CAMS Service Evolution

D7.7 Final Dissemination and Exploitation Report

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1 Executive Summary

The project's dissemination and exploitation activities present a crucial element in the success of the CAMEO project, as they ensure that results are taken up by the wider community and are sustainable beyond the initial funding period, thus providing value for money.

This final Dissemination and Exploitation Report provides the detailed descriptions of dissemination activities, exploitable results and related activities at the end of the project (Month 36).

The dissemination plan identified instruments and targets. The interim report and this final report includes activities organised by CAMEO (including workshops, website, news items, etc.) as well as important events attended by CAMEO members (i.e. workshops, conferences, seminars, etc.).

This deliverable also provides the potential exploitation avenues in terms of outputs as well as respective exploitation activities during and after the end of the project, thus fulfilling the requirements of the DoA.

The exploitation section also includes the recommendations for CAMEO outputs and how these have been/ could potentially be, incorporated into operational service.

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2 Introduction

2.1 Background

Monitoring the composition of the atmosphere is a key objective of the European Union's flagship Space programme Copernicus, with the Copernicus Atmosphere Monitoring Service (CAMS) providing free and continuous data and information on atmospheric composition.

The CAMS Service Evolution (CAMEO) project will enhance the quality and efficiency of the CAMS service and help CAMS to better respond to policy needs such as air pollution and greenhouse gases monitoring, the fulfilment of sustainable development goals, and sustainable and clean energy.

CAMEO will help prepare CAMS for the uptake of forthcoming satellite data, including Sentinel-4, -5 and 3MI, and advance the aerosol and trace gas data assimilation methods and inversion capacity of the global and regional CAMS production systems.

CAMEO will develop methods to provide uncertainty information about CAMS products, in particular for emissions, policy, solar radiation and deposition products in response to prominent requests from current CAMS users.

CAMEO will contribute to the medium- to long-term evolution of the CAMS production systems and products.

The transfer of developments from CAMEO into subsequent improvements of CAMS operational service elements is a main driver for the project and is the main pathway to impact for CAMEO.

The CAMEO consortium, led by ECMWF, the entity entrusted to operate CAMS, includes several CAMS partners thus allowing CAMEO developments to be carried out directly within the CAMS production systems and facilitating the transition of CAMEO results to future upgrades of the CAMS service. The CAMEO consortium also has partners from outside CAMS to ensure information/ knowledge exchange from the wider scientific community.

This will maximise the impact and outcomes of CAMEO as it can make full use of the existing CAMS infrastructure for data sharing, data delivery and communication, thus supporting policymakers, business and citizens with enhanced atmospheric environmental information.

2.2 Scope of this deliverable

2.2.1 Objectives of this deliverables

This deliverable D7.7 provides the end of project update on dissemination and exploitation plan.

The objective of D7.7 is to report on the dissemination activities from Month 18 to Month 36 and to provide an update of possible exploitation routes.

2.2.2 Work performed in this deliverable

In this deliverable the work outlined in The Description of Action WP7 T7.4 was performed. The aim being to provide a final update on the dissemination activities as well as the potential for exploitation and their routes.

Feedback from the partners pertaining to both dissemination and exploitation will be garnered throughout the project and be presented in this document

2.2.3 Deviations and counter measures

No deviations have been encountered.

2.2.4 Reference Documents

[1] Project 101082125- CAMEO-HORIZON-CL4-2021-SPACE-01 Grant Agreement

[2] Deliverable 7.2 Dissemination and Exploitation Plan

[3] CAMEO website https://www.cameo-project.eu/

[4] Deliverable 7.6 Mid -term Dissemination and Exploitation Report

2.2.5 CAMEO Project Partners:

(Participant number order)

ECMWF	EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS
Met Norway	METEOROLOGISK INSTITUTT
BSC	BARCELONA SUPERCOMPUTING CENTER-CENTRO NACIONAL DE SUPERCOMPUTACION
KNMI	KONINKLIJK NEDERLANDS METEOROLOGISCH INSTITUUT-KNMi
SMHI	SVERIGES METEOROLOGISKA OCH HYDROLOGISKA INSTITUT
BIRA-IASB	INSTITUT ROYAL D'AERONOMIE SPATIALEDE BELGIQUE
HYGEOS	HYGEOS SARL
FMI	ILMATIETEEN LAITOS
DLR	DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV
ARMINES	ASSOCIATION POUR LA RECHERCHE ET LE DEVELOPPEMENT DES METHODES ET PROCESSUS INDUSTRIELS
CNRS	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS
GRASP-SAS	GENERALIZED RETRIEVAL OF ATMOSPHERE AND SURFACE PROPERTIES EN ABREGE GRASP
CU	UNIVERZITA KARLOVA
CEA	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES
MF	METEO-FRANCE
TNO	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO
INERIS	INSTITUT NATIONAL DE L ENVIRONNEMENT INDUSTRIEL ET DES RISQUES - INERIS

IOS-PIB	INSTYTUT OCHRONY SRODOWISKA - PANSTWOWY INSTYTUT BADAWCZY
FZJ	FORSCHUNGSZENTRUM JULICH GMBH
AU	AARHUS UNIVERSITET
ENEA	AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

3 Project Communication & Dissemination

3.1 Report on Dissemination Activities

As a project, we have taken an active role in conferences, workshops and seminars explaining the project aims and initial results. International liaison work also continues to be an important aspect to the project.

In this last 18 months, CAMEO has been presented 23 times at conferences and workshops as well as at CAMS Service Level Board (SLB) regular meetings.

CAMEO held its final in-person General Assembly at ECMWF premises in Bonn, 3rd and 4th December. This was very well attended with over 50 project partners. Laurence Rouil, Director of CAMS, gave the opening talk. Following this, with project updates from linked Horizon Europe (HE) projects, were: Richard Engelen (CORSO project coordinator), Anna Agusti-Panareda (CATRINE Project Coordinator) and Samuel Remy (CAMAERA Project Coordinator).

The project is actively liaising with these fellow Horizon Europe projects, as mentioned above (E.g. CORSO and CATRINE, amongst others) to ensure synergies are identified and developed.

The project is also liaising with the CAMS Copernicus Service and was represented at their annual General Assembly, Sept 2025.

The CAMEO website has provided regular updates and news items.

A restricted web-based environment has been set up at ECMWF that includes a document repository and acts as the project's collaborative platform. The CAMEO website acts as the main location to showcase all project information and outputs. The details of this are described in D7.3.

As a reminder and as per the DoA, CAMEO dissemination activities are designed around providing/disseminating information to the scientific communities and relevant stakeholders in three areas:

1. Scientific and technical results through
    a. Scientific Publications
    b. Conference Talks
    c. Organised Workshops, providing updates on the project results
    d. Reports to and feedback from Committees and Boards
2. Products through dissemination of
    a. Datasets and accompanying material (e.g. descriptions, meta data)
    b. Algorithms / Specifications
    c. Graphics and animations
3. Progress information through provision of
    a. News items
    b. Public Deliverables
    c. Dissemination Materials (brochures, posters, flyers)
    d. Website and social media

3.1.1 Scientific and technical results

a) Scientific Publications – article in Journal

Title/ DOI	Status
Preparing the future MTG-IRS data assimilation into the CTM MOCAGE for ozone and carbon monoxide forecasts. Olivier Coopmann, Vincent Guidard and Francesca Vittorioso QJRMS	In review
A Probabilistic Approach to Quantify the Uncertainty of the 1 Min Irradiance Estimates from the Copernicus Atmosphere Monitoring Service (CAMS) Radiation Service https://onlinelibrary.wiley.com/doi/10.1002/solr.202500568 Jorge Enrique Lezaca Galeano, Yves-Marie Saint-Drenan, Marion Schroedter-Homscheidt	Published Oct 2025
Assimilation of Water Vapour in the Upper Troposphere–Lower Stratosphere Semane et al. QJRMS, Wiley	In preparation (expected to be published in 2026)

b) and c) Conference and Organised Workshops Talks (Talk/ Poster)

Name	Date	Location	Presenter	Presentation title
PEGASOS Project meeting	26.-27.09.2024	DLR, Germany	Zoi Paschalidi	Evaluating GEMS NRT observations for the HE CAMEO project. (Talk)
ESA Water Vapour Climate Change Initiative- 2 nd User workshop, Jülich , 14-16 October 2024	16.10.2024	Jülich, Germany	Noureddine Semane	Stratospheric humidity analysis. (Talk)
ITM conference	14-18.10.2024	Copenhagen	Hilde Fagerli	Uncertainty estimates for CAMS source receptor policy products. (Talk)
ITM conference	14-18.10.2024	Copenhagen	Renske Timmermans	Source attribution of particulate matter: Evaluation and comparison of different methods in regional chemistry transport models. (Talk)

Name	Date	Location	Presenter	Presentation title
ITM conference	14-18.10.2024	Copenhagen	Zhuyun Ye	Integrating Sentinel-5p TROPOMI SO2 Observations into the Danish Eulerian Hemispheric Model (DEHM) with 3D-Var Data Assimilation. (Poster)
AGU24 Fall meeting	13.12.2024	Washington, D.C., USA	Zhuyun Ye	Modeling SO2 by Assimilating Sentinel-5p TROPOMI Observations for the 2023 Mount Etna Eruption. (Talk)
Meeting on Perspectives on VIS radiance exploitation in NWP	04-06.03.2025	ESRIN Italy	Samuel Queseda Ruiz	Aerosol visible reflectance activities at ECMWF (Talk)
FAIRMODE	5-6..3.2025	Prague	Renske Timmermans & Bruce Denby	CAMEO WP6: Uncertainty estimates of CAMS source receptor policy Products: how the findings and work of this project can contribute to better modelling for assessment and planning. (Poster)
ECMWF 50th anniversary: Workshop on data assimilation: initial conditions and beyond	09.04.2025	Gustav-Stresemann-Institut (GSI), Bonn, Germany	Antje Inness	Exploring synergies in composition and NWP data assimilation. (Talk)
EGU25 conference	28.04.2025	Austria Center Vienna	Andrea Bolignano/ Mihaela Mircea	Assimilation of SO2, CO, HCHO and O3 satellite data with Optimal Interpolation implemented in Atmospheric Modelling System MINNI. (Poster)
EGU25 conference	29.04.2025	Austria Center Vienna	Zoi Paschalidi	Integrating geostationary satellite data into CAMS: Insights from the CAMEO HE project & GEMS data assimilation. (Talk)

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Name	Date	Location	Presenter	Presentation title
EGU25 conference	29.04.2025	Austria Center Vienna	Alessandro D'Ausilio/Mihaela Mircea	Assessing the impacts of assimilating SO2 TROPOMI retrievals with MINNI and DART at the European scale: a case study of the Mount Etna eruption. (Talk)
EGU25 conference	30.04.2025	Austria Center Vienna	Flora Kluge	Evaluation of BVOCs in IFS-COMPO using online BVOC emission modelling. (Poster)
EGU25 conference	30.04.2025	Austria Center Vienna	Zhuyun Ye	Improvements and challenges of modeling air pollutants by assimilating Sentinel-5p TROPOMI observations. (Poster)
UNECE Task Force meeting on Emission Inventories and Projections, workshop on emission uncertainties	13.5.2025	Warsaw	Jeroen Kuenen	Estimating emission uncertainties for Europe. (Talk)
8th Conference on Energy & Meteorology	2-5.06.2025	Padova	Jorge Lezaca	Spatial resolved and localized uncertainty analysis of the irradiance product from the CAMS Radiation Service v4.6. (Talk)
ESA's ECV Precursor CCI User Workshop	11.06.2025	online	Antje Inness	On the use of NO2 retrievals in the CAMS near-real time system and the CAMS reanalysis. (Talk)
CEOS Atmospheric Composition Virtual Constellation (AC-VC) meeting #21	11.06.2025	Takamatsu, Japan (online presentation)	Antje Inness	Uptake of satellite data in the CAMS system. (Talk)

Name	Date	Location	Presenter	Presentation title
Living Planet Symposium 2025	25.06.2025	Vienna	Faiza Azam/Jorge Lezaca	CAMS radiation service for solar energy: Exploring the error space with data-driven and spatially resolved methods and service evolution. (Poster)
GEIA conference,	9-11.07.2025,	Abidjan, Ivory Coast	Jana Markova	Estimation of uncertainty of the isoprene emissions in a global dataset. (Poster)
AeroCom/AeroSat 2025	26.-27.09.2025	DLR, Germany	Yevgeny Derimian	Potential of aerosol core/shell structure retrieval from remote sensing. (Talk)
AeroCom/AeroSat 2025	16.10.2025	Jülich , Germany	Oleg Dubovik	Aerosol components/types: - How do satellite products and models agree? - If and how they can be harmonized? (Talk)
E-Profile's joint ET meeting	4-6.03.2025	ESRIN Italy	Mickael Bacles	Lidars and ceilometers data assimilation from E-PROFILE network into the MOCAGE model. (Talk)

d) Reports to and feedback from Committees and Boards

CAMEO is reported on at monthly CAMS Service Level Board (SLB) meetings to keep CAMS up to date with the latest project developments.

3.1.2 Products through dissemination of

a. *Datasets and accompanying material (e.g. descriptions, meta data)*
b. *Algorithms / Specifications*
c. *Graphics and animations*

Figure 1 shows the dedicated page on the CAMEO website (www.cameo-project.eu) for CAMEO produced public datasets. There are pointers to the deliverables page where the dataset access information is contained within the respective deliverable.

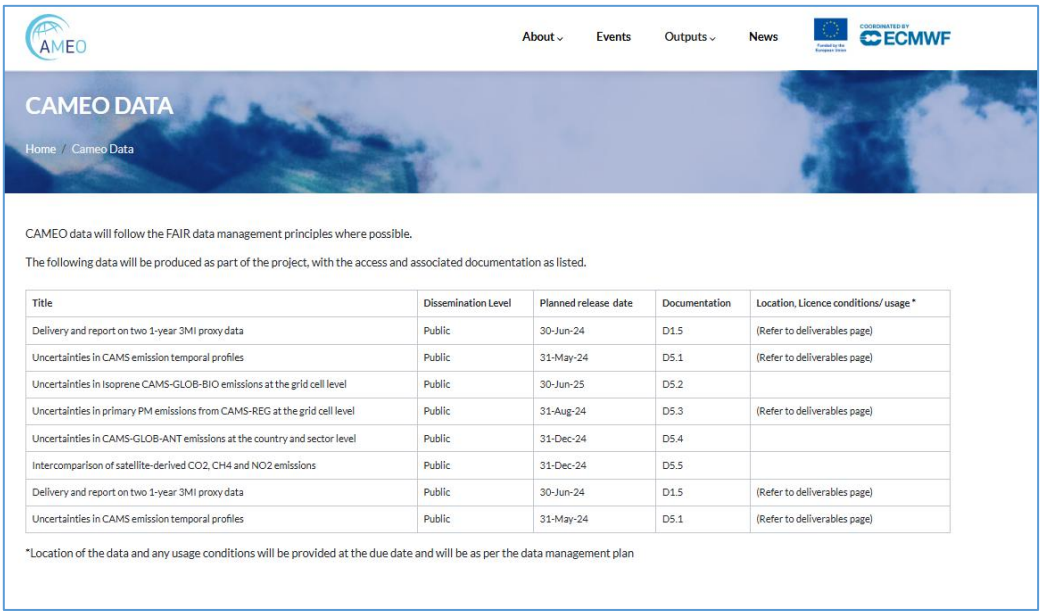


Figure 1: CAMEO Website: Data Page

The CAMEO website https://www.cameo-project.eu/ has been used for News items and public deliverables to date. (Figures 2 and 3). A page is available and ready to list the scientific papers (Figure 4).

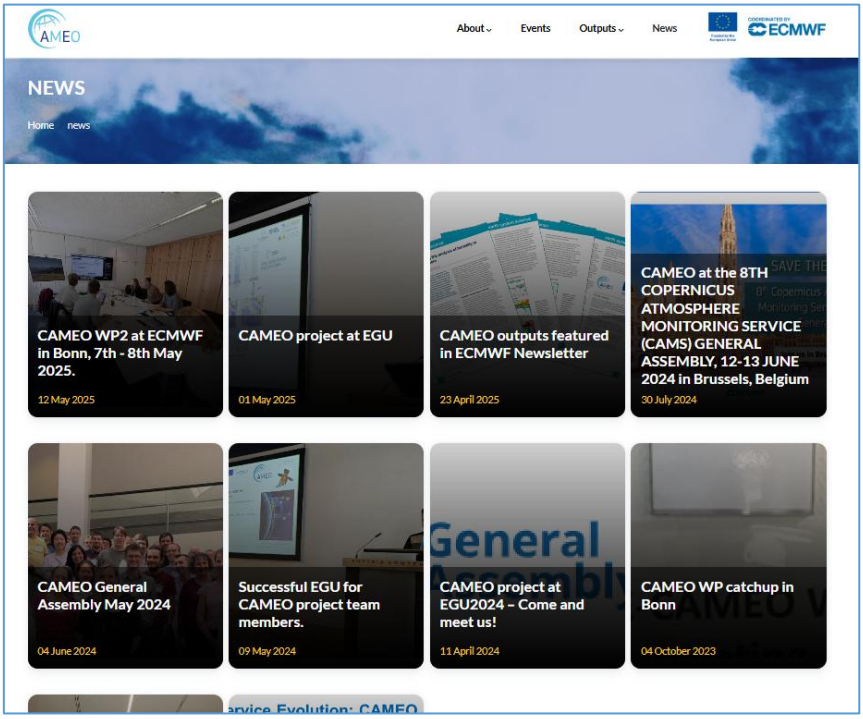


Figure 2: CAMEO Website: News Page

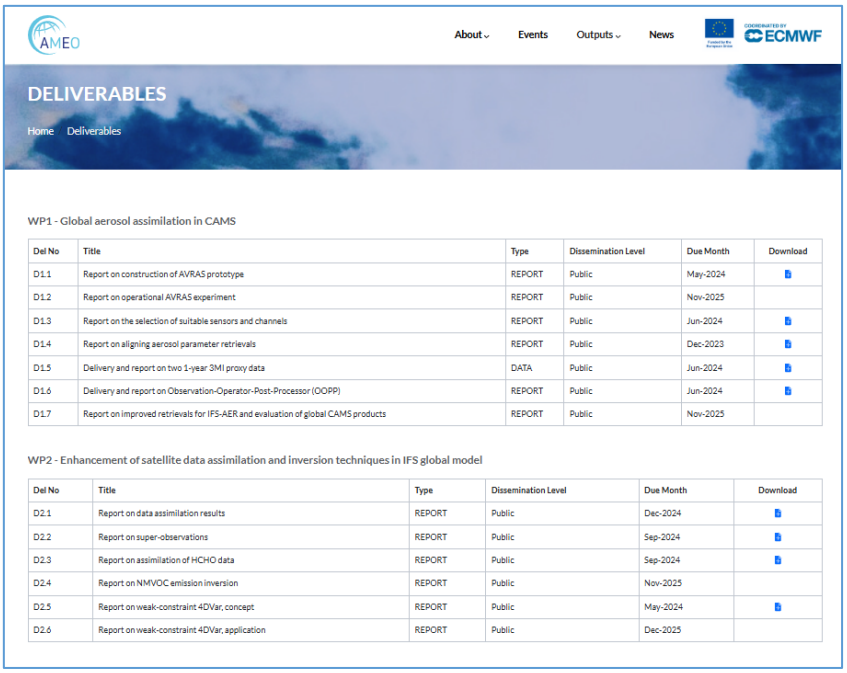


Figure 3: CAMEO Website: Deliverables Page

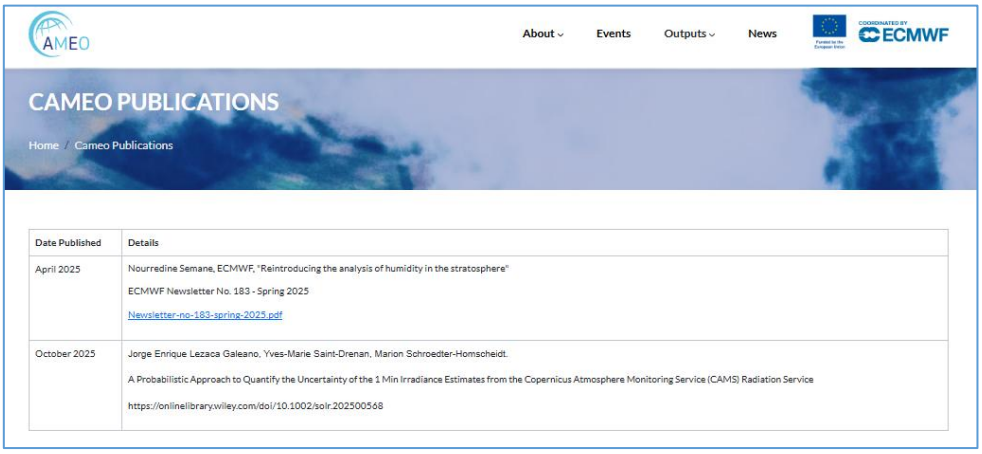


Figure 4: CAMEO Website: Publications Page

CAMEO uses the confluence pages for communication and dissemination within the project. Social media, (Linkedin and X (formerly known as “Twitter”) are not used directly by CAMEO but instead we rely on the established communications channels of CAMS and ECMWF.

CAMEO was one of the projects highlighted by DGDEFIS/ HaDEA attending GEO Global Forum and at ESA Living Planet 2025 (Figure 5).

Figure 5: CAMEO at the DGDEFIS stands and poster at the GEO Global Forum

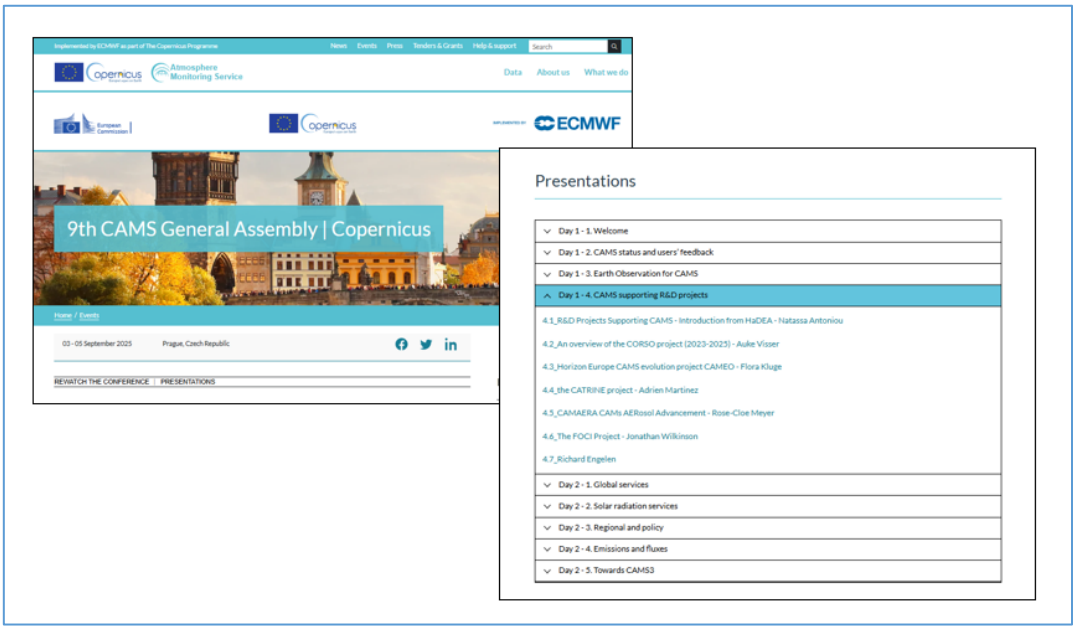
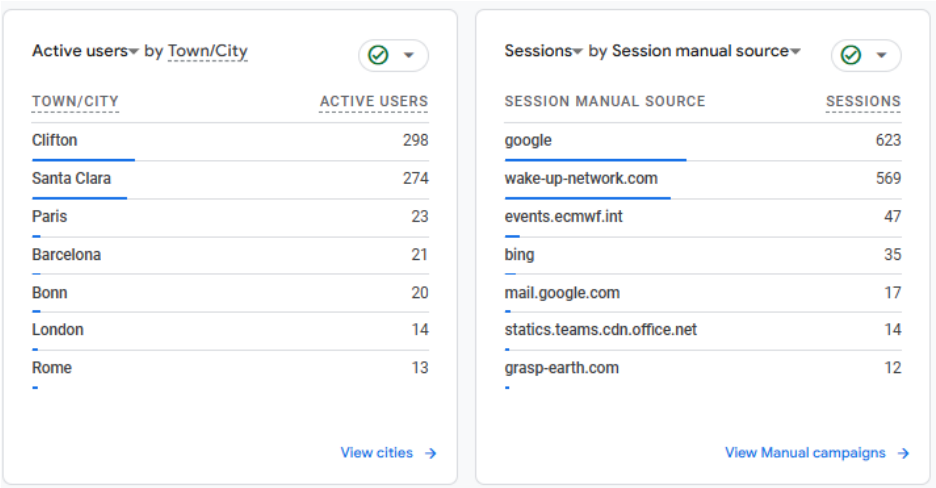


Figure 6: CAMEO at the 9th CAMS General Assembly

CAMEO was also one of the projects presented at the CAMS General Assembly Sept 2025. (Figure 6)

The CAMEO Website went live May 2023. Google analytics has continued to be used to collect and monitor traffic and users.

A series of bots artificially inflated the traffic to the site on the 16th August 2025. (Also seen on several other EU project sites around this time).



Because of this and to reflect the true nature of the CAMEO website, the data charts shown in the following sections are from 1st July 2024 to the 15th August 2025 to show the nominal/ expected traffic.

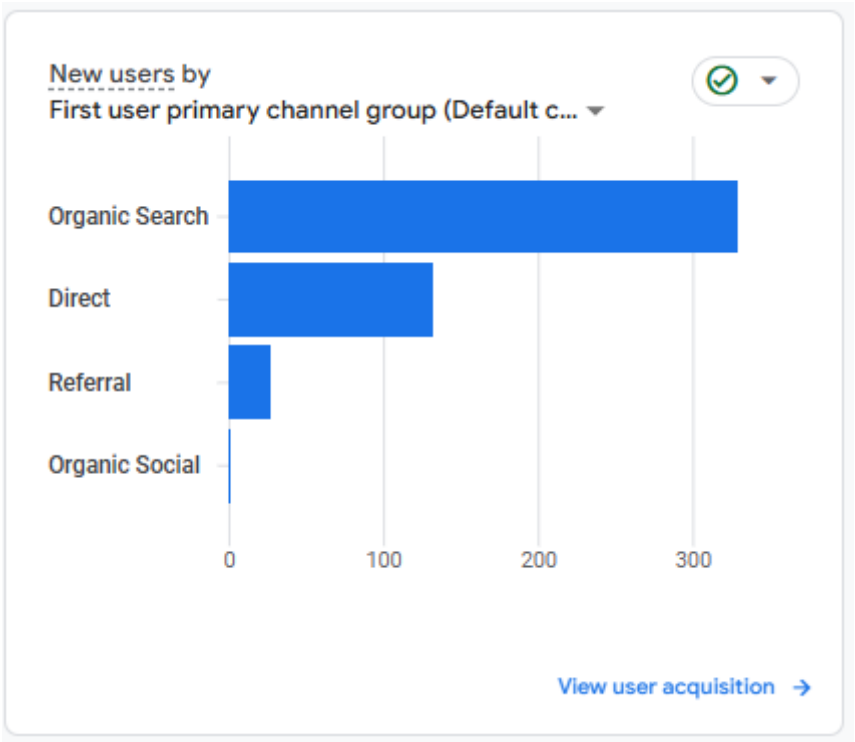


Figure 7: CAMEO Website: Website acquisition,

CAMEO

The majority of users are accessing the website via Organic Search, followed behind by Direct (Figure 7). Proving that the website is easily findable.

	Page title and screen class +	↓ Views	Active users
	Total	1,458 100% of total	511 100% of total
1	Home | CAMEO	557 (38.2%)	356 (69.67%)
2	Team | CAMEO	98 (6.72%)	79 (15.46%)
3	Deliverables | CAMEO	94 (6.45%)	62 (12.13%)
4	Cameo Data | CAMEO	82 (5.62%)	69 (13.5%)
5	Objectives | CAMEO	72 (4.94%)	56 (10.96%)
6	Events | CAMEO	68 (4.66%)	46 (9%)
7	CAMEO Online workshop on atmospheric emission uncertainties | CAMEO	59 (4.05%)	32 (6.26%)
8	Consortium | CAMEO	53 (3.64%)	45 (8.81%)
9	About | CAMEO	51 (3.5%)	40 (7.83%)
10	news | CAMEO	39 (2.67%)	29 (5.68%)

The statistics show over 500 users with 1400 plus views (Figure 8). These results have steadily increased as we progressed through the project and uploaded the deliverables and datasets when they became available.

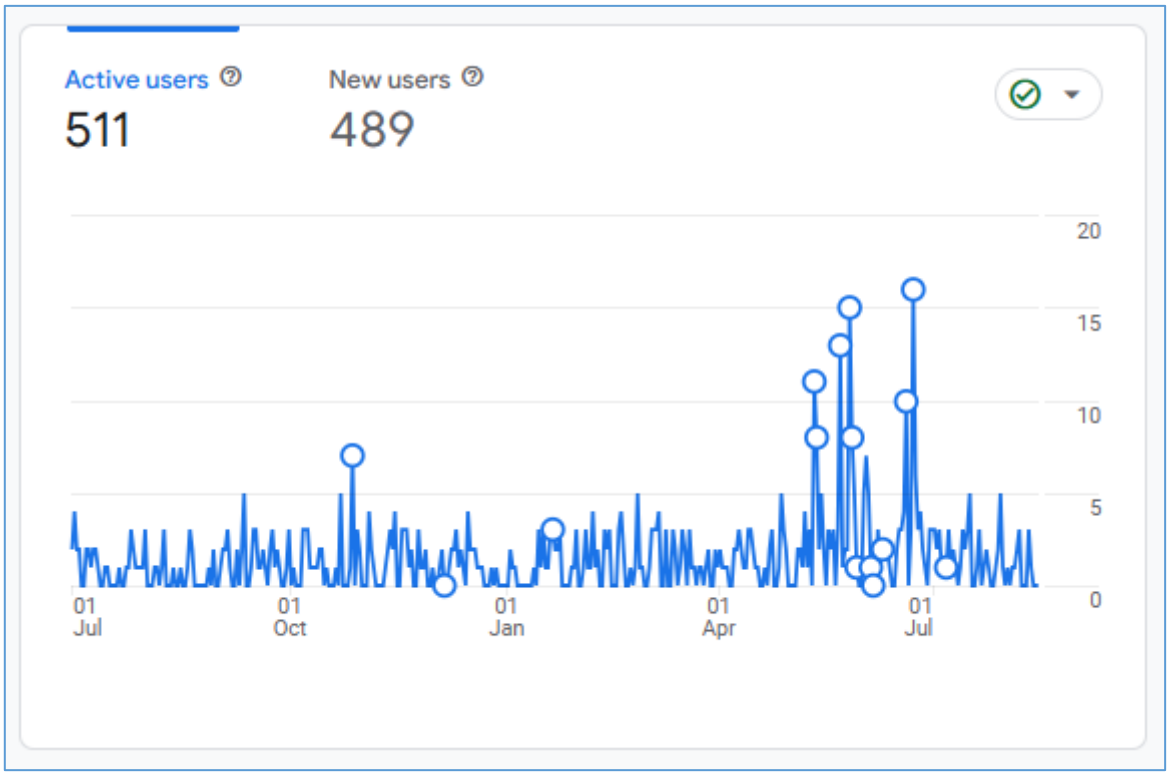


Figure 8: CAMEO Website: Number of users

	Page title and screen class	Views	Active users
	Total	1,458 100% of total	511 100% of total
1	Home | CAMEO	557 (38.2%)	356 (69.67%)
2	Team | CAMEO	98 (6.72%)	79 (15.46%)
3	Deliverables | CAMEO	94 (6.45%)	62 (12.13%)
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10	news | CAMEO	39 (2.67%)	29 (5.68%)

Figure 9: CAMEO Website: Number of views and top pages accessed

The most viewed are the home page followed closely by the team page and the deliverables pages

Figure 11 shows the users per country. Overall there is good access from around the world, but the data shows that most are within the European continent.

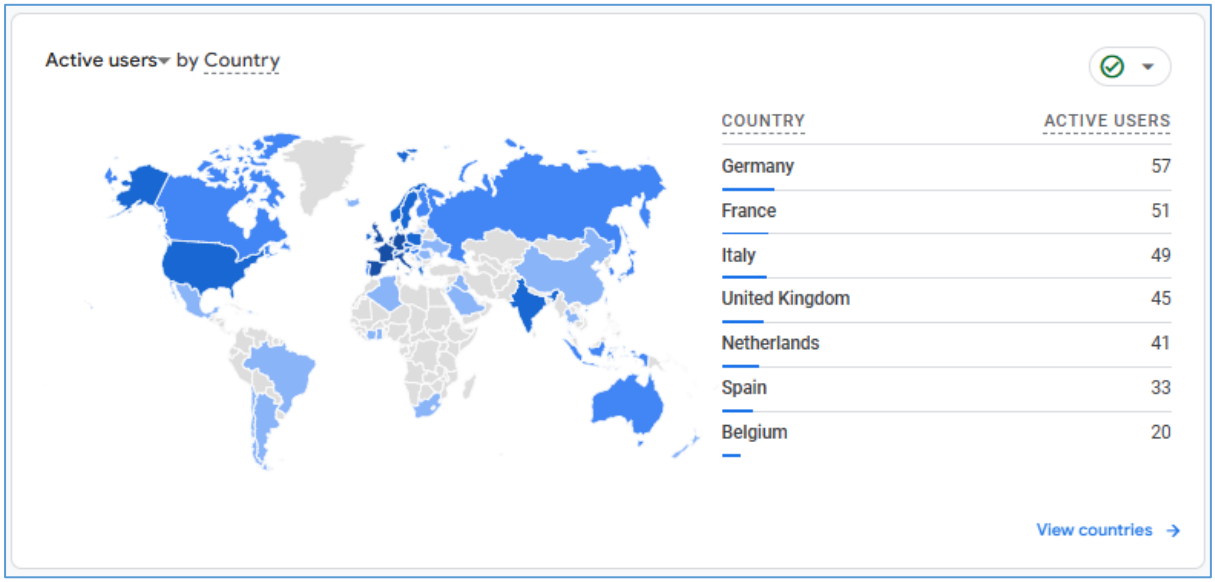

Figure 11: CAMEO Website: Users per country.

4 Exploitation Plan

The earlier deliverable, D7.2, already outlined potential exploitation avenues, as per Table 2 below.

Table 1: Summary of Exploitation Findings produced at the start of the project

Exploitable Results/ Products or Outputs	• Regional CAMS production systems ready for O3 and NO2 satellite retrievals from novel instruments (S4, IRS) • Global CAMS production systems ready to assimilate aerosol, O3 and NO2 satellite retrievals from new instruments (S4, 3MI, IASI-NG, S5, GEMS and TEMPO) • Improved aerosol satellite retrievals specifically for use in CAMS • Better regional CAMS air quality products with direct benefit for users and European air quality reporting • Better knowledge of uncertainty of CAMS emissions, solar energy, deposition and policy products and the communication of the uncertainty to users. • Better CAMS products thanks to improved emissions and information about emission uncertainties • Delivery and report on two 1-year 3MI proxy data • Uncertainties in CAMS emission temporal profiles • Uncertainties in Isoprene CAMS-GLOB-BIO emissions at the grid cell level • Uncertainties in primary PM emissions from CAMS-REG at the grid cell level • Uncertainties in CAMS-GLOB-ANT emissions at the country and sector level • Intercomparison of satellite-derived CO2, CH4 and NO2 emissions • Better exploitation of HCHO data satellite retrievals from existing and upcoming satellites by the CAMS global system thanks to newly developed biogenic emission inversion system.
Exploitation Activities during the Project	• Any dataset that has been identified as public will be made available to external scientists. • Project reports with recommendations will support uptake/implementation activities in CAMS and potentially other frameworks, already during the project. • CAMEO was presented at the CAMS GA in June 2023. (CAMEO updates will be included at all CAMS GA's). • Presentations at external conferences eg EGU and AGU, once project results are available
Exploitation Activities after the end of the Project	• Any dataset that has been identified as public will be made available to external scientists. • Project reports with recommendations will support uptake/implementation activities in CAMS and potentially other frameworks.
Consortium-wide/Joint Exploitation	• Outputs will be shared publicly as much as possible through documentation and peer-reviewed literature. • Presentations at external conferences eg EGU and AGU, once project results are available

4.1 Update on the Exploitable Findings at the end of the project and Recommendations for carrying forward the CAMEO developments into CAMS

The following section compiles tables of CAMEO results and outcomes with regard to the potential to be taken over by CAMS. The developments could lead directly to updates of the global and regional CAMS production systems and to improved data products, or be suggestions for the mid and long-term development of CAMS services. The tables will summarise the maturity level (https://en.wikipedia.org/wiki/Technology_readiness_level) and recommended additional efforts required for the application in CAMS.

CAMEO recognises that the decisions about the updates of CAMS production system and data products lies with the CAMS management.

4.1.1 Components for the Global Production system

Development	Maturity level TRL (1-9)	Required further steps for uptake by CAMS	Impact/ potential improvements	WP
Aerosol Visible Reflectance Assimilation System (AVRAS)	5	Developments in IFS-COMPO CY49R1, needs to be tested in CY50R1 when released. Bespoke RT parameters for MODIS in MFASIS are needed.	Similar impact as Aerosol Optical Depth (AOD) assimilation	1
Harmonization of remote sensing retrievals and CAMS	5	Adjustment of aerosol optical properties and possibly size distributions	More consistent treatment of aerosol with respect to remotely sensed properties	1
Off-line operator	7	Evaluation of model parameters (i.e. single scattering albedo)	Operator can be used to compare CAMS-derived optical properties with retrievals	1
GEMS NO2 data assimilation	6	Data monitored in CY49R1. More work (bias correction?) needed before potential activation in CY50R1.	Data lead to degradation of surface NO2 and O3 compared to Chinese AQ data	2
TEMPO NO2 data assimilation	7	Data monitored in CY50R1. Potential activation in CY50R1 or 50R2.	Limited impact on NO2 analysis, but reduced tropospheric O3 bias	2
GEMS O3 assimilation	5	Data monitored in CY49R1. More assimilation tests needed.	Data quality until now not good enough to assess impact.	2

Development	Maturity level TRL (1-9)	Required further steps for uptake by CAMS	Impact/ potential improvements	WP
TEMPO O3 assimilation	5	Data monitored in CY50R1. More assimilation tests needed.	Impact after recent algorithm update needs to be assessed.	2
Preparation for Sentinel-4 and Sentinel-5	4	Code in place to monitor data in CY50R1 or beyond.	No NRT data available yet.	2
Novel super-observation software for NO2	5	Technically difficult to apply in NRT compo suite. Further tests needed with CAMS inversion system.	Improved treatment of observation errors, but limited impact on NO2 analysis	2
Using positive and negative TROPOMI NO2 data in CAMS super-observations	7	Code in place, needs new BUFR extraction for compo-suite. Include in CY51R1.	Reduced NO2 bias, especially in background areas	2
Revisited isoprene and other bVOC emissions treatment and degradation chemistry	7	Prototype in place. Code to be included in CY51R1	Limited impact	2
Novel super-observation software for HCHO	3	Software available but not tested in CAMS system yet.	Improved treatment of observation errors.	2
HCHO assimilation system	6	Technically ready but more fine tuning needed (e.g. background errors)	Limited impact	2
Isoprene emissions inversion and simplified TL/AD of isoprene chemistry	5	Prototype ready. Review of simplified chemistry. Code to be included in CY51R1.	Limited impact, pending on the HCHO assimilation system	2
Weak constraint 4D-Var for stratospheric ozone	8	Code ready and implemented in CY50R1.	Limited impact and not recommended to be activated	2
Stratospheric humidity analysis	9	Activated in CAMS and ECMWF NWP in CY50R1	Improved forecast scores for T and RH	2
Weak constraint 4D-Var for stratospheric humidity	6	Prototype in place. Code to be included in CY51R1	Improved background fit to MLS data	2
Assimilation of MLS water vapour	8	Code in place in CY49R2 and 50R1. Potential activation in CAMS reanalysis EAC5.	Improved stratospheric water vapour analysis field	2

Development	Maturity level TRL (1-9)	Required further steps for uptake by CAMS	Impact/ potential improvements	WP
IFS-COMPO ensemble	3	Verification of uncertainty result, and description of input uncertainty	Proof of concept	6

4.1.2 Components for the Regional Production system

Development	Maturity level	Required further steps for uptake by CAMS	Impact	WP
SO2 VCN (S5P) Assimilation in regional models	7	Evaluation done at model level, but not on ensemble side. Would need ensemble evaluation	Small impact because of noisy observations	3
CO TC (S5P) Assimilation in regional models	6	Not all models have assimilated that species	Noticeable impact	3
HCHO TC (S5P) Assimilation in regional models	6	Not all models have assimilated that species	Small impact especially at surface because of noisy observations	3
O3 TC (S5P) Assimilation in regional models	6	Not all models have assimilated that species	No large impact, sometimes small degradation at surface	3
E-profile ATB Assimilation in regional models	6	Only evaluated in one model in CAMEO. Would need major other steps to have all models ready to assimilate these data.	Noticeable good impact	3
VIIRS AOD (NOAA) Assimilation in regional models	6	Only evaluated in some models. Would need major other steps to have all models ready to assimilate these data.	Little impact on surface PM2.5	3
Sentinel-4 Assimilation preparation in regional models - OSSE	5	Only evaluated in some models on synthetic data. Would need full evaluation with real data.	Little impact for NO2 without emissions optimisation	3

Development	Maturity level	Required further steps for uptake by CAMS	Impact	WP
IRS (product and radiance) Assimilation preparation in regional models - OSSE	5	Only evaluated in some models on synthetic data. Would need a careful review to evaluate which products would better fit in a regional production system, depending on real datasets produced.	Good impact in LOTOS-EUROS for NH3, good impact for CO and O3 in MOCAGE	3

4.1.3 Global data sets

Development	Maturity level	Required further steps for uptake by CAMS	Comments	WP
3MI proxy data on Polder (AOD, SSA, …)	6	Eg further verification might be required	Used for verification and data assimilation	1
Dry and wet deposition data for sulphur and nitrogen	6	Already in use	Used for verification	4
Desert dust total deposition over the Atlantic from mass balance	6	Already in use	Used for verification	4

4.1.4 Emissions uncertainty products

Development	Maturity level	Required further steps for uptake by CAMS	Comments	WP
Uncertainties in isoprene CAMS-GLOB-BIO emissions at the grid cell level	4	Define methodology to include the isoprene emissions uncertainty information with the full time-series of CAMS-GLOB-BIO and with the newly added years. Investigate possibility of emission uncertainty for species other than isoprene.	Product implemented and tested by IFS-COMPO and within CAMEO	5

Development	Maturity level	Required further steps for uptake by CAMS	Comments	WP
Uncertainties in CAMS-REG emissions at the grid cell level	4	Update processing to cover all CAMS species (GHG + air pollutants) Coupling to production process of the CAMS-REG emissions for full consistency between emissions and uncertainties. Ongoing discussion with users on formats and interpretation of the data	Product implemented and tested by selected CAMS regional AQ modellers within CAMEO Based on the experience acquired for GHG emission uncertainty under CHE, CoCO2 and CORSO projects, including validation with numerical experiments Manuscript is being prepared to support further use of the product in the scientific community	5
Uncertainties in CAMS emission temporal profiles	4	For some sectors/temporal resolutions, current approach is relatively simple and should be refined. Define if 'aggregated to a year' temporal uncertainty should be equal to the yearly/sectoral uncertainty Ongoing discussion with users on formats and interpretation of the data	Product implemented and tested by selected CAMS regional AQ modellers within CAMEO	5
Uncertainties in CAMS-GLOB-ANT emissions at the country and sector level	3	Missing sectors, pollutants and uncertainty in the gridded distribution	Prototype of the product developed under CAMEO	5

4.1.5 Deposition and radiation uncertainty products

Development	Maturity level	Required further steps for uptake by CAMS	Comments	
Extended ground observation database integrating also SYNOP code based observations of radiation	6	None		4

Development	Maturity level	Required further steps for uptake by CAMS	Comments	
Use of ground observations from stations providing only global irradiation observations	4	Not recommended to use in CAMS, this implies also that a spatially high resolved online bias correction is not a possible service extension as thought initially.	due to quality issues with SYNOP observations and missing QC options due to missing 3-component observations of radiation	4
Method to quantify uncertainty of global and direct radiation at each point of time and space of the CAMS Radiation Service	4	The method provides very detailed uncertainty information with percentiles of an uncertainty distribution. This is likely overwhelming for typical users. A method to condense the information for the standard and expert mode-typical users needs to be derived.		4
SHAP-based quantification of importance of input data and intermediate processing parameters on radiation uncertainty	6	Can be used as assessment method to monitor CAMS Radiation Service evolution in future.		4
Understand user requirements from the solar sector & provide a showcase of soiling and related CAMS IFS parameters	4	Study shows that existing CAMS products serve the solar energy sector with respect to soiling additionally to the solar resource information.		4
Method to quantify uncertainty of global CAMS deposition products	6	Implementation as a regular monitoring tool for CAMS service evolution		4
Uncertainty (standard deviation) of global CAMS deposition products, averaged monthly	6	Repeated assessment		4

4.1.6 Policy support

Development	Maturity level	Required further steps for uptake by CAMS	Comments	WP
Proof of concept: Propagation of emission uncertainty into air quality forecast (using Local fraction or ACT)	TRL 3	Better quantification of the emission uncertainties themselves. Better understanding of how to combine temporal and total (sector/yearly) uncertainties - both in terms of emission uncertainties themselves and their propagation into the AQ forecast		6
Demonstration of how city definition (for source and/or receptor) affect the quantification of source contributions from city to itself			Results from this work can and will be introduced in CAMS2_71bis during 2026/2027	6
Demonstration of how resolution affect the quantification of source contributions from city to itself		Should demonstrate if there are convergence at at certain resolution	Results from this work can and will be introduced in CAMS2_71bis during 2026/2027	6

Development	Maturity level	Required further steps for uptake by CAMS	Comments	WP
Demonstration of how methodologies for source apportionment affect the quantification of source contributions from cities, countries and sources to cities		Will be further discussed, and model data will be made available for further analysis in FAIRMODE	Conclusions from this work will be included in the documentation of the CAMS2_71bis service Local fraction method and a redistribution of interaction terms from the surrogate model to specific sectors will be introduced in CAMS2_71bis during 2026	6
Evaluation of modelled source attribution with observational bases source attribution	TRL3	Requires expertise and thorough analysis of each PMF dataset to identify potential match with CTM sources - difficult to perform in an operational setting at the moment. For NRT then PMF analysis needs to be available NRT Adding more detailed source sector attribution in the CTMs can benefit such evaluations	Alternatives such as online evaluation to NRT source specific EC or OC is considered instead More detailed source sector attribution by tagging will be introduced in CAMS2_71bis during 2026	6

CAMEO

Development	Maturity level	Required further steps for uptake by CAMS	Comments	WP
Fine scale (250mx250m) modelled forecast for cities	TRL 6/7	The system needs to be set up operationally. To our knowledge, at present it is only the EMEP model that can do such calculations, and other models would need to be extended with similar capabilities.	Downscaling of NO2 significantly improves bias and correlation at EEA stations in the 79 cities. Running uEMEP for the 79 cities as part of the operational CAMS Policy service is computationally feasible and can provide more relevant information on exceedances	6
Uncertainties from global BICs into regional scale modelling			Not worth implementing in the current form, even if global ensemble runs are done operationally	6
Uncertainties of global products arising from emissions, initial conditions, meteorology and model errors	TRL3	More work on the specification of perturbations, and correlation between perturbations	This work provides a prototype of a global CAMS ensemble, which can be used as a basis if future work is envisaged in this direction.	6

4.1.7 Emissions data

Development	Maturity level	Required further steps for uptake by CAMS	Comments	WP
Satellite-derived NO_2 emissions using DECSO	7	NOx emissions of DECSO are operational made available each month. The connection with CAMS has to be refined.	Currently only anthropogenic emissions are evaluated. DECSO makes also the soil emissions available that can be incorporated in the analysis	5
Satellite-derived CO_2 and CH_4 emissions				5

4.2 Additional recommendations for CAMS from the WP teams

The Work package teams were asked to provide further recommendations for CAMS and their response based on the criteria listed is below

1. High level recommendations for changes or updates to CAMS services based on the results
2. What should be implemented?
3. Are there any gaps/ future research needed

4.2.1 WP1:

1. High level recommendations for changes or updates to CAMS services based on the results

- Dust scheme based on Dubovik (2006) shows better agreement in SSA than the scheme based on Woodward (2001) - suggested to change it in the CAMS model.
- Suggested to modify the assimilation approach of aerosol optical depth (AOD) using multiple wavelengths and /or fine-coarse modes in order to better constrain aerosol speciation (Organic matter, dust)
- Revise the optical properties particularly single scattering albedo, for some aerosol species such as dust and organic matter for better agreement with satellite retrievals and better exploitation of polarimetric observations (i.e. 3MI).
- Suggestion also to add another bin in addition to coarse and fine mode.Aerosol reflectance yielded comparable results to the more established assimilation of AOD, particularly over Europe, and should be pursued further.

2. what should be implemented?

- The assimilation of aerosol reflectance with direct use of cloud-screened reflectance data

3. Are there any gaps/ future research needed

- Collaboration with DWD / NWP SAF to add more aerosol capabilities to the reflectance operator.
- Assimilation of L2 (cloud-screened) reflectance data
- Continued collaboration with satellite data providers and retrieval community to continue the harmonization process.

4.2.2 WP2:

1. High level recommendations for changes or updates to CAMS services based on the results

- CAMEO has prepared the global CAMS system for the assimilation geostationary retrievals from GEMS and TEMP and eventually S4.
- More research is needed to increase the impact of DA on surface NO2, HCHO and Ozone concentration. The increased temporal resolution of the geostationary data does currently not lead to strongly increased impact at the surface

2. What should be implemented?
    - Activation of TEMPO NO2 data in CY50R2 or CY51R1.
    - Further testing of GEMS NO2 assimilation required, e.g. developing bias correction, before potential activation in CY51R1.
    - Further testing of TEMPO and GEMS ozone data when data quality allows
    - Further work needed to assess impact of novel super-observation method in CAMS inversion system
    - Use of positive and negative TROPOMI NO2 data in ECMWF super-observation method in CY51R1. Code in place. Only requires setting up new routine BUFR extraction and fetchobs change.
    - Activation of HCHO (TROPOMI, TEMPO) assimilation in CY51R1 after further fine-tuning.
    - Inclusion of bVOC inversion code in CY51R1 and decision on activation.
    - Decision on activation of MLS stratospheric water assimilation in CAMS reanalysis EAC5
3. Are there any gaps/ future research needed
    - Further work on weak-constraint 4D-Var for stratospheric humidity. Potential implementation in CY51R1.While the code for the weak-constraint 4D-Var for stratospheric ozone is included in CY50R1 it was decided not to activate it because of the small impact.
    - Quality assurance and testing of S4 retrievals

4.2.3 WP3:

- to CAMS services: Investigate the possibility to use Sentinel-4 and IRS products to improve emissions, possibly in NRT, to be used in the regional services
- to CAMS services: Further evaluate the assimilation of Sentinel-4 products in regional models to initialise the forecasts (already in the current CAMS2_40_bis implementation plan)

4.2.4 WP4:

1. High level recommendations for changes or updates to CAMS services based on the results
    - Deposition should be included (as much as possible) in the routine CAMS evaluation.
    - Make showcases, examples and connect further to libraries as PVLIB, provide good examples e.g. jupyter notebooks on how to make use of uncertainty information, what is the value to have uncertainty information, how to use it in an educated manner.

2. What should be implemented?
    - It would be great/very useful if dust (and maybe others) deposition products from mass balance (derived from remote sensing) could be made available in near-real time or close for evaluation purposes.
    - Couple PV and Agri-PV (radiation, deposition/soiling, vegetation growth depending on temp, precip, soil temp).

- Fill the gap of nowcasting, provide probabilistic nowcasting to continue the pathway to provide data and its uncertainty.

3. Are there any gaps/ future research needed

- There are large gaps in the observational datasets for deposition, anything that provides information on deposition outside of Europe/US/East Asia is welcome (INDAAF over West Africa is an exception and is very useful indeed).
- Provide seamless access to historic data (CAMS), climate scenarios (C3S), nowcasting (future CAMS) and forecasts for dayahead (CAMS).
- Fully understand relationship of soiling and CAMS information, develop routine products.
- SHARP analysis is an internal tool to understand how different input variables contribute to the total radiation uncertainty. It is not planned for dissemination.
- The CRS uncertainty is ready as prototype, but needs more testing and postprocessing before potential implementation as CAMS product.

4.2.5 WP5:

1. High level recommendations for changes or updates to CAMS services based on CAMEO results

- The emission uncertainty products developed within CAMEO have proved to be useful for CAMS inverse modelling applications and uncertainty propagation in air quality products
- Detailed guidance on their usage and interaction with end users is needed, since the implementation of the emission uncertainty into the AQ modelling chain is very challenging (complexity in interpreting the data correctly and use it in a correct way)
- The integration of CAMEO emission uncertainty products within CAMS product portfolio will require allocating dedicated efforts to continue their maintenance and improvement

2. what should be implemented?

- The emission uncertainty products developed for CAMS-REG, CAMS-TEMPO and CAMS-GLOB-BIO can be used as a first estimate for the development of CAMS air quality uncertainty products

3. Are there any gaps/ future research needed

- For some sectors and/or species and/or temporal resolutions, current approaches to estimate uncertainties associated to CAMS-REG, CAMS-TEMPO and CAMS-GLOB-BIO are relatively simple and should be further refined.
- Uncertainty estimates associated to CAMS-GLOB-ANT should be completed by including missing sectors, species and refining the uncertainty information from the country to the grid cell level.
- Further investigate how to combine uncertainties provided by CAMS-REG (country-, sector- and pollutant-dependent at the grid cell level) and CAMS-TEMPO (country-, sector-and pollutant-dependent per time step)

- Investigate possibility of adding the uncertainty information to species other than isoprene in the CAMS-GLOB-BIO dataset.
- Quantify the uncertainty associated to the CAMS emission products not covered under CAMEO, including CAMS-GLOB-SHIP, CAMS-GLOB-SOIL, CAMS-GLOB-OCEAN and CAMS-GLOB-VOLC.
- Develop methods to quantify error correlations between pollutants to support multi-species inversions or using co-emitted species as additional constraint.
- Development of a protocol for the evaluation of estimated emission uncertainties

4.2.6 WP6:

1. High level recommendations for changes or updates to CAMS services based on CAMEO results

2. What should be implemented?

- The city definition as used at present in CAMEO should be updated with the source defined as either city core or FUA, and the receptor as either population weighted core city and/or FUA, or the centre grid with highest concentration
- Consider a redistribution of the interaction terms from the surrogate model (and BF and LF) avoiding interpretation difficulties by users and improving representation of actual agriculture and other sectoral contributions influenced by non-linear chemistry
- Evaluation of the CAMS policy support products with PMF is only recommended for PMF profiles with clear tracer species, i.e. residential biomass combustion, sea salt and to some extent dust and shipping profiles.
- Running downscaled (250x250m) regional EMEP model runs for the 79 cities as part of the operational CAMS Policy service is computationally feasible and can provide more relevant information on exceedances

3. Are there any gaps/ future research needed

- Improved emissions are still needed, e.g : Refine spatial allocation of residential biomass emissions (and other sources) to better represent local practices.
- (Evaluation of) source attribution is still a challenging topic that needs further attention. Comparing model results to Positive Matrix Factorisation (PMF) data is complex due to differences in each PMF dataset characteristics and difficulty in isolating sources requiring thorough analysis of the PMF profiles to identify its potential match with CTM sources. Its inclusion in operational CAMS evaluation processes is furthermore hampered by delays in availability of PMF data. Alternatives like near real-time source specific elemental carbon or organic aerosol observations and tracer monitoring may be more suitable for this.
- Develop urban source attribution modelling tools by combining the regional background information with source attribution from local models with increased resolution and more detailed local traffic emissions information, including non-exhaust sources for better attribution of the local traffic contributions.
- Emission uncertainties are too uncertain (!) for them to be used in propagation of emission uncertainties in air quality forecast
- The definition of perturbations in order to setup a global atmospheric composition ensemble is a complex matter that deserves further research

4.3 Summary and conclusions of Recommendations to CAMS

The developments within CAMEO have prepared the global and regional CAMS systems for the data assimilation of new and upcoming satellite retrievals. The global system is ready to assimilate datasets from the new geostationary atmospheric composition (AC) retrievals from GEMS and TEMPO, in preparation for the first data from Sentinel-4. The regional models are able to assimilate S5P SO_2 data, and a selection of models can also assimilate S5P CO, HCHO, and ozone retrievals as well as VIIRS AOD data. OSSEs have been conducted to prepare the regional models for data from Sentinel-4 and IRS. The assimilation of MLS water vapour retrievals developed in CAMS has demonstrated clear benefits for both NWP and CAMS applications. The assimilation of novel 3MI retrievals has been supported through the development of flexible offline observation operators.

Both the global and regional systems show small to neutral impacts from data assimilation of satellite data, in particular for surface concentrations. The most impactful assimilated observations prepared for in CAMEO for the regional models have been the surface lidar data. It is therefore recommended to further pursue the assimilation of these data sets despite the increased technical overhead. A common conclusion for both regional and global models is that meaningful impacts on longer-range forecasts can only be achieved by simultaneously optimising emissions within the data assimilation framework.

CAMEO has further developed data assimilation methods, in particular for global aerosol assimilation. Aerosol reflectance assimilation has reached a basic performance level comparable to the global CAMS system assimilating AOD retrievals. Updates to the radiative transfer model (MFASIS aerosols within RTTOV) and the provision of cloud-screened radiance L2 data are prerequisites for continued testing and further development of this approach. CAMEO has also provided recommendations for the global aerosol modelling framework (optical properties, speciation), aiming at improved harmonisation between aerosol retrievals and modelling in order to enhance aerosol data assimilation.

The CAMEO uncertainty product developments for radiation, deposition, emissions, and policy applications have attracted strong user interest, but have also raised questions regarding the applied methods, verification, and practical use of these data. Any operational provision of CAMS uncertainty products should address these aspects in a satisfactory manner before the uncertainty products are added to the CAMS portfolio. A machine learning approach has been applied to attribute errors in CAMS radiation products to input variables, which could be applied to other CAMS products in the future. The emission uncertainty products developed within CAMEO have proven useful for CAMS inverse modelling applications and for uncertainty propagation in air quality simulations. Developments related to policy products have led to improved methodologies and have highlighted both the necessity and feasibility of running ultra-high-resolution (250 m) model scenarios for NO_2. Finally, the definition of suitable perturbations for setting up a global atmospheric composition ensemble for uncertainty forecasting remains a complex topic and requires further research.

5 Conclusion

This deliverable, D7.7 has provided an update of the dissemination and exploitation activities at the end of the project.

For the dissemination we have achieved our aims to disseminate via a set of identified instruments namely a website, news items, scientific conferences, workshops and committee/board meetings and scientific papers.

The exploitable products have been listed along with the WP leaders and Project Coordinator's project recommendations for CAMS.

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