Data
Models
Inventories

PARIS

Process Attribution of Regional Emissions

GA 101081430, RIA

2nd Periodic Report

1 July 2024 – 31 December 2025

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1. EXPLANATION OF THE WORK CARRIED OUT AND OVERVIEW OF THE PROGRESS

During the second reporting period, the focus of the project has shifted from infrastructure build-up and methodological development towards consolidation, integration, and delivery. The initiated collaborations with the two sister projects AVENGERS (https://avengers-project.eu) and EYE-CLIMA (https://eyeclima.eu), both funded under the same call as PARIS, have been further expanded.

Inventory compilers engagement

Since the previous reporting period, engagement with the inventory compilers from the eight focus countries has significantly progressed. Results from multiple inverse modelling systems are produced in harmonised formats and compared using a common analytical framework. This led to country-specific annexes delivered in 2024 and 2025, which have been provided and actively discussed with inventory agencies. Engagement has matured into an annual cycle of presentation, feedback and refinement, demonstrating clear progress towards operational use of top-down results in national inventories. The UK, Netherlands, and Ireland include PARIS results to their respective National Inventory Documents (NID, formerly NIR). The inter-comparison tool hosted on the ICOS Carbon Portal is fully operational and supports rapid, transparent analysis across gases, countries and years.

Expansion of F-gas Observational Network

The expansion of the European F-gas observational network has progressed from site establishment to sustained operation and integration into inversion systems. Continuous measurements at Taunus and Capo Granitola, upgrades at Monte Cimone, and flask sampling at Hegyhátsál, Birkenes and Cabauw are now fully operational, with quality-controlled datasets feeding into AGAGE and ICOS infrastructures. Data that were previously unavailable are now routinely used in the inverse modelling, extending national-scale verification capability into Southern and Eastern Europe. Multi-model inversion inter-comparisons have been completed using harmonised inputs and evaluated with the fluxy tool. A key outcome since last year is the successful detection and independent verification of a major SF_6 point source in Germany, demonstrating the concrete inventory relevance of the expanded network.

Methane (CH_4) Observations and Inversions

CH_4 activities have advanced from infrastructure deployment and initial inversions to integrated, multi-system analyses. Portable IRMS deployments in Germany and Romania have delivered new isotope datasets, while delays at Hegyhátsál have been resolved and redeployment scheduled, ensuring continuity. Continuous optical isotope measurements at Heathfield are now fully operational, with additional deployments planned. Crucially, the first large-scale methane inversion using InTEM and data from 33 ICOS stations for 2018–2023 has been completed, representing a major milestone beyond last year's preparatory phase. The use of additional models such as RHIME, ELRIS, and ICON-ART-DWD are now producing complementary estimates, including fossil/non-fossil source separation using ethane (C_2H_6). While sector-specific reconciliation with inventories is still under development, the foundations are now in place, and the project has moved from data acquisition to robust top-down emission assessment.

Nitrous Oxide (N_2O) Observations and Modelling

Significant progress has been achieved in harmonising N_2O observations and aligning top-down and bottom-up approaches. Calibration strategies at Hegyhátsál have been fully revised, historical datasets reprocessed, and data made publicly available via the ICOS Carbon Portal. A harmonised European N_2O observational dataset has now been established in collaboration with AVENGERS and EYE-CLIMA, exceeding the scope described last year. Inverse modelling teams have completed aligned inversion experiments for multiple domains, revealing strong seasonal and inter-annual variability.

To address some of the discrepancies revealed, isotopic N_2O flux measurements at a Swiss cropland site have been made, directly supporting process-model development. National-scale implementations of DayCent and LandscapeDNDC have moved from planning to execution, marking clear progress toward integrated reconciliation.

Fossil Fuel Carbon Dioxide (CO_2) inference and detectability

New measurements and modelling studies are being conducted to determine the detectability of fossil fuel CO_2 emissions using atmospheric data. Top-down evaluation of fossil fuel CO_2 fluxes is challenging due to the influence of terrestrial biosphere on CO_2 concentration measurements. Through PARIS, continuous oxygen and carbon dioxide measurements at Weybourne and Heathfield in the UK have been continued and rigorously quality-controlled, while mitigation measures are in place following delays in establishing a new site in the Netherlands. The purpose of these observations is to infer fossil fuel CO_2 emissions using Atmospheric Potential Oxygen (APO), a quantity derived from simultaneous CO_2 and O_2 measurements that is insensitive to biosphere fluxes. A dedicated modelling study on APO sensitivity has been completed, providing critical guidance for future inversions. The CO_2 Blind Verification Challenge has continued, with a published protocol and first round of experiments completed. The project has focused on identifying structural uncertainties and detectability limits, a necessary step toward credible operational use.

Organic Matter (OM) in Aerosols and Black Carbon (BC)

Activities on aerosols and black carbon have progressed from proof-of-concept analyses to scalable European frameworks. Continuous OM monitoring in Dublin has produced a near-complete, high-quality dataset, and a novel PMF–machine learning source attribution method has been developed and applied. The BC FLEXPART–FLEXINVERT system has been successfully tested with multi-site observations, showing improved model–data agreement. Since last year, harmonised datasets have expanded, inversion capabilities have matured, and collaboration with EYE-CLIMA has been continued. These advances provide a solid basis for European-scale BC emission estimates and future integration with inventory assessments.

Visibility and Exploitation

Since the previous reporting period, PARIS has moved decisively from internal development to outward-facing impact. Data products are now publicly available through established European infrastructures such as ICOS, modelling tools such as fluxy are being adopted beyond the project, and results are actively discussed with inventory agencies, the EEA and other policy-oriented stakeholders. Scientific visibility has increased through publications and conferences, while targeted outreach has strengthened policy relevance. Crucially, the project has laid a durable legacy: shared infrastructures, harmonised workflows, trusted relationships with inventory compilers, and validated methodologies that can be sustained through follow-on funding and integration into routine European inventory verification processes.

Overall Progress and Next Steps

PARIS has made strong and tangible progress and is clearly on track, as confirmed and appreciated by the Scientific Advisory Board. The project faced some minor delays due to staff changes and technical issues but without impacting the overall project success.

The SAB highlighted the scale and quality of the scientific advances, the delivery of datasets at a high standard, and major progress in flux inversions using both existing and newly generated data. The harmonization of model outputs and the clarity of harmonized visualizations produced with the fluxy tool were identified as major strengths, as was the project’s ability to deliver detailed, high-quality analyses across a wide range of spatial and temporal scales. Collectively, the second reporting period marks a transition from pilot-scale research to a coherent, inventory-facing verification system, while also laying the groundwork for sustained legacy and post-project exploitation.

1.1 OBJECTIVES

I) QUANTIFY TOP-DOWN EMISSIONS FROM A SELECTION OF EUROPEAN COUNTRIES OF ALL THE MAJOR GHGS REPORTED UNDER THE UNFCCC (CO_2, CH_4, N_2O AND F-GASES), AND BLACK CARBON AEROSOL (BC) REPORTED UNDER CLRTAP.

Work towards Objective I has progressed rapidly over the reporting period. The PARIS project has continued to expand and consolidate the European observational infrastructure for greenhouse gases (CO_2, CH_4, N_2O, F-gases) and black carbon through the addition of new stations, upgrades to existing sites, and targeted field campaigns, including methane isotope measurements. Observational data from up to 43 European sites have been harmonised, quality controlled, and made available through shared platforms, enabling their consistent use across multiple inverse modelling systems. Inversions for GHGs and BC have been completed or are on-going for a range of European domains, supported by parallel developments in transport modelling and data handling.

Building on this foundation, recent work has focused on applying multiple inverse modelling frameworks in parallel and improving their comparability through common data formats and inter-comparison tools. These tools allow consistent evaluation of national-scale emission estimates across gases and models, as well as comparison with reported inventory values. Coordination with related European projects, notably EYE-CLIMA and AVENGERS, has supported alignment of methods and datasets, helping to place PARIS results within a broader European context. Overall, the work towards this objective is ongoing, with core milestones either achieved or progressing as planned.

II) QUANTIFY THE CONTRIBUTION OF MAJOR SOURCE SECTORS OF GHG AND BC EMISSIONS AND ORGANIC MATTER AEROSOL (OM) ABUNDANCE THROUGH THE IMPLEMENTATION OF INNOVATIVE MEASUREMENT AND ANALYSIS TECHNOLOGIES.

Progress towards Objective II has focused on developing and testing approaches for attributing emissions to major source sectors using a combination of observational, modelling, and analytical techniques. During the previous reporting period, preparatory work was undertaken to configure inverse modelling systems capable of distinguishing between broad source categories, such as fossil and non-fossil emissions. In parallel, a protocol for a “blind verification challenge” was developed to assess the ability of inverse systems to detect known perturbations introduced into emission fields under controlled conditions; this exercise is ongoing and continues to inform understanding of system sensitivities.

More recently, these efforts have been complemented by advances in aerosol source attribution, including the development and application of a method combining positive matrix factorisation with machine-learning techniques to analyse organic matter aerosol composition. For CH_4, isotopic and co-emitted tracer observations have begun to be incorporated into inverse modelling frameworks, allowing exploratory assessments of sectoral contributions in selected regions. While many of these approaches are still under development or testing, they collectively represent incremental progress towards more detailed source attribution, with milestones either completed or continuing according to plan.

III) DERIVE TIME- AND SPACE-RESOLVED FLUX ESTIMATES FOR GHGS WITH COMPLEX OR UNCERTAIN SOURCE DISTRIBUTIONS (N_2O, F-GASES)

Work towards Objective III has advanced through sustained expansion of the observational basis for gases with complex or uncertain source distributions, particularly N_2O and F-gases. The European F-gas observation network has been strengthened through the establishment of new continuous or flask measurement sites in Germany, Norway, Hungary and southern Italy, alongside continued operation of existing stations.

Inversions for F-gases covering up to the end of 2024 and earlier years have been completed, with more recent observations being prepared for inclusion in forthcoming inversion cycles. Inter-comparison tools developed within PARIS have supported consistent comparison of flux estimates across transport and inversion systems.

For N_2O, calibration strategies for high-frequency measurements were revised, and historical datasets from 2018 onwards were reprocessed to ensure consistency for inverse modelling. A harmonised European N_2O dataset has been assembled and made accessible via the ICOS Carbon Portal. Inverse modelling for selected domains has identified seasonal and spatial patterns that differ from those implied by bottom-up estimates, highlighting the value of improved observational coverage. Preparatory work has also continued on biogeochemical models (DayCent and LandscapeDNDC) for national-scale applications, including the integration of isotope information, to support complementary process-based flux estimates. Collaboration with AVENGERS and EYE-CLIMA has further supported harmonisation of data and methods. Overall, progress towards this objective is ongoing, with key components in place and further refinements underway.

IV) PRODUCE DRAFT ANNEXES TO THE ANNUAL NATIONAL INVENTORY REPORTS (NIR) FOR A SELECTION OF 'FOCUS' COUNTRIES.

Progress towards Objective IV has been characterised by continued engagement with national inventory compilers and incremental development of the technical framework required for producing draft Annexes to National Inventory Reports (now called National Inventory Documents, NIDs). During the previous reporting period, PARIS established close working relationships with inventory teams in the focus countries, sharing preliminary results and gathering feedback on expectations and formats. Inventory compilers expressed particular interest in seeing results from multiple independent inverse modelling systems, which guided subsequent coordination efforts within the consortium.

In response, significant work has been undertaken to align modelling frameworks, harmonise data flows, and conduct systematic comparison exercises across gases and modelling setups. A dedicated inter-comparison tool was developed and implemented on the ICOS Carbon Portal to support transparent and repeatable analysis. A common template for national annex chapters has been prepared, enabling consistent presentation of results. Draft Annexes, publicly available for the eight focus countries were prepared for the 2025 and 2026 inventory reporting cycles. The work towards this objective remains ongoing, with milestones achieved to date providing a structured basis for continued annual engagement and refinement.

1.2 EXPLANATION OF THE WORK CARRIED OUT PER WP

1.2.1 WORK PACKAGE 1 – PROJECT MANAGEMENT AND COORDINATION

O1.1: Ensure timely implementation of the work plan

O1.2: Facilitate communication between partners and organise project meetings

O1.3: Coordinate reporting to, and communication with, the European Commission

O1.4: Coordinate financial, managerial, and contractual issues across the consortium

O1.5: Establish a data management plan, and facilitate data QA/QC, data sharing and archival

O1.6: Enable effective communication of project outcomes with the public and stakeholders

1.2.1.1 WP1 – EXECUTIVE SUMMARY

PARIS is coordinated by Utrecht University (UU) and co-coordinated by the University of Bristol (UNIVBRIS). The transfer of the formal coordinator role from UNIVBRIS to UU was required because UK partners were ineligible to coordinate Horizon Europe projects at project start. To ensure continuity, UNIVBRIS remained actively involved as co-coordinator, with UU and UNIVBRIS jointly managing the project. Scientific and administrative coordination is led by two dedicated project managers based at UU and UNIVBRIS.

During the second reporting period, the management structures defined in the Grant Agreement remained unchanged, having proven effective. These structures provided a stable organisational framework for the consortium. The second Annual Meeting was held in Teddington, UK, in May 2025, and the third Annual meeting online in January 2026. Both focussed on scientific progress. Work Package (WP) leads met regularly, either on a scheduled or ad-hoc basis, and reported to the management team three to four times per year. These meetings enabled early identification of deviations from the work plan or delays and facilitated timely corrective actions.

Some minor delays in deliverables and milestones occurred, mainly due to instrument deployment delays or technical malfunctions. In some cases, reporting lagged behind the completion of the work, as deliverable | milestone due dates indicate the completion of activities rather than submission of reports. Overall, the project continues to run smoothly, without major issues, supported by the high level of professionalism and engagement across the consortium.

PARIS has continued its proactive collaboration with the two related Horizon Europe projects funded under the same call, EYE-CLIMA and AVENGERS. Although this collaboration requires additional coordination effort, it has proven valuable due to strong scientific overlap, shared objectives, and increased visibility. Joint activities have enhanced impact and supported more effective dissemination and uptake of results.

1.2.1.2 – WP1 - PROGRESS SUMMARY PER WP PARTNER – LEAD: UU

Utrecht University (UU)

UU is responsible for overall project management and serves as the main contact point for CINEA. At project start, UU and UNIVBRIS agreed on a clear distribution of management tasks, jointly forming the management team. During the second reporting period, UU co-organised the Annual Meetings, maintained the management structure, provided templates and guidance to partners, and facilitated consortium-wide and WP-level meetings together with UNIVBRIS. UU also supported the preparation of stakeholder newsletters and played an active role in initiating and promoting collaboration with EYE-CLIMA and AVENGERS at scientific events.

At the request of CINEA, UU coordinated an amendment to the Grant Agreement, focusing on the redefinition and addition of deliverables and milestones.

University of Bristol (UNIVBRIS)

UNIVBRIS acts as co-coordinator and organised project meetings and networking activities. It leads the Early Career Researcher (ECR) network and coordinates the joint newsletter for PARIS, EYE-CLIMA and AVENGERS. During the second reporting period, UNIVBRIS organised the second Annual Meeting and five online ECR meetings. To date, four joint newsletters have been published (https://horizoneurope-paris.eu/newsletters-and-project-stories/).

Wageningen University (WU)

WU leads data management activities within PARIS. This includes preparation of the initial Data Management Plan (DMP) and its update at the end of the first reporting period. During the second reporting period, WU continued as the main data management contact point for the consortium and served as the primary interface with the ICOS Carbon Portal, which functions as the main data repository and documentation platform.

1.2.1.3 – WP1 – TASK REPORT

TASK 1.1 - COORDINATION, ADMINISTRATION AND MONITORING

Establish collaboration agreements between partners. Ensure clear communication between administrative, contractual and financial teams across the consortium. Oversee project progress and ensure all milestones and deliverables are met.

UU is responsible for overall project coordination, in collaboration with UNIVBRIS. A clear distribution of responsibilities was agreed at project launch and remains unchanged, as the management structure has proven effective. UU serves as the main internal and external contact point. Regular consortium- and WP-level meetings ensure adequate project monitoring and support. No changes to the management structure were required during the second reporting period.

TASK 1.2 PROJECT COMMUNICATION AND MEETINGS

Establish communication and collaboration tools and protocols between project partners. Organise and document quarterly online meetings of work package leads and management team. At the start of the project, arrange a project kick-off meeting (online), inviting key members of other consortia funded under HORIZON-CL5-2022-D1-02-01 and other Horizon Europe GHG projects. Coordinate and document annual meetings with PARIS members and stakeholders. Regularly liaise with other Horizon Europe GHG projects and coordinate inter-project meetings.

The communication infrastructure established at project start has been maintained. Collaboration within the consortium is efficient and low-hierarchical, requiring no additional protocols beyond the Grant and Consortium Agreements. UU and UNIVBRIS jointly organised consortium meetings and regular WP lead meetings. The second Annual Meeting was held in May 2025, the third in January 2026. WP leads report regularly to the management team, enabling timely identification of issues and corrective action.

Project managers from UU and UNIVBRIS meet weekly, while broader WP coordination meetings take place several times per year. Except for annual meetings, all meetings are held online using Microsoft Teams.

PARIS continued close collaboration with EYE-CLIMA and AVENGERS. Joint activities include shared conference presentations and meetings, data and knowledge exchange, and collaborative deliverables aimed at inventory compilers. While this collaboration is more intensive than initially planned and increases coordination workload, it significantly enhances impact and coherence.

TASK 1.3 COMMUNICATION WITH EUROPEAN COMMISSION

Establish regular communication with the EC project officer. Communicate any challenges and potential changes to the workplan. Ensure financial and contractual reporting is delivered on time. Help partners to provide deliverables as scheduled in the work plan.

UU acts as the formal contact point for CINEA. Communication with the Project Officer mainly takes place via the Funding & Tenders Portal and by email, the PO is also invited to the annual consortium meetings. During the second reporting period, two amendments to the Grant Agreement were prepared and approved, reflecting joint deliverables with EYE-CLIMA and requested adjustments to deliverables and milestones.

Financial and contractual reporting is scheduled for months 18, 36 and 48. The management team provides templates and tailored support to partners to ensure timely and high-quality reporting. Most deliverables and milestones have been achieved on time, although reporting submissions occasionally lag behind completed work.

TASK 1.4 DATA SHARING AND MANAGEMENT

> *Develop a data management plan within the first 6 months of the project. Facilitate data archival for project partners through the ICOS Carbon Portal (See Section 1.2.7) and ensure that data is publicly accessible in a timely manner. Provide online shared spaces to enable efficient file sharing between consortium members.*

The data management strategy remained unchanged during the second reporting period, having proven effective. PARIS generates large and diverse datasets across multiple gases and modelling approaches, making structured data management essential. Measurement and modelling data from WPs 2–6 are archived and shared via the ICOS Carbon Portal using FAIR metadata conventions and a CC-BY-4.0 licence. BC and OM data (WP7) are archived via EBAS and linked to the ICOS Portal. Datasets are also referenced on the project website.

The Data Management Plan remains publicly available via CORDIS and the PARIS website.

TASK 1.5 EXTERNAL COMMUNICATION AND FACILITATION OF STAKEHOLDER ENGAGEMENT

> *The project manager will establish and maintain the PARIS website. With input from PARIS partners, they will write a stakeholder engagement newsletter. Updates on the project will be disseminated widely through social media.*

UU continued to maintain the project website (https://horizoneurope-paris.eu), which provides information on objectives, partners, methodologies, public deliverables, publications, and links to data repositories. Collaboration with EYE-CLIMA and AVENGERS resulted in joint newsletters, coordinated by UNIVBRIS with support from UU and in collaboration with CMCC and ICOS, webinars, and dissemination activities.

An Early Career Researcher group with almost 50 subscribed members of all three projects was established to support exchange across projects and career stages. To date, 14 ECR meetings have taken place with participation from all three projects.

Social media activity was limited, with dissemination focusing on joint scientific and policy-relevant events. During the first reporting period, PARIS was already well represented at international science conferences and related (project) meetings (e.g. ITMS, WMO, IG3IS). This has been continued and significantly expanded during the second reporting period. Particularly conferences such as the EGU, NCGG or ICOS were targeted, but also more specific conferences such as the GGMT or the International CO_2 conference. PARIS led joint presentations to European policy stakeholders, including Working Group 1 meetings in Brussels, where Draft Annexes were presented to Member State representatives, DG CLIMA and the EEA. The projects also jointly presented results at the UN Climate Change Conference, COP30, in Belém, Brazil (https://www.cmcc.it/it/lectures_conferences/what-you-cant-measure-you-cant-manage-improving-ghg-estimation-for-informed-climate-policy).

1.2.2 WORK PACKAGE 2 – NATIONAL TOP-DOWN, BOTTOM-UP RECONCILIATION

O2.1: Engage constructively with inventory compilers in the focus countries to ensure that that the project deliverables are of direct relevance to those communities.

O2.2: Develop an annual cycle of interaction and feedback with the inventory compilers in the focus counties and the EEA so that the inventory compilers develop an understanding of how we can help them to improve their national inventories.

O2.3: Produce Annex reports to the National Inventory Reports for the focus countries and present these to the inventory teams

1.2.2.1 WP2 – EXECUTIVE SUMMARY

We have engaged with each of the inventory compilers from the eight focus countries through in-person or remote meetings on multiple occasions. The response from each has been extremely positive and encouraging. We provided a separate, country-specific, National Inventory Document (NID) annexes to each of the eight countries in both Oct 2024 and Oct 2025. The latest annex contained comparisons between the latest nationally reported values and the results from at least three inverse models (MO InTEM, EMPA ELRIS, UB RHIME) and two transport models (NAME and FLEXPART) for a total of six inverse estimates. The October 2025 German annex additionally included results from the DWD ITMS-D modelling system. Each has been shared with the respective inventory representatives from the eight target countries. We held either in-person or virtual meetings with each of national inventory representatives in turn, each included the national contact from within the PARIS consortium and an experienced PARIS inverse modelling expert. The feedback that we received from the first annex results in October 2024 and during the PARIS annual meeting in May 2025 have been used to guide improvements to the second annex results in October 2025. For example, for the Dutch we also provided draft annexes for Belgium and the collective BENELUX (combining Netherland, Belgium and Luxembourg) to aid their interpretation. All inverse model results from the October 2025 update were uploaded to the ICOS Carbon Portal and are publicly available from https://doi.org/10.18160/GR1Q-6SK4. A new section on the progress with CO_2 inverse modelling was included in the October 2025 draft annexes.

Considerable effort has been undertaken to align the modelling frameworks and data flows between inverse modelling groups and between the measurement groups. Comprehensive model documentation has also been compiled and made available (PARIS Deliverable D2.3). We have developed comprehensive input and output data format that allows for rapid inter-comparison of each of the modelling setups. We are in the final stages of drafting scientific papers describing both the inter-comparisons and the PARIS results. One of the most notable outputs from the PARIS consortium is the comprehensive inter-comparison tool, fluxy (available on GitHub (https://github.com/openghg/fluxy) and also on the community Jupyter notebook hosted on the ICOS Portal) that allows rapid and extensive analysis of the results from the different inverse systems, including those from outside of the PARIS consortium. An example of the results and outputs are shown in Section 3.

1.2.2.2 – WP2 - PROGRESS SUMMARY PER WP PARTNER

Met Office (MO)

MO is the lead of WP2 and the national lead for the United Kingdom, engaging directly with the inventory compilers. The Met Office have completed two annual updates (October 2024 and October 2025) of their inverse modelling for each of the required gases (CH_4, N_2O, 11 HFCs, 4 PFCs, SF_6 and NF_3) for each period starting in 2008 until the end of the previous year (2023 and 2024 respectively) using two transport models NAME and FLEXPART (starting 2017). The MO have applied their inverse modelling system InTEM using the observations from the established long running AGAGE sites (MHD, TAC, JFJ, CMN, TOB) and from the UK

DECC, Swiss and extensive ICOS networks of CH_4, N_2O and SF_6 observations. The MO have worked alongside others to define a common reporting format for the inverse modelling results, both time-series and flux distributions. Using these templates, the MO have adapted InTEM to output all of the necessary quantities to satisfy the output requirements and co-developed a common Jupyter Notebook for the sharing and comparing of inverse modelling results from each of the modelling groups. Weekly meetings have been held since January 2024 involving each modelling group and extensive comparisons have been undertaken. The common reporting format and the comparison software are significant achievements and enable rapid assessments and consolidation of the inverse modelling results. The MO have also led the inventory interactions with UK, Ireland, Netherlands, Norway and Italy.

Wageningen University (WU)

The WU is the national lead for the Netherlands within PARIS and engaging directly with the inventory compilers. In this reporting period, the contacts with the Dutch Emission Registration have intensified and now also include the RIVM. We interact in various teams to discuss PARIS progress on inverse modelling for CH_4, N_2O, and F-gases. Highly valuable feedback has come from these discussions on the presentation and inclusion of results in the Annexes to the Inventory Documents, contributing a lot to their value and appreciation by the other stakeholders. RIVM has furthermore taken part in multiple discussions with the German and Swiss inverse modelling and inventory teams, which helped PARIS researchers to work towards more useful reports and communication. Contacts with the Dutch partners in PARIS also has laid the foundation for a new national infrastructure proposal in which ICOS/ACTRIS measurements and their inverse model interpretation will become part of the annual cycle to produce the Dutch NID, with open-science access for all stakeholders. This will make use of knowledge and modelling capacity (fluxy) that comes directly from PARIS. There were no deviations from the Annex to report, and no risks or problems have been identified thus far.

Deutscher Wetterdienst (DWD)

The DWD is the PARIS national lead for Germany and engaging directly with the inventory compilers. Further developing the existing relationship with UBA, the German government inventory compiling agency, DWD also engaged with the Thünen Institut, which is responsible for emissions in the agricultural sector. The results of the PARIS project have been presented, compared and discussed with those of the German ITMS project at the combined annual 'Top-down emission estimates' user meetings in September 2024 and September 2025 at Dessau. PARIS representatives participated in the national ITMS project's General Assembly (September 2024 at Karlsruhe and 2025 at Heidelberg) to foster scientific exchange and collaboration.

Norsk Institutt Forluftforskning (NILU)

NILU is the national lead for Norway within PARIS, engaging directly with the inventory compilers. NILU and the UK Met Office had a meeting with the National Inventory group at Statistics Norway in November 2024. Limited data from Birkenes were available at the time, but examples from the Inventory Annex for UK were presented and the representative of the National Inventory group expressed her great interest in the "top-down" results from the F-gas measurements for Norway and rest of the countries in this project. Unfortunately, for the Inventory Annex 2025 – Norway, the 2024 and 2025 data from Birkenes were not available in time due to technical issues in the data transfer from NILU to the PARIS data server.

University of Urbino (UNIURB)

UNIURB is the national lead for Italy within PARIS, engaging directly with the inventory compilers. UNIURB has continued a dialogue with ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale), i.e. the Italian National Environment Protect Agency, including other WP2 partners, to exchange information on updates on emission inventories to improve the knowledge of the spatial distribution of potential emitters in Italy. ISPRA expressed particular interest in the "top-down" inversion results from the F-gas measurements in PARIS as illustrated during an onsite meeting at ISPRA HQ in October 2024 and were keen to discuss the possibility to include the derived results in a future NID; moreover ISPRA were presented the comparison of the results for HFC-134a during the project meeting in February 2025 in Bristol. Further meetings between PARIS WP2 representatives, national leads and ISPRA are being planned. UNIURB represented PARIS at the COP30 in Belem, Brazil.

National University of Ireland Galway (NUIG)

NUIG is the national lead for Ireland, engaging directly with the inventory compilers. NUIG have maintained a dialogue with the Irish National Inventory Reporting team, a subdivision of the Irish Environmental Protection Agency. They are keen to collaborate, exchange information and meet on a regular basis. The UK Met Office, along with NUIG, presented PARIS inverse model results to the Irish National Inventory Reporting team in June 2025 and November 2025. They expressed particular interest in the "top-down" inversion results from the F-gas measurements in PARIS and were keen to see the inclusion of new Irish ICOS methane and nitrous oxide measurements. The PARIS annex chapter for Ireland will be included in the Irish NID 2026.

Atommagkutato Intezet (ATOMKI)

ATOMKI is the national lead for Hungary, engaging directly with the inventory compilers. ATOMKI is in contact with the National Emission Inventory Group of HungaroMet Hungarian Meteorological Service, which is responsible for the reporting of the national emission data to the international bodies (UNFCCC, EMEP, etc.). The group has expressed its interest in the PARIS activity. The first inversion results and emission estimations for Hungary were discussed in a virtual meeting on 2 December 2025.

Swiss Federal Laboratories for Materials Science and Technology (EMPA)

Empa is the national lead for Switzerland, engaging directly with the inventory compilers. Further developing the existing relationship with BAFU, the Swiss government inventory compiling agency, Empa also engaged with the company Carbotech, which is responsible for emissions of synthetic gases in the Swiss national reporting. Furthermore, Empa presented PARIS results to the German UBA, during the joined ITMS-UBA-PARIS meetings in September 2024 and September 2025 at Dessau, and online to the head of the Hungarian inventory team in December 2024 and December 2025. Empa also presented PARIS results at the EGU GA (2024 and 2025, Viennna) and at the WMO IG3IS National-scale Applications Workshop (June 2025, Geneva). Empa hosted a fluxy coding workshop (January 2025) and, together with UNIVBRIS and MO, coordinated the development of the tool. Furthermore, Empa reached out to other European inverse modellers, advertising the use of fluxy. This activity has resulted in MPI Jena joining the fluxy development from outside the PARIS project. Empa was responsible for collecting and harmonising the output from the three inversion systems (RHIME, InTEM, ELRIS) generated in WP3, WP4, and WP5 and engaged with the ICOS Carbon Portal for data upload and publication.

1.2.2.3 – WP2 – TASK REPORT

TASK 2.1 – INITIAL ENGAGENMENT WITH NATIONAL INVENTORY COMPILERS

> *At the outset of the project, we will meet with our national inventory contacts (based on our existing relationships with these teams) from each focus country and the EEA to establish the framework of engagement in PARIS.*

This task was completed in the previous reporting period.

TASK 2.2 – CREATE A TEMPLATE FOR AN ANNEX TO THE NATIONAL INVENTORY REPORT

> *This template will follow a format that allows direct comparison to different aspects of the reported inventories, including down to sector-level where feasible. This template will be provided to all national leads and will be used to efficiently compile top-down emissions estimates for each focus country annually.*

This task was completed in the previous reporting period.

TASK 2.3 – SYNTHESISE RESULTS FROM WP 2-6

Synthesise the results from WP 2-6 into information that is directly comparable and meaningful to inventory compilers and produce country-specific GHG and BC/OM verification reports. The template created in Task 1.2 will be used to pull together the various outputs from WP 3-7.

For each of the target countries, in both October 2024 and October 2025, draft country-specific annex chapters were completed. In addition, a detailed technical description of the utilised modelling frameworks was provided to national inventory teams of each PARIS target country.

The annexes generated in October 2025 included inverse modelling results from four groups MO, UNIVBRIS, EMPA and DWD using their respective inverse modelling systems; InTEM, RHIME, ELRIS and ITMS-D, respectively. InTEM, RHIME and ELRIS used transport model data from two independent atmospheric transport models, NAME and FLEXPART. ITMS-D uses its own independent source of atmospheric transport data (ICON weather and climate model). We reported national emission estimates of CH_4, N_2O, SF_6, NF_3, eleven HFCs (HFC-134a, HFC-125, HFC-32, HFC-143a, HFC-23, HFC-227ea, HFC-245fa, HFC-236fa, HFC-152a, HFC-365mfc, HFC-4310mee) and four PFCs (PFC-14, PFC-116, PFC-218, PFC-318). We included the F-gas observations from the four additional PARIS sites (CBW, HUN, BIR, CGR) and the PARIS N_2O observations from HUN. For each gas and for each country we presented the comparison between the latest nationally reported inventory emission estimates (April 2025) with those that we estimated from the atmospheric observations. The community comparison tool, fluxy (https://github.com/openghg/fluxy), created within the PARIS project, was used extensively to both compare and scrutinise inverse model and inventory estimates but also to generate the necessary output for direct inclusion in each national draft annex. The common format for input and output from the inverse systems, also developed within PARIS, was an essential component for the inter-comparison and annex generation. It has also enabled PARIS to initiate inter-comparisons with our two sister projects EYE-CLIMA and AVENGERS. For some of the countries, e.g. Norway, the low density of the observation network means that meaningful comparisons can only be conducted for a limited number of gases. For a full description of the results please refer to PARIS Deliverable D2.3. The respective inverse modelling results are available from the ICOS Carbon Portal (10.18160/GR1Q-6SK4).

TASK 2.4 – ANNUAL ENGAGEMENT WITH INVENTORY TEAMS

Present the Annexes with the country-specific results to the focus country inventory compilers and the EEA, gain their insights and perspectives and feedback these back to the consortium to maximise the impact of the subsequent reports. This will be an iterative process repeated in December of year 2, year 3 and year 4 of the project. National representatives from within the project from the individual focus countries will lead the project delegation to their national inventory compilers thereby strengthening within-country links. Support will be provided by additional representatives from at least one other country so that best practice can spread across the consortium.

Table 1: Meetings between the National Inventory compilers and PARIS national leads

Country	Meetings Held
Ireland	June 2025, November 2025
UK	December 2024, May 2025, November 2025
Switzerland	May 2024, May 2025, November 2025
Netherlands	October 2024, July 2025, November 2025
Germany	September 2024, September 2025
Italy	October 2024, planning for meeting in early 2026
Hungary	November 2024, December 2025
Norway	November 2024

This task is ongoing and progressing well. Multiple meetings have been held with the different national inventory compilers, WP2 contributors and PARIS national leads as shown in Table 1.

Many of the national inventory leads and the EEA also joined our PARIS annual meeting in May 2025, and they presented some of their key messages and feedback to the whole consortium.

The PARIS work was also presented to the EEA working group 1 in October 2025 and at the WMO IG3IS National-scale Applications Workshop in June 2025 to showcase the work to the broader European inventory community.

In the final stage of the PARIS project, in Autumn 2026, we will reach out to all of the national inventory compilers from the eight target countries and present the PARIS comparisons and 2027 draft annexes to them. These meetings will also look to the future and assess the opportunities for ongoing collaborations.

1.2.3 WORK PACKAGE 3 – EUROPEAN F-GAS EMISSIONS EVALUATION

O3.1: Establish F-gas flask measurements in currently unsampled areas of Europe and integrate new sites into the existing European network.

O3.2: Derive emissions from atmospheric observations (top-down) using different inversion systems and improve source attribution using improved a priori estimates.

O3.3: Reconcile national emission estimates for north-west through south-east Europe inferred from atmospheric data with national inventory reports.

1.2.3.1 WP3 – EXECUTIVE SUMMARY

To achieve these goals, we defined 6 tasks which are centred around improving the F-gas observational capacity, improving emission estimates derived from these observations, comparing these estimates with national emission estimates and communicating the results with the relevant teams for the national inventory reports. This latter task was carried out in close collaboration with WP2. To improve the observational data base, an additional continuous station at Capo Granitola in Sicily was established, as well as two stations (Taunus Observatory in central Germany and Monte Cimone in Northern Italy) were upgraded to full AGAGE stations. In addition, flask collection with subsequent laboratory analysis was established at two new sites (Hégyhátsal in Hungary and Birkenes in Norway) and sampling at the site of Cabauw in the Netherlands was continued. All additional observations have been established in 2024 and have continued through 2025.

The 2024 data have been quality controlled and released (https://meta.icos-cp.eu/objects/ul-KaooRRgyJcWY_EM56UwI8) including both additional continuous stations and flask measurements. They have been incorporated in the first full PARIS inversions, and the results have been submitted for publication (De Longueville et al., 2026, under review). A further highlight from the work carried out in WP3 was the identification of a so far not accounted for point source of SF_6 from a production facility in Germany (Meixner et al., 2025). Interaction with national inventory reporting teams has been intense and is reported in WP2.

Overall, the new measurements have been successfully implemented as planned, the emissions have been derived for all the WP3 target compounds, and the top-down derived emissions have been compared with the national reporting. All tasks have been accomplished or are still running as planned.

1.2.3.2 – WP3 - PROGRESS SUMMARY PER WP PARTNER

In the following we present the work by the partners involved in WP3. All work has been completed according to plan with only very minor deviations.

Goethe University Frankfurt (GUF)

GUF coordinates WP3 and organises regular data quality control meetings. In the second reporting period, GUF continued to operate the MEDUSA system for continuous measurements of F-gases and related species at TOB. Measurements of all F-gases targeted within PARIS have been performed on a two hourly basis and included in European and international (AGAGE) data reviews since February 2023. The data are continuously quality controlled within the AGAGE network. GUF participates in the regular network meetings to ensure the ongoing high data quality.

GUF has further developed and improved a software for regular, unattended sampling of air canisters during the first reporting period and since then samples are regularly collected every second day and analysed in the GUF laboratory. Results are available for all target gases except for CF_4, NF_3, PFC-116 and the minor HFC HFC4310-mee which cannot be measured on the analytical system in use. HFC 365mfc which could not be measured during the first year of sampling has now been added to the list of target species and is regularly reported, although the measurements are close to the detection limit of the instrument. A recent upgrade of the instrument is hoped to lead to improved data quality. The measurements at HUN station are ongoing and will be continued at least until the middle of 2026, which is beyond the proposed two years.

A particular focus of GUF was on the investigation of the SF_6 emissions in Germany, where a so far unaccounted large point source was identified from a production facility. This source accounts for about one third of the German SF_6 emissions. Data from the continuous measurements at TOB are available via the AGAGE web site and also up to the end of 2024 via the ICOS carbon portal: https://meta.icos-cp.eu/objects/ul-KaooRRgyJcWY_EM56UwI8; DOI : 10.18160/JK51-GFYB. This 2024 data submission includes the first year of flask sampling at HUN.

Deutscher Wetterdienst (DWD)

DWD performed a forward simulation of SF_6 with the (Eulerian) ICON-ART-DWD system for the period 2020-2023 using the prior of area and point sources developed within WP3 (ORB, UNIBRIS), thereby paving the way for a SF_6 flux estimate. The analysis of the major point source in the southwest of Germany indicated towards an enhancement compared to the prior resulting in an observation-based estimate of double-digit tons of SF_6 emissions. This supports the results of the other PARIS partners.

Further, in this reporting period technical effort was directed to extend the ICON-ART based THG modelling and inversion system of DWD to ingest point sources and area sources and prepare modelling of HFC-23, HCFC-22, PFC-318 and HCFC-21. The prior emissions were constructed on the desired ICON grid 1007 employing population density data. The test model calculation spans 47 cycles (01.08.2024 - 16.09.2024). Model output is written at the location of observation and its surrounding grid cells, spanning 848 ICON cells in the output Meteograms. The investigation of the fitness of the model and possible improvements for the purpose of emission verification is on-going. Due to the time-varying three-dimensional nature of the concentration distribution, the storage requirements for the model fields can grow prohibitively. Therefore, at DWD, there are now resolution experiments running. As the required spatial resolution depends on the relative spatial distribution of emissions and observations, this question must be addressed for each gas of interest separately. Rather high-resolution runs (6 km grid resolution) proved to require meteorological ensembles to account for transport uncertainty, with the number of ensembles restricted by storage space. Efforts are ongoing to determine the optimal resolution for the application concerning HFC-23, HCFC-22, PFC-318 and HCFC-21.

Norsk Institutt Forluftforskning (NILU)

Within the PARIS project NILU has established flask sampling at the Birkenes station, which continued in the second reporting period. The Medusa-GCMS system at Kjeller has been modified to analyse NF_3 together with all other F-gases reported within PARIS from the Birkenes station. Sampling started in March 2024 every other day, except for two periods between June and August 2025 related to instrumental issues. Discrepancies of CF_4 data from Birkenes compared with the baseline at other European stations are under attention. Birkenes data has been included in regular European data reviews and flask sampling at Birkenes is planned to continue to the end of 2026.

University of Urbino (UNIURB)

During the second reporting period the Medusa GC-MS instrument at Monte Cimone (CMN) was running and providing hourly measurements of all the F-gases targeted in PARIS and included in European and international (AGAGE) data reviews.

Several measurement gaps occurred due to technical problems. New system configurations, replacement of instrument components and the improvement of instrument working conditions helped to restart measurements. The new continuous monitoring station of Capo Granitola (CGR) run smoothly during the second reporting period with four main data gaps due to some instrumental failures that required site visits to fix the hardware problems. Extra attention is needed for the climatological circumstances at the site, particularly high summer temperatures which can affect the continuity of the measurements.

Atommagkutato Intezet (ATOMKI)

ATOMKI was involved in regular F-gas sampling on the site of HUN ICOS tall tower background station (Hegyhásál, Hungary). In every 4th week, ATOMKI replaced/connected a new flask sampling unit (including 14 flasks) to the 115m high sampling tube. ATOMKI continuously supervised the onsite operation of the F-gas sampling unit at HUN station and kept the sampling lines of the high tower of HUN ICOS station, also in suitable condition of F-gas sampling, running. ATOMKI organised the logistics of sampling between GUF the HUN station, which is in 500 km distance ATOMKI. ATOMKI has also participated in the regular F-gas data review meetings and discussions.

Oekorecherche Büro für Umweltforschung und Beratung (ORB)

Ökorecherche (ORB) has provided estimates of prior emissions of HFCs, PFCs, and SF_6 in Europe for point sources and population-based regional emissions. Point source emissions were calculated based on UNFCCC inventories (https://unfccc.int/ghg-inventories-annex-i-parties/2024), emission data from the E-PRTR (https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/21e758c6-a9ac-4a7d-a64a-19d2ba9eecb7), reporting under the EU F-gas Regulation (https://www.eionet.europa.eu/etcs/etc-cm/products/etc-cm-report-2025-05), and confidential information on production and destruction of different gases. The E-PRTR provides the best basis for point sources because it contains publicly available information on facilities with their precise coordinates. For HFCs and PFCs, data reported under the E-PRTR was used to derive annual point source emission estimates for the years 2007 to 2023. Since the E-PRTR makes no further differentiation between gas species, data from the UNFCCC and EU F gas reporting, together with an expert assessment by ORB was used to determine specific gases.

Swiss Federal Laboratories for Materials Science and Technology (EMPA)

EMPA provided atmospheric transport simulations employing the transport model FLEXPART for all sites observing F-gases and the period 2016 to 2024. Calculations for 2025 are nearly completed. EMPA completed European F-gases inversion for the period 2016 (2013) to 2024 based their ELRIS inversion system and on two sets of transport simulations (FLEXPART run by EMPA and NAME run by MO). A total of 11 HFCs, 4 PFCs, SF_6, and NF_3 was covered by these inversions. Output was prepared in common data formats and shared with MO, UNIVBRIS and finally compiled for inclusion in the draft annex reports. EMPA has coordinated the development of a common model documentation manuscript which was shared with the inventory compilers as a supplement to the annex reports. EMPA shared in the development and coordination of the fluxy inversion intercomparison tool. EMPA contributed to two manuscripts on HFC/PFC inversions and European emission trends (one submitted to EGUsphere, the other to be submitted in May 2026).

Met Office (MO)

Individual F-gas emission estimates (18 in total) for the eight PARIS target countries and northwest Europe were derived by the MO inversion system (InTEM) for 2008-2024, using atmospheric transport from both NAME and FLEXPART and the expanded network of observation sites as described in this report. These results were provided in the common output format as devised by PARIS that is readily ingested by the PARIS intercomparison tool fluxy. Using fluxy, a detailed model intercomparison process was carried out with model output from MO, UNIVBRIS and EMPA. As a result of this intercomparison, various aspects of the modelling processes were better understood, for instance the importance of the choice of the time-varying model uncertainty. The impact of using different transport models was also important in better quantifying the uncertainty of the emission estimates.

University of Bristol (UNIVBRIS)

UNIVBRIS has provided both observational and modelling results for PARIS. On the observational side, the UNIVBRIS has provided quality-controlled daily flask measurements of the major F-gases from the Cabauw station in the Netherlands. From the modelling side, the UNIVBRIS inversion framework RHIME has provided results for all of the F-gases (11 HFCs, 4 PFCs, NF3, SF6) for NW Europe and the eight focus countries using both the NAME and FLEXPART transport models (referred to as RHIME-NAME and RHIME-FLEXPART outputs). The UNIVBRIS also led a submitted publication on HFC emissions and trends from NW Europe, which is currently in the peer review process. UNIVBRIS has coordinated weekly modelling meetings with the MO and EMPA teams.

1.2.3.3 – WP3 – TASK REPORT

THE SCIENTIFIC WORK IN WP3 HAS PROCEEDED ACCORDING TO PLAN. NO MAJOR DEVIATIONS FROM THE WORK PLAN OCCURRED AND ALL MILESTONES AND DELIVERABLES HAVE BEEN MET.

TASK 3.1 – ESTABLISH SAMPLING STRATEGY

> *NAME and FLEXPART simulations for the new sampling locations in Hungary (Hegyhátsál, 115 m AGL), Norway (Birkenes, 75 m AGL) and Italy (southern site, TBD) will be carried out for one year. Three possible locations for the southern Italian site have been identified as Lecce (ECO), Lamezia Terme (LMT) or Capo Granitola (CGR). Observing System Simulation Experiments (OSSEs) using the modelled mole fractions will be performed to design optimal sampling frequency and site operators will be informed of target sampling frequency (approximately 4 times per week averaged over each year). The OSSE will also be used to select one of the three southern Italian sites based on its high sensitivity to regional emissions and low influence from local emissions, while balancing the logistical constraints of transporting samples.*

This task was completed in the previous reporting period.

TASK 3.2 – F-GAS FLASK SAMPLING

> *Flask sampling will be deployed to the three new F-gas measurement sites (Hegyhátsál, Birkenes, southern Italy) and continued at one site (Cabauw, Netherlands). Sampling at all sites will be conducted in accordance with the best possible strategy identified in Task 3.1. Samples from Hungary (Hegyhátsál) will be analysed at GUF, those from Birkenes (Norway) at NILU, those from the Cabauw (Netherlands) at UNIVBRIS and those from the southern Italian site by UNIURB. All analysing laboratories are associated to the AGAGE network and measure against consistent calibration scales. Sampling will be carried out for at least two years at each site (2024 and 2025). Data will be compared against established high-frequency measurement sites to ensure inter-comparability. All measurements will be included in an online inter-comparison tool (GCWerks) for quality control and identification of analytical issues.*

Flask sampling at Cabauw by UNIVBRIS has been continued and will continue during the whole project period. Sampling equipment at Hegyhátsál has been installed by GUF in January 2024 and sampling has continued since then. Sampling at Birkenes has started in March 2024 and is still ongoing. The short delay of three months with respect to the planned start in January 2024 was due to availability of sampling equipment in particular suitable flaks and valves which were late in delivery.

At Capo Granitola a continuous measurement instrument was implemented, delivering high resolution results due to the continuous operation of 12 samples per day. The continues measurements have started in April 2024 and are ongoing. The delay with respect to the planned start (January 2024) was caused by administrative issues and unavailability of equipment. All measurements are being processed via the AGAGE data processing tools and undergo a similar data check and quality control. A special version of GCCompare has been set up and a second intercomparison workshop for the data has been held on June 4, 2025. The data from the flask sampling have been incorporated into the data upload to the ICOS carbon for the year 2024. The data are available under the following link https://meta.icos-cp.eu/objects/uI-KaooRR-gyJcWY_EM56UwI8 with new DOI: 10.18160/JK51-GFYB.

TASK 3.3 – CONTINIOUS F-GAS MEASUREMENTS

Continuous measurements from Taunus will be implemented as part of PARIS by employing a GC-MS Medusa system following AGAGE protocols and sampling at 10 m AGL. Data from four existing continuous measurement stations will also be included in this project: Monte Cimone, Italy (UNIURB), Zeppelin, Norway (NILU), Mace Head, Ireland and Tacolneston, UK (both UNIVBRIS). In addition, data from other AGAGE stations will be available for the project. All measurements will be included in an on-line inter-comparison tool (GCWerks) and consistency with the flask data will be ensured.

The two stations of Taunus and Monte Cimone have been equipped with new MEDUSA GC/MS systems at the starting of the project. The Medusa is the standard instrument type used by the AGAGE network. Measurements at both sites have been running for most of 2023, 2024 and 2025 and the data processing is following the AGAGE standard procedures. Data gaps in both stations have been caused by issues with the heat balance (overheating of laboratory and cooling systems) in the laboratory and the pre-concentration traps used on the instrument (deterioration of temperature control due to detaching thermocouples). The new stations achieve the same precision as other AGAGE sites and are now fully integrated in the quality control of AGAGE. Data from both sites as well as the added continuous site at Capo Granitola are available under https://meta.icos-cp.eu/objects/uI-KaooRRgyJcWY_EM56UwI8 with new DOI: 10.18160/JK51-GFYB.

Fig. 1 shows a comparison of the flask and continuous measurements of HFC 134a at the new and established sites from the PARIS network.

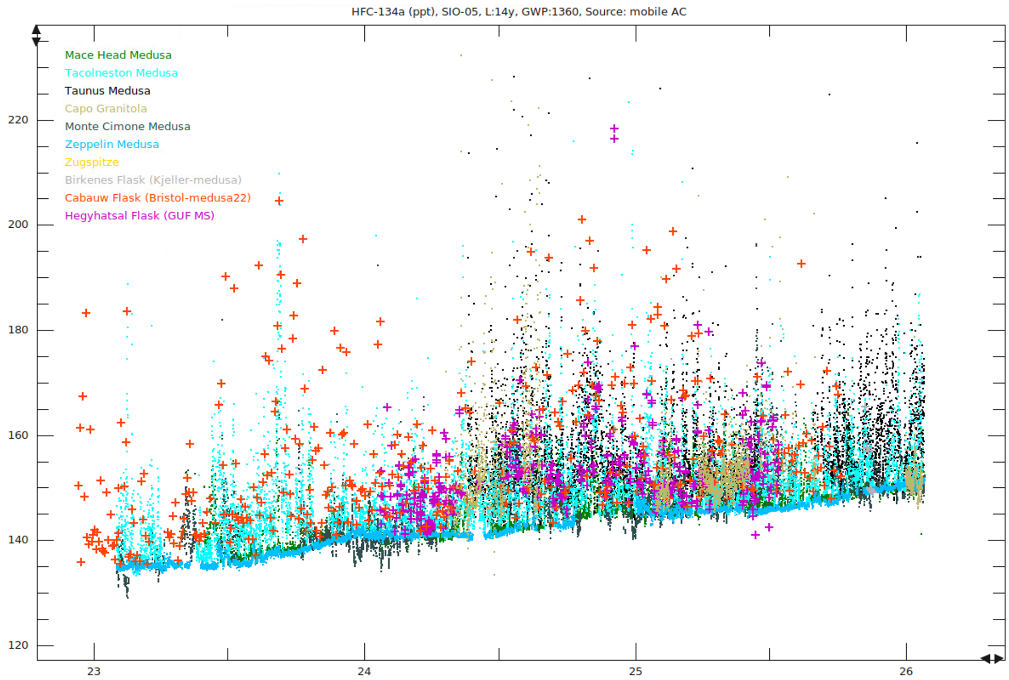

Fig. 1: HFC 134a measurements in ppt from the new and the established sites of the PARIS network. Note that data are preliminary, as the data review for the 2025 data has not taken place yet and not all samples have been analysed. The data review is currently planned for February/March 2026. Preliminary data; do not distribute.

TASK 3.4 – IMPROVED BOTTOM-UP A PRIORI EMISSIONS

Bottom-up emission estimates will be compiled by Oekorecherche (ORB), a specialised small German company. Due to the in-depth knowledge of the location of European F-gas production facilities, ORB will provide estimates of "hot-spots" of F-gas emissions through Europe with a focus particularly on the focus countries of Hungary, U.K., Germany, Italy, Norway, Switzerland, Ireland and the Netherlands, where improved observational data will be available. ORB will also assist other partners (see Task 3.5. and 3.6) in reconciling bottom-up and top-down emission estimates and identifying possible reasons for observed discrepancies (e.g. emission factors in bottom-up estimates).

For SF_6, point source emissions and population-based regional emissions were estimated for the years 2007 to 2022. As for the HFCs and PFCs, E-PRTR data was used as the basis for point source emissions, but no further differentiation by species was necessary since SF_6 is being reported as a single gas. Expert information was used to estimate SF_6 emissions from production, destruction, and semiconductor manufacturing. For production, there was sufficient evidence from the atmospheric measurements and first inverse modelling that the reported emissions by the major European SF_6 manufacturer in Germany are very likely underestimated. This was considered in the estimation of emissions by calculating different emission scenarios that took into account production volumes based on the EU F-gas reporting and different emission factors. Information from National Inventory Documents (NIDs) submitted to the UNFCCC were used as a source. Based on this information, the German SF_6 producer reduced their emission factor significantly in 2014, leading to a reduction in reported annual emissions from 4.4 metric tonnes to 55 kg. Assuming this reduction did not take place as reported by the company, emissions were calculated in an alternative emission scenario. Emissions from destruction facilities and semiconductor manufacturing plants were based on E-PRTR and UNFCCC reporting as well as expert information. Quantities were either taken from the reporting or estimated based on confidential information. Population-based regional emissions of SF_6 from switchgear equipment and disposal of soundproof windows were calculated from the emissions reported under the UNFCCC, together with population data from Eurostat.

Based on this information, MO (Met Office) created netCDF input files to be used as priors in future modelling of SF_6 emissions. For HFCs and PFCs, further work on potin sources and regional emission estimated is ongoing in order to derived netCDF files as input for future modelling.

TASK 3.5 – F-GAS FLUX ESTIMATION

> *F-gas flux estimates will be derived using the established NAME-UB, FLEXPART-UB, NAME-MO, FLEXPART-MO, NAME-EMPA and FLEXPART-EMPA approaches in addition to the new ICON-ART-DWD system to enhance German capability. The new observations (Task 3.2. and 3.3) will be assimilated in addition to existing measurements and national flux estimates will be derived at seasonal to annual resolution. Special focus will be given to improve a priori emission estimates (Task 3.4) and their impact on a posteriori emissions will be assessed. In September of each year, emissions from at least 5 multi-inversions (e.g., NAME-MO, FLEXPART-MO, DWD, etc) based on the observational data of the previous year will be derived. In October of each year, at least 2 (e.g., NAME-MO and FLEXPART-EMPA) model system will provide inversion estimates using the provisional data for first half of the current year.*

Through intensive collaboration between three modelling groups (UNIVBRIS, MO, and EMPA), a harmonised inversion framework was implemented, combining two atmospheric transport models (NAME and FLEXPART) with three inverse modelling systems (RHIME, InTEM, and ELRIS).

The framework utilised observations from European measurement stations (incorporating the new stations from tasks 3.2 and 3.3), covering 2013–2024 and 2017-2024 for NAME- and FLEXPART-based inversions respectively. Annual emissions were inferred at European and national scales for eleven HFCs (HFC-134a, HFC-143a, HFC-125, HFC-32, HFC-23, HFC-227ea, HFC-365mfc, HFC-245fa, HFC-152a, HFC-236fa, and HFC-4310mee), four PFCs (PFC-14, PFC-116, PFC-218, and PFC-318), as well as SF_6 and NF_3. All results were delivered in a standardised format and supported by the development of a dedicated intercomparison tool, enabling consistent cross-model evaluation.

An example result, produced using a centrally hosted Jupyter Notebook at the ICOS Carbon Portal, is shown in Fig. 2. The figure demonstrates good agreement between inversion systems for larger countries and aggregated regions. DWD performed a forward simulation of SF_6 with the (Eulerian) ICON-ART-DWD system for the period 2020—2023 using the prior of area and point sources developed within WP3 (ORB, UNI-BRIS), thereby paving the way for a SF_6 flux estimate. The analysis of the major point source in the southwest of Germany indicated towards an enhancement compared to the prior resulting in an observation-based estimate of double-digit tons of SF_6 emissions. This supports the results of the other PARIS partners.

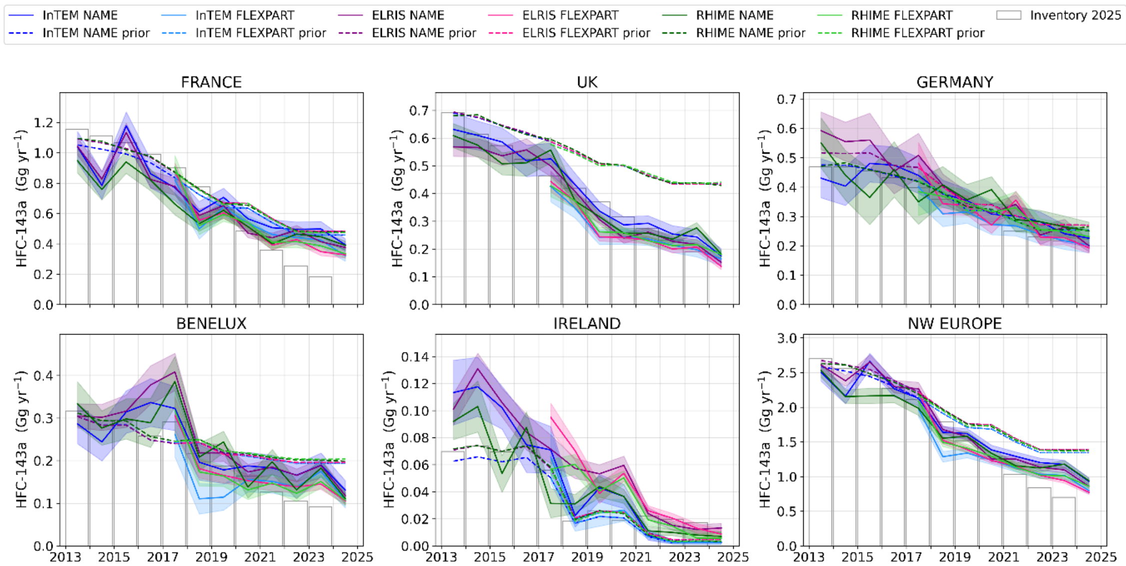

Fig. 2: National/Regional HFC-143a emissions estimated by three inverse modelling systems (InTEM, ELRIS, RHIME) and two different transport models (NAME, FLEXPART). Solid lines and ribbons refer to a-posteriori results and their 68 % confidence interval (CI). A-priori emissions are given as dashed lines, whereas national inventory estimates are given as bars. BENELUX is defined as the sum from Netherlands, Belgium and Luxemburg and NW EUROPE refers to the sum of the other five panels

TASK 3.6 – COMPARISON OF TOP-DOWN WITH UNFCCC REPORTS AND INVENTORY MODELS

Top-down and reported emissions of the F-gases will be compiled for countries constrained by the observational network. In focus countries, these estimates will be compared annually in an Annex to the National Inventory Report. Discrepancies will be discussed considering best available error estimates for both bottom-up and top-down approaches and using knowledge developed in Task 3.4. Stakeholders will be engaged (see also WP 1) by providing them with top-down estimates and identifying possible discrepancies with atmospheric observations.

Annual annexes to the National Inventory Documents (NID) of the eight target countries were produced both in 2024 and 2025 using emission estimates derived from the PARIS inversion framework (Task 3.5). They are publicly available on the project website (https://horizoneurope-paris.eu/deliverables/). The annexes were prepared for all focus countries and provide a systematic comparison between top-down emission estimates and reported UNFCCC inventories. Emission estimates were shared with key stakeholders, including the German Environment Agency (Umweltbundesamt, UBA) and other national inventory reporting teams. Stakeholder engagement activities were coordinated in WP2. All inverse modelling results were made publicly available through the ICOS Carbon Portal (https://doi.org/10.18160/GR1Q-6SK4).

An example comparison figure from the German NID annex is shown in Fig. 3. Derived from the individual results shown in Fig. 2, it demonstrates good agreement between inversion-based emission estimates and UNFCCC-reported emissions.

Contrary to the German GHG inventory, the PARIS inversion results for German SF6 confirmed a dominating point source in south-west Germany, as already documented by Meixner et al. (2025, Fig. 4).

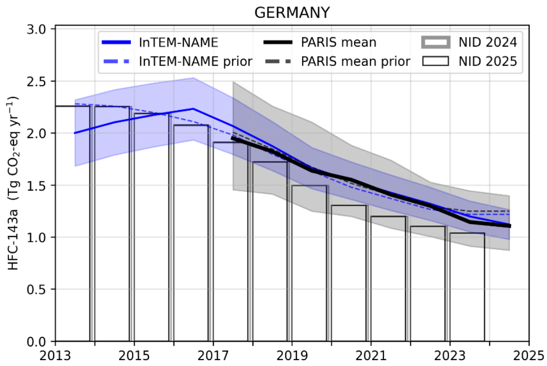

Fig. 3: Verification of the German emissions inventory estimates for HFC-143a. Modelled annual emissions are given as the mean from all models (black line) and the individual result from InTEM-NAME (blue line). The shaded blue area is the 68 % confidence interval (CI) of InTEM-NAME and the shaded grey area encompasses the 68 % CI from all models. National inventory annual totals from the 2024 and 2025 NIDs are given as grey and black bars, respectively.

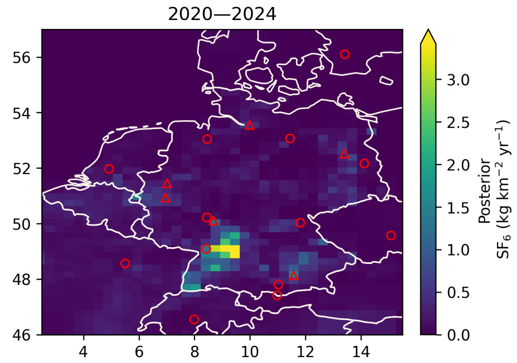

Fig. 4: Spatial distribution of the German average modelled emissions of SF_6 during the period of 2020-2024 (mean from all models). Observing stations are marked with red circles and highly-populated cities are marked with red triangles.

1.2.4 WORK PACKAGE 4 - SECTOR-LEVEL METHANE EMISSION QUANTIFICATION

O4.1: Produce a new set of high-frequency methane isotope observations ($\delta^{13}C$ and δD) from six locations in Europe including three stations with long-term isotope records in the UK, Netherlands, and Switzerland.

O4.2: Improve estimates of methane isotope source signatures across Europe.

O4.3: Derive total methane emissions from atmospheric observations (top-down) using different inversion systems and improve source attribution using isotopic and multi-tracer data.

O4.4: Quantify differences between top-down and inventory emission estimates at the level of individual sectors where possible

1.2.4.1 WP4 – EXECUTIVE SUMMARY

The project is near completion for Objective 4.1 as high frequency measurements have been made, or are currently being made, at Heathfield (UK), Dübendorf (Switzerland), Cluj-Napoca (Romania), Monte Cimone (Italy), Lamezia Terme (Italy), Hegyhátsál (Hungary) and Invergowrie (UK). By the end of the project these measurements will be uploaded to the ICOS Carbon Portal, as has already been done for the Heathfield and Cluj-Napoca data sets. More measurements of source signatures have been made around some of the target sites as part of PARIS and are being used alongside other published sources to provide improved estimates of source signatures for inverse modelling efforts (Objective 4.2). This work is ongoing in the final part of PARIS. Towards Objective 4.3, total methane emissions were derived for 2016-2024 using the UB, MO and EMPA approaches for the eight PARIS focus countries and using additional results from the DWD ICON-D approach for Germany. These results have been submitted to the ICOS Carbon Portal for public access. A NAME-based inversion system has also been developed for estimating regional methane emissions from fossil-fuel (FF) and non- fossil-fuel (non-FF) sources isotope ratio observations. This work is currently being prepared as a journal paper submission. Further progress towards sector-level emissions in the area of Dübendorf employing EMPA's high-resolution FLEXPART-ICON model for Switzerland (1 km x 1 km resolution) and the high-resolution Swiss CH4 inventory. For Objective 4.4 the PARIS top-down estimates of methane emissions were compared to UN-FCCC-reported emissions (for focus countries) during detailed discussions between all model groups and during the meetings held with inventory compilers. Results from these comparisons were presented in draft Annexes for all focus countries. Development of a method for top-down sector level emissions estimation is underway, with the aim to include some sector-level analysis in next year's draft Annex production cycle.

1.2.4.2 – WP4 - PROGRESS SUMMARY PER WP PARTNER

Utrecht University (UU)

Utrecht University operates a CH_4-IRMS system that autonomously pre-concentrates atmospheric CH_4 and measures its isotopic composition (δ^2H and $\delta^{13}C$) with high precision (0.2‰ for $\delta^{13}C$ and 1‰ for δ^2H). In this reporting period the CH_4-IRMS system was deployed for nine months at the ICOS station Monte Cimone (Italy), for one month at the ICOS station Lamezia Terme (Italy), and has been operating at the Hegyhátsál ICOS Class 2 tall tower atmospheric monitoring station since November 2025, where it will remain in operation at least until May 2026. 45 flask samples were collected manually at Mace Head, and 200 flask samples were sampled using the ICOS flask sampler at Monte Cimone. All flasks were analysed at the Utrecht University laboratory for CH_4 mole fraction and isotopic composition.

Deutscher Wetterdienst (DWD)

Total CH_4 emissions estimates for Germany have been derived by the ICON-ART based DWD system firstly for the year 2021 and secondly for the 4-year period 2020-2023. These in-version results have been compared with the other PARIS partners. The output was modified such that the results can be displayed within the fluxy tool developed within the PARIS project.

National University of Ireland Galway (NUIG)

During this reporting period, the University of Galway has provided quality controlled/validated GHG data (including methane) from the Mace Head Atmospheric Research station in Ireland, representing Northen Hemisphere background. The data were used as input for inversion modelling in this WP.

Atommagkutato Intezet (ATOMKI)

Continuous CH_4 concentration measurements continued to be made at the Hegyhátsál ICOS Class 2 tall tower atmospheric monitoring station (Hungary). The GC-IRMS system of the UU was deployed in November 2025, and it has been in operation since then.

Swiss Federal Laboratories for Materials Science and Technology (EMPA)

Since December 2024 continuous CH_4 / C_2H_6 (AERIS MIRA ULTRA) and semi-continuous (one hour cycle time) $\delta^{13}C$- and δD-CH_4 (TREX-QCLAS) measurements are executed at the Empa Campus in Dübendorf, Switzerland. CH_4 / C_2H_6 measurements have been validated by CRDS (CH_4) and GC-MS (C_2H_6) and are available for most of the study period. Data coverage for CH_4 isotope measurements was around 30%, compromised by analytical challenges with the preconcentration device. Continuation of measurements is projected until end February.

EMPA provided atmospheric transport simulations employing the transport model FLEXPART for all European CH_4 observing sites and the period 2016 to 2024. Calculations for 2025 are nearly completed. EMPA completed European CH_4 inversions for the period 2016 (2013) to 2024 based their ELRIS inversion system and on two sets of transport simulations (FLEXPART run by EMPA and NAME run by MO). Output was prepared in common data formats and shared with MO, UNIVBRIS and finally compiled for inclusion in the draft annex reports. EMPA has coordinated the development of a common model documentation manuscript which was shared with the inventory compilers as a supplement to the annex reports. EMPA shared in the development and coordination of the fluxy inversion intercomparison tool. EMPA contributed to several sensitivity inversions for Dutch CH_4 emissions, running with alternative sets of observations site to identify the role of Dutch CH_4 observations in the national flux estimation. EMPA performed forward simulations of CH_4

isotopes and ethane for comparison with EMPA's observations at the site Dübendorf and for UU's observations at the sites Hamburg, Cluj and Lindenberg.

Met Office (MO)

Total monthly CH_4 emission estimates for the eight PARIS target countries were derived by the MO inversion system (InTEM) for 2008-2024, using transport from both NAME and FLEXPART and an expanded network of observation sites (relative to last year's modelling). A detailed intercomparison process was carried out with model output from MO, UNIVBRIS, EMPA and DWD. As a result of this intercomparison, various aspects of the modelling process are currently under investigation: the impact of NAME vs FLEXPART transport; the impact of observation site choice and the unexpected seasonal cycles in modelled emissions estimates.

In partnership with UNIVBRIS, the project developed and tested an inversion system to model emissions of CH_4 from two broad sectors, using CH_4 isotope observations from the HFD and LIN sites. This work demonstrated the potential for this method but also highlighted how it is limited by a current lack of isotope observations, relative to CH_4 mole fraction observations, and by the large uncertainties in our current understanding of CH_4 source signatures.

University of Edinburgh (UEDIN)

UEDIN continued to oversee the isotope ratio measurements being made at the Heathfield NPL site in the UK and support the deployment of the UNIVBRIS deployment to the new purpose built GHG tall tower monitoring site at Invergowrie in Scotland. The Heathfield measurements formed part of a second ICOS CP upload of isotope ratio methane measurements in 2025. This upload was an extension and improvement of the original time series uploaded in 2024. The Heathfield instrument broke down in June 2025 due to a laser failure, which required the complete replacement of the module. This is a custom module with a long lead time, and a replacement is expected for testing by the manufacturer in early 2026 with subsequent redeployment to Heathfield.

University of Bristol (UNIVBRIS)

UNIVBRIS has provided both observational and modelling results in this reporting period. On the observational side, the UNIVBRIS performed a rigorous laboratory testing of an Aerodyne optical instrument for $\delta^{13}C$-CH_4 and ethane, including the implementation of a new calibration procedure for the instrument. The instrument was successfully deployed to the Invergowrie station in Scotland in Nov 2025. On the modelling side, UNIVBRIS has conducted a first inversion study of the isotopic data collected from the Heathfield station in the UK and the Lindenberg station in Germany. The study shows the level of uncertainty that can be obtained in source sector estimates of CH_4 estimates, when accounting for the uncertainty in isotopic source signatures. A draft manuscript of this work has been produced and will be submitted in early 2026.

1.2.4.3 – WP4 – TASK REPORT

TASK 4.1 – OPTIMAL MEASUREMENT SITES FOR NEW OBSERVATIONS

> *NAME and FLEXPART simulations for the prospective new sampling locations for the mobile campaigns will be performed (Lindenberg and Stinkimmen (Germany), Ispra and Monte Cimone (Italy), Saclay and Puy de Dome (France). Observation Simulation System Experiment (OSSE) will be conducted by modelling methane and the isotopic ratios to determine the most useful sites for high frequency methane isotope monitoring campaigns in Europe. The effect of uncertainties in the isotopic source signatures will be included in this assessment.*

Task 4.1 was completed in the first reporting period.

TASK 4.2 - NEW METHANE ISOTOPE MEASUREMENTS

> *High-frequency measurements of $\delta^{13}C$-CH_4 and δD-CH_4 will be established at SOAR (UK) or LUT (Netherlands), Heathfield (UK) and Zürich (Switzerland). Campaigns of 6-12 month duration using a mobile platform making high frequency, high precision isotope observations will be conducted at five addi-*

tional sites between 2022 and 2024. One campaign will take place at Hegyhátsál in focus country Hungary and three others will be chosen based on the OSSEs in Task 4.1. The isotopic composition for both $\delta^{13}C$-CH^4 and δD-CH^4 of the background air will be determined by regular (~weekly) analysis at UU on flask samples collected from Mace Head.

In this reporting period UU measured at Monte Cimone (19-09-2024 to 21-05-2025) – see Fig. 5, Lamezia Terme (10-10-2025 to 7-11-2025) – see Fig. 6, and started measurements at Hegyhátsál on 21-11-2025, which will likely end in May 2026. This adds several thousand isotope measurements to the PARIS-compiled dataset. An additional 45 samples were taken at Mace Head (16-01-2025 to 07-10-2025) and 200 samples at Monte Cimone (13-11-2023 till 08-10-2025). These were analysed at UU over the period to gain an improved understanding of the variation in isotopes of air arriving into the inverse modelling domain.

The measurements of $\delta^{13}C$-CH_4 and δD-CH_4 at Heathfield continued through the measurement period until instrument failure in mid-June 2025. Measurements were flagged between 17 May and 2 June due to an issue with the cryogenic trap. The trap was replaced in June and sampling resumed briefly until the laser failure. A new Aerodyne TILDAS-FD-142 laser absorption spectrometer has been successfully characterised and deployed to the SOAR tall-tower site in Invergowrie, Scotland, to provide high-frequency measurements of ethane (C_2H_6), and $\delta^{13}C(CH_4)$. The deployment was completed in early November 2025 and forms an essential component of expanding observational capability for methane source attribution within the PARIS project, enabling improved fossil-fuel vs microbial emissions discrimination through combined isotopic and ethane constraints.

Extensive laboratory characterisation was performed both prior to and following field installation, including Allan-Variance analyses that established optimal averaging times and short-term precisions comparable to those reported for similar mid-IR absorption systems. The instrument demonstrates excellent stability for CH_4 and C_2H_6, with short-term precisions reaching 0.02 ppb ($^{12}CH_4$), 0.44 ppb raw ($^{13}CH_4$; corresponding to ~4.6 ppt after calibration), and 2.3 ppt (C_2H_6). Field measurements show long-term precisions of 0.1–0.3 ppb for CH_4, 10–20 ppt for C_2H_6, and 0.61–1.5‰ for $\delta^{13}C(CH_4)$, suitable for resolving major source-category differences. A decline in $\delta^{13}C(CH_4)$ precision in mid-December was linked to thermal disturbances during instrument maintenance, after which performance re-turned to baseline as the system re-stabilised. Communication with the instrument manufacturer is ongoing to improve the isotope ratio precision; however, the performance for ethane measurements is excellent.

A preliminary intercomparison with a high-precision reference CH_4 instrument indicates strong correlation (r^2 = 0.91) but a consistent low bias of approximately 10 ppb, attributed to both scale differences and sampling-synchronisation challenges. Further intercomparisons, including isotope-ratio and C_2H_6 validation, will be conducted following deployment of additional reference instruments in the coming months. Data acquisition and processing are fully automated via TDLWintel and GCWerks, with calibration and drift-correction performed offline with developed Python code. The dataset will be shared with project partners via GCCompare once software licensing is finalised. Overall, this milestone re-presents a significant step towards enhancing the regional observational network for methane source apportionment.

Since December 2024 continuous CH_4 / C_2H_6 (AERIS MIRA ULTRA) and semi-continuous (one hour cycle time) $\delta^{13}C$- and δD-CH_4 (TREX-QCLAS) measurements are executed at the Empa Campus in Dübendorf, Switzerland. CH_4 / C_2H_6 measurements have been validated by CRDS (CH_4) and GC-MS (C_2H_6) and are available for most of the study period. Data coverage for CH_4 isotope measurements was around 30%, compromised by analytical challenges with the preconcentration device. Continuation of measurements is projected until end February.

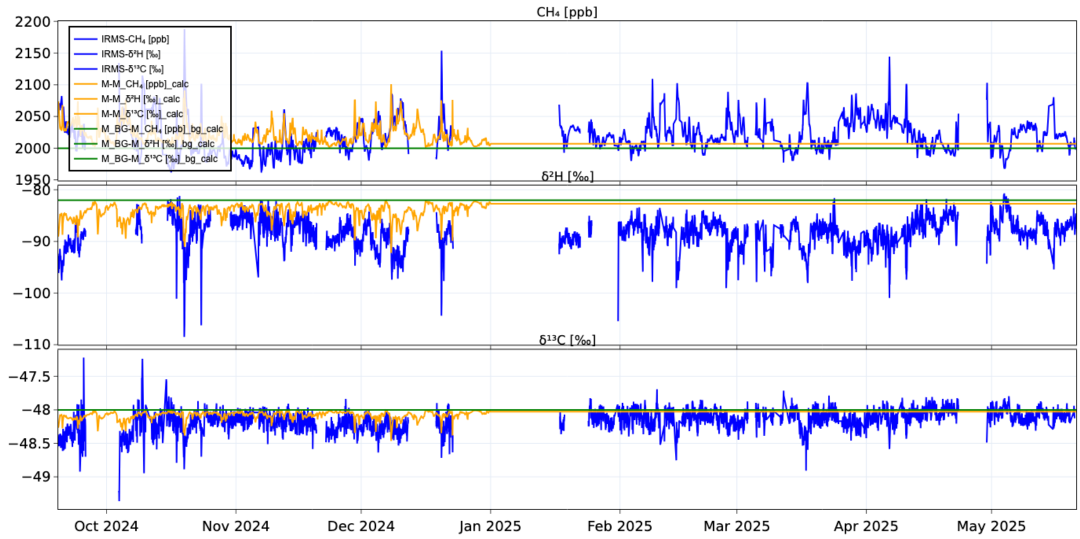

Fig. 5: Monte Cimone timeseries made with the Utrecht University in situ IRMS, with the NM-UMG simulations performed by EMPA

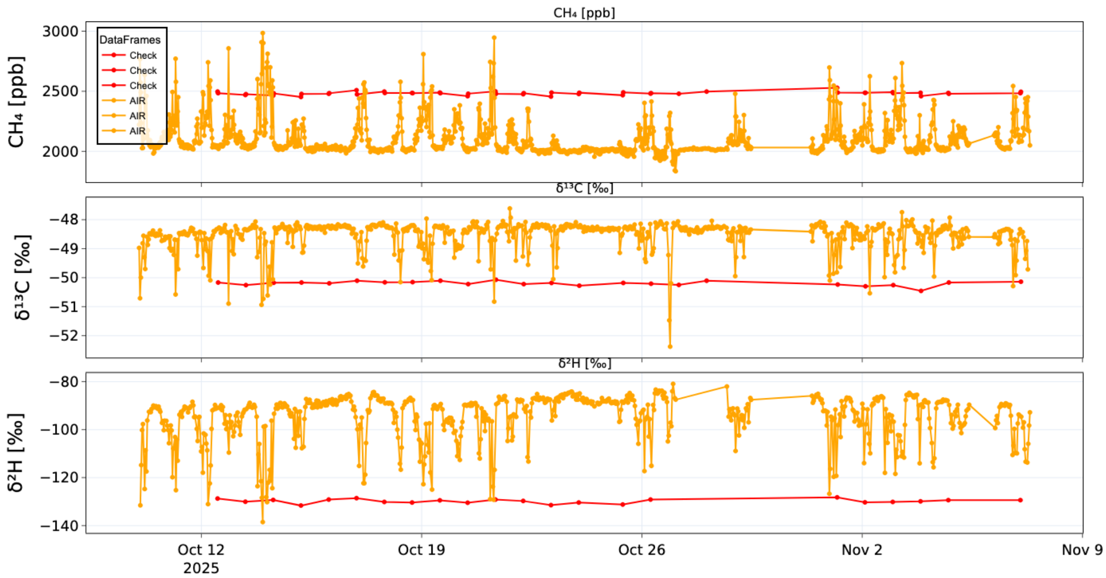

Fig. 6: LMT timeseries made with the Utrecht University in situ IRMS

TASK 4.3 - SOURCE SIGNATURES CHARACTERISATION AROUND SITES

Mobile surveys will be conducted in the vicinity of new measurement sites to characterise isotope source signatures. This will result in many new isotopic source signatures that will augment the growing European database that our teams have developed. (UU, ATOMKI, UEDIN, UNIVBRIS)

In this reporting period source signature measurements were not prioritised – limited campaigns around CMN and LMT found no significant elevations in CH_4.

TASK 4.4 - TOTAL METHANE EMISSIONS ESTIMATION

Total methane emissions estimates will be derived for Europe using the established NAME-UB, FLEXPART-UB, NAME-MO, FLEXPART-MO, NAME-EMPA and FLEXPART-EMPA approaches in addition to the new ICON-ART-DWD system to enhance German capability. Measurements from ICOS and individual national networks (e.g., UK DECC) will be used. In September of each year, emissions from at least 5 multi-inversions (e.g., NAME-MO, FLEXPART-MO, DWD, etc) based on the observational data of the previous year will be derived. In October of each year, at least 2 (e.g., NAME-MO and FLEXPART-EMPA) model system will provide inversion estimates using the provisional data for first half of the current year. (UNIVBRIS, MO, EMPA, DWD)

Total methane emissions were derived for 2016-2024 using the UB, MO and EMPA approaches for the 8 PARIS focus countries and using additional results from the DWD ICON-D approach for Germany. All top-down model results were compiled and compared using the 'fluxy' intercomparison software which has been developed further to allow for even more detailed comparison of seasonal emissions, modelled mole fractions and model uncertainties. The intercomparison of results was carried out at a range of spatial and temporal scales: yearly and seasonally and monthly. Other developments made since last year's intercomparison cycle include the use of both NAME and FLEXPART transport model output by the UB, MO and EMPA inversion approaches and incorporation of further observations from the network of tall-tower observation sites across Europe by all models. Analysis of how the transport model and number of observation sites can impact emissions estimates is ongoing and will be developed further during next year's cycle of emissions estimation.

TASK 4.5 - SECTOR-LEVEL METHANE EMISSIONS

The new CH_4 $\delta^{13}C$ and δD data (Task 3.2) and ethane measurements from AGAGE and ACTRIS will be integrated into inverse modelling systems (used in Task 4.4) to estimate methane emissions from the major source categories (microbial, fossil fuel) for the focus countries where enhanced observations will be available (UNIVBRIS, MO, EMPA)

A NAME-based inversion system has been developed for estimating regional methane emissions from fossil-fuel (FF) and non- fossil-fuel (non-FF) sources concurrently, using methane isotope ratio observations and uncertain isotopic source signatures. Synthetic data tests with this method using isotope ratio observations from two sites in the UK show that this model has the potential to accurately estimate FF and non-FF UK methane emissions using these observations, when isotopic source signatures are fixed at known values. However, emissions estimation becomes less accurate when uncertainties in source signatures, at a level comparable to our current understanding of European signatures, are included in the model. This model was further tested with case studies of UK and German FF and non-FF emissions, using high-frequency isotope ratios observations developed during the PARIS project, from the HFD site in the UK and LIN site in Germany. Results from these tests show limited impact on the uncertainty or magnitude of emissions estimates, when compared with results from the methane-only inverse model which implicitly uses only the spatial distribution of emissions sources to aid with source attribution. This result reflects conclusions given by the synthetic data tests and suggests that the on-going expansion of UK and European methane isotope ratio observations and an im-proved understanding of UK isotopic source signatures will both be important developments for enabling this inverse modelling method to be used to reduce uncertainties in top-down estimates of FF and non-FF methane emissions across western Europe. We are investigating alternative methods for estimating top-down sector-level methane emissions, using a prior estimate of the spatial distribution of sources, potentially for use by the modelling systems involved in the PARIS model intercomparison process.

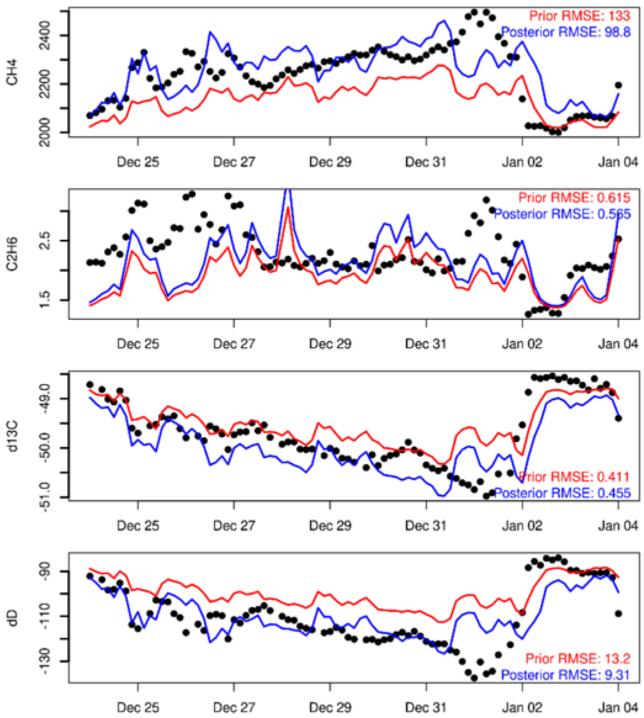

Fig. 7: Time series of observed (black dots) and simulated (red and blue lines) CH_4, C_2H_6, $\delta^{13}C$, δD observed at Dübendorf end of December 2024. Red lines represent prior model simulations and blue lines represent aposteriori simulations after adjusting the source strength for eight separate CH_4 emission sectors.

Using the PARIS observations of CH_4, C_2H_6, $\delta^{13}C$ and δD at the site Dübendorf a first attempt for sector attribution of Swiss methane sources was attempted. Simulations of CH_4 from eight different source sectors were carried out based on EMPA's high-resolution FLEXPART-ICON model for Switzerland (1 km x 1 km resolution) and the high-resolution Swiss CH_4 inventory. High resolution is critical for the very heterogenous source landscape and complex terrain in Switzerland. Two episodes with strong CH_4 enhancements in the winter 2024/2025 were identified as suitable targets for a first trial inversion employing all observed parameters (CH_4, C_2H_6, $\delta^{13}C$, δD). This trial inversion optimised a single factor for each CH_4 emission sector for the selected period and using fixed source signatures and CH_4/C_2H_6 emission ratios for each of the eight emission sectors. The trial inversion successfully brought the simulations into closer agreement with the observations of most parameters (see Fig. 7) only the posterior RMSE for $\delta^{13}C$ somewhat decreased from the prior. For this period, the inversion suggested increased emissions from agriculture and natural gas (factor ~1.5) and waste (factor 8). These very preliminary findings will be further evaluated in the final month of the PARIS project.

TASK 4.6 - COMPARISON OF TOP-DOWN WITH UNFCCC REPORTS

Top-down and reported methane emissions will be compiled for countries constrained by the observational network. In focus countries, estimates at sector-level will be compared (for sectors constrained by the new measurements) annually in an Annex to the National Inventory Report. Discrepancies will be discussed considering best available error estimates for both bottom-up and top-down approaches. Stakeholders will be engaged (see also WP 2) by providing them with top-down estimates and identifying possible discrepancies with atmospheric observations at the sector-level where possible. (UNIVBRIS, MO, WU, EMPA, DWD, ATOMKI, NUIG)

This Task follows on from Task 4.4, which provides top-down estimates of methane emissions from the project's inverse models. These top-down estimates of methane emissions were compared to UNFCCC-reported emissions for the PARIS focus countries during de-tailed discussions between all model groups and during the meetings held with inventory compilers. Top-down results were compared to reported emissions at yearly scales, and any discrepancies were investigated by analysing results at monthly country-level and spatial scales.

Results from these comparisons were presented in draft Annexes for all focus countries, alongside results for the other GHGs (draft Annexes for all countries are available from: https://horizoneurope-paris.eu/wp-content/uploads/sites/914/2026/01/PARIS-D2.3-Draft-Annexes-to-National-Inventory-Reports-1st-update-final-complete-reduced.pdf). Development of a method for top-down sector level emissions estimation is underway, with the aim to include some sector-level analysis in next year's draft Annex production cycle.

DWD contributed the annually resolved ICON-ART based top-down results for Germany 2000-2023 into to the comparison with the inventories, with efforts to resolve the agricultural sector in the Eulerian Model - which is not completely possible to detangle from natural fluxes with the top-down approach. Scientific discussion is ongoing concerning the deviation of the annual cycle between models, and between regions, which cannot be explained yet by filtering for observation conditions. Work is in progress concerning resolution-dependent uncertainty characterization.

1.2.5 WORK PACKAGE 5 – ADVANCING N_2O PROCESS MODELS AND THEIR RECONCILIATION WITH TOP-DOWN ESTIMATES

O5.1: Produce a new set of high-frequency atmospheric nitrous oxide observations from Hegyhátsál, Hungary following ICOS recommendations and homogenize existing datasets.

O5.2: Improve bottom-up (Tier 3) estimates of nitrous oxide emissions from Switzerland, Germany and the UK using biogeochemical models with enhanced, data-informed process attribution.

O5.3: Reconcile sub-annual resolution nitrous oxide emission estimates from Tier 3 process models with national Tier 1 or 2 methods as well as top-down estimates derived from atmospheric data for focus countries.

O5.4: Quantify differences between top-down and model emission estimates for countries constrained by the ICOS and national observation networks.

1.2.5.1 WP5 – EXECUTIVE SUMMARY

Activities within WP 5 have progressed as envisaged in the description of work.

With respect to objective O5.1 calibration strategies for the high-frequency N_2O observations at Hegyhátsál, Hungary, have been revised and automated multi-point calibrations have been established, largely following ICOS recommendations. These observations are ongoing and are regularly submitted to the ICOS Carbon Portal. Other atmospheric N_2O observations had been made available in the first reporting phase (D5.1). For the latest iteration of atmospheric inversions of N_2O these data were large collected through the ICOS ATC, but additional merging/harmonisation is required (Task 5.2) to readily use these data by the inverse modelling groups.

Towards objective O5.3 and O5.4 the inverse modelling teams have prepared inputs for the inversions (transport simulations from NAME and FLEXPART), prior emissions (EDGAR) and defined common protocols and output formats. Inverse modelling results (monthly N_2O fluxes at 25 km x 25 km resolution) were obtained for a common period (2016-2024) by six different combinations of inversion systems and transport models. These results form the basis of N_2O reporting in the draft annexes and the discussion with nation inventory teams. Inversion results for large parts of north-western Europe have been discussed with national inventory teams, highlighting once more the pronounced seasonal cycle and year-to-year variability in emission fluxes seen from inverse modelling and the need for more complex approaches in the bottom-up reporting of N_2O emissions from agricultural soils.

To this end, improve model-based estimates of N_2O fluxes (O5.2), work has progressed in two directions. On the one hand, N_2O flux observations for isotopic source signature estimation were successfully concluded at a cropland site in Switzerland. On the other hand, these observations were employed in tuning of the biogeochemical models Day-Cent and LandscapeDNDC (D5.3). Furthermore, the biogeochemical models Day-Cent and Land-scapeDNDC were applied on the national scale (target countries Switzerland, Germany and UK). Collection of required input data (soil parameters, management practices, climate data) was coordinated between the project partners and was concluded successfully. Results of these simulations are available for comparison with inverse estimates, and first comparisons show partially good agreement but highlight the importance of the timing of management when simulating N_2O emissions from soils.

1.2.5.2 – WP5 - PROGRESS SUMMARY PER WP PARTNER

Utrecht University (UU)

In the second reporting period, UU supported the measurements at the Hegyhátsál tall tower site by knowledge exchange and collaboration with ATOMKI, based on the initial deployment of the UU isotope instrument at Hegyhátsál. UU also contributed to the discussion and interpretation of scientific results, especially the isotope measurements and their use for constraining the process based N_2O production and emission model. Furthermore, UU was involved in the discussions and interactions with the Dutch inventory team on N_2O emissions, bringing in external expertise on re-cent direct flux measurements of N_2O over The Netherlands.

Karlsruher Institut für Technologie (KIT)

In this work package, KIT is responsible for site-scale and national-scale simulations targeting N_2O emissions. Site-scale simulations were carried out to evaluate the ability of the biogeochemical model LandscapeDNDC to simulate the relative contributions of the main N_2O -producing processes nitrification and denitrification. The isotopic quantity site preference (SP) provides in-formation on the relative contributions of these processes, but such field measurements have remained scarce due to their challenging nature. To expand the existing body of measurements, one additional dataset was generated by EMPA for arable land. This dataset, along with a literature dataset obtained from grassland, was used at the site-scale to assess the benefit of SP for model calibration. As the use of SP was expected to constrain the parameter ranges and thereby reduce model uncertainty, a calibration-uncertainty estimation framework was developed. The transferability of calibrated parameter sets across different sites remains to be assessed.

National-scale simulations were carried out to corroborate the magnitude as well as both spatial and temporal patterns of N_2O emissions as obtained from the top-down inversion approaches. To this end, model input datasets on meteorology, soil properties and agricultural management activities were produced and national scale simulations were carried out for the focus countries Germany, Switzerland and the UK.

Atommagkutato Intezet (ATOMKI)

The atmospheric concentration of nitrous oxide is continuously measured at the Hegyhátsál tall tower site at 82 m above the ground using a Los Gatos Research Model 913-0014 Enhanced Performance fast-response $N_2O/CO/H_2O$ analyser. A quality control algorithm was developed that is completed by manual review. Using this method, the historical data back to 2017 have been quality-checked, flagged, and made available for the scientific community in PARIS. The quality-controlled recent data are reported regularly according to the work plan and have been submitted annually to the ICOS Carbon Portal.

Swiss Federal Laboratories for Materials Science and Technology (EMPA)

EMPA provided atmospheric transport simulations employing the transport model FLEXPART for all European sites observing N_2O and the period 2016 to 2024. Calculations for 2025 are nearly completed. EMPA completed European N_2O inversion for the period 2016 (2013) to 2024 based their ELRIS inversion system and on two sets of transport simulations (FLEXPART run by EMPA and NAME run by MO). Output was prepared in common data formats and shared with MO, UNIVBRIS and discussed during weekly modelling meetings. Finally, inversion results were compiled for inclusion in the draft annex reports (D2.3) and uploaded to the ICOS Carbon Portal. EMPA has coordinated the development of a common model documentation manuscript which was shared with the inventory compilers as a supplement to the annex reports. EMPA shared in the development and coordination of the fluxy inversion intercomparison tool. EMPA coordinated a first intercomparison of N_2O inversion results across the sister projects, presenting the results at the EGU GA in May 2025 and in a joint project newsletter.

Empa conducted N_2O, CO_2, CH_4 flux measurements from an agricultural field site with two different crops (sugar beet, winter barley) and two fertilization regimes (NPK, control) at Agroscope Reckenholz, Switzerland over the full growing season (March to December 2024). Each of the four plots was equipped with three automated chambers and provides flux estimates and N_2O isotope information with weekly resolution. Gas sampling bags were analysed at Empa on an automated setup by CRDS spectroscopy (G2401, G5131-i) and post-corrected using a customized MATLAB script (Havsteen et al., 2025). N_2O isotopic source signatures were derived using a two-endmember mixing model (Keeling plot technique). Quality controlled data was uploaded to the ICOS carbon portal (https://doi.org/10.18160/ANQW-32YY, under moratorium until May 2026) and provided to AGS and KIT for improved parametrization of biogeochemical soil models. Further details are provided in M19.

Agroscope (AGS)

AGS is responsible for simulating N_2O emissions from agricultural soils using the biogeochemical model Day-Cent at cropland sites in Switzerland where EMPA has performed special isotope analysis of N_2O fluxes. AGS showed that the adjustment of soil N-cycling related parameters can clearly improve the model. A manu-script describing this work is currently in revision at Nutrient Cycling in Agroecosystems.

For the national-scale simulations, AGS collected agricultural data and used newly available, high-resolution maps that describe which crop type is grown on every single agricultural field (about 30000 in total). In addition, data of i.a. agricultural common practice, fertilisation, soil characteristics and weather were processed in the simulations. For the moment, simulations were performed for 33800 simulation units.

Met Office (MO)

The UK Met Office (MO) have completed monthly inverse modelling for N_2O over 2008-2024 for the eight PARIS target countries and northwest Europe using the MO inversion system (InTEM) using atmospheric transport simulations from both NAME and FLEXPART. A comprehensive set of measurement sites were used in the inversions as described in this report. These results were provided in the common output format as devised by PARIS that is readily ingested by the PARIS intercomparison tool fluxy. Using fluxy, a detailed model intercomparison process was carried out with model output from MO, UNIVBRIS and EMPA forming the basis for the draft annex reports (D2.3) and data publication on the ICOS Carbon Portal. As a result of this intercomparison, various aspects of the modelling processes were better understood, for instance the importance of the choice of the time-varying model uncertainty. The impact of using different transport models was also important in better quantifying the uncertainty of the emission estimates. MO actively participated in the weekly inverse modelling discussions.

University of Bristol (UNIVBRIS)

UNIVBRIS has been coordinating inverse modelling intercomparisons along with MO and EMPA and has been co-convening weekly modelling meetings with MO and EMPA. European N_2O emissions have been derived using the UNIVBRIS inversion method RHIME using two transport models NAME and FLEXPART. These outputs, called RHIME-NAME and RHIME-FLEXPART were derived over the period 2017-2024 at monthly resolution and include the N_2O focus countries for PARIS. These results were included draft annex reports (D2.3) and PARIS data publication on the ICOS Carbon Portal as well as in a wider intercomparison of N_2O emissions results with the two other sister projects EYE-CLIMA and AVENGERS.

1.2.5.3 – WP5 – TASK REPORT

TASK 5.1 – NEW ATMOSPHERIC N_2O OBSERVATIONS

Expanding the existing N_2O network towards the East, the Hungarian tall tower site Hegyhátsál (Hungary) will be extended to include calibrated atmospheric nitrous oxide measurements using an existing Los Gatos laser spectrometer, currently used for flux measurements. Sampling methods and calibration will be installed to produce measurements following ICOS recommendations.

Continuous, in-situ N_2O observations from the tall tower site Hegyhátsál (HUN), Hungary, that are not part of the ICOS monitoring program, were re-evaluated and the instrument calibration procedures updated (see M17). Observations are ongoing and data up to the end of December 2024 were quality controlled and submitted to the ICOS Carbon Portal as part of the European N_2O Obspack (https://hdl.handle.net/11676/roD3cakdtvqRz-mQgyhQIQVn). The data were compared to the closest ICOS N_2O observation, providing additional evidence of a successful calibration strategy (Fig. 8). Observations were also incorporated into the European inverse modelling estimates of N_2O emissions (Task 5.5) and form the backbone of the nation estimate for Hungary (one of the focus countries). Observations continued without interruptions in 2025 and data quality control of these measurements will conclude soon, followed by upload to ICOS Carbon Portal. Measurements will also continue in 2026 beyond the PARIS obligations.

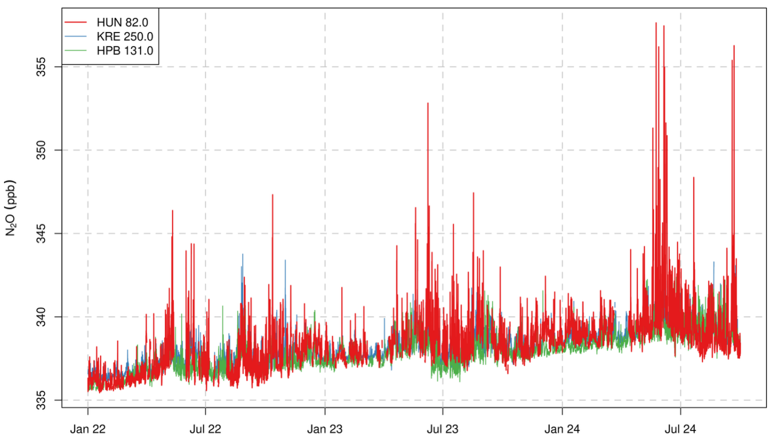

Fig. 8: Time series of fully calibrated N_2O observations (1-hour averages) from Hegyhátsál (red) compared to those carried out at closest ICOS sites HPB, Germany, (green) and KRE, Czech Republic, (blue). Note that only data from 2022 to the end of the common data period is shown (end of Aug 2024 for ICOS sites at time of comparison).

TASK 5.2 COMPILATION OF ATMOSPHERIC N_2O OBSERVATIONS FOR INVERSE MODELLING

N_2O observations across Europe including those outside ICOS sites will be harmonised by cross-comparison of sites/instruments and integration of calibration scales.

Compilation of historical N_2O observations was a major activity in WP5 during the first year of the project (joined with EYE-CLIMA and AVENGERS). Since this first iteration of the data collection, the process was largely simplified by the availability of the initialised harmonised dataset and by the ICOS ATC starting to produce its own annual collection of non-ICOS N_2O observations (European N_2O ObsPack) and making it available at the ICOS Carbon Portal. Nevertheless, within the PARIS inversion workflow these observations still need to be merged with the most recent non-ICOS N_2O observations as provided by PARIS project members (UK DECC and AGAGE networks (UNIVBRIS), Swiss site BRM (EMPA) and Hungarian site HUN (ATOMKI, see Task 5.1)). The result is an observational record across 29 sites of hourly N_2O concentrations and includes harmonised reporting of measurement uncertainty and observed variabilities (both quantities are used in the inversion systems to characterise different parts of uncertainty budget). Fig. 9 showcases the availability of N_2O observations for the 29 sites and their use by the different inversion models. Overall, the data coverage in the period 2019 to 2024 remained relatively stable over time.

Fig. 9: N_2O observational data usage by the different employed inversion models for the period 2019 to 2024. Note that some sites did not report any data during this period (but previously), whereas other sites stopped reporting.

TASK 5.3 SITE-SCALE PROCESS MODEL VALIDATION

We will first identify two to three additional study sites for validation campaigns (flux and process attribution) for relevant cropping systems. One extended growing season of flux, isotope observations and activity data will be collected at sites, including freeze-thaw cycles. Simulations with the isotope version of LandscapeDNDC (SIMONE) for these new sites and for existing data from three grassland sites will be conducted. Simulation results will be compared to observed isotopic and bulk N_2O data to inform improvement of model process description and parameterization.

Within task 5.3 additional observational data on intra-molecular isotopic composition of N_2O soil emissions were gathered (EMPA) and, together with observations from previous campaigns, were used to calibrate two biogeochemical models: DayCent and LandscapeDNDC. Strategies for calibrating N_2O source processes were developed by AGS and KIT to simulate the relative contributions of nitrification and denitrification to total emissions. A detailed report on the observations and the calibration exercise is available as deliverable D5.3.

Observations: EMPA completed their site-scale observations of N_2O and their isotopic source signature on the premises of one of the long-term trials (“Demo trial”) of the AGS site in Reckenholz, close to Zürich. The site allowed sampling from fields under different crop rotation and management practices (mineral fertiliser, NPK, and non-fertilised, Null). EMPA used gas bag sampling with an automatic time integration chamber (ATIC). Weekly bag samples were then analysed for N_2O isotopes (Picarro G5131-i), CO_2 and CH_4 (Picarro G2401-m) in the lab at EMPA. Average weekly N_2O fluxes and isotopic source members were determined using the Keeling plot method. Sampling commenced in mid-February 2024 and continued until the end of 2024 to provide observations for a complete growing season. These observations are described in detail in milestone report M19 and in a manuscript currently in review (Havsteen et al., 2025). Across the sampling period (05.03.2024 to 11.12.2024), the integrated weekly average N_2O flux was generally small and typically below the 75 µg N_2O-N m^{-2} h^{-1} threshold required for isotopic source member determination (gray horizonal line in Fig. 10b). For the NPK treatment, two larger emission pulses occurred in late spring to mid-summer peaking at ~350–400 µg N_2O-N m^{-2} h^{-1} (Fig. 10b). The emission pulses coincided with periods of increased precipitation and followed the two fertilization events (50 kg N ha^{-1} each) applied at the beginning and the end of May (vertical gray dashed lines in Fig. 10). Isotopic source signatures were only measurable during the high flux periods, while the remaining dataset did not offer sufficiently high N_2O fluxes to pass the quality criteria and threshold values ($R^2[N_2O] > 0.7$, flux[N_2O] > 75 µg N_2O-N m^{-2} h^{-1} and Keeling line within ±8 ‰ of ambient air endmember). For periods with sufficiently high fluxes for isotopic analysis, the dataset indicates that N_2O production in the soils at the Demo site was predominantly through bacterial denitrification, with most source signatures clustering within or close to $\delta^{15}N^{SP}$ values reported for denitrification in literature.

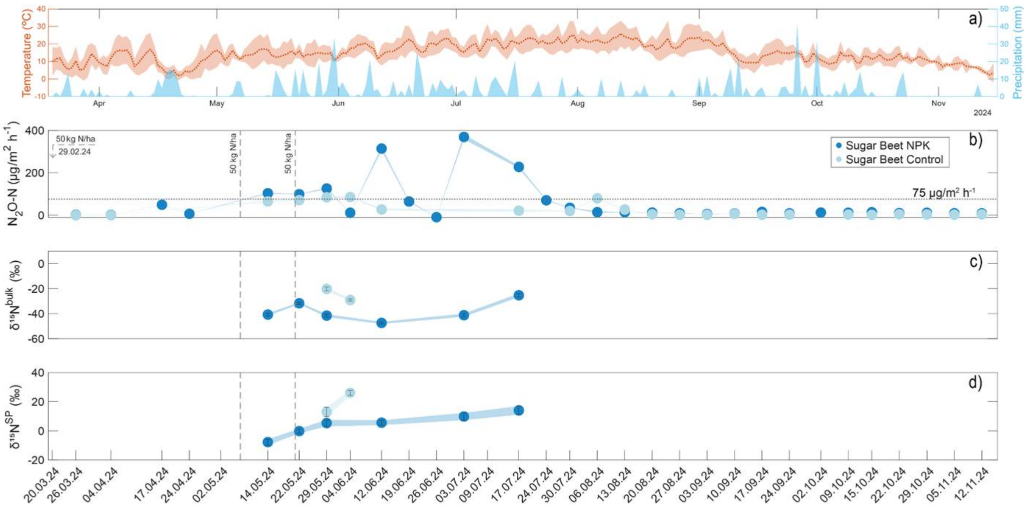

Fig. 10: Seasonal course of N_2O fluxes and isotopic composition for sugar beet under NPK fertilization vs. control of the Demo experiment: (a) daily air temperature and precipitation, (b) N_2O flux (µg N_2O-N m^{-2} h^{-1}), (c) $\delta^{18}O$, $\delta^{15}N^{bulk}$ and (d) site preference ($\delta^{15}N^{SP}$). The stippled line in the N_2O flux graph represents the 75 µg m^{-2} h^{-1} threshold for isotope flux analysis.

DayCent study: AGS simulated N_2O emissions from the soil of sugar beet plots with control (Null) and mineral (NPK) fertilizer treatments at the Demo trial. DayCent simulations were conducted using the model's default settings, a traditional calibration approach, and a so called "expert-informed" approach that utilized inferences from observational methods including the isotope analysis and compared to short-term (2024) field observations. Although, this "expert-informed approach", showed a somewhat lower performance concerning the cumulative N_2O flux (Null: RMSE = 0.37 kg N ha^{-1} yr^{-1}, NPK: RMSE = 0.50 kg N ha^{-1} yr^{-1}) than the traditional calibration (Null: RMSE = 0.15 kg N ha^{-1} yr^{-1}, NPK: RMSE = 0.10 kg N ha^{-1} yr^{-1}) (Fig. 11), it may be considered as more representative and suitable because it better reflected the higher contribution from denitrification shown by the isotope data. This study demonstrates that the inclusion of observational methods, such as isotope measurements, can provide important insight into model function and improve pathway-specific estimation of N_2O emissions in the DayCent model.

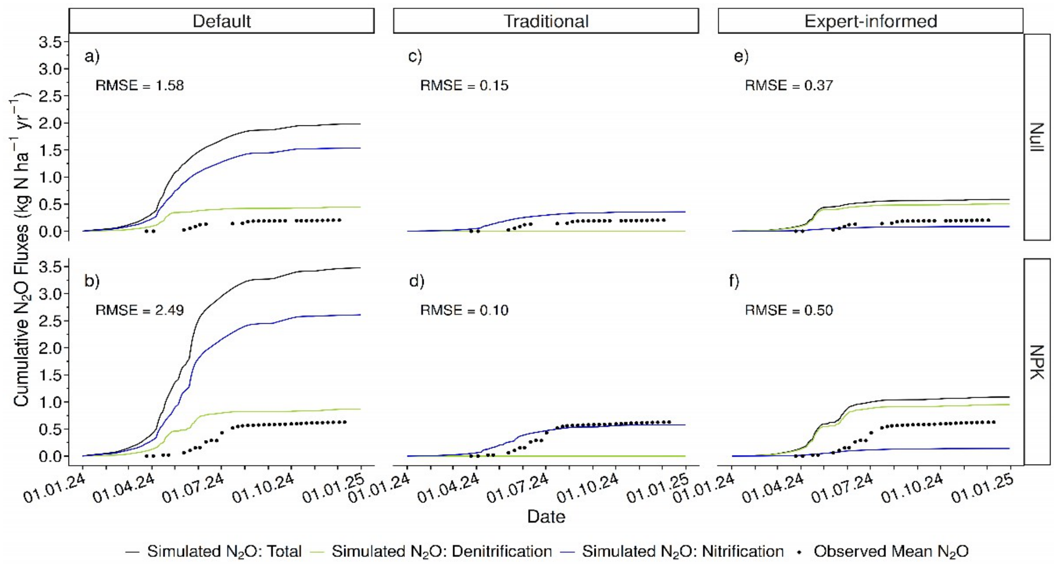

Fig. 11: DayCent simulations of the cumulative N_2O fluxes for the Null and NPK treatments of the sugar beet crop at the Demo site in Switzerland using the default (a-b), traditional calibration (c-d), and expert-informed (e-f) parameter values. Total cumulative N_2O emission (black) and N_2O production from denitrification (green) and nitrification (blue) are represented by the solid lines, and the observed mean cumulative N_2O flux measurements are represented by the black dots. The root mean square error (RMSE) represents the deviation between simulated and measured cumulative total N_2O flux values.

LandScapeDNDC study: KIT developed a calibration-uncertainty estimation framework to assess the benefit of isotope information on calibration of the main N_2O producing processes nitrification and denitrification. In brief, most influential parameters of LandscapeDNDC for N_2O emissions are identified by means of a global sensitivity analysis. Subsequently, parameters are calibrated using measurements and likelihood estimation, which leads to a posterior distribution of parameter vectors. Since it was expected that the additional information on source processes provided by the isotope measurements constrains the plausible parameter sets, the posterior distributions are used to estimate the model parameter uncertainty based on a Monte Carlo resampling approach. The calibration-uncertainty framework was deployed on two datasets, one of which being the dataset of the arable "Demo" site and the other being a dataset obtained earlier by Empa for a grassland site, which is used as an example here.

Using both flux and isotope information to calibrate LandscapeDNDC, the simulated emissions show a much stronger response to management and rewetting events and perform better than the default parameterization when compared to the observations, see Fig. 12. The uncertainty associated with the simulated peak emissions is decreased from the calibration exclusively using N_2O flux compared to the scheme using both N_2O flux and isotope information. This showcases the potential value of isotopic composition measurements of N_2O fluxes, specifically site preference, as a tool to help constrain model parameter uncertainty. In addition, the site preference results reveal a strong model bias towards nitrification in the second half of July that persists following the calibration. Following the rewetting event at the end of July, LandscapeDNDC is slow to respond (if at all) with a recovery of nitrification processes. This additionally showcases the potential for isotopic measurements to identify systematic model biases. Addressing the source of this bias will be the subject of future work.

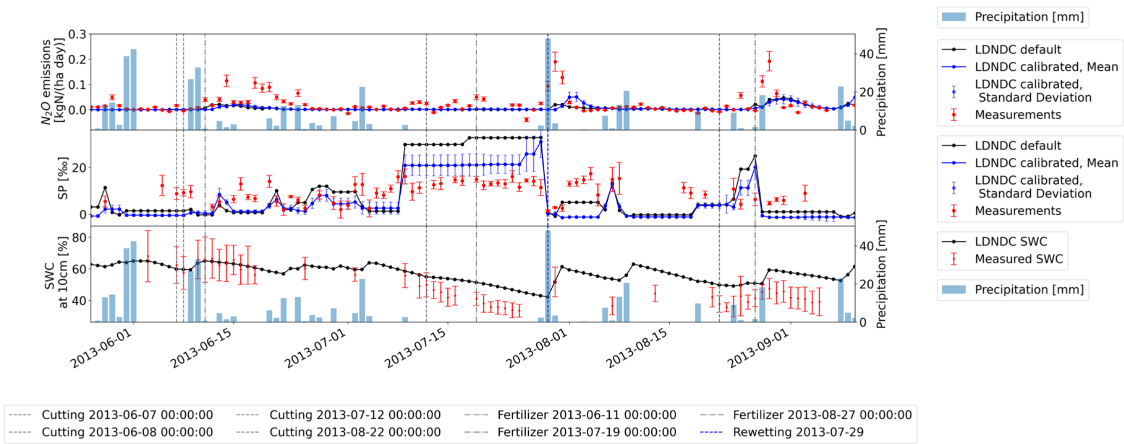

Fig. 12: Results of 17 parameter calibration and model parameter uncertainty evaluation on the site Chamau using both N_2O flux and site preference observations

TASK 5.4 NATIONAL-SCALE PROSSES MODEL SIMULATIONS

Based on the improvements to the model performed in Task 5.3, Landscape DNDC (Switzerland, Germany, UK) and DayCent (Switzerland) will be run for the periods covered by atmospheric N_2O observations. Model input data comprising land cover, meteorology, soil properties, and (agricultural) management will be compiled for these countries.

AGS has calibrated DayCent for cropland (Dos Reis Martins et al., 2022) and permanent grassland (Dos Reis Martins et al., 2024). Collection and definition of agricultural management practices in Switzerland have been conducted. Crop cultivation schedules were determined based on high resolution land use maps from the Swiss Federal Office of Agriculture. AGS used newly available, high-resolution maps that describe which crop type is grown on every single agricultural field (about 30'000 in total). We focus on national emissions between 2021 and 2023, because these maps are of the highest quality. The management of each crop was defined based on what is the most common practice in Switzerland (e.g., dates for tillage or sowing). The fertilization rates were based on Swiss fertilization guidelines. Input data for soils (i.e. clay content and depth) were used from a high resolution, digital soil map. National-scale simulations are performed based on pedo-climatic conditions which are defined based on land use type, regional weather conditions, soil texture, soil depth, and crop rotation for the cropland areas. Weather data was gathered from 26 representative weather stations. AGS is currently working on increasing the spatial resolution of the weather data. For the moment, simulations were performed for 33'800 simulation units.

KIT carried out national-scale simulations for the focus countries Germany, Switzerland and the UK. For these countries, datasets were homogenized to a 1 km by 1 km grid, and LandscapeDNDC simulations were run in daily temporal resolution for the period 2018 to 2024, excluding the spin-up period from 2015 to 2017. Land use and soil information were obtained from the Corine Land Cover and LUCAS data sets respectively, climate data were sourced from the E-Obs, agricultural management such as planting, fertilization, tillage and harvest was based on surveys and national good farming practice. Mineral fertilizer application rates were modelled according to IFASTAT but scaled to national statistics and organic fertilizer amounts were obtained from FAO gridded livestock data. The paramount importance of fertilizer use in agriculture for N_2O emissions resulted in N_2O emissions reflecting spatial patterns of fertilizer application. This is showcased for Germany in Fig. 13 where highest N application rates of more than 200 kg N ha^{-1} year^{-1} in the north-west and south-east coincide with highest N_2O emissions of up to 6 kg N ha^{-1} year^{-1}. Lowest emissions were simulated for the German north-east region where sandy soils dominate which are not conducive for N_2O emissions. These national-scale simulations are available on a daily temporal scale and in 1 km² spatial resolution, so that both spatial and temporal patterns of N_2O emissions as obtained from the top-down inversion approaches can be corroborated (see Task 5.6).

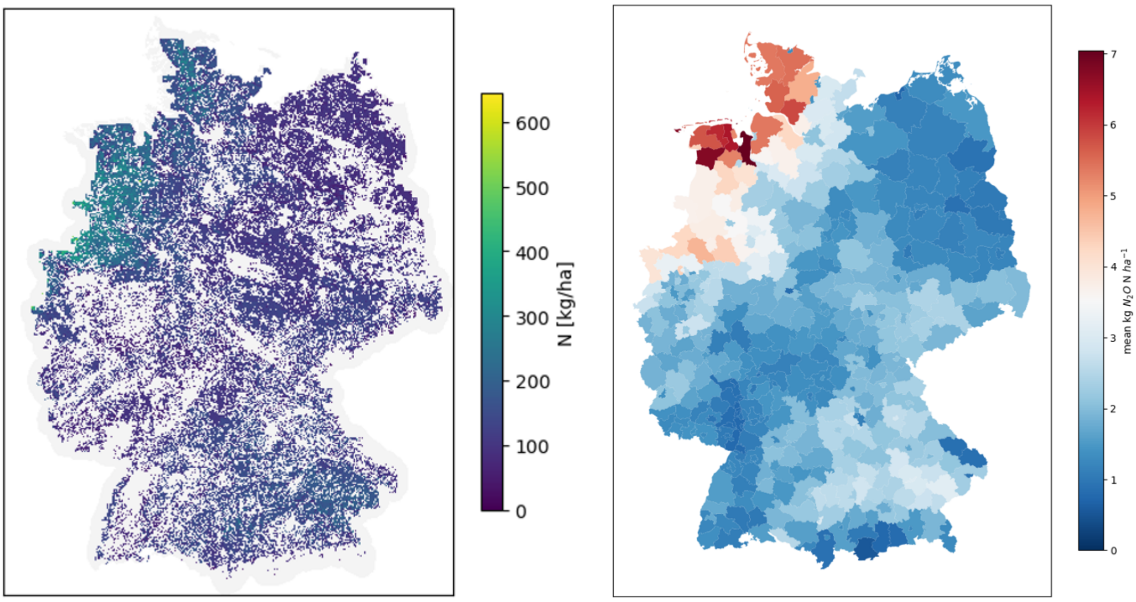

Fig. 13: Total annual N input (left) and resulting N_2O emissions (right) from agricultural soils in Germany in 2018.

TASK 5.5 TOP-DOWN NITROUS OXIDE FLUX ESTIMATION

Nitrous oxide flux estimates will be derived based on the observations collected in Tasks 5.1 and 5.2. Inversions at sub-annual and sub-national scales of N_2O fluxes will be conducted using the NAME-UB, FLEXPART-UB, NAME-MO, FLEXPART-MO, FLEXPART-EMPA, NAME-EMPA approaches. Sensitivity inversions using different a priori emission estimates (Tier 1 or 2 or 3 models) will be conducted and their impact on a posteriori emissions will be assessed. In September of each year, emissions from at least 5 multi-inversions (e.g., NAME-MO, FLEXPART-MO, etc) based on the observational data of the previous year will be derived. In October of each year, at least 2 (e.g., NAME-MO and FLEXPART-EMPA) model system will provide inversion estimates using the provisional data for first half of the current year.

Inverse model results were produced by September 2024 (milestone M20) and September 2025 (milestone M27) as input for WP2 to generate draft annex reports. The latest iteration of inversions incorporated observations from 29 monitoring sites and spanned a common period from 2016 to 2024 for all combinations of inversion systems and transport models (six ensemble members). N_2O fluxes were estimated at a 25 km by 25 km spatial resolution and monthly temporal resolution. All results were delivered in a standardised format and supported by the development of a dedicated intercomparison tool, enabling consistent cross-model evaluation. An example result, produced using the centrally hosted Jupyter Notebook at the ICOS Carbon Portal, is shown in Fig. 14. The figure demonstrates good agreement between inversion systems for Germany since 2019, whereas earlier, due a much sparser measurement network, differences between inversion were larger. For UK, France, Benelux a larger ensemble spread persisted beyond 2019.

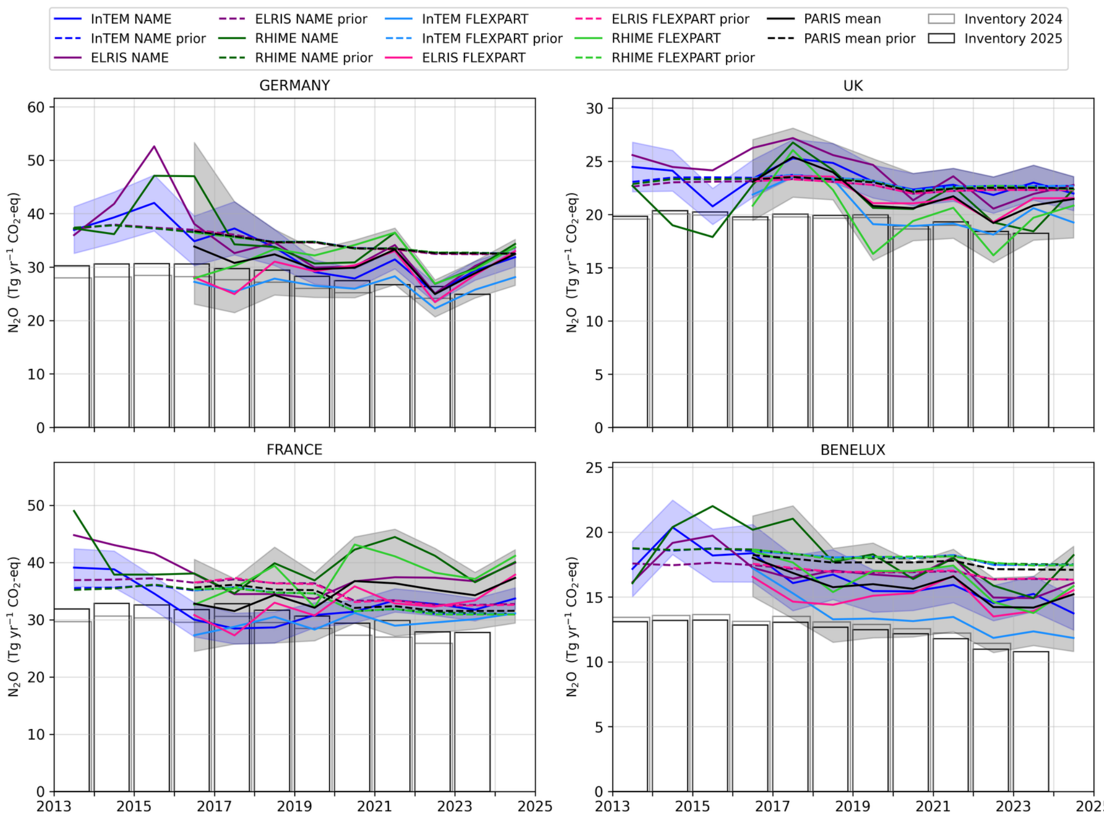

Fig. 14: Verification of the German emissions inventory estimates for N_2O. Modelled annual emissions are given as the mean from all models (black line) and the individual result from each model (colored lines). The shaded blue area is the 68 % confidence interval (CI) of InTEM-NAME and the shaded grey area encompasses the 68 % CI from all models. National inventory annual totals from 2024 and 2025 are given as grey and black bars, respectively.

A key aspect of WP5 is understanding seasonal variability between inverse modelling and biogeochemical modelling. Fig. 15 illustrates the seasonality derived by the inverse models for Germany. There is generally good agreement between the different inversion models on the timing and extent of the summer N_2O emissions peak. Year-to-year variations are likely due to variability in climatic conditions.

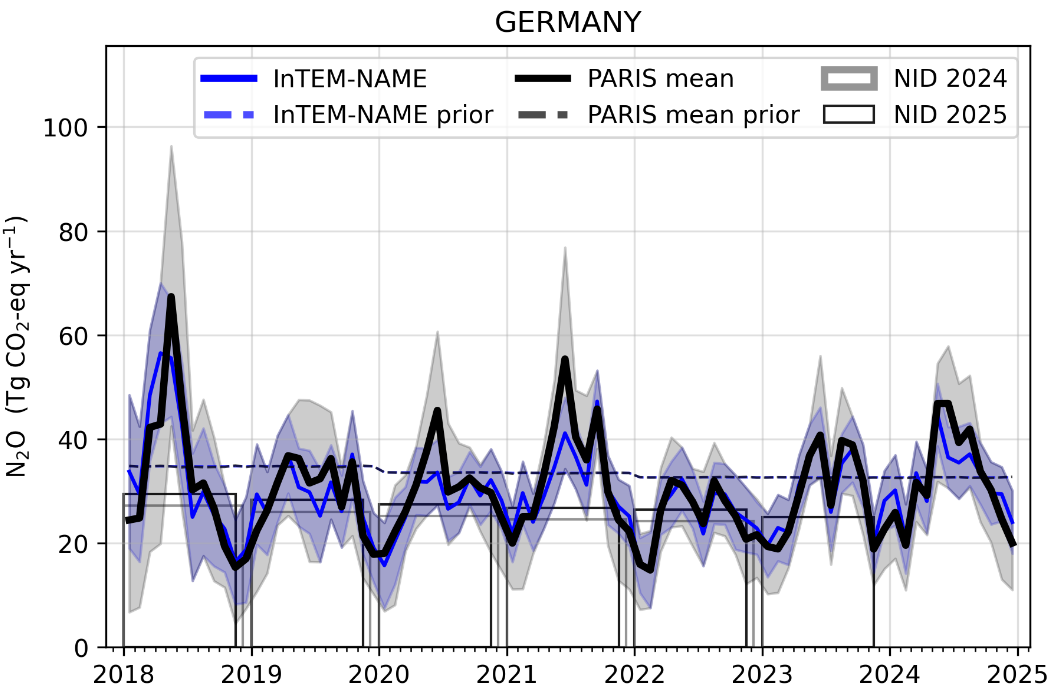

Fig. 15: Verification of the German emissions inventory estimates for N_2O (zoom in to2018-2024). Modelled monthly emissions are given as the mean from all models (black line) and the individual result from InTEM-NAME (blue line). The shaded blue area is the 68 % confidence interval (CI) of InTEM-NAME and the shaded grey area encompasses the 68 % CI from all models. National inventory annual totals from 2024 and 2025 are given as grey and black bars, respectively.

TASK 5.6 COMPARISON OF FLUXES DERIVED FROM DIFFERENT METHODS

Top-down, bottom-up and reported nitrous emissions will be compiled for focus countries and these results will be presented annually in an Annex to the National Inventory Report. Discrepancies will be discussed considering best available error estimates for both bottom-up and topdown approaches. Simulated LandscapeDNDC and DayCent emissions will also be compared to top-down estimates to further improve the models' representation of temporal and spatial variability and used to inform development of more advanced reporting methods. Stakeholders will be engaged (see also WP 2) by providing them with this information.

A first comparison between inverse estimates (Task 5.5) national scale process models (Task 5.4) was conducted. The work in this task will intensify during the final year of the project.

Preliminary comparisons for Switzerland and the DayCent model show general similarity in the seasonality of the N_2O fluxes. However, a quantitative comparison is pending and will require separating agricultural emissions other than from soils in the inversion estimates. Furthermore, updated DayCent simulations, incorporating more sophisticated climate data, are ongoing.

For LandscapeDNDC we observed a good general agreement between simulations and inversion results, but for instance for the UK, the seasonal emissions did not agree. For the UK, inversions showed unimodal distribution across the year, while biogeochemical simulations indicate a bi-modal distribution.

Ongoing work suggests that the mismatch in temporal patterns is due to the oversimplification of the fertilizer application scheme for grasslands, where the entire manure is applied in autumn. This will be followed up upon. The general agreement between simulations and top-down inversions indicates that the combination of bottom-up Tier 3 inventories with top-down inversions is a promising tool for sectorial allocation of emissions calculated from inversions.

N_2O monthly fluxes as derived by LandscapeDNDC will be use as alternative priors in the upcoming round of N_2O atmospheric inversions, replacing the default, annual-average EDGAR prior. These inversions will clarify if a combination of process-based and atmospheric observation-based fluxes can further improve emission estimates and process understanding.

1.2.6 WORK PACKAGE 6 – SEPARATION OF BIOSPHERE AND FOSSIL FUEL CARBON DIOXIDE FLUX

O6.1: Evaluate and improve European capacity for the inference of fossil fuel CO_2 from measurements of CO_2 and O_2

O6.2: Determine the detectability of changes in CO_2 sources and sinks in Europe

1.2.6.1 WP6 – EXECUTIVE SUMMARY

During the second reporting period, WP6 made substantial progress toward its objectives of improving European capability for inferring fossil fuel CO_2 emissions from atmospheric CO_2 and O_2 observations (O6.1) and determining the detectability of changes in European carbon sources and sinks (O6.2). The work focused on maintaining and expanding the atmospheric O_2 and CO_2 observation network, developing and applying inversion frameworks to derive fossil fuel CO_2 fluxes, comparing these estimates with national greenhouse gas inventories, and undertaking modelling experiments to understand the limits of CO_2 flux detectability.

In Task 6.1, UEA successfully continued high frequency O_2 and CO_2 observations at Heathfield and Weybourne throughout the reporting period. These datasets were rigorously quality controlled and uploaded to the ICOS Carbon Portal, meeting the requirements of Milestones M23 and M43 and contributing to Deliverable D6.2. Progress on the deployment of a new O_2 instrument at Zweth, operated by WU and RUG, was slower than anticipated due to staffing changes and instrument failure. Although these issues led to delays relative to Annex I, new staff have been trained, a replacement instrument is being ordered, and deployment is expected in 2026. While this delay affects the timeline of fully establishing the expanded network, it does not compromise the ability of the WP to meet its overarching scientific objectives, as work can proceed using the UK measurements and the new observations at Cabauw, developed under partner project, CORSO.

In Task 6.2 and 6.3, UEA produced updated estimates of fossil fuel CO_2 mole fraction using the combined Weybourne and Heathfield O_2 and CO_2 records together with a regional baseline estimate. UNIVBRIS used these data in preliminary inversions, as reported under Milestones M24, but the derived fossil fuel CO_2 fluxes were substantially higher than national inventory estimates. The updated inversion methodology was further discussed in Milestone M43. The causes of this discrepancy with the inventories are still unresolved and may relate to uncertainties in baseline characterisation or the influence of ocean fluxes, as highlighted in recent published analyses by UNIVBRIS, UEA and WU (Chawner et al., 2024). As a result, it was decided not to include these early inversion results in the draft Annex Reports under WP2. To ensure progress could still be monitored effectively, the Grant Agreement was amended to shift reporting to the updated milestones (M43 and M44) and Deliverable 6.3, without changing the scientific scope of the WP. This deviation ensured transparency while providing time for further investigation.

In Task 6.4, UNIVBRIS and WU completed the first round of the CO_2 “Blind Verification Challenge”, based on the protocol defined in Milestone M21. Each group produced perturbed and unperturbed CO_2 simulations, and the other group attempted to identify the scenarios through independent inversions, with each group using their own transport models. Results summarised in Milestone M25 demonstrated that inversion errors using unperturbed baseline fluxes were similar to, or larger than, the imposed perturbations. This finding has important implications for Objective O6.2, as it suggests that atmospheric transport model uncertainty can be comparable in magnitude to the CO_2 emission changes that European networks aim to detect—such as national scale sectoral reductions over the coming decades.

A second round of experiments, now also involving DWD's forward simulations from the Eulerian ICON-ART-DWD ITMS-Demonstrator (ITMS-D) alongside UNIVBRIS and WU, is planned, to deepen understanding of detectability thresholds.

Throughout this period, WP6 has faced and managed various operational risks. The delay in the Zweth instrument deployment required adjustments in planning, and staffing transitions at UNIVBRIS created pressure on delivery timelines for Tasks 6.2 and 6.4. Recruitment is ongoing, and interim mitigation measures are in place to avoid prolonged delays. Despite these challenges, WP6 remains on track to deliver its core scientific contributions to PARIS. Overall, the WP has strengthened the observational basis for fossil fuel CO_2 evaluation, advanced understanding of the limits of flux detectability, and laid the groundwork for improved top-down verification of national emissions across Europe.

1.2.6.2 – WP6 - PROGRESS SUMMARY PER WP PARTNER

University of Bristol (UNIVBRIS)

UNIVBRIS contributed to the modelling and inversion activities in Tasks 6.2 and 6.4 during this reporting period. Using the fossil-fuel CO_2 mole fraction estimates provided by UEA, UNIVBRIS produced preliminary top-down flux estimates and contributed to Milestones M24 and M43. These early inversions yielded fossil fuel CO_2 fluxes that were significantly higher than national inventory values, and the origins of these discrepancies remain under investigation. Possible factors include baseline representation and ocean-flux uncertainties, as suggested in recent joint analyses with UEA. Because of this, the results were not included in the draft Annex Reports, and the Grant Agreement was amended so progress could instead be reported through updated milestones and Deliverable D6.3.

UNIVBRIS co-led the completion of the first Blind Verification Challenge under Task 6.4, running NAME-based forward and inverse modelling experiments. Their analysis showed that inversion errors in the baseline scenario could mask flux perturbations of magnitudes relevant to European decarbonisation assessments, a finding with direct implications for Objective O6.2. Staffing changes at UNIVBRIS at the end of 2025 introduced some risk of delays to future modelling work, but recruitment is underway and interim measures are in place to maintain continuity.

Wageningen University (WU)

During this reporting period, WU contributed substantially to Tasks 6.1, 6.2, and 6.4. In Task 6.1, WU worked with RUG to prepare the new atmospheric O_2 measurement system intended for deployment at Zweth. Although instrument and staffing issues delayed the installation beyond the original Annex I schedule, WU led the troubleshooting, and a replacement instrument is now being ordered, with deployment expected in 2026. This delay has temporarily reduced the planned observational density in the Netherlands but has not materially affected the broader progress of WP6, as existing datasets from UEA allowed continued development of methods and inversion products.

In Task 6.2, WU supported the integration of O_2 and CO_2 data into the CTEurope–WU modelling system and contributed to discussions on interpreting discrepancies between preliminary fossil fuel CO_2 inversion results and national inventory estimates.

In Task 6.4, WU worked closely with UNIVBRIS to carry out the first round of the Blind Verification Challenge, generating forward simulations using the STILT model and analysing the inversion results provided by

UNIVBRIS. Their findings demonstrated that transport model errors can obscure flux perturbations of magnitudes relevant to European mitigation pathways. Overall, WU's contributions advanced understanding of the structural uncertainties in CO_2 flux estimation and provided essential modelling capacity for evaluating detectability limits, despite unavoidable delays in instrument deployment.

University of East Anglia (UEA)

UEA played a central role in Task 6.1 and Task 6.2, maintaining continuous high-quality O_2 and CO_2 measurements at the Heathfield and Weybourne stations throughout the reporting period. These data were rigorously quality controlled, uploaded to the ICOS Carbon Portal, and contributed directly to Milestones 23 and 43 and Deliverable 6.2. UEA additionally calculated fossil fuel derived CO_2 mole fractions using these measurements and baseline estimates, forming an input to the UNIVBRIS inversion work. One of the highlights of the period was the production of a robust, well documented dataset that underpinned both preliminary inversions and ongoing investigations into baseline and ocean flux uncertainties. No significant deviations occurred in UEA's work, and their steady data production has been essential for maintaining progress.

Rijksuniversiteit Groningen (RUG)

RUG's main work within this reporting period was aligned with Task 6.1, jointly with WU, focusing on the establishment of the new atmospheric O_2 instrument at the Zweth site. RUG supported technical integration, site preparation, and early-stage calibration activities.

However, progress was affected by staffing limitations and instrumental problems that delayed field deployment beyond the timeline foreseen in Annex I. These delays have had some impact on the network expansion planned under WP6, reducing the immediate availability of new APO data streams during this period. Mitigation steps included ordering a replacement instrument and setting a revised deployment timeline for 2026. RUG's continued coordination with WU has ensured that the delay does not compromise the scientific aims of WP6, as the core objectives—improving inference capacity and assessing detectability—remain achievable through continued analysis of existing UK measurements and ongoing model development. Outside of the PARIS project, RUG has delivered measurements of O_2 and CO_2 for the Cabauw station between September 2024 and March 2025 to the project through the ICOS Carbon Portal. The measurements were paused due to maintenance but will be resumed in early 2026.

Deutscher Wetterdienst (DWD)

DWD contributed primarily to Task 6.4 by developing forward-modelled CO_2 simulations that will be used in the second round of the Blind Verification Challenge. During this reporting period, DWD prepared these simulations in alignment with the established protocol from Milestone M21, ensuring they are consistent with the perturbed flux experiment design used by UNIVBRIS and WU. Although DWD's main contributions will be realised in the next reporting phase when the second challenge is executed, this preparatory work has been essential for enabling cross-model comparisons of flux detectability.

No major risks or deviations from Annex I occurred within DWD's contributions during this period. Their involvement strengthens the multi-model framework needed to quantify how transport model uncertainty constrains the capacity of European networks to detect real changes in CO_2 fluxes, directly supporting Objective O6.2.

1.2.6.3 – WP6 – TASK REPORT

TASK 6.1 – ATMOSPHERIC OXYGEN MEASUREMENTS

A new O_2 instrument will be established at Cabauw, Netherlands and run from 2024-2025. In the UK, high frequency atmospheric oxygen measurements at Heathfield and Weybourne will be extended through 2025. These new measurements will be rigorously intercompared against the long record of observations at Weybourne.

During this reporting period, Task 6.1 delivered substantial progress in maintaining and expanding the atmospheric O_2 and CO_2 measurement network required for fossil fuel CO_2 inference. The University of East Anglia (UEA) continued high frequency measurements of O_2 and CO_2 at the Heathfield and Weybourne stations throughout the period. These data were processed using established calibration routines, rigorously quality controlled, and uploaded to the ICOS Carbon Portal, contributing directly to Milestones M23 and M43 and feeding into Deliverable 6.2. The continuity and reliability of these UK measurements ensured that WP6 retained a robust observational backbone.

Parallel efforts in the Netherlands, led jointly by Wageningen University (WU) and the University of Groningen (RUG), focused on establishing a new O_2 measurement system at Zweth. Progress was hampered by unexpected staffing changes and critical instrument failure, which prevented deployment within the schedule defined in Annex I. These factors necessitated ordering a replacement instrument, resulting in a revised deployment timeline targeting 2026. Although this represents a deviation from the original plan, it has not compromised the WP's ability to advance method development and inversion testing, as the UK sites have continued to provide high quality continuous data.

Overall, Task 6.1 successfully maintained key atmospheric O_2 and CO_2 observations, ensured their integration into European data infrastructures, and laid the groundwork for the planned expansion of the measurement network. The main deviation—the delay at Zweth—has been transparently managed, with mitigation measures in place to ensure long-term continuity of the network essential for Objective O6.1. RUG and WU have delivered Cabauw measurements through the partner CORSO project, which can be used while Zweth is under development.

TASK 6.2 ESTIMATION OF FOSSIL FUEL CO2 FLUX USING CO2 AND O2 OBSERVATIONS

Using ICOS CO_2 and flask APO data and the new mini-network of continuous APO observations in the UK and Netherlands, inversions of CO_2 fluxes will be carried out using the NAME-UB and CT-Europe-WU systems. In September of each year, emissions for focus countries based on the observational data of the previous year will be derived with both inversion systems. In October of each year, the NAME-UB system will provide inversion estimates using the provisional data for first half of the current year.

Task 6.2 focused on converting the combined O_2 and CO_2 datasets into fossil fuel derived CO_2 mole fraction estimates and using these to derive top-down fossil fuel CO_2 fluxes. UEA generated updated fossil fuel CO_2 mole fractions by combining the continuous O_2 and CO_2 records from Heathfield and Weybourne with an estimate of the regional baseline. These processed data were supplied to UNIVBRIS for use in inversion systems and provided the core observational input for the reporting period.

UNIVBRIS subsequently performed preliminary inversions using the NAME-RHIME inverse modelling framework, bringing together the new fossil fuel CO_2 mole fraction product and model transport fields. As summarised in Milestones M24 and M43, the resulting fossil fuel CO_2 flux estimates were substantially higher than national inventory values for the UK. The source of this discrepancy is not yet fully understood, but likely contributors include errors in baseline representation and uncertainties associated with ocean–atmosphere O_2 exchange (Chawner et al., 2024). Because the inconsistency could not be reconciled during the reporting period, the WP agreed not to include these preliminary inversion results in the draft Annex Reports under WP2.

Instead, the Grant Agreement was amended so that progress under this task would be assessed via updated milestones (M43 and M44) and Deliverable D6.3, rather than through early annual reporting to national inventory compilers. This deviation ensured that the WP could continue to refine its inversion framework without prematurely releasing uncertain results. Despite the challenges, Task 6.2 has advanced the scientific understanding of the sensitivities and limitations of O_2-based fossil fuel CO_2 quantification and solidified the foundations for the next iteration of inversion products.

TASK 6.3 COMPARISON OF TOP-DOWN WITH UNFCCC REPORTS

> *Top-down and reported emissions of fossil fuel CO_2 will be compiled for focus countries. In these focus countries, these estimates will be compared annually in an Annex to the National Inventory Report. Discrepancies will be discussed considering best available error estimates for both bottom-up and top-down approaches. Stakeholders will be engaged (see also WP 2) by providing them with top-down estimates and identifying possible discrepancies with atmospheric observations. (UNIVBRIS, WU)*

Task 6.3 builds directly on the fossil fuel CO_2 inversion products developed in Task 6.2, comparing them with national greenhouse gas inventory submissions under the UNFCCC. As outlined in Task 6.2, discrepancies revealed in these comparisons are still being investigated and will be the focus of Milestone M44 and Deliverable D6.4.

TASK 6.4 CO_2 BLIND VERIFICATION CHALLENGE

> *The protocol will be shared with PARIS CO_2 modellers and the wider community based on the steps outlined in Section 1.2.2.5. A detailed investigation into the differences between "true" and inferred fluxes will be carried out and areas of agreement or disagreement investigated. These results will be communicated to the ICOS community.*

Task 6.4 made major progress toward assessing the detectability of CO_2 flux changes using European observation networks. During this reporting period, UNIVBRIS and WU completed the first round of the Blind Verification Challenge, following the protocol established in Milestone M21. In this exercise, each group generated perturbed and unperturbed simulations of atmospheric CO_2 using their respective models (NAME for UNIVBRIS and STILT for WU), while the other group attempted to infer which flux scenario each observation set represented through an independent inversion.

The results, documented in Milestone M25, revealed that errors in the inversions using baseline (unperturbed) fluxes were similar to or larger than the influence of the imposed flux perturbations. This is a critical finding: it suggests that model transport uncertainties can be of comparable magnitude to emission changes that Europe aims to detect over the next decades, such as substantial national level mitigation actions. These results advance Objective O6.2 by quantifying the limits imposed by model error on detectability and by identifying where improvements in transport modelling or observational density may be most impactful.

Building on these insights, a second round of Blind Verification Challenge experiments is now being prepared, this time incorporating forward simulations produced by DWD. This expanded multi-model exercise will help establish a more detailed understanding of detectability thresholds across different modelling frameworks. Task 6.4 therefore achieved all major planned milestones during this reporting period and is on track to deliver deeper insight into the feasibility of high-resolution CO_2 emissions verification in Europe.

1.2.7 WORK PACKAGE 7 – SOURCE ATTRIBUTION FOR EUROPEAN AEROSOLS

> *O7.1: Attribute sources of emissions of organic matter (OM) aerosols*
> *O7.2: Quantify European black carbon (BC) emissions at the sector level*

1.2.7.1 WP7 – EXECUTIVE SUMMARY

During this reporting period, Work Package 7 (WP7) has progressed towards achieving its objectives of understanding and attributing sources of organic matter (OM) in submicron aerosols (PM1) in Europe, particularly through continuous measurements and subsequent source apportionment in Dublin (O7.1) and quantification of European black carbon (BC) emissions via preliminary BC inversion modelling over Europe (O7.2).

Under the first objective's Task 7.2, the European sites exhibiting discrepancies between observed and modelled PM2.5 data were identified by comparing the PM2.5 from measurements with Copernicus Atmospheric Monitoring Service modelled PM2.5. This analysis revealed that background sites showed moderate to good agreement, as opposed to sites located in urban and sub-urban areas that indicated significantly worse agreement between model and measurements.

Further, to understand the reason for poor agreement, five sites (Athens, Greece; Bologna, Italy; Bucharest, Romania; Sirta, France and Carnsore Point and Dublin, Ireland) with varying land use characteristics were chosen for detailed source apportionment (SA) study. The SA results revealed organic aerosols (OA) sources such as peat, coal, wood, hydrocarbon-like OA (HOA), biomass burning OA (BBOA), cooking-OA (COA), biogenic aerosols, less oxidised oxygenated OA, and more oxidised oxygenated OA.

These results were compared with the estimates from Community Multiscale Air Quality (CMAQ) and Weather Research and Forecasting - Comprehensive Air Quality Model with Extensions of chemistry (WRF-Chem) models in nested mode at high resolution (12km – 3km). Overall, the CMAQ was overestimating the PM2.5 and its chemical components while the WRF-Chem was underestimating both the OM and BC values. The CMAQ also overestimated the black carbon (BC) and OA components compared to the measurement data across all sites. The overestimation potentially spans from misrepresentation of some sources in the emission inventories and coarse grid modelling result comparison with the source apportionment from point measurements in addition to model uncertainties. Reasons for these discrepancies are being investigated further, by running higher resolution models to improve the emissions attribution to specific grid point where the measurements were conducted as well as examining the impacts from different sector emissions to the modelling results.

Moreover, two joint deliverables (changed accordingly to the first amendment) of this work package with the EYE-CLIMA project were advanced under the second objective O7.2, Task 7.3: preliminary emissions and uncertainties of black carbon (BC) for Europe using the FLEXPART-FLEXINVERT inversion framework, and final emissions and uncertainties of BC with co-optimisation of scavenging coefficients for the period 2015-2023 were estimated using the FLEXPART-FLEXINVERT framework.

Substantial progress has been made towards completing the Task 7.3 and developing the FLEXPART-FLEXINVERT framework for co-optimisation of scavenging coefficients, as well as configuring the inversion framework for BC, utilising harmonised BC observations from 14 measurement sites within the EBAS network. Preliminary inversions for the year 2022 were conducted using this framework and subsequently reported. To provide final estimates of BC emissions, a novel co-optimisation method was developed and implemented in the FLEXINVERT framework.

1.2.7.2 – WP7 - PROGRESS SUMMARY PER WP PARTNER

National University of Ireland Galway (NUIG)

During this reporting period, the University of Galway has identified five sites that showed discrepancies between measurement and model data. Performed source apportionment of organic aerosols in these sites, which revealed various major and minor sources. This source apportionment result was compared with the output from two chemical transport models to understand the variations between model and measurement results. For this purpose, CMAQ and WRF-Chem were run in high resolution nested mode. The model vs. measurement comparison showed discrepancies in black carbon levels and organic aerosol sources, which can be attributed to several reasons such as the gridded model result vs point measurement, uncertainties in emission inventories, sectoral source allocation and urban physics scheme or excessive vertical mixing in the planetary boundary layer scheme. An in-depth investigation of the causes for discrepancies is in progress.

In addition, the data collection, archiving and dissemination was performed during this reporting period. In Dublin, continuous Aerosol Chemical Speciation Monitor measurements were continued, and the validated organic aerosol datasets were successfully archived in the EBAS database, making it publicly accessible. A detailed metadata and standardized data files were prepared and submitted to facilitate data discovery and interoperability.

University of Urbino (UNIURB)

Activities have focused on developing and implementing the FLEXPART-FLEXINVERT inversion system in collaboration with EYE-CLIMA partners. Initially, the inversion system was configured for the European domain with a newly implemented log-normal error distribution capability, and preliminary results were obtained. A comparison of the monthly inversion-derived emission estimates with bottom-up inventories revealed significantly higher emissions in central-northern Europe during March 2022. Subsequently, the inversion results were compared with emission estimates from the AVENGERS project, and the findings were published (PARIS Newsletter; Annadate et al., 2025).

For wet-scavenging coefficient optimisation, five BC tracer particle species were introduced into the FLEXPART transport model. Additionally, the number of measurement sites incorporated in the inversion was increased to 23. The FLEXINVERT system was further developed to introduce a scheme for co-optimisation of scalars along with emissions. To date, several sensitivity tests have been performed using the updated inversion framework, yielding optimised scavenging coefficients. However, the optimised coefficients do not differ significantly from the initial values. This newly developed capability can be applied to optimise wet-scavenging parameters for other aerosol species using FLEXINVERT. The estimation of final emissions for the period 2015-2023 is currently ongoing and has been delayed by a few months, mainly because of extremely long run time of the transport model and newly developed inversion algorithm for co-optimisation of scavenging scalars.

1.2.7.3 – WP7 – TASK REPORT

TASK 7.1 – ORGANIC MATTER AEROSOL SOURCE APPORTIONMENT

> *To identify regions with prominent discrepancies between observed and simulated bulk aerosol concentration, the regional modelling products of Copernicus Atmospheric Monitoring Service (CAMS) will be compared to ACTRIS measurements. At five locations where discrepancies are identified, source apportionment of PM1 aerosol will be performed, to quantify primary versus secondary and anthropogenic versus natural flux contributions and identify major sources contributing to aerosol concentrations. This investigation will cover a one-year period for the five locations and for the full period for new Dublin data.*

During this reporting period, sources of organic aerosols in 5 sites in Europe were identified based on measurement and source apportionment data. Improved source apportionment model (developed for Dublin site) was applied to other European sites where discrepancies between CAMS model and measurements were identified. Firstly, PM2.5 data available from ground-based stations across Europe were statistically analysed by comparing their 24-hour average PM2.5 data with CAMS derived PM2.5. The analysis revealed weak correlations ($r = 0.07$ to 0.33) at urban sites while moderate correlations ($r = 0.41$ to 0.59) were recorded at sites with background characteristics.

To understand the reason for the poor correlation, a detailed source apportionment of organic aerosol was conducted using positive matrix factorisation and compared with source results from WRF-Chem and CMAQ models (Task 7.2 below).

Results of the source apportionment conducted at 6 sites (Athens, Bologna, Bucharest, Carnsore Point, Sirta, and Dublin) revealed OA sources such as peat, coal, wood, biomass burning OA (BBOA), hydrocarbon OA (HOA), cooking-OA (COA), less oxidised (LO-OOA), and more oxidised (MO-OOA) aerosols (Fig. 16).

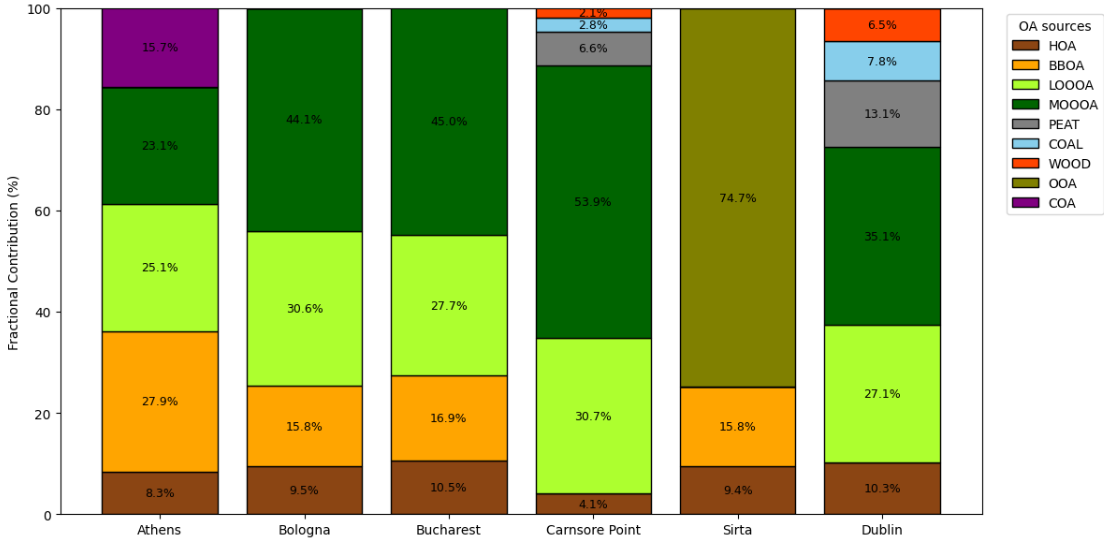

Fig. 16: Fractional contributions of organic aerosol sources in the 5 European sites (Athens, Bologna, Bucharest, Sirta and Carnsore Point) as well as the Dublin site.

All the organic aerosol sources except MO-OOA, LO-OOA and biogenic OA are identified as primary OA factors. At each site, standard protocol for running PMF was followed and the number of sources/factors was decided based on both statistical and physical meaningfulness. Identification of optimal number of sources at each site was guided by multiple criteria, including the diurnal residual patterns of key marker species, and correlation of factors with external tracers such as BC, NOx, humidity, temperature, etc.

The presence of HOA can be attributed mainly to vehicular emissions, which were observed in all sites, contributing from 4.1% (Carnsore Point) to 10.5% (Bucharest) of OA. This shows that an urban site like Bucharest experiences a high influence from traffic contribution while background Carnsore point site has lower contribution form HOA.

A substantial BBOA/wood fraction was observed in Greece (28%) and Bucharest (17%), which underscores the influence of residential wood burning, a major source during colder months. The wood profile possesses a high contribution from mass to charge ration m/z 60, a key tracer of Levoglucosan, that is released during pyrolysis of wood. A good correlation between BBOA and BC from wood burning was observed.

Presence of peat, coal and wood burning at Carnsore point suggests seasonal residential heating patterns and possibly episodic biomass burning events in rural areas. In Dublin, the organic aerosol source contribution followed the trend of MOOOA (35%) > LOOOA (27%) > Peat (13%) > HOA (10%) > Coal (8%) > Wood (7%). Overall, this analysis highlights the presence of both primary and secondary aerosols in all sites. The secondary OA such as LO-OOA and MO-OOA dominated the OA composition, contributing (~60%) of total OA mass.

TASK 7.2: ORGANIC MATTER AEROSOL SOURCES UTILISING REGIONAL MODELLING

> *At the locations where source apportionment has been performed, an online-coupled meteorology and chemistry model that allows speciation of aerosol (including organic matter), WRF-Chem, will be run in nested mode at high resolution (9km – 3km) over regions/ periods of interest using the emission inventories. Sector emission sensitivity studies (by scaling down/enhancing specific emissions) will be performed to identify sectors that could contribute to discrepancies with the speciated ambient aerosol concentrations from Task 7.1. The impact from the missing fluxes on regional climate due to short-term radiative forcing will be assessed.*

In the modelling component of this work, the WRF-Chem model was successfully set up (Fig. 17) and tested for the coarser domain covering the whole Europe and sites in question. The model was configured to simulate organic carbon and black carbon at resolution of 12 km with 35 vertical atmospheric layers.

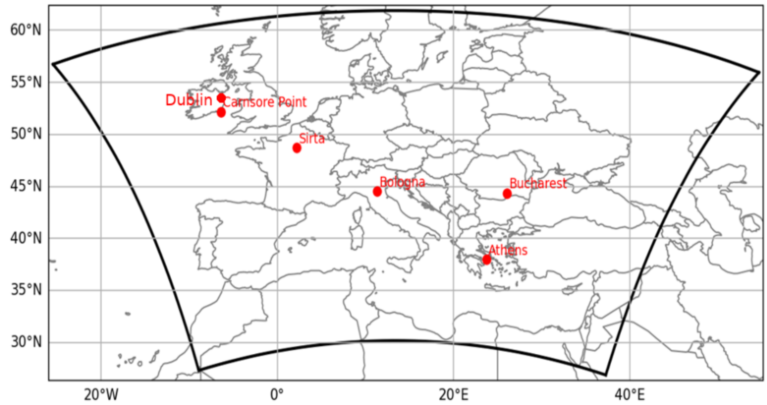

Fig. 17: WRF -Chem model domain to simulate organic carbon (OC) and black carbon (BC), showing the focus sites.

Anthropogenic emissions were obtained from the CAMS global inventory at a 10 km resolution, while biogenic emissions were obtained from MEGAN. Fire emissions were included using the FINN dataset. Meteorological initial and boundary conditions were derived from ERA5 reanalysis data. The model also incorporated detailed representations of cloud microphysics, boundary layer mixing, and radiative processes through the Morrison microphysics scheme, the YSU planetary boundary layer scheme, and the RRTMG radiation scheme. Initial and chemical boundary conditions were taken from WACCM model.

The WRF-Chem model setup described above was used to simulate OC and BC over the European domain, with particular focus on six observational sites. The simulations were conducted using the MOZART–MOSAIC aerosol scheme coupled with the volatility basis set approach. Two chemical configurations were tested: one including aqueous-phase chemistry and one without the aqueous chemistry. Preliminary results indicate that the WRF-Chem model successfully reproduces key meteorological parameters, including temperature (r = 0.8), relative humidity (r = 0.7), etc., as compared to available observational data. This suggests that the meteorological configuration of the model is robust. Further, measurement data such as organic aerosols and black carbon were compared with the estimates from WRF-Chem (Fig. 18). In addition, to better understand inventory vs model's physics influences, CMAQ (the Community Multi-scale Air Quality (CMAQ) – ISAM) simulations were performed at 27 × 27 km resolution for all sites, whereas finer resolutions (9 × 9 km and 3 × 3 km) were performed only for Dublin at this stage. Higher resolution runs for all sites will be performed in the next iteration.

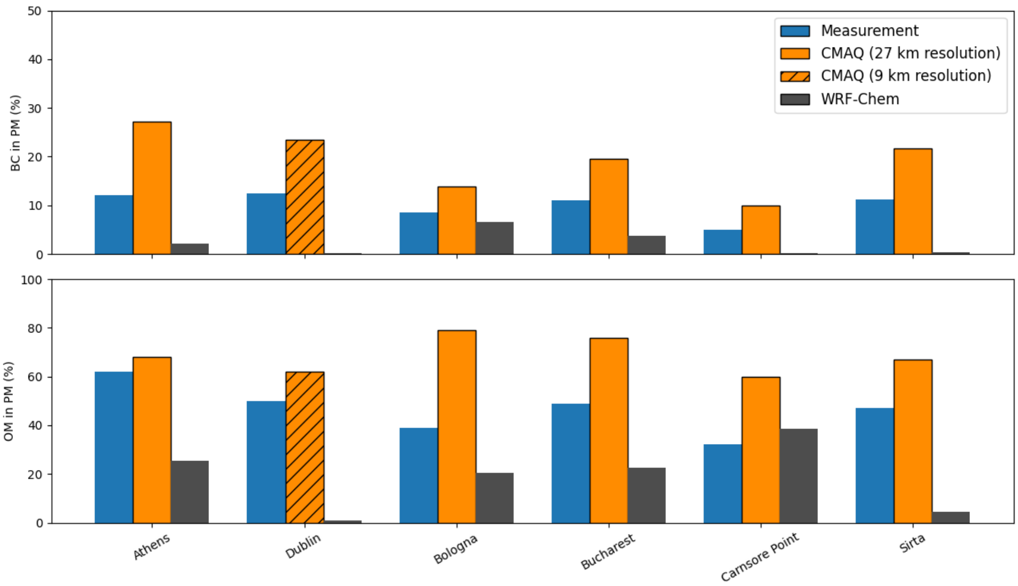

Fig. 18: Relative comparison between measurement and WRF-Chem and CMAQ model data for OM and BC over the focus sites for Jan 2023.

The measurement data included black carbon obtained from Aethalometer and organic aerosols from aerosol chemical speciation monitor. Fig. 18 shows the percentage of BC and OM fraction present in the PM2.5. It was observed that the CMAQ model overestimates the BC compared to measurements across all sites, with the largest bias in Athens (27% vs 12%) and Sirta (22% vs 11%). Overestimation of BC by CMAQ model can be attributed to the coarse grid resolution, uncertainties in emission inventories and other factors that will be examined further. Similarly for organic aerosols, CMAQ predicts higher contributions than measurements, notably in Bologna (79% vs 39%) and Bucharest (76% vs 49%), pointing to an over-representation of organic aerosols.

The comparison with WRF-Chem model revealed considerable model underestimations for Dublin and Sirta, which are urban and suburban sites. This underestimation may be attributed to uncertainties in boundary layer processes and emission inventories. It was observed that, when the aqueous chemistry was excluded, the modelled concentrations of OC and BC were highly underestimated relative to observations, indicating potential uncertainties in primary aerosol emissions or aerosol processes. However, model simulations that included aqueous chemistry did not improve the agreement or representation of secondary aerosol species. This indicates a problem with the current treatment of the aqueous-phase processes in the model. Ongoing work with WRF-Chem focuses on improving aerosol estimation and extending the analysis to include all processes to account for secondary aerosol species.

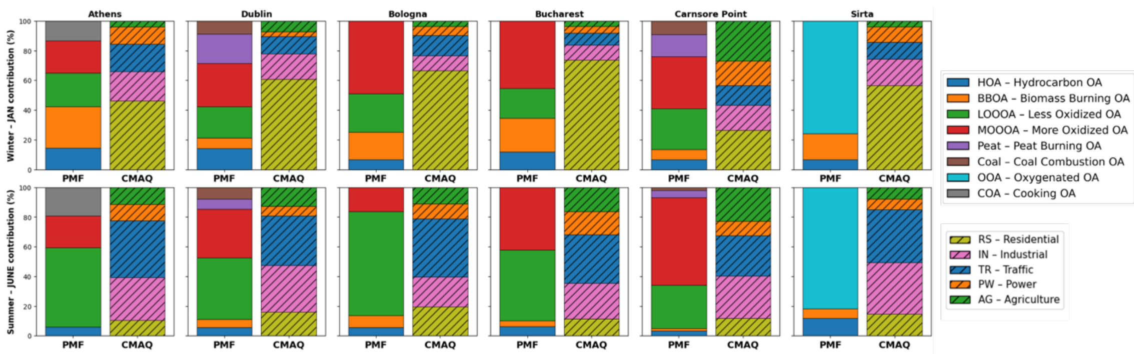

Fig. 19: Relative comparison of organic aerosols sources estimated using measurement data and CMAQ model (Period: winter - JAN 2023 (top) and Summer JUNE 2023 (bottom).

Furthermore, the PMF resolved sources of organic aerosols were compared with the CMAQ resolved sources (Fig. 19). The source categories resolved by CMAQ were residential, industrial, traffic, power and agriculture, while the source categories resolved by PMF were discussed in the earlier sections. In winter, the PMF-resolved HOA (~ 6 to 15%) closely corresponds to the CMAQ traffic contribution (~ 8 to 19%) across all sites.

Primary factors resolved by the PMF, such as Biomass, Peat and Coal burning, cooking OA, combined with parts of secondary sources arising from residential heating (Lei et al., 2025), agree quite well with the CMAQ residential sector contribution of 20-60% in winter and 5-20% in summer, although CMAQ might be overestimating this contribution. The results also suggest that cooking emissions were largely embedded within residential source categories in the model. Further tests and comparisons between sources as well as sector sensitivity is ongoing.

Agricultural sector contribution was largely missing from the PMF results, while CMAQ indicated up to 20% contribution calling for in-depth analysis and sector sensitivity studies. To address this, CMAQ model will be run at 9km resolution for all sites and then compared with the PMF results, moreover, sector sensitivity by switching on and off the sources will be performed. These findings underscore the importance of comprehensive source apportionment analysis to identify both the primary and secondary sources of aerosols with the models. This study can help to refine the emission inventories and improve the regional air quality modelling across Europe.

TASK 7.3 (AMENDED): ESTIMATION OF EUROPEAN BLACK CARBON FLUXES

BC emissions from Europe will be estimated based on Observations from 13 ACTRIS sites using the Bayesian inversion framework FLEXINVERT. First, preliminary results will be derived for the whole European domain for 2022. Then, the methodology will be refined with a co-optimisation of the scavenging coefficients to estimate European fluxes from 2015 to 2023. These estimates will be compared to bottom-up inventories of BC emissions.

Modelling work for obtaining preliminary BC emissions from Europe for 2022 using 13 ACTRIS/EMEP sites has been completed. For this work, harmonised BC atmospheric concentration data and BC prior inventory (LRTAP) were provided by the EYE-CLIMA collaborators. Aerosol absorption coefficient data measured by 7-wavelength filter absorption photometers (Magee, AE33) were converted to equivalent black carbon using mass absorption cross sections derived from co-located elemental carbon measurements where available or using default instrument values. FLEXPART model runs performed for the 13 stations were driven by the ECMWF (ERA5) meteorological fields with a horizontal resolution of 0.5˚. Multiple sensitivity inversions were performed using different prior inventories, seasonal and a season-al priors, altitude-based observation selection, and exclusion of urban stations. Inversion estimates for European BC using 13 measurement stations obtained for different sensitivity tests are shown in Fig. 20. Comparison of monthly BC emissions from inversions with bottom-up estimates revealed significantly elevated emissions in March 2022.

Substantial model development efforts were carried out for introducing a new co-optimization method for wet scavenging coefficients with EYE-CLIMA modelling group. The work to introduce this new method in the FLEXINVERT+ framework is completed. Additionally, the FLEXPART model was introduced with 5 species to separate wet deposition from different scavenging pathways. In the inversion system, the state vector was appended with four scavenging scalars, and the cost function was modified to produce optimized scavenging scalars. Multiple tests were performed to test the algorithm and to obtain the optimized BC wet scavenging parameters. The work for producing European flux estimates for 2015-2023 is underway. The comparison of final long-term estimates with the bottom-up inventories are on-going and will be finished before the end of March 2026.

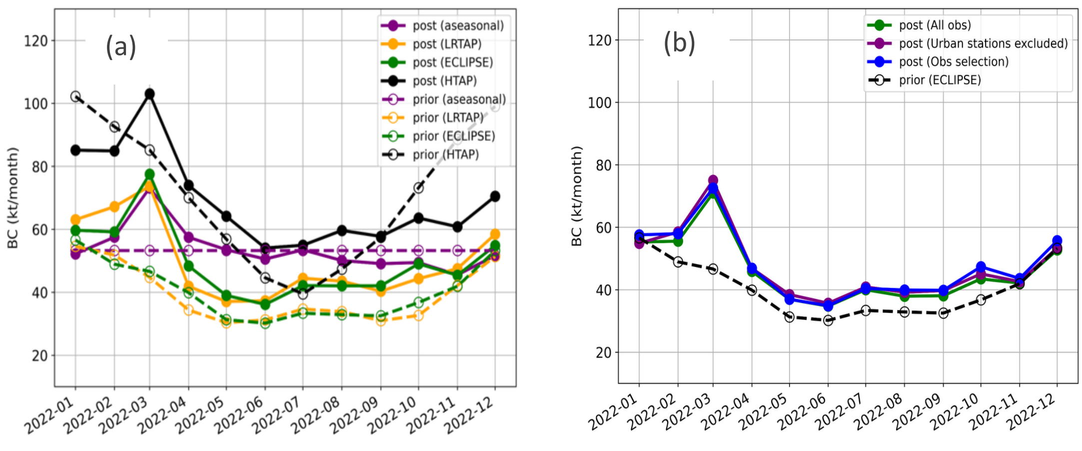

Fig. 20: Comparison among (a) prior (dotted lines) and posterior emissions (solid lines) for different prior emission inventories, and (b) posterior emission estimates for different observation selection criteria.

1.3 IMPACT

Since the previous reporting period, PARIS has moved from establishing core capabilities towards demonstrating sustained, repeatable application of atmospheric observations and modelling in an inventory-relevant context. While last year's impact report emphasised network establishment, harmonisation and methodological development, the current reporting period shows progress in operational continuity, multi-year analyses, structured intercomparison, and deeper, more systematic engagement with national inventory compiler teams. The scientific outputs are now more directly aligned with inventory and policy needs.

BUILDING AND EXPANDING INFRASTRUCTURE

During the first reporting period, PARIS focused on establishing key observational infrastructure, particularly for F-gases and APO/O_2 measurements. New continuous F-gas observation sites were installed in Germany (Taunus), Southern Italy, Norway and Hungary, addressing major spatial gaps in southern and eastern Europe. Continuous APO measurements were maintained at UK sites, and preparations began for a new site in the Netherlands. On the modelling side, shared data formats and evaluation tools were put in place to support future intercomparisons.

In the current period, these infrastructures have transitioned from setup to sustained operation. The new and upgraded F-gas sites are now fully integrated into AGAGE and ICOS data streams, delivering quality-controlled, publicly archived time series that are routinely used in inversion studies. For N_2O, continuous tall-tower observations at Hegyhátsál have been established as a long-term backbone for eastern Europe, with historical data reprocessed to ensure consistency. Methane isotope infrastructure has expanded from pilot deployments to multi-site, high-frequency measurements across several countries, while aerosol and BC observational datasets have been consolidated and archived in EBAS.

On the modelling side, national-scale biogeochemical models (DayCent and LandscapeDNDC) and multiple inverse systems are now running routinely for multi-year periods, enabling systematic reconciliation exercises. Some planned infrastructure (e.g. additional APO/O_2 site) experienced delays, but mitigation measures ensured continuity of method development by using data of closely located stations. Overall, the emphasis has shifted from infrastructure creation to consolidation, continuity and reuse.

B) HARMONISING MEASUREMENTS AND EXPANDING NETWORKS

The previous report highlighted major progress in harmonising measurements, particularly for F-gases and N_2O. Common calibration scales, standardised quality control procedures, and harmonised data formats were introduced. For methane, the project reported substantial progress in isotope capability, including portable and continuous systems, described as achieving very high coverage relative to the global state of the art.

During the current reporting period, harmonisation efforts have been extended and embedded across work packages. Harmonised N_2O datasets now combine ICOS and non-ICOS observations into a consistent European record suitable for inversion modelling. Methane isotope, ethane, and mole-fraction measurements are increasingly processed within shared workflows and validated against reference instruments, improving internal consistency.

Network expansion has continued in a targeted manner (e.g. additional isotope-capable CH_4 sites, flask sampling for F-gases, expanded BC datasets), but with a clearer recognition of remaining gaps. Compared to last year, the project now places greater emphasis on documenting uncertainties and limitations arising from network density, rather than on coverage alone. The harmonised datasets are now actively used in multi-model analyses rather than primarily prepared for future use.

C) ALIGNING MODELS AND FRAMEWORKS

Previously, alignment efforts focused on establishing common data flows, initiating intercomparison tools on the ICOS Carbon Portal, and conducting early comparison exercises across gases. Initial inversions (e.g. methane using InTEM) were completed, and preparatory work began on process-based models and APO-based fossil fuel CO_2 evaluation. A blind verification challenge for CO_2 detectability was launched.

In the current period, these modelling frameworks have been applied systematically across multiple gases, countries and years. Multiple inverse systems and transport models are now routinely compared using shared protocols and the fluxy intercomparison framework. For methane and F-gases, aligned multi-model inversions cover more than a decade in some cases. For N_2O, monthly flux estimates from several inversion–transport combinations are directly compared with Tier 3 process-model outputs on consistent temporal scales.

More advanced attribution approaches—such as isotope-informed methane inversions, O_2-based fossil fuel CO_2 estimation, and aerosol source attribution combining PMF and inversion—have progressed to more structured set-ups with a greater emphasis than last year on identifying unresolved issues (e.g. transport errors, source signature uncertainty, baseline representation).

D) ENGAGING WITH INVENTORY COMPILER TEAMS

In the first year, engagement with inventory compilers was emerging and exploratory. Initial results were shared with the inventory teams, templates for national annexes were developed, and first annexes were anticipated for delivery in late 2024. The emphasis was on reducing barriers and initiating dialogue.

Engagement has now matured into a structured, iterative process for several gases. Country-specific annexes comparing top-down estimates with UNFCCC inventories have been delivered and discussed for multiple countries and years, particularly for methane, F-gases and N_2O. Feedback from inventory teams has directly informed methodological refinements, presentation formats and uncertainty communication.

For more experimental components (e.g. fossil fuel CO_2 separation, sector-level methane attribution, aerosol inversions), engagement has focused on explaining capabilities and limitations. Compared to last year, the interaction has shifted from expectation-setting to co-interpretation, while remaining cautious about claims of readiness for routine inventory inclusion.

E) COLLABORATION EFFORTS AND FUTURE STEPS

The project reported extensive collaboration with sister projects (EYE-CLIMA, AVENGERS), international networks (AGAGE, CAMS), and external partners. These collaborations supported data sharing, tool development, and early methodological advances, and were framed as a foundation for future impact.

These collaborations have continued and become more tightly integrated with core project outputs. Joint intercomparisons, shared modelling experiments, and coordinated engagement with inventory stakeholders have been intensified. Tools and datasets developed within PARIS are increasingly used beyond the project itself and support the uptake within the wider European research community.

Looking forward, the project's focus has narrowed to sustaining key observations, refining uncertainty characterisation, and maintaining dialogue with inventory teams beyond the project lifetime.

Relative to last year's impact report, PARIS has progressed from establishing capabilities to demonstrating sustained application and structured evaluation. The scientific impact has become more concrete through multi-year analyses, documented intercomparisons and an increasing number of publications, while societal and policy relevance is increasingly reflected in informed engagement with inventory compilers. Unfortunately, there is no realistic pathway to sustain long-term involvement beyond PARIS due to a lack of financial support.

1.4 UPDATE OF THE PLAN FOR EXPLOITATION AND DISSEMINATION OF RESULTS

The strategy for communication, dissemination and exploitation is described in detail in the Grant Agreement (Chapter 2.2) and the Dissemination & Exploitation Plan (D1.4). The outreach strategy of PARIS aims to inform relevant target groups, actively disseminate project results, and support the exploitation of project outputs. This strategy remained unchanged during the second reporting period (D1.5). The present chapter provides an update on the main outreach activities building on those reported previously.

During the second reporting period, the PARIS consortium produced Annexes to the National Inventory Documents for 2024 and 2025. This activity is described in detail in the work progress for WP2 (Chapter 1.2.2). The annexes form part of the project deliverables and are publicly available on the PARIS website (https://horizoneurope-paris.eu). Making these annexes openly accessible ensures transparency and allows policymakers, researchers, and other stakeholders to directly benefit from PARIS outputs. In addition, PARIS disseminates project products, datasets and peer-reviewed publications via the ICOS Carbon Portal (https://data.icos-cp.eu/portal/#{%22filterKeywords%22:[%22PARIS%22]}), the EBAS portal (https://ebas-data.nilu.no/Default.aspx), and also the PARIS website. This multi-platform dissemination strategy enhances visibility and promotes the uptake of high-quality data across the European research and policy community.

Knowledge exchange is fostered through personal interactions at and contributions to several meetings and conferences (e.g., EGU, NCGG, ICOS) joint field campaigns, and dissemination activities such as journal and conference contributions. Collaboration with the sister projects EYE-CLIMA and AVENGERS has been actively encouraged. As a result, PARIS participated in 3 joint webinars (https://horizoneurope-paris.eu/meetings/), organised by AVENGERS, and initiated 4 joint newsletters (https://horizoneurope-paris.eu/newsletters-and-project-stories/), published on the project website and also distributed by email (Copernicus ECMWF). These joint initiatives strengthen cross-project synergies, provide timely updates on scientific progress, and support community building among researchers across Europe.

PARIS has established a network of nearly 50 Early Career Researchers (ECRs) across the three projects and has facilitated regular meetings among them. To date, 14 ECR meetings have been held across the two reporting periods, circulated chaired by the ECRs. The ECR network fosters early-stage scientific collaboration, knowledge sharing, and professional development. As most ECRs are now in a later stage of their projects, the continuity of the meetings will be discussed for the final year.

Following the success of the first splinter meeting at EGU 2024, a second splinter meeting was organised at EGU 2025 (https://meetingorganizer.copernicus.org/EGU25/session/54609). During this meeting, the fluxy tool was presented as a key PARIS output (https://github.com/openghg/fluxy; https://horizoneurope-paris.eu/fluxy-a-new-tool-for-comparing-greenhouse-gas-fluxes-from-inversion-models/). The demonstration of fluxy at the EGU highlights PARIS' contribution to advancing transparent and reproducible multi-model greenhouse gas analyses, facilitating adoption by both research and inventory communities.

Social media activities remain a lower priority. Instead, dissemination focuses on coordinated presentations of the sister projects PARIS, EYE-CLIMA and AVENGERS at international scientific conferences. In this context, the UK partners produced a short promotional video describing PARIS and its contribution to the science underpinning greenhouse gas emission tracking (https://www.youtube.com/watch?v=DkzbJtnLg-s). This video serves as a clear, accessible resource for wider audiences, raising awareness of PARIS' scientific outputs and their relevance for climate policy.

During the first reporting period, PARIS took the lead in increasing the visibility of the project group at the European policy level. In the second reporting period, this has been continued. PARIS was invited for a second presentation at the Working Group 1 meeting in Brussels in October 2025, providing an opportunity to present key results, engage with Member States and highlight activities across PARIS, EYE-CLIMA and

AVENGERS. This engagement strengthens the link between science and policy and demonstrates PARIS' role in supporting evidence-based decision-making at the European level.

In addition, all three projects were presented, in collaboration with CMCC, at the COP2026 in Belém, Brazil (https://www.cmcc.it/lectures_conferences/what-you-cant-measure-you-can't-manage-improving-ghg-estimation-for-informed-climate-policy). Participation in COP2026 underscores the global relevance of the outputs of PARIS and its sister projects and highlights the project's contribution to improving greenhouse gas monitoring for international climate action.

2. FOLLOW-UP OF RECOMMENDATIONS AND COMMENTS FROM PREVIOUS

The Scientific Advisory Board has been updated during the 3rd Annual Meeting. The members unanimously acknowledged the substantial progress achieved by PARIS and the large volume of work delivered to date.

The project is considered fully on track, with particularly impressive advances in measurement density, modelling capability, and systematic intercomparison activities. Tools such as FLUXY, the close engagement with national inventory compilers, and the production of data annexes to National Inventory Reports were highlighted as major achievements, demonstrating both scientific excellence and policy relevance. At the same time, the SAB noted concerns regarding the sustainability of these activities beyond the project's duration and available resources, underscoring the importance of early legacy planning.

The SAB emphasized that PARIS is making significant contributions to both scientific understanding and policy-relevant emission assessment. Strong engagement with inventory teams, supported by robust observational and modelling outputs, has already generated increasing interest from policymakers and international organisations. The SAB identified a clear opportunity to further expand visibility beyond the scientific community, particularly through targeted engagement with EU institutions and global stakeholders.

Several strategic recommendations were provided to strengthen impact and long-term value. These included expanding outreach to policymakers, improving data accessibility through user-friendly visualization tools, strengthening uncertainty communication through clearer documentation and constructive framing, fostering international collaboration with key global partners, and developing clear guidance for non-expert users of FLUXY. The SAB also recommended consolidating results from PARIS and related projects into a strategic presentation for Directorate-General–level engagement, maintaining active communication with policy-focused institutions such as the European Environment Agency (EEA), and actively leveraging discrepancies between top-down and bottom-up emissions to stimulate scientific discussion and enhance credibility with inventory teams.

Meaningful progress has been made in implementing these recommendations. Outreach beyond the scientific community is ongoing, including regular engagement with inventory teams and presentations to the EEA, with results such as German SF_6 analyses already having a broad impact. Data accessibility continues to improve through the active development of FLUXY, with discussions underway on post-PARIS pathways to sustain the tool. Model documentation for PARIS inversions has been completed, representing an important step toward more transparent uncertainty communication, although further work remains. Efforts to develop guidelines for non-expert FLUXY users are ongoing, and opportunities for international collaboration with partners such as the US and China are being explored in upcoming activities.

Work is also underway to consolidate results from PARIS, AVENGERS, and EYE-CLIMA into a strategic, high-level presentation, with plans for early-summer engagement potentially involving CINEA or the EEA. Targeted outreach to policy institutions has continued, including presentations to the EEA in 2025 and potential follow-up in 2026. Demonstrations of inversion systems and tools to external stakeholders remain a priority, although further expansion will depend on follow-on funding. Importantly, the active use of top-down versus bottom-up emission discrepancies in discussions with inventory teams is already well established and ongoing, contributing directly to scientific dialogue and increased confidence in results.

Overall, the SAB concluded that PARIS has achieved exceptional scientific progress and established a strong foundation for sustained policy relevance. Continued emphasis on communication, international engagement, institutional embedding, and long-term funding will be essential to secure the project's legacy and maximize the long-term value of its tools, datasets, and methodologies.

Table 2 gives an overview of previous SAB recommendations and their progress, as presented during the Annual Meeting in January 2026. The project has successfully addressed the SAB recommendations from the first year, demonstrating strong progress in scientific outputs, stakeholder engagement, and policy relevance. Key areas for ongoing focus include sustainability beyond the project's duration, refinement of uncertainty communication, and expansion of international collaboration and visibility among policy makers.

Table 2: SAB recommendations after the first reporting period and their progress

Recommendation	Progress
Expand outreach to policy makers	Ongoing: Presentations to inventory teams and EEA; German SF_6 findings have had wide impact.
Improve data accessibility by developing visualisation tools	FLUXY under continuous development; post-PARIS opportunities being explored.
Enhance uncertainty communication e.g. by documentation and constructive framing	Model documentation for PARIS inversions completed; further work ongoing.
Foster international collaboration	Potentially feasible in upcoming work.
Develop clear guidelines for non-expert users for fluxy	ongoing
Consolidate results into strategic presentation, e.g. at DG-level	Ongoing; exploring option for early summer, considering involvement of CINEA/EEA.
Maintain active communication and knowledge sharing	Presentations to EEA scheduled for 2025, exploring options for 2026; seeking follow-on funding for tool demonstrations.
Leverage top-down vs. bottom-up discrepancies	Actively ongoing, stimulating scientific discussion and enhancing credibility.

3. EXPLOITATION PRIMARILY IN NON-ASSOCIATED THIRD COUNTRIES

Not applicable

4. OPEN SCIENCE

The Open Science strategy of PARIS has not changed. PAIRS commits to the FAIR principles, referring to data but also metadata and any other outcome. Arrangements with the ICOS Carbon Portal have been made to deposit data, archive it, and make it available according to the FAIR principles. All data will be distributed under a CCBY4 data license (see https://www.icos-cp.eu/data-services/about-data-portal/datalicense). Metadata is licensed as public domain (CC0). For WP7, the Dublin site is registered on EBAS and new aerosol data will be deposited there in a similar manner to previous campaigns/project data for this site.

To ensure data findable, any dataset will have assigned a Handle PID that resolves into a landing page with a qualified link to the dataset. DOIs can be minted also for example for collections of data through the ICOS Carbon Portal (see https://doi.icos-cp.eu/) and are linked to the datasets through the Handle PID. Before uploading to the ICOS Carbon Portal, the data will be curated by experts from the ICOS Carbon Portal to ensure suitable data format and the availability of rich metadata. Data directly related to the PARIS deliverables and that requires easy citation in publications will be assigned a DOI. Information on the available data sets is also available on the project website.

The main outcome of the project is digital data. In addition, we expect scientific publications, which will follow EU-guidelines for open access and archival and be listed on the project website. Code created in this project will be freely available, where possible distributed through GIT repositories. Jupyter notebooks for data/model analyses will be archived on the ICOS Carbon Portal.

5. DEVIATIONS FROM ANNEX 1 AND ANNEX 2 (IF APPLICABLE)

5.1 TASKS/OBJECTIVES

The tasks and objectives of PARIS have not changed. The scientific work during the second reporting period focussed on data processing and the preparation of the annexes.

As initiated in the precious reporting period, PARIS continued its intensive engagement in the collaboration with EYE-CLIMA and AVENGERS. Besides the scientific collaborations, PARIS also aligned with EYE-CLIMA and AVENGERS on dissemination activities, including joint presentations and newsletters, webinars and the early career researchers' network.

On request of CINEA, PARIS re-installed several deliverables and milestones. The amendment was accepted in December 2025.

Overall, PARIS is on track and progressing well.

5.2 USE OF RESOURCES

The use of resources is provided in the financial statements of the individual beneficiaries. Summarising, PARIS is well on track with budget and person months regarding the tasks in the second reporting period. We see some over-, respectively underspending particularly due to the legacy in recruitment from the first reporting period and the unequally distributed tasks as explained in the 1st Periodic Report. For the second reporting period, the observed deviations are reasonable, and no further action was required.

No transfer of costs categories has been requested.

Adjustments to previous financial statements are not applicable.

Response to the 1st Suspension of payment letter (received 27 March 2026)

1) As regards average rates for personnel costs: declared average rates for personnel costs (EUR/person-month) deviate significantly from the budgeted rates in the GA for BEN10 ORB (PM rate deviation (-38,46%) > Partner to explain the difference in average personnel costs per month between what was envisaged at GAP stage and the average personnel costs per month claimed in RP2 in the Technical Report (CORE) section 5. DEVIATIONS FROM ANNEX 1 AND ANNEX 2 5.2 Use of resources.

> The budgeted rates in the GA are a mean and do not distinguish between salaries for senior and junior staff members, whom involvement depends on the stage of the project. At the beginning of the project a senior researcher developed the conceptualization and methodologies, in a later stage a junior researcher took over applying the concept and entering data.

BEN1 UU For reported travel costs '' International conference: AGU conference dec. 2024 J. van Es, Washington'' of total value 3.536,41 EUR > please explain in the Technical Report (CORE) section 5. Why this cost deviates from the foreseen cost in DoA Table 3.1h “2 trips to international conferences including AGU/Austria (2,5 K€ each)”.

The 2.5k€ are a mean cost estimation, this should have been stated more clearly in the GA. The AGU as a yearly conference in the USA requires a higher budget (3.5k€) than the annual EGU in Austria (1.5k€).

5.2.1 UNFORESEEN SUBCONTRACTING

Not applicable

5.2.2 UNFORESEEN USE OF IN KIND CONTRIBUTIONS

Not applicable

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7. DOCUMENT HISTORY

Version	Publication date	HISTORY OF CHANGES
1.0	13 November 2025	WP leader and beneficiaries informed about scientific and financial input required, and reporting template provided
	31th January 2026	All WP contributions received; draft version 1st Periodic report prepared
	10 February 2026	Draft version sent to WP leads for check and feedback
	20 February 2026	Feedback received
	27 February 2026	Report finalised and submitted
	2 April 2026	Response on the requested additional information (Letter of suspension of payment, received 27 March 2026) added to the report, resubmission of the report