Estimating terrestrial carbon fluxes in an atmospheric perspective – combining constraints from Eddy Covariance and mixing ratio observations

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MPI-BGC Jena

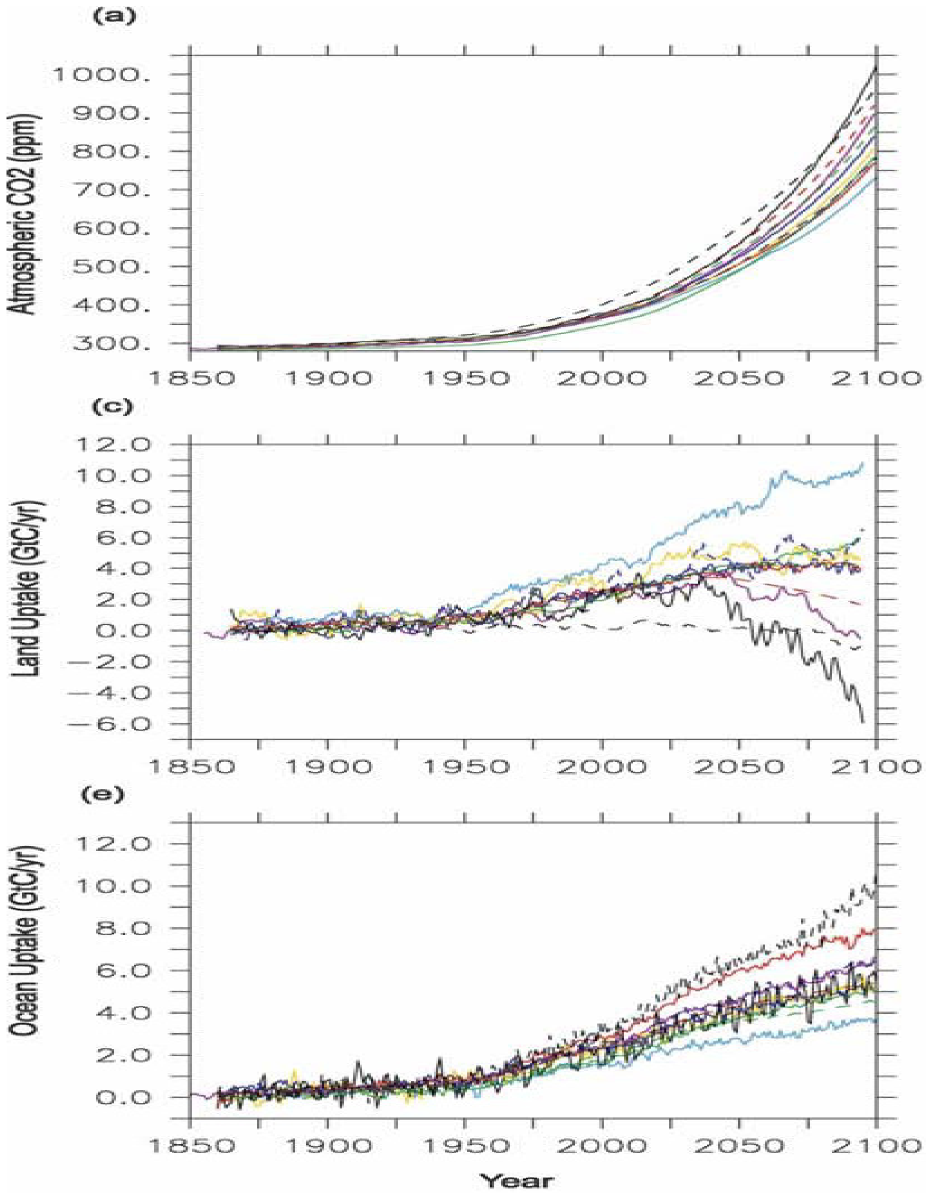
ICOS integrated carbon observation system

ICOS INWIRE

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

motivation

- Large dispersion between models output
- Large uncertainties in climate carbon cycle projection
- Need to understand the processes



[Friedlingstein et al., 2006]

Estimating the carbon budget

Bottom up approach

- Upscale EC measurements, representativity < 1km^2

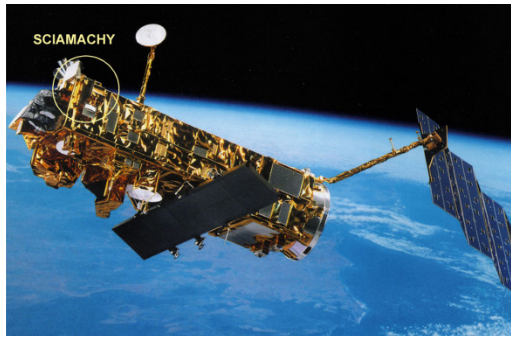
- Biosphere models optimized with EC data

0.27±0.16 GtCy^{-1} for 2000–2005, [Schulze et al., 2009]

Top down

- In situ

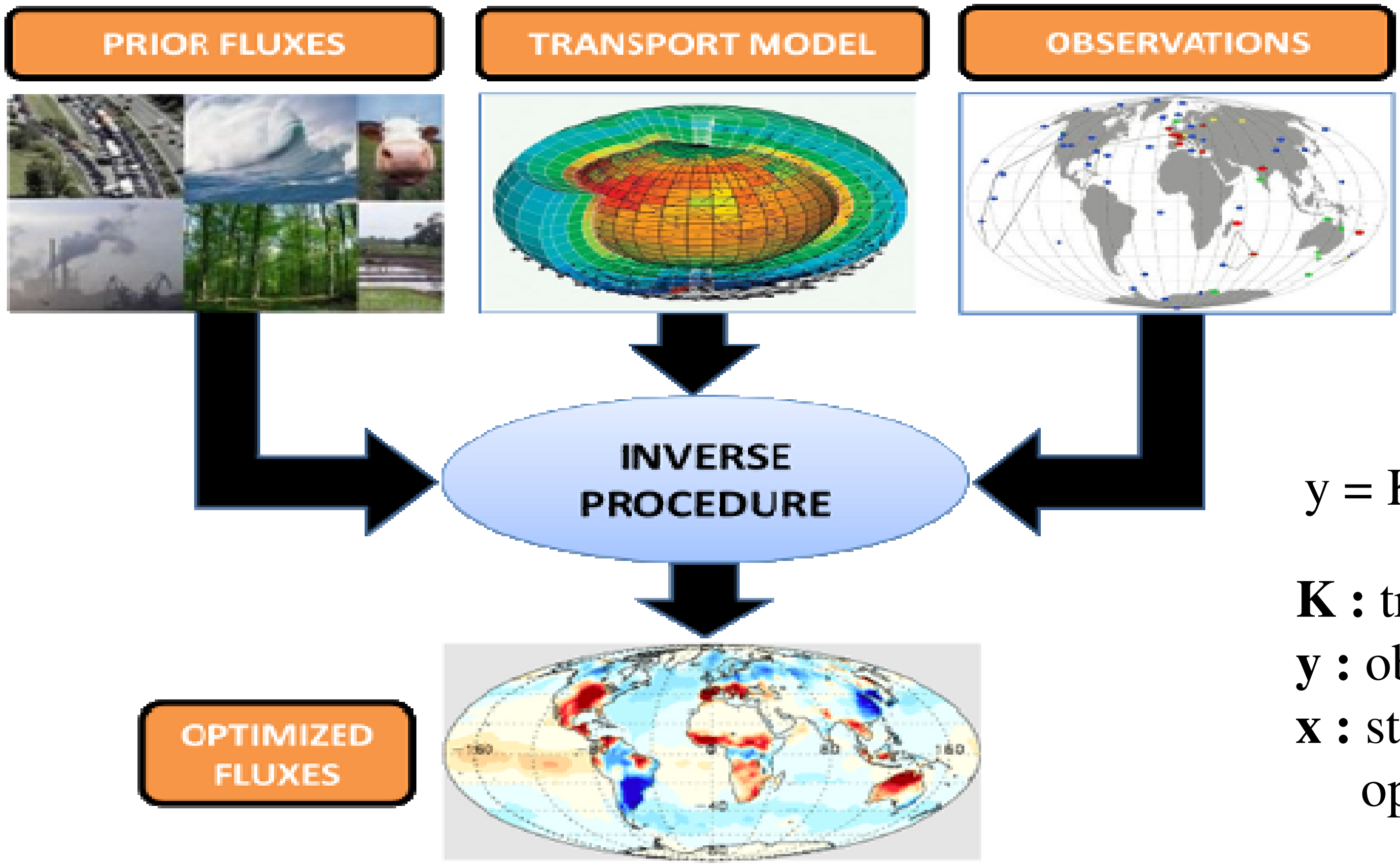
0.44±0.45 GtCy^{-1} for 2001–2004, [Peylin et al., 2013]



- Satellite

1.03±0.47 GtCy^{-1} for 2003-2010, [Reuter et al., 2014]

Atmospheric inversions



$y = Kx + \varepsilon_y$

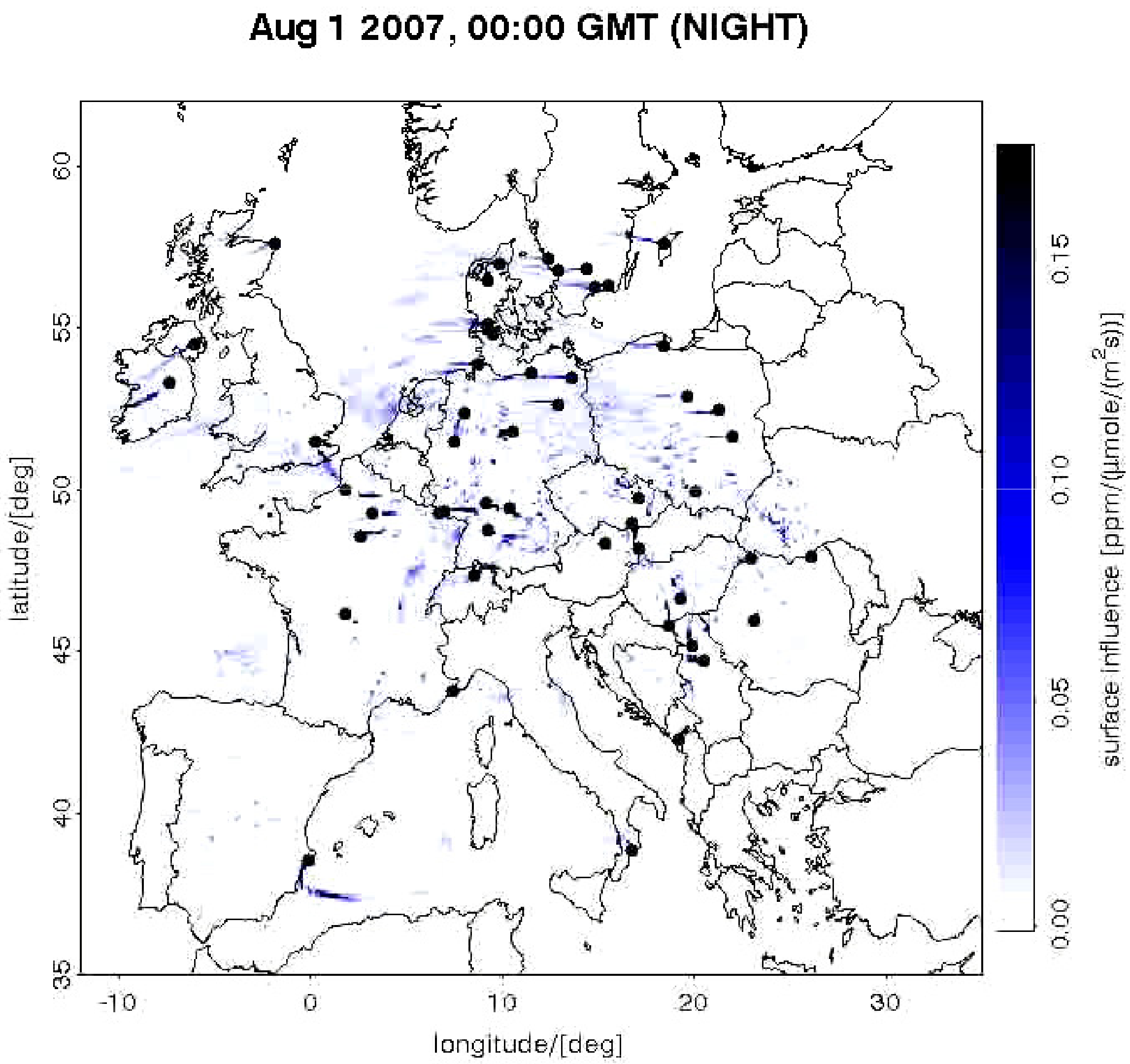
K : transport operator
y : observations
x : state space to be optimized

Cost function :

$$J = \underbrace{(Kx - y)^T C_y^{-1} (Kx - y)}_{\text{Observational}} + \underbrace{(x - x_{prior})^T C_{prior}^{-1} (x - x_{prior})}_{\text{prior}}$$

Observational and prior constrain

How does an atmospheric network “see” fluxes ?



Stochastic Time Inverted Lagrangian Transport (STILT)

- Ensemble of particles released at measurement locations
- Time reversed
- Particles driven by wind + turbulent process
- Footprint calculation.

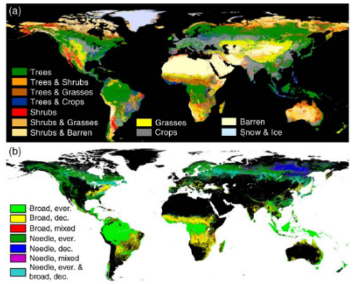
Footprints available through ICOS CP

VPRM prior - optimization

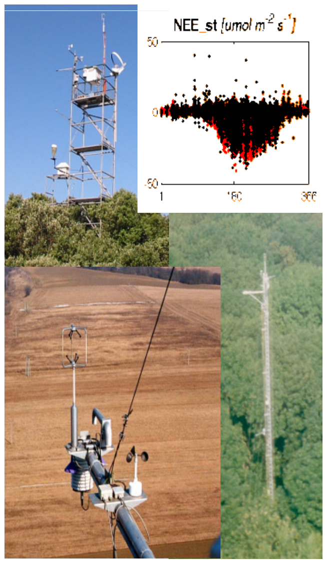
Vegetation **P**hotosynthesis **R**espiration **M**odel (**VPRM**)
[Pathmathevan et al., 2008]

Initial optimization of parameters against Eddy Cov. **α, β, λ,** and $\mathbf{PAR_0}$

vegetation classes (8)



SYNMAP land cover [Jung et al., 2006]



Eddy Cov. data

$$NEE = GEE + R \leftarrow \boxed{= \alpha \cdot T + \beta}$$

ECMWF, NCEP, WRF or site measurements

$$= \lambda \cdot \frac{PAR}{\left(1 + PAR / \mathbf{PAR_0}\right)} \cdot \mathrm{Tscale}(T) \cdot \mathrm{Pscale}(LSWI, EVI) \cdot \mathrm{Wscale}(LSWI) \cdot EVI$$

MODIS surface reflectance 8 day, 500 m

VPRM optimization – standard error

Jackknife delete-1

- $SE_{jack} = \left(\frac{n-1}{n}\sum\left(\hat{\theta}_i - \hat{\theta}\right)^2\right)^{1/2}$ where $\hat{\theta} = \sum_{i=1}^{n} \hat{\theta}_i / n$
  the average flux estimation excluding 1site at a time

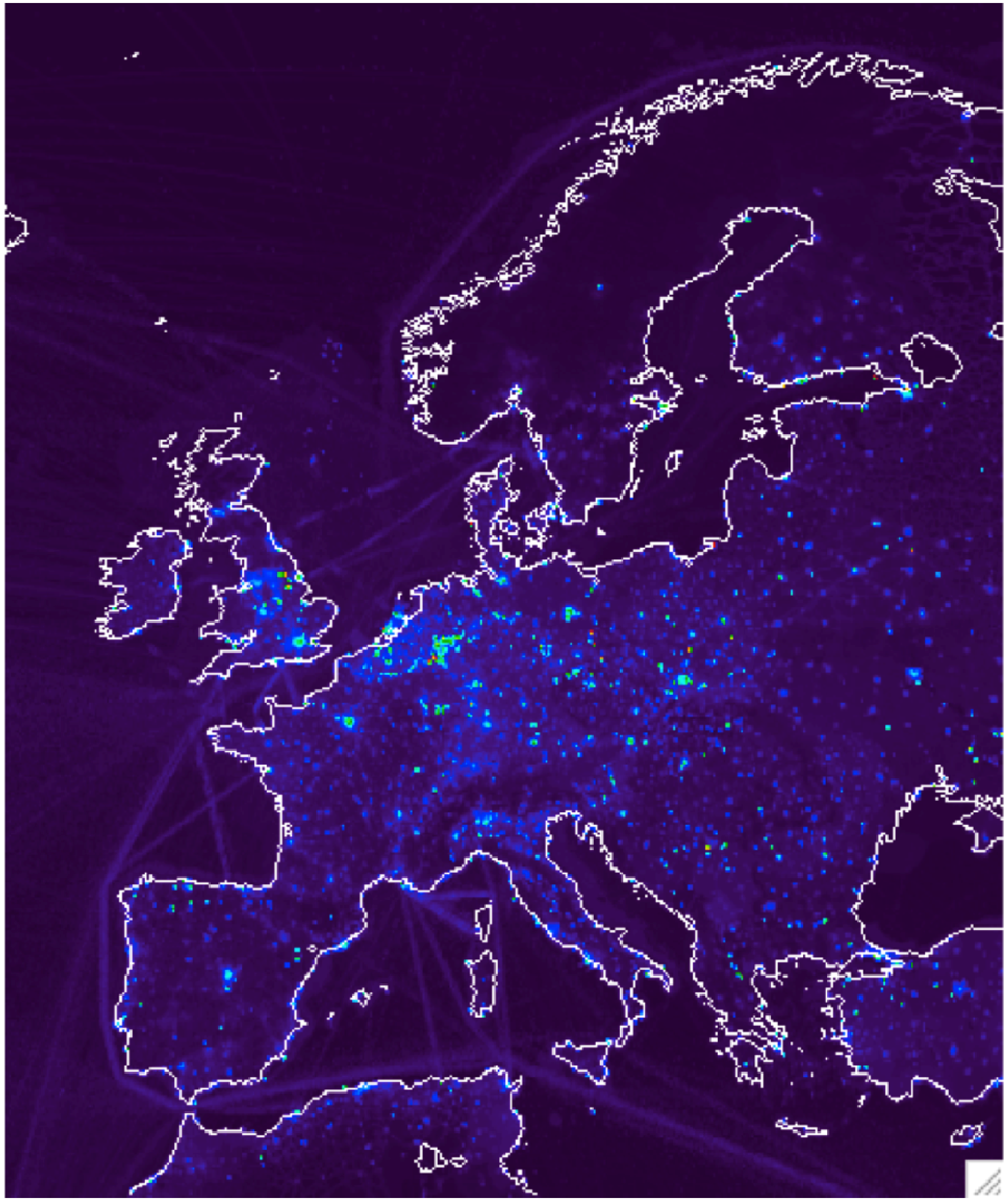
- n=47 sites, EC data 2007

- EU Carbon uptake 0.96 ± 0.54 $GtCy^{-1}$

	NEE [GtC/y]	NEE uncertainty [GtC/y]	Number of sites	Fraction of land area [%]
Evergreen forest	-0.165	0.039	16	16.5
Deciduous forest	-0.174	0.020	5	4.4
Mixed forest	-0.025	0.176	2	8.4
Open shrub	-0.201	-	1	13.8
Savanna	-0.012	-	0	0.3
Crop	-0.443	0.502	8	51.0
Grass	0.059	0.026	15	5.6
Total	0.960	0.536	47	100

Fossil fuel priors

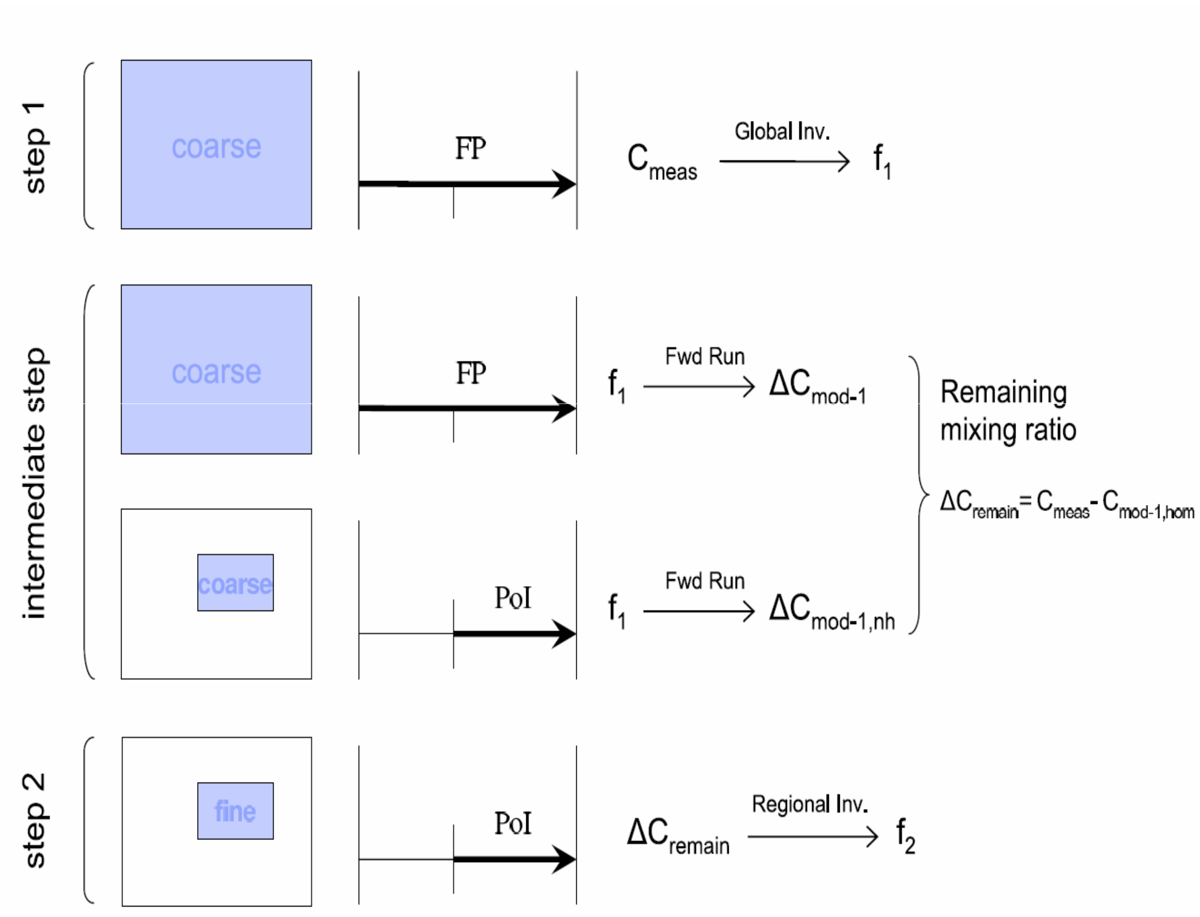
- Fossil fuel signal need to be properly quantified for meaningfull biosphere flux optimization
- Edgar v4.1 at 0.1°
- IPCC category and fuel type differentiation
- Time factors applied to create hourly temporal resolution
- Emissions year to year variations scaled according to BP energy statistics at national level



Jena regional inversion system

TM3-STILT – two step inversion

- Input : Atmospheric observations, prior fluxes (biospheric, ocean, fossil fuel)
- TM3 global inversion 5° x 4°
- STILT regional inversion 0.25° x 0.25°
- State space: 0.5° resolution, 3hourly flux optimization

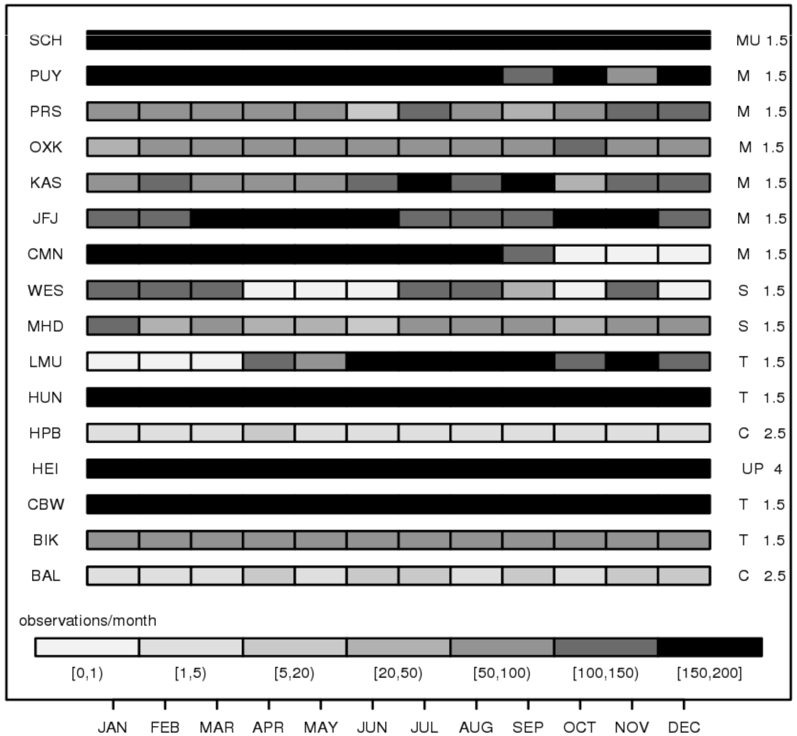


Rödenbeck et al., 2009

Inversion setup

- 16 stations
- Continuous and flask
- Synthetic obs. times according to real obs.

Data coverage

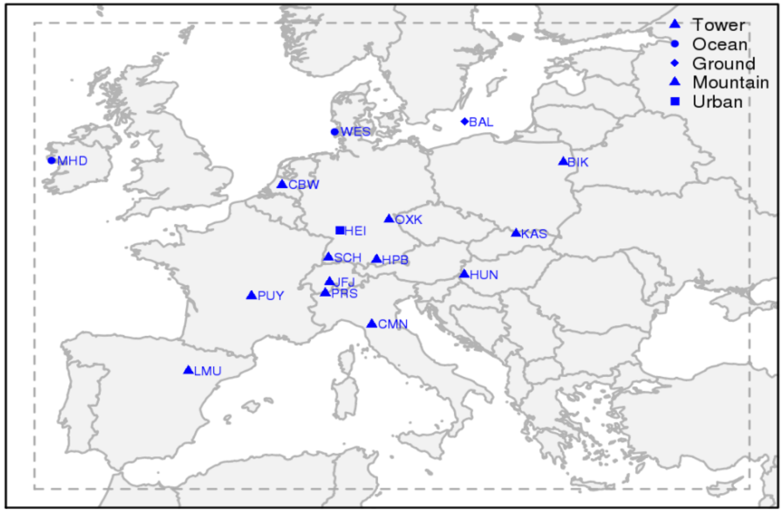


Model-data error in ppm

S	C	M	T	UP
1.5	2.5	1.5	1.5	4

S: Near shore
C: Continental (surface)
M: Continental (Mountain)
T: Continental (Tall tower)
UP: Urban polluted

Measurement error: 0.3 ppm



Inversion setup – prior error structure

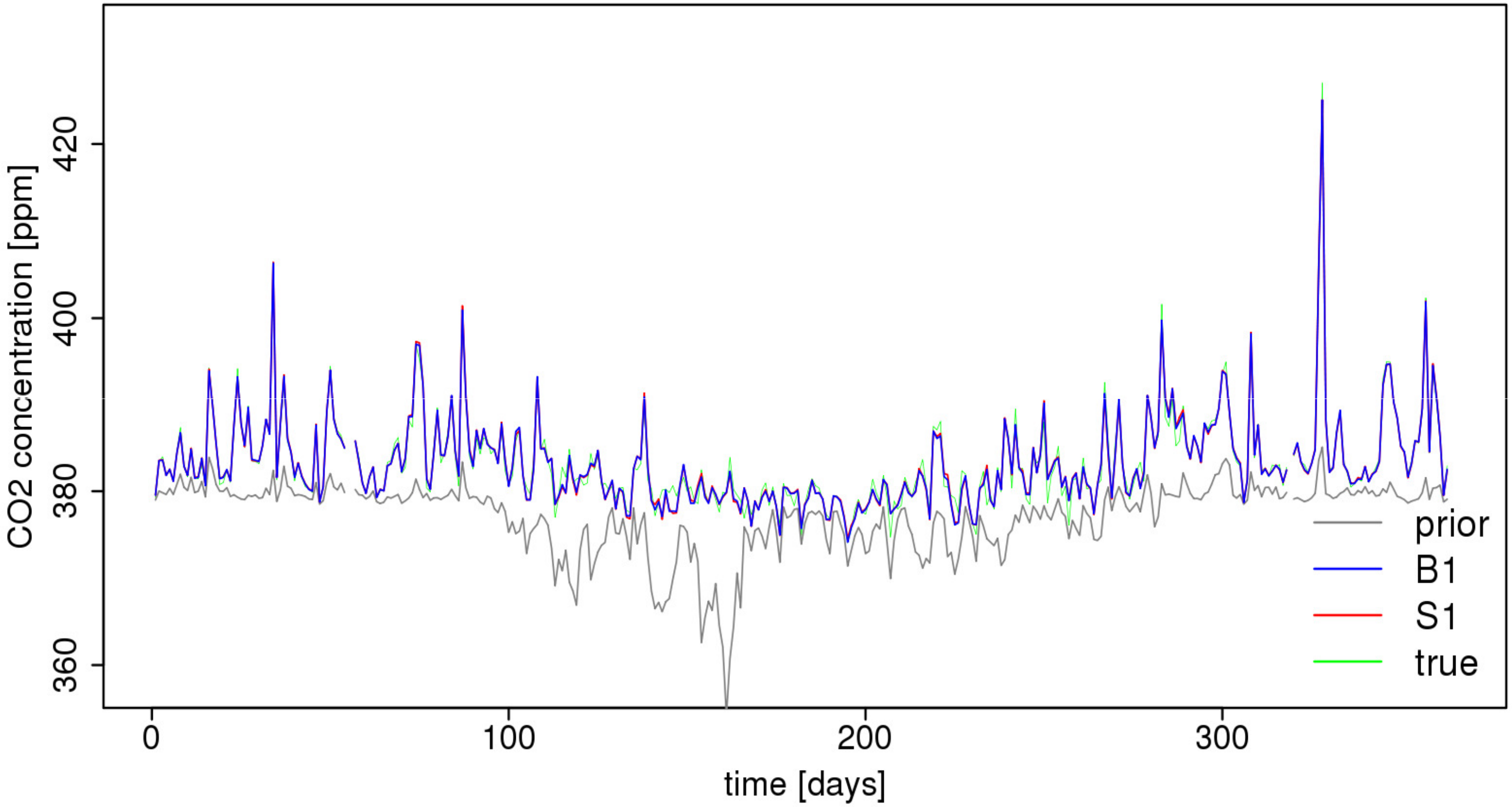
- Data driven error structure
- 30 days, 100 km error correlations
- Sensitivity tests on the error structure

We aim at:

- European carbon estimates
- Network assessment

- B1 case: Error inflation only to the spatio-temporal component (covariance matrix)
- S1 case: Error inflation by adding a bias term flat in time, respiration shape

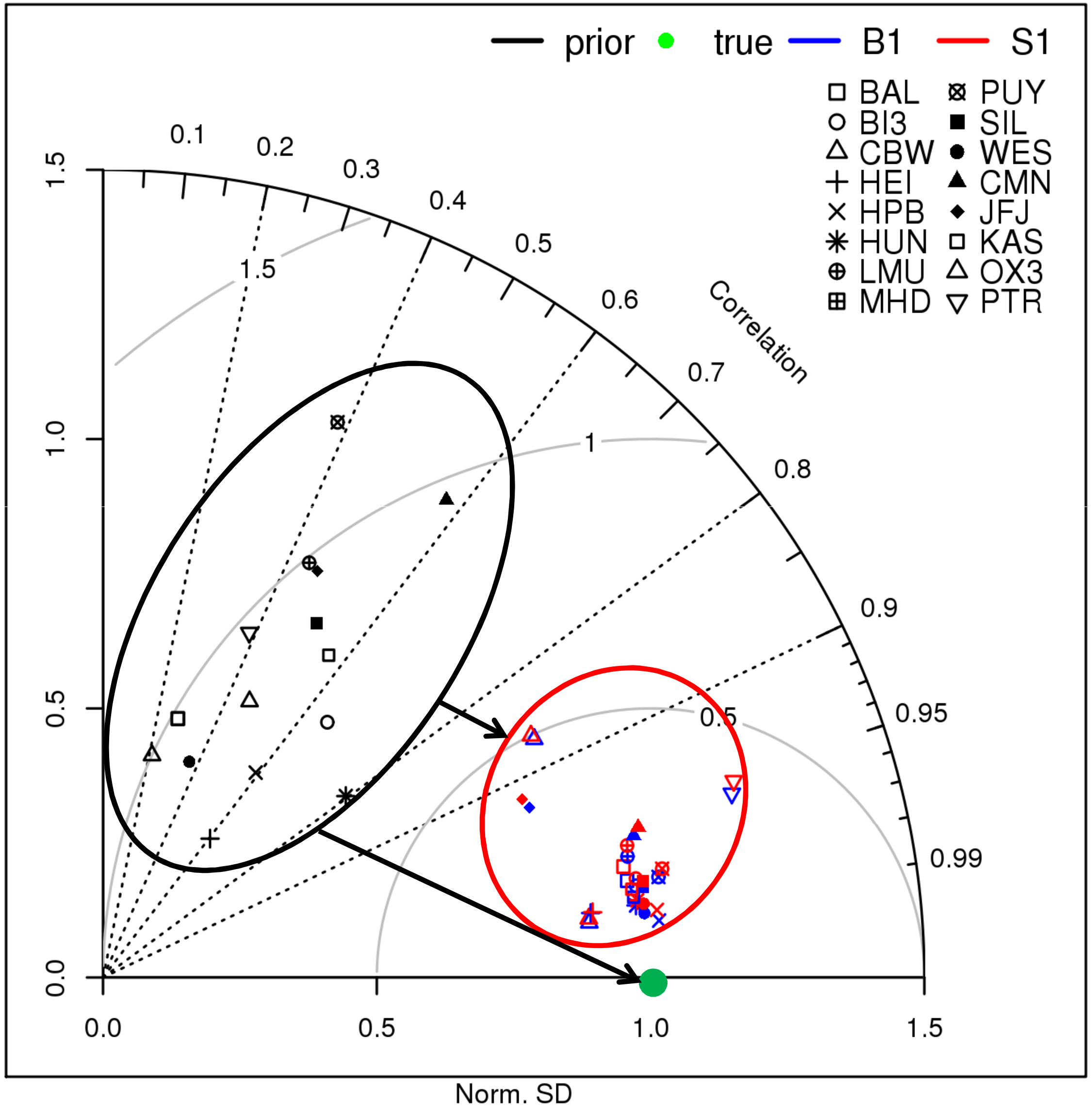
Pseudo data inversion – concentration time-series



Daily averaged concentration time series for Schauinsland

Kountouris et al., 2016a in preparation

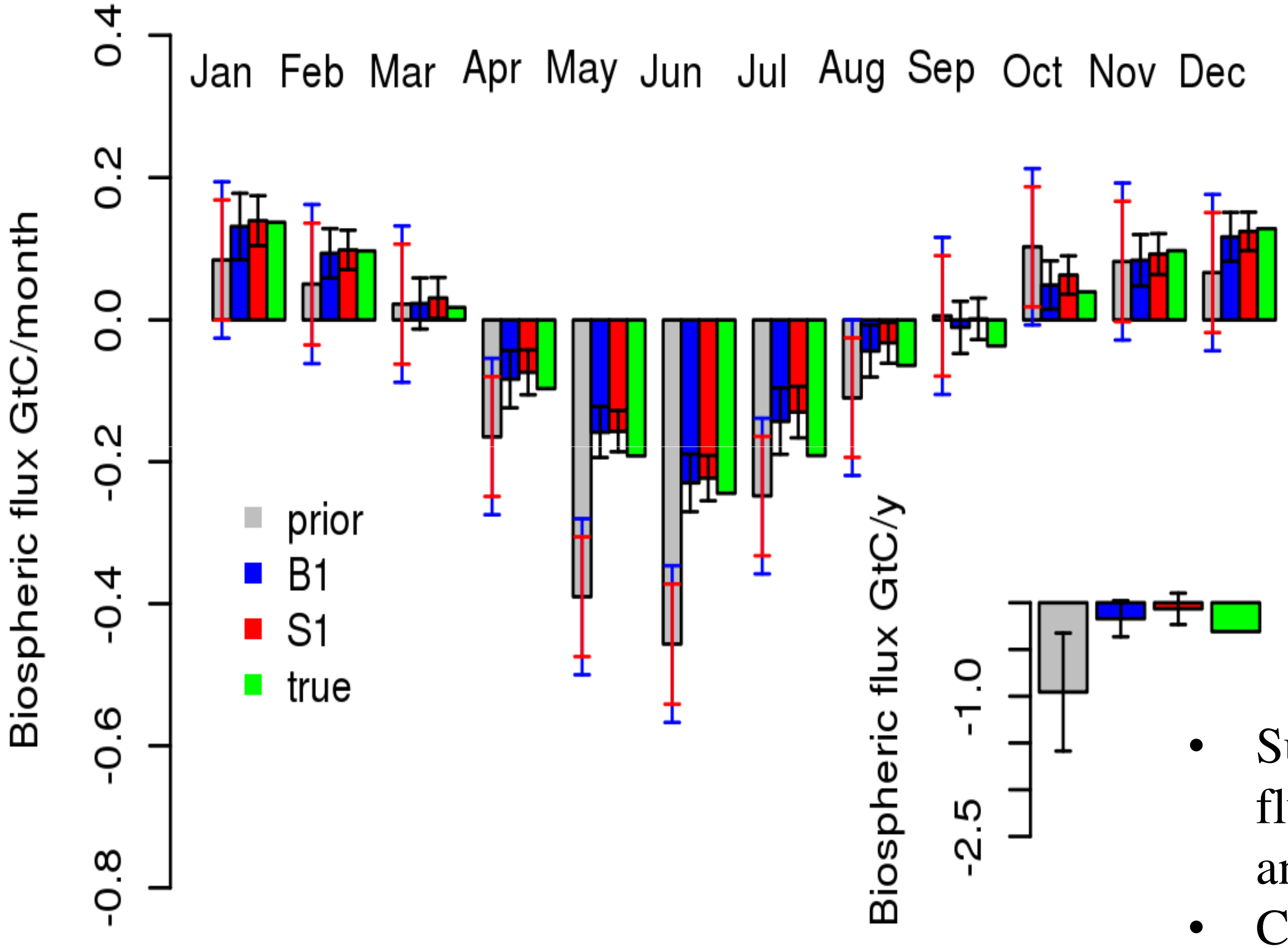
Pseudo data inversion – Goodness of fit



- Good fitting performance
- Comparable performance for both error structures
- Larger flexibility in **B1** (no bias term) → smaller residuals

Kountouris et al., 2016a in preparation

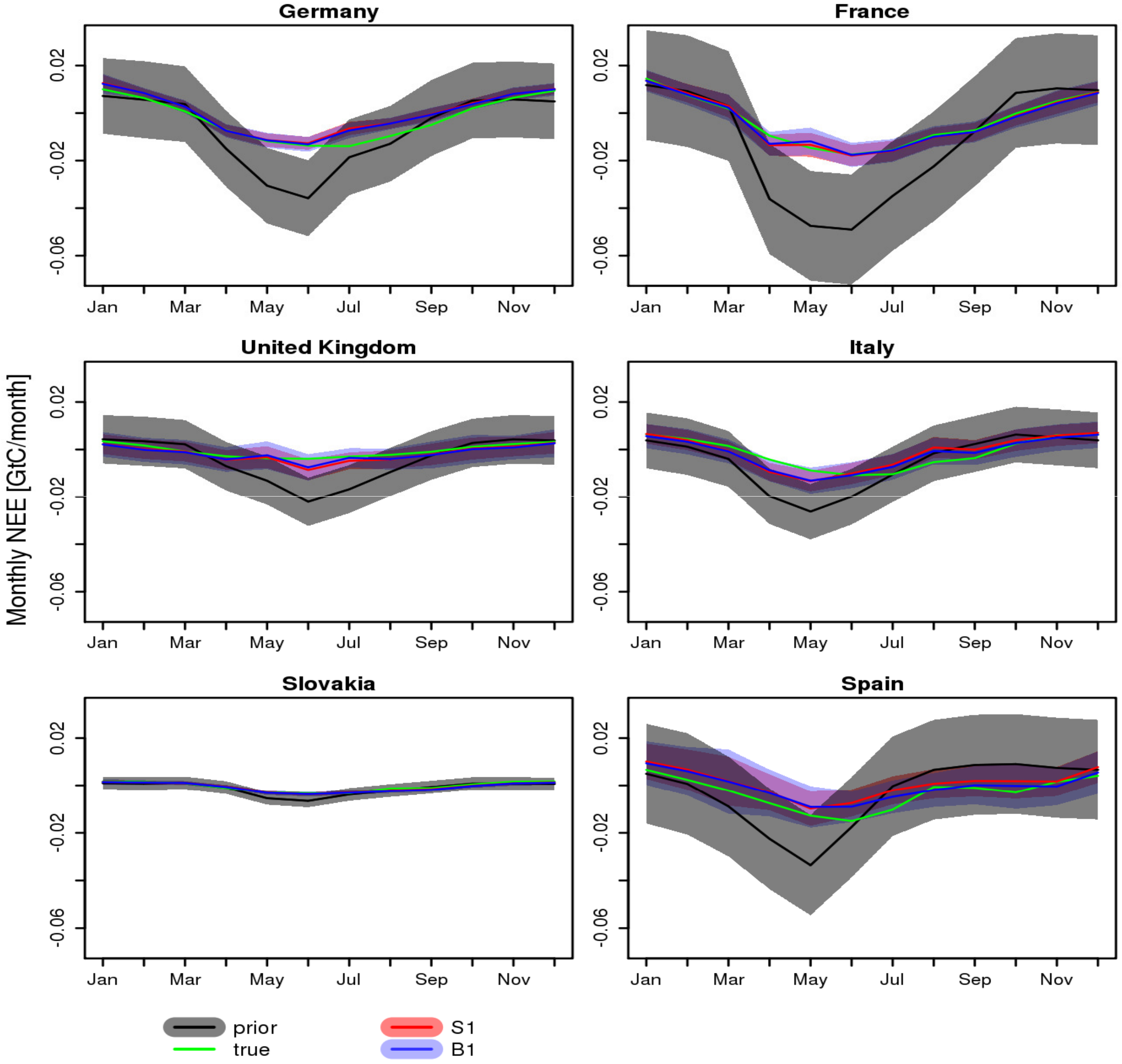
Pseudo data inversion – EU-scale C budget



Kountouris et al., 2016a in preparation

- Successfully retrieved fluxes at monthly and annual scales
- Case **S1** (with bias) results to lower posterior uncertainties

Pseudo data inversion – Country-scale C budget

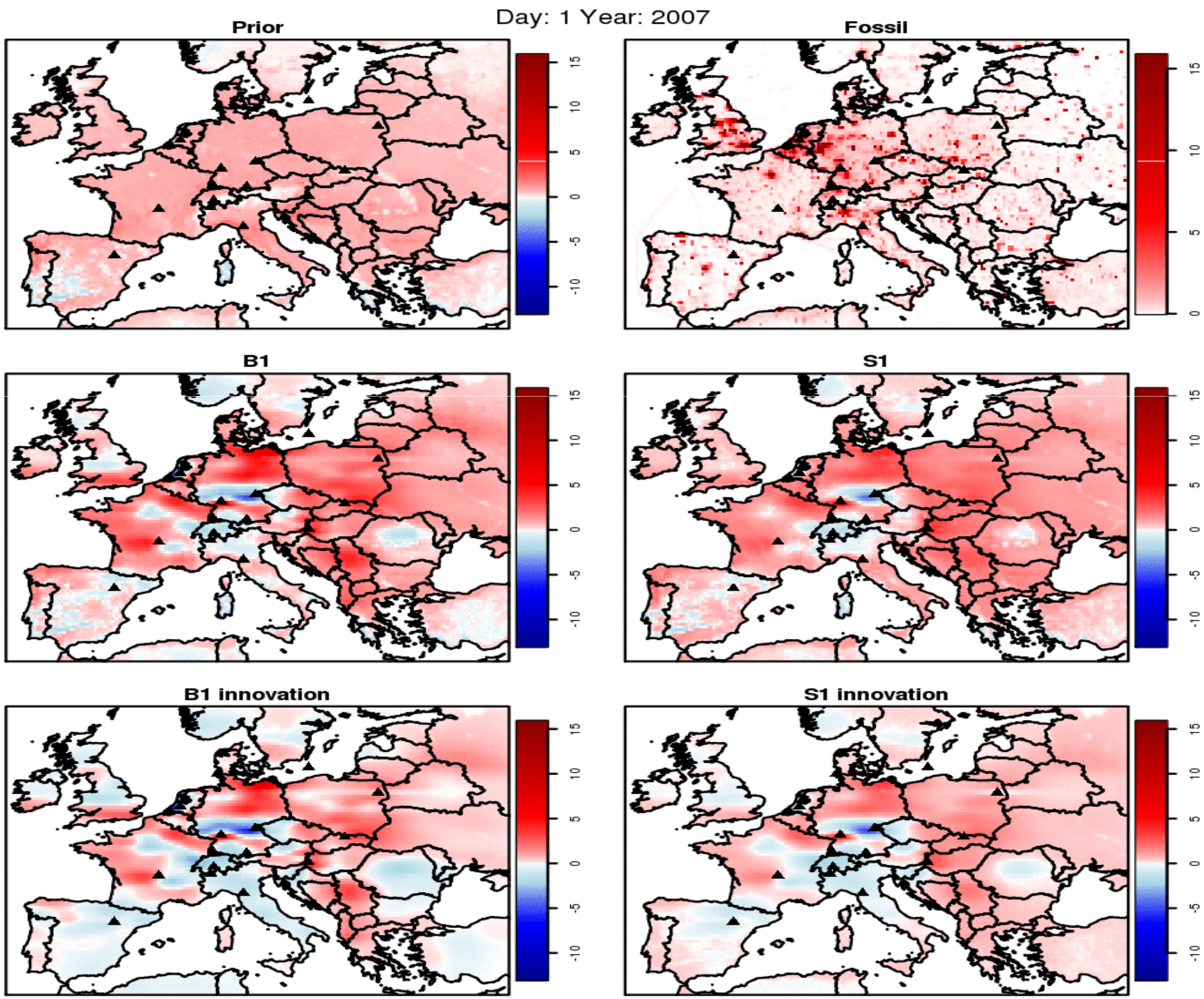


Kountouris et al., 2016a in preparation

- Successfully retrieved fluxes at monthly scales
- Significant correction also for badly constrained countries.

Real data inversion 2007

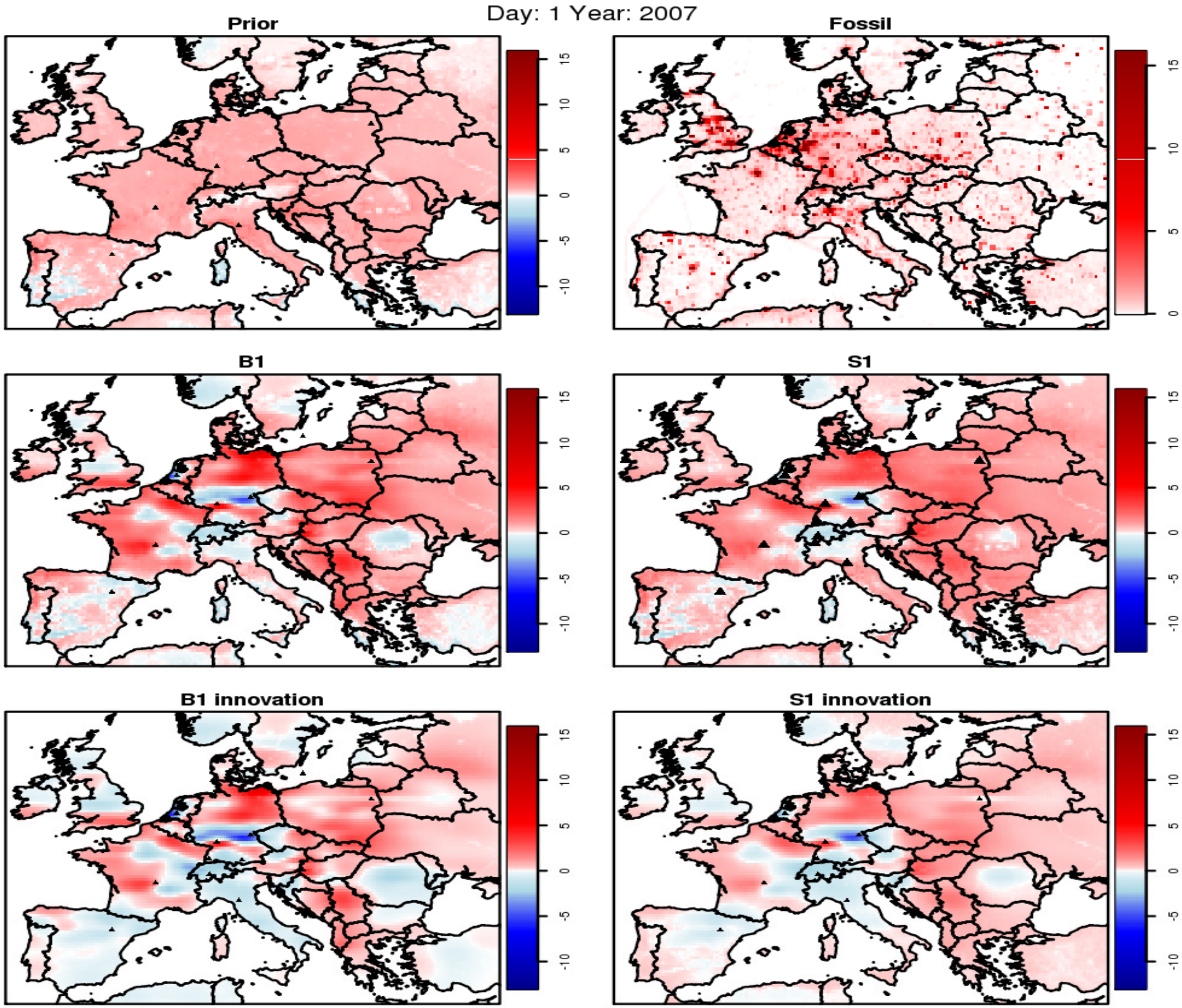
Daily averaged flux estimates in gC d^{-1} m^{-2}



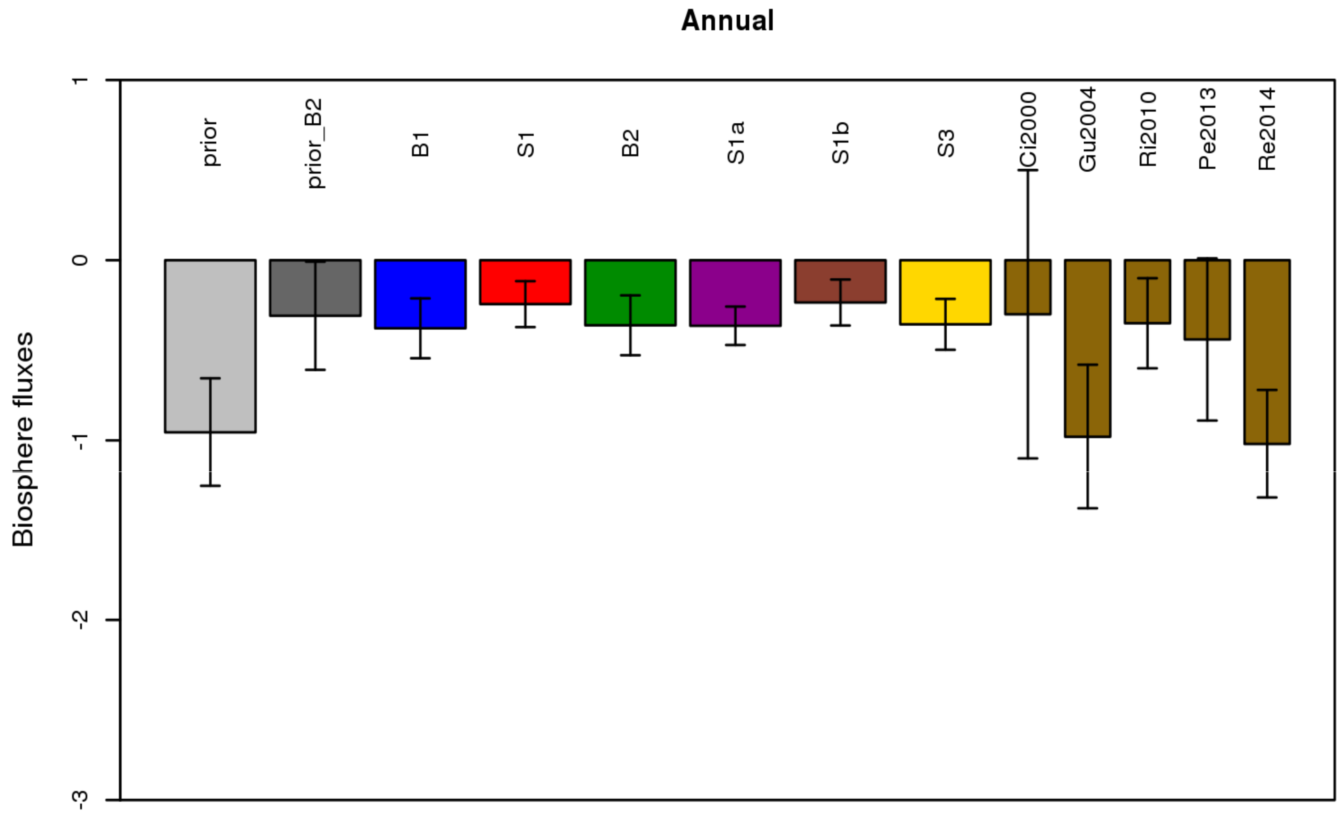
Reasonable fine structure is revealed where an atmospheric constrain is provided

Need for better coverage – more data streams to constrain better the fluxes

Real data inversion 2007



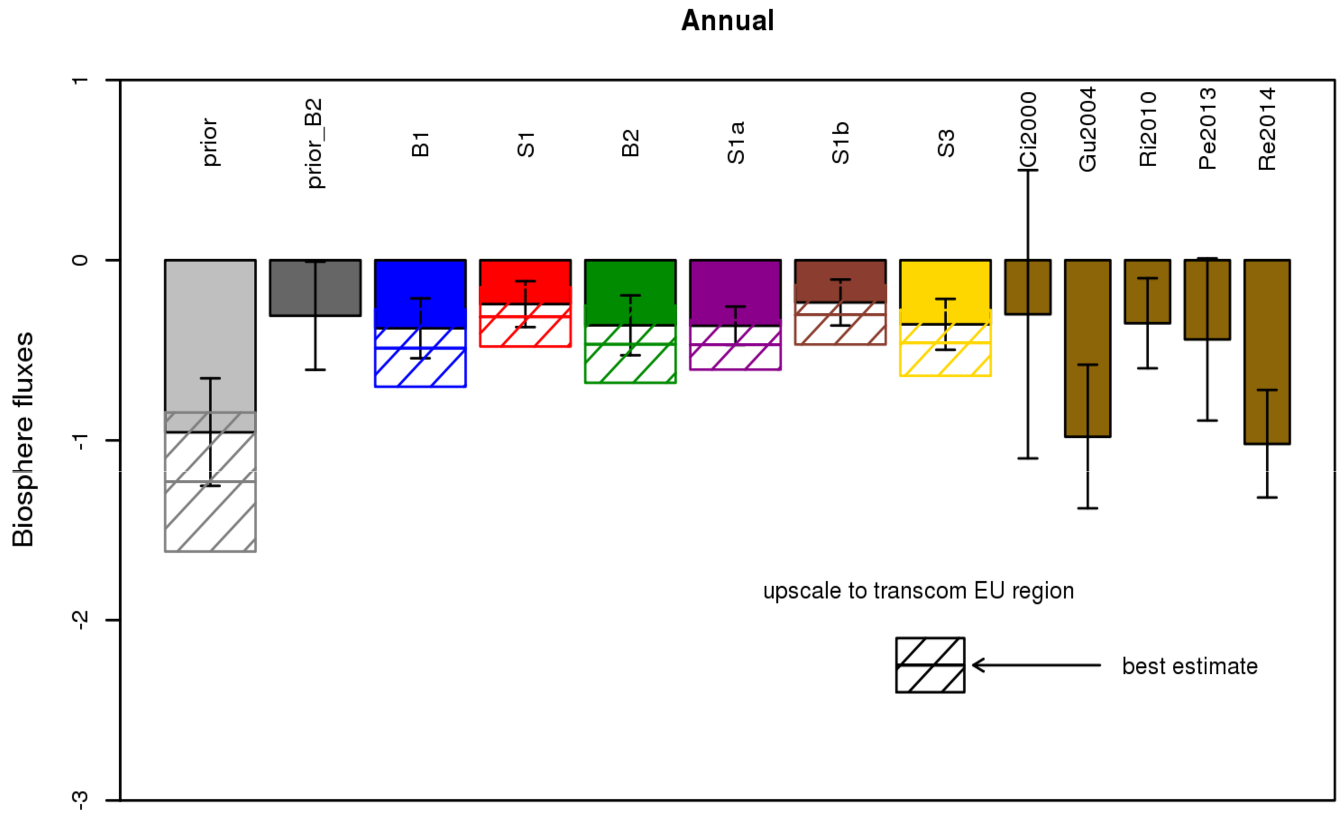
Real data inversion 2007



Kountouris et al., 2016b in preparation

European sink ranges between 0.23 - 0.38 GtC y^{-1}

Real data inversion 2007



Kountouris et al., 2016b in preparation

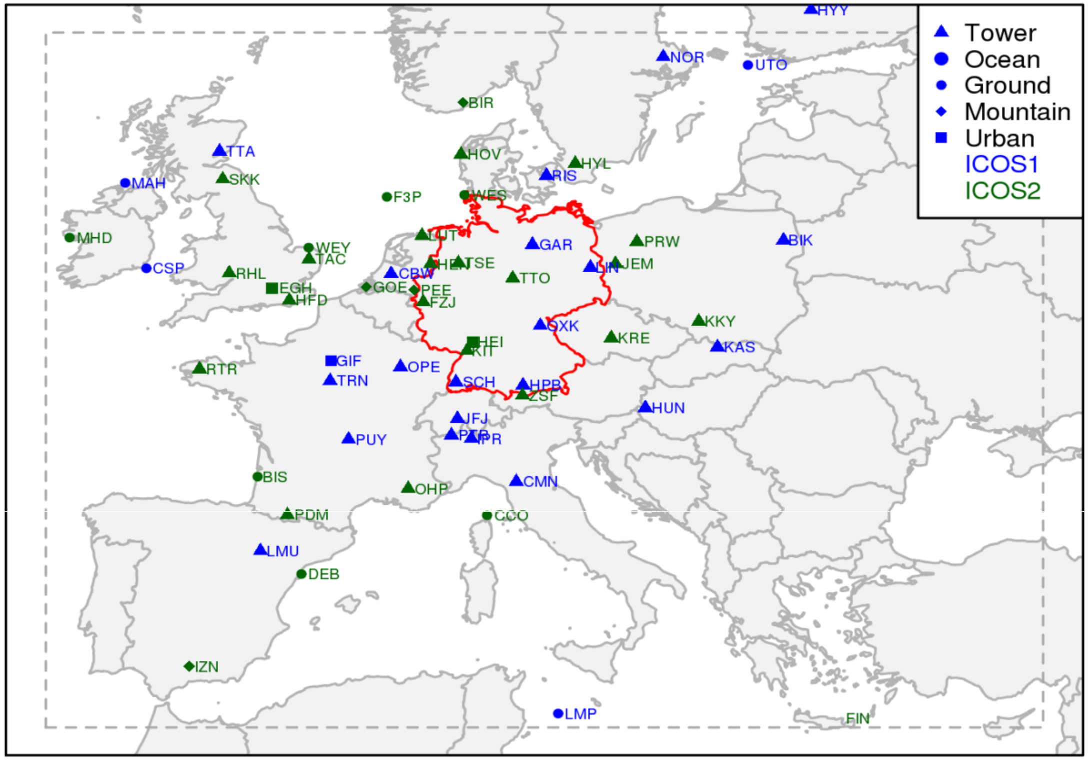
European sink ranges between 0.23 - 0.38 GtC y^{-1}
0.30 -0.49 GtC y^{-1} up-scaled to Transcom region

Network assessment

- Assess ICOS network in terms of uncertainty reduction

- Measurement location impacts flux uncertainties

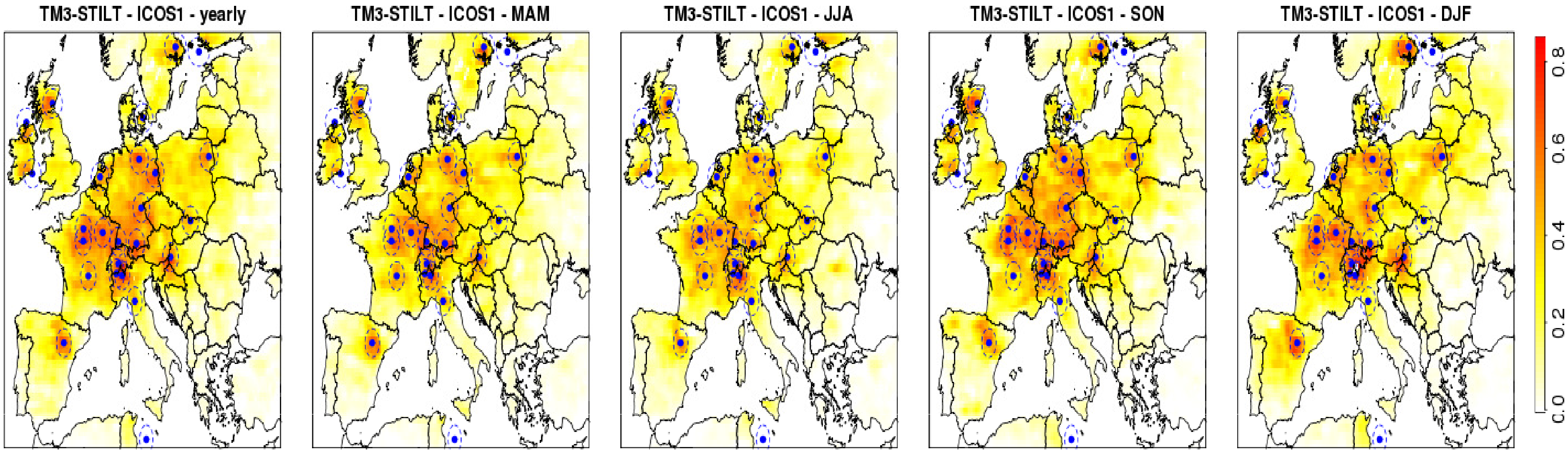
- Help decision makers to built optimal network



Monte Carlo method

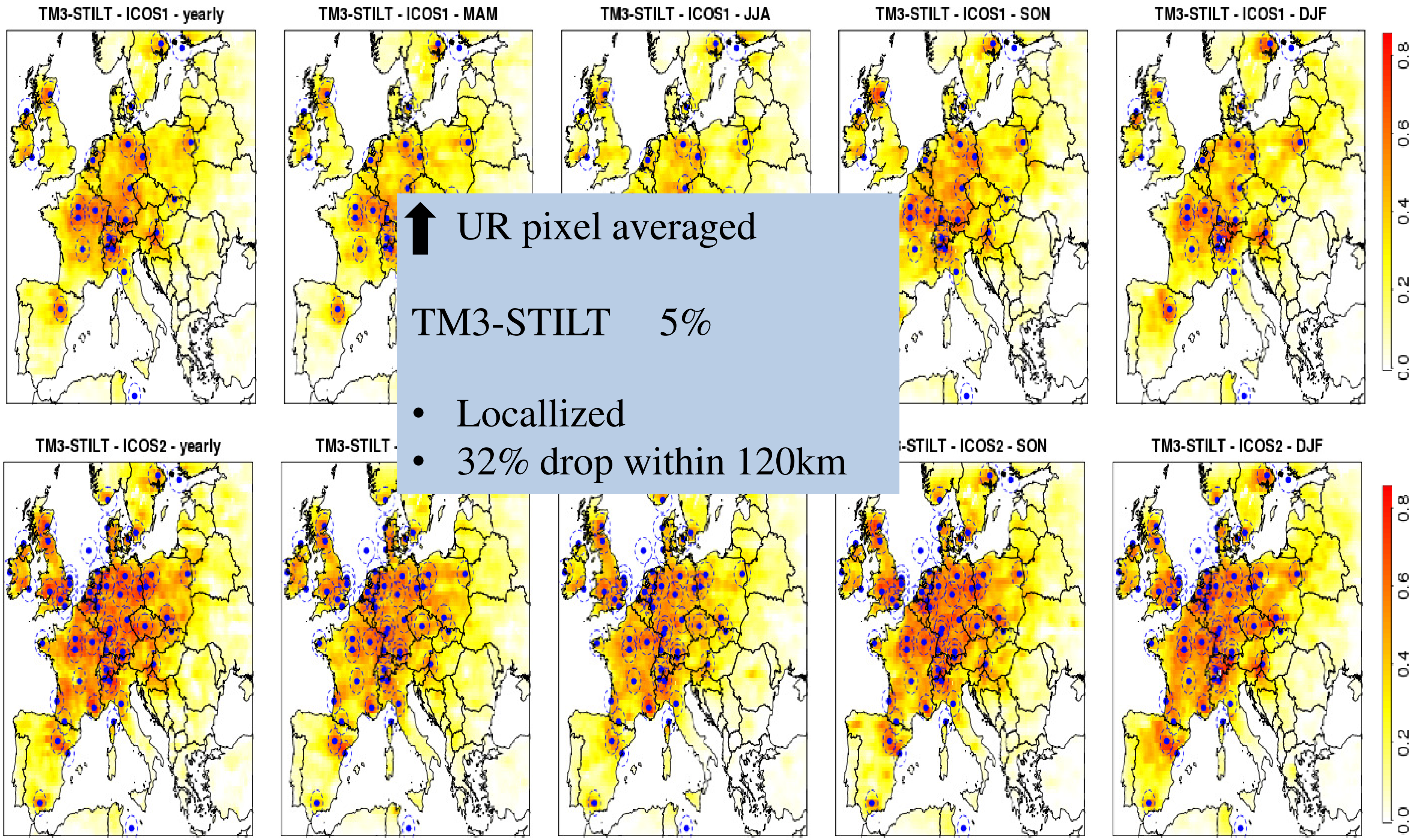
- 40 ensemble members
- Each member contains flux and observation error realizations
- Retrieved uncertainty reduction at country and pixel scale, annual/seasonal
- 3 inversion systems (MPI, VUA, LSCE)
- Joint protocol
  - ✓ Common domain
  - ✓ Same prior and observation uncertainties

Uncertainty Reduction assessment ICOS current



UR = 1 – Ups/Upr   Ups = *f*(Upr, Uy, Transport)

Uncertainty Reduction assessment ICOS future



⬆ UR pixel averaged

TM3-STILT 5%

- Locallized
- 32% drop within 120km

Kountouris et al., 2016c in preparation

Summary

- Data driven procedure from local to continental-scale to infer terrestrial fluxes
  - Prior fluxes : VPRM optimized at local scale using EC-data
  - Post fluxes : Inversion at meso-scale using CO_2 mixing ratios
- Site selection for VPRM optimization can lead to significant biases
- Flux estimates can be successfully retrieved down to country and monthly scales
- Spatially resolved flux estimates suffer from possibly biased f.f. contribution
- The information gain is localized near atmospheric stations
- Data coverage must be increased to capture flux variability at higher resolution