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On the use of seasonal to decadal climate predictions for decision-making in Europe

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Contents

Abstract

The importance of climate information for decision-making in sectors susceptible to climate variability and change is widely recognised. Advancements in climate science have led to an increased interest in seasonal to decadal climate predictions (S2DCP) although in Europe little is known about the practical use of these climate predictions. To fill this gap we conducted a systematic literature review on the use of seasonal and decadal climate predictions in Europe and a workshop with European climate service providers to elicit their knowledge and experiences.

We found that although the use of S2DCP across Europe is still fairly limited particular sectors such as energy, water, insurance, and transport are taking the lead in Europe. The central role of the European Centre for Medium-Range Weather Forecasts and National Met Services as the main providers of seasonal forecasts in Europe was also highlighted. Perceived barriers to the uptake of S2DCP tend to be associated with low skill and reliability of models but also with factors such as relevance, usability, and accessibility to S2DCP by the end-users.

Some of our findings are consistent with past experiences outside Europe where the uptake of seasonal forecasts for decision-making has a longer history. For example, the interaction between actors, the usability of the information provided, and the importance of institutional and social factors have all been noted as important aspects influencing the use of these climate predictions by end-users. Further research with decision-makers is needed to better understand the use and potential benefits of S2DCP in Europe.

Keywords: *seasonal; decadal; forecast; predictions; decision-making, Europe.*

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1. Introduction

Climatic conditions have shaped societies for millennia. Since the emergence of Numerical Weather Prediction (NWP) and computer models in the 1950s, it has become possible to anticipate future weather a few days ahead. Weather forecasts and their associated warnings now save lives and money to societies across the world. For example, weather forecasts generate an estimated net benefit of $26.4 billion to the United States economy each year (Lazo et al., 2009). Climate models, developed from NWP models, produce forecasts, predictions or projections at a range of temporal and spatial scales. The temporal scales that have received most attention include the century timescale which use long-term experiments to produce climate change projections; and the seasonal timescale which use observed states of the ocean and atmosphere to initialise climate models to produce seasonal forecasts. Recently, the decadal timescale has received increased attention (Meehl et al., 2009). Seasonal predictions cover "the next month up to a year into the future" and the information is provided as monthly or seasonal means (Goddard et al., 2012, p. 622). Of a more experimental nature, decadal predictions are run 10 years into the future and the information is presented as annual to decadal averages (*ibid*).

In Europe, long-term climate change projections have received the most attention from decision-makers (Alcamo et al., 2007, Biesbroek et al., 2010). Developments in the science and models underpinning the study of climate variability and change have led to an increased interest in seasonal to decadal climate predictions[1] (S2DCP) (Hewitt et al., 2013, Buontempo et al., submitted). In theory, S2DCP have the potential to respond to the needs of sectors and activities which are susceptible to, and influenced by, climate variability and change by helping to inform decision-making, improving operational activities, and enhancing profitability (Harrison et al., 2008a). For example, the susceptibility of the agricultural sector to weather conditions and the potential to use seasonal forecasts of relevant weather parameters to inform decisions and plan activities in agricultural systems is widely recognised (e.g. by improving the timing for sowing, ploughing, and harvesting of crops; help timing fertilizer application) (Doblas-Reyes et al., 2006, Cantelaube and Terres, 2005, The World Bank, 2008). Other European sectors such as water resource management, energy, insurance, disaster management, forestry, and health have also been identified as potential beneficiaries of seasonal forecasts (Harrison et al., 2008c, The World Bank, 2008).

However, little is known about the use of S2DCP in decision-making in Europe. To improve current knowledge, we first conducted a systematic literature review of academic publications and grey literature on the use of S2DCP for decision-making in Europe. However, given the paucity of publications we conducted an expert elicitation workshop with European climate service providers. The aim of the workshop was to elicit existing knowledge and experiences from experts working at the interface between the production of climate science/predictions and the users of such information in order to improve our understanding of the use of S2DCP in Europe. Overall, workshop participants represented a total of 11 countries, two

[1] In this paper, we use the word forecast to refer to seasonal forecasts and predictions to refer to decadal climate predictions. When referring to both seasonal and decadal timescales we use the term climate predictions or the acronym S2DCP.

European organisations, and various sectors including water, energy, tourism, and health.

The next section summarises the main aspects underpinning the development of S2DCP and some of the challenges associated with decadal predictions. Section 3 describes the methods used to conduct the systematic literature review and to elicit experts' knowledge during the workshop. Section 4 presents the main findings from both the systematic literature review and the expert elicitation workshop. This section focuses on the producers of S2DCP in Europe, the users (and potential users) of such predictions as well as the main perceived barriers to their uptake. Examples of the use of S2DCP outside Europe will also be used in this section to draw parallels between Europe and other parts of the world. Section 5 provides concluding remarks.

2. The development of seasonal to decadal climate predictions

Due to the chaotic nature of weather, forecasting of weather beyond a 2-week period is practically impossible (Troccoli, 2010). However, as seasonal predictability is influenced by components of the climate system (e.g. oceans and land surface) that change at a slower rate than weather events it is possible to have insights into how future climate may evolve (Doblas-Reyes et al., 2013). The El Niño–Southern Oscillation is the main climatic phenomenon influencing predictability on the seasonal timescale (Palmer et al., 2005, Harrison et al., 2008b, Doblas-Reyes et al., 2013). Decadal predictions sit between seasonal forecasts and climate change projections and, as a result, the climate variability associated to these timescales is mainly influenced by changing atmospheric composition associated with increasing greenhouse gases and slow changes in ocean circulation leading to changes in sea surface temperature (Goddard, 2012).

The development of seasonal forecasts has advanced considerably in recent years with the use of dynamical methods based on coupled general circulation models (CGCMs) (Palmer et al., 2005, Troccoli, 2010). However, due to the uncertainty of CGCMs with regard to the initial conditions and model equations, efforts have been made to develop multi-model ensemble systems which incorporate independently derived models as a way of representing that uncertainty (Palmer et al., 2005). In a multi-model ensemble different predictions from various forecast systems are computed in order to produce a more reliable and skilful estimate of the forecast probability, which in dynamical forecasting is a way of accounting for model uncertainty (Doblas-Reyes et al., 2005).

The development of decadal predictions is still experimental and numerous challenges persist including how decadal prediction systems should be developed, what information can be supplied, and the skilfulness of those predictions (Meehl et al., 2009, Murphy et al., 2010, Cane, 2010). Notwithstanding, the science base for developing decadal predictions is rapidly evolving and new advances in knowledge are certainly promising even if uncertain (Meehl et al., 2014). Furthermore, potential benefits of decadal predictions for decision-makers across a range of sectors have also been identified (Cane, 2010; Vera et al., 2010). For instance, Metha et al. (2013) examine the Missouri River Basin in the United States where decadal climate variability explains a large percentage of the total precipitation, runoff, and streamflow in the area affecting a range of sectors including agricultural production, reservoir management, and urban areas. Through engagement with basin stakeholders Mehta et al. (2013) explored the information needs of decision-makers regarding decadal climate predictions. They found that the potential to use decadal climate outlooks in the Missouri River Basin was extensive. For instance, in the management of river flows and reservoirs these outlooks could be coupled with hydrology models to help predict reservoir inflows; manage trade-offs between agriculture, fish and wildlife, and recreational uses of water within the basin area; and inform urban water agencies in their budgeting and capital investment.

The potential to improve developmental collaborations between seasonal and decadal timescales also exist as both types of climate predictions use the same general circulation models and global observing systems and, as a result, improvements achieved in one part of the system can potentially enhance other elements of that system (e.g. observations, models) (Goddard et al., 2012).

In Europe, a number of projects and initiatives have emerged for developing multi-model ensemble seasonal, inter-annual, and/or decadal climate predictions (see e.g. Palmer et al., 2000, 2004; Hewitt, 2005) and more recently the CMIP5 (cmip-pcmdi.llnl.gov), EUPORIAS (Hewitt et al., 2013; Buontempo et al., submitted) , SPECS (www.specs-fp7.eu), and NACLIM (naclim.zmaw.de) projects.

3. Methods

3.1. Systematic literature review

The first step to our analysis involved conducting a literature review of academic publications and grey literature on the use of S2DCP for decision-making in Europe (Dessai and Bruno Soares, 2013a). The search for peer-reviewed literature was based on the systematic approach applied by Ford et al. (2011) and conducted using the ISI Web of Knowledge and a set of specific keywords to help target relevant publications (e.g. seasonal, decadal, prediction, forecast, use, stakeholder, decision) (see Appendix A for further details). A filtering process was then applied to exclude non-relevant publications and a total of 209 peer-reviewed publications were found (Appendix A). The majority of these publications however (204 out of 209 publications) focused on the latest developments in S2DCP science and modelling and only five publications looked at the potential to apply S2DCP in particular sectors. No examples of the practical use of S2DCP in decision-making in Europe were found in the peer-reviewed literature.

A second literature review – focusing on grey literature – was performed using Google and Google Scholar search engines and a similar combination of keywords and filtering process as to those applied to the systematic literature review (Appendix A). Out of the 18 returned publications on S2DCP in Europe only one example of an organisation using seasonal forecasts was found in the grey literature (Dubus, 2014, 2013, 2012).

3.2 Expert elicitation workshop

Given the limited number of publications and knowledge on the use of S2DCP in Europe we organised a workshop with European climate service providers (Dessai and Bruno Soares, 2013b). The aim of the workshop was to elicit existing knowledge and experiences from experts working at the interface between the production of the climate science and the users of such information in order to advance current knowledge on the use of S2DCP in Europe. A total of 25 experts from a range of European climate services providers attended the workshop including National Meteorological and Hydrological Services (NMHS) as well as other organisations working at this interface (see Appendix B for further details). Experts were selected based on their knowledge and expertise in the subject area within their organisations (cf. Meyer and Booker, 1991).

Experts' knowledge and expertise was captured by methods of knowledge elicitation (cf. Ericsson et al., 2006) which can be used in novel and emergent areas of research to help determine what is currently (un)known as well as what is worth investigating in a particular field (Meyer and Booker, 1991). These included interactive groups discussions to probe and elicit experts' knowledge (Hoffman et al., 1995). The elicitation focused on three key issues: 1) identifying users and potential users of S2DCP; 2) identifying the flows of information from providers to users (here described as chains); and 3) identifying barriers and solutions to the use of climate predictions.

To map the users of S2DCP, experts worked in mixed groups and were asked to identify users and potential users of S2DCP in Europe, providing as much detail as possible of each user. Experts were then asked to place each user identified in a matrix according to how they make use of S2DCP and different prediction lead time. The prediction lead time encompassed forecasts up to a month (monthly/sub-seasonal forecasts); from a month up to a year (seasonal forecasts), annual (annual forecasts), and decadal (up to 10 years climate predictions). In terms of how those organisations are currently using S2DCP, these were categorised as: using S2DCP in a strategic and/or operational way (e.g. strategic planning of activities; use of S2DCP in operational models); using S2DCP moderately (e.g. they may consult a particular seasonal forecast but that information is not used in any specific model application); aware of S2DCP but not using them; and not aware of S2DCP and also not using them. Each group then discussed their findings in their matrix and reported in plenary to all workshop participants.

In order to identify the providers and the chains of S2DCP in Europe experts were asked to describe a known chain of S2DCP provision and the stages through which climate information travels from its inception to its use in decision-making. Working in groups, experts were then asked to discuss the various chains and try to merge them by finding commonalities and linkages between them.

To identify perceived barriers to the use of S2DCP and solutions to overcome those barriers participants were asked to brainstorm, discuss, and cluster the main barriers to the use of S2DCP in small groups. Each group was then asked to do the same with regard to solutions to overcome the barriers identified. They then reported back the main findings from their table at the end of the session.

4. The use of seasonal to decadal climate predictions in Europe

The remainder of the paper is based on findings that arose from both the systematic literature review and the expert elicitation workshop.

As noted above, further advances in climate science and models studying the El Niño Southern Oscillation has led to higher levels of predictability and skill in seasonal forecasts allowing the uptake of this type of forecasts to inform decision-making processes in other regions of the world (e.g. USA, Australia, Brazil) (Dilling and Lemos, 2011; Vogel and O'Brien, 2003; Lemos et al., 2002). As a result, lessons learned from other regions of the world will be noted to help draw parallels with the European context.

4.1. Who are the users and potential users of seasonal to decadal climate predictions in Europe?

Recent efforts in the development of seasonal forecasts (and to a certain extent decadal predictions) have increased the availability of climate predictions at these timescales in Europe. Nevertheless, the practical use of S2DCP is still an emerging area and existing literature mainly focuses on the models underpinning the science and the potential for using this type of climate predictions in Europe. The only example in the (grey) literature of a European organisation using seasonal forecasts was the case of Electricité De France (EDF). The company has been using weather/climate forecasts and projections (e.g. monthly-seasonal-annual forecasts and climate change projections) for more than 30 years to manage its operations (Dubus, 2013, Dubus, 2012). Although the majority of EDF's operations are affected (to different extents) by weather and climate conditions it is hydro-power production and the demand for power that are most susceptible to precipitation and temperature variability and change, respectively. EDF has been progressively using probabilistic weather forecasts from ECMWF Ensemble Prediction System as well as monthly forecasts (which can go up to a year in some applications) in their decision-making processes (Dubus, 2013, Dubus, 2012). The company is also aiming to extend these forecasts to a prediction lead time of 3 up to 6 months in the near future (*ibid*). However, information from probabilistic forecasts can be difficult to integrate into existing and complex operational tools and, as a result, tailoring seasonal forecasts will be required if these are to be fully integrated in EDF's application models.

A total of 125 users (including 72 potential users) of S2DCP across a range of European sectors were identified during the workshop. Of these, 53 were identified by the name of the organisation in question. Figure 1 below illustrates these users where each icon corresponds to an organisation identified by participants according to the sector of their main activities, the prediction lead time of the S2DCP they currently use, and how they use that information within the organisation (Figure 1).

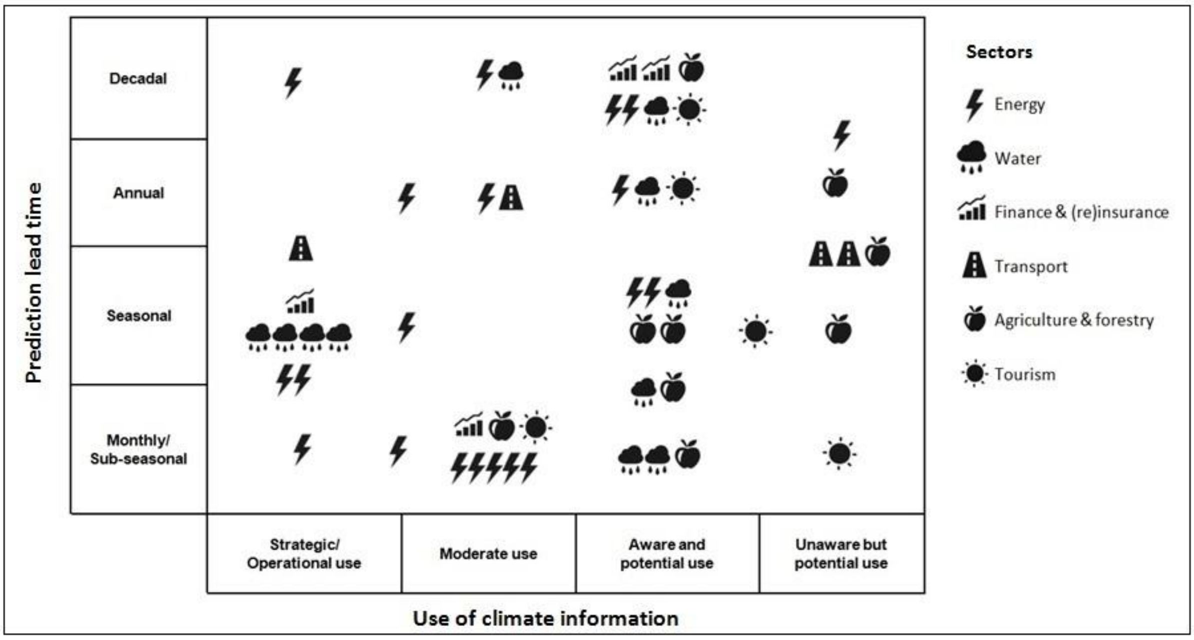

Figure 1 – Organisations identified by experts according to the sector of their activities, the type, and use of climate information.

Organisations already using S2DCP at a strategic/operational level were described with a greater level of detail by experts than those not currently using S2DCP. These 'early adopters' of S2DCP were largely associated with the energy, water, financial and (re)insurance, and transport sectors which mainly use forecasts with a lead time prediction of a month up to a season (Figure 1). Ideal typical early adopters tend to be perceived as role models in the uptake of new ideas, concepts, or information (Rogers, 2010). In this case, early adopters of S2DCP were differentiated by experts as those already using these kinds of forecasts either in a strategic and/or operational or moderate way within the organisations. The energy sector was prominent amongst these early adopters with 14 organisations identified by experts although in some cases different experts identified the same organisation (i.e. EDF). Contrary to other sectors, some of the organisations identified in the energy sector also seem to use annual to decadal climate predictions.

The majority of these early adopters use S2DCP to improve the management of their activities, products, and outputs with a view to improve efficiency and, for those in the private sector, increase profitability. As a result, the uptake of S2DCP is generally associated with a degree of relative advantage (e.g. increased efficiency, economic profit) amongst those adopting and using these new kinds of climate predictions (Rogers, 2010). The use of S2DCP in these organisations ranged from using these climate predictions as additional information to climatology to a more advanced use of the information in operational/dynamical models to support specific decision-making processes within organisations.

Some of the users (28 out of 53) identified by experts included organisations that may or may not be aware of these kind of predictions but with perceived potential to benefit from their use. These organisations covered a whole range of sectors such as energy, water management and resources, financial and insurance, agriculture, forestry, tourism, and transport covering different sectors and prediction lead time (Figure 1).

Although an emergent area, the potential use of decadal climate predictions was also highlighted for a range of sectors including energy, finance and (re)insurance, water management and resources, agriculture and forestry, and tourism. The water sector for example, was identified by experts as having the potential to benefit from information ranging from sub-seasonal forecasts up to decadal climate predictions.

4.1.1. Other potential users

In other instances, experts only identified particular sectors with potential interest in using these types of climate predictions. These covered the remaining 72 users identified by experts and included sectors such as health, and emergency, urban planning and civil protection (Figure 2).

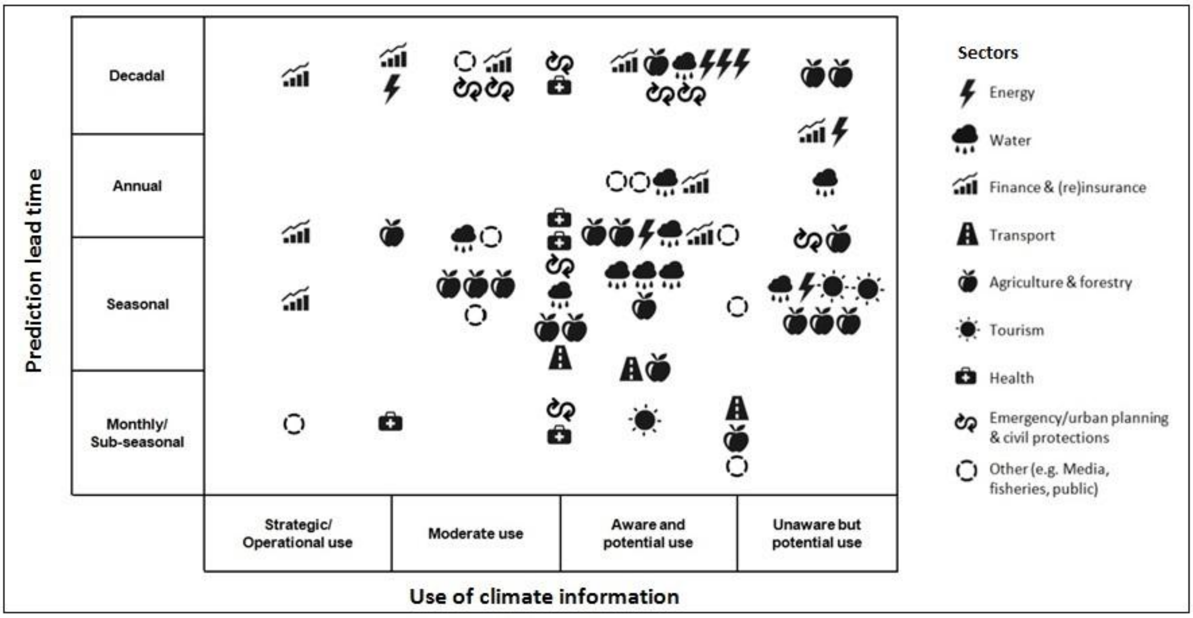

Figure 2 – Sectors identified by experts as using S2DCP or of potential use organised by the type and use of climate information.

Although some sectors already seem to be using S2DCP (e.g. finance and (re)insurance, energy, agriculture) the majority of sectors identified are either aware or unaware but not currently using these types of climate predictions (Figure 2).

Increasing the uptake of S2DCP across European organisations and sectors would require first of all making decision-makers aware of S2DCP. Besides becoming aware of these types of climate predictions there are however a range of factors influencing the use of new climate information such as S2DCP. For example, Marshall and Ash (2011) examined the reluctance of Australian graziers in using seasonal forecasts. Their study showed that factors such as accuracy, lead time, and appropriate spatial and temporal scale of the forecasts were not the main factors potentially influencing the uptake of this new technology (although it could increase their usability). Instead, other considerations such as the potential economic and environmental benefits were regarded as more important in the adoption of seasonal forecasts if they were to become available.

Looking at the factors underpinning the use of seasonal forecasts by decision-makers, Lemos et al. (2012) find that these tend to be associated with three main conditions: an appropriate fit between the information provided and users' needs; the interaction between producers and users; and the interplay of the new climate information with other kinds of information used in decision-making. In their proposed model, these conditions need to be addressed if the climate information being provided is to be used to inform decision and policy-making. These experiences and legacies from beyond Europe are important lessons to consider in the emergent context of S2DCP in Europe.

4.2. What are the flows of information from producers to users of seasonal to decadal climate predictions in Europe?

During the workshop a total of 37 chains of climate information provision were identified by experts. In 27 out of the 37 chains identified, ECMWF consistently emerged at the beginning of the chains by providing weather and seasonal forecasts (which go up to 7 months prediction lead time) to its members including European NMHS (e.g. French, Spanish, German, Norwegian, Portuguese) but also directly to private organisations and national research centres. Post-processing and/or tailoring data for specific customer needs tends to be carried out by NMHS before reaching end-users. In other cases, this work is being performed by in-house research and expertise although this tends to be associated with an existing level of resources and capacity within organisations (cf. Pagano et al., 2002).

In some chains, NMHS were also identified as the main provider of climate information with others acting as boundary organisations (see below) between the NMHS and the end-user. For example, the Norwegian NHMS currently provides statistical forecasts to CBF (a Norwegian energy consultant) who then tailors those forecasts into specific data for energy traders.

In addition, not all chains of climate information provision were constrained to European providers. For example, the US Climate Prediction Centre based at NOAA's National Centre for Environmental Prediction (NCEP) also appeared in some of the chains, alongside ECMWF. However, when this information is translated and/or tailored by others to fit specific users' needs these services tend to have a cost attached. An example is the Weather Services International - a private company with headquarters in the United States - which provides climate information to the financial sector in Europe. This example demonstrates the globalised nature of climate information provision.

During the workshop it was also highlighted that terms such as 'producers' and 'users' are fluid and relative concepts given the complex relationships and chains of climate information provision in the producer-user continuum. For example, NMHS were identified as the producers of climate information and data to other organisations but also as the main users of climate information provided by ECMWF. Figure 3 below illustrates three distinct chains of sub-seasonal (i.e. weather forecasts up to a month prediction lead time) and seasonal forecasts provision in relation to EDF as identified by experts.

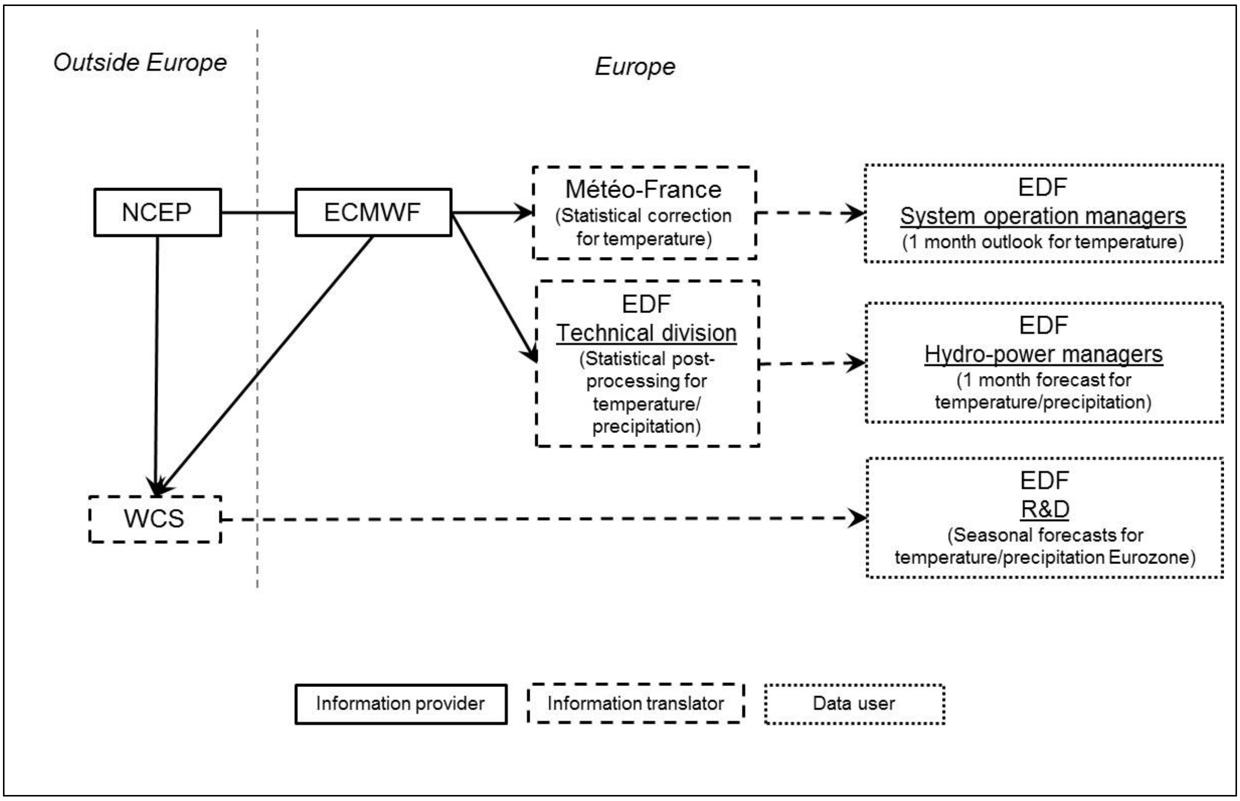

Figure 3 – Three chains of climate information provision identified by experts.

This example, although not exhaustive, helps to illustrate some of the complexity regarding the range of actors and the disparate roles they assume but also the complexity regarding the processes of producing and using such data within each of the organisations involved. In the example above this is briefly illustrated by the use of seasonal and sub-seasonal climate data within EDF where each chain corresponds to different applications of the data in a particular area of activity and decision-making processes (e.g. between hydro-power managers and system operation managers) (Figure 3).

Another interesting aspect is the process of transformation through which climate information becomes useful and usable to the end-user. Figure 3 shows that value is added to the climate information as it moves from the left to the right of the Figure (e.g. ECMWF – Météo France – EDF System Operation Managers). In this context, the role of the so called boundary organisations is an important element as these tend to facilitate the flows of information between producers and users and can assume different roles including the translation of climate information as well as mediation and communication between the various actors involved (McNie, 2007, Buizer et al., 2010, Kirchhoff et al., 2013a, Kirchhoff et al., 2013b). In Figure 3 above, both Météo-france and EDF's Technical Division act as boundary organisations between ECMWF by performing post-processing and communication of that data to different departments within EDF.

The relationships between actors are two-way processes shaped and influenced by a multiplicity of factors and knowledge that flow between them in the development and use of such climate information (Vogel et al., 2007). The processes of interaction between actors and the roles they played in the chains of climate information provision were beyond the scope of the workshop. Future research should however examine the intricacies of such relationships in order to improve our understanding of the typologies of networks and institutional arrangements that are currently being developed in the emerging context of S2DCP in Europe.

The provision of decadal climate predictions was not captured in any of the chains of information identified. Notwithstanding, the development of decadal climate predictions is taking its first steps and is currently an area of increasing research interest (e.g. the ENSEMBLES and CMIP5 projects).

4.3. What are the perceived barriers and solutions to the uptake of seasonal to decadal climate predictions in Europe?

A range of perceived barriers and solutions to increase the use of S2DCP in Europe were identified by workshop experts (see Appendix C for a complete list). Low uptake and use of seasonal forecasts in Europe was generally associated with poor skill of models in Europe, whilst decadal climate predictions were perceived by experts as uncharted territory. An interesting issue raised by experts was the notion of 'windows of opportunity' in Europe (Dessai and Bruno Soares, 2013b). This idea relates to the fact that at times, certain influences/factors which confer predictability will be stronger and/or act in concert. In such situations, signals in the forecast are likely to be stronger and the confidence in climate predictions may be greater than the average skill information would indicate. That confluence of factors (i.e. 'windows of opportunity') may enhance the usability of climate predictions for some users depending on the phenomenon, thresholds, and decisions involved (Brookshaw, 2014).

For example, Maidens et al. (2013) examined the unusually cold winter of 2010-2011 and the influence that certain surface forcings had in the predictability of the North Atlantic Oscillation regime of that winter. Such findings support the "(…) hypothesis that although skill in general over the European region is low, there are grounds for having higher confidence in forecasts for individual years where strong forcings exist." (Maidens et al., 2013, p. 21). Fereday et al. (2012) also examined the influence of strong El Nino conditions with an easterly quasi-biennial oscillation phase in the development of sudden stratospheric warmings which in turn, play an important role in surface conditions ultimately improving climate predictions of the cold conditions of the 2009/2010 winter in Europe.

Outside Europe, where the use of seasonal forecasts has a longer history, the literature shows that the uptake of seasonal forecasts is more likely if the information provided is perceived as accurate, salient, credible but also timely and useful to users' needs (Lemos et al., 2012, Meinke et al., 2006, Pagano et al., 2002). Existing 'windows of opportunity' in Europe can therefore challenge conventional notions that consider low skill as an immutable barrier to the use of seasonal predictions. As a result, perhaps more important than achieving higher levels of skill in the models is to explore these 'windows of opportunity' and match such climatic information with users' needs to help support their decision-making (McNie, 2007).

Although many of the barriers identified related to the lack of skill in the models a significant proportion related to non-technical barriers such as the lack of an interface between users and producers of S2DCP in Europe. In other parts of the world similar barriers tend to be associated with a lack of understanding of the decision-making processes where the climatic information is intended to be used by the producers of the climate information (Dilling and Lemos, 2011). Such barriers highlight the importance of an 'end-to-end' system linking producers and users in a cyclical process which enables a better understanding of information needs and where such processes can be fostered by boundary organisations (Agrawala et al., 2001, McNie, 2007). In this context, solutions proposed during the workshop to improve this interface between producers and users (and other actors in between) included the creation of an umbrella organisation such as a European alliance or climate service partnership to promote interactions between these actors through co-production of services and products (e.g. co-working on real case-study examples). Similar initiatives have taken place elsewhere such as the Climate Services Partnership which is an international platform for collaboration and knowledge sharing between climate information providers and users. At a national level, the German Climate Service Centre is another example of such an interface that allows collaboration between climate scientists and practitioners. Another example in Germany but at the regional level is the North German Climate Office which provides climate information (with a focus on coastal climate) for the general public (Meinke and Von Storch, 2008; Krauss and Von Storch, 2012).

Lack of accessibility and/or awareness of available climate information by users were also raised as a significant barrier to the use of S2DCP in Europe. These included the need to develop data portals (e.g. such as the KNMI's Climate Explorer) for sharing and disseminating information, guidance, and case studies based on the development of factsheets, illustrations, and graphical presentations. The use of technical and scientific language and the difficulties in conveying in a simple way the complexity of the science (e.g. explaining the probability of the climate predictions and the limitations and assumptions in the models) were also perceived as barriers when engaging with non-experts. Communication issues are intrinsically linked to the relationship and interaction between the various actors engaged in the user-producer continuum (Vogel et al., 2007, Lemos et al., 2012) and ensuring continuous engagement and dialogue between these groups was highlighted as part of the solution to overcome some of the barriers identified. Examining the response of farmers in south eastern United States to seasonal forecasts, Crane et al. (2010) stress that more than simply technical information input, seasonal forecasts need first to be developed within farmers' social networks if such climate information is to be used as a risk management tool. In their study, the need for producers to adapt and adjust their practices was also emphasised to allow a more intricate collaboration between users and producers with the ultimate purpose of translating such knowledge into usable science.

Other perceived barriers to the uptake of S2DCP in Europe related to the reluctance to change existing working practices and protocols within organisations as well as a culture of risk aversion from both producers and users. In their study of water resource managers in the United States, Rayner et al. (2005) uncover that institutional factors such as conservatism and reluctance in changing industry standards and practices significantly influence the use of probabilistic seasonal forecasts by decision-makers.

5. Conclusions

The development of seasonal forecasts has been evolving in recent years although the skill and reability of such forecasts differ considerably across regions. Decadal climate predictions, a more recent endeavour, are now emerging as a research area although a number of challenges persist regarding the development of the science. S2DCP have the potential to inform the planning and management of activities sensitive to weather and climate variability and change, and outside Europe this has been, to different extents, adopted in some sectors and areas (cf. Dilling and Lemos, 2011).

To advance our understanding and knowledge regarding the use of S2DCP in Europe a systematic literature review and an expert elecitation workshop were conducted. Findings from this study have highlighted the central role of the ECMWF and NMHS as the main providers of seasonal forecasts in Europe whilst current users of seasonal forecasts are found in sectors most sensitive and susceptible to weather and climate variability and change such as energy, water, reinsurance, and transport. Many of the perceived barriers to the uptake of S2DCP are linked to the limited skill and reliability in Europe. Other barriers however relate to non-scientific aspects such as the lack of communication and engagement between the producers and end-users of S2DCP and the need for bridging this gap in order to improve the relevance and usability of the climate information being produced and provided to users across Europe.

The study conducted was bound by methodological factors that influenced both the collation process and the analysis performed. For example, the approach adopted to conduct the literature review was based on a pre-selection of key terms which confined the search potentially leaving out relevant literature. Commercial interests in a competitive market which are common in the private sector may have also affected our access to relevant publications. Finally, the methods of knowledge elicitation adopted to conduct the workshop are also bounded by particular factors e.g. data collated as a function of the experts present and a snapshot in time of experts' knowledge and experiences (cf. Meyer and Booker, 1991).

Notwithstanding, this analysis provides a starting point for understanding the current and emergent landscape of S2DCP in Europe. Further research is required to help advance knowledge and further explore some of the issues raised in this analysis. For example, the chains of climate information provision identified during this study unveiled some of the complexity of the networks of relationships and actors involved in the production, translation, and use of climate information in Europe. In addition, the different roles played by actors across those networks also revealed the fluid nature of the relationships and roles assumed by actors in different contexts. Exploring in more depth the nature and functional mechanisms of these relationships and the roles played by actors would therefore help to understand, for example, not only at which points in the chains of climate information provision value is added but also the purpose of such processes in relation to informing decision-making.

Given the limited empirical evidence on the use and uptake of S2DCP in Europe it is important to reflect on the experience and legacies of using such climate predictions outside Europe. An important lesson to retain is that the provision of climate predictions to users is not, in many instances, enough to ensure that the information will be used in practice. Institutional factors, social aspects, communication between actors, and the adequacy and usability of the climate information are just some examples of the barriers to the uptake of S2DCP outside Europe. Such empirical contributions need to act as a reference in the emerging context of S2DCP in Europe if we are to avoid similar obstacles in the uptake and diffusion of these types of climate predictions for the benefit of society.

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Appendix A

The search for peer-reviewed literature was based on the systematic approach applied by Ford et al. (2011). The search was conducted using the ISI Web of Knowledge and spanned the period between 1900 and February 2013. A set of specific keywords were used to help target the publications relevant to this study. These are listed below.

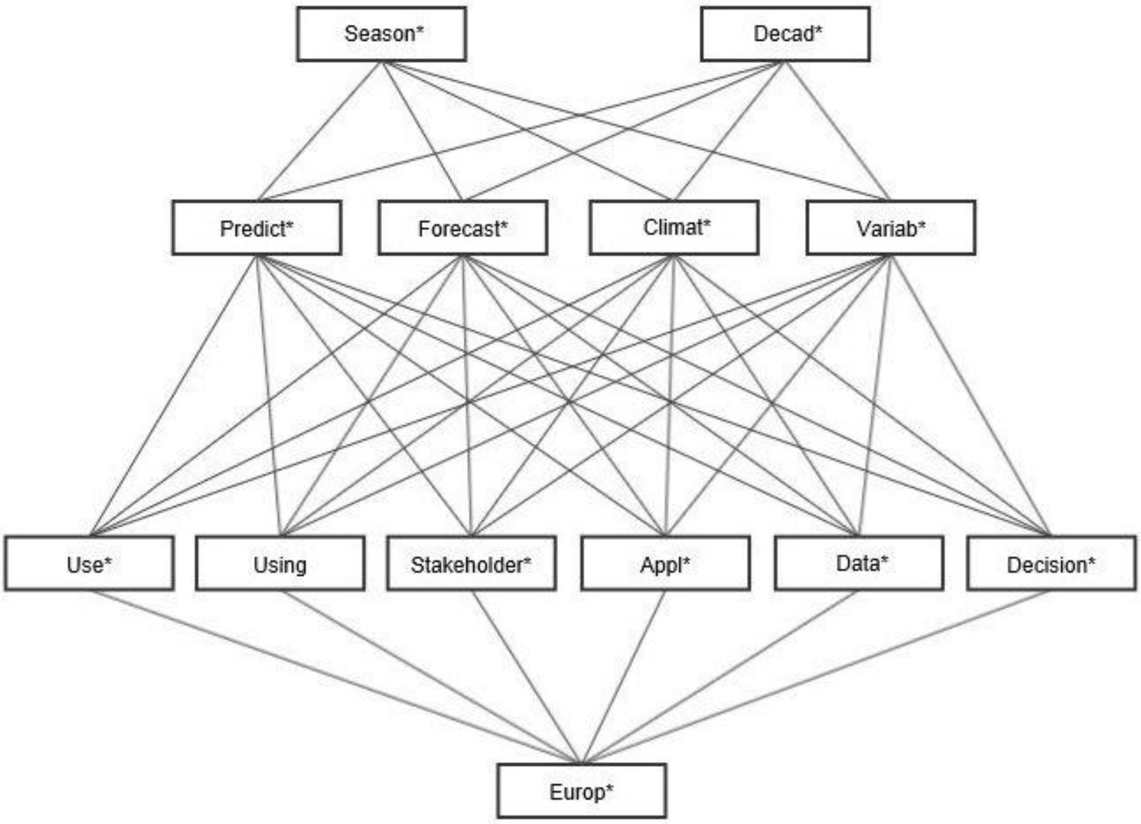

Figure A.1. – Keywords used to search peer-reviewed literature.

This search involved 48 different combinations of the keywords selected. A 1st stage filtering process was applied to these results (see Table below), whilst in the ISI Web of Knowledge browser, in order to exclude non-English publications and those from research areas not relevant to this study (e.g. medical research, sport sciences, ornithology, biotechnology). Non-peer reviewed publications such as letters, corrections, abstracts, book chapters, and editorial material were also excluded. This returned a total of 4,377 peer-reviewed publications.

A 2nd stage of filtering was then performed in order to apply an inclusion/exclusion criteria based on the content of the publications (see Table below). Based on the results from this filtering there are no peer-review publications that examine the practical use of S2DCP in Europe. However, there are five publications that focus on the potential use of seasonal predictions across different sectors in Europe as well as 204 publications on the increasing development of skill and models, which enable the delivery of this type of climate information.

Given the novelty of S2DCP, another literature review was also performed focusing on grey literature in order to gather other relevant literature indexed in electronic databases. Grey literature includes working papers, book chapters, reports, unpublished data, thesis, policy documents, conference abstracts, and personal correspondence. This review was performed using Google and Google Scholar search engines. Although it would be sensible, for the sake of analytical consistency, to use the exact same keywords as those used in the peer-reviewed literature review (see above) these were not suitable due to the vast amount of irrelevant results mainly due to use of wildcards. Wildcards can be used in a search query to represent unknown characters e.g. the asterisk (*) represents any group of characters, including no character. As a result, we used combinations of the keywords used in the peer-reviewed literature but without using wildcards. The keywords used are listed below.

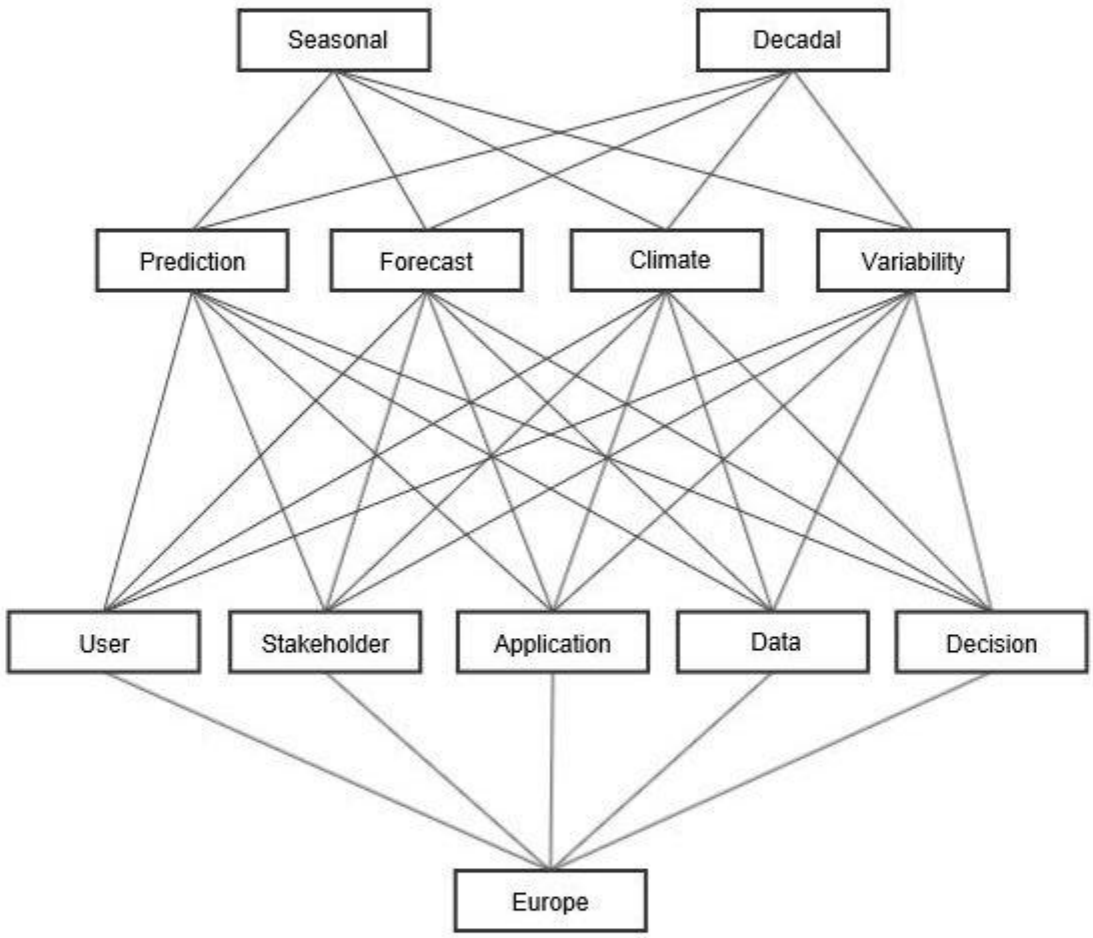

Figure A.2. – Keywords used for searching grey literature.

A 1st stage filtering process was immediately applied to the results in order to exclude non-English publications and literature not relevant to this study. The literature was then imported into Endnote where a 2nd stage of filtering was performed in order to apply the inclusion/exclusion criteria set out for this study (see table below). Only three publications in the grey literature were relevant and included in this study.

1st stage – keyword search

	Peer-review literature	Grey literature
Inclusion criteria	English language Indexed to the ISI Web of Knowledge; Published literature (articles, books).	English language Publications in Gogle and Google Scholar.
Exclusion criteria	Non-English literature; Not indexed in the ISI Web of Knowledge; Letters, corrections, conference proceedings, editorial material; Literature not related to this study area.	Non-English literature; Not included in search engines; Literature not related to this study area.

2nd stage – Title and abstract review

	Peer-review literature and grey literature
Inclusion criteria	Literature on the practical use of S2DCP in Europe; Literature on the potential to use S2DCP in Europe; Literature on the development of skill and S2DCP models in Europe.
Exclusion criteria	Non-related S2DCP literature (e.g. literature on climate change impacts, vulnerability studies).

Table A.1. – Inclusion and exclusion criteria used to filter the peer-reviwed and grey literatures.

Appendix B

Organisation	Sector of expertise	Participant	Country
Agencia Estatal de Meteorología	Meteorology	Ernesto Rodríguez-Camino	Spain
CETaqua	Water	Laurent Pouget	Spain
ECMWF	Meteorology	Laura Ferranti	Europe
Electricité de France	Energy	Laurent Dubus	France
ENEA	Energy	Matteo de Felice	Italy
Climate Service Center	Climate	Teresa Zölch	Germany
IPMA	Meteorology	Mariana Bernardino	Portugal
KNMI	Meteorology	Janette Bessembinder	The Netherlands
KNMI	Meteorology	Roeland van Oss	The Netherlands
KNMI	Meteorology	Geert Jan van Oldenborgh	The Netherlands
UK Met Office	Meteorology	Anca Brookshaw	United Kingdom
Meteo Norway	Meteorology	Rasmus Benestad	Norway
Metéo-France	Meteorology	Jean-Pierre Ceron	France
Meteo-Romania	Meterology	Roxana Bojariu	Romania
MeteoSwiss	Meteorology	Christoph Spirig	Switzerland
Predictia	Roads	Daniel San-Martin	Spain
Predictia	Roads	Max Tuni	Spain
SMHI	Meteorology	Lars Bärring	Sweden
TEC	Tourism	Adeline Cauchy	France
University of Cantabria	Meteorology	Maria Dolores Frias	Spain
University of Cantabria	Meteorology	Maria Eugenia Magarino	Spain
University of East Anglia	Research	Clare Goodess	United Kingdom
UKCIP	Climate	Roger Street	United Kingdom
World Health Organization	Health	James Creswick	Europe
Climate-Insight	Climate	Mike Harrison	United Kingdom

Table B.1. - List of workshop participants.

Appendix C

	Perceived barriers	Solutions
Skill and reliability	Unknown skill Poor/low reliability Not exploring ‘windows of opportunity’ Lack of deterministic skill Marginal value of seasonal predictions Decadal predictions as uncharted territory	Improving models and skill in Europe Investing in R&D Develop predictions that go beyond the usual temperature/precipitation forecasts
Capacity, relevance, and usability of information	Limited resources/capacity by producers/users Limited capacity to respond to users’ needs Inadequacy of available/requested information (spatial/temporal resolution) Limited capacity by users to ingest climate information Lack of awareness of/interface with boundary organisations Need to focus on reliable variables that are relevant to users Inability to exploit and demonstrate benefits of S2DCP to users	Understand users’ needs and how information is used Co-production of services, products, and support to improve interactions between users-producers New/improved interfaces between users and producers (e.g. better data portals for sharing and disseminating of information and events) Share guidance, case studies, peer products Demonstrate benefits and added value of using S2DCP/advertise success stories (e.g. case studies) Boundary organisations as information ‘pushers’
Accessibility, communication, and training	Difficulties in accessing climate information Lack of awareness on available products Lack of tools to exploit forecast information Complexity of the products Difficulty in understanding scientific language and terminology Difficulty in communicating uncertainty Lack/limited support to users (e.g. guidance, case-studies, peer-products)	Education, training, and regular engagement and dialogue between users and producers Use plain language and convenient formats to communicate with users Clear information on limitations and assumptions made when developing models and products Illustrations, factsheets, graphical presentations

Other barriers and solutions	Reluctance in changing existing practices Culture of risk aversion Lack of knowledge on climate science Lack of financial investment Costs of climate information Complexity of climate-related impacts Climate impacts forecasts not perceived as priority Perceptions of vulnerability	Break existing practises Simplify access to data (technical, cost, policy)

Table C.1. – Main perceived barriers and solutions to the use of S2DCP in Europe.

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