ECMWF Copernicus Procurement

Invitation to Tender

Copernicus Europe's eyes on Earth

Copernicus Climate Change Service Volume II

Technical preparations for C3S Seasonal Initialization and Global Reanalysis: Enabling an Ensemble of Data Assimilation for the Ocean

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1 Introduction

ECMWF as the Entrusted Entity for the Copernicus Climate Change Service (C3S) invites tenders for a service related to the development of an ensemble of data assimilation for the ocean in support of climate services development, specifically the initialization of the ECMWF seasonal forecasts, and as part of a coupled ocean-atmosphere global reanalysis.

More information on C3S and 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 development within this tender will advance the ocean data assimilation capabilities used in the initialization of seasonal forecasts and generation of coupled Earth System reanalyses. Both seasonal forecast and Earth System reanalyses are key elements of the Copernicus Climate Change Service. Specific targets of the tender work are the better utilization of the Earth system observations by provision of more accurate reanalyses, and provision of reliable uncertainty estimates. The implemented developments are expected to be used in the production of the next generation of C3S's Reanalysis System (ERA6) which will be conducted using a coupled data assimilation methodology (at 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 towards mid 2021. The developments will also contribute to the production of ocean initial conditions for the next ECMWF seasonal forecasting system SEAS6, by preparing ocean initial conditions spanning several decades, with corresponding uncertainty estimates. 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.

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 annual service contracts*. The expected duration of the Framework Agreement is 26 months, with a maximum end date on 31 December 2020.

2.1 Scope of service

The current ECMWF ocean data assimilation suites generate an ensemble of ocean reanalyses, where each member of the ensemble evolves independently. The next step in the development is to use the ensemble perturbations to specify the flow-dependent background-error covariance matrix in the variational data assimilation system NEMOVAR. This interactive ensemble is called Ensemble of Data Assimilation (EDA).

The scope of this tender involves the developments required for the transition to an operational service of a number of improved data assimilation capabilities for the ocean, that have developed during the FP7 project ERA-CLIM2 (work package 2, deliverables 2.1, 2.3), and are now considered scientifically matured for operational implementation, namely:

- Improved capabilities to assimilate satellite observations of the ocean surface are needed, including variational bias correction schemes and multi-scale flow-dependent background error covariances.
- A feasible implementation of high-resolution ensembles with incremental variational methods also requires a multi-grid capability in the ocean.
- A diagnostics package for evaluation of the EDA and tuning of the ensemble, as well as advance ensemble generation methods.

The developments shall be integrated in the NEMOVAR-OOPS software repository, and implemented in the ECMWF ocean reanalysis (ORA) suite, which is managed by the python-based ec-Flow work flow package.

The successful Tenderer shall:

- Adopt working standards and procedures that conform to those at ECMWF and C3S in particular;
- Use the ECMWF IFS code management system;
- Perform, where required, impact experiments using ECMWF's High-Performance Computer;
- Work closely together with ECMWF expert team;
- Carry out working visits to ECMWF on a regular basis, as required for advancing the project.

2.2 Specification of work

WP1: Tuning of the long-term evolution of the background error covariance model parameters

The background error covariance model in NEMOVAR requires the specification of variances and correlation parameters for temperature and for the transformed variables "unbalanced" salinity and "unbalanced" sea surface height (SSH). Currently a heuristic procedure is used to specify these covariance parameters. It is essentially the same procedure that was used in the ocean reanalysis ORAS4 (Balmaseda *et al.* 2013). Temperature and unbalanced salinity variances are parameterized in terms of the background density state, while unbalanced SSH variances have a simple latitudinal dependence. The correlation parameters are associated with parameters of the implicit diffusion-based correlation model. The number of implicit iterations is chosen to model an approximate Gaussian function. The correlation length scales correspond to the square root of the diagonal elements of the diffusion tensor. Their specification is very simple for all variables, being based on constant values with some minor modulation to account for anisotropy near the equator. There is no objective procedure to tune the constants in either the variance or length-scale parameterizations.

The lack of any dependence of the background error covariances on, for example, the time-evolving observing system is a serious limitation for reanalysis. This is illustrated in Figure 1, which shows a 40-year time series of the globally averaged observation-space representations of the specified and expected temperature background error standard deviations (BESD) in the upper 50 m (blue and red curves, respectively) from ORAS4. The expected BESD are computed using Desroziers diagnostics (Desroziers *et al.* 2005). Discrepancies between the blue are red curves are an indication of sub-optimality in the error covariance specifications. Seasonal variations in the specified and expected BESD are reasonably consistent. However, there is a noticeable decreasing trend in the expected BESD that is not present in the specified BESD. This trend roughly mirrors the increasing trend in the number of observations (black curve) and reflects the fact that the background state is becoming steadily more accurate, especially in the final decade as a result of the assimilation of Argo data. This important influence of the observation network on background error is not captured by the state-dependent parameterization used in ORAS4 (and CERA).

Different methods for objective specification of the background error parameters have been developed in ERA-CLIM2. Methods also exist for the atmospheric part of the IFS, which could be applied to the ocean component. These methods need to be assessed regarding scientific (converge of minimization, resulting fit to observations) as well as computational performance in reanalyses applications. The recommended method should be implemented in the ECMWF system. This is the scope of work package 1.

Activities to be covered in WP1:

- Development of techniques enabling tuning of the background error covariance parameters allowing to adapt the modelled covariance to the evolving observation network for ORCA1_Z75 and ORCA025_Z75 grids.
- To implement the selected methodologies in the NEMOVAR and ECMWF suite environment.
- Performance of multi-cycle tests. This requires collaboration with ECMWF experts to test and optimize the techniques within the context of ocean and coupled data assimilation for usage in ERA6. The successful Tenderer shall setup experiments, maintain during run time, analyse and write up reports.

Deliverables expected:

1. Solution for tuning of the background error covariance model parameters. Code delivered and implemented in NEMOVAR-OOPS. Documentation of the developments. (Deadline: T0+9)
2. Ancillary normalization factors provided for the ORCA1_Z75 and ORCA025_Z75 configurations for a range of possible decorrelation length scales typical of a 5-day and a 12-hours assimilation window. (Deadline: T0+12)
3. Code including the modification of the ECMWF ORA ecFlow suite and related scripts to allow online tuning of the background error covariance model parameters and documentation of the modifications. (Deadline: T0+18)

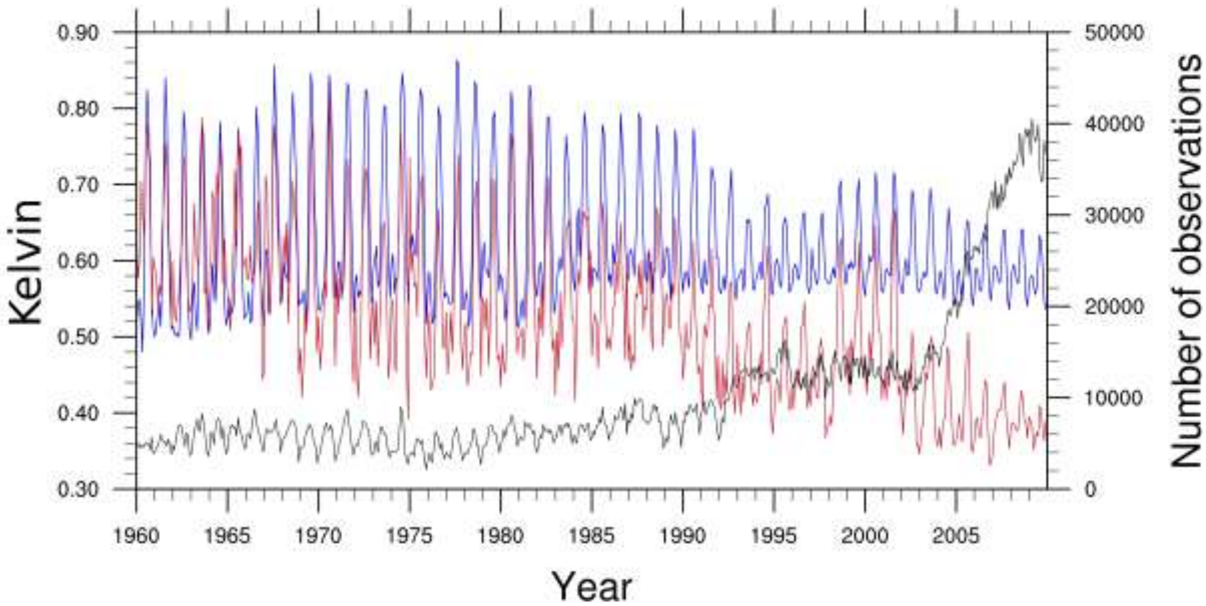

Figure 1: *Time series of monthly-averaged temperature BESD in ORAS4: specified BESD (blue curve) and expected BESD (red curve) computed using Desroziers diagnostics. The black curve shows the number of observations as a function of time (right axis).*

WP2: Proof-of-concept ocean suite using Hybrid Background Error covariance matrix in support of flow-dependent errors and multiple spatial scales

Generalized hybrid Background error Covariance Matrix B prototype capable of using flow dependent ensemble based information and handling multiple spatial scales in the correlation model has been developed in NEMOVAR within the ERA-CLIM2 project (Weaver *et al.* 2017, Waters *et al.* 2015). General flow-dependent B formulation implemented in NEMOVAR supports two complementary methods to exploit the ensemble information. The first method (method B-par in what follows) enables the possibility of using the ensemble perturbations for estimation of background error covariance parameters: variances and correlation length scales in the diffusion based correlation model. Optimal filtering procedures accounting for the ensemble size addressing sampling error in ensemble estimated parameters were designed. The second method (method B-emp) allows to use the ensemble perturbations for construction of a low-rank sample covariance matrix. Spurious long distance correlations arising from sampling noise are eliminated using localization based on the diffusion operator.

Activities to be covered in WP2:

- Improve further the above methodology to produce a feasible and scalable proof-of-concept hybrid ensemble-based B, suitable for routine ocean reanalysis scout experiments. Note that an acceptable production time of an ensemble of 10 members of ocean reanalyses, including sea-ice assimilation, at ¼ of degree and 5 days assimilation window should be around 3 years/month.
- Develop more efficient and scalable filtering and localization procedures, as to allow the target production time. See above for the acceptable production time.
- Develop related code and implement it in the latest version of NEMOVAR-OOPS (version 5).
- Carry out all necessary testing in the ECMWF ORA suite via multi-window experiments.
- Propose and develop a computationally efficient hybrid B configuration effectively using the ensemble information and capable of resolving multiple spatial scales shall be proposed. This configuration shall be tested in the ORA suite developed in WP4 by producing at least 1-year long of ocean reanalyses scout experiment.
- Setup all necessary experiments, maintain during run time, analyse and write up reports.

Deliverables expected:

1. Assessment of scientific and computational performance of method B-par above. Optimize the work-flow configuration and scripts. Code in NEMOVAR-OOPS git repository, code documentation and performance report. (Deadline: T0+12)
2. Solution for more efficient/scalable localization procedures for method B-emp above. Code in NEMOVAR-OOPS git repository. Code documentation. Assessment of scientific and computational performance (report). (Deadline: T0+20)
3. Proof of concept and recommendations. All the solution above shall be tested in ORA suite developed in WP4 via 1 year-long scout experiments. Report on performance with recommendations for hybridization choices and filtering procedures. (Deadline: T0+26)

WP3: Multi-grid capabilities for multiple loops incremental 3D-var in the ocean

NEMOVAR is based on an incremental variational approach. Currently, all the incremental minimization loops use the same resolution as the ocean model. This is costly, and a serious handicap for development of high resolution ocean ensembles. The background error correlation model, parameter filter and localization operator, are all based on the implicitly formulated diffusion operator, which is inverted using a linear Chebyshev iteration solver. The convergence rate and therefore the computational efficiency of the solver depend on the grid resolution and correlation length-scales and decreases with the grid resolution and for longer scales.

Activities to be covered in WP3:

NEMOVAR follows the multi-incremental variational approach adopted in the atmospheric IFS data assimilation, where the total non-linear cost-function is minimized iteratively with updated trajectories with provided in outer loops at higher resolution, which linear minimizations carried out in inner loops at lower resolutions. However, NEMOVAR does not have yet the capability of conducting outer and inner loops at different resolutions. A capability for handling of multiple resolution ocean grids in NEMOVAR is required. This implies methodology and software. A flexible transfer operator should allow to test various multi-resolution configurations, namely: i) multi-incremental variational formulation with the inner loop at lower resolution than the model, ii) multi-grid techniques for the implementation of the diffusion based correlation model in the background error covariance and iii) diffusion-based localization operator and multi-scale B formulation with the long length-scale component on lower-resolution grids. The multi-incremental formulation shall focus on two particular ocean grids: the ORCA025_75 levels for the outer loop and ORCA1_75Levels for the inner loop.

Deliverables expected:

1. Code in support of multi-grid capabilities implemented and demonstrated to perform in NEMOVAR-OOPs version. Code documentation. (deadline T0+12)
2. Code that implements capability for multiple grid enabled in the ORA suite. User manual (deadline T0+18)
3. Performance report, regarding code optimization, computational cost, and accuracy of the solution of multi-grid configurations. Recommendation for optimal configuration (deadline T0+24)

WP4: Improved use of observations of the ocean surface (SST and altimeter-derived Sea Surface Height)

Further exploitation of SST and SSH observations from altimeter is needed in the current ECMWF ocean data assimilation. Assimilation of SST shall be enabled in the ECMWF system, instead of the current nudging approach. This will allow to progressively move from the use of L4 to L3 or L2 data. Better assimilation of SST will also allow strong control of the ocean state via vertical correlations. Another serious handicap for the efficient assimilation of altimeter SSH anomalies is the need of an a-priori estimation of the Mean Dynamic Topography. The current approach at ECMWF is to estimate the MDT from a multi-year assimilative experiment conducted a-priori. This is expensive, unaffordable in coupled data assimilation and introduces vulnerabilities. A safer solution is the on-line estimation of the MDT via on-line bias estimations built-in the code.

Activities to be covered in WP4:

- Enable the assimilation of L2 SST in the NEMOVAR-OOPS version of ECMWF and vertical projection of the information. The successful Tenderer shall provide a quality controlled test-data set of L2 SST. Solutions for vertical projection of the SST information, compatible with the B formulations in WP1 and WP2 are required. The successful Tenderer shall provide the necessary code and advice on both the experimental design and evaluation as well as the parameter choice for physical and flow-dependent propagation of the SST information in the vertical.
- Multi-scale and flow dependent background error covariances for the assimilation of L2-SST. A practical solution is having a combination of two different B corresponding to different time scales, with varying weights depending on the flow or the observation coverage. The successful Tenderer should implement software package in NEMOVAR-OOPS, following the framework for hybrid B developed WP2.
- The successful Tenderer should also provide solutions for on-line estimation of the MDT in support

of the assimilation of altimeter-derived sea level anomalies. The successful Tenderer should implement and test this solution in the ECMWF ORA suite.

Deliverables expected:

1. Implementation of a validated version for online estimation of Mean Dynamic Topography (MDT) in NEMOVAR-OOPS, supporting the assimilation of sea –level altimeter data. (T0+9)
2. Comparison report contrasting the MDT online and current offline estimations (T0+12)
3. Code for the assimilation of SST observations (either L2 or in-situ) with flow-dependent vertical decorrelation scale, including pre-processing of observations – e.g. quality control, observation operator, thinning and superobing, as well as recommended settings for flow-dependent multi-scale covariances to be used in the reanalyses configurations. The necessary code shall be in the NEMOVAR-OOPS repository. (T0+15)
4. A pilot example of assimilation of L2 SST data in the ECMWF ORA suite, including the L2 observational data set. The demonstration shall consist of several 5 year ocean reanalysis scout experiments for the periods 1985-2000, 1994-1999 and 2007-2012. The experiments shall be conducted using the ECMWF ORA suite, (T0+24)
5. Report on performance of the SST assimilation. (T0+26)

WP5: Ensemble System Design, Optimization, Ensemble generation and Evaluation

Throughout the project, the different developments will be integrated in the NEMOVAR-OOPS framework and ORA suite. The integration shall be carried out with close collaboration with ECMWF experts. Ensemble generation methods shall be improved by including treatment of model error via stochastic physics formulations. Diagnostics of the ensemble of reanalyses should be provided.

Activities to be covered in WP5:

- The successful Tenderer shall visit regularly ECMWF for discussions on code design and integration options and shall account travel costs accordingly in the Pricing Tables in annex.
- An efficient ORA suite for the ocean EDA shall be designed and implemented. The suite should contain specific separate tasks for gathering, processing and distributing the ensemble information. Solutions for efficient handling of the I/O load in the ensemble-based system shall be provided.
- Ensemble generation methods for treatment of model error via stochastic physics formulations should implemented and tested.
- Relevant diagnostics to evaluate the ensemble shall be proposed and provided as part of the evaluation reports. These developments need to be fully tested in the ECMWF suites.

Deliverables expected:

1. Implementation of an EDA ORA suite for efficient handing of I/O load, allowing for flexible length of assimilation window, different flavours of hybrid B, and variable number of ensemble members and perturbation strategies. (Deadline: T0+9)
2. Implementation, testing and evaluation of stochastic physics in the ocean for ensemble generation. (Deadline: T0+12)
3. Report on the sensitivity of WP1 static B formulation to the assimilation window length. (Deadline T0+18)
4. Evaluation of the impact of flow dependent background error covariance parameters for in data assimilation experiments for historical periods for which the observation network has significantly changed. (Deadline: T0+24)

5. Proof of concept scout experiment including the recommended choices of ensemble and hybrid B to be used in the reanalyses configurations in coordination with WP1-4, including diagnostics (Deadline: T0+26)

WP0: Contract Management and Technical Coordination

The Tenderer is requested to specify in the tender proposed contract management and technical coordination activities as well as a contract implementation plan (Gantt chart) and distribution of responsibilities and roles.

As part of the general project management description the Tenderer shall include, the following elements (this is not an exhaustive list):

- Quarterly, annual and final reports shall be provided in accordance with the Framework Agreement Clause 2.3.
- An implementation plan for the year N+1 shall be provided in February of the year N for ECMWF approval.
- Regular teleconferences and visits with ECMWF and a proposal for involvement of ECMWF in major project reviews shall be provided as part of the management plan (cf. Section 3).
- Participation at the C3S Assembly Meetings (cf. Section 3).
- A proposed payment plan shall be provided as part of the proposal. The payment plan shall be based on quarterly payments for routine services work packages and shall be based on milestones completion and associated deliverables for development related activities.
- If relevant, a list of sub-contractors and details of their contribution, key personnel, legal names and addresses shall be provided. The Tenderer shall describe how the Framework Agreement, in particular Clause 2.9, has been communicated down to all their sub-contractors.

The table below provides the template to be used by the contractor to describe deliverables for this work package. All deliverables shall be numbered as indicated. The Tenderer shall provide preliminary versions of the completed tables as part of their bid.

Deliverables for this work package shall include the following reports:

WP0 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 15/01, 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	Report	Draft Implementation plan YYYY *YYYY being the Year n+1*	Annually on 28/02
D0.y.z-YYYY	Tenderer	Report	Finalised Implementation plan YYYY *YYYY being the Year n+1*	Annually on 31/10
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-YYYY	Tenderer	Other	Letter from auditor with an opinion specific to C3S contract YYYY *YYYY being the Year n-1*	Annually

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 limited to maximum 7% of the planned use of the resources.

2.3 Schedule

Activities shall be performed in the context of a 26-months Framework Agreement, with a maximum end date on 31 December 2020. The start of the contract (T0) is expected to take place in November 2018.

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

Work Package 0: T0 + 26 months

Work Package 1: T0 + 18 months

Work Package 2: T0 + 26 months

Work Package 3: T0 + 24 months

Work Package 4: T0 + 26 months

Work Package 5: T0 + 26 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 has to 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

The Tenderer shall account for working visits to ECMWF (Reading, UK) to cover collaboration needs on each of the above described technical workpackages. For each workpackage, 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.

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 meeting planned in 2020 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 expected are outlined in section 2. These will be in the form of reports and IFS code. Requirements for each type are described in the following subsections.

The number of milestones is not restricted, but they should be designed as markers of demonstrable progress in service development and/or quality of service delivery.

3.3.1 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).

3.3.2 IFS code

Contributions to the IFS code will be delivered into IFS branches that can be easily incorporated in the development branch for ERA6.

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 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	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 3, Table 5 and Table 6 in Volume IIIB) + 2 per each Work package description (Table 4 in Volume IIIB)
Pricing Table	No limitation

Table 1: 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 the necessary expert(s) providing the skills required for providing services that meet the technical requirements set out in section 2.

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

The Tenderer shall provide a detailed implementation plan of proposed activities for the duration of the Framework Agreement. Deliverables and Milestones should be consistent with the technical requirements specified in section 2.

The Tenderer is requested to specify management and coordination activities within a dedicated Work Package (WP0).

5 Additional information

5.1 References

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

Weaver AT, Chrust M, Ménétrier B, Piacentini A, Tshimanga J, Yang Y, Gürol S, Zuo H. 2018. Using ensemble-estimated background error variances and correlation scales in the NEMOVAR system. CERFACS Technical Report TR/PA/18/15 (report prepared for the ERA-CLIM2 EU-FP7 project). Available at https://cerfacs.fr/wp-content/uploads/2018/01/TR-PA-18-15.pdf.

Desroziers G, Berre L, Chapnik B, Poli P. 2005. Diagnosis of observation, background and analysis error statistics in observation space. *Q. J. R. Meteorol. Soc.* **131**: 1433-1452.

Waters J, Lea DJ, Martin MJ, Mirouze I, Weaver AT, While J. 2015. Implementing avariational data assimilation system in an operational 1/4 degree global ocean model. *Q. J. R. Meteorol. Soc.* **141**: 333–349.

M. J. Rodwell, S. T. K. Lang, N. B. Ingleby, N. Bormann, E. Holm, F. Rabier, D. S. Richardson, M. Yamaguchi: Reliability in ensemble data assimilation, *Q. J. R. Meteorol. Soc.* **142**: 4430454.

5.2 Acronyms

3D-Var	Three-dimensional Variational data assimilation
C++	Object-oriented programming language
C3S	Copernicus Climate Change Service
ECMWF	European Centre for Medium-Range Weather Forecasts
EDA	Ensemble of Data Assimilation
EU	European Union
Fortran	FORmula TRANslation programming language

FP7	Framework Program 7
IFS	Integrated Forecasting System
ITT	Invitation to Tender
MDT	Mean Dynamic Topography
NEMO	Nucleus for European Modelling of the Ocean
NEMOVAR	Variational Data Assimilation for NEMO
NWP	Numerical Weather Prediction
OOPS	Object-Oriented Programming language
ORA	Ocean ReAnalysis
PDF	Portable Document Format
SST	Sea Surface Temperature
SSH	Sea Surface Height