ECMWF Copernicus Procurement

Invitation to Tender

Copernicus Atmosphere Monitoring Service

Volume II

Developments of greenhouse gas aspects in the global CAMS system

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1 Introduction

Some of today's most important environmental concerns relate to the composition of the atmosphere. Ozone distributions in the stratosphere influence the amount of ultraviolet radiation reaching the surface. In the troposphere, aerosols, ozone and other reactive gases such as nitrogen dioxide determine the quality of the air around us, affecting human health and life expectancy, the health of ecosystems and the fabric of the built environment. The variable abundance of the reactive gases changes the oxidation capacity of the atmosphere and controls therewith also the abundance of long-lived greenhouse gases. The composition of the troposphere and the associated deposition fluxes are major components of the biogeochemical cycles of carbon, nitrogen and sulphur and iron, which affect the land and marine eco systems. Dust, smoke and volcanic aerosols affect the safe operation of transport systems and the availability of power from solar generation, the formation of clouds and rainfall, and the remote sensing by satellite of land, ocean and atmosphere.

The increasing concentration of the greenhouse gases and the various aerosol-weather feedbacks are prominent but often uncertain drivers of climate change. In the wake of the agreement signed in Paris at the UNFCCC's 21st Conference of the Parties (COP-21) in December 2015, the need to monitor and to inform about the effectiveness of mitigation efforts for anthropogenic emissions of key greenhouse gases has become more acute and prominent. With its global coverage (or regional in the case of geostationary platforms), Earth Observation has a decisive role to play within such a monitoring system, complementing ground-based observations, "bottom-up" estimates of the emissions (included in official reporting) and atmospheric transport modelling.

To address these environmental concerns, there is a need for data and processed information. The Copernicus Atmosphere Monitoring Service (CAMS) has been developed to meet these needs, aiming at supporting policymakers, business and citizens with enhanced atmospheric environmental information.

Within its first phase (2015 – 2020, Cop1), the Service consolidated many years of preparatory research and development to deliver a range of operational services. In its second phase (2021 – 2028, Cop2), these services are further consolidated, improved and expanded to address all the existing and emerging societal needs related to the atmospheric environment. The CAMS service portfolio consists of the following service elements:

a) Daily production of real-time analyses and forecasts of global atmospheric composition;

b) Reanalyses providing consistent multi-annual global datasets of atmospheric composition with a stable model/assimilation system;

c) Daily production of real-time European air quality analyses and forecasts with a multi-model ensemble system;

d) Reanalyses providing consistent annual datasets of European air quality with a frozen model/assimilation system, supporting in particular policy applications;

e) Products to support policy users, adding value to "raw" data products in order to deliver information products in a form adapted to policy applications and policy-relevant work;

f) Solar and UV radiation products supporting the planning, monitoring, and efficiency improvements of solar energy production and providing quantitative information on UV irradiance for downstream applications related to health and ecosystems;

g) Greenhouse gas atmospheric inversions for CO_2, CH_4 and N_2O net surface fluxes, allowing the monitoring of the evolution in time of these fluxes;

h) Climate forcing from aerosols and long-lived (CO_2, CH_4) and shorter-lived (stratospheric and tropospheric ozone) agents;

i) Anthropogenic and natural emissions, based on inventory data and modelling, for the global and European domains;

j) Observation-based emission estimates of atmospheric pollutants for the global and European domains;

k) Observation-based anthropogenic emission estimates of CO_2 and CH_4 for the global domain and emission hotspots.

This Invitation to Tender (ITT) is mainly targeting the CAMS service elements described under items (a), (b),(g) and (k).

1.1 Definitions

Definitions specific for this ITT are defined below.

Global Service Provider: ECMWF is the provider of global products

Global Production System: the modelling and data assimilation infrastructure used to provide the CAMS global analyses and forecasts of atmospheric composition, the global reanalysis, and the emerging services to monitor emissions of several greenhouse gases and atmospheric pollutants.

2 Contract Summary

This ITT, entitled "Development of greenhouse gas aspects in the global CAMS system", is for further development of the Global Production System of CAMS operated at ECMWF, with a specific focus on the greenhouse gases. The modelling of atmospheric CO_2 and CH_4 relies on the accurate representation of their surface fluxes. In order to represent the high variability of these fluxes in both time and space, their biogenic component is modelled. These biogenic fluxes depend on the accurate depiction of the land surface processes, including vegetation, currently represented by the Leaf Area Index (LAI), soil processes and hydrology. The Successful Tenderer shall improve the representation of the LAI and wetland fraction variability, and the CO_2 and CH_4 respiration processes by:

1. implementing and testing a processing chain to update the wetland fraction maps within the model in near-real-time (NRT[1]) based on available satellite-based wetland extent products.
2. implementing a processing chain to update the LAI within the model in NRT, based on the most recent observation-based products.
3. introducing carbon pools to improve the representation of the autotrophic and soil respiration in the land surface model.

All the developments shall be implemented and tested in the stand-alone land surface model and evaluated with surface flux observations as well as analyses and other dynamic vegetation models (e.g. for the evaluation of trends). The final tests will be performed by ECMWF with the coupled atmospheric composition model and evaluated with atmospheric observations to assess the impact

[1] NRT in this document means as close to real-time as possible given current observational constraints. The application in the CAMS global forecasting system shall consider that the forecasts are produced in real-time.

of the various developments in the CAMS Global Production System, but the successful Tenderer shall provide support to this evaluation in case it happens during the duration of this contract.

In addition, the successful Tenderer shall deliver memoranda and reports to document the requested developments and provide expertise to the team working on the global production system at ECMWF regarding greenhouse-gas aspects. The ITT targets organisations with considerable experience in the field of CH_4 emissions from wetlands including the use of near-real time remote sensing observations to estimate wetland extent, the classification of wetland types, and more generally the representation of wetland emissions of CH_4 in global models. Experience with the modelling of dynamic vegetation, LAI and carbon pools is also required.

3 Technical Specification

3.1 General Requirements

3.1.1 Background

The concept for an anthropogenic CO_2 and CH_4 emissions Monitoring and Verification Support (CO2MVS) capacity as part of the CAMS portfolio is based on the recommendations from the European Commission's CO_2 Monitoring Task Force[2]. As shown in Figure 1, it comprises an integrated system approach capable of inferring emissions from observations (space and in-situ), prior information (such as bottom-up emission estimates from inventories and reporting) and modelling as well as data assimilation capabilities.

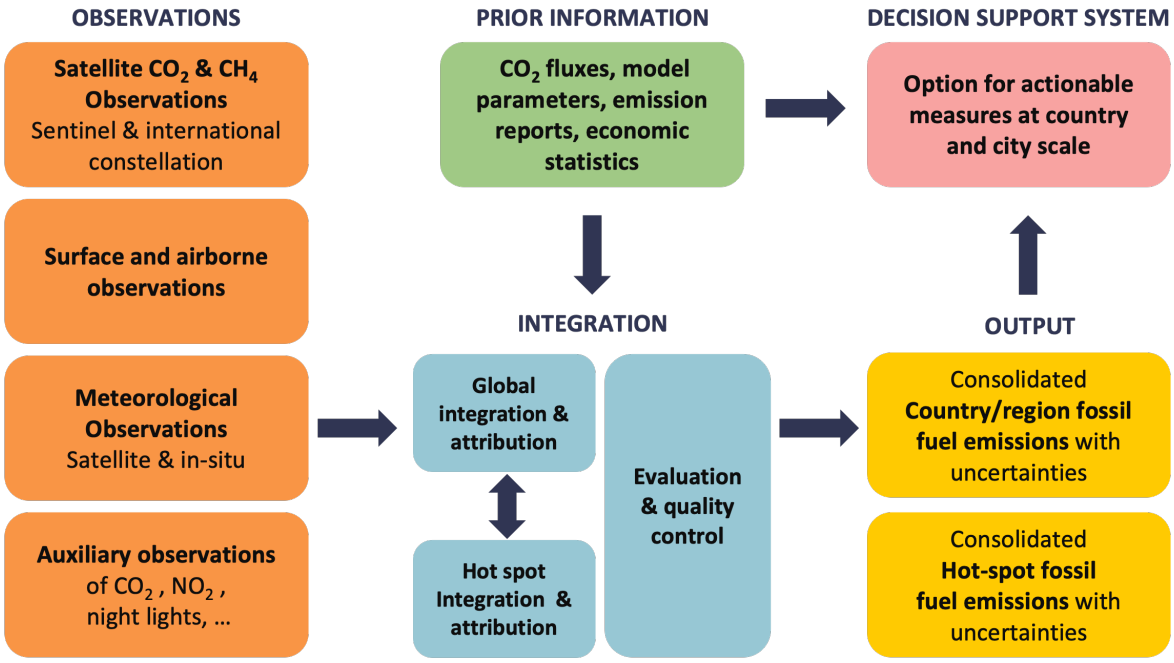

Figure 1 *Main building blocks of the functional architecture of a future CO_2 and CH_4 human emissions monitoring system*

The top four priorities for the new CO_2 and CH_4 service element during phase 2 of CAMS (2021 – 2028) are:

[2] The reports from the CO2 Task Force can be found on https://www.copernicus.eu/en/news/news/new-co2-green-report-2019-published

- Transform the various related research activities into a mature pre-operational (and then operational) system that can deliver the required monitoring and verification support capacity.
- Support the European Commission and EU member states with the global stocktake in 2028 using Earth Observation data and state-of-the-art modelling capabilities in order to provide accurate and globally consistent estimates of emissions, their uncertainties and their reductions.
- Support the European Commission and EU member states with the implementation of the EU Methane Strategy as well as the Global Methane Pledge through a capability for detecting and monitoring global super-emitters.
- Contribute to international coordination frameworks related to the monitoring of greenhouse gas concentrations and fluxes, such as the Global Greenhouse Gas Watch (G3W) of the World Meteorological Organisation (WMO) and the International Methane Emissions Observatory (IMEO) of the United Nations Environment Programme (UNEP).

As recommended in the second CO_2 report from the CO_2 Monitoring Task Force, the future CO2MVS capacity will deliver the following high-level products as defined by user requirements:

1. Detection of emitting hot spots such as megacities or power plants,
2. Monitoring of the hot spot emissions to assess emission reductions of the activities,
3. Assessing emission changes against local reduction targets to monitor impacts of the Nationally Determined contributions (NDCs),
4. Assessing the national emissions and changes in 5-year time steps to estimate the global stocktake.

The CO2MVS services shall, in the long term and in some well-identified instances and situations, provide additional evidence on the amount of anthropogenic CO_2 and CH_4 emissions reported by national statistical offices and, in particular, help to identify and assess the uncertainties and gaps associated with their emission inventories. More generally, the CO2MVS will provide the European Union with a comprehensive and consistent picture on the actual level of emissions and their reductions by all countries worldwide. The new service element is targeted for operational status in 2027 based on observations from the planned CO2M satellite constellation and other satellite sensors.

As part of the ramp-up activities for the CAMS CO2MVS capacity, ECMWF is extending the CAMS global assimilation and forecasting system with the capabilities to estimate emissions of satellite-observed greenhouse gases and air pollutants. The aim of this global system ("Global integration & attribution" in the figure above) is to routinely monitor emissions and natural fluxes at global scale close to real-time based on observations from operational satellite missions, including the detection of strong hotspot sources (especially for CH_4 and NO_x). This ITT is asking for specific developments of the CAMS global system to improve its modelling capabilities. The ITT also asks for contributions to the evaluation of both modelling and data assimilation developments to ensure the CAMS global system becomes fit-for-purpose by the time of its operational implementation.

3.1.2 Overview of CAMS global production system

The CAMS Global Production System is a specific configuration of ECMWF's Integrated Forecasting System (IFS). It is used to provide global real-time forecasts and analyses of atmospheric composition as well as to provide reanalysis products.

Modules for atmospheric composition and related physical processes have been integrated in the IFS. This integration makes it possible (i) to use the detailed meteorological representation of the IFS for

the simulation of the atmospheric transport and sink, source and conversion processes of constituents, (ii) to use the IFS variational data assimilation system to assimilate satellite observations of atmospheric composition, and (iii) to simulate feedback processes between atmospheric composition and meteorological variables.

In the current operational configuration, the IFS is run with the tropospheric chemistry mechanism CB05 and the stratospheric mechanism from the BASCOE model. For aerosol, the IFS is using a bulk aerosol scheme, while the option of a modal scheme is being developed. The operational chemistry and aerosol schemes are coupled to enable the simulation of secondary aerosols. The simulation of wet and dry deposition is currently carried out in separate modules but using similar methods that justify a more unified approach. The IFS also includes CO_2 and CH_4 as separate tracers and work is in progress to add $^{14}CO_2$ (radiocarbon) and APO (Atmospheric Potential Oxygen). Although various surface fluxes for the first two species are currently prescribed, the IFS is directly coupled to the ecLand, formerly known as CHTESSEL, land surface model for the natural biosphere fluxes of CO_2 (Boussetta et al., 2021, doi:10.3390/atmos12060723) including a new photosynthesis module based on the Farquhar, von Caemmerer and Berry model. A simple parameterisation for the wetland emissions of CH_4 based on Bloom et al. (2017, doi:10.5194/gmd-10-2141-2017) is also part of the IFS land surface model.

Full documentation of the atmospheric composition aspects of the IFS as they relate to the COMPO configuration used for CAMS can be found in Part VIII of the IFS Documentation[3]. A description of the land surface model can be found in Part IV, Chapter 8[4].

The core of this ITT is the further development of the greenhouse gas modelling and the related parameterisations for removal processes and surface fluxes in the IFS. While data assimilation of atmospheric composition using the IFS is a key component of CAMS, major contributions to improvements of data assimilation aspects are not subject of this contract. However, the successful Tenderer shall contribute to the testing of both modelling and data assimilation developments, as outlined in the specific work package below.

3.1.3 IFS land surface model

The IFS uses the ecLand land surface model. ecLand is originally based on the Carbon-Hydrology Tiled ECMWF Scheme for Surface Exchanges over Land (CHTESSEL), but was renamed to better reflect the foreseen modular extensions as well as the code sharing with the wider science community. ecLand includes a representation of soil, vegetation, snow, mountains, and water bodies and the associated energy, water and carbon exchanges with the atmosphere. This includes a multi-layer soil scheme and a multi-layer snow scheme representing thermodynamics and water transfer processes. A mixed-layer scheme for resolved and sub-grid water bodies is one of the latest added components. Satellite-based land-use maps and monthly varying vegetation-soil descriptions (for Leaf Area Index and Albedo) specify ancillary conditions, while processes like evapotranspiration, snow and ice melting/sublimation, percolation and runoff are explicitly taken into account. The natural land carbon cycle is represented by modelled soil respiration, parameterised with a so-called Q10 scheme and modulated by a land-use dependent basal respiration, and a photosynthesis scheme that simulates the CO_2 assimilation by plants or gross primary production. The CO_2 residuals of assimilation and respiration processes compose the Net Ecosystem Exchange. The land surface

[3] https://www.ecmwf.int/en/elibrary/81630-ifs-documentation-cy49r1-part-viii-atmospheric-composition
[4] https://www.ecmwf.int/en/elibrary/81626-ifs-documentation-cy49r1-part-iv-physical-processes

model benefits from continuous benchmarking of its main prognostic variables and fluxes against in-situ and satellite remote sensing products and is used across all ECMWF forecasting applications.

ecLand is already providing the hydrological and CO_2-specific carbon cycle exchanges with the atmosphere, and it also includes a model component for natural CH_4 fluxes. A simple CH_4 wetland scheme has previously been introduced in ecLand based on Bloom et al., 2017[5]. This scheme uses forecasted soil temperature and respiration to simulate flux variability; the wetland extent is based on the monthly climatology of GIEMS v3.1 obtained for the 2010-2019 period (Prigent et al., 2007[6],2020[7]), combined with monthly ecLand-CaMa-Flood inundation maps for 2019. The permanent water and rice paddies are removed. Verification against all atmospheric CH_4 observations of all TCCON sites has been positive, and the scheme has been included in the CY49R1 upgrade of the IFS in Q4 2024.

ECMWF will provide access to the Integrated Forecasting System and the High Performance Computing (HPC) system for the model developments in this contract together with support/training on performing the model simulations (in addition to the public availability of the code on https://github.com/ecmwf-ifs). The successful Tenderer shall implement and test the developments first in the offline land surface model (ecLand) and afterwards in the online coupled land-atmosphere model at ECMWF before final completion of the various tasks.

3.1.4 Cycle upgrades and code submissions

The development of the operational CAMS Global Production System (o-suite) is organised in version upgrades (cycles) following the IFS development schedule that occur every 12 to 18 months. Each cycle upgrade is linked to a fixed timeline for the submission of new code and a testing period with the combined new developments (e-suite). While the aim of this contract is to provide prototype systems in the ecLand environment, the successful Tenderer shall be mindful of these operational implementation constraints. All code developments shall be carried out in accordance with the relevant ECMWF guidelines and procedures regarding coding standards and the use of version-control and issue-tracking systems. The requested developments will be at the heart of the IFS land surface modelling. The successful Tenderer shall therefore work closely with the ECMWF land surface development team to ensure the developments are in line with CAMS and Numerical Weather Prediction (NWP) requirements. The successful Tenderer shall also be mindful of relevant parallel developments, especially those being funded through the European Union's Horizon Europe programme. An example is the Concerto project (https://www.projectconcerto.eu).

3.2 Work packages

The ITT contains the following work packages (WP):

- WP1: Implement the use of near-real-time wetland extent observations to update monthly mean climatologies in ecLand
- WP2: Implement the use of near-real-time Leaf Area Index observations to replace current monthly-mean climatologies in ecLand
- WP3: Introduction of carbon pools and development of respiration flux modules in the ecLand model
- WP4: User support and documentation of service

[5] https://gmd.copernicus.org/articles/10/2141/2017/
[6] https://doi.org/10.1029/2006JD007847
[7] https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2019JD030711

- WP0: Management and coordination

For WP1 – WP3, the Tenderer shall include in their proposal a clear development plan, including deliverables and milestones, that will result in the described outcomes. The plan shall also include regular technical progress meetings with ECMWF. For WP0 and WP4, the Tenderer shall take the required Deliverables from the tables in the respective sections below.

Tenderers shall complete the relevant table in Volume IIIA as part of their bid. Volume IIIA will be used by the Tenderer to describe the complete list of deliverables, milestones and schedules for each work package. All milestones and deliverables shall be numbered as indicated. All document deliverables shall be periodically updated and versioned as described in the tables.

3.2.1 Work package 1 (WP1) – Implement the use of near-real-time wetland extent observations to update monthly mean climatologies in ecLand

The information of wetland extend is crucial to simulate CH_4 wetland fluxes at global scale. In ecLand the implemented CH_4 wetland model relies on the use of a monthly mean climatology based on the GIEMSv3.1 dataset (2010-2019; Prigent et al., 2020[7]) and ecLand-CaMa-Flood (Boussetta et al., 2021) inundation maps for 2019. The aim of this work package is to improve the dynamics of the wetland extent maps in the ecLand CH_4 wetland model by addressing the four topics below.

- The successful Tenderer shall develop and test methodologies to improve the specification of wetland extent in ecLand compared to the current use of monthly climatologies by using relevant satellite observations. The new methodologies shall be focused on their use in the IFS forecasting system, but also take into account the application to global reanalyses. The feasibility of the approach shall be tested and he requirements shall be defined in terms of (i) availability and quality of microwave satellite observations in near-real time and (ii) using observations on a daily basis instead of using monthly or 10-day periods. This will likely require an adaptation of current retrieval algorithms, and the pre-processing and post-processing of satellite observations and surface water extent products.
- The successful Tenderer shall aim for a spatial resolution of these satellite-derived wetland cover maps of around 10 km and a temporal resolution of up to 10 days. This shall lead to an improvement in the representation of the surface inundated extent in small wetlands which are often missed with coarse resolution products.
- The successful Tenderer shall also process the satellite-derived wetland maps to remove the non-wetland water bodies (e.g. lakes and rice paddies) and add undetected unsaturated peatland areas as in the GIEMS-Methane Centric database[8].
- The successful Tenderer shall introduce the classification of the wetland types (for instance with GLWD data-driven classification, Lehner et al., 2024[9]), accounting for differences in hydrology and vegetation type. The wetland type map shall be used for evaluation purposes initially, and eventually to provide recommendations for the disaggregation of model parameters. The inclusion of permanent lakes and reservoirs would open the possibility to expand the wetland model to include CH_4 emissions from permanent water.

The processing of the satellite data can be done in Python outside the IFS Data Assimilation system, providing flexibility on the timing (latency) and approach for pre-processing (e.g. reformatting of observations and input ancillary data) and post-processing of the retrieval for the wetland extend.

[8] https://essd.copernicus.org/preprints/essd-2024-466/essd-2024-466.pdf
[9] https://essd.copernicus.org/preprints/essd-2024-204/

Indicative list of required deliverables:

- Consolidated workplan to develop, implement, and evaluate near-real time wetland extent maps in ecLand
- Development and evaluation of high-resolution satellite-based wetland extent maps as close to real-time as possible
- Development and evaluation of the use of these satellite-based wetland extent maps in the offline version of ecLand to improve the current use of climatological wetland extent maps.
- Documentation of developments and their use in ecLand

3.2.2 Work package 2 (WP2) – Implement the use of near-real-time Leaf Area Index observations to replace current monthly-mean climatologies in ecLand

The state of vegetation in ecLand is given by the Leaf Area Index (LAI), crucial for deriving the plant assimilation and transpiration activity. Currently a **climatology** based on satellite observations is used for the representation of LAI. The monthly 1 km LAI climatology covers the 2010-2019 period. It is based on recent data from the Copernicus Global Land services (CGLS) database. The original satellite data are from the global LAI Version 2 data (GEOV2)[10]. This Version 2 product is generated at 1 km spatial resolution from Collection 3 of SPOT/VEGETATION data, from 1999-2014, from Collection 0 of PROBA- V data for 2014 to 2016 and from Collection 1 of PROBA-V data for 2017 to 2019[11]. The climatology is then disaggregated into high and low vegetation components ensuring the conservation of the total LAI value and an accurate seasonal variability[12]. This climatology is used within ecLand to drive the surface carbon exchange module.

As well as changes in LAI, the sensitivity of the fluxes to environmental changes is also influenced by acclimation processes. The acclimation with temperature is driven by the growth temperature, usually calculated as the mean temperature of the previous 10 to 30 days. However, in operational NWP systems the computation of mean temperature is not readily available. Currently in ecLand the thermal acclimation is based on the soil temperature as a proxy for growth temperature.

The successful Tenderer shall develop and evaluate a methodology to use more up-to-date satellite-based LAI information in the ecLand model, following for instance the approach proposed by Boussetta et al., 2015[13]. This shall include the definition and creation of the data acquisition pipeline and pre-processing of the required near-real-time (NRT) data including gap filling and disaggregation into high and low LAI. The NRT data shall be made consistent with the current monthly mean climatology and a gap-filling procedure shall be developed and tested. Finally, to further improve the model response to the environmental variables, an exponential moving average approach to compute the growth temperature in near-real time shall be implemented for the thermal acclimation processes in ecLand and IFS.

The developments shall therefore consist of the following elements:

- Assess the availability of NRT satellite-based 10-day LAI data, with a specific focus on the provision of these datasets from the Copernicus Land Monitoring Service (CLMS)[14].

[10] Verger et al., 2023, https://doi.org/10.1016/j.jag.2023.103479
[11] https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-lai-fapar?tab=doc ; https://land.copernicus.eu/global/sites/cgls.vito.be/files/products/CGLOPS1_PUM_LAI1km-V2_I1.33.pdf
[12] https://confess-h2020.eu/wp-content/uploads/2021/08/confess-d1-1-v1-0-.pdf
[13] https://www.sciencedirect.com/science/article/abs/pii/S0034425715001054?via%3Dihub
[14] https://land.copernicus.eu/en/products/vegetation

- Develop and test a methodology to harmonize the LAI data from different sensors to a common reference (bias correction) to create a consistent data record, also consistent with the current climatology. This harmonisation shall be based as much as possible on proven methodologies in the peer-reviewed literature.
- Develop and test a methodology to gap-fill the resulting 10-day LAI maps. This could be making use of the existing climatology, if this provides the best results.
- Develop adequate quality control procedures to ensure the resulting LAI data sets can be used in an operational forecasting system.
- Implement and evaluate the use of the 10-day LAI data in the offline version of ecLand including an assessment of the impact on GPP and latent heat fluxes.
- Implement and test a parameterisation for biogenic growth temperature as an exponential moving average for acclimation processes in ecLand and assess the impact on GPP and latent heat fluxes.

The Tenderer shall include in their proposal a clear development plan, including deliverables and milestones, that will result in the above described outcomes. The plan shall also include regular technical progress meetings with ECMWF.

Indicative list of required deliverables:

- Consolidated workplan to develop, implement, and evaluate the use of near-real time satellite-based LAI data in ecLand.
- Development and evaluation of a methodology to harmonize the LAI data from different sensors to a common reference.
- Development and evaluation of a methodology to gap-fill the resulting 10-day LAI maps.
- Development of adequate quality control procedures for the produced LAI data.
- Implementation of a parameterisation for biogenic growth temperature in ecLand
- Documentation of developments and their use in ecLand

3.2.3 Work package 3 (WP3) – Introduction of carbon pools and development of respiration flux modules in the ecLand model

The simulation of the carbon fluxes in a land surface model assumes the presence of carbon pools or reservoirs exchanging carbon. For example, the autotrophic respiration associated with plant tissue growth and maintenance depends on the amount of carbon allocated to the different plant tissues (leaves, wood, roots) and the heterotrophic respiration associated with decomposition of organic matter requires the representation of a carbon substrate from the dead biomass from litter and organic carbon within the soil. In ecLand model, the current representation of the sum of the autotrophic and heterotrophic respiration fluxes (known as the ecosystem respiration flux R_{eco}) is based on a sum of the autotrophic respiration from leaves (taken as a fraction of the net carbon assimilation by the plant) and the rest of the components being dependent on a fixed PFT-dependent reference respiration (R_0) modulated by temperature, soil moisture and snow cover (Boussetta et al., 2013, 2021, IFS documentation[3]). With the inclusion of carbon pools for the leaves, wood, roots, fine and coarse litter and soil organic carbon, it will be possible to improve the various respiration fluxes and their dynamics. As the timescales of the different pools can be very different, it is paramount that the carbon pool model is modular and allows to switch on and off the dynamics of specific pools depending on the application (e.g. decadal simulations with ecLand offline and daily IFS coupled runs to produce CO_2 forecasts and analyses in CAMS). Note that the current ecLand

model has a simple LAI growth module (Boussetta et al., 2021) which is currently not used operationally, but it could be incorporated or revised in the new carbon pool model. The simple CH_4 wetland model recently developed in ecLand uses the CO_2 reference respiration parameter as a proxy for the C substrate. Since the production of CH_4 emissions associated with the anaerobic decomposition process in wetlands is largely controlled by the availability of suitable carbon substrates, one of the aims of this WP will be to explore the coupling between the decomposition module developed for CO_2 and the CH_4 wetland model.

Another underlying motivation for introducing carbon pools in the ecLand is to eventually provide the opportunity to use new satellite observations, such as above-ground biomass (AGB) products, and allow a closer coupling with other carbon modules, like the fire model being developed at ECMWF (SPARKY, McNorton and di Giuseppe, 2024). An initialization approach will need to be established based on observation-based data whenever possible. This is particularly important for the slowly varying carbon pools which will need to be part of the prescribed fields for the CAMS forecast and analysis system. Considerations of consistency with soil organic carbon stock dataset (https://soilgrids.org) used for the soil hydrology (Choulga et al., 2024[15]) currently used operationally in the IFS will also be important.

As the changes in the terrestrial biogenic carbon pools represent the accumulated effect of the fluxes from and to the atmosphere, we also expect that the monitoring of the changes in the carbon pools will result in a closer alignment with the carbon reporting of the Agriculture Forestry and Other Land Use sector by the national inventories through the accounting of changes in carbon storage.

The successful Tenderer shall implement a modular approach for the modelling of carbon pools in ecLand. Only the carbon pools that are relevant for respiration shall be considered at this stage and defined such that they can be initialised, either by observations (now or in the future) or other offline models/data sets. In either case, the specific methodology and required data sets for initialisation shall be specified and tested.

The successful Tenderer shall also develop and test the respiration modules to improve CO_2 (autotrophic and heterotrophic) and CH_4 (anoxic decomposition in CH_4 wetland model) fluxes in the ecLand model.

The successful Tenderer shall propose and implement a simple but effective and modular representation of the main carbon pools in the terrestrial biosphere in the ecLand model. The modularity will address the level of complexity required for the different applications in the global CO2MVS and the different offline and online ecLand applications covering different timescales. Particularly attention shall be given to the carbon pool initialisation strategy, considering the different applications. The Tenderer shall include in their proposal the foreseen observational and modelling data sets that will be used for the evaluation of the developments.

Indicative list of required deliverables:

- Consolidated workplan to develop modular Carbon pool model for ecLand and associated developments in the respiration model
- Implementation of Carbon pools, including a procedure for their initialisation, and respiration module in the offline version of ecLand with documentation

[15] https://hess.copernicus.org/articles/28/2991/2024/

- Evaluation of ecLand Carbon pool module with observations and intercomparison with TRENDY models and other relevant datasets
- Technical testing in online version of ecLand in IFS and update of IFS documentation

3.2.4 Work package 4 (WP4) – User support and documentation of service

The objective of this work package is to provide support to users of the delivered products and services.

ECMWF has established a centralised Copernicus Service Desk to provide multi-tiered technical support to all users of CAMS data, products, tools and services. The Service Desk handles user queries through a ticketing system and distributes these queries to specialists when needed. Dedicated staff at ECMWF provide basic support in the form of self-help facilities (FAQs, Knowledge Base, online Forum, tutorials etc.) as well as individualised support on technical queries related to the Atmosphere Data Store (ADS), data formats, data access etc. In addition, ECMWF staff provide specialised scientific support to address questions related to its industrial contributions to CAMS, e.g., in the areas of global forecasting of atmospheric composition.

All CAMS contractors are expected to contribute to the delivery of multi-tiered technical support for the data and/or services they provide. Such specialised user support shall take the form of direct response to individual user queries via the Service Desk facility, as well as contributions to FAQs, Knowledge Base, and user guides. Contractors may also be requested by the CAMS Service Desk to contribute to support questions in the online Forum.

Tenderers shall include in their proposal the level of user support service on Service Desk tickets as a specific Key Performance Indicator (KPI) with a target value of 80% of the assigned specialised user queries being resolved within 15 days after being informed by the CAMS Service Desk.

The successful Tenderer shall contribute to the relevant documentation. Documentation of CAMS is an integral part of the service provision and is directly linked to the Atmosphere Data Store. The technical and scientific specification of each service shall be documented in the CAMS Knowledge Base as linked from the Atmosphere Data Store. The Successful Tenderer shall therefore support the updates of the Knowledge Base based on the latest developments.

The Successful Tenderer shall accommodate for eventual needs in providing technical and scientific expertise in support of CAMS communication and training activities. The Tenderer shall specify in the bid the experts intended to be allocated to provide this support.

Requests to support activities may be raised on for example:

- Contribute with content specific input to training, education and capacity building material: development and/or review of learning resources in the domain of the contract, participation in train-the-trainer events and Massive Open Online Courses (MOOCs);
- Contribute with content specific input to user-oriented communication material such as slides, story maps and user testimonials;
- Contribute and attend User Uptake workshops and stakeholder meetings. Presentations in your mother tongue may be asked to be provided;
- Input to the User Requirements Database (URDB) with user requirements (cf. template as provided during the negotiation process) as well sharing needs and aspirations as raised by potential new user communities;

If applicable, a small budget may be proposed to cover such resources. Details on the expected activities and the budget shall be refined during the negotiation/contract preparation phase.

Minimum list of required deliverables:

WP4 Deliverables			
#	*Type*	*Title*	*Due*
D4.Y.Z-yyyy	Other	Contribution to CAMS Knowledge Base to ensure up-to-date information about products and services covered under this contract	Annually
D4.Y.Z	Report	Summary of support to CAMS user support, communication and training activities.	Due 1 month before contract end date
…			

3.2.5 Work package 0 (WP0) – Management and coordination

The following management and coordination activities are part of WP0 and shall be briefly described, and completed if necessary, in the bid:

- Management, planning and coordination of the different Work Packages activities and corresponding resources, including the appropriate tools used to monitor them.
- Contractual obligations as described in the Volume V Framework Agreement Clause 2.3 “Reporting and Planning” and its Annex 5 “Report content”.
- Meetings organisation and/or attendance (classified as tasks and listed in a separate table as part of the proposal):
    - ECMWF and the Successful Tenderer will organise a Kick-Off Meeting during the first month of implementation of the contract. Additional interim/ad-hoc progress meetings might be required. All meetings shall be classified as “Milestones” under Volume IIIA “Pricing and deliverables” Excel sheet, tab “Deliverables List”.
    - ECMWF will host monthly teleconference meetings to discuss CAMS service provision, service evolution and other topics (Service Level Board). The Prime Investigator and/or Service Manager appointed by the Successful Tenderer will represent the Successful Tenderer in such meetings.
    - ECMWF and the Successful Tenderer will organise Progress Review Meetings, linked to Payment Milestones, every six months unless otherwise agreed.
    - ECMWF will organise annual CAMS General Assemblies. The Successful Tenderer is required to attend these meetings with team members covering the various topics that are part of this ITT.
    - Successful Tenderer’s internal meetings.
    - Tenderers can propose additional project internal meetings (annual face-to-face meeting and monthly teleconferences) as part of their response.
- Quality assurance and control: the final quality check of the deliverables prior the submission to ECMWF should be made by the prime contractor (contents, use of ECMWF’s templates for deliverables and reports, format, deliverables/milestones numbering and naming, typing errors, etc.).

- Implementation of checks, controls and risk management tools for both the prime contractor.
- Communication management (ECMWF, stakeholders, internal communication).
- Management of personal data and how this meets the requirements of Clause 2.8 and Annex 6 “Personal Data Protection” of the Volume V Framework Agreement.
- Sub-contractor management, including dispute resolution, e.g., the prime contractor is responsible for settling disagreements, although advice/approval from ECMWF may be sought on the subject.
    - A list of sub-contractors, if any, describing their contribution and key personnel shall be provided, as well as back-up names for all key positions in the contract. The Tenderers shall describe how the Volume V Framework Agreement, in particular its Clause 2.9 “Sub-contracting”, has been flowed down to all their sub-contractors.

Minimum list of required deliverables:

WP0 Deliverables				
#	*Responsible*	*Nature*	*Title*	*Due*
D0.Y.Z-yyyyQx	Tenderer	Report	Quarterly Implementation Report (QIR) yyyyQx *yyyyQx being the previous quarter (e.g. 2024Q3 due on 15/10/2024)*	Quarterly on 15/04, 15/07 and 15/10
D0.Y.Z-yyyy-Part1	Tenderer	Report / Other	Annual Implementation Report (AIR) for year yyyy - Part 1 including: • the Quarterly Implementation Report (QIR) yyyyQ4, and • the preliminary financial information *yyyy being the Year n-1*	Annually on 15/01
D0.Y.Z-yyyy-Part2	Tenderer	Report	Annual Implementation Report (AIR) for year yyyy - Part 2 *yyyy being the Year n-1*	Annually on 28/02
D0.Y.Z	Tenderer	Report	Final Report	By the end of contract
D0.Y.Z-yyyy	Tenderer	Report	Annual Implementation Plan for year yyyy *yyyy being the Year n+1*	Annually on 30/09
D0.Y.Z-yyyy	Tenderer	Other	Copy of prime contractor's general financial statements and audit report for year YYYY *YYYY being the Year n-1*	Annually, not later than on 15/12(1)
D0.Y.Z	Tenderer	Other	Updated KPIs (list, targets, etc.) after review with ECMWF	1 year after start of contract

WP0 Milestones				
#	*Responsible*	*Title*	*Means of verification*	*Due*
M0.Y.Z-KOM	Tenderer	Kick-Off Meeting	Minutes of Meeting	30 days after start of contract

M0.Y.Z-PMxqqYY	Tenderer	Progress Review Meeting #PMx being the Payment milestone number, #qq - the quarter and #YY - a year during which the Payment Milestone is due *xx being the iteration number of the PRM*	Minutes of Meeting	~ as a minimum linked to the Payment Milestone.
M0Y.Z-SLB[2]	Tenderer	CAMS Service Level Board meeting	Attendance	Every month
M0.y.z-CAMSGA-YYYY	Tenderer	CAMS General Assembly YYYY	Attendance	Annually, not later than on 15/12[1]
M0.Y.Z-Interim-QQYY	Tenderer	Interim progress review meeting if payment period is 6 months or longer	Minutes of Meeting	Regular intervals

[1] These due dates are indicated to frame the corresponding deliverables and milestones schedule only, consequently the following shall be considered by the Tenderer:

- the general financial statements shall be sent by the contractor as soon as available,
- the schedule of the Progress Review Meetings shall be aligned with the different Payment Milestones during the contract negotiation,
- depending on the year, the CAMS General Assembly may take place at a different period of the year.

[2] All iterations for this recurring SLB meeting do not need to be listed by the Tenderer, i.e., only one row shall be added in Volume IIIA "Pricing and deliverables" Excel sheet "Deliverables List".

4 General Requirements

4.1 Implementation schedule

The Framework Agreement will run for 29 months, ideally from 1 May 2026 to 30 September 2028. The Tenderer shall provide a detailed implementation plan of proposed activities for the full period.

4.2 Deliverables and milestones

The Tenderer shall provide the list of deliverables and milestones (cf. ITT Volume IIIA "Pricing and deliverables", Excel spreadsheet "Deliverables List") for each Work Package. All deliverables and milestones must be consistent with the activities and objectives described in Section 3 of this ITT Volume II:

- A deliverable is a substantial, tangible or intangible good or service produced as a result of a project (see also the deliverable definition in this ITT Volume V Clause 1.2 and Clause 3.2). In other words, a deliverable is an outcome produced in response to the specific objectives of the contract and is subject to acceptance by both ECMWF's Technical Officer (TO) and Contract Management Officer (CMO).
- Milestones should be designed as markers of demonstrable progress in service development and/or quality of service delivery (see also the milestone definition in this ITT Volume V Clause 1.2). They should not duplicate deliverables and shall not attract the budget under Volume IIIA "Pricing and deliverables", Excel sheet "Deliverables List".

The following shall apply to the deliverables and milestones:

- The deliverables and milestones should be consistent with the technical requirements specified in Section 3.
- When defining deliverables, please assign **the precise** dates (DD/MM/YYYY) to each of them.
- All contract reports and deliverables shall be produced in English.
- The quality of reports and deliverables shall be equivalent to the standard of peer-reviewed publications and practice.
- Unless otherwise specified in the specific contract, deliverables shall be made available to ECMWF in electronic format (PDF/Microsoft Word/Microsoft Excel or compatible) via the Copernicus Deliverables Repository portal. See also Section 4.7 in what regards the data provision.

Volume IIIA "Pricing and deliverables" (cf. Excel sheet "Deliverables List") of this ITT shall be used by the Tenderer to describe the complete list of deliverables, milestones and schedules for each work package (due dates). Please note that:

- All deliverables and milestones shall be numbered as per the following format DX.Y.Z (for deliverables) and MX.Y.Z (for milestones), where X is the WP number, Y is the task number and Z is the deliverable or milestone number in this task. Deliverables delivered annually should be numbered DX.Y.Z-yyyy, where yyyy is the year the deliverable refers to (e.g. DX.Y.Z-2016). Deliverables delivered quarterly should be numbered DX.Y.Z-yyyyQx, where yyyyQx is the quarter of the year the deliverable refers to (e.g. DX.Y.Z-2016Q1, DX.Y.Z-2016Q2). The same numbering format shall be applied for the milestones. Continuous deliverables at higher frequency can be labelled in the same way as quarterly deliverables.
- Each deliverable shall have an associated resource allocation and price (cf. column I "Nb of PM allocated" and column J "Estimated price"), while the only resource type to be considered is "payroll" (the total of these allocated resources and prices shall therefore amount to the total price associated with payroll in Volume IIIA spreadsheet "Costs and Prices"). Milestones should not have such associated resource allocation, unless otherwise agreed.
- The Tenderers shall provide a due date for each proposed deliverable and milestone (in accordance with those indicated in Section 3):
    - The Tenderers shall ensure that the proposed due dates of deliverables and milestones are realistic and achievable. **Any dependencies on input data (whose origin must be specified) shall be detailed and also accounted for in the risk table**.
    - It is advised to schedule the submission/completion of the last deliverables and/or milestones associated to a Payment Milestone not later than 15 days before the expected date of completion of the said Payment Milestone (i.e. when all deliverables have been submitted by the contractor and all milestones have been completed by the concerned parties).

4.3 Acquisition of necessary data and observations

The Successful Tenderer shall acquire the relevant emission inventory and observational or ancillary data sets and make them available for use in all CAMS activities related to the provision of emission estimates for the regional and global production systems and for distribution to users.

4.4 Data and IPR

It is a condition of EU funding for CAMS that ownership of any datasets developed with CAMS funding passes from the suppliers to the European Union via ECMWF. Ownership will pass from the date of creation of the datasets. Suppliers will be granted a non-exclusive licence to use the datasets which they have provided to CAMS for any purpose.

All software and products used by the successful Tenderer to produce the CAMS datasets will remain the property of the successful Tenderer, except for those components which are acquired or created specifically for CAMS purposes, with CAMS funding, and which are separable and useable in isolation from the rest of the successful Tenderers' production system. The identity and ownership of such exceptional components will be passed to the European Union via ECMWF annually. The successful Tenderer will be granted a non-exclusive licence to use them for any purpose in line with the Terms and Conditions of the Framework Agreement

It is expected that data sets (including databases) generated or acquired by the successful Tenderer will be delivered via the Atmosphere Data Store (ADS). The section below indicates generic requirements for these datasets in terms of standards and conformity.

Provision of data and products:

Suppliers will make the output of their work available to CAMS users via the ADS, by uploading their data and products to a designated server. Suppliers will have to agree with ECMWF on the data formats to be used. ECMWF will only accept data in formats that follow internationally recognised standards. Such standards must be open (i.e. non-proprietary), managed by a recognised international standardisation body (e.g. ISO, WMO, OGC, etc.), or any de-facto standard. Open source software should also exist that can read and write files of these standards. Serialisation formats (e.g. NetCDF, XML, JSON) should be supported by standard schemas and conventions. All text-based formats should be encoded in UTF-8. ECMWF will implement tools to check the compliance of the provided data and products to the agreed standards before they are added to the ADS. Examples are data uploaded to the ADS in WMO GRIB edition 1 and 2, NetCDF files conforming to CF-1.6, or greater.

Every dataset and/or service provided shall be documented using the appropriate metadata standards (e.g. ISO 19115, INSPIRE Directive 2007/2/EC).

Particular attention shall be paid to the file naming convention to ensure consistency between the various ADS datasets. The specific details shall be agreed with the ADS team at ECMWF during the kick-off meeting of the contract.

4.5 Communication

The successful Tenderer shall support ECMWF in its communication activities for the CAMS services, where they are related to the activities described in this ITT. Examples are contributions to the Copernicus State of the Climate report, CAMS web site news items, and CAMS brochures and flyers. All communication activity must be agreed with the ECMWF Copernicus Communication team in advance. This includes, but not exhaustively, communication planning, branding and visual style, media outreach, website and social media activity, externally facing written and graphic content and events. Agreed activity would also need to be evaluated and reported on, once complete, so that success measures and KPIs can be provided to the European Commission.

4.6 Key performance indicators

Contractors shall report to ECMWF on a set of Key Performance Indicators (KPIs) suitable for monitoring various aspect of service performance. These will be used in the overall monitoring of the CAMS programme.

The table below provides the template to be used by the Tenderer to describe the KPIs, relevant for this ITT, together with performance targets, delivery schedules and explanations if needed. Please note that the listed KPIs form part of the overall set of KPIs comprising the full CAMS service portfolio; the successful Tenderer therefore might have to provide KPI values for a KPI in support of services outside this ITT.

All KPIs shall be labelled and numbered as indicated. All KPIs shall be periodically updated as described in the tables. Tenderers shall provide preliminary versions of the completed tables as part of their bid.

The list of KPIs shall be reviewed with ECMWF in the second year of the contract and updated if necessary.

KPI #	KPI Title	Performance Target and Unit of Measure	Frequency of Delivery	Explanations / Comments
KPI_1				
KPI_2				
KPI_3				
KPI_4				
KPI_5				
KPI_6				

5 Tender Format and Content

General guidelines for the tender are described in Volume IIIB. Specific requirements to prepare the proposal for this particular tender are described in the next sub-sections.

5.1 Page Limits

As a guideline, it is expected that individual sections of the Tenderer's response do not exceed the page limits listed below. These are advisory limits and should be followed wherever possible, to avoid excessive or wordy responses.

Section	*Page Limit*
Executive Summary	2
Track Record	2 (for general) and 2 (per entity)
Quality of resources to be Deployed	2 (excluding Table 1 in Volume IIIB and CVs with a maximum length of 2 pages each)
Technical Solution Proposed	2 + 3 per Work package (Table 2 in Volume IIIB, the section on references, publications, patents and any pre-existing IPR is excluded from the page limit and has no page limit)
Management and Implementation	6 (excluding Table 3, Table 5, Table 6 and Table 7 in Volume IIIB) + 2 per each Work package description (Table 4 in Volume IIIB)

Pricing Table	No limitation

Table 1: *Page limits*

5.2 Specific additional instructions for the tenderer's response

The following is a guide to the minimum content expected to be included in each section, additional to the content described in the general guidelines of Volume IIIB. This is not an exhaustive description and additional information may be necessary depending on the Tenderer's response.

5.2.1 Executive Summary

The Tenderer shall provide an executive summary of the proposal, describing the objectives, team and service level.

5.2.2 Track Record

The Tenderer shall demonstrate for itself and for any proposed subcontractors that they have experience with relevant projects in the public or private sector at national or international level. ECMWF may ask for evidence of performance in the form of certificates issued or countersigned by the competent authority.

5.2.3 Quality of Resources to be Deployed

The Tenderer shall propose a team that meets at least the following requirements:

- A senior team member (Prime Investigator) with more than 5 years of experience in managing activities related to this ITT;
- At least two additional senior team members with more than 5 years of experience on performing activities related to the various aspects of this ITT.

These team members shall be involved in the activities of this ITT at a minimum level of 10% of their total working time. The successful Tenderer shall also appoint a Service Manager, which will be its primary contact for contractual delivery and performance aspects.

5.2.4 Technical Solution Proposed

The Tenderer is expected to provide a short background to the proposed technical solution to demonstrate understanding of the solution proposed. This should include background of the Tenderer's understanding of the Copernicus Atmosphere Monitoring Service, and the current state of monitoring and forecasting of global greenhouse gases in the atmosphere.

An exhaustive and detailed description of the proposed technical solution for all work packages described above, including any ramp-up or mobilization phase, shall be given. The Tenderer shall indicate in detail its development plan for the proposed developments in the three main work packages. Finally, for the model development aspects, the Tenderer shall indicate its proposal for required input data sets and observations/products to be used in the optimization of model parameters and final evaluation of the model performance.