Global fossil fuel data assimilation framework (FFDAS) and an experiment of error estimation

Yilong Wang

The increase of atmospheric CO_2 concentration from Industrial Era is primarily caused by the anthropogenic emissions. In traditional inversion system, fossil fuel CO_2 emission is assumed perfectly known, which will mistakenly report errors from anthropogenic fluxes into natural fluxes. Currently, many atmospheric inversions focus on natural fluxes at global scale and anthropogenic fluxes at local scale, but few attempts on fossil fuel CO_2 at global scale has been made. My PhD study aims at establishing a global Fossil fuel data assimilation (FFDAS) with the application of $^{14}CO_2$ and CO observation data. The first task is to establish the performance of a ^{14}C network and the most cost-effective sampling strategy to quantify emissions. Under the framework of an analytical inversion, I am working on the estimation of error sources and their amplitude.

Global fossil fuel data assimilation framework (FFDAS)
and an experiment of error estimation in Europe

Yilong Wang, Grégoire Broquet, Philippe Ciais, Felix Vogel,
Frédéric Chevallier, Nikolay Kadygrov, Rong Wang,
Philippe Peylin, Marielle Saunois

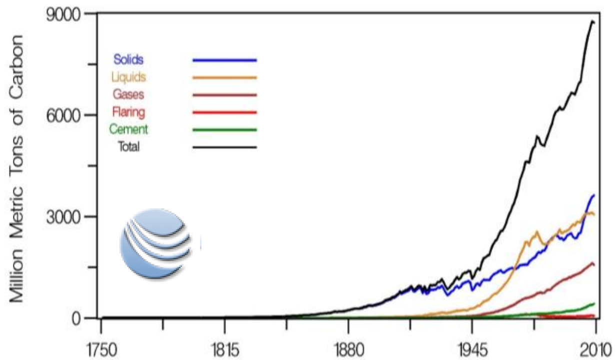
2013.11.13

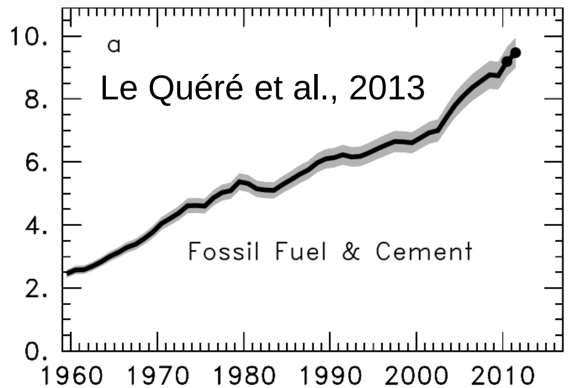
SINO-FRENCH INSTITUTE FOR EARTH SYSTEM SCIENCE

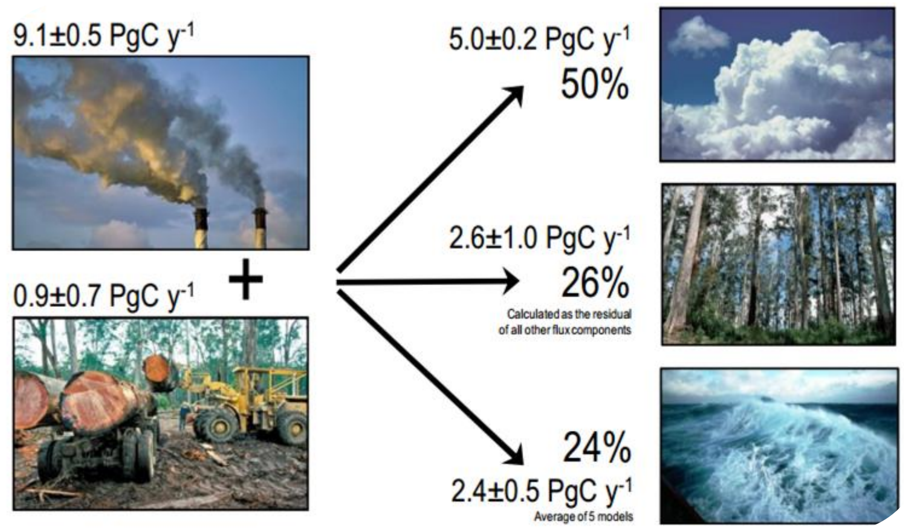
Outline

- Monitoring anthropogenic CO_2 emissions
- Global and regional inversions of CO_2 fluxes
- Objectives of PhD study
- Some preliminary results

Fate of Anthropogenic CO_2 Emissions (2010)







- Half of the anthropogenic emissions remain in the atmosphere
- The increase of atmospheric CO_2 concentration is primarily caused by the anthropogenic emissions from Industrial Era

The need for better estimates of anthropogenic fluxes

- There is large uncertainties of fossil fuel emission: year 2007/global
  - PKU: 7.83 Pg C (90% CI: 6.04 ~ 9.31 Pg C)
  - IEA: 7.87 Pg C
  - EDGAR: 8.57 Pg C
  - CDIAC: 8.57 Pg C
  - EIA: 9.06 Pg C

- Between-models uncertainty can be as large as 7-19% of the mean for some regions (Ciais et al., 2010)
- Significant uncertainties in the anthropogenic inventories at global/annual scale to 2-3° / hourly resolution
- Inversions mistakenly report the errors from anthropogenic fluxes into natural fluxes

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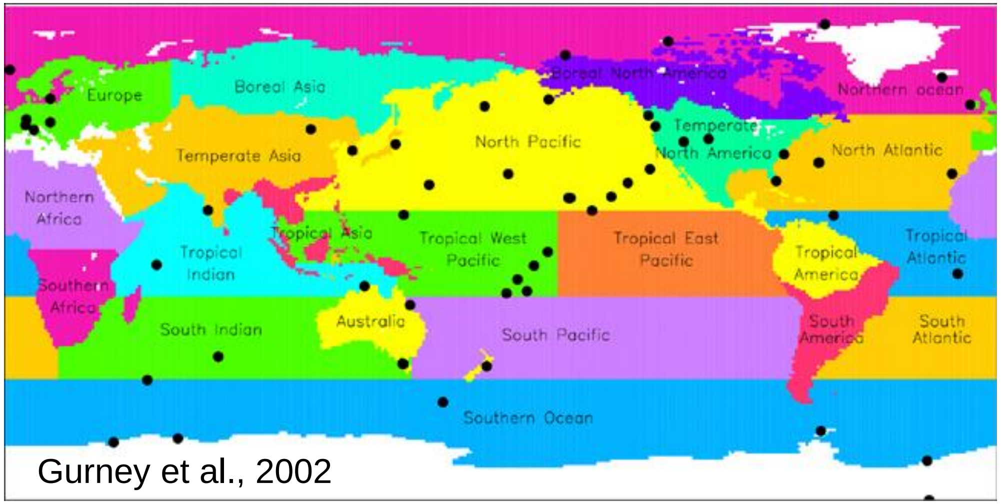
Traditional configuration of global inversions

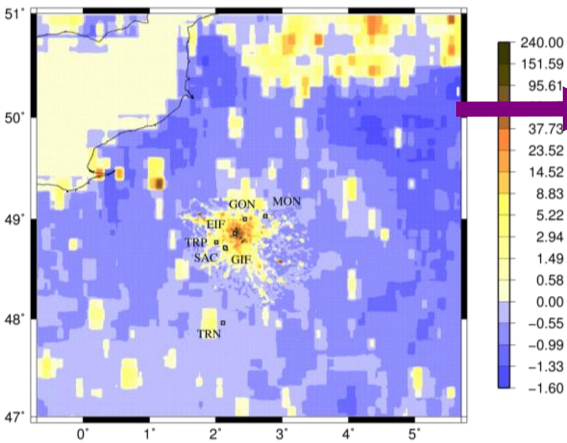
- In situ weekly and continuous (hourly) measurements
- Separate the global natural sink between
  (1) the ocean and land
  (2) Latitudinal bands
  (3) the different continents & oceans
- Atmospheric transport models at 2-3° horizontal resolution



Gurney et al., 2002

Regional inversions with purely CO_2

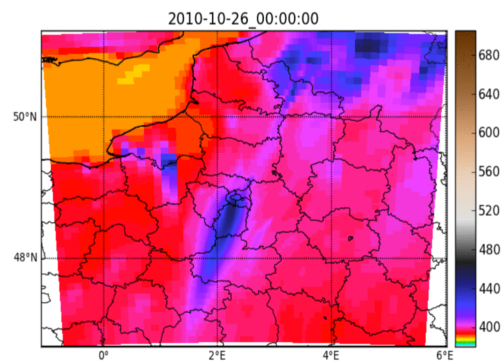
PRIOR FF: AIRPARIF
PRIOR NEE: C-TESSEL



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

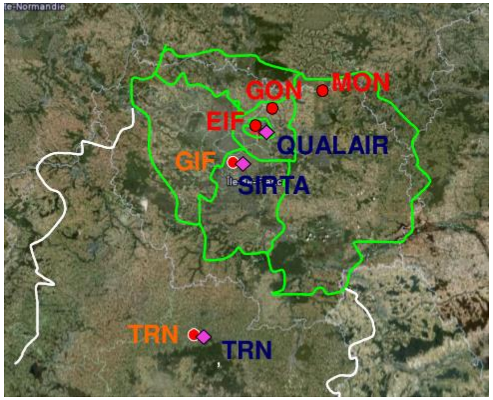
Analytical inversion
(transport matrix built with response functions to individual flux components)

CHIMERE IdF config
2km resolution



corrections to total NEE and FF in IdF at 6-hour resolution

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

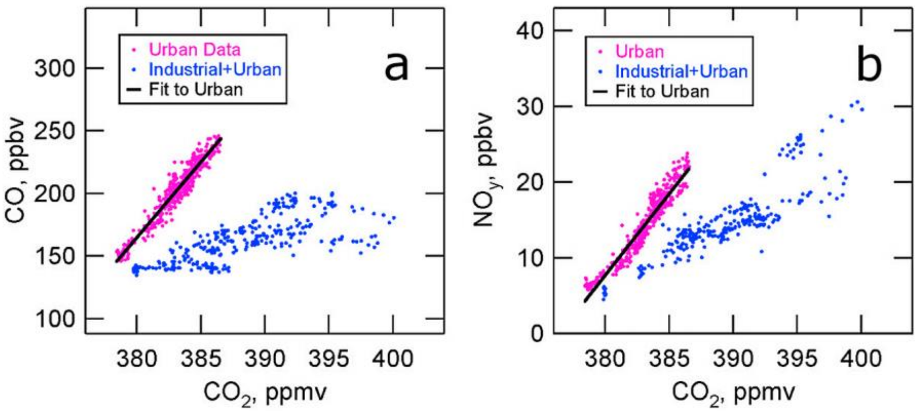


Model error ~5 ppm

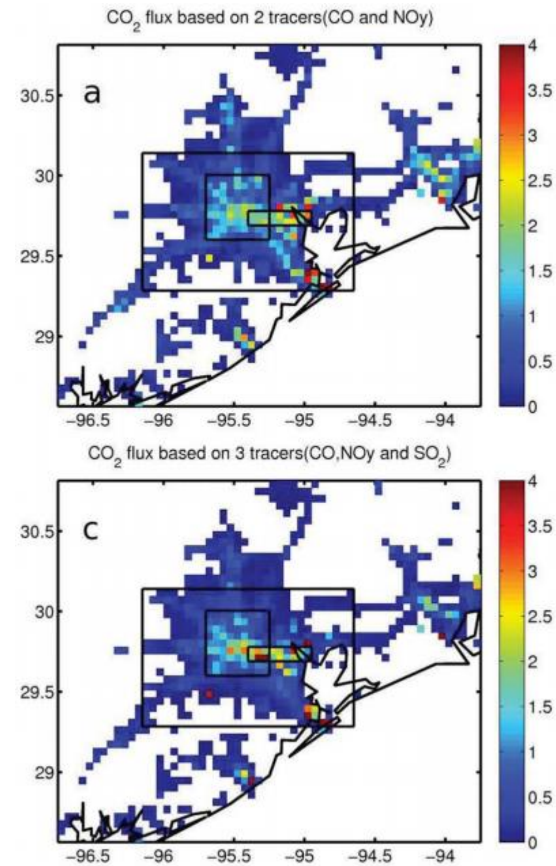
OPTIMIZED FLUXES
and uncertainties

Slide by Grégoire

Regional inversions of anthropogenic fluxes



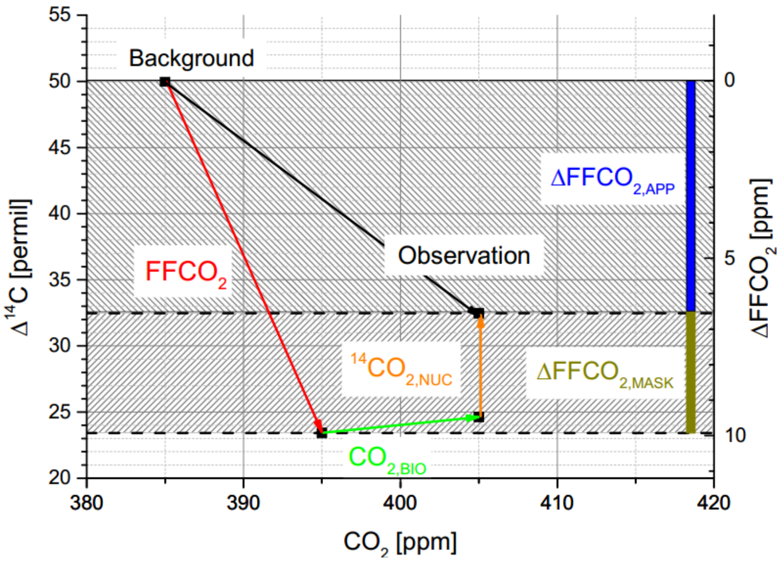
- Use of co-emitted species to help separate natural and anthropogenic emissions
- Strong correlations between the emissions of CO_2 and $CO/NO_x/SO_2$... for specific sectors
- Use of CO and NO_x inventories to calculate CO_2 fluxes

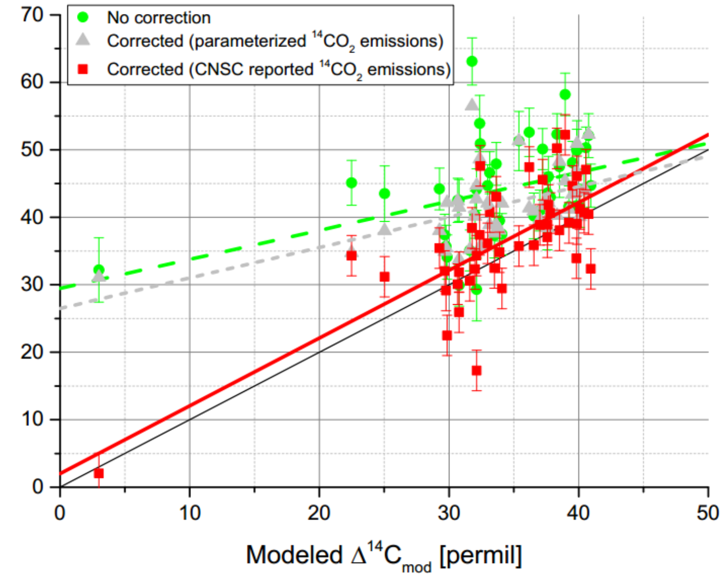


Brioude et al., 2012

Regional inversions of anthropogenic fluxes

- The depletion in $^{14}CO_2$ gives insights about fossil fuel CO_2 emissions

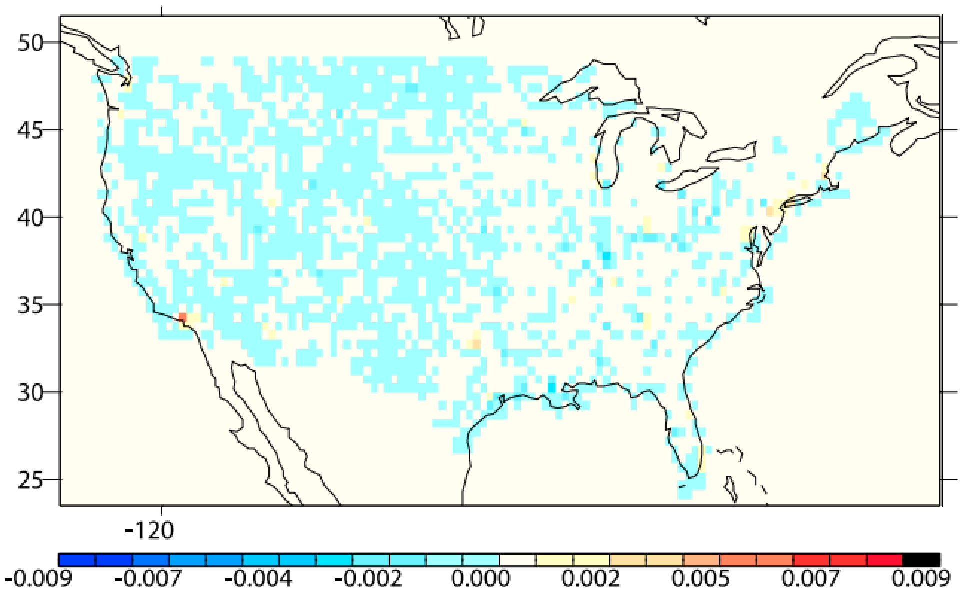




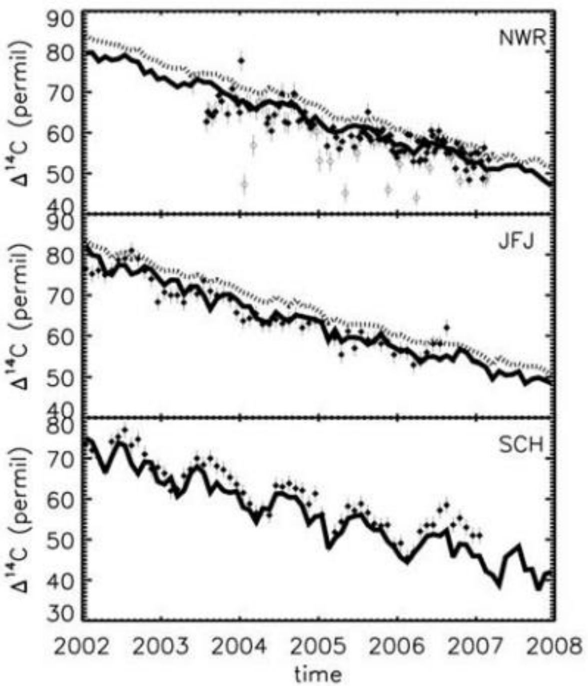
Vogel et al., 2013

Potential inversions for anthropogenic fluxes at global scale

- Existing FFDAS use nightlights and population to constrain the spatial distribution of national fossil fuel CO_2
- $\Delta^{14}CO_2$ does indeed provide a good tracer for recently added fossil fuel CO_2
- CO inversion can also help constrain the inversion of $FFCO_2$



Rayner et al., 2009



Turnbull et al., 2009

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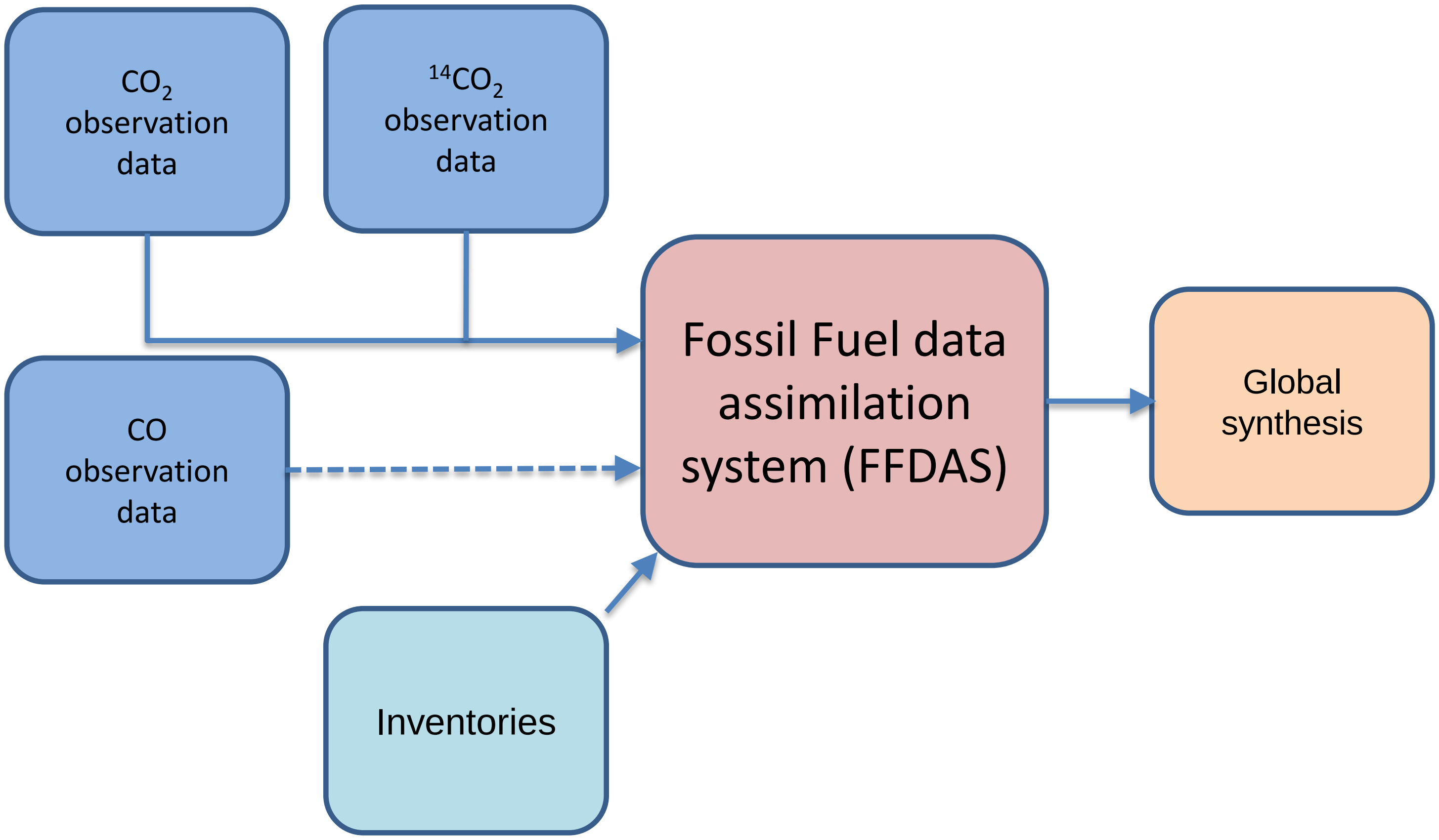
Objectives of PhD study



Objectives of PhD study

- Potential of $^{14}CO_2$ networks to constrain FFDAS
- 1^{st} order inversions with $^{14}CO_2$ measurement: inversion of flux
- Potential of CO networks to constrain FFDAS and 1^{st} order inversions with CO measurement
- 2^{nd} order inversions: inversion of emission factors + additional degrees of freedom in the flux space
- Identification of additional anthropogenic indexes that could be added to atmospheric measurements to constrain the FFDAS
- Final set-up of the 3^{rd} order inversions: inversion of emission factors + additional degrees of freedom in the flux space + activity indexes

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Configurations and Assumptions

- Test different ^{14}C networks more or less dense
- Global scale, with LMDZ and analytical inversion, cutting the world to ~50 regions
- Fluxes at monthly resolution
- Assume a true inventory and a biased prior
- $FFCO_2 \approx \Delta^{14}CO_2$ at first stage

Analytical inversion: least-squares analysis equations

BLUE analysis:

$s_a = s_b + K(y-H[s_b])$

, to minimize the total error variance:

$K = BH^T(HBH^T + R)^{-1}$

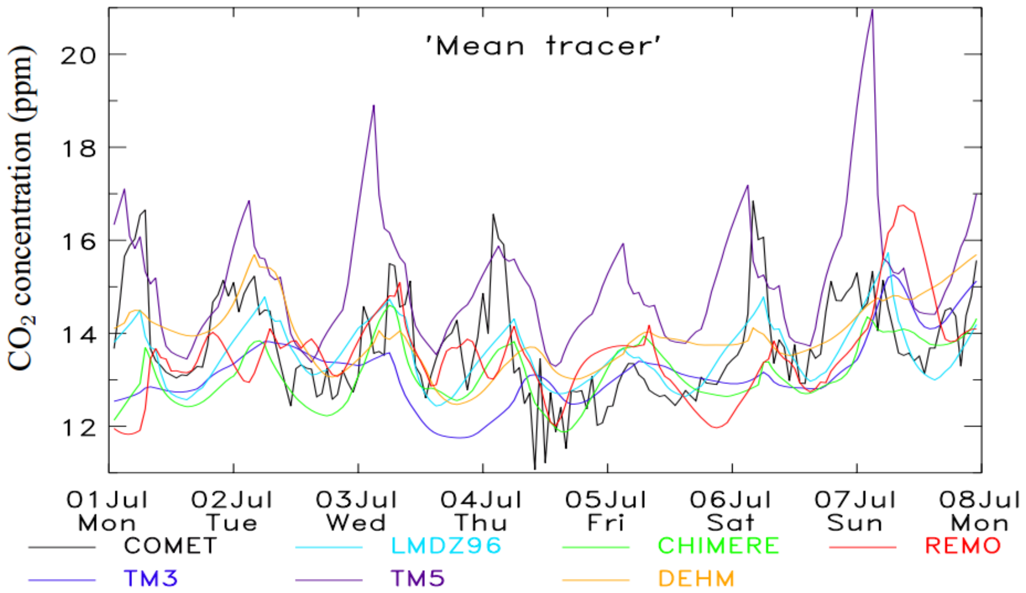
$A = (I - KH)B$

, where B is the prior covariance matrix of fluxes, R is the covariance matrix describing the expected difference between the observational data and model simulations

Error sources

$$R = R_{meas} + R_{transp} + \ldots$$

- Measurement error: observation error covariance
- Transportation error: The contribution of transport model differences to the simulated concentration std-dev is quite large at typical sites used in global inversion

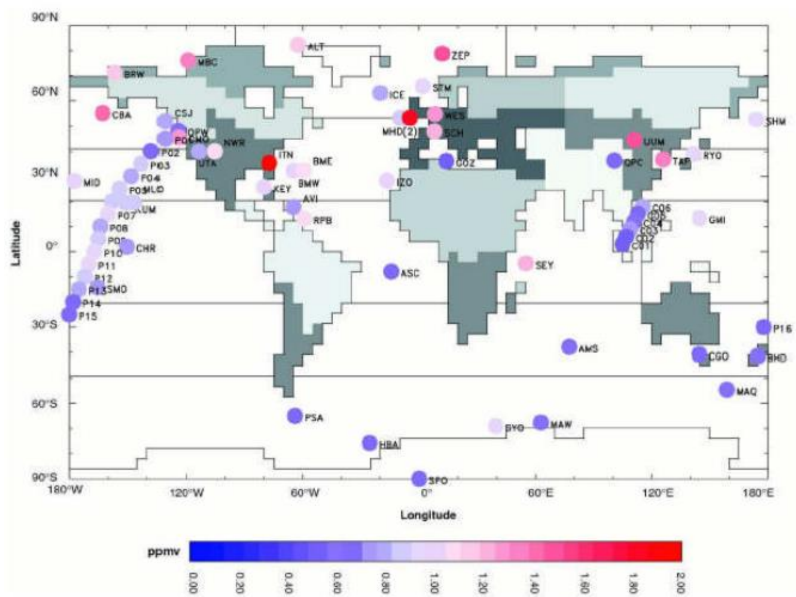


Peylin et al., 2011

Error sources

$R = R_{meas} + R_{transp} + R_{aggreg} + \ldots$

•Aggregation error:
caused by a too coarse resolution of the fluxes for the inversion



Bousquet et al., 2000

Error sources

$R = R_{meas} + R_{transp} + R_{aggreg} + R_{resp}$

•Representation error:
$^{14}CO_2$ measurement will be given as equivalent at the resolution of LMDZ grid cell (2.5° x 3.75°) while fossil fuel CO_2 is not homogeneous and largely affected by local sources

Preliminary results

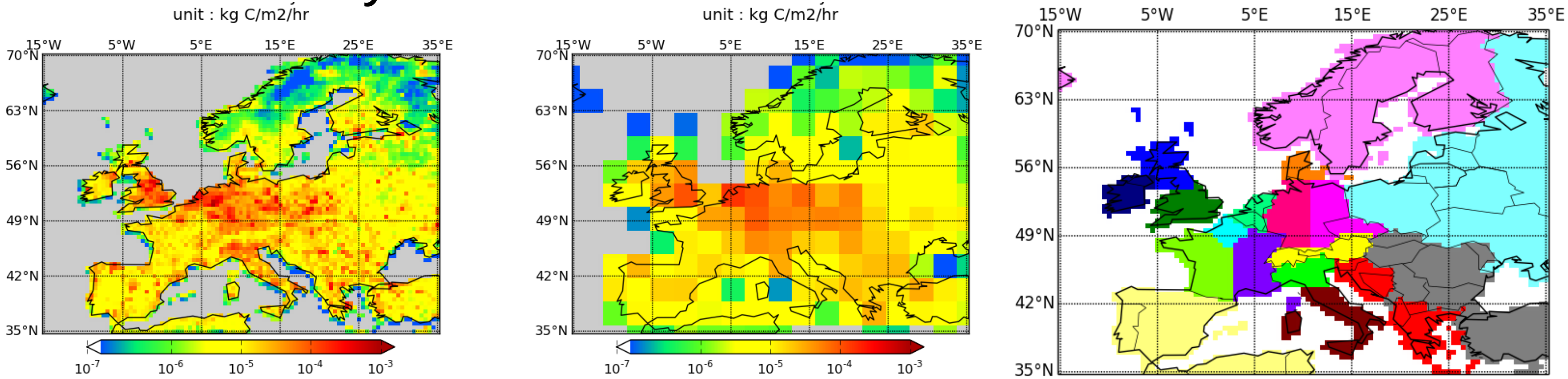
An Experiment with CHIMERE at 0.5° in Europe for Jan. and Jul.

Fluxes (PKU & IER inventory) at 3 types of resolution

- 0.5° / hourly
- 3° / 3hourly
- 18 large regions / monthly mean

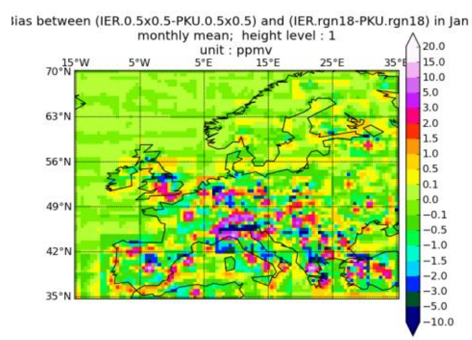
Concentrations at 2 types of resolution

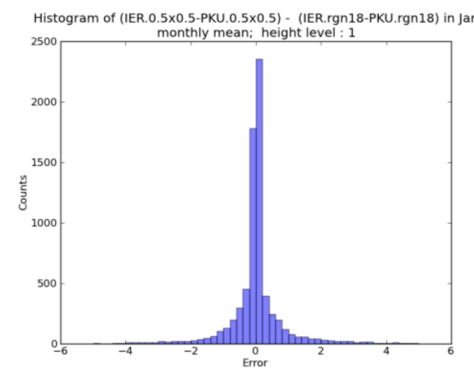
- 0.5° / hourly
- 3° / 3hourly



Error estimation for Europe

- R_{meas} about ±(2-5) ‰ $\Delta^{14}CO_2$, indicating an error about -2 ~ 2 ppm (Levin et al., 2003)
- R_{aggreg} + R_{repr} ~ about -1~1 ppm in the whole region, but large bias exits
- $\Delta^{14}CO_2$ about 1 ~ 3‰ between near stations in Europe, which means about 0.5 ~ 1.5 ppm (R_{repr})
- R_{transp} about 1ppm (Peylin et al., 2011)





Thank you!