Matching new demands of Climate Services with evolving Earth system modelling and prediction capabilities

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Matching new demands of Climate Services with evolving Earth system modelling and prediction capabilities

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Foreword

Dr. Chris Hewitt, Climateurope Coordinator

It is once again my pleasure to introduce the third, and final, publication in the Climateurope publication series on the state of European Earth system modelling for climate services.

The first publication in 2017[1] focused on the state-of-the-art of European Earth system modelling to explain and illustrate the abilities and limitations of Earth system models in relation to the potential for climate services. The second publication in 2019[2] updated the first and gave special attention to the best use of climate models and Earth system models to underpin climate services, including support for their interpretation to strengthen the science base of climate services. This final one focusses on matching the new demands of climate services with evolving Earth system modelling capabilities. The publication series is intended to have a wide readership including the scientific community, and decision- and policy-makers from industry, professional federations and public sector.
The backdrop and motivation for the publication series is the continued and growing awareness among decision-makers of the relevance and importance of climate information to a range of social and economic issues. To attempt to better inform such decisions a market of climate services is emerging. The climate services are based on climate data and scientific knowledge covering the past, present and possible future climates. A key component of the data and knowledge, particularly concerning the future climate, is derived from numerical models of the climate and the associated Earth system including physical, chemical and biological processes. The European Commission has been supporting Climateurope (www.climateurope.eu), a coordination and support action, under the Horizon 2020 framework programme, to build an environment and a range of activities around Earth system modelling and climate services. One key activity is the production of this publication series to map and analyse relevant initiatives, challenges and emerging needs relating to Earth system modelling and climate services in Europe, involving expertise from a range of stakeholders. I hope this publication is of interest and use.

[1] Doscher et al (2017), available at https://doi.org/10.17200/Climateurope.D6.5/1

[2] Martins et al (2019), available at https://doi.org/10.17200/Climateurope.D6.8/1

1 Introduction

It is important to have a good working definition of climate services. The Global Framework for Climate Services provides a description for climate services as the provision of climate information to assist decision-making (Hewitt et al, 2012). The European Commission (EC2015) provided a more detailed description as part of their Roadmap for climate services as 'the transformation of climate-related data into customized products such as projections, forecasts, information, trends, economic analysis, assessments, counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for society at large'.

The "European research and innovation roadmap for climate services" and the programs it has stimulated have led to much stronger links between providers and users of climate knowledge and information. There is a focus on understanding the processes and consequences of climate change and variability as well as improving knowledge on climate related decision-making. Climate services increasingly link users' needs to climate knowledge. The difference between a climate service and climate research is that it focuses on serving user requirements. Apart from helping to prepare to manage the effects of climate change, one of the main aims of climate services is to provide up to date climate related knowledge and information which can be further used to reduce climate related disaster risks, and to improve welfare.

In this report we review two recent climate service market surveys. Climate service providers include international and national initiatives, operational and research-based providers, among others. Types of users are also diverse, including business, research and education, policy makers, NGOs, politicians, the general public and the media. The division between users and providers is not always clear, since users may also become climate service providers and vice versa. Climate services require a range of tools and datasets: observations, re-analyses, and climate models. There is a need for functioning infrastructure that can deliver tools and data. In this report we update the state of modelling, make the case for observations and explore novel ways of integrating models with services. We interpret the service provision through the lens of the stakeholder or users and highlight projects that have offered different solutions to a range of challenges. There is now a new generation of platforms providing tools and data to a wide range of stakeholders and they are an essential part of integration, efficiency and standardisation. Finally, we outline the recommendations for sustaining the work and the legacy of the Climateurope project following its end in January 2021, which include running webstivals, updating information on the website, and sustaining the network through events at conferences, and upkeeping the Climateurope social media networks.

2 The market

In the period 2016-2018 the European H2020 projects EU-MACS and MARCO analysed the climate services market. The insights from EU-MACS regarding obstacles and mechanisms underlying less than optimal uptake were used to edit and differentiate projections made in the MARCO project. Within these projects a broad definition of "climate services market" was used (Fig 2.1.).

2.1 Current market and prospects

The current market size in Europe (2016) is estimated to be in the range of 3 to 8 billion Euros, with an expected growth rate around 9-10% for the next years (Perrels et al., 2019). There is a good basis for such growth with the growing attention for the impact of climate change in various sectors, the EU-requirement to have national adaptation strategies and implementation and the ongoing research related to climate services.

A large part of the supply of climate services comes from the public sector or is financed by the public sector. Due to EU and national policy regulations, governments are also relatively large users of climate services. The private or commercial sectors have an estimated share of about 30-35% in the use of climate services and this is expected to grow. Private companies are more active in the part of the value chain near the final users with services that translate climate information to the context of the users (Perrels et al., 2019) often with a shorter time horizon and where climate information is often combined with non-climate information.

The most important user sectors up till now are water management, energy, agriculture, spatial planning, education, business services, and forestry (Perrels et al., 2019). In Eastern and South-eastern Europe fewer providers of climate services are found (Hoa et al., 2018). Awareness and international and national policies are probably more important for the growth of the market than economic growth and available budget (Perrels et al., 2019).

2.2 Barriers, opportunities and recommendations

Obstacles for the uptake of climate services (Bessembinder et al., 2019; Hoa et al., 2019; Mysiak et al., 2018; Stegmaier et al., 2019; Hewitt et al., 2020):

- Time horizons and quality indicators used do often not match user needs
- Limited awareness of impact of climate change and potential benefit of climate services
- Lack of incentives and lack of overview of available climate services
- Lack of integration of information from different disciplines and insufficient

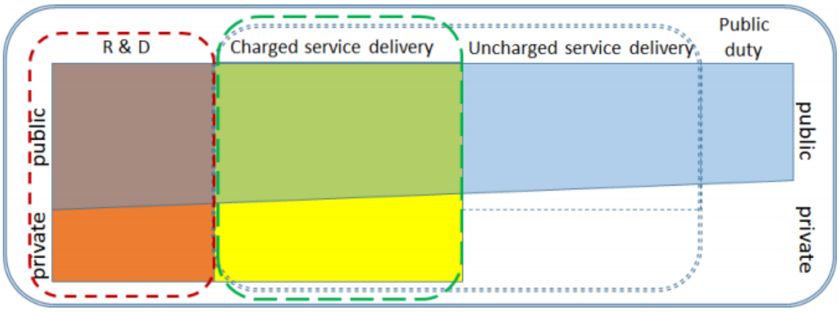

Figure 2.1 Different delineations of the term "market for climate services": climate services are included that generate or use at least some climate information. (Source: Perrels et al., 2019)

background knowledge to extract value from climate information

- The costs for certain climate services

Obstacles for development and delivery of climate services (Perrels, 2018; Cavelier et al., 2017; Le Cozannet et al., 2017):

- Lack of standards related to quality of climate services
- Limited availability of easily useable and updated climate data or mismatch with user needs
- Lack of expertise to integrate information from different disciplines
- Legal limitations to what governmental providers are allowed to provide
- Lack of interesting business models and knowledge about user requirements
- Limited resources for operationalization of climate services.
- free access to climate data by commercial providers for developing climate services

Hoa et al. (2019) mention that there are market opportunities in Central and Eastern EU Member States particularly in sectors poorly covered until now (e.g. health, tourism, finance). The increased uptake of climate services in the financial sector may have a large follow-up effect in other sectors (Perrels et al., 2019; Cavelier et al., 2017). If the obstacles can be reduced or even resolved this may offer opportunities:

- A climate services observatory may give better overview of available climate services.
- Policies that incite or regulate the use of climate services, stimulate standardization, transparency and accountability or support climate services brokerage and more information on the benefits of climate services will increase the awareness and sense of urgency (Perrels et al., 2019; Stegmaier et al., 2019).
- Exploration of new and more interesting business & resourcing models for climate services.

Stegmaier et al. (2019) give governance approaches to promote climate services: state-centred, business-centred and network-centred, each with different policy measures. All three approaches can result in a significant increase in uptake of climate services, but the network-centred approach tends to offer the best prospects.

It is still not straightforward for researchers, providers and users to know which climate services have been developed and are available. The MARCO-project proposed a market observatory that monitors the supply and demand across Europe (Perrels et al., 2019). This could also help to analyse the challenges and potential gaps between the available climate services and actual user requirements. The prevailing view of experts in the field is that, overall, the benefit potential of currently available climate services is as yet poorly exploited (Hewitt et al., 2020; Perrels et al., 2019).

3 Modelling

Climate models are developed and used to provide a better understanding of key processes governing the climate and describe how climate might change under different emission scenarios. This information serves as the scientific basis for many climate services aimed at providing tailored information to decision makers and policy makers. This section provides an update of climate models development priorities and how these can enhance the accuracy and the salience of climate services. We note that there is often a substantial time lag of up to several years between scientific findings on one side and developed climate services on the other.

3.1 Earth system modelling development priorities for climate services

Through the funding of key research projects, the EU support has been essential to sustain the European leadership in climate science and Earth System Modelling. Recognizing that Earth System Models (ESMs) are essential tools for supporting climate policy-making and the Paris Agreement, Horizon 2020 Work Programme 2018-2020 launched the call "Developing the next generation of Earth System Models" (LC-LCA-18-2020). Actions under this call were asked to address in a novel way one or more of the competing demands surrounding the advancement of ESMs.

Climateurope has prepared a paper with "Recommendations to Horizon Europe on research needs for Climate Modelling and Climate Services" (Climateurope Deliverable 4.4). Among the recommendations, the more relevant for ESM development include: informing climate mitigation policy, enhancing adaptation and resilience to extremes, supporting the formulation of adaptation strategies, and strengthening the links between the climate modelling and climate service communities (Hewitt et al., 2020).

Development areas to address the above recommendations include: developing a wide range of likely and feasible overshoot scenarios; enhancing the level of process realism and the representation of uncertainties in models; addressing the remaining large uncertainties with regard to regional patterns and magnitude of changes; tailoring climate information for local impact analyses; and the shared development of techniques to enhance efficiency in extracting information from climate data.

3.2 Progress with Earth system modelling applications in CMIP6

Earth system models applied in coordinated Coupled Model Intercomparison Projects (CMIP) constitute the backbone for many climate service applications. Currently, many climate services still rely on data and information based on CMIP5 (Taylor et al., 2012) that was also instrumental to the IPCC 5th assessment report (IPCC, 2013). More recently, the 6th phase of CMIP (CMIP6) has produced a large number of new simulations and despite some delays many CMIP6 results are now being assessed in the 6th assessment cycle of the IPCC. Compared to CMIP5, CMIP6 ESMs have been improved in many aspects and are generally run at higher horizontal resolution, which also leads to improved credibility of the results.

3.3 Progress in the evaluation of climate models and ESMs

Climate and Earth System Models are continuously being improved both in terms of better describing relevant processes and in terms of improved ability to simulate features of the climate system. The model evaluation procedure relies on relevant observational data (see section 4 below) but also on good tools for evaluation. Further, it is important to have good experimental protocols in place so that comparison to relevant observations can be done. It is also worth stressing the importance of model intercomparison in this context so that information from large ensembles of climate scenarios can be evaluated in relation to each other.

The Earth System Model eValuation Tool (ESMValTool) (Eyring et al., 2020) is a routine benchmarking tool with diagnostics and performance metrics that provides a growing number of state-of-the-art analyses to be applied to single or multiple models, or to observations used by the European climate modelling community. Triggered by the increasing complexity of ESMs that are incorporating more details and completely new processes, ESMValTool is under constant development. The number of available diagnostics and reference data sets is being expanded over time funded by different European and national projects. Currently, it is extensively used to evaluate CMIP6 simulations. Results are made available on a public website (https://cmip-esmvaltool.dkrz.de/) to speed up the process of incorporating new scientific findings into climate services.

3.4 Operational climate prediction

Climate prediction aims at providing future climate forecast information for time scales that range between three weeks and up to about a decade into the future (Doblas-Reyes et al., 2013). Both ESMs and empirical-statistical methods are used for the task. As listed by Merryfield et al. (2020) the challenges include: forecast initialization and ensemble generation; initialization shock and drift; understanding the onset of model systematic errors; bias adjustment, calibration, and forecast quality assessment; model resolution; atmosphere-ocean coupling; sources and expectations for predictability; and linking research, operational forecasting, and end user needs. Bringing relevant stakeholders together with scientists behind these methods has demonstrated benefits to ensure that society has access to the best possible weather and climate prediction science (Merryfield et al., 2020).

Recently Smith et al. (2019) showed that using a large multi-model ensemble of CMIP5 GCMs, decadal climate is more predictable than previously thought. Smith et al. (2019) proposed a new approach to better evaluate the benefit of initialization with observations, thereby improving our understanding of the sources of skill. Other scientific studies showing improved quality with specific relevance to European conditions involve Kruschke et al. 2014; 2016 and Schuster et al. 2019 addressing extra-tropical cyclones, storm tracks and blocking frequency over the North-Atlantic and Europe in a climate prediction perspective. Part of the improved skill was due to higher horizontal resolution in the GCMs. CMIP6 experiments are becoming available for analysis also for the dedicated MIP (Model Intercomparison Project) on Decadal Climate Prediction Project (DCPP, Boer et al., 2016). DCPP emphasizes the need for larger ensembles and more frequent initializations (annual instead of five-yearly).

The WCRP recently initiated the Grand Challenge on "Near-Term Climate Prediction" NTCP (GC-NTCP, Boer et al., 2016) to "support research and development to improve multi-year to decadal climate predictions and their utility to decision makers". On a European level the ongoing H2020 project EUCP (Hewitt and Lowe, 2018) and the C3S tender targeting a prototype climate service for climate predictions (Copernicus C3S_34c Prototype Service for Decadal Climate Predictions) are of special relevance to the development of NTCP.

3.5 Recent developments in CORDEX

Regional climate modellers, for Europe especially through EURO-CORDEX (Jacobs et al., 2020) and Med-CORDEX (Ruti et al., 2016), are focusing on further improving regional climate modelling and information integration methods that can improve climate services. Both fine-scale process-level changes in the climate system and robust assessment of regional change are developed in this context. Central initiatives are the CORDEX Flagship Pilot Studies (FPS) and the large ensembles of new simulations from CORDEX-CORE (Coordinated Output for Regional Evaluations).

The consistent set-up in CORDEX-CORE (with defined global climate models downscaled by a defined set of regional climate models) with 25 km resolution is now an important part of CORDEX for all continents on a global scale. First results from the CORDEX-CORE simulations have been assessed by Coppola et al. (2020a). The EURO-CORDEX matrix of RCP-GCM-RCM combinations is currently being substantially expanded by a large number of new simulations by nine RCMs operated under a C3S contract. In two recent papers 55 GCM-RCM combinations under the forcing scenario RCP8.5 are analysed for model performance (Vautard et al., 2020) and for climate change in the 21st century (Coppola et al., 2020b). In another study Christensen and Kjellström (2020) evaluate a subset of the full EURO-CORDEX matrix as a test for assessing ensemble spread aiming at improving experiment design. Further exploitation of these datasets has large potential for adding better information about robustness and uncertainties to strengthen climate services.

Most traditional climate models have relatively coarse spatial resolution which hampers a realistic representation of convective precipitation. Recently, studies on high-resolution convection-permitting models have shown i) more realistic simulation of convective precipitation extremes and ii) a stronger climate change signal for summertime precipitation extremes (e.g. Belušić et al. 2020; Lenderink et al., 2019). The FPS on the Alpine region is the first large experiment where such models are being compared to each other in some detail (Coppola et al., 2018). This is an important first step in identifying robust features and uncertainties that both need to be addressed by climate services. Activities involving convective-permitting RCMs are also part of the current H2020 projects and in other regional projects like the Nordic Convection Permitting Climate Projections project (NorCP, Lind et al. 2020) or on national level as in the UK (UKCP18). Those efforts are providing research and output for an improved quality base for downstream climate services.

The FPS LUCAS (Land Use & Climate Across Scales) addresses the impact of land use changes on climate in Europe across spatial and temporal scales (Rechid et al. 2017). This is important from a climate services perspective as land use has changed substantially over the 20th century and it has not been assessed to what extent such changes may have influenced historic changes in climate. It is also highly important for the future when changes in land use may be expected, not least in connection to climate change mitigation activities.

4 Observations

Information about climate in the past is essential for development of many different climate services. Roughly, this information can be divided in two major groups, direct observations, e.g. station observations, and products derived from them e.g. reanalysis or gridded climatology. Direct observations are a key element in climate monitoring, a basic climate service. On the other hand, reanalysis and gridded products, beside climate monitoring and other services can be crucial for development of climate models, in terms of model skill assessment, bias-adjustment or detection and attribution studies. Nowadays, many different products, previously dispersed in different countries and portals, have been combined and converted to climate services and made available via Copernicus Climate Change Service (C3S), specifically Climate Data Store (CDS).

4.1 Reanalysis

One of the milestones in the past few years is publication of global ERA5 (C3S, 2017) and ERA5-Land (C3S, 2019) reanalyses. Main characteristic of both data sets is unprecedented high-resolution in time and space. Additionally, the ERA5 Observation Feedback Archive contains all observations assimilated in the reanalysis, together with information about the quality.

UERRA (Uncertainties in Ensembles of Regional Reanalysis; Schimanke et al, 2019) regional reanalysis for Europe, contains data of the atmosphere, the surface and near-surface as well as for the soil. High resolution data from UERRA allows subcontinental analysis especially ones related to the extremes. In particular, UERRA provides outputs on vertical levels that were introduced following the needs of the wind energy sector. The new regional reanalysis will be built with the improved system of the UERRA project (CERRA - Copernicus European Regional Reanalysis) and forced by the global ERA5 reanalysis (C3S, 2020a).

Preparation of European regional reanalysis for the two Arctic subdomains has started (C3S, 2020b). This regional reanalysis can potentially fill the very large gap in data coverage due to sparse observations over this region, but lack of the observations can put some limitations in the development of such a product. Some previous research on regional reanalysis over polar region shows that results are mixed in terms of skill in comparison to global reanalysis that was used as a driving input on boundaries (Bromwich et al, 2015).

4.2 Gridded observations and climatologies

In addition to reanalyses, improved gridded climatology for different climate variables and derived indices are available for Europe and several subdomains. The main dataset and probably mostly used is E-OBS gridded climatology (Cornes et al, 2018). Additional regional gridded products that are available are: Nordic Gridded Climate Dataset (NGCD; Lussana et al, 2018), long-term Alpine precipitation reconstruction (LAPrec; Auer et al, 2007); Alpine precipitation grid dataset (APGD; Isotta et al, 2014); and the CarpatClim dataset that covers the wider Carpathian region (Szalai et al, 2013). For all of them additional indices and indicators are also available.

4.3 Direct observations and data rescue

Beside constant developments in the field of climate services and improvements of different products, direct station observations still have high priority for many users, indicating importance of high quality and availability of these data but also a need for proper maintenance and extension of the meteorological networks with both automatic and traditional stations. Furthermore, direct observations are also used as an input for re-analysis production, for verification and validation of climate models, for bias-adjustments of climate models and they are the basis for gridded observational datasets.

During recent years availability, amount and quality of reanalysis and gridded products significantly increased, but availability and accessibility to the station observations is still limited. The Climate Explorer is an example of an online platform, which provides relatively easy access to databases such as GHCN and ECA&D, or pre-calculated indices derived from station observations. One way to increase the volume of available observations is the transformation of data from paper logs or tapes into machine-readable format that is easy for a wide usage. The C3S Data Rescue Service is designed to facilitate and coordinate the rescue of weather and climate data. It closely collaborates with the World Meteorological Organization, International Data Rescue (I-DARE) and Atmospheric Circulation Reconstructions over the Earth (ACRE) initiatives. The portal provides information about different rescue projects around the world, but also allows registration of the new data rescue projects. Tools and guidelines for data rescue practitioners are also available.

4.4 Satellite observations and data rescue

Since the era of satellite observations began decades ago, the time series of directly observed parameters and climate state variables derived from them are often long enough to be useful for both climate studies and climate services. Some of the products were already in use for many years, such as observations of sea ice conditions, while others such as observation of soil moisture, precipitation, surface solar radiation or atmospheric composition became more attractive during the last decades. One of the main advantages of satellite observations is the spatial coverage and high horizontal resolution.

Satellite observation is mainly delivered through ESA Copernicus Open Access Hub and Copernicus Space Component Data Access system, but many derived products prepared by different institutions in Europe, are now also available via C3S Climate Data Store.

5 Integration of climate modelling and climate services

In the last years, a strong societal demand has emerged for useful, actionable, credible and reliable information on the causes and consequences of climate variability and change (van den Hurk et al. 2018). This stresses the need to co-develop climate services for action, encouraging the collaboration between science and humanities on the one hand, and between researchers and stakeholders on the other hand (Krauß 2020).

Climate models are an integral part of many of the climate services that are currently being developed and delivered. In this sense, strengthening the links between climate models and climate services communities seems essential to enhance the scientific basis for climate services and ensure best exploitation of climate information for the benefit of users (Hewitt et al., 2020). Climate services can benefit from improvements in climate models, including the enhancement of spatial and temporal resolution and the better description and understanding of processes and uncertainties. Conversely, climate services can help climate models better address new scenarios and/or challenges related to user needs, achieving solutions that are feasible, sustainable, equitable and inclusive. Below, some proposals to strengthen the linkages between the climate modelling and climate services communities are highlighted.

5.1 Joint design of simulations

Although climate model development is often motivated and directed by societal needs, a clear feedback mechanism is lacking (van den Hurk et al. 2018). Interaction with users has generally been acknowledged as a key part of the development of climate services, yet actual users often do not have direct contact with climate modellers. Climate services provided to stakeholders need to be embedded in their decision-making context. Therefore, services need to provide tailored local- and stakeholder-specific information to reach the right audience in the right format and in a timely manner. Climate service development benefits from further development of tools and guidance for tailoring climate data (downscaling, bias adjustment, climate model evaluation, tools to generate tailored indices). Efforts to overcome this limitation are being pioneered by the Copernicus Climate Change Service (C3S), which is building upon the results of other projects such as EURO-CORDEX (in downscaling and bias-adjustment) and IS-ENES (in evaluation and standardization). Additional efforts are also addressed to increase the interaction between climate and impact research, e.g. ERA4CS projects and Sectoral Information System (SIS) projects of C3S.

5.2 Inter- and transdisciplinary approaches

In the last few years, substantial progress has been achieved in the definition of flexible co-production frameworks (Norström et al. 2020, Bremer et al. 2019) aimed to be applied to various climate services settings. However, additional efforts can be devoted to enhance the cross-pollination between social and natural sciences and the definition of appropriate guidelines for compiling, sharing and merging climate and economic impact data (Hewitt et al., 2020). Despite the progress made in terms of interdisciplinary advancements, transdisciplinary collaboration is considered the way forward for reaching meaningful knowledge co-production. Todays' challenge is how to operationalize collaboration between individuals from research, policy and civil society sectors for impact (Cundill et al. 2019). In this sense, various efforts have been devoted to the design of transdisciplinary collaboration committing to do science together with society (e.g. international global sustainability initiative Future Earth).

5.3 Artificial intelligence

Special emphasis is being placed on the possibilities that machine learning (ML) and artificial intelligence (AI) offer for both climate modelling and climate services. These disciplines will provide insights on how to best deal with the large amount of climate data currently available. On the one hand, this can provide improvements of processes representation in climate models and, on the other hand, it can help tailor climate data to the specific needs of different socio-economic sectors. ML will in particular be needed in two critical research issues concerning both the climate modelling and climate services communities, namely extreme events and observational gaps, which are both limited by the scarcity of observations (Hewitt et al., 2020).

5.4 Alternative tools for communication and user engagement.

Tools such as storylines, visualization, case studies or narratives can be used to bridge the gap between model outputs and management and policy recommendations. These tools are increasingly exploited in the climate services arena to support the communication of climate issues and enhance user engagement. Each of them fulfils different functions and differs in the type of information provided and the addressed type of audience.

- Storyline: A storyline is used to explore a range of plausible futures, understood as possible future climate change scenarios
- Case study: A case study describes a particular weather or climate event that takes place over a specific location and time period. A case study can be used to better understand a climate event, and to illustrate how available knowledge can help

improve climate resilience and climate change adaptation.

- Narrative: A narrative is used to add context to storylines by integrating the perspectives, values, and knowledge of stakeholders as well as to place case studies within the storyline, e.g., look at the frequency and severity of an event and how this is going to change in the future.
- Online platform: Online platforms (e.g. DSTs) are used to provide climate service solutions for a broad audience, and have the potential to be tailored to a particular stakeholder.
- Other tools: Other tools increasingly being used include serious games, art, citizen science and other visualisation and dissemination materials.

6 Success stories

In this chapter we present a few examples of successful initiatives funded by H2020, ERA4CS, Copernicus and Climate-KIC.

6.1 Platforms

6.1.1 Copernicus Climate Change Service

- The key stakeholders

C3S is a public and free service supporting heterogeneous pools of users with very different needs, from members of academic institutions, e.g. researchers interested in very large volumes of raw data coming from climate projections, to decision-makers looking for a simple rendering of a statistical analysis based on several sources of data, and a growing number of private sector firms.

- Progress and future plans

C3S is a well-established resource for climate services worldwide. It provides authoritative, quality-assured information to support adaptation and mitigation policies. The Climate Date Store counts 35 000 users and it delivers some 50 TB data per day.

All the functional building blocks are operational and enriched by allowing users to derive sector-specific indices or indicators. With Copernicus' first phase coming to an end in 2021 planning for the future should consider the evolution of the application sectors, of science/societal drivers, of the technical infrastructure, of the international landscape. Areas of expansion are decadal, sub-seasonal predictions, attribution studies, which were trialled during the first phase.

- Stakeholder engagement and feedback

As C3S aims at making information relevant and usable for any downstream exploitation, different mechanisms of user requirements collection are in place: workshops, forum, surveys, direct contact, active development and sharing of toolbox custom-made applications. The Sectoral Information System, developing and delivering sector-specific demonstrators, acts as a direct interface with the users. All C3S user feedback converges to a centralised user requirement database and is then analysed to identify the fundamental aspects of the programme that would need to be further developed.

- Challenges

Climate services and the development in the underpinning climate research are part of the priorities of the European political agenda but more effort is required to ensure that the operationalisation is facilitated and streamlined. There is a need to ensure that future initiatives build upon the investments of the last few years especially in the operational element of climate services such as Copernicus Climate Change. Similarly, renewed effort should be put towards standardisation, quality assurance and governance. The more the climate data makes its way into the fabric of our everyday life the more the sustainability of a dedicated effort towards these activities must also be ensured. A final challenge is related to understanding the climate service as a public good as big private players have entered the arena.

6.1.2 OASIS Hub

Oasis Hub is a global aggregator for both free and chargeable catastrophe, extreme weather, climate change and environmental risk data, tools and services. It also provides commercial services in data set enhancement, data aggregation and commercialisation. It aims to help users to understand the wealth of global, public and private sector data, tools and services available to assist their risk assessment, climate adaptation and resilience needs. Oasis Hub (supported by Climate KIC and H2020) was created as a collaboration between business and academia, with businesses stating needs in finding good quality global data and academia and SME's needing a hub to more quickly create research impact, dissemination and innovation of their data, tools and services.

- Key stakeholders

A wide range of professionals and students from multiple sectors and from across the world are using the information to integrate into risk management systems, assess risk in building and infrastructure development and assess global supply chain vulnerability to climate change. Other uses include ICT companies developing risk assessment platforms for a range of sectors, as well as being used by disaster risk responders.

- Progress and future plans

Oasis Hub members (over 1400) come from a wide range of sectors, including insurance, finance, development, engineering and consultancy. In the future it intends to continue to aggregate environmental, catastrophe and risk assessment information data, tools, models and services, in particular from the academic, commercial and local government sectors. HOASIS Hub also plans to develop a compare the market approach around data, tools and services – enabling users to more clearly understand the type of data and tools they need for their particular purposes.

- Stakeholder engagement and feedback

The Hub engages with users in a range of ways including: newsletters, social media and direct communications with members; collaboration with insurers, finance, business, academia and SME's on the development of new data, tools and services to encourage and use co-design and co-production approaches.

- Challenges

There are a range of barriers for the aggregation and dispersal of data and tools to wider society. Barriers to data, tools and services availability include, among others:

- Low resolution global data from large public data centres, difficult to access and cut if not an expert;

- Global lack of understanding of what type of data is needed;

- Damage and loss data unavailable – as currently restricted commercially;

- There are 'Islands of excellence' in research, but there remain large barriers to innovation and scaling at institutional level.

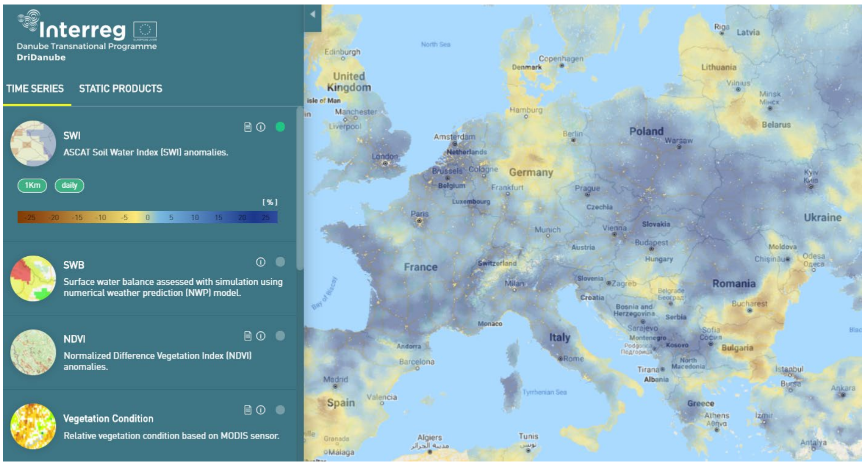

Figure 6.1 Drought Watch webtool (https://droughtwatch.eu/)

6.2 Projects

6.2.1 DriDanube

- Stakeholders

Governmental, Commercial, Farmers, Research

- Challenges

Water scarcity and droughts hit the Danube region frequently with large impacts on the economy and welfare of the people. Currently the drought management is reactive, dealing mainly with losses and damages, cooperation between key actors is missing and formal legislation mostly does not exist. The focus should shift from recovery to protection, i.e. from crisis management to risk management.

- Objective

Increase the capacity of the Danube region to manage drought related risks; help all stakeholders involved in drought management to become more efficient during drought emergency response and to prepare better for the next drought.

- Solution

A tool that will help detecting drought, as well as a Strategy document, compiled together with the stakeholders at over 30 national and international seminars and conferences, which will give clear guidance for overcoming the gaps in the drought decision-making processes and improve drought emergency response. Drought Watch (Fig. 6.1) is an open web-based tool which enables more accurate and efficient drought monitoring and early warning. The service integrates various drought indices on soil moisture and conditions of vegetation, including a large volume of the most recent remote sensing products. In addition, Drought Watch integrates near real time observations of drought impacts on vegetation collected by over 1000 people (farmers, agricultural and forestry experts) across 10 Danube countries.

6.2.2 CarpatClim and DanubeClim

- Stakeholders

Research, Commercial, Governmental

- Challenges

International cooperation and environmental management require climatological databases covering large areas. National (hydro)meteorological services however have different measuring networks, instruments, data management tools and data quality control methods which lead to inhomogeneity in the climatological fields.

- Objective

Ensure data harmonization between Carpathian countries and production of gridded climatologies per country; improve the availability and accessibility of a homogeneous and spatially representative time series of climatological data through data rescue, quality control, and data homogenization.

- Solution

Develop a Climate Atlas as the basis for climate assessment and further applied climatological studies as well as for drought monitoring in the Larger Carpathian Region in the frame of the European Drought Observatory.

6.2.3 WINDSURFER - Wind and Waves for Insurance, Forestry and Offshore Energy

- Stakeholders

Commercial

- Challenges

Extreme winds pose major risks to life, property and forestry, while extreme ocean waves can impact offshore infrastructures and coastal communities. Climate Services that provide improved assessments of extreme wind and wave hazards and how they might change in the future are needed to help private and public organisations adapt.

- Solution

WINDSURFER is a ERA4CS/JPI Climate project that is bringing together eight leading research institutions across Europe to co-develop new methods, tools and assessments of extreme wind and wave risk with a focus on Insurance, Forestry and Offshore Energy. In particular, WINDSURFER has developed improved datasets of current and future wind and wave hazards to help assess risks.

6.2.4 ARISE - Agriculture: Resilient, Innovative and Sustainable Enterprise

- Stakeholders

Smallholder farmers, commercial banks, governments

- Challenges

Extreme weather events such as droughts and floods and erratic rainfall patterns result in lower crop yields, higher and more volatile food prices, exacerbating poverty and malnutrition. Smallholder farmers need to be supported to build resilience to climate change in part by better integration into supply chains and improved strategies for managing farming risks.

- Objective

To overcome the challenges by exploring the use of farm-to-regional or country-level metrics allowing to optimally design and increase investments at farm-level. The ARISE project (Climate KIC), seeks to enable both private and public decision makers to design local-to-regional interventions that allow to sustainably increase agricultural production while reducing its exposure to rising climate risk. Ultimately, more sustainable food production and improved market access, as well as higher incomes for smallholder farmers, are achieved, in addition to reducing exposure to climate and weather risks across all value chain stakeholders.

- Solution

Develop risk analytics tools supporting the design of innovative financial and insurance products that have the ability to capture the risk profile induced by the adoption of particular production technologies. The solution has broader relevance for countries in which agricultural policies often rely on subsidies. The embedding of forward looking, climate/weather metrics in capital budgeting and credit scoring models can spur the transition to a more sustainable way of supporting key economic sectors, while recognising how different stakeholders contribute strategic value along the supply chain.

7 Climateurope's legacy

Over the past five years, the Climateurope community has grown from almost nothing, to a thriving group of climate services users and providers. This has been achieved through in person and virtual meetings, which have continued to grow and thrive in 2020 despite the COVID-19 pandemic. In this chapter, we provide recommendations for sustaining the work and legacy of the Climateurope project following its end in January 2021.

7.1 Webstivals

The Climateurope festivals have brought together communities of climate researchers and climate service users and providers in an engaging and interactive environment (Kotova et al., 2017). Over the last year, driven by worldwide travel restrictions from the COVID-19 pandemic, they have evolved into an innovative online format, the webstivals. Recordings, scribing outputs and reports from the Climateurope festivals and webstivals will remain available on the website after the project ends.

There is an appetite for continuing the legacy of the Climateurope webstivals and webinars which are easier to arrange than physical ones and require fewer resources. It has been proposed that volunteers are found to arrange these online events.

7.2 Website

The Climateurope website has provided a repository for all the information gathered in the project. It will be maintained by CMCC as a live site until June 2021, and then as a static site until December 2025.

7.3 Network

Climateurope has created a vibrant and active network of over 380 members. The network has provided a sense of community and a resource for knowledge sharing for climate service users and providers across Europe, and to some extent beyond. In order to maintain the community created by the network, it has been suggested that a regular Climateurope event is held at one of the major conferences (e.g., EGU, EMS, ICCS, ECCA). This would be run as a special session with a networking event.

7.4 Social media

Climateurope has established and runs two successful social media accounts; a Twitter account with over 2 100 followers, and a LinkedIn account with over 210 followers. The LinkedIn account has gathered a potentially self-sustaining community which could continue beyond the end of the Climateurope project with some minimal input from volunteer moderators.

References

Auer, I., et al., 2007. HISTALP - historical instrumental climatological surface time series of the Greater Alpine Region. Int. J. Climatol., 27, 17-46, doi: 10.1002/joc.1377

Belušić, D., et al., 2020. HCLIM38: A flexible regional climate model applicable for different climate zones from coarse to convection-permitting scales. Geosci. Model Dev., 13, 1311–1333, DOI: 10.5194/gmd-13-1311-2020

Bessembinder, J., et al., 2019. Need for a common typology of climate services. Clim. Serv., 16, Dec 2019, https://doi.org/10.1016/j.cliser.2019.100135

Bremer, S., et al., 2019. Toward a multi-faceted conception of co-production of climate services. Climate Services, 13, 42–50.

Boer, G. J., et al., 2016. The Decadal Climate Prediction Project (DCPP) contribution to CMIP6, Geosci. Model Dev., 9, 3751–3777, https://doi.org/10.5194/gmd-9-3751-2016.

Bromwich, D. H., et al., 2015. A comparison of the regional Arctic System Reanalysis and the global ERA-Interim Reanalysis for the Arctic. Q. J. R. Meteorol. Soc., 142(695), 644–658. https://doi.org/10.1002/qj.2527

Cavelier, R., et al., 2017. Conditions for a market uptake of climate services for adaptation in France. Clim. Serv., 6, 34-40, https://doi.org/10.1016/j.cliser.2017.06.010

Christensen, O.B. and Kjellström, E., 2020. Partitioning uncertainty components of climate change in a large ensemble of European regional climate model projections. Clim. Dyn., in review.

Copernicus Climate Change Service (C3S), 2017: ERA5: Fifth generation of ECMWF atmospheric reanalysis of the global climate. Copernicus Climate Change Service Climate Data Store (CDS), accessed 3 April 2020, https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-pressure-levels?tab=doc

Copernicus Climate Change Service (C3S), 2019: C3S ERA5-Land reanalysis. Copernicus Climate Change Service Climate Data Store (CDS), accessed 3 April 2020, https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land?tab=doc

Copernicus Climate Change Service (C3S), 2020a: Copernicus regional reanalysis for Europe (CERRA) accessed 3 April 2020 https://climate.copernicus.eu/copernicus-regional-reanalysis-europe-cerra#

Copernicus Climate Change Service (C3S), 2020b: Copernicus Arctic Regional Reanalysis Service, accessed 3 April 2020 https://climate.copernicus.eu/copernicus-arctic-regional-reanalysis-service

Coppola, E., et al., 2018. A first-of-its-kind multi-model convection permitting ensemble for investigating convective phenomena over Europe and the Mediterranean. Clim Dyn. https://doi.org/10.1007/s00382-018-4521-8

Coppola, E., et al., 2020a. Climate hazard indices projections based on CORDEX-CORE, CMIP5 and CMIP6 ensemble. Clim. Dyn. (submitted).

Coppola, E., et al., 2020b. Assessment of the European climate projections as simulated by the large EURO-CORDEX regional climate model ensemble. Journal of Geophysical Research: Atmospheres, 125, e2019JD032356. Accepted Author Manuscript. https://doi.org/10.1029/2019JD032356

Cornes, R., et al., 2018. An Ensemble Version of the E-OBS Temperature and Precipitation Datasets, J. Geophys. Res. Atmos., 123. doi:10.1029/2017JD028200

Cundill, G., et al., 2019. Large-scale transdisciplinary collaboration for adaptation research: challenges and insights. Global Challenges 3: 1700132

Doblas-Reyes, F. J., et al., 2013. Initialized near-term regional climate change prediction, Nat. Commun., 4, 1715, https://doi.org/10.1038/ncomms2704.

EC, 2015. A European Research and Innovation Roadmap for Climate Services', European Commission, Directorate-General for Research and Innovation, European Union, Print: ISBN 978-92-79-44341-1, doi:10.2777/702151.

Eyring et al., 2020. Earth System Model Evaluation Tool (ESMValTool) v2.0 – an extended set of large-scale diagnostics for quasi-operational and comprehensive evaluation of Earth system models in CMIP. Geosci. Model Dev., 13 (7), 3383-3438, doi: 10.5194/gmd-13-3383-2020.

Hewitt, C., S. Mason, and D. Walland (2012), The global framework for climate services, Nat. Clim. Change, 2, 831–832, doi:10.1038/nclimate1745.

Hewitt, C. D., et al., 2020. Recommendations for future research priorities for climate modelling and climate services, Bull. Amer. Meteor. Soc. (Online) https://doi.org/10.1175/BAMS-D-20-0103.1

Hewitt, C.D., Lowe, J.A., 2018. Toward a European climate prediction system. Bull. Am. Meteorol. Soc. 99, 1997–2001. https://doi.org/10.1175/BAMS-D-18-0022.1

Hoa, E., A. Perrels and Thanh-Tâm Lea, 2018. From generating to using climate services – How the EU-MACS and MARCO projects help to unlock the market potential. Clim. Serv., 11, 86-88, https://doi.org/10.1016/j.cliser.2018.08.001

Hoa, E., Lê, T. T., Cortekar, J., 2019 . Recommendations, MARCO Deliverable 2.7

Isotta, Francesco A., et al., 2014. The climate of daily precipitation in the Alps: development and analysis of a high-resolution grid dataset from pan-Alpine rain-gauge data, Int. J. Climatol., 34, 1657-1675, doi: 10.1002/joc.3794.

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324.

Jacob, D., Teichmann, C., Sobolowski, S. et al., 2020. Regional climate downscaling over Europe: perspectives from the EURO-CORDEX community. Reg Environ Change

20, 51. https://doi.org/10.1007/s10113-020-01606-9

Krauß, W., 2020. Narratives of change and the co-development of climate services for action. Climate Risk Management 28: 100217.

Kotova, L., Costa, M.M., Pérez, M.J.R., Whiffin, F., Garrett, N., Bessembinder, J., Buonocore, M., Newton, P., Hewitt, C.D., 2017. The first Climateurope Festival: Climate information at your service. Clim. Serv. 6, 80–81. https://doi.org/10.1016/j.cliser.2017.07.005

Kruschke, T., et al., 2014. Evaluating decadal predictions of northern hemispheric cyclone frequencies, Tellus A, 66, 22830, https://doi.org/10.3402/tellusa.v66.22830

Kruschke, T., et al., 2016. Probabilistic evaluation of decadal prediction skill regarding Northern Hemisphere winter storms, Meteorol. Z., 25, 721–738, https://doi.org/10.1127/metz/2015/0641.

Le Cozannet, G., et al., 2017. Sea level change and coastal climate services: The way forward. J. Mar. Sci. Eng. 5 (4), p. 49. https://doi.org/10.3390/jmse5040049

Lenderink, G., et al., 2019. Systematic increases in the thermodynamic response of hourly precipitation extremes in an idealized warming experiment with a convection-permitting climate model. Environ. Res. Lett. 14, 074012. 10.1088/1748-9326/ab214a

Lind, P., et al., 2020. Benefits and added value of convection-permitting climate modeling over Fenno-Scandinavia. Submitted to Climate Dynamics.

Lussana, C., O.E. Tveito and F. Uboldi, 2018: Three-dimensional spatial interpolation of 2m temperature over Norway. Q.J.R. Meteorol. Soc., doi:10.1002/qj.3208

Merryfield, W.J., et al., 2020. Current and emerging developments in subseasonal to decadal prediction. Bull. Amer. Meteor. Soc., 0, doi:10.1175/BAMS-D-19-0037.1

Mysiak, J. et al., 2018. Brief communication: Strengthening coherence between climate change adaptation and disaster risk reduction. Natural Hazards and Earth System Sciences. 18. 3137-3143. 10.5194/nhess-18-3137-2018.

Norström, A. V. et al. (2020) Principles for knowledge co-production in sustainability research. Nature Sustainability 3: 182-190.

Perrels, A., et al., 2019. Prospects for Climate Service Market Dynamics - projections, enhancement measures, and innovation options - a bi-project synthesis report. EU-MACS/MARCO D5.3.

Perrels, A. 2018. A structured analysis of obstacles to uptake of climate services and identification of policies and measures to overcome obstacles so as to promote uptake, EU-MACS Deliverable 5.1

Rechid, D., et al., 2017: CORDEX Flagship Pilot Study LUCAS - Land Use & Climate Across Scales - a new initiative on coordinated regional land use change and climate experiments for Europe. 19th EGU General Assembly, EGU2017, 23-28 April, 2017, Vienna, Austria., p.13172, Vol. 19.

Ruti, P. M., Somot, S., Giorgi, F., et al., 2016. Med-CORDEX Initiative for Mediterranean Climate Studies, Bulletin of the American Meteorological Society, 97(7), 1187-1208. https://doi.org/10.1175/BAMS-D-14-00176.1

Schimanke, S et al., 2019: UERRA data user guide, SMHI, http://datastore.copernicus-climate.eu/documents/uerra/D322_Lot1.4.1.2_User_guides_v3.3.pdf

Schuster, M., et al., 2019. Improvement in the decadal prediction skill of the North Atlantic extratropical winter circulation through increased model resolution, Earth Syst. Dynam., 10, 901–917, https://doi.org/10.5194/esd-10-901-2019

Smith, D.M., et al., 2019 Robust skill of decadal climate predictions. npj Clim Atmos Sci 2, 13, https://doi.org/10.1038/s41612-019-0071-y

Stegmaier, P., et al., 2019. Policy Implications and Recommendations on Promising Business, Resourcing, and Innovation for Climate Services, EU-MACS Deliverable 5.2.

Szalai, S., et al., 2013. Climate of the Greater Carpathian Region. Final Technical Report.www.carpatclim-eu.org.

Taylor, K.E., Stouffer, R.J. and Meehl, G.A., 2012. An overview of CMIP5 and the experiment design. Bull Am Meteorol Soc, 93(4), pp.485–498.

van den Hurk, B., wt al., 2018. The match between climate services demands and Earth System Models supplies. Climate Services, 12, 59–63. Doi: 10.1016/j.cliser.2018.11.002

Vautard, R., et al., 2020. Evaluation of the large EURO-CORDEX regional climate model ensemble. Submitted to J. Geophys. Res.

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