ECMWF Copernicus Procurement

Invitation to Tender

Copernicus Climate Change Service

Diagnostics of the Earth System energy balance derived from observations and reanalyses

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1 Introduction

ECMWF, as the Entrusted Entity for the Copernicus Climate Change Service (C3S), invites proposals for developing diagnostics of the energy balance of the Earth System from observations and reanalyses in support of the C3S climate monitoring applications. More information on C3S and its global monitoring services can be found at following webpages:

- https://climate.copernicus.eu/about-c3s,
- https://climate.copernicus.eu/products/climate-reanalysis.

Quantification of the Earth's energy imbalance (EEI) and its distribution among the different components of the climate system (atmosphere, ocean, land, sea ice) is fundamental to understanding and monitoring climate change (von Shuckmann et al 2016). The EEI is the rate of energy accumulation in the climate system, the most fundamental process of anthropogenically forced climate change. The distribution of energy among subsystems has important implications for changes in surface temperature and atmospheric-oceanic circulation, and for regional aspects of climate change (e.g. decline of Arctic sea-ice). Data sparseness is a key limitation of observational products for global evaluations of the energy budget. Reanalyses are a perfect complement, as they represent four-dimensional gridded descriptions of all climate sub-systems and are in principle ideal for energy budget diagnostics. However, these data sets involve limitations such as temporal discontinuities arising from the ever-changing observing system and non-conservation of energy during the data assimilation process. Therefore, methods to merge different datasets that account for their error characteristics are required for quantification of the energy cycle and its associated uncertainty.
Since the energy budget diagnostics include multivariate and integrated aspects of the Earth system, they have the potential to become a powerful tool for the evaluation of the climate quality of both reanalyses and observational datasets.

The main goal of this contract is to expand the C3S monitoring capabilities to quantify the Earth System Energy Budget (EEB), its imbalance (EEI), as well as the associated uncertainty. The successful tender shall develop the required EEB and EEI diagnostic packages, provide recommendations on required datasets, interact with ECMWF experts to apply the diagnostics to the C3S monitoring suite and to evaluate the ERA6 production streams.

This document describes the scope and technical requirements for the services tendered.
The specific objectives and technical requirements are described in section 2. General requirements are presented in section 3. Information about the tender format and content is in section 4. Section 5 contains a list of acronyms and reference documents.

ECMWF intends to award a Framework Agreement with one service contract. The expected duration of the Framework Agreement is 30 months, with expected start date in Q2 2025.

2 Technical Requirements

2.1 Scope of Service

In the past few years there have been substantial advances on improved quantifications of the EEI using combination of top-of the atmosphere (TOA) radiation from CERES-EBAF satellites, atmospheric reanalyses and temporal variations of ocean heat content from ocean reanalyses (e.g. Trenberth et al 2014, Loeb et al 2022). In addition, estimations of TOA from satellite measurements together with vertically integrated atmospheric energy budget from ERA5 can be used for the estimation of surface fluxes (Trenberth and Fasullo 2017, Liu et al 2020, Mayer et al 2022). The divergence of vertically

integrated quantities from atmospheric reanalyses can be used to estimate atmospheric horizontal transports, which in turn, combined with estimations of the ocean transports via variational methods can be used to quantify energy budgets at regional scale (Mayer et al 2017, Mayer et al 2018). These estimations of transports and storage terms in the atmosphere and ocean are key components for the inventory of energy storage terms that is regularly undertaken (e.g Von Schuckmann et al 2022).

The successful bidder shall:

- Implement and provide robust and up-to-date methods, diagnostics software, and recommend datasets for estimating EEI and EEB and their uncertainty in terms of global budgets as well as meridional heat transports of ocean and atmosphere and ocean storage. The data sets should include atmospheric reanalysis, in particular ERA5, and ocean reanalyses.
- Provide diagnostics for regional budgets including at least two focus regions, one of them being the Tropical Pacific.
- Apply the EEB and EEI diagnostics to evaluate the quality of the ERA6 production streams during 2025 and 2026.

The successful Bidder shall adopt working standards and procedures that conform to those at ECMWF and C3S, in particular:

- Provide, where required, detailed reports, software in python and associated documentation;
- Use as input the datasets provided by C3S and recommended additional observational datasets if required for the diagnostics;
- Work closely together with ECMWF expert teams;
- Carry out working visits to ECMWF, as required for advancing the project.

2.2 Specification of Work

2.2.1 WP1: Develop diagnostics for routine monitoring for global and Earth energy budget and its geographical distribution.

2.2.1.1 Activities

This work package consists of the following activities (subject to negotiation):

- Implement and provide robust and up-to-date methods, diagnostics software and datasets for estimating EEI and EEB and their uncertainty in terms of global budgets as well as meridional heat transports of ocean and atmosphere and ocean storage.
- The activity shall be based atmospheric and ocean reanalyses from the Copernicus Services.
- Diagnostics for regional budgets should include at least two focus regions, one of them being the Tropical Pacific.
- The diagnostics should allow yearly updates of the EEB/EEI.
- Recommendations for the latency time required to obtain robust estimates depending on the availability of the input datasets are required.
- Evidence backed recommendations on the feasibility of a suitable diagnostic for monitoring atmospheric moisture transports

- The diagnostics will provide temporal records of global EEI/EEB, meridional ocean and atmospheric heat transports and storage, with yearly frequency and -at least- spanning the period 2000-2024.
- The Bidder should provide an update the above record to include the year 2025 and delineate a suitable methodology for annual updates
- The diagnostic software should be written in python, delivered to the ECMWF Git-Hub with appropriate documentation and visualization tools, and include a test-case for reproducibility of results.

2.2.1.2 Deliverables required.

- D1.1 Diagnostic package and input datasets for global and regional EEB/EEI monitoring, with recommendations on feasibility for operational implementation (T0+18 months). Deliverable nature: Software and documentation.
- D1.2 Temporal records of the global EEB/EEI, meridional ocean and atmospheric heat transports and storage for the period 2000-2024, together with uncertainty estimates, with a yearly temporal resolution. Summary report on lessons learnt from these temporal records. (T0+18 months)
- D1.3 Update of the temporal records above to include the year 2025 (T0+24).

Below a summary of the nature of deliverable, criteria for evaluation, metrics and approving authority

WP1: Deliverable table					
#	Indicative timeline	Nature	Evaluation Criteria	Metrics	Approving Authority
D1.1	T0+18	Software and Documentation.	Software in python, delivered in Git-Hub, with appropriate documentation and test-case provided. Software should include the provision of graphical output. Proposed methods and input datasets sound.	Software functional and results reproducible when tested. Methods and dataset proposed are state of the art.	ECMWF - Technical Officer
D1.2	T0+18	Dataset and report.	Data readable, and figures interpreted. Report scientifically sound and informative	ECMWF experts able to reproduce figures in report from the input datasets. ECMWF relevant experts understand and accept the interpretation of the lessons learnt.	ECMWF - Technical Officer
D1.3	T0+24	Dataset and report, updated	Data readable and interpretable.	ECMWF experts able to reproduce the dataset and	ECMWF - Technical Officer

		diagnostic package if applicable	Report scientifically sound and informative.	figures in report with diagnostics package provided ECMWF relevant experts understand and accept the interpretation of the lessons learnt.	

Table 1: WP1 deliverable table

2.2.1.3 Milestones

- EEB/EEI diagnostic package and required input data tested and illustrated with a proof of concept (T0+10)

2.2.2 WP2. Evaluation of the climate quality of ERA6 production streams with selected EEB/EEI diagnostics

2.2.2.1 Activities

The multivariate and integrated nature of the EEI/EEB diagnostics make them a powerful tool to evaluate the climate quality of reanalysis. In this work package, the tendered will propose discerning and agile diagnostics for the evaluation of ERA6. The selected diagnostics will be applied both to the ERA6 pre-production scout experiments as well as to the ERA6 production streams.

The following activities are envisaged (subject to negotiation):

- Selected diagnostics of global and regional EEI/EEB will be applied first to the ERA6 short scout experiments, and report on the climate quality of the results.
- The diagnostics should be interfaced with the ERA6 production streams to provide prompt monitoring.
- The Bidder is encouraged to communicate potential quality warnings to the ERA6 reanalysis team.
- When applicable, the results from ERA6 scouts and production streams will be compared with those of ERA5.
- The tendered will attempt to relate differences in the EEI/EEB in ERA6 and ERA5 to the different setups in the ERA5 and ERA6 configurations (e.g. resolution, observations, model version, aerosol forcing and coupling options).
- The Bidder should communicate on a regular basis their assessment on the climate quality of ERA6 scouts and production streams.

2.2.2.2 Deliverables required

- D2.1 Preliminary evaluation of the climate quality of ERA6 scouts and production streams (T0+12). Report or presentation.
- D2.2 Evaluation of the climate quality of ERA6 using EEI/EEB diagnostics (T0+30). Report designed to enhance the evaluation metrics for reanalysis quality.

WP2: Deliverable table					
#	Indicative timeline	Nature	Evaluation Criteria	Metrics	Approving Authority
WP2.1	T0+12	Report or presentation	Bidder provides relevant and clear feedback.	Reanalysis Team and ECMWF experts understand the assessment. Lessons learnt and open questions clearly formulated.	ECMWF - Technical Officer
WP2.2	T0+30	Report formatted to feed into the EQC for climate reanalyses	Feedback on ERA6 climate quality scientifically sound and relevant.	Reanalysis Team and ECMWF experts understand the assessment. Lessons learnt and open questions clearly formulated.	ECMWF - Technical Officer

Table 2: WP2 deliverable table

2.2.2.3 Milestones

- A subset of selected EEB/EEI diagnostics for evaluation of ERA6 identified and applied to ERA6 scout or production experiments (T0+6)
- Selected EEB/EEI diagnostics interfaced with ERA6 production streams (T0+12)

2.2.3 WP0 Management and Technical Coordination

2.2.3.1 Activities

This work package will focus on contract management, including internal controls. The following management aspects shall be briefly described in the bid:

- Contractual obligations as described in the Framework Agreement Clause 2.3 on reporting and planning.
- Meetings (classified as tasks and listed in a separate table as part of the proposal):
  - ECMWF will organise annual C3S General Assemblies. The successful Bidder is required to attend these meetings with team members covering the various topics that are part of this ITT.
  - ECMWF will host monthly teleconference meetings to discuss C3S service provision, service evolution and other topics. The Prime Investigator appointed by the successful Bidder will represent the successful Bidder in such meetings.
  - ECMWF will organise six-monthly project review meetings (linked to Payment milestones).
  - Bidders can propose additional project internal meetings (kick-off meeting, annual face-to-face meeting and monthly teleconferences) as part of their response.
- Quality assurance and control: the quality of reports and Deliverables shall be equivalent to the standard of peer-reviewed publications. The final quality check of the deliverables should be made by the prime contractor (contents, use of ECMWF reporting templates for deliverables and reports, format, deliverable numbering and naming, typos…); all reports in this project shall be in English. Unless otherwise specified, the specific contract Deliverables shall be made available to ECMWF in electronic format.
- Communication management (ECMWF, stakeholders, internal communication).
- Resources planning and tracking using the appropriate tools.

- Implementation of checks, controls and risk management tools for both the prime contractor and subcontractors.
- Subcontractor management, including conflict 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 subcontractors describing their contribution and key personnel shall be provided, as well as back-up names for all key positions in the contract. The Bidder shall describe how the Framework Agreement, in particular Clause 2.9 has been flowed down to all their subcontractors.
- Management of personal data and how this meets the requirements of Clause 2.8 and Annex 6 of the Volume V Framework Agreement.

Bidders shall complete the relevant table in Volume IIIA as part of their bid, which shall include the deliverables and milestones for this work package already indicated in the tables below. Volume IIIA will be used by the Bidder 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.

2.2.3.1.1 Deliverables required

Deliverables covering the coordination of the contract and contractual and financial reporting obligations towards ECMWF shall be in agreement with Volume IIIB section 5.4. An example of an overview can also be found in the Table below. Deliverables for this work package shall include the following administrative and programmatic reports:

WP0 Contractual Obligations Template				
#	*Responsible*	*Nature*	*Title*	*Due*
D0.y.z-YYYYQQ	Bidder	Report	Quarterly Implementation Report QQ YYYY *QQ YYYY being the previous quarter*	Quarterly on, 15/04, 15/07 and 15/10
D0.y.z-YYYY	Bidder	Report	Annual Implementation Report YYYY *YYYY being the Year n-1*	Annually on 28/02
D0.y.z	Bidder	Report	Final report	60 days after end of contract
D0.y.z-YYYY	Bidder	Other	Preliminary financial information YYYY *YYYY being the Year n-1*	Annually on 15/01
D0.y.z-YYYY	Bidder	Report	Implementation plan YYYY *YYYY being the Year n+1*	30/09
D0.y.z-YYYY	Bidder	Other	Copy of prime contractor's general financial statements and audit report YYYY *YYYY being the Year n-1*	Annually
D0.Y.Z	Bidder	Other	Updated KPIs (list, targets…) after review with ECMWF	One year after start of contract

Table 6: Administrative and Programmatic Deliverables

WP0 Milestones				
#	*Responsible*	*Title*	*Means of verification*	*Due*

M0.Y.Z-Px	Bidder	Progress review meetings with ECMWF / Payment milestones	Minutes of meeting	~ Every 6 months

Bidders shall provide preliminary versions of the completed tables as part of their bid.

ECMWF will provide the templates for reports and plans at T0.
The successful Bidder shall keep reporting documents short and factual. Contract management and technical coordination is expected to stay within 7-10% of the planned use of the resources.

2.3 Schedule

Activities shall be performed in the context of a 30-months Framework Agreement, with expected end date on 31 December 2027. The start of the contract (T0) is expected to take place in June 2025. 5.
Work packages are all expected to start in T0 and run in parallel according to following time schedule:
Work Package 0: T0 + 30 months
Work Package 1: T0 + 24 months
Work Package 2: T0 + 30 months

3 General Requirements

3.1 Schedule

The Bidder is expected to provide a detailed time plan and schedule as part of the tender response. The proposed time plan and schedule shall address the main tasks, inputs, outputs, intermediate review steps, milestones, deliverables and dates. Regular progress meetings will be held with ECMWF during the contract to assess project status, risks and actions.

ECMWF has to prepare annual Implementation Plans, which must be approved by the European Commission before they can enter into force. The implementation plans will take full stock of service reviews, performed thoroughly on an annual basis, as well as of the continuously evolving user requirements and corresponding service specifications. The successful Bidder shall therefore provide each year for ECMWF approval an updated detailed plan of proposed activities including Deliverables and Milestones, using the Work Package table template in Volume IIIB, which will form part of this Implementation Plan. The successful Bidder shall also report on a quarterly and annual basis (for more details please see Volume V Framework Agreement for this ITT)

3.2 Meetings and working visits

It is expected that most of the work will be carried out remotely. Still, the Bidder shall account for working visits to ECMWF (Reading, UK or Bonn, Germany) to cover collaboration needs on each of the above-described technical work packages. For each work package, the Bidder is expected to propose a working visit plan for the full duration of the contract and shall account for the linked travel and subsistence costs in the pricing table.
Around every 12 months, ECMWF organises general assembly meetings to bring together all C3S service providers. The successful Bidder is expected to attend the general assembly and needs to account for this meeting in its price.
The successful Bidder is also expected to attend regular teleconference meetings to discuss the service provision and contractual aspects. The cost of organising and attending any additional meetings shall also be covered by the successful Bidder and shall be included in the tendered price.

3.3 Deliverables and milestones

Deliverables shall be consistent with the technical requirements as specified in section 2. These can be in the form of documents or reports, data sets or databases, software, web services and user support. A deliverable is a substantial, tangible or intangible good or service produced as a result of the project. In other words, a deliverable is an outcome produced in response to the specific objectives of the contract and is subject to acceptance by the technical contract officers at ECMWF.

Each Deliverable shall have an associated resource allocation (person-months and financial budget, resource type: payroll only). The total of these allocated resources shall amount to the requested budget associated with payroll.

Milestones shall be designed as markers of demonstrable progress in service development and/or quality of service delivery. They shall not duplicate deliverables.

Requirements for each type are described in the following subsections.

3.3.1 Software

Unless stated otherwise the software packages should be written in python and delivered to the ECMWF Git-Hub.

3.3.2 Documents and reports

All project reports 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, or, where explicitly stated, in the ECMWF JIRA system). Reports that need to be included into full-stock-of-service documents (Quarterly and Annual Implementation Reports, Draft and Final Implementation Plans) shall be provided in Microsoft Word.

3.4 Key Performance Indicators

At the end of each year, a service readiness review shall take place that will include assessment of a set of Key Performance Indicators (KPIs). The KPIs shall be designed to quantify different aspects of quality of service against the requirements described in this document.

As part of the bid, the Bidder shall specify a proposed set of KPIs appropriate for the service. These initial specifications shall be refined together with ECMWF during the first 6 months of the contract.

Guidance can be found at https://op.europa.eu/en/publication-detail/-/publication/91e255c0-e5b2-11ea-ad25-01aa75ed71a1/language-en/format-PDF/source-172982372.

3.5 Data and IPR

It is a condition of EU funding for C3S that ownership of any datasets developed with C3S 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 C3S for any purpose

All software and products used by the successful Bidder to produce the C3S datasets will remain the property of the successful Bidder, except for those components which are acquired or created specifically for C3S purposes, with C3S funding, and which are separable and useable in isolation from the rest of the successful Bidders' production system. The identity and ownership of such exceptional components will be passed to the European Union annually. The successful Bidder will be granted a non-exclusive licence to use them for any purpose.

3.6 Ad hoc Support

Whilst communications and user engagement, training and support activities are not part of the scope of this ITT, the bidder shall accommodate for possible needs in providing technical and scientific expertise in ad hoc support of these activities. The bidder shall specify in the bid the experts intended to be allocated to provide this support and a small budget may be proposed.

4 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.

4.1 Page limits

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

Section	*Page Limit*
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	30 (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	10 (excluding Table 4 and Table 5 in Volume IIIB) + 2 per each work package description (Table 3 in Volume IIIB)
Pricing Table	No limitation

Table 5: *Page limits*

4.2 Specific additional instructions for the Bidder'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 Bidder's response.

4.2.1 Executive summary

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

4.2.2 Track Record

The Bidder and any proposed subcontractor must demonstrate substantial experience in executing relevant projects within the public or private sectors, either on a national or international level. ECMWF may ask for evidence of performance in the form of certificates issued or countersigned by the competent authority.

4.2.3 Quality of Resources to be Deployed

The Bidder shall propose a team that meets at least one of 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 Bidder shall also appoint a Service Manager, which will be its primary contact for contractual delivery and performance aspects.

4.2.4 Technical Solution Proposed

The Bidder shall give a short background to the proposed solution to demonstrate understanding of that solution and of the C3S context. This section shall also include information on any other third-party suppliers that are used as part of the technical solution, and a statement of compliance for each requirement formulated throughout this document, describing how the proposed solution maps to the requirements.

4.2.5 Management and Implementation Plan

The Bidder shall provide a detailed implementation plan of proposed activities for the duration of the framework agreement. Deliverables shall be as close as possible as those specified in section 2. Should the bidder deviate from the requested deliverables, these deviations should be justified, and the proposed deliverables should be consistent with the technical requirements specified in section 2. The number of milestones is not restricted, but they shall be designed as markers of demonstrable progress in service development and/or quality of service delivery.

5 Additional Information

5.1 References

Liu, C., and Coauthors, 2017: Evaluation of satellite and reanalysis-based global net surface energy flux and uncertainty estimates. J. Geophys. Res. Atmospheres, 122, 6250–6272.

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Trenberth, K. E., and J. T. Fasullo, 2017: Atlantic meridional heat transports computed from balancing Earth's energy locally. *Geophys. Res. Lett.*, **44**, 1919–1927.

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5.2 Acronyms

EEB	Earth Energy Budget
EEI	Earth Energy Imbalance
C3S	Copernicus Climate Change Service
CERES	Clouds and Earth Radiant Energy System
CERES - EBAF	Clouds and Earth Radiant Energy System (CERES) Energy Balanced and Filled
CV	curriculum vitae
DA	Data Assimilation
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
EDA	Ensemble of Data Assimilations
ERA5	ECMWF fifth full-observing-system atmospheric reanalysis
ERA6	ECMWF forthcoming sixth full-observing-system atmospheric reanalysis
EU	European Union
HPC	High-Performance Computing
ITT	Invitation to Tender
JIRA	Atlassian software development tool
KPI	Key Performance Indicator
PDF	Portable Document Format
TOA	Top of the Atmosphere
WP	Work Package