ICOS-D inverse modelling using the CarboScope regional inversion system

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MPI-BGC Jena

ICOS integrated carbon observation system

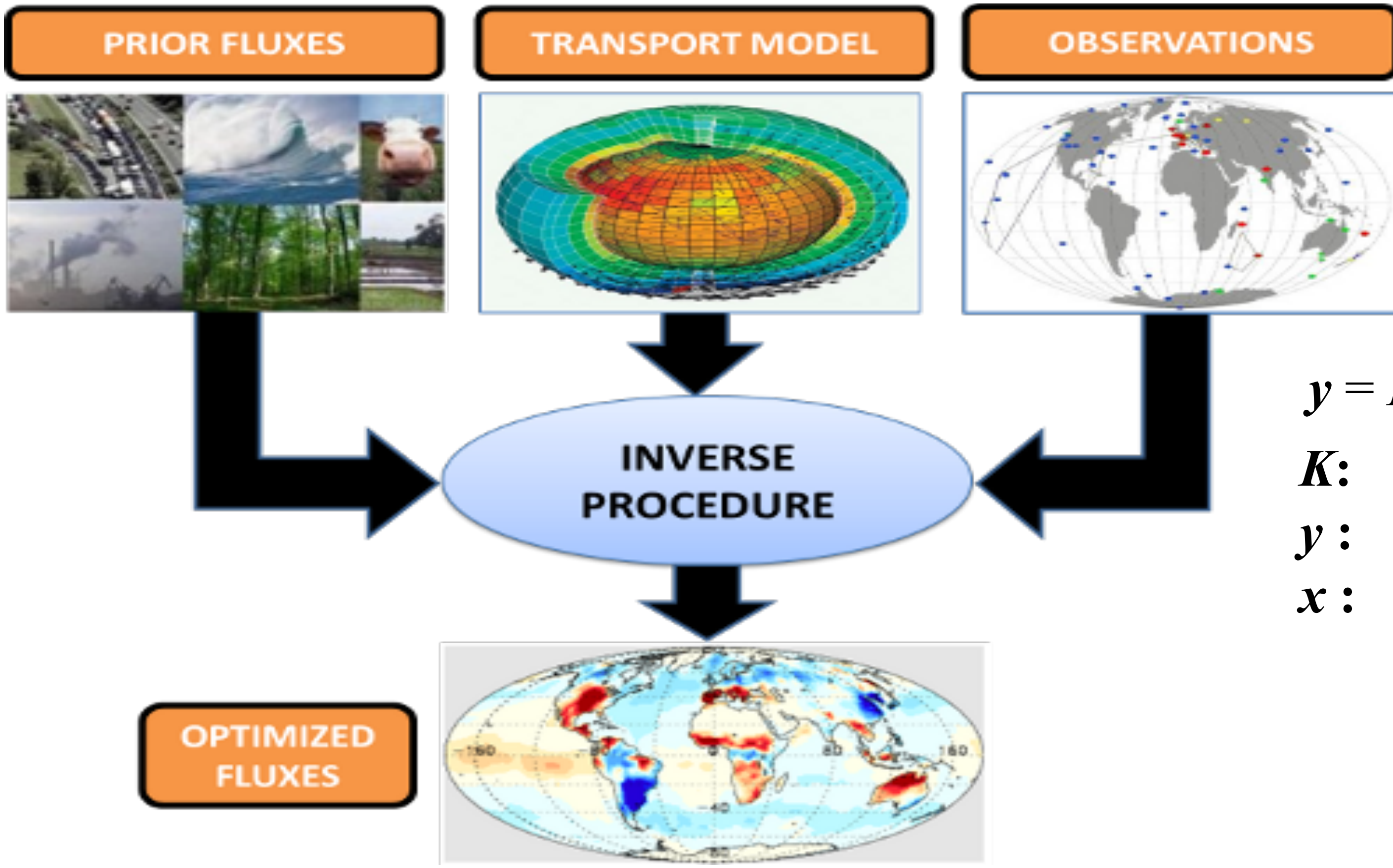
ICOS INWIRE

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

Overview

- The inversion system
- Synthetic data inversion
- Real data inversion
- Uncertainty in atmospheric transport
- Summary

The Inversion system



$$y = Kx + \varepsilon_y$$

K: transport operator

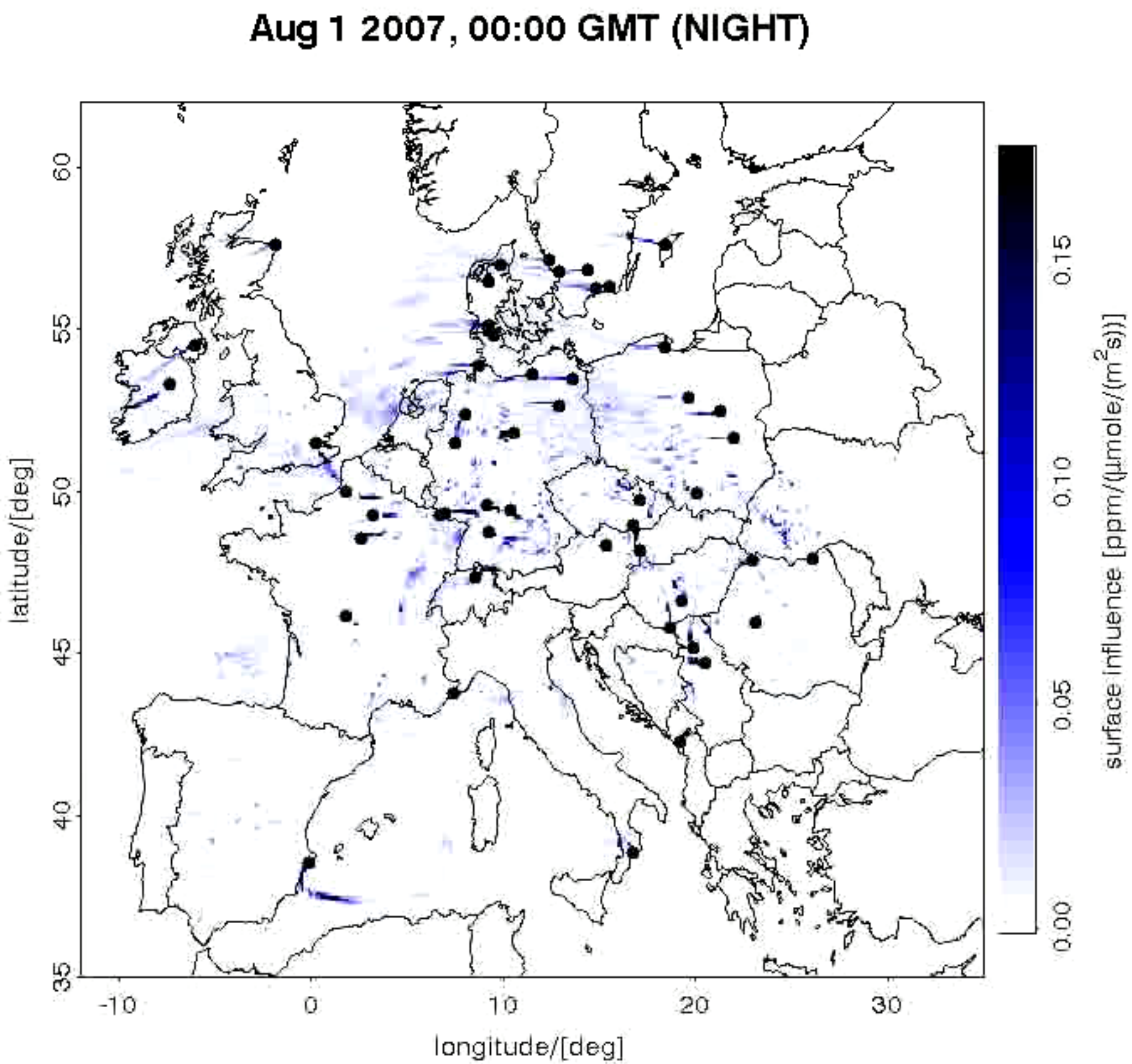
y: observations

x: state vector to be optimized (biosphere-atmosphere exchange fluxes)

Cost function:

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

How does an atmospheric network "see" fluxes ?



Stochastic Time Inverted Lagrangian Transport (STILT)

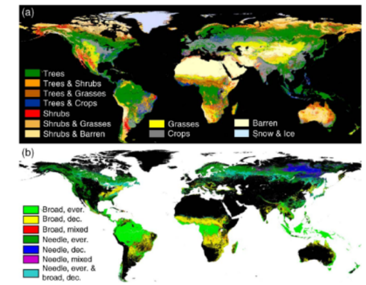
- Ensemble of particles released at measurement locations
- Time reversed
- Particles driven by wind + turbulent process
- Footprint calculation
- NRT possible (ECMWF forecasts)

=> **Footprints available through ICOS CP**

VPRM prior - optimization

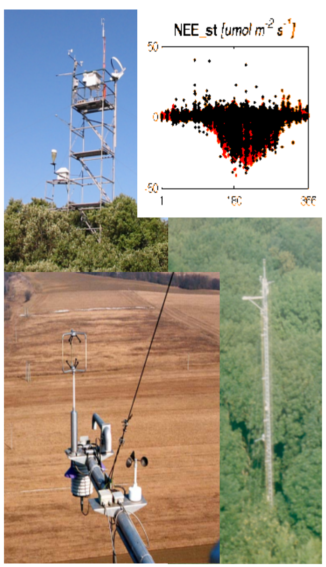
Vegetation **P**hotosynthesis **R**espiration **M**odel (**VPRM**)
[Pathmathevan et al., 2008]

Initial optimization of parameters against Eddy Cov. **α, β, λ,** and **PAR_0**



vegetation classes (8)

SYNMAP land cover
[Jung et al., 2006]



Eddy Cov. data

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

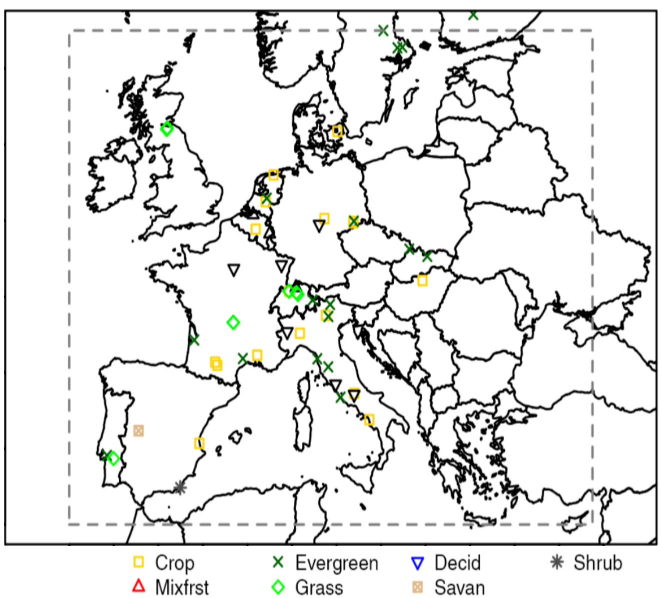
ECMWF, NCEP, WRF or site measurements

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

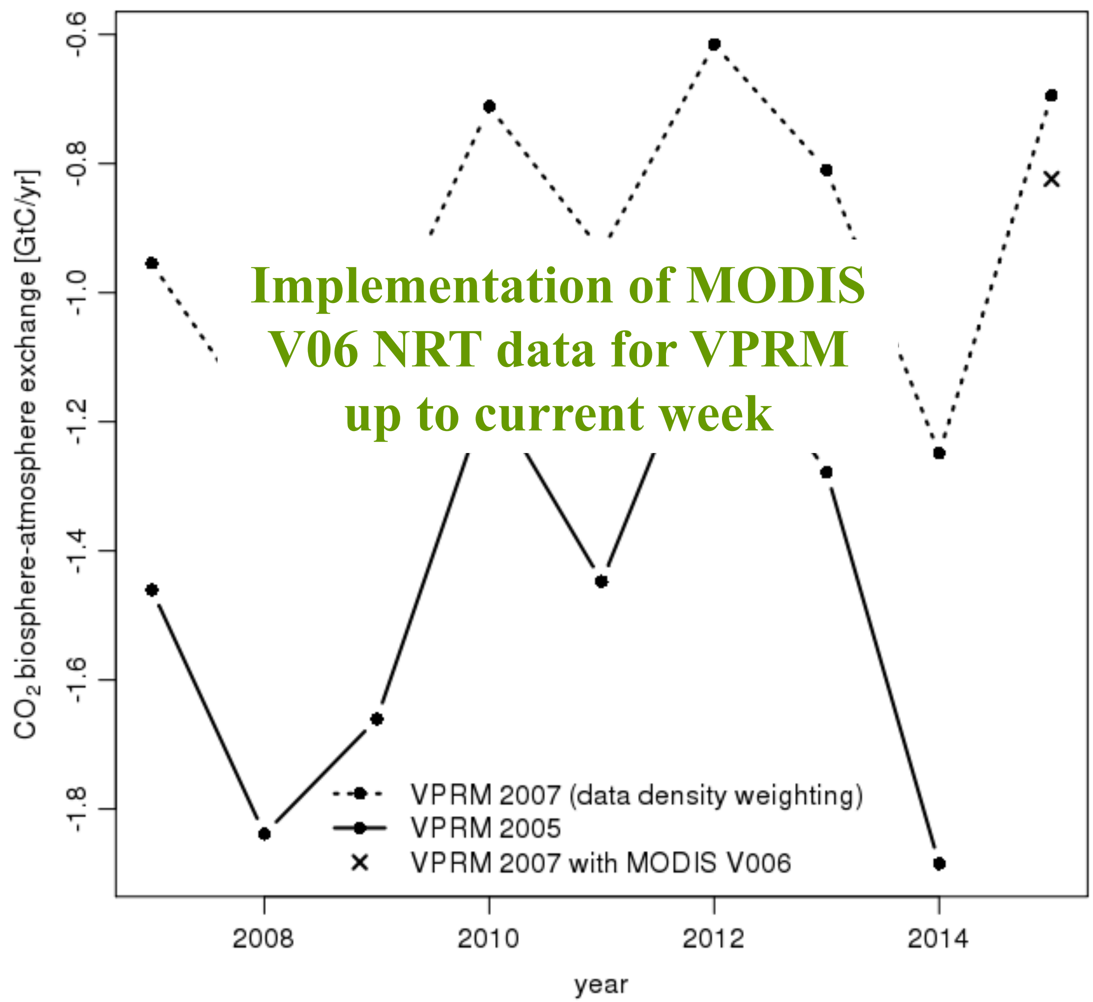
MODIS surface reflectance
8 day, 500 m

VPRM prior - optimization

- Optimizing 4 parameters for each of 6 vegetation types
  (30 parameters)
- Temporal data coverage matters
  => data density weighting

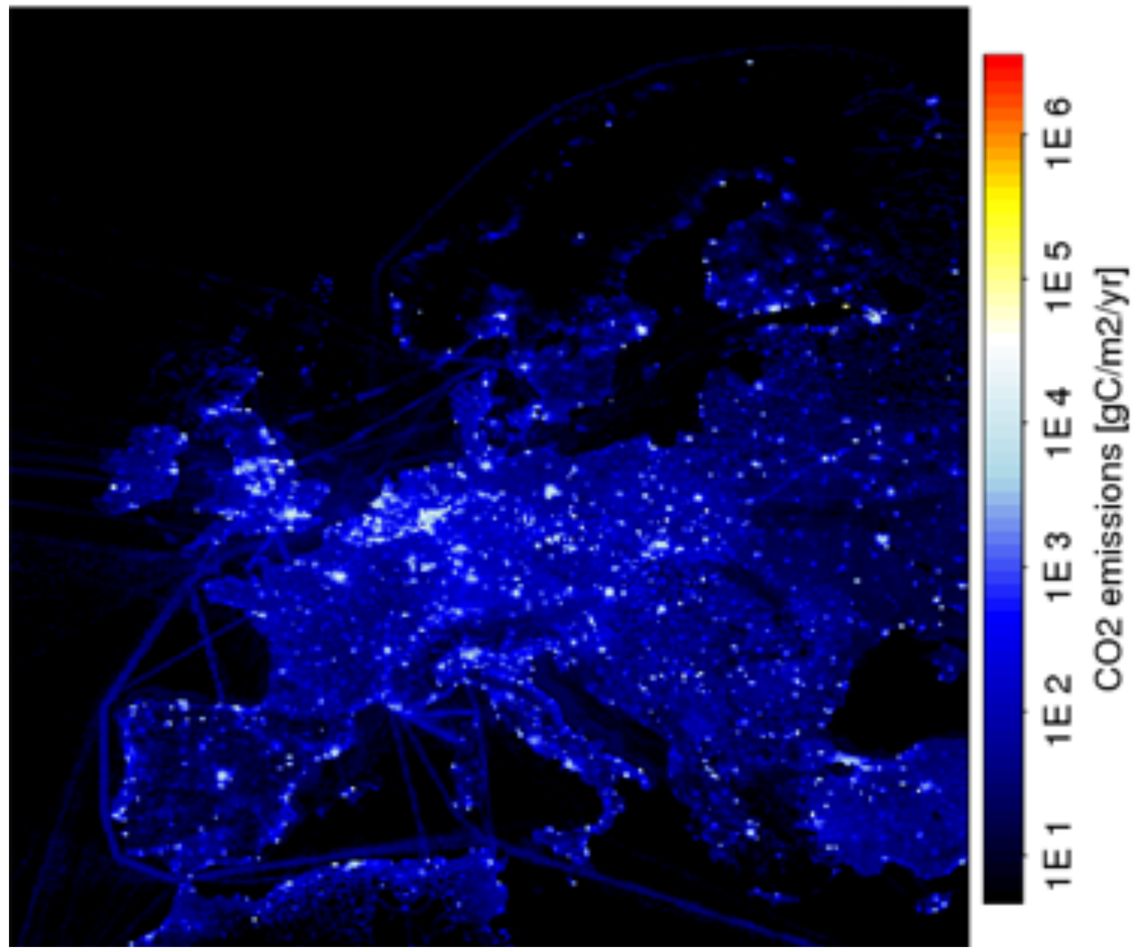


Annual domain-wide biosphere-atmosphere fluxes using VPRM



Fossil fuel prior fluxes

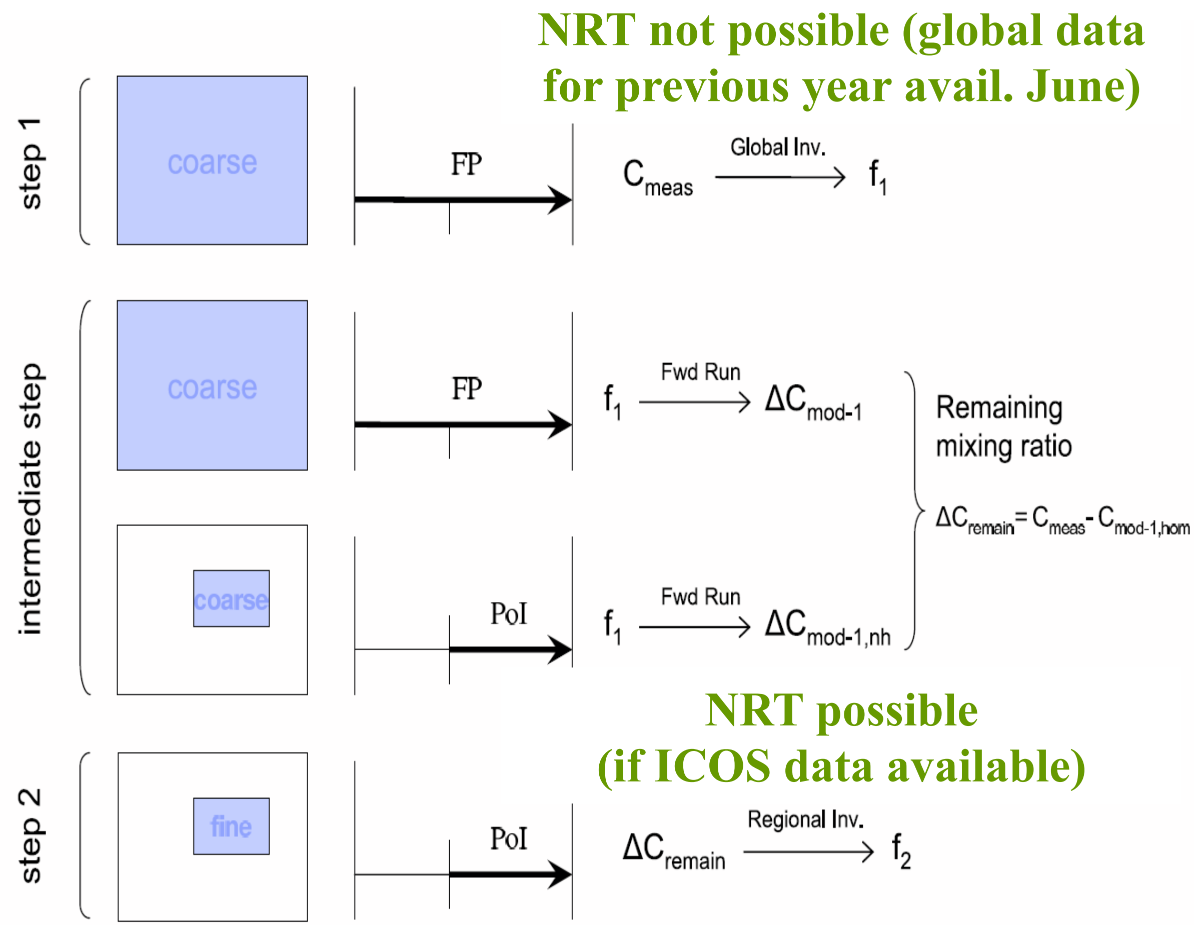
- EDGAR v4.3 at 0.1º
- CO_2 and CH_4 (and CO)
- IPCC category and fuel type differentiation
- Time factors applied to create hourly temporal resolution
- Interannual variations scaled according to BP energy statistics at national level
- Extrapolation to 1-2 years after BP statistics
  => current year available



Jena regional inversion system

TM3-STILT – two step inversion

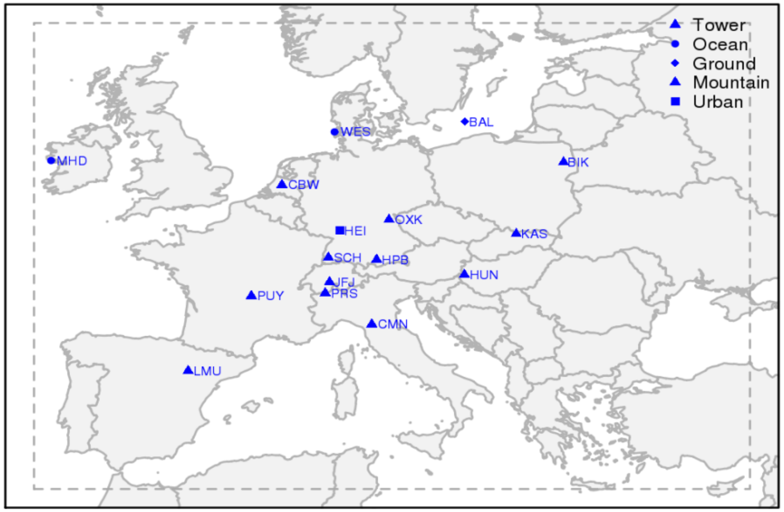
- Input : Atmospheric observations, prior fluxes (biospheric, ocean, fossil fuel)
- TM3 global inversion 5° x 4°
- STILT regional inversion 0.25° x 0.25°
- State space: 0.5° resolution, 3hourly flux optimization



Rödenbeck et al., 2009

Inversion setup

Atmospheric observations:



- 16 atmospheric stations (2007) (Continuous measurements and flask sample analysis)
- Daytime 11-16 local (mountain: 23-04)

CO_2 Model-data mismatch error in ppm (for weekly time scales)

S	C	M	T	UP
1.5	2.5	1.5	1.5	4

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

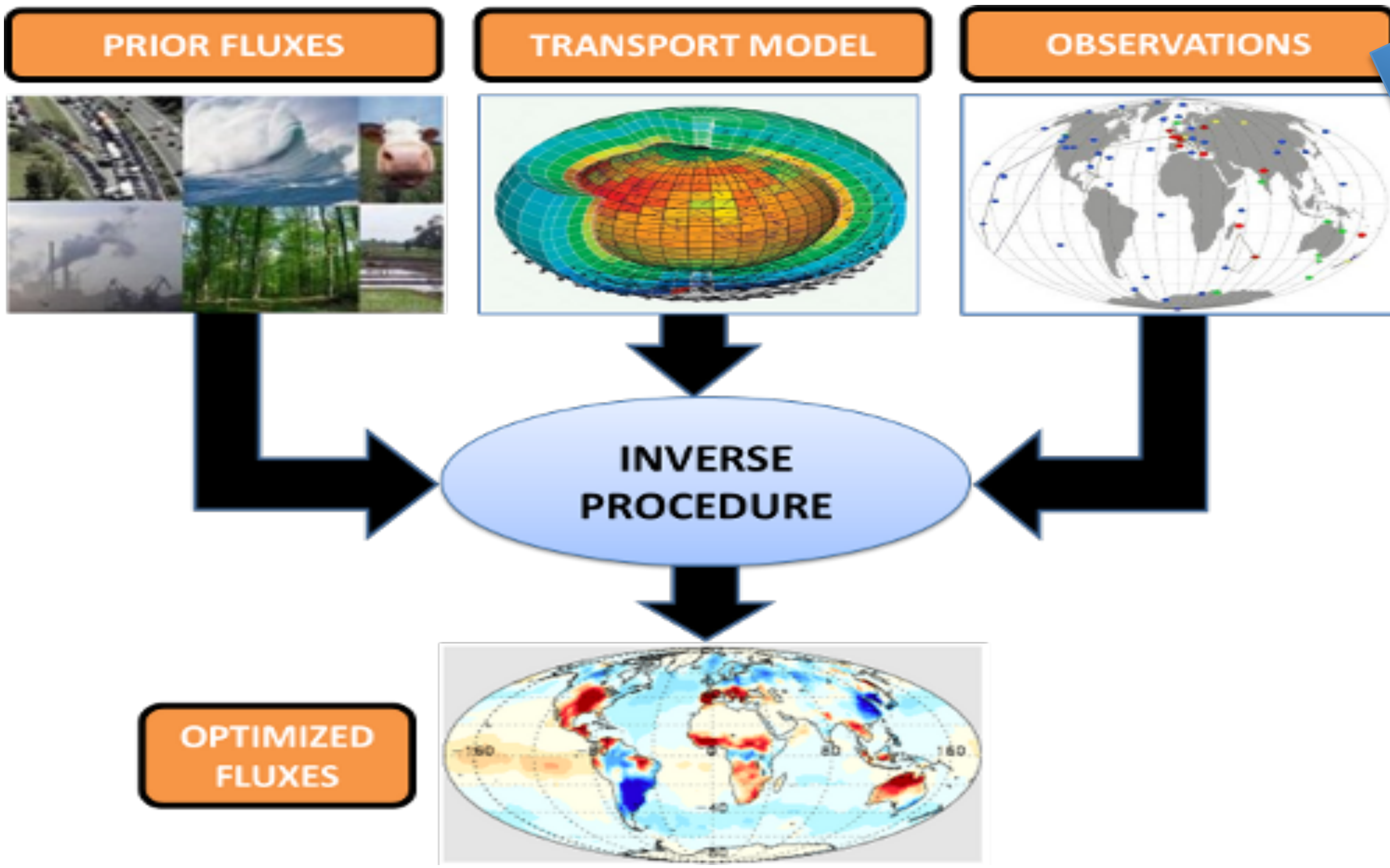
Prior error structure (derived from differences prior fluxes – flux observations):

- Diagonal: 2.3 µmoles/m^2/s (daily fluxes, 0.5x0.5 ° lat-lon)
- error correlations: 30 days, 100 km

=> error inflation needed to obtain consistency with global inversions
0.3 GtC/yr for annual and domain wide aggregated prior error

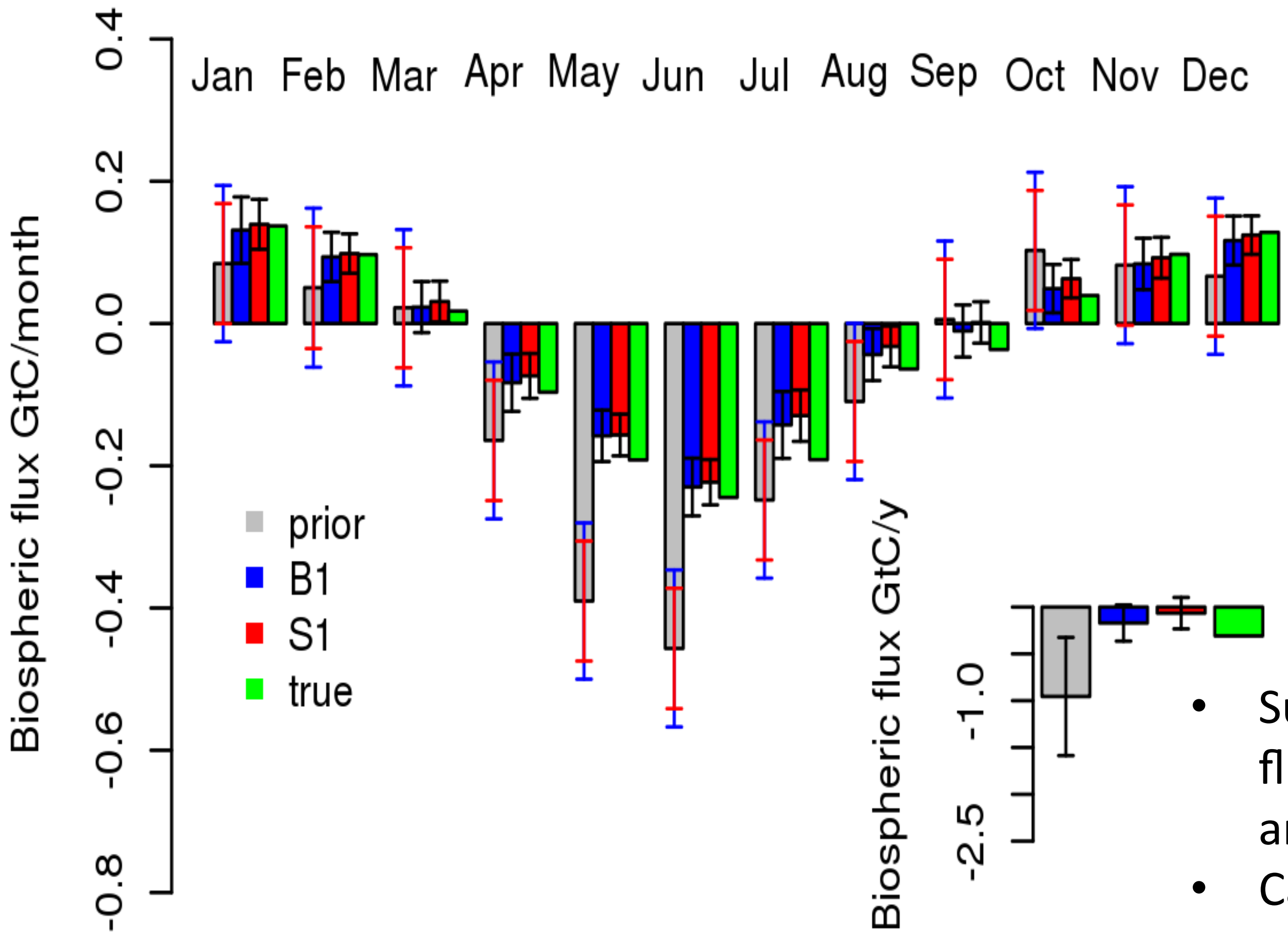
- B1 case: Error inflation (scaling of covariance matrix)
- S1 case: Error inflation by adding a bias term (constant in time, respiration shape)

Synthetic data inversion



Pseudo observations generated using BIOME-BGC as "truth"

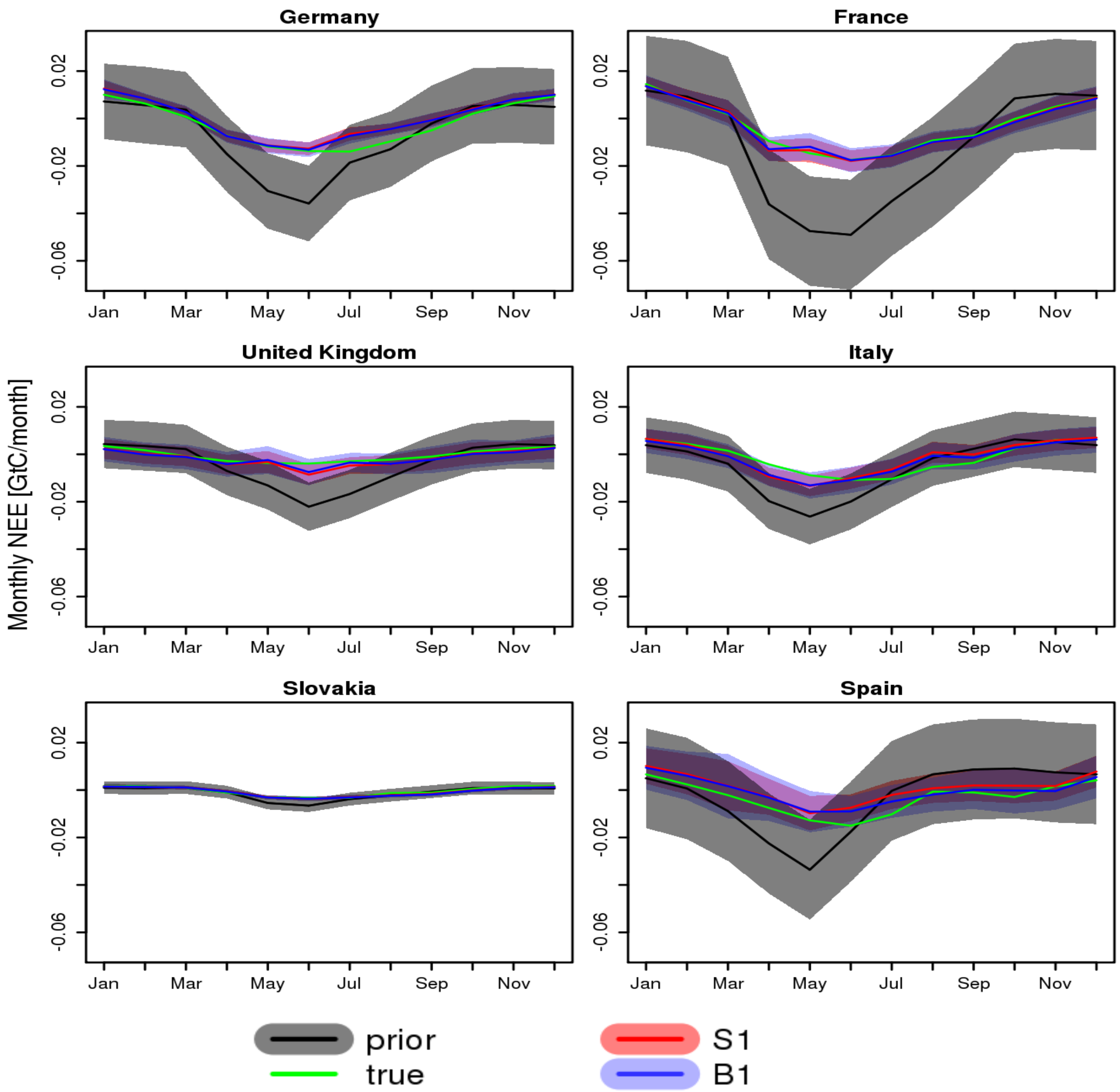
Pseudo data inversion – EU-scale C budget



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

Kountouris et al., 2016a ACPD

Pseudo data inversion – Country-scale C budget



Kountouris et al., 2016a ACPD

- Successfully retrieved fluxes at monthly and national scales
- Reduction in Uncertainties (prior -> posterior) larger for countries with more observations

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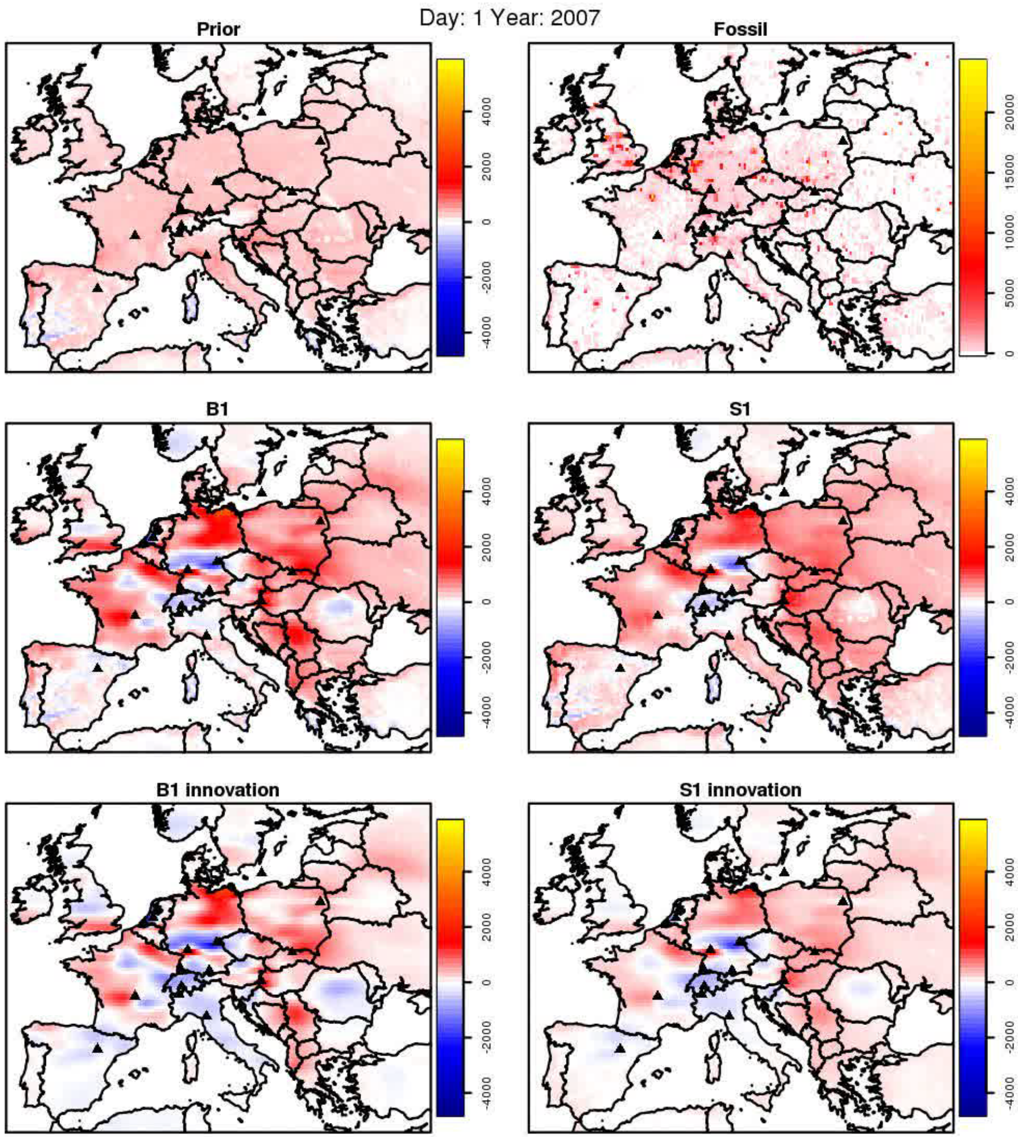
Real data inversion 2007

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



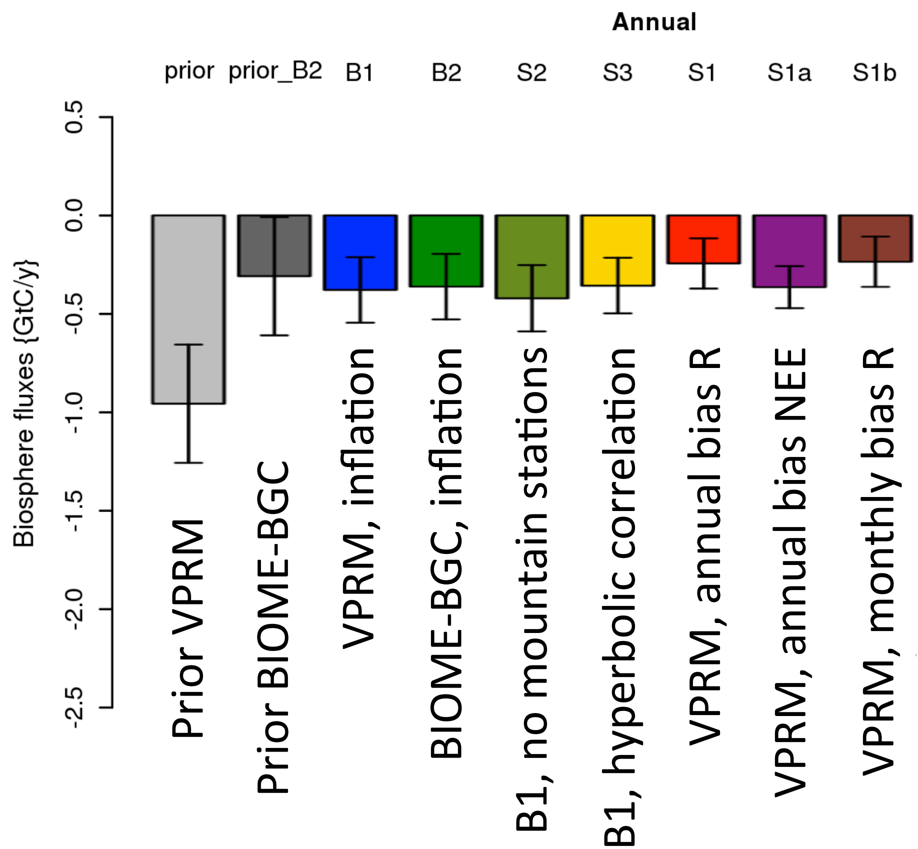
Small scale structure: vegetation coverage, radiation, temperature (a priori)

Larger scale corrections from atmospheric constrain

Innovation: posterior – prior

Kountouris et al., 2016b ACPD

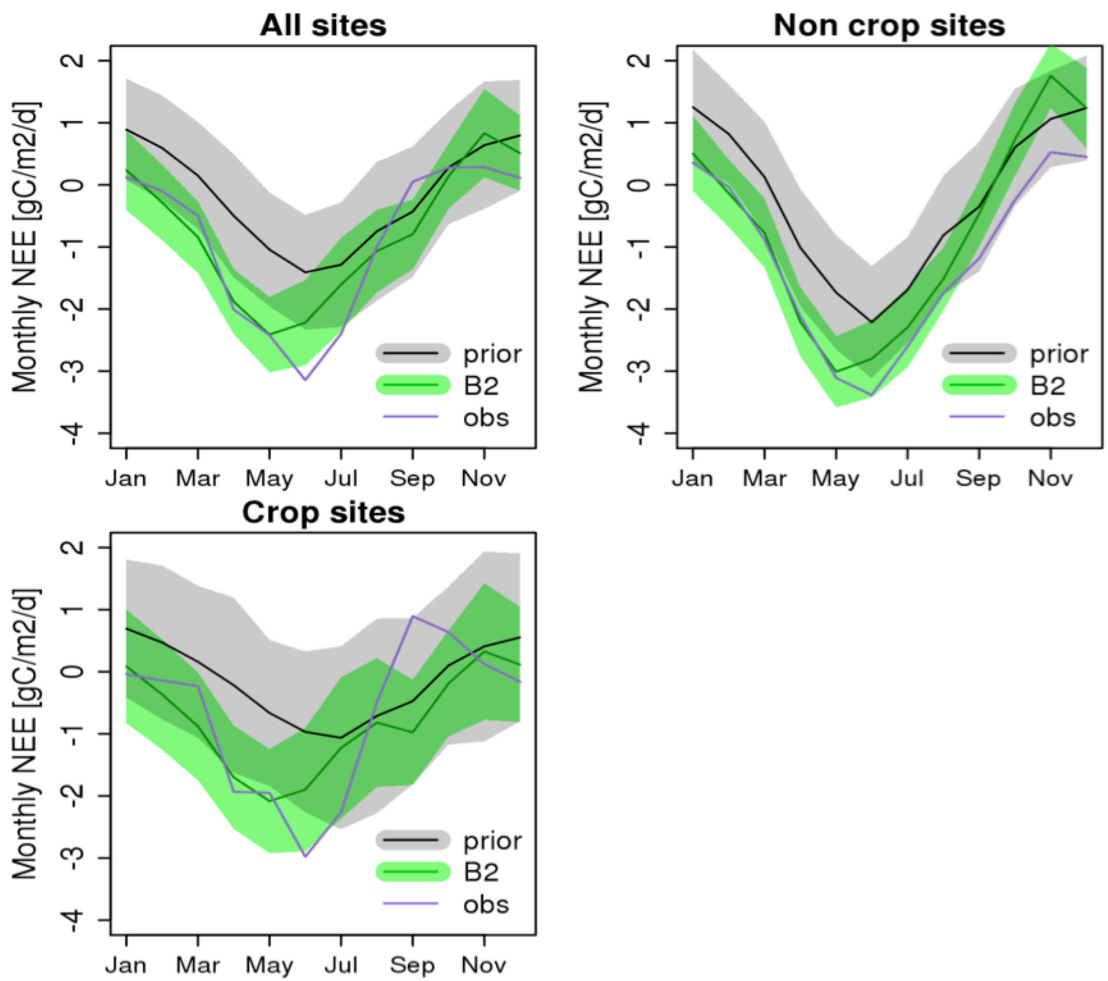
Real data inversion 2007: Domain-wide C-budget



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

Kountouris et al., 2016b ACPD

Real data inversion 2007: Validation



Extracting posterior fluxes at Eddy Covariance Flux sites comparison to independent flux observations
(case B2, BIOME-BGC prior fluxes not dependent on flux observations)

Kountouris et al., 2016b ACPD

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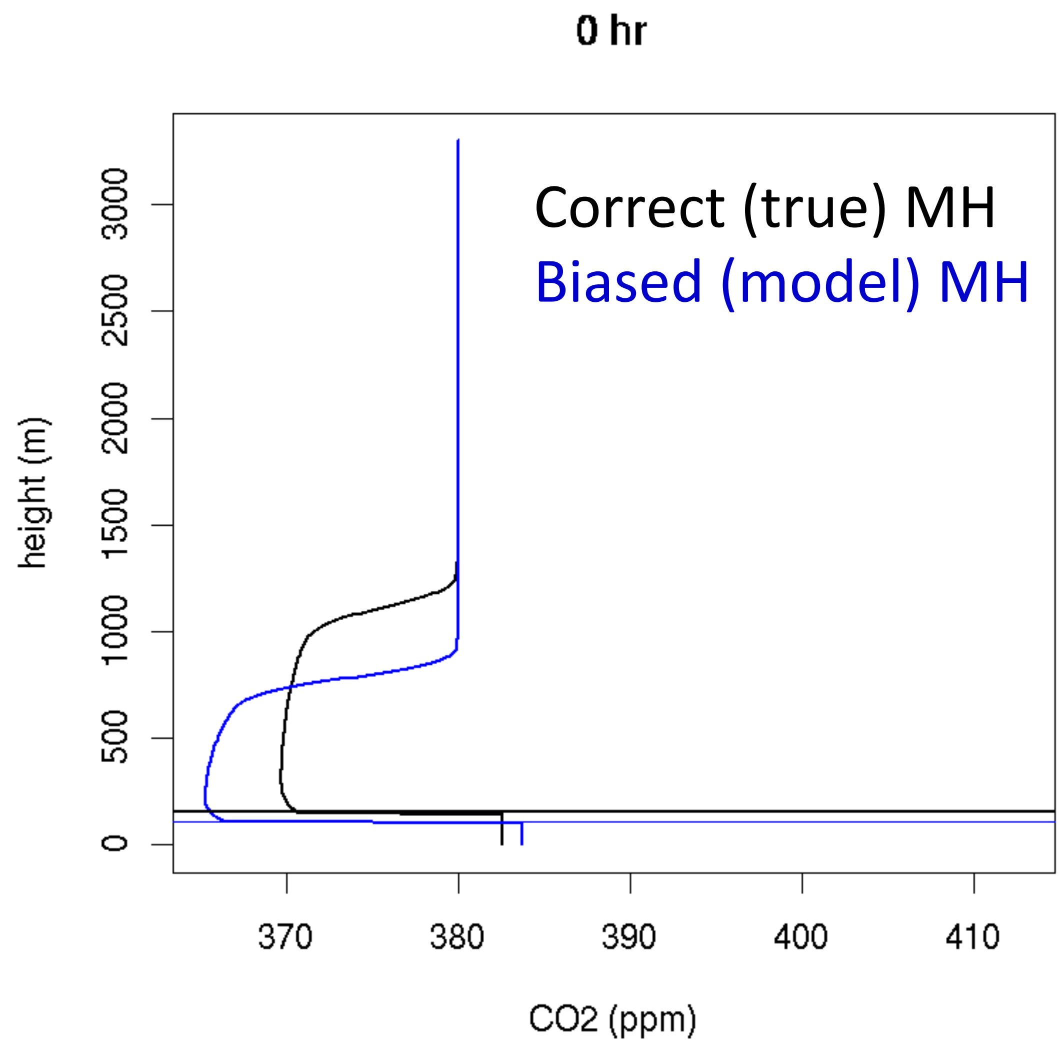
Impact of Uncertainty in Vertical Mixing

Conceptual model

- Diurnal cycle CO_2 fluxes
- Diurnal cycle mixing height
- Subsidence

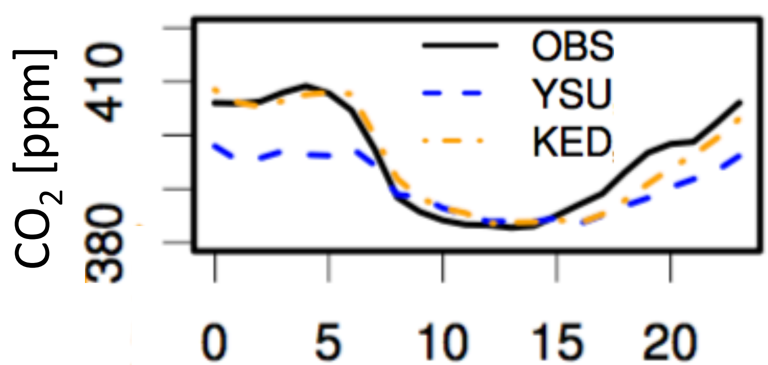


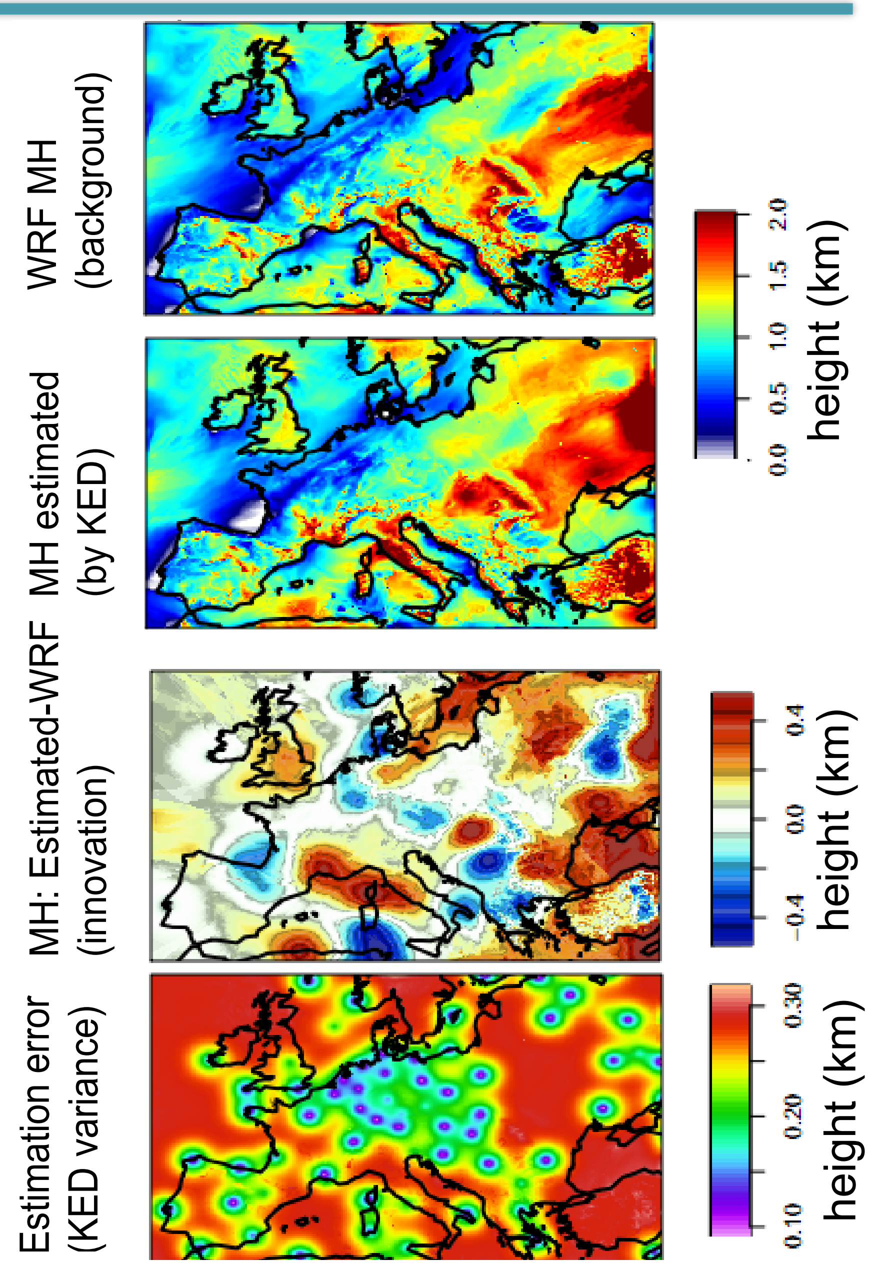
Impact of Uncertainty in Vertical Mixing

"assimilating" mixing heights
(example: 9 Sep. 2009, 12:00)

- derived from IGRA data (radiosonde profiles)
- using KED (Kriging with external drift, Drift term WRF-MH)

Average diurnal cycle CBW Sep. 2009



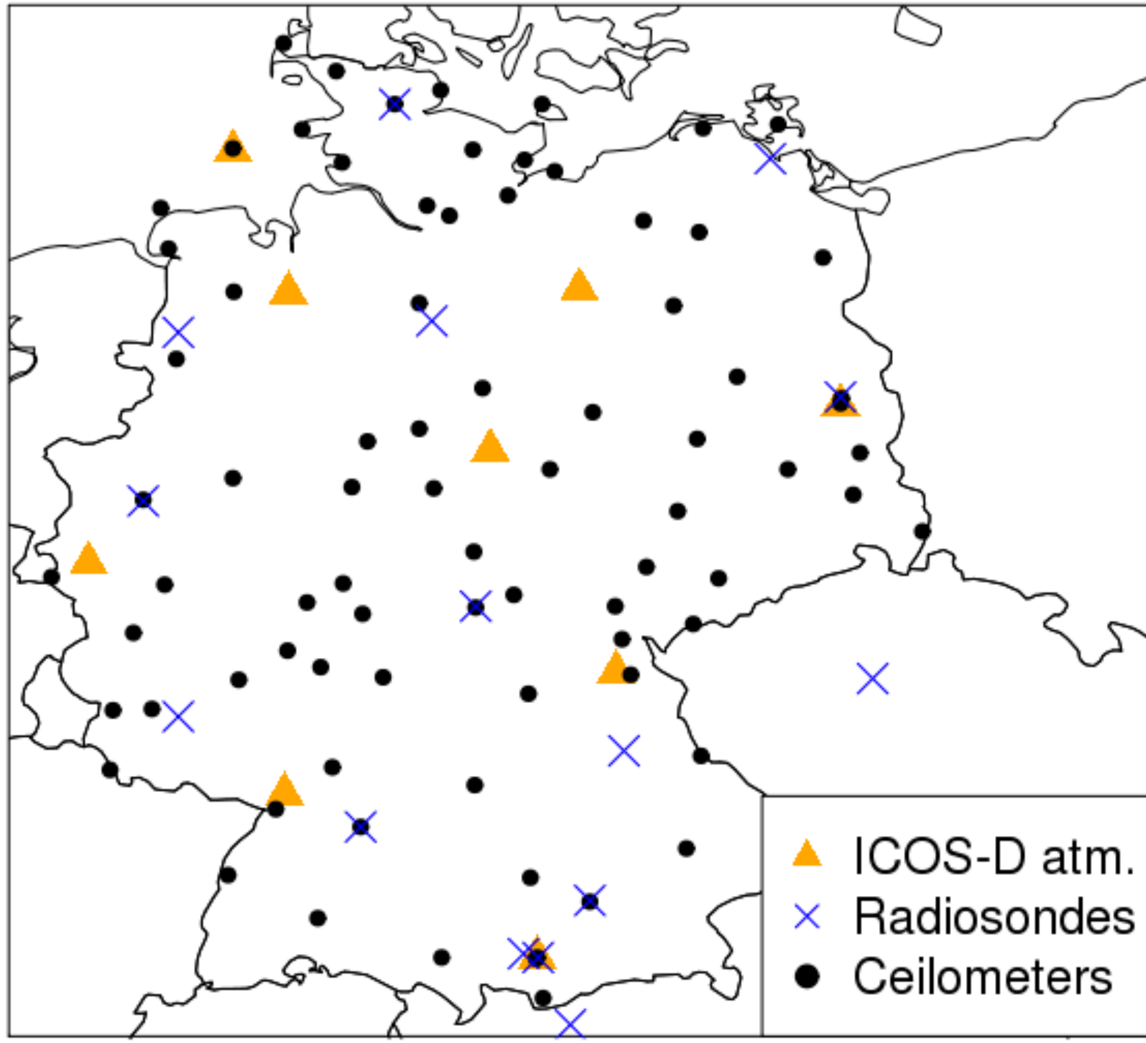


[Kretschmer et al., 2013 & 2014]

Using additional data streams: PBLH

DWD Ceilometer network

- 80 + ceilometers
- Nearby ICOS atmosphere stations
- Co-located surface stations
- Validation of ceilometer PBLH against radiosonde PBLH
- ECMWF PBLH (7 km res.) as „transfer standard“



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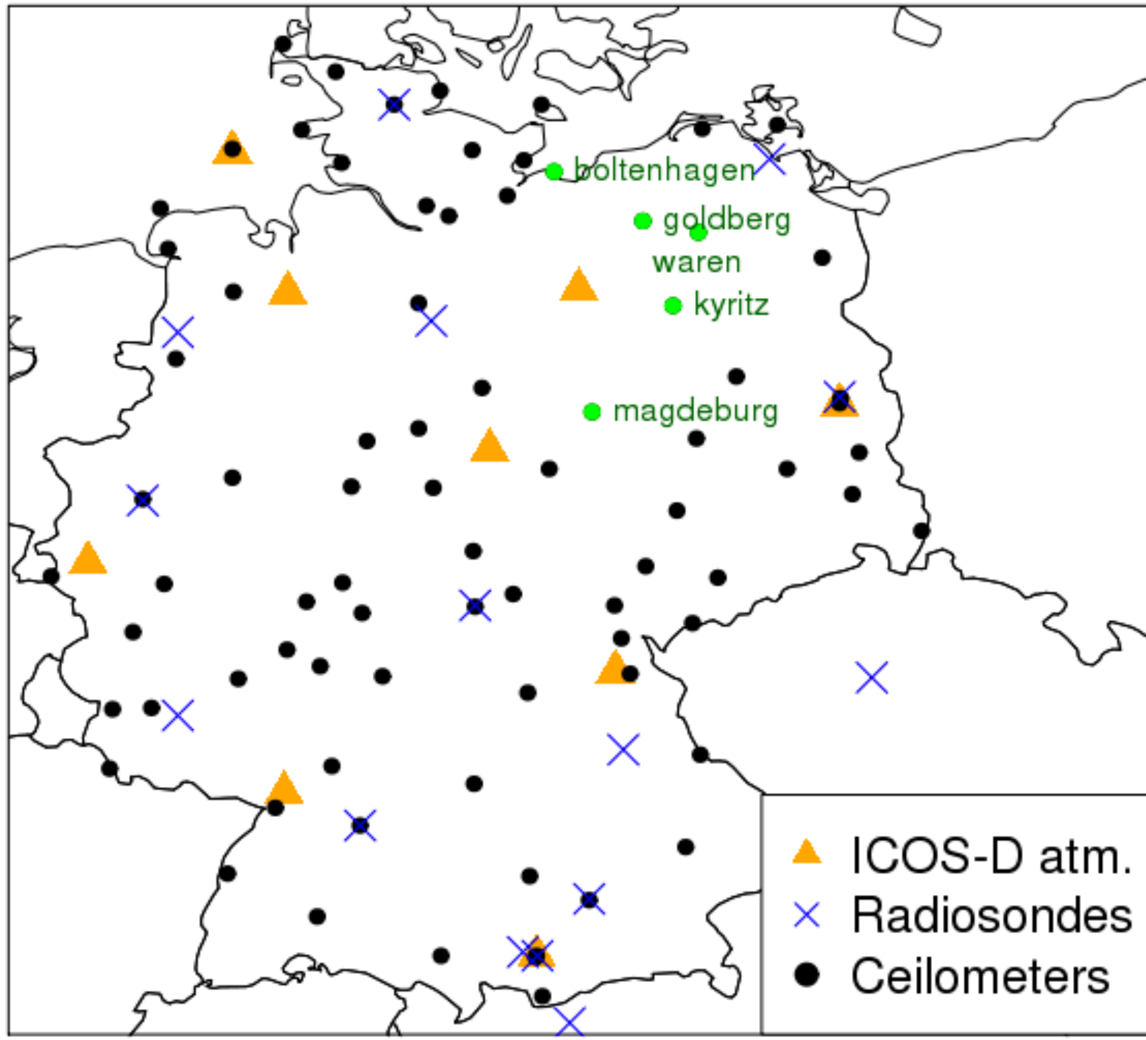
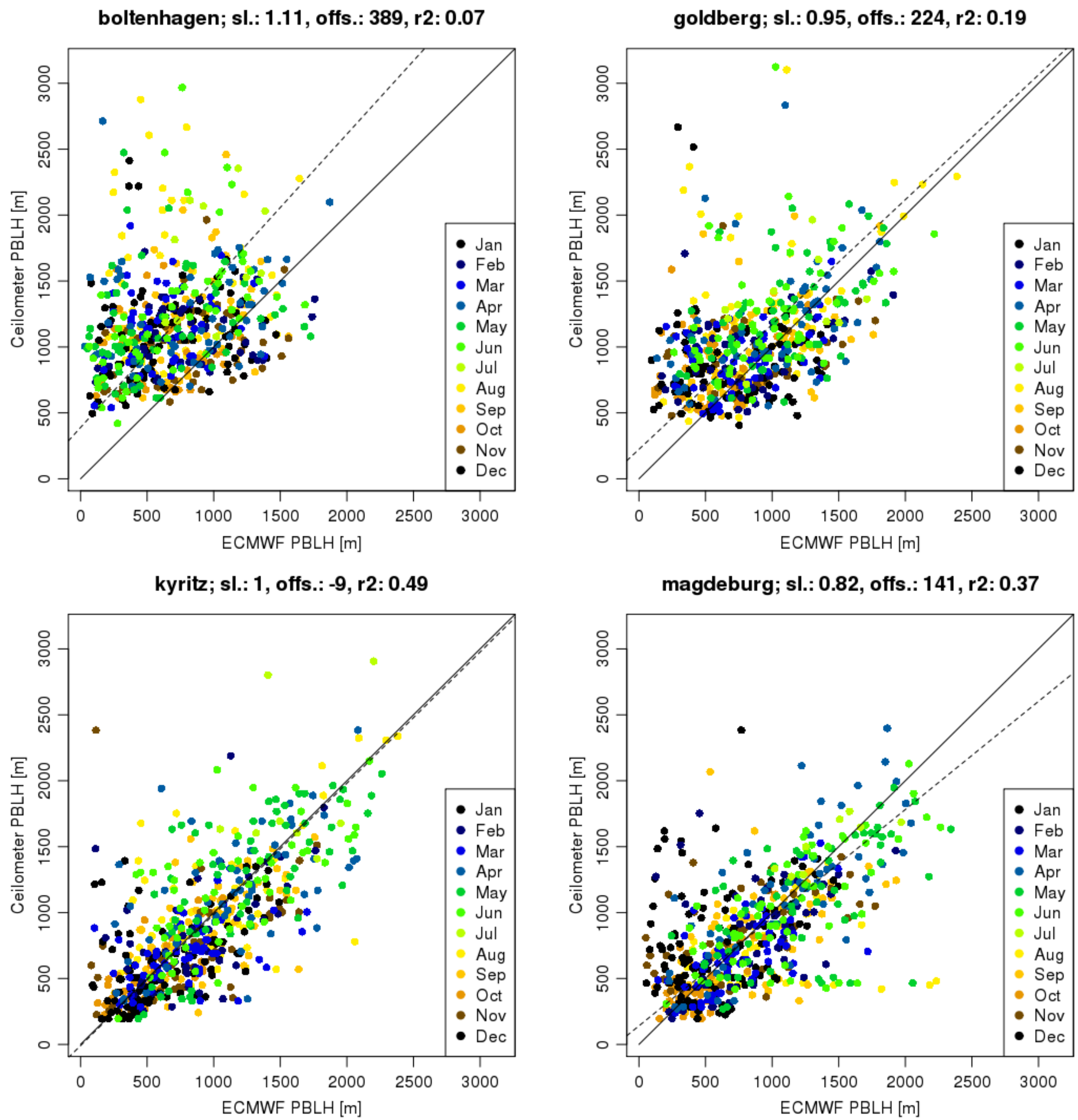


Using additional data streams: PBLH

Ceilometer vs. ECMWF

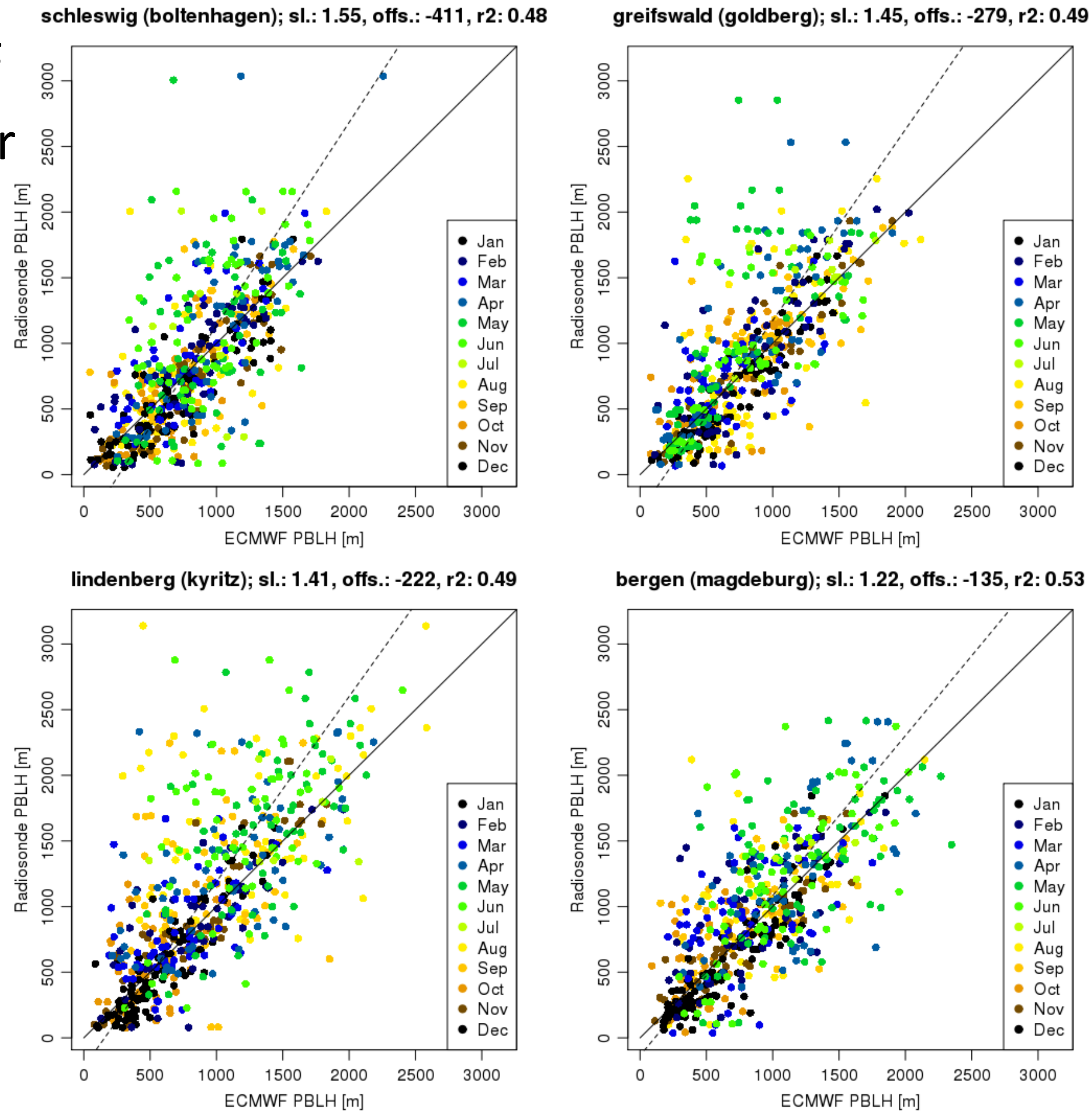
- First of 3 candidate PBLH chosen
- Only QC flag >1
- 15 s data -> hourly
- Rain excluded (weather data from co-located surface station)
- Only 10:00-14:00
- Up to 50% explained variance



Using additional data streams: PBLH

Radiosonde vs. ECMWF

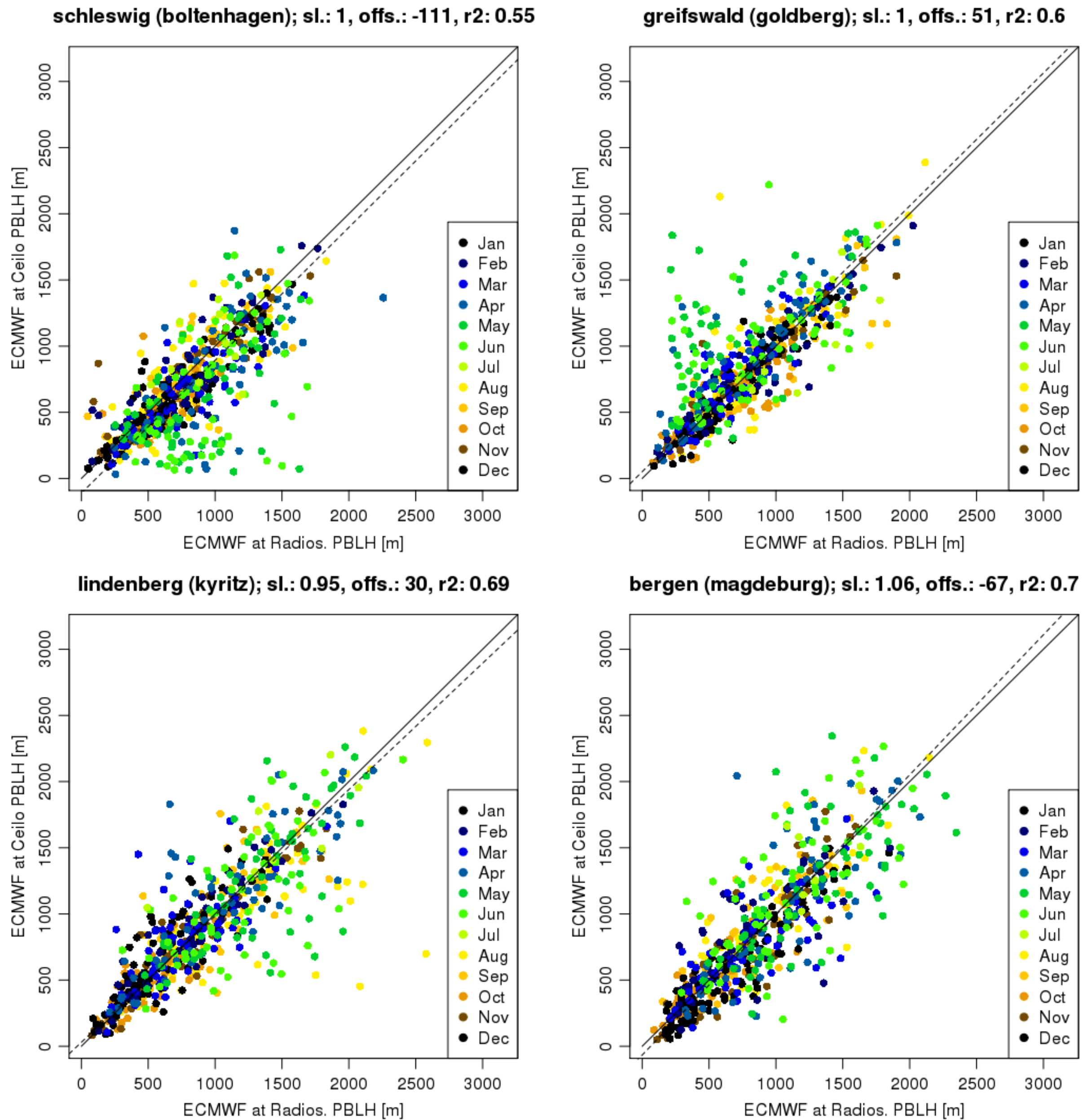
- Validation of transfer standard
- around 50% explained variance



Using additional data streams: PBLH

ECMWF vs. ECMWF

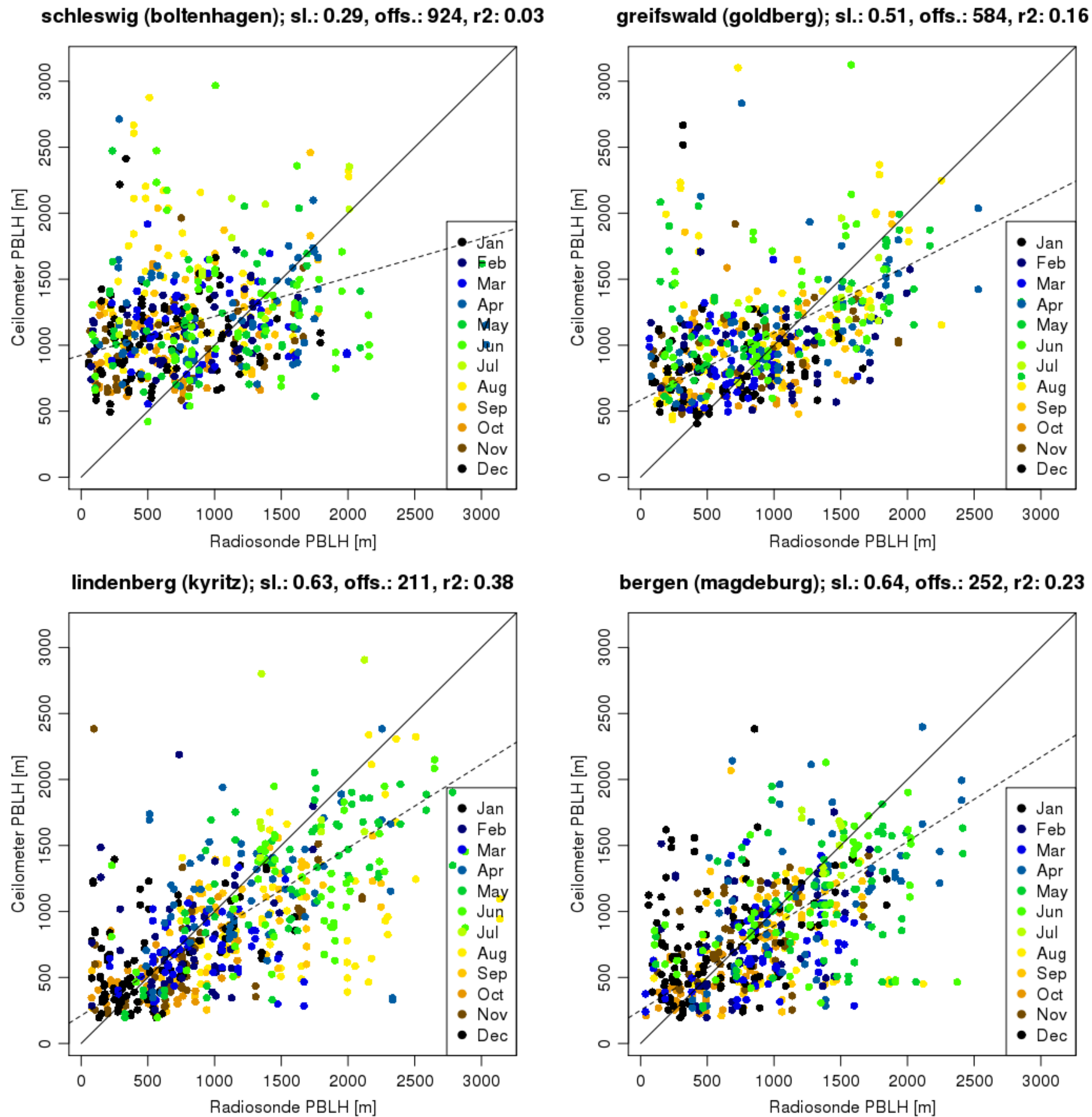
- Radiosonde and ceilometer locations 80-140 km apart



- around 70% explained variance

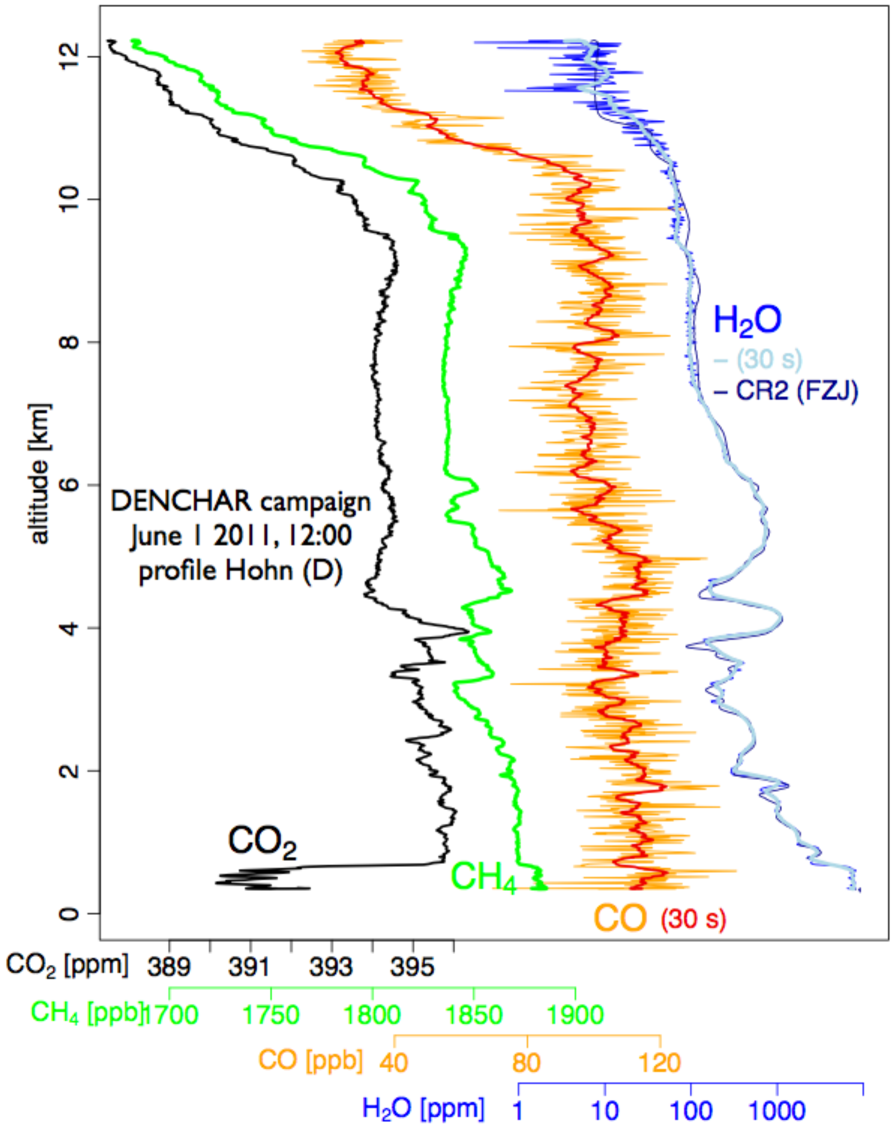
Using additional data streams: PBLH

Ceilometer vs.
Radiosonde



- 20-40% explained variance

Using additional data streams: regular profiles



- Regular vertical profiles of GHGs from airliners

Summary

- Data driven approach from local to continental-scale to infer fluxes from the land biosphere
- Flux estimates can be successfully retrieved down to country and monthly scales
- Spatially resolved flux estimates potentially affected by assumed emissions => fossil CO2 prior at higher resolution for filtering
- up-to-date inversion products possible with near-real time data
- Utilizing mixing heights from ceilometers seems possible
- **Outlook**: H2020 proposal VERIFY (Observation-based system for monitoring and verification of greenhouse gases)
    - Multiple emission inventories, Multiple NEE flux priors
    - Validation against IAGOS profiles
    - High-res. ffCO_2 simulations for dense observations within hotspot region