Regional, country scale carbon budgets: where do we stand?

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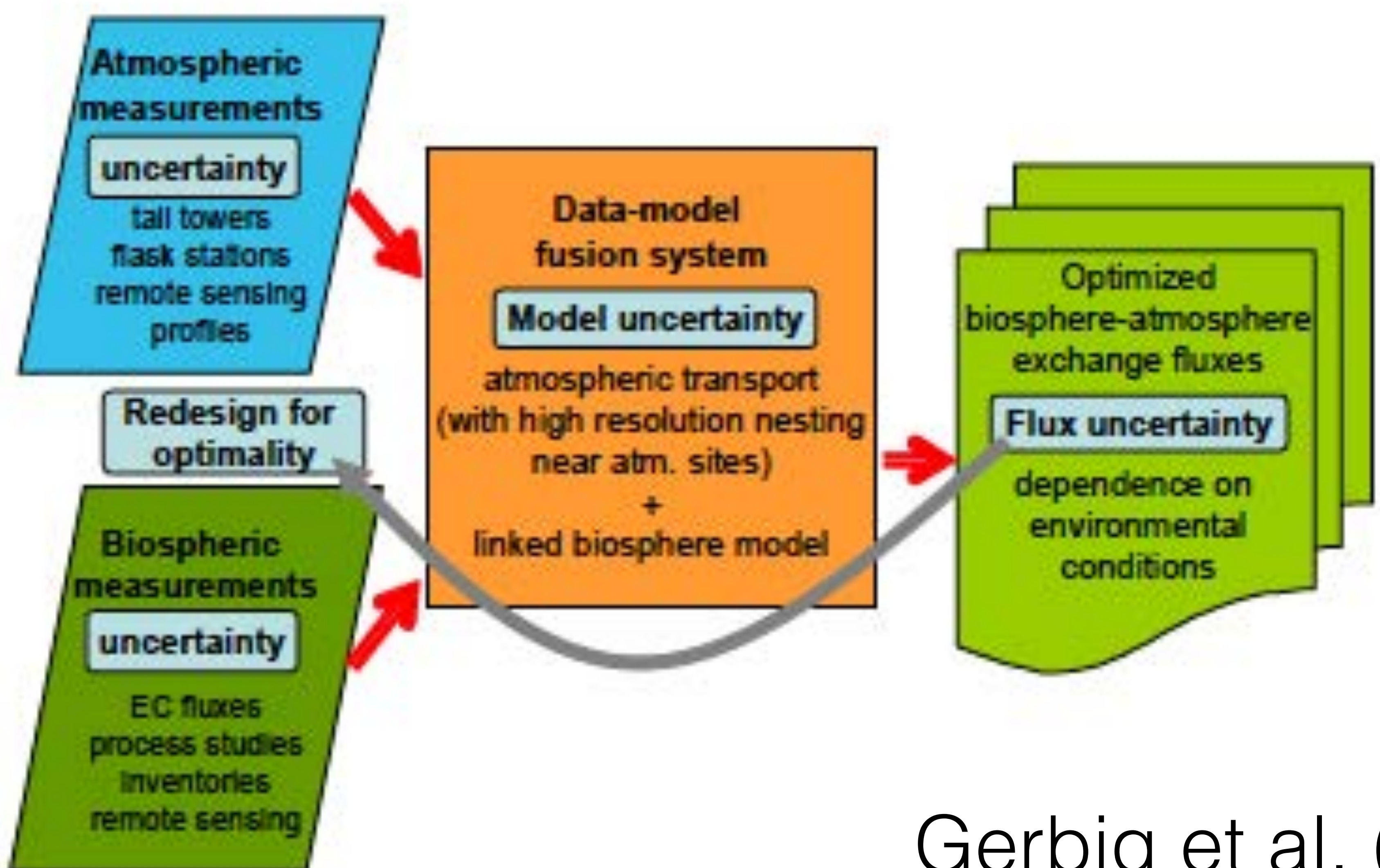
Regional carbon budgeting

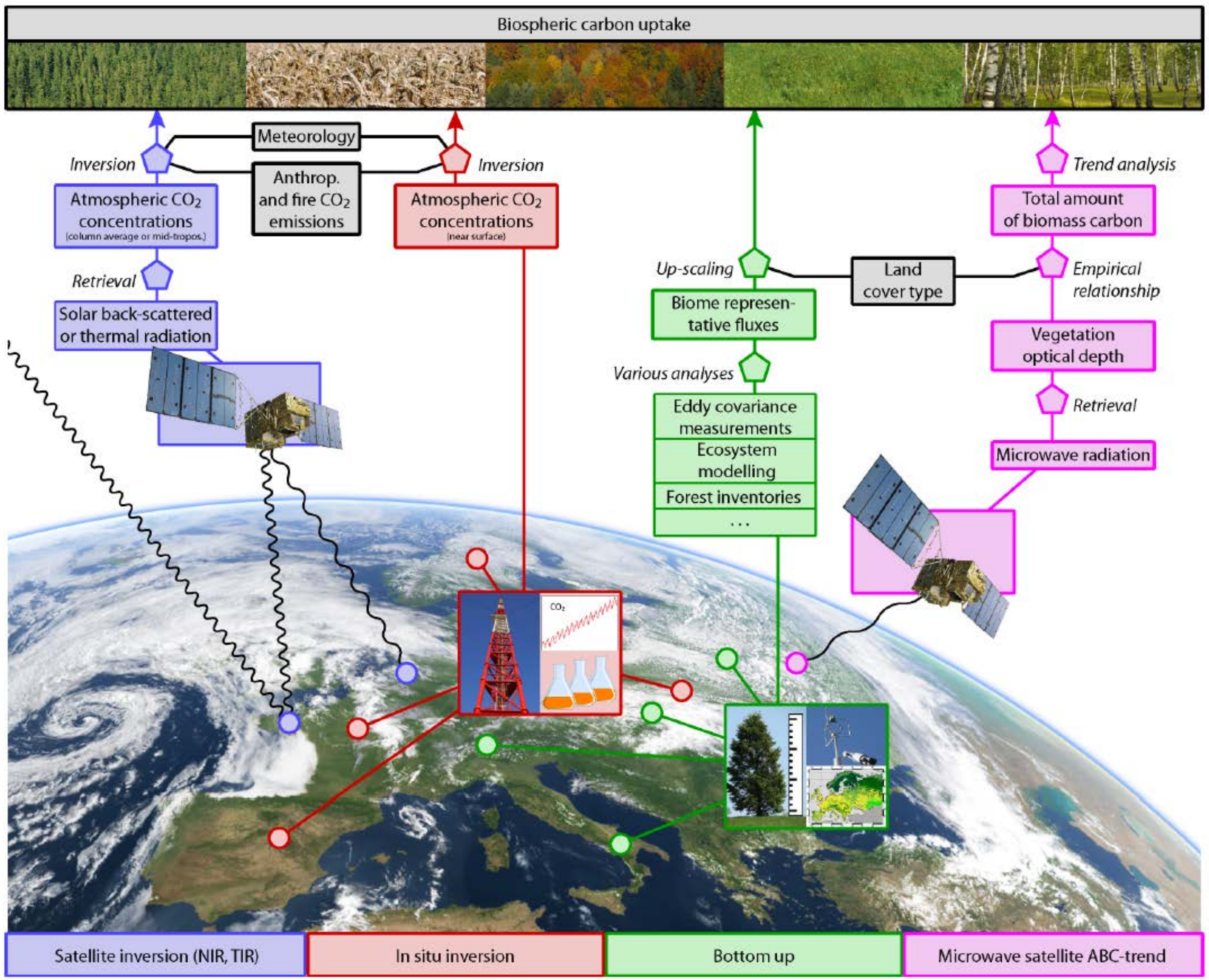
- Some issues with mesoscale models
- Where uncertainties meet regional budgets: future satellite requirements
- What has changed since Paris?
- Closed country budgets?

The data fusion system we all aim to have



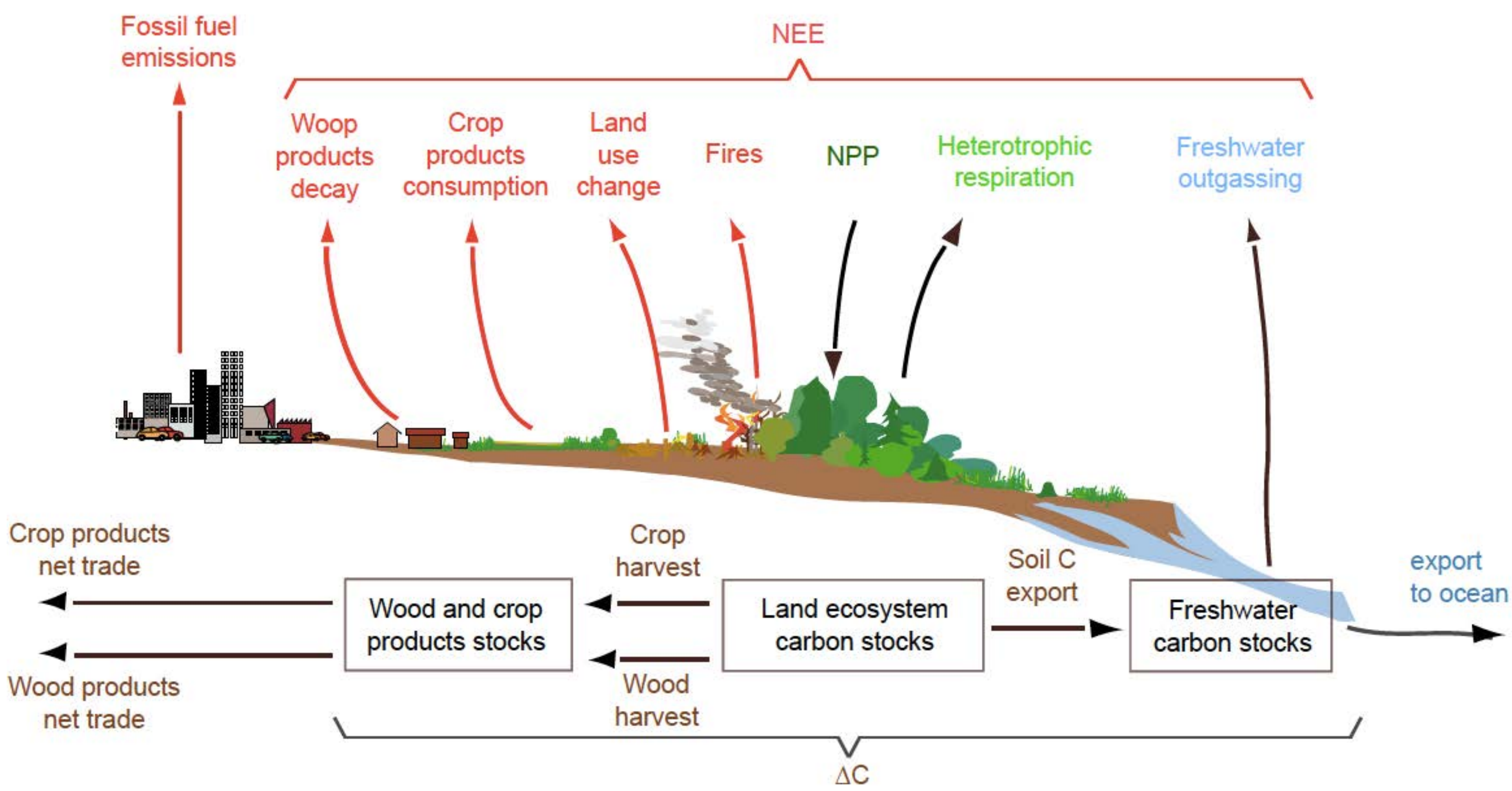
Gerbig et al. (2009)

But we want more…

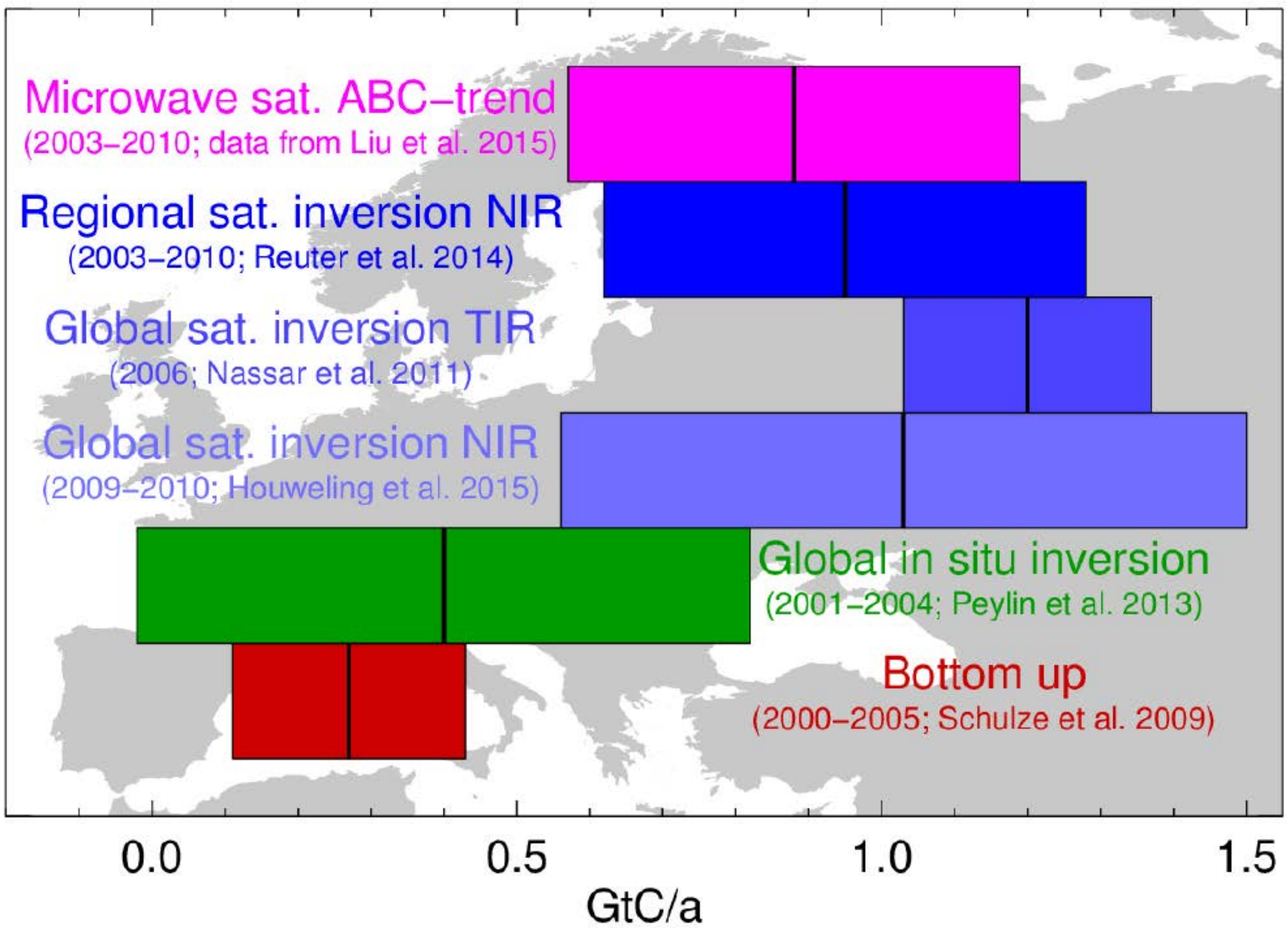


Reuter et al., 2016

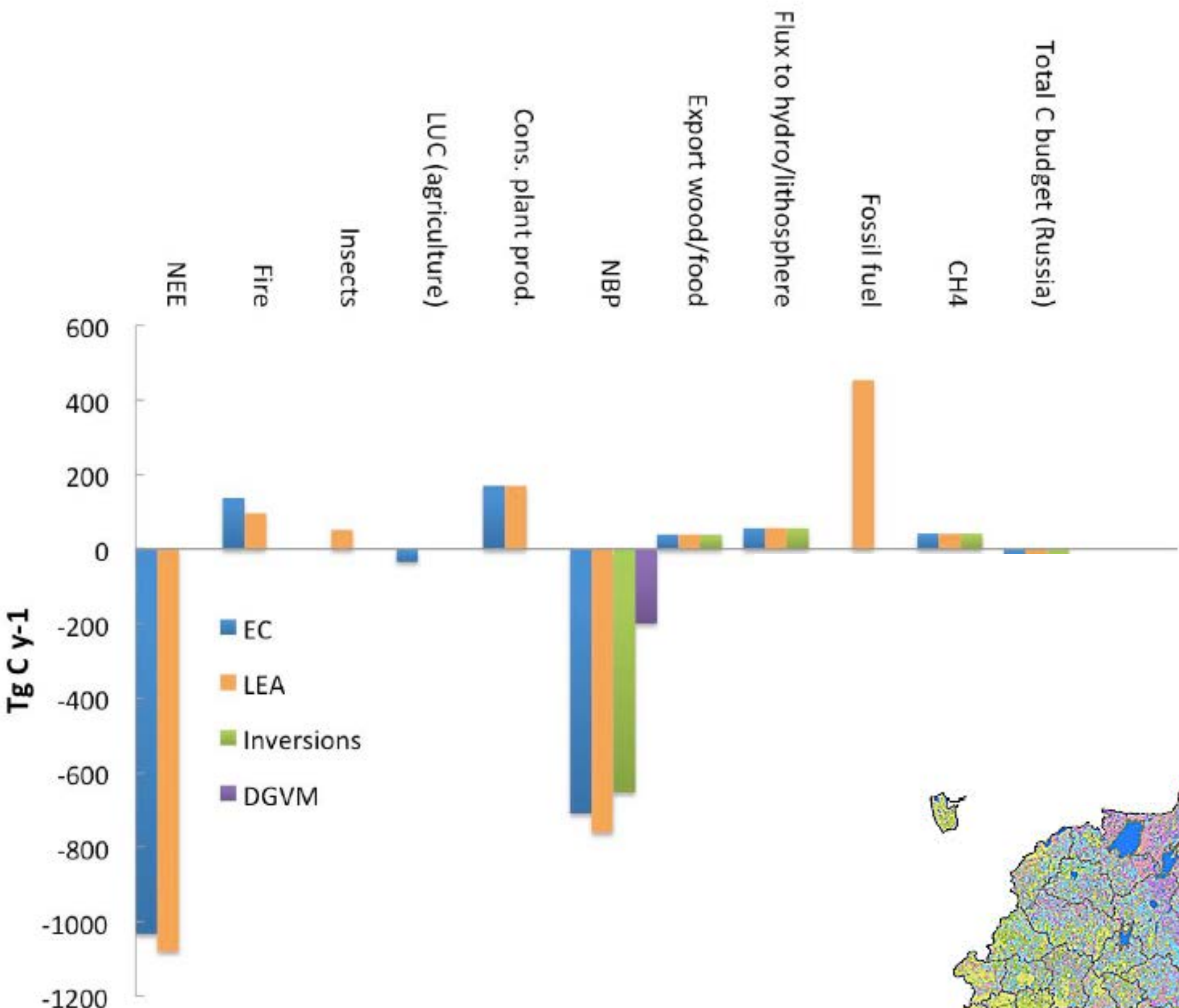
The bottom up balance



How good are we at that?



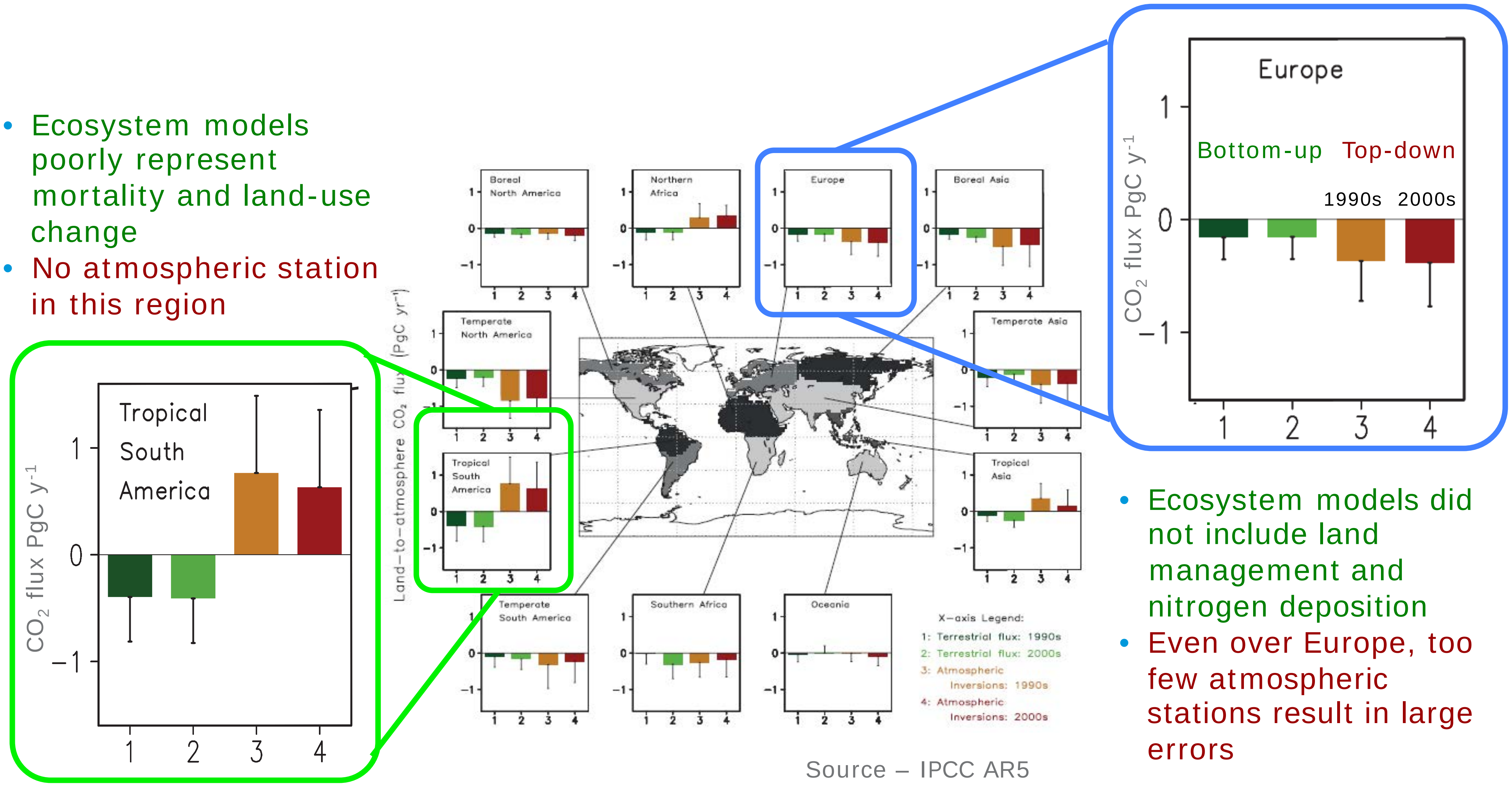
Continental carbon balance…



Dolman et al, 2012

(un)closed budgets at the continental scale

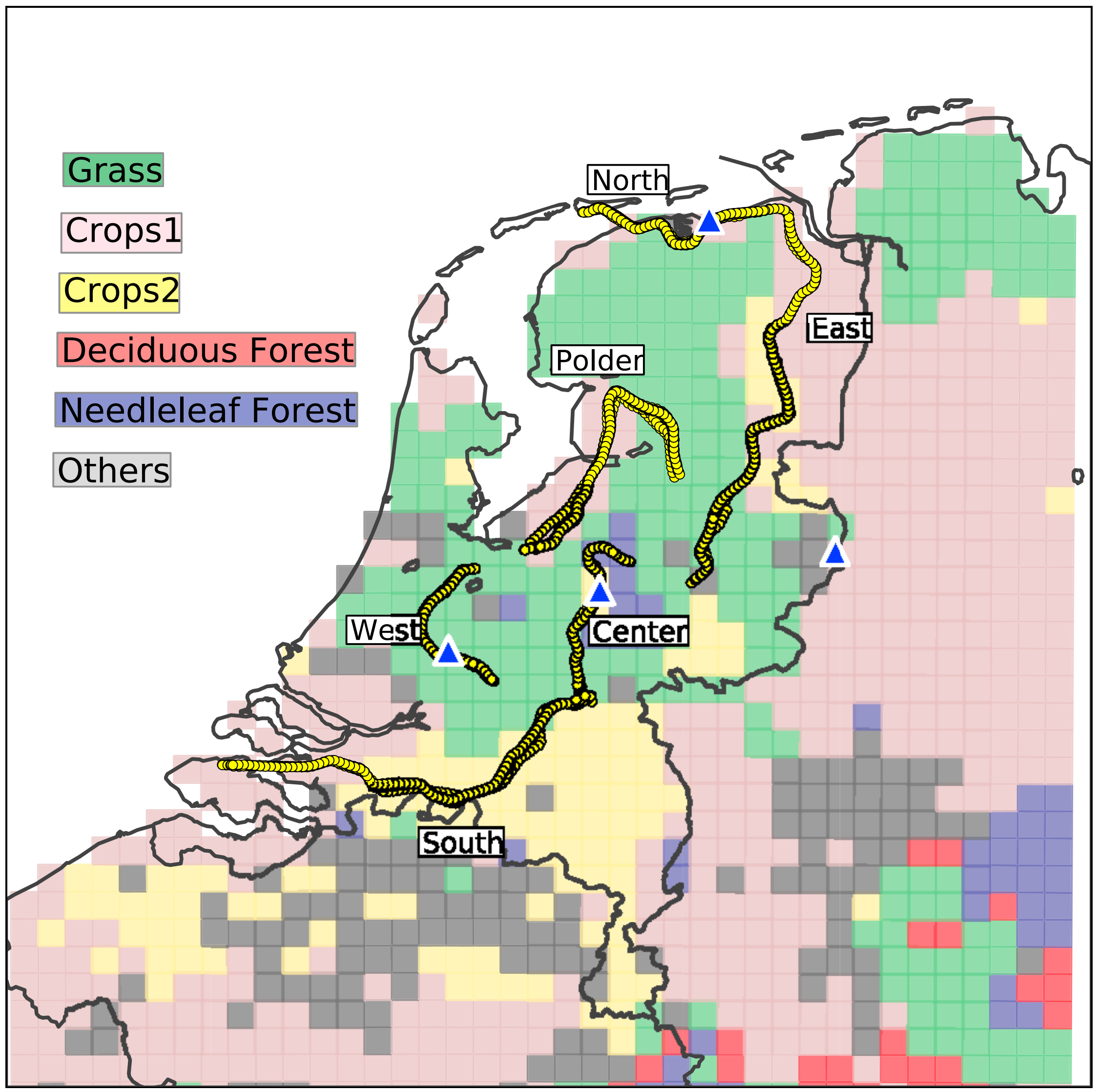
- Ecosystem models poorly represent mortality and land-use change
- No atmospheric station in this region



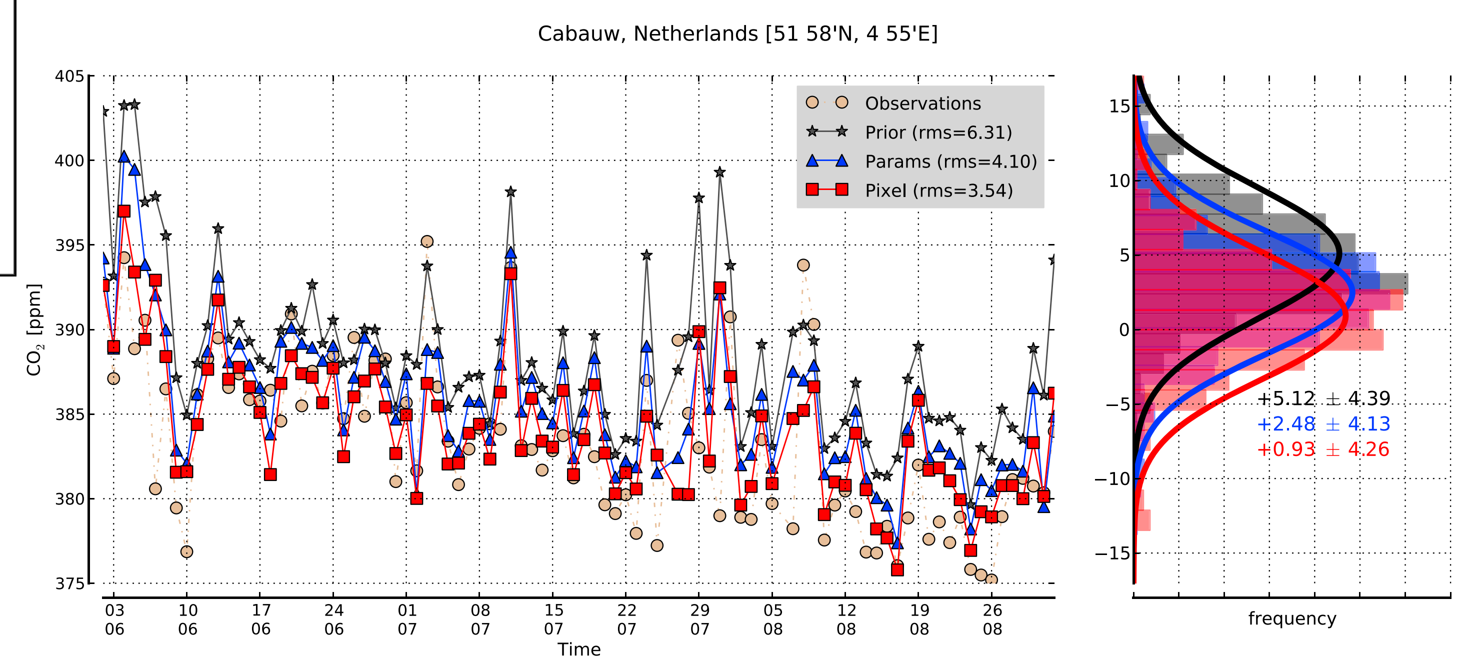
- Ecosystem models did not include land management and nitrogen deposition
- Even over Europe, too few atmospheric stations result in large errors

- Large discrepancies between bottom-up models and atmospheric inversions
- Tropics and high latitudes regions have almost no observation
- Large uncertainties ~100% on regional budgets !

Country scale budgets

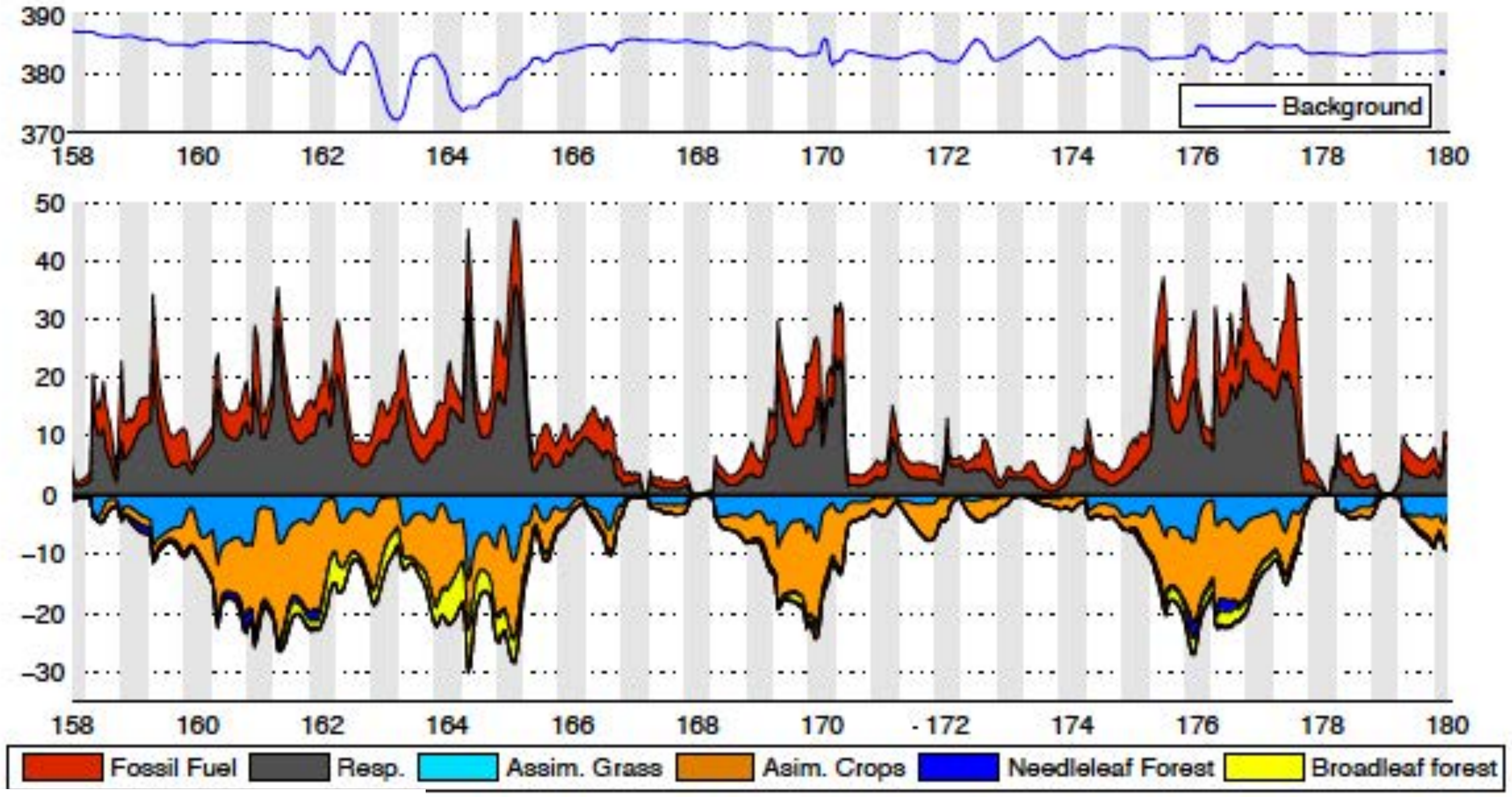


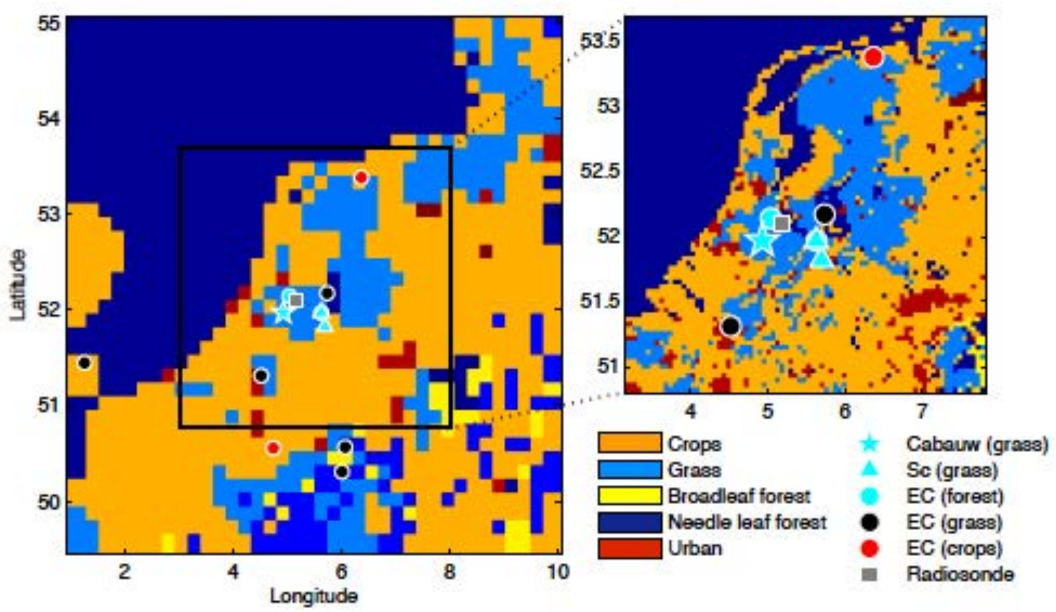
6 ecoregions
pixel and parameter inversion
ensemble Kalman filter
comparison with aircraft data



Meesters et al., 2012, JGR

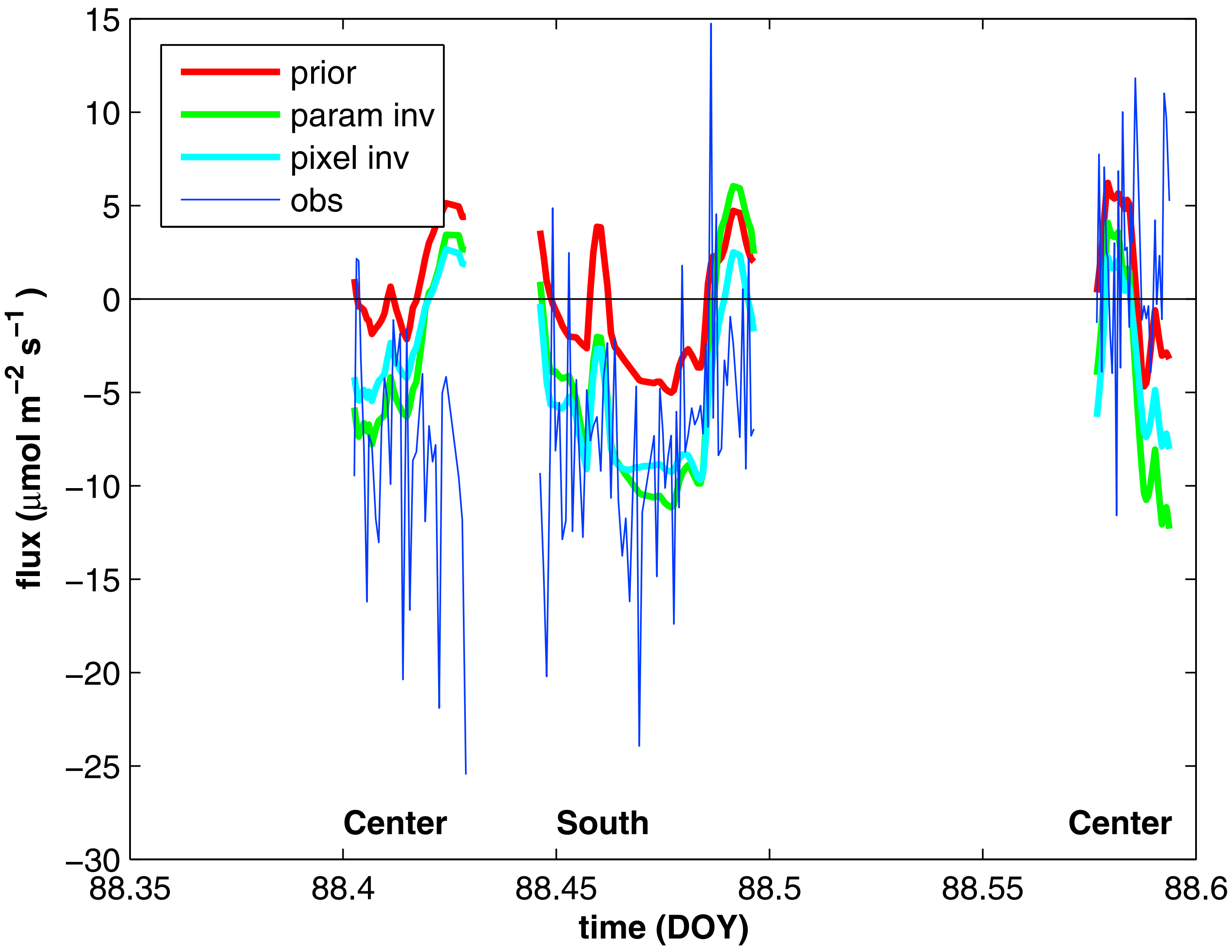
Contributions of fossil and land use





Tolk et al., 2009

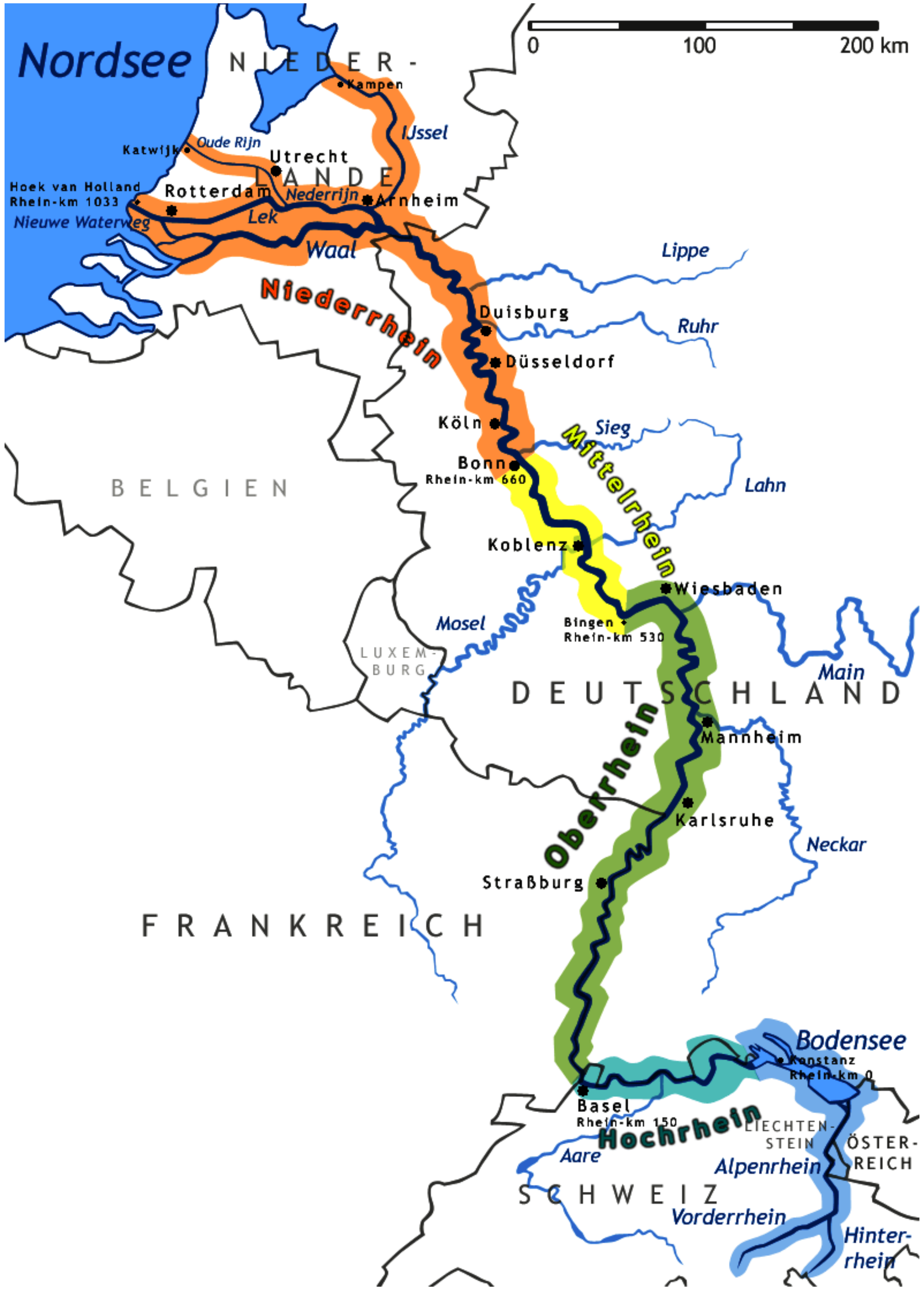
Comparing with aircraft fluxes



Meesters et al., 2012

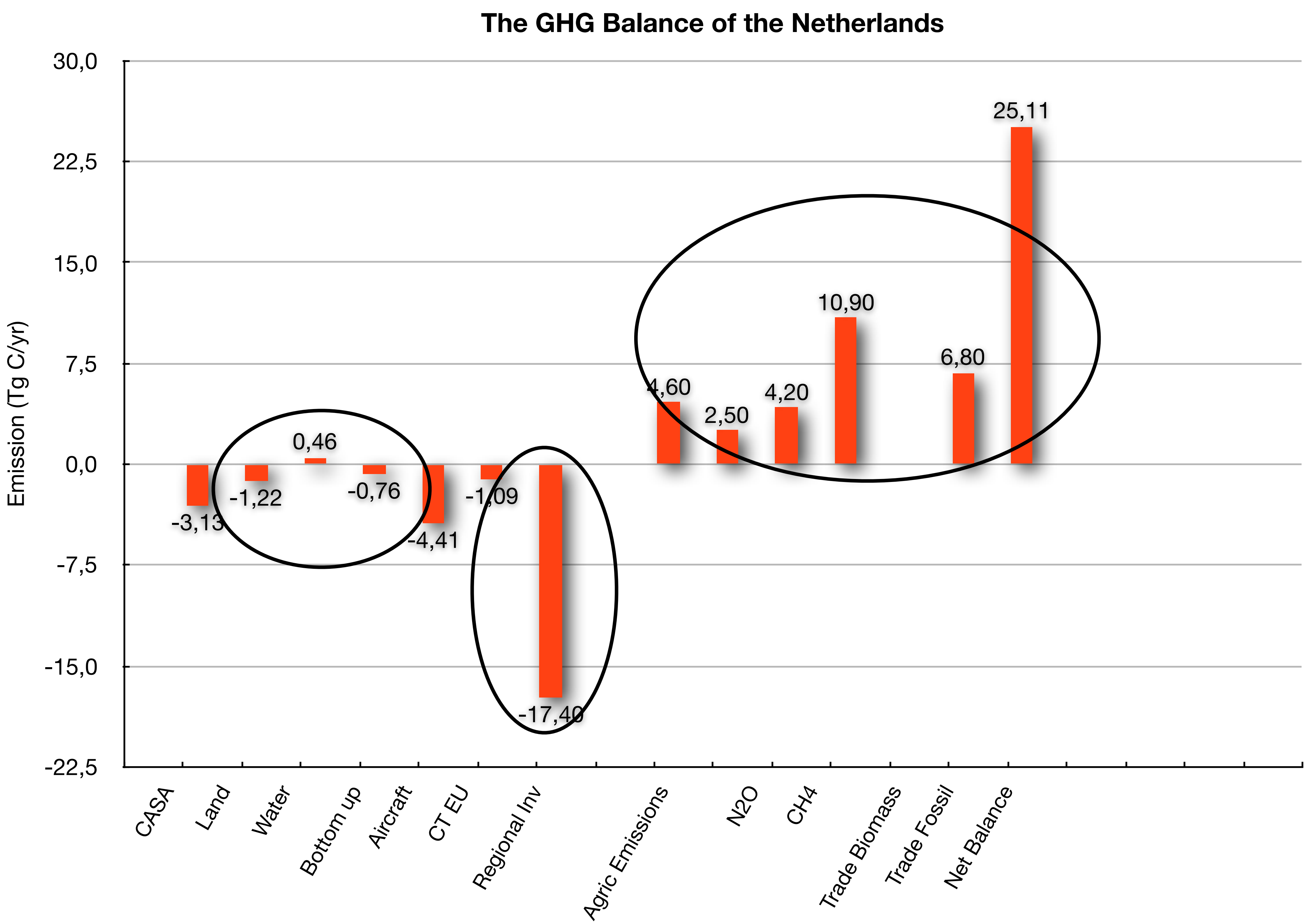
Inland waters

- Input Rhine at border TOC 2.5 TgC yr^{-1}
- Evasion Rhine 34.6 Gg C yr^{-1}
- Evasion Scheldt 0.136 Tg C yr^{-1}
- Lake IJssel outflow is 133 Gg C yr^{-1}; evasion is 20 Gg C yr^{-1} (scaled)
- Others (18% of the surface area of the country is water) 0.27 Tg C yr^{-1}
- Total 0.46 Tg C yr^{-1}



Sources: Abril, 2002; Hofmann et al., 2008; Bareta, Ruardi, 1989

The GHG Balance of the Netherlands



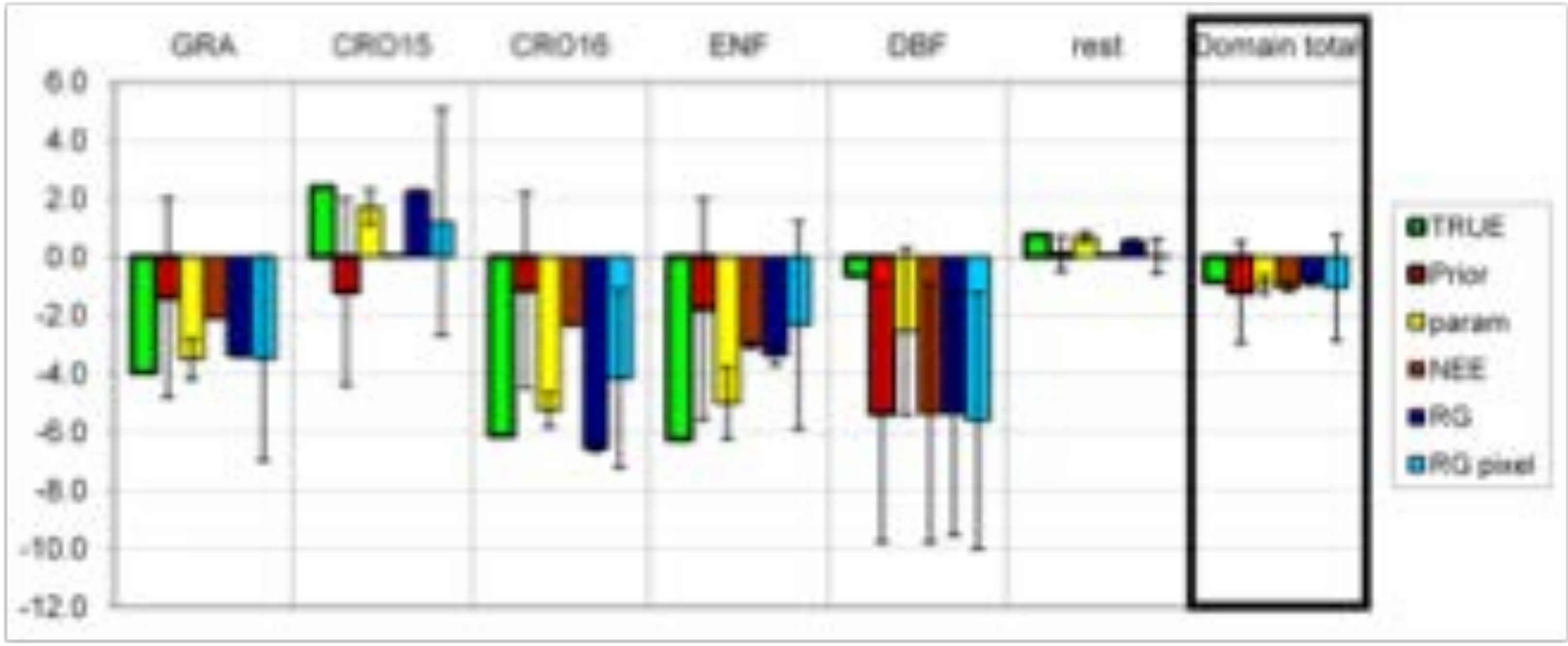
Trade date courtesy Glen Peters

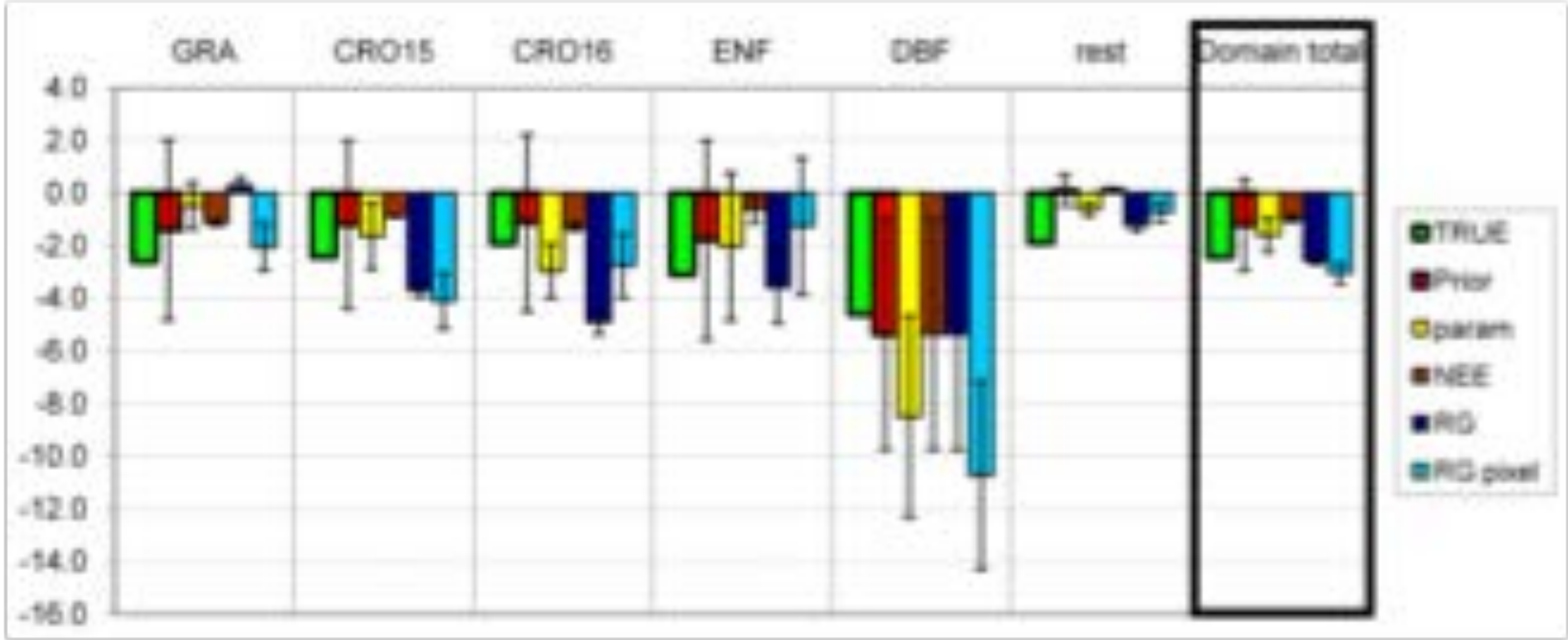
Atmosphere: sources of error

Source of uncertainty	Type or error	Size	Impact on observational strategy	Reference
Transport Model	Advection	~5 ppm (summertime)	avoid regions with complex flows	Lin and Gerbig, 2005
	PBL mixing	~3.5 ppm (summertime)	Vertical profiling, column observations	Gerbig et al., 2008
	Convection	No estimate		–
	Mesoscale processes	~2–3 ppm (summertime)	Avoid regions with mesoscale flows	Van der Molen and Dolman (2007), Tolk et al., 2008
Transport and Flux Model	Grid resolution	~1 ppm @ 200 km (summertime)	Choice of representative stations	Gerbig et al., 2003
Flux Model	Prior uncertainty	2-8 ppm*** (summertime)	network elements distributed according to prior uncertainties	P. Peylin, personal communicarion, 2008
	Aggregation	Depending on Aggregation and Model		Gerbig et al., 2006
Measurement	Precision, accuracy	0.1 ppm (targeted)	WMO	WMO

Gerbig et al., 2009

Synthetic study





Tolk et al., 2011 ACPD

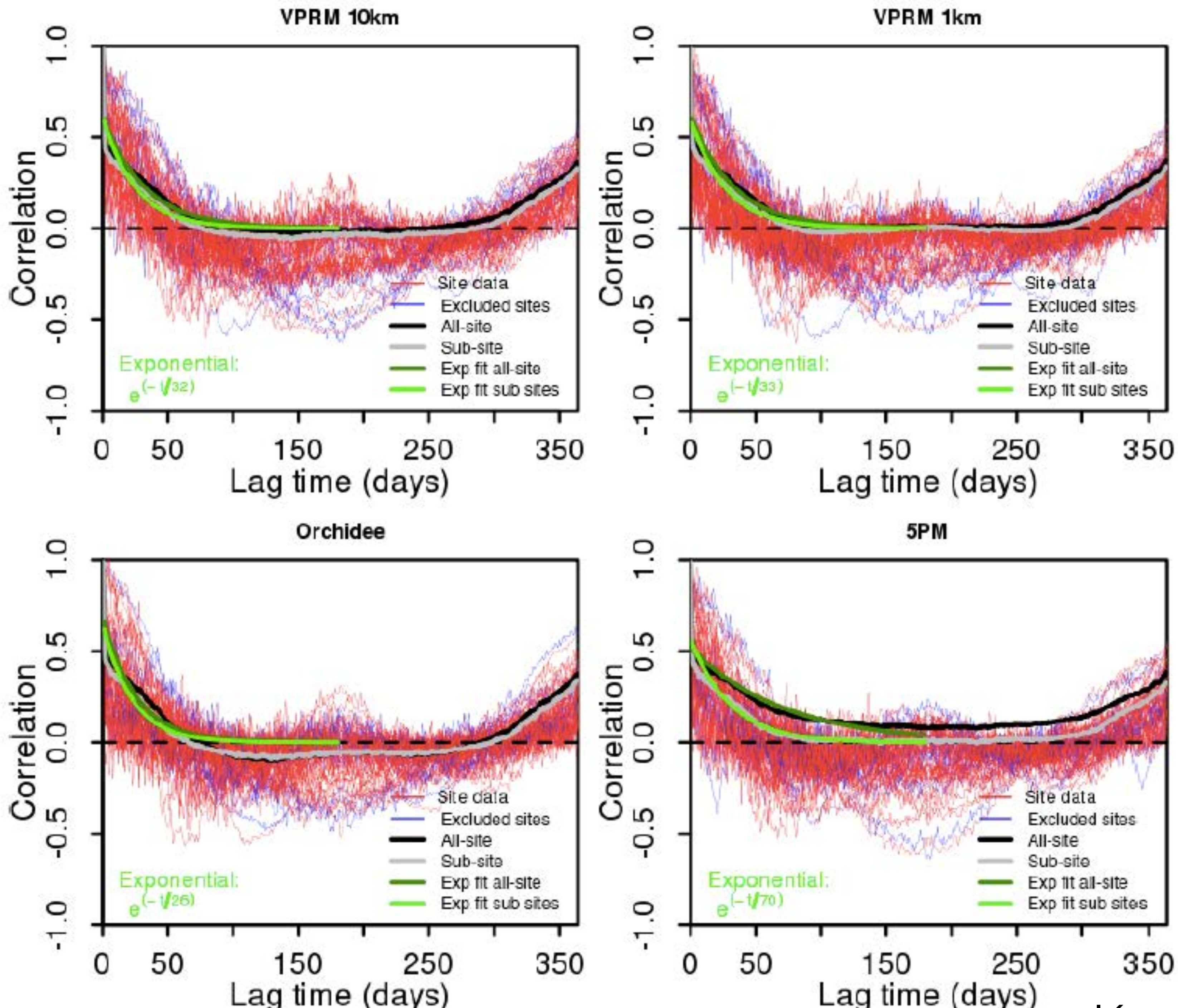
Different inversion schemes tested with different "priors"

Lack of improvement in mean NEE for most land-use classes

Models are **overconfident** (model structure important)

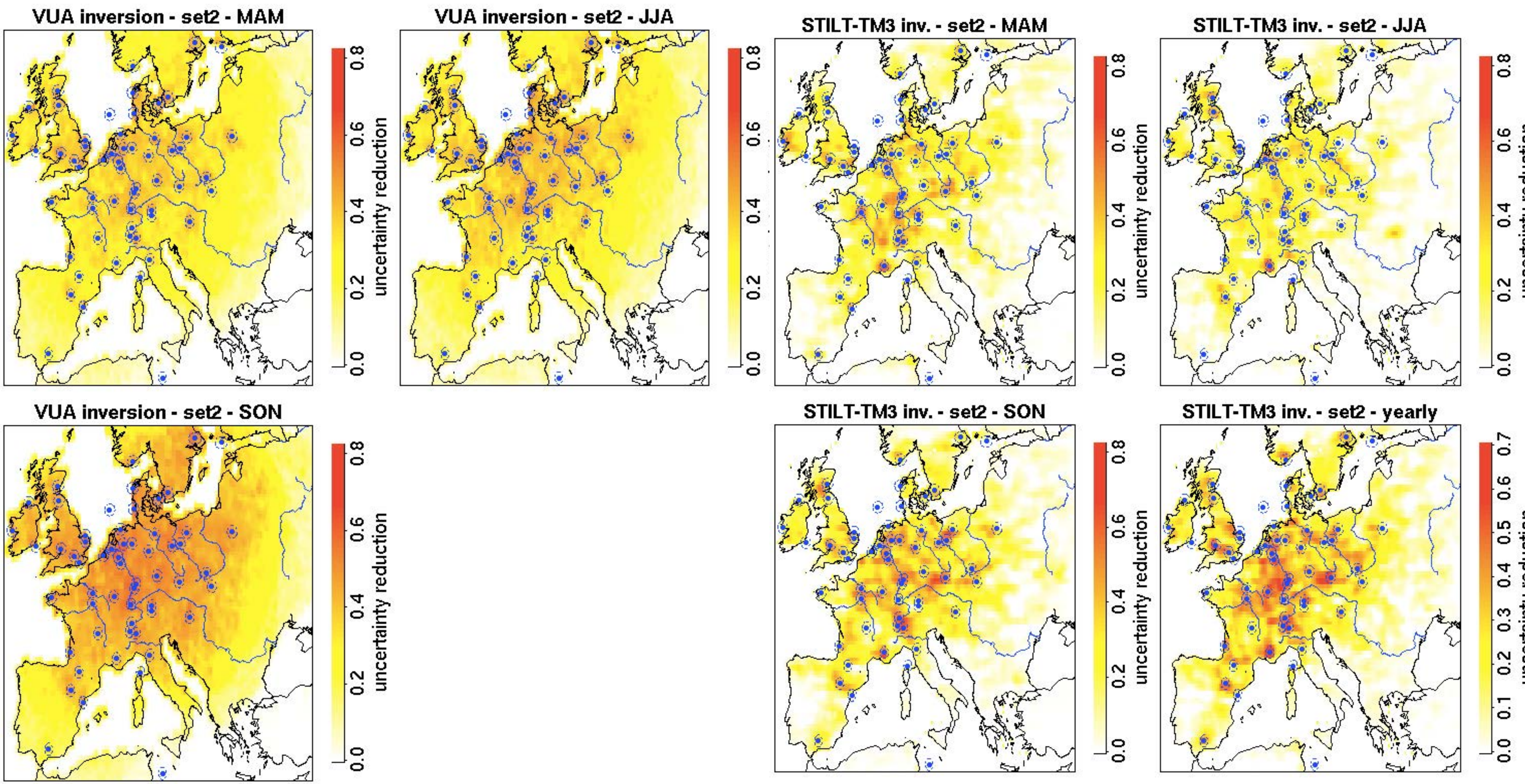
Scaling NEE from prescribed spatiotemporal patterns most susceptible to these errors

Structure: correlation length scales

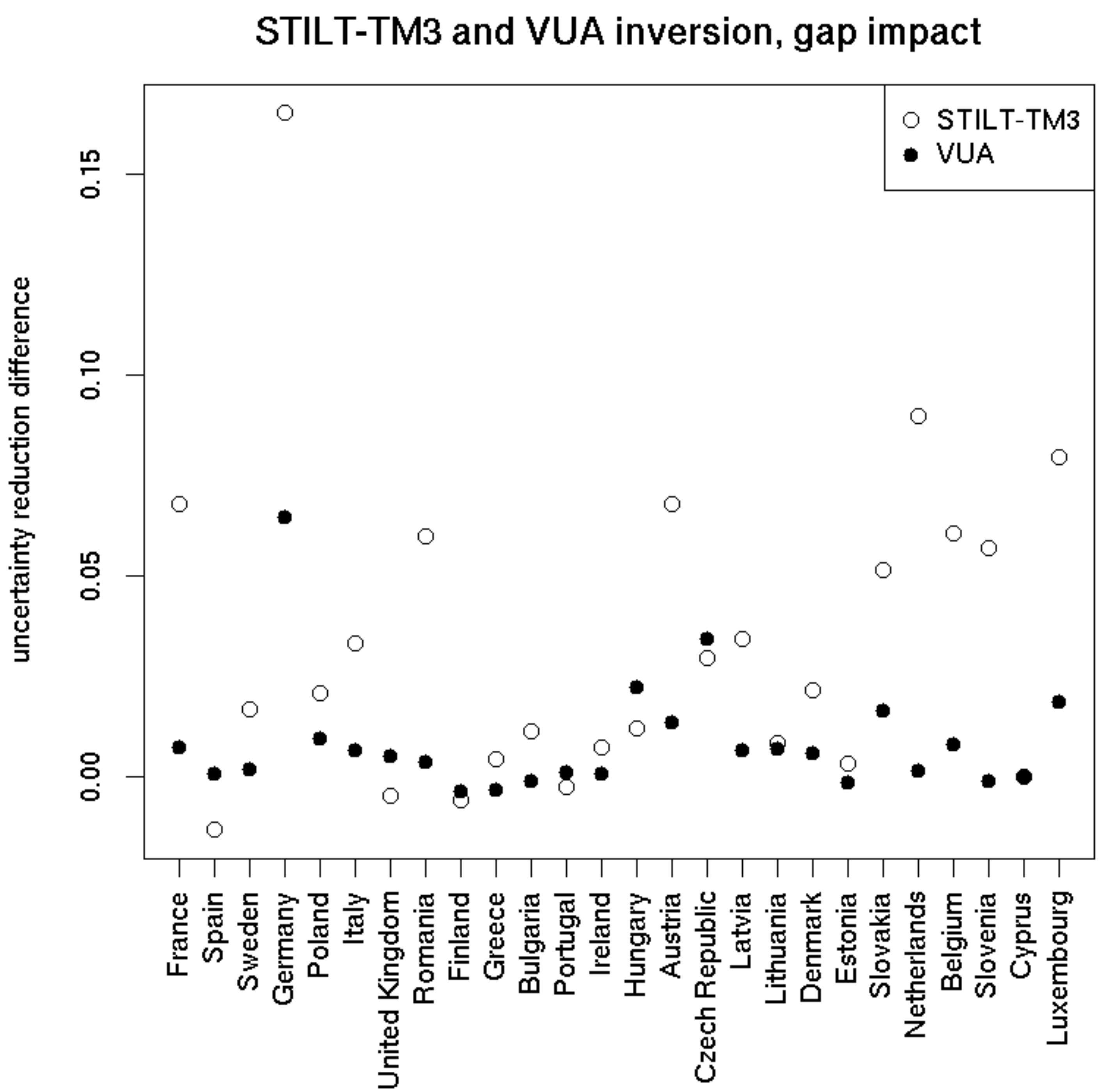


Kountouris et al, 2015

Mesoscale inversions



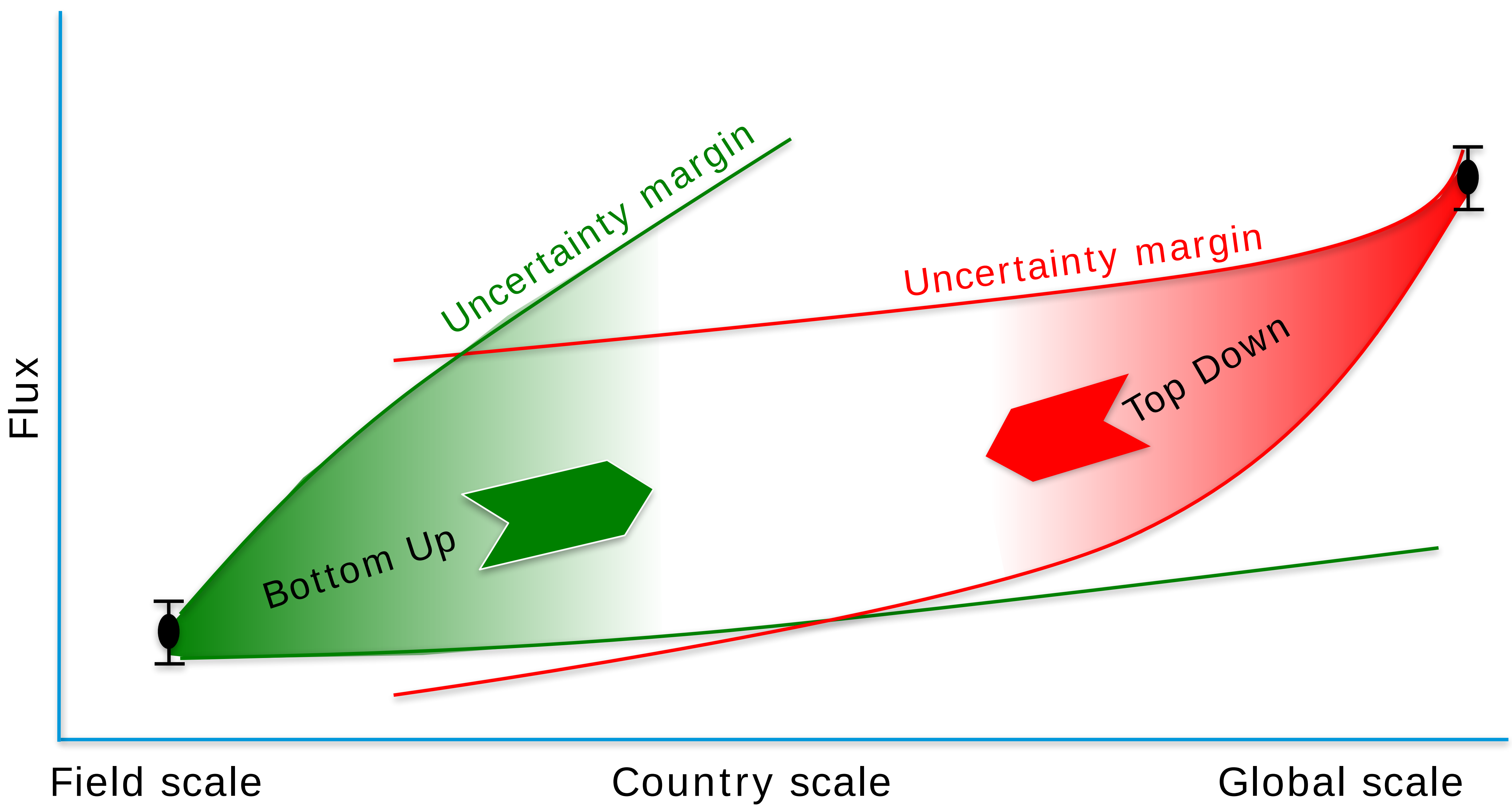
Uncertainty reduction at country scale



No “observations’ in Germany

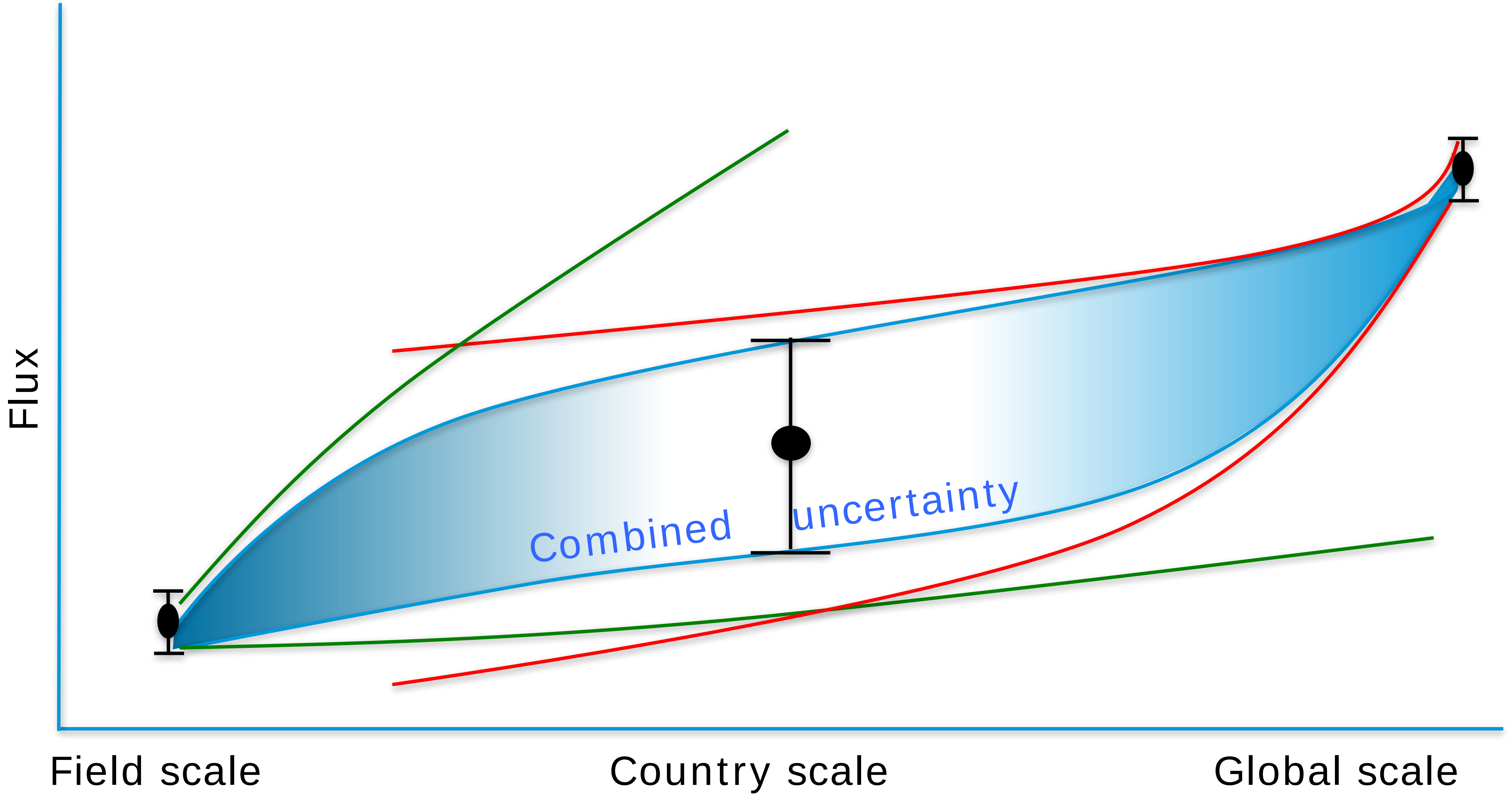
Impact wider than just surrounding areas

Bridging scales

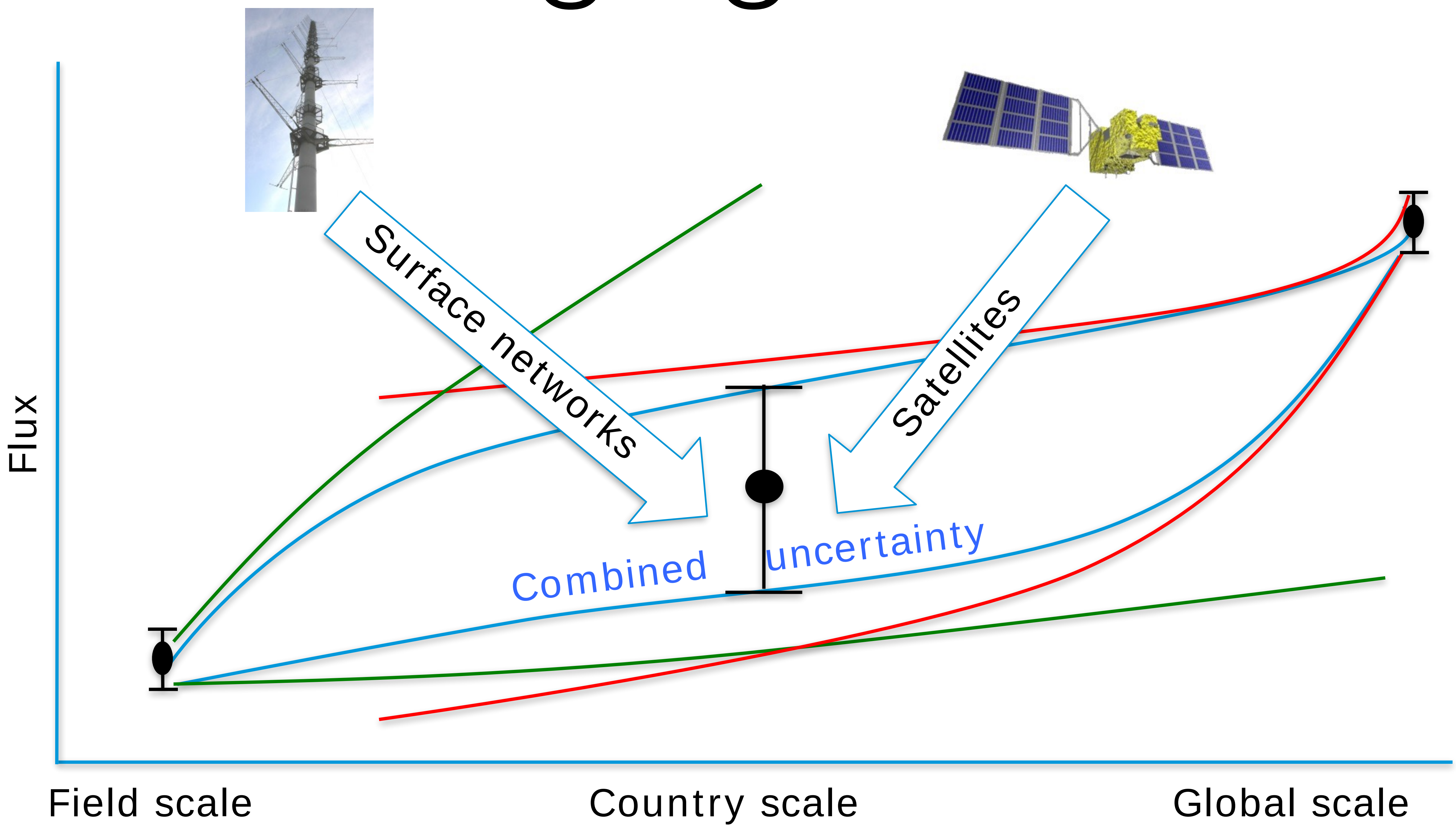


Slide Sander Houweling

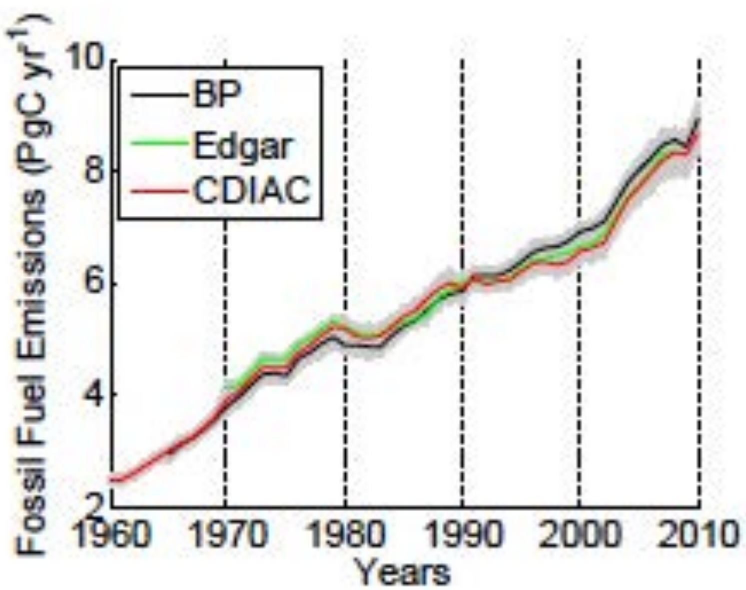
Bridging scales

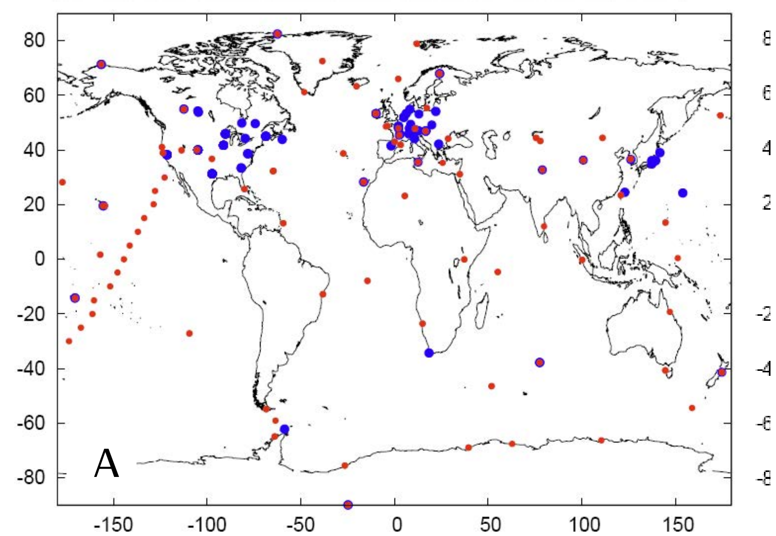


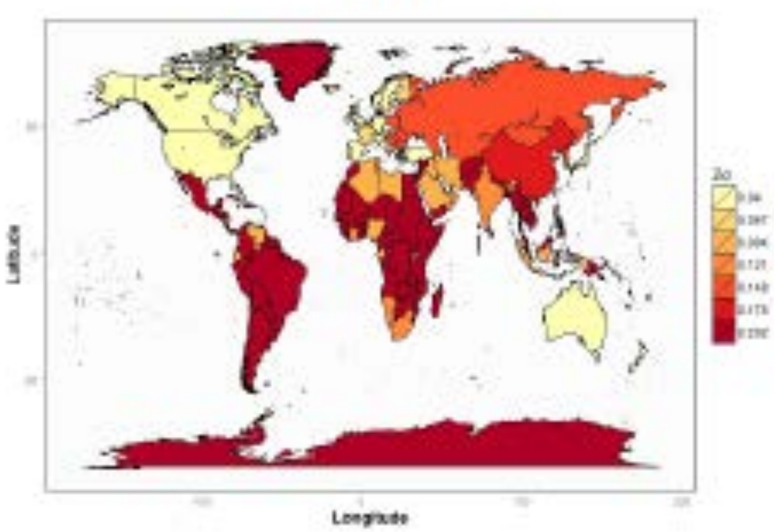
Bridging scales

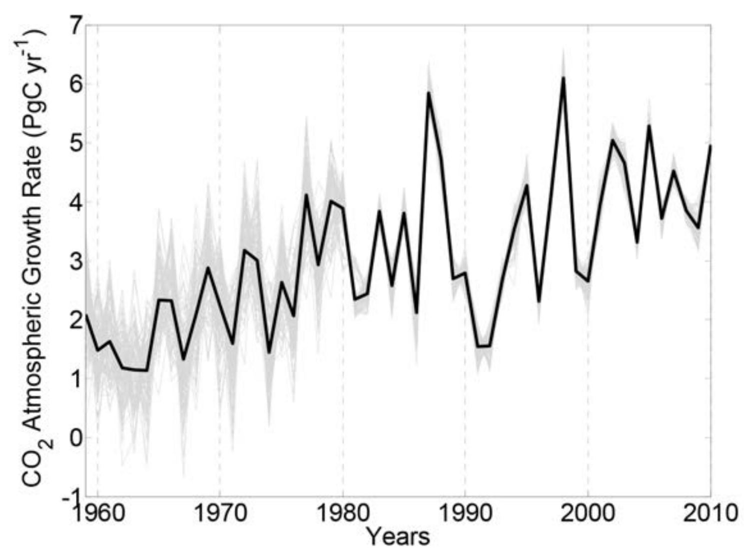


The increasing importance of fossil fuel emissions





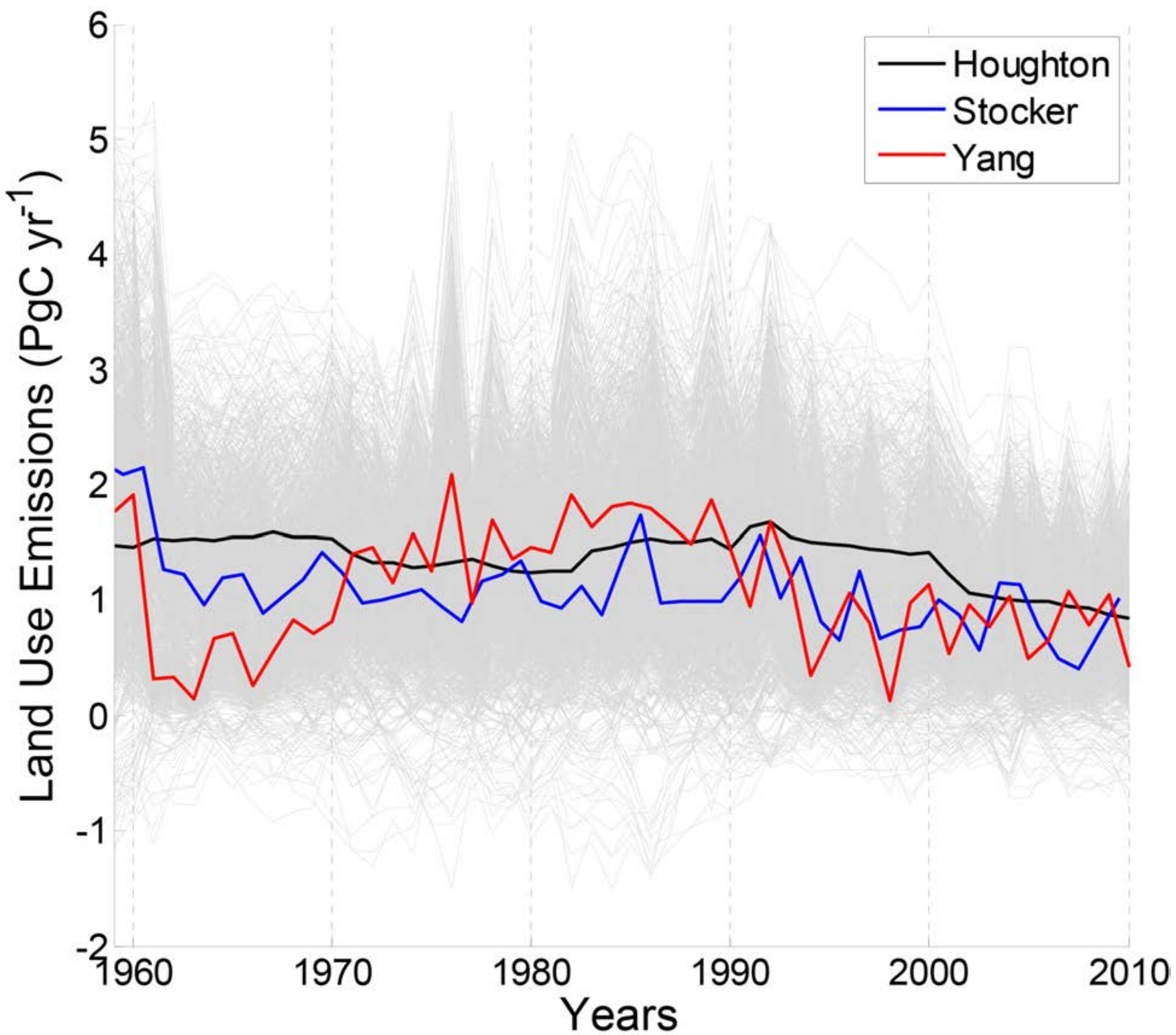




The 2σ uncertainties in **fossil fuel emissions** have increased from 0.3 Pg C yr^{-1} in the 1960s to almost 1.0 Pg C yr^{-1} during the 2000s due to differences in national reporting errors and differences in energy inventories.

Ballantyne et al., 2015

Uncertainties in land use



While uncertainties in growth rate have gone down, those in land use have remained the same

Variable	Decadal mean values and standard deviations 1960s	1970s	1980s	1990s	2000s
Atmospheric CO_2 ($PgC\,yr^{-1}$; $\partial C/\partial t$)	1.75	2.72	3.42	3.18	4.14
Mean of standard deviations	(0.60)	(0.61)	(0.22)	(0.18)	(0.16)
Standard deviation of the means	(0.61)	(0.91)	(1.21)	(1.40)	(0.82)
Land use emissions ($PgC\,yr^{-1}$; E_L)	1.16	1.28	1.42	1.15	0.89
Mean of standard deviations	(0.76)	(0.64)	(0.65)	(0.67)	(0.63)
Standard deviation of the means	(0.25)	(0.11)	(0.13)	(0.23)	(0.12)
Fossil fuel emissions ($PgC\,yr^{-1}$; E_F)	3.09	4.76	5.53	6.45	7.89
Mean of standard deviations	(0.15)	(0.24)	(0.30)	(0.35)	(0.47)
Standard deviation of the means	(0.44)	(0.41)	(0.33)	(0.24)	(0.69)

Ballantyne et al., 2015

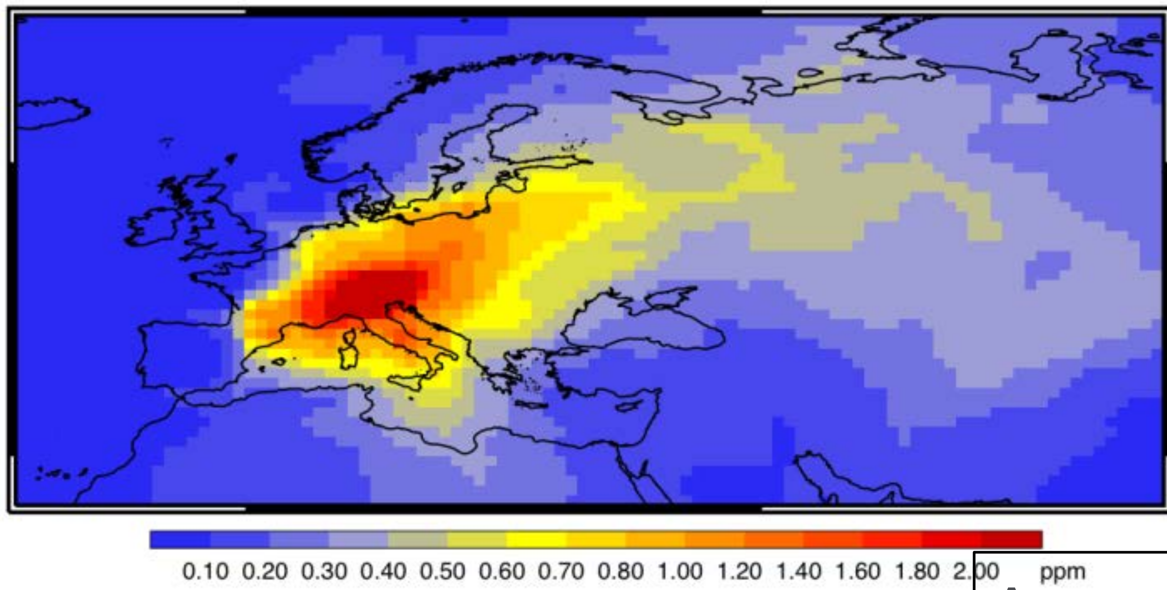
Two key issues…

- Renewed emphasis on fossil emission sources
- Requires rethinking of strategy (scaling)

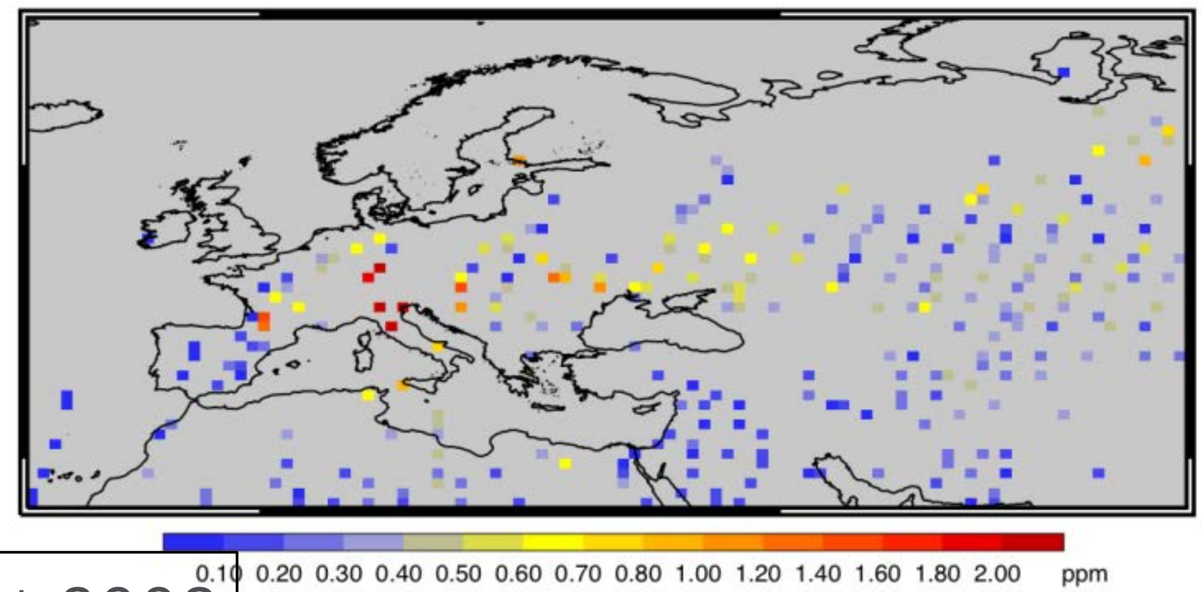
Are satellites the answer?

Carbon cycle and climate

Heat wave induced CO_2

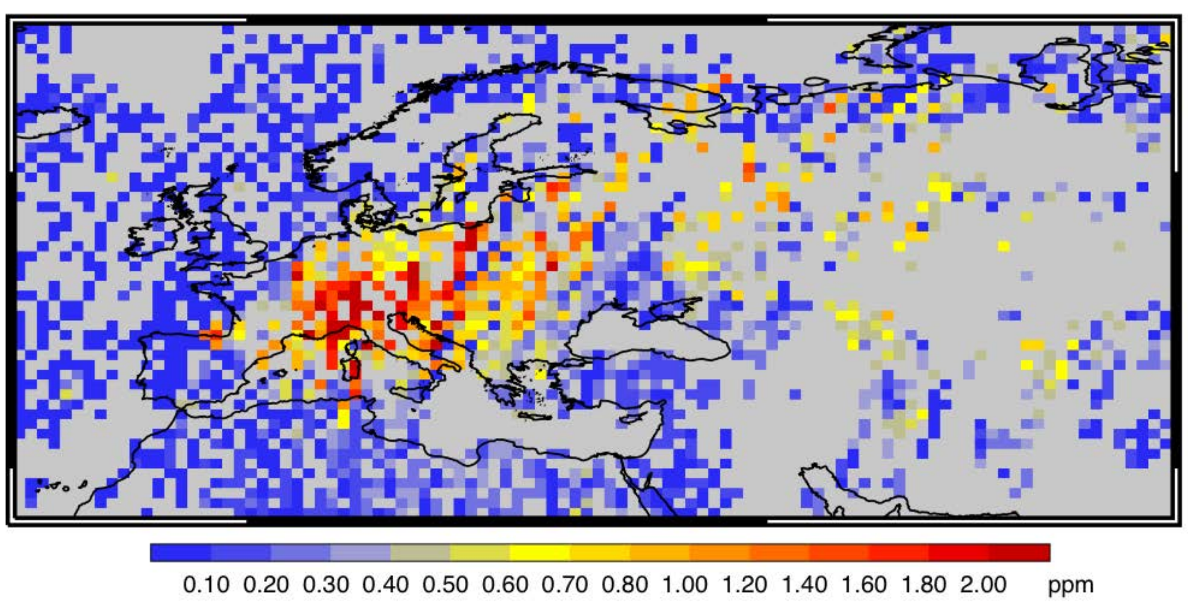


GOSAT

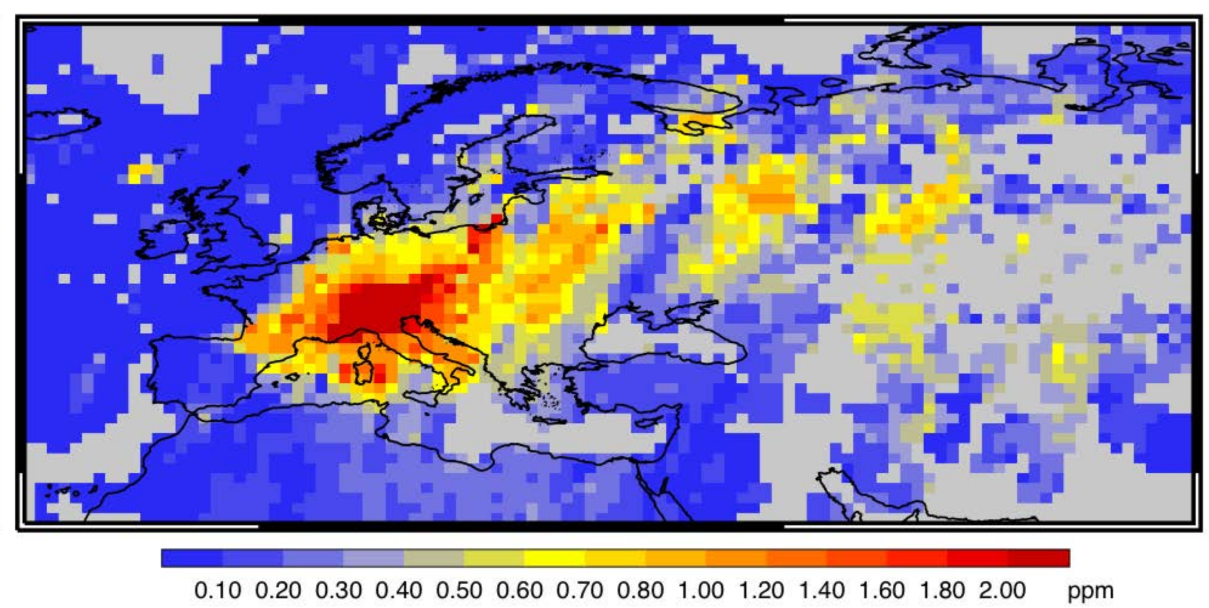


August 2003

OCO-2



Future



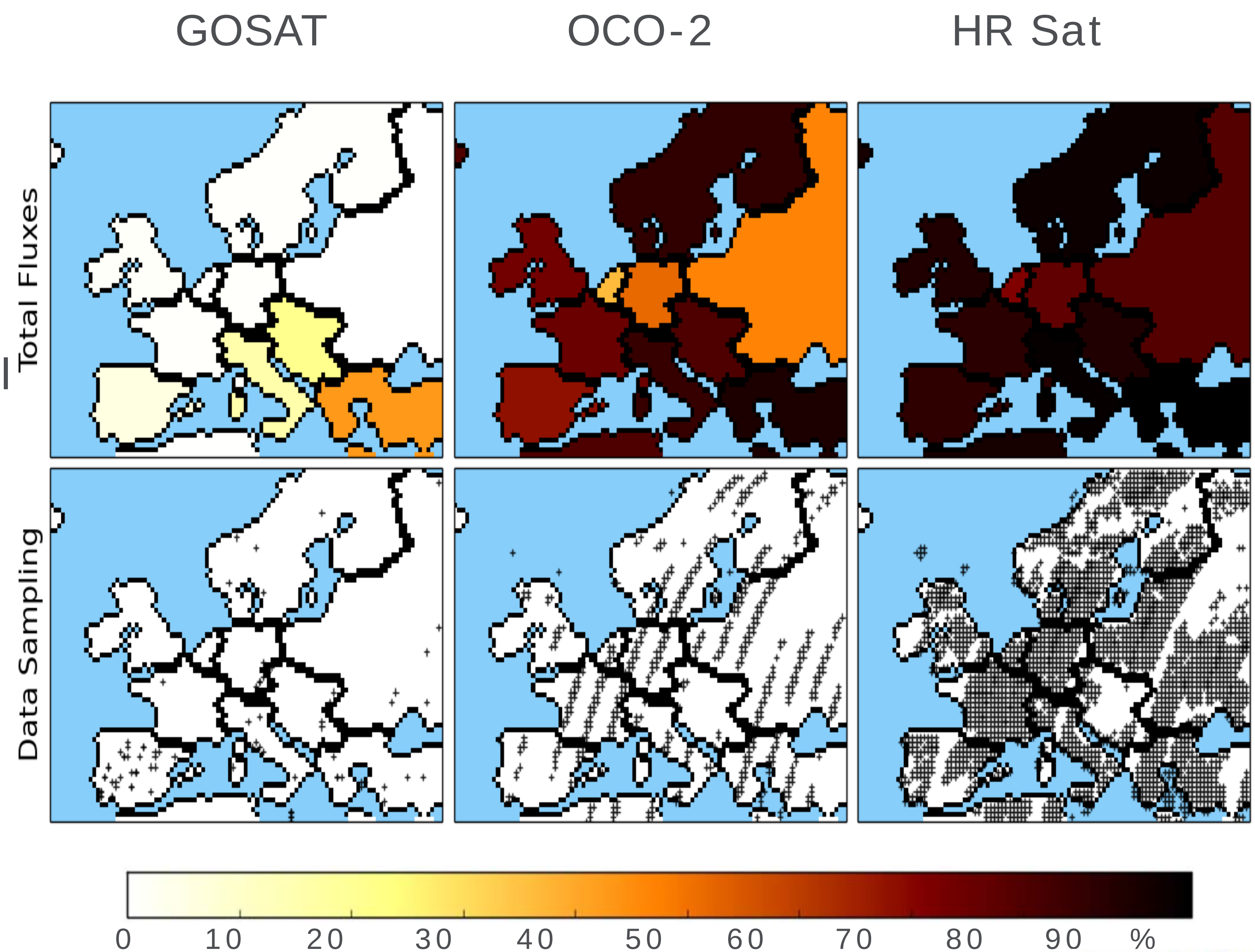
HR satellite is needed to detect carbon-cycle anomalies

Estimating CO_2 fluxes at country-scale

Error reduction after one week of observations for black-bordered regions using a meso-scale model

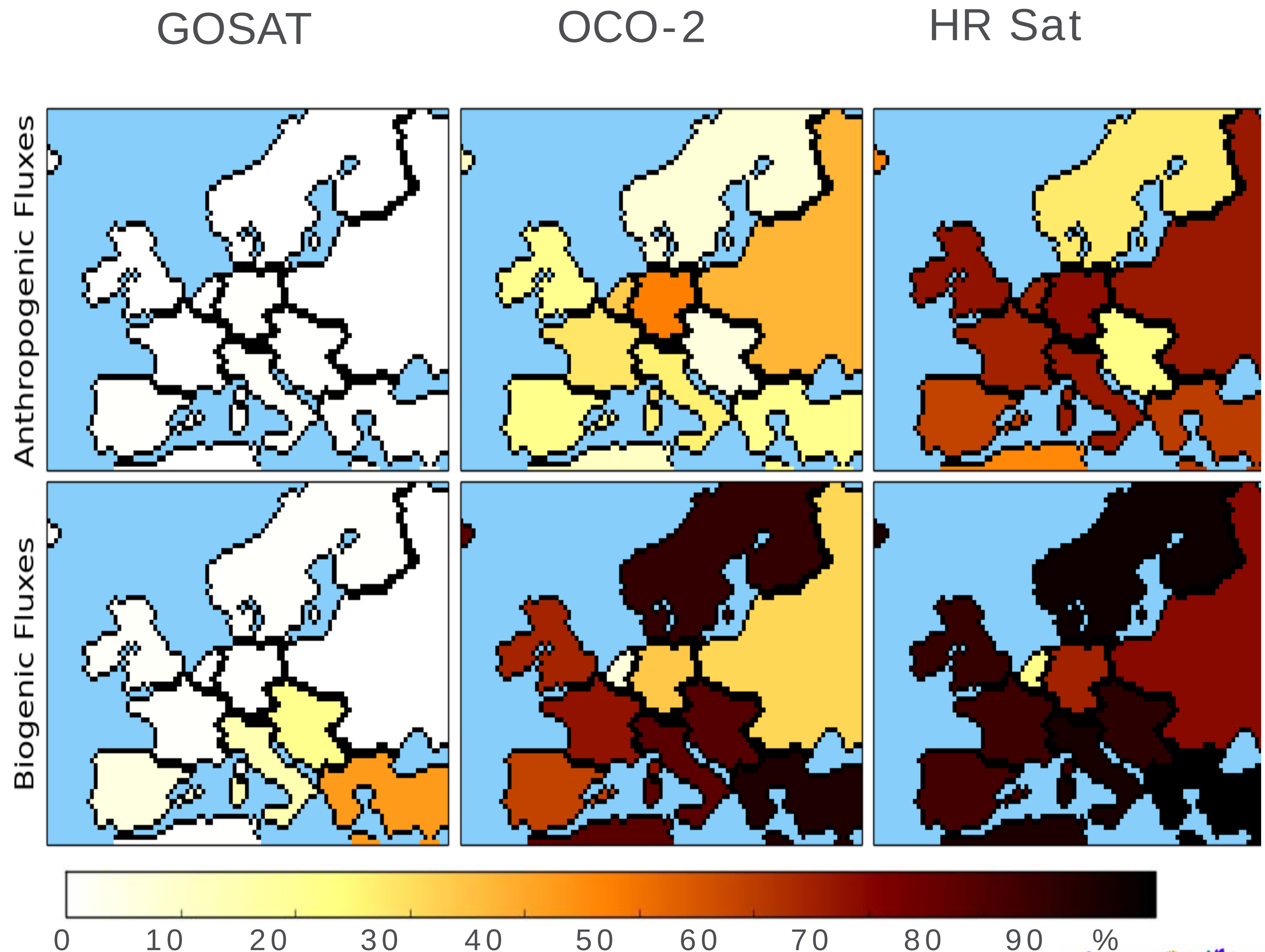
Note that smaller regions are more difficult.

HR Sat better due to combination of large swath (200 km), small samples (2×3 km^2), high accuracy.



Broquet et al

Separating CO_2 fluxes at country-scale



Attempt to separate total flux in biogenic and anthropogenic components

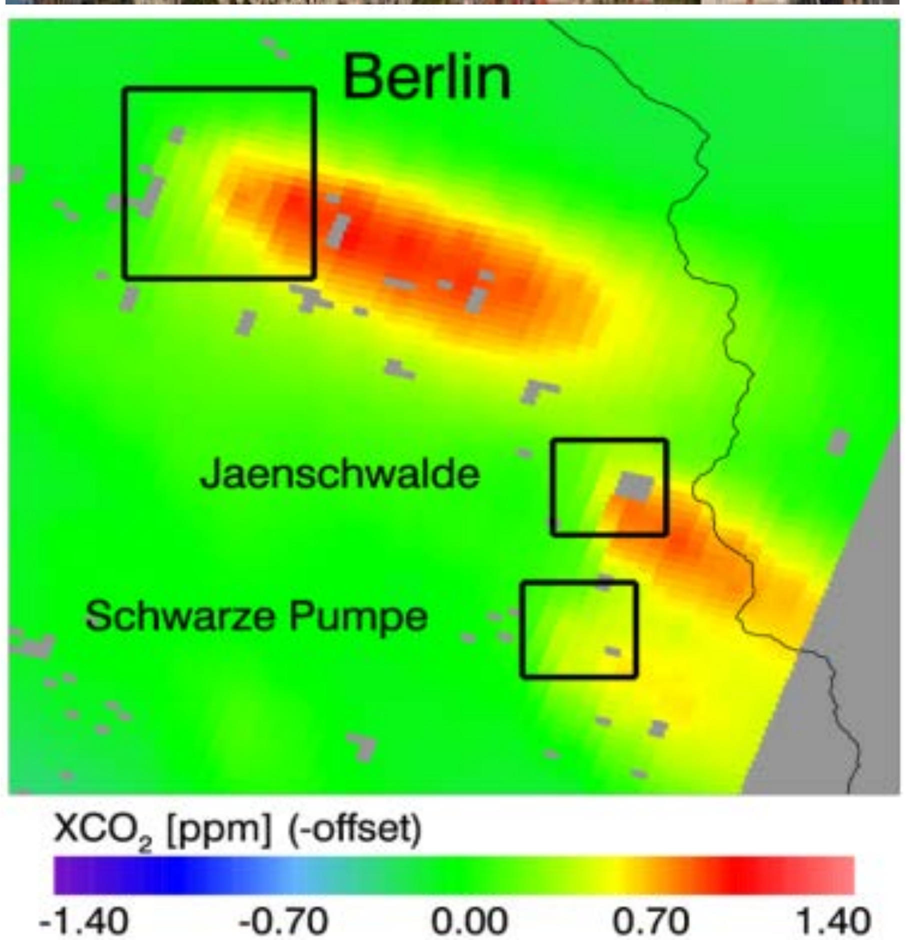
Control vector of 44 flux budgets per day:
11 land areas (no ocean)
2 periods per day
2 type of fluxes

Prior uncertainty (weekly):
30% anthropogenic
50% biogenic

HR satellite data provides the potential to separate anthropogenic and biogenic emissions on country scale

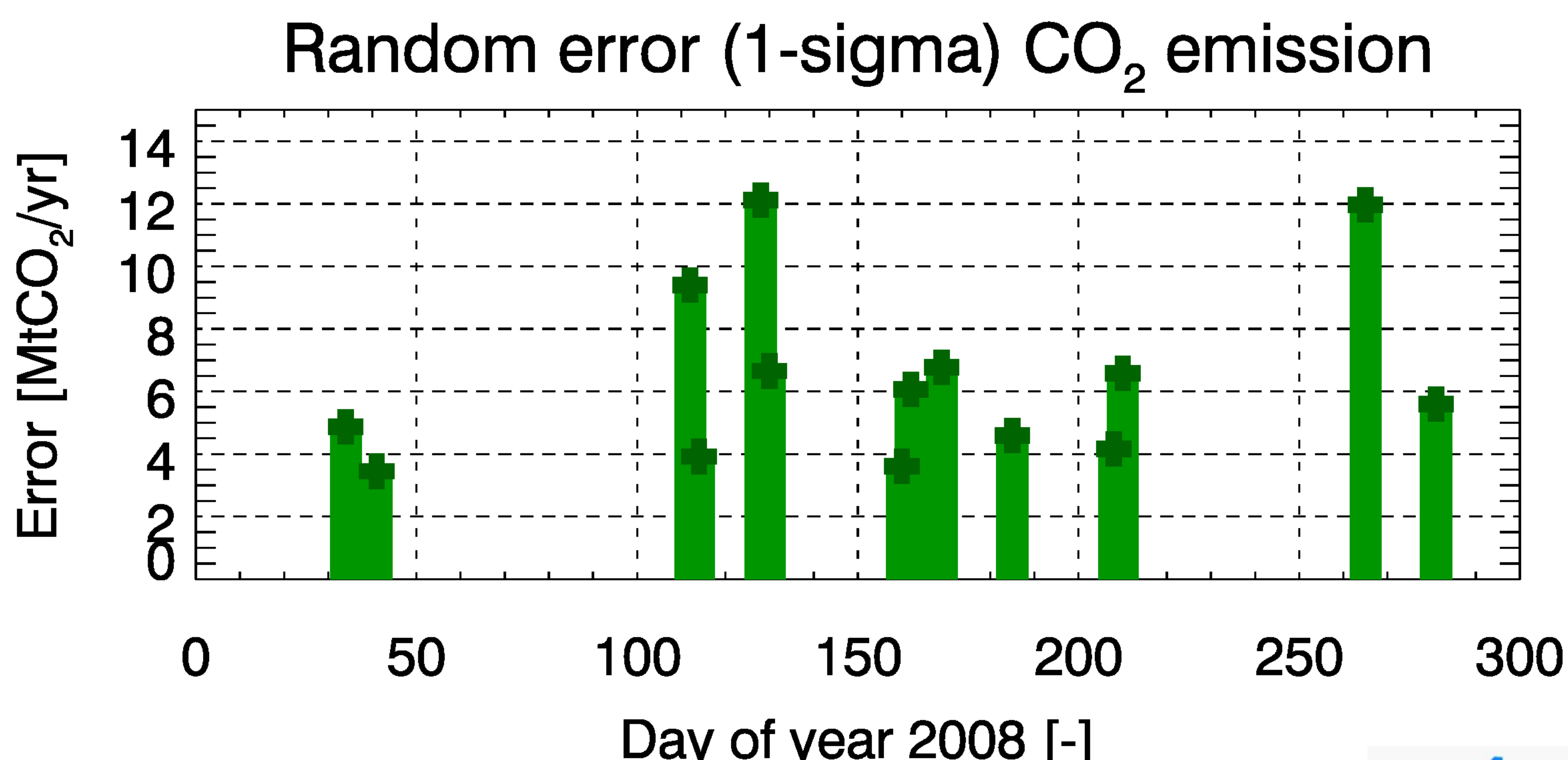
Broquet et al

Estimating CO_2 fluxes at local-scale



Berlin

- Reported emission of 46 Mt CO_2 per year
- Targeted uncertainty 7 Mt CO_2/yr (single overpass estimate)



Bovensmann et al

Conclusions

- To be able to detect reductions in fossil fuel we need to refocus (observations, models)
- Substantial errors in setup, *a priori* structure of the mesoscale inversions (very little real inversions)
- At the country scale the uncertainties are enlarged, but this may provide the key to future development: a country scale RECAPP

A post-Paris look at climate observations

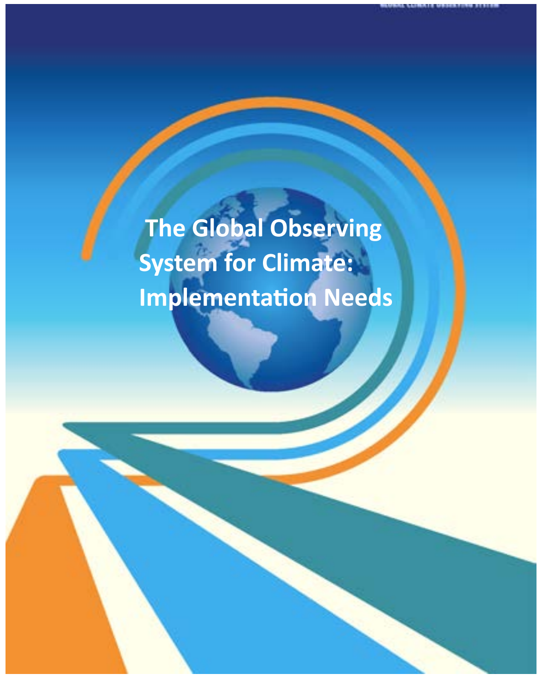
To the Editor — The Paris Agreement[1] of the United Nations Framework Convention on Climate Change in December 2015 was

variables (ECVs) have been defined: they aim to describe key aspects of the behaviour and composition of the land, oceans and

reminder to the observing community to deliver the data that will underpin progress. ❐

GCOS 2016 Implementation Plan Draft for SC-24

Action T67:	**Improve Global Estimates of Anthropogenic GHG Emissions**
Action	Continue to produce annual global estimates of emissions from fossil fuel, industry, agriculture and waste. Improve these estimates by following IPCC methods using Tier 2 methods for significant sectors. This will require a global knowledge of fuel carbon contents and a consideration of the accuracy of the statistics used.
Benefit	Improved tracking of global anthropogenic emissions.
Timeframe	oOn-going, with annual updates.
Who	IEA, FAO, Global Carbon Project (GCP), Carbon Dioxide Information Analysis Center (CDIAC), Emissions Database for Global Atmospheric Research (EDGAR)
Performance Indicator	Availability of Improved estimates.
Annual Cost	10-100k US$

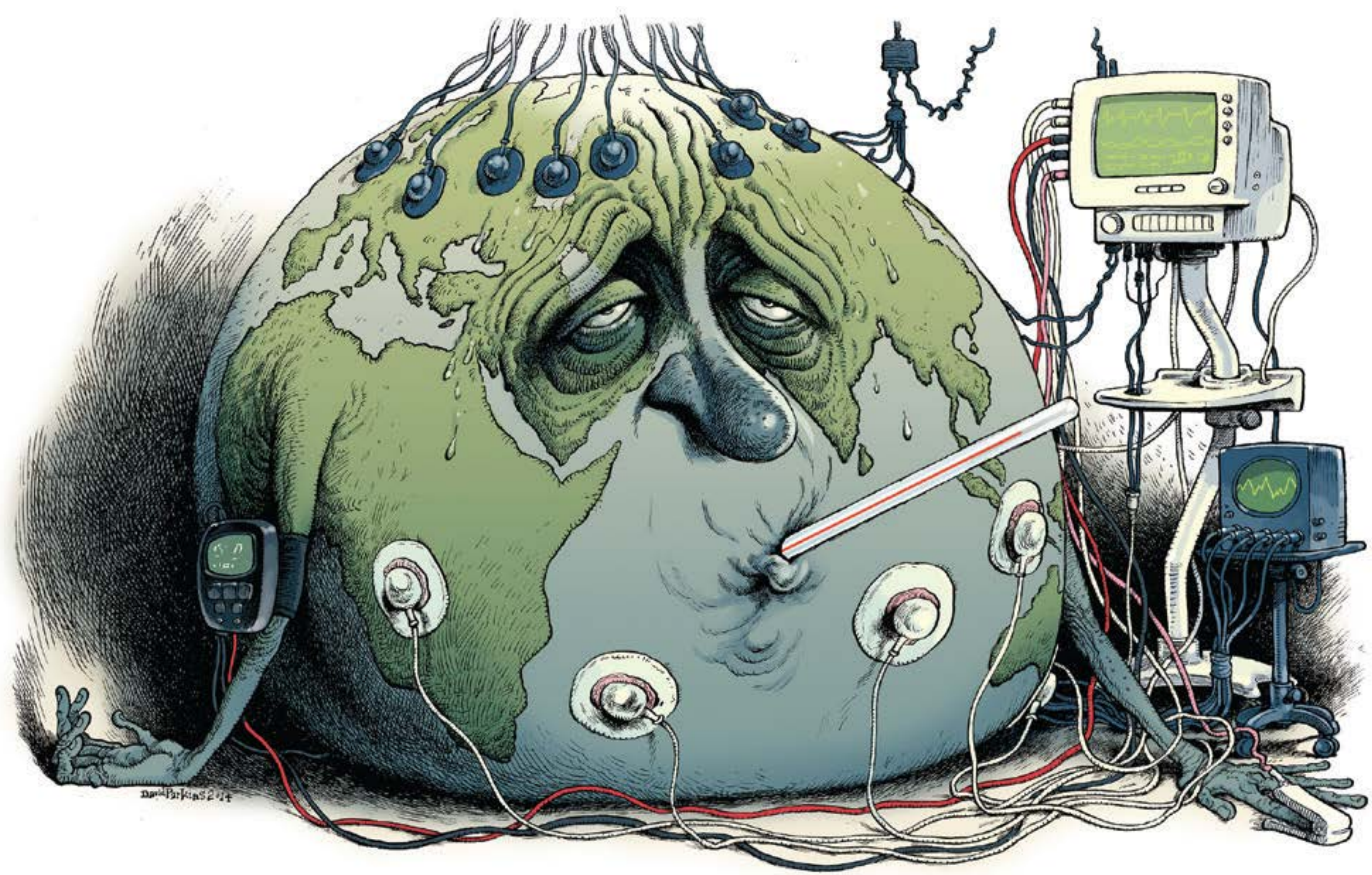


Action T71:	**Prepare for a carbon monitoring system**
Action	Preparatory work to develop a Carbon monitoring system to be operational by 2035. Development of comprehensive monitoring systems of measurements of atmospheric concentrations and of emission fluxes from anthropogenic area and point sources, to include space-based monitoring, in situ flask and flux tower measurements and the necessary transport and assimilation models.
Benefit	Improved estimates of national emissions and removals.
Timeframe	Initial demonstration results by 2023 – complete systems unlikely before 2030.
Who	Space agencies.
Performance Indicator	Published results.
Annual Cost	10-100B US$

What is needed

- Extend *in situ* observations through ICOS, and ^{14}C efforts
- Provide harmonised bottom up data for countries within Europe and outside
- Do HR mesoscale inversions (set up model inter comparisons à la Transcom)
- Identify bottlenecks, uncertainties etc. through thorough analysis of bottom up and top down

Thank You



Credit: Victor & Kennel, Nature Climate Change, 2014.