EYE-CLIMA Outlook no.1

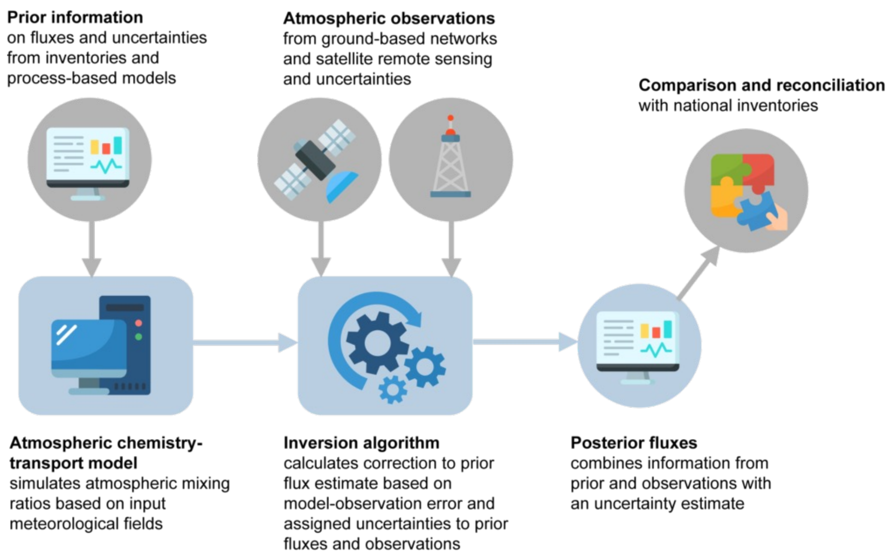
January, 2024

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 policy to reduce emissions.

EYE-CLIMA Outlooks summarise key findings and project outcomes from the preceding project year, which are most relevant for users. This Outlook covers the first year of the project (January to December 2023) and focuses on atmospheric inversions, particularly the input data used: prior emissions and the observations used to constrain the inversions. These input data are some of the key deliverables from the first year of the project.

Atmospheric inversions

Changes in atmospheric concentrations[1] represent the integrated effect of human plus natural emissions and removals, atmospheric transport, and any chemical reactions in the atmosphere. As an example, CH_4 emissions from a landfill will be transported in the atmosphere, become mixed with CH_4 emissions from other sources such as natural wetlands or leaks from coal, oil, and gas infrastructure and be partially oxidised in the atmosphere (by the OH radical). Atmospheric models can simulate atmospheric concentrations by modelling the transport, chemistry, emissions, and removals of various gases and aerosols – this is known as forward modelling.



It is also possible to effectively run these models in reverse – a process known as inverse modelling – that is a model of atmospheric transport and chemistry can be used to relate changes in atmospheric concentrations to changes in emissions and removals. The inversion then finds the patterns of emissions and removals that best match the observed atmospheric concentrations using statistical optimization methods. This is a powerful methodology as it enables observations of concentrations and meteorology to be used to estimate emissions and removals, which can then be used to evaluate independent estimates of emissions and removals, such as those reported by governments to the UNFCCC.

EYE-CLIMA will have a strong focus on improving both the accuracy and resolution of regional inversions. In EYE-CLIMA, inversions will be run at high resolution (0.2° or ~20km) over Europe, to provide spatially and temporally resolved emissions and removals to facilitate comparisons with nationally reported estimates.

Despite the potential of inversions, challenges arise. Inversions are constrained by observations, but observations are sparse and may have data gaps. Moreover, inversions are generally under constrained, that is, there could be more than one solution for the emissions and removals, which is compatible with the available observations. Because of this, inversions need an initial 'best guess', or prior estimate, of the emissions and removals.

The inversion finds the most probable solution, which is consistent with the observations, but where the constraint from the observations is insufficient, it relies on the prior estimate. The performance of inversions is being improved with expanding observation networks and the addition of satellite instruments, which orbit the Earth and provide observations at regular intervals. There is also a new impetus to improve

[1]Technically it is the *mixing ratio* that is measured, i.e., the ratio of mass or (moles) of a given gas (e.g. CH_4) to that of air

and track estimates of emissions and removals in the context of the climate challenge. Interest in the inversion methodology is expected to grow as the coverage of observations expands and the prior estimates and atmospheric models improve.

The first year of EYE-CLIMA was largely about documenting and improving the observation-based data (Work Package 1) and bottom-up modelling of prior emissions and removals (Work Package 2). From 2024, the focus will increasingly be on inversions (Work Package 3), and emission attribution and reconciliation with emission estimates from national inventories (Work Package 4). This EYE-CLIMA Outlook Summary focuses on observations and prior emissions.

Observations

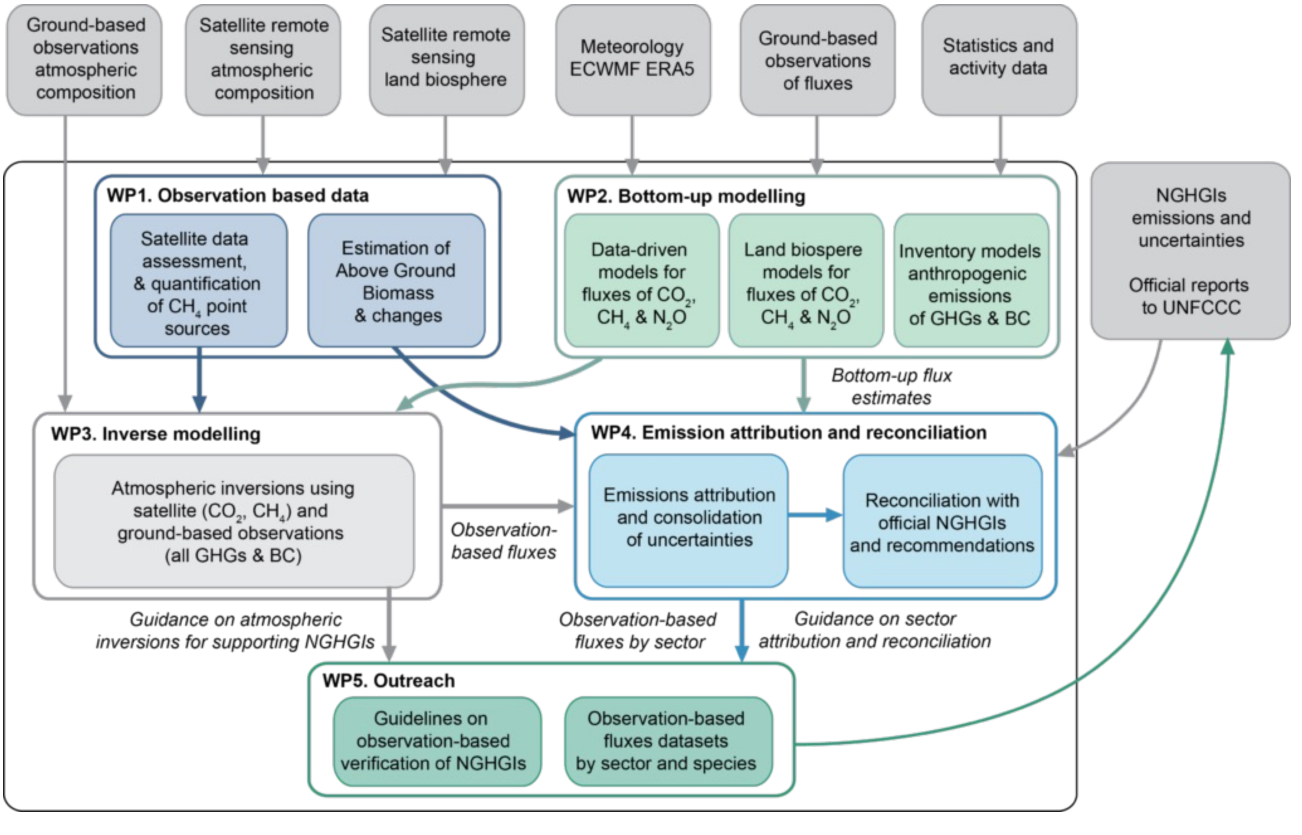
There is a range of different observation data that will be used in EYE-CLIMA.

Remote sensing measures different variables based on the amount of reflected or emitted radiation from the Earth's surface. Remote sensing maps of above ground biomass (AGB), and its changes, will support the modelling of CO_2 emissions and removals in the land-use land-use-change and forestry (LULUCF) sector.

Satellite retrievals of total column CH_4 (the average CH_4 concentrations seen though a 'column' of the atmosphere and for which the notation, XCH_4, is often used) will be used to estimate large CH_4 emission sources and in regional atmospheric inversions. Retrievals of CO_2 total columns (XCO_2) will be used in atmospheric inversions to estimate land-biosphere CO_2 emissions and removals.

Ground-based atmospheric observations cover atmospheric mixing ratios (CO_2, CH_4, N_2O, and selected F-gases) and concentrations (black carbon) from ground-based sites and will be used in inversions. For CO_2 and CH_4, these observations will be in addition to remote sensing data.

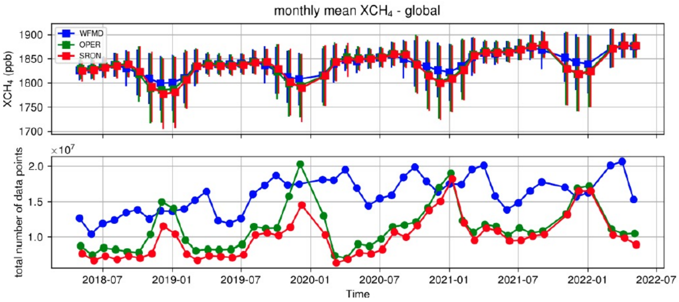
Meteorological data will be used to drive the atmospheric transport models used in the inversions, and as input to process-based models of the land biosphere, which will be used to estimate emissions and removals of CO_2, CH_4 and N_2O.



Deliverable 1.1: Assessment of CH_4 column data from TROPOMI

A comparison was made between three different algorithms used to estimate XCH_4 from the TROPOspheric Monitoring Instrument (TROPOMI) and XCH_4 from instruments in the ground-based network, TCCON. Although XCH_4 from all algorithms compared well with TCCON, one of the XCH_4 products (WFMD) has some notable differences compared to the other two (the official and SRON), and it can be expected that surface fluxes from inversions over Europe will differ somewhat depending on the chosen dataset. The WFMD product, however, provides better data coverage, which is useful for detecting emission plumes.

A comparison of inversions over Europe using each of the three datasets is planned.

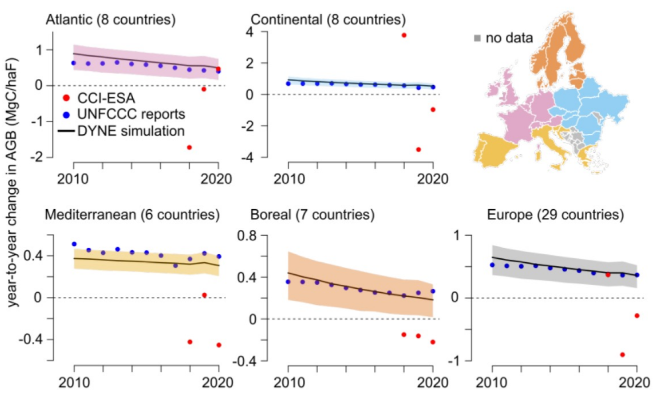


Time series of TROPOMI monthly mean XCH_4 representative for the European domain (top) and the corresponding number of measurements (bottom).

Deliverable 1.7: Review of biomass and biomass change datasets

Various biomass datasets were reviewed to benchmark national GHG inventories and help separate human activities from natural processes:

1. European Space Agency Climate Change Initiative (ESA-CCI) maps utilise remote sensing, including radar, lidar, and optical sensors.
2. Biomass change maps based on Vegetation Optical Depth (L-VOD) have a relatively long observation period starting from 2010.
3. Avitabile et al. (2023, JRC) has a European biomass map for 2020 that is calibrated to sub-national statistics consistent to national GHG inventories.



European forest biomass derived from L-VOD and modelled forest regrowth show a declining trend in carbon uptake (from Ritter et al. in review 2024).

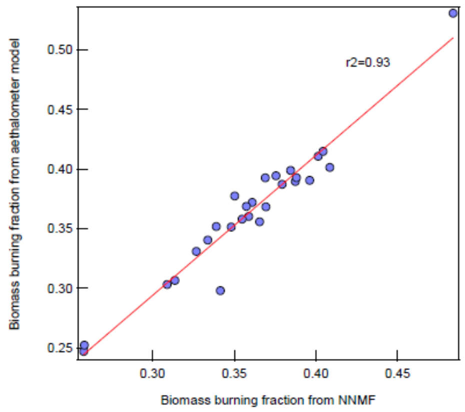
Prior data on emissions and removals

Independent inventory estimates of human emissions of CO_2 (fossil fuels, biofuels, biomass burning, and cement production), CH_4, and N_2O will be used in combination with the process-based model estimates as prior information in the inversions. The prior information needs to be spatially (at least 0.2° or ~20km) and temporarily (order of hours to weeks) distributed. The inclusion of uncertainty information is an important element of the prior data, as it gives information to the inversions on how much the emissions and removals can be modified to be made consistent with the observations.

Independent estimates of natural emissions and removals of CO_2, CH_4 and N_2O are also needed. These will be produced by a variety of process-based models, at the necessary spatial and temporal resolution.

Deliverable 1.10: Concentrations of equivalent-BC from traffic and other sources

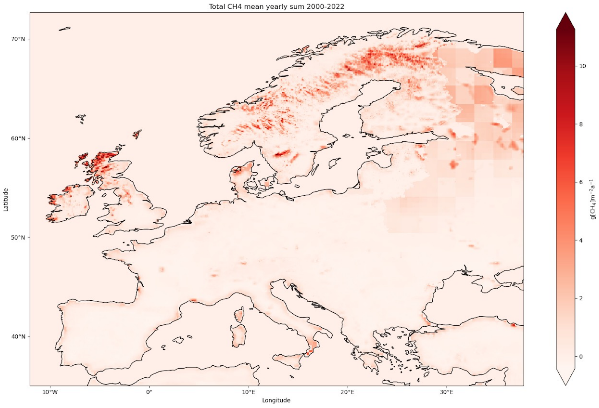
EYE-CLIMA has prepared a new harmonised timeseries of equivalent-BC (eBC) concentrations for 28 sites in Europe. In addition, EYE-CLIMA has developed a new algorithm to apportion eBC concentrations to traffic and non-traffic (e.g. biomass burning) sources using specific features of BC for each of these source types, which can be seen in measurements. The new method builds on previous existing methods but avoids large uncertainties and spurious negative concentrations in the output and is computationally more efficient. The time series' of eBC from these sources will be used in inversions estimate the emissions.



Comparison of eBC concentrations from biomass burning as derived by EYE-CLIMA's method compared to an existing reference method

Deliverable 2.3: Land biosphere emissions and uncertainties of GHGs

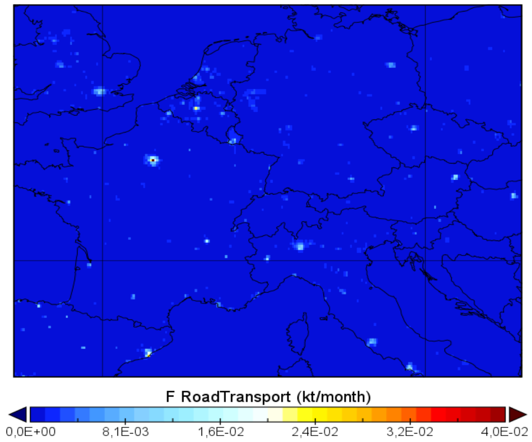
Bottom-up information on land biosphere emissions (1990-2022) of greenhouse gases (CO_2, CH_4, N_2O) has been provided in high spatial and temporal resolution based on three ecosystem models, ORCHIDEE, LPJ-GUESS and JSBACH. The runs were made using climate forcing at 0.1° (~10 km resolution) daily resolution over Europe. The model results will allow for the assessment of GHG budgets, their trends, seasonality, and variability for different ecosystem types including forests, grasslands, croplands, and peatlands. These fluxes will be used in the prior information for high resolution atmospheric inversions.



Mean land biosphere methane fluxes from the JSBACH-HIMMELI model within the area of EYE-CLIMA European domain. Peatland emissions in northern Europe are the dominant biosphere source in Europe.

Deliverable 2.8: Anthropogenic emissions and uncertainties of GHGs and BC

Bottom-up information of historic emissions (years 1990 – 2019) of relevant compounds (F-gases, CH_4, N_2O, BC) has been provided in high spatial (0.1°) and at monthly resolution based on activity data and emission factors from the GAINS model. Emission data for EU27 countries as well as Switzerland, Norway and UK are available by source sector and provided with bottom-up uncertainty estimates. Conceptually they are comparable with national emission inventories, however, they reflect harmonized emission quantification methods and downscaling to a 0.1° grid (~10 km resolution).



Gridded BC emissions from Road Transport for western Europe (Jan 2010)

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