Data

Models

Inventories

PARIS

Process Attribution of Regional Emissions

GA 101081430, RIA

1st Periodic Report

1 January 2023 – 30 June 2024

TABLE OF CONTENT

FIGURES AND TABLES

FIGURES

TABLES

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

During the first reporting period the project focussed on I) setting up and deploying infrastructure, II) harmonising measurements and expanding measurement networks, III) aligning models and frameworks, and IV) engaging with inventory compiler teams. PARIS (https://horizoneurope-paris.eu) initiated and fostered 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.

Inventory compilers engagement

We have engaged with inventory compilers from eight focus countries, who are eager to see the project's first results later this year. Initial results from at least one inverse model (MO InTEM or EMPA ELRIS) have been shared with representatives from the UK, Switzerland, Ireland, and Germany, while the Netherlands, Italy, Hungary, and Norway will see their results in Autumn 2024. Feedback has been positive and constructive, and the next step is to organize meetings with each inventory organization to present results from at least three inverse models. Significant efforts have been made to align the modelling frameworks and data flows, with comparison exercises conducted for seven gases using different setups. A comprehensive intercomparison tool has been created on the ICOS data portal for rapid and extensive analysis. A template for national annex chapters has been developed, with the first annexes for the eight countries to be created in Autumn 2024, based on the intercomparison tool's plots.

Expansion of F-gas Observational Network

One objective of PARIS is to expand the European network of F-gas observations to achieve a denser network, enabling the quantification of emissions in previously unmonitored regions, particularly in Southern and Eastern Europe. Over the first 18 months, PARIS has established a continuous observation site at the Taunus Observatory in Germany and additional sites in Norway, Hungary, and Southern Italy. All measurements are progressing, with a data quality control workshop held in July 2024. Inversions for F-gases for 2022 and previous years have been conducted using data from established stations, with additional data to be incorporated in 2025 inversions. Intercomparison tools have been developed to facilitate seamless comparison and interchangeability of transport and inversion schemes.

Methane Observations and Inversions

PARIS has progressed observations of atmospheric methane by measuring in situ ambient air isotope ratios and source signatures for Europe. A unique portable IRMS instrument has been deployed to Lindenberg, Germany, and Cluj, Romania. The deployment at Hegyhatsal has been delayed by 9 months due to the replacement of a broken critical system component. The technical issues have been solved, but deployment is now first scheduled for Monte Cimone, Italy, in September 2024 before the system will be re-deployed at Hegyhátsál in 2025.

A quasi-continuous optical measurement system at the Heathfield tall tower in the UK is operational, with similar measurements in Zurich planned for 2026. Delays in delivering another optical system have postponed its deployment to early 2025 in Invergowrie, UK. Data gathering and quality review procedures are progressing. The first methane inversion using InTEM with data of 33 ICOS stations for 2018-2023 has been completed, and other systems are being set up to estimate emissions. The RHIME system will use ethane and methane data to differentiate fossil fuel and non-fossil fuel emissions.

Another system will cover Germany's 2021 emissions for comparison in September 2024. Work to quantify differences between top-down and inventory estimates by sector is yet to begin, pending the completion of related objectives.

N_2O Observations and Modelling

Calibration strategies for high-frequency N_2O observations at Hegyhátsál, Hungary, were revised, establishing automated multi-point calibrations following ICOS recommendations, with updated datasets now available on the ICOS Carbon Portal. Historical data from Hegyhátsál were re-calibrated from 2018 onwards for inverse modelling.

A harmonized set of N_2O in-situ observations across Europe was created in collaboration with AVENGERS and EYE-CLIMA, consisting of continuous and flask observations from 43 sites, now accessible on the ICOS Carbon Portal. Inverse modelling teams have prepared inputs, prior emissions and defined common protocols and output formats. Inversion results for the UK and Swiss domains highlight pronounced seasonal emission flux cycles, differing from bottom-up estimates. To reconcile these estimates and further improve biogeochemical models, N_2O flux observations for isotopic source signature estimation were established at a Swiss cropland site, with weekly measurements capturing emission dynamics. Preparatory work on biogeochemical models DayCent and LandscapeDNDC for national-scale application in Switzerland, Germany, and the UK has started, with data collection coordinated among involved groups.

Fossil Fuel CO_2 inference and detectability

Atmospheric Potential Oxygen (APO) measurements are being used to evaluate fossil fuel CO_2 emissions. Evaluating fossil fuel CO_2 fluxes using atmospheric data is challenging due to the influence of terrestrial biosphere fluxes on CO_2 concentration measurements. PARIS is establishing a new APO measurement site in the Netherlands and maintaining two existing sites in the UK. Progress includes continuous measurements at Weybourne Atmospheric Observatory (WAO) and resumed measurements at Heathfield (HFD) in January 2024. The site in the Netherlands is expected to start measurements in summer 2024. A recent modelling study on APO sensitivity by the PARIS team will aid future data utilization in inverse modelling. Additionally, a "blind verification challenge" has been proposed to determine the detectability of CO_2 sources and sinks in Europe, involving synthetic CO_2 pseudo-observations and scenario identification by inverse modelling teams. A protocol was developed and published, initial results are expected by the end of 2024 and a more comprehensive experiment planned thereafter.

Organic Matter in Aerosols and Black Carbon

Significant progress has been made towards understanding and attributing sources of organic matter (OM) in submicron aerosols (PM1) in Europe and quantifying European black carbon (BC) emissions. Continuous online monitoring of OM in Dublin was conducted, resulting in a high-quality dataset with over 95% coverage for 2023. A new method combining rolling Positive Matrix Factorization (PMF) and machine learning was developed for OM source attribution, applied to the Dublin data, and will soon be available in the EBAS database. The Black Carbon FLEXPART-FLEXINVERT inversion system was tested using BC observations from 13 stations, showing improvement in model-data agreement despite occasional misses of high pollution episodes. This progress sets a solid foundation for broader analyses and future data submission, extending OM aerosol analysis to other European locations. Additionally, a close collaboration with the project EYE-CLIMA has been started, particularly on the estimation of BC emissions from Europe based on ACTRIS sites data.

Visibility and Exploitation

PARIS established and intensified its collaboration with several European projects to ensure visibility and enhanced exploitation of results. Several data sets are publicly available via the ICOS Carbon Portal. The consortium published initial research findings in peer-reviewed journals and participated in conferences, with more publications expected in the next phase. Additionally, PARIS fostered knowledge exchange and collaboration through networks, webinars, and a project website, with ongoing efforts to increase visibility and accessibility of their data and findings.

Overall Progress and Next Steps

The project is progressing well, with significant advancements in observational networks, inverse modelling, and data analysis tools. Upcoming steps include organizing of and participation in meetings to present results, deploying new measurement instruments, and continuing the development of harmonized datasets for emission estimation. Minor delays in instrument deployment and data collection are being managed without impacting the overall project timeline.

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 the objective is ongoing. The PARIS project expanded the European network GHG and BC emissions observations by new stations and fieldwork campaigns, including isotope data measurements for methane. Data were harmonised, inversions for GHG and BC data of up to 43 European sites are ongoing or were completed and intercomparison tools were developed for seamless comparison and interchangeability of transport and inversion schemes. Efforts were aligned in collaboration with the projects EYE-CLIMA and AVENGERS.

The work and milestones towards the objective are in progress or have been achieved.

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.

Work towards the objective is ongoing. Models are being prepared and set up to differentiate e.g., fossil fuel and non-fossil fuel emissions. A protocol for a "blind verification challenge" to test the ability of inverse modelling systems to identify perturbations intentionally introduced into flux fields has been developed. The "blind verification challenge" is ongoing. Alongside this, a new method combining PMF and machine learning for OM source attribution was developed and applied.

The work and milestones towards the objective are in progress or have been achieved.

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

Work towards the objective is ongoing. The PARIS project has expanded the European network of F-gas observations by establishing new continuous observation sites in Germany (Taunus Observatory), Norway, Hungary, and Southern Italy. Inversions for F-gases for 2022 and previous years have been conducted, with additional data to be incorporated in the 2025 inversions. Intercomparison tools have been developed to facilitate the comparison and interchangeability of different transport and inversion schemes, enhancing the robustness of the flux estimates.

Calibration strategies for high-frequency N_2O observations at Hegyhátsál were revised, and historical data from 2018 onwards were re-calibrated for inverse modelling. This helps in improving the accuracy of N_2O flux estimates over time. A harmonized set of N_2O observations across Europe was created, including continuous and flask observations from 43 sites, now accessible on the ICOS Carbon Portal. This comprehensive dataset is crucial for developing time- and space-resolved flux estimates. Inverse modelling results for the

UK and Swiss domains revealed seasonal emission flux cycles that differ from bottom-up estimates, highlighting the effectiveness of these refined observation and modelling efforts.

Modelling efforts also include isotope data. Preparatory work on biogeochemical models (DayCent and LandscapeDNDC) for national-scale applications in Switzerland, Germany, and the UK has begun, with coordinated data collection. These models are intended to provide detailed flux estimates for GHGs like N_2O.

Collaboration with projects like AVENGERS and EYE-CLIMA facilitated the creation of a harmonized set of N_2O observations, which is essential for robust spatial and temporal flux estimation.

The work and milestones towards the objective are in progress or have been achieved.

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

The work towards the objective is ongoing. PARIS is in close contact with inventory compilers from the focus countries, sharing data and collaborative working towards the draft Annexes. Based on received feedback, inventory compilers are eager to see the project's results from at least three inverse models. Significant efforts have been made to align the modelling frameworks and data flows, with comparison exercises conducted for seven gases using different setups. A comprehensive intercomparison tool has been created on the ICOS data portal for rapid and extensive analysis. A template for national annex chapters has been developed, with the first annexes for the eight countries to be created in Autumn 2024, based on the intercomparison tool's plots.

The work and milestones towards the objective are in progress or have been achieved.

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 initial coordinator, University of Bristol (UNIVBRIS). The change of coordinator from UNIVBRIS to the UU was mandatory as UK partners were excluded from coordinating Horizon Europe projects. However, the consortium decided to keep the initial coordinator involved as co-coordinator and UU and UNIVBRIS are joining forces to manage PARIS. The project management included the scientific and administrative coordination, led by two project managers located at the UU and UNIVBRIS.

During the first months of PARIS, the primary management structures were established according to the Grant Agreement (GA). The management structure provided the organisational requirements to the consortium. The consortium met at the kick off meeting held in Utrecht, NL (January 2023) and the 1st Annual Meeting in Bristol, UK (January 2024). The WP leads met during regular or on-demand WP meetings, and report regularly 3-4 times a year to the management team. These monitoring meetings aimed to ensure timely recognition of problems, deviations from the initial working plan, or delays due to any reason and taking adequate and timely action on such issues.

The project is running smoothly and without significant problems, particularly due to the high level of professionalism and engagement of all involved partners. We faced some minor delays in deliverables and milestones because of several reasons such as e.g., deployment delays or malfunction of instruments. Besides this, PARIS has proactively initiated several collaborative activities with the two other EU projects funded alongside it, EYE-CLIMA and AVENGERS. While these additional efforts require careful coordination, the collaboration has proven to be highly valuable due to the significant overlap in scientific objectives and increased visibility as project group. By joining forces, the projects are able to amplify their impact. Furthermore, this collaboration results in joint deliverables, for which an amendment of the GA is requested by the CINEA and in progress.

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

Utrecht University (UU)

The UU is responsible for the overall core project management. When launching the project, the UU and UNIVBRIS agreed on a dedicated tasks distribution and both groups form the management team (Table 1). The UU is the contact for the CINEA and responsible for reporting towards it.

Within the first reporting period, the UU organised the kick-off meeting and set up the overall management structure, provided the beneficiaries and partner organisations with relevant information and documents, prepared templates, and facilitated together with UNIVBRIS project meetings on consortium and WP level. The UU supported UNIVBRIS in the preparation of the first stakeholder newsletter, a joint effort together with the projects EYE-CLIMA and AVENGERS. Besides this, the UU took an active role in initiating and fostering the collaboration between the three projects and presented this collaboration at several scientific events to create awareness.

University of Bristol (UNIVBRIS)

UNIVBRIS functions as co-coordinator, involved in the organisation of project meetings and networking events. UNIVBRIS is also the lead of the ECR network and responsible for the newsletter as a joint effort of PARIS, EYE-CLIMA and AVENGERS. In the first reporting period, UNIVBRIS organised the 1st Annual Meeting in Bristol, and in total 9 online ECR meetings. A first, introductory newsletter was published in February 2024, a follow-up is in progress and planned for September 2024.

Wageningen University (WU)

The WU is responsible for the data management within PARIS. This task included the preparation of the initial data management plan and its update at the end of the first reporting period. The WU is also the main contact to connect the PARIS consortium with the ICOS Carbon Portal, which functions as data repository and as a sharing and documentation platform for the PARIS consortium.

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.

The UU is responsible for the overall core project management, in collaboration with UNIVBRIS. When launching the project, the UU and UNIVBRIS agreed on a dedicated tasks distribution and both groups form the management team. Table 1 gives an overview of the agreed task distribution.

During the first months of PARIS, the primary management structures were established according to the Grant Agreement (GA). The UU functions as main contact point for overarching administrative, contractual and financial related issues related to PARIS internally but also externally. The project management team is in contact with supporting teams of beneficiaries and associated partners to ensure adequate project monitoring and sufficient support of the consortium.

Led by the UU, a Consortium Agreement (CA) was established in project month 3 as supplementary to the Grant Agreement. All beneficiaries and associated project partner from the UK and Switzerland signed the agreement, which has been submitted as deliverable D1.1. Within the first reporting period the consortium decided to add NPL as associated partner, which also signed the CA.

To monitor the progress of the project, the management team organises regular meetings on consortium and WP level as described in Task 1.2. The management team also streamlined the submission procedure for deliverables and milestones by close communication, providing templates and feedback on the reports, and a finalising check before submission.

Table 1: Task distribution with the Project Management Team from the UU and UNIVBRIS. The WU as responsible for the PARIS data management is also included.

UU	UNIVBRIS	WU
Financial, administrative & contractual issues - Grant agreement - Consortium agreement (D1.1) - Financial reporting - Consortium management, incl. overarching organisation and monitoring of progress	Supporting organisation of meetings and network events	Overall data management and collection (D1.2, D1.3)
Overview, communication with and reporting towards the EU, including deliverables & milestones	Setup and maintenance of network for early career scientists including training, career development plans, input for outreach	
Setup and maintenance of website	Lead stakeholder engagement newsletter	
Overall communication to and maintenance of the consortium		
Joint tasks		
Coordination & networking with AVENGERS, EYE-CLIMA		
Outreach & dissemination activities		
General secretarial activities		

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.

A communication infrastructure was integrated from the beginning of the project. This included particularly email and dedicated email lists prepared by UNIVBRIS on consortium and WP level as the main communication channel within the consortium. The project participants are closely collaborating, which results in low-hierarchical communication structures with no contact barriers or the need of additional collaboration or communication protocols except for the Grant and Consortiums Agreement, which are signed by all partners.

The UU in collaboration with UNIVBRIS organised and facilitated the consortium meetings and initiated the first WP leader meetings. The consortium met at the kick off meeting held in Utrecht (January 2023, milestone report M2) and at the 1st Annual Meeting in Bristol (January 2024). The WP leaders met during regular or on-demand WP meetings, and report regularly 3-4 times a year to the management team. For each WP are dedicated meeting time slots reserved at the annual meetings to foster in-person, in-depth discussions. These meetings aim to monitor the overall progress and ensure timely recognition of problems, deviations from the initial working plan, or delays for any reason and taking adequate and timely measures. In conjunction with this, the management teams of the UU and UNIVBRIS are in close contact by email and meets weekly (project managers) and 3-4 times a year (incl. coordinators, WP1 meetings). Except for the annual consortium meetings, which take place in person, the PARIS meetings are held online, using Microsoft Teams as a platform.

Table 2: Overview of PARIS meetings, on consortium and WP level

WP | Consortium Level	Lead Organiser	Date | Platform	Type of meeting	Target audience | mean number of participants
PARIS consortium	UU	January 2023	Kick off meeting*	PARIS consortium and externals | 50 (of which 10 online)
PARIS consortium	UNIVBRIS	January 2024	1st Annual Meeting*	PARIS consortium and externals | 59 (of which 22 online)
WP leader	UU/UNIVBRIS	June 2023	1st WP leader meeting*	PARIS management & WP leader | 11
WP leader	UU/UNIVBRIS	September 2023	2nd WP leader meeting*	PARIS management & WP leader | 11
WP leader	UU/UNIVBRIS	April 2024	3rd WP leader meeting*	PARIS management & WP leader | 9
WP1	UU	Bi-weekly	Project managers meeting	PARIS project managers | 2
WP1	UU/UNIVBRIS	February 2023	Project management team meeting*	PARIS coordinators & project managers | 4
WP1	UU/UNIVBRIS	May 2023	Project management team meeting*	PARIS coordinators & project managers | 4
WP1	UU/UNIVBRIS	November 2023	Project management team meeting*	PARIS coordinators & project managers | 4
WP1	UU/UNIVBRIS	March 2024	Project management team meeting*	PARIS coordinators & project managers | 4
WP1	UU/UNIVBRIS	May 2024	Project management team meeting	PARIS coordinators & project managers | 4
WP1	UU/UNIVBRIS	June 2024	Project management team meeting	PARIS coordinators & project managers | 4
WP2	DWD	September 2023	Meeting with German inventory team (UBA)	National representatives on GHG emissions | 10
WP2	MO	December 2023	UK National Inventory Steering Committee (NISC)	National representatives on GHG emissions | 50
WP2	MO	May 2024	UK National Inventory Steering Committee (NISC)	National representatives on GHG emissions | 50
WP2	EMPA	May 2024	Meeting with Swiss inventor team	National representatives on GHG emissions | 10
WP3	GUF	April 2023	WP3 meeting*	WP participants | 10
WP3	GUF	April 2024	WP3 meeting	WP participants | 8
WP4	UEDIN	May 2023	WP4 meeting*	WP participants | 8
WP4	UEDIN	September 2023	WP4 meeting	WP participants | 8
WP4	UEDIN	November 2023	WP4 meeting*	WP participants | 8
WP5	EMPA	Weekly since Nov. 2023	PARIS modeller meeting*	PARIS modelling groups | 10
|WP5	EMPA	6-monthly	WP5 meeting*	WP participants | 8
WP5	EMPA	May/June 2024	Sub-meetings on N_2O flux observations and biogeochemical models	WP participants | 5
WP6	WU	February 2023	WP6 data management	WP6 PI, PARIS data management team | 4
WP6	UNIVBRIS	February 2023	WP6 data management	UNIVBRIS, WU | 4
WP6	UNIVBRIS	May 2023	WP6 meeting*	WP participants | 8
WP6	UNIVBRIS	September 2023	WP6 meeting*	WP participants | 8
WP6	UNIVBRIS	February 2024	WP6 meeting*	WP participants | 5
WP6	UNIVBRIS	April 2024	WP6 meeting	WP participants | 6
WP7	NUIG	Biannual	WP7 meeting	WP participants | 5
WP7	NUIG	September 2023	Aerosol WP meeting of PARIS, EYE-CLIMA, AVENGERS	Aerosol related participants of the three projects | 12

Joint activities with EYE-CLIMA and AVENGERS on management level, individual scientific exchange not listed				
PARIS EYE-CLIMA AVENGERS	Coordinators, project managers	Jan./Feb. 2023	Kick off meetings PARIS, EYE-CLIMA, AVENGERS	Introduction of projects by the respective coordinators to the other consortia
PARIS EYE-CLIMA AVENGERS	PARIS	March 2023	HE projects collaboration meeting, online*	Projects overlap and options for collaboration discussed
PARIS EYE-CLIMA AVENGERS	PARIS	June 2023	HE projects collaboration meeting, in person at NCGG*	Collaboration discussed
PARIS EYE-CLIMA AVENGERS	PARIS	September 2023	HE projects collaboration meeting, online	Collaboration discussed
PARIS EYE-CLIMA AVENGERS	PARIS	September 2023	ECR meeting	Introduction of projects by the respective coordinators to the ECRs
PARIS EYE-CLIMA AVENGERS	PARIS	November 2023	HE projects collaboration meeting, in person at CoCO2/CORSO meeting	Collaboration discussed; projects presented individually & a joint project poster
PARIS EYE-CLIMA AVENGERS	PARIS	January 2024	Annual meeting PARIS*	Stakeholder engagement session
PARIS EYE-CLIMA AVENGERS	PARIS	March 2024	Stakeholder engagement meeting*	Stakeholder engagement
PARIS EYE-CLIMA AVENGERS	PARIS	March 2024	WG1 meeting of member states, DG Clima & EEA	Preparation of joint project introduction presentation (given by EEA)
PARIS EYE-CLIMA AVENGERS	PARIS	April 2024	EGU2024 joint splinter meeting*	Presentation of projects and engagement discussion with participants
PARIS EYE-CLIMA AVENGERS	AVENGERS	May 2024	HE projects collaboration meeting, online	Joint Webinars
PARIS EYE-CLIMA AVENGERS	PARIS	June 2024	Email communication	Upcoming newsletter
PARIS EYE-CLIMA AVENGERS	PARIS	June 2024	Email communication	Preparation Cluster event

* Minutes available for the consortium

PARIS, EYE-CLIMA and AVENGERS as the three projects funded under the same call, HORIZON-CL5-2022-D1-02, are in close contact for collaborative research and dissemination activities. This includes, e.g., participation in consortia meetings and exchange of outcomes. However, due to the scientific overlap, the consortia decided to also I) present the projects as a project group sharing the same objectives, e.g., by joint presentations at conferences, II) exchange data and knowledge between project participants, and III) collaborate on deliverables to increase the overall impact towards the envisaged target group of inventory compilers.

The overarching aim of the collaboration is to significantly reconcile and improve the national GHG inventories and by this better mitigation measures with respect to climate change. The collaboration is much more intensive than initially intended, which results in higher workload due to extra alignment of efforts and data harmonisation. An overview of activities on management level are listed in Table 2.

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.*

As stated in the Grant Agreement, the UU functions as main contact for the CINEA. The responsible project officer (PO) of the CINEA was invited to meetings at consortium level in Utrecht and Bristol. The PO was informed about significant deviations from the Grant Agreement. Main communication channels are the EU Funding&Tenders portal and email.

Because of the preparation of two joint deliverables together with EYE-CLIMA (D7.2 and D7.4 (former M29)), an amendment has been requested. The amendment has officially been launched and will be finalised in the second reporting period.

The financial and contractual reporting for PARIS is due in project months 18, 36, and 48. The consortium has been provided with templates prepared by the project management and support to individual partners to ensure timely delivery of the reports towards the funding agency. As described in Task 1.1, the same strategy of providing templates and tailored support is used for the deliverables and milestones to ensure high-quality documents ready for public sharing.

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 consortium prepared a Data Management Plan (DMP), led by the WU. The initial DMP was submitted as deliverable D1.2, an update as D1.3.

PARIS aims to significantly increase our knowledge about greenhouse gas emissions, the evaluation and combination of scientific approaches, and a progressive use of collaborative data. With 17 European partners focussing on emissions of common greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), as well as black carbon (BC), organic matter (OM), and new emissions estimates for fluorinated gases (F-gases), large data sets from measurements and modelling are created. This makes the implementation of a tailored data management strategy, right from the beginning of the project essential for collaboration and data exchange. The DMP implements the procedures for this and ensures FAIR access to and re-use of research data generated by PARIS.

As the DM Plan is a key element of project management, it describes preparation, handling, preservation, and storage of data collected and generated by PARIS. The DMP is a living document and will be updated or adjusted over the course of the project whenever significant changes arise. The DMP is a public document and available on CORDIS but also on the project website.

Data and document sharing is organised via the ICOS carbon portal for data of the WPs 2-6, as also described in the DMP. This includes shared compilation of meta data conventions to ensure FAIR data. Data are available under a CCBY4 licences. Data of WP7 (BC and OM related) are available via the EBAS data base and linked to the ICOS Carbon Portal. All data sets are also linked via the project 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 has established the project website (https://horizoneurope-paris.eu), which was launched in December 2022 to coincide with the start of the project. The website shares the objectives of the project, information about involved organisations and links to available PARIS data on the ICOS Carbon Portal / EBAS. For each WP, visitors are provided with details about ambitions, methodologies and planned tasks. Outcomes of PARIS, such as public deliverable and milestone reports, and related scientific publications are also available.

PARIS is closely collaborating with EYE-CLIMA and AVENGERS. This leads to several joint communication and dissemination activities. UNIVBRIS and UU produced a joint newsletter introducing all three projects and in collaboration with CAMS (Copernicus Atmospheric Monitoring Centre, https://atmosphere.copernicus.eu). Instead of an annual newsletter only for PARIS, as initially planned, the projects agreed on preferably bi-annual joint newsletters with contributions of PARIS, EYE-CLIMA and AVENGERS, under the lead of UNIVBRIS and the UU. The frequency and timing of publication will be aligned with scientific output to ensure the newsletters as a valuable and useful dissemination activity. The next edition of the newsletter will be re-leased in September 2024 to line up with advertising a joint webinar to be held in October for inventory compilers. The next projects newsletter with also be advertised with the monthly CINEA newsletter circulation to improve reach.

Alongside a joint newsletter, the projects also produce joint webinars, which are organised in collaboration with CMCC (Euro-Mediterranean Centre on Climate Change, https://www.cmcc.it). A first webinar was held by AVENGERS on atmospheric inverse modelling, the second is planned on inventory compiler engagement with contributions of PARIS partners from EMPA and MO in October 2024.

To foster communication and exchange on all levels and between the three projects, PARIS established an Early Career Researcher group with almost 50 subscribed members of all three projects. The group meets several times a year, presenting actual work and offers the opportunity for informal discussions. The meeting is organised as an online meeting, with alternating chairs from all projects. To date nine ECR meetings have taken place (Table 3), where participants from all three projects presented their work including project overviews given by the coordinators.

Table 3: Overview of Early Career Researcher meetings, organised by UNIVBRIS

Date	**Speaker | Project**	Chair | Project
9th May 2023	Kick off meeting	A. Grant | PARIS
6th June 2023	S. Defratyka | PARIS T. Varga | PARIS	L. Häffner | AVENGERS E. Schoenmakers |AVENGERS
27th June 2023	J. Thanwerdas |AVENGERS A. Ramsden | PARIS	J. van Es | PARIS & D. Kivits | PARIS
7th September 2023	M. Tenkanen | EYE-CLIMA K. Adcock | PARIS	L. Lei | PARIS & S. Defratyka | PARIS
26th September 2023	T. Röckmann | PARIS R. Thompson | EYE-CLIMA M. Scholze | AVENGERS	A. Grant | PARIS
31st October 2023	D. de la Cuesta Otero | PARIS C. Xavier | AVENGERS	Maria Tenkanen | EYE-CLIMA, Jianyong Ma | EYE-CLIMA
5th December 2023	L. Warnecke | EYE-CLIMA L. Haeffner | AVENGERS	Emmal Safi | PARIS, Remco de Kok | PARIS
6th February 2024	J. Ma | EYE-CLIMA E. Schoenmakers | AVENGERS	Carlton Xavier | AVENGERS, Sophie Vanmill | AVENGERS
14th May 2024	S. Vanmill | AVENGERS A. van der Woude | PARIS	Y. Villalobos |
17th September 2024	J. Havsteen | PARIS H.C. Asokan | AVENGERS	P. Andrews |
3rd December 2024	K. Savin | PARIS R. Nanni | AVENGERS	J. Thanwerdas | AVENGERS

Activities such as conference presentations e.g., at the EGU2024, were actively promoted on X (@HorizonEU_PARIS). X was also used to advertise vacancies and recirculate posts about PARIS. However, the consortium focusses more on scientific dissemination activities and less on social media activities. Social media activities are less relevant for projects such as PARIS and are consequently lower prioritised. Instead of promoting the visibility of just PARIS on social media, the project management has also chosen to approach on collaborative presentations of the projects PARIS, EYE-CLIMA and AVENGERS as project group with a focus on research related events such as scientific conferences.

PARIS took the lead to elevate the visibility of the project group not only at scientific events but also at the European policy level. PARIS prepared, in collaboration with AVENGERS and EYE-CLIMA, a joint presentation for the Working Group 1 meeting in Brussels in March 2024, which included representatives from each Member State, DG Clima, and EEA. The member state representatives, who coordinate national emissions inventories and are knowledgeable both politically and scientifically, are part of discussions about the current emissions status reported to the EEA. They address questions and challenges encountered during the reporting phase of NIRs. The meeting was an excellent opportunity to inform the member states about the projects and highlight the approach of PARIS, EYE-CLIMA and AVENGERS.

PARIS also successfully applied to present the projects at a CINEA/DG RTD cluster event in October, which focusses on policy relevant updates to EC staff, highlighting scientific developments to the COP and/or EU climate policy agenda.

Table 4: Communication and dissemination activities related to PARIS; affiliated authors are in bold letters

Type of activitiy	**Publication platform**	year	**Author(s)**	Title	Link
Peer-reviewed publication (OA)	Journal | Atmos. Chem.Phys.	2023	Rödenbeck, C., **Adcock, K.E.,** Eritt, M., Gachkivskyi, M., Gerbig, C., Hammer, S., Jordan, A., Keeling, R.F., Levin, I., Maier, F., **Manning, A.C.,** Hoossen, H., Munassar, S., **Pickers, P.A.,** Rothe, M., Tohjima, Y., Zaehle, S.	The sustainability of atmospheric oxygen measurements to constrain western European fossil-fuel CO_2 emissions and their trends	https://acp.copernicus.org/articles/23/15767/2023/#section12
Peer-reviewed publication (OA)	Journal | Atmos. Chem.Phys.	2024	Chawner, H., **Saboya, E., Adcock, K.E., Arnold, T.,** Artioli, Y., Dylag, C., Forster, G.L., **Ganesan, A.,** Graven, H., Lessin, G., Levy, P., **Luijkx, I.T., Manning, A., Pickers, P.A., Rennick, C.,** Rödenbeck C., **Rigby, M.**	Atmospheric oxygen as a tracer for fossil fuel carbon dioxide: a sensitivity study in the UK	https://acp.copernicus.org/articles/24/4231/2024/#section12
Peer-reviewed publication (OA)	Journal | Earth Sys. Sci. Data	2023	**Adcock, K.E., Pickers, P.A., Manning, A.C.,** Forster, G.L., Fleming, L.S., Barningham, T., Wilson, P.A., Kozlova, E.A., Hewitt, M., Etchells, A.J., MacDonald, A.J.	12 years of continuous atmospheric O_2, CO_2 and APO data from Weybourne Atmospheric Observatory in the United Kingdom	https://essd.copernicus.org/articles/15/5183/2023/#section11
Peer-reviewed publication (OA)	Journal | Nature communications	2023	**Van der Woude, A.M., Peters, W.,** Joetzjer, E., Lafont, S., Koren, G., Ciais, P., Ramonet, M., Xu, Y., Bastos, A., Botía, S., Sitch, S., **de Kok, R.,** Kneuer, T., Kubistin, D., Jacotot, A., Loubet, B., Herig-Coimbra, P.-H., Loustau, D., **Luijkx, I.T.**	Temperature extremes of 2022 reduced carbon uptake by forests in Europe	https://www.nature.com/articles/s41467-023-41851-0#Sec2
SMP	EGU2024	2024	**Walter, S., Röckmann, T.,** Thompson, R., **Ganesan, A.,** Scholze, M.	Verification and reconciliation of estimates of climate forcers	https://meetingorganizer.copernicus.org/EGU24/session/50668
PICO	EGU2024	2024	**Van Der Woude, A.,** Hooghiem, J., **De Kok, R., Luijkx,** I., Van de Sande, M., Kaushik, A., Miller, J., **Peters, W.**	An atmospheric data assimilation system combining biomass and atmospheric CO_2 data for constraining biosphere carbon fluxes	https://doi.org/10.5194/egusphere-egu24-10117

PICO	EGU2024	2024	**Lei, L.**, Fossum, K., Lin, C., Ceburnis, D., Afzal, A., Spohn, T., Chevassus, E., O'Dowd, C., **Ovadnevaite, J.**	Multi-year variations of sub-micron aerosol composition and sources in Ireland	https://doi.org/10.5194/egusphere-egu24-2653
Oral	NCGG9	2023	**Walter, S., Ganesan, A., Röckmann, T., Grant, A. & the PARIS team**	PARIS - Process Attribution of Regional emISsions	https://www.ncgg.info/ncgg9/pro-gramme
Oral	NCGG9	2023	**Engel, A. and the PARIS team**	Expanding the European observational network for halogenated greenhouse gases	https://www.ncgg.info/ncgg9/pro-gramme
Oral	CoCO2 / CORSO	2023	**Röckmann, T. & the PARIS team**	PARIS - Process Attribution of Regional emISsions	https://coco2-project.eu/events/coco2-final-meeting-and-corso-ga-meeting
Oral	EGU2024	2024	**Annadate, S., Maione, M.,** Cesari, R., Falasca, S., Giostra, U., Gonella, B., Moricci, F., **Arduini, J.**	Estimates of HFC-134a Emissions over Europe informed by observations show a recent increase	https://doi.org/10.5194/egusphere-egu24-19215
Oral	EGU2024	2024	**van Es, J., van der Veen, C.,** Menoud, M., Baciu, C., Hmoudah, M., **Henne, S., Röckmann, T.**	Continuous monitoring of the isotopic composition of methane in Cluj-Napoca	https://doi.org/10.5194/egusphere-egu24-9424
Oral	EGU2024	2024	**Saboya, E., Manning, A. J.,** Levy, P., **Henne, S.,** Stanley, K. M., Pitt, J., Young, D., Say, D., Grant, A., **Arnold, T.,** Rennick, C., Tomlinson, S. J., Carnell, E. J., Artoli, Y., Stavart, A., Spain, T. G., **O'Doherty, S., Rigby, M., Ganesan, A.**	Using atmospheric measurements to evaluate recent bottom-up trends and seasonal patterns in U.K. and Swiss N_2O emissions	https://doi.org/10.5194/egusphere-egu24-19246
Oral	EGU2024	2024	**Meixner, K., Engel, A., Schuck, T. J.,** Wagenhäuser, T., Couret, C., Meinhardt, F., Stanley, K. M., **Manning, A. J.,** Jordan, A., Gutièrrez, X., Kneuer, T., Kubistin, D., Lindauer, M., Mueller-Williams, J.	Evidence of ongoing SF6 emissions in Germany	https://doi.org/10.5194/egusphere-egu24-11352
Oral	EGU2024	2024	**Sivan, M.,** Sun, J., **Röckmann, T.,** Martinerie, P., Farquhar, J., Krol, M. C., Paandey, S., Menoud, M., Dasgupta, B., Hagnegedar, M. A., **Veen, C. V. D.,** Popa, M. E.	Evolution of atmospheric methane clumped isotope anomalies since the 1990s reconstructed from firn air measurements	https://doi.org/10.5194/egusphere-egu24-7562
Poster	EGU2024	2024	**Walter, S., Ganesan, A.,** Scholze, M., Thompson, R., **Röckmann, T.**	PARIS, AVENGERS, EYE CLIMA - Verification and reconciliation of estimates of climate forcers	https://meetingorganizer.copernicus.org/EGU24/EGU24-17381.html
Poster	EGU2024	2024	Chung, E., **Arnold, T., Rennick, C., Safi, E.,** Kikaj, D., Thornton, B., **Manning, A., Henne, S., Ganesan, A.,** and Karstens, U.	Use of multiple atmospheric chemistry transport models to interpret high frequency methane isotope ratio measurements at independently managed sites	https://doi.org/10.5194/egusphere-egu24-19775
Poster	EGU2024	2024	**Varga, T.,** Major, I., Bán, S., Baráth, B. Á., **Röckmann, T., van Es, J., van der Veen, C., and Molnár, M.**	Methane and carbon dioxide observations at Debrecen, Hungary: mole fraction and isotope ratio measurements in three different seasons	https://doi.org/10.5194/egusphere-egu24-7845
Poster	EGU2023	2023	**Walter, S., Ganesan, A., Röckmann, T., and Grant, A. and the PARIS team**	PARIS - Process Attribution of Regional emISsions	https://doi.org/10.5194/egusphere-egu23-3759

Poster	CoCO2 / CORSO	2023	**Walter, S., Ganesan, A.,** Scholze, M., Thompson, R., **Röckmann, T.**	PARIS, AVENGERS, EYE-CLIMA - Verification and reconciliation of estimates of climate forcers	https://coco2-project.eu/events/coco2-final-meeting-and-corso-ga-meeting
Poster	EGU2024	2024	**Walter, S., Ganesan, A.,** Scholze, M., Thompson, R., **Röckmann, T.**	PARIS, AVENGERS, EYE-CLIMA - Verification and reconciliation of estimates of climate forcers	https://doi.org/10.5194/egusphere-egu24-17381
Poster	EGU2024	2024	Havsteen, J., Fatima, M., Brunamonti, S., Hausmaninger, T., Pogany, A., Well, R., **Mohn, J.**	Challenges in N_2O isotope measurements using CRDS analysers	https://doi.org/10.5194/egusphere-egu24-17480
Poster	EGU2024	2024	**Mohn, J.,** Zeyer, K., Müller, M.J., Schlauri, P., Vollmer, M.K., Brito Melo, D., **Henne, S.**	Measurement of atmospheric methane and ethane at a suburban site using mid-IR absorption spectroscopy	https://doi.org/10.5194/egusphere-egu24-16736
Poster	EGU2024	2024	**Molnar, M., Barath, B. A., Varga, T., Major, I., Ban, S., and Haszpra, L.**	Novel, optimized and compact gas handling system for the HUN tall tower ICOS station	https://doi.org/10.5194/egusphere-egu24-19252, 2024
Oral	IG3IS spring webinar	2024	**Manning, A., Ganesan, A.**	Guidance for national GHG emissions estimation using atmospheric data	https://community.wmo.int/en/meetings/spring-webinar-series-ig3is
Oral	Working-Group 1 meeting	2024	R. Fernandez on behalf of PARIS, AVENGERS, EYE-CLIMA	New projects on emission verification	https://horizoneurope-paris.eu/paris-in-brussels/
Oral	National Conference of the Environment Chemical Division of the Italian Chemical Society	2023	**Arduini, J., Annadate, S.,** Cesari, R., Falasca, S.	Long-term emission estimates of radiatively active species at the regional scale using inverse modelling techniques: science for service	
Oral	5th AISAM conference	2024	**Arduini, J., Annadate, S.,** Giostra, U., **Maione, M.**	MEDUSA-GC/MS solution, the most recent cryotechnology applied to the continuous analysis of climate-altering substances in air samples	https://www.conftool.pro/congresso2024aisam/index.php?page=browseSessions&print=export&presentations=show

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 and they are keen to see the first results from the project later this year. Initial results from at least one inverse model (MO InTEM or EMPA ELRIS) have been shared with inventory representatives from the UK, Switzerland, Ireland and Germany. The remaining four countries, the Netherlands, Italy, Hungary and Norway will see their first results in Autumn 2024. The feedback from the inventory compilers has been positive and constructive. The next step in this process will be to organise meetings with each inventory organisation to present the results from at least three inverse models.

Considerable effort has been undertaken to align the modelling frameworks and data flows between inverse modelling groups. Comparison exercises have been conducted between the inverse modelling results for seven different gases for a range of different setups, for example using different priors, data selection and baseline options. A comprehensive intercomparison tool (community Jupyter notebook hosted on the ICOS Portal) has been created on the ICOS data portal that allows rapid and extensive analysis of the results from the different inverse systems. An example of the results and outputs are shown in the progress description for Task 2.3.

A template for the national annex chapter has been developed, based on the annexes delivered to the UK and Swiss inventory compilers. These will be created for the first time for each of the eight target countries in Autumn 2024 and will form the basis for the interaction with the inventory compilers at that time. The plots for the annex chapters will all be created within the intercomparison tool.

1.2.2.2 – WP2 - PROGRESS SUMMARY PER WP PARTNER

Met Office (MO)

The Met Office, lead of WP2, 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 of MO, UNIVBRIS and EMPA have been held since January 2024 involving each modelling group and initial comparisons have been made. The common reporting format and the comparison software are significant achievements and will enable a rapid assessment and consolidation of the inverse modelling results.

Wageningen University (WU)

WU has set up an effective communication with the head of the Dutch Emission Registration, including regular update and exchange focused on emission verification and (inverse) modelling of emissions. Exchange of information was further facilitated by providing a webinar on inverse modelling designed for the Early career researchers meetings. First discussions on the contents of a NIR annex were completed. WU contributed to the “CO_2 verification games” protocol for WP5, commenting on the appropriateness of the chosen scenarios for verification from the NIR perspective.

Deutscher Wetterdienst (DWD)

Building on the existing relationship with the Umweltbundesamt (UBA), the German government inventory compiling agency, DWD presented the preliminary results from the PARIS projects to UBA in September 2023. DWD also invited a PARIS representative from the MO to present the first PARIS results to the ITMS (national programme) workshop in October 2023. The feedback from these meetings has shaped the planning for the engagement with UBA in Autumn 2024.

Norsk Institutt Forluftforskning (NILU)

NILU contacted the National Inventory group, at the Environmental Agency. They expressed their interest in the “top-down” results from the F-gas measurements in this project. Collaboration will be intensified in the second reporting period as soon as the first results are available to discuss. We are in the process of setting up a meeting for Autumn 2024, preferably in-person, with the Norwegian inventory team.

University of Urbino (UNIURB)

UNIURB have started a dialogue with the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), i.e. the Italian National Environment Protect Agency, and, in particular, with the unit responsible for the compilation of the National Inventory Reports of F-Gases. Both organisations are keen to collaborate and exchange information, this will be intensified in the second reporting period. We are in the process of setting up a meeting for Autumn 2024, preferably in-person, with the Italian inventory team.

National University of Ireland Galway (NUIG)

NUIG have started a dialogue with the Irish National Inventory Reporting team, a subdivision of the Irish Environmental Protection Agency. They are interested to collaborate, exchange information and meet on a regular basis. NUIG along with the MO presented initial InTEM to the Irish National Inventory Reporting team in October 2023. 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 measurements.

Atommagkutato Intezet (ATOMKI)

ATOMKI contacted the National Emission Inventory Group of the Hungarian Meteorological Service, which is responsible for the reporting of the national emission data to the international bodies (UNFCCC, EMEP, etc.). The group expressed its interest in the PARIS activity and is waiting for the first results. Collaboration will be intensified in the second reporting period.

Swiss Federal Laboratories for Materials Science and Technology (EMPA)

As part of our existing partnership with the Swiss inventory team (Federal Office of the Environment) two annual meetings took place during the PARIS period. During the meetings our standard updates to the annex of the Swiss NIR (non-PARIS work) were discussed. In addition, the expected outcomes of the PARIS activities and their potential impact on the Swiss reporting to the UNFCCC were elaborated.

In addition, EMPA took part in two meetings of the larger supporting group of the Swiss NIR. A presentation on the capabilities of inverse modelling in relation to the ICOS measurement network was contributed by EMPA, again promoting PARIS activities.

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.*

The inventory teams in each of the eight target countries have been contacted and a process of interaction has been developed. Formal meetings have taken place with the UK and Swiss delegates, at these meetings the full set of results from each gas for one inverse model have been presented and discussed in detail. Preliminary presentations have been given to Irish and German delegates to set the scene with what to expect in Autumn 2024. The other four country delegates have been contacted and they are keen to see the first results for their respective countries. The new observations (starting in 2024) from Italy, Hungary, Norway and the Netherlands that are being collected will enable the model resolution for these countries to be significantly enhanced.

For example, in Germany, building upon existing relation with DWD's national inventory contacts, initial contact for the purposes of the PARIS project was made by DWD during a visit to Umweltbundesamt (UBA) (19th September 2023). Results from both the national project "Integriertes Treibhausgas-Monitoringsystem für Deutschland (ITMS)" and PARIS results were presented. Particular interest was shown by UBA concerning the PARIS F-gas results and also the PARIS CH_4 trend results for Germany. Discussions on user requirements (e.g., time coverage, timing of ingestions of inversion results in the annual cycle of inventory production, desirable sectorial splits) were followed up during the ITMS General Assembly 17-20th October 2023 with both UBA and Thünen-Institut. During the same meeting, with the purpose of fostering collaboration between PARIS and ITMS, MO presented PARIS results (19th Oct 2023). The importance of stability and reproducibility of inversion estimates, and their uncertainty bounds have been highlighted. It was agreed that a thorough scientific discussion of inversion results with the inventory experts was necessary before wider circulation. A regular date in September each year has been agreed on to present the PARIS inversion results together with the ITMS inversion results, allowing a comparison between the results of various groups and a consistent interpretation.

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.*

A template annex has been developed building on the format used in the UK annex chapter to the existing UK National Inventory Report (NIR, https://unfccc.int/documents/627789). The template format for each annex for each gas in turn is:

- The long-term trends of Northern and Southern Hemisphere mole fractions for the gas.
- The estimated spatial maps of flux for the gas over the particular focus country averaged over 4 years.
- The annual country emission totals of the gas comparing the inverse results (as a composite from the different inverse systems) with the most recently reported inventory.

The country totals from the inverse modelling are directly compared with the reported emissions for each gas. The results from the different inverse models will be combined to present a single comparison with the inventory estimates. The uncertainty in the estimates in each inverse model will be propagated to the final composite result. The new intercomparison tool developed by MO, UNIVBRIS and EMPA will be used to generate the data required to populate each draft national annex chapter to enable a smooth flow of data from observation to model result. Meta data information from each model such as e.g. model version, observations used, or priors, will also be stored on the ICOS portal to enable effective data management and traceability.

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.*

This task focusses on the second reporting period as the final annex chapters, i.e. synthesis reports will be created bases on the upcoming results.

For each target country a bespoke report will be generated in the form of a draft national annex chapter. They will present for each gas, maps of flux estimates and graphs of national totals with their associated uncertainties directly compared to the national inventories. Along with the individual gases, composite hydrofluorocarbons (HFC) and perfluorocarbons (PFC) graphs, combined using 100-year Global Warming Potentials from the appropriate IPCC Annual Report, will also be presented and directly compared to the latest reported inventory estimates. Following discussions with each inventory compiler representative, the format and design of each draft national annex chapter will evolve to ensure that they are of maximum benefit to the recipient country. Each draft annex chapter will also be shared with the EEA after the appropriate discussion with, and the agreement of, the national inventory representative.

An example showing the comparison with the inventory across the North-West of Europe for HFC-143a is shown in Fig. 1 and the spatial distributions are shown in Fig. 2. An example of the time-series comparison between the models and the observations are shown in Fig. 3. The three inverse systems shown are: InTEM (UK Met Office), ELRIS (EMPA) and RHIME (University of Bristol). In these examples, all three are using UM meteorology and the NAME transport model. The plots are just some of the examples of the direct outputs available from the intercomparison tool.

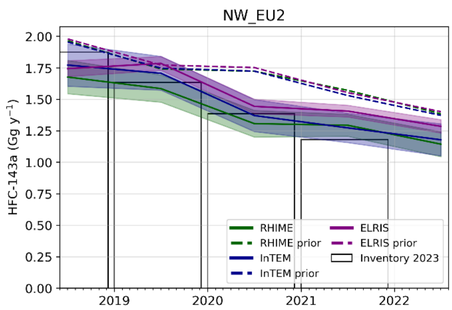


Fig. 1: HFC-143a emissions for North-West Europe (Ireland, UK, The Netherlands, Belgium, Luxembourg, Germany and France) are shown, comparing the 2023 inventory with the three inverse systems

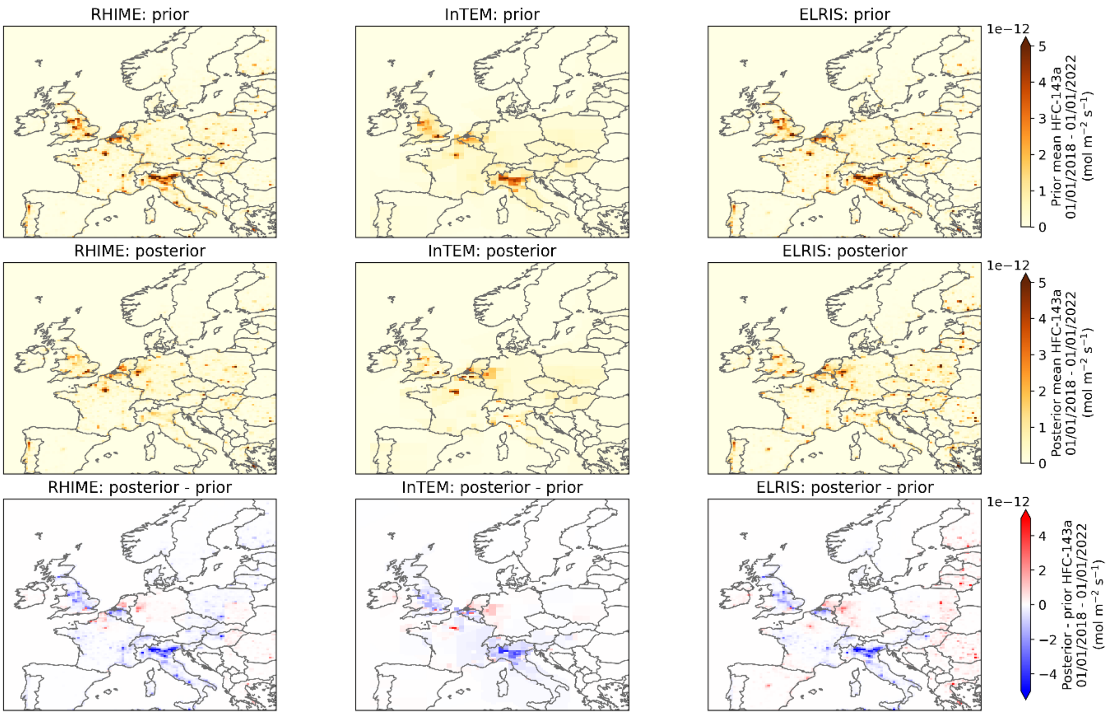


Fig. 2: Spatial distribution of HFC-143a from the three inverse models, averaged 2018-2022 (RHIME column 1, InTEM column 2 and ELRIS column 3). The prior is from EDGAR V8 and shown in the top panel. The posteriori solutions are shown in the middle panel and the difference between the posteriori and prior solutions are shown in the lower panel.

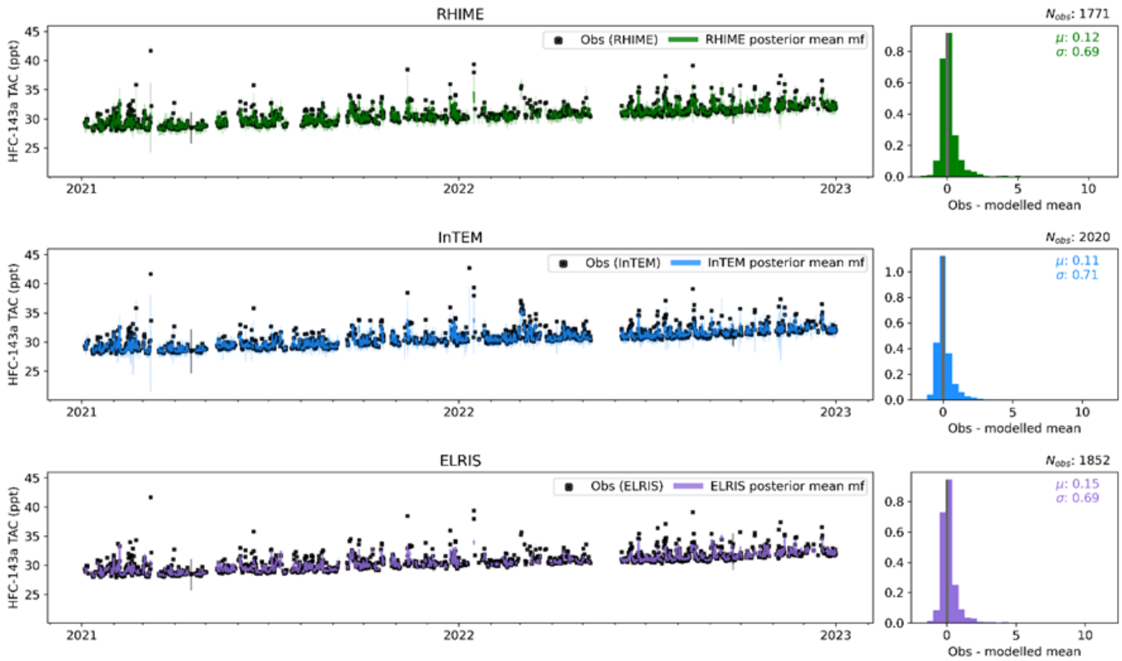


Fig. 3: Tacolneston (TAC) observations and posterior mean HFC-143a mole fractions for three inverse modelling systems for 2021-2022. Absolute differences between the modelled and observed mole fractions are given as histograms on the right, with the mean and standard deviation of these distributions given in coloured text.

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.

This task has yet to be undertaken as it relates to Dec 2024, 2025 and 2026. We have a clear working plan to ensure the delivery of the first draft annex chapters by Autumn 2024. Our weekly meetings in 2024 have significantly improved our understanding of the different inverse systems and we are now working on ways to combine the output into one clear estimate taking account of the different uncertainties in the different inverse systems. When we present the PARIS results to the inventory compilers our aim will be to ensure the two-way interaction will be of maximum benefit to both parties. The leads at these meetings will all be national representatives from within the consortium. We will also liaise closely with our two sister projects Avengers and Eye-CLIMA to ensure smooth messaging to each national inventory complier.

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

The main objective of this WP is to expand the European network of F-gas observations to have a denser observational network, which would allow quantification of emissions in regions so far not covered by observations. Southern Europe and Eastern Europe are specific regions for which so far, no observations are available on a regular basis. These measurements will be used to create an improved estimate of European emissions of F-gases. PARIS focuses on the most important F-gas climate forcers in Europe (HFC-134a, -143a, -125, -32, -227ea, -365mfc, -152a, HFC-23, HFC-245fa, HFC-43-10mee, PFC-14, -116, -218, -318, NF_3, SF_6). Countries for which an improved observational data base will be available are shown in grey in Fig. 4. Specific target countries, with planned interactions with National Inventory Compilers are in dark grey.

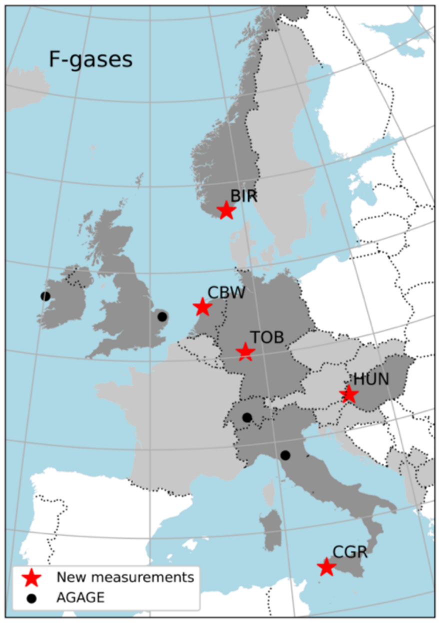


Fig. 4: New sites (red stars) for flask or continuous measurements of F-gases. At least two years of measurements are planned for each site. The black dotes show existing stations. For all stations data will be intercompared and quality controlled as to produce consistent data.

During the first 18 months of PARIS, we have succeeded in establishing a new continuous site at the Taunus Observatory (TOB), Germany, using the AGAGE Medusa system, and establishing three additional sites at Birkenes (BIR), Norway and Hegyhátsál (HUN), Hungary, for flask measurements and continuous measurements in Southern Italy (Capo Granitola (CGR), Italy). All measurements are running as planned and a first specific quality control workshop with participants from 12 institutions has been held in July 2024.

Inversions for the F-gases have also been performed for the year 2023 and preceding years. These inversions already use data from the stations at Cabauw (CBW, The Netherlands) and TOB, where available. As of the year 2024, the additional data will be incorporated in inversions to be performed in 2025. The 2024 inversions (for 2023 and preceding years) have been intercompared between the different modelling groups and tools have been created to ease the intercomparison and for seamless inter-changeability of transport schemes and inversion schemes for the different set-ups.

1.2.3.2 – WP3 - PROGRESS SUMMARY PER WP PARTNER

Goethe University Frankfurt (GUF)

GUF has installed a new MEDUSA system for continuous measurements of F-gases and related species at TOB. Measurements of all F-gases targeted with in PARIS have been performed on a two hourly basis and included in European and international (AGAGE) data reviews. Some gaps occurred in the year 2023 due to technical problems with the sample loops used to pre-concentrate the F-gases prior to the measurements. These problems have been solved and the instrument is now running with only small data gaps. A further issue is the temperature inside the measurement container. It is planned to upgrade the air-conditioning to ensure stable measurements during summer 2024. GUF has further developed software for regular, unattended sampling of air canisters. This automated sampling system has been installed at HUN in January 2024 and since then samples are regularly collected every second day. First samples have been analysed in the GUF laboratory. Results are available for all target gases except for CF4, NF3, PFC-116 and the minor HFCs

HFC-365mfc and HFC4310-mee which cannot be measured on the analytical system in use. Data will be made available through the ICOS carbon portal

Deutscher Wetterdienst (DWD)

DWD has so far not performed any emission estimates or model runs for F-gases, mainly due to problems with recruiting of staff, which have now been solved. First experiments concerning SF_6 point source emissions will start in June 2024 (for the year 2021, followed by 2022). Work had been concentrated on technical preparations for F-gas modelling from specific given point sources and prescribed area sources with the ICON-ART model. This will make use of DWD's operational Numerical Weather Prediction (NWP) wind fields from the ICON model, and the trace gas forward modelling and inversion methods developed in the national project ITMS-M-DWD.

Norsk Institutt Forluftforskning (NILU)

NILU started collecting flask samples at BIR in March 2024. The planned milestone was to start the flask sampling in January 2024. The later start was due to a delay in the flask delivery. The flasks samples are collected at 75m mast inlet every second day. The analysis on the Medusa-GCMS at Kjeller, Norway of the first month of samples shows that the results are on the same level (comparable) with the existing high-frequency measurement stations in Europe. Enhanced values of HFC-32 and HFC-125 are observed due to a leaking air conditioner at the station.

University of Urbino (UNIURB)

The Medusa GC-MS instrument at Monte Cimone (CMN) is running and providing hourly measurements of all the F-gases targeted in PARIS and included in European and international (AGAGE) data reviews; several gaps occurred in the year 2023 due to technical problems with the standard pre-concentration traps, solved by replacing the failing parts. Following Observing System Simulation Experiments (OSSEs) performed by the modeller groups at MO, UNIVBRIS and EMPA, the site of Capo Granitola (CGR) in south-west Sicily has been selected as the most suitable sampling site in Southern Italy. Given the logistics of the selected site, is has been possible, in agreement with the whole consortium, to modify the planned activity: instead of collecting flask samples, a Gas Chromatograph-Mass Spectrometer (GC-MS) equipped with an automatic pre-concentration sampler (ADS) has been installed at GCR in April 2024. This instrumentation allows continuous observations of all the F-gases targeted in Paris. A sample is collected every hour, with every sample run bracketed between two standard runs. This change implied a slight delay in the start of operations at CGR, but at the same time allowing a higher frequency of measurements. Results are available for all target gases except for SF6, CF4, NF3, PFC-116, due to the capabilities of the analytical system.

Atommagkutato Intezet (ATOMKI)

An automatic, remotely controllable sampler unit was installed at the HUN tall tower GHG monitoring site in cooperation with GUF in January 2024. Since then, an air sample has been taken every second day. The samples are shipped to GUF for analysis.

Oekorecherche Büro für Umweltforschung und Beratung (ORB)

The role of ORB in the project is to provide improved bottom-up emission estimates for the inverse modelling groups based on their detailed knowledge of emissions processes, including industrial production and use. It was decided that a focus will be on SF_6, HFC-23, HFC-227ea, PFC-14, PFC-116, PFC-218, and PFC-318, for Europe, with a focus on Hungary, the United Kingdom, Germany, Italy, Norway, Switzerland, Ireland, and the Netherlands. Different approaches for the different gases have been discussed (see description of Task 3.4 below). Data have been compiled and a first assessment of possible point sources for SF_6 has been produced and circulated to the WP3 partners.

Swiss Federal Laboratories for Materials Science and Technology (EMPA)

EMPA conducted atmospheric transport simulations (footprints) for three potential sites for new F-gases observations in Southern Italy (OSSE). Footprints were analysed to identify source areas to which the new observations would be sensitive. Based on this analysis the site of Capo Granitola (CGR) was selected as the most suitable site as it will be sensitive to major source areas on the Italian west coast (Rome, Naples). EMPA has completed a first set of European F-gases inversion for the period 2018 to 2022 based their ELRIS inversion system and on two sets of transport simulations (FLEXPART run by EMPA and NAME run by MO). Together with MO and UNIVBRIS, EMPA has worked on standardising inverse modelling inputs and outputs in netcdf format, enabling the seamless and rapid intermix between transport model and inversion method. Standardised output formats enable rapid intercomparison across different inversion runs contributed by the three involved modelling systems (ELRIS, InTEM, RHIME) by a common Jupyter Note-book hosted at the ICOS Carbon Portal, to which EMPA contributed. Discussions during weekly modelers meetings (MO, UNIVBRIS, EMPA) have led to various improvements in the EMPA inversion system.

Met Office (MO)

The Met Office have completed a first run through of their inverse modelling for each of the F-gases for the period 2018-2022 using their inverse modelling system InTEM using the observations from the established long running AGAGE sites (Mace Head (MHD), Tacolneston (TAC), Jungfraujoch (JFJ), CMN, TOB). 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 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 initial comparisons have been made. The common reporting format and the comparison software are significant achievements and will enable a rapid assessment and consolidation of the inverse modelling results.

University of Bristol (UNIVBRIS)

UNIVBRIS has performed daily flask sampling and measurement from the Cabauw station (CBW). In addition, UNIVBRIS has been coordinating inverse modelling intercomparisons with MO and EMPA. UNIVBRIS has derived preliminary emission estimates for HFC-134a, -143a, -227ea, -125, -32 and PFC-218 for 2018-2022. Highlights include the creation of an emissions visualisation Python notebook that intercompares results from different groups using a newly created standardisation of output formats across the WP3 modelling groups.

1.2.3.3 – WP3 – TASK REPORT

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.*

OSSE simulations for the three possible Italian sites have been performed by EMPA. Fig. 5 shows results for the three sites for HFC134a for the year 2021. The simulations show that all three sites should expect rather similar distributions of pollution. Due to the positioning of the station with respect to very nearby local pollution, and the capability to sample air from northern Africa, the site of Capo Granitola in Sicily was finally chosen.

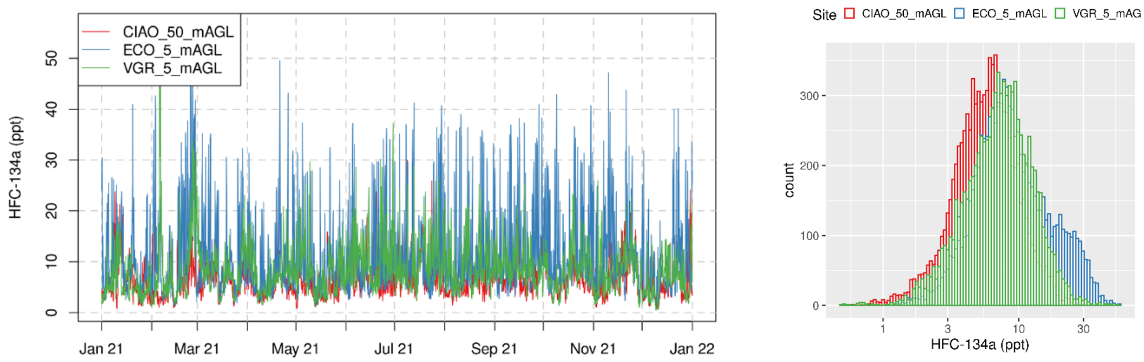


Fig. 5: OSSE simulations for the three candidate Italian sites performed by EMPA using transport from the FLEXPART model and emissions from EDGAR (7.0_FT2021) Capo Granitola (CGR (accidently VGR in graphics)) was finally chosen. In contrast to initial planning, continuous measurements have now been implemented at Capo Granitola.

NAME and FLEXPART footprints for the additional sampling sites (Cabauw, the Netherlands; Hegyhátsál, Hungary; Birkenes, Norway and Capo Granitola, Italy) have been started and are now continued on a regular basis and will be used for the inverse modelling. The NAME footprints will also be available on a regular basis for the new sites in the comparison tool GCCompare. This is currently (May 2024) implemented and should be ready by mid 2024.

A flask sampling strategy has been discussed and it was agreed that flask samples should be taken preferably during the early afternoon when the boundary layer has broken up, so that a wider footprint is achieved. To get a representative sampling, it was decided not to take samples during special events but rather stick to a 2-day strategy, i.e. take samples every second day.

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 started in January 2024. Sampling at Birkenes has started in March 2024. 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.

As explained in Task 3.1., Capo Granitola was chosen as the Italian site, and it was decided to implement a continuous measurement instrument. Due to the continuous operation 12 samples per day are possible instead of a sample every second day. This was deemed to deliver much more information by the consortium, so the change was decided unanimously. The continues measurements have started in April 2024. The delay with respect to the planned start (January 2024) was caused by administrative issues and unavailability of equipment. Both issues are solved, and measurements are running on a regular scheme. As mentioned in the task description, all measurements are now being processed via the AGAGE data processing tools and will undergo a similar data check and quality control. A special version of GCCompare has been set up and a first intercomparison workshop for the first few months of data has been scheduled for 8th July 2024. Fig. 6 shows a screenshot from the intercomparison tool showing a comparison of HFC-152a from the three flask sampling sites with the MEDUSA measurements at Mace Head (preliminary data).

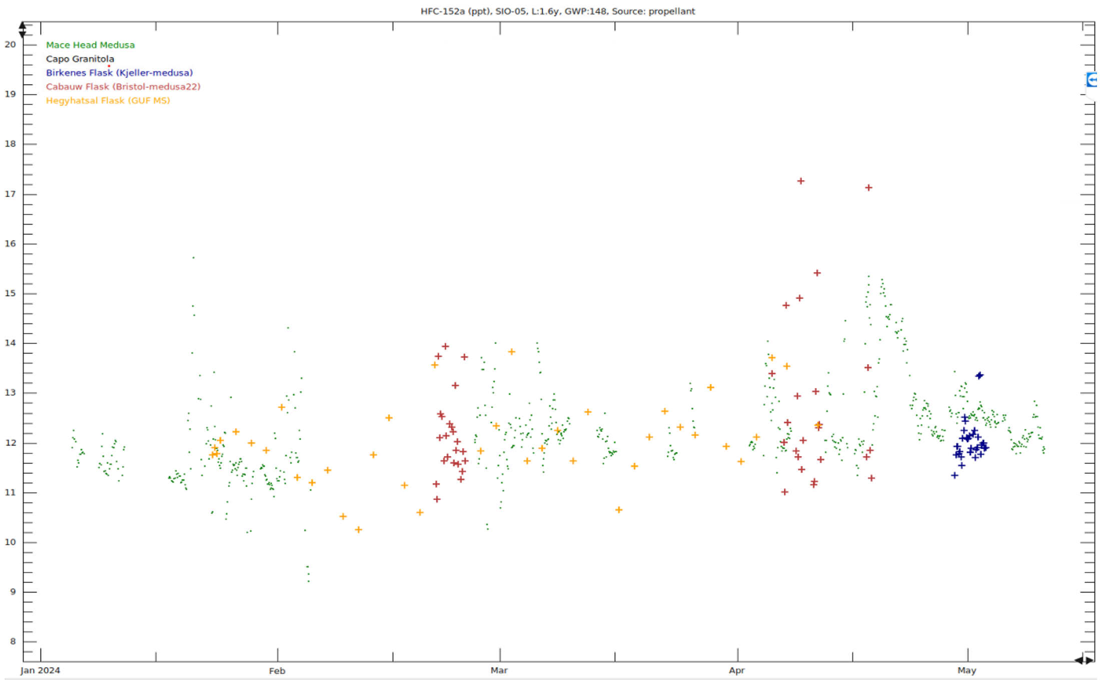


Fig. 6: Example of comparison of HFCs 152a for the new flask measurements at Hegyhátsál, Birkenes and Cabauw which are operated through PARIS to expand the network. The continuous measurements at Mace Head (Ireland) by the MEDUSA instrument operated by UNIVBRIS are shown as a reference.

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 intercomparison 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. The MEDUSA is the standard instrument type used by the AGAGE network. Measurements at both sites have been running for most of 2023 and the data processing is following the AGAGE standard procedures. Data gaps in both stations (Fig. 7) 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). A method to solve the problems with the pre-concentration traps has been developed and additional air-conditioning systems are being installed. The new stations achieve the same precision as other AGAGE sites and are now fully integrated in the quality control of AGAGE. A first Paris specific data review meeting with a focus on all non-AGAGE measurements including the flask measurements has been held on July 8, 2024. It is planned to hold these meetings at least annually in order to identify any data issues.

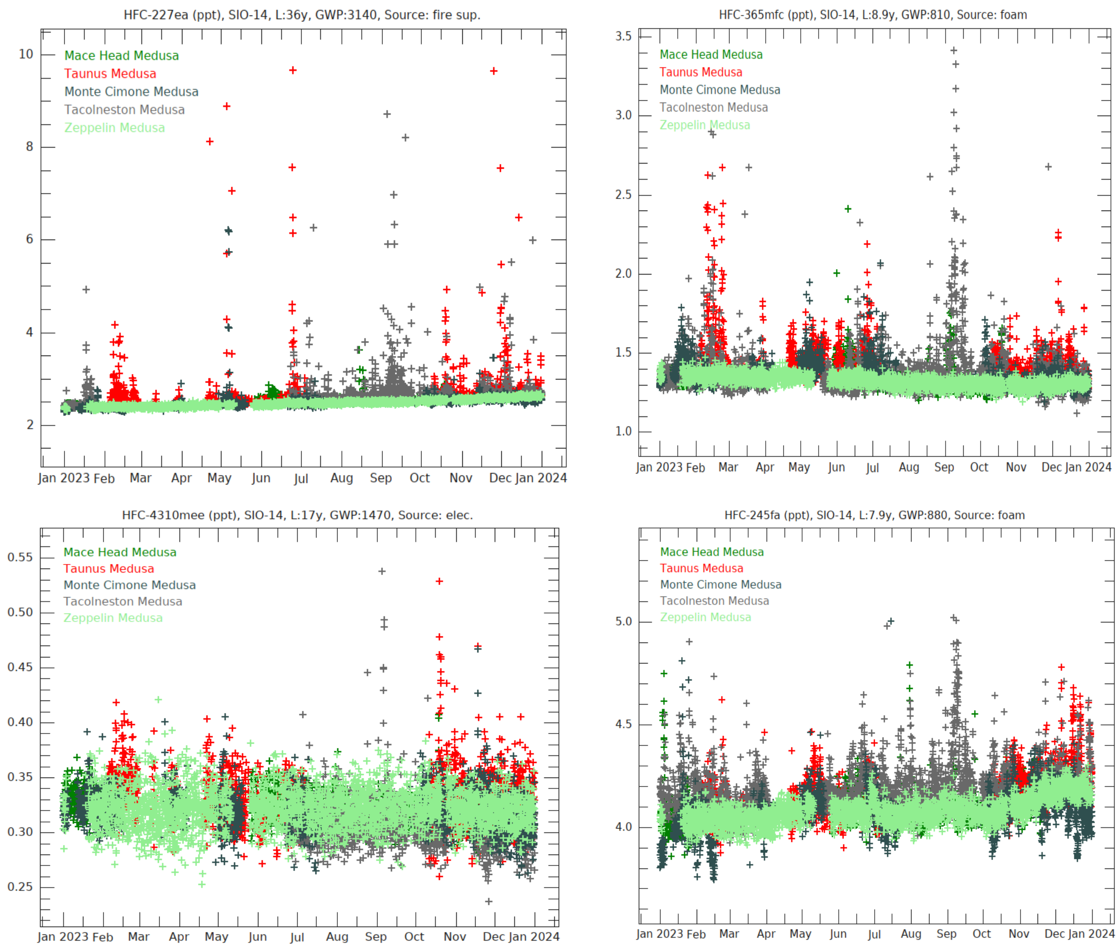


Fig. 7: Example of comparison of 4 different HFCs for the continuous measurements' sites included in the project. The two new sites equipped with MEDUSA GC/MS instruments are Monte Cimone (Italy, operated by UNIURB, dark green) and Taunus (Germany, operated by GUF, red).

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).*

ORB will provide emission estimates for different F-gases, with a focus on SF6, HFC-23, HFC-227ea, PFC-14, PFC-116, PFC-218, and PFC-318, for Europe, with a focus on Hungary, the United Kingdom, Germany, Italy, Norway, Switzerland, Ireland, and the Netherlands. Yearly estimates will be first produced for the year 2023, followed by estimates for previous years. From 2025 onwards, yearly estimates will be produced by September for each year until the end of the project.

Within the first reporting period, work has started with a focus on SF_6, the strongest greenhouse gas on a per molecule basis. The approach is different for each gas due to different source characteristics. Strategies for all target gases have been developed.

Depending on the sources of the F-gas emissions, different approaches have been decided on to derive improved bottom-up estimates:

For SF_6, production is the largest point source of emissions. ORB has extended knowledge on the locations and production volumes and will derive emission estimates based on these point sources. For more diffuse SF_6 emissions from different use types, ORB will provide a single emission estimate value to be assigned to each grid based on population density. Reasoning for this approach is the fact that diffuse SF_6 emissions mainly occur from the use of SF_6 in electrical switchgear (medium and high voltage). Switchgear equipment is relatively evenly distributed throughout Europe with a focus on urban centres (shown as an example for some high-voltage switchgear equipment in Germany in Fig. 8).

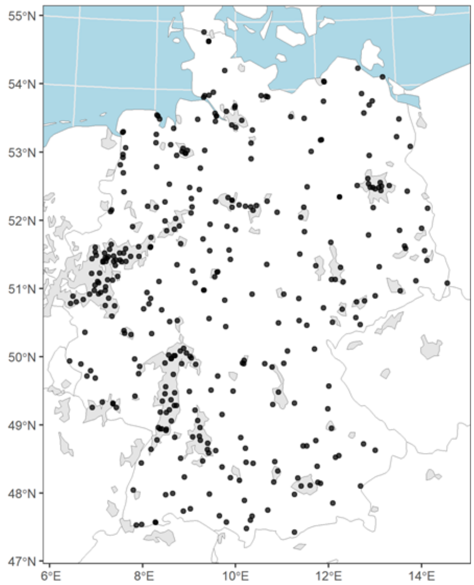


Fig. 8: Location of some high-voltage switchgear equipment in Germany (black dots) with urban areas (in grey). Location data based on https://de.wikipedia.org/wiki/Liste_der_Schaltanlagen_im_Höchstspannungsnetz_in_Deutschland, urban areas from https://www.naturalearthdata.com.

Emissions of HFC-23 (fluoroform) occur mainly as a by-product from the synthesis of HCFC-22 (chlorodifluoromethane). Only a few countries in Europe produce HCFC-22, namely one company each in France, Germany, Italy, and the Netherlands. Emissions from these point sources will be estimated based on detailed knowledge on the production capacities of HCFC-22 and the occurring HFC-23 quantities.

In Europe, HFC-227ea emits mainly from production, the use in metered-dose inhalers (MDIs), for fire-protection, as a foam-blowing agent, and from destruction. Point sources are limited to production and destruction, and emissions will be estimated based on available knowledge on capacities.

Emissions of PFCs will be estimated based on their remaining sources in Europe, namely semiconductor manufacture. Locations of semiconductor fabrication plants and production volumes will be used to estimate emissions from these point sources. ORB has conducted projects to assess emissions from semiconductor manufacturing in the past and will utilize this knowledge for the current project. Emission estimated per gas will be provided to the modelling team in the form of Excel sheets with the year of emissions, coordinates (latitude and longitude) of the point sources, and quantities of emitted gas in metric tons.

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.

Significant work has been undertaken in this task to be ready for the first national inventory comparison. Intensive exchange between the three modelling groups (UNIVBRIS, MO, EMPA) has let to standardised data formats for inverse modelling allowing the interchange of atmospheric transport model (NAME, FLEXPART) and inverse modelling systems (RHIME, InTEM, ELRIS). A first set of European emissions of HFC-134a, HFC-143a, HFC-125, HFC-32, HFC-227ea, HFC-23 and PFC-218 has been produced for the three models. An example result, generated from the centrally hosted Jupyter Notebook hosted at the ICOS Carbon Portal, is given in Fig. 9, indicating good agreement for the larger countries and aggregation areas between the inversion systems and across different a-priori distributions.

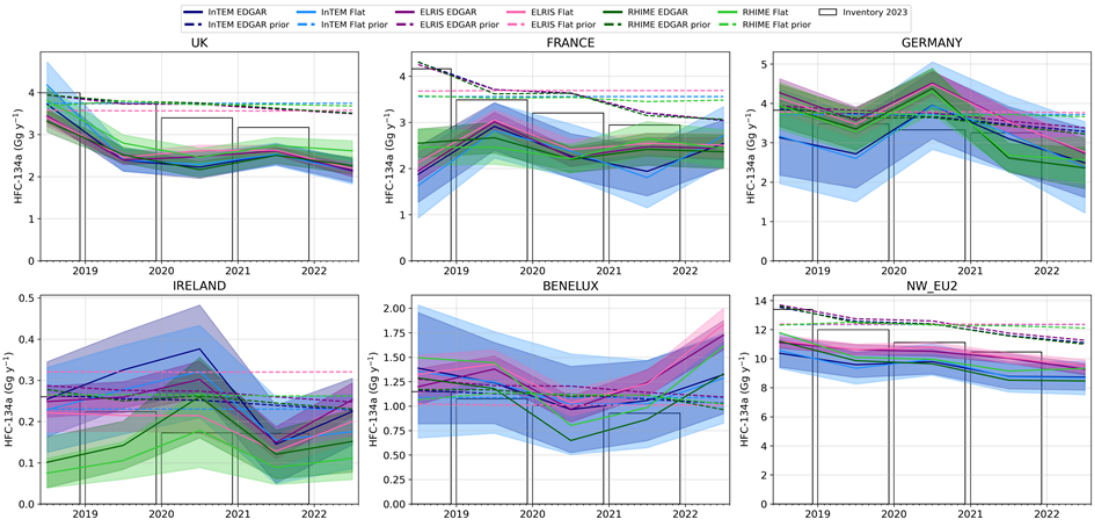


Fig. 9: National HFC-134a emissions estimated by three inverse modelling systems (InTEM, ELRIS, RHIME) and two different a-priori emission distributions (EDGAR, flat). Solid lines and ribbons refer to a-posteriori results and their 1-sigma uncertainty. A-priori emissions are given as dashed lines, whereas national inventory estimates are given as bars. BENELUX is defined as the sum from Netherlands, Belgium and Luxemburg and NWEU_2 refers to the sum from all 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.

This task has not been started yet. The results of the first PARIS inversions (Task 3.5) based on fully quality controlled observational data will be available by Fall of 2024. Preliminary inversions based on preliminary data have been performed, but these are only for internal use so far. Emission estimates which will be shared with stakeholders like the German Environmental Protection Agency (Umweltbundesamt, UBA) and national inventory reporting teams, and which are based on fully quality controlled data will become available in September 2024.

Some preliminary work is ongoing on a case-by-case basis, e.g. for German SF_6 emissions (Fig. 10).

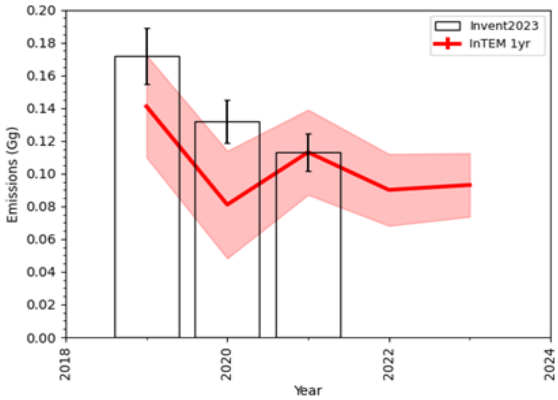


Fig. 10: Top-down (InTEM) estimate of German SF_6 emissions for the years 2019 to 2023 based on all available SF_6 observations compared to reported emissions from 2023 inventory. Both estimates agree quite well on the overall emissions strength, yet the top-down estimates suggest a very inhomogeneous distribution with a large point source in South-Western Germany, which is not well in line with the bottom-up estimates. Further work to better understand this is under way.

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 has made significant progress towards creating new observables for methane in the form of in situ ambient air isotope ratios and source signatures for Europe (Objectives 4.1 and 4.2). A unique portable IRMS instrument setup has been deployed to two locations so far – Lindenberg, Germany and Cluj, Romania – for continuous measurement of $\delta^{13}C\text{-}CH_4$ and $\delta D\text{-}CH_4$. These measurements were supplemented with mobile sampling campaigns to understand the source signatures in the surrounding area. A critical instrument component broke during the installation at Hegyhátsál (HUN), and te instrument has been under repair in the later part of this reporting period but with a new deployment scheduled for Monte Cimone, Italy in September 2024.

An optical measurement system making quasi-continuous measurements of $\delta^{13}C\text{-}CH_4$ and $\delta D\text{-}CH_4$ has been in operation at the tall tower Heathfield station (WMO-GAW site) in the UK and measurements in Zurich using a similar system are scheduled to be underway by 2026. Delivery from the manufacturer of another optical-based system (for $\delta^{13}C\text{-}CH_4$ and ethane amount fractions) was delayed, therefore leading to subsequent delays in setup and deployment to a third site for continuous ambient air monitoring. This new instrument is now scheduled to be deployed in early-2026, rather than late-2025, to a new purpose-built tall tower site at Invergowrie, UK. These delays and minor technical interruptions will not impact the delivery of the project overall. There has been some delay to gathering data from the different platforms and developing the procedures for quality review before creation of the dataset for upload to the ICOS Carbon Portal.

Objective 4.3 was to derive total methane emissions from atmospheric observations (top-down) using different inversion systems and improve source attribution using isotopic and multi-tracer data. A first inversion of methane with InTEM using 33 ICOS stations has been completed on a monthly timeframe from 2018 through to the end of 2023. The other inverse systems are being actively setup to complete their first emission estimates. Inversion system RHIME is also being setup to make combined use of ethane and methane data and, separately, combined use of methane and isotope data, in order to estimate fossil fuel and non-fossil fuel CH_4 emissions. A third independent inversion system setup is in progress and will initially cover Germany's 2021 emissions, ready for comparison with the other systems in September 2024.

Work to quantify differences between top-down and inventory emission estimates at the level of individual sectors is yet to start. This work relies on output and understanding from objectives 4.2 and 4.3, which are well underway.

1.2.4.2 – WP4 - PROGRESS SUMMARY PER WP PARTNER

Utrecht University (UU)

UU activities so far included the IRMS deployments for new carbon and hydrogen isotope ratio measurements of methane namely in Cluj-Napoca, Romania, and Hegyhátsál (HUN). The goal was to investigate the typical source mix of methane in these regions and investigate whether the observations agree with emission inventories. This data capture also included mobile surveys alongside the continuous in situ deployment to investigate suspected sources, and measurements from previous deployments in Hamburg and at the ICOS station Lindenberg are also under evaluation.

We faced a delay because the instrument broke after being installed in Hegyhátsál, and the manufacturer could only deliver a repair unit after 9 months. This has been solved, the instrument is repaired and ready to be installed now first at Monte Cimone, Italy (CMN), scheduled for September 2024. A re-installation at Hegyhátsál is planned for 2025. Flask sampling has already started at Monte Cimone in January 2024. Additionally, a year-long flask measurement campaign in Debrecen (Hungary) by ATOMKI with flask samples coming to UU for stable isotope ratio analysis has been completed, and air samples from the European background station Mace Head have been analysed for CH_4 isotopic composition.

Deutscher Wetterdienst (DWD)

The Emission Verification group has been working on the DWD 'ICON-ART' based system for application in the PARIS project. In the reporting period, the ICON-ART based forward modelling system has been developed and improved, including appropriate interfaces so that it is ready for a first year-long run of methane concentration simulations for Europe. Approximately 50 tracers of methane are chosen according to region (e.g., Germany) and sector (e.g. agriculture). The DWD inversion system has also been developed, building upon the method of synthesis inversion. The necessary uncertainty information has been implemented in a working version and meteo-ensemble based uncertainty estimation has been introduced, ready for tuning to obtain the first DWD top-down CH_4 inversion results for single months in June 2024. The inversion results covering the whole year of 2021 are expected in August 2024 and are planned to be discussed with UBA (in September).

National University of Ireland Galway (NUIG)

NUIG continue to manage the new measurement stations in Ireland that will provide data for assimilation into the inversions. Flask sampling has also begun for stable isotope ratio analysis from Mace Head to allow constraints on the isotope ratios of air arriving into the western part of the European modelling domain.

Atommagkutato Intezet (ATOMKI)

ATOMKI had CH_4 amount fraction measurements approved by ICOS in the last months following installation of a new gas handling system at the Hegyhátsál (HUN) monitoring site (https://meetingorganizer.copernicus.org/EGU24/EGU24-19252.html). The site is prepared for deployment of the GC-IRMS system by the UU, and the instrument is scheduled to HUN in 2026.

The group started a sampling campaign within the city of Debrecen to measure the stable isotope ratios and radiocarbon (four times daily for two weeks in each of the four seasons), to provide an understanding of the different methane source contributions in this area.

Swiss Federal Laboratories for Materials Science and Technology (EMPA)

EMPA initiated rooftop sampling for CH_4/C_2H_6 analysis by direct absorption spectroscopy (AERIS MIRA ULTRA) in November 2023 and implemented a two-point calibration approach with hourly drift correction and span calibration twice per day. Intercomparison measurements were conducted with GC-MS (Agilent Technologies) for C_2H_6, CRDS (Picarro, model 2401) for CH_4 and a second AERIS analyser and indicate good agreement for both accuracy and temporal variability. Currently the automation and data processing are upgraded, applying a customized, LabVIEW automated calibration setup. The TREX-QCLAS instrumentation for CH_4 isotope measurements has been re-established and is currently applied for intercomparison measurements on cylinders in collaboration with the National Institute of Water and Atmospheric Research (NIWA, New Zealand).

EMPA set up and completed atmospheric transport simulations (FLEXPART driven by ECMWF inputs) for inverse modelling for 40 sites across Europe and the period 2018-2023. Hourly footprints (source sensitivities) were produced using the same output grid definition as applied by MO for their NAME model. First CH_4 inversions based on these transport simulations were calculated using EMPA´s ELRIS inversion system. Additional high-resolution FLEXPART simulations were conducted for the newly established C_2H_6 and CH_4 isotope measurements at Dübendorf, Switzerland. Generated footprints were used for forward simulations of CH_4 isotopic composition. Prior to observation start, similar simulations were conducted for several sites around Zürich, Switzerland, in order to select an optimal site for isotope measurements with a potentially large contribution from non-agricultural sources.

Met Office (MO)

The Met Office have completed a first run through of their inverse modelling for CH_4 for the period 2018-2022 using their inverse modelling system InTEM using the observations from 33 stations across Europe, predominately the ICOS network. 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 to understand the different approaches of the different inverse systems. The common reporting format and the comparison software are significant achievements and will enable a rapid assessment and consolidation of the inverse modelling results expected in the next few months.

University of Edinburgh (UEDIN)

UEDIN have led the data analysis of the Heathfield continuous isotope ratio measurements using the long-term permanent deployment of NPL's optical instrument at the site. The data analysis and QA-QC procedures have led to a new dataset from the project for upload to the ICOS carbon portal. A major instrument failure in January 2024 led to a three month down time, however, the instrument is running again following repair and this should not have a major impact on eventual multi-year inversion calculations. Progress is being made on understand what is needed to harmonise isotope ratio measurements across the PARIS capable network, this includes measurement of common reference materials between UU and NPL for calibration of the optical δ^2H measurements, and the use of model output to understand periods of background measurement when the ambient air data sets can be directly compared.

University of Bristol (UNIVBRIS)

UNIVBRIS has been coordinating inverse modelling intercomparisons with MO and EMPA and has derived preliminary emission estimates for CH_4 for 2018-2022. Highlights include the creation of an emissions visualisation Python notebook that intercompares results from different groups using a newly created standardisation of output formats across the WP4 modelling groups. A methane isotope/ethane instrument from Aerodyne Research Inc has been purchased and delivered to UNIVBRIS in June 2024. The delivery is a lot later than planned and the relevant milestones have been pushed back 6-8 months to ensure the instrument setup and deployment can be made.

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.

In order to decide the location of continuous isotope and ethane measurements in Switzerland, the FLEXPART-COSMO/IFS model was used to simulate methane mole fractions for two established continuous Swiss Plateau sites (Beromünster (BRM) and Lägern-Hochwacht (LHW)), a background site (Jungfraujoch (JFJ)), two exploratory new sites (Breite and Dübendorf, Empa laboratory building). COSMO 1 km analysis was used for the Alpine domain and ECMWF-HRES for the rest of the domain. Emissions were taken from Meteotest EKAT (2015) for Switzerland and from TNO for the rest of Europe. Background mole fractions were taken from the JFJ site. This study found that the modelled values matched the variability of the observations in time, but not in amplitude (modelled values were about 40% too small). Methane mole fractions were also modelled using monthly transport footprints from NAME III v7.2 (the UK Met Office's Numerical Atmospheric Modelling Environment) for 26 ICOS and DECC sites for all of 2021. Monthly fluxes were taken from the UK NAEI for the UK and EDGAR v6.0 for European lat/lons. Background mole fractions were modelled at the domain edges using the monthly ECMWF CAMS v19 CH_4 volume mixing ratio dataset. Similarly to FLEXPART-COSMO/IFS model, the NAME model found that the simulated mole fractions matched the time-variation in observations well, however, lthough there was some underestimation by the modelled values at some sites (notably LUT and PAL).

Sites were 'shortlisted' based on the mix of sources detected and the magnitude of modelled mole fractions, however, ultimately the availability of infrastructure to maintain new measurements at the sites was a decisive factor. Hegyhátsál, Hungary (HUN) was chosen based on the mix of fossil and non-fossil sources simulated and Monte Cimone, Italy (CMN) based on pollution detection thesholds. Deployment of the IRMS instrument is scheduled for HUN and CMN in 2024 and 2025. High-resolution FLEXPART simulations were also conducted (based on 1 km meteorological analysis by MeteoSwiss) for forward simulations of CH_4 isotopic composition at sites in Zurich to select an optimal site for isotope measurements with a potentially large contribution from non-agricultural sources. The site of the Empa laboratory was ultimately found to be the best option for creation of a new measurement dataset using the quasi-continuous optical based instrument.

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 additional 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 $\delta^{13}C\text{-}CH^4$ and $\delta D\text{-}CH^4$ of the background air will be determined by regular (~weekly) analysis at UU on flask samples collected from Mace Head.*

High-frequency measurements of $\delta^{13}C\text{-}CH_4$ and $\delta D\text{-}CH_4$ are established at Heathfield and this data set is due for upload to the ICOS carbon Portal following a period of analysis and development of quality procedures (see Fig. 11 for full data set of stable isotope ratio measurements from 2021 to 2024). Some gaps in the timeseries have occurred due to instrument component failures. The most recent breakdown occurred early in 2024 when a trap overheated and destroyed the packing material used to trap methane from large sampling volumes. This was replaced, however, owing to the different properties of the new trap some time was needed to understand how well it was functioning and to optimise the methane trapping and elution.

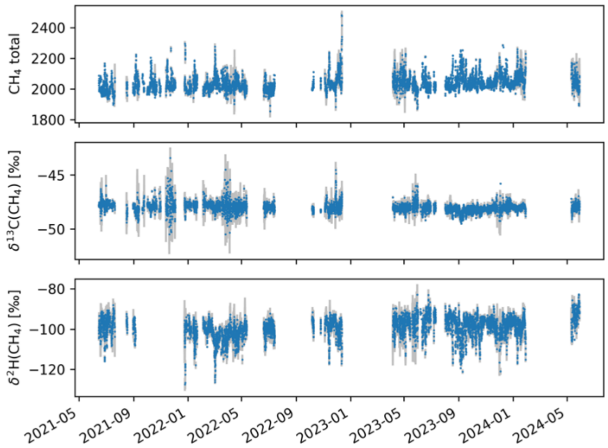


Fig. 11: Showing results from Heathfield of stable isotope ratios and amount fractions of methane, following developed quality procedures. These data will be uploaded to the ICOS Carbon Portal for dissemination.

The SOAR site in Scotland is due to be commissioned in summer 2024 and the new optical instrument for deployment there is currently being setup at UNIVBRIS. There has been a delay to this work of 6-8 months following the late delivery of the instrument from the manufacturer.

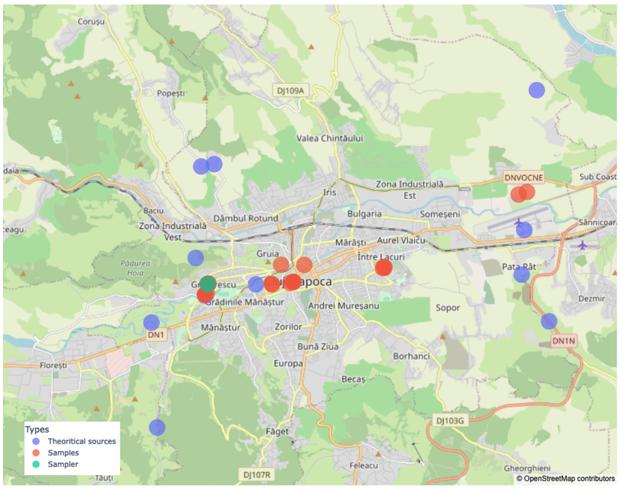
Measurements campaigns of 6-12 months duration using a mobile platform making high frequency, high precision isotope observations have so far been conducted at two sites since 2022 (Lindenberg in Germany and Cluj in Romania). The work performed on the continuous data-series indicate that the nighttime accumulation plays an important role for the diurnal evolution of the CH_4 mixing ratio and both the δD and $\delta^{13}C$. The isotope source signature suggest that the enhancements can be explained by a combination of leakages from the gas network, combined with microbial sources. Wind directions indicates that the city centre contributes strongly to these emissions. A further campaign was due to take place at Hegyhátsál towards the end of 2023, however, technical issues with the instrument prevented this. Nonetheless the ICOS HUN site in Hungary is running well following investment of a new sampling and analysis methodologies there and will be available for hosting the instrument at a later date. It is expected that the IRMS instrument's next deployment following maintenance will be Monte Cimone in Italy in September 2024. Isotopic composition for both $\delta^{13}C\text{-}CH_4$ and $\delta D\text{-}CH_4$ of the background air has also started with regular (~weekly) analysis at UU on flask samples collected from Mace Head.

Sampling in Zurich for CH_4/C_2H_6 analysis by direct absorption spectroscopy (AERIS MIRA ULTRA) commenced in November 2023 and results have been validated via inter-comparison measurements with GC-MS (Agilent Technologies) for C_2H_6, CRDS (Picarro, model 2401) for CH_4. A laser spectrometer based system (TREX-QCLAS) for CH_4 isotope measurements has been re-established for PARIS and in situ measurements are due to commence over the coming months.

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)

a)



b)

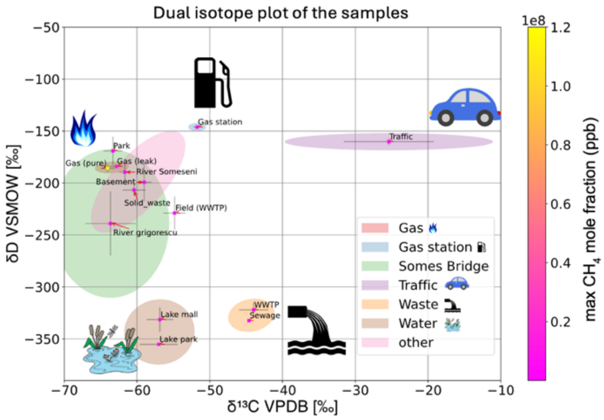


Fig. 12: a) Map of Cluj and the sampling locations around the site used in this study by UU.

b) Dual isotope plot with the source signatures of the sampling in Cluj-Napoca calculated using a Keeling plot approach (dots). Colours are according to the maximum mole fraction observed. Ellipses are created around sampling locations with similar sources.

In PARIS mobile surveys are being conducted in the vicinity of new measurement sites to characterise isotope ratio source signatures in the region of continuous measurement sites. The aim is for this to result in new isotopic source signatures measurements that will augment the growing European database that our teams are continuing to develop. Fig. 12a shows locations around the Cluj city were air samples were selected during the time of continuous measurements by the in situ IRMS. More than 100 samples to determine the methane mole fraction, $\delta^{13}C$ and δD, were collected from different sources on 5 different days. The detected sources in this region were traffic, the gas network, a gas station (fossil), lakes and waste. Sources were sampled at least three times, however, some only had enhancements during one or two of the samplings, in which cases additional sampling was conducted. The data of each re-sampled location are utilized to calculate the source signature via the keeling plot approach. Selected results of each Keeling plot are shown in Fig. 12b.

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)

Significant work has been undertaken in this task to be ready for the first national inventory comparison in autumn 2024. Intensive exchange between three of the modelling groups (UNIVBRIS, MO, EMPA) has resulted in standardised data formats for inverse modelling enabling the rapid interchange of atmospheric transport model (NAME, FLEXPART) and three of the inverse modelling systems (RHIME, InTEM, ELRIS). Comprehensive inter-comparison software has been co-developed across the groups. This new tool enables detailed investigation of the different modelling systems to be conducted efficiently and in-depth.

For methane, monthly NAME-MO results using 33 stations across Europe (ICOS and national networks) 2018-2023 have been completed (Fig. 11). The other modelling systems are nearing completion of their inversions and the first inter-comparisons of methane will begin in summer 2024. Fig. 13 and Fig. 14 give an impression of the outcome of the modelling activities.

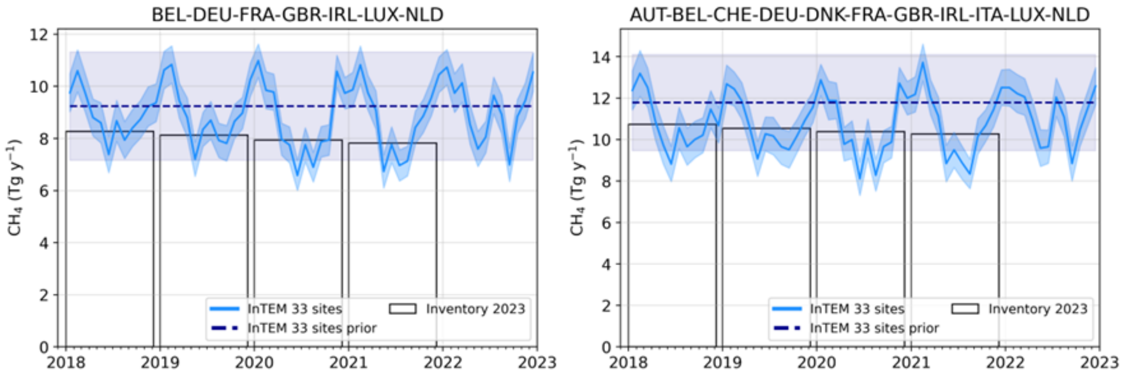


Fig. 13: Monthly InTEM posterior methane flux estimates (light blue) using 33 sites compared to prior mean flux estimate (dashed dark blue) and inventory flux estimates as reported to the UNFCCC (black bars) in 2023. These estimates are given for two broad regions, which are defined by their 3-character ISO-3166 codes.

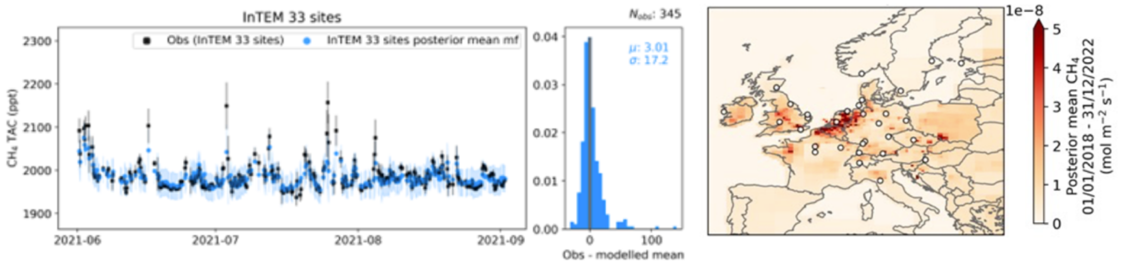


Fig. 14: (Left) Three months of observed (black squares) and InTEM posterior modelled (blue circles and shading) methane mole fractions from the Tacolneston (TAC) site in SW England. Statistics representing the modelled mole fractions' fit to observations over this period are given in the histogram plot. (Right) InTEM mean posterior methane flux across Western Europe, averaged from monthly inversions between 2018 and 2022. Observation site locations are shown as white circles.

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)

Modelling work has begun for this task and significant progress has been made. The first results will be available in 2025. The methodology for sector-level methane emissions has been established with a publication in process. A preliminary case study using UK $\delta^{13}C$ and δD measurements and the UK DECC network has been performed for further extension into a Europe-wide analysis. The DWD system is ready to ingest any tracer with fluxes defined on its triangular grid. The interface to ingest sector specific or combined sector specific priors is ready, run and tested for given, time constant fluxes but options for time profiles (daily, weekly, annually) are there. The interface to ingest any observations in ObsPack format will be implemented in the next reporting period.

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 directly from Task 4.4 from which new top-down estimates of CH_4 emissions will come. First outcomes are given in Fig. 13 and 14. The first results related to this task, where these new top-down estimates are compared to the inventories, are expected in Autumn 2024 as part of the draft National Inventory Annex reports. These will be presented to the respective national representatives by Winter 2024 as detailed in the work plan and alongside results for the other GHGs.

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 a first updated dataset is available on the ICOS Carbon Portal (see also milestone report M17).

Re-calibration of historical data from Hegyhátsál was carried out, making observations from 2018 onwards available for inverse modelling. These data were included in deliverable D5.1 and milestone M18. In order to establish a harmonised set of N_2O in-situ observations across Europe, PARIS cooperated with the sister projects AVENGERS and EYE-CLIMA. The resulting data set contains in-situ continuous and flask observations from 43 sites in a uniform format. The procedures of data collection, quality control and harmonisation was described in deliverable D5.1 and data are available and searchable through the ICOS Carbon Portal. They can be readily used by the inverse modelling groups of all three projects.

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. Inversion results for the UK and Swiss domain have been inter-compared, highlighting once more the pronounced seasonal cycle in emission fluxes seen from inverse modelling, which does not currently agree with bottom-up estimates. In order to improve these bottom-up estimates (O5.2), work has progressed in two directions.

On the one hand, N_2O flux observations for isotopic source signature estimation have been established at a cropland site in Switzerland and will provide critical tuning data (M19) for the biogeochemical models used in this WP. A series of automatic time integration chamber measurements allows for flux and source signature estimation on a weekly basis, sufficient to capture the dynamics of changing N_2O emissions due to management and climate. On the other hand, preparatory work on the biogeochemical models DayCent and LandscapeDNDC for their application on the national scale (target countries Switzerland, Germany and UK) has just started (only after month 16 and 19, respectively). Collection of required input data (soil parameters, management practices, climate data) has been coordinated between the involved groups.

1.2.5.2 – WP5 - PROGRESS SUMMARY PER WP PARTNER

Utrecht University (UU)

Within WP5, the UU contribution focusses on the second reporting period. So far, the UU supported the preparation and the measurements at the Hegyhátsál tall tower site by knowledge exchange and collaboration with ATOMKI.

Karlsruher Institut für Technologie (KIT)

In this work package, KIT is responsible for site-scale and national-scale simulations targeting nitrous oxide emissions. Since site-scale measurements are in progress, work so far has focused on national-scale simulations. Process model simulations of nitrous oxide emissions for Germany, Switzerland and the UK require input datasets on meteorology, soil properties and agricultural management activities. Especially for soil properties and agricultural management, different datasets have become available in the recent past, but aggregation levels and access rights are variable. For this reason, KIT is in the process of compiling and comparing available datasets in order to select the most pertinent datasets to use for the respective countries. Work by KIT has just begun recently.

Atommagkutato Intezet (ATOMKI)

The atmospheric concentration of nitrous oxide is continuously measured at the Hegyhátsál tall tower site. 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.

Swiss Federal Laboratories for Materials Science and Technology (EMPA)

EMPA compiled a European dataset of surface in-situ N_2O observations for the use of inverse modelling. The data were made available through the ICOS Carbon Portal and documented as part of the deliverable report D5.1. EMPA compared seasonality in N_2O fluxes as obtained from inverse modelling for the Swiss domain with that obtained for the UK. Inverse modelling for the European domain using EMPA´s ELRIS inversion system was set up for the period 2018-2023. Results are presently analysed. EMPA initiated flux measurements of N_2O, CO_2, CH_4 from an agricultural field site at Agroscope Reckenholz (AGS), Switzerland in February 2024. Due to technical issues, measurements were delayed and will continue until end 2024. Data transfer is foreseen in project month 25.

Agroscope (AGS)

AGS is responsible for simulating N_2O emissions from agricultural soils using the biogeochemical model DayCent at two specific cropland sites in Switzerland where EMPA will perform special isotope analysis of N_2O. During the first reporting period, the initial setup and calibration of the DayCent model for crop and grasslands have been performed. The goal is to verify whether the contribution of the two processes that form N_2O are correctly captured by the model. If this is not the case, the model will have to be re-calibrated or improved.

Furthermore, the model will be used to simulate N_2O emissions of the total cropland and grassland area in Switzerland. For this purpose, agricultural data needs to be collected and a representative management for each simulation unit needs to be defined. The results will be compared against atmospheric inversions, with a special focus on seasonal variation.

Met Office (MO)

The Met Office have completed an initial run of their inverse modelling for N_2O using their inverse modelling system InTEM using the observations from the established UK DECC sites (MHD, TAC, RGL, HFD, BSD). The MO have worked alongside other partners, principally UNIVBRIS and EMPA, 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 November 2023 involving the three Lagrangian inverse modelling groups (MO, UNIVBRIS and EMPA). Initial comparisons of inversion results have been made and the inversion protocol is currently updated. The common reporting format and the comparison software are significant achievements and will enable a rapid assessment and consolidation of the inverse modelling results.

University of Bristol (UNIVBRIS)

UNIVBRIS has been coordinating inverse modelling intercomparisons along with MO and EMPA and has derived preliminary emission estimates for UK N_2O emissions for 2013-2022. Highlights include the creation of an emissions visualisation Python notebook that intercompares results from different groups using a newly created standardisation of output formats across the WP5 modelling groups.

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.

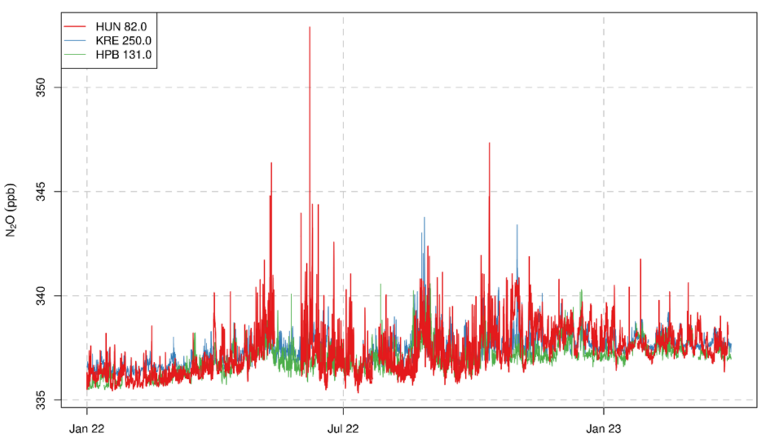


Fig. 15: Time series of fully calibrated N_2O observations (1-hour averages) from Hegyhátsál (red) compared to those carried out at closest ICOS sites HPB, Germany, (green) and KRE, Czech Republic, (blue).

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 April 2024 were quality controlled. The data were compared to the closest ICOS N_2O observation, providing additional evidence of a successful calibration strategy (Fig. 15). Data from 2022 onwards were uploaded to the ICOS Carbon Portal for use within PARIS (M17) and future open publications. Historical data, from 2017 onwards, were re-evaluated and integrated into the N_2O data compilations (D5.1).

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.

Since a similar task was foreseen for the sister projects (AVENGERS, EYECLIMA), work was aligned between the projects, which included e.g. compilation of data, aligning formats and metadata. NILU (as part of EYECLIMA) provided a draft software tool, which was developed during the VERIFY project, and a first round of historical N_2O observations (prior to ICOS, e.g. from InGOS, previously submitted to WDCGG).

ICOS-CP (as part of AVENGERS) with NILU and EMPA contacted station PIs about contributing additional historical and on-going (non-ICOS) observations to this data collection task. EMPA further developed a software tool for data collection, harmonisation and conversion to an ICOS-like consistent output format. ICOS-CP uploaded the N_2O data collection to the ICOS Carbon Portal and data are publicly available for online visualisation and download. The published data set comprises observations from traditional GC-ECD systems as well as modern laser spectroscopy instruments. In addition to continuous observations, publicly available flask observations from the NOAA network were included. A total of 50 time series from 43 observing sites (Fig. 16) are included, covering the period 2005 to the end of January 2024. Of these sites 28 were reporting continuous observations in 2023, although some of these (ICOS NRT) remain preliminary at the time of compilation. A more detailed description of the data collection, harmonisation and characterisation process are available in D5.1.

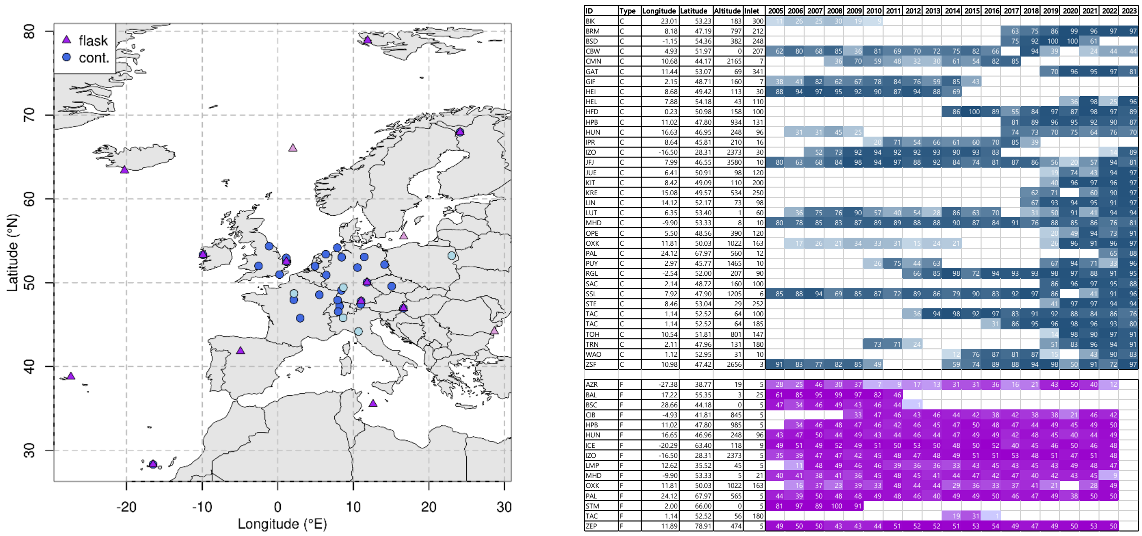


Fig. 16: (left) Map of sites included in the present data collection. Blue circles continuous and purple tri-angles flask sampling observations. Light colours indicate sites which were not reporting observations in 2023 (continuous) and 2022 (flasks) anymore. (right) Availability of N_2O observations at European site as included in compiled data set. Darker colours indicate greater availability. For continuous observations availability is given in percent (blue), for flask sampling availability is indicated as the number of flask pairs per year (purple).

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.

EMPA together with KIT and AGS evaluated potential agricultural sites for local N_2O flux and isotope measurements. It was finally decided to put up the observations on the premises of one of the long-term trials

("Demo trial") of the AGS site in Reckenholz, close to Zürich. The site offers the largest variety of treatments and best possible controls, provides easy and fast access and allows sampling from fields under different crop rotation and management practices. EMPA set up gas bag sampling with an automatic time integration chamber (ATIC). Weekly bag samples are then analysed for N_2O isotopes (Picarro G5131-i), CO_2 and CH_4 (Picarro G2401-m) at EMPA. Average weekly N_2O fluxes and source isotopic signatures are then calculated using the Keeling plot method. Sampling commenced in mid-February 2024 and will be continued until the end of 2024 to provide observations for a complete growing season (M19). AGS simulated N_2O emissions in grass-clover ley fields of the Demo trial and compared DayCent N_2O emissions due to nitrification and denitrification to short-term (2021-2022) field observations. AGS developed an R-script to compile and record model parameters related to the annual N-budget of model simulations.

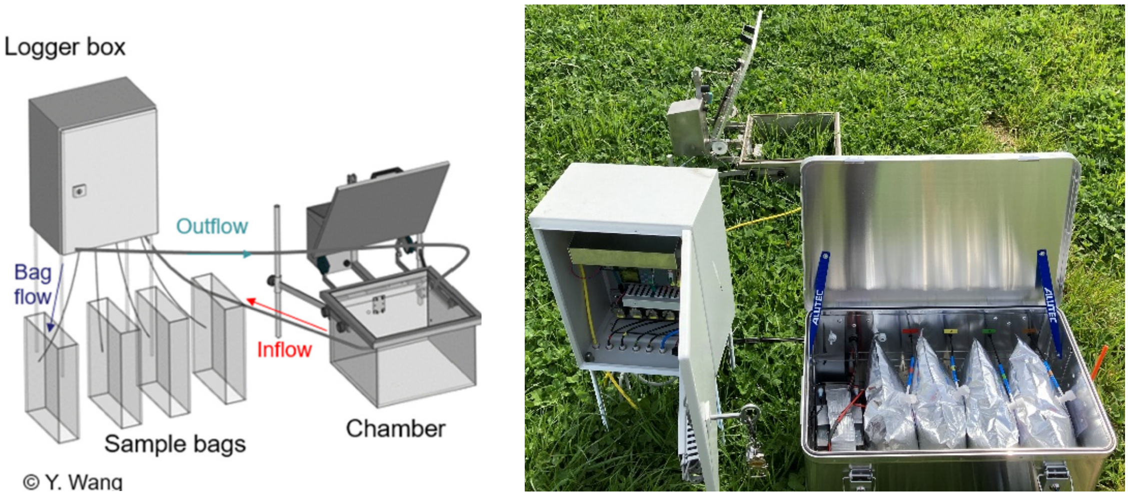


Fig. 17: Schematic and photograph of gas bag sampling with an automatic time integration chamber (ATIC).

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.*

Dedicated work on this task by AGS started in project month 16 and will be intensified from month 19 on in close collaboration with KIT.

Preparatory work by AGS on the DayCent and by KIT on the LandscapeDNDC progressed. Different sources of required input data for the different target countries (Germany, Switzerland, UK) were discussed during two meetings between AGS, KIT and EMPA. KIT is in the process of assessing different sources of input for soil properties and agricultural management to prepare the decision of input data to be used for the national-scale simulations. AGS has calibrated DayCent for cropland and permanent grassland. A preliminary DayCent system has been set up for national-scale simulations (weather and soil data implemented, agricultural management strongly simplified). Collection and definition of agricultural management practices in Switzerland has been started.

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.

As already described in WP3 and WP4, transport simulations (FLEXPART, NAME) were completed for 40 sites across Europe. European scale N_2O inversions were set up by MO, UNIVBRIS and EMPA using the observational input collected in D5.1 and EDGAR and WETCHART bottom-up emissions as a priori. National inversions for the UK (InTEM by MO, RHIME by UNIVBRIS) and Switzerland (EMPA) were completed for recent years. The seasonality of N_2O emissions as obtained from the inversions for both countries were compared to each other and to a bottom-up estimate for the UK. Large seasonal differences were obvious for the UK with emissions obtained from inverse modelling peaking considerably later in the growing season than suggested by the bottom-up estimate (Saboya et al., JGR Atmos, in review). Peak emissions for Switzerland, again as obtained from inverse modelling, seem to occur even later in the year than in the UK and has a slightly larger relative amplitude (Fig. 18).

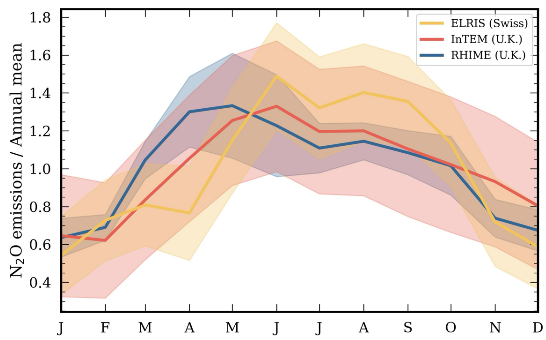


Fig. 18: Scaled annual cycle of national N2O emissions as estimated for the UK (InTEM and RHIME) and for Switzerland (ELRIS).

Differences in fertiliser application practices between the two countries and the dominance of cattle manure use on pastures (dominating source according to Swiss bottom-up inventory) are the likely drivers between the seasonal differences. Updated inversions and comparisons with the biogeochemical models (Task 5.4) will further investigate these emission dynamics. Averaged UK top-down (measurement-derived) N_2O emissions were higher in regions corresponding to a higher number of cattle holdings in England (Fig. 19). This could suggest a relationship between organic (cattle manure) fertiliser applications and UK N_2O emissions. Clearly, further investigation is needed and will be carried out during the second reporting period based on further inverse and biogeochemical modelling.

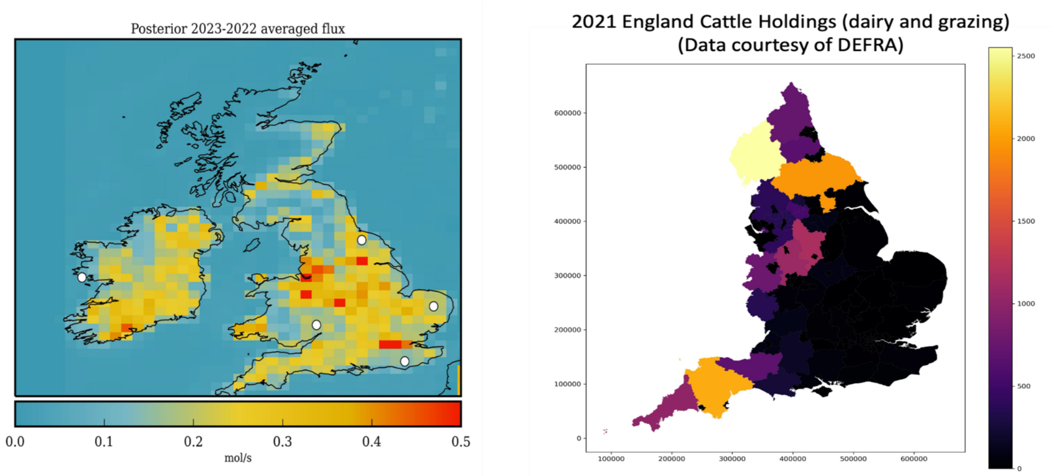


Fig. 19: Averaged RHIME UK N_2O emissions (left) and distribution of 2021 cattle holdings in England (right).

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.

Work on this task is planned for the second reporting period and has not yet started.

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

Fossil fuel CO_2 fluxes are challenging to evaluate using atmospheric data, because CO_2 concentration measurements are strongly influenced by fluxes from the terrestrial biosphere. For Objective 6.1, we are focusing on deploying and using atmospheric measurements of Atmospheric Potential Oxygen (APO), a quantity that is derived from O_2 and CO_2 observations. APO is influenced by fossil fuel CO_2 emissions and oceanic fluxes, but, unlike CO_2 observations alone, is insensitive to the very large CO_2 and O_2 fluxes from the terrestrial biosphere (Pickers et al., 2022). PARIS is adding a new APO measurement site in the Netherlands and maintaining two existing sites in the UK. Modelling studies will then be carried out to determine the value of these observations for constraining fossil fuel CO_2 emissions in the UK and Netherlands. Progress to date on this component has focused on establishing the PARIS APO measurement record. Measurements have continued at Weybourne Atmospheric Observatory (WAO), UK, since the beginning of PARIS. Measurements at Heathfield (HFD) in the south of England restarted in January 2024, following a period of instrumental down-time. The establishment of an instrument at Cabauw, The Netherlands has been changed to an alternative station, Zweth (Rotterdam, The Netherlands). The collaboration with the EU project CORSO offers the option to get data of a second site in the Netherlands as one of the focus countries in PARIS. For both projects, Cabauw was initially planned, and as CORSO is on European scale the distribution of instruments fits for both projects and data will be shared. Data from the UK are available for first analysis and modelling activities, first data from Cabauw are expected to be available from autumn 2024 on to continue. The instrumentation at Zweth will be established in spring 2025 and will give additional local scale fossil fuel information.

A modelling study on the sensitivity of APO observations to various uncertain factors (e.g., ocean fluxes) was recently published by the PARIS team (Chawner et al., 2023), paving the way toward more complete utilisation of the data in inverse modelling systems later in the project.

To meet our second objective of determining the detectability of sources and sinks of CO_2 in Europe, we have proposed a novel "blind verification challenge". Each group will generate synthetic sets of CO_2 pseudo-observations using their chosen atmospheric transport model, and the PARIS inverse modelling teams must try to identify how the fluxes used in the model simulations differ from some common reference run. To date, we have defined and provided the protocol for this experiment (M21, Kivits et al., 2023), and forward model simulations are underway. In the initial phase of this experiment, inverse modelling groups will attempt to identify one of five scenarios from the synthetic data, which will be "unblinded" toward the end of 2024. After this phase, the protocol will be updated, and a more comprehensive experiment will be undertaken, potentially involving external partners.

1.2.6.2 – WP6 - PROGRESS SUMMARY PER WP PARTNER

University of Bristol (UNIVBRIS)

UNIVBRIS have co-authored the blind verification challenge protocol (M21, Kivits et al., 2023). We have developed CO_2 forward simulations using NAME, building on the system outlined in White et al. (2019) and Chawner et al. (2024).

Wageningen University (WU)

WU developed the new APO instrument. WU also authored the blind verification challenge protocol an compiled the flux datasets for it. WU developed CO_2 forward simulations using STILT as used in Van der Woude et al. (2023), and started developing a framework for regional inverse modelling of carbon fluxes over Europe.

University of East Anglia (UEA)

UEA re-established APO measurements at Heathfield and continued measurements at Weybourne. QA/QC Weybourne data and published full record in Adcock et al. (2023).

Rijksuniversiteit Groningen (RUG)

RUG co-developed the new APO instrument.

Deutscher Wetterdienst (DWD)

No activity in the first reporting period due to delays in recruitment.

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.

Parts of this task are complete, and parts are ongoing. Atmospheric measurements of atmospheric O_2 and CO_2 have continued at Weybourne throughout the project. The recent data collected during PARIS have been uploaded to the ICOS Carbon Portal (M23) and are available from https://meta.icos-cp.eu/objects/j4LzdHQiq3fPgfNeXHruC0Bb. Heathfield atmospheric O_2 measurements ceased before PARIS started in November 2022, due to site access issues. These were resolved in November 2023 and the measurements were restarted in Jan 2024. As noted above, the planned measurements for Cabauw are being relocated to Zweth and are expected to begin early 2025.

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.

During this phase of the project, the focus has been on developing CO_2 simulations and establishing inverse modelling systems for estimating CO_2 fluxes from CO_2 mole fraction data. Forward CO_2 simulations have been intercompared between the NAME-UB and CT-Europe-WU models. An example of forward simulations for the Mace Head site using NAME-UB and CT-Europe-WU are shown in Fig. 20. Initial fossil-fuel CO_2 emissions estimates will be generated in the next few months, initially using only CO_2 observations (WU), and fossil-fuel CO_2 timeseries derived from APO observations (UEA/UNIVBRIS). These estimates will serve as a benchmark against which improved simulations using CO_2 and APO observations will be evaluated later in the project.

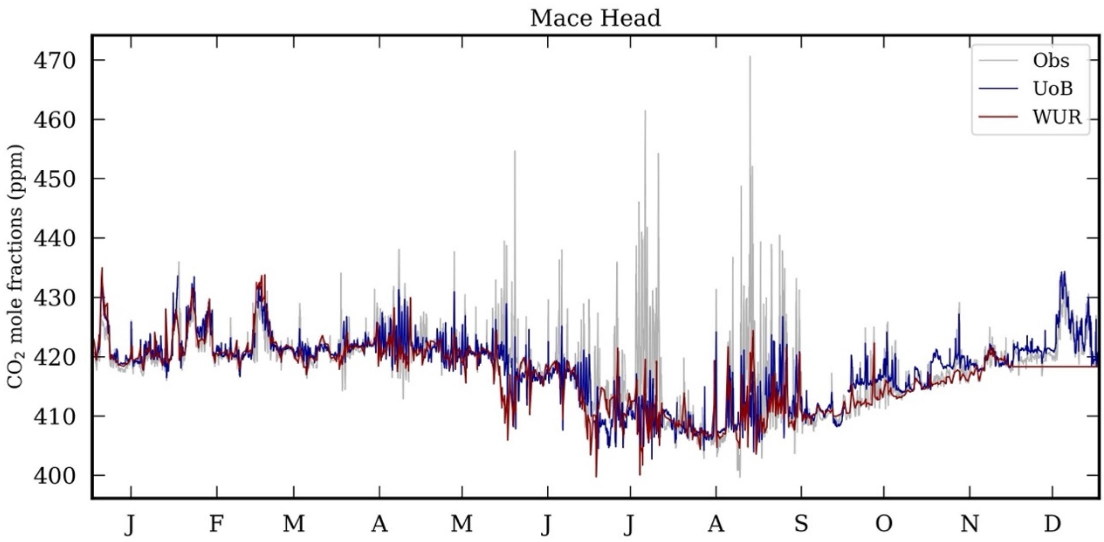


Fig. 20: Time series of hourly measured (grey) and forward simulated atmospheric CO_2 mole fractions at Mace Head station, Ireland for the year 2021. Forward simulations produced using NAME-UB are shown in blue and those produced using CT-Europe-WU are shown in red.

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)

Based on the preliminary inversions performed during the summer of 2024 (Task 6.2), contributions to draft NIR Annexes will be prepared for the UK and Netherlands on the detectability of fossil fuel CO_2 fluxes in late 2024 (WP2). In the first round of draft Annexes, we will describe the state-of-the-art on CO_2 flux inference, informed by our benchmark inversions. The drafts will outline our plans for future improvements, which will then be implemented in the draft Annexes in future years.

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.

A detailed protocol for the first phase of the blind verification challenge has been developed and published (M21, Kivits et al., 2023). Effort has since been focused on developing the "forward" CO_2 simulations for all ICOS and UK DECC network sites using NAME-UB and CT-Europe-WU. Fig. 21 shows forward simulations using NAME-UB for two different scenarios (one with the 10% highest emitting power station emissions across Europe switched off and one in which transport-related emissions from Germany have been halved). Between months 16 and 24, UNIVBRIS and WU will develop their inverse modelling systems and will perform the first round of inversions on six pseudo-datasets that have been created by each other. This is in progress.

They will attempt to identify which scenario each model simulation corresponds to, and results will be unblinded in month 24. Based on the outcome of this phase, the protocol will be refined, and a second phase will begin in the next reporting period, in which external partners will be invited.

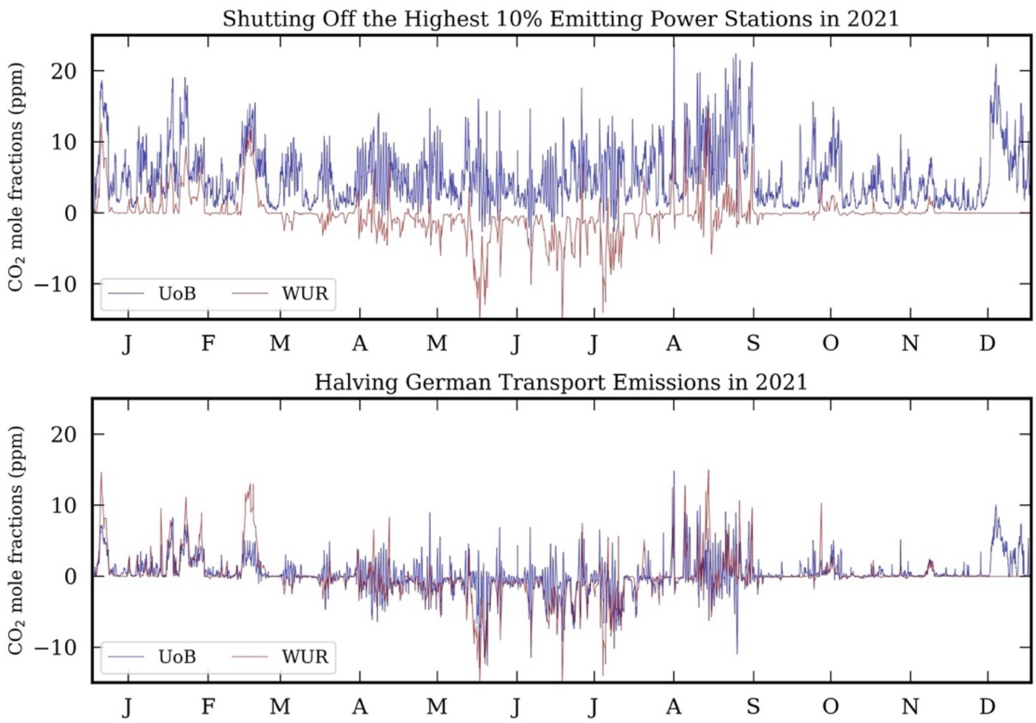


Fig. 21: Forward simulated CO_2 mole fraction perturbations from the background at Mace Head station, Ireland using NAME-UB (blue) and CT-Europe-WU (red). Upper panel shows simulations for the scenario where the highest 10% emitting power stations in Europe are shut down. Lower panel shows simulations for the scenario where German transport emissions are halved in 2021.

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 the first reporting period WP7 has progressed toward 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).

One of the key achievements, under the first objective (O7.1), was the continuous online monitoring of OM in Dublin using the Quadrupole Aerosol Chemical Speciation Monitor (Q-ACSM). The instrument was thoroughly maintained and regularly calibrated, ensuring the collection of high-quality data resulting in a dataset with an impressive >95% data coverage for 2023. The validated OM dataset was subsequently archived in the EBAS database with detailed metadata (https://doi.org/10.48597/ZY3X-VC6G and https://doi.org/10.48597/U9G2-MNV8) to ensure open access and promote transparency, collaboration, and informed decision-making.

A new method for OM source attribution was developed by combining advanced rolling Positive Matrix Factorization (PMF) and machine learning techniques. The method has enabled to separate locally emitted oxygenated organic aerosol vs. transported via long-range transport and was applied to the Dublin data (year 2023). While an upload of the source apportionment data to the EBAS database was not originally planned, it was deemed important to do so in order to ensure open access and promote transparency, collaboration, and informed decision-making. Since currently there is no standardised submission tools or procedures available for the source apportionment data, the PARIS WP7 team has engaged EBAS on this. The working group with members from EBAS, PARIS and another EU project RI-URBANS was created to develop these procedures and data will be submitted after the tools are finalised.

For the second objective (O7.2), the Black Carbon FLEXPART-FLEXINVERT inversion system, a hierarchical Bayesian inversion method, has been set-up and tested for the European domain (January–April 2020 period). BC observations from 13 measurement stations were used for the preliminary inversions. The modelled BC concentrations were simulated for these stations. Overall, the FLEXPART model is able to capture the diurnal variability in the BC concentrations. However, it occasionally misses some high pollution episodes. The posterior concentrations generally show an improvement in the model-data agreement.

Overall, the progress made in WP7 during this period has been pivotal in advancing objectives of the project. The high-quality OM dataset and new source apportionment method in Dublin not only serves as a benchmark for identifying discrepancies between observed and simulated data in other regions but also provides a solid foundation for broader analyses. Moving forward, the focus will remain on finalizing the data submission process and extending OM aerosol analysis to additional European locations, thereby continuing to enhance our understanding of organic aerosol sources across Europe. While the test FLEXPART-FLEXINVERT inversion setup and preliminary results will enable to quantify European black carbon (BC) emissions.

There were no deviations from the initial plan, except for the Task 7.3, which was for PARIS slightly amended to facilitate better interaction with the EYE-CLIMA project and to avoid a duplication of the efforts. The amendment included consolidation of deliverables and adjustment of the due dates to enable the consistency between the two projects.

1.2.7.2 – WP7 - PROGRESS SUMMARY PER WP PARTNER

National University of Ireland Galway (NUIG)

During this reporting period, the University of Galway (formerly NUIG) has focused on the online measurements in Dublin and further source apportionment development for organic matter (OM). The key activities involved continuous online OM observations in Dublin, data processing, data quality control, source apportionment of measured OM and dissemination efforts. As a result, the processed and validated dataset achieved a 95% coverage rate, ensuring high reliability and usability. In addition to bulk OM measurements, new advanced OM source attribution method was developed by combining rolling Positive Matrix Factorization (PMF) based on SoFi Pro and machine learning techniques to enable oxygenate organic aerosol separation into locally originated and regionally transport-ed components, which was not possible with standard source apportionment methods. In terms of data archiving and dissemination, the validated OM dataset from Dublin was successfully archived in the EBAS database, making it publicly accessible. Detailed metadata and standardized data files were prepared and submitted to facilitate data discovery and interoperability. Additionally, ongoing efforts are being made to communicate and standardize the submission process for uploading OM source apportionment results to the EBAS dataset.

The main achievements during this period include the successful continuous monitoring of OM aerosols with high data coverage and robust validation procedures, the public availability of the validated OM dataset in the EBAS database, and the combination of advanced rolling-PMF and machine learning models for detailed source apportionment of OM. The source apportionment method developed and tested in Dublin enables its further application to other locations across the Europe, thereby enhancing the understanding of aerosol sources and contributing to better air quality management on a broader scale. Finally, a WRF-Chem model has been setup and tested on Galway HPC system to enable high resolution runs after the source apportionment for European sites is finalised.

University of Urbino (UNIURB)

Following the initiated amendment to the work plan, UNIURB activity in WP7 has been carried out in collaboration with the sister project EYE-CLIMA. EYE-CLIMA is providing BC harmonized time-series from 13 ACTRIS sites, a-priori fluxes from Europe, and expertise on FLEXINVERT. UNIURB is responsible for the joint Task 7.3 (Estimation of European Black Carbon fluxes), and the joint deliverables D7.4 (former milestone M29) - Preliminary emissions of BC for Europe, and D7.2 - Final emissions of BC for Europe. In this first reporting period, Black Carbon FLEXPART-FLEXINVERT inversion system has been set-up and tested for the European domain. BC observations from 13 ACTRIS measurement stations were used for the preliminary inversions.

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, significant progress was made in the measurements and method development for the source apportionment of organic matter (OM) aerosols, a critical component of Task 7.1. The research team at the University of Galway (formerly NUIG) conducted continuous observations of OM in submicron aerosols (PM1) throughout 2023 (Fig. 22), utilizing the Quadrupole Aerosol Chemical Speciation Monitor (Q-ACSM).

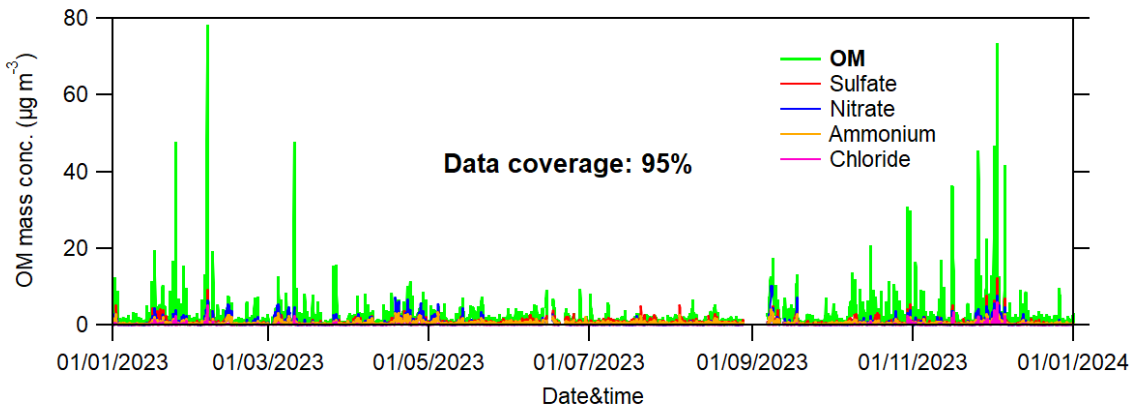


Fig. 22: Time series of observed OM mass concentration and other non-refractory species (sulfate, nitrate, ammonium, and chloride) in Dublin for 2023. Data coverage reached 95%.

The equipment was meticulously maintained and regularly calibrated to ensure precise data collection. The raw data underwent comprehensive processing and rigorous quality control measures, including anomaly detection, data correction, and cross-validation with data from collocated instruments and a nearby EPA monitoring station. This resulted in a highly reliable dataset with 95% coverage. Importantly, the validated OM dataset from Dublin has been archived in the EBAS database, making it publicly accessible and facilitating further research and analysis (Fig. 23, D7.1).

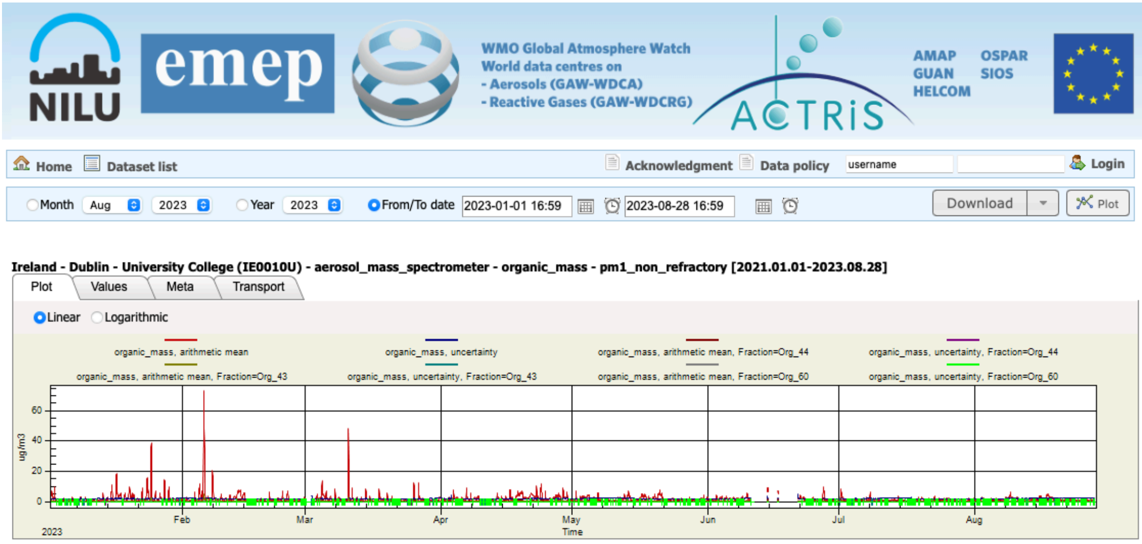


Fig. 23: Screenshots showing uploaded OM data on EBAS website

For OM source apportionment, advanced rolling Positive Matrix Factorization (PMF) based on SoFi Pro software was employed. This analysis identified six OM factors from distinctly different sources and formation processes: primary organic aerosols (POA) from peat, wood, and coal burning, hydrocarbon-like organic aerosols (HOA) from traffic and residential oil burning, and two types of oxidized organic aerosols (OOA)—less oxidized and more oxidized OOA (LOOOA and MOOOA). Additionally, an innovative machine learning model was developed to further distinguish the oxidized organic aerosols into locally originated and regionally transported components, providing a more nuanced understanding of OM sources (Fig. 24). While an upload of the source apportionment data to the EBAS database was not originally planned, it was deemed important to do so in order to ensure open access and promote transparency, collaboration, and informed decision-making. Since currently there is no standardised submission tools or procedures available for the source apportionment data, the PARIS WP7 team has engaged EBAS on this. The working group with members from EBAS, PARIS and another EU project RI-URBANS (https://cordis.europa.eu/project/id/101036245) was created to develop these procedures and data will be submitted after the tools are finalised.

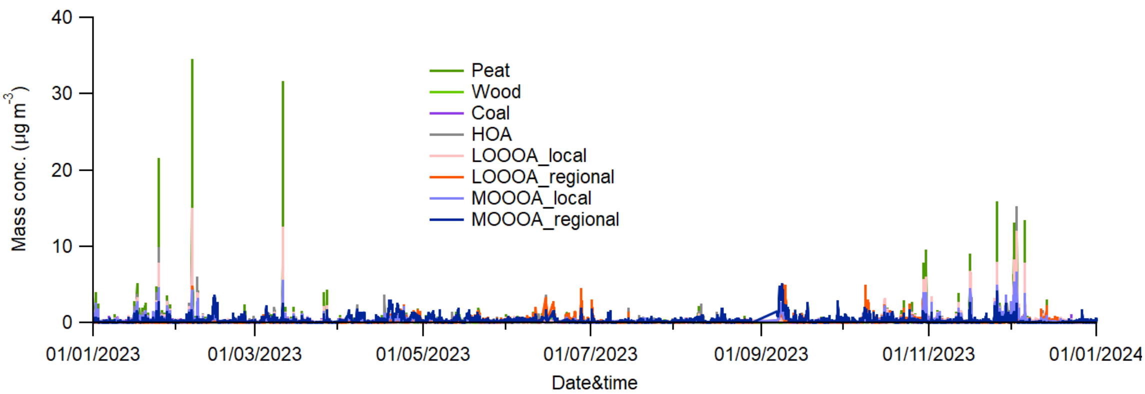


Fig. 24: Time series of OM factors identified by rolling PMF and machine learning approach, including primary OM factors from peat, wood, coal burning and traffic/oil burning (HOA), and two oxidized OM factors, i.e., LOOOA and MOOOA from local sources and regional transport.

These results have several important implications for Task 7.1. The high-quality data and detailed source apportionment in Dublin serve as a benchmark for identifying discrepancies between observed and simulated aerosol concentrations in other regions. The insights into primary and secondary sources, as well as anthropogenic and natural contributions, are crucial for understanding why there are discrepancies between observed data and CAMS modelling outputs. This information helps pinpoint which source sectors contribute to these discrepancies, thereby enhancing the accuracy of regional aerosol models. Additionally, the methodologies and findings from Dublin can be applied to other locations, facilitating a comprehensive analysis across multiple sites to meet the task's broader objectives.

The comparison of regional modelling products of Copernicus Atmospheric Monitoring Service (CAMS) with ACTRIS measurements are ongoing and will enable the further source apportionment method application to the 5 European sites where the discrepancies between model and measurements are the largest.

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.*

The execution of this task is planned for the second reporting period. In this reporting period, some preparational work has been done in advance. The WRF-Chem model has been setup and tested on Galway HPC system to enable high resolution runs after the source apportionment for the European sites is finalised. The task is on time. The measurements and source apportionments are ongoing, the modelling experiments will continue as originally planned after the measurement and source apportionment exercises are finished.

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.*

For the preliminary emissions of BC for Europe milestone, the FLEXPART-FLEXINVERT inversion system for a test case was setup and inversions for the period January–April 2020 were performed. For the inversion, the black carbon (BC) observations from the measurement stations reported in Table 5 were considered.

Measurement sites with relatively high concentration values, likely to be affected by local pollution sources (e.g., urban sites), were discarded.

Table 5: The list of measurement stations used in the inversions for the test case.

Station number	Site name	Latitude	Longitude	Altitude asl (m)
001	Jungfraujoch	46.55	7.99	3578
003	Melpitz	51.53	12.93	86
004	ZugspitzeSchneefernerhaus	47.42	10.98	2671
005	LeipzigEisenbahnstrasse	51.35	12.41	120
008	Montsec	42.05	0.73	1571
009	El Arenosillo	37.10	-6.73	41
010	Montseny	41.77	2.35	700
011	Pallas	67.97	24.12	565
012	Observatoire Perenne de l'Environnement	48.56	5.51	392
013	Puy de Dôme	45.77	2.96	1465
015	Mt Cimone	44.18	10.70	2165
017	Birkenes II	58.39	8.25	219

Fig. 25 shows the location of the measurement stations in the study domain. BC emissions were log-normally distributed, thus it is very likely that the uncertainty on the emissions is also log-normally distributed. Therefore, the inversion setup using normal and log-normal distributions for the prior flux errors was tested.

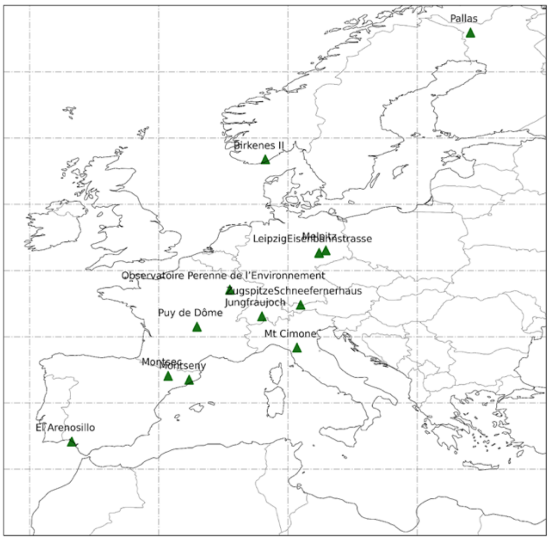


Fig. 25: Study domain with the measurement stations

I) MODELLED BC CONCENTRATIONS USING FLEXPART

The modelled concentrations were well simulated for the stations included in the inversion setup. For most stations, FLEXPART sensitivities could capture the diurnal variability in the BC concentrations. FLEXPART occasionally missed some high pollution episodes. The urban measurement sites were not used in the inversion because of relatively high measured concentrations and the potential influence of local emission sources. Fig. 26 shows the observations and FLEXPART simulated concentrations for a few stations in the modelling period. The posterior concentrations generally show an improvement in the model-data agreement.

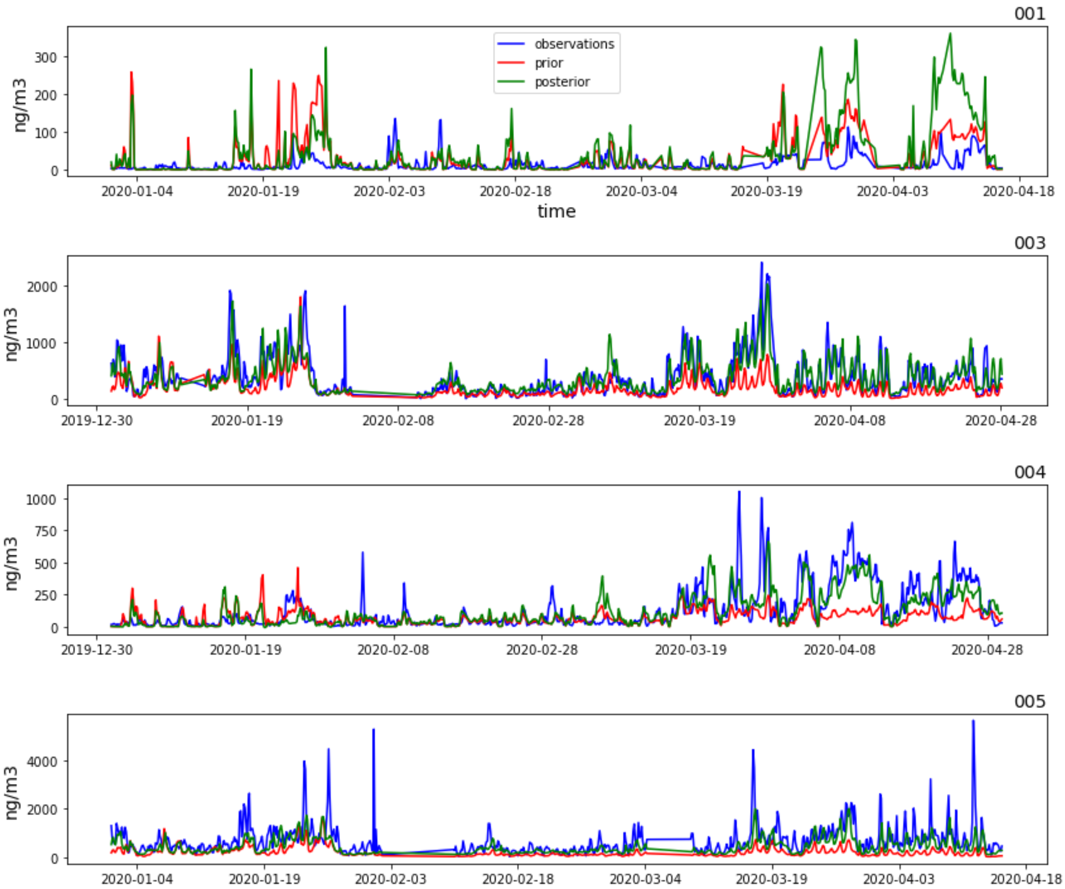


Fig. 26: Comparisons between modelled black carbon prior (in red) and posterior concentrations (in green), and the observations (in blue) measured at stations 1–5 (Table 1) from January to April 2020.

II) PRIOR AND POSTERIOR EMISSIONS

The ECLIPSEv6 emission inventory as prior information in the inversions (Fig. 27 (a)) was used. ECLIPSEv6 emissions include the basic emission sectors of transportation, waste burning, industrial combustion and processing, energy conversion, and residential and commercial combustion. Biomass burning emissions were adopted from the Global Fire Emissions Database, Version 4.1s. The posterior emission flux for the inversion performed with the normal distribution of prior errors is displayed in Fig. 27 (b). Fig. 27 (c) shows the discrepancies between the prior and the posterior emissions.

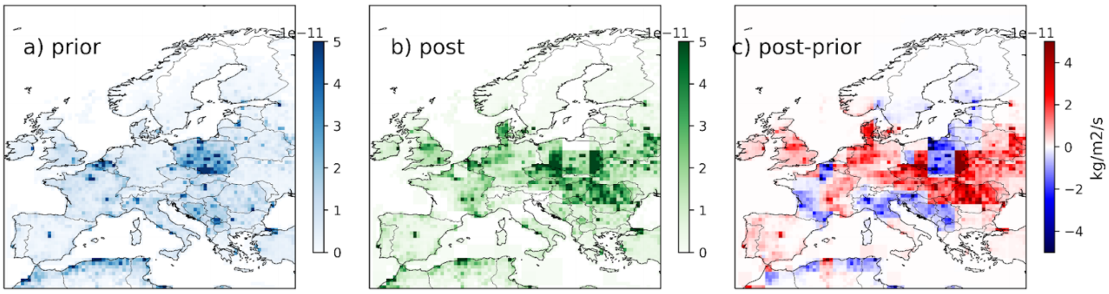


Fig. 27: The a priori (a), and a posteriori (b) fluxes and the difference between prior and posterior fluxes (c) of black carbon in the study domain for January–April 2022 using normally-distributed prior flux errors.

The fluxes obtained using the log-normal case is shown in Fig. 28. The log-normal distribution gives smoother posterior emissions across the spatial grid than the normal distribution (Fig. 28 (b)). This is clearly evident when looking at the difference between posterior and prior fluxes for Poland and northeast Europe (panels c in Fig. 27 and 28).

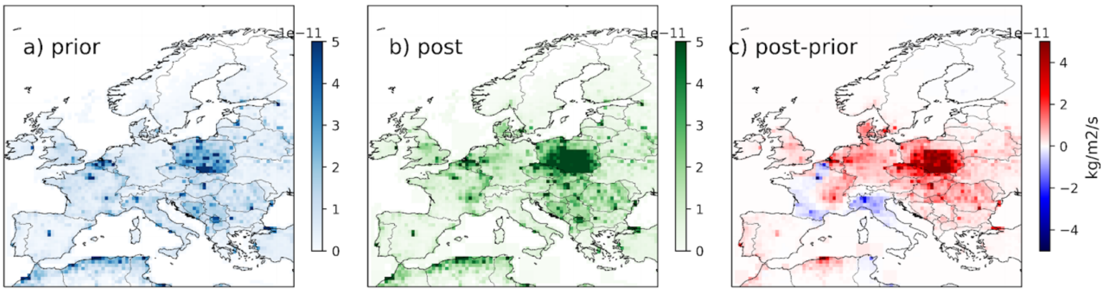


Fig. 28: The a priori (a), and a posteriori (b) fluxes, and the difference between prior and posterior fluxes (c) of black carbon for the inversion performed using the log-normal error distribution in the study domain for January–April 2022.

1.3 IMPACT

PARIS is making significant progress in enhancing GHG emission monitoring and modelling. Through expanded observational networks, harmonized measurements, multi-model inversions, and the engagement with inventory compilers, PARIS contributed to more accurate and actionable emission estimates. The outcome of PARIS has a high scientific and also societal impact as results are critical for the evaluation of efforts taken so far to reduce GHG emissions and further developing effective mitigation strategies.

BUILDING AND EXPANDING INFRASTRUCTURE

During the first reporting period, the PARIS project successfully established new continuous observation sites for F-gases at the Taunus Observatory in Germany, in Norway, Hungary, and Southern Italy. This expansion aims to densify the European network, enabling more accurate emission quantifications, particularly in previously unmonitored regions of Southern and Eastern Europe. The intercomparability of both measurements and inversion systems is a pre-requisite for high quality emission estimates. For the measurements, a high level of standardisation (particularly in the AGAGE related MEDUSA instruments and in the calibrations between the different laboratories) is achieved through a common calibration scale and standardized data evaluation and quality control procedures. For the inversion systems a standardisation is achieved through using common data formats allowing a seamless interchange between different transport models and inversion systems. Evaluation tool for such comparisons have been implemented on the ICOS carbon portal. The improved knowledge of the sources of F-gases will allow for a better emission control and more targeted measures to reduce emissions.

PARIS is also establishing a new APO measurement site in the Netherlands, and maintaining and continuing measurements at two existing sites in the UK. Progress includes continuous measurements at Weybourne Atmospheric Observatory (WAO) and at Heathfield (HFD), and soon at the Zweth site as part of the Ruisdael Observatory in the Netherlands.

HARMONIZING MEASUREMENTS AND EXPANDING NETWORKS

PARIS has harmonized high-frequency N_2O observations across Europe and compiled a comprehensive dataset of continuous in-situ and consistent flask observations from 43 sites. Calibration strategies were revised, and historical data from Hegyhátsál, Hungary, were re-calibrated from 2018 onwards. This harmonized approach ensures the accuracy of N_2O flux estimates and supports robust spatial and temporal analysis. The PARIS N_2O data set is now available on the ICOS Carbon Portal.

CH_4 observation capabilities have also been enhanced, particularly for isotopic composition. PARIS has produced new high-frequency CH_4 isotope measurements and isotope source signatures, both available for use by the scientific community. A portable IRMS instrument was deployed at Lindenberg, Germany, and Cluj, Romania, with future deployments planned for Monte Cimone, Italy, and Hegyhátsál, Hungary. Continuous optical measurement systems were established at the Heathfield tall tower in the UK, with additional systems planned for Zurich and Invergowrie. With these measurements, PARIS has realized the best coverage of high-resolution isotope measurements worldwide. These new datasets will allow for detailed analysis and differentiation of methane emissions from various sources, and the results are expected to contribute to sector level emissions discrimination to target mitigation activities. This is a critical reality check for the current bottom-up methods that are used for reporting GHG emissions. Thus, high quality top-down estimates of methane have the potential to quickly impact the policy initiatives on methane mitigation.

ALIGNING MODELS AND FRAMEWORKS

Significant efforts have been made to align modelling frameworks and data flows. Comparison exercises for seven gases using different setups have been conducted with different models, and a comprehensive intercomparison tool has been developed which is available on the ICOS data portal for rapid analysis. These tools ensure seamless comparison and interchangeability of transport and inversion systems, enhancing the reliability of emission estimates.

Inverse modelling has progressed, with the first methane inversion using data from 33 ICOS stations completed with InTEM. Additional systems are being set up to estimate emissions, including the RHIME system, which will use ethane and methane data to distinguish between fossil fuel and non-fossil fuel emissions. Preparatory work on biogeochemical models (DayCent and LandscapeDNDC) for national-scale application in Switzerland, Germany, and the UK has started, focusing on detailed flux estimates for GHGs like N_2O.

Atmospheric Potential Oxygen (APO) measurements are being used to evaluate fossil fuel CO_2 emissions. Evaluating fossil fuel CO_2 fluxes using atmospheric data is challenging due to the influence of terrestrial biosphere fluxes on CO_2 concentration measurements. A recent modelling study on APO sensitivity by the PARIS team will aid future data utilization in inverse modelling. Additionally, a "blind verification challenge" has been initiated to determine the detectability of CO_2 sources and sinks in Europe, involving synthetic CO_2

pseudo-observations and scenario identification by inverse modelling teams. Improving the methodology for testing inverse model performance for identification of CO2 flux changes and for inference of fossil fuel CO2 fluxes have a high impact on progressing GHG emission monitoring and modelling.

Significant progress has been made towards understanding and attributing sources of organic matter (OM) in submicron aerosols (PM1) in Europe and towards quantifying European black carbon (BC) emissions. Besides the provision of a high-quality dataset based on continuous online monitoring of OM in Dublin, a new method combining rolling Positive Matrix Factorization (PMF) and machine learning techniques was developed for OM source attribution, and applied to the Dublin data. The Black Carbon FLEXPART-FLEXINVERT inversion system was tested using BC observations from 13 stations, showing improvement in model-data agreement although the system still occasionally misses high pollution episodes. This progress sets a solid foundation for broader analyses and incorporating more data streams in the future. This will allow us to extend OM aerosol analysis to other European locations, an effort with a high regulatory potential.

ENGAGING WITH INVENTORY COMPILER TEAMS

Engagement with inventory compilers from eight focus countries has been a key component of the PARIS project. Initial results from inverse models have been shared with representatives from the UK, Switzerland, Ireland, and Germany, with positive and constructive feedback received. Further meetings with inventory agencies are planned to present results from at least three inverse models, fostering collaboration and ensuring that findings are incorporated into national reports. A template for national annex chapters has been developed, with the first annexes expected in Autumn 2024.

This engagement significantly contributes to reducing barriers between inventory teams and GHG researchers and exchanging knowledge between countries with evaluation programmes in different stages of development. With only a few countries worldwide, and only two in Europe (the UK and Switzerland, via our team), who routinely report their emissions using bottom-up (inventory) and top-down (atmospheric data-based) methods together, PARIS helps to significantly increase the uptake of this joint approach to emissions evaluation. This is also supported by the collaboration with the sister projects EYE-CLIMA and AVENGERS and will be intensified in the second reporting period.

COLLABORATIVE EFFORTS AND FUTURE STEPS

PARIS has fostered several collaborations during the first reporting period, which will be continued and intensified in the second one, particularly with EYE-CLIMA, AVENGERS and the Copernicus Atmospheric Monitoring Systems (CAMS), but also with the projects isoMET and AGAGE, or individual external partners such as the Centre for Excellence in Regional Atmospheric Environment, China.

These collaborations facilitated intensive exchange of data and knowledge, and have resulted in harmonized data sets, comprehensive intercomparison tools, and shared efforts in expanding observational networks, as well as an enhanced engagement with national inventory compilers, leading to significant improvements in the accuracy and detail of e.g., GHG data sets or the development of an advanced machine learning model for oxygenated organic aerosols (OOA) source attribution. This enhanced understanding is crucial for better model predictions and informs air quality management and policy decisions. Such collaborations exemplify the benefits of international cooperation in advancing scientific research and developing innovative solutions to complex environmental challenges. The PARIS team has taken the lead to intensify such collaborations, promote them by dedicated dissemination activities and will continue with this effort. Through these activities, PARIS is taking significant steps towards more accurate and comprehensive GHG emission monitoring, ultimately contributing to more effective climate change mitigation strategies.

1.4 UPDATE OF THE PLAN FOR EXPLOITATION AND DISSEMINATION OF RESULTS

The strategy for communication, dissemination, and exploitation has been described in detail in the Grant Agreement, Chapter 2.2. The following measures had been defined:

Dissemination - Annexes to National Inventory Reports for submission to the UNFCCC for eight focus countries. Scientific publications and open publication of data. Continued participation in scientific assessment reports (WMO, IPCC, etc.). Workshop or conference session hosted jointly with other projects funded under this call and IG3IS, TransCOM, etc. Continued input to IPCC reporting guidelines.

Exploitation - Annexes to National Inventory Reports. Long-term engagement of PARIS team in national inventory refinement processes. Knowledge exchange between PARIS team members from countries with wide range of expertise and levels of engagement with inventory process. Open publication of data and analysis tools

Communication - Open access publications, open data (FAIR principles), publication of analyses. Publicly accessible data visualisation tools and explanatory resources. Public-facing summaries of PARIS outcomes (news releases, blogs, etc.). Sharing of resources and public updates through website and social media.

DISSEMINATION

Within the first reporting period, the PARIS consortium was particularly progressing towards the main foci for impacts which are the annually produced **Annexes to the NIRs**. This is described in detail in the work progress for WP2 (Chapter 1.2.2). Annexes to National Inventory Reports, available in the second reporting period, will either be included as part of a country's NIR submission (if requested by the country) or archived through the ICOS Carbon Portal.

Besides this, PARIS **actively disseminates the products and datasets from measurements, model footprints and emissions estimates**. A report on the detectability of CO_2 fluxes has been published as Blind Verification Challenge protocol (M21). The protocol provides input to the European Monitoring Verification Support (MVS) and details the impacts of mixed top-down and bottom-up emission registration efforts. It is based on a realistic diversity of transport errors, and a realistic set of emission reports, to use in real verification. PARIS collaborates with several projects, e.g., the EU project CORSO on complementary APO measurements at two Dutch stations (Cabauw, Zweth) and complementary fossil fuel inference methods ($^{14}CO_2$ and APO from CORSO, APO from PARIS). Several members of the PARIS team are also members of the AGAGE network (https://www-air.larc.nasa.gov/missions/agage/) , and our deployment of new F-gas flask measurements aims to represent a model that can be used rolled out across the AGAGE network to extend global F-gas observing capabilities. As a first step towards this, the AGAGE software hierarchy (GCWerks/GCCompare) has been extended to allow a better inclusion of flask data. Data sets, partly as joint data sets together with EYE-CLIMA and AVENGERS, are publicly available via the ICOS carbon portal (https://data.icos-cp.eu/portal/#{%22filterKeywords%22:[%22PARIS%22]}). The PARIS website also links to the available data sets. This effort is ongoing. The respective data management is described in the DMP (D1.3).

PARIS already published the first results as **peer-reviewed journal contributions** (Table 4). Given the natural time-consuming process of research publication the number of publications is expected to increase significantly in the second reporting period, towards the end and beyond of the project. A similar timeline is expected for **conference contributions**. Up to now, the PARIS consortium provides more than 20 journal and conference contributions.

EXPLOITATION

Exploitation focuses on three key areas: developing long-term collaboration with national inventory teams and embedding top-down information in national inventory refinement processes, knowledge transfer between groups with differing levels of expertise in top-down and bottom-up emissions evaluation, and open data sharing and the provision of tools for data exploitation by the wider scientific community.

As described in Chapter 1.2.2, the consortium is working towards draft annexes to the national inventory reports. The consortium initiated first contacts and meetings to set-up trustful long-term collaborations with the inventory teams of our focus countries. The feedback is of the inventory teams is positive and knowledge exchange is appreciated.

The PARIS consortium has a wide range of expertise in top-down and bottom-up emissions evaluation, atmospheric measurements and modelling, and levels of engagement with national inventory teams, and participates in several European and international projects (e.g., CAMS, AGAGE, ACTRIS, CARIBIC). **Knowledge exchange** is one the one hand fostered by personal exchanges during meetings and conferences, joint field campaigns and dissemination activities such as journal or conference contributions. Such activities are natural in collaborative environments such as PARIS and related projects. Besides this, we actively encouraged the **collaboration with our sister projects EYE-CLIMA and AVENGERS**. We have identified overlapping scientific activities (Fig. 29) and align them. We shared our common data output format for better alignment and harmonisation of data, and we are collaborating on joint deliverables. PARIS is also fostering joint outreach activities such as conference contributions (Table 4).

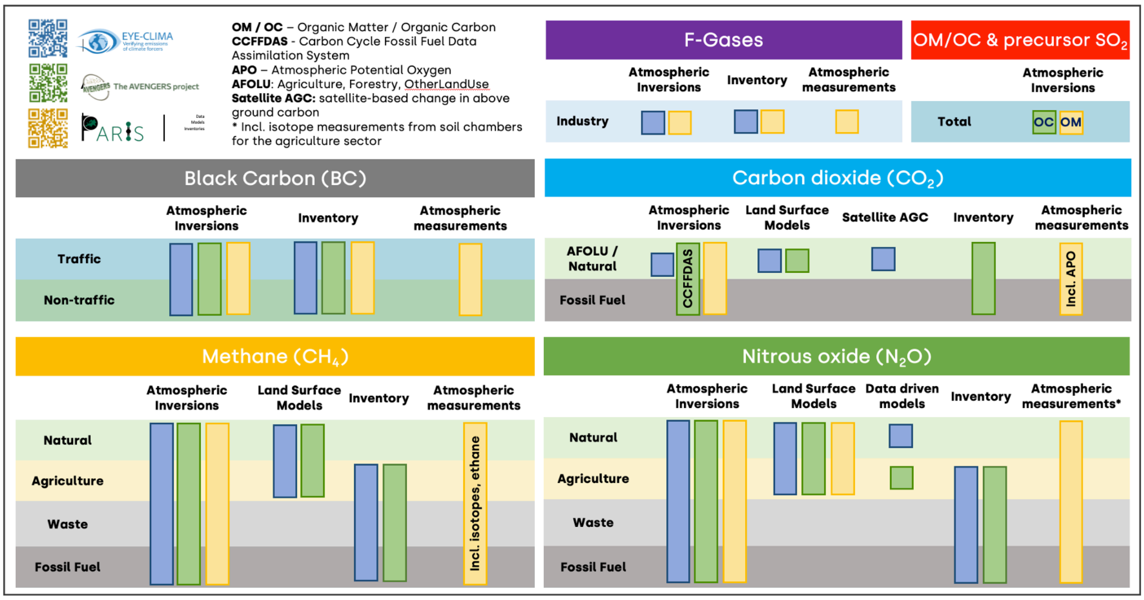


Fig. 29: Overview of scientific overlap between the three sister projects PARIS, AVENGERS and EYE-CLIMA. The overview is part of the joint poster presentations given in the first reporting period (Table $) to demonstrate collaboration opportunities.

To further expand networking and knowledge exchange, PARIS established a **network of almost 50 Early Career Researchers** (ECRs) of all three projects and organised regular meetings between them (Table 3). This network aims to create a platform for talks, discussions, and collaborations among ECRs within our communities. We have kicked off with a series of informal talks by and for ECRs. These sessions provide a relaxed environment to share research, exchange ideas, and gain valuable feedback from peers.

To facilitate face-to-face interactions, PARIS coordinated a first **splinter meeting at the EGU** in 2024. This meeting was intended to meet in person, discuss joint activities and build networks. Key discussions focused on terminology, practices, and collaboration among projects. Particularly sector definitions across projects, intercomparisons EU practices across countries and the need for mandatory data sharing protocols and formats, the use of an ensemble of transport models, and exploring differences in meteorological inputs was discussed. Outreach efforts highlighted the importance of joint webinars, targeted communication on methodologies, and progress reports. Topic-focused seminars were suggested and the importance of clear messaging regarding targets and additional reduction measures was highlighted. Regular coordinator meetings were affirmed, with previous discussions on uncertainties referenced. The implementation of the recommendations from this splinter meeting is in progress.

To ensure that the wider scientific community can fully exploit the unique datasets generated in PARIS, all data generated so far are fully **open access**, and well documented on the ICOS Carbon Portal and the EBAS data base. The PARIS website (https://horizoneurope-paris.eu/data) links to these data sets to enhance visibility and findability.

COMMUNICATION

As described for Task 1.5, the UU has established a **project website**, which shares the objectives of the project, involved organisations and links to available PARIS data on the ICOS Carbon Portal. Visitors are provided with details about ambitions, methodologies and planned tasks for each WP, and have access to outcomes such as deliverable and milestone reports. Related scientific publications are also available and updated regularly.

The consortium focusses on scientific dissemination activities. **Social media** activities are less relevant for projects such as PARIS and are consequently lower prioritised, but part of the communication. An account on X has been created for PARIS (@HorizonEU_PARIS), and first results and activities such as e.g. conference presentations, webinars or fieldwork have been promoted. Instead of focussing on promoting the visibility of PARIS individually on social media, the project management has chosen to approach on **collaborative presentations** of the sister projects PARIS, EYE-CLIMA and AVENGERS as project group with a focus on international research related events such the EGU or the NCGG (see Table 4). The project group was also presented by a poster during the final General Assembly of the CoCO2 project, in collaboration with CORSO.

The PARIS approach was promoted during a spring **webinar series** of IG3IS | World Meteorological Organization (wmo.int), presented to the inventory and GHG inverse modelling community. Alongside fostering the visibility during scientific events, PARIS participates in joint webinars organised by AVENGERS and initiated joint **newsletters**, together with CAMS, AVENGERS and EYE-CLIMA.

PARIS took the lead to also increase the visibility of the project group on **European policy level**. We engaged with national inventory agencies to discuss user requirements and future services. Key stakeholders, including the CO_2 Monitoring Task Force, advisory boards, and the European Commission, are targeted attendees. A joint presentation has been prepared by the project management for a Working Group 1 meeting in Brussels in March 2024, a valuable opportunity to engage with the member states and highlighting PARIS, EYE-CLIMA and AVENGERS projects during the AOB section of the meeting. PARIS successfully applied for a CINEA/DG RTD cluster event, focussing on policy relevant updates to EC staff, highlighting our latest scientific developments to the COP and/or EU climate policy agenda later this year.

Further activities are planned for the second reporting period when more research results are expected. This includes the extension of data sets and open data tools, high impact publications but also news articles and press releases related to scientific publications. We will also intensify the release of blogs via the PARIS website to reach a wider audience.

As described in the GA, PARIS will utilise the Open GHG frameworks to provide a portal through which researchers and the public can view and manipulate PARIS data and gain an understanding of how and why the data are being collected and used. This is in progress. One part of this is already live but so far just for the UK component: https://openghg.github.io/decc_dashboard/.

2. FOLLOW-UP OF RECOMMENDATIONS AND COMMENTS FROM PREVIOUS

Not applicable

3. EXPLOITATION PRIMARILY IN NON-ASSOCIATED THIRD COUNTRIES

Not applicable

4. OPEN SCIENCE

Open science within PARIS focusses on -by the UNESCO recommended- pilar of open scientific knowledge, particularly on scientific publications and open research data and software tools. To ensure knowledge integration and reuse of data, PARIS 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. 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.

The data management as basis for successful open science is described in detail in the Data Management Plan (D1.3).

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

5.1 TASKS/OBJECTIVES

The scientific work is proceeding according to the tasks and critical objectives stated in the grant agreement. As an additional activity, PARIS engaged in an intensive collaboration with EYE-CLIMA and AVENGERS. This led to highly successful collaborations e.g., in inventory engagement, outreach and data harmonization for modelling. To avoid duplicate work and make best use of the resources, two deliverables will be pursued in a joint effort with the EYE-CLIMA project. This is presently being formalized via a contract amendment. An overview of requested changes is given in History of Changes table of the amendment.

Besides the scientific collaborations of the core research program, PARIS also aligned with EYE-CLIMA and AVENGERS on dissemination activities, including joint presentations and newsletters, upcoming webinars and an early career researchers' network.

In agreement with the consortium, UNIURB changed from flask measurements to continuous F-gas measurements for scientific and administrative reasons (see Chapter 1.2.3.3, Task 3.2). This has also been implemented in the amendment of the GA.

Due to technical reasons, some measurements were delayed but with no significant impact on our overall objectives or tasks. Sampling at Hegyhátsál and Birkeness is now on track, though Birkenes faced delays due to flask availability. Continuous measurements at the new Medusa sites (Mte Cimone and Taunus) experienced interruptions due to cooling system failures, which have since been resolved. Technical issues with the laser spectrometers at Heathfield and the mobile IRMS systems of the UU were resolved, and the delayed laser spectrometer for SOAR-Invergowrie was delivered in June 2024. At Heathfield, APO observations were offline from Nov 2022 to mid-Jan 2024 due to site access issues, which is now resolved. The BC/OM data show a one-week data gap due to relocating the Dublin site, but measurements continued and resulted in a 95% data coverage for 2023, affirming the new site's suitability and preserving observation integrity.

A few consortium partners faced delays due to a lack of qualified applicants for advertised positions within PARIS. These problems in recruiting staff led to redistributions within the affected teams (KIT, DWD and GUF), but without effect on the tasks of the groups. In the meantime, suitable candidates have been hired.

Overall, the delays are not impacting the tasks as described, and 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 researchers. Summarising, most partner underspent budget and person months in the first reporting period, one overspent. This is mainly for two reasons:

RECRUITMENT

A delay of recruitment was reported for the partner KIT, DWD and GUF. This has been solved. Other partners intended to hire staff members in the upcoming reporting period because of dedicated tasks and spent less resources in the first reporting period. E.g. NUIG used only 2% of its budget for personnel costs as it intends to hire in the second reporting period, which was anticipated in the planning. RUG started co-developing the new APO measurement system and invested in hardware, however, a dedicated technician will be hired in the second reporting period. Thus, no personnel costs are declared so far.

UNEQUALLY DISTRIBUTED TASKS

Tasks and related costs within a project are not equally distributed over the lifetime of a project. Some, such as e.g. set-up of instrumentation or initiating procedures are implemented in the start phase of a project, while sample measurements, data evaluation or publishing results are part of a later or final phase of a project. As an example, GUF has spent 64% of its budget for other goods and services because of the set-up of a new station for F-gas monitoring and RUG spent a similar amount for hardware of the new APO measurement system. For the same reason, ATOMKI spent 87% of its travel budget to set-up the measurements at Hegyhátsál. ORB spent 51% of its budget and 53% of its person months because of the establishment of a dedicated workflow, to be used as a template in the next reporting periods and the necessary data preparation for this. As the opposite, NILU clearly underspent its budget as almost 40% of its total budget are reserved for flask measurements which will take place in the second reporting period.

For the project partners not required to financially report towards the EU (UK, CH) the situation is comparable to the one of the beneficiaries. Overall, 24% of the total budget and 23% of the PM have been spent so far by the beneficiaries and the UK/CH partners. The project management, in collaboration with the responsible WP leaders, is monitoring the progress of tasks and resource distribution closely and will take measures if necessary. For this first reporting period, the observed deviations are reasonable and no further action was required.

For UNIURB, the person months in WP7 are part of an amendment, requested to increase from 19 to 30 person month due to an internal shift in personnel from a senior to junior researcher. The shift is cost neutral.

No transfer of costs categories has been requested.

Adjustments to previous financial statements are not applicable.

Clarifications based on the Suspension to Payment Deadline letter (8 October 2024):

a) Significant deviation of the average rates for personnel costs

UNIURB: In the first reporting period, the permanent staff (one full professor and one associated professor) share of efforts exceeded the projections because the junior researcher's 3-yr contract started at month 13. In the second reporting period, the cost of the permanent staff will be lower in correspondence with the increase in the efforts of the junior researcher. In this way the average cost will be rebalanced. Alongside, the permanent staff hourly cost of the PI exceeded the projections because she shifted from the role of associated to full professor.

ATOMKI: Due to difficulties in finding qualified personnel less amounts have been spent on personnel costs. The human resource issue has been solved, and there have been no delays in the work planned. The planned PM rates per WP will be used after all.

b) Claiming travel and OGS costs although no personnel costs are claimed

KIT: Travel costs have been made by the KIT team leader to join the PARIS kick off meeting, who is part of the project and functions as the beneficiary representative. Allocated person months are reserved for the non-permanent staff to be hired on the project, thus no personnel costs have been claimed.

RUG: Travel costs have been made by the RUG team leader to join the PARIS kick off meeting, who is part of the project and functions as the beneficiary representative. The OGS costs refer to set-up/replacement of measurement instrumentation which could not be delayed to ensure data collection. Allocated person months are reserved for the non-permanent staff to be hired on the project, thus no personnel costs have been claimed.

c) Unforeseen OGS costs

ATOMKI: Wind measurements are essential for the evaluation of trace gas measurements in both work packages 3 and 5. The failure of the anemometer could not be foreseen at the time of budgeting, however, the instrument had to be repaired within the shortest possible time so as not to lose valuable data.

Clarifications based on the 2nd Suspension to Payment Deadline letter (19 November 2024):

a) Equipment costs

RUG:

1. Regarding the declared costs items "customized Ultra-low gas cooler type EC30C" and "Vapor Trap, 8 L, -90 C", the partner should further explain the reasons for the deviation from Annex 1 and necessity of these costs for implementation of the action, with reference to specific task(s) in the work plan in Annex 1 for which this equipment was used.

According to Annex 1, Task 6.1, RUG has the obligation to measure/monitor the atmospheric O2 concentration with high precision for a period of a year. While preparing the measurement setup in our laboratory, it turned out that continuous, intense drying (to a very low dew point) the inlet air is absolutely crucial for high-quality results. Given the necessity of the ultra-low drying for the proposed measurements, this equipment is essential to fulfil our tasks.

2. Additionally, the rate of actual use for the action (currently confirmed as 100%) should be further explained in the same section of the technical report.

These goods are uniquely usable for the project. After the project, we see no new tasks for these pieces of specialized equipment. Drying air is often necessary, only not to these ultra-dry conditions.

b) Other goods, works and services

RUG:

Regarding the cost item *"EL-FLOW Select F-201CV-100 Mass Flow Controller" the partner should further explain the reasons for the deviation from Annex 1 and the necessity of the purchase for the implementation of the action, with reference to specific task(s) in the work plan in Annex 1 for which this device was used.*

Our Mass flow controller, foreseen for the measurement setup proposed in Task 6.1, broke down beyond repair. As this piece of equipment is essential for the setup to accurately measure the atmospheric O2 concentration, it had to be replaced.

5.2.1 UNFORESEEN SUBCONTRACTING

Not applicable

5.2.2 UNFORESEEN USE OF IN KIND CONTRIBUTIONS

Not applicable

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6. DOCUMENT HISTORY

Version	Publication date	HISTORY OF CHANGES
1.0	20th June 2024	WP contributions received; draft version 1st Periodic report prepared
	9th July 2024	Draft version sent to WP leads for feedback
	25th July 2024	All WP leader feedback received
	20th August 2024	Report finalised and send out to WP leaders for check
	28th August 2024	Report submitted
	15th October 2024	Clarifications added to chapter 5.2 – Use of Resources / report re-submitted