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EUROPEAN SPACE AGENCY

EARTH OBSERVATION PROGRAMME BOARD

Status of the Cooperation between ESA's Climate Change Initiative and the EC's Copernicus Climate Change Service

Summary

This paper summarises the status of the working relationship between the European Space Agency's (ESA) Climate Change Initiative (CCI)[1] and the Copernicus Climate Change Service (C3S), as outlined in ESA/PB-EO(2018)27, Annex 3.

Current discussions focus on the new climate programme – COMPASS (Climate Observations and Monitoring for Policy Action Support from Space, ESA/PB-EO(2021)60) - in preparation for the ESA Ministerial Council in 2022. Recently the Contribution Agreement for the European Centre for Medium Range Weather Forecasting (ECMWF), being the entrusted entity for C3S, has been approved for a second phase, starting 2021. Over recent years detailed scientific and technical discussions have taken place to further the cooperation between CCI and C3S. This paper, prepared by ESA and commented by ECMWF, takes stock of the current success and provides an outlook on future activities.

Action

[1] CCI is the commonly used name for the Earth Watch Programme on "Global Monitoring of Essential Climate Variables" (GMECV)

GMECV Participants are invited to take note of the paper.

1. INTRODUCTION

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

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 currently 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 until the end of 2027. 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.

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 (GCOS-200[1]). Essential Climate Variable (ECV, Bojinski *et al. 2014*[2]) products generated by CCI and C3S activities are systematically added to the online ECV inventory[3], 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). GCOS is currently updating their 2016 implementation plan[4], moving towards redefining ECV needs, moving from investigating trends in individual ECVs to characterising the integrated climate system and its component Earth system cycles, which requires high levels of consistency across different ECVs. Both, CCI and C3S are involved in the process providing their respective expertise in creating climate data records.

As explained in the following sections, CCI and C3S objectives and activities are inherently complementary and support each other. Close coordination and

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[1] GCOS status report, 2015, https://library.wmo.int/pmb_ged/gcos_195_en.pdf and GCOS Implementation Plan, 2016, https://library.wmo.int/opac/doc_num.php?explnum_id=3417
[2] Bojinski *et al*., 2014, The Concept of Essential Climate Variables in Support of Climate Research, Applications, and Policy
[3] https://climatemonitoring.info/ecvinventory/
[4] https://library.wmo.int/doc_num.php?explnum_id=3417

effective collaboration between the two programmes have taken place and strengthen both, ultimately benefitting European citizens.

2. 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).

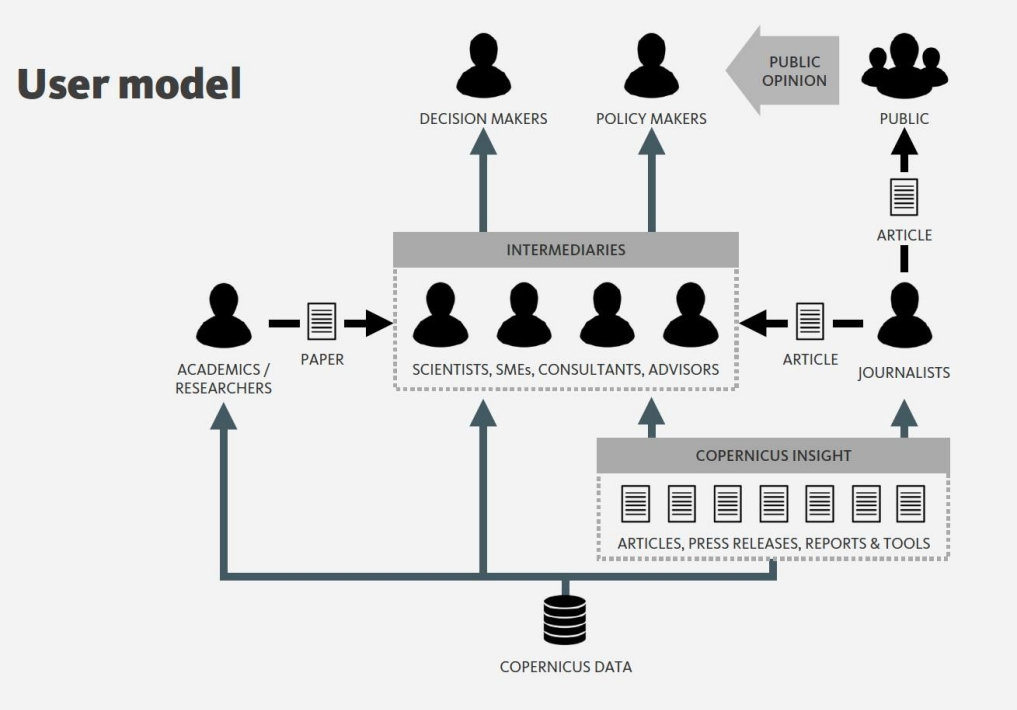

Figure 1: C3S user model. The design of the CDS is especially focused on the "intermediaries" in the central box.

The EC has entrusted ECMWF with the implementation of C3S on the basis of a Contribution Agreement that defines the scope and objectives of the service, as well as legal and administrative procedures and constraints. The Contribution 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), designed to simplify the access to and the processing of climate data by a diverse community of users so that usable and useful climate information could be produced. Along with the data, the CDS provides quality assurance and expert support to users. A particular focus is put on those users at the top of the value chain which can transform the data into products for their own users or other intermediaries downstream. The final objective of this cascading chain of climate services is the provision of effective climate information to planners, policy and decision makers as well as other sectoral users (the central box in Figure 1). The CDS also includes cloud-based computational resources, designed to support the elaboration of workflows and applications close to the data and thus reducing the need to download large volume of data.

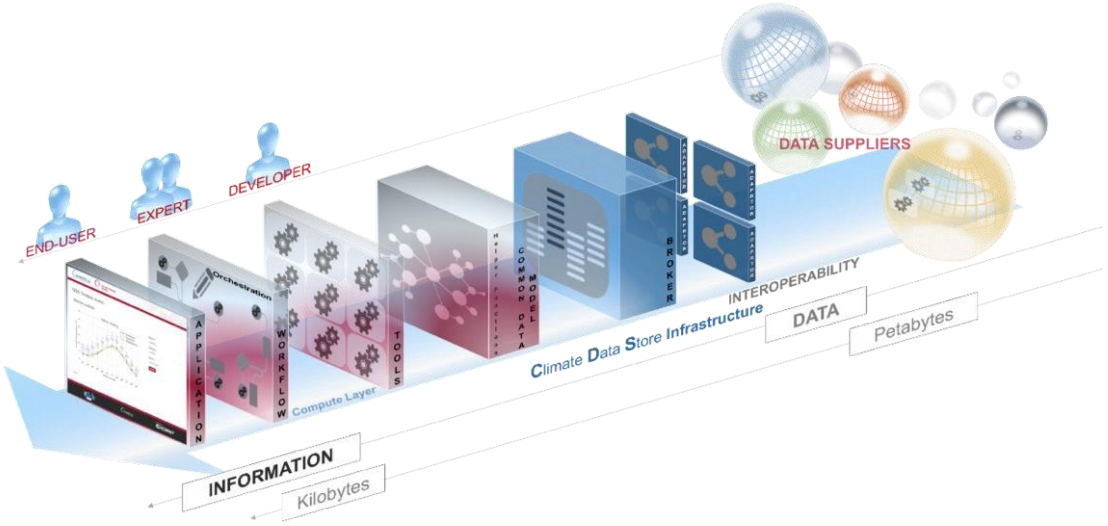

Figure 2: Architecture of the cloud-based Climate Data Store and its user interfaces.

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, climate reanalyses, seasonal forecast data products, and climate model simulations including projections. Information about each dataset is presented in a consistent way. All 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. A major evolution of the CDS infrastructure is expected in 2022. This will further enhance the connection with the WEKEO platform and more general with all the DIAS.

3. THE ESA CLIMATE CHANGE INITIATIVE

The European Space Agency (ESA) established the Climate Change Initiative (CCI) in response to UNFCCC needs for global information quantifying climate change. CCI was implemented in overlapping phases as depicted in Figure 4. 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, the Copernicus Sentinel constellation and other contributing missions.

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.

Meanwhile CCI comprises 450 world-leading experts across ESA Member States to generate global multi-mission and multi-decadal datasets satisfying the requirements for 22 Essential Climate Variables (ECVs) defined by GCOS, working with UNFCCC. These datasets have fully characterised uncertainties and are validated using independent, traceable, in-situ measurements. They provide an impartial yardstick to understand climate processes and to improve and validate climate models, thereby enhancing the quality, credibility and exploitation of model predictions. To further the link between the climate observation and modelling community, CCI has set up the Climate Modelling User Group (CMUG) 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. ESA, in particular the Climate Office, have recently been selected to host the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project (CMIP) International Project Office (IPO), which is currently implemented (ESA/PB-EO(2021)9). In addition, CCI developed a CCI Open Data Portal, the CCI toolbox, the Climate from Space App, as well as various data visualizations and other resources for outreach and education (see www.climate.esa.int).

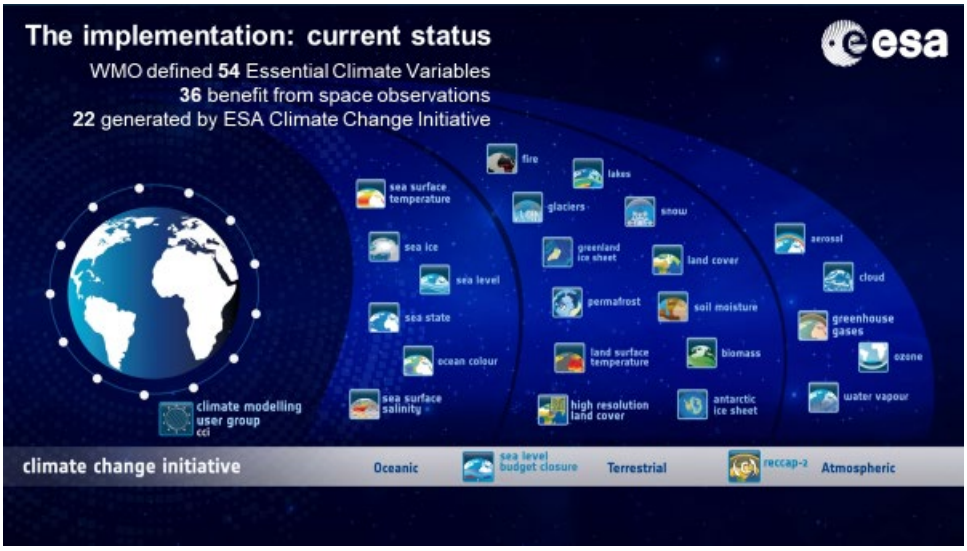

Figure 3 CCI currently addresses 22 ECVs out of 54 WMO defined ECVs.

CCI has published more than 950 peer reviewed papers since 2009. CCI scientists made a major contribution in the IPCC's Fifth Assessment Report and Special Report on Oceans and the Cryosphere in a Changing Climate. IPCC released its Assessment Report for Working Group I (AR WG I)[1] on the physical evidence base in August 2021, which is the strongest and most significant IPCC report to date. It addresses the physical understanding of the climate system and climate change and draws from 14,000 scientific publications. The team comprises 234 authors from more than 60 countries. CCI contributed significantly to the report with a noticeable number of lead, coordinating and contributing authors (~ 20) and reviewers (~ 10) from the CCI community and an increased uptake of CCI led publications (~ 75) being referenced (~ 270 in text citations).

The new climate programme – COMPASS (ESA/PB-EO(2021)60) – is currently discussed by ESA member states, for approval at the ESA Ministerial Council in 2022. The suggested focus of COMPASS will be to

- **Continue and expand** the work supported over the last decade by the successful ESA Climate Change Initiative, and
- Additionally respond to **new requirements** for EO to support the UNFCCC Paris Agreement, as well as climate aspects of the UN SDGs, and other international drivers such as CBD, UNCCD, IPBES.

[1] https://www.ipcc.ch/report/ar6/wg1/

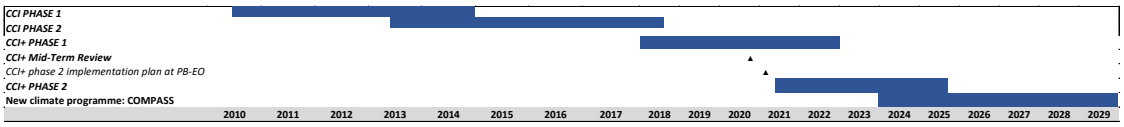

Figure 4: Phasing of the CCI, CCI+ and COMPASS programme. CCI ran from 2009-2017, at which point the extension of CCI, CCI+, started and is running until 2026. The new climate programme, COMPASS, is intended to cover the period 2023-2029.

4. COMPLEMENTARITY OF PROGRAMME OBJECTIVES

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 as such but rather procures, via open competitive tenders, products and services from a set of reputable suppliers. These activities often including any short-term developments needed to maintain and/or improve the quality of data and services. The main objective of the programme is to provide European citizens with reliable operational access to the best available information about past, present and future climate, ensuring maximum benefit from existing research and technical capabilities in Europe.

The complementary objectives of the two programmes are reflected in the different ways that success is measured. A key performance indicator for CCI is its contribution in terms of scientific excellence to further our knowledge about the changing climate, quantified by 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 to transform climate data into actionable information.

CCI	CCI+		GCOS-200	Uptake		C3S	
			Atmospheric				
		§4.5.3	Water Vapour	->			L1
		§4.5.4	Cloud Properties	->			L1
		§4.7.1	Carbon Dioxide	->		L6	L2
		§4.7.2	Methane	->		L6	L2
		§4.7.4	Ozone	->		L4	L2
		§4.7.5	Aerosol	->		L5	L2
		§4.3.5	Precipitation				L1
		§4.3.6	Surface Radiation Budget				L1
		§4.5.5	Earth Radiation Budget				L1
			Oceanic				
		§5.3.1	Sea-Surface Temperature	->		L3	L3
		§5.3.2	Sea-Surface Salinity				
		§5.3.3	Sea Level	->		L2	L3
		§5.3.4	Sea State				
		§5.3.5	Sea Ice	->		L1	L3
		§5.3.7	Ocean Colour	->			L3
			Terrestrial				
		§6.3.4	Lakes	->			L4
		§6.3.5	Snow Cover				
		§6.3.6	Glaciers & Ice Caps	->		L8	L4
		§6.3.7	Ice Sheets	->			L4
		§6.3.8	Permafrost				
		§6.3.10	Landcover	->			L5
		§6.3.13	Above-Ground Biomass				
		§6.3.15	Fire Disturbance	->			L5
		§6.3.16	Soil Moisture	->		L7	L4
		§6.3.17	Land-Surface Temperature				
		§6.3.9	Albedo			L9	L5
		§6.3.11	FAPAR			L9	L5
		§6.3.12	Leaf Area Index			L9	L5

Figure 5: 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), shown as two separate columns in the table under C3S. The arrows indicate CCI heritage.

5. AREAS OF COLLABORATION

5.1. ESSENTIAL CLIMATE VARIABLES

ECV data products constitute a large and significant component of the CDS catalogue. The Technical Annex of the C3S Contribution Agreement includes a table of 38 ECVs that could be addressed by C3S. These are listed in Figure 5 above (in the right columns), with reference to the corresponding sections in GCOS-195. The left 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 2021. 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.

As of 2021, 16 ECVs have been transferred from CCI to C3S, including the 2nd phase of C3S. To note, by 2018, data products for 12 ECVs were available in the CDS, with heritage in CCI. Based on detailed scientific workshops in 2020, priorities in collaboration have been defined, including transferring expertise on new ECVs, such as biomass, permafrost and land-surface temperature, enhancing the link to the modelling community through the provision of vegetation parameters and root-zone soil moisture, as well as addressing new topics, such as biodiversity and terrestrial hydrology.

The C3S contracts for the 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 (C3S2_312a Volume II).

Feedback collected by C3S from its users regarding ECV data quality and suitability is 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.

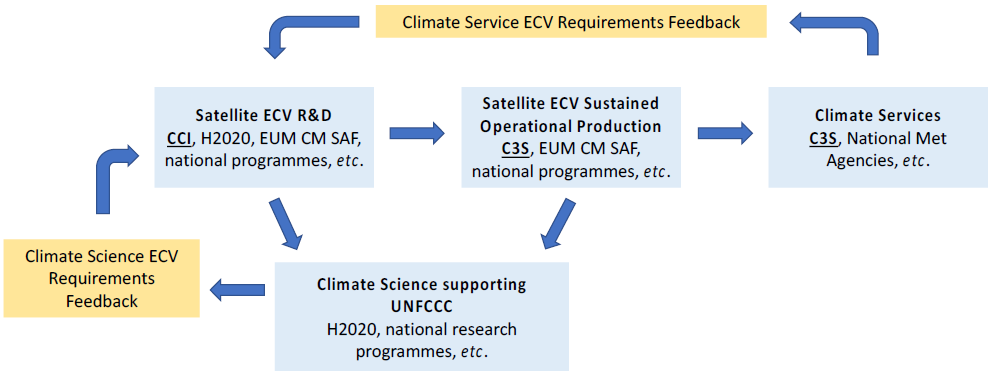

Figure 6: Flow of ECV R&D into climate services and climate science, showing also the feedbacks of requirements from users. The respective roles of CCI and C3S are shown

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.

5.2. 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 (climate.esa.int/data) (Figure 7). The CCI portal also contains extensive documentation and information about the programme. A separate python-based toolbox has been developed to support analysis and visualization of the CCI ECV data products. The CCI Toolbox has been implemented as both a downloadable application (github.com/cci-tools) and cloud-based web application (cate.climate.esa.int). The CCI Toolbox is geared to the requirements of scientific users of satellite-based ECV data. It is built for analysis and combining of multiple CCI ECV data sets drawn from the CCI Open Data Portal, together with external data sets, including in future, ECV datasets held by the C3S-CDS. The adopted technology allows the CCI toolbox to support highly complex scientific analyses.

Figure 7: Datasets available in the CCI Open Data Portal. https://climate.esa.int/odp

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.

As of 2021, a mature draft of a Joint CCI-C3S Data Standards for Satellite-Derived ECVs has been completed, and is planned to formally replace the CCI Data Standards across both ESA and ECMWF programmes in 2022. The establishment of a common data standards across CCI and C3S accelerates the seamlessness from science to operations, and cultivates downstream opportunities for further engineering collaboration. Moreover, CCI and C3S are in collaboration on solutions to visualise the dataset-level mapping between both programmes for the benefit of their respective data portals, due for initial implementation in 2022. Additionally, an ongoing collaboration on exploration of workflows common to both CCI and C3S toolboxes continues.

5.3. LINKING THE CLIMATE MODELLING AND OBSERVATION COMMUNITIES

In response to WCRP's call to establish a CMIP-IPO, ESA was selected as the host institution for this project office. This will entail the Director, programme and science and communication officer. CMIP provides the focal point for the leading national and international entities in climate modelling and is the main resource for the IPCC assessment of climate projections. Moreover, CMIP is a major user of EO-based climate observations for model development, assimilation and evaluation. Scientific research into the underlying mechanisms and trends of the changing climate and its projection into the future through climate modelling provide the basis for adaptation and mitigation activities in response to the UNFCCC Paris Agreement. They are hence becoming increasingly important to provide crucial input to international decision making and policy.

C3S included in the Contribution Agreement the plan to appoint a CMIP liaison officer to ensure a robust coordination between C3S and CMIP office. Such a person, who is expected to start toward the end of 2022, will also work with C3S EQC function to ensure a common approach on quality attributes and assessment could be put in place for climate projections.

Once the CMIP-IPO will be established close links with the C3S liaison officer will be established and common activities agreed.

7. COORDINATION

Coordination between CCI and C3S takes place at programme management level and is based on the following principles:

- CCI and C3S have complementary objectives, both addressing UNFCCC needs, with a common science basis in GCOS.
- CCI provides the science; C3S translate the science into services to meet societal needs CCI is a research programme; C3S is an operational service.
- C3S collects and provides CCI with relevant user feedbacks.
- CCI ECV projects define their research and development priorities in response to these user feedbacks.
- CCI and C3S each have separate governance mechanisms but share a common interest.
- CCI and C3S have a common interest in linking the climate observation and modelling communities.
- Close coordination is ensured by attending each other's key programmatic and technical meetings (e.g. CCI colocation meetings;

C3S General Assemblies and selected user forums), by following and evaluating relevant tenders and by collaborating on technical activities.
- The coordination between CCI and C3S intends to ensure efficient complementarity in CCI and C3S 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 Colocation meetings.
- Ad-hoc bilateral meetings on specific issues, as required.
- Mutual participation in main ECV project reviews.
- Collaboration on linking the climate modelling and observation communities through coordinated support to the CMIP-IPO.

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. 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.

The European Commission has approved 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 but these at this stage are only optional activities. The main strategy for C3S remains the consolidation and the enhancement of the service elements developed in the first phase of the programme. For the CDS in particular, this means that a larger set of ECVs could 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.

8. CONCLUSIONS AND OULOOK

The cooperation between CCI and C3S has continued successfully over recent years, also being demonstrated through the high number of transitions of ECVs from CCI to C3S (16 out of 22). In 2020, scientific and technical workshops were carried out, recommendations are summarised in section 5.1 and 5.2, respectively. Common R&D activities are on-going, already responding to the findings of the scientific and technical workshops in 2020 (e.g. with regards to additional activities in cci_soil moisture for root-zone soil moisture). A mature draft of a Joint CCI-C3S Data Standards for Satellite-Derived ECVs has been completed and is planned to formally replace the CCI Data Standards across both ESA and ECMWF programmes in 2022. Future work will focus on collaborating on bringing the climate observation and modelling communities closer together, through mutual support to the CMIP-IPO.

Continued effective coordination between the CCI and C3S continue to benefit all stakeholders, including users and providers, and strengthens the European leadership in Earth Observation for climate science and services.