Co-ordinated by ECMWF

CoCO2
Prototype system for a Copernicus CO_2 service

WORK PACKAGE 5: CONNECTING SCALES AND UNCERTAINTIES

CoCO2 information day

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(ECMWF, EMPA, ICOS ERIC, CEA, MPG, TNO, ULUND, VUA, WUA, CMCC, FMI, iLAB, MF)

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WP5 Rationale

WP Objective:

Improve the representation of uncertainties in inversions, in order to:

- Obtain realistic a posteriori flux / parameter uncertainties
- Optimize the weighing of information elements that are used to constrain the inverse problem
- Facilitate the information exchange between sub-systems operating at different scales (e.g. global system and high-resolution local systems)

Focus & approach:

- Focus on the following aspects: boundary conditions, sampling biases, transport uncertainty, inversion design options, posterior uncertainty estimation
- Methods: Real data / OSSE, Global / Regional models, Benchmarking using independent Obs.

WP5 structure

Max Planck Institute for Biogeochemistry

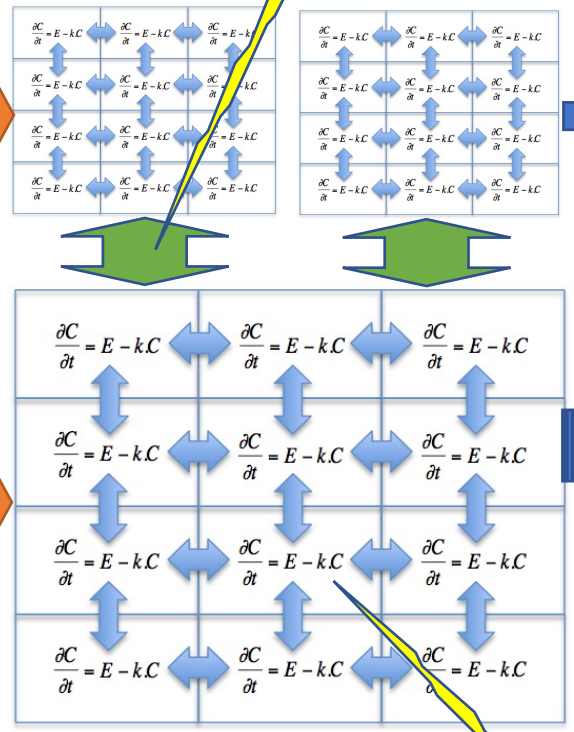
WP5.2

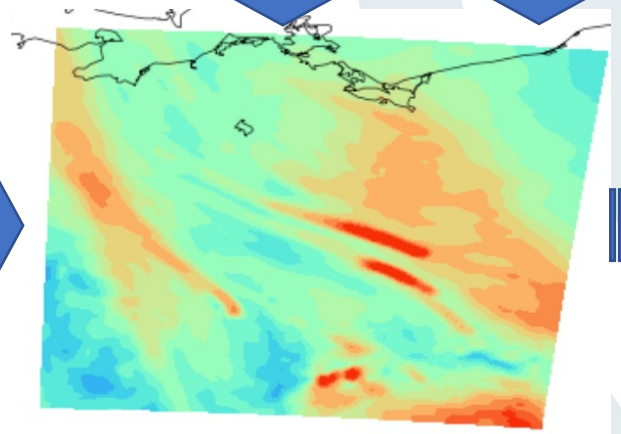
WP5.1 ECMWF

WP5.4 VU VRIJE UNIVERSITEIT AMSTERDAM

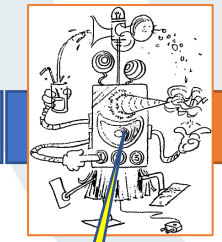
LUND UNIVERSITY

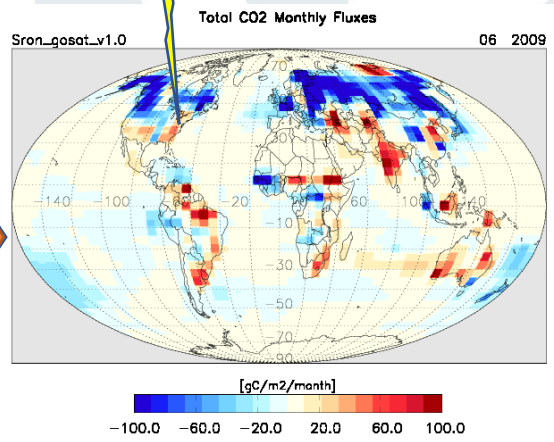
WP5.6





GHG Mixing Ratios





GHG Mixing Fluxes

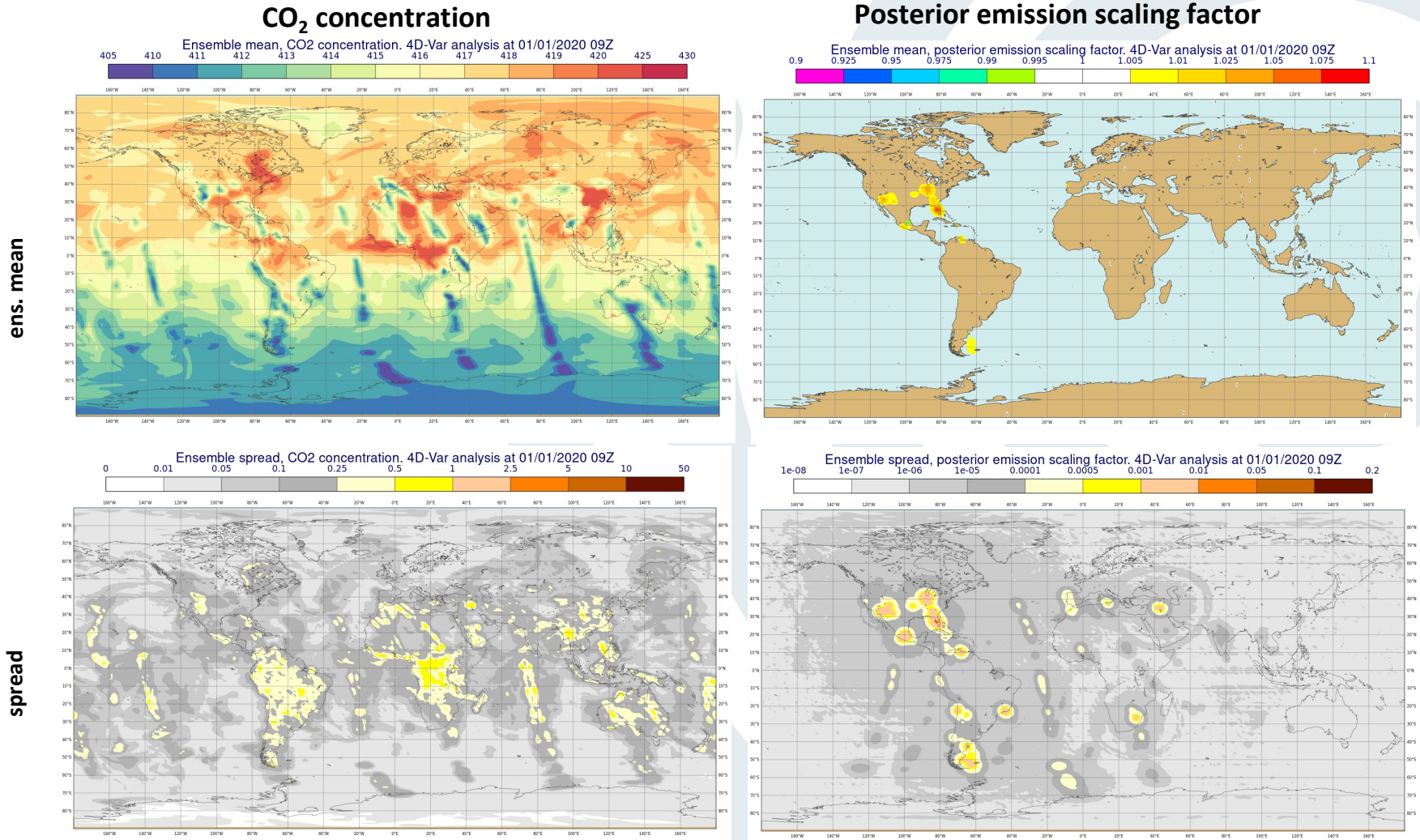
WP5.3 cnrs

WP5.5 iLab

T5.1: Information transfer Global - Local

Ensemble of Data Assimilation with emission inversion for CO_2

- Ensemble generated by perturbing surface emissions + meteorology with each member using perturbed observations in each 4D-Var minimisation;
- Initial perturbations are re-drawn in each cycle from a log-normal distribution, they are spatially- and sector-dependent but uncorrelated;
- Only satellite observations currently assimilated (IASI, GOSAT, OCO-2);
- OSSE system for evaluation (synthetic observations drawn from the control member assimilated into the ensemble members) currently under testing;
- Only short assimilation window tested so far (12h) – to be extended in 2023;
- Static background covariance matrix used (flow-dependent uncertainty derived from the ensemble not yet propagated forward in time).



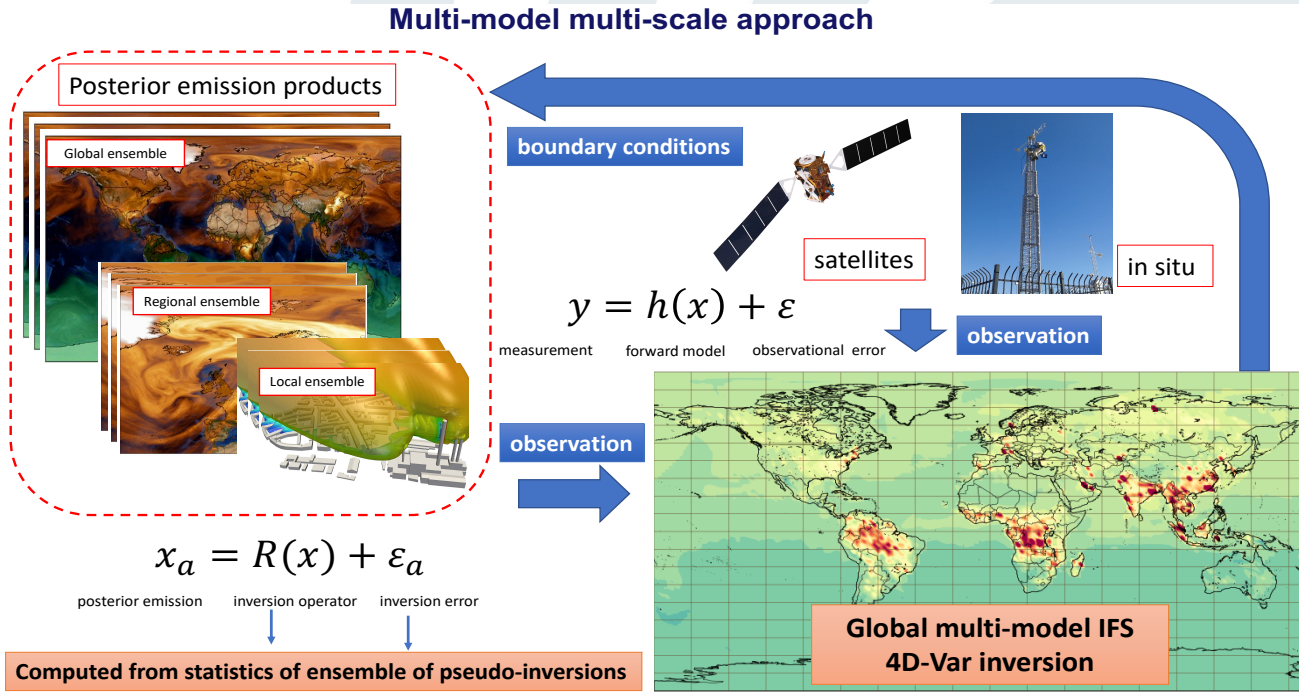
Outcome: posterior distribution of both concentrations and emissions.

Link to task 5.3: can provide boundary condition uncertainty for local inversion models

T5.1: Information transfer Global - Local

Assimilation of regional/local products into the global IFS

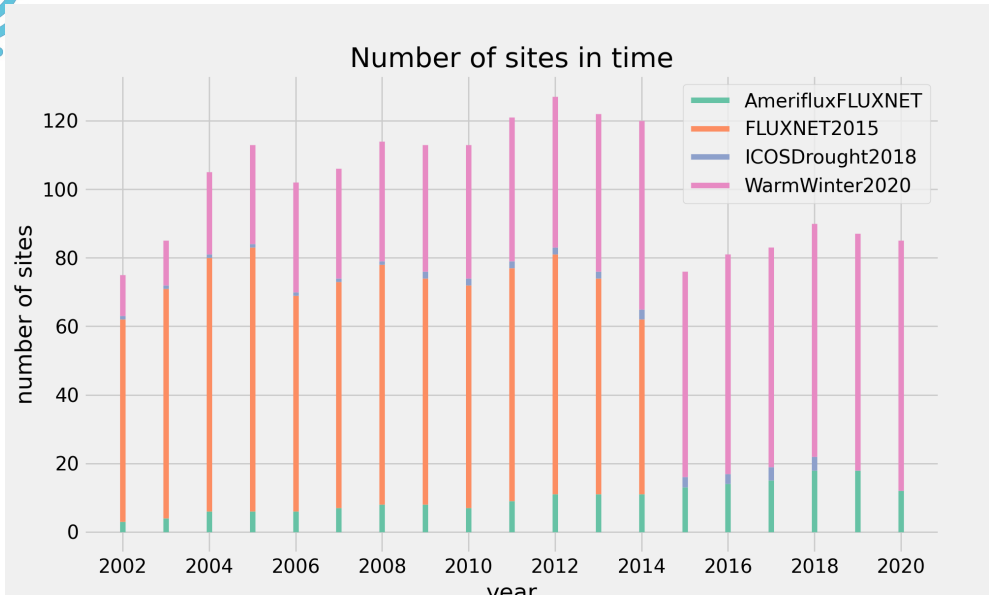
- Methodology has been presented and discussed during WP4 meeting.
- Ensemble statistics from perturbed regional/local inversion systems will be used to provide the required information (averaging kernel of inversion, inversion error) to assimilate each products into the global IFS system.
- Two-step process:
  - 4D-Var IFS inversion using satellite observations and generation of posterior IFS ensemble.
  - Assimilation of external regional/local products into the IFS using the ensemble information from IFS and external products (EnKF-like step).
- Atmospheric 3D state from global IFS inversion will in turn be used to provide boundary conditions to the limited area inversion systems (two-way flow of information).
- Activity will start in Q2 of 2023.



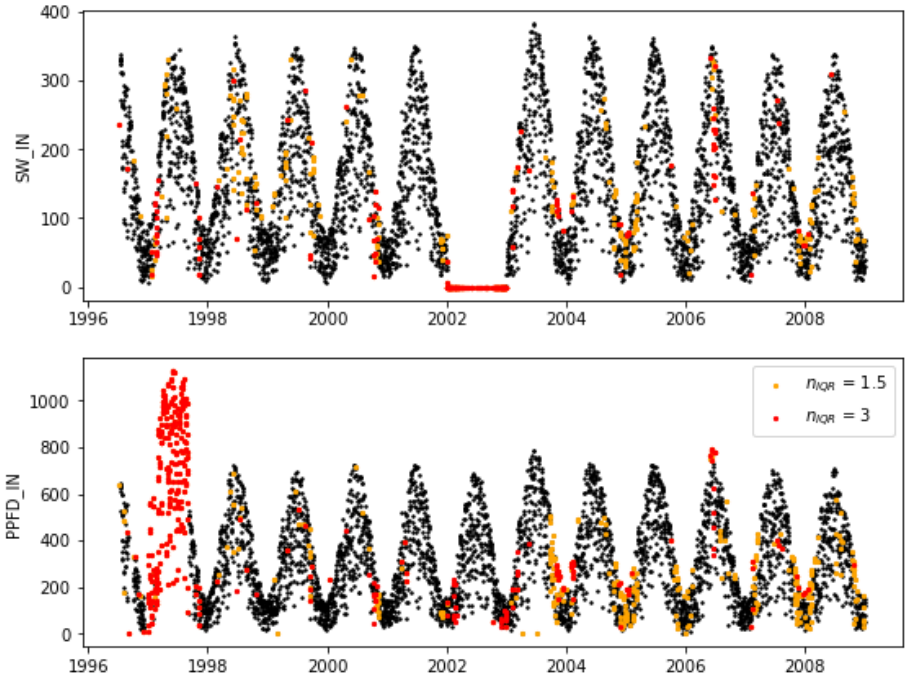
Task 5.2: Toolbox to Assess and quantify errors of biogenic CO_2 fluxes

- Jacob Nelson, Martin Jung, Dario Papale, Gab Abramowitz
- Leveraging the modelevaluation.org infrastructure for site level model runs at flux towers
- Updating, improving and complementing flux tower data base
  - 1918 site years between 2002-2020 from 257 sites
  - Gap-filled meteo forcing data (also extended back in time for spin-up)
  - Newly developed QA/QC flags for flux tower data (Jung et al. In prep)
  - Processed and gap-filled time series from MODIS (vegetation indices, LSTs) for diagnostic and machine learning models (FLUXNET-EO, Walther et al. 2022)
  - Daily LAI estimated from regression of measured maximum LAI and MODIS vegetation indices
  - Soil properties extracted from SoilGrids

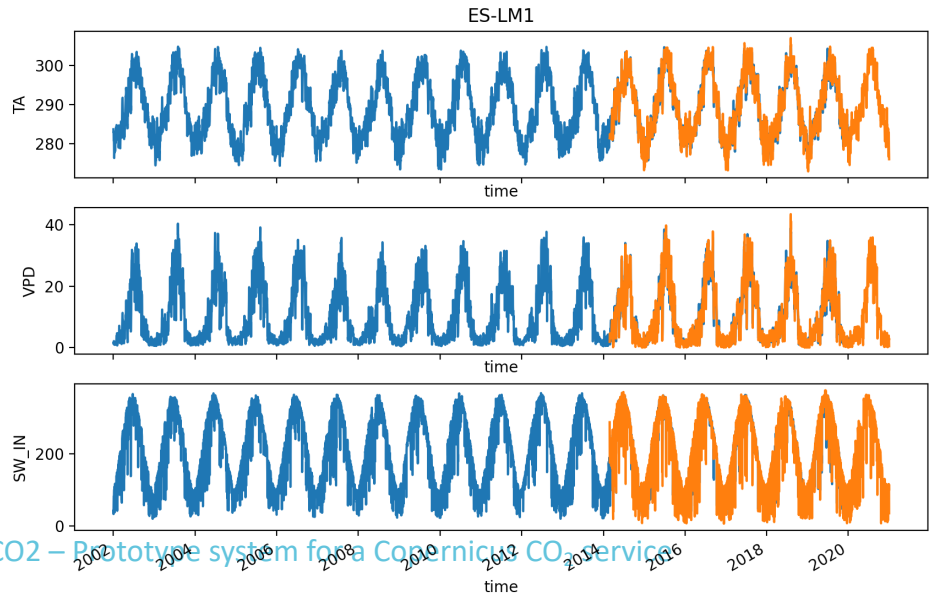
Fluxtower data compilation



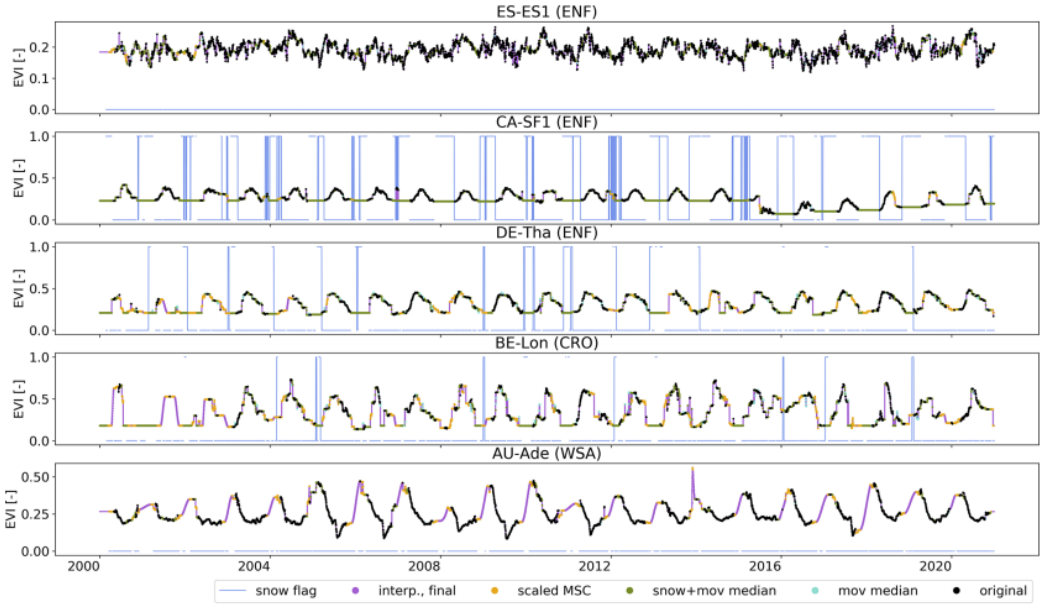
Improved QC



Gap-filled and extended meteo



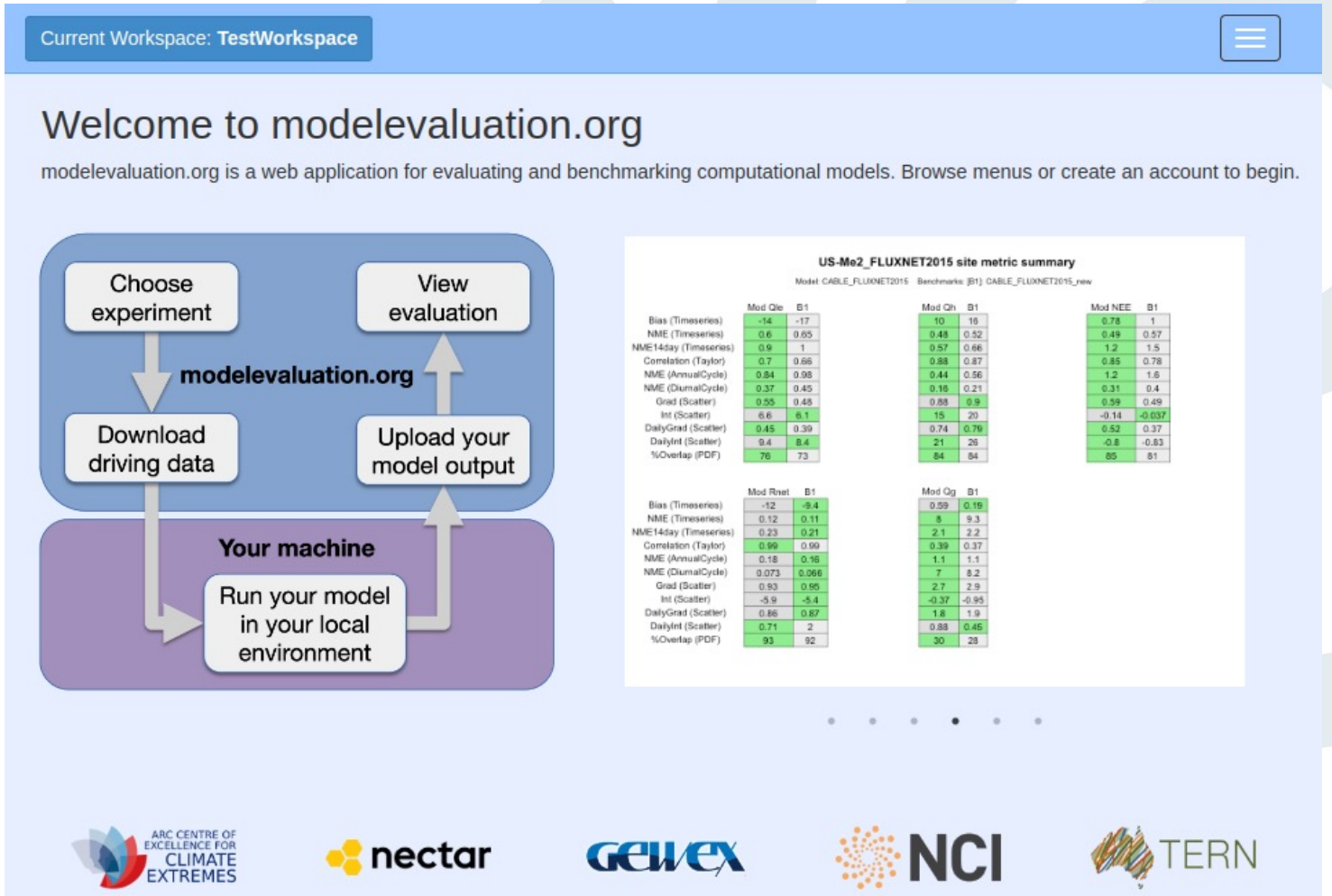
Satellite data



Task 5.2: Toolbox to Assess and quantify errors of biogenic CO_2 fluxes

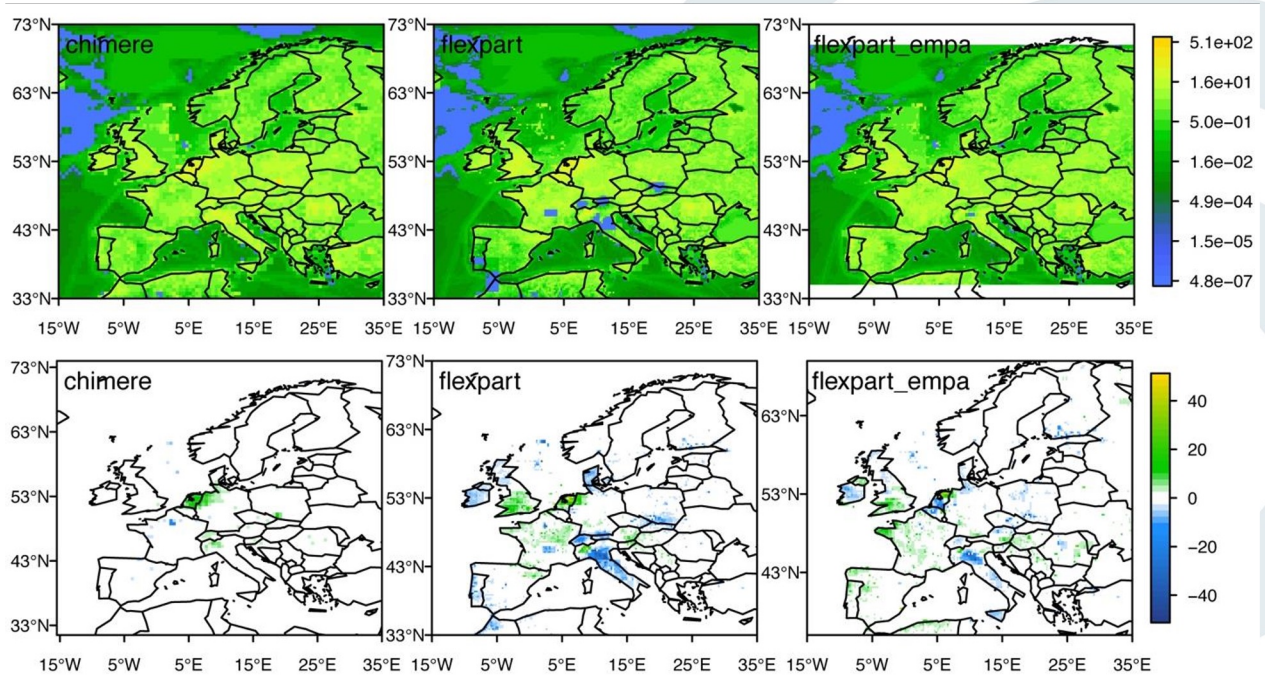
ME.org

- A CoCO2 workspace was set-up
- Flux tower data were uploaded
- FLUXCOM-X cross-validation results added (consistent setup with global run of WP2)
- Currently still a bug in running automated evaluation routines



Task 5.3 - Assess inversion uncertainties

Objective: assess uncertainties in regional inversions using a dedicated tool, the Community Inversion Framework



Posterior fluxes (top) and increments (bottom) from three CH4 inversions using CIF

Activities in 2021:

- Support for extending CIF :
  WRF-Chem (DLR), STILT (MPI-Jena),
  TM5-MP (TNO / VU), ICON-Art (Empa),
  Ensemble methods (FMI, DLR, Empa)
- CIF participation to CH4 inter-comparison over Europe (three inversions configurations provided)
- Extension of CIF to satellite observations (tested with TROPOMI, GOSAT, OCO2)

Ongoing effort:

Coordination with T5.1 to elaborate an integrated experiment between the two tasks:

- Generation of IFS boundary conditions and meteorological forcings ⇒ 50 members
- Planned exercice with several models using as many boundary conditions and meteorological fields as affordable and assess corresponding uncertainties

Task 5.4: Accounting for correlated uncertainty in satellite data

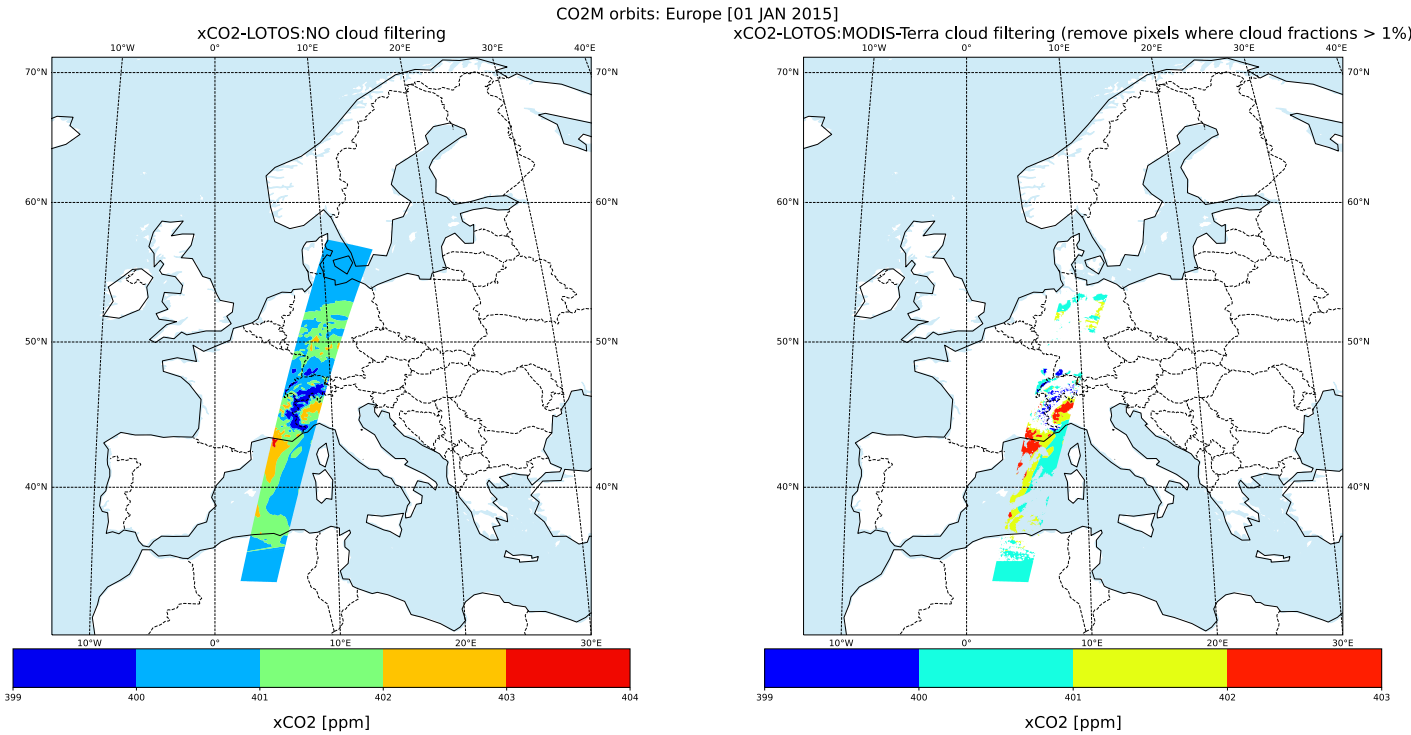
Objective: Assess the impact of uncertainties in CO2M satellite data in regional scale inverse modelling of national surface fluxes of CO_2

Activities in 2021:

- A workshop was organized this discuss the setup of the experiments to be conducted.
- As input to these OSSE's a full year of CO2M pseudodata is needed, which were delivered by EUMETSAT but without XCO2 values and errors.
- To complete the CO2M dataset CHE nature runs are used in combination with the Buchwitz et al (2013) error parameterization.
- The work was interrupted because of a change in personnel, but has meanwhile been resumed

Ongoing & next efforts:

- The aim is to finish the CO2M dataset at the end of 2021
- The OSSEs are planned for the final year, which should still allow us to deliver in time.

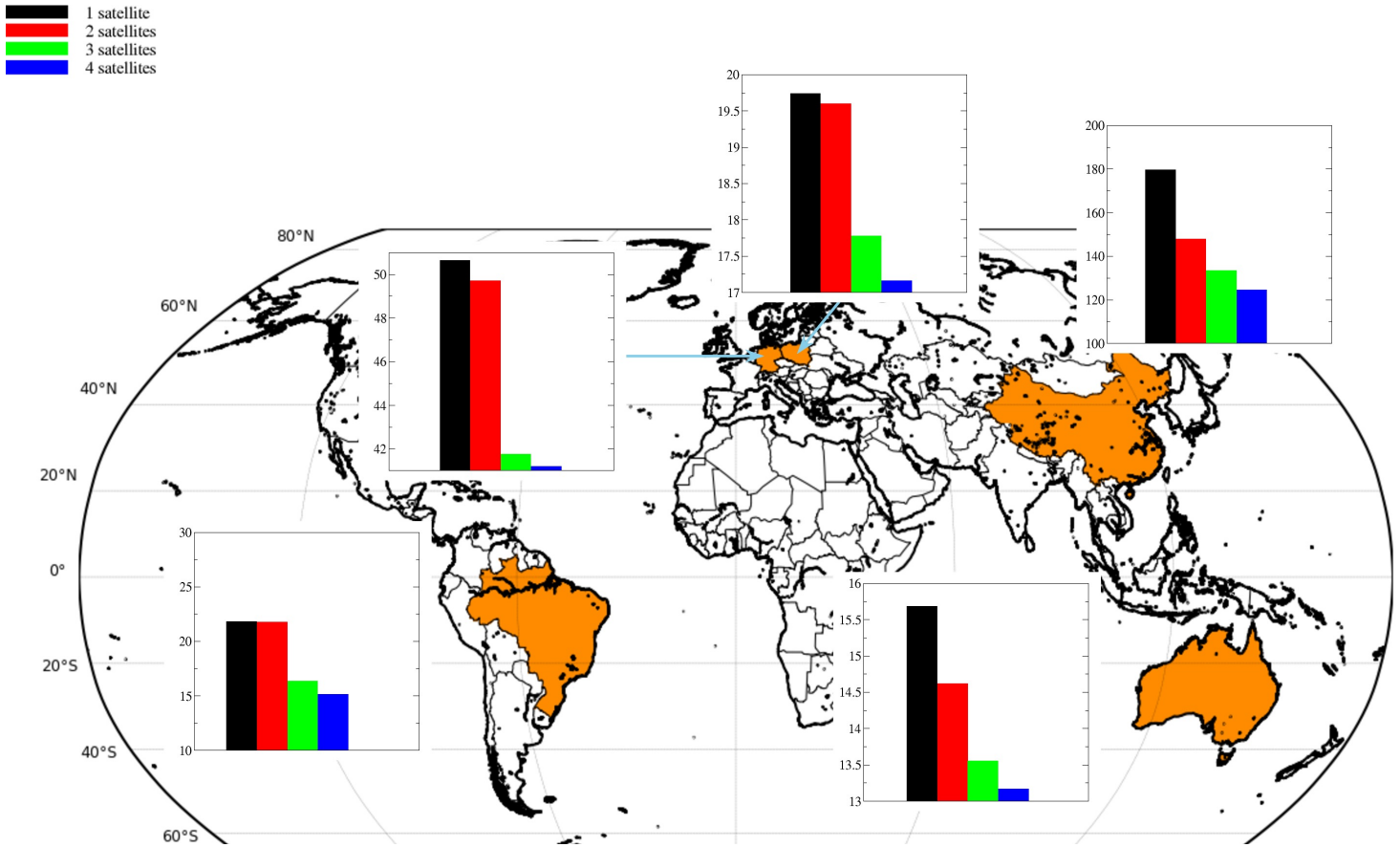


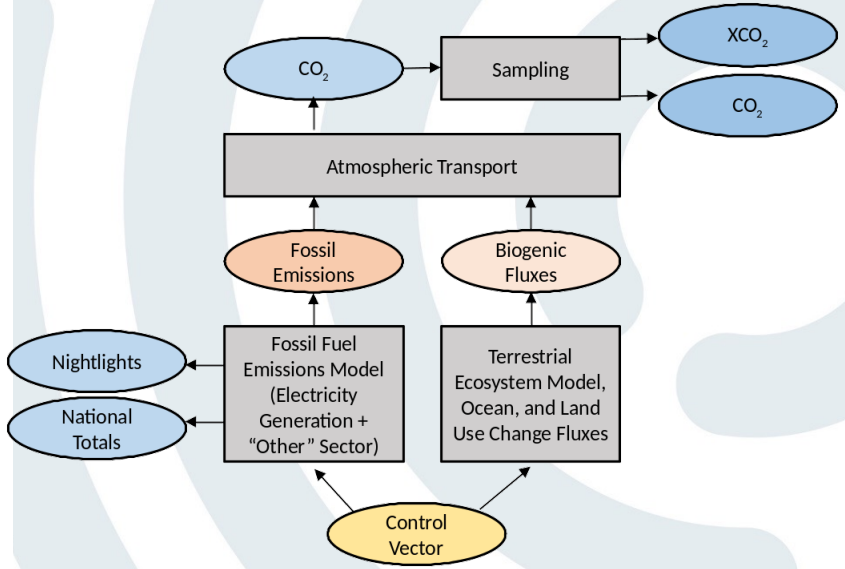
Task 5.5: QND and data assimilation sensitivity studies

Perform DA sensitivity studies and QND experiments to investigate the impact of different design aspects of the inverse modelling/DA approach on accuracy of the fossil fuel emissions

Question\Partner	iLab/Lund	LSCE	FMI	DLR	TNO
in situ network	Y	Y	Y	Y	
inclusion of C14	Y	Y			
length of assimilation window	Y		Y		
prior uncertainty description	Y		Y		Y
setup of control vector	Y	Y			
approximation of posterior uncertainty quantification	Y		Y		
Support of CO2M Task Force	Y				

CCFFDAS Posterior Uncertainty in country-scale fossil fuel emissions from other sector in 1 week of June



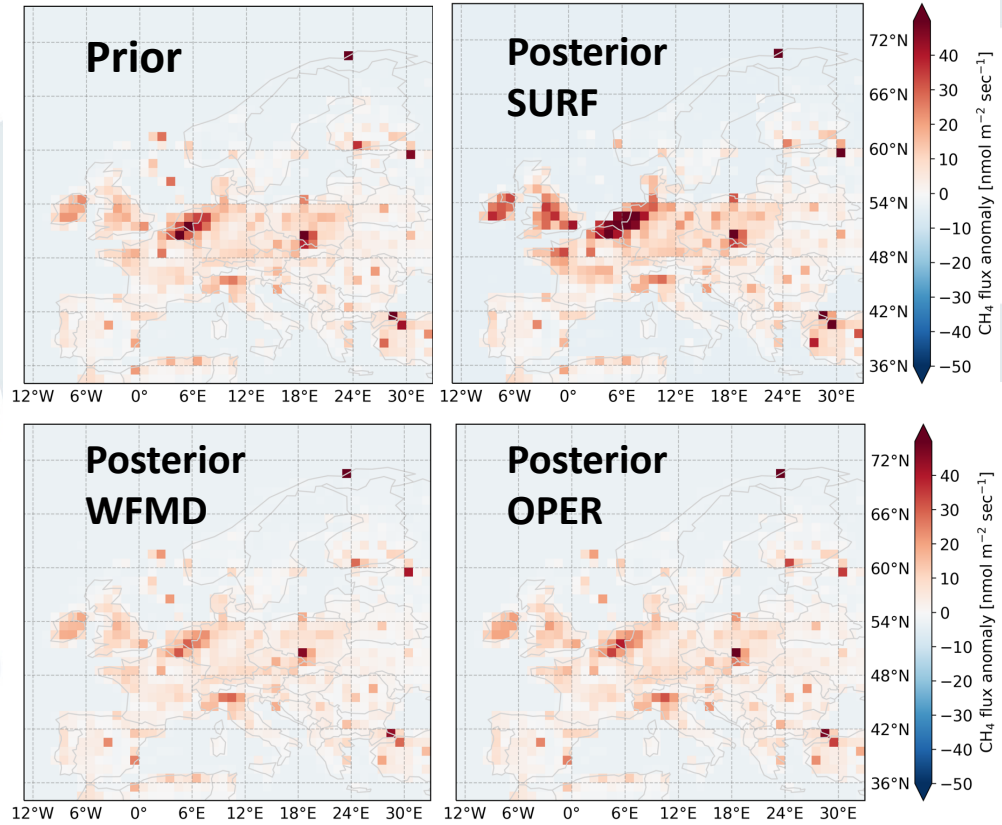


Task 5.5: QND and data assimilation sensitivity studies

European CH_4 fluxes are estimated using CTE-CH_4 model by assimilating data from surface in situ network and satellite (S5P TROPOMI).

Spatial anomalies show:

- Anthropogenic emission enhancement in central Europe
- Emission enhancement is strong in cities
- Emission enhancement in western Europe is largest when surface data is assimilated, and weakens when using satellite data is assimilated
- No significant changes in location of hot spots from the prior



Spatial anomaly (estimates – regional mean) of prior and posterior anthropogenic fluxes over Europe, averaged over 2018
Tsuruta et al., in prep.

CO_2 inversion intercomparison

Ensemble of 8 inversions based on combinations of:

- 2 inversion systems (LUMIA and CSR)
- 2 regional transport models (FLEXPART and STILT)
- 2 global transport models (TM3 and TM5)

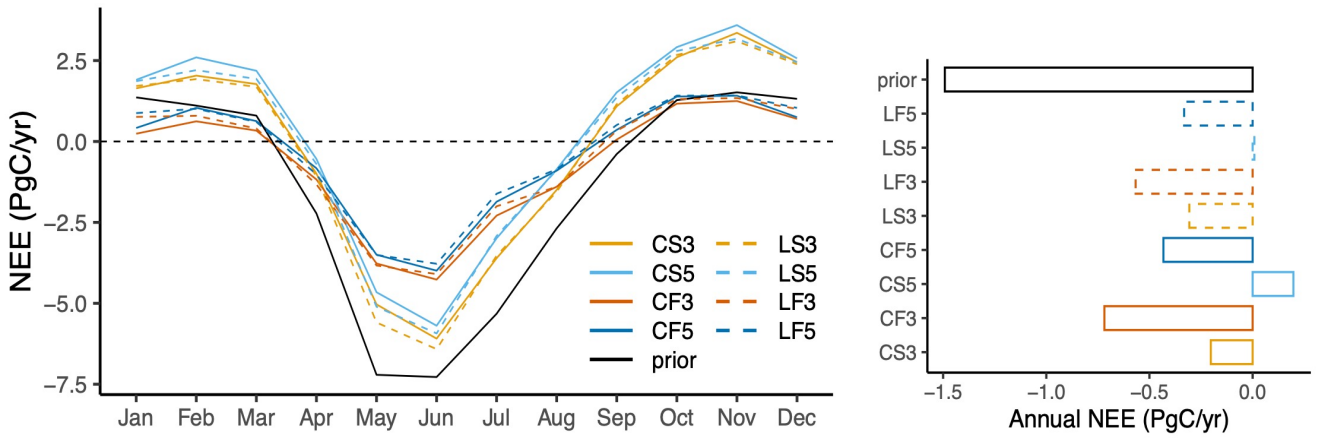


Figure 1: Left panel refers to posterior monthly NEE estimated using eight inversions, including prior NEE shown in black colour, with CSR (solid lines) and LUMIA (dashed lines), and right panel denotes the corresponding annually aggregated fluxes. Orange and red colours correspond to TM3 and dark/light blue to TM5. Orange and light blue colours refer to STILT and red and dark blue to FLEXPART.

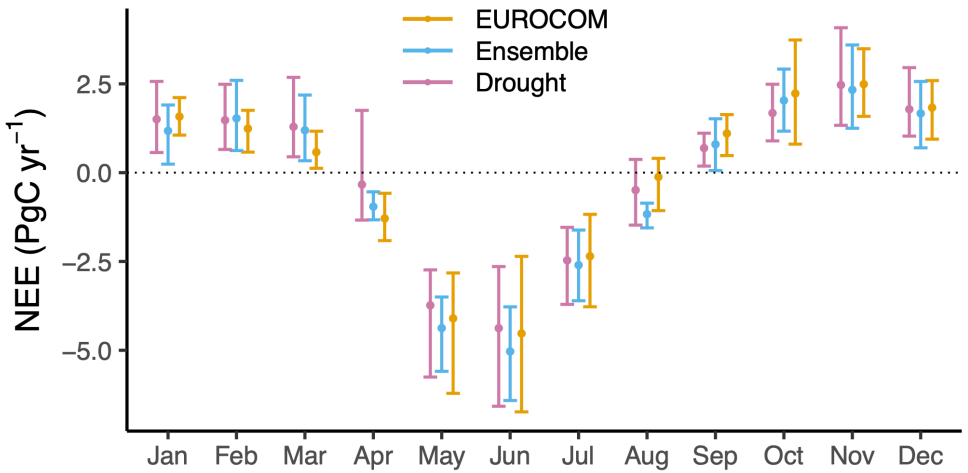
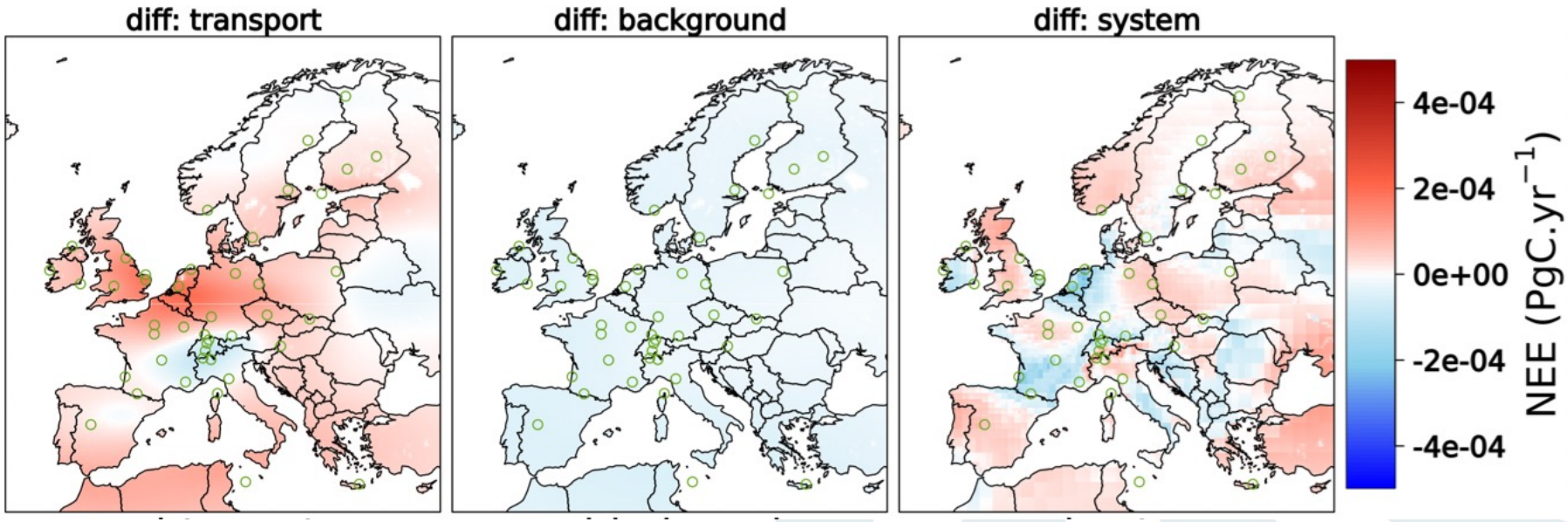


Figure 9: Comparison of monthly NEE estimates calculated as the mean of six inversions taken from Monteil et al. (2020), denoted as "EUROCOM", eight inversion members conducted in our study (set-ups listed in Table 2), denoted as "Ensemble", and five inversions used in Thompson et al. (2020) for the 2018 drought study denoted as "Drought". The error bars refer to the spreads (min/max) over the respective members amid each ensemble of inversions.

CO_2 inversion intercomparison



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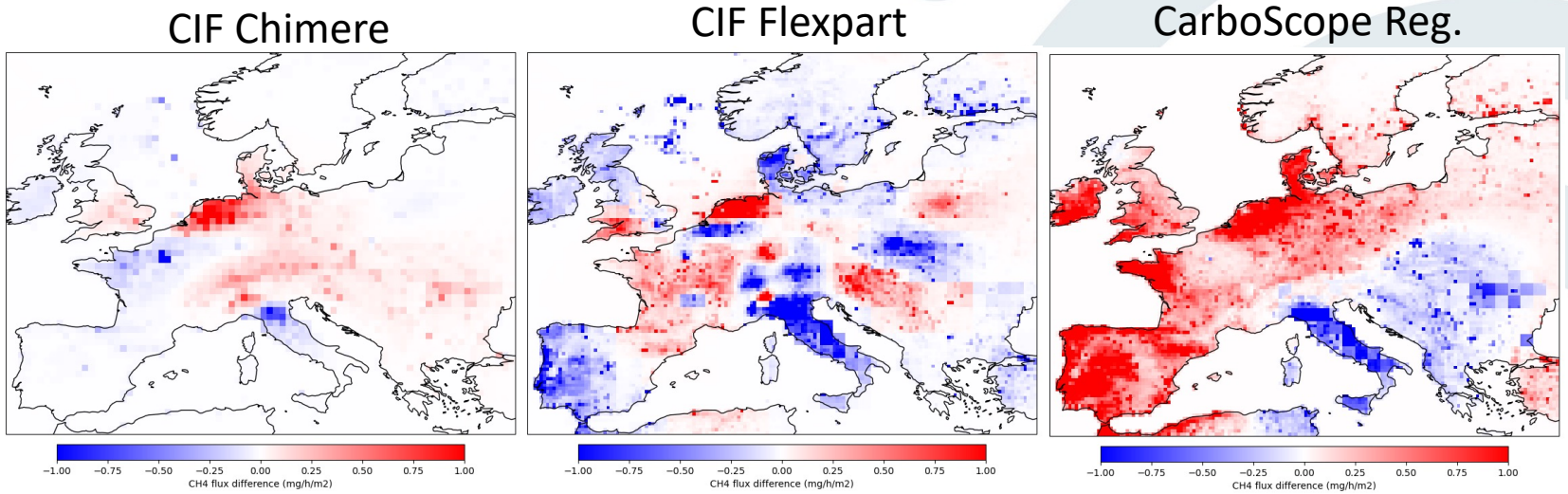
Task 5.6: Uncertainties in European inversions of CO_2 and CH_4

CH_4 inversion intercomparison, submissions received:

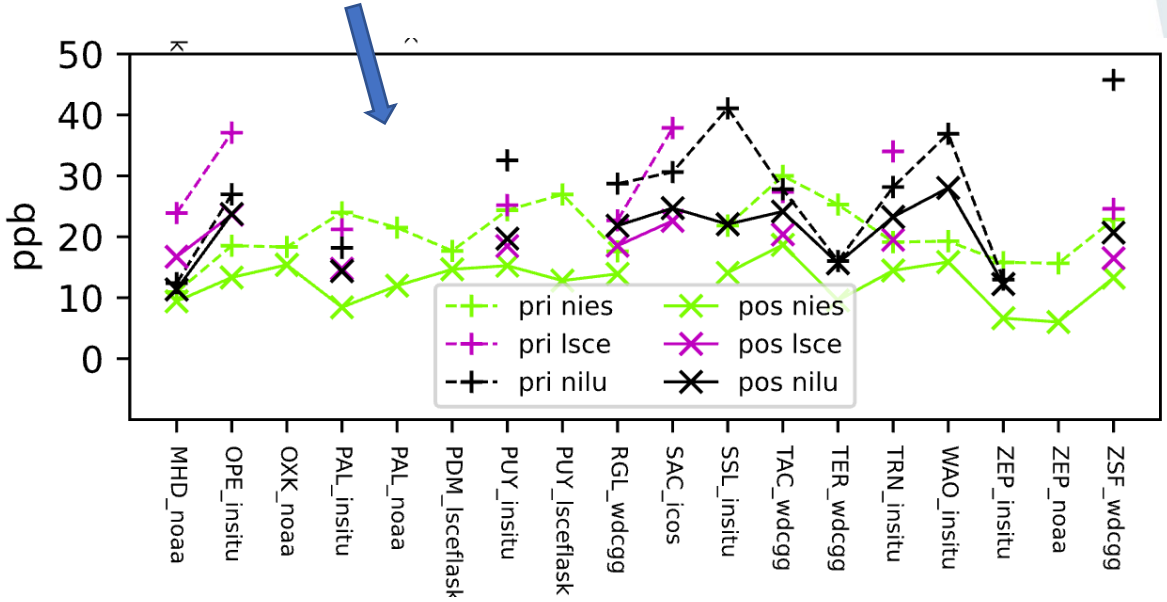
Group	Model	Gridded Fluxes	Country totals	CH_4 mixing ratios	Valid data	Exp.
Uni Lund	Lumia					Base/Exp1
MPI-Jena	CarboScope					Base/Exp1
FMI	CTE-CH_4					Base
NIES	NTFVAR2.0					Base
LSCE	CIF-Chimere					Base
NILU	CIF-Flexpart					Base
EMPA	ICONDA					Base/Exp 1
NIM						Base

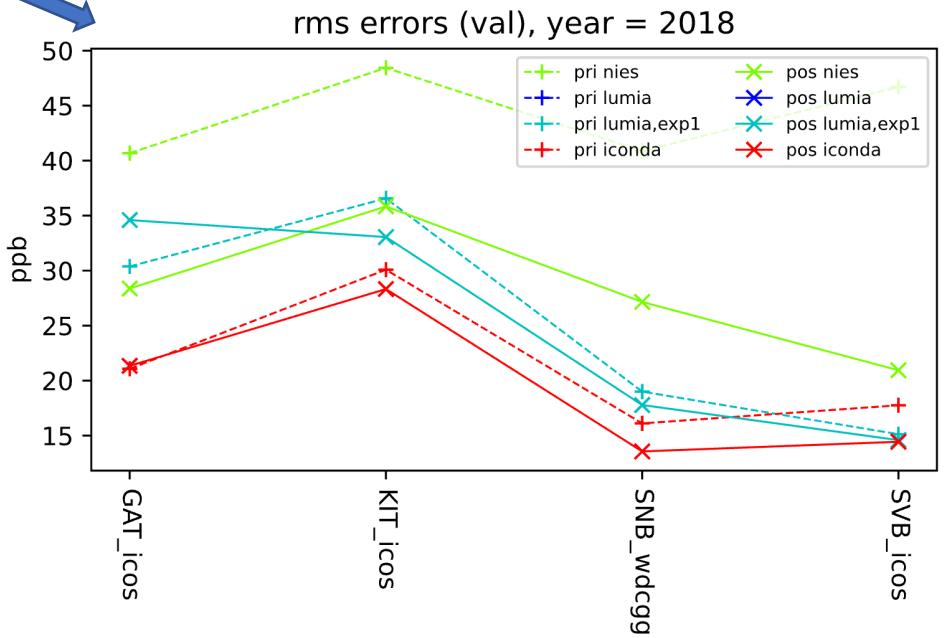
Task 5.6: Uncertainties in European inversions of CO_2 and CH_4

A posteriori – a priori emission differences for 2016



Evaluation: using fit residuals & using independent data





Expected outcomes from WP5

- **Methodology for linking scales (global/regional/local -> T5.1)**
- **Toolbox for benchmarking terrestrial carbon models (CoCO2 workspace at ME.org -> T5.2)**
- **Community Inversion Framework incl several transport models (T5.3)**
- **Synthetic CO2M satellite dataset & assessment of uncertainties in CO2M derived fluxes (T5.4)**
- **Investigation of design aspects of CO2MVS (T5.5), e.g.:**
  - **# of sat in constellation**
  - **in-situ vs XCH4**
- **Analysis of intercomparison studies (T5.6):**
  - **Impact of transport model & system set up in CO2 inversions**
  - **European CH4 inversion intercomparison**

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THANK YOU

This presentation reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

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