Climate Change Communication and User Engagement: A Tool to Anticipate Climate Change

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1 Introduction

Climate change, its causes and impacts have received considerable attention since a couple of decades (van Alast 2006). The already observed changes in climate, especially warming trends, are projected to become more apparent and severe at the end of the century (IPCC 2014a). However, although less attention has been put in the medium-range climate changes, climate is already changing now and adaptation is therefore unavoidable, becoming an immediate priority across many sectors (Füssel 2007). The time horizon for climate adaptation can vary from a few months to many decades. Some aspects of climate change can be predicted with reasonably high confidence in the medium-range (e.g. changes in average temperature) whereas others are associated with larger uncertainties (e.g. changes in hurricane tracks and intensity). The list of climate-sensitive sectors includes agriculture, forestry, energy, water management, public health and insurance, among others. Planned adaptation to

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climate change means the use of information about present and future climate conditions to review the suitability of current and planned practices, policies and infrastructure (Thomson et al. 2006; García-Morales and Dubus 2007). Adaptation planning involves therefore addressing questions about how different future climate conditions will be from those observed in the past. According to that, adaptation measures aim at finding a balance between the risks of acting too early or too late to adapt to the future climate change conditions. Depending on the specific sectors, adaptation to climate change may have close links with natural resource management, sustainable development, disaster preparedness or urban planning (Füssel 2007).

Increasing temperatures, decreasing water availability, and a growing frequency of extreme events can, independently or in combination, have many implications for the different economic sectors (IPCC 2014b). Uncertainty about how these aspects are likely to be in the next months or seasons makes difficult to anticipate economic risks for climate-sensitive sectors (Goddard et al. 2010). Here is where climate predictions in the medium-range time horizon have a role to play. Although they cannot be as specific as weather forecasts (which can tell the temperature for tomorrow or how much rain to expect with high accuracy), climate predictions can provide probabilistic information about the likelihood of occurrence of certain outcomes. That is, the probability of experiencing cooler, normal or warmer than average temperatures in the upcoming months with useful skill. This is because the basis for climate prediction lies in components of the climate, such as the ocean and the land surface, that vary slowly compared to individual weather events (Doblas-Reyes et al. 2013).

The concept of climate services arose with the aim of making climate predictions user-oriented (Street 2016). Climate services refer to the transformation of climate-related data, together with other relevant information, into customized products that may be of use for the society at large (Street et al. 2015). In this way, predictions, trends, economic analyses, or counselling on best practices are considered climate services. As such, these services include data, information and knowledge that support adaptation, mitigation and disaster risk management.

Although the use of climate services in the business sector is far from being generalized, they have recently been suggested to be capable to provide additional value for the renewable energy and the re/insurance sectors, among others. Even though these sectors do traditionally use historical records of past events to inform current risks (e.g. Landberg et al. 2003), this practice is changing as climate change is likely to affect the regularity and intensity of extreme events. For example, understanding and quantifying the change in wind resources in the next season is a key factor, since this information can support the wind energy sector when taking decisions on energy production, as well as other management actions, ahead of time (Torralba et al. 2017, Lynch et al. 2014; Troccoli 2010). There are emerging opportunities of climate predictions to be used by re/insurance companies, including those that specialize in business interruption, life insurance, agriculture and other areas where the potential risk is changing. Indeed, the changing risks between the recent past and the not so distant future are of great interest to the re/insurance sector because even slight changes in climate characteristics can translate into large impacts on the risk management and expected losses (Botzen et al. 2010).

While the insurance and the renewable energy sectors are starting to deal with probabilistic predictions in the medium-range, the application of these predictions to agriculture still sees many challenges, since attention in this sector has been traditionally focused on short-term weather forecasts (up to 2 weeks) and climate projections (20–100 years). However, results obtained in previous studies concerning the wine crop reveal that adaptation measures at the sub-seasonal and seasonal scale are increasingly given a higher priority (Neethling et al. 2016; European Commission 2016).

1.1 The Role of User Engagement and Communication in Climate Change Adaptation

To make adaptation to climate change effective, the different climate-sensitive sectors need to be aware of the problem they are facing. At this stage, the climate service community is responsible of assessing and communicating the vulnerability to climate change to the climate-sensitive sectors. Thus, establishing an understanding of the user decision-making process is key to ensure that the climate service will be tailored to the user needs. In doing so, it is recognized that climate is often not the most important issue to users and that sometimes more effort should be put in identifying users' sensitivities, thresholds and risk tolerances related to climate within the user decision-making (Davis 2012).

A continuous interaction with users is central for their effective engagement, where communication, co-design, co-production and co-evaluation are important (Street 2016). At the beginning of the interaction, users often ask for climate information tailored to a near-exact time and place. However, climate predictions cannot provide this level of detail, and it is important to make the user understand that the provided climate information illustrates broad changes, representing the variation of climatic conditions over a time period longer than hours or days. Similarly, the usefulness of typical climate predictions at coarse spatial resolutions is very limiting for some users that need finer information for a specific location. This aspect is currently being approached by the climate science community, for example through statistical downscaling methods, where a statistical relationship is established between observations and simulated large-scale variables, like atmospheric surface pressure (Jones et al. 2011). Due to its probabilistic nature, climate information often can be perceived as untailored, unintuitive, hard to understand and therefore difficult to apply in decision-making contexts (Bruno-Soares and Dessai 2016). Therefore, communicating the uncertainty of probabilistic climate predictions needs to be done effectively, so that users can clearly understand and apply climate services to their decision-making while managing the potential risks and opportunities of future climate variability. To help with that, the climate science community is currently working on translating climate services into cost savings for the climate-sensitive sectors (Christel et al. 2016).

1.2 The Role of Visualization in Climate Change Adaptation

The appropriate development of graphical visualizations to communicate climate data is fundamental to the provision of climate services to guide climate change adaptation decisions (Daron et al. 2015; Kaye et al. 2012). Graphical visualizations are necessary to spread climate information and products beyond the developers' community, helping the user to interpret and use the information as simply and quickly as possible (Christel et al. 2017). In addition, the spread of climate information needs to be done in ways that are effective and also attractive. In this way, awareness of the potential application of seasonal forecasts is raised and probabilistic information is put into a usable form for decision-makers. However, designing intuitive and meaningful visual representations in the climate context faces a variety of challenges, from the heterogeneity of climate-related data (e.g. spatial, temporal, multi-variate…) to the heterogeneity of user groups (e.g. users with different skills, interests, knowledge…). Despite the emergence of climate services and the increasing use of online platforms to disseminate climate information (Australian BoM 2016; IRI 2016; IPCC 2016), there is still limited empirical evidence of how different individuals and sectors interpret different visualisations of climate data.

Climate-sensitive sectors are often reluctant to use medium-range climate predictions because they do not fully understand their usefulness and application. The improvement of communication strategies is therefore fundamental to stimulate the use of climate predictions within decision-making processes, which requires providing information about the opportunities and limitations of this type of information. Taking a list of recommendations for the visual communication of climate predictions to users as a departing point (Davis et al. 2016), this work describes how these recommendations have been integrated in the co-production process of different climate services. Through practical examples involving climate services for agriculture, renewable energy and insurance, this study aims to illustrate the importance of user engagement and science communication to adapt to medium-range climate change. The aim and design journey of each selected climate service is described. The given examples encompass both the visualization and description of climate data, which can help deliver a clear message to climate-sensitive end-users.

2 Climate Services for Climate Change Adaptation

This research arises from a previous study (Davis et al. 2016) and from our experience with users, which allowed us to identify the challenges regarding the visual communication of climate predictions to users and decision-makers of climate-sensitive sectors. Often, different techniques are used to communicate climate information, and this can be confusing for the users, who may interpret information very differently and have diverging expectations regarding the amount of risk they are willing to take. Moreover, there is a gap between the scientific data available and the information needed for decision-makers to adapt to climate change (Asrar et al. 2013). Therefore, training on how to interpret probabilistic information, tailored visual interfaces or information centers are helpful to connect the providers of information and the user needs in the face of climate change. The results presented in Davis et al. (2016) suggested that decision-makers could benefit from improved accessibility, communication and understanding of climate predictions if certain recommendations are followed. The following sections describe how some of these recommendations have been incorporated in the design process of three climate services aimed at helping climate-sensitive sectors to anticipate and adapt to medium-range climate change.

2.1 Climate Services for Agriculture

2.1.1 What?

Participatory approaches such as consultation, product co-design and promotion of interactive events are useful to engage different stakeholders, improve adaptive capacity and inform adaptation measures in agriculture (Adger 2003, Bojovic et al. 2015). Establishing a bi-directional communication between users and producers of climate information is a prerequisite for the development of effective climate services (Street 2016). SECTEUR https://climate.copernicus.eu/secteur, a EU Copernicus Climate Change Service (C3S) project, is taken here as a practical example of the application of participatory tools in user engagement and co-production in the field of climate services. The SECTEUR project involves researchers working together with private and public sector organizations to understand their climate data requirements with the aim to deliver better-tailored information that supports decision-making. Agriculture and insurance are two of the climate-sensitive sectors covered by the project. In the case of agriculture, working directly with winegrowers allows focusing on technical feasibility, market needs and gaps faced by the wine sector that could be filled with additional research by the scientific community.

2.1.2 How?

The project is engaging and interacting with a wide number of organizations through a survey and various workshops that help establishing an inventory of existing needs and user requirements in terms of climate data and climate impact indicators (Bojinski et al. 2014). For agriculture, climate predictions about how the growing season of the wine crop is likely to be (e.g. drier than normal, normal or wetter than normal) are useful for winegrowers, because the sooner they can plan

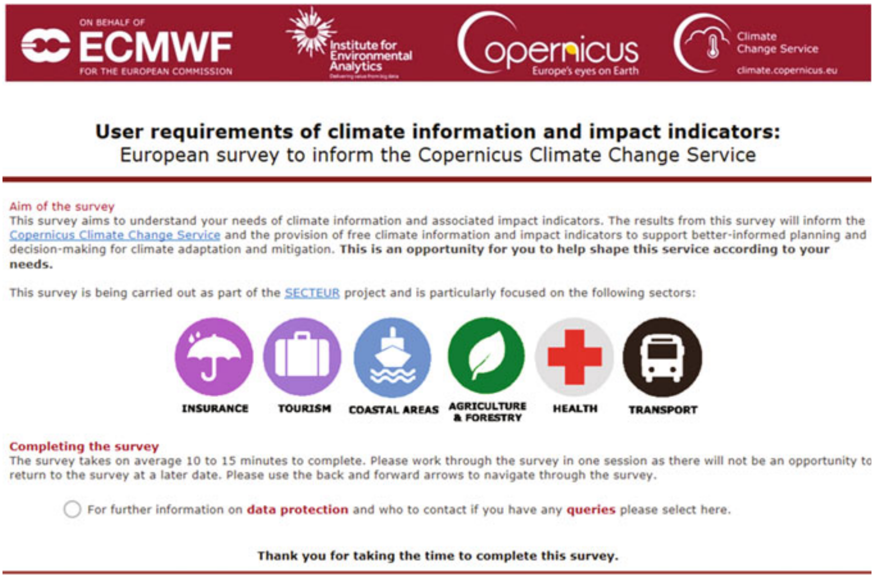

Fig. 1 Landing page of the SECTEUR participatory tool to gather information on user requirements of climate information and impact indicators for each of the climate-sensitive sectors involved in the project

their decision-making, the better they will be able to prevent the deleterious effects of extreme climate events. For example, if a dryer than normal season is expected, a wine producer can decide to maintain a thicker canopy in grapevines in order to retain humidity and protect the plant from excessive evapotranspiration. On the other hand, if the season is predicted to be exceptionally wet, and if economically feasible, the winegrower can decide to reduce the canopy to decrease disease effects by fungi, or take other decisions such as the acquisition of fungicides in advance.

Results from the SECTEUR survey (Fig. 1) were not available during the preparation of this manuscript. However, some requirements of climate information from different users in the wine production chain were identified in a workshop devoted to the wine sector. Wine producers and irrigation consortia identified mean temperature and mean precipitation during the growth cycle of grapes as useful in regions where forecast shows skill for the selection of varieties, the definition of dates for managing practices, or the estimation of crop yields. The research community pointed at a need for more detailed data. Variables such as daily temperature, precipitation, wind and relative humidity are used to simulate the grape growth and other variables involved in this process, such as evapotranspiration or soil water balance. In the case of environmental agencies, indices like the drought index (Hayes et al. 2011) are useful to develop climate scenarios for mitigation strategies as well as to advice farmers on best practices.

2.2 Climate Services for Energy

2.2.1 What?

The visualization tool project Ukko (http://project-ukko.net/) is a prototype for wind energy developed within the framework of the EUPORIAS project (www.euporias.eu). The tool provides robust information on the future variability of the wind resource based on probabilistic climate predictions. With the aim to raise awareness of recent advances in medium-range climate predictions, the prototype puts probabilistic information into a usable form for decision-makers in wind energy. It addresses multiple user profiles in the wind energy sector, from operations and maintenance teams to grid operators or energy traders. The tool has been developed by an interdisciplinary team made of climate scientists, data visualization specialists and designers that provided complementary perspectives. Using engagement and communication channels, the design of the prototype reached various audiences and attained high levels of visibility (Christel et al. 2017).

2.2.2 How?

The visualization tool uses data on 10 m wind speed obtained from the seasonal prediction system (System 4, Molteni et al. 2011) of the European Centre for Medium-Range Weather Forecasts (ECMWF), which produces a climate forecast using 51 ensemble members. An ensemble corresponds to a group of simultaneous climate simulations characterizing climate predictions that are conducted using slightly different initial conditions.

As a result, the online tool presents a map with seasonal wind predictions visualized with line symbols that represent the predicted wind speed through line thickness, the forecast quality (representing the quality of the forecast system) through opacity, and predicted trend of wind speed through line tilt and colour (Fig. 2, legend on the right). Trend in wind speed is displayed as the likelihood of wind speed falling in each of the following categories in the coming months: normal wind (about average wind speed for the region), below normal wind (low wind speed for what is usual in the region) and above normal wind speed (high wind speed for what is usual in the region).

Project Ukko consists of a global map with a data overlay designed to enable users to quickly detect global patterns and trends in future wind conditions. This display allows drawing the user's attention immediately to the areas with larger probabilities of significant changes in wind speed. Following the well-known visual mantra of overview first, zoom and filter, details-on-demand (Schneiderman 1996), the user can also drill into detailed prediction breakdowns at a regional level.

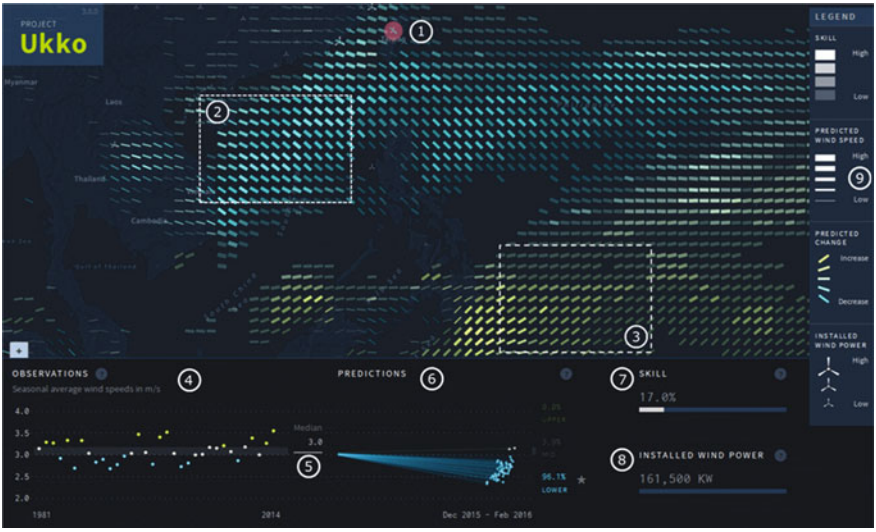

Fig. 2 Project Ukko data visualization tool and results for the predicted season (December 2015–February 2016): 1—selected geographical region, 2—area of high probability of reduced wind speed compared to climatology, 3—area of high probability of increased wind speed compared to climatology, 4—seasonal average wind speed in the selected geographical region over the last 30 years based on the ERA-Interim reanalysis, 5—median wind speed over the last 30 years based on ERA-Interim, 6—wind prediction for the next season (the percentage of simulations in each of the terciles gives the probability to lower, equal or higher than normal wind speed conditions), 7—skill or measure of how well the prediction system has performed over the last 30 years in the selected region, 8—currently installed wind power in the selected region, 9—legend of symbols used in the visualization (skill: opacity, predicted wind speed: line thickness, predicted wind speed trend: line tilt and colour, installed wind power: wind turbine)

Selecting a region on the map opens a panel with additional information (Fig. 2, bottom), including the past 30 years of wind observations, the full distribution of prediction results from the 51 ensemble members for the specific predicted year, the skill level and the current wind power installed capacity in the selected region. As seasonal predictions are probabilistic, they give the probability of occurrence of certain outcomes rather than a single ‘yes-no’ deterministic prediction. For this reason, having an idea of the full distribution of ensemble values is important to fully understand and read a given prediction. A visual representation of a cone of rays—the probability cone (Fig. 2, #6), emanating from typical (median) value of the historic data (Fig. 2, #5) was designed to communicate probabilistic information in a simple way (using the x axis as a conceptual time line from the past to the future prediction).

2.3 Climate Services for Re/Insurance

2.3.1 What?

The website Seasonal Hurricane Predictions (www.seasonalhurricanepredictions.org) is an online platform that brings together predictions from different centres that specialize in Atlantic hurricane forecasting (including universities, governmental agencies, private companies and other organizations as sources). It has been developed by an interdisciplinary team of scientists, graphic designers and visualization specialists in close collaboration with a global re/insurer. The platform has the objective to track seasonal hurricane predictions and the evolution of hurricane activity, which officially runs from the beginning of June to the end of November, and to make them available to both advanced users and non-specialists. On the one hand, the website offers extensive information to promote understanding of the factors that contribute to these meteorological phenomena, with devastating consequences, and to help explaining why different seasonal forecast models can produce different predictions. On the other hand, sections offering scientific content, such as model details or the possibility to download data, are directed to advanced users. The platform provides information of special interest for the re/insurance sector, which uses seasonal hurricane predictions not only for model validation or risk assessment but also in aspects of their decision-making. To date, the platform is displaying predictions from 21 different forecast systems and it is open to any centre interested in participating.

2.3.2 How?

Predictions from the different forecasters are collected through an online form that each of the centres needs to fill every time they have a new prediction and want to display it in the website. Predictions issued in March–April, May–June and July–August are individually submitted online. Whereas some centres only issue a prediction for the whole season, other centres provide additional predictions as the season progresses. This is important to consider, since the closer to the hurricane season, the better the prediction should be. The last predictions provided by each forecaster are regularly averaged to compute the number of hurricanes that are expected to affect the North Atlantic basin in the upcoming season. The range of the prediction is given by the minimum and the maximum of the individual submitted predictions. The level of activity of the predicted hurricane season (low, medium and high) is indicated by a colour code according to the limits defined by NOAA (2016). The selected colour scale is readable by colour-blind users. A yellow hurricane symbol indicates that the level of activity for the hurricane season is predicted to be low. If the hurricane symbol is orange, it indicates that there is a medium level of predicted hurricane activity, whereas a red hurricane symbol indicates that the level of predicted activity is high. Apart from the predicted

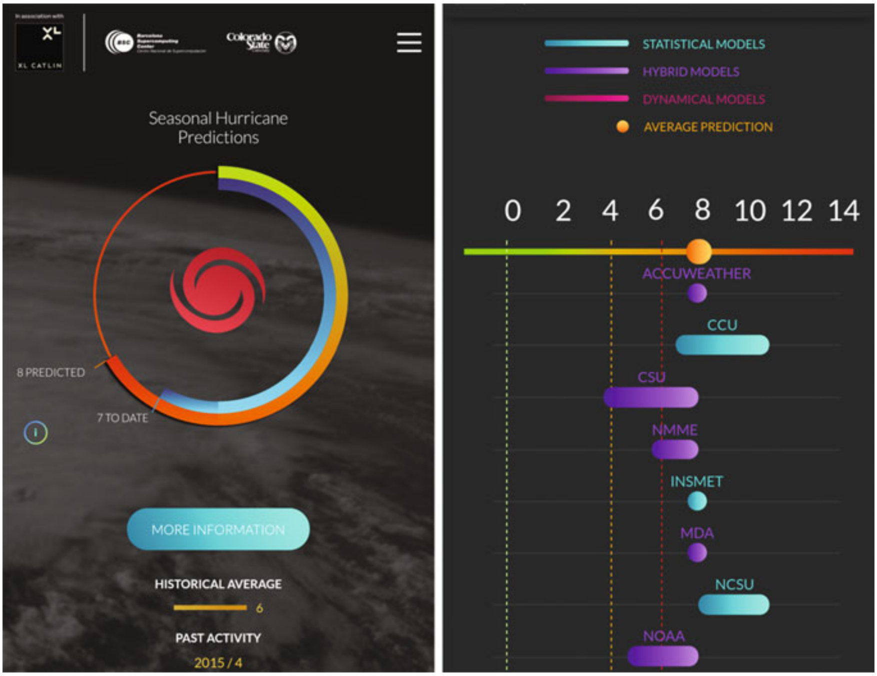

Fig. 3 Seasonal Hurricane Predictions data visualization tool for mobile devices with the results for the predicted hurricane season (June–November 2016). Left: homepage with the number of hurricanes predicted (8 hurricanes), the number of hurricanes that occurred to date (7 hurricanes), the hurricane symbol in red, indicating high hurricane activity, the historical hurricane average since year 1966 (6 hurricanes/season), and a list with the past activity per year since 1966 (shown when scrolling down). Right: panel for advanced users that opens after clicking on "More information" on the left image with the predictions from the individual forecasters in different colours according to the type of model. The average prediction is shown by the orange ball, and the dotted lines from left to right correspond to the limits for low, medium and high activity defined by the NOAA

number of hurricanes, the actual number of hurricanes that have occurred to date in the current season is also shown. In addition, the hurricane activity in previous years (since 1966) is reported. This information can be useful to put the current prediction in context for the different media because it is usually considered a valuable information resource.

The website contains not only predictions of hurricanes but also for other variables like major hurricanes, named storms and accumulated cyclone energy. A graph is displayed for each variable, where the predictions provided by each centre are displayed according to the type of model applied (Fig. 3, right). Considered model types are statistical, dynamical and hybrid, and they are represented in different colours in the graphs. Note that when the mouse hovers over a particular prediction, other predictions from the same forecaster issued in other months are also highlighted to allow the comparison and assessment of the prediction evolution through time.

2.4 *Opportunities for Climate Change Adaptation*

Applying participatory and visualization tools in climate services development can help shape effective products, but their application also faces challenges (Table 1). The climate services described in this work are the result of a co-production process with users from the agriculture, wind energy and insurance sectors. Whereas the users provide information about their needs and types of decision-making to help tailoring the service to their specific requirements, they also express a need to get clear information that helps them to understand how to handle prediction uncertainty with confidence (Otto et al. 2016).

According to users in the agriculture sector, climate change adaptation in the medium-range involves taking decisions during the growth cycle of grapevines. Each step of this process plays an important role in the development of grapes with ideal characteristics for wine making. Viticulture practices such as canopy management, irrigation, or the use of agrochemicals are applied differently by users according to the grape variety and the *terroir* (concept that involves factors like climate, soil type and geomorphology). These practices, directed to optimize the quality of wine and grape trading in the market, are strongly related to climate variability. Medium-range climate predictions have been identified in previous studies to be useful for adaptation to climate change (Neethling et al. 2016; Soret et al. 2016), and this idea is reinforced by the workshops conducted as part of the SECTEUR project.

According to users from the wind energy sector, climate change adaptation in the medium-range involves taking strategic decisions related to renewable investments and integration of wind energy into the energy grid system, which is intricately tied to the variability of climate (Davis 2012). Any change in the predicted wind resource affects the predicted energy yields, which directly influences cash flow and therefore, return on investment. There is the possibility that not enough energy is generated to cover costs or to satisfy energy demand during periods of high demand peaks (e.g. heatwaves or extremely-cold periods). In this sense, having accurate medium-range wind predictions is becoming increasingly important to anticipate the lack of balance between supply and demand. From the interactions with different users in the wind energy chain, it was identified that many can benefit from medium-range climate predictions. This is the case, for example, of operations and maintenance teams that need to schedule operations during the less windy periods, grid operators that need to know the amount of renewable energy that will go into the grid to schedule power plant operations, or financial teams that benefit from having a balance of the energy they can produce in the upcoming months to anticipate cash flow.

For users in the re/insurance sector, climate change adaptation in the medium-range involves adopting strategic decisions related to risks that are continuously changing when compared to the past. As climate change is predicted to increase the frequency and severity of extreme weather events, economic losses caused by natural catastrophes can also increase significantly (Botzen et al. 2010).

Table 1 Main challenges of three examples of climate services tailored to agriculture, energy and insurance and how they can help to adapt to climate change

Climate service	Description	Climate change adaptation	Challenges
Climate service for agriculture: *SECTEUR*	Participatory approach for user engagement to identify user requirements and decision-making (wine crop)	– Decision-making during the grapevine growth cycle – Grape trade in the market	– User engagement – Forecaster engagement – Tailor climate information to user's requirements – Communicate probabilistic information and prediction reliability – Make the tool attractive and usable – Sustain the tool's use in the long range
Climate service for energy: *Project Ukko*	Visualization tool for the wind energy sector	– Planning maintenance and operations – Energy trading – Estimation of budgets – Meet the balance between supply/demand	
Climate service for insurance: *Seasonal Hurricane Predictions*	Visualization platform of the seasonal hurricane activity for the re/insurance sector	– Catastrophe evaluation – Loss estimation – Pricing determination – Capital allocation determination – Claims team preparation and client warning	

The best strategy for re/insurers seems to be incorporating expected changes in probabilities of weather extremes in assessing exposure, pricing and risk management. Users from the re/insurance sector attending the SECTEUR workshop identified the assessment of risk exposure to be useful for catastrophe evaluation and losses estimation. Knowing the probability of occurrence of extreme events in the near future, re/insurance companies can determine pricing and restrict pay-outs through upper and lower limits (deductibles) of liability or by imposing restrictions and exceptions to insurance contracts. Climate predictions can also be useful to direct the allocation of capital towards situations where risks are more likely to occur, and can also be used for client warning or claims team preparation when an affectation is foreseen.

2.5 *Challenges for Climate Change Adaptation*

It is currently very difficult to get an overview of what medium-range climate predictions can do for all the sectors, possibly because climate services are evolving very quickly and many different actors are becoming progressively involved. Although this can be seen as a limitation to the use of climate predictions, it also creates challenges (Table 1). One of this challenges involves user engagement, ensuring an exchange of information about the user needs with the climate services research community in order to maximize the impact of what the large variety of available sources of climate information can offer to them.

Identified limitations can be divided between technical and those related to the user's perception of climate data. A technical barrier for the widespread use of climate services is that climate modelling resource capabilities are limited by the cost of the computational resources used to produce climate predictions, and so they tend to be semi-operational (not run continuously). The challenge of making these predictions operational involves user's interest in sustaining the tool in the long range. Limitations related to users perception may arise because the link between the use of medium-range climate predictions and adaptation to climate change is not always clear. Adaptation has been traditionally envisaged in the long-range, when climate projections have been undoubtedly considered useful tools, whereas climate change effects in the medium-range time scale are perceived to a lesser extent. The challenge here lies in clearly communicating these concepts to the potential users of climate services and in the generation of appropriate tools to support this communication.

The challenges to have fully-operational climate services that are actually used by users are many, and depend on the particular service and the familiarity of users with climate information. For example, user engagement is one of the challenges shared by the three climate services presented in this study. In this case, the climate service for re/insurance was the least demanding in terms of user engagement, since the re/insurance company was interested in the platform from the beginning, as both a way to gather useful information and as an additional tool to announce their activities. Conversely, a higher engagement effort was directed to encourage forecasters to provide information on their hurricane predictions as a source of data for the climate service. In this case, the website was developed first, putting special attention in the visualization and design part, and it was eventually introduced to forecasters. From our experience, it really makes a difference when forecasters are faced with an operative tool rather than an idea of a platform-to-develop. A bigger effort, however, was needed to engage users in the wind energy sector. These users are generally familiar with weather and climate variability and see the potential of using medium-range climate predictions in their decision-making, but they tend to ignore how for simplicity. More efficient and targeted forms of engagement are needed to build trust in this sector, since prediction uncertainty is often seen as a barrier to the application of climate predictions (Otto et al. 2016; Taylor et al. 2015). The climate service for agriculture was the most demanding in terms of user engagement, since medium-range climate predictions are completely unfamiliar to this sector. For this reason, the presented climate service for agriculture focuses in user engagement for the framing and integration of user needs at early stages of the data product design. Integration of the user from the beginning is essential to avoid unrealistic expectations, but it also adds knowledge about which sources of uncertainty are the most relevant.

Tailoring climate information to user requirements is another challenge shared by the three climate services presented here. Tailoring encourages providers to recognize the differing information requirements of users and improves the bi-directional communication between users and providers. Tailoring information follows the same gradient as in the case of user engagement. Namely, the process was easier in the case of the re/insurance climate service, since the user was already aware of the type of climate information that best suited their needs. More interaction between users and providers was needed for the wind energy climate service, where sharing information and learning from each other was recognized as key for developing best practices. An important tailoring effort is also foreseen for the agriculture climate service, although this constitutes a next step after the current identification of users' needs.

Although not a straightforward topic, communicating probabilistic information and prediction reliability is necessary to apply climate predictions in climate change adaptation decision-making. In this sense, providers must ensure that both the probabilistic nature of predictions and its associated quality are adequately communicated and correctly interpreted by users. Because of the different expertise and previous knowledge in the selected sectors, this aspect is expected to go most smoothly in the case of the re/insurance climate service, whereas it might face more challenges in the agriculture sector. Users from the re/insurance sector are regularly dealing with risk information, meaning they are already familiar with probability and uncertainty concepts. Therefore, they are keener on incorporating probabilistic climate predictions to their decision-making. Users in the wind energy sector are also quite used to weather predictions (up to 2 weeks), but identify uncertainty as a barrier to incorporate medium-range climate predictions in their decision-making. Although the agriculture traditionally relies on meteorological data, users are rarely aware of the usefulness of probabilistic climate information, or familiar with the concept of uncertainty. It is thus the job of the research community to communicate these concepts to the potential users of climate information. When communicating uncertainty it is particularly important to emphasize what we actually understand and to recognize that with improvements in the research, some uncertainty sources may reduce in the future.

In addition to the previously described challenges, making a tool that is attractive and usable is yet another issue. In this case, the climate services for re/insurance and energy are the two conceived as visualization tools. In both cases, visualization was important to raise awareness of the potential applications of medium-range predictions and to put probabilistic information into a usable form for decision-makers. This process required establishing a solid collaboration between experts from very different disciplines including design and art, since visually representing probabilistic information entails a compromise between scientific soundness, functionality and aesthetics (Christel et al. under review).

The last challenge, which is generally faced by climate services developed in a research environment, refers to the sustainability of the service in the long range. Namely, these tools are normally developed under the financial support of a particular project and, when the project ends, stakeholders' investment in the tool's maintenance is not guaranteed. Further investment largely depends on the successful development of climate models and tools that are actually incorporated in the regular decision-making of the climate-sensitive sectors. This requires increasing the quality and reliability of the predictions as well as the successful dissemination of the use of climate information among the different sectors.

3 Conclusions and Future Steps

The appropriate application of participatory approaches and graphical visualizations to communicate climate data is fundamental to the provision of climate services that can guide climate change adaptation decisions. Although climate services have been proven to be useful to inform decision-making of climate-sensitive sectors, their use is still not widespread. Limitations to more efficient development and more extensive use of climate services relate to user engagement, tailoring of climate information and communication of probabilistic information and prediction reliability.

In the first instance, it is necessary to understand the user's decision-making processes and ensure that the climate service will be suited to their needs. In fact, climate is often not the most important issue to users, and efforts should be rather directed to identify user's sensitivities, thresholds and risk tolerance related to climate and within their decision-making processes. Once the relevant processes are well understood, it is important to maintain a clear, consistent and regular communication with users. Additional work is needed to implement standardised options regarding accessibility and visual communication of climate predictions towards the development of climate services. For instance, a clearer distinction should be made between climate projections and climate predictions, as end-users tend to assume that these two products show the same information. In addition, the common conception that medium-range climate forecasting is inaccurate and unreliable, makes user engagement challenging. It is therefore important to build a mutual understanding regarding the realistic scope of a climate service and the value that it could add to the sector. Application of economic incentives to demonstrate the added value of climate predictions is an approach that needs to be further explored. All these initiatives (standardization, use of economic incentives, etc.) are meant to facilitate the communication of the usefulness of climate information to the users. Although the users may differ, the challenges we face when trying to engage and understand the decision-making processes of any user affected by climate change are universal. The tools shown here can be replicated to many other sectors, such as water management, solar energy, health, etc., which are influenced by climate variability over medium-range timescales. To sum up, more effort needs to be directed to improve the aspects described here as well as to develop alternative ways of climate data visualization in order to make climate services operational, and therefore, sustainable in the long-range.

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