THEME ENV.2012.6.1-1

EUPORIAS

(Grant Agreement 308291)

European Provision Of Regional Impact Assessment on a

Seasonal-to-decadal timescale

Deliverable D 12.1

Systematic literature review on the use of seasonal to decadal climate and climate impacts predictions across European sectors

Date Submitted: 28/02/2013

Deliverable Title	*Literature review of the use of S2D predictions across all sectors*	
Brief Description	*Systematic literature review of the use of S2D predictions across all sectors*	
WP number	12	
Lead Beneficiary	*Suraje Dessai, University of Leeds*	
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Creation Date Version Number Version Date	28/02/13 V.1.2	
Deliverable Due Date Actual Delivery Date		
Nature of the Deliverable	x	*R - Report*
		P - Prototype
		D - Demonstrator
		O - Other
Dissemination Level/ Audience		*PP - Public*
	x	*PU - Restricted to other programme participants, including the Commission services*
		RE - Restricted to a group specified by the consortium, including the Commission services
		CO - Confidential, only for members of the consortium, including the Commission services

Version	**Date**	**Modified by**	**Comments**
V1.1.	22/02/2013	Marta Bruno Soares	
V1.2.	28/02/2013	Marta Bruno Soares	

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1. Executive Summary

This report presents a literature review whose aim is to provide an overall understanding of the current state of the use of seasonal to decadal (S2D) climate and climate impacts predictions across European sectors.

Although there has been an emerging effort to develop the science underpinning seasonal climate predictions in Europe, such initiatives have not yet led to a significant uptake and use of this type of climate information by users in their decision-making processes.

Based on this literature review, the only example of a European organisation using and applying seasonal predictions to inform their operational activities and management decisions is the case of Electricité De France (EDF).

Other relevant publications found (both peer-review and grey literature) mainly focused on the development and new findings on the science and models in which S2D predictions will potentially be further developed; whilst very few examined more closely the potential of using seasonal predictions in practice, most of these in the agricultural sector. Decadal predictions are still in their infancy so there were no examples of their use in decision-making.

This literature review also examined selected examples of the application of seasonal climate forecasts beyond Europe since their development and use has a longer history in other parts of the world. These examples, focusing on agriculture, health, and water management, summarise how seasonal forecasts are being used to inform decision-making.

2. Project Objectives

With this deliverable, the project has contributed to the achievement of the following objectives (DOW, Section B1.1):

No.	Objective	Yes	No
1	Develop and deliver reliable and trusted impact prediction systems for a number of carefully selected case studies. These will provide working examples of end to end climate-to-impacts-decision making services operation on S2D timescales.		X
2	Assess and document key knowledge gaps and vulnerabilities of important sectors (e.g., water, energy, health, transport, agriculture, tourism), along with the needs of specific users within these sectors, through close collaboration with project stakeholders.	X	
3	Develop a set of standard tools tailored to the needs of stakeholders for calibrating, downscaling, and modelling sector-specific impacts on S2D timescales.		X

4	Develop techniques to map the meteorological variables from the prediction systems provided by the WMO GPCs (two of which (Met Office and MeteoFrance) are partners in the project) into variables which are directly relevant to the needs of specific stakeholders.		X
5	Develop a knowledge-sharing protocol necessary to promote the use of these technologies. This will include making uncertain information fit into the decision support systems used by stakeholders to take decisions on the S2D horizon. This objective will place Europe at the forefront of the implementation of the GFCS, through the GFCS's ambitions to develop climate services research, a climate services information system and a user interface platform.		X
6	Assess and document the current marketability of climate services in Europe and demonstrate how climate services on S2D time horizons can be made useful to end users.		X

3. Detailed Report

3.1. Introduction

This literature review aims to understand and assess the current state of the use of seasonal to decadal (S2D) climate and climate impacts predictions across European sectors.

In the context of the EUPORIAS project, the S2D timescale encompasses predictions that range from 1 month up to 10 years. The main European sectors being addressed include energy, water, health, agriculture, forestry and tourism.

Section 3.2 introduces the methodology adopted to perform this literature review. Section 3.3 introduces the science underpinning the development of S2D climate prediction in Europe. Section 3.4 presents the main findings of the review of the literature on the use of S2D climate and climate impact predictions (hereafter shortened to S2D predictions) across Europe. Section 3.5 highlights some examples of how S2D predictions are being used outside Europe to inform decision-making across sectors. Section 3.6 provides concluding remarks.

3.2. Methodology for searching and filtering the literature

In order to collate existing literature on the use of S2D predictions across European sectors two distinct literature reviews were performed. The first literature review covered peer-reviewed publications whilst the second focused on grey (or gray) literature.

The search for peer-reviewed literature was based on the approach applied by Ford et al. (2011). This review was performed with ISI Web of Knowledge using a set of specific keywords to help target the publications relevant to this study (Appendix 1 provides full details of how the review was conducted).

The second literature review – focusing on grey literature – was performed in order to gather other literature of interest not indexed in electronic databases. In this context, grey literature refers to any publication in print and/or electronic format which is not controlled by commercial publishers including working papers, book chapters, reports, unpublished data, theses, policy documents, conference abstracts, and personal correspondence (Petticrew and Roberts, 2008, Hopewell et al., 2007). This review was performed using Google and Google Scholar search engines using a combination of keywords similar to those used in the peer-reviewed literature.

To these results a two-stage filtering process was applied using inclusion and exclusion criteria in order to remove publications not relevant to this study.

Literature focusing on the use of S2D climate information beyond Europe was also used to inform this report (see Section 3.5). This was deemed important as there is a considerable amount of literature on the subject due to the advances in the science, models, and use of S2D in other parts of the world.

Contrary to the other two literature reviews, this search was not based on a systematic approach due to the vast amount of literature available. Instead, relevant literature from outside Europe was gathered whilst processing and filtering the other two searches (i.e. literature excluded from the other two searches due to their non-European focus but nonetheless relevant in terms of the use of S2D climate information). In some cases, further literature was gathered to supplement a particular example.

3.3. Background information on S2D climate predictions

Seasonal forecasting can be generally understood as "(…) the prediction of the climate of forthcoming seasons, and in particular the extent to which the expected climate differs from the climate of previous years" (Stockdale et al., 2010, p.55). However, due to the chaotic nature of weather, forecasting beyond a 2 week period is practically impossible (Troccoli, 2010). Nonetheless, as seasonal predictability is influenced by components of the climate system that change at a slower rate than weather events (e.g. oceans and land surface) it is possible to have insights into how future climate may evolve (Doblas-Reyes et al., 2006). In the context of seasonal prediction, the El Niño–Southern Oscillation (ENSO) is a good example of a climatic phenomenon that influences predictability on the seasonal time-scale (Palmer et al., 2005, Harrison et al., 2008b, Frias et al., 2010).

Seasonal to interannual predictions can be developed based on statistical (or empirical) and dynamic models (Harrison et al., 2008b). Whilst statistical modelling is normally based on "(…) regional historical relationships between physical variables such as temperature and precipitation with statistical models"; the latter, a more recent endeavour, makes use of complex dynamical numerical models of the different components of the earth system (Troccoli, 2010, p.251). In recent years, the development of seasonal predictions has advanced considerably with the use of dynamical methods based on fully coupled general circulation models (CGCMs) (Palmer et al., 2005, Troccoli, 2010). However, due to the uncertainty of CGCMs with regard to both initial conditions and models' equations, efforts have been made towards the development of 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 different 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).

Due to the increase in computing capacity and improved collaboration at international and national levels, a number of initiatives for developing multi-model ensemble seasonal forecasting have emerged in recent years across Europe. An example includes the operational multi-model seasonal forecast known as European Operational Seasonal to Interannual Prediction (EUROSIP) which encompasses three operational European seasonal forecast models by the European Centre for Medium-range Weather Forecast (ECMWF), Météo-France, Met Office, and National Center for Environmental Prediction (NCEP) (Stockdale et al., 2010, Yuan and Wood, 2012).

Since 2006, the World Meteorological Organization (WMO) begun to designate the so called Global Producing Centres (GPCs) for Long Range Forecasting (from 30 days up to two years). To be designated as a GPCs, a centre needs to comply with a set of common standards (e.g. a fixed forecast production cycle, standard forecast products, and WMO verification standards) in order to ensure consistency and usability of products. There are currently 12 GPCs worldwide, 3 of which in Europe (i.e. ECMWF, UK Met Office, and Météo-France) (Stockdale et al., 2010).

In Europe, the capability for seasonal predictions has been evolving through a number of co-ordinated research projects funded by the European Union. The Prediction of Climate Variations on Seasonal to Interannual Timescales (PROVOST) project, funded by 4th Framework Environment Programme, examined the ability of multi-model ensembles to produce more reliable probabilistic forecasts than single-model ensembles (for more on this project see Palmer et al., 2000). Following on from that, the development of a European Multi-model Ensemble System for Seasonal to Inter-annual Prediction (DEMETER) project was funded by the 5th Framework Environment Programme (2000-2003). This project developed a multi-model ensemble system based on seven European global coupled ocean-atmosphere models[1] and its main aim was to advance the multi-model ensemble predictions based on state-of-the-art global coupled ocean-atmosphere models (for more on the DEMETER project see Palmer et al., 2004). The latest endeavour on seasonal forecasts, the ENSEMBLES project, was funded by the 6th framework Programme (2004 to 2009) [2]. This multi-model ensemble for seasonal-to-annual forecasts comprised of five global coupled atmosphere-ocean climate models from different centres[3] (Weisheimer et al., 2009). Its main objectives included developing an ensemble prediction system based on state-of-the-art global and regional earth system models (developed in Europe); quantifying and reducing uncertainty regarding physical, biological and human-related feedbacks in the system; and using the outputs of the ensemble prediction in a number of applications such as agriculture, health, energy, water resources, and weather risk and insurance (Hewitt, 2005).

Another important effort in the context of seasonal to decadal forecasting has been the development of new approaches to integrate weather and climate. Although developed as separate disciplines, similar physical principles and challenges characterise weather and climate forecasting, and as a result attempts to understand and characterize the climate system at all space and time scales have been occurring (Hurrell et al., 2009). The concept of seamless prediction is a good example of such advances as it attempts to bring together weather forecasting and climate change projections and provide forecasts at various timescales and spatial resolutions (Palmer et al., 2008, Harrison et al., 2008b). To our knowledge, this type of approach is only currently being pursued by the UK Met Office (the Unified Model), Météo-France (ARPEGE system), and ECMWF (EC-Earth system) (Hazeleger et al., 2010).

This type of approach is of particular interest in the context of decadal predictions as these sit between seasonal predictions and climate change projections. Decadal timescales are believed to be mostly influenced by changing atmospheric composition (associated with increasing greenhouse gases) and slow changes in ocean circulation leading to changes in the sea surface temperature (Goddard, 2012). However, the development of decadal

[1] The modelling partners at DEMETER were CERFACS, ECMWF, ENVG, LODYC, Météo-France, UK Met Office, and MPI. For more information on the DEMETER project and models used go to http://www.ecmwf.int/research/demeter/

[2] For more on the ENSEMBLES project go to http://ensembles-eu.metoffice.com/index.html.

[3] The ENSEMBLES project included models from the UK Met Office, Météo France, the European Centre for Medium-Range Weather Forecasts, the Leibniz Institute of Marine Sciences at Kiel University, and the Euro-Mediterranean Centre for Climate Change (CMCC-INGV) in Bologna (Weisheimer et al., 2009).

predictions is still fairly experimental and challenges abound including how decadal prediction systems should be developed, what information can be supplied, and the skilfulness of those predictions (see e.g. Meehl et al., 2009; Murphy et al., 2010; Cane, 2010). Nonetheless, the potential benefits for this type of climate information across different sectors (e.g. agriculture, water management, energy, health) have been recognised in the literature (see e.g. Vera et al., 2010; Cane, 2010) and a few efforts have been made towards the development of decadal predictions such as the PREDICATE[4] and ENSEMBLES projects.

In a recent paper, MacLeod et al. (2012) assess the skill of decadal predictions based on ENSEMBLES multi-model decadal hindcasts. Their findings suggest that the predictability of the models is largest over the tropics (and low everywhere else); the prediction skill for temperature comes from long-term trend (global land and annual global land-sea trends); and there is no skill with regard to precipitation predictions (for more see Mcleod et al., 2012).

The most recent initiative in this domain, the Coupled Model Intercomparison Project-5[5] (CMIP5) which is a co-ordinated project on climate change experiments including decadal experiments, will further our understanding of decadal predictions.

Under the 7th Framework Programme, the Seasonal-to-decadal climate Prediction for the improvement of European Climate Services[6] (SPECS) project and the North Atlantic Climate Variability (NACLIM) project, aim to continue developing and further existing knowledge and science towards seasonal to decadal predictions in Europe.

3.4. The use of S2D predictions across Europe

S2D predictions can be used to respond to the needs of those sectors whose activities are affected and influenced by climate variability and change by helping to inform decision-making, improving operational activities, or enhancing sales and increasing profitability (Harrison et al., 2008a). However, although the development of S2D science and models in Europe has been expanding in recent years, the practical use of this type of climate information is still an emerging area. In other parts of the world (e.g., United States, Australia) the development of S2D science has a longer history than in Europe and, as a result, the use and application of S2D predictions is more advanced. Nonetheless, efforts have been made in recent years and the use of S2D forecast information across European sectors is now taking its first steps.

[4] PREDICATE stands for Mechanisms and Predictability of Decadal Fluctuations in Atlantic-European Climate.
[5] For more on the CMIP5 initiative go to: http://cmip-pcmdi.llnl.gov/cmip5/).
[6] For more on the SPECS project go to: http://www.specs-fp7.eu/SPECS/Home.html.

Given this context, it is perhaps not surprising that only one example of the practical use of this type of climate information was found in this literature review (see section 3.4.1. below). A small number of publications explored the potential to use and apply S2D predictions in practice and these will be described below (section 3.4.2.).

3.4.1. The use of S2D predictions – The EDF case

Climatic conditions and weather are critical factors for the supply and demand of energy (Boulahya, 2010; Rothstein and Halbig, 2010; Harrison, 2010; Dubus, In Press). The majority of operations and activities are affected by climate (e.g. demand depends on temperature for heating/cooling); whilst production from renewables depend on climatic variables (precipitation, wind, solar radiation) (Dubus, 2010). Not surprisingly then, the economic value of using climate forecasts in the energy sector has been examined by many (e.g. Frei, 2010; Barthelmie et al., 2008; Teisberg et al., 2005).

In Europe, Electricité De France (EDF) has been using weather forecasts for more than 30 years to manage its operations. These include real-time forecasts, monthly-seasonal-annual forecasts, and climate change projections and the main providers are Météo-France and the European Centre for Medium-Range Weather Forecasts (ECMWF) (Dubus, 2013, Dubus, 2012).

As electricity cannot be stored, it is crucial for EDF to ensure a strict balance between energy production and consumption. Its production is based on a range of mechanisms (e.g. nuclear reactors, hydro power units, thermal, wind farms, and solar) all of which involving different processes (e.g. stock management, demand forecasts, forecasts of production from renewables). In addition, all of these processes are affected (to different extents) by weather and climate conditions which raises a number of challenges (e.g. different discrete and continuous variables to be considered, non-linear systems, technical constraints) that need to be considered for operational management of energy production as well as the development of policies and long-term investments (Dubus, 2010).

In France, the demand for power is highly dependent on temperature which normally implies higher demand when temperature decreases and *vice-versa*. For example, during winter months an extra anomaly of -1ºC on average can lead to an increase in energy consumption for heating of approximately 2,300MW (Dubus, 2010). In order to better manage and improve its efficiency and optimisation, EDF has been increasing its use of probabilistic temperature forecasts using the ECMWF Ensemble Prediction System (EPS). These have been used to understand temperature up to 14 days ahead and to forecast power demand and energy prices on the market, as well as to compute financial risk indicators and determine hedging strategies. Currently, there is information available up to 3 weeks ahead particularly during winter months and/or when the observed anomaly is strong.

However, the type of information provided by probabilistic weather and climate forecasts can be difficult to integrate into existing operational models and tools as these are already very complex. Much work is then needed to tailor S2D forecasts so that they can be used more explicitly in application models and not only as qualitative information in decision-making processes.

Another challenge for EDF relates to water resources and their impact in hydro-power capacity. The inter-annual variability in the availability of water resources (linked to precipitation and temperature) can seriously affect the capacity for production as the variability between months can quickly change the conditions for production (e.g. from a rainy winter to a very dry and warm spring) (Dubus, 2010, Dubus, 2012, Dubus, 2013). In addition, the ability from hydro-power to produce energy almost instantly offers the capacity to deal with unexpected peaks in energy consumption (Dubus, 2010).

EDF uses precipitation monthly forecasts to manage its hydro-power generation which requires accurate precipitation forecasts (from tomorrow's forecast up to a year). ECMWF EPS precipitation forecasts are available up to 32 days but their skill is weak. To overcome that limitation, an analogue method is used to provide information on local temperature and precipitation over 43 river basins. A hydrological model is then applied to calculate probabilistic forecasts of streamflow. Overall, the analogue method adds value to the ECMWF monthly forecasts which are skilful over North Atlantic/Europe and improve precipitation (and temperature) forecasts. EDF's hydrological model is further improved with these downscaled forecasts as low flows are well represented whilst very high flows (leading to floods) are not so well represented but are still better captured than reference methods in general. EDF is planning to extend these seasonal forecasts up to 3 to 6 months lead time (Dubus, 2013, Dubus, 2012).

Although progress has been made in the use of probabilistic forecasts some challenges remain including: the need for end-users' to understand probabilistic forecasts; how to integrate and use these forecasts in complex operational tools already in place; how to compute extreme values from 51 model runs; and how to mix 14 days/monthly and longer lead times approaches.

Power demand and hydro-power production are currently the most weather dependant fields across EDF's operations. Progress has been made in the use and application of probabilistic forecasts (i.e. ECMWF EPS) and monthly forecasts are now used in decision-making processes although this information is still not included in tools and application models.

According to EDF's experience in the area, seasonal forecasts are being requested by end-users although these are still not widely used mainly due to their limited understanding of this type of forecasts as well as the lack of tailoring of forecasts to operational needs. To overcome such challenges it is essential to provide training for users as well as a strong collaboration and communication between producers and users to develop products and applications of probabilistic forecasts (Dubus, 2013, Dubus, 2012).

3.4.2. The potential use of S2D predictions across European sectors

As mentioned above, the literature reviews on the use of S2D predictions in Europe did not return many publications suggesting that that this area of research is very much an emergent field in Europe. Nonetheless, a significant amount of literature was collected regarding latest developments in S2D science and modelling as well as some publications on the potential application of this type of information to decision-making processes across Europe with a particular emphasis on the agricultural sector.

Agriculture production is highly dependable on weather conditions such as rainfall, temperature, solar radiation, as well as humidity and wind speed (Doblas-Reyes et al., 2006). As agriculture in Europe is mainly intensive, weather conditions are one of the main uncertainties with regards to crop yield assessment and management (Cantelaube and Terres, 2005). As a result, seasonal forecasts of relevant weather parameters can help inform decisions in terms of production activities and management of agricultural systems (Doblas-Reyes et al., 2006, Cantelaube and Terres, 2005, The World Bank, 2008).

Palmer et al. (2004) describe the potential for using seasonal forecast information in crop simulation models based on the DEMETER project. In agriculture, current crop simulation models estimate crop growth and yield and can be important tools for decision makers. These models, such as the World Food Studies Model (WOFOST) perform crop yield forecasts based on a regression analysis comparing simulated crop indicators and historical yield series for Europe and at national level (Palmer et al., 2004). However, under the current system, when a crop yield forecast is developed the weather conditions leading up to harvest time are unknown and therefore, the provision of seasonal forecasts can be extremely helpful in providing additional information for the crop season. The DEMETER project developed a new method to provide seasonal forecast information to crop simulation models. This method involved running the crop model on each member of the ensemble in order to derive a probability distribution function (PDF) of the crop yield. These PDFs could then be utilised by end users to quantify the benefits and risks of particular weather-related decisions (Palmer et al., 2004, Cantelaube and Terres, 2005).

Others have also examined the potential for using seasonal forecasts from the DEMETER multi-model ensemble system to simulate crop yield modelling and/or predict final yields before harvesting in Europe (see Cantelaube and Terres, 2005; Marletto et al., 2007; and Semenov and Doblas-Reyes, 2007).

In general, agriculture is regarded as one of the main beneficiary of S2D forecasts which could potentially improve overall production and agricultural activities including (The World Bank, 2008, Harrison et al., 2008c):

- Timely sowing, ploughing, irrigation, and harvesting of crops;
- Help timing fertilizer application and pest disease control;
- Mitigate damage from frost, erosion, caused by precipitation and wind as well as drought;
- Optimize storage and transport of agricultural products and enhance pasture and animal production which are affected by rainfall, temperature, and wind.

Improved precipitation forecasts for water resource management could also help forecast river levels by examining runoff (e.g. manage basins where dangerous flows can form quickly and few gauges in place to manage it). The energy sector would also benefit from wind speed monthly forecasts for wind generation as well as monthly precipitation forecasts for hydroelectric power generation. Other sectors have also been recognised as potential users of S2D predictions such as insurance, disaster management, forestry, and health. However, no specific information was provided with regard to their needs in terms of the type of S2D predictions needed to aid their decision-making processes (Harrison et al., 2008c, The World Bank, 2008).

In order to advance the use of S2D predictions in Europe it is fundamental that climate services providers recognise and address a number of issues including: identify users' needs (both real and perceived); identify those decisions that are susceptible to be affected by climate variability; focus on those activities with viable decision options; and develop effective communication and collaboration between users and producers (Harrison et al., 2008b).

In Europe, the use and application of S2D predictions in decision-making processes is still emerging. According to the literature review performed only one case – EDF – was found as an example of an organisation using this type of climate information to inform their management decisions and operational activities. Beyond that, only vague references on the potential to apply S2D predictions to the agricultural sector were found along with a broad overview of how S2D can potentially benefit certain sectors if this type of climate information is to be used more widely. Another potential reason for the lack of literature (particularly grey literature) on the use of S2D climate predictions may be due to competitive economic activities as some organisations and companies may already use S2D but may choose not to communicate this information for strategic reasons.

Given this lack of literature in-depth interviews and survey will be performed across European sectors to fill the gap in our understanding of users' needs with regard to S2D climate predictions.

The following section introduces a few examples of how S2D predictions are being used outside Europe.

3.5. Exploring the use of S2D climate predictions beyond Europe

Higher levels of predictability and skill in seasonal forecasting in other parts of the world such as the tropics have led to greater development, use, and applicability of this type of climate information in recent years. This section introduces some examples of how S2D predictions are being used elsewhere looking at particular sectors. Efforts were made to concentrate on the literature whose main focus was the practical application and use of seasonal predictions in decision-making contexts. Although not comprehensive, this section aims to provide examples of how S2D climate predictions are being used in different countries and in particular sectors as well as how the predictions were developed and with what purpose.

3.5.1. Agriculture

As mentioned previously, the agricultural sector is identified in the literature as one of the main potential beneficiaries from the availability of seasonal forecasts for management practices and decision-making (Dilley, 2000, Meinke and Stone, 2005). In addition, in recent years further advances in the climate science and models focusing on the El Niño Southern Oscillation (ENSO) made it possible to predict events in regions such as Sub-Saharan Africa (SSA) and Northeast Brazil (Vogel and O'Brien, 2003, Lemos et al., 2002).

The Brazilian state of Ceará was the first to adopt seasonal predictions in 1989 to manage drought conditions (Nobre and Lacerda, Undated). The first successful case in terms of applying seasonal forecast information also occurred in this Brazilian state in 1992 when government used forecasts to warn local farmers of an emminent El Niño and provide them with drought-tolerant seeds. Such initiative resulted in a substantial increase of farmers' yield compared to what was expected (Patt et al., 2005). Since then, the Ceará's forecasting agency (i.e. FUNCEME) has been continuously developing seasonal forecasts (based on a range of primary data from institutes in the USA, Europe, and Brazil) to inform government sectors involved in agricultural policy-making and drought relief (Lemos et al., 2002). The primary target of these forecasts are still subsistence farmers who depend on the rainy season for their livelihoods (normally a mix of corn and bean crops as well as some livestock). Every year in December, FUNCEME starts issuing three-month probabilistic forecasts (February to April) expressing the likelihood of the outcome of the rainy season (i.e. total amount of precipitation) being above or below normal (Lemos et al., 2002). However, despite seasonal predictions being available to end-users (i.e. local rainfed farmers) different factors have limited the use of seasonal forecasts in Ceará. Although the governemnt's initiative in 1992 of distributing drought-tolerant seeds was a success, the program only made available high quality seeds when planting conditions were adequate which was based on seasonal climate predictions. This situation created tensions and resentment amongst farmers who find themselves excluded from the decision-making process of when to plant (Lemos et al., 2002). Since then, government has adjusted its policies and seeds are now made available independently of the 'apropriate conditions' being in place or not. Other factors limiting the use of seasonal forecasts included unrealistic expectations and a negative perception by the farmers in terms of the forecasts provided (e.g. 'innacuracy' of the forecast due to spatial and temporal differences across the region); as well as the existing lack of resources and socio-economic conditions amongst farmers which limits their capacity to respond and adapt to climatic variability independently of the quality of the seasonal forecasts.

The potential for using seasonal forecasts to inform farmers' decisions on type of crops, planting dates, and other measures to help them manage their activities is widely recognised in the literature, especially that focusing on least developed countries (see e.g. IDRC, 2010; Patt, 2007). The African continent, and in particular the SSA, has the longest history of Regional Climate Outlook Forums[7] (RCOFs). RCOFs were set up by the World Meteorological Organization and aimed to bring National Meteorological Services and users together in order to develop, discuss, and disseminate potential applications of a rainfall seasonal forecast (and sometimes other climatic variables) (Hansen et al., 2011). These started in 1997 and focused primarily in the agricultural sector in least developed countries (Hansen et al., 2011, Patt et al., 2007). Since then, a number of studies have looked at how seasonal forecasts have been adopted and used (or not) by African farmers and the main obstacles and limitations in the uptake of this type of climate information (see e.g. Hudson and Vogel, 2003; Patt et al., 2005; Archer et al., 2007). Lack of resources (e.g. access to financing and land) represented one of the main challenges faced by farmers as well as other factors such as access and information content of the forecasts provided (e.g. forecasts available too late, not provided in local languages, not sufficiently accurate) (Hansen et al., 2011).

Much of the literature on the application of S2D predictions to the agricultural sector points towards the importance of developing this type of climate information in a context of

[7] Regional Climate Outlook Forums (RCOFs) were set up by the World Meteorological Organization with support from other international climate centres (e.g. International Research Institute for Climate Research – IRI –, UK Met Office, Météo-France). Currently there are 13 RCOFs across the world. For more go to: http://www.wmo.int/pages/prog/wcp/wcasp/clips/outlooks/climate_forecasts.html

collaboration and trust between the users and the producers of such forecasts. In their study, Crane et al. (2010) examined the response by farmers in the southeastern United States to seasonal climate forecasts. Their findings stressed 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 realised as a risk management tool. In addition, the need for producers to adapt and adjust their practices was also emphasised in order to allow a more intricate collaboration between users and producers (so called 'co-production' or 'end-to-end' approaches) with the ultimate purpose of translating such knowledge into 'usable science' (Crane et al., 2010).

Marshall and Ash (2011) examine the reluctance of Australian graziers to adopt and use seasonal forecasts. Their study showed that the factors such as accuray, lead time, and appropriate spatiala nd temporal scale of seasonal forecasts were not regarded as the main factors potentially influencing the uptake of this new technology by graziers (although it could increase their usability). Instead, other considerations such as potential economic and environmental benefits were perceived as more important factors in the adoption of seasonal forecasts if they were to become available.

3.5.2. Health

Weather and climate affect human health and are linked to many human diseases, from cardiovascular mortality from heatwaves to the transmission of infectious diseases (Patz et al., 2005). In fact, many existing mosquito-borne diseases such as malaria and dengue fever that kill thousands every year, are related to climate variability (WHO and WMO, 2012). Malaria is one of the most important climate-sensitivie diseases in the world and examples of the relationship between the transmission and spread of malaria and the interannual climate variability associated to ENSO in Africa have been reported in several studies (see e.g. Zhou et al., 2004; Hay et al., 2002; Thomson et al., 2006).

Since the 1990s, climate information has been explored by the World Health Organisation (WHO) in its attempt to control and prevent malaria (Patt et al., 2007). A Malaria Early Warning and Response System[8] (MEWS) was developed in 1998 under the auspices of the WHO as a coordinated approach to tackle the disease (World Climate Programme, 2007). The MEWS include seasonal forecasts as well as other components (e.g. climate monitoring, vulnerability analysis, and planning response) (for more see Roll Back Malaria Cabinet Project, 2001). The first operational MEWS in Southern Africa focused on Bostwana, where malaria is considered one of the main public health issues in the country. In Botswana, as in other parts of the Southern Africa region, interannual variability

[8] The MEWS was developed by the Roll Back Malaria partnership, the IRI, and health ministries in Africa. For more see World Climate Programme (2007).

associated to ENSO influences climate and is a good basis for predicting malaria incidence (Thomson et al., 2006). Botswana's early warning system was developed based on DEMETER ensemble forecast system (see section 3 above) which provides forecasts of seasonal precipitation and risk of malaria months ahead of the peak of malaria season (Thomson et al., 2006, Palmer et al., 2004). As a result, decision-makers in Bostwana now have longer lead times on the likely occurrence of malaria and consequently, more time to plan, prepare, and manage the risk of malaria (WHO and WMO, 2012).

Climate variability also affects other regions of the world (see e.g. WHO and WMO, 2012). For example, climate variability will increase the potential for tropical diseases such as malaria as well as other infectious diseases to spread across the south of Europe (Semenza and Menne, 2009).

The relationship between human health and climate variability goes beyond infectious diseases and can also be associated with other extreme events and environmental issues such as floods, droughts, and heat waves (WHO and WMO, 2012). For instance, the 2003 heat wave in Europe, which killed more than 22,000 people in a 2-week period, is a good example of the impact that climate variability (in this case an increase in temperature above normal conditions) can have on human health (Patz et al., 2005).

3.5.3. Water resources

In a water management context, seasonal forecasts can be used to facilitate and improve operational performance (e.g. planning of irrigation systems, ground water pumping capacity, and surface water storage) as well as contribute towards better emergency flood management and relief operations. As a result, improved seasonal predictions can potentially contribute to decision-making on issues of water security, river basin management, and facility development (Harrison et al., 2008c).

Plummer et al. (2009) describe the development of a seasonal water availability prediction service in Australia which was introduced by the government to address issues of water availability and drought affecting the country in recent years. Although the Bureau of Meteorology (BoM) has operated a seasonal climate prediction service since 1989 its primary concern has been temperature and rainfall. As a result, information on water availability was not provided despite the value that streamflow predictions could have for water allocation outlooks, planning and managing water use and drought, cropping strategies, and to inform water markets. This operational seasonal water availability service was developed by the BoM based on various components including the dynamical climate model Predictive Ocean Atmosphere Model for Australia 3 (POAMA-3); a coupled climate and earth system simulator (ACCESS) which is based on a seamless prediction approach; historical climate data; statistical downscaling models; and an hydrological model (for more on this project see Plummer et al. 2009). Most importantly, this service was tailored to user needs involving them in the review of forecast performance in order to ensure that the information needed to inform their decision-making is being provided. The seasonal streamflow forecast service is now operational[9] although improvements to this service will keep occurring as new information, models, and science develop. Amongst other features, the service aims to release new 3-month seasonal forecast at the beginning of each month; respond to requests for information within 2 working days; re-validate forecast models every year with the latest available data (Australian Government, Undated).

A number of forecast sites were selected based on user needs, availability of data and forecasts skill. These sites include water storage and irrigation areas in different parts of Australia which are used for various purposes (e.g. irrigation, domestic use, urban water supply, hydro-electric power). These sites are managed by organisations which provide information and forecast verification (Australian Government, Undated).

This section has reviewed several longer-standing initiatives involving the use of seasonal climate predictions outside of Europe. These experiences contain potentially important lessons for the further development of such approaches in Europe.

3.6. Conclusions

The development of seasonal climate predictions has been evolving in recent years although skill and predictability differ across different regions. A recent endeavour, decadal predictions are now emerging although a number of challenges remain regarding the development of the science. In Europe, S2D climate predictions are still taking the first steps particularly regarding the practical use of this climate information to inform decision-making. In fact, the only example found in the literature of the use of S2D on the ground was the case of EDF in France. Although encouraging, the adoption and proliferation of seasonal predictions by other sectors and organisations is still far from reality. In other regions where seasonal forecasts have a longer history, past experiences have led users, in some instances, to doubt the credibility, saliency, and legitimacy of this type of climate information. Irrelevant and non-taylored information, mis-communication, and mis-use of seasonal climate predictions are some of the factors that have led to disbelief in their usefulness.

Such experiences and legacies should be considered in the emerging context of S2D climate predictions in Europe to ensure similar errors are not repeated. Ultimately, overcoming such challenges will require a more efficient interaction and collaboration between scientists and decision-makers, "(...) with the end-user driving the skill assessment

[9] For more on seasonal streamflow forecasts developed go to http://www.bom.gov.au/water/ssf/index.shtml.

of the entire end-to-end forecasting system through real world forecast applications" (Coelho and Costa, 2010, p. 1).

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Appendix 1

This appendix provides full details of how the two literature reviews were conducted in this study.

- **Peer-reviewed literature**

The search for peer-reviewed published literature was based on the approach applied by Ford et al. (2011)The search was conducted in 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.

Level 1 Season* **OR** Decad*
Plus one of the following
Level 2 Predict* **OR** Forecast* **OR** Climat* **OR** Variab*
Plus one of the following
Level 3 Use* **OR** Using **OR** Stakeholder* **OR** Appl* **OR** Data* **OR** Decision*
Plus one of the following
Level 4 Europ*

This search involved 48 different combinations of the keywords selected. A 1st stage filtering process was applied to these results, 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 1 below). Based on the results from this filtering there are no peer-review publications that examine the practical use of S2D predictions 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.

- **Grey literature**

Given the novelty of S2D predictions another literature review was also performed focusing on grey (or "gray") 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 (Petticrew and Roberts, 2008, Hopewell et al., 2007). 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[10]. As a result, it was decided to use combinations of the keywords used in the peer-reviewed literature but without using wildcards. The keywords used are listed below.

Level 1 Seasonal **OR** Decadal
Plus one of the following
Level 2 Prediction **OR** Forecast **OR** Climate **OR** Variability
Plus one of the following
Level 3 User **OR** Stakeholder **OR** Application **OR** Data **OR** Decision
Plus one of the following
Level 4 Europe

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 1 below).

The publications identified in the literature reviews as relevant to this study were then brought together (both peer-reviewed and grey literature) and considered in conjunction whilst preparing this report.

Table 1 below lists the inclusion and exclusion criteria used to filter through the peer-reviewed and grey literature.

[10] Wildcards can be used in a search query to represent unknown characters e.g. the asterisk (*) represents any group of characters, including no character.

Table 1 - Inclusion and exclusion criteria for the literature reviews performed.

	Inclusion criteria	**Exclusion criteria**
1st stage – keyword search		
Peer-review literature	Language – English; Indexed to the ISI Web of Knowledge; Published literature (articles, books);	Non-English; Not indexed in the ISI Web of Knowledge; Letters, corrections, conference proceedings, editorial material; Literature not related to this study area
Grey literature	Language – English; Publications in Google and Google Scholar	Non-English; Not in search engines/non-relevant publications;
2nd stage – Title and abstract review		
Peer-review and grey literature	Literature on the practical use of S2D in Europe; Literature focused on the potential to use S2D in Europe; Literature on the development of skill and S2D models in Europe.	Non-related S2D literature (e.g. literature on climate change impacts, vulnerability studies)

4. Estimated Effort for this Deliverable

Total budgeted effort for this deliverable (from DOW) was 9.5 person months.

	Person-Months	**Person-Months (in-kind)**	**Period Covered**
14	3.1		6 November – 28 February
Other	1.56		
Total	4.66		