Co-ordinated by ECMWF

CoCO2
Prototype system for a Copernicus CO_2 service

WP4 HIGHLIGHTS

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and the WP4 team

CoCO2 1st General Assembly

16/11/2021

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Overview WP4

Local scale – Point sources and Cities

T4.1 Local scale model performance assessment and improvement
EMPA, *WU, CEA,VUA, MPG, FMI, TNO, DWD, ENPC, ECMWF*

T4.2 Local inversion approaches for efficient processing of plume images with a large spatial and temporal coverage
FMI, *CEA, EMPA*

T4.3 Local inversion approaches using atmospheric transport models
ENPC, *CEA, iLab, WU, UEDIN, FMI, VUA, AGH*

National scale

T4.4 National scale inversions
DLR, UEDIN, *TNO, DWD, EMPA, CEA, ENPC, VUA, FMI, ULUND, ECMWF, AGH*

T4.5 Guidance and synthesis between the local and regional scale estimates
CEA *+ all*

Task 4.1. Local scale models: performance assessment & improvement

(1) Develop library of plumes from isolated sources and from complex source clusters

- Definition of simulation cases and model systems
- Setup of simulations following detailed protocols
- Running simulations

Deliverable D4.1 M6

1st example

Starting

(2) Assess and optimize model performance

- Intercomparison of models
- Comparison with observations (in-situ, remote sensing)
- Assessment of transport model uncertainties

Deliverable D4.2 M24

Task 4.1. Local scale models: performance assessment & improvement

Identified cases

Case ID	Description	Time period
BEL	Power plant Bełchatów, Poland	6 + 7 June 2018
JAE	Power plant Jänschwalde, Germany	22 + 23 May 2018
LIP	Steel plant Lipetsk, Russia	13 June 2019
MAT	Power plant Matimba, South Africa	25 July 2020
PAR	Paris urban area, France	Jan, Mar, Aug 2018
NL	Randstad area, Netherlands	21-02-2018 to 27-02-2018 29-06-2018 to 05-07-2018
BER	Berlin urban area, Germany	18-27 July 2018

Point sources (BEL, JAE, LIP, MAT)

Cities & clusters (PAR, NL, BER)

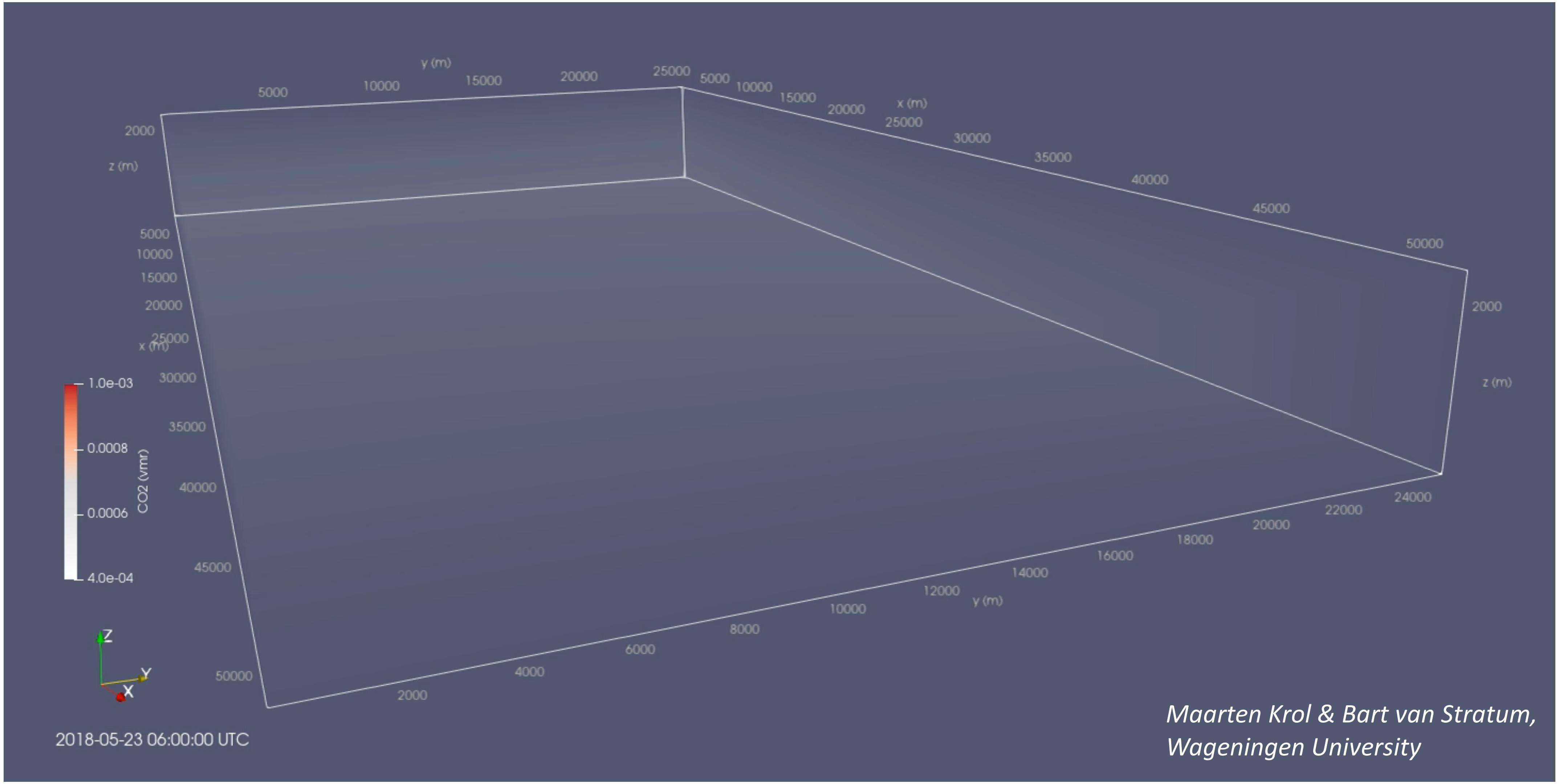
Model-cases matrix

	BEL	JAE	LIP	MAT	PAR	NL	BER
COSMO-GHG	O	O	O	O			O
WRF-CHEM					O		
ICON-ART	O	O					
LOTOS-EUROS	O	O				O	O
WRF-GHG	O	O	O	O			O
DALES						O	
MicroHH	O	O	O	O			

Details see Deliverable D4.1

Task 4.1. Further development of MicroHH

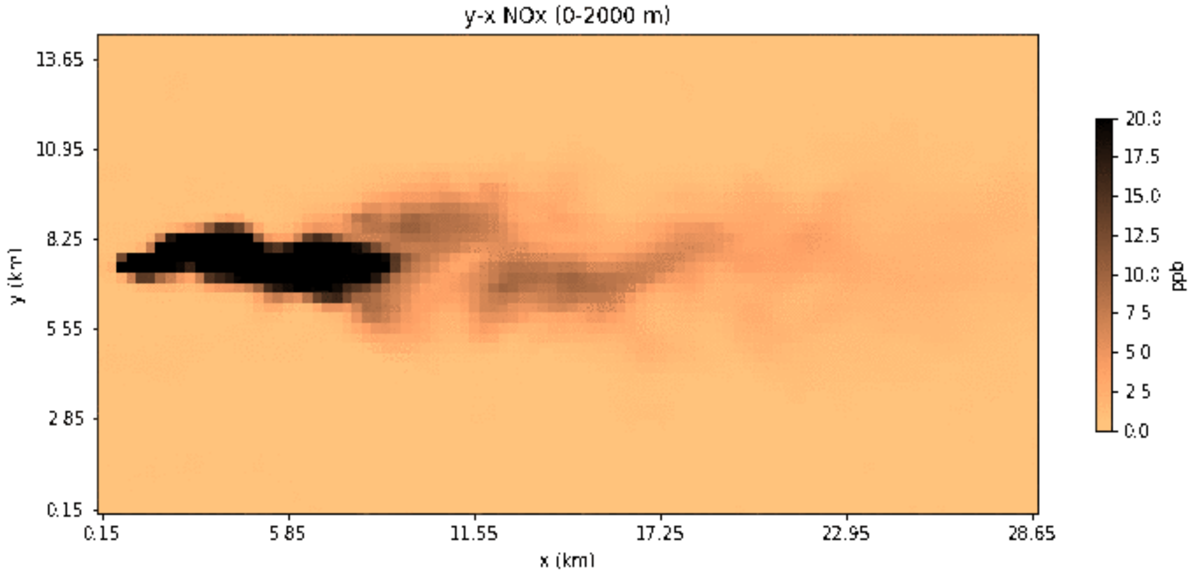
Hot buoyant plume of coal power plant Jänschwalde

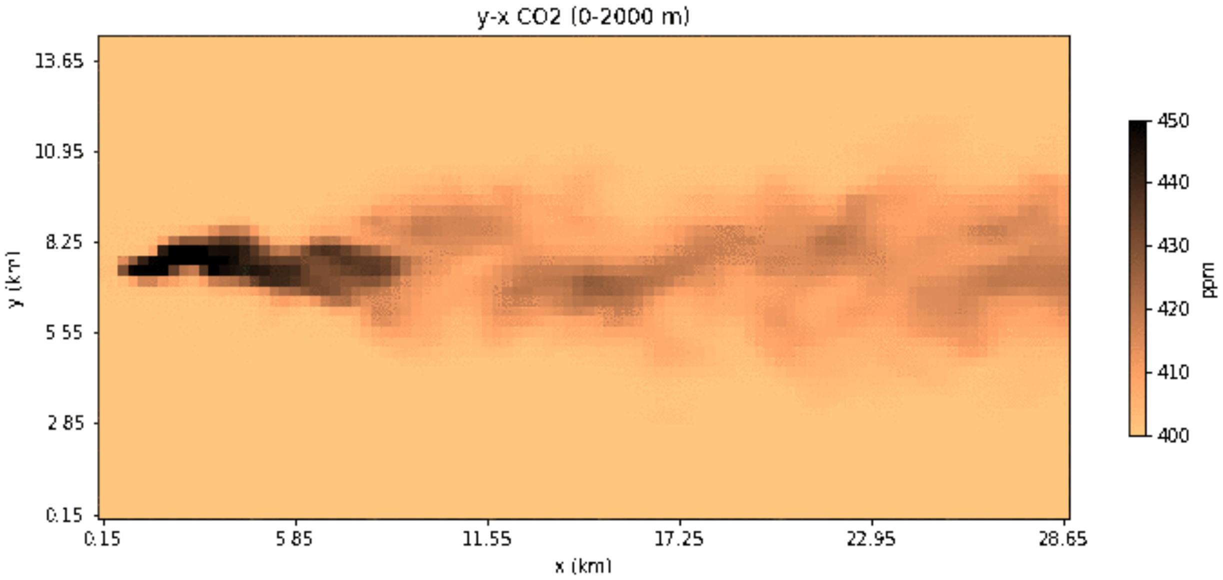


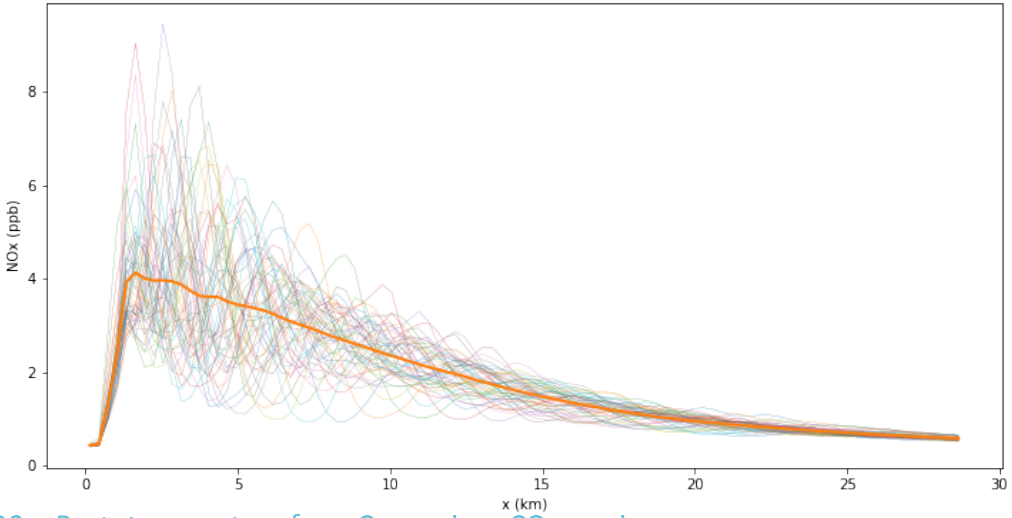
Maarten Krol & Bart van Stratum, Wageningen University

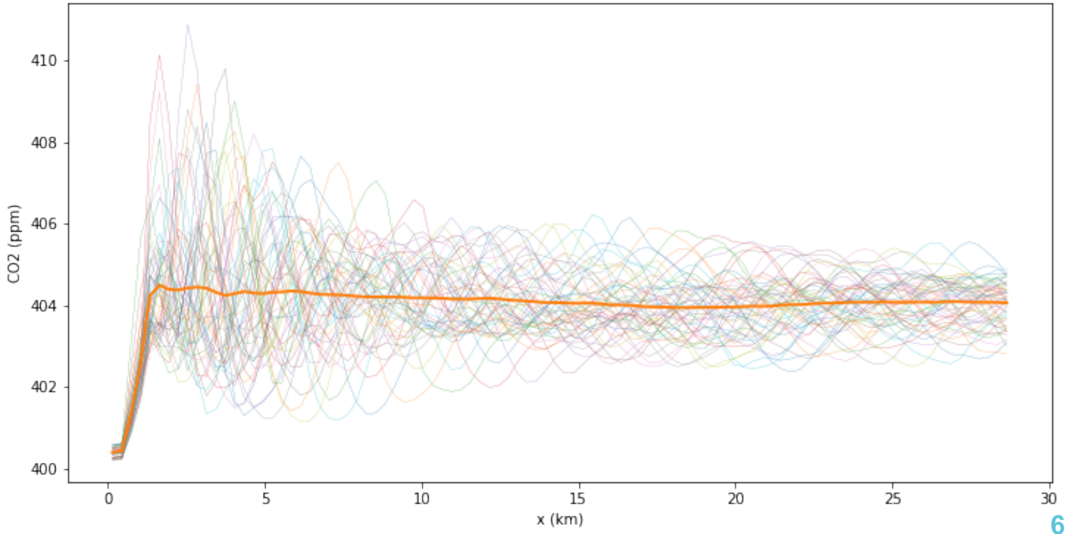
Task 4.1. Further development of MicroHH

Efficient simplified plume chemistry to study NO_x and CO chemistry









Maarten Krol & Bart van Stratum

Task 4.2: Efficient plume detection & quantification methods

Quantification of local and city plumes

(1) Method development:

- Local inversion approaches
- Light methods, efficient
- Automatic, large spatial and temporal coverage
- Python package https://gitlab.com/empa503/remote-sensing/ddeq

On-going

Deliverable D4.3 M12

(2) Characterizing

- Understanding limitations

On-going

(3) Benchmarking

- Test protocol
- Recommendations of methods

Draft available

2022

Deliverable D4.3 M24

Task 4.2: Supporting plume detection with computer vision methods

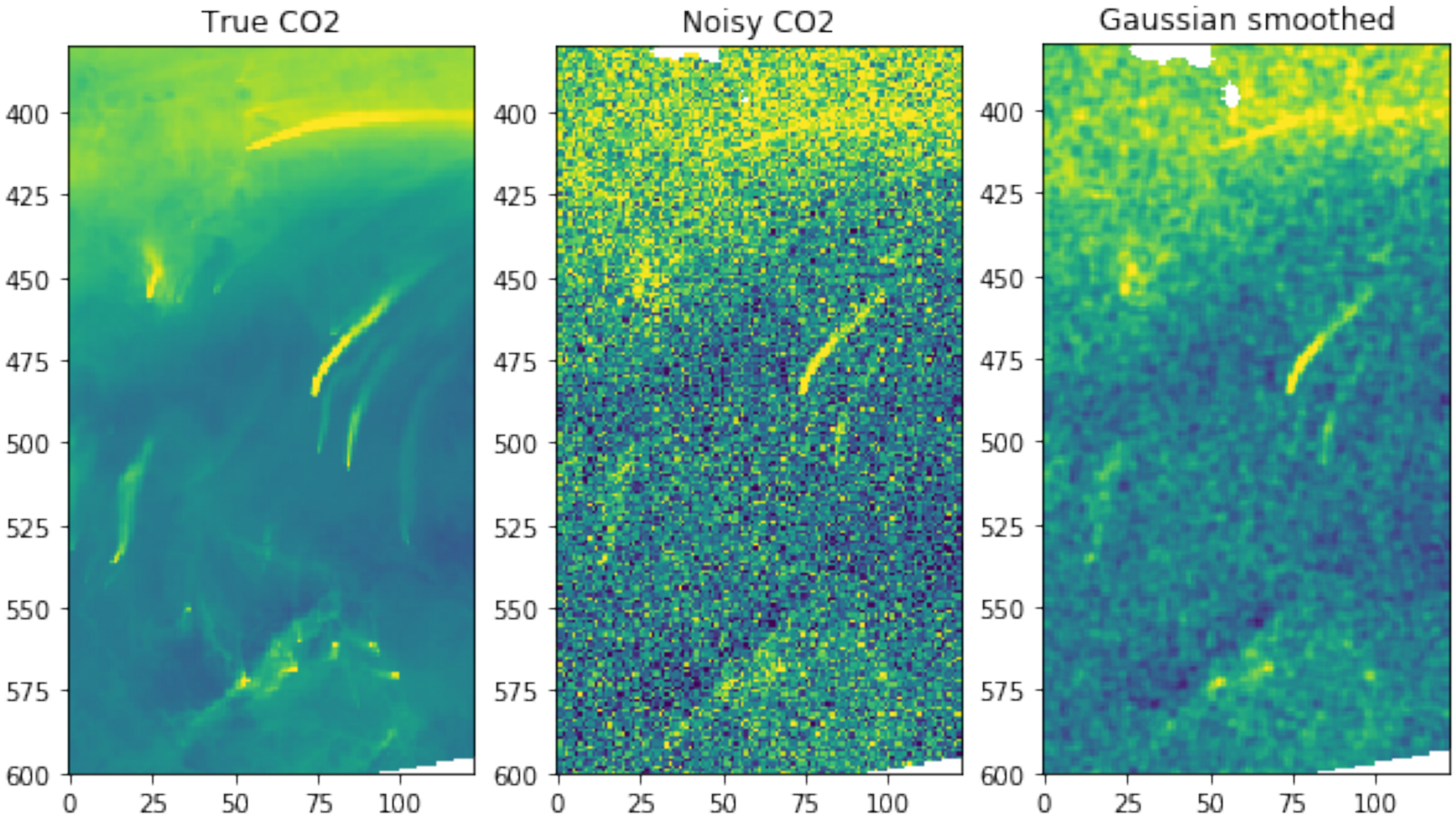


Image De-noising with BM3D sparse reconstruction method

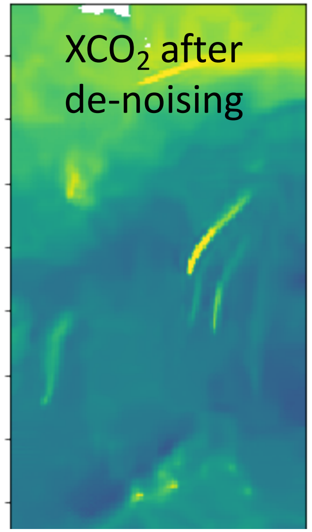
Method is able to transfer information from less noisy NO_2 to more noisy XCO_2 images

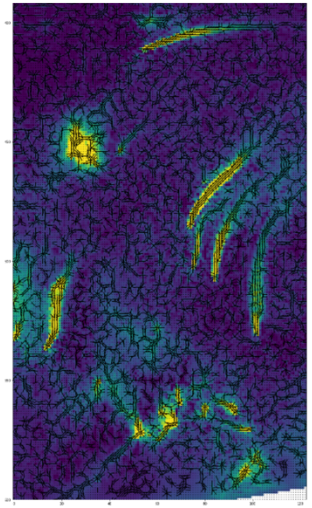
Erik Koene & Gerrit Kuhlmann, Empa

Task 4.2: Supporting plume detection with computer vision methods

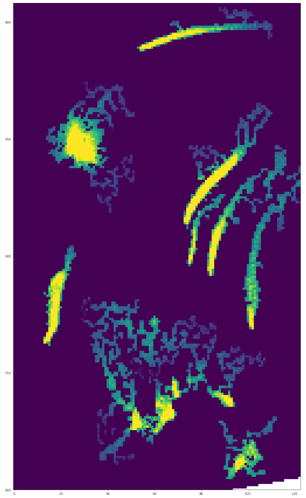
- **Denoising:** Remove noise but keep signal
- **Inpainting:** Hallucinate plumes below clouds to connect separate plume segments
- **Rolling ball method:** Improved background estimation
- **Ridge-finding techniques:** automatic plume detection (detection of elongated structures)

Erik Koene, Empa





Elongated structures



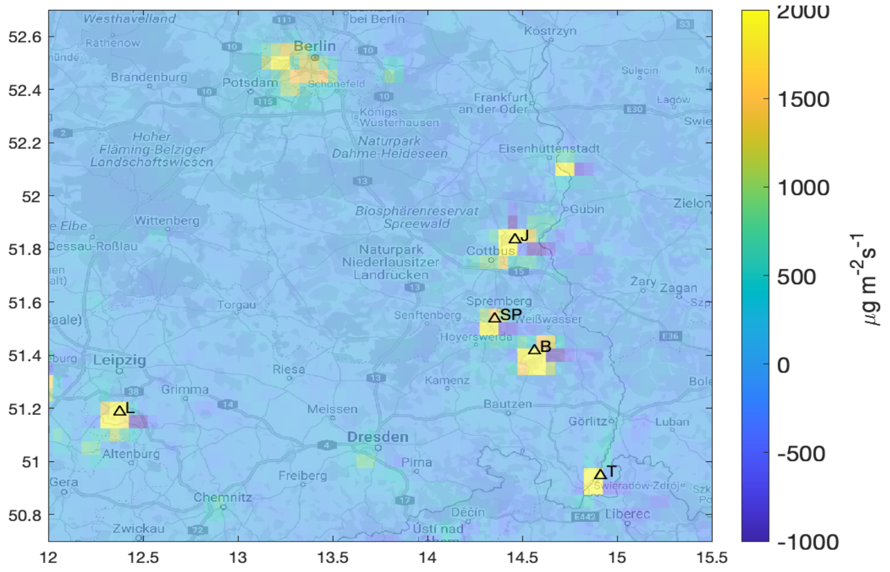
Elongated and city structures

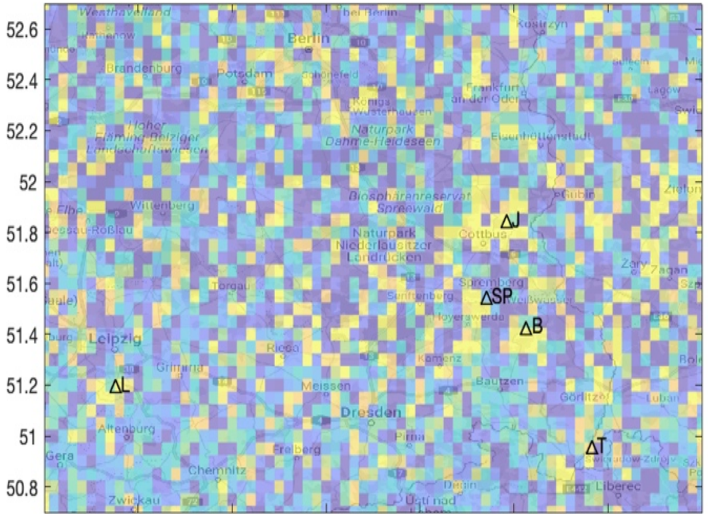
Task 4.2: Divergence method

$$D = \nabla \cdot F = E - S$$

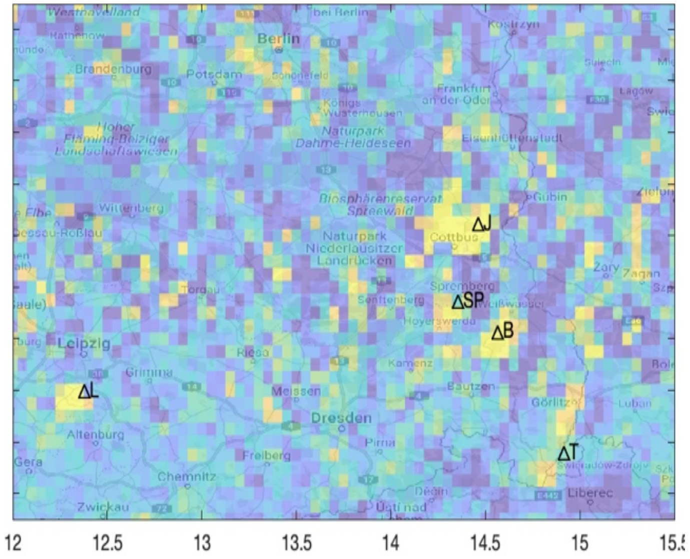
Flux divergence equals emissions – sinks (Beirle et al. 2019)

CO_2 divergence computed from COSMO-GHG simulated anthropogenic XCO_2 enhancements for full year 2015 (noise-free reference)





Divergence from noisy and cloudy synthetic satellite XCO_2



Divergence from de-noised (2D-convolution) XCO_2

Janne Hakkarainen, FMI

Task 4.3: Local inversions using atmospheric transport models

- **Objective**: develop approaches using information from models at high resolution.

→ **estimates of the sources in complex situations** where the light approaches (T4.2) face limitations

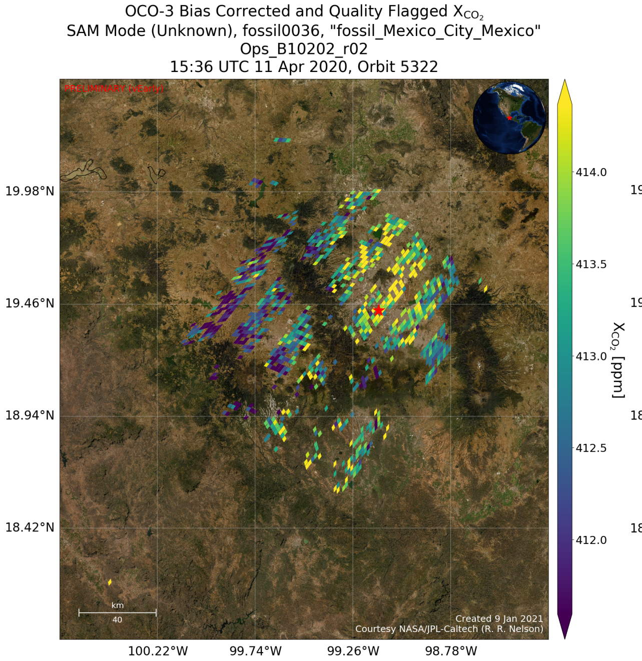
→ **insights on spatial & sectoral distribution for cities**

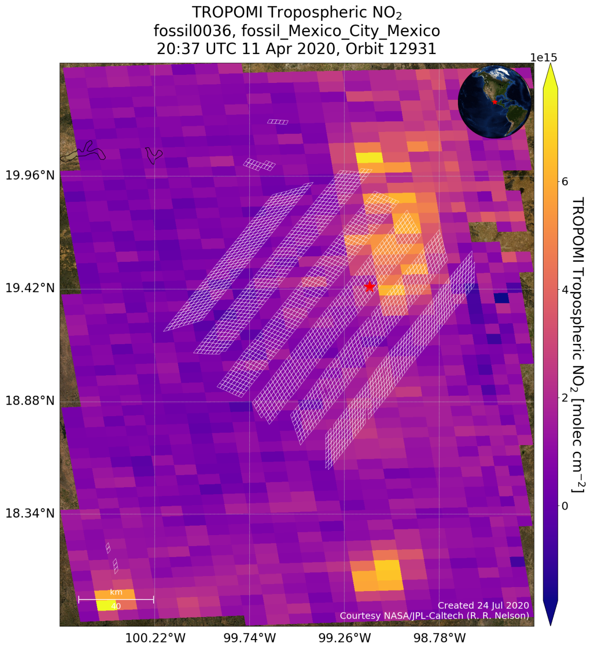
- Methods implemented using:
  - → simulations from T4.1 and pseudo CO2M obs
  - → TROPOMI or OCO-3 images

- Plume detection and inversion can be mixed or separate in two steps

→ Co-emitted species (e.g. NO_2) can be used to strengthen both.

Snapshot Area Map (SAM) of XCO_2 over Mexico by OCO-3: comparison to TROPOMI NO_2 (source: JPL)

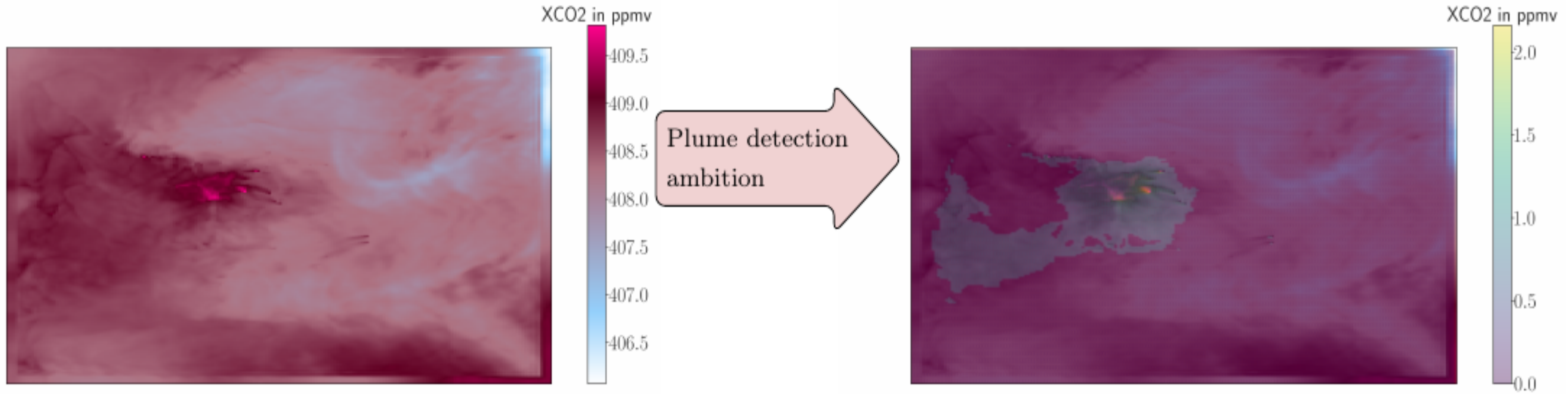


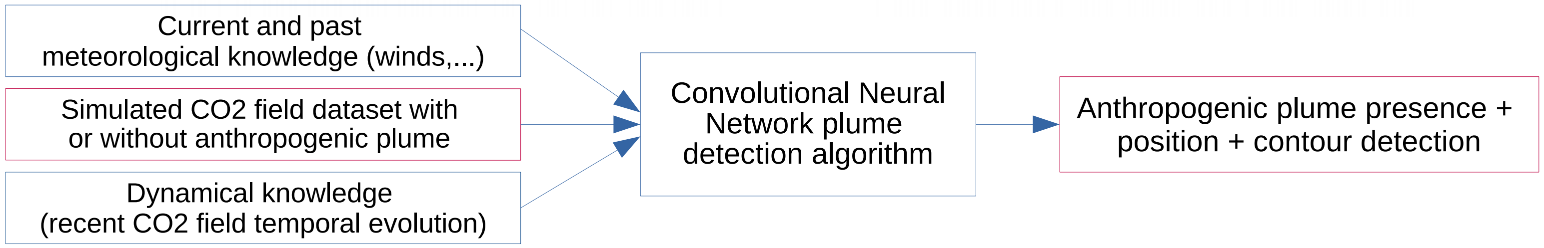


Subtask 4.3.1: New inversion methods

- **Objective**: **new inversion methods to overcome uncertainties in the plume chemistry-transport modelling**
- **Current investigations at CEREA-ENPC:**
  - **Plume detection based on Convolutional Neural Networks**
  - Non local evaluation metrics to compare modelled and observed plumes which does not penalize isometries

Tests (training and evaluation) with a 1-year simulation of the hourly XCO_2 fields in the Paris area, tracing the plume from Paris and other bio and anthropogenic components
Simulations by LSCE/Suez-Origins (Lian et al., 2021)
→ **need for a larger dataset ?**





Subtask 4.3.1: New inversion methods

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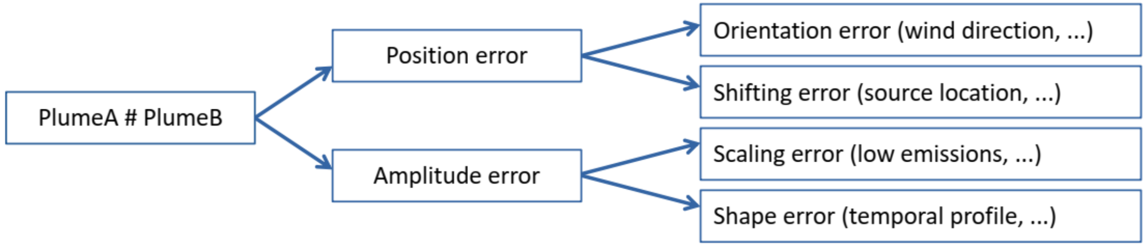
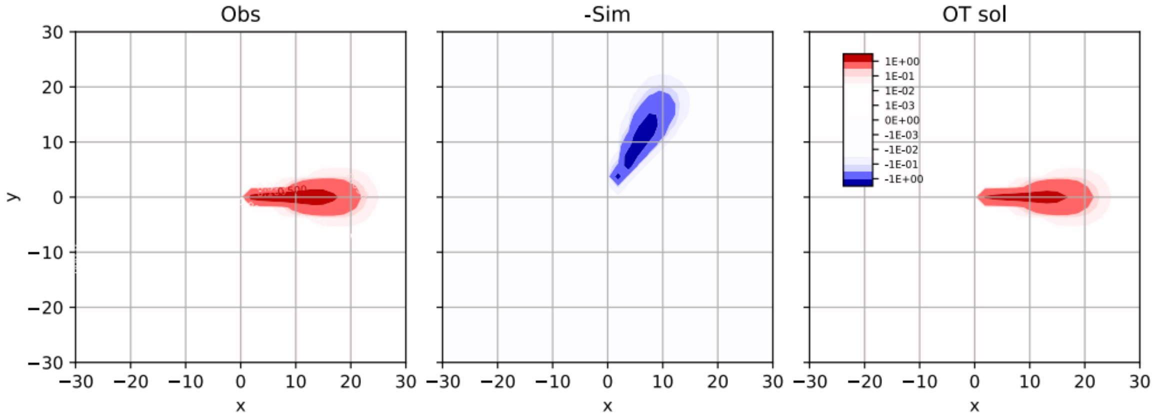
- **Current investigations at CEREA-ENPC:**
  - Plume detection based on Convolutional Neural Networks
  - **Non local evaluation metrics to compare modelled and observed plumes which does not penalize isometries**

Usual metrics interpret any type of errors into amplitude error (double penalty issue)



Tests with academic models: computation of the optimal transport between two plumes (~evaluate fictive kinetic energy required to push and transform a plume into another one)

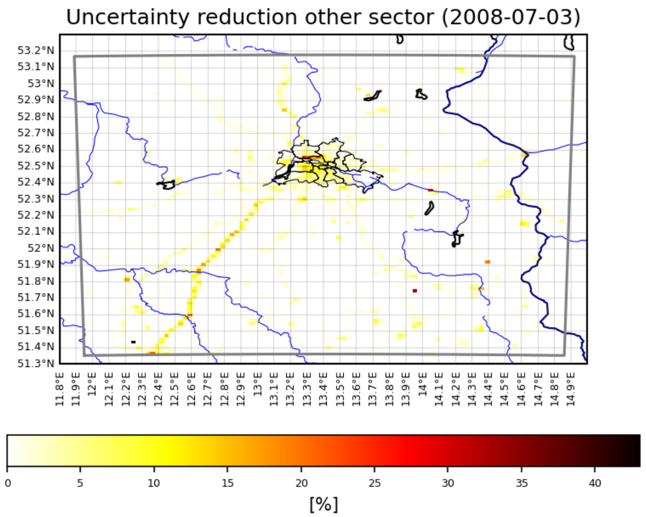


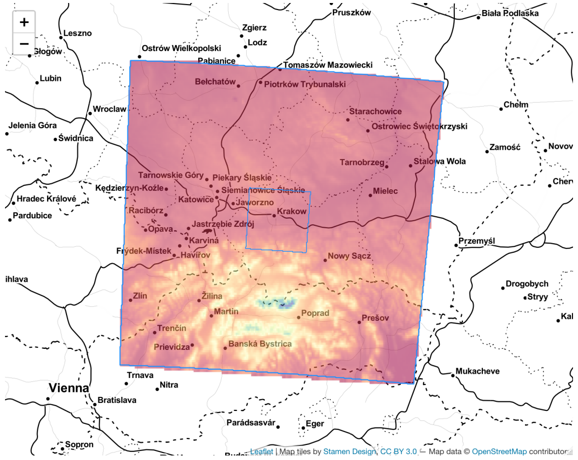
- Plans: comparing results from 4.3.1 to the light approaches in T4.2

Subtask 4.3.2: Optimal configuration for city inversions

Objective: optimise the configuration for city statistical inversions. Testing different approaches:

- a **local scale CCFFDAS system** controlling activity parameters underlying the biogenic fluxes and emissions for different sectors, with application to **Berlin** (iLab)
- an **EnKF approach** to test the sensitivity to model resolution and to the sectorial definition of the control vector, with application to the **Randstad region** (VUA)
- an **analytical inversion** system to test the sectoral resolution of the control vector and the ability to capture urban bio fluxes, with application to **Krakow** (AGH)
- Analysis of observed **CO_2:CO and CO_2:NO_2 ratios over cities across Europe** to assess the potential of multi-tracer inversion frameworks (UEDIN)



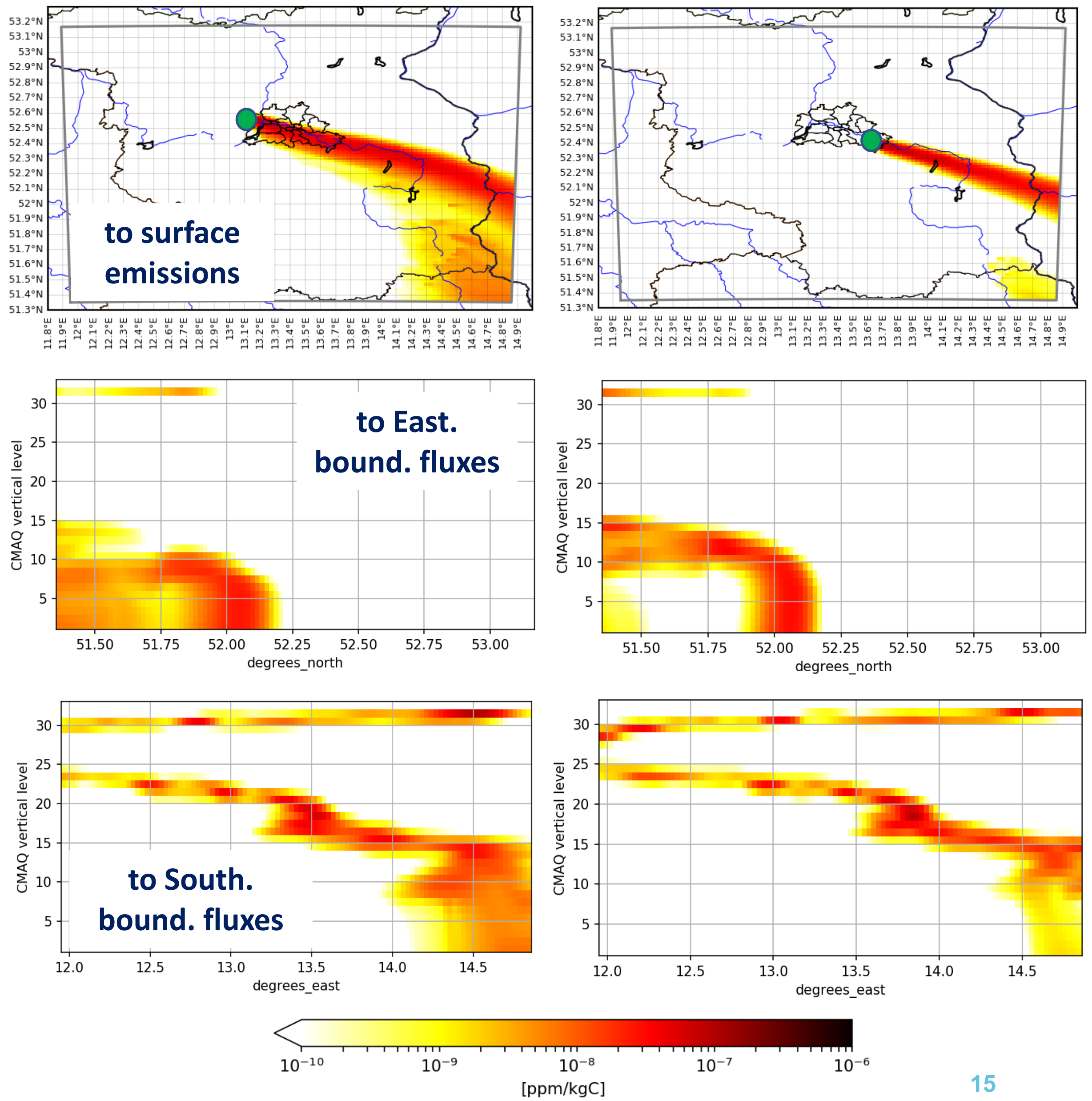


1km and 200m resolution nested configuration

Subtask 4.3.2: Optimal configuration for city inversions

On-going XCO_2 « footprint » simulations for the CCFFDAS over Berlin (iLab)

- for the assimilation of XCO_2 data
- based on CMAQ model at 2 km res over a 200 km x 200 km domain (31 vertical levels)



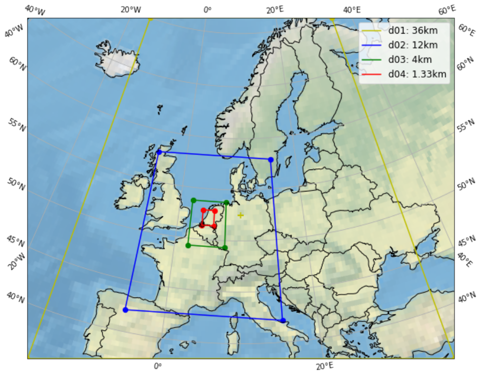
Computation of the sensitivity of 2 km x 2 km XCO2 data to surface emission and to lateral fluxes at the boundaries of the modeling domain

for one day in summer (July 3 2008)

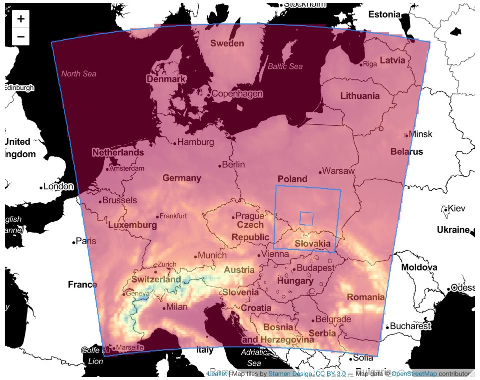
Task 4.4: National scale inversions

- Mainly for EU countries, especially for Germany, France, the Netherlands and the UK
- → CO_2 but also CH_4 inversions
- → using pseudo/real in situ/satellite CO_2/co-emitted species data for CoCO2 ref years (2018, 2021)
- → key datasets: CO2M pseudo-data but also TROPOMI, OCO-2/3 & ICOS
- **Objective of the intercomparisons:**
- → Evaluating standard (fed by WP2-7) and country specific configs, obs networks (impact of CO2M) and methods
- → Assessing their complementarities
- Feeding WP6 & WP8: estimates for GST1 and for assimilation into prototype & supporting developments of national systems

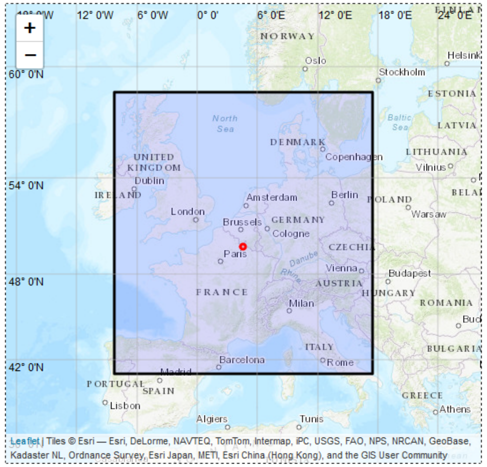
Nested configuration at VUA



5 km – 1 km – 200 m nested configuration at AGH



6.5 km res configuration envisaged by EMPA



Initial commitments

	France	Germany	The Netherlands	Poland	Finland	UK	USA
DLR		■	■				
UEDIN	■	■	■	■	■	■	
TNO	■	■	■			■	
DWD		■					
EMPA		■	■				
CEA / ENPC	■						
VUA			■				
FMI					■		
ULUND	■	■			■		■
ECMWF	■	■	■	■	■	■	■
AGH				■			

Task 4.4: National scale inversions

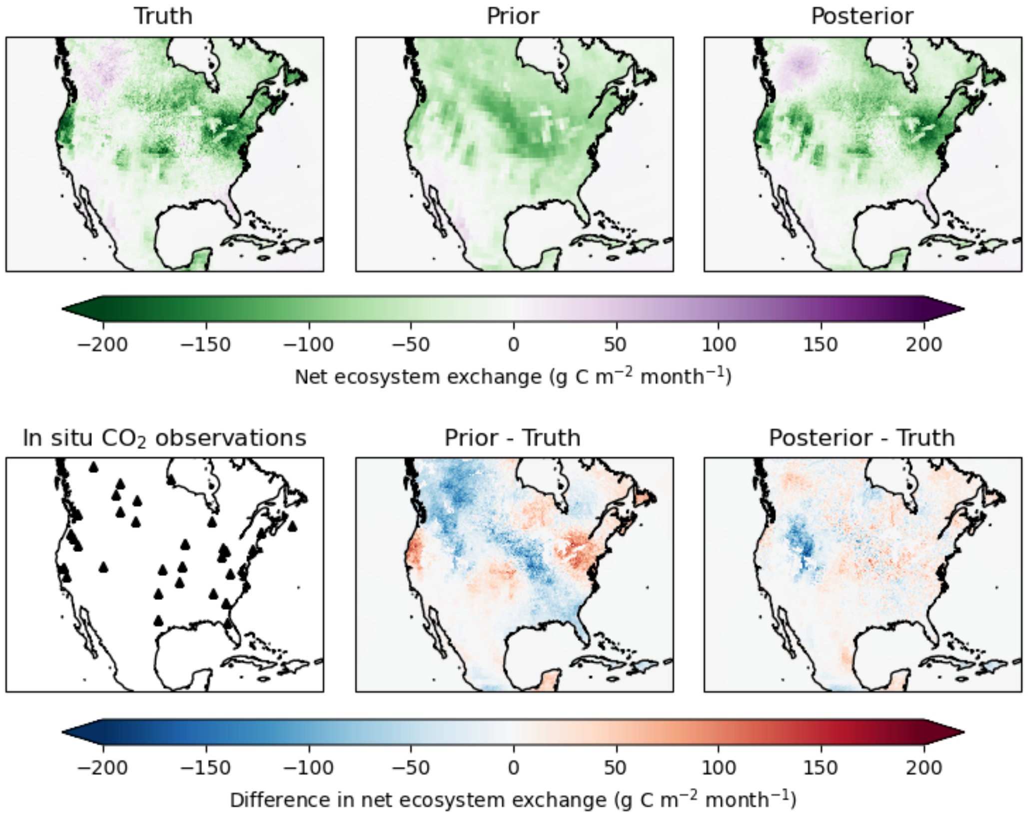
Building a protocol

- **Practical frame for the inter-comparisons**
  → retro-planning (for D4.6 and potential submissions to GST1), format/grids, reference years, data storage, timing with other WPs, CO2M simulations, interface with WP6…
  → harmonization with WP5 (WMO-IG3IS) protocol for national CH_4 emission inversion
- **Defining the standard configurations of the inversions**
  → common obs datasets (survey in WP7, satellite products), obs selection, type of BCs, meteo forcing, flux products, use of « lateral fluxes »…
- **Survey, meetings, living document: a lot of internal and cross-WP discussions**

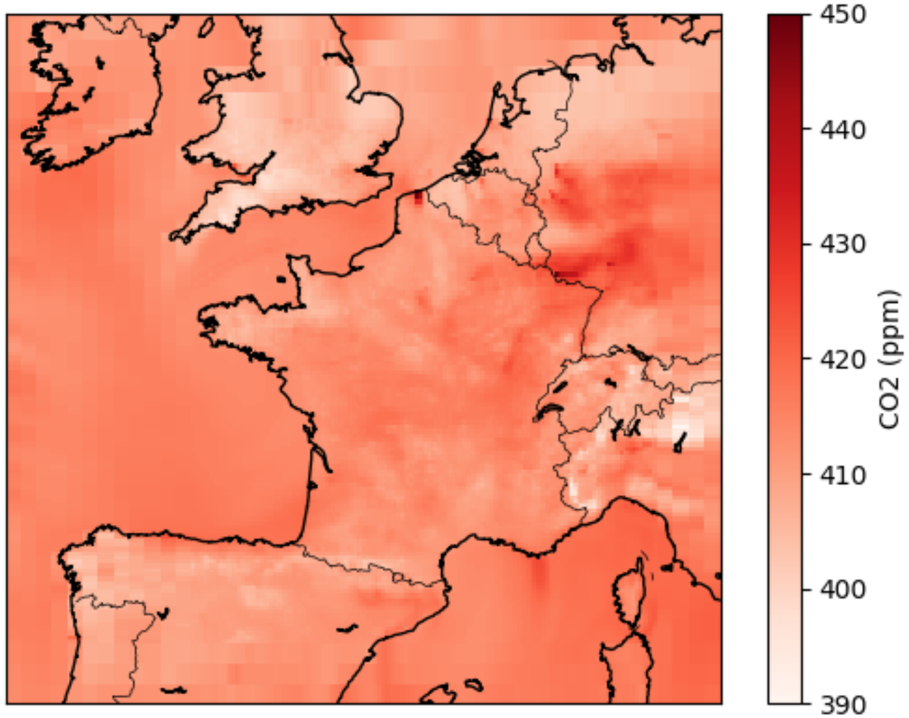
Task 4.4: National scale inversions

Setting-up the inversion configurations

- Using temporary inputs
- **Community Inversion Framework (CIF)** used by several groups: supporting standard practices



First CO_2 inversions for the USA with the TRACE Regional Atmosphere-Carbon Ensemble system using WRF-Chem and an EnKF approach at ULUND



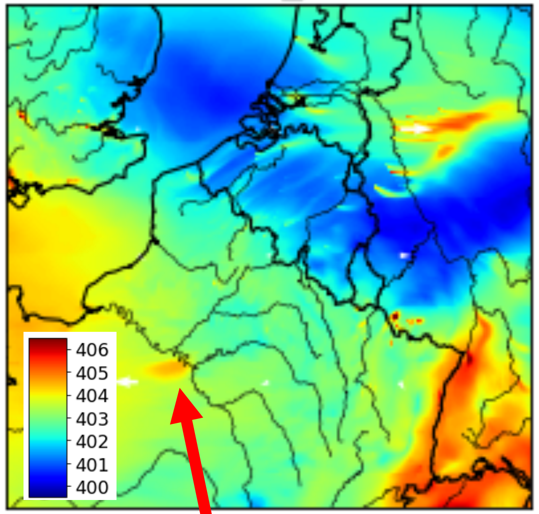
CO_2 simulation (at 10 km res over France) with the CIF-CHIMERE configuration for France at LSCE

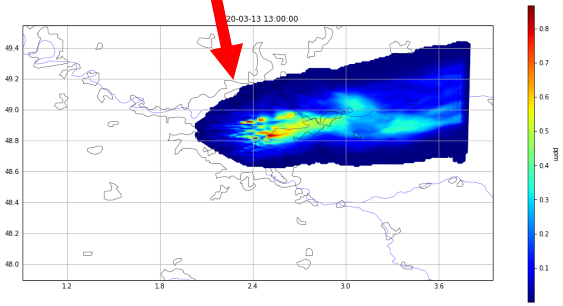
Task 4.5: Guidance & synthesis of the local and regional estimates

Synthesis of WP4, confronting results from local & national scale inversions

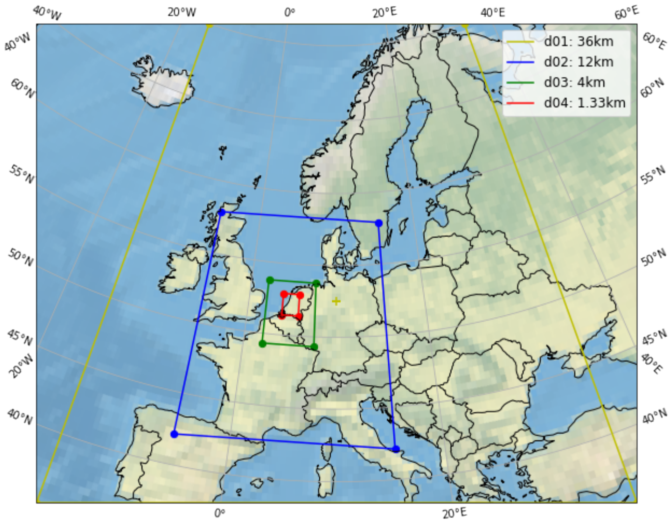
- Perspective on the use of high res model for local scale inversions from T4.1-3
- Reconciliating instant / local and national estimates: tests cases covered by local inv. (T4.2-3) and gridded national inv. (T4.4) and nested configurations
- Benchmarking test cases and criteria, guidance for the multiscale prototype in WP6 and the development of local, regional or nested systems

XCO_2 in Western Europe at 2 km res (Santaren et al., 2021, AMT)

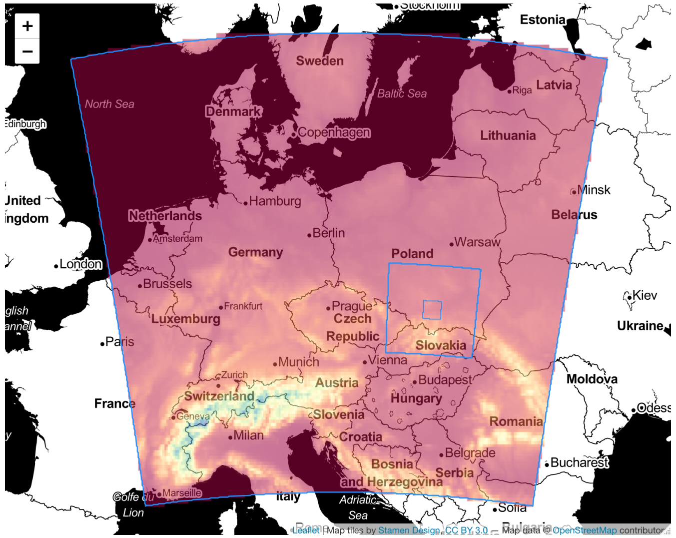




XCO_2 over the Paris area at 1 km res (sim by J. Lian; Figs. by A. Danjou, LSCE)



Nested configuration at VUA



5 km – 1 km – 200 m nested configuration at AGH

WP4 Deliverables

- D4.1 Definition of simulation cases and model systems for building a library of plumes (lead: WU) M06
- D4.2 Assessment of plume model performance (lead: Empa) M24
- D4.3 Documentation of plume detection and quantification methods (lead: Empa) M12
- D4.4 Benchmarking of plume detection and quantification methods (lead: FMI) M24
- D4.5 Perspectives on the use of atmospheric transport models for local scale inversions (lead: ENPC) M26
- D4.6 Intercomparisons of national-scale inversions (lead: MPG) M34
- D4.7 Ensemble of estimates for assimilation into prototype (lead: UEDIN) M30
- D4.8 Synthesis and recommendations (lead: CEA) M36

Perspectives for the coming year

- The detailed inter-comparison protocols for T4.1, T4.2 and T4.4 (with implications for T4.3 and T4.5) are nearly finalized
- Timeline kept tight for the second year
- Many modelling and inversion systems will have to be ready soon

  → with inputs from other WPs
- Regular and fruitful meetings at WP and task levels

  → should be maintained