EYE-CLIMA Outlook no. 2

January, 2025

EYE-CLIMA aims to improve estimates of emissions and removals of the most important greenhouse gases: CO_2, CH_4, N_2O and six F-gases (i.e., synthetic gases containing fluorine), as well as aerosols containing black carbon to support European and international policies to reduce their emissions.

EYE-CLIMA Outlooks summarise the key findings and project outcomes from the preceding project year that are most relevant for users. This Outlook covers the second year of the project (2024). This Outlook describes some of EYE-CLIMA's work on the use of satellites in estimating emissions at high resolution and process-based modelling, in addition to a summary of the main deliverables from 2024.

All project information and deliverables are accessible at https://eyeclima.eu/

Using high-resolution satellite instruments to determine methane emissions

Reducing fugitive emissions from fossil fuel production is a cost-effective way of reducing total CH_4 emissions, with additional opportunities to reduce agricultural and landfill CH_4 emissions. EYE-CLIMA develops methods to support monitoring of fossil fuel related and other point-source emissions of CH_4.

Enormous progress has been made in detecting mega-emitters of CH_4 from gas and oil facilities, as well as from large landfills, from medium-resolution satellite instruments, such as TROPOMI. EYE-CLIMA builds on these technological advancements and develops a preoperational system for estimating emissions from mega-emitters and incorporating these estimates into emission inventories.

Furthermore, EYE-CLIMA uses high-resolution hyperspectral and multispectral satellites, such as PRISMA, EnMAP, and EMIT, as well as dedicated satellites, such as MethaneSAT and CarbonMapper to identify and quantify medium to large emission sources of CH_4.

Sentinel 5P (Image credit: European Space Agency)

EYE-CLIMA works on improving the identification of CH_4 plumes from satellite observations in areas with high background mixing ratios, and quantifying the emissions, using machine learning and atmospheric transport modelling. Data from high-resolution satellite instruments are also combined with data from coarser-resolution satellite instruments, e.g., TROPOMI on Sentinel 5P. Emission estimates derived from satellite observations are included in emissions inventories.

In the initial phase of the project, most of the focus is on preparation and comparisons of different satellite data products, and the use of satellite observations in preliminary inversion estimates.

Deliverable 1.2: TROPOMI, GOSAT and GOSAT-2 XCH_4 inter-comparisons

Methane (CH_4) data from TROPOMI, GOSAT, and GOSAT-2 satellite instruments were compared against each other and assessed against ground-based TCCON data. TROPOMI's operational, SRON, and WFMD datasets agree well globally, with WFMD offering better coverage but showing larger differences in Europe. WFMD excels in detecting emission plumes but varies in quantifying emissions. GOSAT and GOSAT-2 datasets have lower coverage than TROPOMI, with proxy retrievals outperforming full physics methods in regional flux analysis, especially in Europe. All datasets have low biases (<20 ppb), with FOCAL and UoL-FP performing best for GOSAT and NIES leading for GOSAT-2.

For more information see the deliverable D1.2 available here:
https://eyeclima.eu/products/public-reports/

Process-based modelling of GHG fluxes

EYE-CLIMA employs three state-of-the-art process-based ecosystem models to further the understanding of the impacts of specific land management practices (e.g. fertilizer application, fallow periods between crop rotations, grazing intensity, forest age structure and thinning intensity) on GHG fluxes from agro-systems.

Process-based models simulate water, energy, carbon and nitrogen dynamics at site to global scales and at high temporal resolution (e.g., half-hourly time steps). Vegetation is usually represented by multiple Plant Function Types (PFTs) and multiple carbon pools, and soil is usually disaggregated into different columns, with soil hydrology represented. Typical inputs to the models include temperature, precipitation, solar radiation, wind, and atmospheric CO_2. Most models cover management such as fertilization, tillage, harvest, and peat drainage.

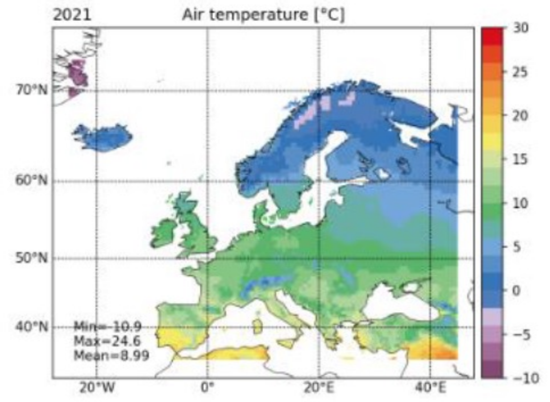
In-situ flux and satellite land biosphere observations are used to calibrate key model parameters related to the transfers of carbon and nitrogen in the different soil-plant-atmosphere reservoirs. In later phases of the project, factorial experiments will be used to assess the contribution of different management practices on fluxes across Europe.

In the early phase of the project, the input data to the process models is improved, and the process model results are used as priors in the inversions.

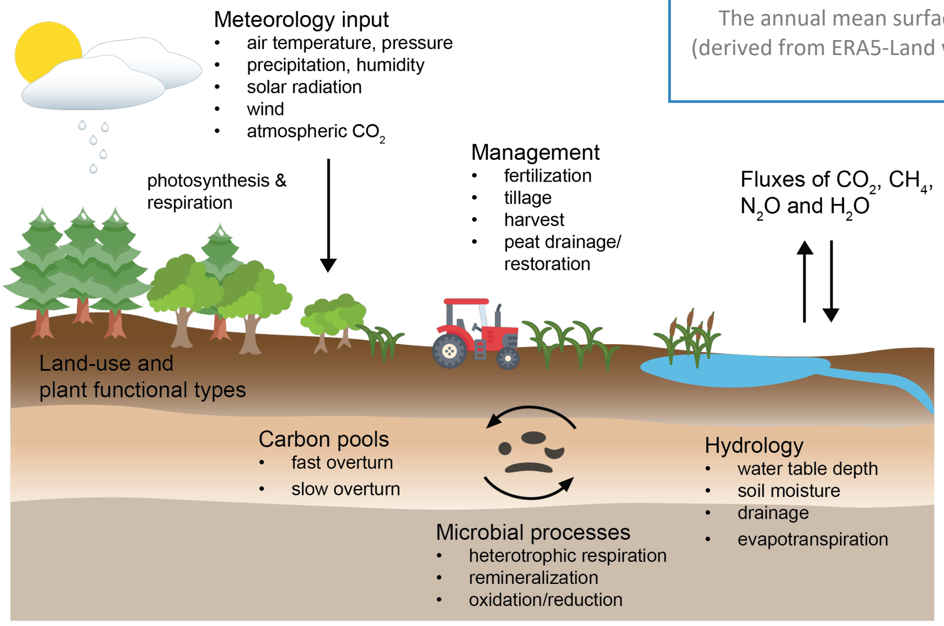
Deliverable 2.1: Input driving datasets for process-based models

Input datasets for simulating CO_2, CH_4, and N_2O fluxes in Europe using ORCHIDEE, LPJ-GUESS, and JSBACH models have been described. Key datasets include ERA5-land climate data bias-corrected with CRU data (updated to 2022), HILDA+ land use/cover changes, SoilGrids for soil organic carbon, MIRCA2000 for cropland management, and GLW2 for livestock density. Forest management uses NFI and Pucher et al. (2022) datasets for forest age and height. Most datasets derive from prior projects like VERIFY and EYE-CLIMA. These inputs will be continuously updated to refine model calibration and validation.

For more information see the deliverable D2.1 available here: https://eyeclima.eu/products/public-reports/



The annual mean surface temperature forcing for 2021 (derived from ERA5-Land with CRU monthly bias correction).

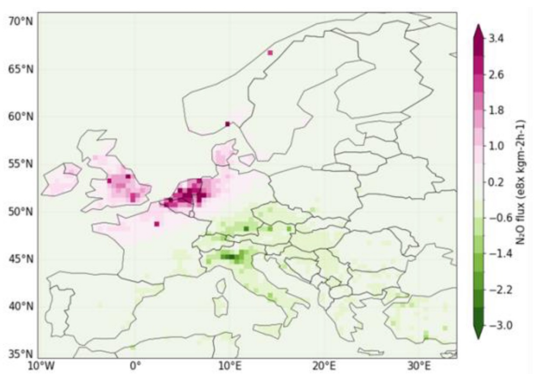


Schematic showing the main input data and processes in the models of the land biosphere

Deliverable 3.1: Preliminary flux estimates of CO_2, CH_4 and N_2O at 0.5°

Atmospheric inversions of CO_2, CH_4, and N_2O fluxes were performed for Europe (EU27+3), optimizing land biosphere fluxes of CO_2 and fluxes of CH_4 and N_2O. Inversions, based on ground-based and satellite data, currently span 2005–2022 for CO_2, 2016–2021 for CH_4, and 2015–2020 for N_2O but will be expanded and updated to cover the period 2005-2023 by April 2025.

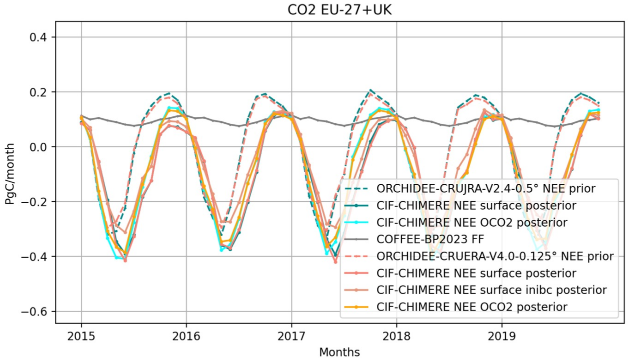
The inversions adjust a prior emission estimate (based on inventories and/or process-based models) by assimilating atmospheric observations.



Annual mean N_2O posterior minus prior flux difference from the CIF-FLEXPART inversion at 0.5°×0.5° from 2015 to 2020.

For CH_4, the posterior emission estimate is 25% higher compared to the prior, driven by emission increases in central and southern Europe. For N_2O the posterior emissions were increased relative to the prior in western Europe, particularly in the UK and and Benelux countries. CO_2 inversions confirm European ecosystems as sinks, but uncertainties persist.

For more information see the deliverable D3.1 available here: https://eyeclima.eu/products/public-reports/

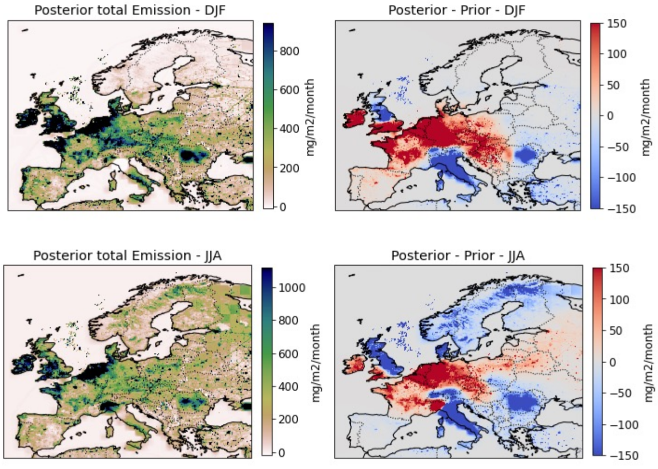


Monthly mean net ecosystem exchange (NEE) fluxes of CO_2 integrated over EU27 plus UK. Data from two prior NEE estimates (dashed lines) and different inversion estimates (solid lines) are shown. The black line indicates the fossil fuel emission estimate used in the inversion.

Deliverable 3.3: Preliminary fluxes of CO_2, CH_4 and N_2O at 0.2° from 2018

The feasibility and performance of high-resolution (0.2°×0.2°) atmospheric inversions for CO_2, CH_4, and N_2O fluxes in Europe were evaluated. The inversions show how the prior emission estimate is shifted to the posterior estimate based on observations. CH_4 inversions reveal an increase in emissions in the posterior relative to prior in Central Europe and reductions in southern and northern regions, partly correcting overestimated prior geological emissions. The N_2O emissions a posteriori show a 21% overall reduction, with decreases in southern and central regions but increases in the UK and parts of northwestern Europe, relative to the prior. For CO_2, the computations at 0.2°×0.2° proved to be too computationally demanding with the current version of CIF-CHIMERE thus work is underway to run CHIMERE on GPUs to shorten the computation time.

For more information see the deliverable D3.3 available here: https://eyeclima.eu/products/public-reports/



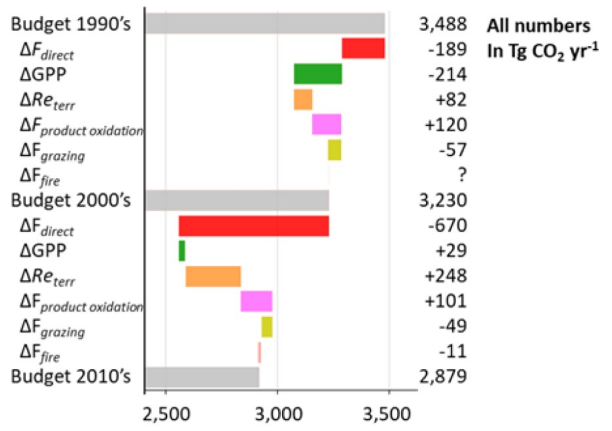
Seasonal mean spatial distribution of CH4 estimates from CIF-FLEXPART inversion at a higher resolution of 0.2°× 0.2° grid in the year 2019: prior (left panel), posterior (middle panel) and posterior increments computed as (posterior – prior) (right panel).

Paper and Deliverable 4.4: Carbon and greenhouse gas budgets of Europe: trends, interannual and spatial variability

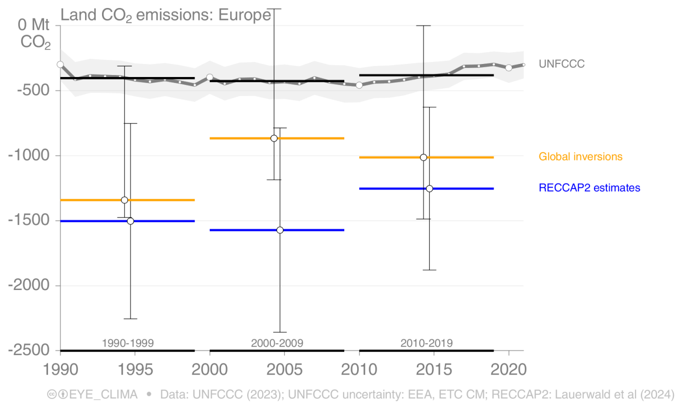
European greenhouse gas (GHG) fluxes (CO_2, CH_4, N_2O) were synthesized, combining bottom-up (BU) and top-down (TD) estimates from 1990–2019 from previous projects. BU estimates detail emissions by sector, distinguishing anthropogenic emissions and land-atmosphere exchanges. TD analyses use global and regional inversions (0.5° resolution) to refine spatial patterns of sources and sinks across Europe. The study highlights spatiotemporal variability, local emission hotspots, and trends in fossil CO_2 and land fluxes. Results emphasize interannual variability in Europe's GHG budget and contribute to ongoing climate assessments.

This deliverable is now published as Lauerwald et al., Carbon and greenhouse gas budgets of Europe: trends, interannual and spatial variability, and their drivers, *Global Biogeochemical Cycles*, 2024, and has been used to develop the EYE-CLIMA first Progress on Targets Report. The full report is available here:

https://eyeclima.eu/products/policy-briefs/



Evolution of European CO_2 budget over the last three decades (Lauerwald et al. 2024).

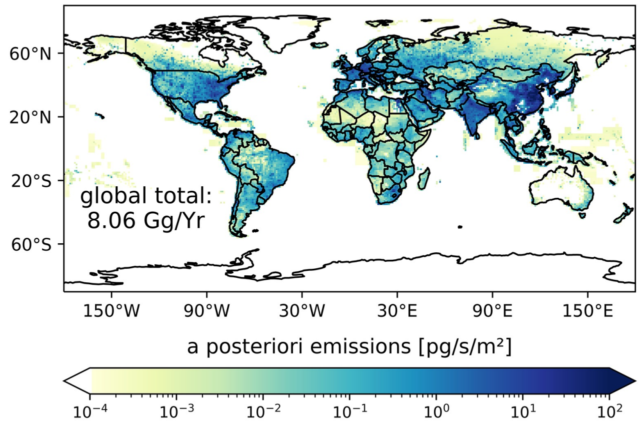


Summary of different land CO_2 emission estimates from the EYE-CLIMA Progress to Targets report.

Paper: A global analysis SF_6 emissions and concentrations

Global emissions of sulfur hexafluoride (SF_6), a potent greenhouse gas, were analysed from 2005 to 2021 using inverse modeling, using observations and simulations to estimate emissions. Key findings include: 1) US emissions reduced by half relative to 2005, but were still twice the reported values; 2) EU emissions declined, especially after 2018 due to stricter regulations; 3) China's emissions quadrupled, surpassing global trends; 4) National reports underestimated emissions the US, EU, and China; 5) Emissions are rising in poorly monitored areas like India and Africa; 6) Global totals align with past estimates but depend on the priors; 7) Northern Hemisphere emissions peak in summer.

Vojta et al. (2024), *Atmospheric Chemistry and Physics*
https://acp.copernicus.org/articles/24/12465/2024/



Estimated SF_6 emission from the inverse modelling (combining prior emission estimates and observations.

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