Data
Models
Inventories

PARIS

Process Attribution of Regional Emissions

GA 101081430, RIA

Full year of N_2O data, uploaded to the ICOS portal - 1st round

Deliverable D5.2			
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Responsible scientist	Stephan Henne		
Contributors	Anita Ganesan UNIVBRIS, Alistair Manning MO		
Internal reviewers			
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Horizon Europe Cluster 5: Climate, energy and mobility

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1. Changes with respect to the DoA (Description of the Action)

While the data upload was delayed for technical reasons, the relevant data were exchanged with the inverse modelling groups and with the inventory teams of the PARIS focus countries on time for producing the draft Annex reports.

2. Dissemination and uptake

The data uploaded to the ICOS Carbon Portal form the basis for Annex reports in WP2. As such they have been shared with the relevant project partners prior to the completion of D2.3. Final data products are all available publicly on the ICOS Carbon Portal for use by other scientists and practitioners and have been shared with national inventory compilers (e.g., the Dutch inventory team has based the figures produced by themselves for their annex to the 2026 NID report on these data).

3. Short Summary of results

The inversion modelling systems employed in PARIS, represented by a total of six combinations of inversion systems (RHIME, InTEM, ELRIS) and transport models (NAME, FLEXPART) were used to estimate N_2O fluxes across Europe for the common period 2016 to 2024, with NAME-based inversions starting earlier. Inverse modelling results include monthly N_2O fluxes at a spatial resolution of 25 km x 25 km and country aggregates for the European domain. These were collected in commonly defined data formats and made publicly available (https://doi.org/10.18160/GR1Q-6SK4). Results were visualised by the inversion-intercomparison tool fluxy and figures of the included data were semi-automatically produced, forming the basis of the PARIS annex drafts submitted to the nation inventory teams of the PARIS focus countries.

4. Evidence of accomplishment

Inverse modelling results (including flux estimates as well as observed and simulated atmospheric mole fractions) from the individual inversions are available on the ICOS Carbon Portal:

ELRIS-FLEXPART, https://meta.icos-cp.eu/objects/FTUWRIr4Un4fETBUgcQp4qHA

ELRIS-NAME, https://meta.icos-cp.eu/objects/MOJbmoZ-f42MBphbpFY3bGDb

InTEM-FLEXPART, https://meta.icos-cp.eu/objects/ZILjPVFmFANnim9bpe9UCqAe

InTEM-NAME, https://meta.icos-cp.eu/objects/TlAicGVTtNRABBoycqSgrQzO

RHIME-FLEXPART, https://meta.icos-cp.eu/objects/WryaayEmhxy6Um7jsc_ZyQQQ

RHIME-NAME, https://meta.icos-cp.eu/objects/Sct_2uBOLpeJB4gHRSultN1r

4.1 Introduction | Background of the deliverable

Inverse model estimates based on atmospheric observations are one of the central results of the PARIS projects as these are shared with national inventory teams to validate their bottom-up reporting. The observation-based inverse estimate is considered to be largely

independent of the bottom-up reporting and allows the identifications of potential issues in the bottom-up reporting in areas well covered by the observing network. In the case of PARIS eight focus countries were chosen for inter-comparison, most of which exhibit good long-term observational coverage, but with few targeted because of emerging new observations. The primary result of the inversion systems applied in PARIS are spatially resolved fluxes with, in the case of N_2O, monthly resolution. These data are aggregated to national totals on timescales (annual) relevant for GHG reporting to UNFCCC. Hence, an actionable dataset is created for direct comparison for the inventory teams. Inversion results are delivered in a timely manner, meaning that the results presented here and communicated to inventory teams in October 2025, contain emission estimates up to the end of 2024. In April 2026 the national inventories need to include emission estimates for 2024 as well. Therefore, the PARIS dataset allows direct comparison up to the latest possible reporting year. Details of the comparison of inversion results and UNFCCC reporting are contained in PARIS deliverable D2.3. Here, the delivered dataset and its use is outlined.

4.2 Scope of the deliverable

The delivered dataset comprises inverse modelling results of European N_2O surface fluxes from six different combinations of inverse modelling systems (RHIME, InTEM, ELRIS) and transport models (NAME, FLEXPART). The common period 2016-2024 is covered for which the observational network is most dense, and uncertainties of flux estimates smallest. Due to the limited network coverage in southern, eastern and northern Europe it is recommend to focus interpretations of the delivered flux estimates on north-western Europe (Ireland, UK, France, Benelux, Germany).

4.3 Content of the deliverable

The inverse methodology was described in detail elsewhere (e.g., model documentation supplement to D2.3). Performance of the chose inverse setup for N_2O was analysed in M41. Here, the data product itself is described, whereas interpretation of the inverse modelling results is provided through D2.3.

The uploaded datasets comprise three types of data:

1. Monthly N_2O flux estimates (including prior and posterior estimates and their uncertainties) at a spatial resolution of 25 km x 25 km

   Relevant variables are described as part of the standardised netcdf format for inversion results (flux file) in **Error! Reference source not found.** and https://github.com/openghg/fluxy/blob/devel/data/templates/README_templates.md
2. Country aggregates of monthly N_2O fluxes for western European countries (areas well-covered by observations network). Prior and posterior values and their uncertainties and covariances between individual regions are reported. These data are contained in the same files the spatially resolved fluxes.

   Relevant variables are described as part of the standardised netcdf format for inversion results in **Error! Reference source not found.** and (flux file):

https://github.com/openghg/fluxy/blob/devel/data/templates/README_templates.md

3. Time series of observed and simulated N_2O mole fractions
   Relevant variables are described as part of the standardised netcdf format for inversion results in *Tabl* and (concentration file):
   https://github.com/openghg/fluxy/blob/devel/data/templates/README_templates.md

Each of the six sensitivity inversions that form the PARIS ensemble is available as a pair of flux and concentration files. In the following a few example plots of the available data are presented as created with the comparison tool fluxy.

Spatially resolved flux information is shown in Fig. 1 for all six PARIS inversions. The displayed fluxes are the a priori (netcdf variable **`flux_total_prior`**) and a posteriori fluxes (**`flux_total_posterior`**) averaged from the monthly data contained in the dataset to a mean for the period January 2017 to December 2024. Since the employed inversion systems all work with a reduced inversion grid (regions in which individual factors are optimised to arrive at the a posteriori results), two additional variables are provided in the netcdf files which provide results at the resolution of these reduced inversion grids (**`flux_total_posterior_inversion_grid`**, **`flux_total_prior_inversion_grid`**). Furthermore, uncertainties of the spatially resolved fluxes are provided in variables **`stdev_flux_total_prior`** and **`stdev_flux_total_posterior`** or, if non-Gaussian uncertainties are involved, as a percentile range in variables **`percentile_flux_total_prior`** and **`percentile_flux_total_posterior`**.

An example of country total N_2O flux data is given in Fig. 2. The displayed fluxes are the a priori (**`flux_total_prior_country`**) and a posteriori estimates (**`flux_total_posterior_country`**), available at monthly resolution and collected across all six inversion datasets. Uncertainty bands for the a posteriori either are given either by the standard deviation of a Gaussian distribution (**`stdev_total_posterior_country`**) or by a percentile range for non-Gaussian distributions (percentile_total_posterior_country). The uncertainty of the a priori fluxes is contained dataset (**`stdev_total_prior_country`**, **`percentile_total_prior_country`**) but omitted from the plot. Not contained in the dataset are the countries' reported emissions (black bars). These need to be obtained from the common reporting tables (CRT) available at UNFCCC.

Time series of observed and simulated N_2O mole fractions are discussed as part of M41 and various visualisations can be found therein. Variables are listed in Table 3. Several of these variables are optional because different inversion systems make different assumptions about how to split the total mole fraction (at least a split into boundary conditions (**`mf_bc_prior`** and **`mf_bc_posterior`**) and total mole fractions (**`mf_prior`** and **`mf_posterior`**) is available).

Table 1: Variables for spatially resolved fluxes defined in the standardised netcdf format for inversion results (flux file).

Grid variables	Units	Dimensions	Description
flux_total_prior	mol m^{-2} s^{-1}	time, latitude, longitude	Prior total <species> fluxes
flux_total_posterior	mol m^{-2} s^{-1}	time, latitude, longitude	Posterior total <species> fluxes
stdev_flux_total_prior	mol m^{-2} s^{-1}	time, latitude, longitude	Standard deviation of prior total <species> fluxes
stdev_flux_total_posterior	mol m^{-2} s^{-1}	time, latitude, longitude	Standard deviation of posterior total <species> fluxes
Optional variables			
flux_total_prior_inversion_grid	mol m^{-2} s^{-1}	time, latitude, longitude	Prior total <species> fluxes on the reduced inversion grid
flux_total_posterior_inversion_grid	mol m^{-2} s^{-1}	time, latitude, longitude	Posterior total <species> fluxes on the reduced inversion grid
stdev_flux_total_prior_inversion_grid	mol m^{-2} s^{-1}	time, latitude, longitude	Standard deviation of prior total <species> fluxes on the reduced inversion grid
stdev_flux_total_posterior_inversion_grid	mol m^{-2} s^{-1}	time, latitude, longitude	Standard deviation of posterior total <species> fluxes on the reduced inversion grid
Alternative to stdev for non-Gaussian PDFs			
percentile_flux_total_prior	mol m^{-2} s^{-1}	time, percentile, latitude, longitude	Percentile of prior total <species> fluxes
percentile_flux_total_posterior	mol m^{-2} s^{-1}	time, percentile, latitude, longitude	Percentile of posterior total <species> fluxes
percentile_flux_total_prior_inversion_grid	mol m^{-2} s^{-1}	time, percentile, latitude, longitude	Percentile of prior total <species> fluxes on the reduced inversion grid
percentile_flux_total_posterior_inversion_grid	mol m^{-2} s^{-1}	time, percentile, latitude, longitude	Percentile of posterior total <species> fluxes on the reduced inversion grid

Table 2: Variables for country-aggregated fluxes defined in the standardised netcdf format for inversion results (flux file).

By-country variables	Units	Dimensions	Description
flux_total_prior_country	kg yr^{-1}	time, country	Country-total prior <species> fluxes
flux_total_posterior_country	kg yr^{-1}	time, country	Country-total posterior <species> fluxes
stdev_flux_total_prior_country	kg yr^{-1}	time, country	Standard deviation of country-total prior <species> fluxes
stdev_flux_total_posterior_country	kg yr^{-1}	time, country	Standard deviation of country-total posterior <species> fluxes
Alternative to stdev for non-Gaussian PDFs			
percentile_flux_total_prior_country	kg yr^{-1}	time, percentile, country	Percentiles of country-total prior <species> fluxes
percentile_flux_total_posterior_country	kg yr^{-1}	time, percentile, country	Percentiles of country-total posterior <species> fluxes
Optional			
covariance_flux_total_posterior_country	kg^2 yr^{-2}	time, country, country	Covariance of country-total posterior <species> fluxes

Table 3: Variables defined for observed and simulated concentrations at observing sites included in the standardised netcdf format for inversion results (concentration file).

Observation variables	Units	Dimensions	Description
platform	-	platform	Identifier of observing platform
mf_observed	mol mol^{-1}	index	Observed mole fraction of <species> in dry air
Simulated variables			
mf_prior	mol mol^{-1}	index	Prior simulated mole fraction of <species> in dry air
mf_posterior	mol mol^{-1}	index	Posterior simulated mole fraction of <species> in dry air
mf_bc_prior	mol mol^{-1}	index	Prior simulated boundary condition mole fraction including site bias
mf_bc_posterior	mol mol^{-1}	index	Posterior simulated boundary condition mole fraction including site bias
Optional			
stdev_mf_prior	mol mol^{-1}	index	Standard deviation of prior simulated mole fractions due to state vector uncertainty
stdev_mf_posterior	mol mol^{-1}	index	Standard deviation of posterior simulated mole fractions due to state vector uncertainty
mf_bias_prior	mol mol^{-1}	index	Prior simulated mole fraction site bias
mf_bias_posterior	mol mol^{-1}	index	Posterior simulated mole fraction site bias
mf_outer_prior	mol mol^{-1}	index	Prior simulated mole fraction contribution from distant regions
mf_outer_posterior	mol mol^{-1}	index	Posterior simulated mole fraction contribution from distant regions
Alternative to stdev for non-Gaussian PDFs			
percentile_mf_prior	mol mol^{-1}	index, percentile	Percentile of prior simulated mole fraction due to state vector uncertainty uncertainty
percentile_mf_posterior	mol mol^{-1}	index, percentile	Percentile of posterior simulated mole fraction due to state vector uncertainty
Uncertainty variables			
stdev_mf_total	mol mol^{-1}	index	Total model-data-mismatch uncertainty applied in inversion
Optional			
stdev_mf_observed_repeatability	mol mol^{-1}	index	Repeatability uncertainty of observed mole fraction
stdev_mf_observed_variability	mol mol^{-1}	index	Variability of observed mole fraction within aggregation interval
stdev_mf_model	mol mol^{-1}	index	Model uncertainty of simulated mole fraction

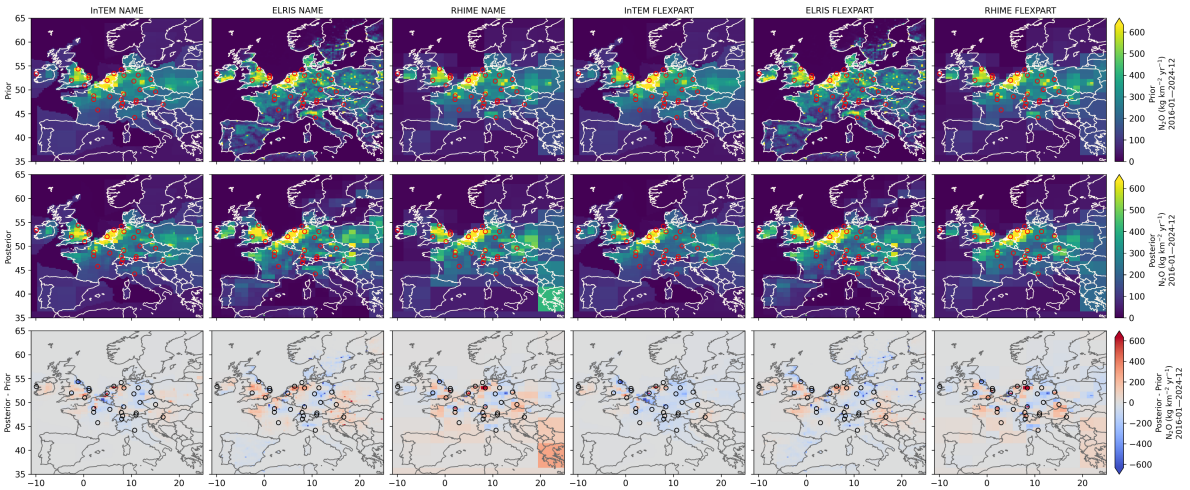

Fig. 1: A priori (top), a posteriori (middle) fluxes and their differences (bottom) for the six PARIS N2O inversions (columns). For each panel the monthly flux data was aggregated for the period January 2016 to December 2024.

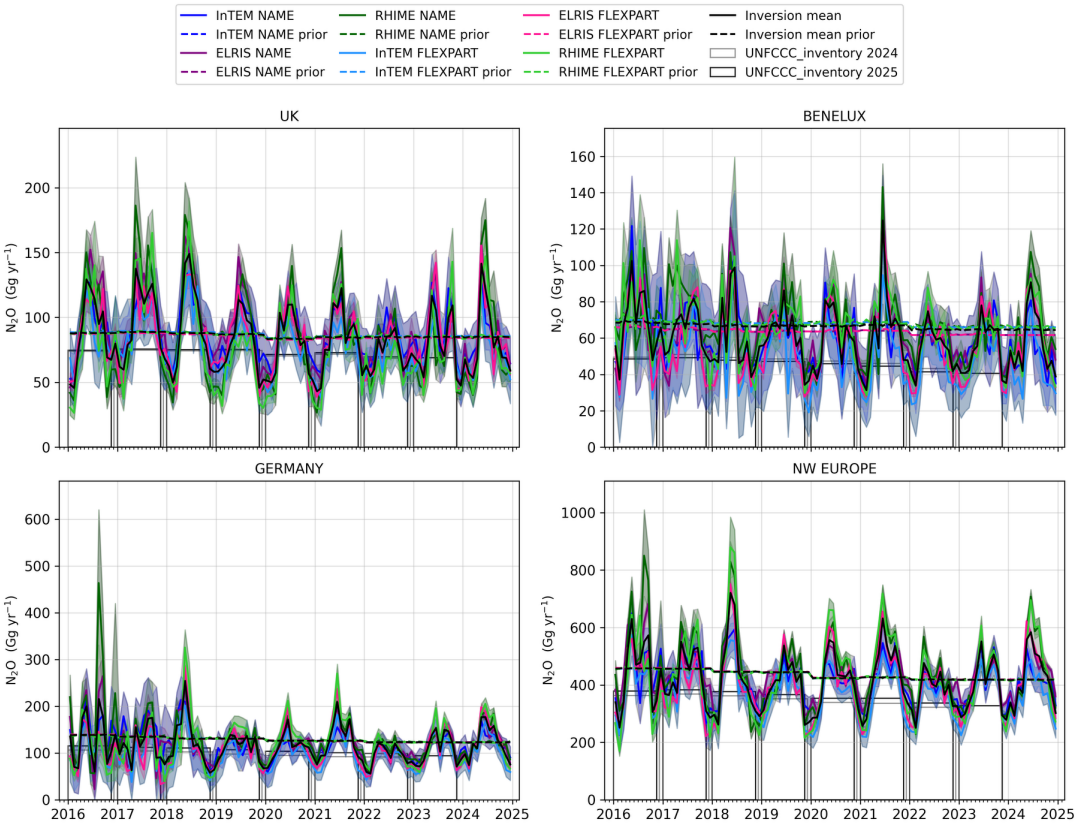

Fig. 2: Time series of country total, monthly a priori (dashed lines), a posteriori (solid lines) N2O emissions and their uncertainties (shading). For comparison, bottom-up (inventory data not part of this deliverable) flux estimates are shown with annual bars.

4.4 Conclusion and possible impact

The uploaded inversion results form the basis for the production of PARIS draft annexes (D2.3) and are shared with the national inventory teams and wider scientific community. Results will be directly used by the Dutch and Irish inventory compilers in their upcoming (2026) inventory document for the UNFCCC. An update of the current dataset is expected by October 2026 and will then include flux estimates until the end of 2025.

The standardised data format and the open-source fluxy visualisation and inter-comparison tool (https://github.com/openghg/fluxy) ensure easy access to the inversion results and inter-operability with other inverse modelling groups (for example as part of a synthesis between the PARIS, EYE-CLIMA and AVENGERS projects as shared in the 4th common newsletter in Dec 2025).

4.5 References

Ganesan, A., Manning, A., Henne, S., De Longueville, H., Ramsden, A., Brito Melo, D., Danjou, A., Andrews, P., Murphy, B., Redington, A., and Pitt, J.: Inverse modelling results for European non-CO2 greenhouse gas emissions, ICOS ERIC - Carbon Portal, 2026.

5. History of the document

Version	Author(s)	Date	Changes
0.1	Stephan Henne	2026-02-01	First draft
0.2	Stephan Henne	2026-02-18	Final draft
0.3	Anita Ganesan	2026-02-19	Review