ECMWF Copernicus Procurement

Invitation to Tender

Copernicus Climate Change Service

Volume II

Multi-model Operational Hydrological Seasonal Prediction Service

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1   Introduction

Copernicus is the European Union's flagship Earth-observation programme created to achieve operational monitoring of the atmosphere, oceans, and continental surfaces. It aims to provide reliable, validated information services for a range of environmental and security applications. The Copernicus Climate Change Service (C3S) responds to environmental and societal challenges associated with climate change. The service gives access to information for monitoring and predicting climate change and thus helps support adaptation and mitigation. C3S produces and brokers a wide range of data and products describing the past, present and future of the climate system. This includes global and regional reanalyses, Essential Climate Variables (ECVs), near-term climate predictions, climate projections and a variety of sectoral climate information. The data are offered to users through the C3S Climate Data Store (CDS) and the Atmospheric Data Store (ADS).

CDS and ADS are instances of the same underlying core infrastructure (generically referred as CDS infrastructure). Designed as a distributed system and an open framework, this shared infrastructure provides web-based and API-based retrieve facilities to a wide catalogue of datasets, applications and other digital information. It also provides a development platform (Toolbox) which allows the creation of web-based applications operating on the datasets and products available in the catalogues.

The CDS Toolbox is a platform that can be used by developers to create web-based applications that use the datasets and products available in the CDS catalogue. These applications are subsequently made available to end-users. Users are given some control over the applications by interacting with web form elements. For instance, enabling selection of a range of dates or a geographical area of interest, which are then used to parameterise the application.

2   Context

During the first phase of Copernicus (Cop1), through the Sectoral Information System (SIS), C3S addressed the needs of multiple sectoral users both in Europe and at the global level. Under Copernicus 2 (Cop2), operational SIS activities will cover the water, energy, insurance and agriculture sectors. This tender relates to the water sector.

For the water sector the available information at C3S supports both the climate adaptation effort and seasonal-scale planning for a broad range of water managers, in e.g., water allocation, flood management, ecological status and industrial water use.

At the seasonal timescale, different datasets relevant to the water sector are already provided through the CDS. These are generated by different multi-model systems, designed and implemented to: (i) meet the requirements of the current users, (including assessing uncertainty); (ii) be computationally efficient to run; (iii) be as simple as possible to maintain and document.

The available information comes from **three** different activities of hydrological seasonal forecasting, available in the CDS.

The first one is derived from the **Copernicus Emergency Management Service (CEMS)**. The Global Flood Awareness System (GloFAS) and the European Flood Awareness System (EFAS), jointly developed by the European Commission and the Copernicus Emergency Service Hydrological Forecast Computational centre, currently operated by the European Centre for Medium-Range Weather Forecasts (ECMWF), are global and pan-European hydrological operational forecast and monitoring systems independent of administrative and political boundaries. The two systems couple state-of-the art weather forecasts with hydrological models at the global and on European scale, respectively. They provide users with hydrologically relevant information on river conditions as well as continental and global overviews and reference datasets, such as reforecasts and hydrological reanalyses. At seasonal time scale, EFAS and GloFAS hydrological models are driven by the ECMWF seasonal forecast system ensemble (S5) updated monthly.

Information about the CEMS products (in particular hydrological datasets) is available at the following link: https://cds.climate.copernicus.eu/cdsapp#!/provider/provider-cems-without?tab=overview.

The second element is the C3S **Global MULti-model hYdrological SeaSonal prEdictionS**, delivering reforecasts, operational forecasts and reference hydrological reanalysis for key Essential Climate Variables (ECVs). The ECVs are produced using a multi-model ensemble containing four state-of-the-art hydrological models for lead times of up to six months at the GloFAS spatial resolution of 0.1∘ globally and at 50 selected stations. The hydrological models are driven by the ECMWF season forecast system ensemble (S5), updated monthly.

The third element is the C3S European Hydrological seasonal forecasts of river discharge, provided with the **Operational Service for the water sector (https://climate.copernicus.eu/operational-service-water-sector)**. The system provides monthly updates for two hydrological ensemble systems: (1) a multi-model parameter perturbed E-HYPEcatch ensemble at catchment resolution, and (2) a model ensemble at the 5 km EFAS drainage network, consisting of the E-HYPEgrid, VIC-WUR and LSFLOOD hydrological models. All simulations are driven by the ECMWF seasonal forecast system ensemble (SEAS5). The LISFLOOD model output is provided by EFAS.

3   Contract summary

The envisaged 24-months contract covers the provision of two operational services to produce timely, high quality, probabilistic pan-European and global multi-model hydrological seasonal forecast and retrospective forecasts (hindcasts) information, and to make such information available through the CDS, in synergy with the CEMS hydrological seasonal forecasting component. For simplicity and clarity, the Invitation to Tender (ITT) is divided into two separate lots, one for the global scale and the other for the pan-European one. Tenderers may respond to one or both Lots.

For each Lot, ECMWF intends to award a single framework agreement for a period of 24 months, with the right to extend for a further 24 months at ECMWF's discretion, which shall be implemented via Service Contracts expected to commence in Q1 2022.

The services will be built on the two already existing service components:

- the C3S Global multi-model hydrological Seasonal prediction Service, currently under a demonstration phase.
- the C3S European Operational Sectoral Information System (SIS) for the Water Sector. The existing service provides seasonal hydrological prediction and climate change impact indicators at the pan-European scale including all time horizons (historical, seasonal and multi decadal) within a single framework. The operational service for Europe under this contract is expected to focus on the multi-model seasonal forecast component only.

The operational services under these contracts must:

- migrate the full systems including all model components from ECMWF's current High Performance Computing Facility (HPFC) in Reading to the new HPCF in Bologna;
- after successful migration, maintain and guarantee a continuation of the two services components that deliver multi-model retrospective forecasts (hindcasts) and operational hydrological seasonal forecasts to the Climate Data Store at the global and pan-European scale;
- offer and implement solutions to ensure a consistent approach between the two components;
- provide elements for the service evolution;
- Include GloFAS (at the global scale) and EFAS (at the European scale) seasonal forecasts from the CEMS as an integral part of the multi-model systems.

The contracts will provide a global (Lot 1) and pan-European (Lot 2) forecast at a daily resolution updated every month. The outputs of this ITT will constitute the inputs that downstream users can use to develop their own value-added forecasting services (e.g. services for agriculture, water supplies, hydropower etc.), at the seasonal range. Note that the current ITT is designed to cover only the maintenance, support and upgrades of the operational systems and production of datasets, their availability in the CDS and accessibility through delivery of complete documentation.

4   Technical specification

4.1   Description of the existing services

The two existing services meet the following high-level objectives that must be met by the operational services under this contract:

- Provide a multi-model hydrological seasonal prediction system using state of the art hydrological models at high resolution; one service at pan-European level, the second one at the global scale;
- Deliver a flexible, agile and scalable production chain;
- Guarantee the traceability of the provenance of the data by using the ecFlow workflow manager;
- Provide quality control software and workflows;
- Provide Level-2 support through the Copernicus User Support;
- Provide support to the provision of EQC materials, specifically the completion of Quality Assurance Reports.

The existing technical solution for the seasonal forecast component of the two SIS hydrological forecast services rely on an operational multi-model system, run on the ECMWF infrastructure by ECMWF using the ecFlow job-scheduler and delivered to the CDS. Details of this interface are available at: https://confluence.ecmwf.int/display/ECFLOW/ecflow+home.

The two systems are currently running on ECMWF's HPCF in Reading (https://www.ecmwf.int/en/computing/our-facilities/supercomputer), but this facility will be taken out of commission by May 2022, so the systems will need to be migrated to the new HPFC in Bologna before that date (https://www.ecmwf.int/en/about/media-centre/focus/2021/fact-sheet-supercomputing-ecmwf).

4.2   Lot 1: Multi-model operational hydrological seasonal prediction service at the global scale

Lot 1 covers the provision of the multi-model hydrological seasonal forecast and retrospective forecasts (hindcasts) information service at the global scale. This service is built on the C3S Global Multi-model hydrological Seasonal prediction Service.

4.2.1   Background information on C3S Global MULti-model hYdrological SeaSonal prEdictionS

The Global MULti-model hYdrological SeaSonal prEdictionS provides a set of daily hydrological seasonal predictions based on hydrologic models and ECMWF SEAS5 ensemble at global coverage and the same spatial resolution as GloFAS (0.1 degree). The ECVs cover all major components of the hydrologic cycle. The added value of this dataset is based on a multi-model ensemble of hydrologic/land-surface models produced at a daily time step. All four models are validated against observations, delivering information about the quality of the seasonal predictions.

The four diverse hydrological models have a consistent setup employing identical geophysical information, so that differences between outputs are due to differences in process descriptions only. All hydrological

models share a common streamflow routing algorithm (mRM) to minimize uncertainties derived from the river network characterisation and its parameterization.

The dataset provides retrospective forecasts (hindcasts) (1993–2019) and operational forecasts (2020–2021) for nine Essential Climate Variables (or ECVs) for the multi-model ensemble based on the four state-of-the-art hydrological models and the full SEAS5 ensemble forecast (downscaled and bias-corrected before forcing the hydrological models) for lead times up to six months at a spatial resolution of 0.1◦ globally and daily time step. The hydrological and land surface models are initialised using ERA5 reanalyses before simulating the seasonal river discharge (and related variables) forecasts using the SEAS5 meteorological forecasts.

The production chain is operated directly in the ECMWF IT infrastructure. The production chain is operated with the ecFlow suite. The ecFlow environment is modularised (i.e., separation of initialisation, creation of initial hydrologic conditions, and operational forecast, downscaling, bias-correction, archiving and CDS upload). This allows the inclusion of new datasets, meteorological seasonal forecasts and hydrological models with minimal effort. The ecFlow suite provides an overview of the entire production chain and clear traceability of provenance of data and workflows, as well as a way to monitor production to ensure timeliness. Ecflow enables a seamless integration into continuous operationalization.

This service also provides a comprehensive documentation and user support to maximize the user uptake of the products and thus the benefit of the service for users. The service provides the Evaluation and Quality Control (EQC) materials for the completion of Quality Assurance Reports and Level-2 support through the Copernicus User Support.

Hydrological models	HTESSEL / mRM JULES / mRM mHM / mRM PCRG / mRM
Initialization	ERA5-driven hydrological simulations
Meteorological seasonal forecasts	ECMWF SEAS5
Bias adjustment	Quantile mapping for all forcing variables to bias adjust SEAS5 compared to ERA5-L
ECVs	10 as reported in Table 2
Horizontal coverage	Globe
Horizontal resolution	0.1 x 0.1 degrees grids
Temporal coverage & Update frequency	Six-month forecasts with daily resolution, updated monthly (availability according to Copernicus access conditions)
Temporal resolution	Daily
File format & conventions	Grib2 (netcdf4 files will be available in the CDS)

Table 1: Summary of the current hydrological seasonal forecasts information at the global scale available at C3S

Symbol	Long name	Standard name	Unit (CF v1.7)	Definition	Positive direction
Tsurf	Average surface temperature	surface_temperature	K	Average of all vegetation, bare soil and snow skin temperatures	
P	total precipitation	precipitation_flux	kg m-2 s-1	Average of total precipitation (Rainf+Snowf)	downwards
ET	Total evapo-transpiration	water_evaporation_flux	kg m-2 s-1	Sum of all evaporation sources, averaged over a grid cell	downwards
PET	potential evapotran-spiration	water_potential_evapo-ration_flux	kg m-2 s-1	The flux as computed for evapotranspiration but with all resistances set to zero, except the aerodynamic resistance	downwards
SWE	Snow water equivalent	snow_water_equivalent	Kg m-2	The amount of liquid water contained within the snow pack	Into grid cell
Qsm	snowmelt	surface_snow_melt_flux	kg m-2 s-1	Average liquid water generated from solid to liquid phase change in the snow	solid to liquid
SM	Percentage of water wrt the available volume	Total volumetric soil moisture	%	Volumetric soil moisture content in the soil layers at the end of each model time step	Inside grid cell
Qr	Total runoff	runoff_flux	kg m-2 s-1	Average total liquid water draining from land	into grid cell
Qp	Discharge (gauge level)	N.A	m3 s-1	Water volume leaving the cell	downstream
Q	Gridded river discharge	N.A	m3 s-1	Water volume leaving the cell	downstream

Table 2: Essential Climate Variables (ECVs) produced within the C3S Global MULti-model hYdrological SeaSonal prEdictionS production chain. All variables are produced on a global scale at a resolution of 0.1 deg.

4.2.2 Description of the activities & deliverables

This Lot covers the operation and maintenance of all the infrastructure and services listed above, necessary to allow continued access to hydrological seasonal forecast data present and expected in the C3S catalogue at the end of 2021.

The tasks are:

- To migrate the existing computational suite from ECMWF's HPCF at Shinfield, Reading to the new system in Bologna;
- To deliver an ensemble of hydrological models designed to extract local relevant information, together with metrics and information about the model performances;
- To provide reference simulations of hydrological variables based on forcing as close as possible to observations for at least 25 years and updated in near real-time (e.g. to be used to define the initial conditions);
- To generate retrospective forecasts (hindcasts) and operational seasonal forecasts of hydrological variables with lead time of 6 months, driven by latest ECMWF seasonal ensemble forcing data at the global scale;
- To provide a set of key ECVs timeseries at daily time step and current spatial resolution for all datasets (historical, hindcasts and real-time forecasts);
- To generate and provide key ECVs datasets at monthly time step and current spatial resolution;
- To provide all the relevant user documentation, user support and input quality assessment in the CDS;
- To provide a technical solution to integrate CEMS-Flood GloFAS hydrological seasonal forecasts into the multi-model service. GloFAS is expected to be available with a higher spatial resolution in 2022-2023.

The mandatory deliverables are the following:

- Fully migrated production suite in ECMWF's HPCF in Bologna completed well in time before the decommission of ECMWF's current HPC, expected at the latest at the end of May 2022.
- Consolidation of state-of-the-art hydrological multi-model seasonal forecast modelling chains to produce and deliver reference simulations, retrospective forecasts (hindcasts) and operational forecasts of daily and monthly timeseries of a set of key Essential Climate Variables (ECVs) and skill scores to the CDS, with leadtime of 6 months. The list of ECVs will be proposed by the tenderer and discussed with C3S/ECMWF. The operational chain should include:
  - Updates of initial hydrologic states;
  - Downscaling and bias correction of meteorological seasonal forecasting data, as relevant, and information about skills of the adjusted fields;
  - Generation of the ensemble of hydrologic variables;
  - Quality checking through quality control software and workflows;
  - Any needed recalibration activity;
  - Provision of data to the Climate Data Store.
    This includes the provision of data and files containing abstracts, detailed descriptions of dataset, variables, etc., following the integration process detailed [here](). Monthly timeseries provided to the CDS, together with access to daily forecasts and retrospective forecasts (hindcasts).
- Bug fixing and model maintenance.
- Comprehensive documentation and full traceability, including for each entry catalogue: a product user guide and one document describing models' specifications.
- Provision of technical user support to the CDS user community.
- Provision of training material.
- Quality control of products and service through continuous error diagnostics and skill scores.
- Inputs to Quality Assurance Reports (QAR) developed in the C3S Evaluation and Quality Control (EQC) activities. An example of a CDS dataset with published QAR can be found here (this dataset serves as an example of QAR).
- Provision of Level-2 support to the Copernicus Help desk through the Jira ticketing system with agreed KPIs (for example, 85% of Level-2 tickets should be resolved within 15-working days). The contractor will provide an email address which acts as the single contact point.
- Contribution to C3S communication and outreach activities related to hydrological seasonal predictions.

The tenderer for this Lot 1 shall propose concrete strategies for the delivery of ECVs selection, hindcasts, skill assessment, bias correction/adjustment methods and specific technical solutions for them. **The solutions proposed by the successful contractors of the Global (Lot 1) and pan-European (Lot 2) components will be discussed and agreed with both contractors and C3S/ECMWF to ensure a common strategy is achieved at the beginning of each contract. Section 4.10.1 contains a list of requirements to ensure consistency between Lot1 and Lot2.**

The tenderer may take into consideration and propose costs for optional development contributions such as:

- further technical developments - initialization datasets or techniques, bias-adjustment, ensemble generation, uncertainty quantification, upgrades of model components, use of upgraded or more numerical weather prediction models from the multi-model C3S seasonal forecast – with the purpose of improving the forecast quality and the uncertainty characterization at the seasonal timescale. Any technical development shall be proposed as a separate Work Package, with an associated cost and discussed with C3S/ECMWF.
- scientific developments that assure the evolution of products and service.

Generic model development is out of scope in this activity, as are developments of methodology without prospect of implementation within the time horizon of the proposal.

4.2.3   Model resolution and ensemble size

The current C3S Global MULti-model hYdrological SeaSonal prEdictionS service delivers data at 0.1 degree resolution for 4 different hydrological models forced by the ECMWF SEAS5 (see Table 1). It is a requirement that the tenderer will deliver data at least at the same resolution and the same model ensemble size but preferably to a larger scale (number of hydrological models, or combination of hydrological and Numerical Weather Prediction models).

Any proposed plans in improving the model resolution and drainage networks is to be discussed with ECMWF/C3S and it should be done in consistency with GloFAS (from the CEMS Service).

4.3   Lot 2: Multi-model operational hydrological seasonal prediction service at the pan-European scale

Lot 2 covers the provision of the multi-model hydrological seasonal forecast and retrospective forecasts (hindcasts) information service at the pan-European scale.

This service is built on the C3S Operational Sectoral Information System for the Water Sector (https://climate.copernicus.eu/operational-service-water-sector).

4.3.1   Background information on the C3S Multi-model operational hydrological seasonal prediction service for Europe

The Operational Service for the Water Sector for Europe aims to help a broad range of water managers to plan their activities at short, seasonal horizons, as well as adapt their strategies in order to mitigate the effects of climate change. The intended user is in the fields of, for instance, water allocation, flood management, ecological status and industrial water use, but the provided services and information is also relevant in adjacent sectors, such as energy and agriculture. The service offers state-of-the-art hydrological climate information and seasonal forecasts for the water sector available through datasets and interactive web applications.

The implemented operational hydrological seasonal forecast system at European scale produces forecasts (January 2021- to present) and retrospective forecasts (hindcasts) (1993-2016) of monthly mean river discharge, up to a seven-month horizon. Ten hydrological models (E-HYPEcatch x8, E-HYPEgrid and VIC-WUR) are running in the system plus the additional member LISFLOOD is contributing from the EFAS seasonal forecasting system from CEMS, for a total of eleven models. The output resolution is at catchment delineations for the E-HYPEcatch models, and at 5 km scale EFAS drainage network for the three 5 km models.

The added value of this dataset is based on a multi-model ensemble of hydrologic/land-surface models produced at a monthly time step. All models are validated against observations, delivering information about the quality of the seasonal predictions.

The production chain is operated directly in the ECMWF IT infrastructure, with an ecFlow suite. The ecFlow job scheduler is modularised (i.e., separation of initialisation, creation of initial hydrologic conditions, and operational forecast, downscaling, bias-correction, archiving and CDS upload). This allows the inclusion of new datasets, meteorological seasonal forecasts and hydrological models with minimal effort. The ecFlow suite provides an overview of the entire production chain and clear traceability of provenance of data and workflows, as well as a way to monitor production to ensure timeliness. ecFlow enables a seamless integration into continuous operationalization.

The operational service is also supported by comprehensive documentation and user support to maximize the user uptake of the products and thus the benefit of the service for users. The hydrological seasonal

forecast is also available through an interactive web application "Hydrological seasonal forecast explorer" that presents the monthly hydrological seasonal forecasts of river discharge and the probability of river discharge deviating from normal conditions for the season.

The service provides the Evaluation and Quality Control (EQC) materials for the completion of Quality Assurance Reports and Level-2 support through the Copernicus User Support.

Hydrological models	E-HYPEcatch x8, E-HYPEgrid , VIC-WUR LISFLOOD from EFAS
Initialization	CEMS-Meteo driven hydrological simulations
Meteorological seasonal forecasts	ECMWF SEAS5
Bias adjustment	Quantile mapping for temperature and precipitation to bias adjust SEAS5 compared to CEMS -Meteo
ECVs	River discharge (m3/s). Definition: Volume rate of water flow, including sediments, chemical and biological material, in the river channel averaged over a time step through a cross-section.
Horizontal coverage	Europe (CEMS-Meteo domain)
Horizontal resolution	Catchment scale (average subcatchment size of 215 km^2 ; E-HYPEcatchx8) 5-kmx5-km grid (E-HYPEgrid, VIC-WUR, EFAS-LISFLOOD)
Temporal coverage & Update frequency	Seven-month forecasts, updated monthly (availability according to Copernicus access conditions)
Temporal resolution	Monthly
File format & conventions	NetCDF 4 - Climate and Forecast (CF) Metadata Convention v1.6, Attribute Convention for Dataset Discovery (ACDD) v1.3

Table 3: Summary of the current Hydrological seasonal forecasts information at pan-European scale available at C3S

4.3.2   Description of the expected activities & deliverables

This Lot covers the operation and maintenance of all the infrastructure and services listed above, necessary to allow continued access to hydrological seasonal forecast data present in the C3S catalogue .

The tasks are:

- To migrate the existing computational suite from ECMWF's HPCF at Shinfield, Reading to the new system in Bologna;
- To deliver an ensemble of hydrological models designed to extract local relevant information, together with metrics and information about the model performances;
- To provide reference simulations of hydrological variables based on forcing as close as possible to observations for at least 25 years and updated in near real-time (e.g. to be used to define the initial conditions);
- To generate retrospective forecasts (hindcasts) and operational seasonal forecasts of hydrological variables with lead time of at least 6 months, driven by latest ECMWF seasonal ensemble forcing data at the global scale;
- To provide a set of key ECVs timeseries at daily time step and current spatial resolution for all datasets (historical, hindcasts and real-time forecasts);
- To generate and provide key ECVs datasets at monthly time step and current spatial resolution;
- To provide all the relevant user documentation, user support and input quality assessment in the CDS;
- To provide a technical solution to integrate CEMS-Flood EFAS hydrological seasonal forecasts into the multi-model service. EFAS is expected to be available with a higher spatial resolution in 2021-2022.

The mandatory deliverables are the following:

- Fully migrated production suite in ECMWF's HPCF in Bologna completed well in time before the decommission of ECMWF's current HPC, expected at the latest at the end of May 2022.
- Consolidation of state-of-the-art hydrological multi-model seasonal forecast modelling chains to produce and deliver reference simulations, retrospective forecasts (hindcasts) and operational forecasts of daily and monthly timeseries of key Essential Climate Variables (ECVs) and skill scores to the CDS, with lead time of at least 6 months. The current operational water service for Europe provides monthly data to the CDS. This ITT requires a delivery of daily and monthly data to the CDS. The list of ECVs will be proposed by the tenderer and discussed with C3S/ECMWF. The operational chain should include:
  - Updates of initial hydrologic states;
  - Downscaling and bias correction of meteorological seasonal forecasting data, as relevant, and information about skills of the adjusted fields;
  - Generation of the ensemble of hydrologic variables;
  - Quality checking through quality control software and workflows;
  - Any needed recalibration activity.
- Provision of data to the Climate Data Store:
  This includes the provision of data and files containing abstracts, detailed descriptions of dataset, variables, etc., following the integration process detailed [here](). Monthly timeseries provided to the CDS, together with access to daily forecasts and retrospective forecasts (hindcasts).
- Bug fixing and model maintenance.
- Comprehensive documentation and full traceability, including for each entry catalogue: a product user guide and one document describing models' specifications.
- Provision of technical user support to the CDS user community.
- Provision of training material.
- Quality control of products and service through continuous error diagnostics, and skill scores.
- Inputs to Quality Assurance Reports (QAR) developed in the C3S Evaluation and Quality Control (EQC) activities. An example of a CDS dataset with published QAR can be found here (this dataset serves as an example of QAR).
- Provide Level-2 support to the Copernicus Help desk through the Jira ticketing system with agreed KPIs (for example, 85% of Level-2 tickets should be resolved within 15-working days). The contractor will provide an email address which acts as the single contact point.
- Contribution to C3S communication and outreach activities related to hydrological seasonal predictions.

The tenderer for this Lot 2 shall propose concrete strategies for the delivery of ECVs selection, hindcasts, skill assessment, bias correction/ adjustment methods and specific technical solutions for them. **The solutions proposed by the successful contractors of the Global (Lot 1) and pan-European (Lot 2) components will be discussed and agreed with both contractors and C3S/ECMWF to ensure a common strategy is achieved at the beginning of each contract. Section 4.10.1 contains a list of requirements to ensure consistency between Lot1 and Lot2.**

The tenderer may take into consideration and propose costs for optional development contributions such as:

- further technical developments - initialization datasets or techniques, bias-adjustment, ensemble generation, uncertainty quantification, upgrades of model components, use of upgraded or more numerical weather prediction models from the multi-model C3S seasonal forecast – with the purpose of improving the forecast quality and the uncertainty characterization at the seasonal timescale. Any technical development shall be proposed as a separate Work Package with an associated cost and discussed with C3S/ECMWF.

- scientific developments that assure the evolution of products and service.

Generic model development is out of scope in this activity, as are developments of methodology without prospect of implementation within the time horizon of the proposal.

4.3.3   Model resolution and ensemble size

The current operational water service delivers data at the catchment level (for the E-YPEcatch model and 8 ensemble members, with an average subcatchment size of 215 km2) and at 5kmx5km grid resolution (for three different hydrological models), run on ECMWF SEAS5 (see Table 2). The tenderer will deliver at least at the same resolution and the same model ensemble size, but preferably to a larger scale (number of hydrological models, or combination of hydrological and numerical weather prediction models).

Any proposed plans in improving the model resolution and drainage networks is to be discussed with ECMWF/C3S and it should be done in a way that is consistent with EFAS (from the CEMS Service).

4.4   Common requirements (Lot 1 & Lot 2)

4.4.1   Production Suite

The production chain should be flexible, scalable and extendable. The existing production chain for the pan-European and the global systems are implemented in an ecFlow suite (see: https://confluence.ecmwf.int/display/ECFLOW/ecflow+home), with a modular approach. This allows the inclusion of new datasets, meteorological seasonal forecasts and hydrological models with minimal effort. The current system is setup in the IT environment of the ECMWF's HPCF in Reading which is being decommissioned, therefore the operational suite is required to be migrated to the ECMWF's HPCF in Bologna well before its expected decommission by end of May 2022.

The numerical weather prediction model used as a forcing will be the latest version of the ECMWF seasonal forecast system (which currently is SEAS5).

ECMWF seasonal forecast data and historical forcing data may be either extracted from the CDS or directly from ECMWF/MARS data and any third-party datasets used as inputs to the hydrological models should be listed by the tenderer.

4.4.2   Real time data delivery

The daily initial conditions/historical simulations, daily and monthly timeseries forecasts shall be delivered once a month to C3S reliably and according to an operational schedule, between the C3S seasonal forecast release day and 3 days afterwards.

The two Services (Lot 1 & Lot 2) shall deliver operationally immediately after successful migration of the existing computational suite from ECMWF's HPCF at Shinfield, Reading to the new system in Bologna.

4.4.3   Historical simulation, retrospective forecasts (hindcasts) and forecast data delivery requirements

A comprehensive set of retrospective forecasts (hindcasts) is required for each modelling chain. retrospective forecasts (hindcasts) must be made with identical model versions, and in as similar a way as possible to the real-time forecasts. Retrospective forecasts (hindcasts) must be produced as a fixed set when an upgrade of the system is introduced. Upgrades in the retrospective forecasts (hindcasts) could also be asked by ECMWF/C3S within the duration of the contract. Forecasts must cover at least 6 full calendar months from the nominal start date for all ensemble members. In the case of lagged-start ensembles, the effective time coverage of the products must be at least 6 months. The full seasonal retrospective forecasts (hindcasts) period should be the same for Lot 1 and Lot 2 (the pan-European and Global systems).

Retrospective forecasts (hindcasts) at the daily resolution and monthly averages will have to be made available. Daily hindcasts could be either delivered to the ECMWF MARS archiving system or through a distributed dataset. Monthly averages may be delivered to the CDS disks. The costs of the proposed solutions must be presented and shall include:

- the cost of retrospective forecasts (hindcasts) production;
- the required volume for archiving (if in MARS or any other external distributed system);
- the estimation of costs of System Billing Units (SBUs). A description of the ECMWF HPC SBU is available here: https://confluence.ecmwf.int/display/UDOC/HPC+accounting.

Monthly-updated daily hydrological historical simulations using forcing dataset as close as possible from observations (for example, interpolated observed field, or reanalysis such as ERA5/ ERA5T) are expected to be delivered for the multi-model systems for a historical period as long as possible and updated in near real-time, over a consistent period between the two Lots in the CDS. Those are multi-decadal simulations aiming to reproduce hydrological observations, used to generate reference hydrological data and for monitoring purposes.

4.4.4 Upgrade in modelling suite

Any upgrade of the modelling suite during the contract should follow a clear and specific strategy. For example, changes in the seasonal forecast model (SEAS5) or changes in the hydrological models require different solutions. The tenderer is asked to provide detailed specific solutions based on the proposed and planned strategy in any upgrading of the modelling suite.

Any upgrade in the modelling suite requires the production of new reference simulation and retrospective forecasts (hindcasts) over the whole domain at the modelling resolution (e.g. grid size). Tenderer should describe the strategy and the associated cost of recalibration of the hydrological models and generation of reference simulation for the whole domain, including costs in terms of SBUs and data volume.

4.4.5 Additional requirements

4.4.5.1 Consistency of the two systems

To ensure consistency between Lot1 and Lot2 services, proposed solutions will be discussed with C3S/ECMWF at the negotiation stage and common approaches for the two Lots will be discussed at the beginning of the contracts and during specific Lot1 and Lot2 common meetings.

The tenderer is asked to provide detailed specific solutions and concrete strategies in terms of:

- Delivered ECVs- a subset of the same ECVs is to be delivered by the 2 services. Relevant ECVs from GloFAS and EFAS will be made available to the contractors for the multi-model ensemble offering;
- Common retrospective forecasts (hindcasts) period;
- Skills metrics will be delivered to the CDS as an extra downloadable variable in both services;
- If the 2 Lots will deliver different bias correction strategies, the methodologies need to be very well described and available to the users with a common approach;
- Common period and strategy for historical simulations.

4.4.5.2 Quality control, support and documentation

Quality control procedures (including automatic procedures) shall be put in place to check the quality of forecast data before transmission to ECMWF. The precise methods should be proposed by the tenderer and will be agreed as part of the negotiations. In the case of ECMWF detecting possible problems with the data, providers are expected to give timely support to resolve problems quickly, and at the latest 24 hours before the product release date. Each forecasting system version needs to be documented, at a level which defines how the data were produced and allows users to understand version changes. The datasets themselves will

also need to be documented to allow discovery by users via the CDS. The data providers will be responsible for making this documentation available as required.

Continuous monitoring of the Service is expected and regular reports describing the conclusions should be provided every six months. Such reports shall contain the summary of technical problems encountered and their respective solutions and moreover what actions were undertaken in order to prevent the problems happening again.

The contract is expected to provide support to C3S on a number of fronts:

1. Technical support to the CDS team, on matters related to the operation of the infrastructure. As this is a service with operational status, this means timely responses in case of problems detected using an efficient workflow to get the answer and the possible fixes quickly.

2. Support to specific user questions which relate to the hosting, archiving and the quality control of the original data and which go beyond the expertise of Copernicus User Support (CUS). A procedure should be defined and implemented, to accommodate such requests and provide timely answers. Level-2 support is provided through the Copernicus User Support (operating a Jira ticketing system) with agreed Key Performance Indicators (KPIs; for example, 85% of Level-2 tickets should be resolved within 15-working days). The contractor shall provide an email address which acts as the single contact point.

3. Maintenance of the data documentation, which is provided to the users through the CDS and that is an integral part of the CDS catalogue entries. Detailed documentation for the operators regarding the whole production and archiving chain must also be provided.

4. Support to the Evaluation and Quality Control function. The contractor shall coordinate with and support the work of the EQC by a) completing and updating the respective quality assurance templates (QAT) hosted in a Content Management System (CMS) in order to produce standardised quality assurance reports (QARs); b) performing and documenting recommended checks and tests ahead of publication; and c) reviewing EQC material produced independently, guidance to users. (See Section 4.10.3).

5. Support is also required for related C3S activities, including communication and outreach. While for most such cases the needs on this contract are expected to be minimal, consideration should be given to allowing resources to cover these aspects. Any communication activity related to this work must be agreed with the ECMWF Copernicus Communication team in advance. This includes, but not exhaustively covers, communication planning, branding and visual style, media outreach, website and social media activity, externally facing written and graphical content and events.

The contract management activities shall be managed in separate work package; the structure and content expected from this work package are described in the next section.

4.4.5.3   Evaluation and Quality Control

Published datasets will need to be evaluated by the EQC activity (Evaluation & Quality Control). The Copernicus Climate Change Service offers an Evaluation & Quality Control Function, which provides quality assurance and fitness for purpose information all of data, tools and applications published by C3S (https://climate.copernicus.eu/quality-assurance-copernicus-climate-change-service).

The C3S Evaluation and Quality Control (EQC) function has been designed to provide assessments of the technical and scientific quality of all C3S products and services, including their value to users. This function is being performed by independent evaluators within a separate contract, in close coordination with the service providers.

The contractor will produce products that are in line with the quality assurance criteria set out by the EQC function and will also liaise with EQC (both C3S and its contractors) as appropriate. This includes, in particular, the completion and updating of the respective quality assurance templates (QAT) hosted in a Content Management System (CMS) in order to produce standardised quality assurance reports (QARs). These are

presented to users via a synthesis table in the EQC tab of the respective CDS catalogue page. Apart from the independent assessment (where applicable), all fields in the QAT are designed to be populated by the contractor (An example us provided here: https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-pressure-levels-monthly-means?tab=eqc).

A consultation process is foreseen between EQC evaluators and the successful tenderer before the start of the EQC workflow to define the respective QARs to be produced including their level of granularity. It is envisaged to keep the number of QARs to a manageable level and focus effort on those artefacts that are public and published applications (and datasets) within the CDS.

Therefore, the tenderer needs to allocate sufficient effort to support the C3S EQC function – including completion of the Quality Assurance Templates and the delivery of high-quality user guides.

Deliverables expected: one complete Quality Assurance Template for the production of Quality Assessment Reports for each dataset.

4.4.5.4   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 tenderer's 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.

5   General requirements

5.1   Implementation schedule

The tenderer shall provide a detailed implementation plan of proposed activities for the first two-year period and implementation scenarios for the remaining two years, as described in Section 3 above.

5.2   Deliverables and milestones

Deliverables should be consistent with the technical requirements specified in section 4. A deliverable is a substantial, tangible or intangible good or service produced as a result of the contract. In other words, a deliverable is an outcome produced in response to the specific objectives of the contract. Deliverables are subject to acceptance by the technical contract officers at ECMWF. All contract reports shall be produced in English and be submitted in electronic format, via the Copernicus Deliverables Repository portal.

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

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

The following contract management details shall be briefly described in the bid:

- Contractual obligations on reporting on implementation and forward planning.
- Meetings (classified as tasks and listed in a separate table as part of the proposal):
  - ECMWF will host quarterly teleconference meetings to discuss C3S service provision, service evolution and other topics.

- o ECMWF will organise a project review meeting before the end of the 2-year contract in order to discuss the optional extension activities.
  - o Tenderer can propose additional contract internal meetings (e.g. kick-off meeting, regular meetings to monitor contract performance, meetings between the 2 Lots) as part of their response. Most such meeting should be held by remote participation.
  - o ECMWF will organise annual C3S General Assemblies. The successful Tenderer is expected to attend these meetings with team members covering the topics that are part of this ITT.
- A check on the quality of the deliverables should be made by the prime contractor before submission to ECMWF (to cover contents, use of relevant ECMWF reporting templates, format, deliverable numbering and naming, punctuation, spelling and grammar, etc).
- Resource 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.

The standard deliverables and milestones of administrative character are listed below.

WPXX00 Deliverables				
#	*Responsible*	*Nature*	*Title*	*Due*
D1.y.z-yyyyQq[1]	Tenderer	Report	Quarterly 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 Report YYYY [Part 1]; *YYYY being the Year n-1*	Annually on 15/01
D0.y.z-YYYY	Tenderer	Report	Annual Report YYYY [Part 2]; *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	Annual Implementation plan YYYY; *YYYY being the Year n+1*	Annually on 30/09
D0.y.z-YYYY	Tenderer	Other	Copy of prime contractor's general financial statements and audit report YYYY; *YYYY being the Year n-1*	Annually
D0.y.z	Tenderer	Report	Updated KPIs (list, targets…) after review with ECMWF	One year after start of contract

WPXX00 Milestones				
#	*Responsible*	*Title*	*Means of verification*	*Due*
M0.y.z-Px	Tenderer	Review meeting with	Minutes of meeting	At each Payment

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[1] Deliverables (and Milestones) shall be numbered as per the following format DX.Y.Z (MX.Y.Z), where X is the WP number, Y is the task number and Z is the Deliverable (Milestone) number in this task. Deliverables delivered annually should be numbered DX.Y.Z-yyyy, where yyyy is the year the Deliverable refers to (e.g. DX.Y.Z-2016, DX.Y.Z-2017). Deliverables delivered quarterly should be numbered DX.Y.Z-yyyyQx, where yyyyQx is the quarter of the year the Deliverable refers to (e.g. DX.Y.Z-2016Q1, DX.Y.Z-2016Q2). The same numbering format shall be applied for Milestones. Continuous deliverables at higher frequency can be labelled in the same way as quarterly deliverables.

		ECMWF		Milestone due date

Tenderer shall complete the relevant table in Volume IIIA as part of their bid, which includes the details of deliverables and milestones for all work packages and the schedules for each work package.

5.3 Key performance indicators

Contractors shall report to ECMWF on a set of Key Performance Indicators (KPIs) suitable for monitoring various aspects of service performance.

The table below provides the template to be used by the Tenderer to describe the KPIs, relevant for this ITT, together with performance targets, delivery schedules and explanations, as needed.

All KPIs shall be periodically updated as described in the tables. Tenderer shall provide preliminary versions of the completed tables as part of their bid.

KPI	KPI Title	Performance Target and Unit of Measure	Frequency of Delivery	Explanations / Comments
KPI_1				
KPI_2				

6 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.

6.1 Page limits

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

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

Table 4: Page limits

6.2 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.

6.2.1 Executive summary

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

6.2.2 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.

6.2.3 Quality of resources to be deployed

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

- A senior team member with more than 5 years of experience in managing activities related to this ITT (referred to as Service Manager). This person will be the point of contact on technical matters.
- A team member with experience of managing projects and contracts of this type and size (referred to as Contract Manager). This person will be the main point of contact for administrative matters.
- Team members with demonstrated experience in 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.

6.2.4 Technical solution proposed

The tenderer is expected to provide a short background to the proposed technical solution to demonstrate understanding of the solution proposed, as well as an exhaustive and detailed description of the proposed technical solution and its organisation into work packages.