THE COPERNICUS PROGRAMME AND ITS CLIMATE CHANGE SERVICE

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***Abstract*: This paper provides an overview of the European Union's Earth Observation Programme, Copernicus, dedicated at monitoring the planet Earth and its environment for the benefit of all European citizens. The Programme offers information services based on satellite Earth Observation, in situ (non-space), and modelling data. The paper focuses on one of the six Copernicus Services, the Copernicus Climate Change Service, which provides comprehensive climate information covering a wide range of components of the Earth-system (atmosphere, land, ocean, sea-ice and carbon), maximising the use of past, current and future earth observations (from in-situ and satellite observing systems) in conjunction with modelling, supercomputing and networking capabilities to produce a consistent, comprehensive and credible description of the past, current and future climate, via the generation of a large number of Essential Climate Variables (ECVs).**

Keywords—Copernicus; Climate Change; Climate Data Records; Sentinels

I. INTRODUCTION

Copernicus is the European Union (EU) flagship programme for monitoring the Earth's environment using space and in-situ observations. Copernicus delivers operational data and information services on a range of topical areas. Based upon these baseline services, many other value-added products can be tailored to more specific public, policy or commercial needs (see Fig. 1).

a.

Fig. 1. Conceptual description of the Copernicus Programme (source: European Commission)

Copernicus includes six core thematic services: Atmosphere monitoring, Land Monitoring, Marine Environment Monitoring, Emergency Management, Security and Climate Change. The **Atmosphere Monitoring** Service includes monitoring for air quality and UV forecasts at global and european level, greenhouse gases, climate forcing and emissions. The **Land Monitoring** Service includes the monitoring for water management, agriculture and food security, land-use change, forest monitoring, soil quality, urban planning and natural protection services. The **Marine Environment Monitoring** Service includes the monitoring for marine safety and transport, oil-spill detection, water quality, ocean forecasting and the polar environment. The **Emergency Management** Service supports mitigating the effects of natural and manmade disasters such as floods, forest fires and earthquakes and contribute to humanitarian aid exercises. The **Security** supports peace-keeping efforts, maritime surveillance and border control. Last but not least, the **Climate Change** Service (C3S) cuts across all the above themes and is about providing authoritative, quality-assured information about the past, current and future states of the climate in Europe and worldwide.

One key and probably unique feature of the Copernicus programme is that Copernicus products including the information services provided are freely and openly accessible to users.

All of the Copernicus core Services heavily rely on the combined availability of satellite, in-situ and modeling information to derive the products and services across the thematic areas mentioned above. A critical component of the Copernicus programme is therefore its Space Component.

II. THE COPERNICUS SPACE COMPONENT

The space component of the Copernicus programme is developed by the European Space Agency - ESA (see http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus) and consists of a series of missions, called Sentinels, each of which being based on two satellites to fulfil revisit and coverage requirements, providing robust datasets for Copernicus Services. These missions carry a range of technologies, such as radar and multi-spectral imaging instruments for land, ocean and atmospheric monitoring:

- Sentinel-1 provides all-weather, day and night radar imagery for land and ocean services

- Sentinel-2 provides high-resolution optical imagery for land services
- Sentinel-3 provides high-accuracy optical, radar and altimetry data for marine, climate change and land services
- Sentinel-4 and Sentinel-5 will provide data for atmospheric composition monitoring from geostationary orbit and polar orbit, respectively
- Sentinel-5 Precursor will bridge the gap between Envisat (Sciamachy data in particular) and Sentinel-5
- Sentinel-6 will provide radar altimetry data to measure global sea-surface height, primarily for operational oceanography and for climate studies

In addition to data provided by the Sentinel satellites, the missions contributing to Copernicus play a crucial role, delivering complementary data to ensure that a whole range of observational requirements is satisfied. The Contributing Missions include missions from ESA and EUMETSAT, from space agencies of their Member States, and international third party mission operators that make some of their data available for Copernicus. It is quite clear that the Copernicus core services need these third party data from contributing missions. This is particularly the case for the Copernicus Climate Change Service (see next section), which provides long term climate data records for a number of key Essential Climate Variables (ECVs) and therefore relies on historical (and reprocessed) data from early satellites and in-situ networks.

III. THE COPERNICUS CLIMATE CHANGE SERVICE

The Copernicus Climate Change Service (C3S) routinely monitors and analyses more than 20 ECVs to build a global picture of our climate, from the past to the future, as well as developing customisable climate indicators for relevant economic sectors, such as energy, water management, agriculture, insurance, health…. Although the C3S portfolio is much broader than Earth Observation based climate information (multi-model seasonal forecasts, climate projections at global and regional level, sectoral impact indicators, etc. are also included in the Service) this paper focuses on monitoring aspect of the Service and in particular the Earth Observation based information.

As stated above, C3S monitors a number of key ECVs and in turn ambitions to strongly contribute to the newly published implementation plan of GCOS (Global Climate Observing System). C3S is now becoming operational, the technical infrastructure is being developed and the first industrial activities have been kicked off. Climate monitoring information is routinely produced and available at climate.copernicus.eu, and the ECVs are being generated either via global reanalyses (this is the case for most of the atmospheric variables) or through the production of long term climate data records (CDRs). Although progressively, these CDRs will greatly benefit in the future from the family of Sentinel missions, they currently heavily rely on third party missions from NASA, NOAA, ESA, EUMETSAT and other Space Agencies. It is expected that data from JPSS will also contribute in the future to the generation of these CDRs and ECV datasets, as well as feed into the next generation reanalyses.

A. C3S global reanalysis

Reanalysis is a major component of C3S. Although currently the C3S climate monitoring products are generated by C3S (Dee et al., 2011 [1]), a major deliverable to the C3S is the replacement of ERA-Interim with a new atmospheric reanalysis of the satellite era, ERA5. ERA5 is based on the recent version of the ECMWF IFS (Integrated Forecasting System) and offers many improvements over ERA-interim: a much higher vertical and horizontal resolution, an improved use of satellite data including some reprocessing activities undertaken by EUMETSAT, a quantification of analysis uncertainty, to name a few. ERA5 is in production mode at the time of writing and the expected completion of ERA5 is around the end of 2018. This dataset represents a significant asset for model and data assimilation developments, model verification and calibration, initialisation of reforecasts, and obviously the production of high quality global ECV datasets.

The higher quality of ERA5 over ERA-Interim is illustrated in the figure below:

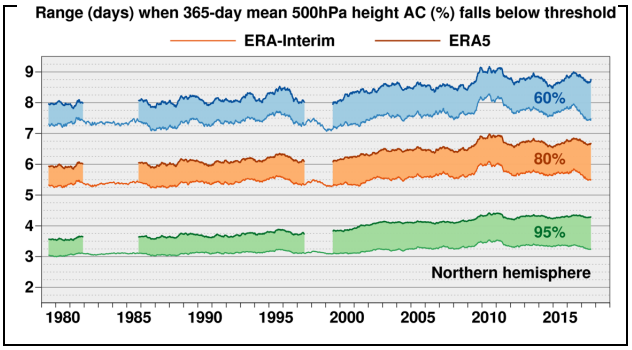

Fig. 2. *ERA5 production status at the end April 2018. Skill of forecasts started from ERA5 reanalysis fields compared to those initiated from the ERA-Interim reanalysis*

ERA5 clearly relies on the availability of high quality datasets, which highlights the importance of the role of space agencies such as EUMETSAT, NOAA, ESA and NASA in providing these data and working with the reanalysis producers. ECMWF is currently considering the next phase of Copernicus, beyond 2020, and is starting preparations towards ERA6, a fully coupled global reanalysis. At this horizon, it is expected that data from the Sentinel fleet as well as JPSS will fully contribute, in addition to the "classical" satellite data currently assimilated, to the generation of this future global reanalysis.

B. C3S ECV datasets

As mentioned above, ECV gridded datasets are also part of the C3S portfolio. The list of the ECVs proposed for C3S are listed in the table below (organised by themes):

Atmospheric physics	precipitation
	Surface radiation budget
	Water vapour
	Cloud properties
	Earth Radiation Budget
Atmospheric composition	Carbon dioxide
	Methane
	Ozone
	Aerosols
Ocean	Sea Surface Temperature
	Sea Level
	Sea Ice
	Ocean Colour
Land, hydrology & cryosphere	Lakes
	Glaciers
	Ice sheets and Ice Shelves
	Soil Moisture
Land biosphere	albedo
	Land cover
	FAPAR
	Leaf Area Index
	Fire

These ECV datasets rely on long term CDRS and exploit satellite data from a wide number of Space Agencies. The specificity of this activity stems from its operational nature. As for other components of C3S, the operational production of these datasets builds upon the research and development from the scientific community in Europe and worldwide. For example, most of the teams involved in the production of these datasets have engaged with the ESA Climate Change Initiative (CCI) programme, where new science and new algorithms can be tested and implemented, for the benefit of the operational C3S. C3S also benefits from initiatives such as the EUMETSAT Satellite Application Facilities (SAFs) and brokers some datasets from other Copernicus Core Services. Discussions are underway to extend this exchange of information and data within the context of a cooperation with the National Centers for Environmental Information (NCEI). This strategy of interoperability and distributed access to environmental information is at the heart of the Copernicus programme.

IV. Conclusions

The Copernicus Climate Change Service (C3S) is one of the six core Services of the Copernicus Programme, probably one of the most ambitious Earth observation programme ever established. C3S covers an significant number of ECVs, via reanalyses or earth-observation based climate data records, and in fine provides an operational contribution to GCOS. While progressively building upon the upcoming source of observations provided by the Sentinel missions, C3S will continue to rely on satellite programmes such as Eumetsat EPS-SG and MTG, as well as international missions such as NOAA-NASA JPSS.

Acknowledgments

The authors have used information and illustrations from the European Commission and the European Space Agency websites for the description of the Copernicus Programme and its space component.

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