TENDER FOR

Copernicus Climate Change Service

Global Climate Projections: Data Access, product generation and impact of front-line developments

PART 1: Response to tender

Project name: C3S - Metrics and Access to Global Indices for Climate Projections (C3S-MAGIC)

Reference: ITT Ref:C3S_34a – Lot 2

Client: ECMWF Administration Department - Procurement Section

Contents

1 Introduction

The Copernicus Climate Change Services (C3S) is designed to provide software and data to support decision taking and impact assessment in sectors that are affected by alterations in climate characteristics. An important source of information for these assessments are projections generated with Global Climate Models (GCMs). Extensive past experience with the use of GCM projections for climate change impact assessment has revealed that credibility of model results and tailoring its output to local characteristics are important bottlenecks of this practice (*8*).

The C3S tender "Global Climate Projections: Data Access, product generation and impact of front-line developments" (GCP) seeks solutions that allow to assess GCM projections using well-established metrics, and manipulation tools to allow tailoring the outputs to the users' needs. Expectations expressed in one of the winning SIS applications are cited in the following text box:

> **Excerpt from the Sectoral Information System tender SWICCA:** "The GCP-software should assist water and environment consultancies across Europe in: (1) finding relevant existing datasets, (2) selecting a domain and a time-period, (3) extracting specific variables, (4) quality assurance, and (5) re-formatting the variables to self-explanatory files (incl. metadata and linkages to source data). Additional functionality would be (6) bias correction towards observations, (7) quality specification of data suitability for different purposes…. The GCP software should include functions to display transient time-series of these variables in absolute terms, but also with metrics of relative change between optional time slices (i.e. future conditions vs present) of their annual cycle. Finally, it is important to note that the software has to be perfectly transparent."

This call thus asks for the development of software to calculate standardized characteristics (metrics, statistics, time series) from available climate model output. Some of these characteristics are pre-defined, while others require user input.

The members of the bidding consortium for the project C3S - Metrics and Access to Global Indices for Climate Projections (C3S-MAGIC) (Table 1) have experience in climate modelling and model data, in the definition and use of the above-mentioned characteristics, and in the development of web-based tools to access the data and perform standard operations with them. Most of them have worked together in the past on related projects. The proposed solution builds on this earlier experience.

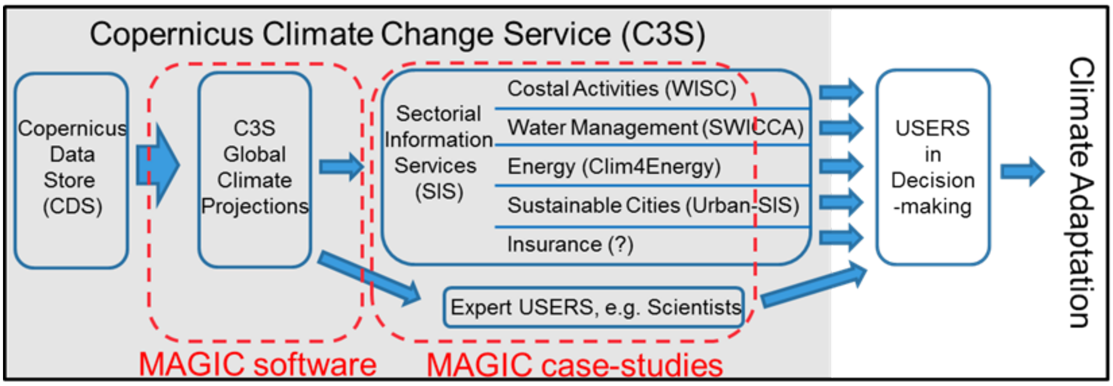

FIGURE 1: STRUCTURE OF THE CHAIN TO COLLECT MODEL DATA IN THE CDS, TAILORING OF THE INFORMATION IN C3S-MAGIC, TO BE FURTHER PROCESSED BY EXPERT USERS OR THE SIS PORTALS TO SUIT A WIDE RANGE OF USERS.

In short, our solution consists of extending an existing web portal designed for analysing climate data (climate4impact.eu) with the capability to manipulate and combine the data according to the specifications set forth in the ITT. The necessary software for these manipulations will mainly be taken from existing tools that have been developed by the partners. The climate4impact.eu web site will be equipped with an interface that accepts commands from the user and displays the results. The system design allows interaction with different data stores and (web) interfaces, and will therefore act as a hub both for the SIS project portals to collect tailored information from the CDS, but also for expert users that do not need the intermediate step of the SIS. The proposed structure of the project is displayed in Figure 1, where the C3S-MAGIC software acts to collect and tailor information from the CDS for further use by either expert users, or by the SIS portals. Primarily the SISs, but also expert users, provide user requirements to C3S-MAGIC.

TABLE 1: THE CONSORTIUM

Acronym	Name	Country	Relevant expertise
KNMI	Royal Netherlands Meteorological Institute	NL	Climate modelling & evaluation Data access Climate data manipulation User interactions
BSC	Barcelona Supercomputing Center	ES	Climate modelling Climate services Software development Performance optimization User interactions
DLR	Deutsches Zentrum für Luft- und Raumfahrt (DLR)	DE	Climate modelling and evaluation
ISAC-CNR	Institute of Atmospheric Sciences and Climate – Consiglio Nazionale delle Ricerche	IT	Climate modelling Software Development
NLeSC	Netherlands e-Science Center	NL	Climate modelling Research software Data management Data analytics Visualization
SMHI	Swedish Meteorological and Hydrological Institute	SE	Climate modelling Climate services Software development User interactions
URead	University of Reading	UK	Climate modelling Software development

2 Track record

2.1 Consortium as a whole

The core of the consortium is formed by institutes that have been working together in the past on (FP7/H2020-funded) projects aimed at developing software tools to explore climate (model) data. Some of the most relevant projects and their key products are listed in Table 2. Additionally, the Netherlands e-Science Center (NLeSC) and the University of Reading (URead) are part of the consortium. They contribute to the development and implementation of the software architecture within which the applications to calculate metrics, time series, etc. are run.

TABLE 2: PARTICIPATION OF CONSORTIUM PARTNERS IN EU PROJECTS THAT CREATED TOOLS FOR THE EXPLORATION OF CLIMATE MODEL DATA.

Project	Consortium members involved	Product generated (relevant for present tender)
ES-ENES (FP7 grant 228203)	KNMI, SMHI, DLR, BSC	Climate4impacts.eu (*36*)
ES-ENES-2 (FP7 grant 12979)	KNMI, SMHI, DLR, BSC	Climate4impacts.eu (*36*)
CLIPC (FP7 grant 607418)	KNMI, SMHI	Data visualization tool
EMBRACE (FP7 grant 282672)	KNMI, SMHI, DLR	ESMValTool (*12*)
SPECS (FP7 grant 308378)	KNMI, BSC, SMHI	s2dverification (*32*)
Distributed funding	KNMI	Climate Explorer (*34*)
NextDATA (Italian National Project of Interest)	ISAC-CNR	Geonetwork portal for observations (*40*), General data portal (*43*), Online downscaling tool (*41*), Climate model diagnostics (*42*)
CRESCENDO (Horizon 2020)	DLR, KNMI, SMHI, URead	ESMValTool (*12*)

The consortium has the right mix of expertise, experience and background to successfully fulfil the project (Table 1). This is further shown in the next subsections, where each partner is described in general terms as well as in view of the requirements originating from the call.

2.2 KNMI

2.2.1 Short summary

The Royal Netherlands Meteorological Institute (KNMI) is the Dutch national weather service. It is an agency of the Ministry for Infrastructure and the Environment. Primary tasks are weather forecasting and the monitoring of weather, climate, air quality and seismic activity. KNMI is the national research and information centre for meteorology, climate, air quality, and seismology.

KNMI focuses on monitoring and warning for risks with an atmospheric or seismic origin. In addition, KNMI offers advice and strategy prospects for both acute and future dangers. We strive to make our high-quality knowledge and information in the area of weather, climate, and seismology operationally available 24 hours a day, seven days a week. In addition, we continuously extend and deepen this knowledge in co-operation with research institutes, universities and businesses. As a scientific institute KNMI contributes to the international climate research and contributes to the process and reports of the Intergovernmental Panel on Climate Change (IPCC).

KNMI has a long record of activities related to climate services, both on the national as well as the European to global scale. It has been involved in several EU-funded projects which provide users (policy makers, the scientific community, commercial partners) with tailored science-based assessments through our Climate Services activities as well as detailed state-of-the-art datasets. It provides these assessments and datasets using sustained and operational IT based services (ECA&D, Climate Explorer, KNMI Datacentre, climate4impact.eu).

2.2.2 Project references

The IS-ENES climate4impact (*36*) (C4I) website is oriented towards climate change impact modelers, impact and adaptation consultants, as well as other experts using climate change data. On C4I access to data and quick looks of global climate models (GCM) is provided, as well as regional climate models (RCM) and downscaled higher resolution climate data. C4I uses the ESGF infrastructure, but also has its own data store. The portal provides data transformation tooling for tailoring, mapping and plotting capabilities. Guidance on the use of climate scenarios, documentation on the climate system, frequently asked questions and examples in several impact and adaptation themes are presented and described, along with the steps required to connect GCM data to impact model input data. C4I is developed in the FP7 funded IS ENES projects, and co-developed with CERFACS, SMHI, University of Cantabria and Wageningen University. KNMI is the leading partner and hosts the portal.

KNMI have developed the KNMI Climate Explorer (*34*), an interactive web site that gives access to a large number of climate data, both from observations and model output. It allows the user to perform a large variety of operations on the data, like filtering, extracting, statistics (e.g., means, variance, extremes), and correlations between data.

KNMI is involved in a proposal to a Copernicus SIS call called WISC. It aims at the coastal and the insurance sectors by delivering information on the wind storm risk in Europe.

2.3 BSC

2.3.1 Short summary

The Barcelona Supercomputing Center - Centro Nacional de Supercomputación (BSC) combines unique high performance computing facilities and in-house research departments on computer, life, and Earth sciences, and computational applications. Established in 2006, the Earth Sciences Department of the BSC, hereafter BSC-ES, worked on atmospheric composition modelling. The designation of Professor Francisco J. Doblas-Reyes as Director of BSC-ES in 2014 initiated the merging of the Climate Forecast Unit of the Institut Català de Ciències del Clima (IC3-CFU), which he was leading and that in a short time became a main European actor in the development of climate services based on climate prediction, into the department. The newly merged department is structured around four groups, three of which will be involved in this project, with more than 50 employees, including technical and support staff. The climate prediction group aims at developing a climate forecast system based on the EC-Earth model and performs regular assessments of the characteristics of this forecast system compared to all other operational and quasi-operational systems available in the world. The Earth system services group ensures that the outcomes of the department reach society, both in the public and private sectors, and continuously sample the needs of a range of users in the insurance, agriculture and renewable energy sectors. The computational Earth sciences group is a unique ensemble of physicists and computer engineers that develop computational and Big Data solutions for the weather, air quality and climate modelling communities. The BSC-ES international activity includes the coordination of the two World Meteorological Organisation (WMO) regional centres specialised in sand and dust warning and forecasting, as well as the participation in climate services initiatives like the Climate Services Partnership (CSP). Members of the BSC-ES participate in committees of the World Climate Research Programme (WCRP), such as the CLIVAR Scientific Steering Group for Virginie Guemas, the PI of this project.

2.3.2 Project references

Over the past 5 years, the BSC-ES members have participated in several projects relevant to this project, out of which one Seventh Framework Programme (FP7) and one Horizon 2020 projects excel.

PRIMAVERA (PRocess based climate sIMulation: AdVances in high-resolution modelling and European climate Risk Assessment) is an H2020 project which aims to develop a new generation of advanced and well-evaluated high-resolution global climate models, capable of simulating and predicting regional climate with unprecedented fidelity, for the benefit of governments, business and society in general. Within this project, BSC-ES leads the work package dedicated to the development of metrics for process evaluation. These includes improving existing metrics and developing original ones to assess the model representation of dynamic and thermodynamic aspects within each model component, as well as their coupling and retroactions and their sensitivity to climate change. Furthermore, BSC-ES is coordinating the work package devoted to ensure that the project outcomes are both useful and actionable for key sectors (wind energy, power system, insurance and transport) by involving end-users in the co-production process.

The EUPORIAS (EUropean Provision Of Regional Impact Assessment on a seasonal-to-decadal timescale) project intends to improve our ability to maximise the societal benefit of developing climate prediction capability. Since 2012 the 24 project-partners, representing a diverse community ranging from UN organisations to small enterprises, have been increasing the resilience of the European Society to climate change by demonstrating how climate information can become directly usable by decision makers in different sectors. The main outcome of EUPORIAS will be the development and the delivery of robust and usable seasonal to decadal probabilistic predictions of the impact of high risk events. These predictions will focus on the water, energy, health, transport, food security, infrastructure, forestry and tourism sectors on timescales from seasons to years ahead.

The CLIM4ENERY tender (Copernicus; under review) will deliver energy-relevant indicators of climate trends and variability. BSC-ES leads the work package dedicated to deliver wind power generation products.

Other European projects where the BSC-ES is involved playing a role on seasonal forecast quality evaluation and the development of interactions with the users are EUCLEIA, PREFACE, IMPREX, ECOMS2 and ERA4CS.

2.4 DLR

2.4.1 Short summary

The Deutsches Zentrum für Luft- und Raumfahrt (DLR) is the German national research establishment for aeronautics, astronautics, and energy technology within the Helmholtz-Gemeinschaft der Forschungszentren (HGF). DLR is represented in this project by the Institute of Atmospheric Physics (DLR-IPA). The institute develops and applies demanding methods including lidar, radar, airborne instruments, satellite analysis, and complex modelling tools. The modelling department at DLR-IPA leads the development of the ECHAM/MESSy Atmospheric Chemistry (EMAC) model and the Earth System Model Evaluation Tool (ESMValTool) in collaboration with other partners and regularly supports international climate and ozone assessment reports. DLR-IPA has long-term experience in global Earth system modelling and the evaluation of Earth system models with observations, the analysis of multi-model climate projections, in situ air-borne measurements, and processing of satellite data. It supports industry and society with expert-knowledge concerning a sustainable development. DLR-IPA participates in and coordinates many national and European research projects related to this work.

2.4.2 Project references

DLR-IPA is project PI for the community-developed ESMValTool that allows for routine comparison of single or multiple models, either against predecessor versions or against observations. The priority of the effort so far has been to target specific scientific themes including the evaluation of Essential Climate Variables (ECVs) with observations and the calculation of corresponding performance metrics. The tool is being developed in such a way that additional analyses or variables that are required in this project can easily be added. It thus forms an ideal starting point for this work. The ESMValTool is a community effort open to both users and developers encouraging open exchange of diagnostic source code and evaluation results from the CMIP ensemble. This will facilitate and improve ESM evaluation beyond the state-of-the-art with the goal to run the tool alongside ESGF as part of a routine and operational evaluation of CMIP model simulations while utilizing observations and reanalyses available in standard formats (obs4MIPs / ana4MIPs) or provided by the user.

In addition, DLR-IPA is represented in several scientific steering committees of the World Climate Research Programme (WCRP) related to this work, thus ensuring that the work in this project is aligned with international strategies. These include the Chair position of the CMIP Panel that traditionally has the responsibility for direct coordination and oversight of CMIP, as well as memberships on the WCRP Working Group on Coupled Modelling (WGCM), the Chemistry-Climate Model Initiative (CCMI), the WCRP Data Advisory Council’s (WDAC) Observations for Model Evaluation Task Team, and the Working Group on Numerical Experimentation (WGNE) / WGCM Climate Model Metrics Panel.

2.5 ISAC-CNR

2.5.1 Short summary

The Institute of Atmospheric Sciences and Climate (ISAC) is part of the Italian National Research Council (CNR), the largest public research institution in Italy and a multidisciplinary institution that actively participated to the several past programs of the EU. ISAC-CNR has solid experience in earth observations and in the study of atmospheric and climate processes. Its research activities include climate reconstructions and numerical modeling of weather and climate, with a particular focus on high-mountain climates, the hydrological cycle, downscaling techniques and weather and climate predictability. ISAC has a long track record of projects, activities and interdisciplinary collaborations for the study of impacts of climate change in the fields of hydrology, ecosystems and natural risks.

2.5.2 Project references

ISAC-CNR is currently developing and implementing metrics and postprocessing tools for climate data in several relevant national and international projects. In particular, in PRIMAVERA (H2020) ISAC-CNR is focusing on the development of process-based metrics tailored for different regions and seasons, assessing Pacific variability and its teleconnection to Europe, measuring climate variability and predictability in the Extra-Tropics. In CRESCENDO (H2020) it will implement new metrics to assess ESM spatial and temporal trends in land and vegetation cover resulting from improved representation of land-use change and vegetation dynamics. ISAC-CNR is participating in ECOPOTENTIAL (H2020), providing model scenario data for ecosystem impact modelling, including statistical and stochastic downscaling of large-scale scenario information, with development of tools for the comparison with available earth observations. ISAC-CNR plays a major role in NEXTDATA, an Italian National Project of Interest aimed at the development of archives and tools for retrieval, storage, access and diffusion of environmental and climate data from mountain and marine areas. New postprocessing and validation tools are also being developed in the framework of the CLIMATE-SPHINX (Climate Stochastic PHysics HIgh-resolutioN eXperiment) PRACE supercomputing project. In the past ISAC-CNR participated in several European projects which allowed to build tools and experience useful for the proposed work. These projects include ACQWA (FP7), StratoClim (FP7), TERRABITES (COST), ECLISE (FP7), CIRCE (FP6), SEADATANET II (FP7) and ICE-ARC (FP7).

2.6 Netherlands e-Science Center

2.6.1 Short summary

The NLeSC coordinates and conducts a scientific program, working with both academia and industry, on the interface of e-infrastructure (computing, data) and domain sciences varying from climate science, astronomy, chemistry to humanities amongst others. The Center has been set up by the Dutch Research Council (NWO) and the national e-infrastructure organization (SURF). NLeSC has expertise in data handling, big data analytics and efficient computing. In climate science the expertise of NLeSC is in efficient computing and the combination of disparate compute resources as well as in data management, data analytics and visualization of large data sets. NLeSC coordinates a platform for national and European e-Science activities. NLeSC maintains an e-science technology platform containing software tools, interfaces, and libraries to deal with and extract information from large amounts of (distributed) data, requiring large computing infrastructures, high-speed networks, and high-resolution visualization equipment. Moreover, in many cases data and results, as well as compute kernels and full scientific workflows, are made sharable among multiple collaborating parties. NLeSC makes use of the e-infrastructure facilities of SURF. NLeSC brings in expertise through a group of e-science Research engineers.

2.6.2 Project references

NLeSC has a portfolio of about 40 multiyear research projects together with academic partners and is involved by employing dedicated e-science research engineers. Climate data access, distribution and visualization has been set up in the 'Summer in the City' project with Wageningen University on high resolution urban forecasting, 'ERA-URBAN' with the same group on high resolution urban atmospheric reanalysis, 'eWatercycle' on hydrological global forecasts and visualization with TU Delft, 'eSALSA' on global climate modelling on heterogeneous architecture (see www.esciencecenter.nl).

NLeSC is participating in the H2020 PRIMAVERA project. Employees of NLeSC have been involved in many national and international climate research projects, such as FP7 IS-ENES, IS-ENES2, SPECS, EMBRACE and ECLISE (see Table 2 for references).

2.7 SMHI

2.7.1 Short summary

SMHI is a public body with some 670 employees under the Swedish Ministry of Environment, running both governmental services and commercial businesses. SMHI is providing decision-support to a broad range of end-users, based on meteorology, hydrology, oceanography and climate information. The institute is responsible for national monitoring and modelling in these fields, data archives and refinement of information for societal needs. The institute has a long tradition in developing customized products and services (today mostly as web applications), as well as 24/7 production of forecasts with early warnings, and operates the dissemination of flood alerts to other EU member states in the EFAS system for EU Copernicus. It has a strong R&D focus with 110 full time scientists and just as many in IT. Currently, it is adapting according to EU open data strategy and the INSPIRE directive with open archives in standard formats, metadata catalogues, download facilities and APIs. SMHI is active in many GEOSS, Copernicus and ESA projects. SMHI is representing Sweden in relevant international organizations, e.g. ECMWF, WMO, EUMETSAT and IPCC. The institute is involved in many national and international projects and is currently coordinating collaborative FP7 projects, for instance SWITCH-ON www.water-switch-on.eu developing commercial products for water management based on Open Data (e.g. from Copernicus). The SMHI management system has been certified under the quality standards ISO 9001 and ISO 14001.

2.7.2 Project references

SMHI will make use of in-house software tools, for instance: on hydrological modelling (HYPE, HBV), seasonal forecast production system (Aegir), distribution-based scaling of climate model data (DBS), data tailoring and merging (WHIST), along with a number of scripts for pre- and post-processing in R or MATLAB. In addition, SMHI will re-use in-house components of existing running software for the visualisation tools (WMS, WFS and time-series manager) in the Service Demonstrator. As far as possible, existing software will be used also from other developers or companies. The SMHI tools are normally with open source code. For hardware, SMHI has besides its own supercomputers (the latest one with 641 nodes of 16 processors each) access to large storage space and computing clusters at the National Supercomputer Centre (NSC) at Linköping University, where e.g. many of the Rossby Centre climate model simulations for the CORDEX downscaling project have been carried out. The collaboration with NSC ensures a high quality working environment with large data quantities for demanding climate simulations. Also downscaling and hydrological impact models are run at supercomputers to reduce time for computing and data transfer between tools.

SMHI is involved in a number of C3S Sectoral Information Systems (SIS) tenders currently in negotiation: SWICCA (SIS for water management, contracted by SMHI), Clim4Energy (SIS for Energy, contracted by LSCE) and Urban SIS (SIS for Other sector, contracted by SMHI).

2.8 URead

2.8.1 Short summary

The Department of Meteorology at the University of Reading (URead) is the largest in Europe with over 100 staff, 50 PhD students and over £40M in current research contract funding. The Department hosts core groups from the NERC-funded national centres of atmospheric science (NCAS) and earth observation (NCEO), including the divisional leads for the NCAS climate division, the NCAS Models and Data division, and the NCEO data assimilation division. It is a key component of the Reading University Walker Institute for Climate System Research, established to promote integrative research in understanding the risks and opportunities from changing climate.

2.8.2 Project references

URead is involved in a number of FP7 projects, including the coordination of CLARIFY-2016 (a large NERC grant on Cloud-Aerosol-Radiation Interactions and Forcing), participation in EMBRACE (which aims to make targeted improvements to key process failings in present-day ESMs to reduce systematic biases), and participation in CLIPC (a FP7 project to provide access to climate information of direct relevance to a wide variety of users).

URead is also involved with MyOcean (and MyOcean2, i.e. the Copernicus Marine Service), having developed the INSPIRE- compliant View Service, which enables all MyOcean data products (including models and in situ observations) to be interactively visualized in a web browser, using open web standards. Additionally, URead lead the development of the visualization tools for GeoViQua (focusing on the visualization of uncertainties in Earth Observation and model data), led CHARMe (developing a system enabling users to comment and annotate climate datasets), and led MELODIES (developing Linked Data techniques for sharing and visualizing environmental data).

3 Quality of resources of participants

An overview of involved persons and their main tasks in the C3S-MAGIC project is listed in Table 3. Detailed descriptions of key persons are given below.

TABLE 3: HUMAN RESOURCES PROFILES.

Title	Broad description of work in relation to Service	Persons involved (CVs added)	Qualifications	Effort in months
KNMI				
Project Manager	Management and Coordination	Bart van den Hurk	Climate science, stakeholder interaction, project and team management	1.7
Service Manager	Daily project management	tbd		5.7
Administrator	Administration	tbd		3
Scientist	Time series	Andreas Sterl	Climate scientist	4.2
Scientist	Tailored Product	Henk van den Brink	Coastal safety, extreme events	4.2
Team lead / developer	WP3.2	Wim Som de Cerff	Agile development, climate4impact architect	1.6
Senior developer	WP3.2	Maarten Plieger	ADAGUC core developer	2.4
Developer	WP3.2	Andrej Mihajlovski	WPS processing service developer	4
BSC				
Team leader	Metrics, combination of multi-model products and time series	Virginie Guemas	Head of the BSC-ES Climate Prediction group	3.5
Scientist	Energy sector	Albert Soret	Head of the BSC-ES Earth Service group	3
Scientist	Insurance sector	Louis-Philippe Caron	Climate scientist	6
IT	Adaptation of s2dverification tools and interfacing with ESMValTool	Nicolau Manubens	s2dverification maintainer	7.6
Post-doctoral scientist	Metrics, combination of multi-model products and time series	tbd		7.2
Post-doctoral scientist	Energy and insurance sector	tbd		14
DLR				
Team Leader	Development of ESMValTool and calculation of performance metrics; International strategies	Veronika Eyring	Climate scientist and head of the DLR-IPA Earth system model evaluation group	1.5
Scientist	Development of ESMValTool and calculation of performance metrics	Axel Lauer	Climate scientist	8.5
ISAC-CNR				
Team Leader	Metrics related to extremes and climate indices	Jost von Hardenberg	Climate scientist	5.6
Scientist	Ensemble clustering products	Susanna Corti	Climate scientist	5.2
Scientist	Impacts in the water sector and downscaling	Elisa Palazzi	Climate scientist	4.2
Scientist	Metrics	Chiara Cagnazzo	Climate Scientist	2

Title	Broad description of work in relation to Service	Persons involved (CVs added)	Qualifications	Effort in months
		NLeSC		
Team Leader	Overseeing software development, liase between software engineers and climate scientists	Wilco Hazeleger	Climate scientist and Director/CEO of NLeSC	1
Computer Scientist	Software architect	Willem van Hage	Data scientist, coordinator of database and analytics research at NLeSC	3
Computer Scientist	eScience Engineer	tbd	Scientific software engineer	10
Computer Scientist	eScience Engineer	tbd	Scientific software engineer	10
		SMHI		
Team Leader	Overseeing connections with SWICCA and user needs	Berit Arheimer	Hydrologist, head of hydrological research at SMHI, coordinator of the C3S SWICCA project on water management	1
Hydrologist	IT system manager	Ingela Oleskog	Hydrologist and Service Manager	1
Computer Scien-tist	Software engineer	Per Lewau	IT specialist	1.3
Scientist	Data processing and climate indices	Peter Berg	Climate scientist	2
		URead		
Team Leader		Bryan Lawrence		0.15
Computational Scientist	Software engineering	Simon Read		6.55

3.1 Quality of resources KNMI

KNMI has a long history in climate modelling, that goes back to the early 1990s. Since 2006 KNMI has led the European EC-Earth consortium that developed a climate model based on ECMWF's IFS. Based on the EC-Earth development, KNMI took part in many international (EU) projects in the area of climate modelling. SPECS and EMBRACE are some recent examples. Within the two ES-ENES projects KNMI participated in the development of tools to access climate model data. The climate4impact.eu website has been built largely by KNMI as part of the ES-ENES-2 project. The KNMI Climate Explorer (climexp.knmi.nl) is an internationally well appreciated and frequently used web-based climate analysis tool, disclosing a large ensemble of climate projections, reanalysis products and data sets. In 2014 it received 3000 visitors making 100.000 graphs per month. The Climate Explorer was acknowledged in 10-15 scientific publications during 2014.

Bart van den Hurk has developed a scientific career at the Royal Netherlands Meteorological Institute (KNMI) as researcher, involved in studies addressing modelling land surface processes in regional and global climate models and constructing regional climate change scenarios. He is strongly involved with the KNMI global modelling project EC-Earth, and is co-author of the land surface modules of the European Centre for Medium Range Weather Forecasts (ECMWF). He lead the FP4 project ELDAS (on soil moisture modelling) and Hor2020 IMPREX (on hydrological extremes), in addition to a number of national research projects. From 2014 onwards he occupies the chair "Climate Interactions with the Socio-

Ecological System" at Institute for Environmental Studies at Amsterdam Vrije Universiteit. Between 2007 and 2010 he was chair of the WCRP-endorsed Global Land-Atmosphere System Studies (GLASS) panel, and between 2006 and 2012 member of the council of the Netherlands Climate Changes Spatial Planning program. Since 2008 he is member of the board of the division “Earth and Life Sciences" of the Dutch Research Council (NWO-ALW). He is convener at a range of incidental and periodic conferences, and editor for Hydrology and Earth System Science (HESS). At KNMI he was a member of the Coregroup Institute Reorganisation between 2011 and 2013. He now leads the R&D department on Weather and Climate modelling at KNMI.

Andreas Sterl is a Senior Scientist at KNMI’s Climate Modelling Department. He has been working on climate modelling, especially the coupling between ocean and atmosphere models, for years. With this expertise he contributed to the development of EC-Earth. Within EMBRACE he worked on vertical ocean mixing and on the development of diagnostics for the Southern Ocean, which are now part of the ESMValTool. Aside from his work on climate modelling, he manages the Dutch Argo Programme, the Dutch contribution to the global network of ocean profiling floats.

Henk van den Brink is a Scientist at KNMI’s Climate Modeling Department. His expertise is on extreme winds and sea surges, and their statistical extrapolation to return periods beyond 10,000 years. He has experience in working with both global models (especially the seasonal forecasts of ECMWF) and high-resolution models (especially HARMONIE, the operational weather forecast model at KNMI). Together with Eindhoven University he developed a tool which calculates the extreme surge levels from the mean sea level pressure patterns over the North Sea.

Wim Som de Cerff (MSc.) is a senior developer at the R&D Observations and Data Technology division of the KNMI and has over five years’ experience leading Agile software development in R&D projects. His main expertise is on data services. He is and was work package leader and developer in research projects, active currently in SPECS, EUPORIAS, CLIPC, and IS-ENES2. He was scrum master of a team developing tools for automatic monitoring of the operational KNMI production chains using Spunk and Neo4J as a platform. Within KNMI he is Product Owner of the KNMI Data centre (data.knmi.nl), an operational service providing open data and INSPIRE compliant data services.

Maarten Plieger is Software Engineer GEO-ICT at the Royal Netherlands Meteorological Institute (KNMI). In 2008 he obtained his Master in Physical Geography from Utrecht University. He has over eight years of experience in web visualization and processing. His expertise is software development and implementing standards. Maarten is team lead of the ADAGUC GIS data visualization and dissemination software. He is an excellent developer and is highly skilled in C++, Java and Javascript. In the IS-ENES climate4impact project he builds web processing services to calculate climate indices and continues developments on the ADAGUC software. Maarten has experience with security mechanisms like OpenID, Oauth2 and x509 which are applied in ESGF, climate4impact and EUDAT.

Andrej Mihajlovski is a skilled software engineer with years of experience in Java development. After his work in commercial trading, developing trading algorithms at several companies, he decided to go back to his research roots. He is now working at KNMI, developing OGC services for the CLIPC project.

3.2 Quality of resources BSC

Virginie Guemas holds a PhD in Climate Physics from Paul Sabatier University (Toulouse), awarded the Adrien Gaussail Prize. She is head of the Climate Prediction Group at BSC-ES and an expert on seasonal to decadal climate prediction. She is member of the WCRP (World Climate Research Program) CLIVAR (Climate and Ocean Variability, Predictability, and Change) SSG (Scientific Steering Group), principal investigator (PI) of the nationally funded PICA-ICE project focused on Arctic climate predictions (2013-2015) and Work Package leader within the EU H2020-funded PRIMAVERA project focused on high-resolution and model development to be started in November 2015. She contributed to the IPCC (Fifth Assessment Report).

Albert Soret holds a PhD in Environmental Engineering from the Polytechnic University of Catalonia (Barcelona). He is head of the Services group at BSC-ES. He is a postdoc researcher with 10 years of experience in earth sciences. His research focuses on assessing the impact of climate on socio-economic sectors through the development of user-oriented services that ensure the transfer of the technology developed and the adaptation to a rapidly changing environment. He is Work Package leader within the CLIM4ENERGY project tender (Copernicus; in revision). Between others, he is participating in the EC-FP7 projects: NEWA, EUPORIAS, SPECS.

Louis-Philippe Caron is a post-doctoral fellow and the lead researcher for the hurricane activities at BSC-ES and a member of the WMO panel on seasonal tropical cyclone prediction. He is the PI of the nationally-funded RESPONS project and also participates in the EC-FP7 SPECS project. His research focuses on long-term (seasonal and multi-annual) forecasting of hurricane activity. He has also been involved with the insurance sectors for nearly 3 years.

Nicolau Manubens is the main developer, maintainer and coordinator of the developments within the s2dverification R package of high performance tools for climatic data retrieval and statistical analysis since its creation 2 years ago. He has a 5-year Computer Science degree from the Universitat Autònoma de Barcelona (UAB). He has designed and implemented a web application and its associated relational database and he has further experience with database development, HTML, PHP, CSS, JavaScript and Python in few other projects. He has experience in the use computing nodes and scheduling systems in a GNU/LINUX environment and in bash scripting and, more deeply, in R scripting language. He has gained a deep understanding of the stages in software development, as well as a valuable experience in control versioning systems, development strategies in a collaborative team and dealing with problems that require a clever data access strategy and where efficiently manipulating large amounts of data is a challenge.

3.3 Quality of resources DLR

DLR-IPA has long-term experience in Earth System Model evaluation, including pioneering work in the calculation of performance metrics, and is PI of the ESMValTool. In addition to the work in this project, the ESMValTool will also be further developed in other projects under the lead of DLR, including FP7 EMBRACE, Horizon 2020 CRESCENDO, and the ESA Climate Change Initiative (CCI) Climate Model User Group (CMUG), which will benefit the work in this project.

Dr Veronika Eyring is Senior Scientist at DLR and Head of the ESM evaluation group. She is Associate Professor at the Ludwig-Maximilians-University in Munich (Germany) and maintains a strong collaboration with NCAR as Affiliate Scientist and with the University of Exeter as Honorary Visiting Professor. Her research focuses on Earth system modelling and model evaluation with observations. She has authored many peer-reviewed journal articles and has contributed to IPCC climate and WMO ozone assessments since 2004, most recently as lead author of the climate model evaluation chapter of IPCC AR5. She is PI of the ESMValTool and involved in WCRP through her roles as Chair of the CMIP Panel and member of the scientific steering committees for CCMI, WGCM, the WDAC Observations for Model Evaluation Task Team, and the WGNE/WGCM Climate Model Metrics Panel.

Dr Axel Lauer studied meteorology in Munich (Germany) and obtained his PhD on aerosols from the Free University of Berlin (Germany). He has excellent programming skills and long-term experience in climate modelling and the evaluation of models with observations, documented in a variety of peer-reviewed publications. He is core developer of the ESMValTool. Before joining the Earth system model evaluation group at DLR, he spent five years as a researcher at the International Pacific Research Center in Honolulu (U.S.) studying clouds, aerosols and their interactions and two years at the Institute for Advanced Sustainability Studies in Potsdam (Germany) as group leader investigating the impact of black carbon and of other aerosols on air quality and climate.

3.4 Quality of resources ISAC-CNR

Jost von Hardenberg is a researcher at ISAC-CNR focusing on numerical climate modelling, geophysical flows, biosphere-climate interactions, the hydrological cycle and precipitation downscaling. He has significant experience in the management and analysis of large numerical climate datasets and is PI of several supercomputing grants (e.g. Climate-SPHINX - PRACE 2015-2016 and ECE3CLIM - ISCRA B, CINECA). He is responsible for the numerical global climate model simulations performed by ISAC-CNR. PI for ISAC in CRESCENDO.

Susanna Corti is a senior researcher at ISAC-CNR. In 2010-2013 she worked as consultant at ECMWF for the EU-funded project THOR (Thermohaline Overturning at Risk?). Before joining ISAC-CNR she spent five years at CINECA where she has contributed to a number of EU-funded projects on climate research. Her research focuses on atmospheric predictability, weather regimes, seasonal forecasting, diagnosis of low-frequency variability and systematic errors in A-OGCM integrations, large-scale monsoon circulation and term climate variability and predictability. PI for ISAC in PRIMAVERA.

Elisa Palazzi is a researcher at ISAC-CNR working on the study of the climate system and Earth-System processes, with a focus on the current and future evolution of the hydrological cycle and precipitation in mountain regions and climate downscaling/upscaling methods. Significant experience in diagnostic tools to compare data from climate models and observations. Lead participant for Italy of the Global Network for Observations and Information in Mountain Environments (GEO-GNOME), a component of GEO/GEOSS. Responsible for ISAC-CNR in ECOPOTENTIAL.

Chiara Cagnazzo is a researcher at ISAC-CNR working on climate variability and predictability and the stratosphere-troposphere coupling. She has large experience in development of Earth System Models and global scale model evaluation. She is responsible at ISAC for the global modelling activity in the EU StratoClim Project.

3.5 Quality of resources Netherlands e-Science Center

NLeSC bridges e-infrastructure, computer and data science and applications in scientific domains with high quality software solutions. NLeSC has access to SURFs national HPC, data storage and network facilities. NLeSC maintains an eScience technology platform, containing libraries, kernels etc used in science projects. NLeSC re-uses these generic software tools and tailors them to specific projects. NLeSC brings in expertise through a group of eScience Research engineers. They are experts in data management, analytics (e.g. statistics, machine learning, language processing), and efficient computing.

Prof. Wilco Hazeleger is Director/CEO of the Netherlands eScience Center and professor in Climate Dynamics at Wageningen University. He was head of Climate Research divisions at KNMI from 2006 until 2014. He worked on coupled climate processes, predictability and extremes. He was strongly involved in developing climate and sea level scenarios for adaptation to climate change in the Netherlands. He initiated and led the EC-Earth consortium that contributed to CMIP5 and will do so in CMIP6. He was involved in many FP7 projects on climate data and modelling.

Dr. Willem van Hage is Senior eScience Research Engineer at NleSC and guest researcher at the VU University Amsterdam. He obtained his PhD in computer science while working for the Netherlands Organisation for Applied Scientific Research (TNO) in 2009. He was head of research of the visual analytics tech startup SynerScope B.V. His main research topics in the past 10 years are augmented sense making, visual analytics, information integration, and semantics. He was principal investigator in the US ONRG funded SAGAN and COMBINE projects and work package leader in the EU FP7 project NewsReader and the Dutch BSIK COMMIT Metis and Data2Semantics projects, all dealing with large scale information analysis.

3.6 Quality of resources SMHI

SMHI has a designated record in global and regional climate modelling. Since 2011, SMHI is leading the development of the Earth System Model EC-Earth. Starting 2014, SMHI is leading the EC-Earth consortium. SMHI has advanced the discipline of regional climate modelling by leading the CORDEX project. In 2014 the international CORDEX office was awarded to SMHI. During the ongoing EU-EMBRACE project, SMHI was core developer of the ESMValTool, used in this project. SMHI has rich experience in stakeholder engagement and climate services.

Berit Arheimer (female) (h-index = 20), PhD and Associate Prof., is head of the hydrology research at SMHI, and expert in modelling and operationalization of tools for environmental analysis. She has over 20 years of experience in interdisciplinary research with some 50 peer-reviewed papers. She is leading a working group of 20 scientists and is national representative of IAHS, Unesco-IHP and has had several international scientific assignments, e.g. in WMO, HELCOM and OSPAR. She has long experience in climate impact assessments and is experienced as project coordinator, steering committee member, work package leader, convener of international workshops and chair of regular international working groups.

Ingela Oleskoug (female), Master of Science in Hydrology, currently working as IT System manager and team coach for the three main systems that are used for collecting observations to SMHI and transmitting observations to WMO countries over the GTS. She has ten years of experience in working with IT design at the interface between database migration and user requirements in meteorology and for operational hydrology.

Per Lewau (male), Master of Science in Computer Science, with more than 15 years of experience in software development and web architecture. He is currently working as team leader for development of web-based visualisation tools for water and climate assessments at

SMHI. Has been responsible for tool development in several EU projects and for the Swedish implementation of the Water Framework Directive, where SMHI develops web-based tools for water management to Water Authorities.

Peter Berg (male), PhD in Earth sciences, has been working with developing global and regional climate models, and in multiple collaborations with impact modellers, developing and applying bias correction methods, and investigating precipitation characteristics at multiple scales. Thereby, he has a long experience in producing data for impact modellers, as well as communicating specifics and uncertainties of the provided data.

3.7 Quality of resources URead

The Department of Meteorology at the University of Reading (URead) has received the highest research rating of 5* in all UK Research Assessment Exercises, indicating an international reputation in all aspects of research.

Bryan Lawrence leads both the Centre for Environmental Data Archival at the UK Science and Technology Facilities Council, STFC, and the Models and Data Division at the UK National Centre for Atmospheric Science (based at the University of Reading). He is an acknowledged expert on data management, with a background in climate modelling and earth observation. He was one of the prime originators of the Earth System Grid Federation, led the case for the UK JASMIN supercomputer, and was on the project working team that procured the UK ARCHER supercomputer. He has been working on integrating data and compute services for nearly twenty years, with experience in grid computing, cloud computing, linked data, ISO and OGC standards, and many other relevant technologies.

Simon Read has worked as a software engineer on various scientific projects since completing his PhD at the University of Sheffield in 2010, including a post-doctoral research position at Imperial College London where he designed and built a biomechanical application in C++/Eigen3. Simon joined the climate science community in 2014 as a core member of the UK Earth System Model team, based at Reading. There he is developing climate model evaluation software in collaboration with the UK Met Office, Plymouth Marine Laboratory and others. He is also familiar with the data backend of ESMValTool, part of work package 3.1, having coupling it to the ESGF.

4 Technical solution

4.1 Summary

The requested output of this ITT is software to calculate and present metrics, statistics, time series, and some products tailored to applications from climate model data. We propose to implement such software on the existing climate4impact platform (*36*). In this way we can show developments to users and receive feedback. The developed services will be deployed on the CDS once it becomes available. The software will be built on existing tools from the KNMI Climate Explorer (*34*) and the ESMValTool (*12*) which, as part of this work, will integrate the s2dverification package (*32*), and elements of the UK Met Office AutoAssess software, for a comprehensive calculation of performance metrics and other products. The software design is modular and portable, and allows migration to other platforms and interfaces, most important being CDS.

4.2 Background

The *"[...] Climate Data Store (CDS), [is] a distributed facility for providing information about past, present and future climate in terms of Essential Climate Variables and derived climate indicators*" (*26*). It is intended to hold and/or give access to a great variety of climate model data and enable interactive calculation of derived variables. The purpose of this tender is to develop such software. The software has four major components:

1. A user interface through which the user states which calculation they want to be performed, and through which the result is presented (in graphical and numerical form),
2. An interface to the CDS through which the data sets necessary for the fulfilment of the request are obtained,
3. A layer in which the data sets are prepared. This especially includes the interpolation to a common space/time grid if more than one data set is involved, and
4. A set of routines that perform the required operations on the data sets.

The climate4impact (*36*) portal has been developed as part of the IS-ENES FP7 project. It contains a faceted search interface to a variety of climate model data, most notably those available via the ESGF nodes (CMIP5 data). It is possible to visualize and calculate climate indices, but not to perform sophisticated data manipulation operations. It also provides users with a secured workspace, where they can download and upload data, watch the status of running jobs, and start new processing jobs. Two screenshots from the climate4impact user-interface are shown in Figure 2.

The KNMI Climate Explorer *(34*) holds copies of many data sets (observations and model) and allows for a large variety of data manipulation and investigation. However, the amount of data that can be held is limited, and the visualization is basic.

The ESMValTool (*12*) is a set of diagnostics and performance metrics that allows for routine comparison of single or multiple CMIP models, either against predecessor versions or against observations.

s2dverification (*32*) is a package publicly available from the Comprehensive R Archive Network. It holds tools to assess model performance in terms of mean state, seasonal to decadal variability and ensemble spread. Both ESMValTool and s2dverification have to be installed on the user’s computer.

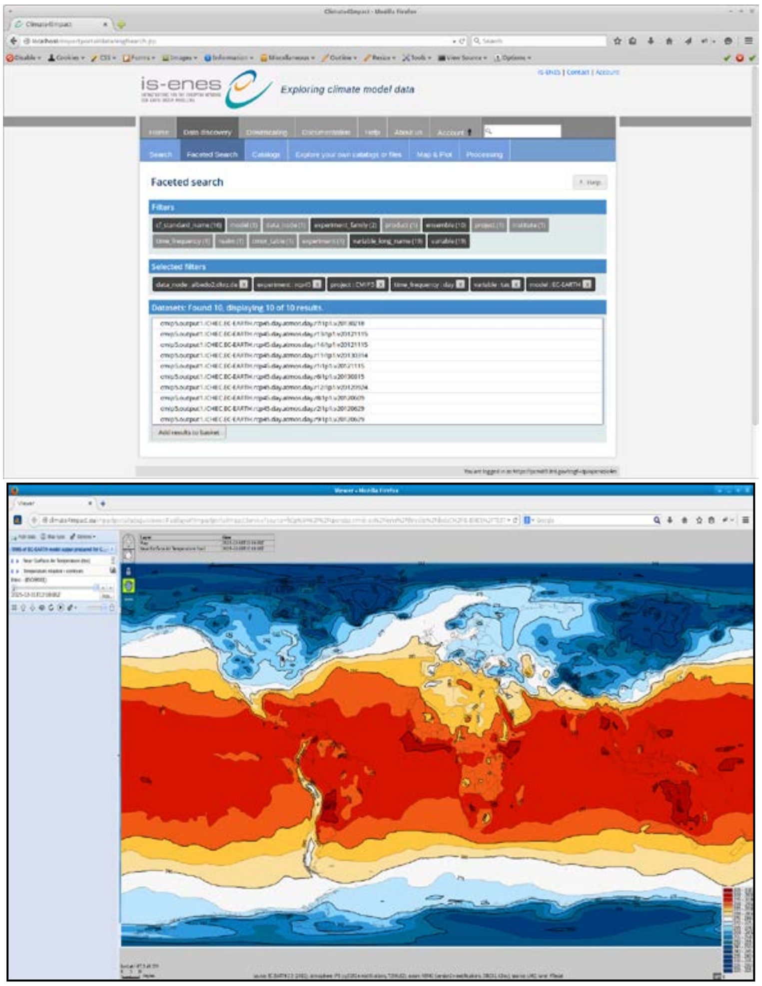

FIGURE 2: SCREENSHOTS OF THE CURRENT CLIMATE4IMPACT.EU PORTAL, WHICH WILL FORM THE BASIS OF THE USER INTERFACE OF THE SYSTEM AND WILL BE EXTENDED TO ACCOMMODATE NEW METRICS (E.G. FROM ESMVALTOOL AND S2DVERIFICATION).

Auto-Assess complements the ESMValTool performance metrics by assessing key underlying processes (e.g. (*31*) and (*20*)) as well as high-level performance metrics of the type proposed by (*28*). Auto-assess is currently being re-written in Python using the Iris package (*35). It* will be released in 2016. We intend to combine elements of Auto-Assess with ESMValTool, which will give the combined benefits of the global reach of ESMValTool with the wide range of diagnostics/ metrics in Auto-assess and supported backend in Iris.

4.3 Overview of required deliverables

The call asks for five deliverables (see Table 4). Four of them are software tools, while the fifth is the organization of a workshop together with the Lot-1 tenderer to organize the interactions between the two lots.

Three of the four software deliverables (D2.2-D2.4) are interactive tools, while one (D2.1) is intended to be run once-and-for-all on the climate model data sets available in the CDS. As a result a set of metrics will be available for each of the models as a new set of metadata. We here propose to build this deliverable using the same techniques as for the other three, but restrict access to authorized persons. The results are stored along with the models and are displayed to the interactive user on request: a click on an icon next to the name of the data set will display a page with the corresponding scores.

TABLE 4: OVERVIEW OF DELIVERABLES ACCORDING TO THE CALL AND RELATED TASKS.

del. no. (ITT)	Description	Characteristics & activities needed	Contributing deliverable from the work packages (work packages: see section 6)
all	software architecture	• interface with lot 1 • define data flow • user interface	D2.2, D3.1, D3.2, D3.3
D2.1	software to compute set of metrics	• collect/define metrics • develop software • apply metrics	D3.1, D3.2, D4.1, D4.4
D2.2	software to compute generic multi-model products	• interactive tool • define generic products • software to compute products	D3.2, D3.3, D4.2, D4.3, D5.1, D5.2, D5.3, D5.4, D6.3
D2.3	software to compute time series	• interactive tool • software to compute time series	D3.2, D3.3, D4.3, D6.1, D6.2, D6.3
D2.4	tailored software	• identify user needs • interactive tool • develop software	D3.2, D3.3, D4.3, D7.1, D7.2, D7.3, D7.4, D7.5
D2.5	organize workshop	• keep interface with Lot 1	D2.1

4.4 Software Architecture[1]

4.4.1 Development management

Requirements for the software interfaces with Lot 1 and the user applications (Deliverables D2.1-D2.4 of the ITT) will be gathered at a workshop jointly organised with Lot 1 (see WP2). Incremental changes to these requirements will be gathered at subsequent video conferences and face-to-face meetings between consortium partners to synchronize development between WP3/4 contributors and WP5-7. On top of this twice a year a (virtual or face-to-face) collaborative development sprint session will be organized between software developers for an accelerated development towards the end product (see also Section 5).

Creating the envisioned architecture while interacting with developments in WP4-7 and Lot 1 calls for an Agile[2] (38) approach. As we are not co-located, standups will be done by

[1] In this and the following sections we frequently refer to the work packages into which the work will be divided. The work packages are described in section 6.
[2] Agile Software Development is a set of software development methods in which requirements and solutions evolve through collaboration between self-organizing, cross-functional teams. It promotes

phone at a regular interval. This interval will be weekly or bi-weekly. Within WP3 we will have regular coding sprints, planned when needed and appropriate. We also plan two day coding sprints with Lot 1 to test the Docker deployments and data access. During the joint Lot1/Lot2 workshop we can decide on the frequency of these coding sprints.

Since 2001, Agile development and Scrum (a form of Agile development) in particular have revolutionized software development and in many context provided solutions to improve successful product development. We believe that the proven concepts and principles behind Agile & Scrum, such as transparency, empirical process control, iterative and incremental development and self-managing teams are critical for successful product development and delivering the fit-for-purpose solutions.

4.4.2 Software design choices

A central design choice for software developed in Lot 1 and Lot 2 is to bring the calculation to the data, instead of downloading data dumps and performing calculations locally. This implies that the software developed for Lot 2 will run on the same infrastructure as Lot 1. This is further illustrated in Figure 1 in Annex 1.

A number of design decisions will thus be made in Lot 1 that have to be followed in C3S-MAGIC, regardless of their implementation. A number of assumptions are made about the forthcoming design of the Lot 1 infrastructure. These assumptions include:

- Lot 1 will use a container/virtual machine-based design and the chosen implementation of this will be Docker;
- The access and invocation systems that will be used will be based on HTTP and standards build on top of that, such as the Open-source Project for a Network Data Access Protocol (OPeNDAP) and Open Geospatial Consortium standards Web Processing Service (WPS), Web Mapping Service (WMS) and Web Coverage Service (WCS);
- The main data exchange format will be NetCDF.

In a large scale computing infrastructure with multi-tenancy, such as the one we assume Lot 1 will provide, there is a strong need for user access control, both for reasons of security and for resource management. We will conform to the design decision made about security and access control protocols and technology made in Lot 1.

All code will be kept in GitHub for version control and distribution to all the tender partners and external parties.

We will use and contribute to existing open source software projects (e.g., ESMValTool, Iris, recipy, climate explorer, s2dverification, etc.) whenever possible, instead of developing software from scratch.

We will build on existing project results, such as climate4Impact.eu, ESGF, the ESMValTool community effort, and functional utilities currently present in the KNMI Climate Explorer and s2dverification.

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adaptive planning, evolutionary development, early delivery, continuous improvement, and encourages rapid and flexible response to change.

All software will be submitted to unit tests, regression test, built tests and continuous integration tests. End-to-end user tests will be performed in collaboration with WP5-7.

For development and testing purposes, it will be enabled to run tasks developed by WP4, WP5, and WP6 as stand-alone command line tools on a local machine by means of Docker containers.

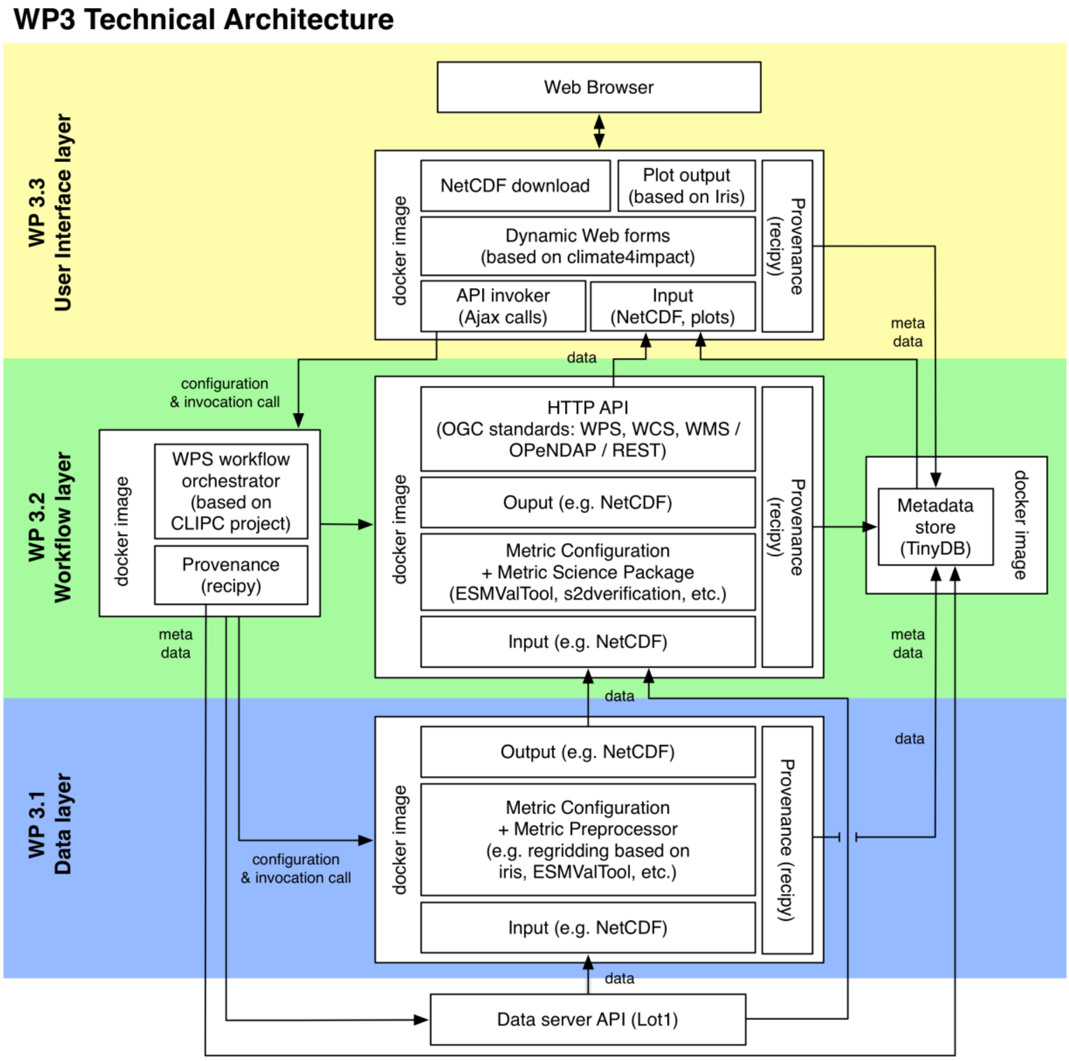

FIGURE 3: OUTLINE OF THE TECHNICAL ARCHITECTURE. FOR ACRONYMS SEE ANNEX II.

4.4.3 Software architecture overview

WP3 is subdivided in three tasks, each developing a layer of the Lot 2 infrastructure. The architecture of the layered infrastructure is shown in Figure 3. WP3.1 (blue in Figure 3) will develop a layer responsible for reading data from the data sources provided by Lot 1, and performing pre-processing steps that are necessary for subsequent tasks. WP3.2 (green in Figure 3) will develop an orchestration layer and invokes the metrics, time series, multi model, and tailored calculations developed in WP4-7, and keep provenance trails of each invocation. WP3.3 (yellow in Figure 3) provides the user interface that allows the user to invoke tasks, view and download the results, and inspect the provenance. This user interface will be tested and deployed in the climate4impact.eu portal. In the portal specific widgets will be added to request feedback from the users. This will be used as input for continuous improvement of the software system. Climate4imapct provides access to the data in ESGF, which will be used until the solutions from Lot 1 become available.

A more detailed description of each task is given in section 6, Table 16.

4.5 Metrics

Metrics of performance measure different aspects of model-data correspondence. This can be a simple distance (bias), a measure of variability, or the correspondence between patterns. They can take the form of a single number, a map of performance numbers or a diagram, and it can apply to daily, monthly or annual time scales. Several metrics have been proposed in the literature, and a lot of them have been incorporated in the ESMValTool, the s2dverification package, and other software packages. Table 5 contains a list of metrics that we will implement in the ESMValTool in the context of C3S-MAGIC. Some of them will be ported from other packages. In case of duplicates (metrics present in more than one package) the partners will choose the most suitable implementation by consensus. The final metrics package can be routinely run for either the historical simulation (EH1: Historical ensemble, 1850 to at least 2005, imposed changing concentrations and forcings) or the AMIP simulation (EH2: AMIP ensemble, 1979 to at least 2008, prescribed SST and sea-ice concentration, other forcings as in Historical ensemble above).

While a metric is intended to measure model quality, an index (see Section 4.6) is intended to express a certain state of the model. A clear separation between “metric” and “index” is not always easy to give. The lists in Table 5 and Table 6 may be adjusted when appropriate.

TABLE 5: LIST OF METRICS TO BE PROVIDED. REGION-SPECIFIC METRICS CAN BE COMPUTED BASED ON USER-SPECIFIC REQUIREMENTS FORMULATED IN WP7.

Name and responsible partner	Description	Characterises	Form
RMSE [DLR]	Error-variance for several variables	Climatological variable-specific model-data variance distance for the global domain and selected regions (including “all land”) at different temporal resolutions	Single number per model and variable calculated against different observational datasets or reanalyses if available
Mean bias [DLR]	Error-variance for several variables	Climatological variable-specific model-data mean distance for the global domain and selected regions at different temporal resolutions	Single number per model and variable calculated against different observational datasets or reanalyses if available
Taylor diagrams [DLR]	Standard deviation and correlation	Polar grid plot where the radial coordinate refers to the standard deviation of the model and the angular coordinate is defined by the inverse cosine of the correlation between model and observation	2D plot displaying, for each model and each variable, the distance to a reference (obs or reanalysis)
Reichler-Kim [DLR]	Error-variance, aggregated across selection of variables	Climatological overall model-data distance (not variable-specific)	Single number per model

Name and responsible partner	Description	Characterises	Form
Major modes of climate variability [DLR]	Correlations/RMS Differences	Metrics for ENSO, AMO, PDO, NAM, SAM, SST, PSL and PR sigma as well as a mean score	single value per model and per mode of climate variability plus mean score
Teleconnection patterns [BSC]	RMS between observed and modelled patterns of variability modes obtained through classification methods. Examples: Weather Regimes in the North Atlantic and North Pacific regions, sea ice modes clusters, etc. (*15*)	Representation of teleconnections in several regions through classification methods. This metric informs users which model is the best in their region and process of interest.	single value per model and per pre-defined mode/region
Reliability of model large-scale variability spectra [BSC]	Relative bias in the percentage of occurrence and the persistence of each mode obtained through a classification	Representation of the spectra of variability in several regions	Single-value per model and per mode/region
Blocking indices [ISAC-CNR]	Mono and bi-dimensional blocking indices (*7*)	Extra-tropical atmospheric climate variability and large scale circulation	Longitudinal profiles and spatial maps.
Stratosphere-troposphere coupling [ISAC-CNR]	Zonal-EOFs of the daily averaged, zonally averaged, year-round geopotential height	used to identify surface patterns that are the most connected with stratospheric variability: the spatial patterns and indices of the NAM and the SAM (*3*)	Area-weighted spatial correlations of NAM/SAM patterns between models and reanalyses at different altitudes

In addition to the metrics listed in Table 5, the AutoAssess utility contains a number of specific metrics to express model skill for reproducing particular modes of climate variability or flow patterns (such as African Easterly Waves, the Madden-Julian Oscillation, aerosol patterns, conservation of mass and energy, storm tracks and stratospheric variability). Some of these metrics will be incorporated in the C3S-MAGIC system, to be decided later. Many of these metrics can also be generated for specific domains and time periods, to meet user demands as formulated in WP7.

The metrics will be applied to the climate model output available in the CDS. This task involves the collection of the relevant input data (observations or reanalyses). They will be stored in the CDS. If available, data sets already in the CDS will be used. For each of the assessed models a score table containing the values for each metric will be provided. Together with an explanation of the metric's scope, this table will enable the user of the climate model data to make an educated choice of the models most suitable for his/her purposes.

To apply the metrics efficiently to a lot of model runs a (semi-)automatic system is needed. The system will make it easy to

1. compute the metrics for a newly available model run;

2. re-compute the metrics for existing runs if new (better) observations/reanalyses become available;
3. add new metrics;
4. (re-)compute metrics for different (historical) time periods.

In all cases, the score-card will be generated automatically as an HTML page that is associated with the corresponding model run.

The system to calculate the metrics will be integrated with the interactive tool for model assessment that is developed as the second deliverable of this call (next section).

4.6 Multi-Model Climate Indices

Climate indices represent diagnostic quantities which allow to characterize the mean state, variability and dynamics of the climate system and to characterize climate changes at a global and at a regional scale. Changes in particular in the statistics (such as frequency and severity) of extreme events can potentially have a significant impact on ecosystems and human activities.

Multi-model time series of climate indices will be available either after averaging the fields from different models on a common grid or by combining time series computed on each model individually. As both methods have their pros and cons, the user will be given the choice. Box-plots are used to provide a graphical representation of the distribution for multi-model indices, potentially including the display of percentile bands. Different combinations of indices from subsets of models (including options to base these subsets on weights provided by the metrics; WP4) will be enabled.

TABLE 6: CLIMATE INDICES TO BE IMPLEMENTED.

Name and responsible partner	Description	Characterizes	Form
Global and regional averages [ISAC-CNR, BSC]	Global and regional averages of the main climate variables, including ECVs and mass and radiative fluxes. Dynamical indices such as the QBO zonal wind index based over averages in given latitudinal bands.	Global diagnostics of model state and variability	One time series for each model, ensemble average and box-plots or percentile bands for a model ensemble.
Pre-defined indices [ISAC-CNR, BSC]	Pre-defined indices, such as the NINO 3.4 SST anomaly, SOI and teleconnection indices such as NAO, based on differences between anomalies averaged over regions.	Model variability, circulation modes, teleconnections	One time series for each model, ensemble average and box-plots or percentile bands for a model ensemble.
User-defined climate indices [BSC]	User-defined selection of combination of regions, variables and operation, including option to apply weights in these operations, and applying block averaging or running means.	Any characteristic of mean state, variability, or teleconnection requested by the user.	One time-series per model

Name and responsible partner	Description	Characterizes	Form
Multi-model Indices [BSC]	User-defined averaging of individual model indices applying user-selected weights that could come out of Performance Metrics from WP 4.	Any characteristic of the mean state and variability, or teleconnection requested by the user.	One time-series for the multi-model ensemble.
Teleconnection indices [ISAC-CNR]	Teleconnection indices based on Principal Component Analysis, consistent with metrics defined in WP4.	Teleconnection patterns, atmospheric circulation modes	One time series for each model, ensemble average and box-plots or percentile bands for the ensemble.
ETCCDI Extremes [ISAC-CNR]	Descriptive indices of extremes defined by the Expert Team on Climate Change Detection and Indices (ETCCDI)(*10*).	Characteristics of extremes, including frequency, amplitude and persistence. They allow to gauge changes in weather and climate extremes.	Spatial maps of time averages and time-series of averages over user-selected regions. Ensemble average and box-plots or percentile bands for a model ensemble.
HY-INT [ISAC-CNR]	Measure of hydro-climatic intensity, integrating metrics of precipitation intensity and dry spell length (*17*).	Changes in the hydrological cycle.	Spatial maps of time averages and time-series of averages over user-selected regions. Ensemble average and whisker plots for a model ensemble.

Trend calculation will be provided for climate indices time series, with evaluation of significance compared to the null-hypothesis of no trend. In addition to standard significance tests, Monte Carlo methods (such as time-shuffling) can be implemented.

Variables will be prioritized following the concept of GCOS *Essential Climate Variables* (5). Table 6 lists indices which will be implemented. Note that some indices overlap with the metrics as listed in Table 5. As for the metrics, the partners will choose the most suitable implementation by consensus in case of duplicates (indices present in more than one package).

4.7 User Requirements and Tailored Products

C3S-MAGIC will provide products tailored to the needs of the coastal (KNMI), water (SMHI & ISAC-CNR), insurance and energy (BSC) sectors. A list of products to be implemented is given in Table 7.

TABLE 7: TAILORED PRODUCTS TO BE PROVIDED.

Name and responsible partner	Description	Characterizes	Form
Surge [KNMI]	Height of storm surge along North Sea coast	Water level at coast	One time series per model for each coastal point

Name and responsible partner	Description	Characterizes	Form
Wave Height [KNMI]	Wave height along North Sea coast	Wave heights	One time series per model for each coastal point
ETCCDI extremes [ISAC-CNR]	Indices of extremes defined by ETCCDI	Frequency, amplitude and persistence of extremes	One spatio-temporal field per model for selected study areas
Stochastically downscaled precipitation [ISAC-CNR]	Precipitation, downscaled using the RainFARM technique, for selected study areas/basins	Extreme precipitation, subgrid-scale variability and uncertainty	Ensemble of spatio-temporal fields of high-resolution precipitation for selected areas. Multiple stochastic realizations per model.
Time series of data relevant for the water-sector [SMHI]	precipitation, snowfall, temperature, evapo-transpiration, relative humidity, solar radiation, wind	Water-management related variables	Time series for given area in defined format
Drought indicator [SMHI]	Change in number of consecutive dry days (CDD) (or other drought related climate index)	Drought risk	One transient time series per model + multi-model estimate of future change in CDD
Capacity factor of wind power [BSC]	Ratio of average estimated power to theoretical maximum power	Wind power generation	Multi-model spatio-temporal fields at global and regional scale
Heat waves [BSC]	Episodes of abnormally hot weather which may be accompanied by high humidity	Frequency and amplitude of extreme hot events	Multi-model spatio-temporal fields at global and regional scale
Cold spells [BSC]	Wintertime episodes of cold weather	Frequency and amplitude of extreme cold events	Multi-model spatio-temporal fields at global and regional scale.
Actuaries Climate Risk Index [BSC]	Risk index that reflects changes in frequency and magnitude of key climate indicators and elements of hazard, exposure and vulnerability	Comprehensive index containing socioeconomic information serving the needs of actuaries and stakeholders	Multi-model spatio-temporal fields at global and regional scale.

4.7.1 User Requirements

The C3S-MAGIC consortium includes partners that are involved in Sectoral Information System (SIS) tenders (contracted or currently in revision): BSC for insurance (under revision) and energy (CLIM4ENERGY), SMHI for water (SWICCA) and sustainable cities (UrbanSIS), and KNMI for coastal activities (WISC). The relation between C3S-MAGIC and SIS and the position of the user cases considered in the C3S-MAGIC are depicted in Figure 1. The C3S-MAGIC software must serve the users, and the tailoring of the climate projection output products produced in WP4-6 requires careful interaction with experts in the fields of interest.

User consultation is a key element in the SIS projects and is not duplicated in C3S-MAGIC. Instead, two rounds of user consultation will be held in conjunction with the user requirement inventory activities carried out in the SIS tenders. One round is aimed at the broad scientific audience to inventory their wishes for generic and general-purpose products. The second one will be targeted at the specific sectors addressed in WP7. Through their contacts with relevant parties from the specific sectors the partners will take an inventory of their needs and wishes. A list of relevant contacts from the partners' networks, both within and outside the context of the various SIS projects, is given in Table 8. Detailed descriptions of the sectoral surveys are given below.

TABLE 8: SECTORS AND USERS THAT WILL BE INVOLVED IN THE PROJECT TO DEFINE USER REQUIREMENTS

Sector	Copernicus or EU Project(s)	Involved partners	No. of case studies	No. and Type of organisations involved*	European countries involved
Coastal Areas	WISC	KNMI	5	2 UN, 1 RI, 3 SME	UK, NL
Water Management	SWICCA	SMHI, ISAC-CNR	14	5 SMEs, 2 PB, 2 RI, 5 UN	AT, DE, GR, IT, NL, SP, SE
Energy	Clim4Energy, NEWA	BSC, SMHI,	5	3 PB, 3 RI, sev UN	FR, SP, GB, DE, IT, SE, FI, NO Pan-European domain
Insurance	WISC; SECTEUR (C3S-52, under revision)	KNMI, BSC			NL, UK, SP
Sustainable Cities	UrbanSIS	SMHI	3	Sev UN, PB, RI	IT, NL, SE
Impact Research	EUPORIAS, SPECS, SWITCH-ON, IMPREX, PRIMAVERA	KNMI, SMHI, BSC	1-10	Sev UN, PB, RI	Pan-European domain

* UN = University; RI = Research Institution, PB = Public Body, SME = Small/Medium Enterprise

4.7.2 Coastal sector

KNMI will deliver software that translates climate model output into (hourly) time series of sea surge and sea water level for a large number of coastal stations around the North Sea. The time series is derived from the evolution of the MSLP patterns within a user-defined area. The connection between the MSLP patterns and the surge levels are derived by decomposing the MSLP into the most dominant patterns (via EOFs), which are subsequently linked to the surge levels by multiple linear regression. The regression coefficients are derived from observed MSLP patterns (e.g., ERA-Interim) and observed surge levels at the coastal stations.

The advantages of this approach are that it gives good results for extreme surge levels, is computationally fast, rather insensitive for variations in spatial resolution, independent of the model-specific parameterization of the 10m wind speed, and requires only limited knowledge of the end-user about the relation between surge and wind. This makes this tool very appropriate to get a first impression for a possible climate signal in extreme sea surges for the North Sea directly from climate model output, without the need to run extra models.

Intercomparison of observed and modelled return levels of the (skew) surge may help to quantify the models' ability to generate extreme synoptic-scale depressions.

The WISC project is designed to provide information on storm damage. In that project is KNMI involved in the generation of adequate storm data derived from historical archives and climate projections. Interactions between WISC and C3S-MAGICS will benefit both projects.

4.7.3 Water/hydrology

C3S-MAGIC will identify software requirements for water management based on user requests in the on-going work of C3S-SIS for water management (the SWICCA project). The user requests in SWICCA will be derived from a survey including 15 case-studies across Europe, dealing with water management related to water allocation and drought (in Spain and Italy), Risk management of floods (in Austria, Slovakia and Sweden), Ecological status (in Greece, Italy and Sweden) and Industrial use (in Greece, Germany, The Netherlands and Sweden). The case-studies for water management cover potential future changes in, for instance, withdrawals permissions, impact-based forecasts, hydropower regulation schemes, biodiversity, or drinking water supply.

Thus, specified tailoring is needed for the climate projections to be directly useful in water management applications, which also includes content and functionality of metadata catalogues for efficient data search. In SWICCA this work is made manually at present while waiting for the C3S-MAGIC software. The C3S-MAGIC software should assist water and environment consultancies across Europe in: (1) finding relevant existing dataset, (2) selecting a domain and a time-period, (3) extracting specific variables, (4) quality assurance, and (6) re-formatting the variables to self-explanatory (incl. metadata and linkages to source data) ASCII files or excel (which is often used by water managers) for direct download. Additional functionality would be (6) bias correction towards observations, (7) quality specification of data suitability for different purposes (e.g., which variables are more reliable than others in each projection or among projections). Main variables of interest for applications in water management and policy are precipitation (all kinds merged), snowfall, temperature, evapotranspiration, relative humidity, solar radiation and wind. The C3S-MAGIC software will include functions to display transient time-series of these variables in absolute terms, but also with metrics of relative change between optional time slices (i.e. future conditions vs present) of their annual cycle.

Evaluating the impact of changes in water-related risks at local scale, such as hydrological risks, wildfires and local impacts on ecosystems and protected areas, will require the development of further specific study cases. For instance, to allow the estimation of impacts associated with changes in extremes, the use of descriptive indices of extremes defined by ETCCDI (*10*) will be explored, in collaboration with local users and agencies. Direct contacts with end-users and assessment of user needs in protected areas being developed in the H2020 ECOPOTENTIAL project will be leveraged.

The problem of downscaling climatic information to the needed local scales will be addressed using a simple stochastic precipitation downscaling technique developed at ISAC-CNR (RainFARM; (*27*), (*9*)), which has been implemented as a postprocessing tool. It provides high-resolution precipitation data from coarse scale GCM information, and allows a more realistic representation of sub-grid precipitation variability and of precipitation extremes, crucial for impact studies in the water sector (*16*).

4.7.4 Energy

The ability to anticipate with accuracy the variations in energy supply and demand is essential to stabilize, strengthen and secure the energy network as a whole. The demand of electricity is highly sensitive to temperature. While cold spells during winter months represent high-risk periods for energy security in northern Europe, in southern Europe hot spells during summer months are the source of high risks to the stability of the energy network. On the supply-side the integration of renewable energies into the energy mix across Europe has added a resource that is dependent on the highly variable climate. Today, wind power provides the greatest share of renewable energy supply in Europe. Hence, the dependence of the energy network on the fluctuating climate system requires the capability to continually adjust energy supply and demand.

Thus there is a need to further tailor, validate, harmonize and improve the presentation and communication of climate information for the past and the future to the energy users. Energy-significant climate extremes are provided, including temperature related climate variables that are indicators for supply security and network stability, and indicators for renewable energy sources (wind power). Multi-model ensembles from re-analyses and climate projections will be processed in a range of future conditions supporting planning operations.

4.7.5 Insurance

In an insurable context, extreme events are those impacting property and people the most. These extreme events can take several forms: storms, heavy rainfall and flooding, heat waves and drought. In Europe, hydro-meteorological events (storms, floods, and landslides) account for more than half of the reported damages due to natural disasters since 1980, followed by extreme temperatures, droughts and forest fires (*11*). Because insurance is under-written on an annual basis, insurers have traditionally used historical records of past events to inform current risks. However, this practice is beginning to change as climate change is projected to significantly affect the regularity and intensity of extreme events. Changes in odds and/or characteristics in these extreme events are of great interest to the insurance industry because even slight changes can translate into large impacts on risk distribution/ management and expected losses due to large, global risk exposure.

In the insurance sector erratic statistics of extreme events dominate the risk assessment of loss of property and people. The Actuaries Climate Risk Index (ACRI) (*6*) combines elements of hazard, exposure and vulnerability into a risk index. Climate data are inputs to the hazard component of ACRI. Further combination with local property and vulnerability information leads to assessments of transient evolution of the ACRI.

4.8 Methods

WP4 will use ESMValTool version 1.0 (v1.0), so this is also a natural starting point for the backend developed in WP3. To increase efficiency and flexibility, the ESMValTool data backend will be re-engineered in fully object-oriented python. This will make use of Iris (*35*), in addition to some basic NetCDF libraries, and will then serve as the data backend for the entire project (WP4-7), providing pre-calculation of derived variables and conversion of data to a common grid. The use of the Iris climatological python library in the data backend will be a major improvement, replacing the current NCL variable derivation scripts that are cumbersome to launch from python. Iris is a fast developing and well supported python library, managed by a large development team at the UK Met Office. The clean, simple programming interface provided by Iris will make the backend code simpler and easier to maintain. Iris has integral regridding tools, but we will supplement them with ESMF regridding (e.g., *37*) where required.

The s2dverification package (*32*) is a highly modular and flexible set of functions which aims at loading model and observational data from any database in a configurable way, assessing model performance in terms of mean state and variability on seasonal to decadal timescales and displaying them. s2dverification is open-source software in which the developments from any user can be incorporated after a thorough quality check following a merging procedure controlled by the maintainer, Nicolau Manubens. New functions are frequently being included and strong efforts are on-going on the profiling and optimization of these functions.

Traceability and provenance are important aspects of a (pre-)operational evaluation of CMIP models with observations (WP4) and the provision of user-derived products (WP5-7). To document the processes involved, information needs to be catalogued describing the models, observations and versions of the tool used for evaluation (WP4) and for the calculation of other derived products (WP5-7). In this way a record will be preserved and the evolution of a model's performance and derived products can be tracked over time. In WP 3 we will work on appropriate log-files that contain all the relevant information of a specific call of the main script: creation date of running the script, version number, analysed data (models and observations), applied diagnostics and variables, and corresponding references. This helps to increase the traceability and reproducibility of the results. This provenance information will be stored in a central meta data database using the Python package recipy, as well as recorded in the history field of the output NetCDF data.

The technical principles of the software and database structure are discussed in Section 6 and WP3.

The general features of the analysis methodology that is implemented in the C3S-MAGIC facility consists of the following elements:

- Gridding and missing data treatment: standard software from Iris and ESMF will be used to perform spatial interpolation to a common grid, which is to be defined in conjunction with Lot 1. Common time axes will be defined for all data sets, distinguishing between monthly (common averaging procedure) and daily (taking Julian calendar as reference) time axes. Missing data (from observational data sets) are flagged and treated as is implemented in the KNMI Climate Explorer
- Calculation of metrics: performance metrics will be generated for global and regional domains. Methods are as currently implemented in ESMValTool, s2dverification and Climate Explorer. A list of metrics is discussed in Section 4.5.
- Generation of multi-model products: an important functionality of the C3S-MAGICS facility is the selection and (weighted) combination of results from multiple models into a single index or time series. A selection of climate models and time slices can be applied, based on global or regional performance metrics or other predefined selection criteria, such as underlying RCP, or global climate indicators (such as global mean temperature or sea level rise). Climate indices and time series are computed for this selection of models, and averaged according to a flexible weighting algorithm. Further details are provided in the description of WP5. A list of multi-model climate indices is discussed in Section 4.6.

- Tailored products: further postprocessing of GCM-based climate indices or time series is required for tailoring this information to users' needs. The C3S-MAGIC software will provide a number of demonstration applications (see Section 4.7 and WP7), but will not contain the flexibility to accommodate all possible post-processing steps that may be required for future users.

4.9 Equipment to be used

Table 9 provides an overview of the basic equipment and its functions that will be used to carry out the activities listed in this tender.

TABLE 9: EQUIPMENT (INCLUDING HARDWARE AND SOFTWARE) TO BE USED FOR PROVISION OF THE SERVICE

Equipment	Describe Relevant Function	List each WP for which equipment will be used
KNMI		
Workstations	Software development	WP 3, WP 6, WP 7
Software	Visualisation	WP 3, WP 6, WP 7
BSC		
Workstations	Software development	WP4, WP5, WP6, WP7
Software	Metrics, indices, etc.	WP4, WP5, WP6, WP7
DLR		
Workstations	Software development	WP3, WP4
Software	ESMValTool	WP3, WP4
ISAC-CNR		
Workstations	Software development	WP4, WP5, WP6, WP7
Software	Metrics, indices, etc.	WP4, WP5, WP6, WP7
NLeSC		
Workstations	Software development	WP3
Software		WP3
SMHI		
Workstations	Software development	WP7
Software	Metrics, indices, etc.	WP7
URead		
Workstations	Software development	WP3, WP4
Software	ESMValTool, Iris, etc.	WP3, WP4

5 Management and implementation plan

5.1 Project Management

The project is managed and administered by KNMI. The management structure contains an overview of responsibilities, interaction across the consortium and with external stakeholders, a monitoring/reporting protocol, and risk management issues.

5.1.1 Overview of project entities and responsibilities

KNMI is the Tenderer of the project, and coordinator of the consortium and its activities. Contracts with individual partners will be formulated, in which the tasks and responsibilities of each partner will be arranged. The responsibilities for every individual partner are listed in section 6. This includes responsibilities for components of the software and other project deliverables, tasks in the work packages, and interfacing with other software platforms, data sources and users. In case of non-compliance a few steps will be followed. First, solutions will be sought by discussing directly with the partner involved. If this does not work, it will be discussed within the whole C3S-MAGIC consortium whether a transfer of tasks to (an) other partner(s) is possible. In case of structural long-term problems, the contractor may decide to replace the partner after consulting all other partners and ECMWF.

The responsibility for the deliverables of the project (section 6) is charged to the leaders of the work packages in which the deliverables are created. This responsibility includes timing of delivery, functional completeness and quality. This responsibility will be described in the sub-contracts with the individual partners.

Although the formal responsibility for the project and its deliverables is carried by the Tenderer, a Project Board will be installed in which all individual partners are represented by a single person. This Project Board will advise the coordinator on the following issues:

- a change is proposed in the subcontractors working on the Service;
- a change is proposed in the deliverables or other parts of the Service;
- a conflict has occurred (or is likely to occur) with one of the subcontractors;
- ECMWF has not accepted the deliverables or has informed the Contractor about a non-compliance in the Service.

KNMI will introduce the project management web application *Redmine* (*39*) to schedule and monitor the work, and to develop the deliverables together with all subcontractors. KNMI will appoint a "service manager", who will serve as a contact point for ECMWF, to address contractual, financial, and performance aspects.

5.1.2 Internal and external interaction

The C3S-MAGIC consortium will set-up an internal interaction protocol that promotes an efficient development of deliverables and benefits from the expertise across the consortium. For this (virtual or live) **sprint sessions** will be organised regularly, during which partners working together on a particular application will seek solutions to problems by intense collaboration. Sprints will be organised on request. Sprint sessions are not exclusively involving members of C3S-MAGIC. In particular, work sessions with the consortium assigned to the Lot 1 tender of this call (hereafter called Lot 1) will be organised frequently.

The Project Board will organise **3-monthly telecons** in which project progress and status of deliverables are discussed and the Quarterly Reports are prepared. ECMWF is invited as an observer to these meetings.

Early in the project a **dedicated software adjustment workshop** will be co-organised with the consortium assigned to the Lot 1 tender of this call (see D2.5). Directly after this combined workshop an internal C3S-MAGIC workshop will take place. This workshop is to ensure that all partners agree on common software protocols and to clarify the requirements for the software to be developed in WP4-7 to be able to communicate with the technical solution developed in WP3.

A **second internal workshop** is planned for the second half of year 2 when a preliminary version of the technical software (WP3) and some demo cases from WP4-7 are available. The interaction of these components will be tested. At the end of year 1 and in the course of the third project year web-based (virtual) internal **demonstration sessions** will be organised in which many of the software products will be presented and tested.

Demonstration of the C3S-MAGIC software for the different target sectors (D2.4) will be carried out primarily by C3S-MAGIC partners that are active in one or more of the tenders of the Sectoral Information Systems. Via this involvement a close interaction with relevant stakeholders is ensured (see Section 4.7). In addition, a **scoping and/or demonstration workshop** can be organised in collaboration with the consortia carrying out the SIS tenders, to optimize the usability of the toolkit developed. C3S-MAGIC will not carry out a new stakeholder requirement inventory.

Scientific exchange inside and outside the consortium is encouraged, and will lead to co-authored peer-reviewed publications.

5.1.3 Monitoring

To monitor the progress of the project, we have defined Deliverables and Milestones at regular (semi-annual) intervals (Table 14 - Table 20). *Deliverables* are reports (e.g., describing a common view on how to proceed, or a finished piece of software, where *finished* implies the presence of documentation and, if applicable, a manual. A *Milestone* is an objectively checkable achievement, e.g., a working prototype of a piece of software that can be used by other groups to test or implement their software. Through Redmine the progress will be continually monitored. Problems are signalled in time, allowing appropriate actions to be taken (see risk register, Table 21). The following documentation is delivered to ECMWF for information, review and approval:

- All the deliverable documents are first presented to ECMWF for approval before they are made publicly available. In particular, draft versions of the software documentation reports are available to ECMWF and other relevant partners in C3S-MAGIC two weeks before release.
- Periodic progress meetings (normally to be held by teleconference) will be organized with ECMWF to present project status, tasks completion, schedule and risks. Prior to these meetings KNMI will provide a (short) report on the project status and possible issues. The minutes of the monthly and 3-monthly teleconference meetings will be available shortly after the events.

On top of this, the following reports will be delivered, following from the requirements in the ITT (sec. 4.2.4):

- Quarterly, annual and final reports;
- Annual implementation plans;
- Payment plans.

The management deliverables are detailed in Table 14.

Several meetings between KNMI and ECMWF will be scheduled:

- The monthly progress meetings (teleconference) mentioned above;
- A final review meeting at the end of the framework contract.

These meetings may be organised at the premises of ECMWF or KNMI.

5.2 Payment Plan

Being the Contractor, KNMI will receive payments from ECMWF and will distribute the money between the partners. Based on the distribution of work over time as depicted in the Gantt-Chart below (Figure 4), we propose the following payment scheme:

- Payments are made in 14 instalments at 3 month intervals;
- The first payment occurs in month 3, the last in month 42, i.e. three months after the end of the contract;
- Costs for WP 1 and 4 are spread evenly over all instalments;
- Costs for WP 2 is paid in first instalment;
- Costs for WP 3 are spread evenly over instalments 1-11;
- Costs for WP 5+6 are spread evenly over instalments 5-14, i.e., they occur after the first year;
- For WP 7 a fixed amount of 5,000 euros is paid in the first instalment (for the user survey), the rest is distributed evenly over instalments 5-14;
- Payments will only be done after ECMWF have accepted the Quarterly Report.

KNMI will distribute the payments to the partners within four weeks after receiving the money from ECMWF. A Payment Plan based on the principles above is submitted as an attachment. The Payment Plan will be updated regularly during the course of the project in consultation with ECMWF.

TABLE 10: DISTRIBUTION OF BUDGET ACROSS PARTNERS (IN KEUROS).

	WP1	WP2	WP3	WP4	WP5	WP6	WP7	Sum
KNMI	100	35	70			40	50	295
BSC				20	40	25	100	185
DLR			75	90				165
ISAC-CNR				40	30	40	20	130
NLeSC			200					200
SMHI							70	70
URead			85	10				95
Sum	100	35	430	160	70	105	240	**1140**

The allocated budget for each partner is given in Table 10. The total sum we ask for the work described in this tender is 1,139,741.73 k€. In the remainder of this tender all amounts are rounded to k€ for better readability The exact amounts can be found in the accompanying Payment Plan. Differences usually do not exceed 100 €.

6 Work Packages and milestones

To keep the project manageable it is divided into seven work packages. Three of them deal with overarching aspects (management, interface with lot 1, general software lay-out), while the other four aim at producing the four software deliverables requested in the ITT. A graphical overview is given in Table 11. A detailed description of the work packages and subtasks is given below.

TABLE 11: OVERVIEW OF WORK PACKAGES, RELATED DELIVERABLES AND INVOLVEMENT OF PARTICIPANTS (WP LEADERS IN BOLD).

	Software WPs	**WP 4**: Metrics (D2.1)	**WP 5**: Multi-model products (D2.2)	**WP 6**: Time series (D2.3)	**WP 7**: Tailored products (D2.4)
Overarching WPs	Who?	**DLR**, BSC, ISAC-CNR, URead	**BSC**, ISAC-CNR	**ISAC-CNR**, BSC, KNMI	**BSC**, KNMI, ISAC-CNR, SMHI
WP 1: Management	**KNMI**	Project administration, reporting, interfacing with stakeholders			
WP 2: Workshop (D2.5), link with lot 1	**KNMI**, all	Definition of interface. All software developed in this project has to work with this interface			
WP 3: Technical implementation	**NLeSC**, DLR, KNMI, URead	Implementation of the interface; ensuring software flow from user request to presentation of result			

WP 1 concerns the overall management of the project, typical tasks being coordination, reporting, communication and financial administration. WP 2 aims to organise the workshop to be held with the lot 1 winner and to ensure regular contacts with that contractor. Clearly, some overlap with WP 1 exists. However, while WP 1 is predominantly administrative and top-down, WP 2 requires the active involvement and contribution of all partners. The workshop will lay the technical basis on which all software solutions have to be built. All partners need to be involved in the definition of the interface and agree with the solution.

WP 3 produces the backbone of the project. This is software that ensures a smooth translation of a user request into operations. The software (i) puts the data files (model output) needed for the request into place, (ii) performs the required operations, (iii) displays the results to the user, and (iv) saves (or downloads) the results to a user-given place. This work package requires repeated interactions with WPs 4-7 to ensure that a user request is efficiently and reliably translated into actions on the data.

WPs 4-7 produce the software needed to do the actual computations requested by the user. This encompasses the user-interface and routines to calculate a specific index, statistic or metric. WP 4 generates the (pre-defined) model metrics, WP 5 allows calculating climate indices and grouping/selecting models, WP 6 generates specific time series products, and WP 7 is a wrapper for the 4 demonstration use cases.

Figure 4 displays the Gantt Chart of the project. WP3 has to produce the basic software infrastructure to interface the lot 1 solution. WP4 provides an enhanced version of an existing software tool (ESMValTool) which will provide metrics and also serve as a backbone for WP5-7. Therefore WP3 and WP4 have to start right from the beginning of the project, while WP5-7 only start when some basic work in WP 3+4 has been completed. The workshop jointly organised with lot 1 (WP2) will be scheduled as early as possible in cooperation with lot 1. The indicated time (month 3) is only indicative. User consultation in WP7 (organised jointly with SIS contractors) will start before the software coding starts in year 2.

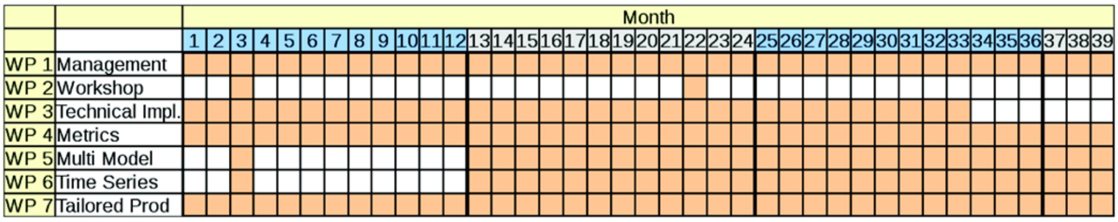

FIGURE 4: GANTT CHART. THE TIME FOR THE WORKSHOPS IS TENTATIVE. THE FIRST ONE HAS TO BE COORDINATED WITH LOT 1, AND THE SECOND ONE WILL TAKE PLACE WHEN WP3 HAS DELIVERED A PROTOTYPE.

Table 12 shows an overview of the work packages, giving tasks and planned efforts. A more detailed description of the WPs, including milestones and deliverables, is given in the subsequent Table 14 - Table 20.

TABLE 12: SUMMARY OF WORK PACKAGES, DELIVERABLES AND PERSONNEL EFFORTS.

Work package	**Deliverable Reference**	**Effort in person-months**
WP1 (Management)	Reporting toward Copernicus (D1.1-1.7)	5 [KNMI]
	Financial administration (D1.2, D1.3)	3 [KNMI]
	Ensure collaboration (D1.8)	2 [KNMI]
Total WP1 Effort		**10**
WP2 (workshops + interface with lot 1)		0.45 [KNMI]
Total WP2 Effort		**0.45**
WP3 (Interfaces and technical implementation)	WP 3.1 (development of backend)	4.5 [DLR], 4 [KNMI], 6 [NLeSC], 6 [URead]
	WP 3.2 (workflow layer)	4 [KNMI], 8 [NLeSC]
	WP 3.3 (user interface)	10 [NLeSC]
Total WP3 Effort		**43**
WP4 (Performance metrics)	WP 4.1 (mean state)	5 [DLR], 1 [BSC], 1.75 [ISAC-CNR], 0.35 [URead]
	WP 4.2 (variability)	3.3 [BSC], 0.35 [URead], 0.25 [DLR]
	WP 4.3 (extremes)	3.5 [ISAC-CNR], 0.25 [DLR]

Work package	Deliverable Reference	Effort in person-months
Total WP4 Effort		**15.25**
WP5 (Statistics)	WP 5.1 (selection of sub-ensemble)	3 [ISAC-CNR]
	WP 5.2 (combination of models)	5.5 [BSC], 0.6 [ISAC-CNR]
	WP 5.3 (agreement between models)	3 [BSC]
Total WP5 Effort		**12.1**
WP6 (Time series)	WP 6.1 (area average)	5.5 [BSC], 1 [ISAC-CNR]
	WP 6.2 (spatio-temporal analysis)	4 [ISAC-CNR]
	WP 6.3 (correlations)	4.2 [KNMI], 0.25 [ISAC-CNR]
Total WP6 Effort		**14.95**
WP7 (Tailored products)	WP 7.1 (user consultation)	5 [BSC], 0.2 [KNMI], 0.4 [IASAC-CNR], 1 [SMHI]
	WP 7.2 (coastal areas)	4 [KNMI]
	WP 7.3 (water/hydrology)	2.5 [ISAC-CNR], 4.27 [SMHI]
	WP 7.4 (energy)	9 [BSC]
	WP 7.5 (insurance)	9 [BSC]
Total WP7 Effort		**36.37**

To synchronize the software development activities across the various work packages a centrally coordinated set of "heartbeat" milestones is defined. At these milestone moments all activities leading to deliverables are reviewed and adjusted where necessary. Table 13 lists these milestones that connect activities in multiple work packages. Milestones that are only applicable to single work packages are not listed here, but in the work package descriptions below.

TABLE 13: OVERVIEW OF "HEARTBEAT" MILESTONES ACTING ON MULTIPLE WORK PACKAGES. NUMBERS OF MILESTONES REFER TO WORK PACKAGES WHERE THEY ARE FIRST LISTED.

Milestone	Sync'ed with	Purpose	Time
M2.1: Interaction workshop with Lot 1	M3.1	Define interface with CDS and Lot 1 software design	±M3
M3.3: Virtual demonstration session: prototype of generic metrics and user interface.	M4.1, M7.1	First layout of software that generates generic and user defined metrics and indices across project partners	M12
M2.2: Internal progress workshop	M3.4, M5.1	Demonstrate successful interaction between software components	M24
M5.2: Virtual demonstration session: test of user-derived products	M5.3, M6.1, M6.2, M6.3, M7.3	First demonstration of user-driven selection of models, metrics and indices	M34
M3.5: Final demonstration: full website functional	M3.5, M4.2	Demonstrate that C3S-MAGIC has the required functionality	M39

TABLE 14: DESCRIPTION OF WP 1.

Work package #	1		Start/End date		M1/M39
Work package title	**Management**				
Budget (k€)	Total	KNMI	Q 2	Q 3	Q 4
	100	100			
Participants (person months)	**KNMI** (10)				
Other main direct cost elements					

Main objectives
The objective of this Work Package is to oversee the whole project and ensure a timely release of all deliverables and milestones. This includes organizing cooperation and synergies, develop strategy to ensure coordination, identify issues and plan solutions, avoid redundancies and overlapping of partner developments. Furthermore, the reporting towards Copernicus and the distribution of payments to the partners are carried out in this WP.

Description of activities

Task T1.1: Reporting towards Copernicus

- Regular contacts with partners to collect information
- Producing report summaries
- Submitting and explaining the summaries to Copernicus

Task T1.2: Financial administration

- Distribution of payments to partners
- Financial reporting towards Copernicus

Task T1.3: Ensure collaboration between partners

- Organize frequent meetings
- Monitor progress via reports and milestones

Deliverables

#	*Responsible*	*Nature*	*Title*	*Due*
D1.1	KNMI	Agenda	Agenda for monthly telecons addressing project status, tasks completion, schedule and risk	Each month, prior to the progress meeting

				with ECMWF
D1.2	KNMI	Report	Preliminary financial information related to the previous year	January of each year
D1.3	KNMI	Report	Financial report on past year, together with audit report	First half of each year
D1.4	KNMI	Report	Quarterly implementation report	Every 3 months
D1.5	KNMI	Report	Annual implementation report	28 February of each year
D1.6	KNMI	Report	Final report	Within two months after end of project
D1.7	KNMI	Report	Key performance indicators (see Chapter 7)	At start, updated on request by ECMWF
D1.8	KNMI (+ Project Board)	Minutes	Minutes of the regular telecons between partners	If necessary; at least every 3 months

Milestones				
#	*Responsible*	*Title*	*Means of verification*	*Due*
M1.1	KNMI	1st Annual Report	report submitted	M14
M1.2	KNMI	2nd Annual Report	report submitted	M26
M1.3	KNMI	Final Report	report submitted	M41

TABLE 15: DESCRIPTION OF WP 2.

Work package #	2		**Start/End date**	**M1/M39**
Work package title	**Workshops + interface with lot 1, C3S coordination**			

Budget (k€)	**Total**	**KNMI**	**Q 2**	**Q 3**	**Q 4**
	34.5	34.5			
Participants (person months)	**KNMI** (0.45), all partners				
Other main direct cost elements	Travel and subsistence, workshop related costs (catering/transport/rooms/equipment etc.); travel costs for consortium				

Main objectives

The objective of this Work Package is to organize and conduct, together with the lot 1 tenderer, a workshop to optimize interactions between the two lots. This concerns a list of technical specifications that must be met to guaranty a smooth interaction between the web-interface produced by lot 1 and the software to be produced by lot 2.

Coordination with lot 1 will be necessary during the whole project, not only in preparation of the workshop.

An internal workshop/progress meeting will be organized in the second half of the second year to demonstrate that software components developed in the different WPs can work together successfully.

Description of activities

Task T2.1: Organize workshop (together with lot 1 tenderer)

Task T2.2: Produce report describing interface between lots 1 and 2

Task T2.3: Secure and organize coordination between lots 1 and 2

Task T2.4: Organize internal workshop in second half of year 2

Task T2.5: Attend annual C3S meetings with other C3S service providers

Deliverables

#	*Responsible*	*Nature*	*Title*	*Due*
D2.1	KNMI (+ lot 1)	Report	Interface between website and software	M4*
D2.2	KNMI	Report	Interface between website and software	M24**

Milestones				
#	*Responsible*	*Title*	*Means of verification*	*Due*
M2.1	KNMI (+ lot 1)	Workshop	Workshop takes place	M2*
M2.2	KNMI	Workshop (internal)	Workshop takes place	M24**

* subject to finding suitable date; report 2 months after workshop

** tentative, 2nd half of year 2. Exact date will depend on progress in WP 3. Report 2 months after workshop

TABLE 16: DESCRIPTION OF WP 3.

Work package #	3		Start/End date		M1/M39
Work package title	Interfaces and technical implementation				
Budget (k€)	Total	NLeSC	DLR	KNMI	URead
	430	200	75	70	85
Participants (person months)	**NLeSC** (24), DLR (4.5), KNMI (8), URead (6)				
Other main direct cost elements					

Main objectives

This WP will develop the interactive software that translates a user request or a predefined set of metrics, diagnostics or climate indices (see WP 4-7) into actual calculations and presents the result to the user (Figure 3).

Description of activities

WP3.1: Development of the backend to read and regrid climate model data available from the C3S Climate Data Store [URead, DLR, NLeSC]

Here we will develop a common backend that reads and regrids climate model data available from the C3S Climate Data Store and serves the required functionality in WP4-7 (blue part of Figure 3).

WP4 will use ESMValTool version 1.0 (*12*), so this is also a natural starting point for the backend developed in WP3. In ESMValTool v1.0, the backend that reads the input data and derives variables is not serving the efficiency needs for a pre-operational or operational application. For this several modifications to the backend are required. This task focuses on a rewrite of the ESMValTool backend by using Iris (*35*) in addition to some basic NetCDF libraries that will then serve as backend across the entire project (WP4-7). The use of the Iris climatological python library replaces the current implementation relying on NCL routines. Iris is a fast developing and well supported python library, managed by a large development team at the UK Met Office.

The new backend in WP3 that serves WP4-7 will have the following capabilities:

- Provide all the climate variables required by WP4-7 on a common grid. The backend will do this by identifying the variables required in the C3S Climate Data Store, deriving additional variables where necessary (using native grids where possible; see methods, Section 4.8). Integral regridding tools in Iris will be supplemented with ESMF regridding where required. Derived/regridded variables can be stored for future use, where storage space permits. This will be done in close collaboration with Lot 1 (see Lot 1 narrative in Annex).
- The backend will provide two forms of software testing. Basic testing for the

backend, together with each diagnostic component in WP4-7, will be provided by having a standard set of input and output files for each diagnostic, and ensuring that the output of the latest version tolerable matches the expected output. Code quality will be ensured by unit testing key backend components, making it easy to identify accidental changes to these components.

- Use of all available computational resources is promoted by the self-contained nature of many of the processing steps in Lot 2, giving opportunities for parallelisation by making use of an object oriented code design, in close collaboration with Lot 1.
- (Pre-)operational evaluation of CMIP models with observations (WP4) and the provision of user-derived products (WP5-7) require traceability and provenance. To document the processes involved, information will be catalogued describing the models, observations and versions of the tool used for evaluation (WP4) and for the calculation of other derived products (WP5-7). In this way a record will be preserved and the evolution of a model's performance and derived products can be tracked over time. Appropriate log-files containing all the relevant information of a specific call of the main script will be created: creation date of running the script, version number, analysed data (models and observations), applied diagnostics and variables, and corresponding references.

WP3.2: Workflow layer API [KNMI, NLeSC]

In WP3.2 the workflow layer will be built (green part in Figure 3), translating the requests from the user, as provided though the web browser interface developed in WP 3.3, into calling the task with the right configurations. This includes calling the ESMValTool functions, if needed. The workflow layer allows for simple job workflows. The tasks (created by WP4-6) will be wrapped into OGC WPS containers. The PyWPS framework is used, which is also used in CLIPC and climate4impact. This allows easy integration with the WP3.3 user interface layer for passing configuration information. This provides the task with the user defined configuration settings enabling the operation. Both input and output data will be in NetCDF. Provenance metadata will be derived from the task output logs and stored in the centralized metadata store for use in the User Interface. To enable this, WP3.2 will define a provenance log template to be used by Task developers. WP 3.2 also provides an interface specification for Task developers in order to fit the Task in the WPS framework to ease integration.

For each Task a Docker container will be created, allowing integration testing and deployment in Lot 1 (see Figure 1 in Annex 1).

WP3.3: User Interface [NLeSC, KNMI**]**

In this subpackage we will build the user interface of the system. This user interface will be a Web portal that invokes Web services that are integrated in climate4impact (yellow part of Figure 3).

The user will be able to get an overview of existing data sources in the C3S Climate Data Store, and the already available derived data, such as metrics, time series, multi modal, and tailored model results. These can be inspected visually, as well as downloaded for local use. The data sources will be browsable and selectable based on these derived aspects and their meta data. For each derived result, the user will be able to view the provenance trace and navigate to the actual software that generated the result. The inspection of derived results will partly be done by means of plots. These plots are generated in WP3.2. In WP3.3, they are treated as data objects which have their own provenance trace.

Deliverables				
#	*Responsible*	*Nature*	*Title*	*Due*
D3.1	URead	Software and documentation	WP3.1 Backend software to read and regrid climate model data available from the C3S Climate Data Store	M39
D3.2	NLeSC	Software and documentation	WP3.2 Simple workflow containers for C3S-MAGIC calculations	M39
D3.3	NLeSC	Software and documentation	WP3.3 user-interface components	M39

Note: the software documentation consists of: release notes, user guide, installation manual, interface descriptions and a software design document.

Milestones				
#	*Responsible*	*Title*	*Means of verification*	*Due*
M3.1	WP 2	interface description	conclusions of workshop available	M4
M3.2	NLeSC	interface prototype	prototype accepted by Copernicus	M8
M3.3	NLeSC	prototype of user-interface	test with all partners during virtual demonstration session	M12
M3.4	KNMI	technically working website; functionality still limited	To be demonstrated at mid-term workshop (M2.2)	M24
M3.5	NLeSC	website ready, full functionality	Acceptance of main deliverable by Copernicus	M39

TABLE 17: DESCRIPTION OF WP 4.

Work package #	4		Start/End date		M7/M34
Work package title	**Metrics**				
Budget (k€)	Total	BSC	DLR	ISAC-CNR	URead
	160	20	90	40	10
Participants (person months)	**DLR** (5.5), BSC (4.3), ISAC-CNR (5.25), URead (0.7)				
Other main direct cost elements	None.				

Main objectives

The objective of this Work Package is to develop and deliver an enhanced version of the ESMValTool software that computes and displays a wide set of performance metrics quantifying the ability of climate models to represent the observed mean state and variability, as well as teleconnections, from the intra-seasonal to the inter-decadal timescale. The performance metrics will be calculated for the daily or monthly mean two-dimensional fields that are listed in the tender for the global mean and selected regions. The performance metrics will be calculated for a 30-year portion of the historical record for the CMIP5 historical and AMIP simulations in comparison to the re-analysis and observational databases that are available from the C3S Climate Data Store and described in Table 1 of the ITT.

Description of activities

The software that will be used and delivered for the WP4 calculations will be an enhanced version of ESMValTool version 1.0 (*12*). We will extend the tool to include specific requirements of the Lot 2 tender. This will be done by extending existing ESMValTool namelists and by implementing new ones. It will also include the interfacing with the UK MetOffice Auto-Assess and s2dverification packages for a more comprehensive calculation of performance metrics.

The backend of the ESMValTool will be revised in WP 3 and will be used within WP 4 (and WP5-7) to read and regrid CMIP model output and observations and reanalyses as available from the C3S Climate Data Store and described in Table 1 of the ITT. WP4 focuses on generic metrics that assess the climatological mean state (Task 4.1), climate variability and teleconnections (Task 4.2), and extreme events (Task 4.3). ESMValTool namelists for sector-specific performance metrics are developed in WP7.

WP 4.1: Generic metrics of model performance to assess the mean state [**DLR**, URead, BSC, ISAC-CNR]

A starting point for the calculation of performance metrics is to assess the representation of simulated climatological mean states and the seasonal cycle for essential climate variables (ECVs, (*33*)). This is supported by a large observational effort to deliver long-term, high quality observations from different platforms and instruments (e.g., obs4MIPs and the ESA Climate Change Initiative (CCI)) and ongoing efforts to improve global reanalysis products. Following (*18*) and similar to Fig. 9.7 of (*13*)), a namelist has been implemented in ESMValTool version 1.0 that produces a "portrait diagram" by calculating the relative space-time root-mean square error (RMSE) from the climatological mean seasonal cycle of historical simulations for selected variables [namelist_perfmetrics_CMIP5.xml]. The code allows comparison of up to four observational data sets. The overall mean bias can additionally be calculated. Different normalizations (mean, median, centered median) can be chosen and the multi model mean/median can also be added. With this namelist it is also possible to perform more in-depth analyses of the ECVs, by calculating seasonal cycles, Taylor diagrams (*30*), zonally averaged vertical profiles and latitude-longitude maps. Here we will extend this namelist to include additional variables from monthly mean two-dimensional fields as listed in the ITT and additional observations and reanalyses products from Table 1 of the ITT. An option to generate several members of observational reference according to their estimated uncertainty will be included through the interfacing with s2dverification so that, for each metric, an estimate can be computed for each member and a confidence interval can be deduced. In addition a namelist will be added that calculates high-level aggregated performance metrics of the type proposed by (*28*).

The Auto-assess software tool will be merged into the ESMValTool. Auto-Assess complements the ESMValTool performance metrics by assessing key underlying processes (e.g. (*31*) and (*20*)). More process-oriented metrics are required in order to minimise the risks of a model being over-tuned to perform well on a small set of metrics while having errors in processes that will turn out to be important for credibly simulating climate change.

Auto-assess currently offers a wide range of metrics, grouped into diagnostic 'areas'. Example areas include African Easterly Waves, ENSO, MJO, Aerosols, Conservation, Storm tracks/Blocking and Stratosphere. Areas comprise anything from five to thirty separate metrics, although most provide a summary metric of some kind. Due to the re-writing of AutoAssess in python/Iris mentioned in sect. 4.2, at present it is not possible to identify specific metrics for implementation in this work package, but we certainly aim to implement some AutoAssess metrics during the timescale of this project.

Additionally, extra-tropical atmospheric large scale circulation indicators, which can be directly associated with more/less persistent weather conditions in different regions, will be provided, such as for example (mono and bi-dimensional) blocking indices (*7*) and a computationally efficient metric for estimating the stratosphere-troposphere coupling and to identify patterns that are the most connected with stratospheric variability (*3*).

WP 4.2: Metrics of model performance to assess climate variability [**BSC**, DLR, URead]

Modes of natural climate variability from interannual to multi-decadal time scales are important as they have large impacts on regional and even global climate with attendant socio-economic impacts. Characterization of internal (i.e., unforced) climate variability is also important for the detection and attribution of externally-forced climate change signals. Internally-generated modes of variability also complicate model evaluation and intercomparison. As these modes are spontaneously generated, they need not exhibit the same chronological sequence in models as in nature. However, their statistical properties (e.g., time scale, autocorrelation, spectral characteristics, and spatial patterns) are captured to varying degrees of skill among climate models. In order to assess natural modes of climate variability in models, the NCAR Climate Variability Diagnostics Package (CVDP) (*25*) has been implemented into the ESMValTool. CVDP evaluates the major modes of climate variability in models and observations, including ENSO, Pacific Decadal Oscillation, Atlantic

Multi-decadal Oscillation, Northern and Southern Annular Modes, North Atlantic Oscillation, Pacific North and South American teleconnection patterns. It includes the calculations of related performance metrics which will be part of the delivered results and ESMValTool software.

NCAR CVDP relies however solely on spatial average and empirical orthogonal function decomposition to assess variability modes. Clustering/classification methods offer an alternative way of identifying variability modes which is more robust in a physical sense and capable of taking into account the possible nonlinear characteristics of a climate field (*1*, *19*). Well-known applications are the identification of the North Atlantic and North Pacific weather regimes or the Arctic sea ice Central Arctic Thinning (CAT), Atlantic-Pacific Dipole (APD) and Canadian-Siberian Dipole (CSD) modes (e.g. *24*, *15*). Through the implementation of an interface with the s2dverification package, the calculations of performance metrics over the spatial structure, the frequency of occurrence and the persistence of these modes will be made available within the ESMValTool for any month or season of interest. These metrics will provide a thorough assessment of the performance of each model in reproducing the observed variability in terms of patterns, spectra and teleconnections.

WP 4.3: Metrics of model performance to assess extreme events [**ISAC-CNR**, DLR]

Assessing the capability of the models in reproducing the statistics of extreme events is of crucial interest for impact modelling in several of the main sectors. To this end, in order to allow to measure characteristics of extremes, including frequency, amplitude and persistence, this task will include in ESMValTool metrics to assess the model performances in simulating selected climate extremes indices for temperature and precipitation defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) (*29*). Additionally, metrics to assess climate model precipitation simulations in terms of bias at different quantile levels (Quantile Bias) (*23*) will be implemented. The intensity of the hydrological cycle, in particular precipitation extremes and droughts, and its changes in time can be characterized implementing the HY-INT index introduced by (*17*).

Deliverables

#	*Responsible*	*Nature*	*Title*	*Due*
D4.1	DLR	Software	ESMValTool namelist that calculates generic metrics for the assessment of the mean state	M12
D4.2	BSC	Software	ESMValTool namelist that calculates metrics for the assessment of climate variability and teleconnections	M24
D4.3	ISAC-CNR	Software	ESMValTool namelist that calculates metrics for the assessment of extreme events	M24
D4.4	DLR	Software	Integrated package of metrics software	M39

Milestones				
#	*Responsible*	*Title*	*Means of verification*	*Due*
M4.1	DLR	Generic metrics defined	aligned with user interface definition	M12
M4.2	DLR	Tested software finalized	WP4 metrics computed within WP3 framework	M39

TABLE 18: DESCRIPTION OF WP 5.

Work package #	5		**Start/End date**		**13/39**
Work package title	**Generic multi-model products**				
Budget (k€)	**Total**	**BSC**	**ISAC-CNR**	**Q 3**	**Q 4**
	70	40	30		
Participants (person months)	**BSC** (8.5), ISAC-CNR (3.6)				
Other main direct cost elements					

Main objectives
The objective of this Work Package is to combine the climate information generated by various climate models into a single estimate of any future climate signal that is optimally suited to ultimately provide the requested (sectoral) climate change information. This 'optimal' estimate will be accompanied by an estimate of the agreement between the various climate models, i.e., the robustness of this estimated future climate signal, or its dependence on underlying assumptions. This WP will also deliver tools to select a subset of representative indicators from the various future climate projections.

Description of activities

WP 5.1: Selection of a sub-ensemble of models and members for present climate and future scenarios according to user-needs [ISAC-CNR]

The main objective of this task is to identify the most probable outcomes from a multi-model ensemble distribution associated to a given emission scenario. A clustering algorithm will be applied to condense the climate information from multi-model ensemble into an optimal sub-set of significantly different projections and predictions associated with a given climate forcing. This technique is already used to characterize the most probable scenarios in an ensemble of weather forecasts (*14*) and this approach, applied at a regional level, can also be used to identify the sub-set of ensemble members that best represent the full range of possible solutions for downscaling applications. The choice of the ensemble members will be made flexible in order to meet the requirements of specific (regional) climate information products, to be tailored for different regions and user needs. For example when the optimal sub-set of precipitation predictions over Europe is used to drive a specific application, the users will be provided with the probabilistic information that is most appropriate for a risk assessment.

WP 5.2: Combination of climate information generated by various climate models into a single estimate of future climate signal [BSC, ISAC-CNR]

Through the publicly available s2dverification package, BSC will deliver functions to compute and display the following types of combined model products:

1) maps (or time series) of (sub-)ensemble mean anomalies for any variable with respect to its mean annual cycle computed on a pre-defined period (e.g. 1971-2000)
2) maps (or time series) of (sub-)ensemble mean variance over any preselected period and variable of interest
3) maps of frequency of occurrences, computed over a selection of models and members, of extreme events (such as heat waves, droughts…) defined through quantiles.

These products will provide an integrated view of the historical evolution and projection of the climate system state in terms of mean state (1), variability (2) and extremes (3), aggregating the multi-model data into a single signal. A selection of models included in the ensemble is allowed by filtering on major drivers such as chosen RCP scenarios, major contributions to global Sea Level Rise, climate sensitivity, metric performance or other dominant features (see WP 5.1).

WP 5.3: Estimate of the agreement between a selection of climate models on a future climate signal [BSC]

Through the publicly available s2dverification package, BSC will deliver functions to compute and display the following types of combined model products:

4) maps (or time series) of percentage of models agreeing on the sign of (sub-)ensemble-mean anomalies and maps (or time series) of spread of the model anomalies
5) maps (or time series) of spread of the model variances for any preselected period and variable of interest

Deliverables				
#	*Responsible*	*Nature*	*Title*	*Due*
D5.1	ISAC-CNR	software	Tools to select a sub-set of ensemble members on major drivers such as chosen RCP scenarios, major contributions to global Sea Level Rise, climate sensitivity, metric performance or other dominant features	M30
D5.2	BSC	software	Tools to aggregate and combine multi-model climate information into a single best estimate of future climate information	M36
D5.3	BSC	software	Tools to estimate the agreement between various climate models on a future climate signal	M39
D5.4	BSC	software	Software to compute generic multi-model products in terms of geographical (global grid-point) fields representing relevant model statistics (e.g. ensemble mean anomalies, indices of internal variability, indices of inter-model differences, frequencies of anomalies exceeding a given percentile or fixed threshold)	M39

Milestones				
#	*Responsible*	*Title*	*Means of verification*	*Due*
M5.1	ISAC-CNR	Preliminary version of tools to select a sub-set of ensemble members on a reduced selection of major drivers	Successful test by other partners of the C3S-MAGIC consortium; to be demonstrated at mid-term workshop	M24
M5.2	BSC	Preliminary version of tools to aggregate and combine multi-model climate information into a single best estimate of future climate mean state and variability	Successful test at virtual demonstration session	M34
M5.3	BSC	Preliminary version of tools to estimate the agreement between various climate models on a future climate signal through percentage computation	Successful test at virtual demonstration session	M34

TABLE 19: DESCRIPTION OF WP 6.

Work package #	6		Start/End date		13/39
Work package title	**Climate index time series**				
Budget (k€)	Total	ISAC-CNR	BSC	KNMI	Q 4
	105	40	25	40	
Participants (person months)	**ISAC-CNR** (5.25), BSC (5.5), KNMI (4.2)				
Other main direct cost elements					

Main objectives

The objective of this Work Package is to compute single-model and multi-model time series of climate indices, for both pre-defined indices and indices defined interactively by the user. Next to indices based on area-averaged quantities, series will be provided that take the spatio-temporal correlations between variables and/or other data-sets into account. Different combinations of indices between models based on weights provided by WP4 will be enabled. Output will be available to the user in both graphical and numerical form.

Description of activities

WP 6.1: Predefined and user-defined indices based on area averages [BSC, ISAC-CNR]

Using the s2dverification package, functions will be provided to select locations or areas, compute area-averages over these regions for any pre-selected variable and combine them through addition or subtraction, with the option of including weights in these operations. The outcome will be time series of climate indices computed for individual models. BSC will also deliver functions combining the climate indices computed from several individual models into a single climate index based on predefined metric-based (from WP4) weights. The time series will optionally represent seasonal or multi-year averages, through either a block average or running average method.

Functions to compute pre-defined indices will be provided, including indices of model dynamics such as the QBO zonal wind index in given latitudinal band, and indices based on differences between anomalies averaged over 2 areas, such as for example the NINO 3.4 SST anomaly, SOI and NAO.

WP 6.2: Indices derived from spatio-temporal analysis of the data and from multiple variables [ISAC-CNR]

ISAC-CNR will deliver functions to compute climate indices derived from spatio-temporal analysis of the data, including options to combine multiple variables into a single index. In particular this task will deliver functions to compute

1) teleconnection indices based on Principal Component Analysis;
2) descriptive indices of extremes defined by ETCCDI (*10*), measuring characteristics of extremes, including frequency, amplitude and persistence;
3) indices of hydro-climatic intensity, such as the HY-INT index (*17*), integrating metrics of precipitation intensity and dry spell length;
4) indices of Northern and Southern Hemisphere annular modes, corresponding to the patterns of variability induced by stratospheric circulation changes.

Options for trend calculation will be provided, including significance testing compared to the null-hypothesis of no trend.

WP 6.3: Correlations [KNMI]

KNMI will provide software to calculate correlations between time series and fields. This makes it possible for the user to investigate dependencies between variables across model runs. This software builds heavily on the concepts of the KNMI Climate Explorer (*34*), including the handling of missing values in the case of observational data. This functionality is often used in the Climate Explorer, and contributes greatly to the understanding of causal and statistical relationships between large scale climate drivers and local impact indicators.

Deliverables

#	*Responsible*	*Nature*	*Title*	*Due*
D6.1	BSC, ISAC-CNR	Software	Tools to compute pre-defined and user-defined single and multi-model climate indices, based on a linear combination of averages over specified grid-boxes	M39
D6.2	ISAC-CNR	Software	Indices of extremes and indices based on spatio-temporal analysis	M39
D6.3	KNMI	Software	Correlation software	M39

Milestones

#	*Responsible*	*Title*	*Means of verification*	*Due*
M6.1	BSC	Tools to compute single model indices	Successful test at virtual demonstration session	M34
M6.2	ISAC-CNR	Teleconnections & extremes	Successful test at virtual demonstration session	M34
M6.3	KNMI	Correlation software	Successful test at virtual demonstration session	M34

TABLE 20: DESCRIPTION OF WP 7.

Work package #	7		**Start/End date**		**1/39**
Work package title	**Tailored products**				
Budget (k€)	**Total**	**BSC**	**ISAC-CNR**	**KNMI**	**SMHI**
	240	100	20	50	70
Participants (person months)	**BSC** (23), ISAC-CNR (2.9), KNMI (4.2), SMHI (5.27)				
Other main direct cost elements					

Main objectives

The main objective of this Work Package is to assure that specific needs of envisaged end users in the selected economic sectors (energy, insurance, water/hydrology and coastal areas) are facilitated by the software. Demonstrator applications will be run across the C3S-MAGIC utilities developed in WP4-6 for a selection of sectors, to verify the usefulness of the software. Additional tailoring applications will be tested for specific sectors, utilizing the Climate Projection data processed by C3S-MAGIC utilities.

Description of activities

WP7.1: User consultation [BSC, ISAC-CNR, KNMI, SMHI]

The partners involved in this WP have close contacts with representatives from the sector for which they intend to deliver tailored products. Part of that interaction takes place via the C3S Sectoral Information Systems (SIS) tenders that currently are under negotiation. Each of the sectoral demos applied in C3S-MAGIC is linked to such a SIS project: WISC for coastal areas, SWICCA for the hydrological sector, and CLIM4ENERGY for the energy sector.

The software requirements imposed on this tender by the different sectors are based on user requests in the ongoing networks and planned activities in the SIS tenders by the participants. For instance, in SWICCA the user requests will be derived from a survey including 15 case-studies across Europe, dealing with water management related to water allocation and drought (in Spain and Italy), Risk management of floods (in Austria, Slovakia and Sweden), Ecological status (in Greece, Italy and Sweden) and Industrial use (in Greece, Germany, The Netherlands and Sweden). The case-studies for water management cover potential future changes in, for instance, withdrawals permissions, impact-based forecasts, hydropower regulation schemes, biodiversity, or drinking water supply.

Common to most sectoral management practice is the local scope of most issues and data needed to support the decision making process. Therefore pan-European datasets as provided by the current tender need to be merged with local data by local authorities or consultancies. Information from Global Climate Projections, as disclosed via the current tender, thus needs to be easily accessible, interpretable and transformed into appropriate resolution and formats. Surveys conducted so far point at difficulties with resolution, map projections, interpretation of variables, unclear metadata and unknown reliability of the projections. User-specific characteristics of metrics and indices produced in WP4 and WP5 (such as selection of region, variables and model aggregation), will be specified in WP7.

WP 7.2: Coastal Areas [KNMI]

Software that translates climate model output into (hourly) time series of sea surge and sea water level for a large number of coastal stations around the North Sea is adapted to the software architecture developed in C3S-MAGICS. To make the tool appropriate for the examination of all main aspects relevant for coastal safety, it will be extended to waves and water levels. Collaboration with WP4 (metrics) and WP5 (multi-model products) will focus on optimizing the selection and aggregation criteria for application in this tool.

WP 7.3: Water/hydrology [SMHI, ISAC-CNR]

Develop software to locate relevant data sets and extract the relevant data for the water sector (see Table 7). Provide quality control and bias correction (if time permits).

The C3S SWICCA project provides a list of climate indices which are defined through direct user interaction in a range of hydrological sectors (including agriculture and flood management), and further indices are defined for the urban case studies within UrbanSIS. These indices will be derived from the available climate model projections. The C3S-MAGIC software will be optimized to meet requirements of accessibility, transparency and tailor-made applicability for this range of sectors. Output from the activities will be change indicators of relevant climate indices useful to support water management decision taking (see Table 7 for list of examples), and also for sustainability issues related to urban infrastructure.

The problem of downscaling climatic information to the needed local scales will be addressed using a simple stochastic precipitation downscaling technique developed at ISAC-CNR (RainFARM (*27*), (*9*)), which has been implemented as a postprocessing tool. It provides high-resolution precipitation data from coarse scale GCM information, and allows a more realistic representation of subgrid precipitation variability and of precipitation extremes, crucial for impact studies in the water sector (*16*). Downscaling of climate information is highly relevant also for extreme rainfall and flood impact for urban sustainability studies, related to the UrbanSIS project.

WP 7.4: Energy [BSC]

BSC will deliver functions to compute climate indices from observations and climate model simulations to provide: a) energy supply indicators for a further understanding of wind power generation as changes in load factors as well as project planning to facilitate better loans and site selections; and b) energy demand indicators such as the frequency of cold spells and heat waves. Those indicators will be defined along with variability estimates known to affect the energy system (extremes relevant for the industry such as percentiles 10, 90 and 95) and an assessment of the influence of climate change. Delivered functions to compute climate indices will be based on the multi-model ensemble approach to estimate ranges of reliable solutions.

WP 7.5: Insurance [BSC]

The changing risks between the recent past and the future are of great interest to the insurance industry because even slight changes in climate characteristics can translate into

large impacts on risk distribution/management and expected losses. BSC will deliver functions to compute and display insurance-tailored metrics from observations and climate model simulations. One such example is the recently introduced Actuaries Climate Risk Index (ACRI), which aims to convey risk associated with extreme events in a statistically robust, yet easy to understand, fashion (*6*). Comprehensive risk indices such as the ACRI, which integrates changes in frequency and magnitude of key climate indicators and elements of hazard, exposure and vulnerability, are crucial for decision making processes.

Deliverables				
#	*Responsible*	*Nature*	*Title*	*Due*
D7.1	KNMI, SMHI, ISAC-CNR, BSC	Report	User requirements for Tailored Products	12
D7.2	KNMI	Software	Software for the coastal sector	39
D7.3	SMHI, ISAC-CNR	Software	Software for the hydrological sector	39
D7.4	BSC	Software	Software for the energy sector	39
D7.5	BSC	Software	Software for the insurance sector	39

Milestones				
#	*Responsible*	*Title*	*Means of verification*	*Due*
M7.1	KNMI, SMHI, ISAC-CNR, BSC	User consultations completed	List of tailored products and variables desired; shown at first virtual demonstration session	M12
M7.2	KNMI, SMHI, ISAC-CNR, BSC	Prototype software and case studies	Case studies defined and first prototype software ready	M28
M7.3	KNMI, SMHI, ISAC-CNR, BSC	Tailored software ready	Successful test at virtual demonstration session	M34

7 Key Performance Indicators

A preliminary set of Key Performance Indicators of C3S-MAGIC refer to specific characteristics of the software delivered by the project:

- **Functionality**: the software carries out the specified functions: collecting model data and observations, calculation of metrics, generation of multi-model products and tailoring operations for a limited set of sectoral applications.
- **Transparency**: the software is well documented, and its results are consistent with a number of predefined benchmark operations on the data defined and applied outside the software environment
- **Connectivity and transferability**: the software can be installed on other platforms, and data access and user interface can be adjusted to interact with the architecture design of the CDS, Lot 1 modules and user interface.

8 Risk analysis and management

Complexity of software and the availability of data and persons are general problems that can be encountered in a software project like C3S-MAGIC. For these general problems the mitigation strategies are given below:

- **Complexity of software/hardware:** the size of the data archives, the complexity of the processing algorithms, and the dependence on adequate computing and data storage & exchange infrastructure are challenging boundary conditions for carrying out the tasks in this project. These risks are mitigated by involving experienced individuals, ensure close collaboration within the consortium and with externals like the Lot 1 team, and by a high frequency of internal consultation by the Project Board that allows reconsideration of tasks or strategies.
- **Availability of data:** the software is designed to work with remotely accessible model and observational data, ultimately interacting with the Climate Data Store (CDS). During the development of the software systems tools and data sets that are already running operationally will be used as a starting position, but software standards will be applied that allow efficient porting to other platforms and data streams.
- **Misfit of the interfacing between the various packages:** the final software will rely on interfacing various software tools that are based on pre-existing software. Insufficient coordination could lead to an inappropriate working of the interface and a loss of functionality and modularity. This risk will be mitigated by increasing the frequency of meetings among the partners if a risk of not reaching a milestones is identified.
- **Availability of persons**: non-availability of persons, e.g. because of illness, maternity leave or job mobility can occur. Partners will identify "backup staff" that can take over the work in case the first responsible person is temporarily not available. Partners are also requested to document their working procedures so that direct colleagues can take over.

A more specific description of risks and the foreseen response strategy is given in Table 21.

TABLE 21: RISK REGISTER

WP	Risk Name	Description	Likeli-hood	Impact	Response Strategy	Year of Service
All	Task unfinished	Partners do not complete Tasks on time	1	4 This will cause part of the work not to be delivered in time	Find resources within the other partners, or change subcontractor	All
All	Key personnel not available	Requires recruiting of new staff	2	3	Reduce: assign other staff member to work on the project	1-3
All	ESGF down periods	ESGF nodes are not accessible	1	4 Software cannot be tested	Reduce: use sites other than ESGF nodes that hold climate model data (e.g., climexp.knmi.nl, climate4impact.eu)	1-3
4	Third party deliverables	Nascent third party metric software (Auto-Assess) is delivered late or cannot be adapted to our data format	2	1	Downscoping of work package to exclude affected metrics	1-3
4-7	Software interoperabil ity	Difficulties in interfacing planned software with ESMValTool	2	3	Adopt different software/write new software	1-2
4-7	Software efficiency	Software tool too slow in interfacing with WP3 backend	2	3	Work with WP3 to find better technical solution/rewrite software/store precomputed values	2-3

9 Compliance table

TABLE 22: COMPLIANCE WITH REQUIREMENTS FROM CALL.

Requirement	ref. in ITT	compliant?	where addressed?
Technical Requirements			
user interaction	3.2.1	Yes	Sect. 4.7; Table 20; WP7.1
implement well-established metrics	3.3.2, 1st para	Yes	Section 4.5; Table 17
develop and implement metrics representative of model variability	3.3.2, 1st para	Yes	Section 4.5, esp. 6th entry of Table 5
develop interactive tools	3.3.2, 2nd para	Yes	Table 19
develop tailored tools	3.3.2, 3rd para	Yes	Table 20
coding standards & languages	3.3.2, 4th para	Yes	Section 6
list of generic and sector-specific products to be developed	3.3.2, 5th para	Yes	Table 5, Table 6, Table 7
Performance Requirements			
detailed time plan	3.4.1, 2nd para	Yes	Figure 4, Table 14-Table 20
annual update of activity plan	3.4.1, 3rd para	Yes	Table 14, D1.5
deliver quarterly and annual reports	3.4.1, 3rd para	Yes	Table 14, D1.4 & D1.8
attend annual C3S service providers' meeting	3.4.1, 4th para	Yes	Table 15, T2.4
attend monthly telecons	3.4.1, 4th para	Yes	Sect. 5.1.3
Deliverables			
software for metrics	3.4.2.2, D2.1	Yes	Table 17
software for generic multi-model products	3.4.2.2, D2.2	Yes	Table 18
software for time series	3.4.2.2, D2.3	Yes	Table 19
software for tailored products In four sectors	3.4.2.2, D2.4	Yes	Table 20
organize workshop	3.4.2.2, D2.5	Yes	Table 15
Data delivery			
provision of data and products	3.4.3.1.1	Yes	use option b) (via web services)

use protocols with recognized standards	3.4.3.1.1, 5th para	Yes	
ECMWF to have credentials to invoke web services	3.4.3.1.1, 5th para	Yes	
provide documentation conforming to standards	3.4.3.1.1, last para	Yes	
implement web-service-based data manipulation facilities	3.4.3.1.2, 1st para	Yes	
ECMWF to have credentials to invoke web services	3.4.3.1.2, 2nd para	Yes	we will comply with all these requirements
format of results compatible with options from 3.4.3.1.1	3.4.3.1.2, 3rd para	Yes	
data open	3.4.3.1.2, 4th para	Yes	
data ownership to ECMWF	3.4.3.2, 1st para	Yes	
ownership of software acquired or produced for C3S to ECMWF	3.4.3.2,2nd para	Yes	
KPIs	3.4.4	Yes	sect. 7
Tender Format			
page limits	4.1	Yes	Sect. 4 (Technical Solution) too long due to the long (required) tables with metrics, indices, etc to be implemented (Table 5-Table 7)
track records	4.2.1	Yes	Section 2
Project Leader's experience	4.2.2	Yes	Section 3.1
team member with experience in diagnostics and validation	4.2.2.2, 1st bullet	yes	Table 3
team member with experience in statistical modelling and post-processing	4.2.2.2, 2nd bullet	Yes	Table 3
Technical solution proposed			
Background	4.2.3.1	Yes	Sects. 4.1 - 4.3
how to engage with users?	4.2.3.1.1, 1st para	Yes	Table 8
how to collect information on existing climate data sets?	4.2.3.1.1, 1st para	No	
list of potential partners for workshops and	4.2.3.1.1, 2nd para	Yes	Table 8

interviews			
exhaustive and detailed description of methods	4.2.3.2	Yes	Sects. 4.4 - 4.8, sect. 6
compliance table	4.2.3.3	Yes	you are just reading it
Implementation plan	4.2.4	Yes	Sect. 5
Reporting	4.2.4, 1st bullet	yes	Sect. 5.1.3
implementation plan for year N+1	4.2.4, 2nd bullet	Yes	Table 14, D1.5
monthly telecons with ECMWF	4.2.4, 3rd bullet	Yes	Sect. 5.1.3; Table 14, D1.8
payment plan	4.2.4, 4th bullet	Yes	Sect. 5.2; annex via procurement site
list of sub-contractors	4.2.4, 5th bullet	Yes	annex via procurement site

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11 Annex I: Expectations of Software Environments

This document was prepared early in proposal development by the CP4CDS Lot 1 team bidding for C3S_34A ITT. It is intended for circulation to help any potential lot 2 bidding team understand our proposed deployment environment.

The deployment of analysis code in the CP4CDS environment is expected to conform to the following release cycle:

1. Codes are developed "locally" and they pull data from the CP4CDS and other CDS interfaces as necessary via internet accessible APIs, beginning with download, and progressing to exploitation of remote data to produce products for local download.
2. Codes are manually deployed into the "Platform as a Service" (PaaS) environment deployed in the backend of the CP4CDS compute solution, and are made available as "capabilities" of the compute solution.
3. Codes are manually deployed in a Docker environment deployed in the backend of the CP4CDS compute solution, and are made available as "capabilities" of the compute solution

The CP4CDS team will support a flexible "software dependency" deployment solution (called SDDS in the following) which is targeted at standard Linux systems based on CentOS/Redhat. Within that we will provide version control and continuous integration testing so that downstream sites (all lot1 sites, and any lot 2 sites which so desire) can have the same versions of the environment at the same time. The combined SDDS for supporting all three modes is depicted in Figure 1.

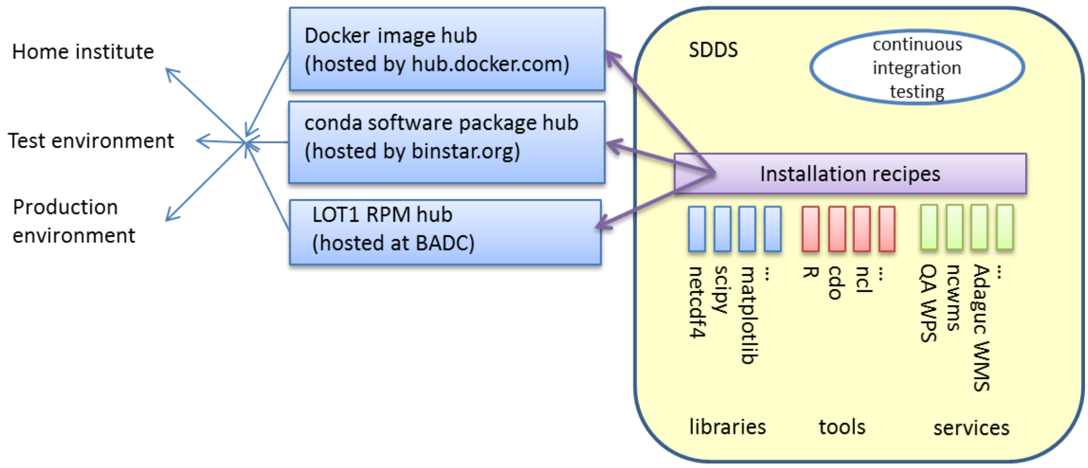

Figure 1 Software Dependency Architecture

We expect that software dependencies that need to managed in the RPM hub and Docker will include many which arise from the codes being developed in Lot2. We will schedule regular meetings with Lot 2 to manage such dependencies. To make migration from mode 1 to mode 2 easier, CEDA will provide Lot2 developers with access to development machines running the SDDS, upgraded as necessary in a release cycle driven by the Lot1/Lot2 interactions. This means registered developers in Lot2 will be free to develop in Mode 1 on their own machines, or utilise Mode 1 development on the centrally provided servers. They may of course develop using a life cycle that begins on their own systems followed by migration to the central servers. All CP4CDS core data will be directly available on the Mode 1 development machines. Mode-1 SDDS development machines will be made available for month 4 of the project. Mode-2 SDDS capabilities will be made available at Month 15; mode-3 capabilities will be made available by Month 30.

Analysis codes are expected to make use of data that might not yet be available via ECMWF or CP4CDS. To that end Lot2 developers will be responsible for managing their own data caches initially, but will liaise with Lot1 to exploit methods for obtaining remote data programmatically. We expect to develop our own specification for configuring the data requirements of the processes to be deployed into the lot 1 environment so that services can construct potential data matches for particular computational interfaces (e.g. find all models which have the appropriate data products necessary to be used as inputs for a specific multi-model product).

12 Annex II: Acronyms in Figure 2

(source: Wikipedia)

API	Application Program interface: is a set of routines, protocols, and tools for building software applications. The API specifies how software components should interact and APIs are used when programming graphical user interface (GUI) components.
OGC	The OGC (Open Geospatial Consortium) is an international not for profit organization committed to making quality open standards for the global geospatial community. These standards are made through a consensus process and are freely available for anyone to use to improve sharing of the world's geospatial data.
REST	In computing, representational state transfer (REST) is the software architectural style of the World Wide Web. REST gives a coordinated set of constraints to the design of components in a distributed hypermedia system that can lead to a higher-performing and more maintainable architecture.
WCS	The Open Geospatial Consortium Web Coverage Service Interface Standard (WCS) defines Web-based retrieval of coverages – that is, digital geospatial information representing space/time-varying phenomena.
WMS	A Web Map Service (WMS) is a standard protocol for serving georeferenced map images over the Internet that are generated by a map server using data from a GIS database.
WPS	Web Processing Service: the OpenGIS® Web Processing Service (WPS) Interface Standard provides rules for standardizing how inputs and outputs (requests and responses) for geospatial processing services, such as polygon overlay. The standard also defines how a client can request the execution of a process, and how the output from the process is handled. It defines an interface that facilitates the publishing of geospatial processes and clients' discovery of and binding to those processes. The data required by the WPS can be delivered across a network or they can be available at the server.