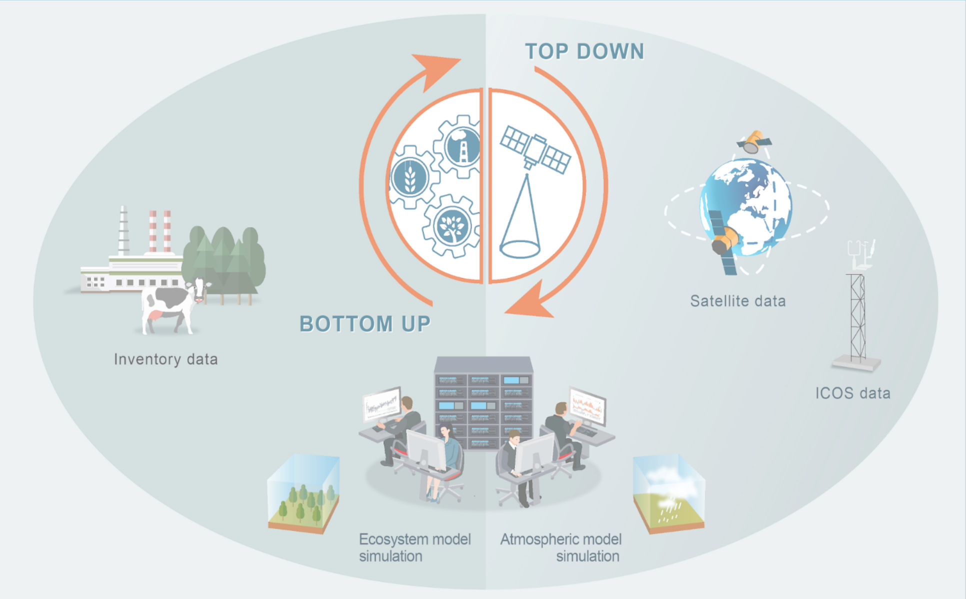
VERIFY General Assembly

WP4 – Rona Thompson and all WP4 participants

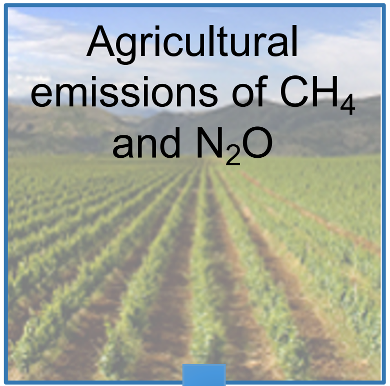
May 9th -11th , 2022

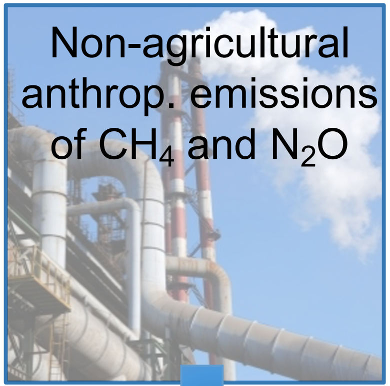


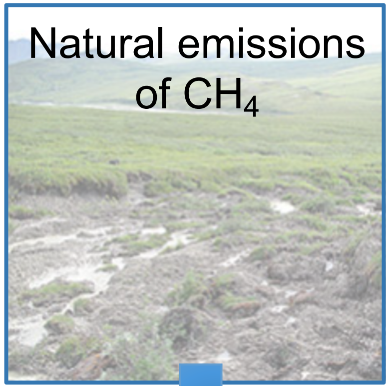
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776810

Overview of WP4

4.1 BU







Process-based and statistical models

4.2 TD

Phase 1: Flux estimates using selected inversions

Phase 2: Flux estimates using CIF

4.3 R&D

- DAS for wetland fluxes CH_4
- High-Res satellite data in inversions
- Suppl. tracers in inversions
- High-Res inversions

Atmospheric inversions

Bottom-up: agriculture

Overview of models and methods

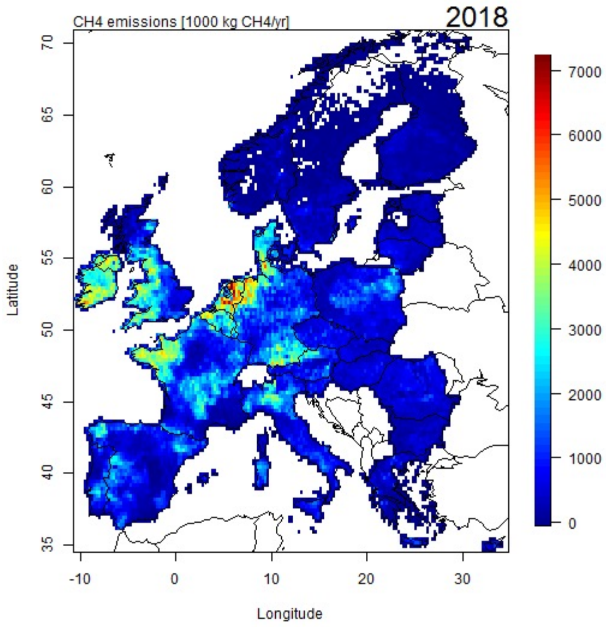
Method/Model	Sources	Notable Inputs
CAPRI Statistical model using emission factors	enteric fermentation (CH_4) manure management (CH_4 + N_2O) direct + indirect emissions (CH_4 + N_2O)	crop areas, yield, livestock densities, nutrient inputs
EDGAR Statistical model using emission factors	enteric fermentation (CH_4) manure management (CH_4 + N_2O) direct + indirect emissions (CH_4 + N_2O)	crop areas, yield, livestock densities, nutrient inputs
ECOSSE process-based land surface model	soil emissions (N_2O) (cropland, grassland, forests)	climate, land-use, nutrient inputs, & soil data

Bottom-up: agriculture

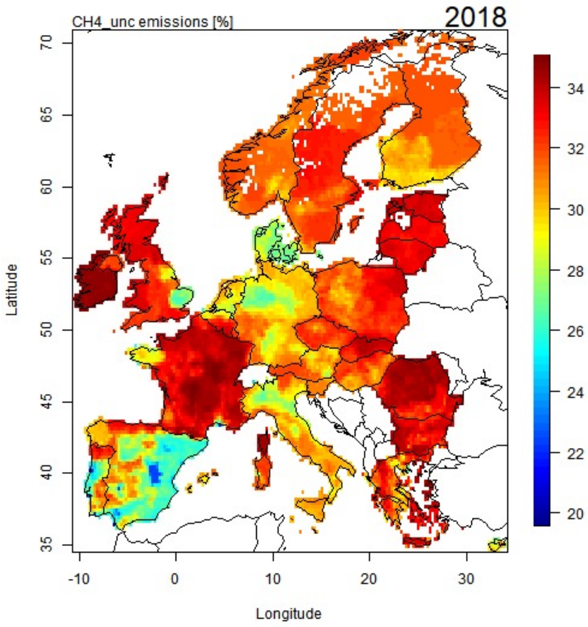
CH_4 emission estimates

CAPRI estimates based on Farm Structure Units (FSUs) at ~10 km resolution using Tier 1 and 2 approaches. Emissions from enteric fermentation estimated using Tier 2 based on energy and nutrient requirements and feed. CH_4 emission estimates biannual 2000-2018.

CAPRI emissions in 2018



CAPRI uncertainties (%) in 2018

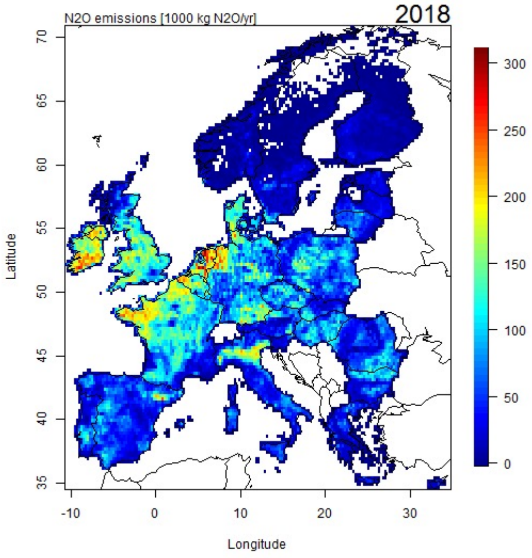


Bottom-up: agriculture

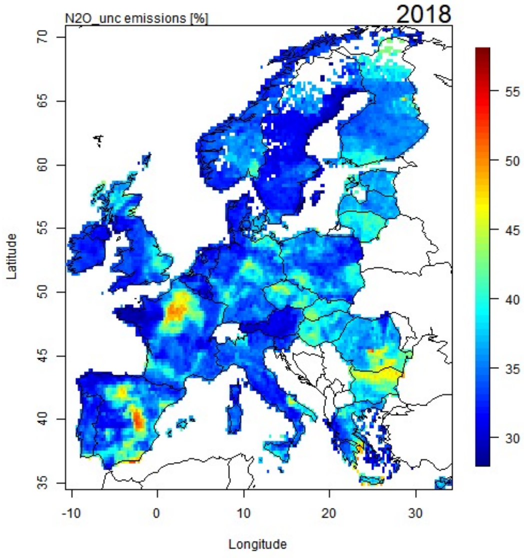
N_2O emissions estimates

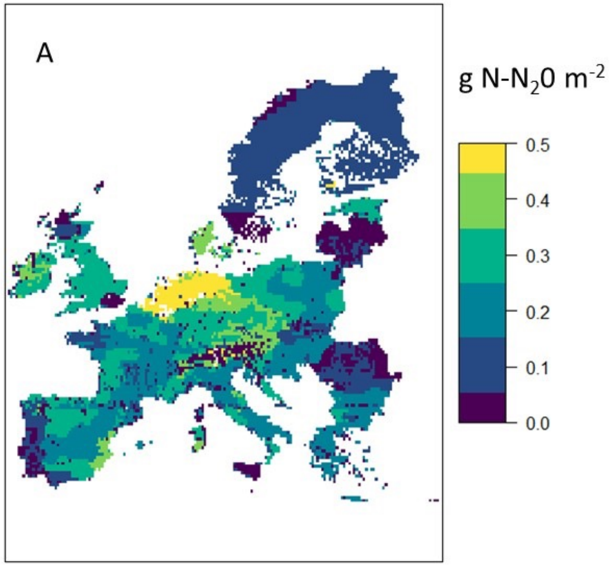
CAPRI estimates based on Farm Structure Units (FSUs) at ~10 km resolution using Tier 1 and 2 approaches. N_2O emission estimates biannual 2000-2018.

CAPRI emissions in 2018



CAPRI uncertainties (%) in 2018



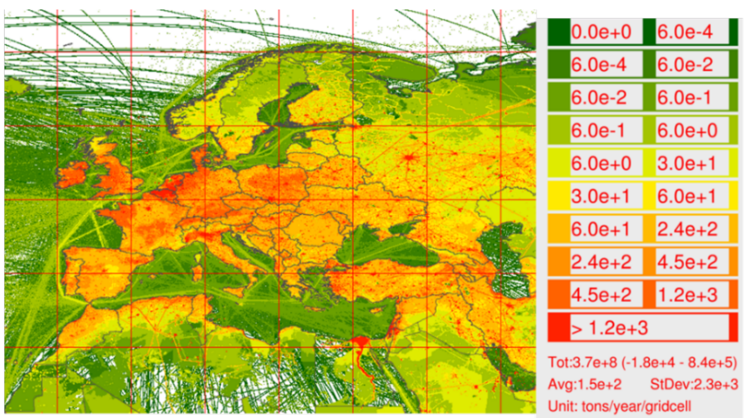


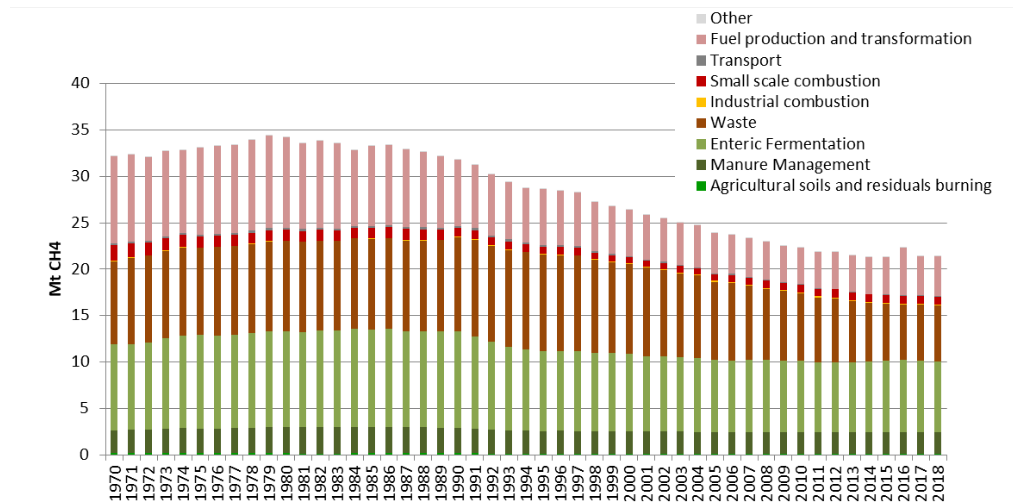
ECOSSE model revised to include new N-fertilizer data and moved from monthly to daily time steps. Simulations made for wheat crops but will be expanded to other crops.

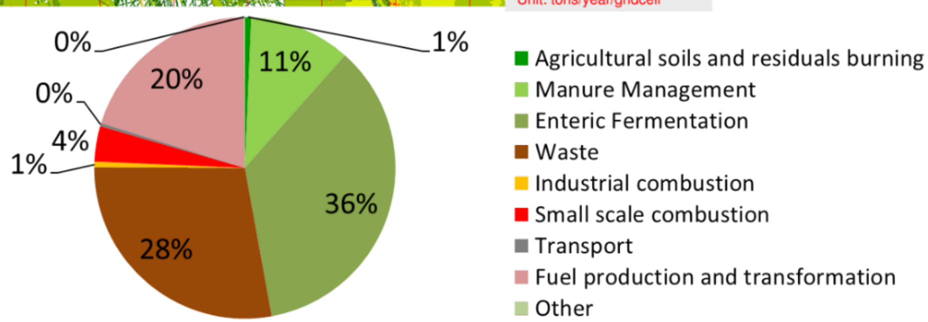
Bottom-up: all anthropogenic

CH_4 emission estimates from EDGAR-v6

Emissions decreased by 33% from 1970 to 2018, mostly in waste and energy sectors





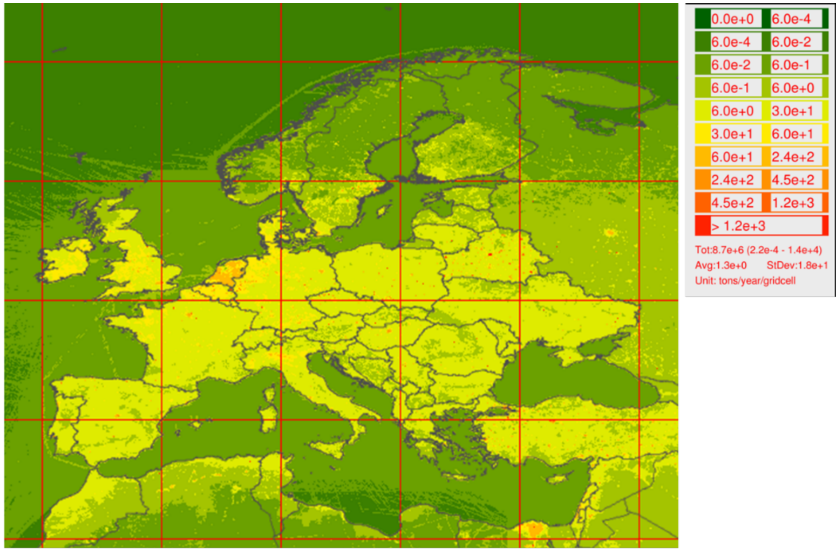


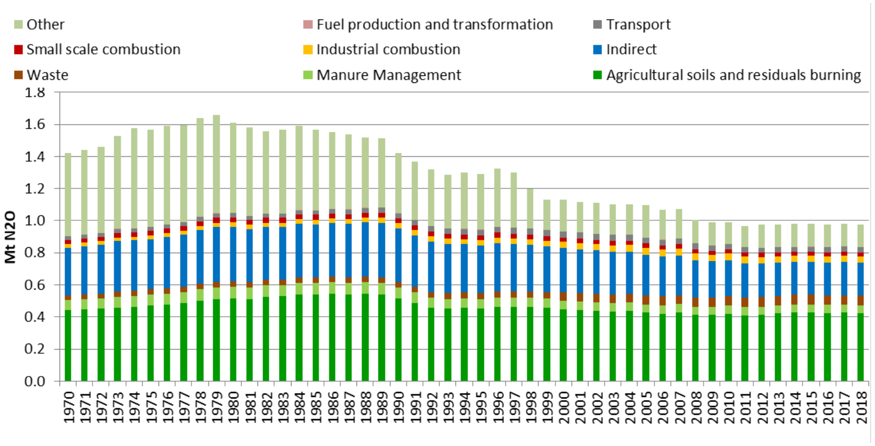
EU27+UK plurality of emissions from agriculture, 48%, next most important is waste, 28%, then energy, 20%

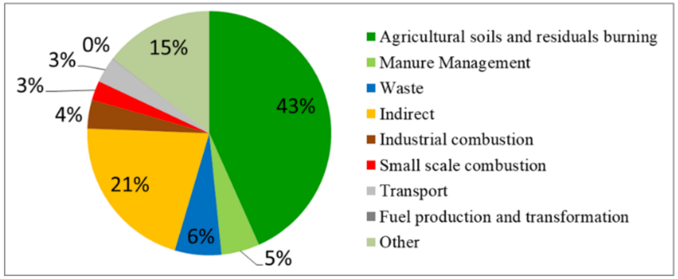
Bottom-up: all anthropogenic

N_2O emission estimates from EDGAR-v6

Emissions decreased by 31% from 1970 to 2018, mostly in the industrial sector





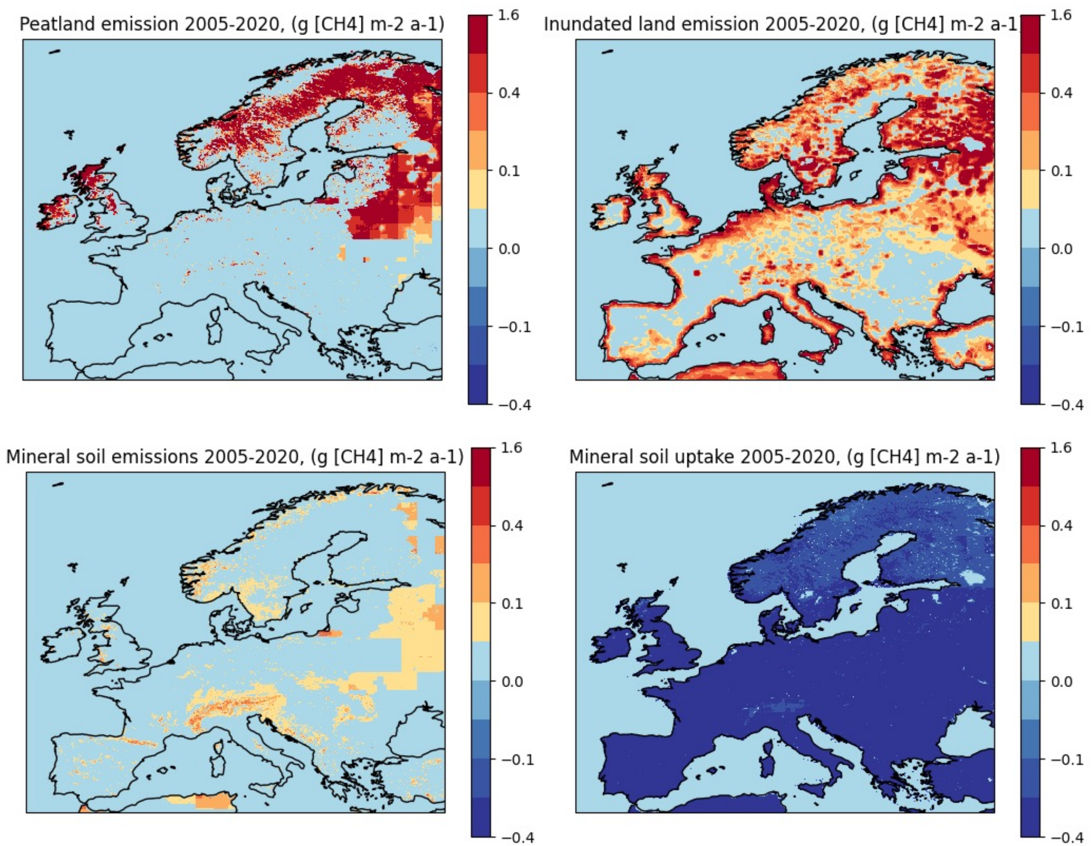


EU27+UK plurality of emissions from agriculture, 69%, next most important is chemicals industry (other) 15%

Bottom-up: wetlands

New models estimates using JSBACH-HIMMELI

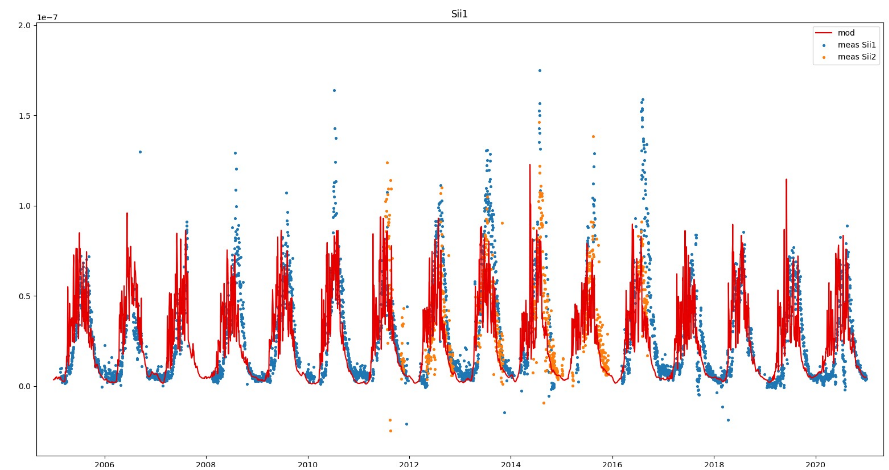
- European estimates at daily and 0.1° resolution covering the period 2000-2020
- Global estimates for 2005-2019 at 1.875° resolution and monthly:
  - Peat = 22 Tg/y
  - Mineral soil = 129 Tg/y
  - Soil uptake = 56 Tg/y

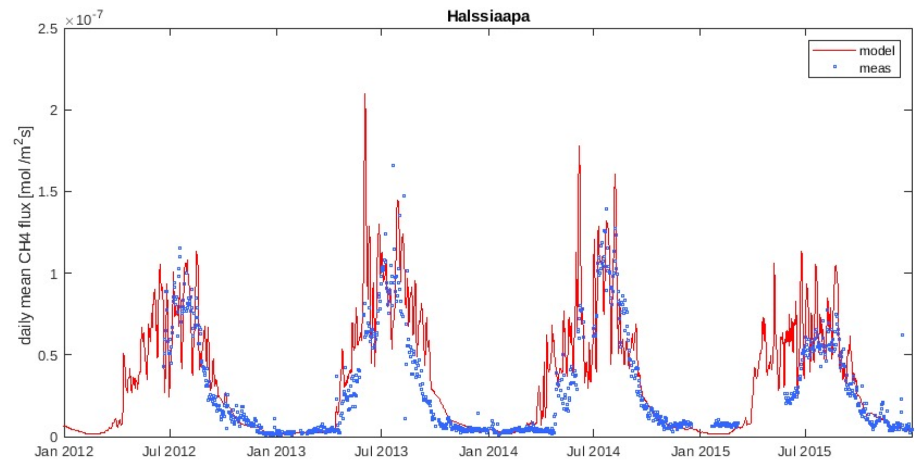


Bottom-up: wetlands

Evaluation of JSBACH-HIMMELI CH_4 fluxes

- Comparison to in-situ flux measurements at 7 pristine European peatland sites
- Good agreement at all sites in terms of seasonality and inter-annual variability





Bottom-up: inland waters

PROCESS-BASED MODEL

Physics
- 1D bulk mixed-layer thermodynamic CSLM

Carbon (multiple pools)
- lake NPP & heterotrophic respiration (modified from Maavara et al. 17)

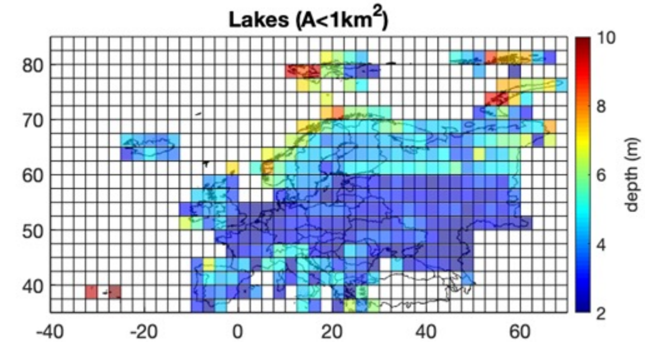
O_2
- O_2 production, water column respiration, Sedimentary O_2 demand, O_2 consumption by CH_4
- Diffusion, TKE mixing & air-water O_2 exchange

CH_4 in Sediment
- Net CH_4 production
- Diffusive and ebullitive pathways

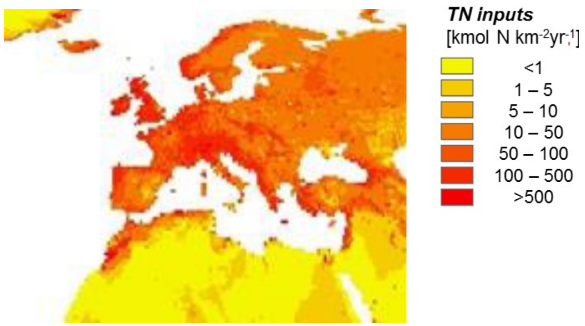
CH_4 in Water Column
- CH4(d) consumption by O_2
- Bubble dissolution
- Diffusion, TKE mixing & air-water CH_4 exchange
- CH4(g) ebullition

UPSCALING: lake clustering approach

• Gridding: 2.5° x 2.5°, Lakes are divided into 4 lake-size classes



• For each grid & class: lake depth, TN and TP loads from watershed



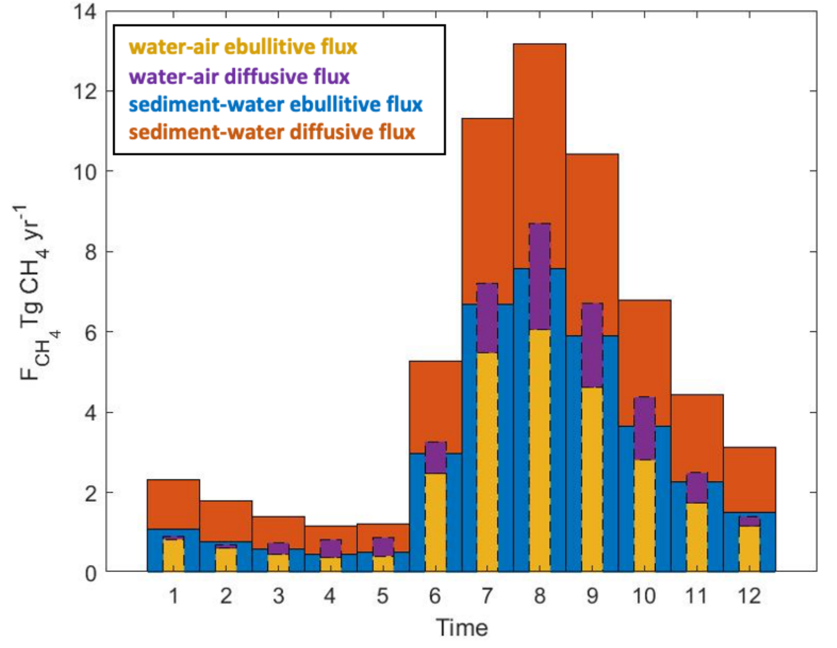
• Model forced by daily climate forcing at each grid (ISIMIP)

• Downscaling to 0.1° (hydrolakes database, Messager et al., 2016)

Bottom-up: inland waters

Spatio-temporal variability in lake CH_4 emissions (diffusive + ebullitive pathways)

Monthly CH_4 fluxes at the European scale (mean 2010-2016)

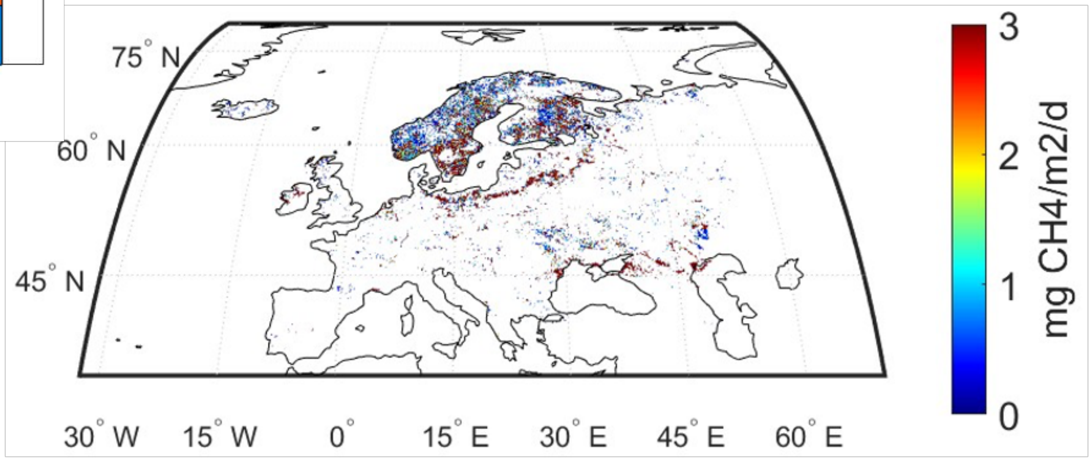


Annual mean fluxes :

- **Total : 3.2 Tg CH_4 yr^{-1}**
- **Diffusion : 0.9 Tg CH_4 yr^{-1}**
- **Ebullition :2.2 Tg CH_4 yr^{-1}**

Estimate extrapolated from Rinta et al.: 2.5 Tg CH_4 yr^{-1}

Distribution (per total area)

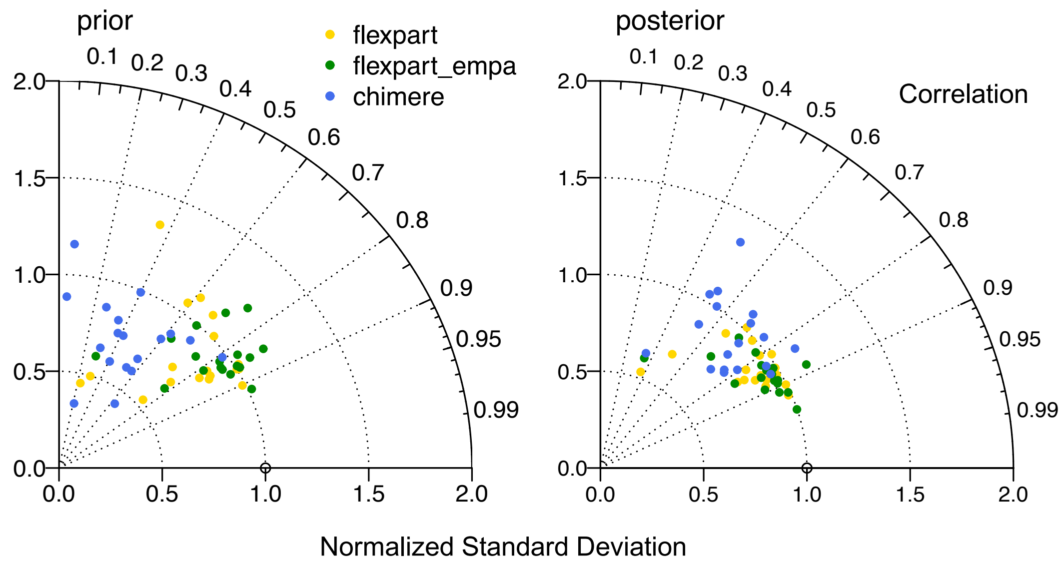


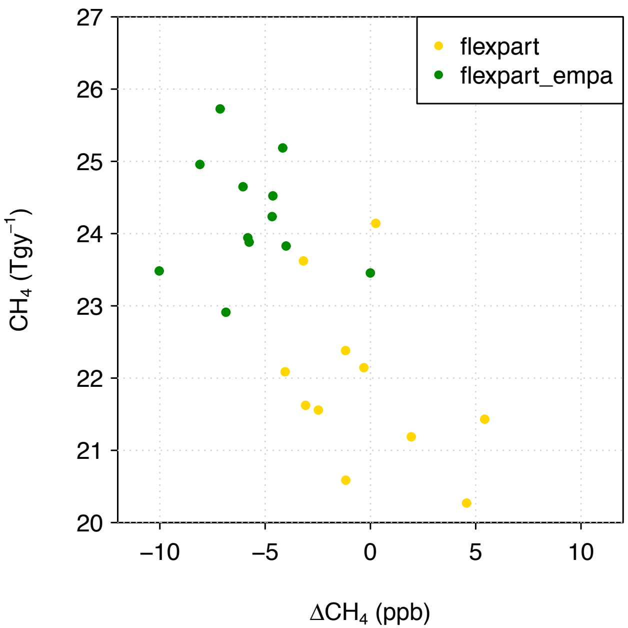
Community Inversion Framework (CIF)

- CIF is community-based set of inversion tools in Python
- CIF interfaced with number of transport models: CHIMERE, FLEXPART, LMDz and TM5
- Prior information for inversions provided by BU models in WP4
- Inter-comparison exercise for CH_4 and N_2O underway the results of which will be used to estimate e.g. transport errors on fluxes

CIF Results: CH_4

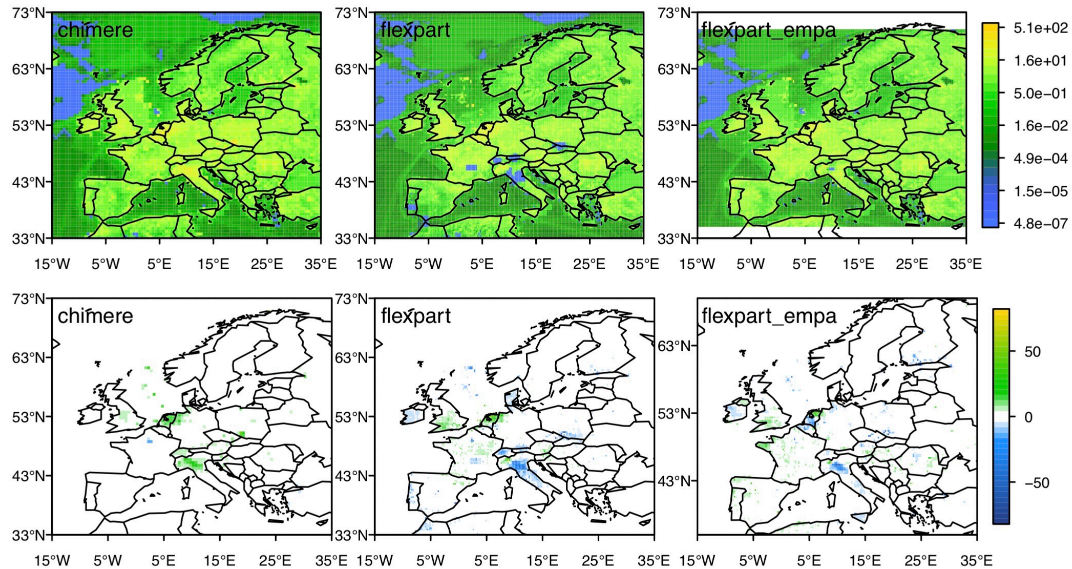
Inversions run by FLEXPART, FLEXPART-EMPA and CHIMERE for 2006-2019



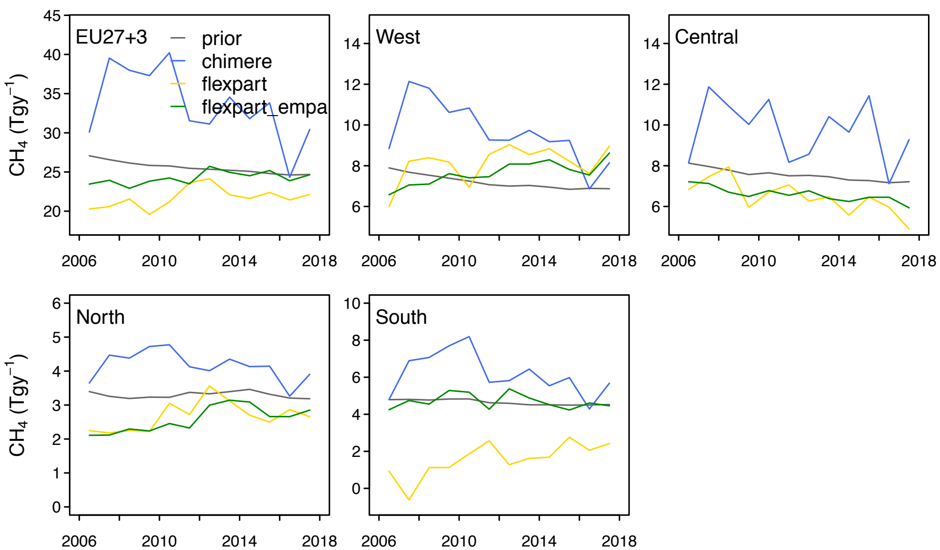


The 2 FLEXPART inversions provided background mixing ratios – found negative correlation between bias in background and total emissions

CIF Results: CH_4



Broadly similar spatial distribution of fluxes but some differences in flux increments (posterior–prior)



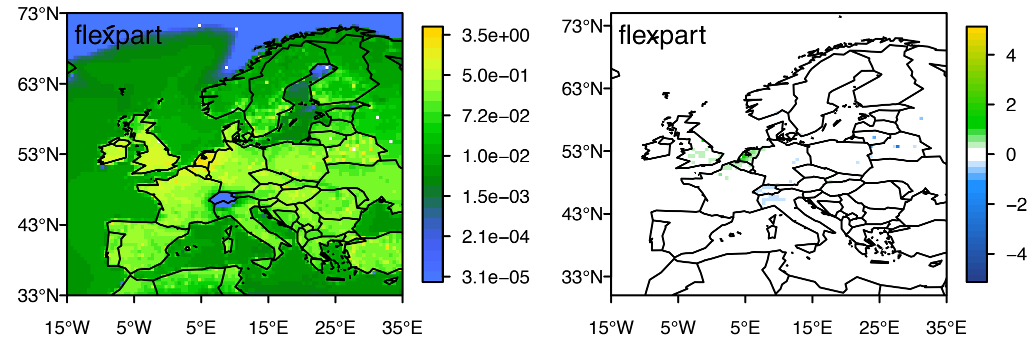
The 2 FLEXPART inversions similar magnitude and multi-annual trends in emissions (except southern Europe)

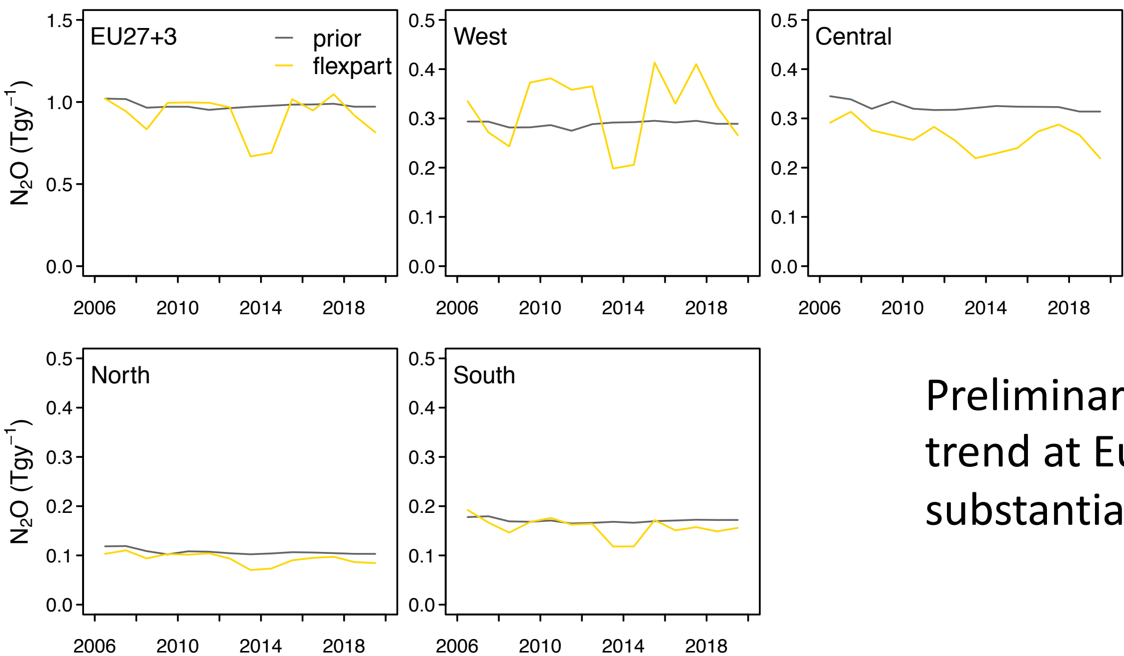
Problem with CHIMERE – will be corrected!

CIF Results: N_2O

Inversion run by FLEXPART for 2005-2019

CHIMERE runs underway!





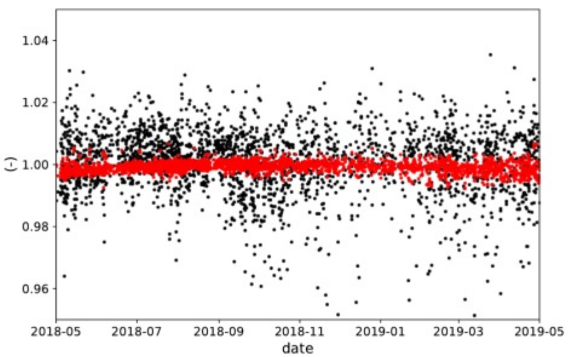
Preliminary results show no significant trend at European scale but substantial inter-annual variability

Use of TROPOMI CH_4

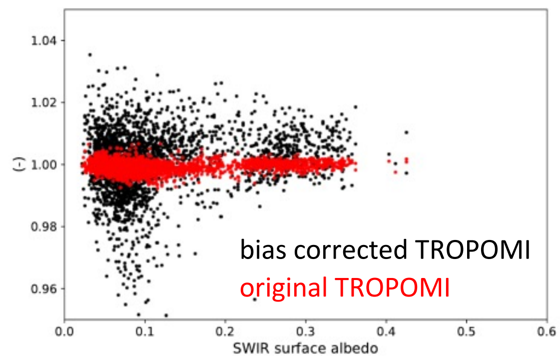
Characterization of TROPOMI CH_4 for use in inversions

Evaluation against TCCON shows mean global bias of 0.9 ± 17.8 ppbv

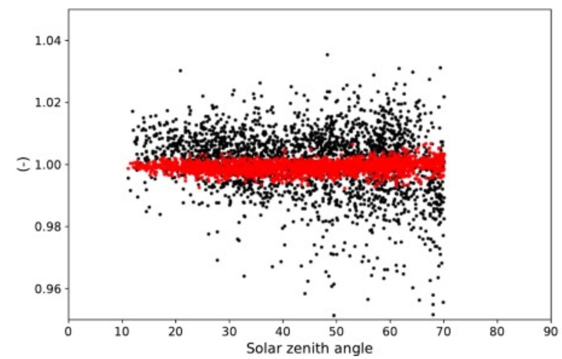
TCCON/TROPOMI XCH_4: time



TCCON/TROPOMI XCH_4: surface albedo

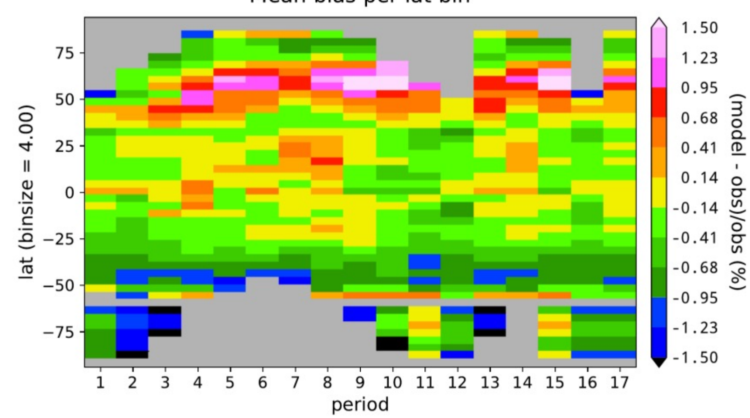


TCCON/TROPOMI XCH_4: zenith angle



Comparison of TM5 (optimized with NOAA surface observations) and TROPOMI show similar biases as with GOSAT, largely explained by TM5's representation of stratospheric age-of-air

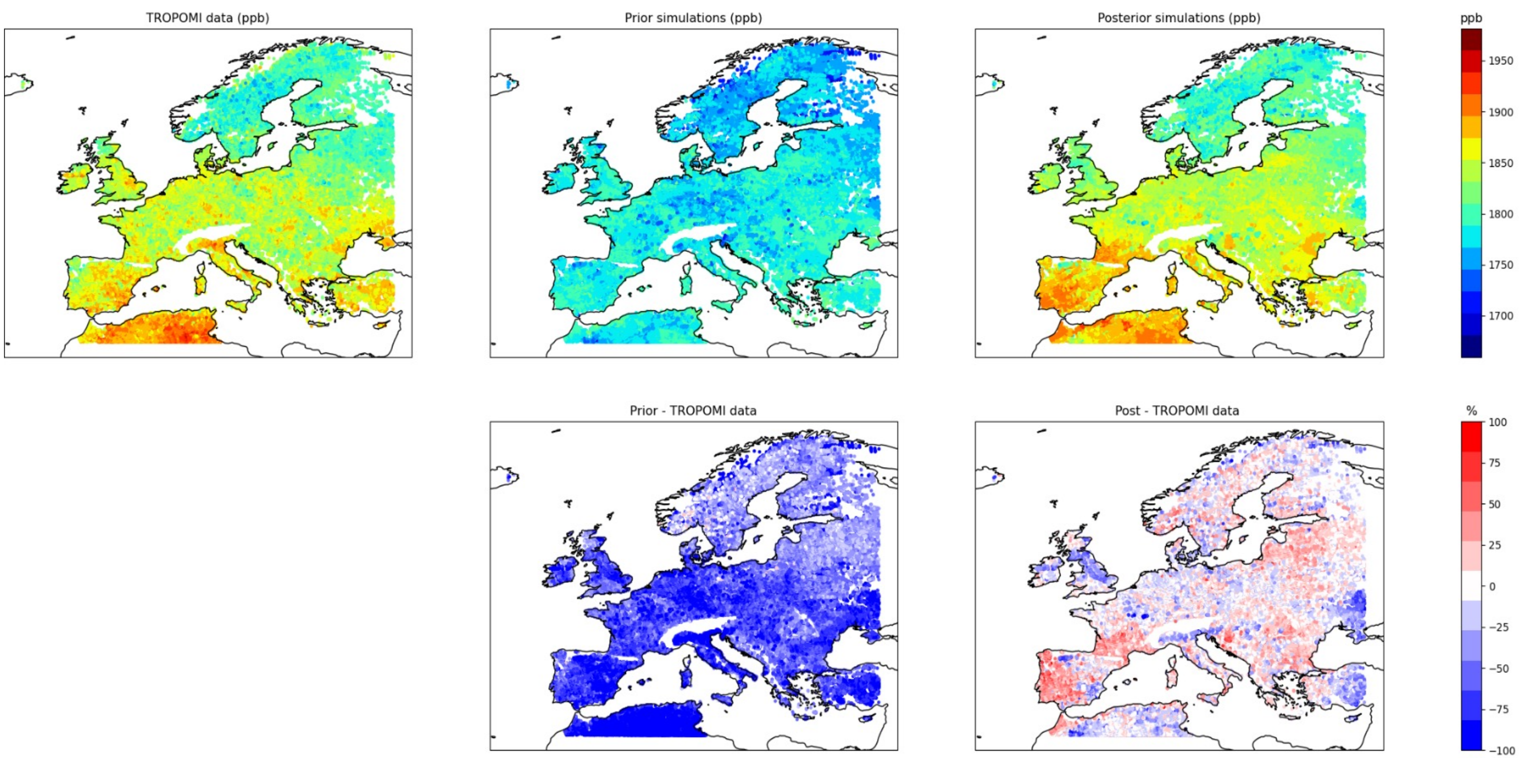
Mean bias per lat bin



Use of TROPOMI CH_4

European inversions using TROPOMI CH_4

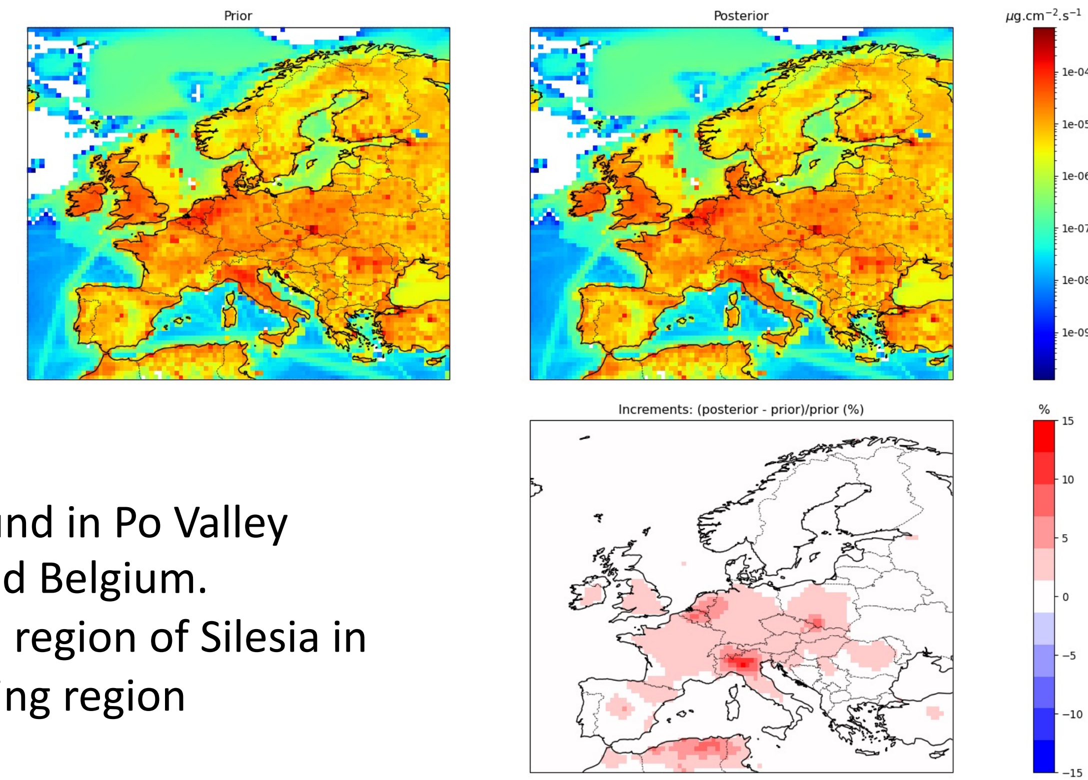
Simulations of TROPOMI XCH_4 using CHIMERE at 0.5° degrees using prior fluxes (same as CIF protocol) and posterior fluxes derived from CIF-CHIMERE inversions for the year 2019



Use of TROPOMI CH_4

European inversions using TROPOMI CH_4

CIF-CHIMERE inversions for 2019 find total EU27+UK emissions of 24 Tg/y in line with estimates using surface-only observations

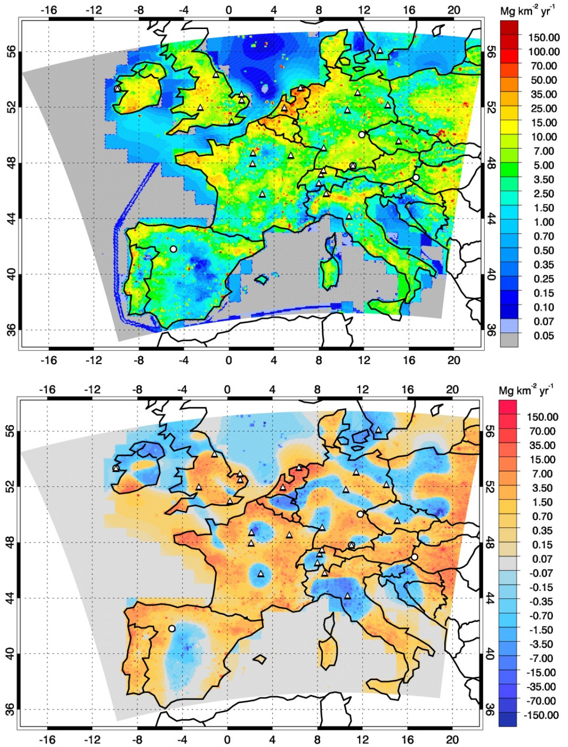


Emission increases of 5-15% found in Po Valley (northern Italy), Netherlands and Belgium. Increases of 2.5% were found in region of Silesia in Poland – an important coal mining region

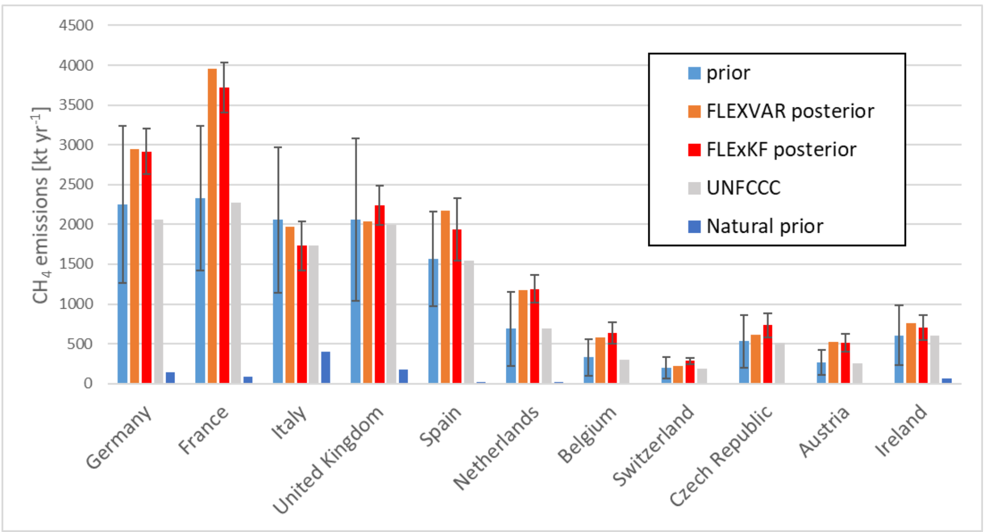
High-resolution inversions of CH_4

- High-resolution simulations for Europe using FLEXPART-COSMO driven by MeteoSwiss meteo fields (COSMO-7) at 7 km resolution
- Background mole fractions provided by TM5-4DVar global optimization
- Fluxes optimized using 4DVar algorithm

Posterior (top) and post-prior (bottom) fluxes for 2018



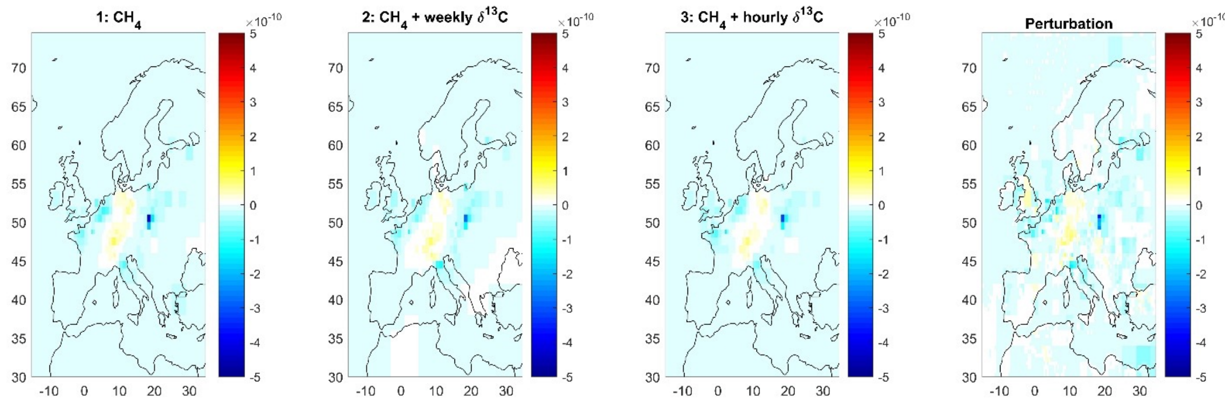
Country totals from different estimates for 2018



Tracers for inversions of CH_4

Use of $\delta^{13}C$ in inversions of CH_4: OSSE with FLEXINVERT for Europe

Comparison flux increments: 1) CH_4 only, 2) CH_4 + weekly $\delta^{13}C$ all sites, 3) CH_4 + hourly $\delta^{13}C$ at 5 selected sites, 4) perturbation (true-prior)



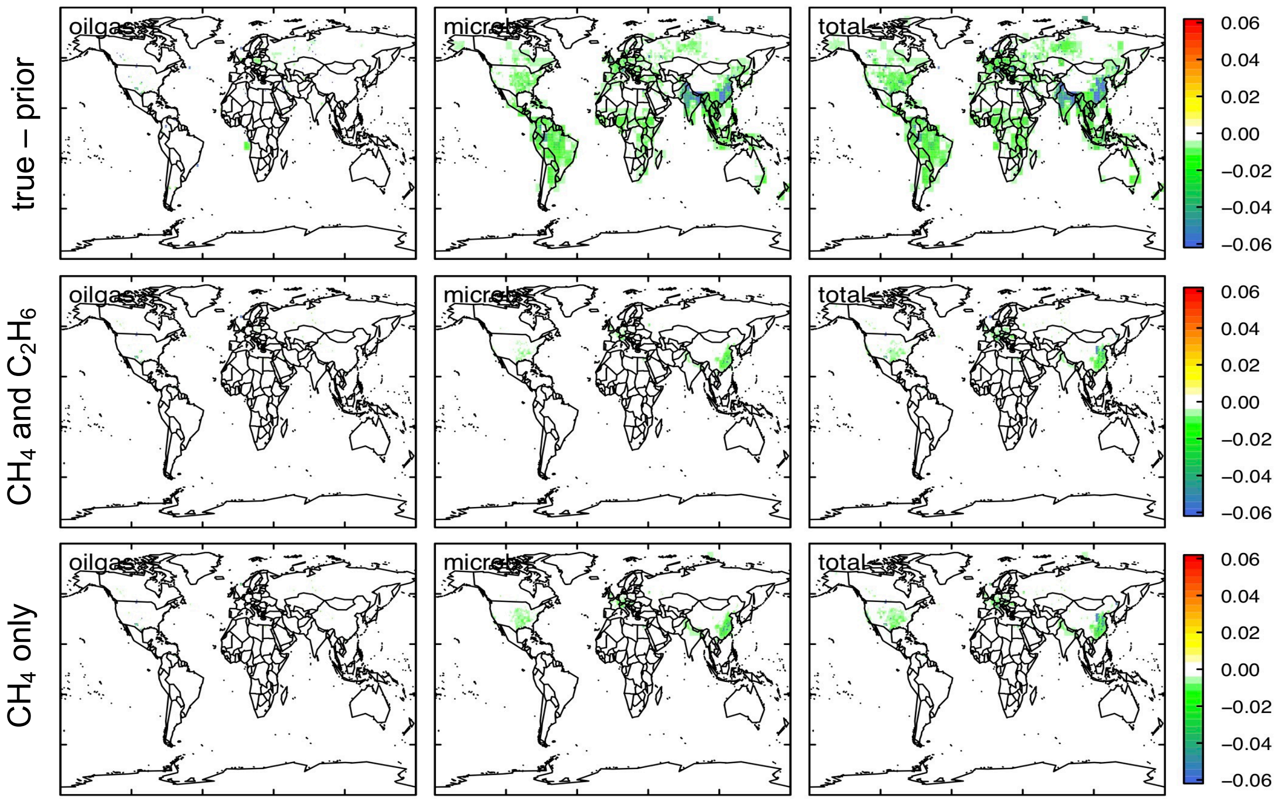
No benefit of including $\delta^{13}C$ observations for retrieving fluxes – at least not with only 5 in-situ sites or flask measurements at all sites

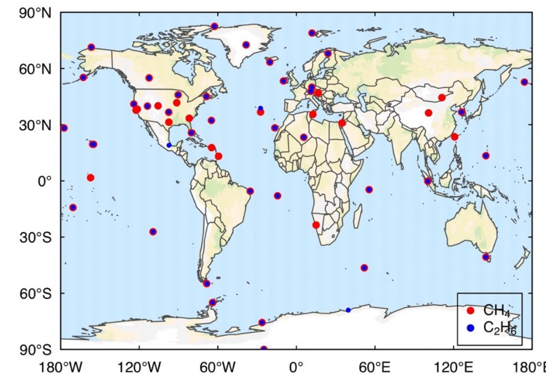
RMSE	CH_4 only	CH_4 + weekly $\delta^{13}C$	CH_4 + hourly $\delta^{13}C$	Perturbation
Microbial	1.047	1.116	1.123	1.425
Fossil	0.694	0.826	0.735	0.946
Total	1.154	1.271	1.249	1.630

Tracers for inversions of CH_4

Use of C_2H_6 in inversions of CH_4: results of global OSSE

Inversions run with FLEXINVERT using synthetic observations at NOAA sites





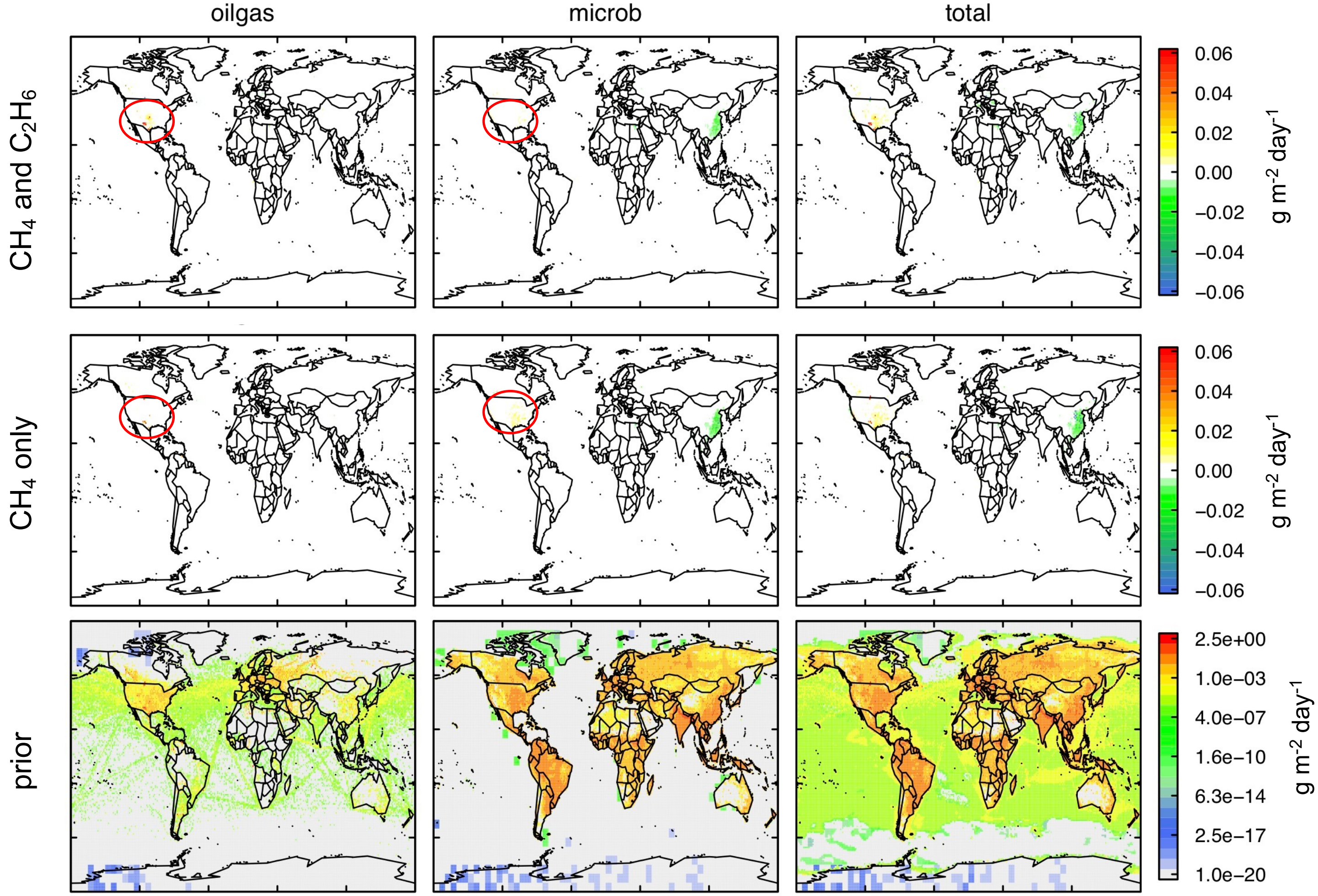
$$G = 1 - \frac{\sum(x_{true} - x_{post})}{\sum(x_{true} - x_{prior})}$$

Gain values (G) for inversions

	Oil & gas	**Micro-bial**	**Total**
CH_4 & C_2H_6	0.25	0.10	0.16
CH_4 only	0.23	0.14	0.19

Tracers for inversions of CH_4

Use of C_2H_6 in inversions of CH_4: results of global inversion

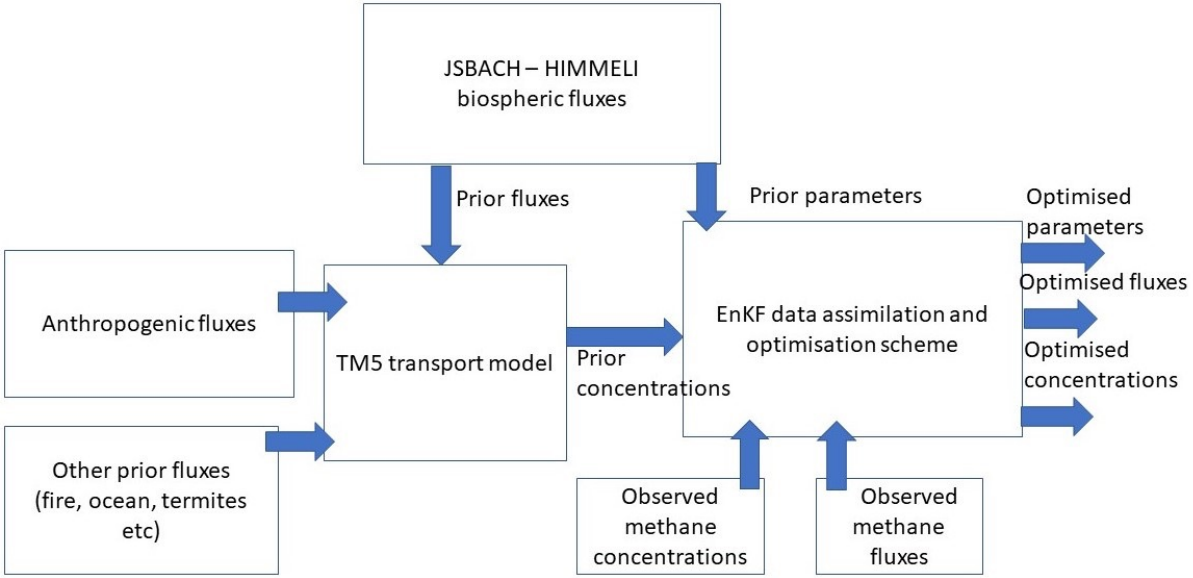


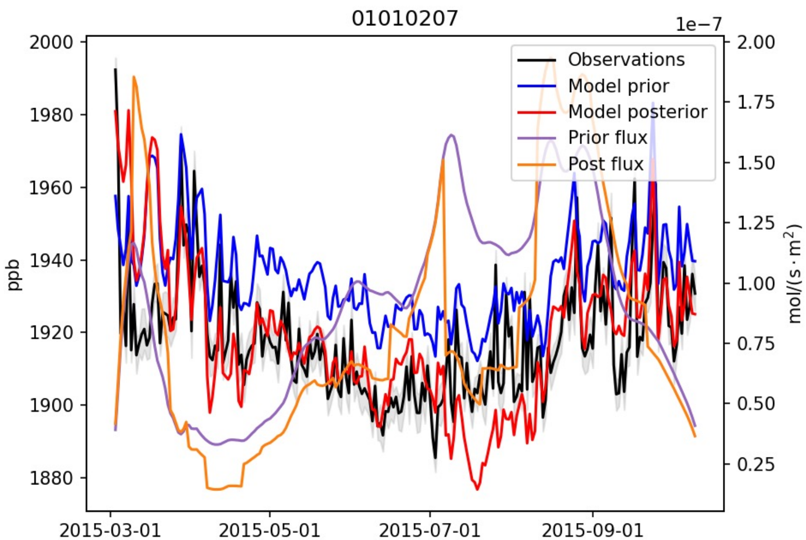
CH_4 and C_2H_6:
oil+gas: 73 Tg/y
microb: 350 Tg/y

CH_4 only:
oil+gas: 64 Tg/y
microb: 351 Tg/y

Data Assimilation System for CH_4 wetland fluxes

New DAS for CH_4 fluxes developed based on HIMMELI peatland flux models and TM5 atmospheric transport model and CTE EnKF data assimilation scheme





Anthropogenic and biogenic (wetland) emissions optimized (4 HIMMELI model parameters) by assimilating atmospheric mixing ratios 2 sites and EC fluxes at 2 sites in northern Finland

Outlook after VERIFY

- CIF inversions
  - analysis of inversions results from model-intercomparison → determine influence of transport errors on fluxes
  - continued use in community (ongoing projects e.g. $CoCO_2$ and new projects, e.g., EYE-CLIMA)
- Model developments
  - ongoing use and developments of process-based and statistical models (CH4-DAS, CH_4 lake fluxes, ECOSSE, CAPRI)
- Ongoing use of TROPOMI data in inversions with CIF

Summary and conclusions

- Agricultural emissions of CH_4 and N_2O from BU models to 2018, EDGAR shows decrease in emissions since 1970 of ~30%
- New spatially resolved uncertainty estimates of agricultural emissions from CAPRI
- New process-based model of lake CH_4 emissions, resolving seasonality → new estimates lake emission for Europe of 3.2 Tg/y
- TD estimates from CIF framework
  - CH_4 fluxes for 2005-2019 from 3 inversions
  - N_2O fluxes for 2005-2019 from 1 inversion (2nd soon)
- First results using $\delta^{13}C$ and ethane tracers for CH_4 inversions show limited benefit for Europe, more potential globally
- New DAS for CH_4 fluxes from wetlands

Thank you for your attention.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776810