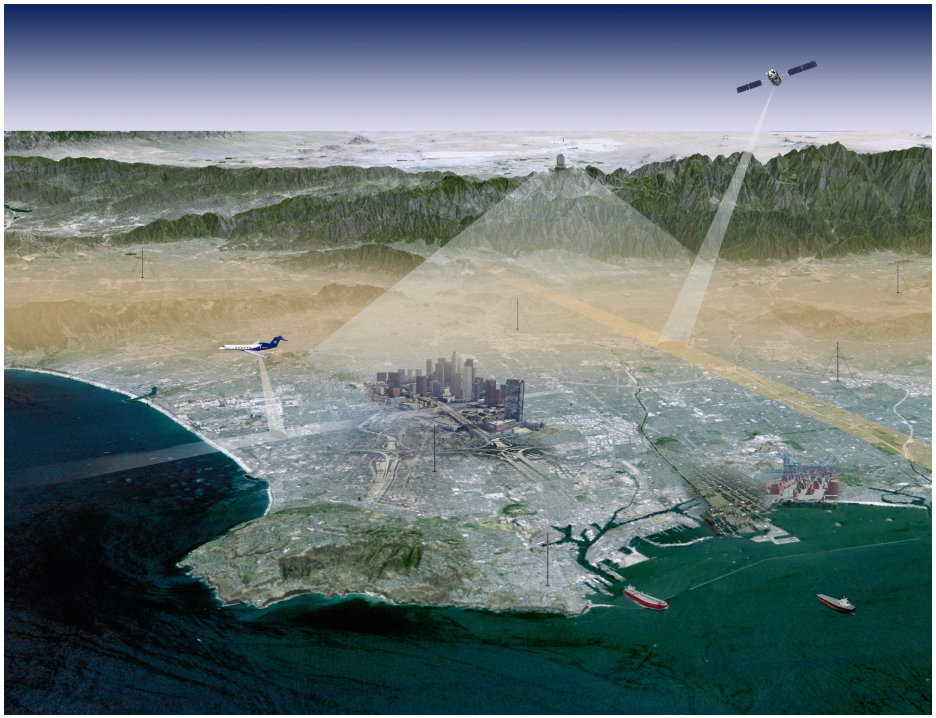
The C40 network

Expectations for the monitoring of city scale emissions

- Cities: more than 75% of CO2 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 CO2 measurement networks**



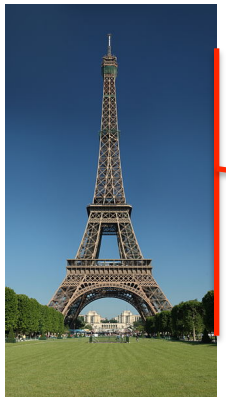
Measurement towers in Indianapolis (NIST/ INFLUX project)

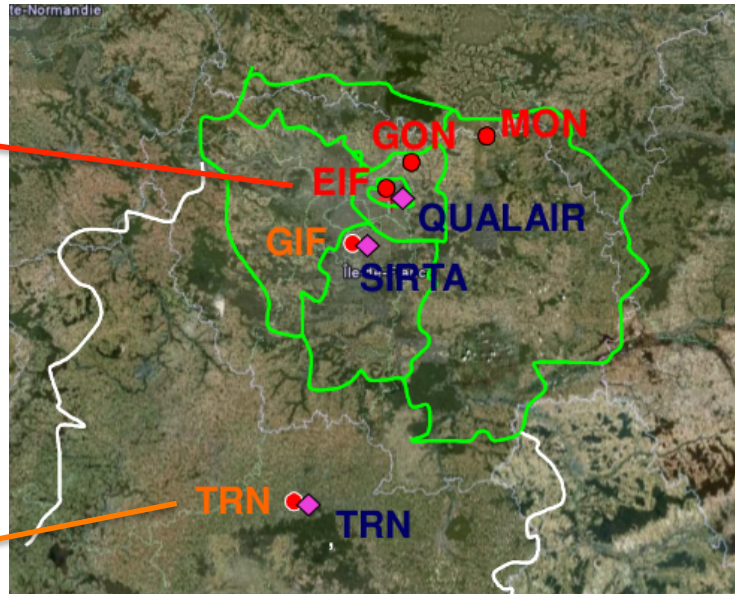


The Megacities project in L.A. (JPL/NASA)

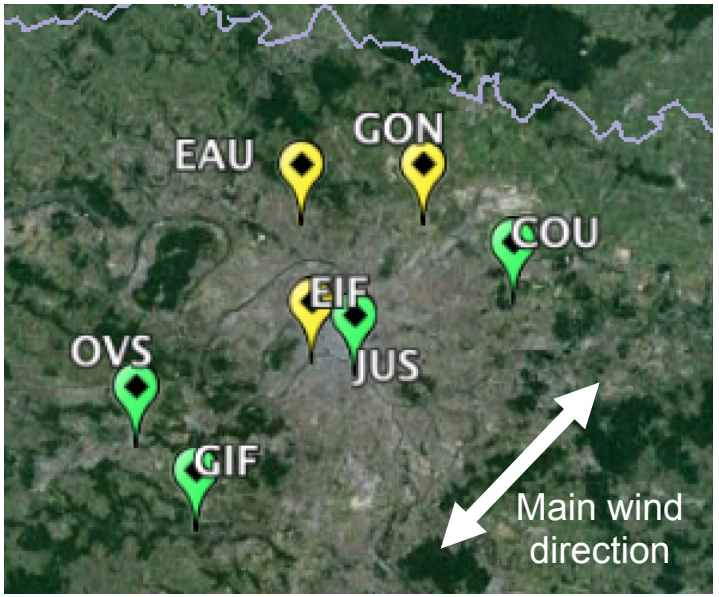
The Paris continuous measurement networks

- **Studies at LSCE for the Paris area : CO2-Megaparis (ANR), Carbocount-city (Climate-KIC) projects, chaire BridGES, le CO2 parisien**





The CO2-Megaparis / ICOS network in the Paris area (mid 2010-mid 2011)

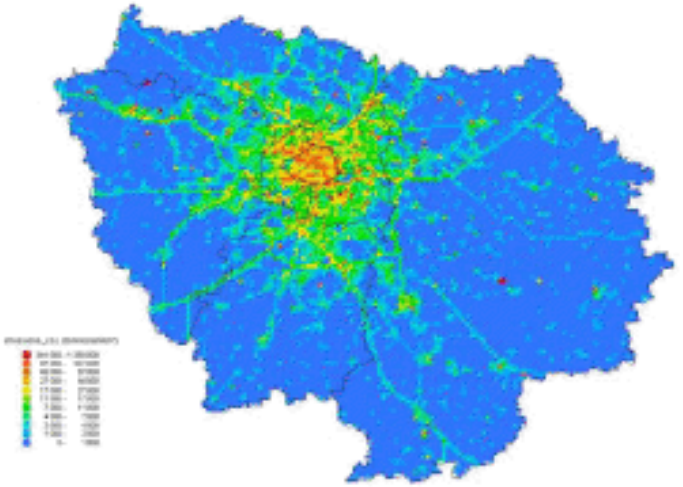


The Carbocount-city / ICOS network in the Paris area (2014-2015)

- **This work exploits the CO2-MP/ICOS data from Aug 2010 to July 2011**

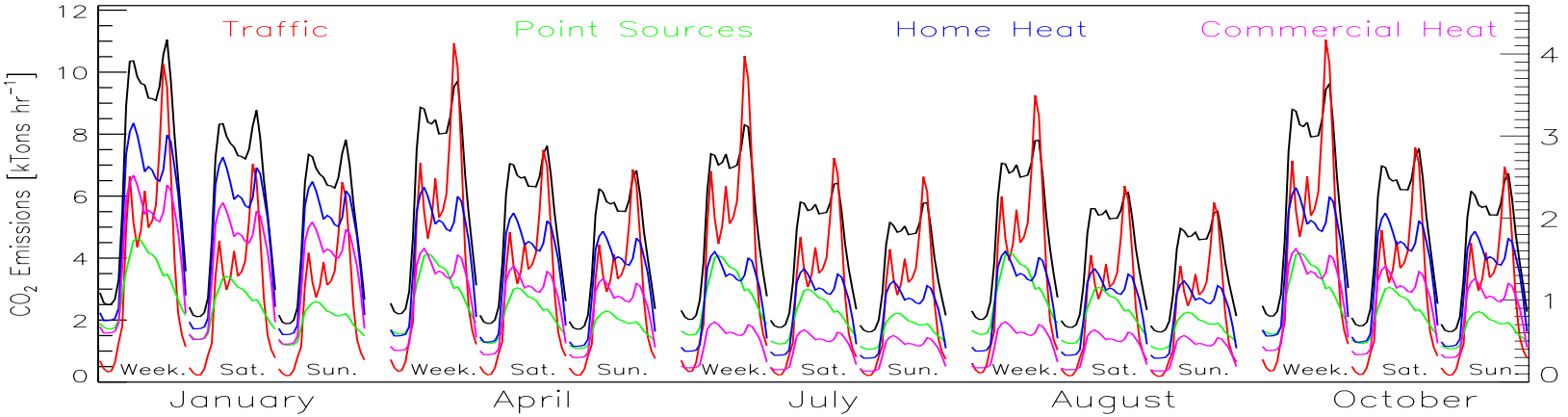
The AIRPARIF inventory (release 2008)

- **Inventory for the Paris area (“Ile de France”)**
- **A good annual mean for 2008**
- **A good spatial distribution**
- but **strong temporal homogeneity**



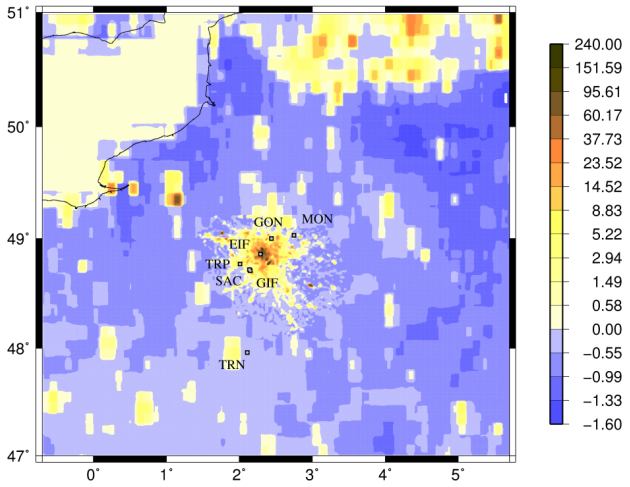
AIRPARIF inventory 2008 (1 km resolution)

Temporal variations of the CO2 emissions per main sector in the AIRPARIF inventory 2008

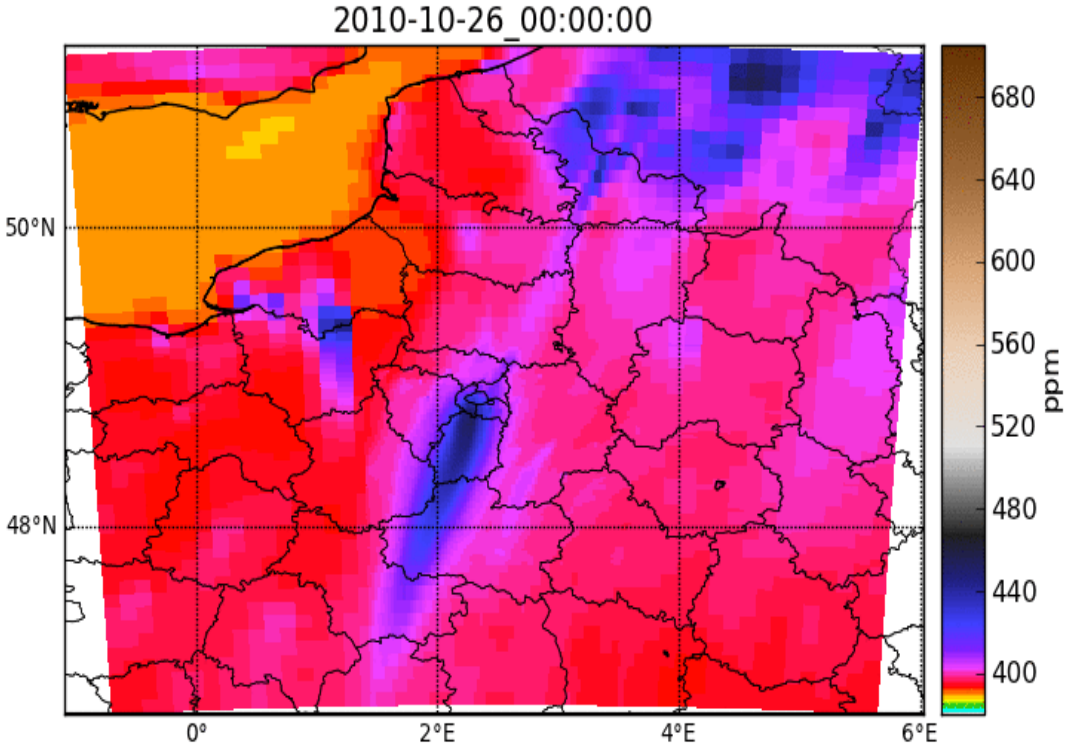


The atmospheric transport configuration

- **Eulerian transport model at 2km res with numerical diffusion:** difficulties to model the strong heterogeneity of the urban CO2 ?



Flux map:
Airparif (FF, Paris area)
EDGAR (FF, rest of the domain)
C-TESSEL (NEE)



Northern France domain for the transport modeling and CHIMERE(2km)-ECMWF(15km) simulation

➢ Initial target of the inversion: **improving the estimate of monthly Paris emissions** solving for fluxes at 6-hour resolution but not the spatial distribution

Comparison of measured vs simulated concentrations

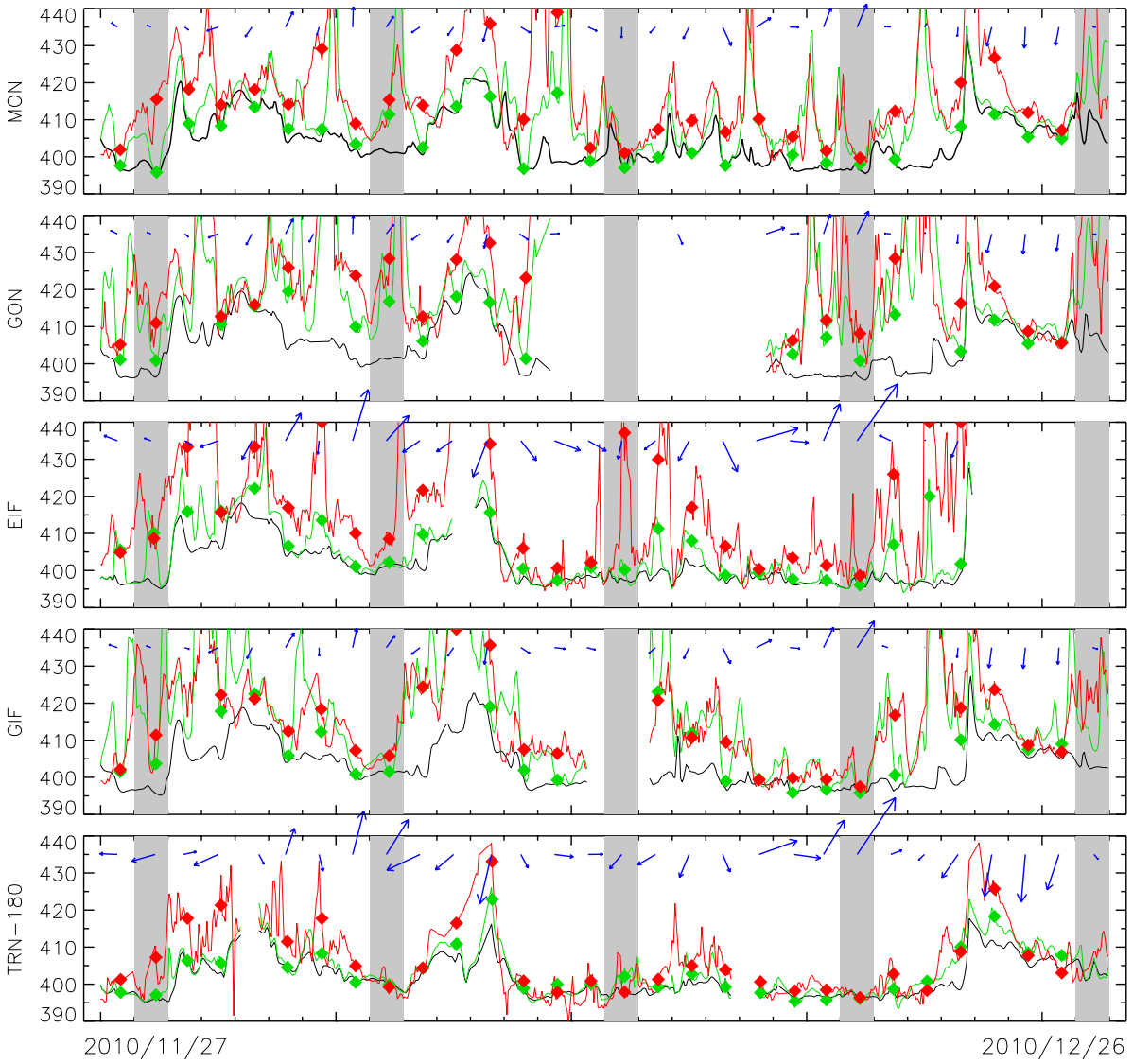
Hourly (lines) and afternoon (12:00-16:00: dots) averages of the concentrations (dec 2010):

Measurements

"Background": model with CO2 from the boundaries (LMDZ-inversion) only

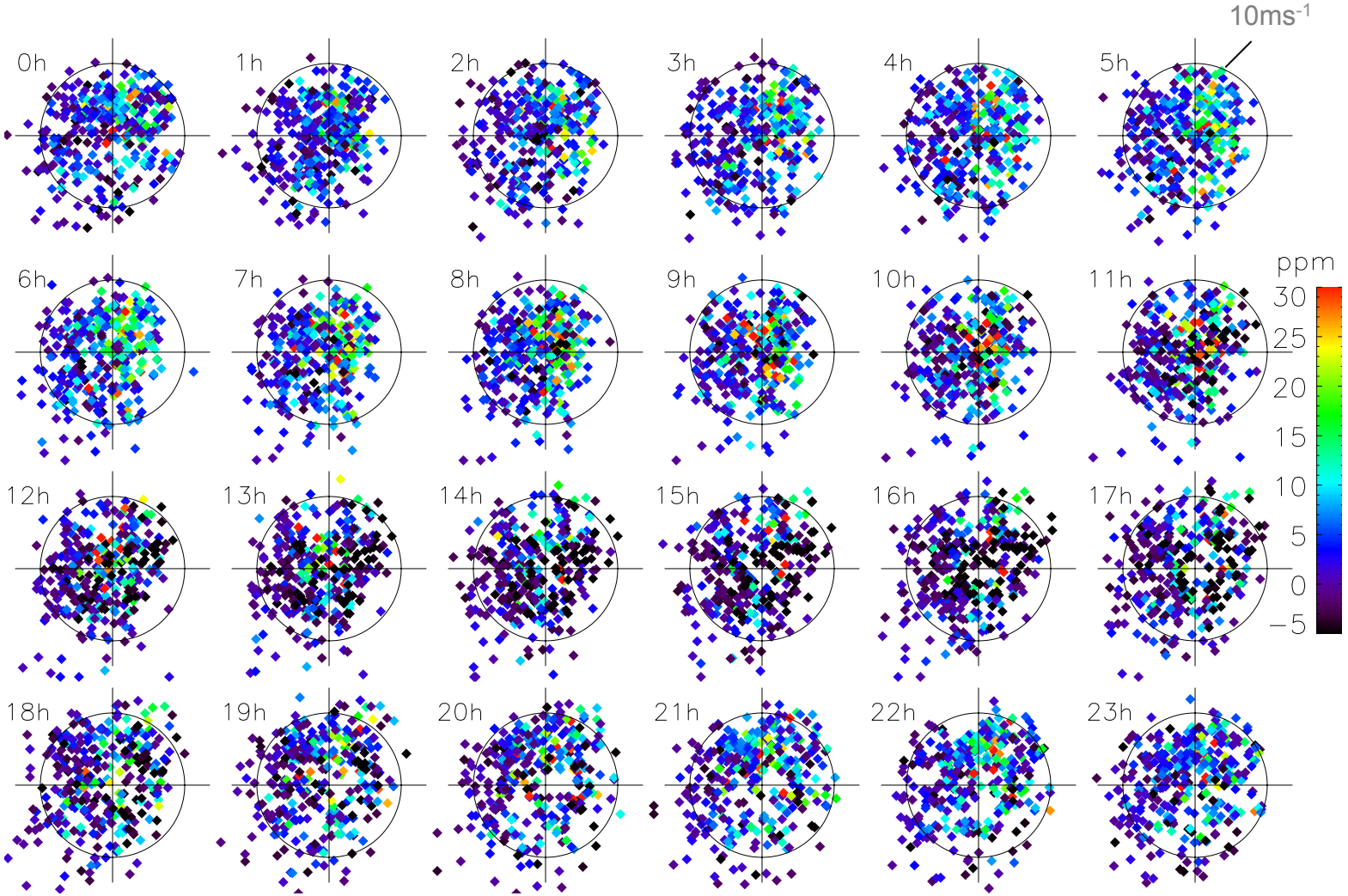
Model (including boundary conditions and fluxes in the domain)

Arrows: daily wind speed and directions



- **Selection of the data in the afternoon and when the wind speed above a threshold (2 to 3 ms^{-1}) for the inversion**

Issues for simulating urban CO2 (1)

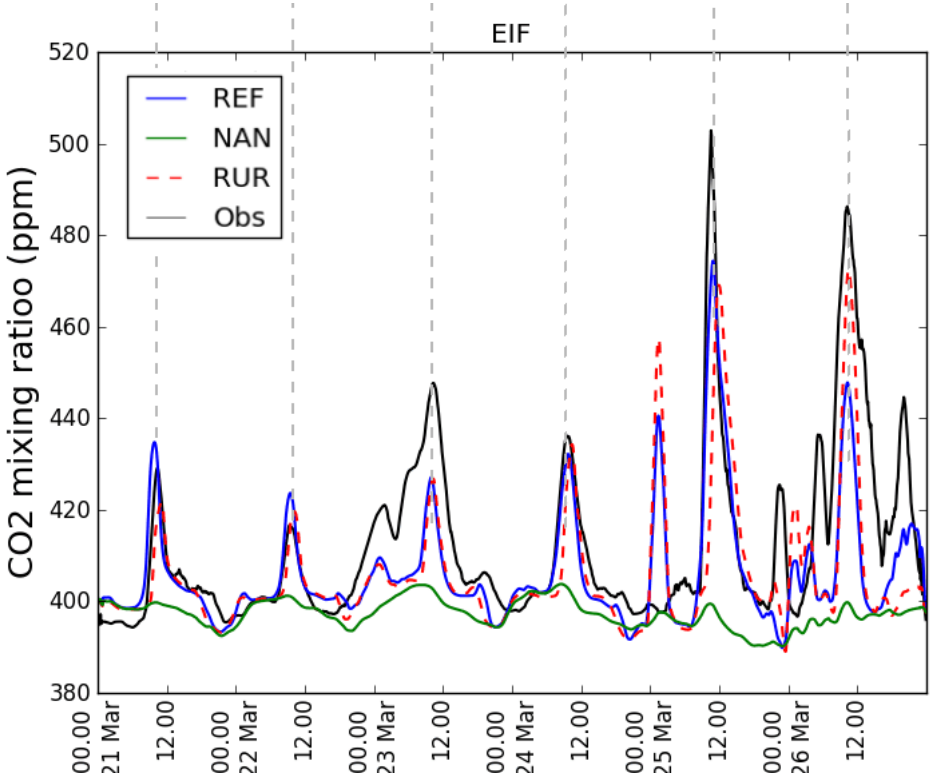


Wind roses of the model-data misfits at EIF for the full year of simulation

Issues for simulating urban CO2 (2)

- **Large misfits unusual for inverse modeling applications**
- **Similar misfits shown by other studies in the urban environment**

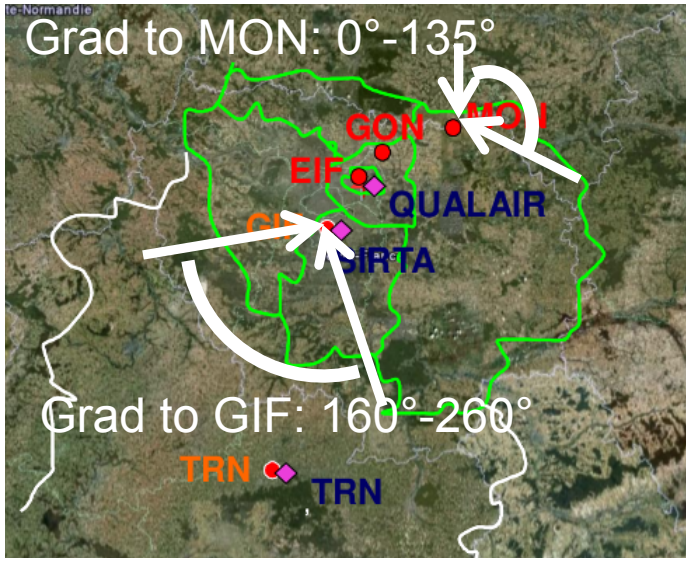
CO2 at EIF from Lac et al. 2013, ACP: REF=a simulation at 2km resolution using a urban scheme (Meso-NH TEB)



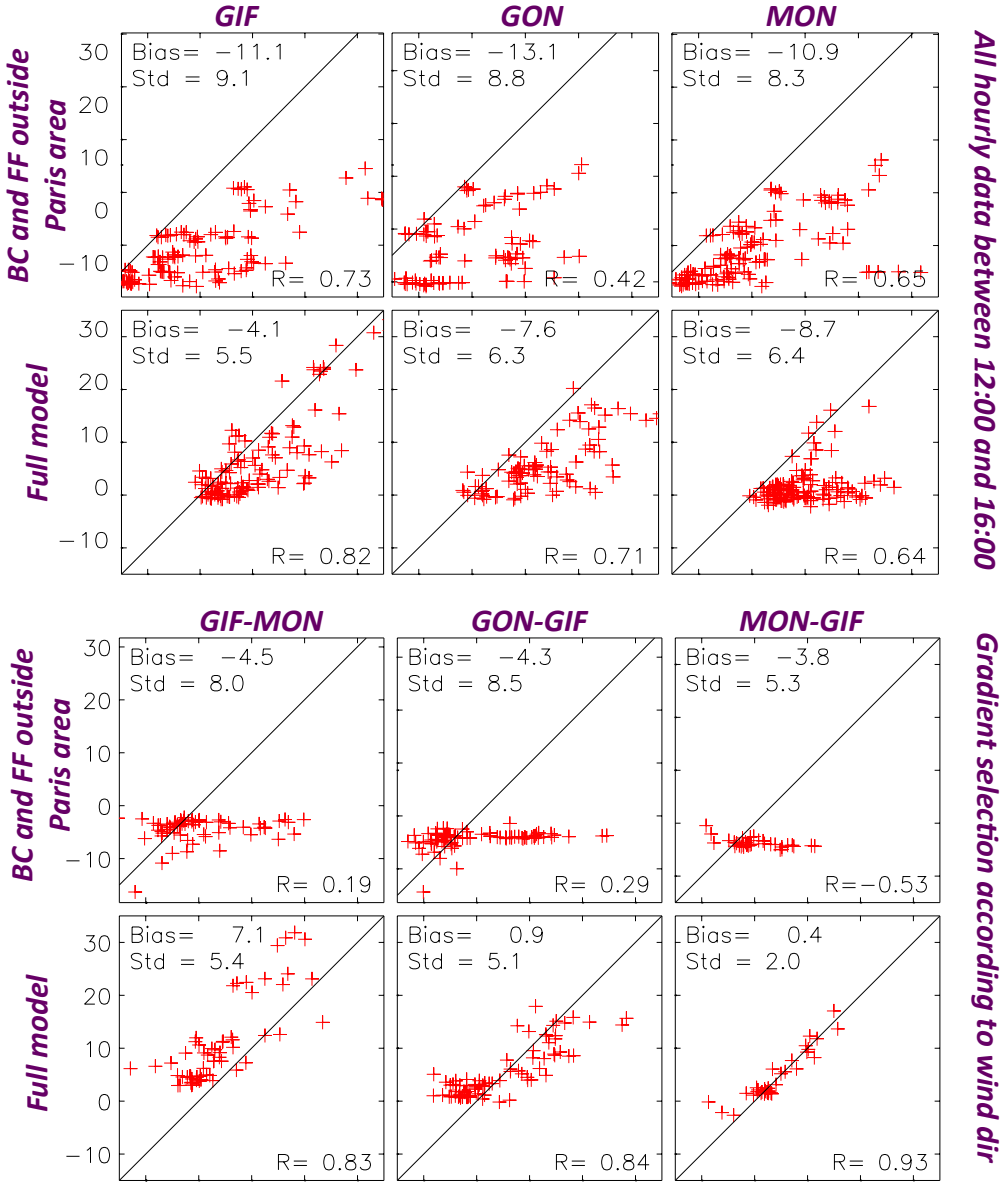
➢ **Lack of understanding of misfits at EIF: the site is ignored for the inversion, use of semi-urban sites only**

Errors from the boundaries: the first gradient selection

Model vs obs: hourly concentrations between 12:00 and 16:00 when the wind speed is above 2ms^{-1} in dec 2010

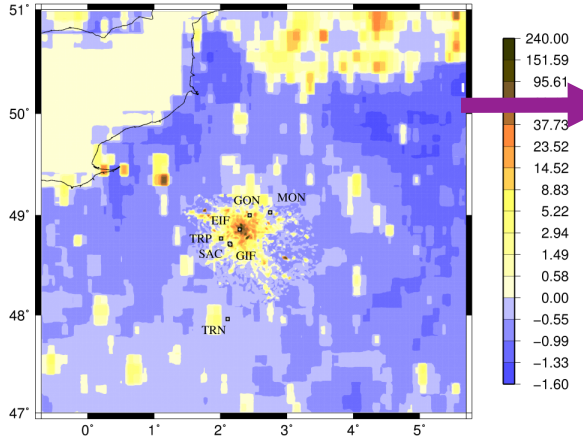


Initial selection of the gradients between semi-urban sites as a function of the wind direction



The inversion general framework: sequence of 1 month inversions

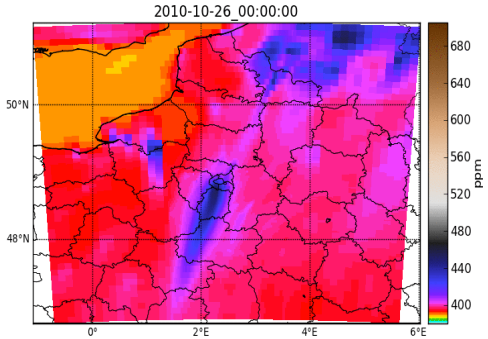
PRIOR FF:
AIRPARIF + EDGAR
PRIOR NEE:
C-TESSEL



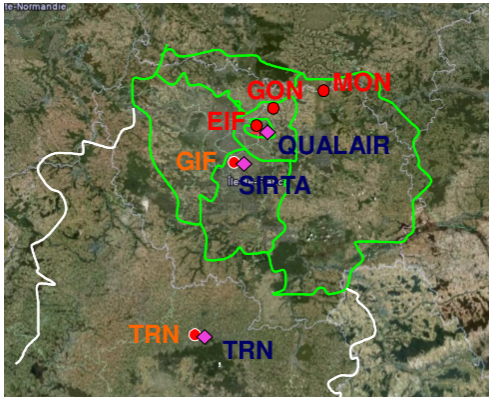
Uncertainty in FF:
20% in monthly fluxes
Correl length ~1 week
for a given 6-hour window

Analytical inversion

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



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



Model error: 3 ppm

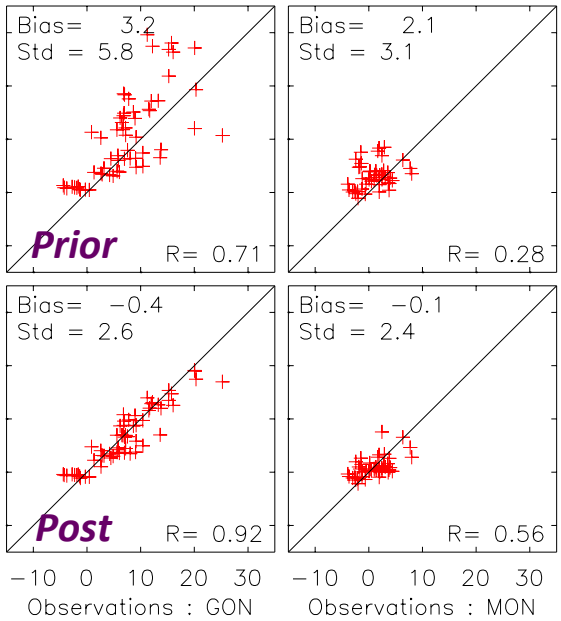
Corrections to total NEE and FF in IdF at 6-hour resolution: rescaling of the Airparif and C-TESSEL maps

OPTIMIZED FLUXES and uncertainties

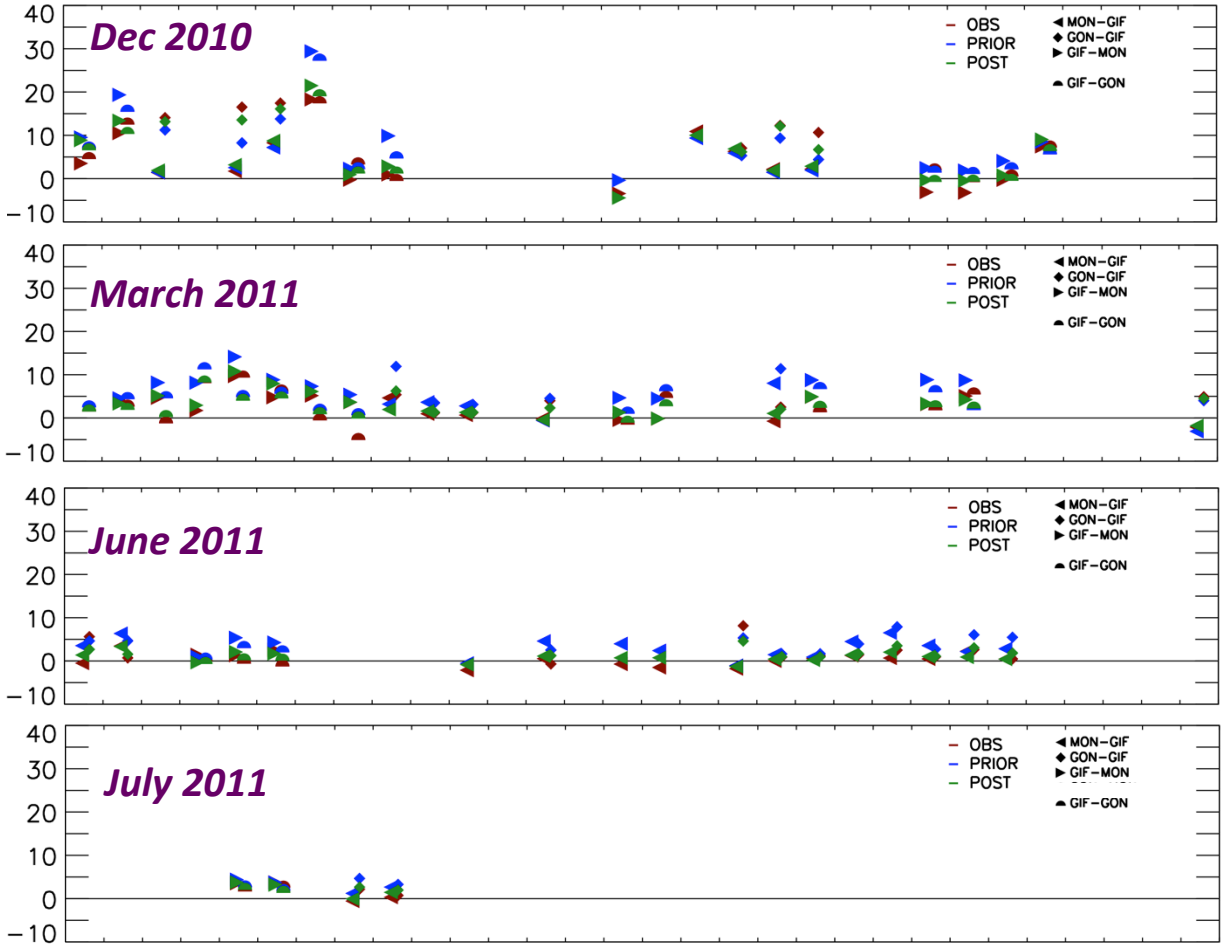
Results: data filtering and model-data misfits

- Significant loss of data
- Good fit to the data after inversion

Hourly model vs meas gradient to GIF in November

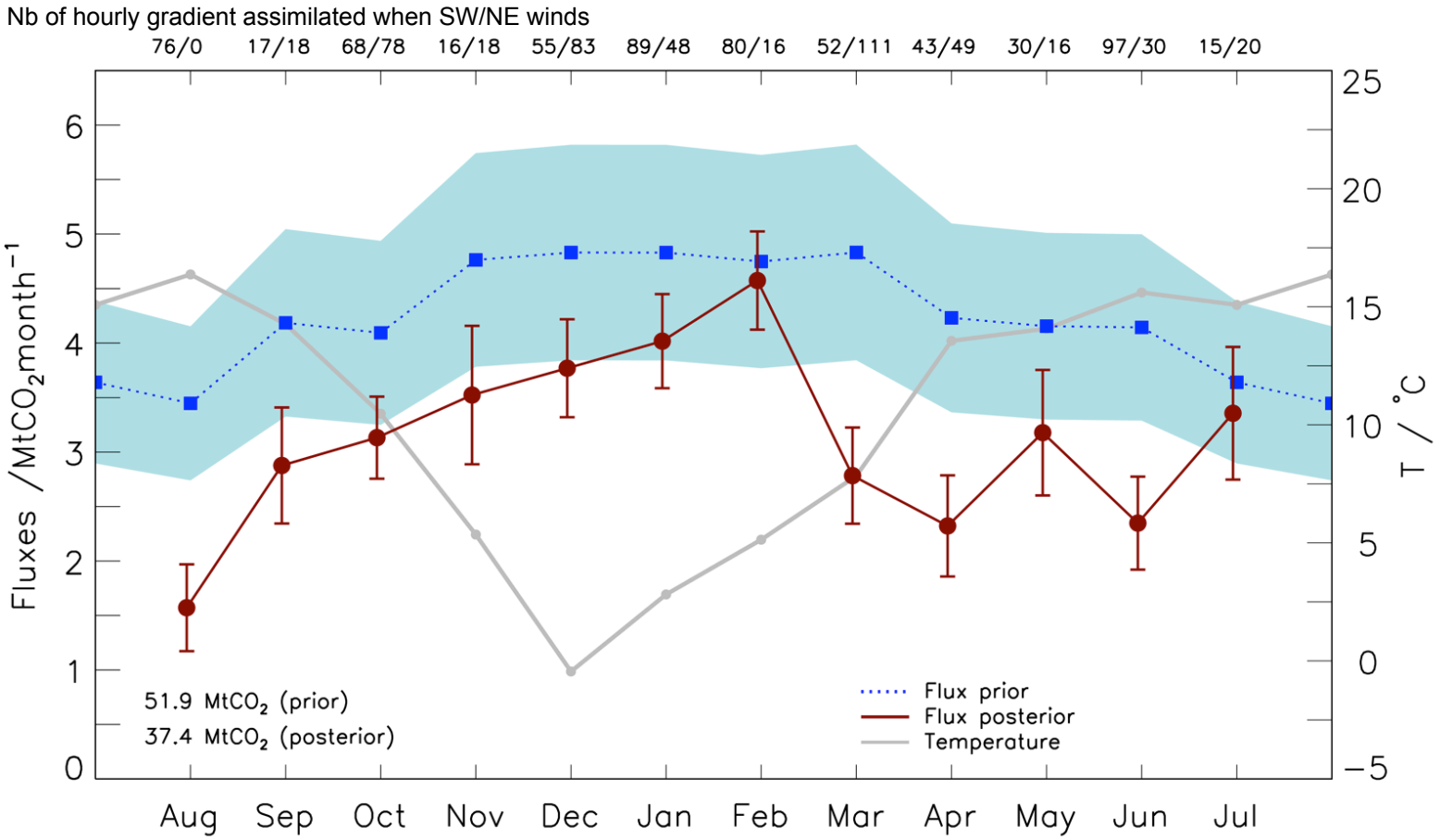


12:00-16:00 averages of the gradients used by the inversion according to the initial selection approach



1 year of monthly estimates (1)

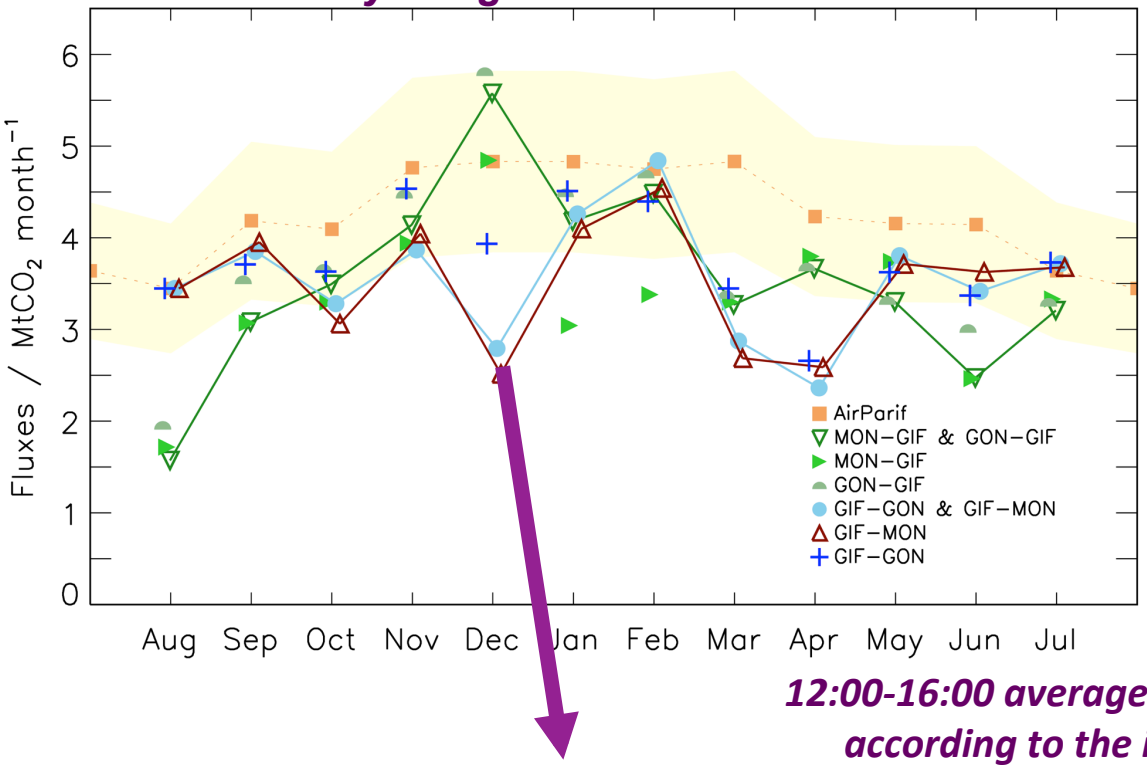
Estimate of monthly budgets of CO2 emissions



- The inversion amplifies the seasonal signal which sounds sensible
- Problems with the variations from Nov to Feb ?

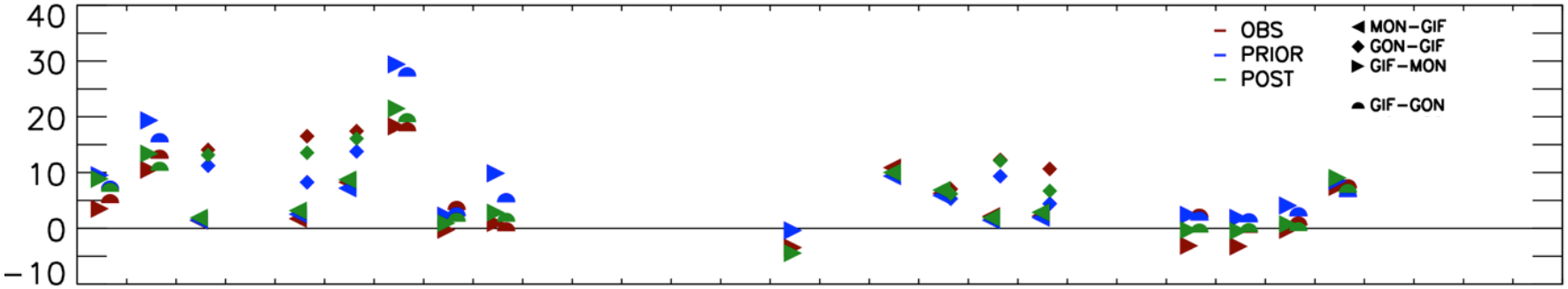
1 year of monthly estimates (2)

Estimate of monthly budgets of CO2 emissions when using subsets of gradients

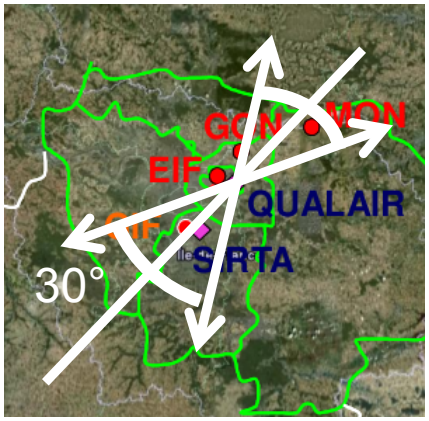


- Gradients to GON of MON often seem to drive the inversion "wrong"
- Some negative observed/modeled gradients: problem of representativity of the selected gradients

12:00-16:00 averages of the gradients used by the inversion according to the initial selection approach (dec 2010)

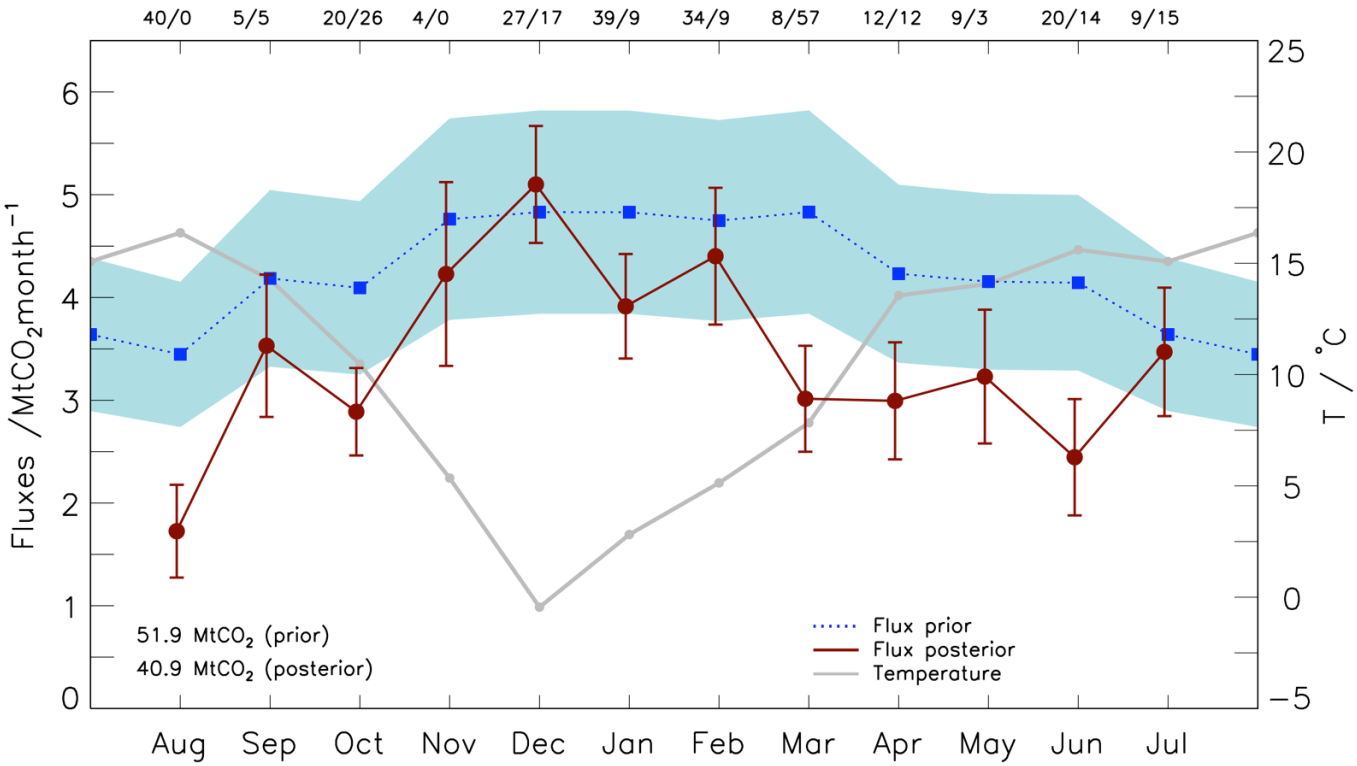


The stricter downwind-upwind gradient selection (1)



New selection of the gradients as a function of the wind direction

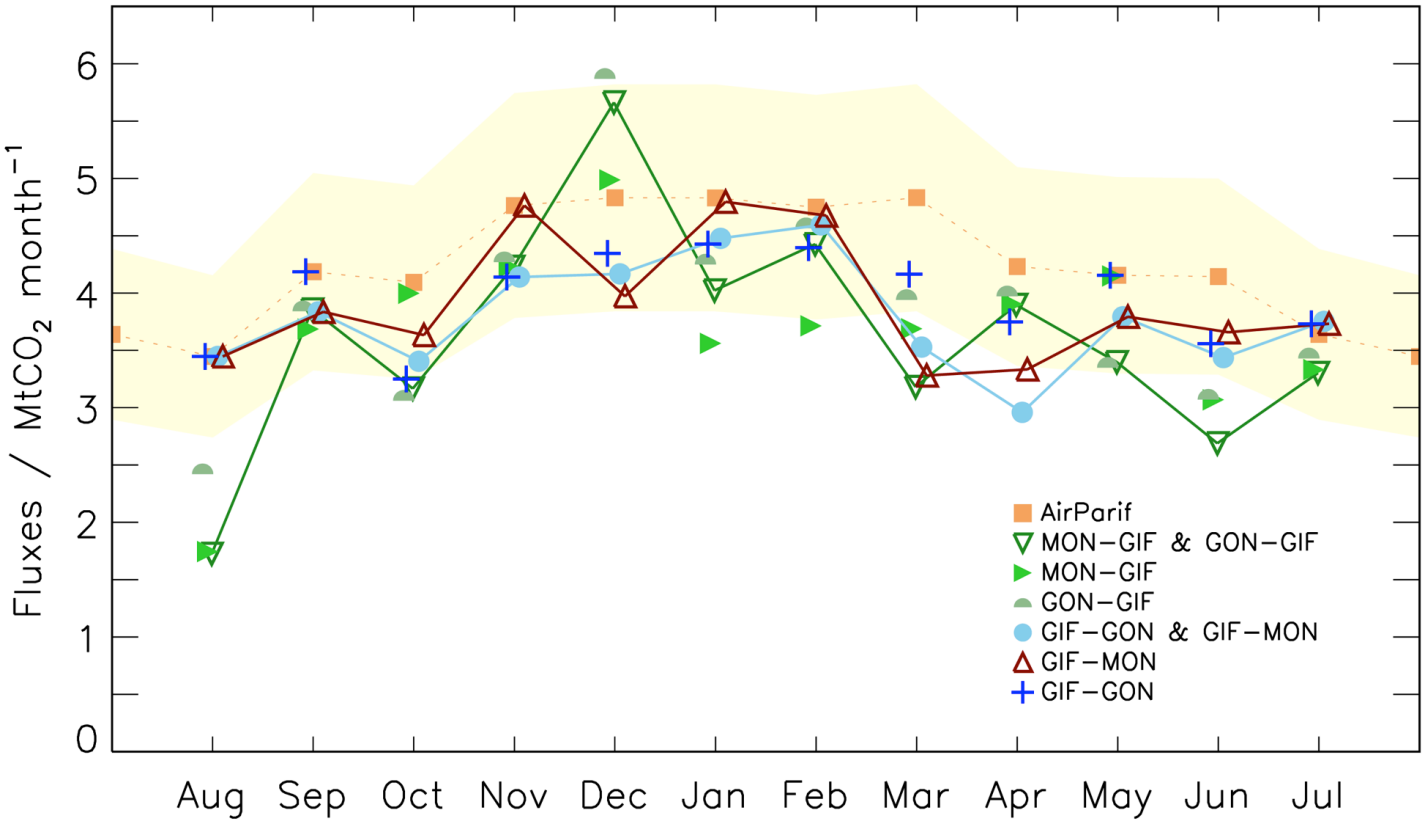
Estimate of monthly budgets of CO2 emissions



- Good agreement with temperature
- Despite the data selection, the model predicts significant uncertainty reductions (except for cases with very few data such as in July)
- The annual budget gets closer to that of AIRPARIF 2010 (approx. 44 MtCO2)

The stricter downwind-upwind gradient selection (2)

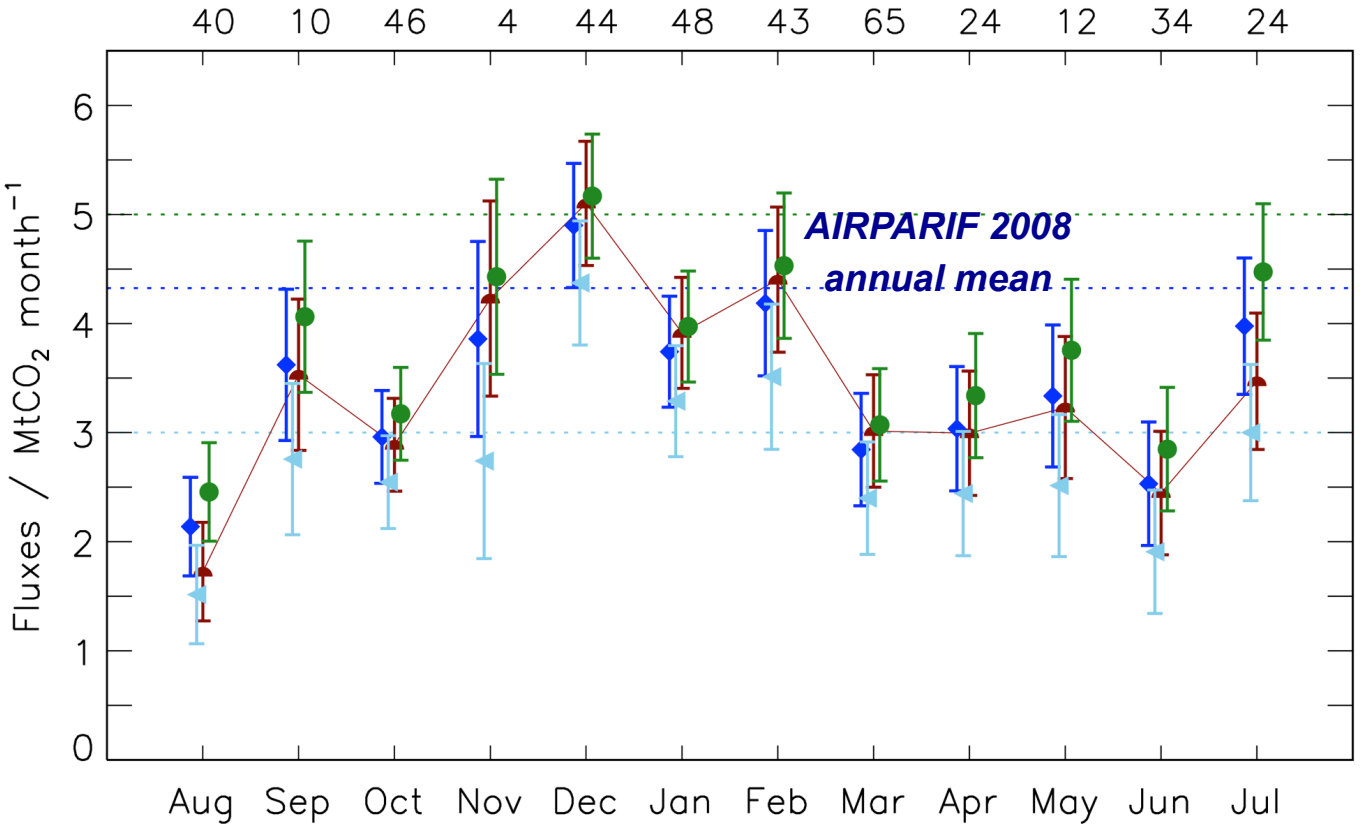
Estimate of monthly budgets of CO2 emissions when using subsets of gradients



- Stronger agreement between the inversions using the different data subsets
- Residual discrepencies (in particular in December) due to residual errors from the remote FF emissions (from NE France, Benelux, Germany when NE winds)?
- Influence of local sources (CDG airport) despite the wind speed selection ?

Tests of robustness

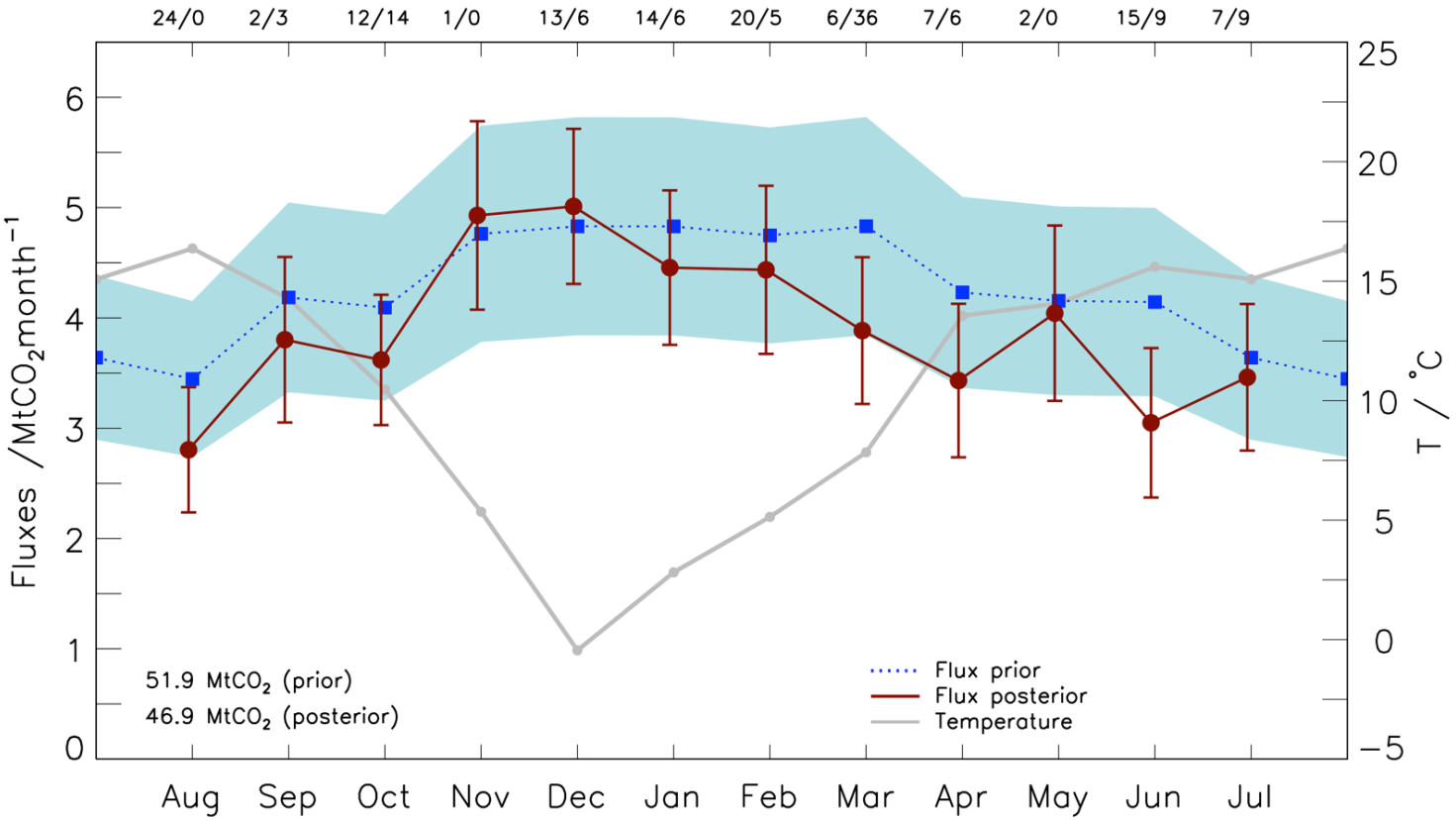
Estimate of monthly budgets of CO2 emissions: results when using AIRPARIF2008 (red) as a prior or flat priors



- Results strongly driven by the observations
- Tests using of Meso-NH (2km res, urban schemes) instead of ECMWF (15km res) meteo forcing for CHIMERE: results are very similar

From spatial to spatio-temporal gradients ?

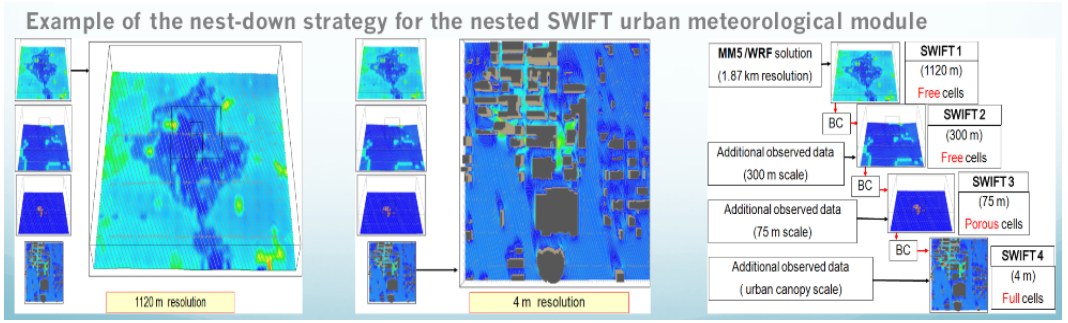
Estimate of monthly budgets of CO2 emissions when using gradients between downwind concentrations at 14:00 to 16:00 and upwind concentrations at 12:00 to 14:00 (2-hour lag time)



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

Upcoming strategies for strengthening the inversion and potentially targeting spatial of sectorial information

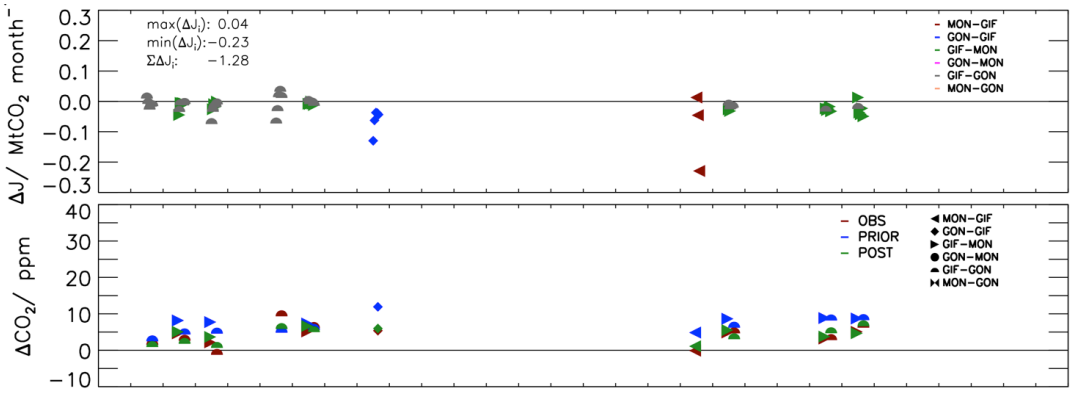
- Need for a ring of sites around the Paris area for a continuous monitoring:
  - ➢ carbocount-city = a step toward a fully encircling network



Source : ARIA Technologies

- Work for a finer data selection
  - ➢ Use model subgrid scale simulations in Carbocount-city (ability to exploit urban data ?)
  - ➢ Finer use of the observation impact analysis
- Use of co-emitted species and C-isotopes measurement

12:00-16:00 averages of the gradients assimilated and of their impact on the monthly budget of CO2 emissions (March 2011)



Conclusion

- Promising results from the CO2-Megaris year of experiment
  - Indicate that AIRPARIF2008 provides too high emissions for mid-2010-mid2011 which is supported by AIRPARIF2010

- However, some discrepancies between results using grad when NE vs SW winds: impact of local or remote fluxes or of the difference in time sampling ?

- Defining a sensible couple of observation and control vectors reveals to be critical due to the mathematical and practical limitations of present inversion systems
  - The gradient approaches used here = a rather simple but important step in this direction which still needs to be refined

- A critical need of studies for characterizing the urban CO2 before exploiting urban measurements

- The present data selection is too strict, need for filtering some useful information from the data presently rejected