Co-ordinated by ECMWF

CO_2 Human Emissions

WP3 - COORDINATING EFFORTS ON UNCERTAINTY TRADE-OFF FOR FOSSIL FUEL EMISSIONS

1st Review Meeting

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14/01/19

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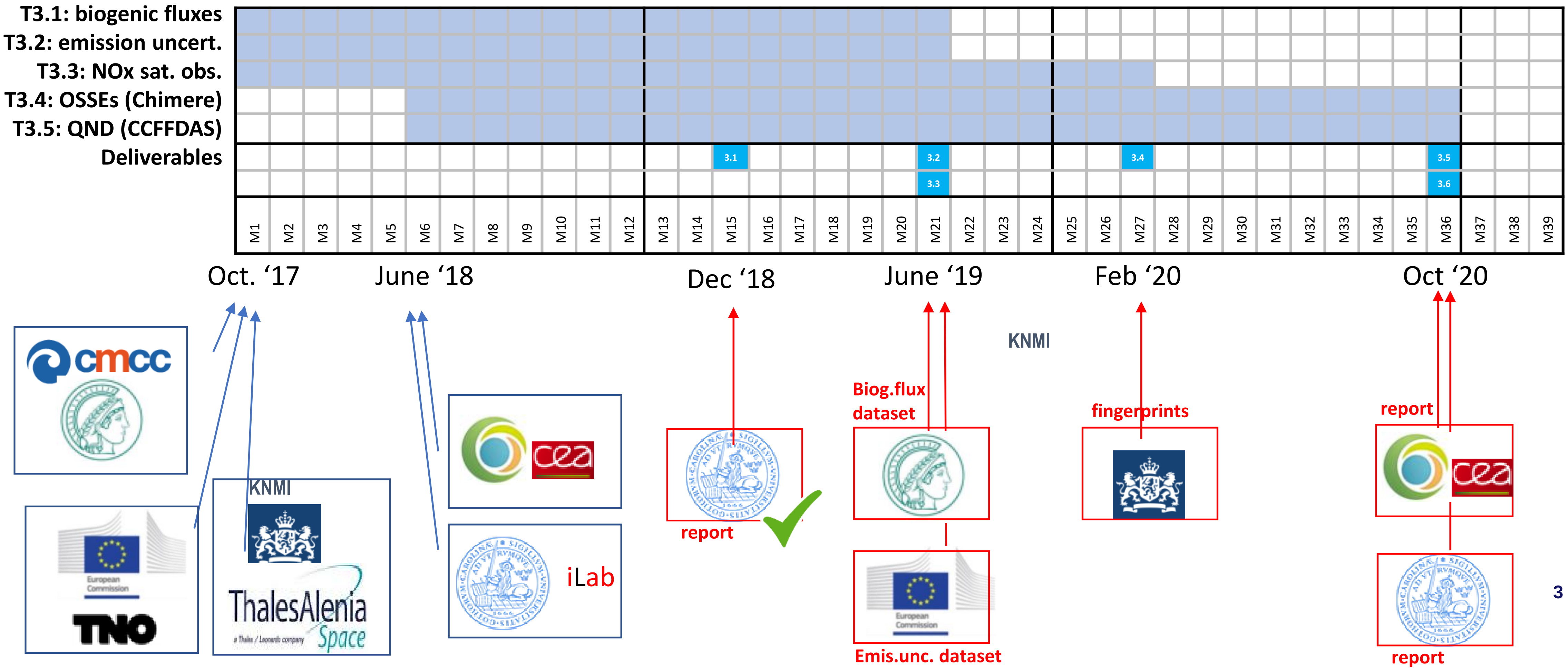
WP3 Objectives

- Provide high-resolution (~km, hourly) prior biogenic fluxes with quantified uncertainties based on upscaling of eddy covariance flux measurements
- Provide prior gridded anthropogenic emissions and their uncertainties and per sector
- Evaluate the current status and possible improvements from enhanced space-borne and in-situ observation scenarios for fossil CO2 emissions quantification based on
  OSSEs (Observation System Simulating Experiments) studies, &
  QND (Quantitative Network Design) studies, with:
  - high-resolution inverse transport modelling of CO2
  - high-resolution modelling of CO2 and co-emitted species (NOx)
  - advanced carbon cycle-fossil fuel data assimilation systems

WP3: Overview and Schedule

Uncertainty trade-off for fossil fuel emissions: 5 Tasks



WP3: Deliverables

- D3.1 Report describing current activities on uncertainty trade-off for fossil fuel emissions (ULUND) -> delivered on time Dec 2018
- D3.2 Net biospheric CO2 fluxes with quantified uncertainties estimated from independent in-situ network of eddy covariance measurements (MPI-BGC) -> on schedule, due June 2019
- D3.3 Fingerprints of fossil CO2 sources with uncertainties based on observations of NOx emissions (JRC) -> on schedule, due June 2019
- D3.4 Fingerprints of fossil fuel CO2 sources with uncertainties based on observations of Nox emissions (KNMI) -> on schedule, due Feb 2020
- D3.5 Report on inversion strategy based on OSSEs with an inverse transport modelling system (LSCE) -> on schedule, due Oct 2020
- D3.6 Report on inversion strategy based on joint QND assessment of atmospheric and terrestrial observation impact in terms of their constraint on fossil and biogenic carbon fluxes in a CCFFDAS (ULUND) -> on schedule, due Oct 2020

Task 3.1 MPI-BGC: Estimate biogenic fluxes and associated uncertainties from independent observations

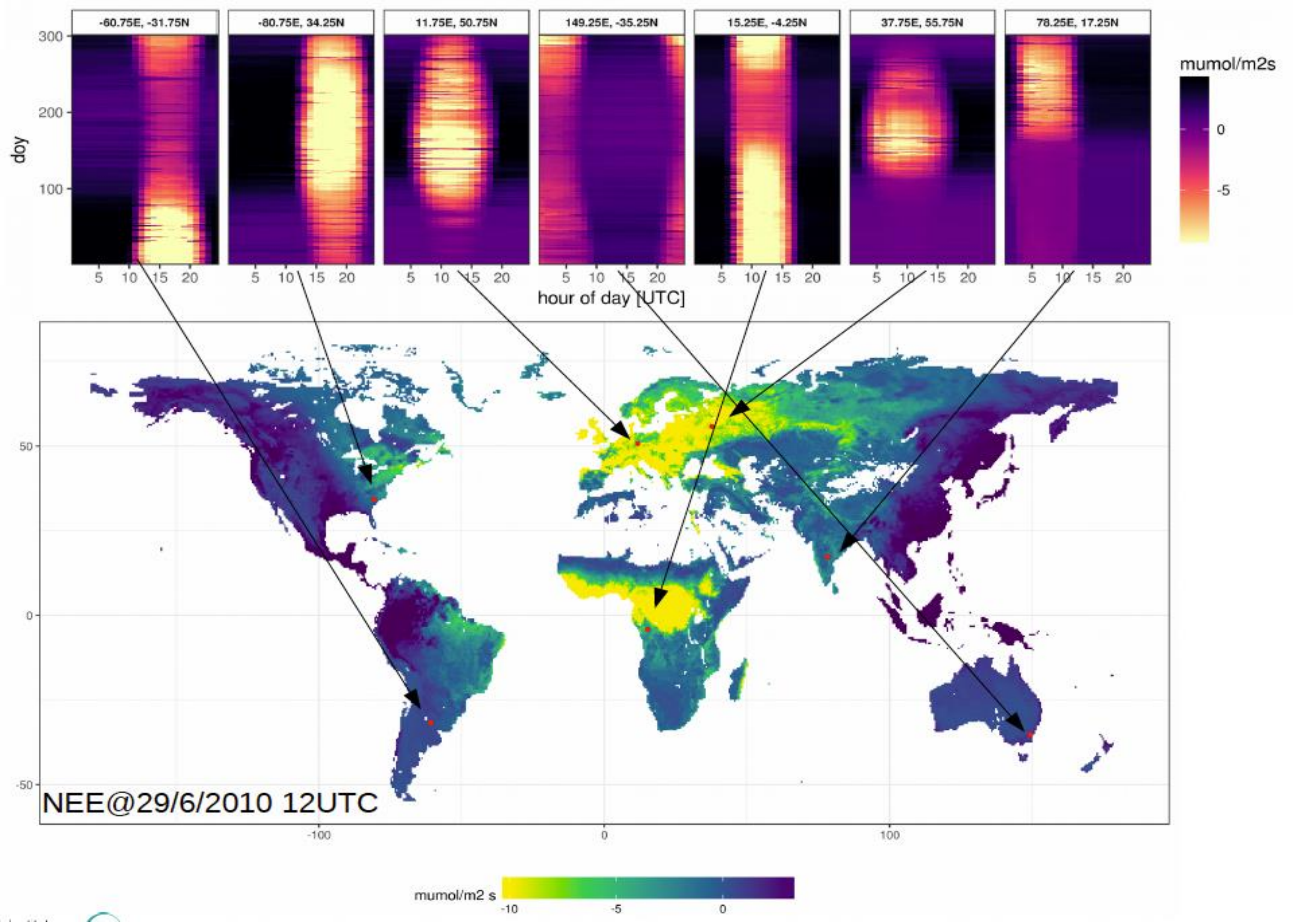
Objective:

Provide a data driven high-resolution product for net biospheric CO2 fluxes with quantified uncertainties based on in-situ eddy covariance measurements.

Progress:

- Produced data-driven estimates of hourly net ecosystem exchange and gross primary productivity using in-situ eddy-covariance measurements with ERA5 meteorology, space-borne measurements and machine learning
- 0.5 deg spatial and 1 hour temporal resolution for the period 2008-2017

First results
Task 3.1



Thanks to Sophia Walther

Task 3.1 Impact and Plans

Estimates of biogenic fluxes help to better constrain anthropogenic fluxes and contribute to study uncertainties in the framework of OSSEs.

Plans:

- uncertainties
- refine spatial resolution
- improve methodology and increase the amount and quality of data
- training data as well as predictors

Task 3.2 JRC/ECMWF: Provide emission uncertainties and correlations from inventories and statistics

Objective: Full assessment of:

- the uncertainty of anthropogenic emissions per country and per human activity (following IPCC guidelines) at high spatial and temporal resolution.
- the emission ratios NOx/CO2 for combustion of fossil and biogenic fuel.

Progress:

- Error propagation (following IPCC) is concluded
- Emissions maps per human activity with upper and lower uncertainty bound are generated
- Covariance matrix setup in discussion with ECMWF
- Sensitivity of the spatial distribution is under investigation

IPCC methodology & input data chain

70 IPCC activities

- Emission Factor (or Estimation Parameter) uncertainty [EF]
- Activity Data uncertainty [AD]

- Combined uncertainty (with error propagation method)

Original cluster

IPCC:
2006 IPCC Guidelines for National Greenhouse Gas Inventories (+ its 2019 Refinements)

20 EDGAR sectors

Pre-processing
- split-up energy sector
- CO2 from coal mining

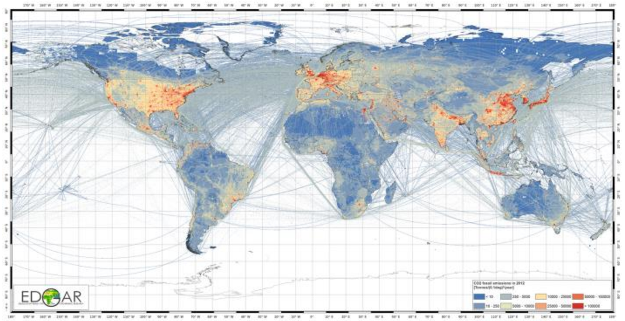
2 types: countries with well/less developed statistical systems

- Combined+corrected uncertainty (with error propagation method)

- Log-normal uncertainty distribution

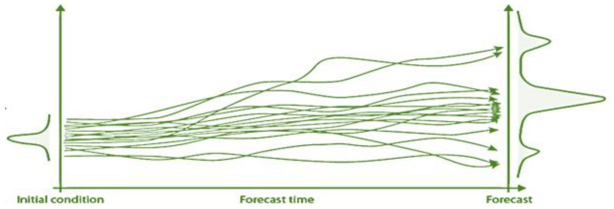
231 countries

Mapping cluster



ENS perturbations

perturbing CO2 anthropogenic emissions per country & per group



7 ECMWF groups

231 countries

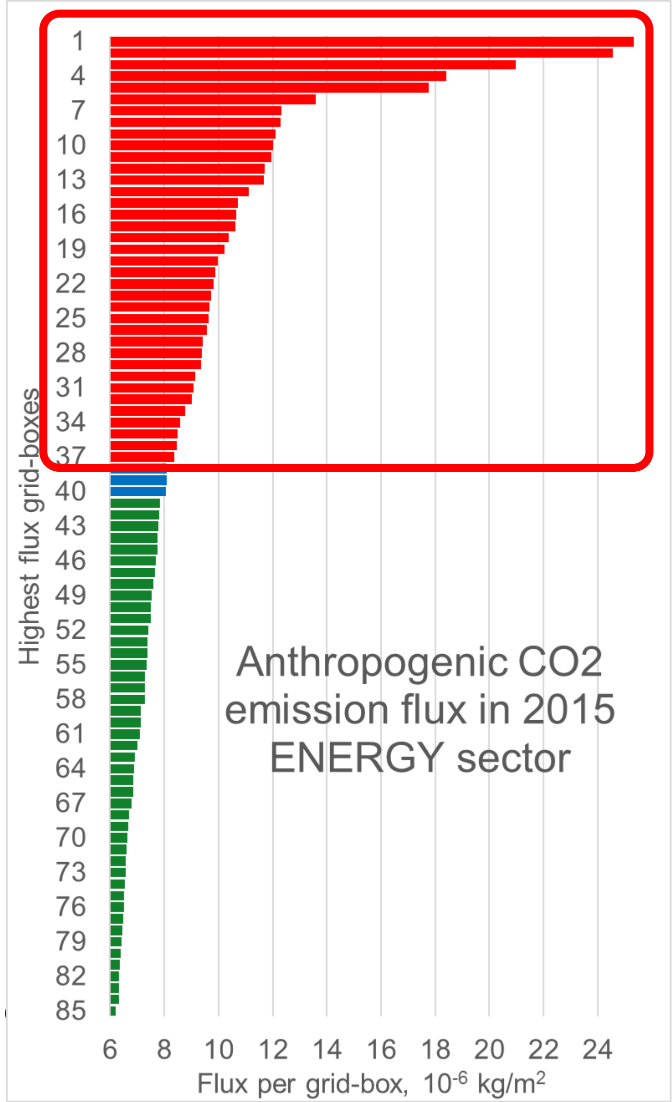
- Combined uncertainty (with error propagation method)

Post-processing
- log-normal mean
- log-normal standard deviation

Perturbation cluster

Thanks to Margarita Choulga

Focusing on energy: super-power plants



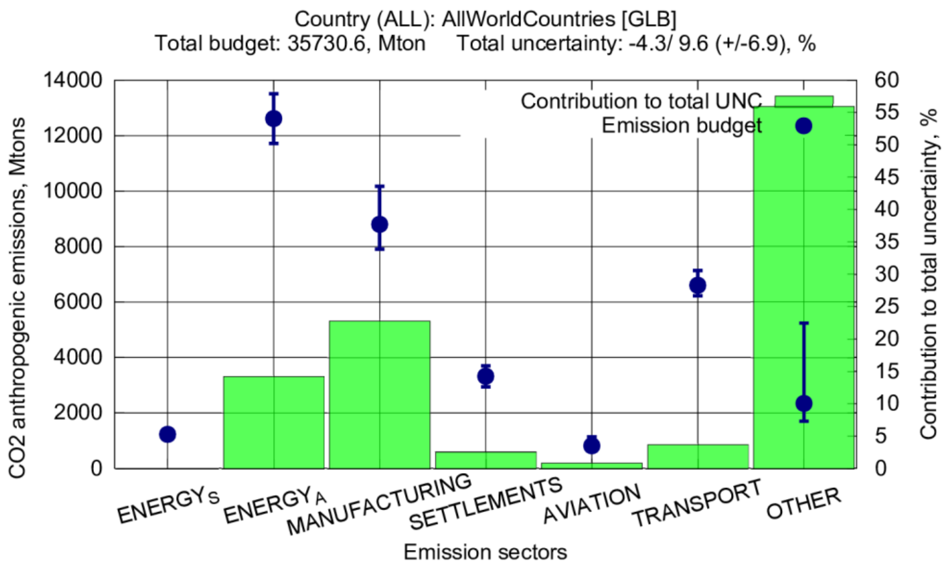
Energy sector grid-boxes with **flux value >= 8.3E-06 kg/m2/s** were considered as **super power plants**.

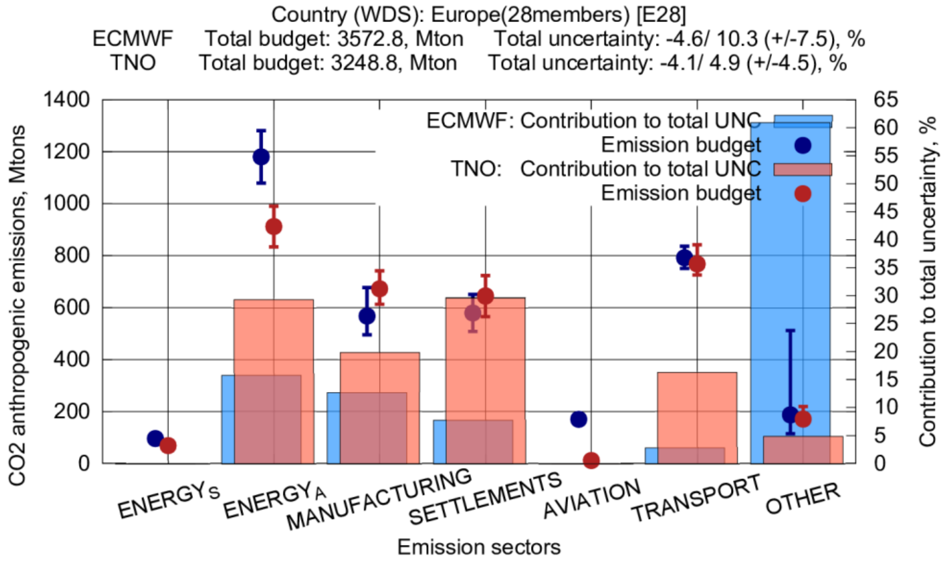
This threshold value was chosen in order to capture European (**Polish** and **German**) most emitting power plants (prior knowledge from TNO).

In total now we **have 37 grid-boxes** considered as super power plants.

Rank	Latitude, º	Longitude, º	CO2 flux in 2015, kg/m2	Countries
17	-32.25	150.95	1.06E-05	Australia [AUS]
14	31.25	120.55	1.11E-05	China [CHN]
22	48.55	119.75	9.82E-06	
23	38.15	106.35	9.74E-06	
33	40.25	111.35	8.76E-06	
37	31.35	121.65	8.35E-06	
12	51.05	6.55	1.17E-05	Germany [DEU]
25	51.85	14.45	9.62E-06	
9	24.15	82.75	1.21E-05	India [IND]
16	24.05	82.65	1.07E-05	
19	11.55	79.45	1.02E-05	
24	21.95	83.45	9.67E-06	
30	22.35	82.65	9.15E-06	
32	21.05	85.05	9.01E-06	
11	35.45	139.65	1.19E-05	Japan [JPN]
28	35.65	140.15	9.39E-06	
35	34.85	134.75	8.50E-06	
21	51.85	75.35	9.87E-06	Kazakhstan [KAZ]
15	29.45	48.25	1.07E-05	Kuwait [KWT]
34	51.25	19.35	8.60E-06	Poland [POL]
1	55.95	37.75	2.53E-05	Russia [RUS]
2	60.35	28.65	2.46E-05	
3	55.75	52.45	2.10E-05	
5	54.75	20.55	1.78E-05	
7	57.05	40.35	1.23E-05	
13	55.55	37.75	1.17E-05	
26	46.35	40.65	9.57E-06	
29	69.35	88.25	9.36E-06	
31	62.15	65.35	9.08E-06	
36	27.05	49.65	8.46E-06	Saudi Arabia [SAU]
10	-26.15	29.15	1.20E-05	South Africa [ZAF]
6	36.75	126.25	1.36E-05	Korea South [KOR]
8	36.85	126.65	1.23E-05	
18	37.75	128.15	1.04E-05	
27	36.45	126.45	9.41E-06	
4	24.25	120.45	1.84E-05	Taiwan [TWN]
20	53.75	359.15	9.97E-06	United Kingdom [GBR]

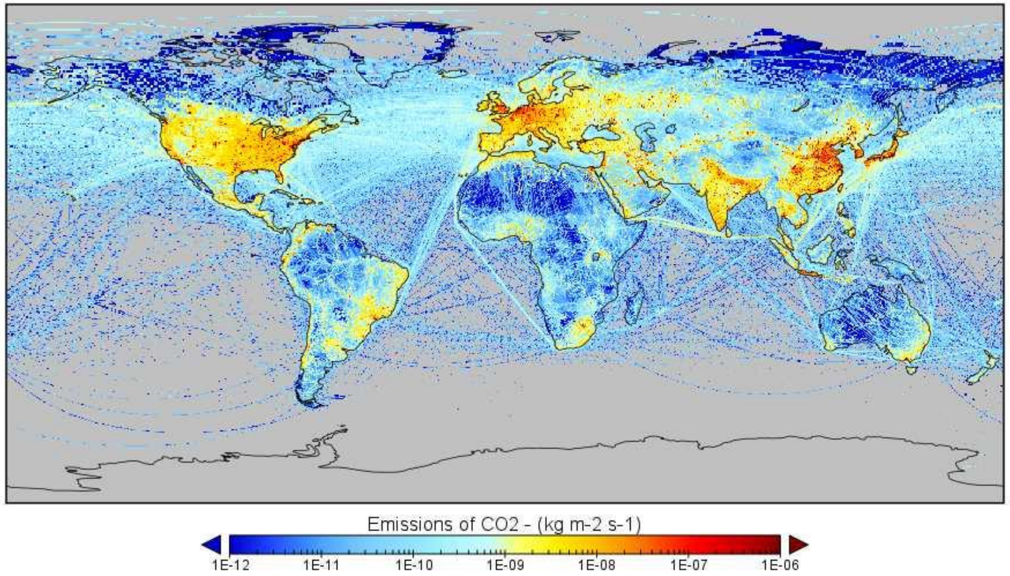
CO_2 Human Emissions global budget 2015

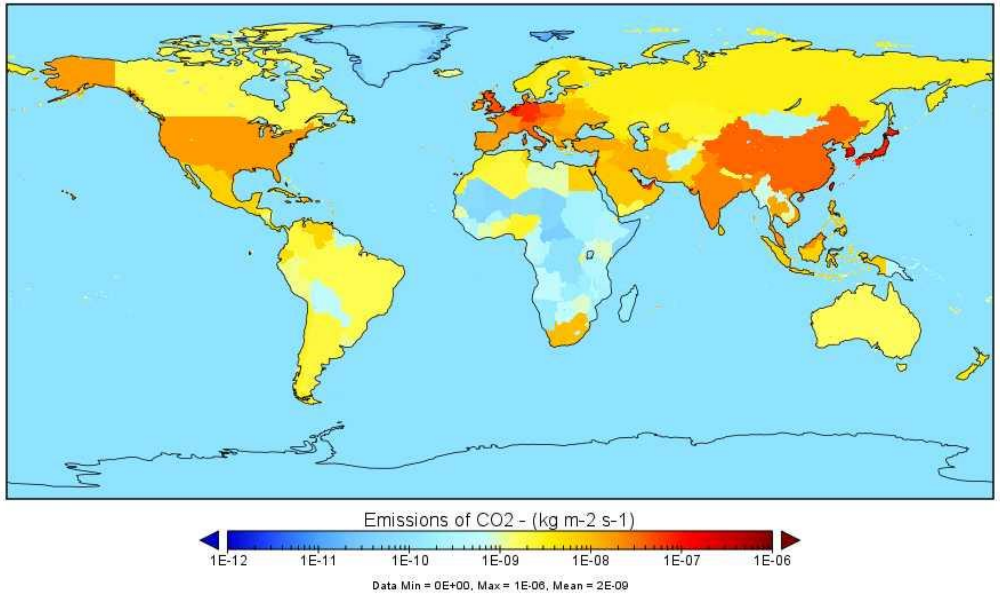




Gr. №	Group name	Note	E-s, Mton
1	**ENERGY_S**	**Power industry** - super emitting power plants	**13’704**
2	**ENERGY_A**	**Power industry** - average emitting power plants	
3	MANUFAC-TURING	**Combustion for manufacturing**	**6’183**
		Iron and steel production	234
		Non-ferrous metals production	91
		Non energy use of fuels	10
		Non-metallic minerals production	1’748
		Chemical processes	534
4	SETTLEMENTS	**Energy for buildings**	**3’322**
		Solvents and products use	61
		Solid waste incineration	137
5	AVIATION	Aviation cruise	815
		Aviation climbing&descent	
		Aviation landing&takeoff	
6	TRANSPORT	**Road transportation**	**5’530**
		Shipping	819
		Railways, pipelines, off-road transport	255
7	OTHER	Agricultural soils	99
		Oil refineries and Transformation industry	1’917
		Fuel exploitation	258
		Coal production	48

Task 3.2: Model Sensitivity on the emissions' spatial distribution





Uncertainty of the spatial distribution depends on:

- the uncertainty of the proxies' data
- the representativeness of the selected proxies

Reference case: spatially gridded (300 EDGAR proxies)

Flat case: distributed uniformly over the country

Case with only power plants distributed:
spatially gridded power plants but other sectors uniformally distributed

Case with all but the power plants distributed:
spatially gridded sectors except power plants.
Are we able to detect anomally of the reported active super power plants (in-/active point sources)?

Task 3.2 JRC/ECMWF: Provide emission uncertainties and correlations from inventories and statistics

Impacts on CHE and beyond

Extra delivery of fugitive CO2 emissions from oxidation in coal mines following the recommendations of the refinement of the IPCC Guidelines (2019)

Planning

- Evaluation of spatial profiles to be concluded
- Evaluation of temporal profiles ongoing
- Evaluation of emission ratios ongoing

Task 3.3 KNMI: Explore the role of satellite NOX observations for estimation of fossil CO_2 emissions

Objective: Use of high-resolution tropospheric NO_2 observations of Tropomi to fingerprint fossil fuel burning / biomass burning

Progress

- First Tropomi NO_2 data set has been made available late 2018 (6 month of data in 2018)

Impacts on CHE and beyond

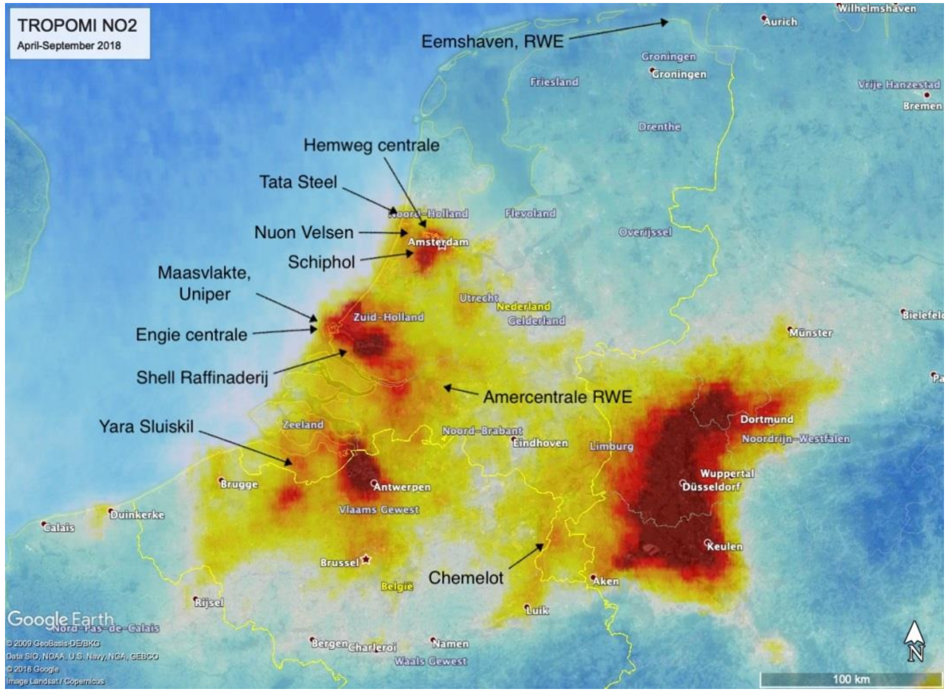
- Detection of (potential changes in) anthropogenic CO_2 hot spots through NO_2 (changes)
- Potential for uncertainty reduction in anthropogenic CO_2 emissions based on sectoral CO_2-NO_2 emission ratios
- Potential added value of ancillary high spatial resolution satellite NO_2 observations for the attribution of CO_2

Planning

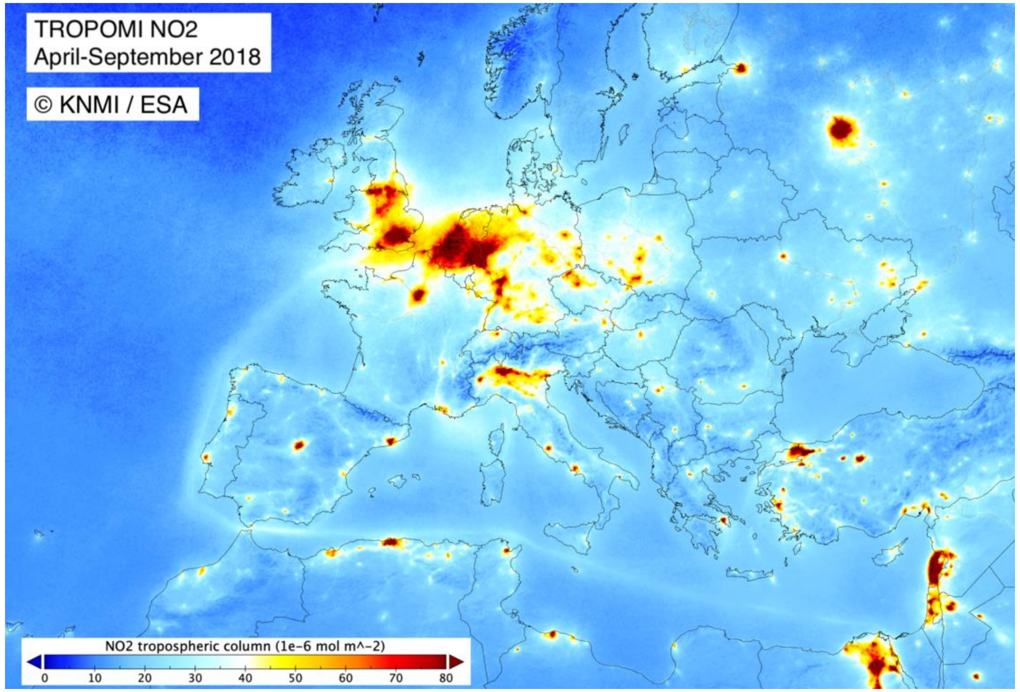
- Derive TROPOMI/DECSO-based NOX emissions for Europe (Apr-Sep 2018)
- Associate with regional CO_2 emissions using emission inventories available within CHE

Task 3.3 Results: Tropomi Tropospheric NO_2 (2018)

Tropomi NO_2 + Top-10 CO_2 emitters in The Netherlands + Schiphol Airport (by Eskes, KNMI)

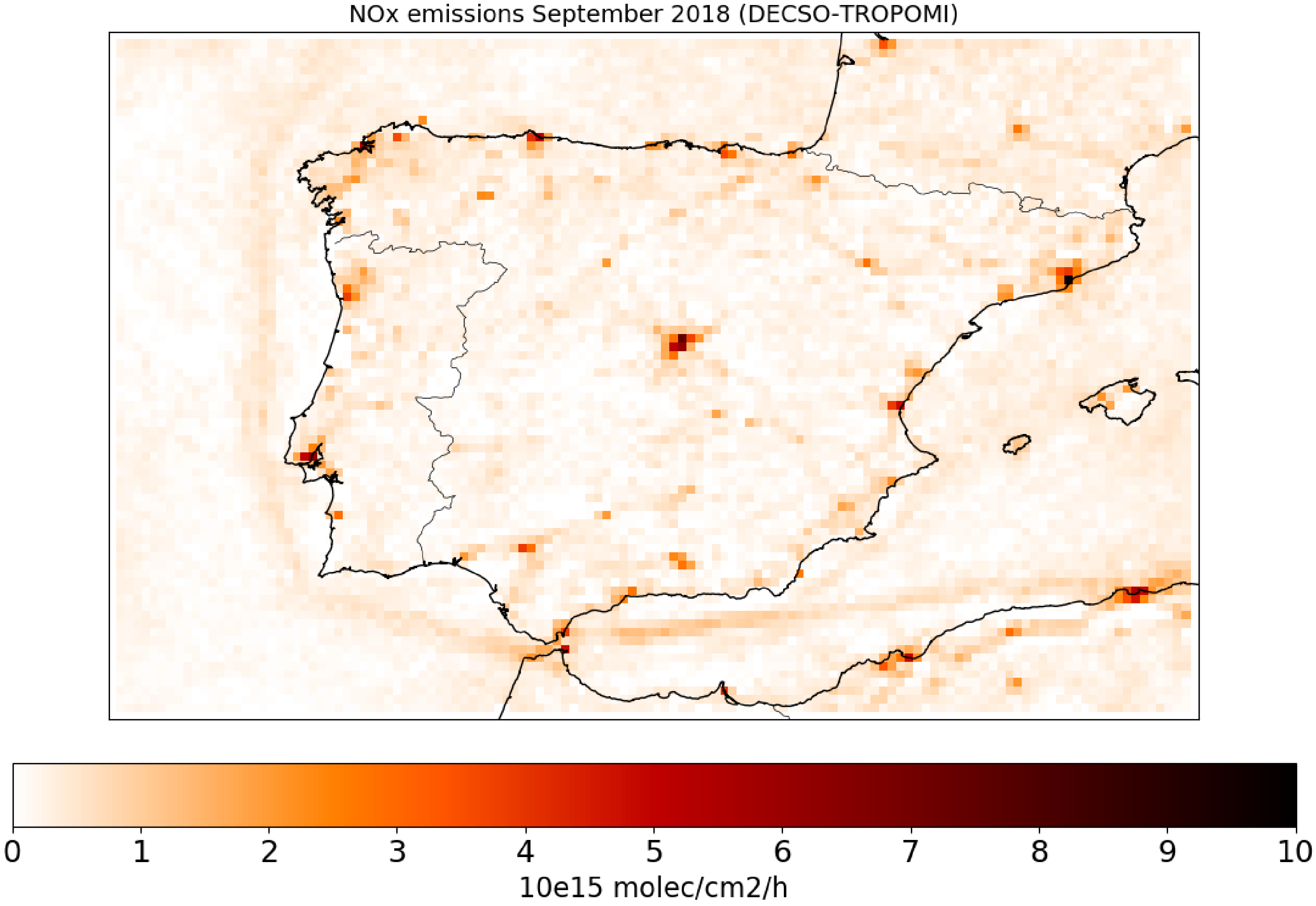


6-monthly mean (apr-Sep 2018) TROPOMI NO_2 distribution over Europe



Thanks to Ronald van der A

Task 3.3 Results: Tropomi Tropospheric NO_2 (2018)



DECSO (NOx inversion algorithm)

was further developed
for TROPOMI

Case study Spain:

illustrated that the quality of the NOx emission estimates is much better than what was previously obtained by using the OMI observations

Thanks to Ronald van der A

Task 3.4 LSCE: Conduct OSSEs with an inverse transport modelling system

Objective:

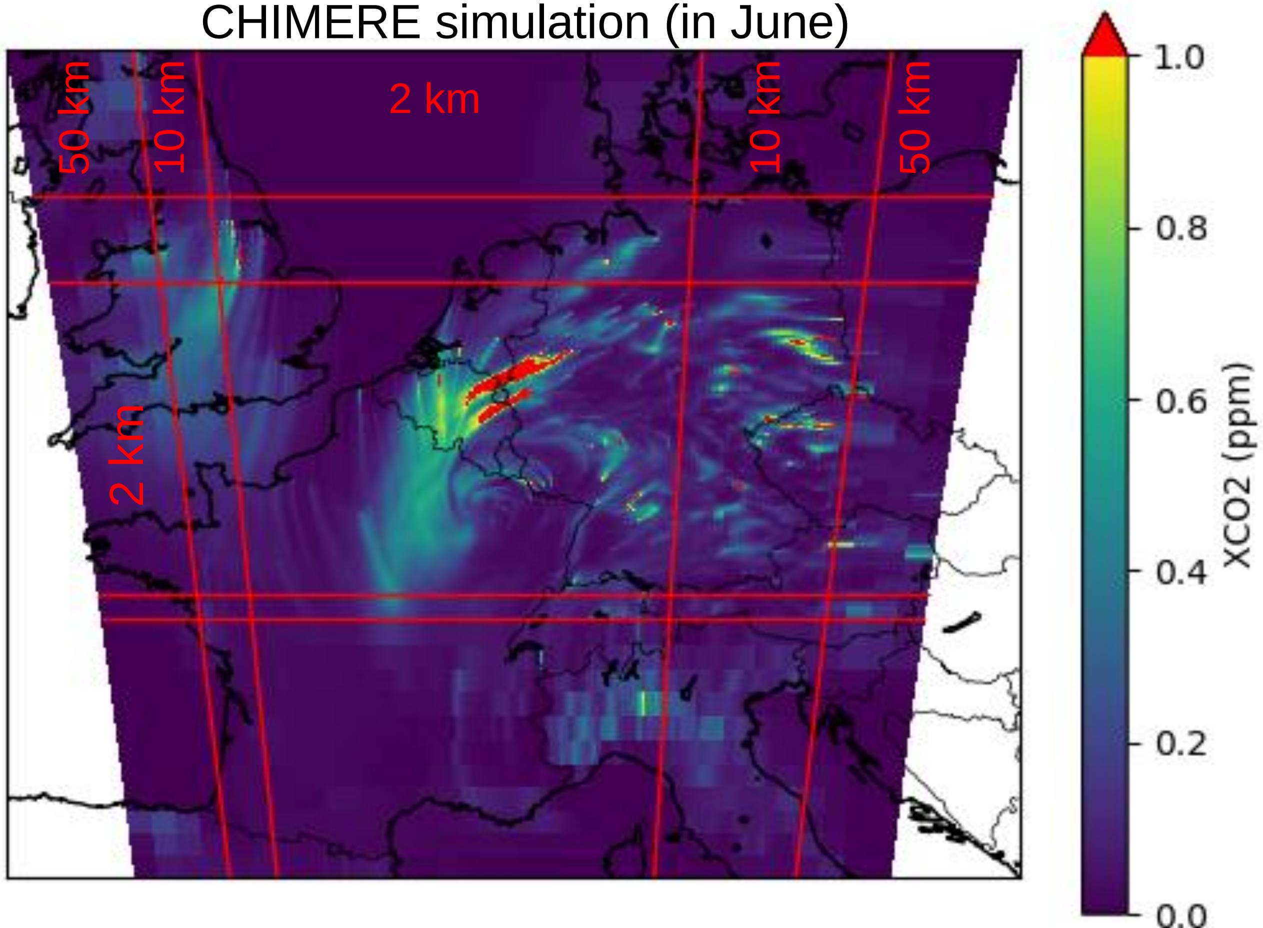
Perform Observation Simulation System Experiments with an atmospheric transport inversion system to assess the potential of XCO2 images (and CO from S5P) for the monitoring of CO2 emissions

Progress:

- Implementation of a CO_2 inversion system with the CHIMERE transport model.
- Simulations are performed on Europe with resolution from 50km on the border to 2km in the centre of the domain (area covering the Northern France and Benelux).
- Tests are conducted to define the control vector and to prepare the assimilation of satellite and in-situ observations.

Task 3.4: CO_2 transport model (CHIMERE) Common to Task 2.3 and Task 4.2

Anthropogenic XCO2 calculated from a CHIMERE simulation (in June)



Domain : Europe from 50 km to 2 km resolution in the center

	Preliminary tests	Goal in CHE
Anth. CO2 emissions	IER 1-5km	TNO 1/10°x1/20° (Task 3.2)
Bio. CO2 emissions	VPRM 8 km	VPRM 1 km (Task 3.1)
Meteorology Boundary conditions	ECMWF CAMS	ECMWF CAMS

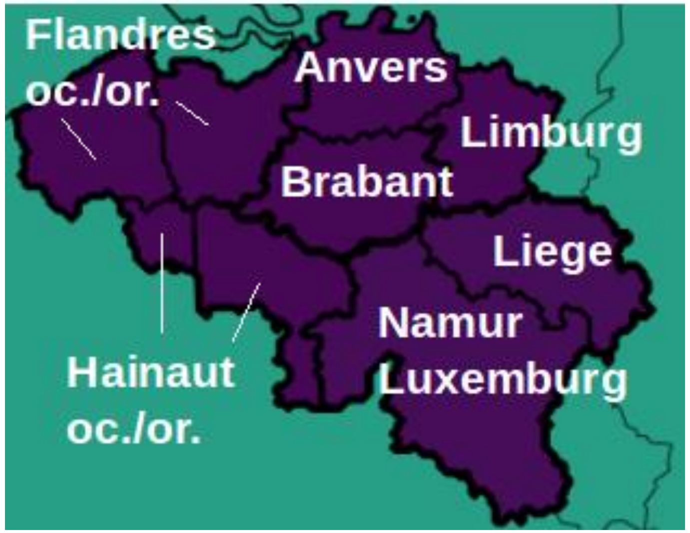
→ Interpolations were performed to match defined domain

Thanks to Frederic Chevalier

Task 3.4: Implementation of the inversion system
Common to Task 4.2

- **Inversion system : analytical Bayesian inversion**
- **First tests**
  - Anthropogenic and biogenic fluxes
  - Control of hourly budgets of 9 administrative regions + rest of the domain
  - Definition of the error covariance matrix:
    - Prior uncertainty of 50% in budget of bio. or anthr. fluxes
    - 3-hour temporal auto-correlation of the prior uncertainty
  - Scenarios of theoretical CO_2 observations
    - High resolution CO_2 space-borne images (σ = 1ppm)
    - CO_2 in-situ continuous measurement networks (σ = 5ppm)

    → **Provide knowledge to optimize the final inversion set-up**

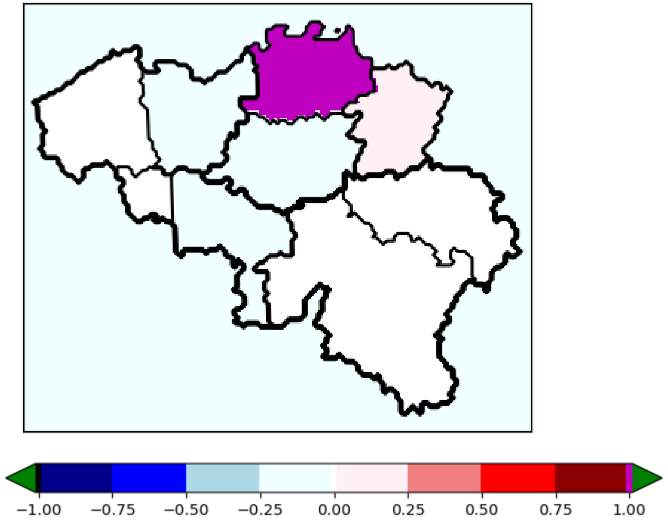


- **Future refinement of the inversion system**
  - → Distinguish between urban areas and power plants in the control vector and extend it to the rest of the domain
  - → Refine prior error statistics based on TNO inventory ensemble made for CHE in WP4
  - → Transport error ?

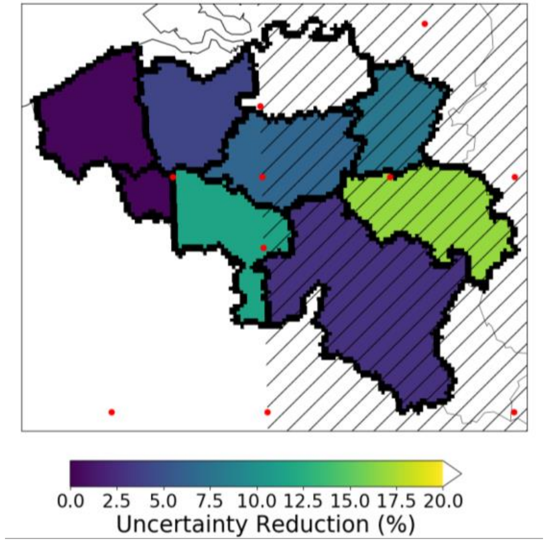
First Results Task 3.4

Study of the separability of the flux component to evaluate the choice of the control vector

Correlation of posterior errors on budget of Antwerp with other regions



Uncertainty reductions between prior and posterior daily anthropogenic budgets



in-situ observations = red points
a satellite pass = hashed area.

Modest uncertainty reduction

Good spatial separation
- Motivates refining the control vector

Possible aggregation errors with surface data
- Optimistic vision?
- Also motivates refining the control vector

➔**Negative correlations associated to relatively high posterior uncertainties are indicative for the difficulty to separate the different flux components**

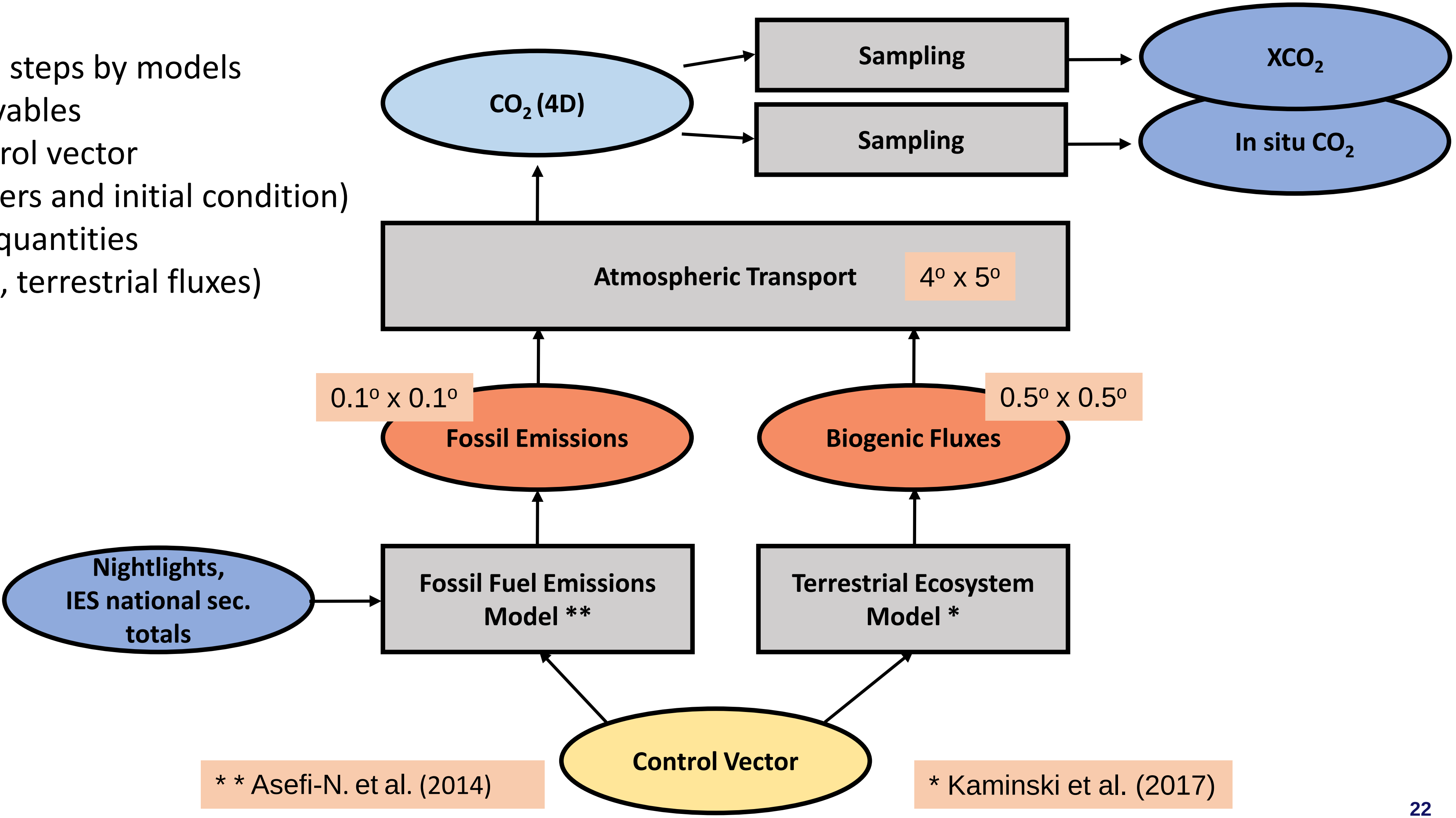
Task 3.5 ULUND/iLab: Perform QND experiments with CCFFDAS

Objectives:

- Develop a prototype Carbon Cycle Fossil Fuel Data Assimilation System that combines models of biogenic and anthropogenic processes with suitable observation operators
- Operate in a Quantitative Network Design mode to evaluate the complementarity (and redundancy) of in situ and remotely sensed CO2 observations in terms of the uncertainty reduction in sectorial fossil fuel emissions

Task 3.5: CCFFDAS overview

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)



Task 3.5: CCFDAS background

- QND: propagation of observational uncertainty through the modelling chain onto control variables ($C(x)^{-1} = M'^{T} C(d)^{-1} M' + C(x_0)^{-1}$) and further onto target quantities ($\sigma(y)^2 = N' C(x) N'^{T} + \sigma(y_{mod})^2$).
- Control vector consists of > 1.5 Mio elements (mainly because of 0.1° global resolution in the fossil fuel emissions model)
- Data:
  - Prior: CARMA database for power plants
  - Observations: IEA sectorial national totals, Nightlights, CO2 concentrations
- Technicalities:
  - M' is of large dimension (~1.5 M x 2 M), exploiting sparsity of M', all non-zero entries are computed.
  - posterior uncertainty calculated iteratively for selected target quantities (N'), e.g. national totals or interesting areas

CCFFDAS: assessments

Default Case ("1 Satellite"):

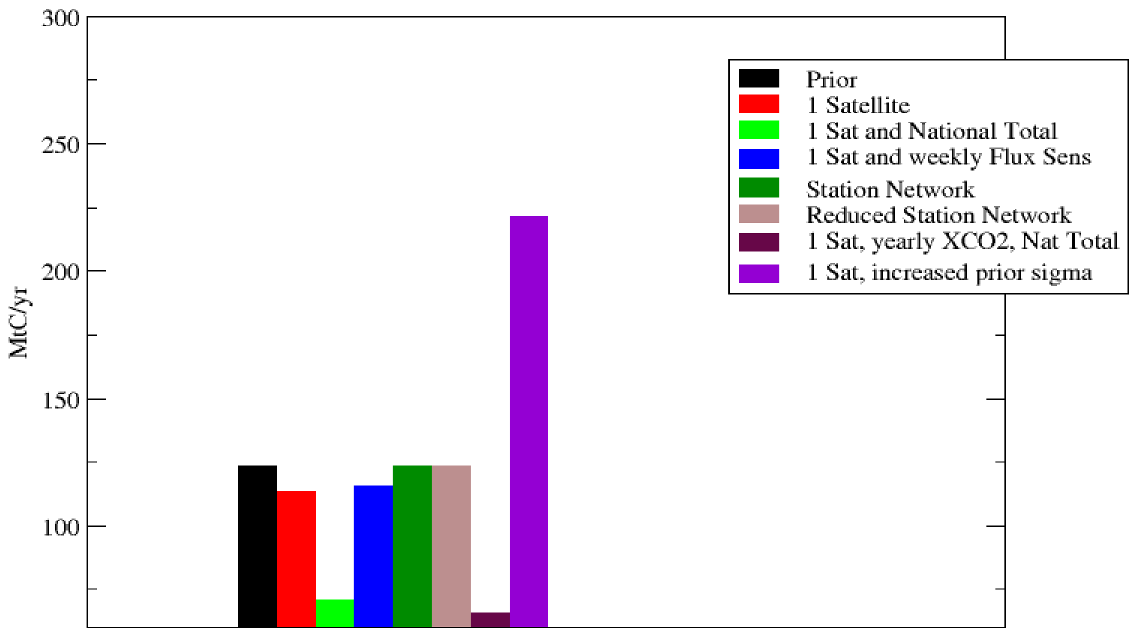
- XCO2 from 1st week in June 2008 as observational constraint
- Nightlights as observational constraint
- Prior uncertainty in EG as in Asefi-N et al. 2014 (for 4 countries increased)
- Annual fluxes, i.e. sensitivity of XCO2 to fluxes over the whole year
- Two sectors: Energy generation (eg), Other sector (os)
- Results are posterior uncertainties in emission rates per sector and country

Sensitivity Cases:

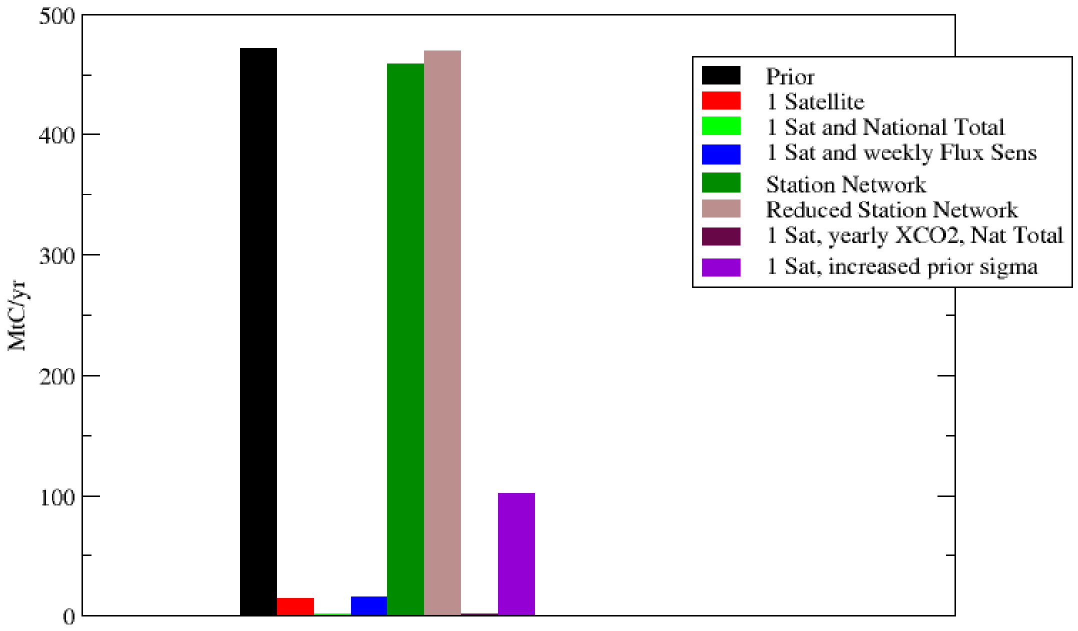
- "1 Sat and National Total": Moderate uncertainty on national totals (2.5-10%) as add. constraint
- "1 Sat, weekly flux sensitivity": Zero sensitivity of XCO2 to fluxes outside 1st week in June
- "Station Network": CO2 from 15 continuous sites instead of CO2
- "Reduced Station Network": Three sites around Australia removed from network
- "1 Sat, yearly XCO2, Nat. Total": all year XCO2 plus national total as add constraint
- "1 Sat, increase prior sigma": Prior uncertainty for all power plants 10 times increased

CCFFDAS: assessments

China – energy generating sector



Australia – other sectors

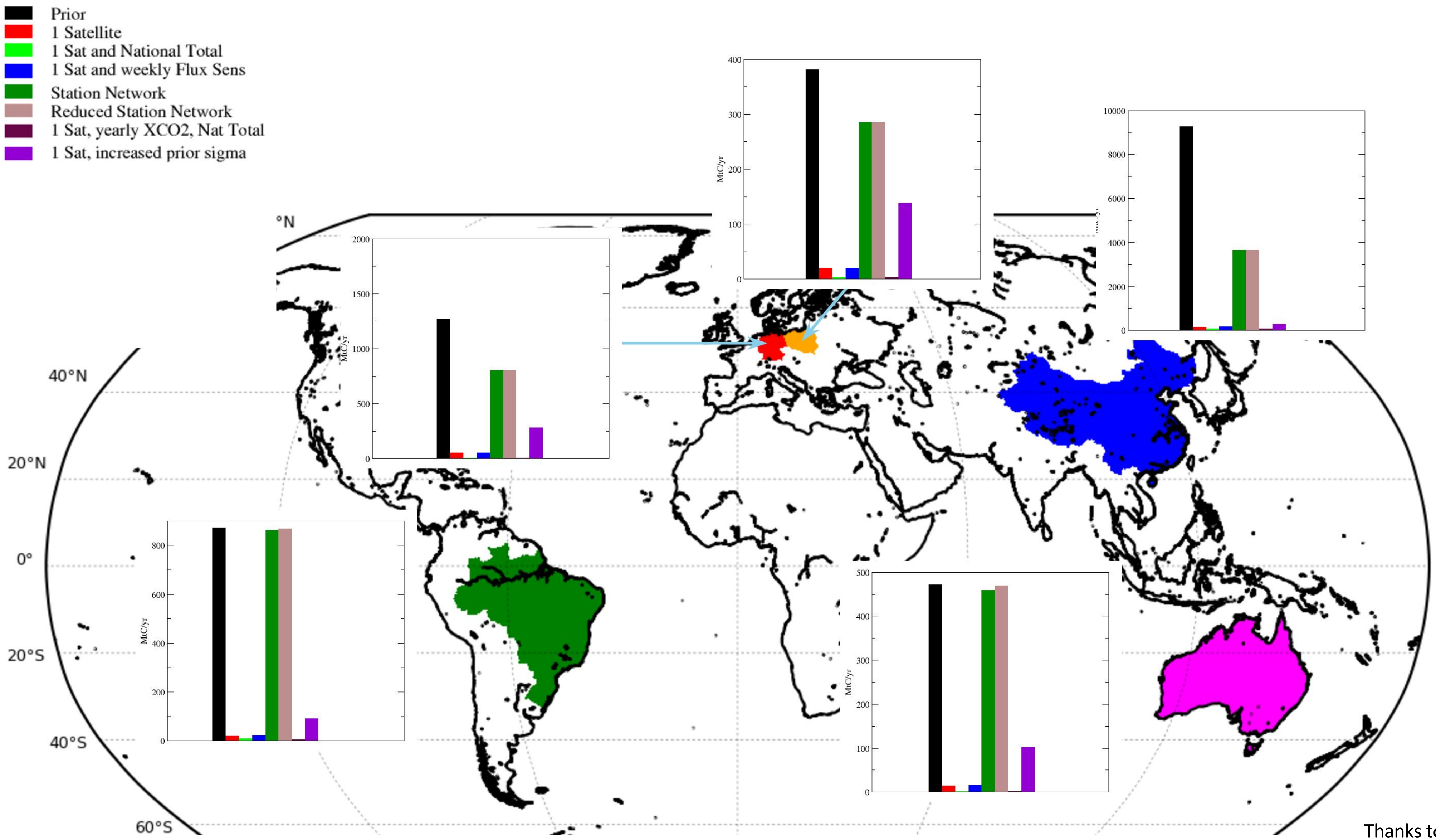


Findings:

- Inclusion of national total as obs. constraint yields considerable performance gain
- Impact of XCO2 on uncertainty reduction much larger than in situ network
- Limited sensitivity to design of in situ network
- Sensitivity to temporal domain in flux and XCO2 space
- High sensitivity to prior uncertainty in energy sector (also for other sector)

Thanks to Thomas Kaminski

CCFFDAS: Other sector uncertainty in comprehensive form



Thanks to Thomas Kaminski

CCFFDAS summary and outlook

Status:

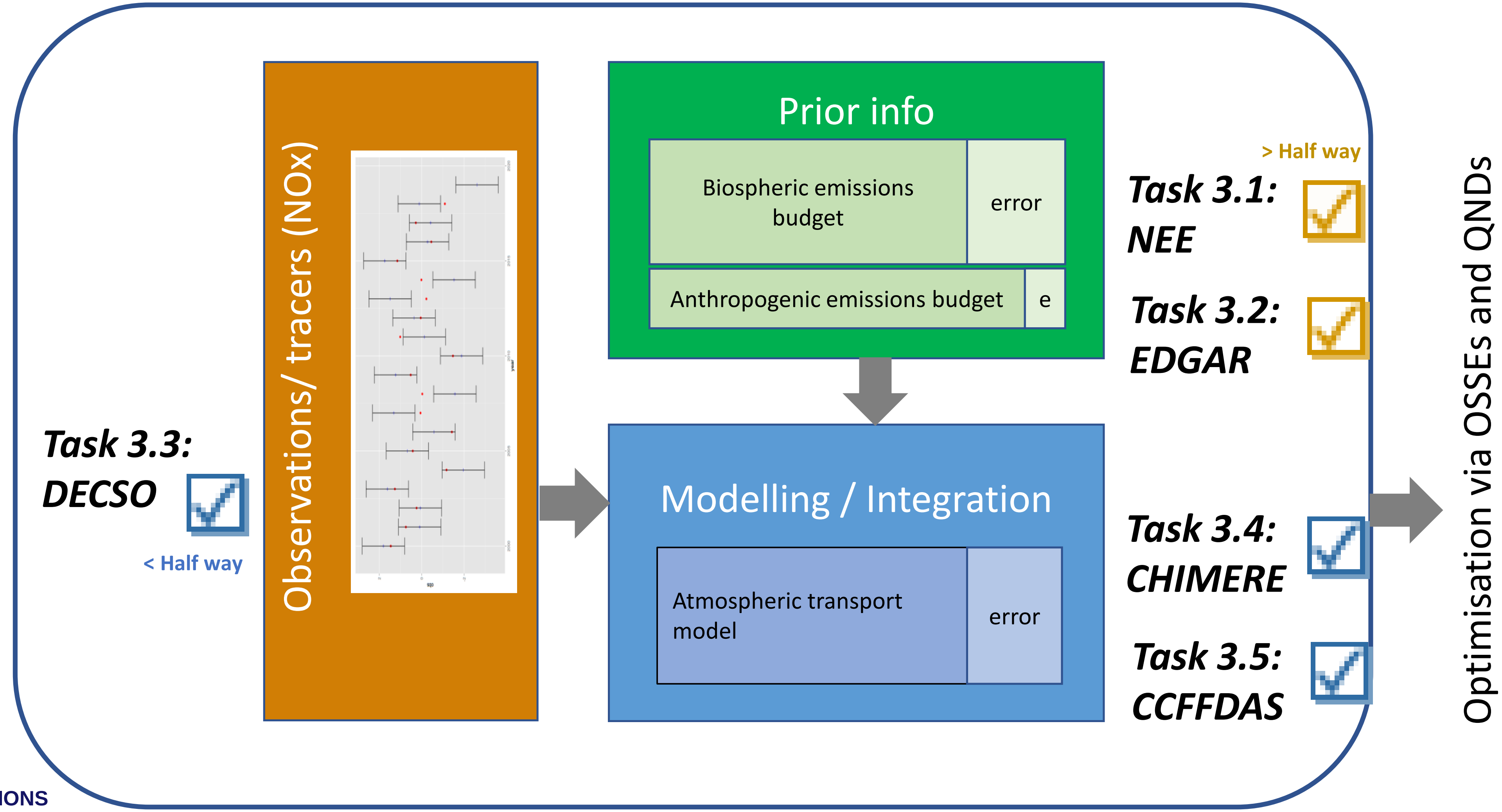
- Prototype QND system around CCFFDAS has evolved into a powerful tool for quick exploration/assessment of design options of the MVS capacity.

Next Steps

- Further systematic assessments, in particular to address (as far as possible) questions by ECMWF or MTF
- Extension of the system, e.g. in terms of data streams, process representations (including natural fluxes)

WP3: Summary

All 5 tasks enhance /optimise the system via OSSEs and QNDs



WP3: Recommendations

- Improve the CCFFDAS quantitative network design system in terms of available observational data streams (e.g. co-emitted species, socio-economic data), representation of surface flux models and their sectorial resolutions, as well as temporal and spatial resolution to the atmospheric component (to match those of the observations anticipated from CO2M), in support of the CO2 MVS capacity.

- Provide reference input datasets (e.g. for the anthropogenic emissions and its uncertainty, the biogenic emissions and its uncertainty, the meteorological data, the observations, the country masks, …) to increase the consistency of the different contributions to the CO2 MVS capacity.

THANK YOU

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14/01/19