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European research underpinning European Climate Services

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Operational climate services such as the Copernicus Climate Change Service (C3S)[1] support sustainability and help build resilience to climate variability and change. Those services rely heavily on climate science results. The five research projects that started in 2014 as part of EU-FP7 Space Research Programme to scope and underpin the C3S have come to an end in early 2018. They were successful in providing global and European reanalysed climate data, air quality data, climate impact IT platforms and extreme event attribution case studies. They also rescued, digitised and made available billion-days of observations of past weather and climate. The results of these European projects are already used for climate mitigation policy advice, disaster risk management and adaptation support in a variety of application areas. In contrast to the ongoing drive to make these research results operational, much less attention goes to the medium and long-term research needs essential for improving and expanding future climate services. Here we argue that follow-on research projects are vital for European climate services to remain state-of-the-art in the future. This follow-on research is more efficient if it takes into account the lessons learned from previous experiences described below.

As part of the 2013 Space Call of the 7th Framework Programme of the European Commission, five research projects started in 2014 that all shared the common objective to develop and advance the methodologies, tools and knowledge required for operational implementation of the Copernicus Climate Change Service (C3S):

1) ERA-CLIM2 (www.era-clim2.eu), which provided a complete description of the evolution of the global climate during the past century, by integrating billions of earth observations and conventional observations into a comprehensive dataset using reanalyses with advanced weather models;
2) UERRA (www.uerra.eu), which provided an even more detailed description of the recent European climate using novel regional reanalysis and downscaling techniques to the 10-kilometre scale (including uncertainty estimates);
3) QA4ECV (www.qa4ecv.eu), which provided datasets for climate variables defined as essential for the Global Climate Observing System (GCOS) for which no earth observation datasets existed so far, as well as a quality assurance system to demonstrate the fitness-for-purpose of those datasets;

[1] Copernicus Climate Change Service (C3S) is one of six services within the EU Earth Observation and Monitoring programme – Copernicus; C3S offers information based on satellite Earth Observation and in situ (non-space) data; see climate.copernicus.eu

4) CLIPC (www.clipc.eu), which provided access to climate data and information through a data service infrastructure which includes (visualisation options of) derived impact-based indicators of climate change and guidance information on the quality and limitations of all data products (including metrological traceability with uncertainty as a quality indicator);
5) EUCLEIA (www.cordis.europa.eu/project/rcn/188836_en.html), which provided interpretations of observed extreme climate and weather events (such as storms, extreme rainfall, heat waves, cold spells and droughts) and developed methods to link these events to human induced climate change.

In order to maximize the synergy between these five projects, a coordination activity was set up from the start to facilitate information exchange among the projects and with relevant Commission DGs and other stakeholders. Besides teleconferences and joint meetings among the project coordinators, coordinated stakeholder liaison activities have been organized, for example on the topic of "uncertainty from the perspective of a decision maker". These helped in providing coordinated input to the Commission DGs linked to the development of the C3S (DG GROW) or linked to other climate services (DG CLIMA, DG Research & Innovation, EEA).

The capabilities developed through these five research projects have already had a large impact on the scientific and technological foundation for the C3S or they will shape possible future extensions. Several of the projects have successfully delivered important content for the C3S Climate Data Store, such as global and regional reanalyses and various data products derived from satellite observations. The projects have also generated major advances in data rescue, for historic weather observations as well as early satellite data records. The data generated in the projects have proven to be indispensable for all sorts of application areas including renewable energy, food security and flood risk reduction. The same data are also used for monitoring progress with the Paris Agreement goals and as a baseline for (regional or global) future climate predictions. Many other outcomes of the research projects have been, or will soon be, incorporated in the C3S. These include, for example, the quality assurance approach developed in QA4ECV, which has been absorbed in the Evaluation and Quality Control (EQC) function of C3S, and the cutting-edge work on attribution science developed in EUCLEIA, which provides the basic ingredients for a pilot operational attribution service being implemented in C3S.

Lessons learned from the five projects go well beyond those, often articulated, general issues of improved communication between scientists and users, better tailored climate data and the need for capacity development. More specific lessons learned from these projects must inevitably lead to follow-on research.

a) Many potential users are not yet aware of the possibilities modern reanalysis data provide and therefore reanalyses should be further promoted as a key resource in policy relevant-documents from area planning on the local scale to IPCC assessment reports at the global scale;
b) More work is needed to assess and reduce long-term biases in reanalysis datasets (due to model parametrization and changes in observation coverage) because they may introduce spurious climate variability and trends;
c) The production of high-resolution regional reanalysis of European climate is a relatively new activity, which requires multiple development strands because it

cannot lean on existing pan-European operational systems; operational systems are either global at a grid resolution up to a few tenths of km or sub-European at a grid resolution of a few km;

d) In addition to the reanalysis datasets developed for individual components of the climate system (atmosphere, ocean, land, cryosphere and chemistry), reanalysis datasets for coupled systems are required for many applications that need consistent information combining time scales and domains from weather to climate and hydrology to air quality;
e) To underpin monitoring policies, the retrieval of climate variables from new satellites (in particular the high resolution Copernicus Sentinels) needs further improvement, including more derived and tailored products and better guidance on issues of representativity, uncertainty and validity;
f) The maintenance of the observation network (in particular for critical in-situ and satellite measurements) and the rescue and quality control of historical data must be seen as an ongoing effort which requires a permanent infrastructure and knowledge base in order to access the observational data required to update and push back the reanalyses into pre-industrial times;
g) Intensive communication and engagement with users is critical to decide on priorities concerning climate variables to be archived, derived indicators to be generated, scales and skill scores to investigate, and quality indicators to be included in data products;
h) Interactive traceability chains are a useful and efficient tool for data users to obtain confidence in the quality, robustness, and limitations of the data records;
i) It is vital for users to have a clear understanding of the scientific uncertainties involved with both reanalysis and observation datasets and of the robustness of the results relevant to the risk estimation of low-frequency variability and climate trends;
j) Uncertainty information should become more ‘actionable’, which requires convergence on how to specify, assess and deal with uncertainty following international metrological norms for presenting quantified uncertainty in a way that builds confidence for decision-making processes;
k) There is a need for an information portal (or services information system) that speaks to all types of users with products tailored to the varied needs of different user groups to be useful in their decision making or scientific applications which includes well-documented provenance of the science and data products;
l) More knowledge on the drivers of extreme events will enable verified assessments of the extent to which weather-related risks have changed due to human influences on climate or identify those types of weather events where the science is still too uncertain to make a robust assessment of attributable risk (linking climate services to weather services and therefore to present-day decision-making about extreme events);

The ability of the C3S to continue to deliver state-of-the-art, user-driven and science-informed climate services is only possible if sufficient funding can be allocated to new research projects that run parallel to the operation of the service and in addition to innovation. Consolidating and developing the necessary advances in climate services, future EU-projects should take into account the lessons learned from the five successfully completed FP7-projects above.