Assessments of in situ and remotely sensed CO_2 observations in a Carbon Cycle Fossil Fuel Data Assimilation System to estimate fossil fuel emissions

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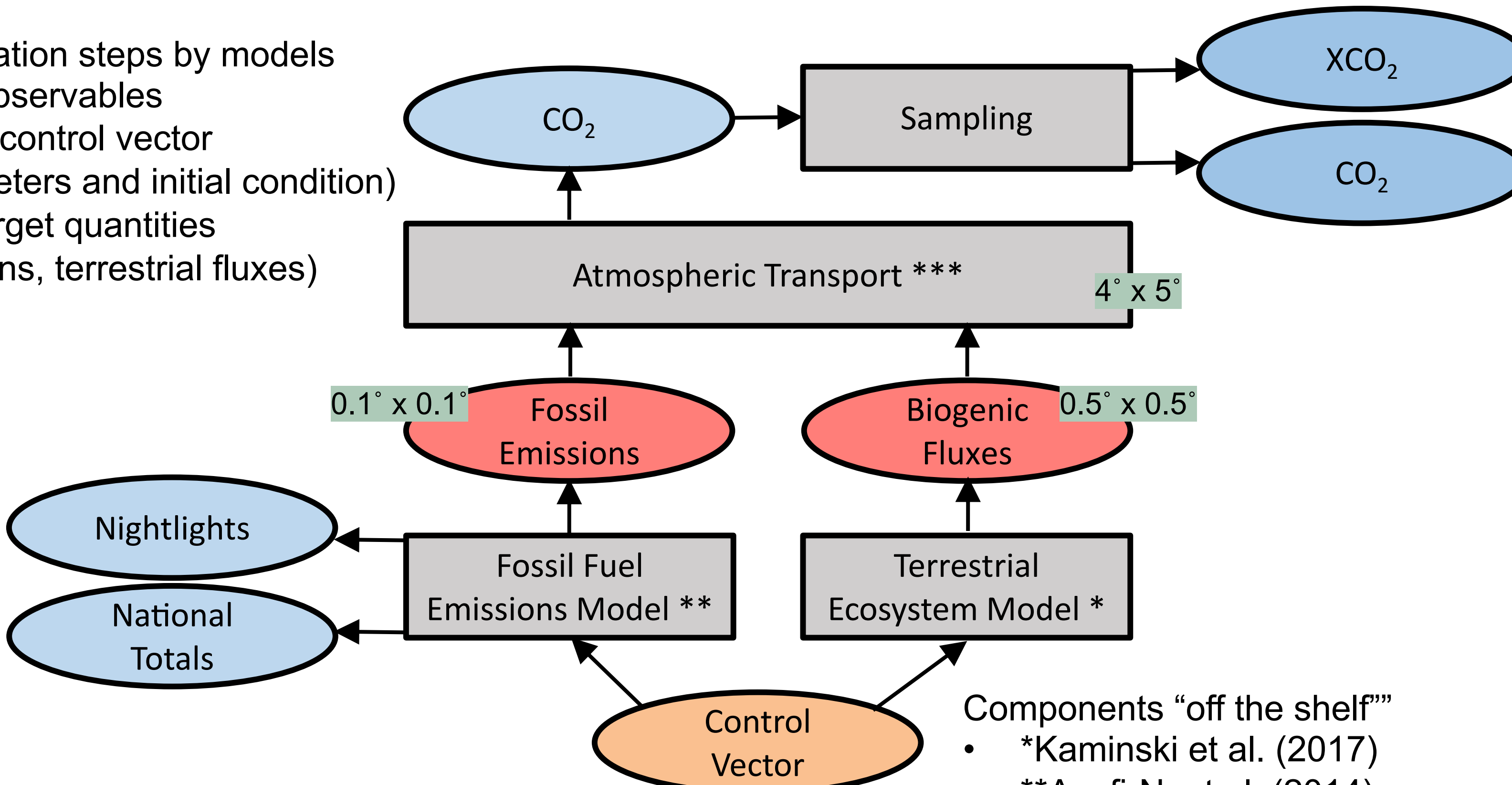
Objectives

- Develop a coupled data assimilation system for natural and fossil fuel fluxes based on process models (CCFFDAS)
- Assess the potential of remotely sensed CO_2 observations to constrain fossil fuel CO_2 emissions for an exemplary 1-week period in 2008 in a Carbon Cycle Fossil Fuel Data Assimilation System
- Test design options for a Monitoring and Verification Support (MVS) capacity

Information flow in CCFFDAS

Boxes: calculation steps by models
Blue ovals: observables
Orange oval: control vector
(model parameters and initial condition)
Red ovals: target quantities
(fossil emissions, terrestrial fluxes)

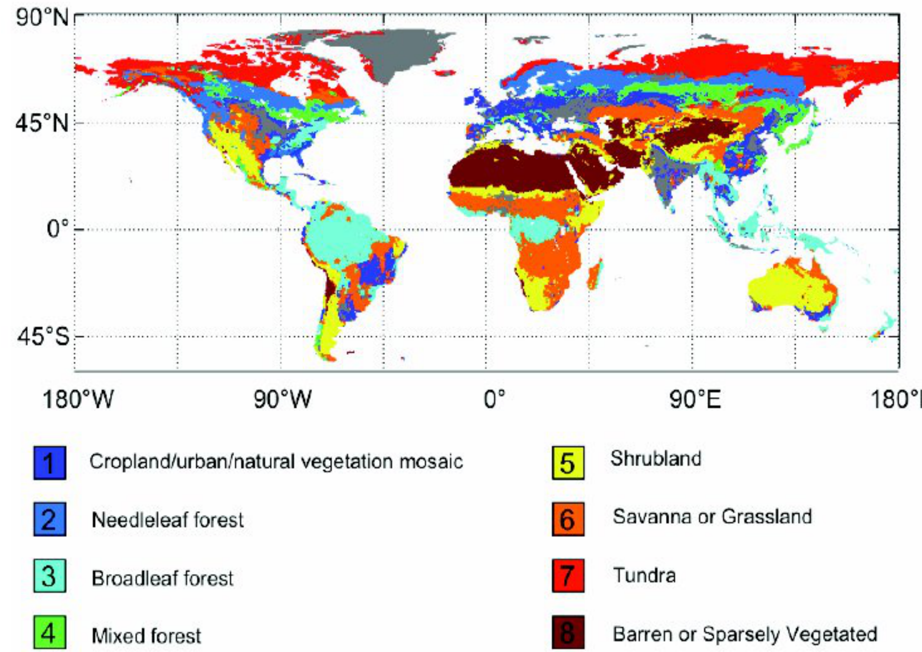


Components “off the shelf””
- *Kaminski et al. (2017)
- **Asefi-N. et al. (2014)
- *** TM3-Heimann&Koerner (2003)

Natural Fluxes

Model based on concept by Knorr and Heimann (1995):

- Globally 0.5 degree
- Running from 2006-2010
- Driven by JRC-TIP FAPAR and WATCH climate
- PFT classification into 8 groups (Knorr et al. 2014)
- Process parameters (for calibration):
    - PFT specific Photosynthetic Light Use Efficiency (ε)
    - PFT specific Temperature dependency of RHET(Q10)
    - spatially constant initial atm. XCO2 value
- TM3 (Heimann and Koerner) fine grid (4x5) for atmospheric transport
- Calibrated against GOSAT XCO2(Kaminski et al., 2017).



Sectorial Fossil Fuel Emissions

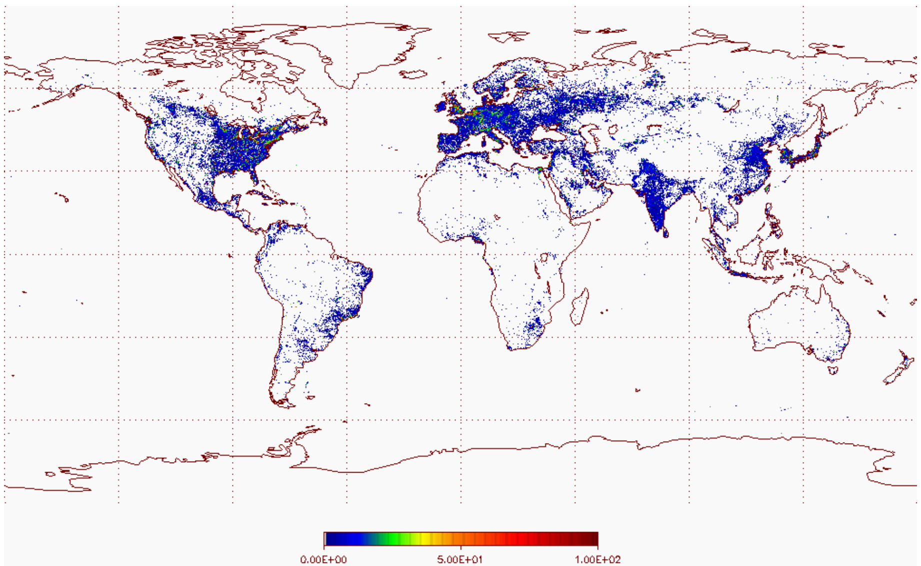
The FFDAS concept allows for making use of the different emission sectors. In this project, we distinguish between two main sectors:

- Electricity production, includes the IEA categories
  - Main activity electricity and heat production
  - Unallocated autoproducers
- Other, includes the IEA categories
  - Other energy industry own use
  - Manufacturing industries and construction
  - Transport, excluding Non-energy use in transport
  - Other

$$F(x,c) = pP(x)g(x)ef(c)$$

Kaya Identity

Observation operators and uncertainties



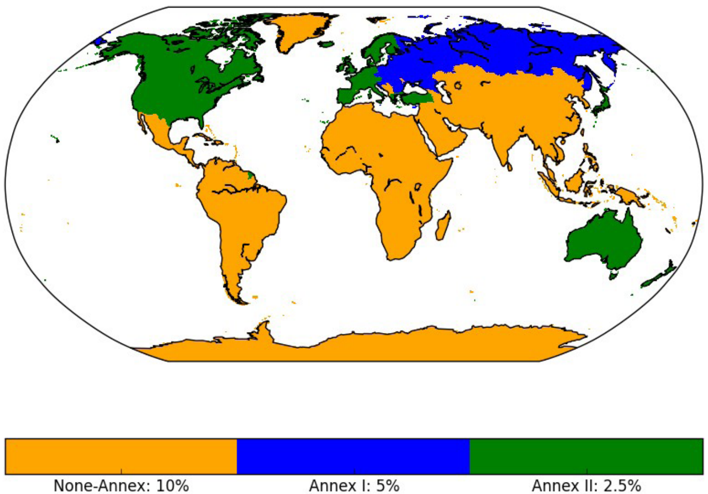
$$O_{\mathrm{NL}} = npP(x)g(x)$$

n: nightlights scaling factor
p: population density scaling factor
P(x): population density in each grid cell
g(x): GDP per capita in each grid cell

Nightlights
12.5% uncertainty

Nightlights from the Defense Meteorological Satellite Program, for 2008 interpolated from 2006 and 2010 data

Observation operators and uncertainties



- National total uncertainty per country-class (over all sectors)
- Distributed to sectors by partitioning variance in proportion to totals
- Not used in default experiment (weekly time scale), only for sensitivity test

$$O_{\text{elec}} = \sum_{i \in c} u(i)$$

u(i): power plants emission in each country

- from CARMA database
- Uncertainties are estimated from the average of the reported standard error from plants listed in the US Energy Information Administration and/or the US EPA Clean Air Market datasets, floor value of 0.01 MtC/yr

$$O_{\text{other}} = \sum_{x \in c} A(x) p P(x) g(x) e f(c)$$

e: global energy intensity of the economy
A(x): area of grid cell
f(c): carbon intensity of energy production for each country

Quantitative Network Design

Uncertainty → $\mathbf{C}(d)^2 = \mathbf{C}(d_{\text{obs}})^2 + \mathbf{C}(d_{\text{mod}})^2.$

What we do know already

$$\mathbf{C}(x)^{-1} = \mathbf{M}'^{\mathrm{T}}\mathbf{C}(d)^{-1}\mathbf{M}' + \mathbf{C}(x_0)^{-1}. \quad (3)$$

Coverage

$$\sigma(y)^2 = \mathbf{N}'\mathbf{C}(x)\mathbf{N}'^{\mathrm{T}} + \sigma(y_{\text{mod}})^2. \quad (4)$$

What we are after

$$\sigma(y_0)^2 = \mathbf{N}'\mathbf{C}(x_0)\mathbf{N}'^{\mathrm{T}} + \sigma(y_{\text{mod}})^2. \quad (5)$$

<u>Notation</u>:

y: vector of target quantities
d: vector of observations
x: vector of unknowns/control variables

d=M(x): model linking unknowns to observations
y=N(x): model linking unknowns to target quantities

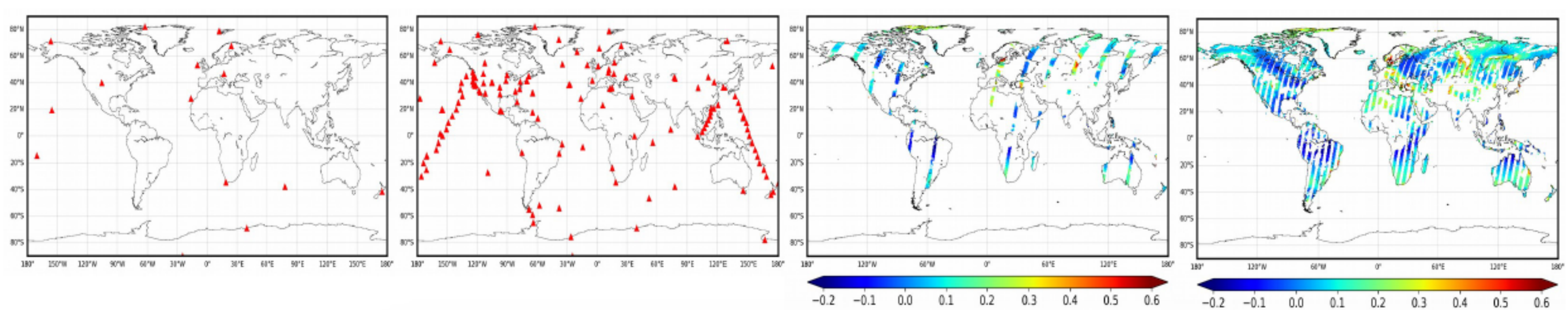
C: covariance of uncertainty

M’ large (1.5m x 1.5m)
- exploit sparsity
- solve (3) iteratively for selected N’

Jacobians via
Automatic Differentiation
(Hascoet & Pascual, 2013)

Assessments for week June 1-7, 2008

		Other sector					Electricity generation sector				
		Emission rate uncertainty (MtC/week)									
Scenario	Description	AUS	BRA	CHN	DEU	POL	AUS	BRA	CHN	DEU	POL
1	surface 15 sites	9.03	16.70	177.31	12.18	4.70	0.28	0.17	2.36	0.43	0.23
2	surface 141 sites	4.57	8.21	8.29	2.60	2.10	0.28	0.17	2.36	0.43	0.23
3	1 satellite (default)	0.30	0.42	3.43	0.97	0.38	0.27	0.17	2.21	0.43	0.23
4	4 satellites	0.25	0.29	2.38	0.79	0.33	0.26	0.17	2.07	0.43	0.23
5	default with ocean	0.29	0.41	2.93	0.94	0.37	0.27	0.17	2.20	0.43	0.23
6	default with repr. error	0.35	0.68	4.68	1.36	0.62	0.28	0.17	2.28	0.43	0.23
7	default with nat. inventory	0.03	0.16	1.84	0.08	0.05	0.04	0.06	1.43	0.07	0.05
		Annual average weekly emission rate (MtC/week)									
-	national inventory	0.90	1.67	17.73	2.43	0.73	1.15	0.22	16.36	1.76	0.83



Assessments for week June 1-7, 2008

with representation error

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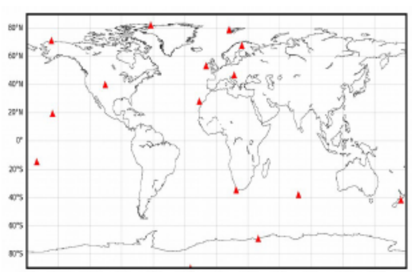

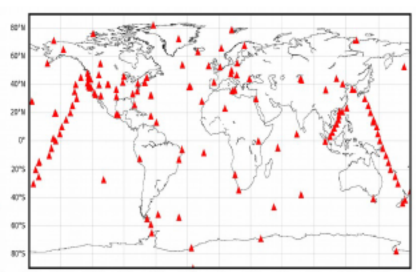

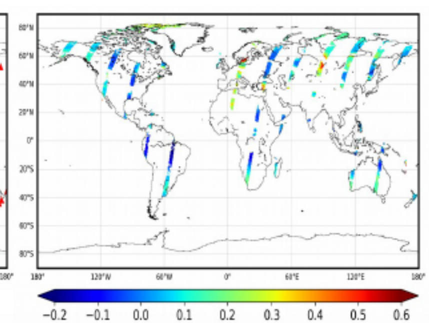

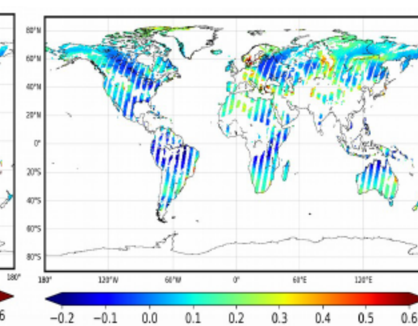

Assessments for week June 1-7, 2008

“Synergy” vs. “Verification” mode

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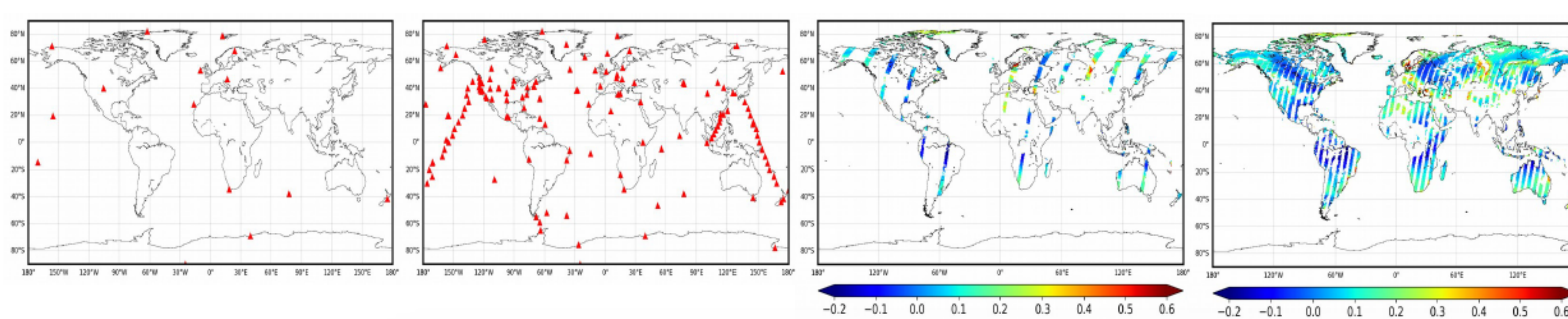
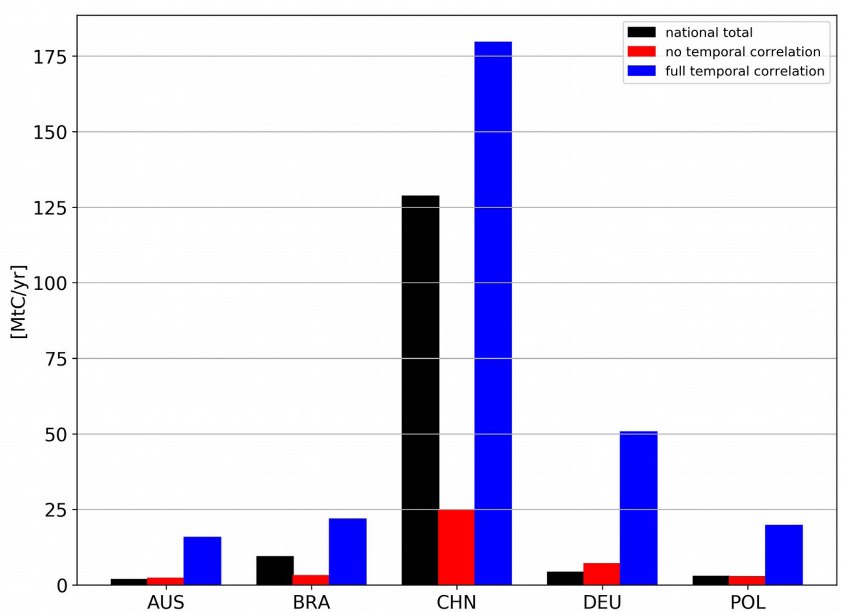


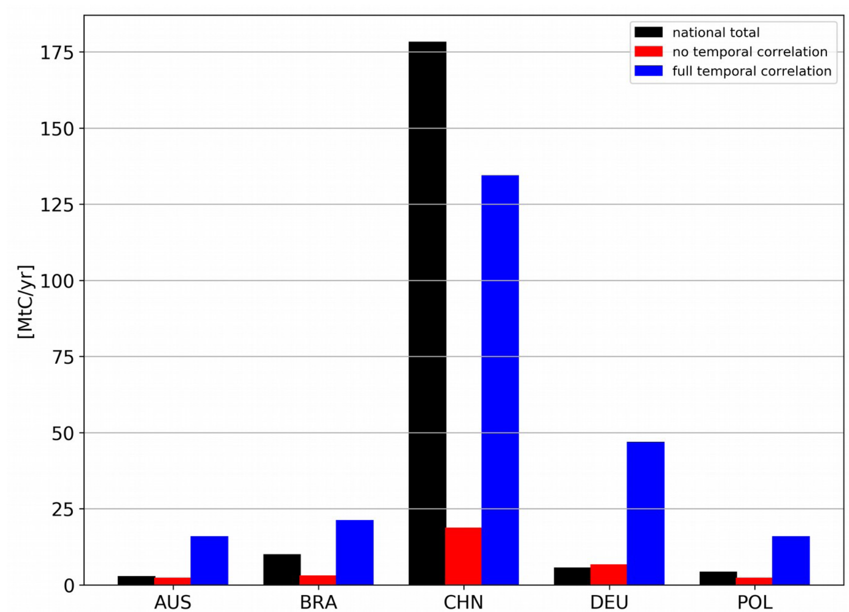
Extrapolation of Posterior Uncertainty to Annual Scale: XCO2 (1 CO2M satellite) + nightlights

Weekly (1st week of June) posterior emission uncertainties scaled to annual values assuming:

- no temporal correlation of weekly uncertainties (red bars)
- full temporal correlation of weekly uncertainties (blue bars)



Other sector



Aggregated over all sectors

Summary and Outlook

- Light Framework developed
- Verification and synergy modes
- Useful to explore (some) design options of
  - Satellite mission
  - Surface network (e.g. ICOS network ...)
  - Inversion component of MVS (control vector, assimilation window, posterior uncertainty ...)
- National and annual scale unc. in range of inventory unc.
- Can refine models and go to higher resolution
- Use further data streams, e.g. radiocarbon as a proxy for fossil fuel, ...
- Use more sectors in fossil fuel model component, e.g. transport, ...