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REPORT

Cooperation between the ESA Climate Change Initiative and the EC Copernicus Climate Change Service

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Reference	ESA-CCI-EOPS-PRGM-RP-18-0212
Issue/Revision	1.0
Date of Issue	09/08/2018
Status	Approved

APPROVAL

Title Cooperation between the ESA Climate Change Initiative and the EC Copernicus Climate Change Service

Issue Number 1	Revision Number
Author Dick Dee, Jean-Nöel Thépaut (ECMWF), Simon Pinnock, Pascal Lecomte (ESA)	Date 09/08/2018
Approved By	Date of Approval

CHANGE LOG

Reason for change	Issue Nr.	Revision Number	Date

CHANGE RECORD

Issue Number	Revision Number		
Reason for change	Date	Pages	Paragraph(s)

DISTRIBUTION

Name/Organisational Unit

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1 DOCUMENT SCOPE

The purpose of this document is to describe the mutually beneficial relationship between the European Space Agency's (ESA) Climate Change Initiative (CCI)¹ and the Copernicus Climate Change Service (C3S).

2 REFERENCE DOCUMENTS

- [RD-1] GCOS-200. The Global Observing System for Climate: Implementation Needs. 2016. Online:
https://library.wmo.int/index.php?lvl=notice_display&id=19838
- [RD-2] GCOS-195 GCOS Status Report, 2015. Available online at
https://library.wmo.int/pmb_ged/gcos_195_en.pdf
- [RD-3] Bojinski *et al.*, 2014 The Concept of Essential Climate Variables in Support of Climate Research, Applications, and Policy
- [RD-4] C3S_312b Volume II Invitation to Tender, Technical Requirements, 2017. Available online at:
<https://climate.copernicus.eu/file/2586/download?token=ouXWU2ZR>

3 INTRODUCTION

CCI is a major research and development (R&D) element of the ESA Earth Watch programme that was established by its Member States in 2009 with funding committed until 2026. The objective of CCI is to support the needs of the United Nations Framework Convention on Climate Change (UNFCCC) by exploiting the long term global Earth observation archives established by ESA and its Member States to develop high-quality Essential Climate Variable (ECV) data records. C3S is a cross-cutting information service established by the European Commission in 2014 as part of its flagship Copernicus Earth observation programme, which is funded by the European Union within its multiannual financial framework. The primary objective for C3S is to support adaptation and mitigation policies in Europe in response to climate change. The Commission has entrusted the European Centre for Medium-Range Weather Forecasts (ECMWF) with the implementation of C3S.

¹ CCI is the commonly used name for the “Global Monitoring of Essential Climate Variables (GMECV)” element of the ESA Earth Watch Programme.

The scientific basis for both CCI and C3S is rooted in the UNFCCC process and its contributing bodies. Both programmes respond to Global Climate Observing System (GCOS) requirements and contribute to its implementation actions [RD-1]. Essential Climate Variable (ECV, [RD-3]) products generated by CCI and C3S activities are systematically added to the recently established online ECV inventory, an initiative of the joint Working Group on Climate of the Committee on Earth Observation Satellites (CEOS) and the Coordination Group for Meteorological Satellites (CGMS).

As explained in the following sections, CCI and C3S objectives and activities are inherently complementary and support each other. Close coordination and effective collaboration between the two programmes strengthen both, and ultimately benefit the citizens of Europe.

4 THE COPERNICUS CLIMATE CHANGE SERVICE

The Copernicus Climate Change Service (C3S) is one of six operational environmental information services established by the European Commission (EC) within the Copernicus Earth Observation Programme. C3S supports climate change adaptation and mitigation in Europe by ensuring reliable access to high-quality data on past, present and future climate, and by enabling users to make effective use of these data, e.g. for monitoring climate change and its impacts, for developing climate services in various industrial sectors, and for policy development and implementation (Figure 1).

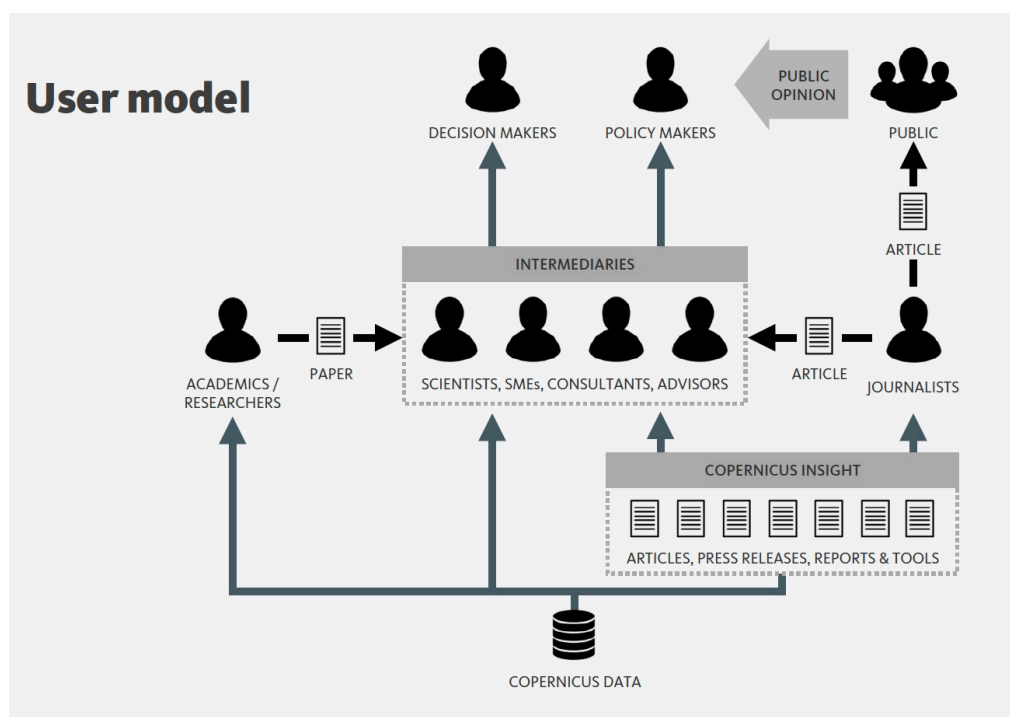


Figure 1: C3S user model. The design of the CDS is especially focused on the "intermediaries" in the central box.

The EC has entrusted ECMWF with the implementation of C3S on the basis of a Delegation Agreement that defines the scope and objectives of the service, as well as legal and

administrative procedures and constraints. The Delegation Agreement requires ECMWF to take maximum advantage of existing knowledge and capabilities available in Europe for the development of C3S products and services. Accordingly, the design and implementation of C3S programme elements is strongly informed by outcomes of research and development funded by national capacities, previous EU Framework Programmes (including projects explicitly tagged as Copernicus precursors), as well as other European research initiatives such as the ESA CCI. To further optimize the use of existing capabilities in Europe, the majority of C3S service provision is realized by third parties selected by ECMWF under competitive tendering rules.

The backbone of C3S is a cloud-based Climate Data Store (CDS, Figure 2), which aims to make it easier for users with varying backgrounds to access complex climate datasets and turn them into useful information products. Along with the data, the CDS provides quality assurance and expert support to users with a particular focus on those who act as intermediaries to planners, decision makers and other consumers of climate information (the central box in Figure 1). The CDS also includes an online toolbox for creating workflows and applications without the need to download data. The CDS toolbox is designed to enable development of downstream climate services by SMEs, in addition to serving institutions concerned with assessment of the impacts of climate change.

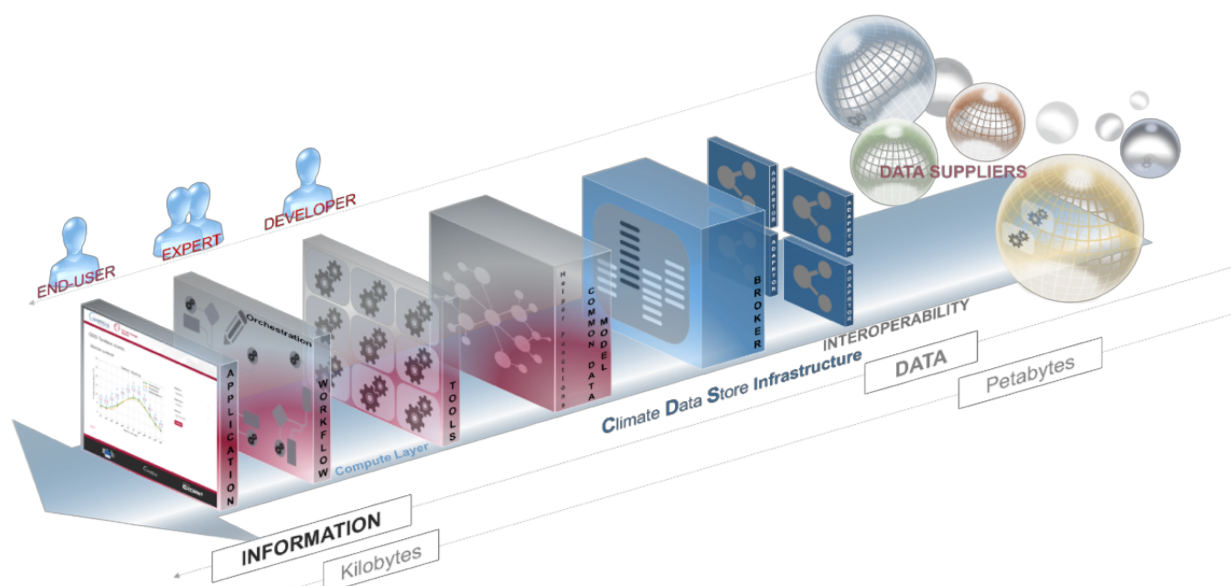


Figure 1: Architecture of the cloud-based Climate Data Store and its user interfaces.

The CDS presents users with a single point of access to a catalogue of climate datasets, including *in situ* and satellite observations, ECV products derived from observations, model-based climate reanalyses, seasonal forecast data products, and climate model simulations including projections. Information about each dataset is presented in a uniform way and data can be selected for download using standard web forms, or they can be accessed in offline applications via the CDS Application Programming Interface (CDS API). Alternatively, users can process, combine and visualize data online using the CDS Toolbox. A first functional version of the CDS was released in June 2018; additional data content and significant performance upgrades are planned throughout 2018 and 2019.

5 THE ESA CLIMATE CHANGE INITIATIVE

The European Space Agency (ESA) established the Climate Change Initiative (CCI) in response to UNFCCC needs for global information about climate change. The overarching goal is to realize the full potential of the long-term global Earth Observation archives that ESA together with its Member states have established over the last forty years, as a significant and timely contribution to the ECV databases required by UNFCCC. The CCI programme is designed to ensure that full benefit is derived from ongoing and planned ESA missions, including ERS, Envisat, the Earth Explorer missions, relevant ESA-managed archives of Third-Party Mission data and the Copernicus Sentinel constellation. CCI performs the research, development and qualification of pre-operational ECV products and processing systems that are then ready to be transferred to operational production externally, but CCI itself does not include the sustained operational production of ECV data sets.

CCI was implemented in overlapping phases as depicted in Figure 3. During the first programme period from 2009-2017 a set of 14 separate ECV projects was established, each addressing the development and production of high-quality climate data records using GCOS requirements as a reference. A Climate Modelling User Group (CMUG) was set up to follow the progress of the ECV projects by providing independent quality assessments from a user perspective. CMUG also provides guidance to ensure maximum consistency among data products associated with different ECVs. In addition, the programme developed a CCI Open Data Portal, the CCI toolbox, as well as various data visualizations and other resources for outreach and education.

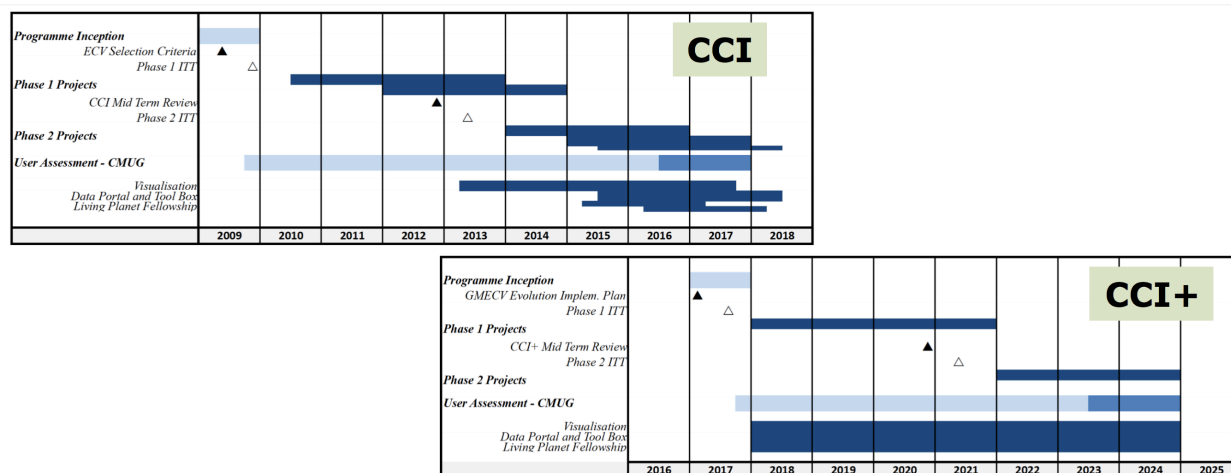


Figure 2: Phasing of the CCI programme

Implementation of an extension of the programme from 2018 to 2026, referred to as CCI+, was agreed by the ESA Member States in 2016. CCI+ has initiated projects to address an additional nine ECVs, and will perform R&D aimed at improving all of the ECV products developed during the first programme period. In addition, a number of targeted cross-ECV

projects will be undertaken to assess the quality and internal consistency of data products spanning multiple ECVs.

6 PROGRAMME OBJECTIVE

The CCI is an R&D programme aimed at developing ECV data products to satisfy the needs of climate science and climate services. Its main objectives are to develop long term multi-mission ECV data products derived from Earth observations based on the best available science, and to demonstrate the viability of ECV processing systems for further operational implementation outside the CCI programme.

As an operational service provider, C3S does not fund research but rather purchases products and services from capable suppliers, including any short-term developments needed to maintain and/or improve the quality of data and services. The objective is to provide European citizens with reliable access to the best available information about climate, ensuring maximum benefit from existing research and technical capabilities in Europe.

The complementary objectives of the two programmes are clearly reflected in the different ways that success is measured. A key performance indicator for CCI projects is the number of scientific publications contributing to IPCC assessment reports. Handover of ECV production systems to an operational environment outside ESA is an explicit objective of the CCI programme.

The bottom line for C3S, on the other hand, is to maximize user uptake of its products and services, and to demonstrate the benefits to society of the Copernicus programme. This is achieved by providing a high quality of service on the Climate Data Store, and by offering the tools and support that C3S users need in order to transform climate data into actionable information.

GCOS-195	CCI	CCI+	uptake	C3S
Atmospheric surface				
4.3.1 Air temperature				
4.3.2 Wind speed and direction				
4.3.5 Precipitation				
4.3.6 Surface radiation budget				
Atmospheric upper air				
4.5.1 Air temperature				
4.5.2 Wind speed and direction				
4.5.3 Water vapour				
4.5.4 Cloud properties				
4.5.5 Earth radiation budget				
Atmospheric composition				
4.7.1 Carbon dioxide				
4.7.2 Methane				
4.7.3 Other long-lived greenhouse gases				
4.7.4 Ozone				
4.7.5 Aerosol				
Ocean surface				
5.3.1 Sea-surface temperature				
5.3.2 Sea-surface salinity				
5.3.3 Sea level				
5.3.4 Sea state				
5.3.5 Sea ice				
Ocean biogeochemistry				
5.3.7 Ocean colour				
5.3.8 Carbon dioxide partial pressure				
5.3.9 Ocean surface acidity				
Ocean sub-surface				
5.4.1 Temperature				
5.4.2 Salinity				
5.4.3 Current				
Land hydrology & cryosphere				
6.3.4 Lakes				
6.3.5 Snow cover				
6.3.6 Glaciers and ice caps				
6.3.7 Ice sheets				
6.3.8 Permafrost				
6.3.16 Soil moisture				
Land biosphere				
6.3.9 Albedo				
6.3.10 Land cover (including vegetation type)				
6.3.11 Fraction of absorbed photosynthetically active radiation				
6.3.12 Leaf area index				
6.3.13 Above-ground biomass				
6.3.15 Fire				
6.3.17.1 Land-surface temperature				

Figure 3: EO derived ECV products addressed in CCI, CCI+ and C3S. For C3S, access to ECV data products is provided under two sets of service contracts (C3S_312a and C3S_312b [RD-4]). The arrows indicate CCI heritage.

7 ESSENTIAL CLIMATE VARIABLES

ECV data products constitute a large and significant component of the CDS catalogue. The Technical Annex of the C3S Delegation Agreement includes a table of 38 ECVs to be addressed by C3S. These are listed on the left side of Figure 4 above, with reference to the corresponding sections in GCOS-195 [RD-2]. The middle section of the figure shows the 22 satellite-based ECVs that are addressed in CCI and CCI+ projects.

The CDS catalogue includes climate data records derived from Earth observations for the majority of ECVs, as shown on the right side of Figure 4. The arrows indicate which of these involve satellite-based products developed in CCI, as of 2018. Climate data records for the remaining ECVs in the list of 38 are or will be derived from model-based reanalyses, *in situ* observations or a blend of both.

At the time of its launch in June 2018, the CDS catalogue offered 10 datasets derived from Earth observations addressing 7 ECVs (see Figure 5). By the end of 2018, data products for

12 ECVs will be available in the CDS, all with heritage in CCI. Access to data products for those 12 ECVs has been secured under a first round of contracts (C3S_312a, Lots 1-9) issued by ECMWF in 2016. A second round of contracts (C3S_312b, Lots 1-5 [RD-4]) issued in 2018 is for continued data access and support for a total of 22 ECVs, as indicated in the last column of Figure 4.

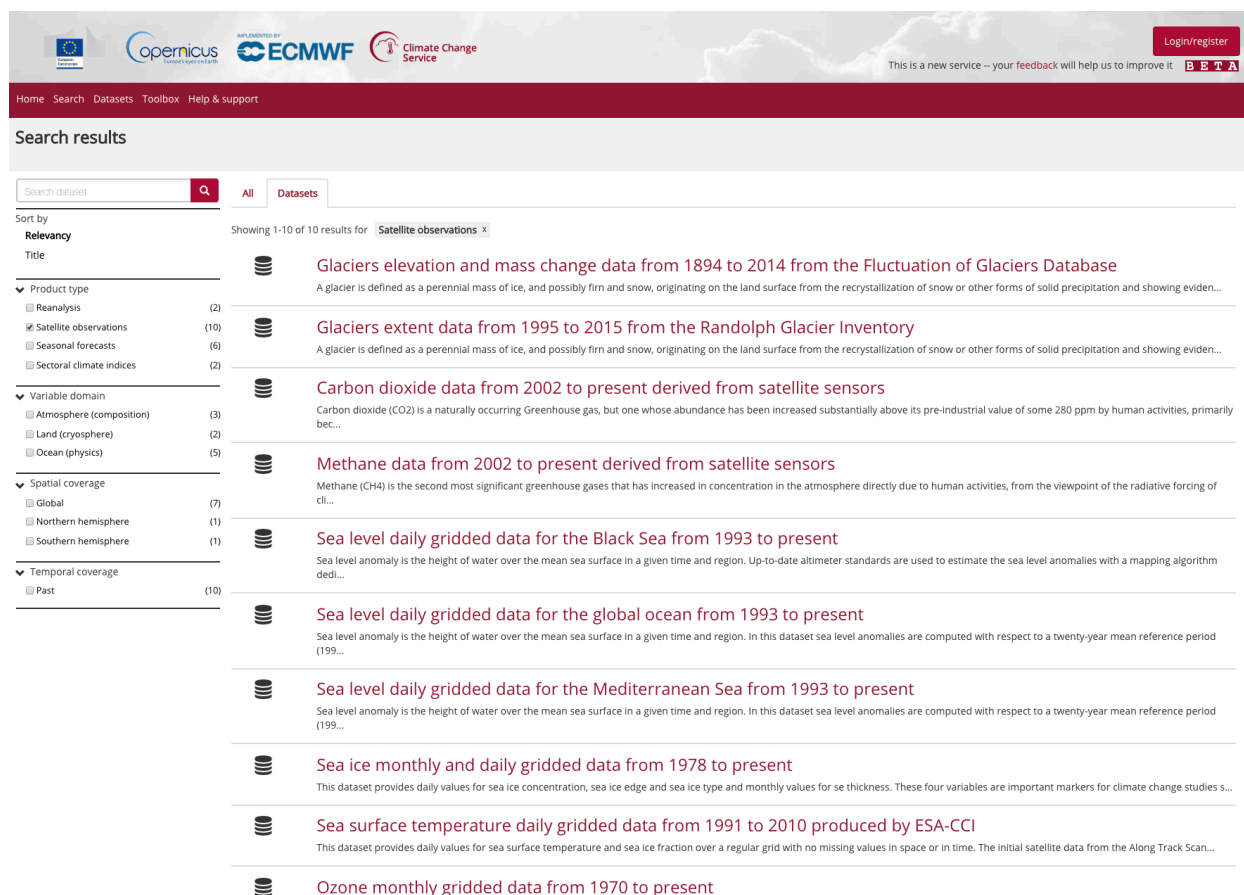


Figure 4: CDS catalogue of ECV products derived from Earth observations (June 2018)

The C3S contracts for provision of ECV data products are designed to ensure reliable operational access to climate data records meeting strict quality criteria. The scope of work for each contract is limited to generation and/or brokering of data products; providing quality assurance information and documentation for users; ensuring access to all data products and documentation via the CDS; and providing expert user support for all products delivered. A detailed description of technical requirements related to timeliness, data availability, data formats, metadata, documentation etc. is available in the invitation to tender documents [RD-4].

Feedback collected by C3S from its users regarding ECV data quality and suitability will be provided to ECV developers, including CCI, to facilitate the development of ECV products that better meet climate service needs.

Figure 6 shows the overall flow of ECV R&D into climate services, with the respective roles of CCI and C3S shown.

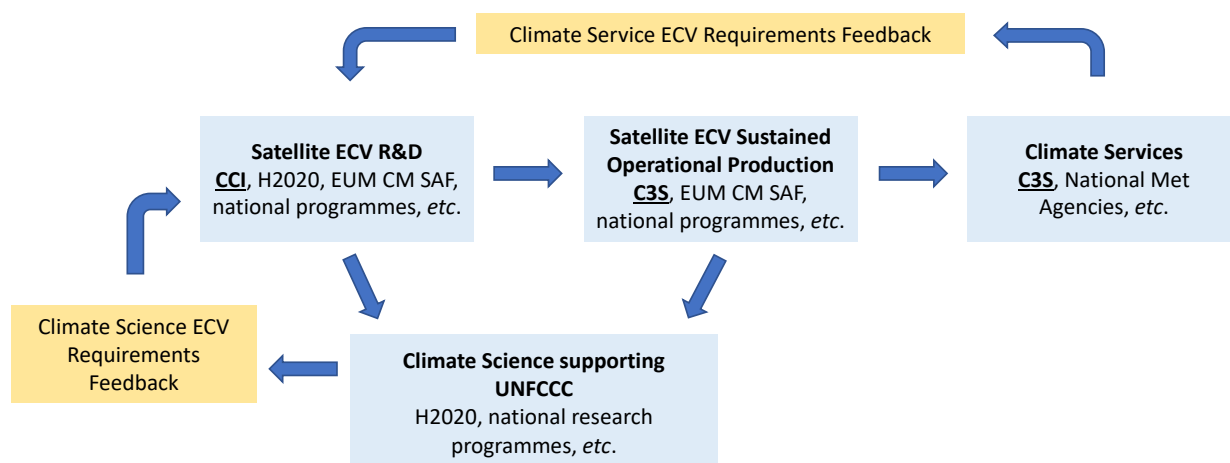


Figure 5: Flow of ECV R&D into climate services and climate science, showing also the feedbacks of requirements from users. The respective roles of CCI and C3S are shown.

ECV-related contracts in both CCI and C3S are placed as a result of open and competitive tenders. The transfer of CCI R&D into C3S operational production is therefore subject to the normal processes of open competition. Such competition is considered to be beneficial to the health of both programmes, when transfer is successful *and* when it is not.

8 DATA ACCESS, TOOLS AND STANDARDS

As described earlier, C3S has developed a Climate Data Store (CDS, cds.climate.copernicus.eu) to provide users with a single point of access to quality-assured climate data and tools, either via the web (e.g. Figure 5) or via an open API that can be used in offline applications. In accordance with Copernicus data policies, all CDS data and products can be used by anyone for any purpose. The CDS infrastructure for data and computing is in the cloud and scalable in terms of data volumes, processing power and number of users. The system has been designed to support interoperability of data from different sources and in different formats. As an operational system, requirements on reliability, usability and speed are paramount.

Beyond the strictly technical aspects, a key challenge for the CDS is to make it easier to use climate data for planning and decision making. Data and tools must be fit for purpose for a large and diverse group of users with varying degrees of expertise in the use of climate data. This has implications for the descriptions of datasets, for user guidance and support, and affects many other aspects of user interfaces to data and tools. Given the complexities of climate science and big data, extensive quality assurance information needs to be available in a form that is both meaningful and helpful to users. The expertise behind the system needs to be highly visible, but cannot be allowed to interfere with ease of use.

The CCI programme has developed its own dedicated Open Data Portal to provide uniform access to all CCI data products (cci.esa.int/data) (Figure 7). The CCI portal also contains extensive documentation and information about the programme. A separate python-based toolbox is being developed to support analysis and visualization of the CCI ECV data products. The CCI Toolbox has been implemented as a downloadable application that can be installed on a user's desktop computer (climatetoolbox.io). The CCI Toolbox mainly satisfies the requirements of scientific users of satellite-based ECV data. It has been designed to facilitate easy access and analysis of multiple CCI ECV data sets loaded directly from the CCI Open Data Portal, together with external data sets, including in future, ECV datasets held by the C3S-CDS. The adopted technology (python) allows the CCI toolbox to support highly complex scientific analyses. The CCI Toolbox is, however, of limited usefulness for the analysis of in-situ and reanalysis-based ECV data sets, and for the general purposes of constructing climate services for downstream users.

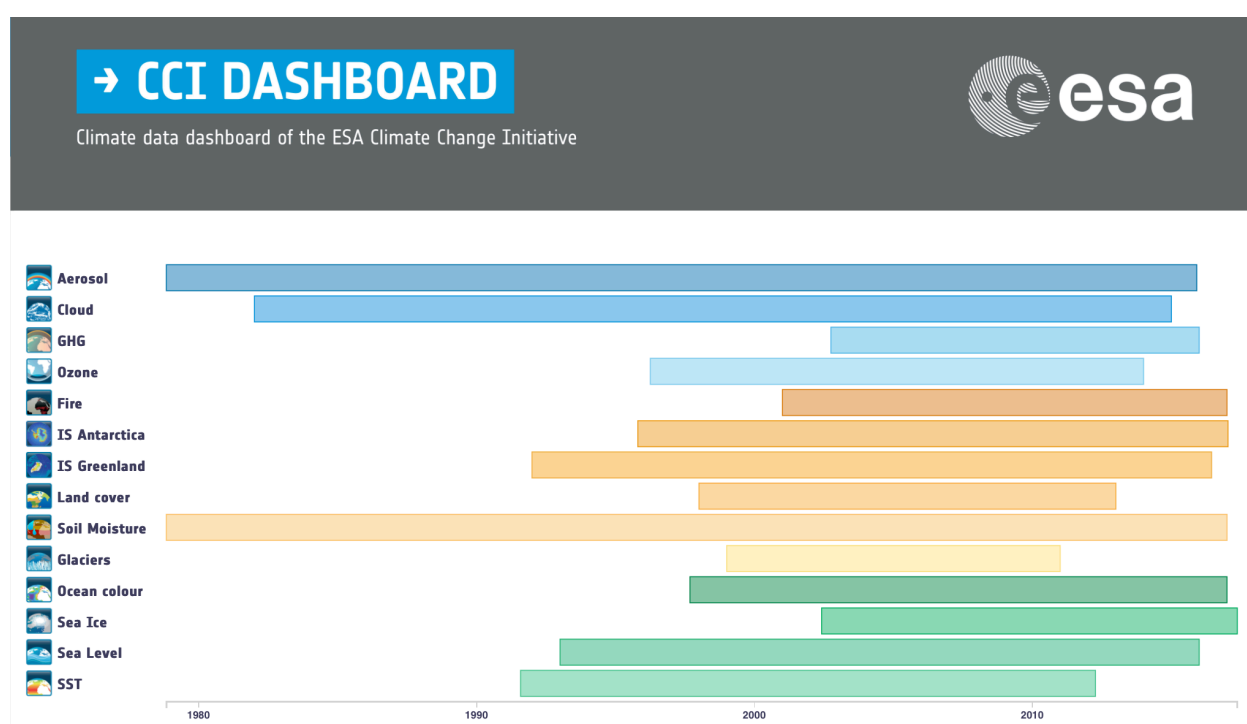


Figure 6: Datasets available in the CCI Open Data Portal. <http://cci.esa.int/sites/default/dashboard/index.html#/>

Both the CDS and the CCI Toolbox rely on the use of standards to be able to process datasets from different sources. Standards are needed for dataset formats, and also for metadata used to describe the datasets. Within CCI substantial efforts have been made on defining data standards appropriate for ECV data products, which has facilitated the inclusion of CCI data products in the CDS. In addition, CCI has imposed common requirements on forms of documentation to be supplied with the data products, which has also been of great benefit to C3S. Conversely, C3S has the opportunity to further refine, consolidate and impose the use of standards within a broader community of suppliers of scientific data. This positive feedback loop can lead to a convergence of standards and conventions that will benefit everyone.

9 COORDINATION

Coordination between CCI and C3S takes place at programme management level with the following objectives:

- To ensure efficient complementarity in CCI and C3S technical activities regarding ECV R&D and ECV Operational Production.
- To ensure CCI responds to C3S requirements for ECV data products, and responds to relevant user feedback collected by C3S.
- To ensure optimal use and value for money in the separate procurements made by CCI and C3S from the common (but limited) pool European science and technological expertise.
- To maximise interoperability between data standards, data portals and toolboxes, for the benefit of users.

Coordination takes place at programme management level through the following mechanisms:

- Mutual participation in tender definition and proposal evaluation activities of CCI and C3S.
- Mutual participation in annual C3S General Assembly and CCI Collocation meetings.
- Ad-hoc bilateral meetings on specific issues, as required.
- Mutual participation in ECV project reviews may also take place when a specific need is identified.

To achieve their respective goals, both CCI and C3S rely on competitive procurement of third-party activities. Fortunately, strong expertise on Earth observations is available in Europe, which is further reinforced by the long-term investments in CCI and C3S. Bidders typically involve a mix of academic institutions, software companies and operational service providers (Figure 8 and Figure 9). However, the specific expertise needed to develop and produce high-quality ECV products resides within small, specialised communities. As a result, many of the same institutions contracted by CCI to develop new ECV products tend to be involved with C3S production activities as well. Clearly, effective coordination and collaboration at programme level is necessary in order to ensure optimal use of resources and good outcomes for both programmes.

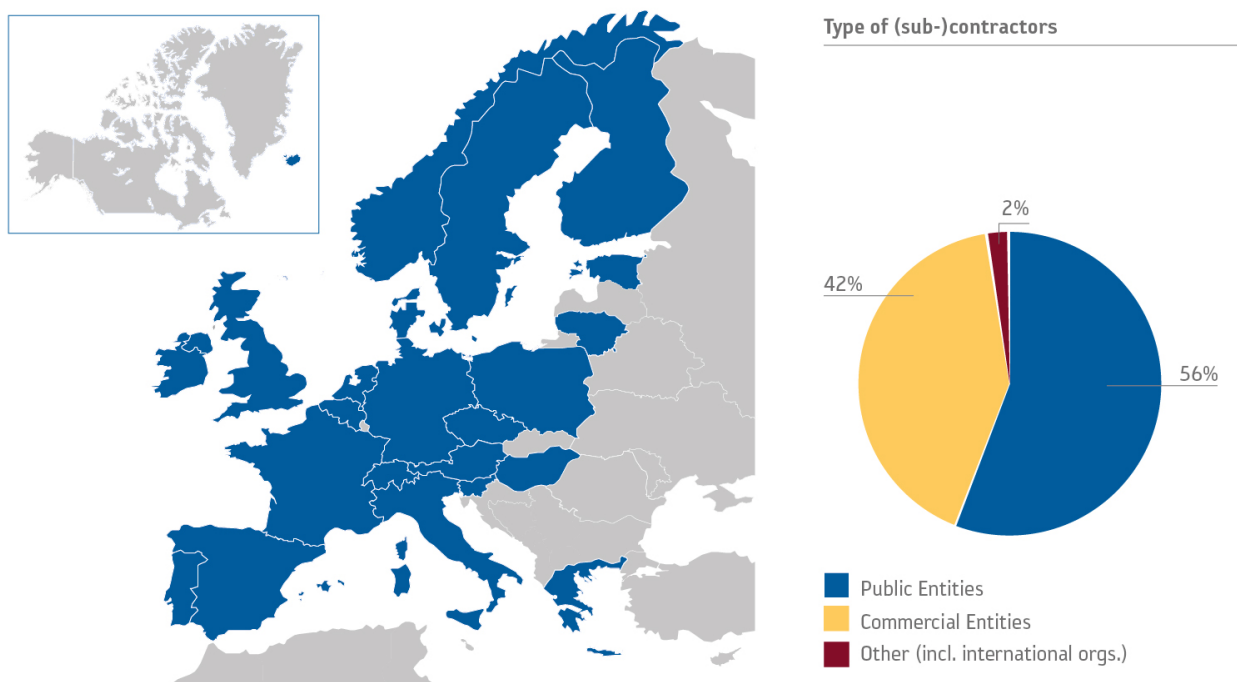


Figure 7: Distribution of 215 entities involved in C3S service contracts (May 2018)

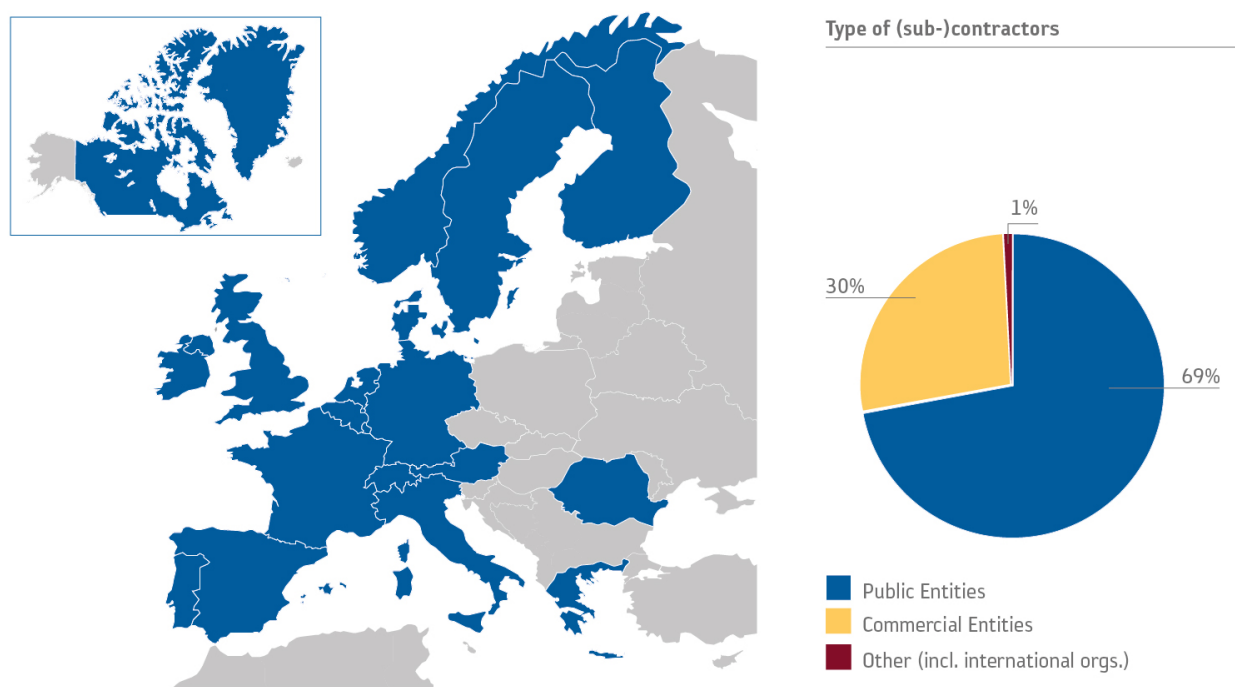


Figure 8: Distribution of the 178 entities involved in CCI contracts (June 2018)

The European Commission is planning the next phase of the Copernicus programme starting in 2021, including the continuation of C3S. Some new service elements have been proposed in response to strong user demand, addressing climate change attribution and decadal forecasting and verification. Nevertheless, the main strategy for C3S will be to consolidate and improve the service elements developed in the first phase of the programme. For the CDS in particular, this means that a larger set of ECVs must be

addressed, and the quality and timeliness of individual ECV data products must continue to improve. Enhanced coordination between CCI and C3S will be a key requirement to be able to achieve those goals.

10 CONCLUSIONS

- CCI and C3S have complementary objectives, both addressing UNFCCC needs, with a common science basis in GCOS
- CCI provides the science; C3S translates science into societal services
- CCI is a research programme; C3S is an operational service
- CCI ECV projects shall respond to user-feedback collected by C3S in defining their ECV development priorities.
- Separate governance but common interest
- Close coordination at programme level – mostly informal
- In practice: attend each other's meetings (CCI collocation; C3S GA); follow/evaluate tenders as needed; collaborate on technical activities
- Win-win