

ECMWF Copernicus Procurement

Invitation to Tender



Copernicus Climate Change Service

Advancing ocean data assimilation
methodology for climate applications

Volume II

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1 Introduction

ECMWF, as the Entrusted Entity for the Copernicus Climate Change Service (C3S), invites proposals for advancing the ocean data assimilation methodology in support of climate applications, specifically Earth System reanalyses and initialization of seasonal forecasts, both key elements of the C3S. More information on C3S, its global reanalysis and seasonal forecast services can be found at following webpages:

- <https://climate.copernicus.eu/about-c3s>,
- <https://climate.copernicus.eu/seasonal-forecasts>,
- <https://climate.copernicus.eu/products/climate-reanalysis>.

The service sought builds on the development already carried out under a previous C3S contract (C3S_321b), which implemented the components needed to enable an ensemble of data assimilations (EDA) for ocean reanalyses. The main goal of this contract is to further integrate these individual components and to develop additional data assimilation (DA) tools so the next generation of C3S climate reanalysis can benefit from better exploitation of the available observations. The activity within this contract will contribute to the following production streams:

- OCEAN6: multi-decadal uncoupled ocean reanalyses for climate studies and initialization of seasonal/decadal coupled forecasts. This will use NEMO4 forced by ERA5 surface forcing, and the latest version of NEMOVAR. The service sought will help to finalize the final configuration of OCEAN6 and assist with monitoring during production. OCEAN6 will also serve as reference and anchor for ERA6, described next. The production of OCEAN6 is intended to start before Q1-2023.
- ERA6: the next generation of C3S’s Reanalysis System which will be conducted using a coupled data assimilation methodology (at an outer-loop level) to provide a monitoring capability for the Earth System, including atmosphere, land, ocean, sea-ice and ocean waves, and to be ready for production in early 2024. The service sought shall advance the ocean and data assimilation methodology to ensure improved exploitation of surface observations.
- ERA6-Ocean-offline: a multidecadal uncoupled ocean reanalysis forced by ERA6 surface forcing, produced in a sequential manner. The service sought aims at improving the reliability of the low-frequency climate signals.

A diagram below describes the interdependencies among these three productions streams.

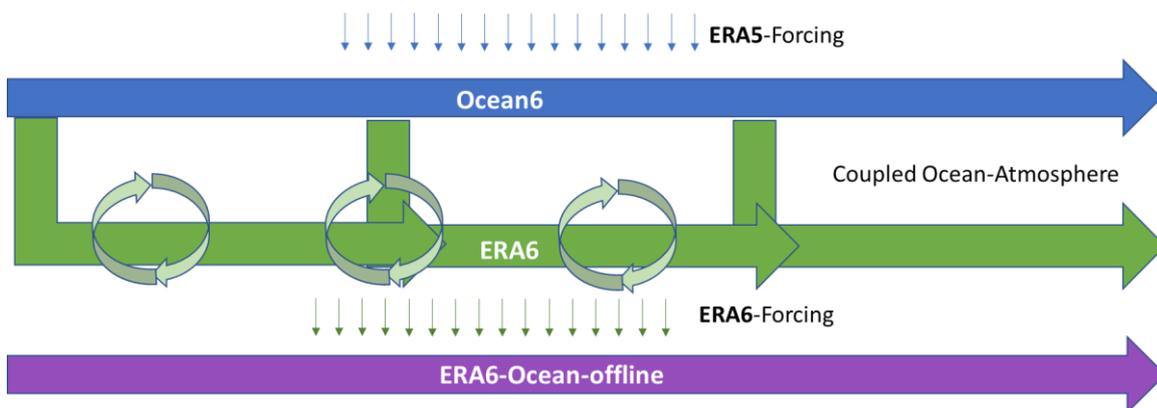


Figure 1: Schematic overview

The ocean data assimilation will be based on the NEMO ocean model, on the NEMOVAR data assimilation system and it will use the (C++ based) Object-Oriented Prediction System (OOPS) infrastructure. The successful tenderer shall run experiments using the ECMWF computer and software infrastructure, and work closely with ECMWF experts on ocean/coupled DA. This document describes the scope and technical requirements for the services tendered.

The specific objectives and technical requirements are described in section 2. General performance 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.

2 Technical Requirements

ECMWF intends to award a Framework Agreement with one service contract. The expected duration of the Framework Agreement is 36 months.

2.1 Scope of Service

In the past few years there have been substantial developments in the NEMOVAR ocean data assimilation system to allow for the account of flow-dependent background errors using hybrid ensemble-variational approaches and improved assimilation of altimeter-derived sea level anomalies (SLA) and sea surface temperatures (SST) observations. These developments, further integrated and ported to the new version of the ocean model NEMO4, will be the basis for OCEAN6 and subsequent ocean data assimilation improvements required for ERA6 and ERA6-ocean-offline.

The successful bidder will be required to deliver on the following areas:

- Integration into the ECMWF reanalysis system of mature ocean data assimilation capabilities required for the transition to an operational service.
- Advanced multi-scale data assimilation methodology for improved treatment of model error, at different temporal and spatial scales, required to enhance the temporal consistency of multi-decadal ocean reanalyses.
- Advanced data assimilation methodology to enable physically consistent coupling between ocean, sea-ice and atmosphere.
- Feasible implementation of 4D-Var allowing for production multi-decadal ocean reanalyses.
- Improvement of the assimilation of interface observations, with focus on sea surface temperature, sea surface height (SSH) and sea ice thickness (SIT).

The successful Tenderer shall:

Adopt working standards and procedures that conform to those at ECMWF and C3S, in particular:

- Use the ECMWF Integrated Forecasting System (IFS) git environment for code integration, JIRA for documenting developments, and provide, where required, detailed reports and code documentation;
- Perform, where required, impact experiments using ECMWF's high-performance computing (HPC) facility;
- 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: Integration of Hybrid Variational-Ensemble data assimilation developments for operational production of OCEAN6

2.2.1.1 Activities

The recent NEMOVAR developments for enabling hybrid ensemble-variational data assimilation were tested in the version v3.4 of the ocean model NEMO. ECMWF is about to upgrade to the most recent version of the NEMO model (NEMO v4), which works with a different horizontal grid, and most importantly, comes with a new multi-category sea-ice model SI3. The NEMOVAR developments include the stochastic physics (SP) parameterizations, multi-grid approaches for efficient minimization, computation of climatological background error (B) matrix parameters, and on-line ensemble diagnostics. The contractor will be required

to integrate them into NEMO4, so that they are functional before the production of OCEAN6, which is envisaged to start no later than 31st March 2023. The developments will be incorporated into the ECMWF system on a continuous basis, so that they can be picked up by ERA6. This continuous integration and refinement of workflow is the subject of WP1 and includes the following activities:

- Implementation and testing of SP options SPPT, SKEB and SPP into NEMO4, and integration of the software in the ECMWF repository.
- Conduction of multi-year EDA scout experiments with SP using the OCEAN6 experimental suite using the ECMWF HPC with full and single precision options. Report on physical and computational performance against benchmark. The aim is to propose a configuration that balances scientific interests and computational requirements – these factors should be considered and discussed.
- Extension of the multi-grid capabilities to enable a hybrid B for the eORCA1 and eORCA025 grids used by ECMWF and deliver the software to the ECMWF repositories. This activity targets efficient and feasible implementation of a localized ensemble covariance matrix.
- Conduction of multi-year data assimilation experiments with the multi-grid capability activated using the OCEAN6 experimental suite. Report on physical and computational performance against benchmark.
- Development and implementation of a diagnostic package in python to monitor ensemble reliability and physical indicators. Diagnosis of the ensemble reliability and unrepresented sources of the error in the ensemble.
- Development and implementation of ensemble calibration techniques, including inflation algorithms to compensate for unrepresented errors; calibration of the ensemble in a multi-year scout experiment.
- Evaluation of the hybrid background error covariance formulations and proposal for a configuration balancing the scientific and computational requirements; in particular evaluate if the formulation combining a static modelled B matrix with localised ensemble covariance matrix is advantageous from the scientific point of view.

2.2.1.2 Deliverables required

- WP1.1 Implement Stochastic Physics (SP) Options in NEMO4 in the ECMWF system, and proof of concept test using double and single precision options. (T0+10 months). Deliverable nature: Software and documentation.
- WP1.2 Adapt the multigrid algorithms developed for the ORCA grids to the new extended (eORCA) grids used with NEMO4, to enable efficient estimation of the hybrid background error covariance B, and inclusion in the OCEAN6 suite. Deliverable nature: Software and documentation. (T0+10 months).
- WP1.3 Deliver and document a set of diagnostics for the ensemble of ocean reanalysis in python in order to compute the reliability of the OCEAN6 ensemble and identify unrepresented sources of errors. Deliverable nature: Software and documentation. (T0+18 months).
- WP1.4 Develop and implement an ensemble calibration algorithm, which may include inflation algorithms to compensate for unrepresented errors. Deliverable nature: Software and documentation. (T0+24 months).
- WP1.5: Diagnose the reliability spread/skill of the OCEAN6 ensemble and associated experiments, and propose calibration and hybridization options for ERA6-Ocean-offline in the context of model error formulations under WP2. Deliverable nature: Report. (T0+34 months).

Below is 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
WP1.1	T0+10	Software and Documentation.	Software accepted in ECMWF repository.	ECMWF experts able to run NEMO4 experiments, in the ECMWF HPC, with Stochastic Physics in prepIFS.	ECMWF - Technical Officer
WP1.2	T0+10	Software and documentation.	Software accepted in ECMWF repository.	ECMWF experts able to run experiments in prepIFS with multi-grid option.	ECMWF - Technical Officer
WP1.3	T0+18	Software and documentation.	Software in python in ECMWF repository Documented.	ECMWF experts able to run the python diagnostics package applied to specific experiments.	ECMWF - Technical Officer
WP1.4	T0+24	Software and documentation.	Software in python/FORTRAN in ECMWF repository.	ECMWF experts able to run the calibration software applied to specific experiments.	ECMWF - Technical Officer
WP1.5	T0+34	Report.	Recommended settings improve benchmark.	Improved scores for ensemble reliability and physical consistency.	ECMWF - Technical Officer

Table 1: WP1 deliverable table

2.2.1.3 Milestones

- Stochastic Physics implemented in the ECMWF NEMO4 version (T0+7).
- Multi-year scout DA experiments with multi-grid and hybrid B using NEMO4 (T0+7).
- Diagnostic package applied to the evaluation of ECMWF ocean data assimilation experiments (T0+18).
- Software for calibration of the ensemble in NEMOVAR git repository (T0+24).

2.2.2 WP2 Improved treatment of model error and advance multi-scale B capabilities.

2.2.2.1 Activities

Explicit treatment of systematic model error is a key component needed for ocean reanalyses to reliably represent low-frequency climate variability.

The ECMWF ocean reanalysis (ORA) system includes a one-step multivariate bias correction algorithm, as described in *Balmaseda et al., 2007*. It consists of an empirical formulation of error in the model tendencies derived from assimilation increments, which has two components: a monthly climatological bias term $\bar{\mathbf{b}}$ estimated *a priori* from assimilation increments sampled from a previous run with similar configuration, and a bias term \mathbf{b}'_c estimated online, which is updated at each analysis cycle c from the assimilation increments of that cycle. The total bias \mathbf{b}_c is then given by

$$\begin{aligned}
 \mathbf{b}_c &= \bar{\mathbf{b}} + \mathbf{b}'_c \\
 \mathbf{b}'_c &= \alpha \mathbf{b}'_{c-1} + \boldsymbol{\varepsilon} \\
 \mathbf{b}'_c &= \alpha \mathbf{b}'_{c-1} + \mathbf{A} \boldsymbol{\delta} x_c
 \end{aligned}
 \quad (1)$$

The temporal evolution of the online bias term follows a process represented by an autoregressive model of the first order [AR\(1\)](#), with a persistence α and a stochastic term $\boldsymbol{\varepsilon}$, which is estimated on cycle c from the analysis increments $\boldsymbol{\delta} x$ via a linear transformation \mathbf{A} from the state variables to the bias control variables (In the current implementation $\boldsymbol{\varepsilon}$ is set to zero in the forecast bias term). The *a priori* $\bar{\mathbf{b}}$ bias term can be seasonally varying. It has the potential to provide a smoother reanalysis by preventing abrupt changes in the

estimation associated with the introduction of new observing systems. The bias correction is used to modify the tendencies of the nonlinear model, both in the background and analysis trajectories.

As discussed in *Balmaseda et al., 2013* and *Zuo et al., 2015*, the current approach has several shortcomings. There is a large uncertainty in the estimation of the parameters (α and A), as well as the dependence on the choice of the period for estimating \bar{b} . There is also an uncertainty in the choice of a model of the temporal evolution of the online bias (e.g., it does not need to be an AR1 process). In addition, the current bias correction is a “one-step” approximation, and it is not yet an integral part of the analysis equation (as discussed in section 3.2 of *Balmaseda et al., 2007*).

The research within this WP will advance the current formulation of model error for objective and robust parameter estimation, and/or propose alternative solutions that fulfils the requirements for temporal consistency of climate signals. The objective characterization of temporal and spatial characteristics of model error, including sea ice, will require the development of diagnostics of the model error using observational information. The characterization of the model error statistics will help to formulate a model for the temporal evolution of the errors, and the specification of the model error (Q) matrix. A further step is the implementation of the weak constraint in NEMOVAR. The developments should consider effective application of the model error in the past poorly observed periods (first component of the current formulation) and how to cycle the model error (second component of the current formulation). The following activities are envisaged (subject to negotiation):

- Characterize temporal and spatial statistics of the model error using Argo T/S in-situ observational information provided by the assimilation, and provide a set of diagnostics tools for model error diagnostics that can be used in the future;
- Develop a model for error in the model tendencies using the observational information above, that can be coupled with NEMO4-SI3 model;
- Develop a formulation for estimation of model error in NEMOVAR in order to allow for estimating the model bias in the minimization. Adopt the multi-grid techniques available in NEMOVAR for its efficient implementation;
- Provide a solution to extrapolate observational information into the past, either using climatological terms as currently done, or other alternatives. Consider if it is possible to deal with this extrapolation in the minimization;
- Ensure that the corrections to the model tendencies from the bias term and the increments - currently done via Incremental Analysis Update (IAU)- are clearly distinct, as to retain the flexibility of applying the assimilation increments via IAU or direct initialization;
- When appropriate, explore the multivariate relations for the bias using EDA diagnostics or climatological ensembles, in combination with machine learning, dimensionality reduction or other approaches.

2.2.2.2 Deliverables required

- WP2.1 Provide an empirical formulation for the temporal evolution of model error tendencies for the different variables (e.g., T, S, pressure gradient, sea-ice properties) derived from the statistical properties of assimilation increments, observational departures or other. The proposed model should include a solution for extrapolation of observational information to the past. The software used to specify the formulation should also be provided (T0+ 18 months). Deliverable nature: Software and Report.
- WP2.2. Formulate a variational weak constraint optimization in NEMOVAR which takes into account the empirical model of model error and the error statistics derived in WP2.1 (T0 + 24 months). Deliverable nature: Software and Report.
- WP2.3 Provide a validation report of the results from experiments covering the recent (post 2000) and early (around 1950) periods. The experiments must have been conducted using the ECMWF ocean data assimilation experimental infrastructure. Deliverable nature: Report (T0+36 months).

WP2: Deliverable table					
#	Indicative timeline	Nature	Evaluation Criteria	Metrics	Approving Authority
WP2.1	T0+18	Software and Documentation.	Methodology for objective formulation of bias parameters sound. Software documented in ECMWF repository.	Tendencies corrections in T/S/Pressure gradient and Sea-Ice variables. Bias formulation includes retrospective use of observational information. Traceability and Reproducibility of results.	ECMWF - Technical Officer
WP2.2	T0+24	Software and documentation.	Software accepted in ECMWF repository.	ECMWF experts able to run experiments in prepIFS with multi-grid option.	ECMWF - Technical Officer
WP2.3	T0+36	Report.	Physical improvement of the estimation. Computational feasibility. Clear identification of risks.	Demonstrated reduction of bias in the assimilation increments. Circulation indexes (AMOC, equatorial currents) not degraded. Demonstrated improvement of temporal variability (e.g. correlation other ocean ECVs).	ECMWF - Technical Officer

Table 2: WP2 deliverable table

2.2.2.3 Milestones

- Empirical model for systematic error in model tendencies formulated. Software (T0+12 months).
- Empirical model of tendency errors coupled with NEMO4-SI3 in ECMWF software repository. Software (T0+18 months).
- Weak constraint implemented in the ECMWF ocean data assimilation experimental suites. Software (T0+ 24 months).
- Decade-long experiments for recent (2000's) and early period (1950's) completed using the ECMWF ocean reanalyses research suite. (T0+30 months).

2.2.3 WP3 Implementation of 4D-Var capabilities for the ocean

2.2.3.1 Activities

ECMWF is pursuing an Earth System approach to data assimilation. At the heart of this strategy is the atmospheric data assimilation system which has successfully used 4-dimensional variational data assimilation (4D-Var). 4D-Var has advantages over 3D-Var in that it uses the tangent linear and adjoint models to implicitly propagate the supplied background error covariances throughout the data assimilation window, leading to more realistic and more flow-dependent error structures. Using this technique, it is possible to extract more information from the observations, as well as being better able to cope with nonlinearities.

Recent developments in NEMO4 and NEMOVAR have shown promise that the tangent linear (TL) and adjoint (AD) models may be sufficiently mature for use in reanalysis. This work package seeks to comprehensively

document the current capabilities, gaps and to progressively implement these features in the ECMWF system.

2.2.3.2 Deliverables required

- WP3.1 Report on TL/AD viability within NEMO4, covering the different processes included and validity of the tangent linear approximation (T0+12).
- WP3.2 Software implementation of 4D-Var for the ocean accepted into the ECMWF repository.
- WP3.3 Report on performance and recommendations for 4D-Var in the ECMWF system, with a comparison against 3D-Var first-guess at appropriate time (FGAT). (T+24). Care and attention shall be given to similarities and differences between the ECMWF atmospheric multi-incremental 4D-Var system.
- WP3.4 Conduct experiments and report on performance of 4D-Var for assimilation of surface observations. (T+36).

2.2.3.3 Milestones

- Develop and implement a 4D-Var capability for short data assimilation windows in the ECMWF ORA suite. (T+12).
- Develop and implement a 4D-Var capability for 5-to-10-day assimilation windows. (T+18).

WP3: Deliverable table					
#	Indicative timeline	Nature	Evaluation Criteria	Metrics	Approving Authority
WP3.1	T0+12	Report.	Evaluation of the tangent linear and adjoint model performance in NEMO4.	Computational performance, validity of tangent linear approximation and accuracy of adjoint quantified.	ECMWF - Technical Officer
WP3.2	T0+18	Software.	Software accepted in ECMWF repository.	ecFlow suite cycles successfully.	ECMWF - Technical Officer
WP3.3	T0+24	Report.	Performance report and comparison of 4D-Var with respect to 3D-Var in the ECMWF system.	Computational performance of single cycle 4Dvar quantified, compared with 3Dvar.	ECMWF - Technical Officer
WP3.4	T0+36	Report.	Report on performance of 4D-Var for assimilation of surface observations in the ECMWF system.	Assessment of multi-year assimilation experiment	ECMWF - Technical Officer

Table 3: WP3 deliverable table

2.2.4 WP4 Improving the assimilation of satellite observations

2.2.4.1 Activities

Recent work on developing the direct assimilation of level-2 (L2) SST observations within the ECMWF ORA system has progressed well. While most technical work has been completed together with a few short scout experiments, further work is needed to push this capability into ERA6. These include i) investigation of the warm increment biases at the base of the mixed layer; ii) running of long-term reanalysis with the full processing chain of L2 SST data including an interface with the ECMWF observation repository and online bias correction; iii) verification against drifter data and evaluation against a reference system.

The ECMWF altimeter assimilation of SLA needs to be developed further to assimilate data from new missions like the reference S6A and wide-swath SWOT, which will become available in the next few years. The later will require adequate treatment of observation error correlation.

Sea Ice Thickness (SIT) information from the merged SMOS-CryoSat-2 SIT product has been reported to have positive impact on the ECMWF Seasonal Forecasting System S5 (*Balan-Sarajini et al., 2021*). The assimilation of L2 and level-3 (L3) SIT data needs to be developed within the ECMWF NEMOVAR system. This development requires works on pre-processing of the SIT data including characterisation of errors from different data sources (e.g., CryoSat-2, SMOS, IceSat-2, SMAP or Sentinel-3); and a new balance relationship from multi-category SI3 model.

The activities in this work package are expected to address the following topics:

- Assimilation of L2 SST: Proposed solution for the adequate vertical propagation of SST information, which may involve the implementation of flow-dependent vertical correlations in the diffusion-based correlation model and implement the recently devised methodology (Weaver et al., 2021, QJRMS) to compute the required normalisation factors in the ECMWF ORA suite; proof of concept of end-to-end SST L2 assimilation in NEMOVAR, including the full data processing chain with L2 SST data from the ECMWF repository; verification against drifter data; and evaluation with long-term reanalysis experiments.
- Assimilation of altimeter-derived SLA: enable the assimilation of wide-swath altimeter SWOT data in the ECMWF analysis system in conjunction with the S6A altimeter information; development of methods to account for correlated observation errors in the NEMOVAR system; identify current gaps in the information chain that prevent the direct assimilation of altimeter information and geoid information.
- Assimilation of SIT: development of assimilation of L3 (or L2) SIT (CryoSat-2 and SMOS) data into the multi-category SI3 model in the ECMWF ORA system, including the formulation of observation errors and, if possible, exploring coupling options for the minimization between ocean and sea-ice variables.

2.2.4.2 Deliverables required

- WP4.1 Report on recommendations on B options to assimilate SST L2 data in NEMOVAR, including comparison of algorithms for efficient computation of flow-dependent vertical scales and verification against independent observations. Options implemented in NEMOVAR. (T+12). Software and Report.
- WP4.2 Proof of concept of end-to-end assimilation of L2-SST in the ECMWF ORA suite, including interface with the ECMWF data repository, bias correction, quality control and verification against drifter data. (T0+24). Software and Report.
- WP4.3 Software implementation of assimilating satellite SIT data in SI3 model with NEMOVAR, specification of observation error, and new balance relationships. (T+24). Software, documentation on algorithms used and user-guide.
- WP4.4 Evaluation report on the impact of assimilating SIT in multi-year NEMOVAR experiments conducted using the ECMWF infrastructure. (T+34). Report.
- WP4.5 Software implementation and report on assimilation of SWOT SLA data including accounting for correlated observation errors (T0+36).

2.2.4.3 Milestones

- Methodologies for efficient computation of normalization factors to allow flow-dependent vertical background error correlation scales implemented in the ECMWF ORA suite (look up table and the one devised in Weaver et al., 2021, QJRMS) (T0+9).
- Multi-decadal end-to-end experiment with L2 SST data DA (T0+15).
- Experiment assimilating SIT data in SI3 model with NEMOVAR (T+18).
- Proof of concept test of accounting for correlated observation errors in SWOT data (T+24).

WP4: Deliverable table					
#	Indicative timeline	Nature	Evaluation Criteria	Metrics	Approving Authority
WP4.1	T+12	Software.	Recommendation on B settings on L2 SST DA. Options functionally implemented in NEMOVAR and accepted in ECMWF repository.	Software ad Report accepted.	ECMWF - Technical Officer
WP4.2	T+24	Report.	Proof of concept end-to-end of L2-SST assimilation in ECMWF system.	Run in ecflo successfully.	ECMWF - Technical Officer
WP4.3	T+24	Software.	Software of SIT DA accepted.	Run in ecflo successfully.	ECMWF - Technical Officer
WP4.4	T+34	Report.	Report on SIT assimilation impact and recommendation on settings.	Report accepted.	ECMWF - Technical Officer
WP4.5	T+36	Software and Report.	Software accepted; Report on method and evaluation to account for correlated obs. Errors in SWOT data.	Run in ecflo successfully; Evaluation report accepted.	ECMWF - Technical Officer

Table 4: WP4 deliverable table

2.2.5 WPO Management and Technical Coordination

2.2.5.1 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 Tenderer 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 Tenderer will represent the successful Tenderer in such meetings.
 - ECMWF will organise six-monthly project review meetings (linked to Payment milestones).
 - Tenderers 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 (Microsoft Word), 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 Tenderer 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.

Tenderers 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 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.

2.2.5.2 Deliverables required

Deliverables covering the coordination of the contract and contractual and financial reporting obligations towards ECMWF shall be in 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:

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

Table 5: Administrative and Programmatic Deliverables

2.2.5.3 Milestones

WPO Milestones				
#	Responsible	Title	Means of verification	Due
M0.Y.Z-Px	Tenderer	Progress review meetings with ECMWF / Payment milestones	Minutes of meeting	~ Every 6 months

Table 6: Administrative and Programmatic Milestones

Tenderers 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 Tenderer 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 36-months Framework Agreement. The start of the contract (T0) is expected to take place in February 2022.

Work packages are all expected to start in T0 and run in parallel according to following time schedule:

Work Package 0: T0 + 36 months

Work Package 1: T0 + 34 months

Work Package 2: T0 + 36 months

Work Package 3: T0 + 34 months

Work Package 4: T0 + 36 months

3 General Requirements

3.1 Schedule

The Tenderer 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 Tenderer 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 Tenderer 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 Tenderer shall account for working visits to ECMWF (Reading, UK) to cover collaboration needs on each of the above-described technical work packages. For each work package, the Tenderer 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. ECMWF expects each working visit to last for one working week.

Around every 18 months, ECMWF organises general assembly meetings to bring together all C3S service providers. The successful Tenderer is expected to attend the general assembly and needs to account for this meeting in its price.

The successful Tenderer 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 Tenderer 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. It will be good practice to organize deliverables along top-level objectives in order to limit their number.

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. Apart from the payment milestone review meetings, all foreseen meetings shall not be classified as milestones but listed in a separate overview table for each work package.

Requirements for each type are described in the following subsections.

3.3.1 Software

Unless stated otherwise software shall be delivered as a git branch of the ECMWF IFS repositories. In some circumstances, such as contributions not specific to the ECMWF infrastructure, software delivered to the NEMOVAR git repository will suffice.

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 Tenderer 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 Tenderer to produce the C3S datasets will remain the property of the successful Tenderer, 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 Tenderers' production system. The identity and ownership of such exceptional components will be passed to the European Union annually. The successful Tenderer 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 eventual 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 Tenderer'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.

<i>Section</i>	<i>Page Limit</i>
<i>Executive Summary</i>	2
<i>Track Record</i>	2 (for general) and 2 (per entity)
<i>Quality of resources to be Deployed</i>	2 (excluding Table 1 in Volume IIIB and CVs with a maximum length of 2 pages each)
<i>Technical Solution Proposed</i>	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)
<i>Management and Implementation</i>	10 (excluding Table 4 and Table 5 in Volume IIIB) + 2 per each work package description (Table 3 in Volume IIIB)
<i>Pricing Table</i>	No limitation

Table 7: Page limits

4.2 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.

4.2.1 Executive summary

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

4.2.2 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.

4.2.3 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 Tenderer 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 Tenderer 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

For each Lot, the Tenderer shall provide a detailed implementation plan of proposed activities for the duration of the framework agreement. Deliverables shall 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. Adjustments to the proposed implementation plan can be made on a biennial basis depending on needs for service evolution, changed user requirements, or other requirements as agreed between the European Commission and ECMWF.

As part of the general project management description the tenderer shall consider the following elements listed in section 2.2.5.1 above.

As part of the general contract management description, the Tenderer shall include the following elements in line with the reporting and planning requirements as laid down in the Terms and Conditions of the Framework Agreement. The table below provides the template to be used by the tenderer to describe the complete list of deliverables, milestones and schedules for the management work package (eg. WPO, cf. template in Volume IIIB section 5.4). All milestones and deliverables shall be numbered as indicated and document deliverables shall be periodically updated and versioned as described in the table.

5 Additional Information

5.1 References

B. Balan-Sarojini, S. Tietsche, M. Mayer, M. Balmaseda, H. Zuo, P. de Rosnay, T. Stockdale, and F. Vitart (2021): Year-round impact of winter sea ice thickness observations on seasonal forecasts, *The Cryosphere*, <https://doi.org/10.5194/tc-2020-73>.

Balmaseda MA, Mogensen K, Weaver AT. (2013): Evaluation of the ECMWF Ocean Reanalysis ORAS4. *Q. J. R. Meteorol. Soc.* **139**: 1132-1161.

Balmaseda, M.A., Dee, D., Vidard, A. and Anderson, D.L.T. (2007): A multivariate treatment of bias for sequential data assimilation: Application to the tropical oceans. *Q.J.R. Meteorol. Soc.*, **133**: 167-179. <https://doi.org/10.1002/qj.12>

Weaver, AT, Chrut, M, Ménétrier, B, Piacentini, A. (2021): An evaluation of methods for normalizing diffusion-based covariance operators in variational data assimilation. *Q J R Meteorol Soc.* 2021; **147**: 289– 320. <https://doi.org/10.1002/qj.3918>

Zuo H, Balmaseda MA, Mogensen K. (2015): The ECMWF-MyOcean2 eddy-permitting ocean and sea-ice reanalysis ORAP5. Part I: Implementation. ECMWF Tech Memo (736)

5.2 Acronyms

3D-Var	Three-dimensional Variational data assimilation
4D-Var	Four-dimensional Variational data assimilation
AD	Adjoint model
AMOC	Atlantic Meridional Overturning Circulation
AR(1)	Autoregressive model of the first order
B	Background-error covariance matrix
CryoSat-2	Follow-on Earth Observing Opportunity Mission of ESA Living Planet
C++	Object-oriented programming language

C3S	Copernicus Climate Change Service
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
eORCA1/025	Ocean tripolar grid at 1/0.25 degrees horizontal resolution at the equator
EU	European Union
FGAT	First-guess at appropriate time
Fortran	FORmula TRANslation programming language
HPC	High-Performance Computing
IAU	Incremental Analysis Update
IceSat-2	Ice Cloud and land Elevation Satellite
IFS	Integrated Forecasting System
ITT	Invitation to Tender
JIRA	Atlassian software development tool
KPI	Key Performance Indicator
L2/3/4	Level 2/3/4
MDT	Mean Dynamic Topography
NEMO(X)	Nucleus for European Modelling of the Ocean (Version X)
NEMOVAR	Variational Data Assimilation for NEMO
NWP	Numerical Weather Prediction
OCEAN6	multi-decadal uncoupled ocean reanalysis version 6
OOPS	Object-Oriented Programming language
ORA	Ocean ReAnalysis
PDF	Portable Document Format
prepIFS	ECMWF application to submit experiments in a standardized way
Q	Model error covariance matrix
S6A	Sentinel 6A Mission
SKEB	Stochastic Kinetic Energy Back-scatter Scheme
SIC	Sea Ice Concentration
SIT	Sea Ice Thickness
SI3	Sea Ice modelling integrated initiative
SLA	Sea-level anomaly
SMAP	Soil Moisture Active Passive Mission
SMOS	Soil Moisture and Salinity Mission
SP	Stochastic Physics
SPPT	Stochastic Perturbed Physical Tendencies
SPP	Stochastic Perturbed Parameters
SST	Sea Surface Temperature
SSH	Sea Surface Height
SWOT	Surface Water Ocean Topography
TL	Tangent linear model
WP	Work Package