Providing Seasonal-to-Interannual Climate Information for Risk Management and Decision Making

White Paper for WCC3

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Lisa Goddard[1], Youcef Aitchellouche[2], Walter Baethgen[1],
Michael Dettinger[3], Richard Graham[4], Peter Hayman[5],
Mohammed Kadi[6], Rodney Martínez[7], Holger Meinke[8]

Additional Contributions: Esther Conrad[1]

[1]International Research Institute for Climate and Society, USA

[2]International Federation of Red Cross and Red Crescent, Senegal

[3]United States Geological Survey, USA

[4]Met Office, UK

[5]Primary Industries & Resources of S. Aus/S. Aus. Res. & Dev. Inst., Australia

[6]ACMAD, Niger

[7] International Research Center on El Niño (CIIFEN), Ecuador

[8]Wageningen University and Research Centre, The Netherlands

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Conclusions:

- The importance and visibility of climate information systems (CIS) has risen dramatically in the last few years, a trend that is likely to continue. CIS provide information that is relevant for climate-related risk management and decision-making. Climate forecasts are important components of CIS, but the utility of CIS goes much further than just forecasting.
- The awareness of seasonal-to-interannual (SI) climate forecasts has also increased considerably since the late 1990s, due in large part to Regional Climate Outlook Forums (RCOFs) and intense media coverage of the 1997/98 El Niño event. However, much more effort must be invested in demonstrating use and increasing utility of these forecasts.
- Increased use and benefit of SI forecasts will occur only with appropriate interpretation or tailoring of climate predictions, particularly in the case of dynamical model predictions. Much work is required to further develop and link SI prediction models with application models (e.g. crop yield prediction)
- Effective CIS must involve all actors and not just the national Meteorological and Hydrological Services (NMHSs).
- A better climate service for decision making must ensure that NMHSs and local climate services be able to respond to local users, often by providing locally relevant information, and those services must be supported even as local need may vary from year to year.
- A culture change is required to build a "chain of communication" that realises the benefits of advances in SI climate predictions to society. The chain must target decision makers responsible for national infrastructures and welfare, and should include also climate intermediaries and NMHSs, sectoral scientists, government, business sectors, media, and others.
- Involving the relevant sectoral scientists and decision makers as collaborating partners very early in the process is critical to ensure relevance, trust, and ownership of climate-related decision systems.
- Using CIS that focus on managing climate variability is an important means of preparing for the near future of climate change.

Recommendations

- Advocate for wider consideration of climate information in climate-impacted decision making and risk management.
- Promote training on communication of climate information for NMHSs and stakeholders; encourage governments to invest in diverse dissemination structures.
- Encourage the implementation of more demonstrations through pilot projects.
- Request more government support for the participation of NMHSs and stakeholders in RCOFs.

- Promote mechanisms for advances in climate science to support existing networks/responsibilities by enhancing understanding and technical capacity for better decision systems and climate risk management
- GPCs, RCCs and NMHSs should maintain and manage a network of key contacts through science collaboration, staff exchanges, regular visits/emails/phones/local workshops/videoconferences.
- Establish and maintain regular tailored climate bulletins to meet specific user requirements
- Document and disseminate the pitfalls, benefits and success stories of climate products at national, regional and global levels.
- Encourage research and technology transfer of methods to tailor climate predictions/projections
- Encourage open access to data from both observations and dynamical models, for present and past conditions.
- Promote investments at international and national levels to improve intermediary structures for climate information
- On-going investments must be placed in continuing to improve dynamical climate systems, including models, data assimilation systems, and ensemble tehniques.

1. Introduction

The history of physically-based seasonal climate forecasts is relatively short and strongly linked to the ability to predict sea surface temperatures in the El Niño region. The first physically-based model forecast of equatorial Pacific Ocean temperatures was produced only in the mid-1980s (Cane et al. 1986). The growing ability to predict El Niño led to a cascade of efforts for developing and improving the seasonal climate forecasts and attempting to make those useful to society. El Niño is the overall dominant influence in regional climate variability worldwide, though other modes of sea-surface temperature variability can be more important in some regions (see e.g. Folland et al., 1991).

In developing a white paper for Understanding and Predicting Seasonal to Interannual Climate Variability from a "user" perspective or from a "producer" perspective, what is immediately clear is how blurred the boundary between these communities has become over the past decade. A "user" may be a decision maker acting individually or as part of a collective. A "user" may also be a translator of information regarding climate variability or its associated impacts such that the information can be used by decision makers. Similarly, a "producer" may be the climate scientist running a dynamical model of the climate on a large computer. A "producer" may be the sectoral scientist that takes the information from the climate model and feeds it through a hydrology model or crop model. Or, the "producer" may be that same translator referred to above that modifies the initial forecast information into a more usable format for the policy or decision maker. In some places the term "producer" even mean "producer of agricultural products" (i.e. a farmer), highlighting the confusion this terminology can cause.

The blurring of boundaries between these communities began when it became clear that effective climate risk management could not be accomplished in isolated communities. It has been an important realization, but much work remains. This white paper is written from the perspective of "users", but not those that have been traditionally targeted as "end users". The "users" voice here is from the translators: those that build on the scientific advances in climate modeling and diagnostics, those that design decision systems for resource management, and those that are participating in the conversation between climate risk management and the prospects of seasonal prediction. The following discussion concerns the advances in providing climate information that are necessary for effective climate risk management at seasonal-to-interannual timescales. These efforts constitute the wealth of research, communication and application that has been attempting to 'bridge the gap' between the traditional 'provider' and 'user' communities.

The paper begins with the historical evolution of developing and using climate information for management and decisions. The discussion then progresses through the current infrastructure of accessing climate forecast information, the gaps between the operational provision of forecasts and their use, considerations for increasing the value of forecast information, some of the lessons learned, and finally we conclude with our view of the way forward. Climate information refers in this paper to both current and historical observations-based data and predictions of future climate conditions, with particular focus on seasonal-to-interannual variations. Most of the attention here will be upon the users' perspective on forecasts, but those forecasts become valuable primarily in context of past climate variations and, where known, the past performances of the forecasts. Also, although this paper focuses on seasonal-to-interannual (SI) climate variability, the context set by the background climate, which may be slowly varying, is well recognized. The successful future of climate risk and resource management depends critically on health of the entire chain of information that the international community is working so hard to forge.

2. The Historical Situation

Until the last decade, plans and decisions that needed climate information often followed an approach based on the long term means of relevant climate variables. For example, maize in a given region was sown in a certain date because the combination of rainfall and temperatures in the following 4-6 months for that region was, on average, the most favorable for the crop growth and development. Plans for distributing water in multipurpose reservoirs (hydroelectricity, irrigation, human consumption) were established with lead times of several months, based on the mean values of the precipitation for the entire year (and in some cases based also on the current situation of for example, snow pack). Health institutions based their action plans for infectious disease outbreaks in a given area considering the long term average temperatures and rainfall of that area. This approach to management is not a general truth, however. It is not uncommon for farmers to use environmental observables to guide their actions. Soil moisture availability, for example, might suggest when to plant what. In particular, resource poor farmers in semi-arid regions are excellent, intuitive risk managers. Of course they are also conservative, they don’t plan for the average season, the plan for the poor season (low plant densities, no or low inputs etc), so they ensure their survival, but never manage to make a real profit, because the miss out in the good years.

Interestingly, the probability that an entire year behaves as an “average” year (e.g., 12 months of “average” rainfall) is virtually zero. Moreover, by definition, the probability that the rainfall of two subsequent trimesters falls in the central (“normal”) tercile, is less than 10%. Still, and up to the 1990’s, planning and decisions in many climate-dependent activities could only be based on these very unlikely “average” or “normal” years.

Where mean conditions have not been used as the default climate “forecast”, resources and risk managers have relied, and often continue to rely, heavily on observed conditions at the time that decisions need to be made for the basis of their forecasts of future eventualities. For example, it has been (and remains) common for managers to base decisions and forecasts of future water supplies solely on observed snowpack and soil moisture for all but the shortest term, multiday problems (Beller-Simms et al., 2008). Observed conditions on the ground have been more reliable and more immediately relevant to the decisions to be made than other climate-science resources for many applications.

Efforts to make these improvements have been prompted, in part, by a growing understanding of the effects of global-scale climate phenomena like El Nino-Southern Oscillation (ENSO) on the climates, resources, and hazards of many regions and a growing expectation that improvements in climate forecasts may provide a basis for decision making that is not currently being exploited. Generally speaking, climate forecasts are forecasts of those variations of the climate system that reflect predictable responses to predictable changes in slowly varying boundary conditions like sea-surface temperatures and radiative imbalances in the Earth's energy budget. Not all possible sources of climate-forecast skill have been identified or exploited, but boundary-condition contributors may include a variety of large-scale air-sea connections (e.g., Redmond and Koch 1991; Mantua et al., 1997; Enfield and Cid-Serrano, 2006; Hoerling and Kumar, 2003), snow and sea-ice patterns (e.g., Cohen and Entekhabi, 1999; Clark and Serreze, 2000), and soil moisture and vegetation (e.g., Koster and Suarez, 2000). Long-term radiative imbalances associated with human-caused emissions of greenhouse gases into the atmosphere have been a focus of much attention on even longer time scales (IPCC, 2007).

Within the past decade, however, climate scientists have begun to identify potential improvements in long-lead, seasons to years ahead climate forecasts (e.g., Krishnamurti et al. 2000; Goddard and Dilley, 2005; Zheng et al. 2006) and to link them with resource models (e.g., Kim et al., 2000; Kyriakidis et al. 2001) or statistical distributions of management-relevant parameters (e.g., Dettinger et al., 1999; Sankarasubramanian and Lall, 2003) to improve the immediacy and, in some cases, the reliability of the climate forecasts for use in management decisions. Consequently, research institutes such as the International Research Institute for Climate and Society (IRI), invested huge efforts to provide synthesized climate forecasts based on the inputs from the international modeling community and started supplying them to climate information providers (National Weather Services, Regional Climate Centers, Specialized Meteorological Centers) and to key socioeconomic sectors (i.e., agriculture, health, water resources, disaster prevention/reduction, etc.). The premise of these efforts was that supplying the best possible seasonal forecasts would immediately result in better decisions and more effective planning activities in those sectors. Efforts were thus concentrated in investing increased efforts in the dynamical models and statistical methods that resulted in forecasts with better skill.

The initial reaction in the different sectoral communities was extremely optimistic: the new seasonal climate forecasts were viewed as tools that would assist these communities to cope better with the immense challenges posed by climate variability on their activities. Planning and decisions in activities that depend on, or are affected by climate would now be better informed.

However, this initial optimistic environment was shortly followed by frustration in both, the climate science community and the socioeconomic sectors, since expectations from both groups were not fulfilled. Excellent achievements were obtained in the climate science community for supplying seasonal forecasts that were continuously improving. Many studies demonstrated the "potential value" of incorporating this information into the decision-making of different sectors (e.g., Hansen, 2002; Cabrera et al., 2007, McIntosh et al., 2007; Hansen et al, 2009; Hammer et al., 2001, Thomson et al, 2006). However, there was little or no evidence that the generated information was effectively being embedded in the policies, planning or decision-making within the sectors. On the other hand, the socioeconomic sectors started receiving vast amounts of information resulting from the seasonal forecasts but in most cases could not find ways to incorporate it in a useful manner for their routine activities.

3. The Current Situation

3.1 Forecast Producers and Their Products

Producers of seasonal forecasts may be broadly categorized according to the geographical coverage addressed. Forecasts with global coverage often require use of dynamical prediction models[1] and producers are limited to centres with capacity for numerical seasonal climate prediction (typically some National Meteorological Services (NMSs) and research centres). Forecasts with competitive skill may also be produced with relatively inexpensive statistical models for some regions, and such models have been developed by a host of producers from individual researchers to NMSs for their country or region. Finally there are centres/activities that synthesize global and regional forecasts from the various local and international sources, and from both dynamical and statistical methods, into consolidated outlooks for a region – specifically the Regional Climate Centres (RCCs) and Regional Climate Outlook Forums (RCOFs – Ogallo et al., 2008). This latter ‘consolidation’ activity also takes place on a national level at some NMSs (e.g. Graham et al, 2006).

a) Forecasts with global coverage

In recent years there has been substantial progress in coordinating and disseminating the output from centers producing forecasts with global coverage using dynamical prediction methods. The aim has been to increase the accessibility and usabilty of the information to NMSs, RCCs and RCOFs, and to make available the benefits of multi-model ensemble combinations (Hagedorn et al., 2005). To coordinate convergence among the forecast centers WMO have defined standards in real-time forecast output and hindcast validation. Centres adhering to the criteria may apply for designation as WMO Global Producing Centres (GPCs) of Long-range Forecasts. Eleven such GPCs have now been designated. A significant further boost to the coordination of GPC output occurred with WMO designation, in 2009, of a Lead Centre for Long-range Forecast Multi-model Ensembles (LC-LRFMME), jointly hosted by the Korean Meteorological Agency (KMA) and the NOAA National Centers for Environmental Prediction (NCEP). The LC-LRFMME has a range of functions, with two central themes:

- to provide a single portal from which users (RCCs, RCOFs, NMSs and GPCs) can access GPC forecast output in common formats;
- to promote research into, and to generate and provide multi-model products from the GPC forecasts.

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[1] An exception would be predictions based on ENSO teleconnections with skill at the global scale (e.g. Stone et al, 1996).

The single portal and uniform presentation introduced by the LC-LRFMME greatly enhances the accessibility and usability of the GPC products, and provides RCCs/RCOFs/NMSs with validated model output from a range of models for use, together with other inputs, in generating a consolidated forecast for their region/country.

In line with WMO criteria, prediction products typically take the form of anomalies in 3-month-mean quantities with a range of 6 months to 1 year ahead. Predicted variables made available include 2m temperature, precipitation, sea surface temperature (SST), mean sea level pressure, 850 hPa temperature and 500 hPa temperature. Anomalies are usually expressed both deterministically, using the mean of the prediction ensemble, and in terms of probabilities for categories (typically tercile categories of the model climatology), based on the ensemble distribution. Some centers also produce and make available forecasts of "extremes", but in general these 'extreme' products not well developed. In these cases extremes forecasts are typically presented as probabilities for outer quintile categories, rather than risk of floods, drought, heat waves or cold spells. Examples of forecast products presently available from producing centres may be viewed at http://www.wmo.int/pages/prog/wcp/wcasp/clips/producers_forecasts.html .

A key question faced in creating or using a consolidated forecast from various prediction inputs is – what are the relative skills of the inputs and of the final product? For this reason GPC accreditation requires provision of hindcast validation according to a WMO defined set of diagnostics and procedures, the Standard Verifications System for Long-range Forecasts (SVSLRF). Such diagnostics are typically available on the websites of the producing centers. In addition, SVSLRF diagnostics from designated GPCs are available in common format on the WMO Lead Centre for the SVSLRF (co-hosted by the Australian Bureau of Meteorology and the Meteorological Service of Canada - http://www.bom.gov.au/wmo/lrfvs/). The SVSLRF information provides a basis for making qualitative judgments on appropriate weights to be given to the GPC products. However, further international cooperation is required to make the validation information more accessible and useable. For example, adherence to a common hindcast period to be used by all GPCs for generating validation diagnostics would be ideal. It must be acknowledged however that – given the current embryonic state of seasonal forecast systems at many centers – such convergence may take sometime to achieve.

The importance of the current role of expert judgment in interpreting both the model predictions and the hindcast skill evaluations cannot be overestimated. Models are not perfect and often require correction, or at least interpretation. Although success with ENSO prediction is encouraging, it is well known that models do not currently represent well many other important modes of intraseasonal-to-interannual variability (e.g. the Madden Julian Oscillation, the North Atlantic Oscillation, the Indian monsoon), and such shortcomings need to be accounted for by forecasters. Hindcast skill assessments also require careful interpretation. Although very useful, most hindcast evaluations represent 'average' skill assessed over many years – and as such they provide little information on the credibility of predicted signals in the context of the unique SST forcing in any particular year (for example when ENSO forcing is strong, Goddard and Dilley, 2005).

The model predictions provided are intended for use by climate professionals (e.g. NMSs, RCOFs, RCCs), to help in construction of consolidated forecasts for users. Although the model predictions are often freely available on the internet, at least in terms of visualized products, data from the current and past forecasts are typically not freely available, or easily accessible. The free availability of maps leads to issues concerning the potential for misinterpretation or confusion in cases when some model predictions conflict with an official consolidated forecast. However, the lack of easily available data reduces the actual use of many of these predictions.

b) Forecasts with regional coverage

Examples of consolidated regional forecasts are those of the Regional Climate Outlook Forums (RCOFs) currently held in Africa and Latin America for some regions with spatial and temporal coherency in rainfall seasonality (Ogallo et al., 2008). RCOFs have have not played a big role in South and Southeast Asia. The Forums are not permanent entities, but are convened ahead of the main rainy seasons (e.g. in May for West Africa, February (August) for the East African short- (long-) rains seasons). Key objectives of the forums are development of a consensus prediction for the region and dissemination of the forecast to application sectors including agriculture, water resources, energy, health and media. The Forums also provide unique opportunities to form alliances between forecast users and producers, for users to feed back requirements to the producers, and also for institutional capacity building. The consensus forecast provides a broad-scale outlook for the region, which may be further elaborated to national scales (with more targeted dissemination) by the NMSs of the regions. To deal with geographical variations in the forecast signals the region is divided into zones, and each zone assigned numerical probabilities for tercile categories of rainfall (see Fig. 1). Analysis of 10 years of real-time consensus seasonal predictions from regional forums convened in Africa shows that, despite some shortcomings, the forecasts have evidence of skill (Chidzambwa and Mason, 2008).

The procedure used to generate the consensus involves a blending of all available evidence, which may include: examination of the principal mode or modes of climate forcing likely to operate over the forecast period, and influence the region (e.g. the status of ENSO, and/or regionally relevant SST anomalies); the prediction skill of the climate models used; the current predictions from dynamical and empirical models. Typically, statistical predictions for individual countries – based on historical links with global SST patterns - form a key component in the consensus. The forecasts are blended where discrepancies occur at national boundaries and may be modified in light of interpretation from regional experts. As is often found with consensus methods, the resulting ‘blended’ forecasts, tend to overestimate probabilities for the average category reducing usefulness for applications (see e.g Chidzambwa and Mason 2008).

Input from predictions from the dynamical modeling centres also play an important role, and standardization of this input, through the WMO GPC criteria, has assisted in its use. Standardised GPC products from the LC-LRFMME were first introduced to the RCOF process at the 23rd Greater Horn of Africa Climate Outlook Forum (GHACOF 23, Mombasa, Kenya, 2-4 March 2009), coordinated by IGAD Climate Prediction and Applications Centre (ICPAC), and are being introduced as key prediction tools available to all RCOFs.

A fully satisfactory objective procedure for optimal blending of all the available information has yet to be agreed upon within the RCOFs – and this was one of the development needs identified at the RCOF Review 2008 (Arusha, Tanzania, November 2008 - WMO report and position papers in preparation). Currently dynamical model predictions are used to inform qualitative adjustments to the consensus forecast. However, objective use of the dynamical forecasts has been initiated at the West Africa Forum (PRESAO) as part of an initiative known as PRESAO – Second Generation (SG). PRESAO is coordinated by the African Centre for Meteorological Applications for Development (ACMAD). Using model hindcasts and observational records for each country, dynamical model predictions are calibrated for each country in the region (see section on tool boxes). The calibration process uses similar statistical tools used in developing the statistical prediction models (the IRI Climate Prediction Tool (CPT) is one of the software packages used) – and skill scores for statistical methods and different GPC models can be generated for each country. This allows the RCOF users to gain an appreciation of the relative strengths and weaknesses of statistical and dynamical predictions. The resulting national forecasts should contain a degree of common modulation consistent with large-scale signals, and thus should require less ad hoc blending when forming the regional consensus. Similarly, in Western South America CIIFEN has organized training activities to improve the capabilities of the Met Services to use statistical and dynamic methods to produce downscaled seasonal forecasts at both regional and national levels. With less need for manual blending, the regional forecasts require less deliberation at the RCOF meeting. For example, using more objective calibration and combination techniques, CIIFEN has established institutional agreements with the Met Services of six countries of the region to produce a unified seasonal climate forecast that is updated every month.

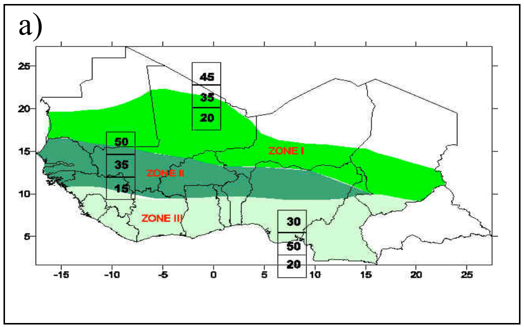

Fig. 1a) PRESAO 11 RCOF consensus forecast – issued 21 May 2008. Vertically stacked numbers show predicted probabilities (top to bottom) of above-average, average, and below-average rainfall.

3.2 Forecast Applications

The types of seasonal forecast applications products thus far developed are quite varied and depend, amongst other things, on the available prediction skill and the target audience. A full review of the status of forecast applications is beyond the scope of this paper. In the following sections some example applications – typical of current capabilities - are illustrated.

a) General applications: Advisory statements

An important and widespread application is provision of advice on seasonal prospects to, for example, government, NGOs, public and media. Such advice often takes the form of written statements (Fig. 2). Because of current imperfections in predictions, such applications are ideally generated using consolidated forecast products developed through expert consensus. However, given the wide availability of seasonal forecasts on the internet, it is likely that statements may in some cases be constructed through relatively inexpert interpretation of limited inputs (e.g. interpretation of output from a single model, which may have limited skill). This situation needs to be addressed through continued education, and through better channeling of forecast information through a global climate service structure (e.g. GPCs to RCCs/RCOFs to NMHSs to users).

1. The probability of rainfall deficit is very low in the sub region. The Probability of rainfall less than Normal equal to 0.20—0.15 and 0.20 in zone I, II and III respectively,
2. A high probability of rainfall higher than normal in zone I and II, and near normal rainfall in zone III (Probability of 0,45—0,50 and 0.50 respectively),
3. In this regards, it is recommended to strengthen the EWS (Early Warning Systems) in place for community protection (flooding risks), plants protection (risks from locust invasion) and public health (likely severe malaria epidemics and other water borne diseases). 05/08

Fig. 2 Statements/advice issued by ACMAD on 21 May 2008 regarding prospects for the July-September 2008 West Africa season. The statements were based on the consensus forecast product shown in Fig. 1. Note: as a postscript heavy rain and flooding in July caused damage and some fatalities in Benin, Burkina Faso, Chad, Gambia Ivory Coast, Niger, Nigeria and Togo.

Forecast statements are typically delivered to the users in a variety of ways, and delivery may cascade through different levels of producer and user. In the case of RCOFs the first opportunity for communication is at the Forum itself. The rainfall forecast might be used, with other inputs, to develop regional basin streamflow predictions and food security assessments, which are then cascaded to relevant users. Disaster Management applications were prominent following the 2008 PRESAO-11 Forum (Figs. 1 and 2 above). Representatives of the International Federation of Red Cross and Red Crescent (IFRC) participated in the Forum, forming a partnership between forecast producer that leads to good understanding of the forecast and its implications. On this basis IFRC acted in a number of ways including: launch of an appeal to raise funds for flood disaster management; emergency stock pre-positioning (items such as drinking water and sanitation equipment); advance securement of visas for staff to enter countries at risk; initiation of community dialogue to increase preparedness to act on output from Early Warning Systems. In their response to the 2008 PRESAO forecast, IFRC adopted a 'no-regrets' approach, in which the probabilities for above-average rainfall were considered sufficient to assume a deterministic forecast of above average. This was a pioneering action of IFRC to prepare for climate impacts rather than wait and respond to an existing impact. It should be noted that considerable capacity building through education or training of IFRC staff on causes of climate variability, the interpretation of probabilistic forecasts and the opportunities and limitations of those forecasts, in addition to IFRC's careful monitoring of the observed conditions, took place prior to their proactive response to the RCOF product. However, it would be interesting to speculate what the agency's response would be to the next forecast, if the high probability event (floods) had not occurred. Credibility is a rather fickle commodity, even when probabilities are specified correctly.

The 'cascade' of forecast information through different levels of producers and users represents an important complement to dissemination of the forecast through media channels. The media play an important role in disseminating top level messages through a wide variety of channels, but cannot be expected to offer advice or enter into dialogue. Moreover, there is still much work to do in enhancing media understanding of the probability forecasts, this is discussed further in Sections 3 & 5.

b) Applications tailored to specific sectors

Developing tailored seasonal forecast products that are useful enough and specific enough to find real-world applications requires persistent collaborations to co-evolve the uses and confidence in the climate products. The direct use of dynamical forecasts, unfiltered by human and statistical corrections, is not yet realistic with the current state of the art models. Some examples illustrating the current state of play are provided below together with references offering more details.

i) Water resource management examples

Predictions of reservoir inflow represent something of an opportunity for applications, being less sensitive, compared to many other applications, to some types of seasonal prediction errors. For large catchments (e.g. covering several model gridpoints) sensitivity to modest position errors in predicted rainfall anomalies is less critical than, for example, in some agricultural applications where local detail may be required. If the predictand of interest is total inflow over a long period (e.g. a 4 or 5 month rainfall season), the sensitivity to modest temporal errors is also reduced. In addition, for older reservoirs, long historical records of inflow are often available allowing relationships between predicted rainfall and observed inflow to be developed and used to make real-time predictions of inflow.

A notable example of the use of model-based climate predictions in reservoir management has been documented by Georgakakos et al. (2005), for the northern California region. The Integrated Forecast and Reservoir Management (INFORM) project aims to directly integrate ensemble forecasts from the US National Centers for Environmental Prediction Global Forecast System and Climate Forecast System into decision making tools already used by Federal and State managers of some of the regions largest reservoirs. The same team has developed similar tools and evaluations on the Nile

(Georgakakos 2006) and in Panama (Graham et al. 2007), in service of a number of very different decision making environments.

In the Philippines, efforts by IRI in partnership with the National Water Resources Board (NWRB) and the national meteorological service (PAGASA) have led to the integration of seasonal climate forecasts of reservoir inflow into water allocations model for the Angat Reservoir. Angat provides 97% of the water supply for metro Manila, irrigation water for rice, and hydropower. Seasonal forecasts help decision-makers at the NWRB to better assess options for distributing water across these multiple uses. While PAGASA had already been providing general precipitation forecast information to NWRB, this effort helped PAGASA build the capacity to use statistical downscaling techniques to produce seasonal forecasts of reservoir inflow. The NWRB's existing reservoir model was revised to include these forecasts, with a user interface that enables them to visualize the uncertainty of projected inflow for a given set of water allocations (Brown et al, 2009).

Objective seasonal reservoir prediction systems – based on dynamical model predictions – have also been developed for West Africa. Météo-France has developed a system to predict flow in the Senegal River. The system is used in management of the Manantali dam (Mali) (Julie and Céron, 2007). Improved management from application of the prediction system has optimized hydro-electricity generation and also enabled a guarantee that artificial flooding, for flood recession farming, can be achieved in three out of four years (compared to once in five years, if no forecast information is used). The Met Office Hadley Centre, working with the Volta River Authority, has developed a system to predict water volume inflow into Lake Volta, Ghana. The predictions are used to aid management of hydro-electricity generation at the plant at Akosombo, which provides approximately 50% of Ghana's electricity (Richard Graham, personal communication).

Full integration of the climate forecasts with other information impacting on decision strategies is not easily won. Without collaborative involvement of climate scientists and decision makers in developing the management tools, there is a danger that tailored forecasts become no more than an elaboration of the original seasonal climate forecast, leaving the user little better off in understanding how to actually apply the information. The INFORM project has involved years of development of both the reservoir management tools and the technologies to obtain and incorporate climate forecasts in the operational setting. More importantly, it has required years of collaboration between the researchers and reservoir managers to define the working constraints and procedures that such a system would need before being used operationally. At this time, the INFORM system is functioning in an operational mode in parallel with the existing decision making procedures so that the decision making agencies can themselves determine whether the system is safe and beneficial. There is a need to share experience more widely, to help bring a fully integrated approach to the various developing applications in this sector.

ii) Agricultural decision making example

CIIFEN implemented a geographic information system for western South America that can incorporate seasonal forecasts as a "layer" of information relevant to dynamic risk of several regional crops types (Figure 3). The agricultural decision tool addresses the vulnerability of designated crops according to the area of intervention of every country spatially. Additional information was added such as layers of exposure to different climate hazards levels. Resiliency levels were estimated on social, economic, political and institutional parameters, land use characterization, water retention capacity, including its topography and texture among other factor. The combination of various information layers allows estimation of vulnerability of specific crops, and the influence of each layer can be weighted according to the region and crop in order to assemble dynamic layers from seasonal forecasts of precipitation, maximum and minimum temperatures. This allows dynamic agro-climatic risk maps to be generated for each crop. The system has been validated in every country in close coordination with expert teams from the NMHSs. Finally, the tool is able to generate maps which are updated following every forecast providing three-month risk scenarios and if monthly climate forecasts are available, every one or two months. Users can visualize the vulnerability layer, forecast layer, and also the associated risk for the next season represented in a simple color scale displayed nest to the map. The system is available through http://ac.ciifen-int.org/sig-agroclimatico/ and is becoming operational in each NMHS in western South America.

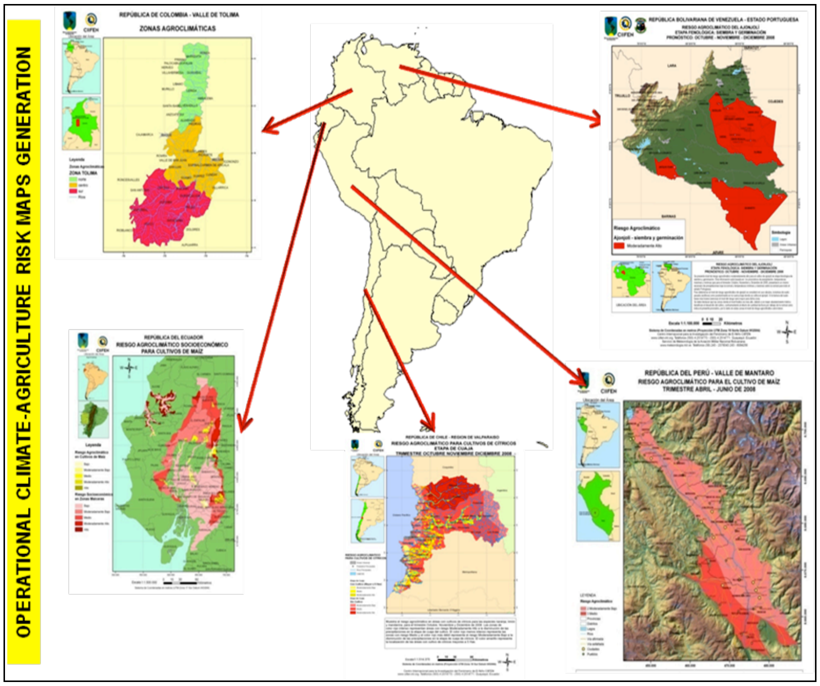

Figure 3. Dynamic Climate Agriculture Risk Maps generated on the basis of seasonal forecast for pilot areas in six countries on Western South America.

iii) Health – malaria example

Current applications in the health sector are probably best developed for malaria prediction in Africa – although applications are still fairly rudimentary. In malaria prone regions incidence is positively correlated with seasonal rainfall totals. Thomson et al (2006) demonstrated potential for using dynamical seasonal predictions to predict malaria incidence in southern Africa. It was demonstrated that ensemble mean November-February rainfall anomalies from three dynamical models of three centres participating in the EU project DEMETER (Met Office, ECMWF and Météo-France) show spatial distributions that are very similar to observed distributions when composited for the 5 years with highest malaria incidence and 5 years with lowest incidence. Multi-model output from the three centres – constituting the EUROSIP multi-model – has since been used as input to Malaria Outlook Forums in Botswana. Together with careful monitoring of the population immunity, the environment and the climate, the climate forecasts are the basis of a Malaria Early Warning System, and have been used effectively by the Ministry of Health in Botswana, in coordination with district authorities, the World Health Organization and regional NGOs.

iv) Other sectors

Climate information and forecasts are being used to help forecast fire activity in peatland areas of Central Kalimantan, Indonesia. Research by IRI, Bogor Agriculture University and CARE Indonesia revealed that rainfall during the dry season from June-October – when most fires are started – is particularly critical in determining the severity of fire activity, and a simple statistical forecast using the observed NINO4 sea surface temperature index can provide decision-makers with 1-2 months early warning of the likely severity of the fire season. Forecasts of NINO4 can increase lead time further. The government of Central Kalimantan province has recognized the potential to use this seasonal forecast to take early action to help reduce fire activity in high-risk years, and a 2008 regulation on fire incorporated the use of this early warning system to help determine when burning to clear land would be too risky (Someshwar, personal communication, 2009).

Additional examples from other sectors include the direct use of dynamical models in seasonal prediction of tropical storm activity (Vitart 2006, Vitart et al., 2007), which is potentially of great value to the insurance sector. Predictions of crop yield have also been the subject of much research interest (Tellus 57A, DEMETER special issue). However, experience from the user viewpoint is currently very limited.

4. Gaps Between the Provision of Climate Information and Its Use

Seasonal forecasts are more widely available than they were 10 years ago, and the dialogue between producers of information, researchers and different categories of decision makers has been enhanced by the Regional Climate Outlook Forums (RCOFs).
However, gaps exist still exist between information provided and information desired. Providers of information do not always understand the users' needs or that the seasonal predictions may not be understood by its possible users. Providers of information also may not understand the kinds of information that decision-makers can act on and appreciate the organizational and decision-making contexts in which potential users operate. Decision makers need to be made aware of the opportunities and limitations of the information being offered and have credible demonstration of use and benefit. In addition, those who would use the information should be made aware that some of the

desired forecast information may not been scientifically feasible at this time, or ever, due to limitations in prediction tools or the inherent uncertainty in the climate system. This awareness on all sides of seasonal climate forecasts requires continuous and receptive dialog, as well as continued effort on all sides to improve the provision and use of the forecast information.

The common or perceived gaps between provision of climate information and its use primarily concern (see also http://www.bom.gov.au/climate/pi-cpp/training/nms/Criticism_SCO_Comments.doc):

- A lack the spatial, temporal and element specificity, given the typical format of seasonal totals, applicable to relatively large areas, for just mean temperature and rainfall totals.
- The way in which information is communicated, such as timing, content, phrasing or language and even the means of delivery, which can all influence the effectiveness of uptake.

As a consequence, in recent years, much research also has been devoted to developing assessment methods to identify, foster, and design improved and sustained connections and services linking the climate community with users. The aim of these efforts has been to support and advance the co-discovery and co-evolution of climate services and applications (Miles et al., 2006). Recent efforts have centered around the concepts of climate services and decision support, which from the climate-information producers side is now understood to be a threefold process: first, involving the generation of useful climate information and predictions, second, translation of that information into forms useful for decision makers, and third, dissemination and communication of the results (Beller-Simms et al., 2008). All three of these processes require regular and intense collaboration with the potential users and decision makers, if the decision supports are to be successful, and are to provide better understanding of decision making and the human dimensions of uses of climate information.

These issues are expanded below with some strategies for improvement.

4.1 Spatial and Temporal Scale

The skill of GCM-based seasonal climate forecasts tends to increase with increasing spatial aggregation relative to a single GCM grid cell (Gong et al. 2003). For example, over NE Brazil, where regional predictability is uniformly high, forecast accuracy was shown to decease for smaller averaging regions, and interpretation of a grid box as representing a single station within it reduces skill further. This should be expected as local realization of weather and climate averages out on the larger scale. Locally specific information therefore has greater uncertainty. One option is translation of larger-scale forecasts to local scale, done either statistically or dynamically, that appropriately considers how the quantitative information, particularly its uncertainty, changes at that scale and at that particular location. Of course, such detailed information also requires sufficient observational records in order to be meaningful.

The temporal resolution of seasonal forecasts is mostly 3-month seasonal means. Often decision makers are more concerned with a particular month or how the characteristics of the weather within the seasonal climate, such as dry spells, start of the rainy season or hot/cold spells, may be different in the coming season. It is the change in characteristics – changing persistence or magnitude of weather events – that leads to the seasonal mean variability. There is encouraging research to suggest that this may be possible in some cases; for example, Robertson et al. (2008) find that the frequency of rainfall within a season exhibits higher predictability than the seasonal total rainfall. Similarly, Lo et al. (2007) find a strong ENSO influence on the start of the Northern Australian wet season, which is an important decision variable for the cattle industry. However, information on higher temporal characteristics of the seasonal climate is not routinely provided by forecast providers. Yet, for some regions MJO-based forecasts are showing considerable promise at this intra-seasonal time scale (Wheeler et al., 2009). These are examples of tailored products most appropriately developed by regional or national climate centres in collaboration with local users and decision makers.

Dynamical or statistical models can be employed to downscale the coarse output of global climate prediction models spatially and temporally to meet the needs for local information. Some examples can be found in the special issue of Tellus (2005, 57A) and by Sun et al. (2006a,b and 2007). A clear benefit of dynamical downscaling over statistical downscaling has yet to be demonstrated, although dynamical downscaling experiments can reveal more information about processes of the climate and its variability. Regardless of downscaling approach, it is necessary to demonstrate and document the ability to predict climate at scales relevant to applications or decisions, such as local values of temperature and precipitation and/or the temporal characteristics of the seasonal climate variables in the specific instances. It is also important to document to what extent prediction quality is improved or degraded relative to the coarser input; higher resolution information does not necessarily guarantee improved quality of the information. In other words, interpretation of large scale predictions to local scale involves considerably more than blind use of models. Care must be exercised when developing such information. Some detail may never be possible to predict. Users must find ways of getting the most out of the level of predicted detail that is feasible – just as producers should strive to increase reliable detail where possible.

RCOFS can play a significant role in closing this gap by motivating participating countries to improve national capacity for seasonal forecasts, including downscaling. A better climate service for decision making must ensure that NMHSs be able to respond to local users, often by providing locally relevant information. Applications that draw on such information encourage the private sector, Government and other stakeholders to invest in the improvement of the forecast capacities.

4.2 Forecast Variables and Their Specificity

Seasonal forecasts are typically provided as probabilistic outlooks for precipitation totals and monthly mean temperature, and these variables have been cited as useful indicators in many applications. However, decision makers often desire more detailed prediction information as described above (e.g., number of warm days, rainy days, onset date, length of season, possible long dry spell within the season, and locally specific information). Decision makers may also require prediction of environmental variables impacted by climate variability that are connected more directly to climate risk and resource management, such as stream flow, crop yield, mosquito distributions. In addition to being variables that may not be included in dynamical models, they span a range of space and time scales: streamflow is an integrator of many rain events (in time and space) and hence tends to strengthen a signal; the date of the last or first frost is very local and a weather event that will be very difficult to forecast; many extreme events are sub-grid-scale and very challenging; crop yields and mosquito distributions are influenced by non-climate effects and sensitive to starting conditions. The prediction of seasonal climate-related variables that are closer to many aspects of applications problems are being actively researched. Also, programs are being develop by different centres (e.g. the PRESAO- SG at ACMAD) to use available science and data to produce forecasts for these elements.

No forecast is complete without a description of its uncertainty. Due to imperfect dynamical models and inherent unpredictability of the land surface – ocean – atmosphere continuum, climate forecasts are necessarily probabilistic. Uncertainties generally increase with forecast lead time and vary with weather situation and location. The methods of generating the forecast probabilities vary among producers. If the dynamical models[2] were perfect, and for example, 70% of the ensemble members had warmer than average temperature, it would be possible to forecast a 70% chance that it will be warmer than average. However, models are not perfect, and calibration of model probabilities based on past probabilistic performance is often required (e.g. Robertson et al. 2004, Coelho et al. 2006?) to produce reliable probabilities. Reliability is one desirable attribute of probabilistic forecasts (Wilks, 1995), and in view of the preceding example: for a reliable forecast, over a large number of cases predicting a 70% likelihood for a warmer than average season, it should turn out to be warmer than average 70% of those cases.

To help users appreciate the necessarily probabilistic nature of seasonal climate forecasts, the forecasts should:

- be accompanied by performance statistics of the previous forecasts (or hindcasts).
- be tailored to the needs of RCCs and RCOFs/NCOFs who may add further regional/national tailoring before delivery by extension services to local users such as individual farmers in local language and including local knowledge whenever possible.

What is to be avoided is the temptation to interpret a probabilistic forecast deterministically, or as an "answer" with no uncertainty. Government or private sector decision makers always work with risk and uncertainty; uncertainty is part of the decision making process. Risk, by definition, is probabilistic. Furthermore, even if a precise

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[2] Note that statistical predictions typically provide an estimate of uncertainty that is determined by training the prediction on past data. Careful attention is required to make sure that such hindcasts of even statistical models are generated independently of the prediction target(s).

deterministic forecast could be issued, that would not necessarily result in a correct decision.

4.3 Communication

Making quantitative and intelligent use of probability forecasts requires an effective chain of communication between information providers and users. As discussed above, forecasts must be presented probabilistically. But are they perceived as such by local users? Do users assimilate this probabilistic information easily? Where the level of climate literacy is low, the potential for misinterpretation and inappropriate use of the forecast is likely to be high. If the climate information is not provided and communicated adequately, the whole system is being ineffective, and to some extent useless or damaging.

Language, phrasing or context is often a gap to proper interpretation of climate information. Often translation could be made by equating the likely climate shifts in terms of environmental indicators. Evidence of the use of indigenous forecasting methods to predict seasonal climate variations have been discovered in several regions (e.g. Roncoli et al. 2002). Different communities may use different indicators, such as observations of clouds, wind or lightning, behaviour of livestock, wildlife or local flora, or even the appearance of certain stars (Orlove et al, 2000). Unfortunately few studies have been done to connect the physical climate system to these environmental indicators, making it difficult for climate scientists to capitalize on the possible connections. Beyond tradition, indigenous climate forecasting has been appealing because it is made for tailored elements and focuses on those crucial elements needed by the community (e.g. onset, length of the season, timing of the rains) at the desired spatial resolution and provided in the understood local language.

Even if indigenous forecasts are not competing, technical jargon may compromise the value of the forecast for applications. For example, the terms "normal," "average," and "climatology" are used too casually (Hartmann, 2002). Efforts are made by producers to use clear and simple language, for example, by including a summary for non-technical users and explaining the main factors and forecast tools. In some cases a glossary may provided to explain terminology (c.f. http://www.cpc.ncep.noaa.gov/products/predictions/90day/seasglossary.html). Such details are also available within the process of RCOF/NCOF to those who can attend. However, this supplementary information is often insufficient or inaccessible to users in remote areas with little access to modern IT facilities.

Many would-be users of climate forecast information rely on the radio. This again emphasizes the importance of a well formed, and well informed, chain of communication. In one example of providing forecasts over the radio, new and easy-to-use technology (RANET system[3]) was introduced in 2000 for dissemination of forecasts

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[3] RANET is a collaborative effort of ACMAD, NOAA, many National Hydro-Meteorological Service, non-government organizations, and communities. These varied partners come together to make weather, water, and climate information available to rural and remote populations, which are often most in need of environmental forecasts, observations, and warnings.

through an organised system to local communities in local language. Other communications technology such as Eumetcast from EUMETSAT are being implemented and tested for dissemination of climate information. However, there is still considerable need to improve the effectiveness of communication of the climate information, by using multiple channels, including press, cell phones, satellite television and the Internet. Positive experiences exist of alliances with local media, who may be open to broadcasting seasonal predictions free of charge (Martinez and Mascarenhas, 2009). Such alliances require coordination, but they can then ensure sustainability of information delivery.

The interaction between providers and users has been historically low within the NMHSs and in the scientific climate community. Along the chain of information, the RCOFs play an essential role in bridging the communication gap. RCOFs and NCOFs can provide a venue for the NMHSs to build strategic alliances with the key stakeholders that can sustain an interaction. Such alliances are especially important in cases where such outreach cannot be supported within the NMHSs. The private sector and the media must also assume responsibility and become part of long term solutions, avoiding the temporary flux of climate information only when the disasters occurred.

Clearly, the media also plays a key role in the climate information chain. In many RCOFs, media professionals are included as a major partner in the discussions with both researchers/producers and users (see also Section 5). Examples of media misinterpretation abound and can result from genuine misunderstanding or a desire for eye-catching headlines. For example, a prediction, by the Met Office (UK) of a 2 in 3 chance of below-median (1971-2000) European temperatures for winter 2005/6 (Graham et al., 2006), was widely interpreted by the UK media as implying a ‘very’ cold winter – even though the forecast itself contained no information on severity (for the UK, two-category precision was the best that prediction skill would allow). To alleviate the risk of media misinterpretation many forecast centers employ media experts in the crafting of the forecast statement, following the reasoning that – as headlines will be written – it is better that the forecasters (rather than journalists) make the first draft. Press briefings are also used by many centers to help convey the correct message to the media. While it is helpful to train the media regarding seasonal climate forecasts, such forecasts do not often make for exciting headlines. Thus, the main goal with respect to the media should be to ensure, at the least, that they understand what the best is that science can do about seasonal forecasts and to understand the dangers of mis-communicating that information.

4.4 ENSO as a Case Study

El Niño is used here as a case study to demonstrate the degree of evolution in climate information systems. Although El Niño 1997-98, was an extraordinary event and the prediction was successfully done before the middle of 1997, many countries did not react or take the necessary actions to cope with the expected climate impacts. One of the main reasons for this was the multiple sources of information. Within western South America, official statements from the national level were ignored by the media and more attention was given to the Global agencies. However, while the global statement indicated the evolution of El Niño, the manifestation of El Niño through climate impacts were not evident in much of northwestern South America until very late 1997 due mainly to the seasonal cycle. The lack of confidence in the National Institutions plus the chaotic dissemination of information, from multiple, and often non-qualified sources, lead some Governments to ignore the best ENSO prediction to date. By the time that El Niño climate impacts were manifest, several Latin American countries were effectively taken by surprise and impacted negatively due to limited planning.

Ten years after the El Niño 1997-98, the climate information management regarding ENSO has become critical. When the media, governments and users are informed about ENSO, however, they retain a fixed idea of the 1997-98 impacts, without possibility of variation. In the first decade of the 21st century, moderate to weak ENSO events have not led to the same dramatic impacts at the local level in western South America that were experienced in 1997-98. Although the climate forecasts have been consistent with that outcome, the final result is that ENSO predictions are becoming useless in some countries due to the disconnect between NIÑO 3.4 evolution and the expectation of local ENSO effects in each country. CIIFEN supported a survey in Latin America about what is ENSO for each country. The finding was that the number of ENSO definitions is close to the numbers of countries involved in the survey. One conclusion was that for Latin America, communicating just ENSO as a forecast can be a particularly ambiguous and confusing way to communicate climate information. Several countries are now more concerned with improving their capacity to consider the wider range of factors that can influence the climate forecasts over the region and concentrating more effort on communicating those forecasts.

5. Techniques for Increasing the Value of Climate Forecast Information

As discussed in the previous section, several gaps exist between the information typically provided in seasonal forecasts and that needed for climate risk management and decision making. Some of these gaps can be addressed by the scientific community, which includes climate and sectoral specialists. Others must be addressed by the larger integrated process that enables actions to be taken and realized in the presence of forecasts of the climate and its impacts.

5.1 Technical Efforts

a. “Translating” climate forecasts into more relevant variables

Operational climate risk management requires knowledge about the likely consequences of the climate. Variables of interest for decision makers often differ from what climate forecasts routinely provide. Instead of seasonal rainfall forecasts, decision makers often require quantities such as crop yields (Meinke et al., 1996) or return on investment (Twomlow et al., 2008), provided probabilistically. Such probabilistic representation of decision variables helps risk managers to conduct rapid assessments of management options. In some cases, this might even mean bypassing climate forecasts and going straight to the decision-relevant variable, often by using several models[4].

In agriculture, modeling can be used to evaluate the efficacy of potential innovations (such as climate forecasts) at various levels of integration: from genetic engineering, to phenotype expression, to crop and cropping system management, to regional governance and policy setting. At the field to farm level, models are already used for operational risk management (Meinke and Stone, 2005) and for the design of more resilient farm business (Rodriguez et al., 2007), while they have also become indispensible in plant sciences to understand and predict the complexity of biological systems (Hammer et al., 2006; Yin and Struik, 2008). Likewise, public as well as private sector policy decisions are increasingly informed by the design of and output from simulation models (e.g. Kokic et al., 2007; Nelson et al., 2007; van Ittersum et al., 2009) including the development of new insurance products (e.g. Barrett et al., 2007; Hertzler, 2007). Connecting agricultural models with climate models remains a substantial challenge for the use of GCMs for operational risk management, but it is not insurmountable (Hansen et al., 2006). The most pressing issue that should be addressed is designing scientifically and statistically robust methods for providing GCM output at the appropriate spatial and temporal scales: while most agricultural models operate at a point scale using historical daily station data as input, GCM output is generally provided for large grid cells with vastly different attributes to the climate data the agricultural models were developed for. Secondly, methods that would readily allow one to obtain reliable probability distributions of forecast variables must be available. This is an essential condition before the information can be used by bio-physical models. Although statistical tools exist for providing calibrated probabilistic information at the right scales (Hansen et al., 2006; Maia and Meinke, 2008), agreed protocols for implementation are lacking.

b. Toolboxes

Providing information probabilistically is absolutely essential for responsible forecast provision. This is emphasized in a WMO report (2005) that explicitly states that only probabilistic forecast systems should be considered for risk management. The report lists four key forecast system attributes, namely (a) consistency (whether the forecasts correspond with the forecaster's judgment); (b) quality (whether the forecast correspond with the observations consistent its issuance); (c) relevancy (whether what is forecasted is of concern to the user) and (d) value (whether the forecasts are/can be beneficial when used). Forecast quality, often also referred to as 'skill', encompasses a wide range of statistical properties and is an essential pre-condition before a forecast can become valuable. Because dynamical models contain notable deficiencies, the quality of dynamically-based predictions can often be improved through the use of statistical post-processing. Freely available software such as the Climate Predictability Tool (CPT: http://iri.columbia.edu/climate/tools/cpt) is one example of a toolbox that can spatially and probabilistically recalibrate predictions from a dynamical model, generally improving the quality of the prediction at a given spatial resolution. The CPT can also be used to produce statistical forecasts based on current or recent observed conditions that

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[4] The term 'model' here refers to any simplified representation of a system that enables the investigation of the properties of that system and allows prediction of future outcomes.

can serve as a comparison to the dynamical prediction. And, the CPT can be used to statistically downscale coarse model predictions, assuming a sufficient history of observations exists at the desired scale.

c. Historical climate records as a tool for decision making

The ‘analogue year’ approach – still often held as the benchmark to be beaten by GCM-based methods - has been successfully used in some regions based on a range of different climate indicators such as SOI (Stone et al., 1996), SST or RMM (MJO predictions based on upper level wind and OLR anomalies, Wheeler et al., 2009). The advantage to such an approach is that the climate information is past observations, so the implications can be readily connected with decision models, and no supercomputer is needed. Some of the obvious problems include difficulties in dealing with short record length and low station density, particularly in developing countries. Non-stationarity due to decadal/multi-decadal climate variability and climate change can also severely limit the usefulness of analogue approaches.

5.2 Chain(s) of Communication Enabling the Use of Climate Information

Decision making in sectors such as agriculture, health or natural resources consists of individual choices to which collective action at local level is often the appropriate response (Adger, 2001). It takes place within specific social and institutional settings that provide the framework within which actions have to be taken. It also takes place within a global setting, where global and national policies influence choices and actions. To help decision makers better negotiate management and policy responses they require quantitative information to supplement their already existing empirical knowledge that is based on years of experience, expert judgment, insight and intuition. Hence, decision making is highly context and scale specific (Adger et al., 2005). Climate science and forecasting might be able to add to this process, it should never try to replace it.

The following discussion relates largely to decision making in agriculture and resource management, two of the most climate sensitive sectors in our economy. While the lessons learned from these examples can be generalized, the sectoral context is critical for the success of the forecast. For illustration purposes, we retained this context.

Here we ask the question: Why is the available information climate information often not used and embraced by decision makers? Lack of ‘ownership’ of the information by the intended end users is clearly one issue and has lead to a growing acceptance among climate scientists that they must move out of their disciplinary confines and engage in a process of continued, shared learning and joint problem solving (Glantz 2003, 2005).

More efficient and effective policies would, at least in principle, result from common approaches and technologies for ingesting climate information that provide decision makers at all levels and scales (from farm/ agribusiness to policy) with more objective, faster and lower-cost information. All stakeholder groups can then objectively compare options, evaluate choices and assess policy or management consequences. Analytical approaches, such as systems modeling, facilitate this process and help stakeholders to identify and choose between inevitable trade-offs along the path to sustainable development (Hammer et al. 2000, Agrawala et al. 2001, Meinke et al. 2006).

Cash et al. (2003) and Cash & Buizer (2005) argue that for climate information to translate into real-life action requires three essential components, namely: salience, credibility and legitimacy. 'Salience' relates to the perceived relevance of climate information: does the system provide information that these users think they need, in a form and at a time that they can use it? 'Credibility' addresses the perceived technical quality of information: does the system provide information that is perceived to be valid, accurate, tested, or, more generally, at least as likely to be 'true' as alternative views? 'Legitimacy' concerns the perception that the system has the interests of the users in mind or, at a minimum, is not simply a vehicle for pushing the agendas and interests of other actors.

Decisions makers usually manage risk holistically and often intuitively (Meinke et al., 2006; Schwartz and Sharpe, 2005), while climate science tends to provide specific, detailed and generally technical information. This can create a perceived lack of science relevance that can be overcome by embedding technological approaches within context specific, multi-stakeholder dialogues. Such participatory processes can translate scientific information into real life action by paying attention to salience, credibility and legitimacy as proposed by Cash et al. (2003). They contain at least two critical elements that need to be reconciled:

1) A participatory process of negotiation, building trust and creating knowledge, and
2) A solid scientific, technical basis that can be used for such knowledge creation.

So far much of the emphasis has been on the latter. We suggest taking a complementary approach: rather than using climate science as the starting point for this process (supply), we need to critically appraise stakeholders' problems or decisions and – in a participatory approach – jointly identify and outline the specific needs for transdisciplinary scientific input. Through this process we can then better match technical options with socio-economically feasible solutions. Here we review some examples of these technologies and suggest ways how they are or might be applied.

5.3 A Human-Centric Approach to the Definition of 'Forecast Value'

A forecast has no value unless someone uses the information, acts upon it and subsequently achieves a better outcome than they would have achieved otherwise (Hammer et al., 2000). This is quite different from the largely technical definitions of forecast quality that has so far dominated forecast assessments (e.g. Wilks, 1995; WMO, 2005). While it is important to establish forecast quality for the basic credibility of the scientific approach on which forecasts are based, the efforts necessary to estimate forecast value extends much beyond the climate science community. To really have an impact on decision making, a more human-centric definition is required. We therefore define 'Forecast Value' as *the features or characteristics of a forecast product and/or forecast service that enables action and satisfies identified and agreed needs of the user community.*

This definition, although it can not be determined by the climate community alone, makes the concept of 'forecast value' tangible and enables useful, meaningful and measurable improvements in climate science by

- highlighting aspects of the forecast system that matters to users through a dialogue about the role and value of science in decision making
- enabling action on the feedback received from users by designing forecast products that comply with user requirements, making forecasts more relevant and useful for society; and
- explicitly considering different relevant temporal and spatial scales when designing new forecast product

Even better understanding the importance of the timing of climate information can affect its uptake. Providing climate information in forms, and at times, that support decisions requires significant understanding of the decisions that must be made and the way that climate information can enter those decisions. For example, one useful approach has been collaborative development of decision calendars (e.g., Pulwarty and Melis, 2001; Corringham et al., 2008) that identify regularly occurring moments when, predictably, existing or needed climate products would be of maximum use to users making, e.g., decisions about sowing crops or releasing water from reservoirs. Developing such information requires persistent collaborations with the potential users, because the full range of ways that climate influences many management systems is poorly known; the climate-information producers need to learn the needs of the users, and the users need to learn the capabilities of the producers.

Howden et al. (2007) suggest a reflective risk management loop that clearly articulates the type of information needed for successful change management in agriculture and natural ecosystems. At the centre of this loop are three interacting domains, namely 'Environment', 'Production' and 'Norms and Values'. At each step a stakeholder dialogue ensures that the needs of these domains are aligned with the scientific knowledge to be created. The following steps form part of this loop:

1. Understand the existing system and scope possible changes to values,
2. Identify likely core issues and decision criteria. Clarify: who, what and when,
3. Assess (climate) impacts and trends, including their uncertainty,
4. Evaluate if impacts matter,
5. Assess the adaptation options, their broader consequences and links,
6. Design and evaluate implementation options.

In cases where the evaluation of the final step is positive, changes to either the environment, to production practice or to the norms and values (which includes policy) will be implemented and the loop starts again, this time with the modified system. In contrast, should the evaluation fail, no action takes place, but the loop continues.

Climate information is required for step 3, while step 5 determines the type of climate information that is needed for better risk management (e.g. onset dates for the wet season). The following example used this framework:

Profitability of the cattle industry in Northern Australia is directly related to the amount of life-weight gain that can be achieved before early monsoonal rains make the transport and marketing of cattle impossible. Cattle producers therefore have to balance their decisions: selling stock too early results in lower weight reducing profits, while waiting too long could prevent selling of cattle all together as access becomes impossible after a certain amount of rainfall. Until recently there was no reliable forecast that cattle producers could use to help in their decision making. Existing forecasts of monsoon onset are meaningless to them, as this is based on meteorological definitions of 'monsoon' that occur long after the 'build up' of the wet season has started and transport routes have become impassable. This motivated Lo et al. (2007) to develop an ENSO based, statistical forecast system that is tailored to the needs of the cattle industry in Northern Australia. Their system probabilistically predicts the wet-season onset date, defined based on the accumulation of rainfall to a predefined threshold determined in consultation with the cattle industry. Consistent with earlier studies, the interannual variability of the onset dates is shown to be well related to the immediately preceding July–August Southern Oscillation index (SOI). Using logistic regression, the probability that onset will occur later than the climatological mean date is predicted. When assessed using cross-validated hindcasts, the skill of the predictions exceeds that of climatological forecasts in the majority of locations in north Australia. At times of strong anomalies in the July–August SOI, the forecasts are reliably emphatic.

5.4 The need for on-going climate science and prediction research for improving the quality *and* value of climate information

Efforts toward interpretation and tailoring of climate predictions can improve the quality and usability of the information, but much research and development is still needed on the development of models and observing systems, which are essential to those forecasts. Not all possible sources of climate-forecast skill have been identified or exploited. Even for those contributors that the scientific community recognizes as contributing to forecast skill certain processes may be inadequately represented in models, or understood through observations. Examples include particularly, land/biosphere-atmosphere interactions and the predictability due to the cryosphere in seasonal-to-interannual predictions. Modern climate-forecast models strive to capture predictive influences from all these conditions (Arakawa, 2000; Goddard and Hoerling, 2006) but forecast skills have grown only grudgingly (Barnston et al., 1994; Livezey and Timofeyeva, 2008). Improvements in our ability to forecast ENSO and its impacts (e.g., Mason et al. 1999), along with whatever other long-lead predictability less exploited climate modes may contribute, remain the focus of attempts to improve climate forecast skills at large scales. Improved models will be necessary to realize such improvements. Deficiencies in nearly all dynamical models in representing certain key physical processes, such as tropical convection and aspects of the tropical upper ocean dynamics, suggest strongly that room for improvement exists.

At still longer time scales, predictability is more difficult to come by. Recognition during the past decade of the comparable role of interdecadal climate variability with seasonal to interannual variability in many areas of the globe has improved our understanding of climate variations overall. However, the difficulties of predicting climate beyond a year have thus far limited the predictive value of that recognition. The climate system is, for most part, too chaotic and internally variable to support most useful, longer lead forecasts of climate variability with current technologies (Smith et al., 2007). Again considerable research is required to develop models that appropriate capture the relevant processes and data assimilation systems that can incorporate the observed state of the climate system that is essential to initialize decadal scale predictions.

As an example of innovative research into the generation and improvement of utility of climate predictions, methods for determining the quality and value of operational climate-forecast products in very specific and often local applications and decisions have been developed (e.g., Hartman et al., 2002). These assessments not only address whether forecasts or other information are good enough for inclusion in decision making but, because nearly all decisions already depend on imperfect information about a wide range of stressors and conflicts, also inform users about how much to trust or value the climate information relative to many other information types and sources. This latter step, it has been recognized, is the more important aspect of climate-information valuation in most real-world applications.

6. Lessons Learned

This section provides a synthesis of lessons learned in RCOFs around the globe after the RCOFs review process held in Arusha, Tanzania in November 2008 (Martinez, 2008). It is based on practical experiences in each region and sets up a good reference for further recommendations.

6.1 Learning About the Users

RCOFs provide a face to face contact. It is not a regular meeting; it is a mutual learning process where users learn about the nature, quality and value of forecasts, become better acquainted with terminology, and more importantly understand the limitations of climate predictions. On the other side, forecast providers learn about user perception of their information, such as their interpretation of a colored map of the terciles. RCOFs have provided the opportunity for the climate community to learn more about the users' profiles and with this knowledge, develop ways to tailor and communicate climate information. Language, native phraseology, ancestral climate knowledge, local culture and the intuition of the color scales are all part of the elements used to better communicate (Power et al. 2007).

Additionally, the RCOFs have allowed for the identification of "key contacts", or relevant actors in the region, who have the capabilities to disseminate, share or transfer information to other contacts with a positive socio-economic effect. These contacts maximize dissemination efforts and reduce the risk that climate information goes unused within a decision making process. Key contacts must include Government officials who provide advice and/or can ensure that climate forecasts reach the authority or decision maker. The list of key contacts should be a widely accessible document that is continuously checked and updated.

6.2 Involving the Media

Climate forecasts generally produce high expectations from media. This situation could be good or bad depending on how a press conference, a personal interview or a newspaper report is handled. Even after several training workshops for journalists in some regions, the results may not be satisfactory. However, it has been demonstrated that efficiency and effectiveness can be obtained by selecting a climate expert, who has communication training, to work with the media. Alternatively, it may be preferable to call on sectoral specialists in the fields of water, agriculture, health, energy and disasters who are trained in the interpretation and applications of climate information, including both recent observations and predictions, as these experts are already communicating other types of information to users (e.g. prices, markets, epidemics, etc.).

Press, radio and TV require different formats to communicate the same forecast and an additional effort to prepare and tailor products according to the interested media can be of value.

Some RCOFs have included the media contacts as participants. They play the roles and responsibilities of key contacts and assist NMHSs for dissemination. Special media sessions have facilitated good communication in some RCOFs. This approach requires regularity and quality of climate forecasts bulletins as well as the media interest, which usually come from the relevance of the provided information for their audience or viewers (Hansen et al. 2007).

Climate forecasts in some regions receive specific spaces in press, magazines and other media without any cost, which provides more visibility to the information. In this case, the media benefit is likely to have been demonstrated.

Press conferences could be the best or the worst way to disseminate Climate Information. Several regions have experienced the negative impact of an ill-handled press conference. The entire effort of producing the forecast, carefully reviewing the statement, and other elements, could be wasted, with a single misstatement of the Official spokesman, generating instead misinformation and lack of credibility with the user community. Experience shows that it is best to disseminate an accurate statement of the forecast that can inform the media, but that is still concise, friendly and explicit.

6.3 Changing the Language

The best way to ensure a communication channel with users is to make the wording of forecast simple. This requires an additional, but worthwhile, effort from climate information providers that usually helps to expand the user community. In such cases, some technical and complex details are omitted leading to an understandable message that can trigger a response from users. Good experiences have been noted in very traditional communities where the climate information has been reworded using some native phraseology, rather than technical jargon. The level of positive reception is evidenced by the further demand for regular information.

6.4 Receiving and Assimilating the User Feedback

The connections along the chain of information are enhanced when their perceptions from users are integrated in the communication process. In some regions the RCOFs have been replicated as National Outlook Fora providing the space to receive the user feedback. An effective process involves listening to users' comments, analyzing them and then integrating them in the communication strategy. For example, CIIFEN receives positive reactions when users see some of their suggestions incorporated in Climate Bulletin. As a consequence, the relationship with users gets stronger and the use and communication of the climate information improves. Climate information providers should be flexible enough to make information available in different formats, wordings and graphical design.

6.5 Involving the Private Sector

One of the best practices in the delivery of climate information to other users, such as the private sector, has been to transform their passive role as listeners into that of actors. This has been achieved when they are requested to participate in the dissemination process. After understanding the potential benefits of climate forecasts, private sector partners become key actors. Funding required for sustainability is increasingly provided by the private sector making their involvement very important in future climate information strategy, especially in developing countries.

6.6 Getting Positive Responses from Governments

An important segment of users is composed of Governments authorities. At the national level, the NMHSs are important liaisons with relevant contacts from the Government. Although it is not an easy process, the identification of experts who can advise authorities about the application of climate forecasts can be highly effective. The initial target for engaging governments may not be the authority (e.g Ministers); it will likely be their technical advisors. Involvement of National authorities from different sectors such as civil protection, planning, agriculture, health, energy, infrastructure, water resources, banking and finance, science and technology among others results in powerful connections that facilitate effective responses to climate information and services at national level. A good practice to implement where possible can be invitation via videoconference of relevant authorities or decision makers to the RCOFs; they get involved, participate in discussions and gain access to RCOF conclusions at a very limited cost.

6.7 Customizing Climate Products

Special bulletins for specific industries or sectors have been one of the best practices with evident results. This requires additional effort, to know user needs and to be able to reflect them in the product. The era of standard weather or climate bulletins is over. Among the many challenges for the meteorological community in its effort to support sustainable economic growth with better climate services, the development of more customized information through more regular interactions with the users is one of the most important. When done properly, the communication process and further user response to climate information is quite effective.

6.8 Getting Involved in User Activities

Users organize several meetings and activities where the climate community, mainly the NMHSs, is invited. Positive response to these invitations builds a stronger relationship, allowing climate information providers to listen and learn about users and their problems some of which may be handled with climate information. It is important and very rewarding to be involved in users' activities as much as possible to lay down the foundation for better application and dissemination of the climate information.

6.9 Generating Trust from Users

To build more trust in the user community, a set of actions are needed. Regular face to face contact, personalized e-mails or phone calls, encourage the user to integrate climate information in his day to day climate sensitive activities. User trust also relies on presentation of climate forecasts and articulating uncertainties and limitations. Users require climate information in spite of the limitations, but these must be informed properly and with transparency (Brown et al. 2008). Such individualized interaction with the user community is often not possible by the limited staff in NMHSs or even regional climate centers. This again highlights the need and the value of the chain of information and the role that local authorities – whether 'boundary organizations', sectoral specialists, government officials or the media – can serve in building a strong climate service network.

6.10 Demonstrating the Effectiveness of Climate Applications

The best way to convince users, involve Governments authorities, media, private sector and others is demonstrating the benefit of incorporating climate information into their efforts. This can be done through pilot projects that document the process and the outcomes over time. Once the results are evident, additional support will come from partners who become more motivated to scale up pilot projects to other geographic areas and/or development sectors. More pilot demonstrations are needed to further document, test and exchange best practices of user-provider interactions.

7. Summary and The Way Forward

Many of the factors that contributed to the under-utilization of the available science-based seasonal climate forecasts were discussed in previous sections of this article. The lessons learned strongly suggest that the way forward needs a "cultural change" in the interaction of the climate science community and the sectors ("users"). A first element of this needed change consists of considering the demand side as the starting point and the main focus of this interaction, as opposed to using a supply-oriented approach (Section 4) (Lemos et al., 2002; Ziervogel, 2004). By placing the main focus in the demand side ("users"), climate information and climate products become just one of the many types of information that feed the decision-making and planning processes in the different socioeconomic sectors (Meinke and Stone, 2005). Just like the many other types of information needed for decisions and planning (e.g., prices, markets), climate products must be available in formats that are understandable, with spatial resolution that make them usable, and provided with adequate lead times to make them actionable.

A second lesson learned is that the sectoral stakeholders and the climate scientists need to approach the ongoing efforts in research and applications of seasonal climate forecasts as a “work in progress”. Up to the 1990’s climate-related decisions could only be made based exclusively on the very unlikely “average” climate conditions described above. The last few years have witnessed significant advances in the ability of the climate science community to provide probabilistic information on the expected climate conditions for the next season, and that information is potentially very useful to assist the decision making and planning activities in the different sectors. Thus, the current capabilities of seasonal climate forecasts allowed stakeholders to evolve from having “nothing” to assist decisions and planning, to having “something”. Climate scientists continue to invest efforts to improve their “something” by enhancing the skill of the forecasts, increasing their spatial resolution, and by improving the ability to forecast climate variables that are more relevant for the different sectors than the total seasonal means (e.g., onset of the wet season, the frequency and duration of dry spells, timing of cold spells, dust density, or the probability of extreme events).

A thrust is now needed to clearly understand the climate-related problems of the sectoral stakeholders, and to translate the climate information at various scales into sectoral products and information that can be directly embedded into decisions and policies. This translation requires that the climate information is communicated using formats and language that can be readily understood, provided at lead times and temporal/spatial resolution that make it actionable, and that it is explicitly and strongly linked to relevant sectoral information. For example, there is a need to develop methods that combine good monitoring systems with climate forecasts and produce streamflow forecasts, crop yield outlooks and infectious disease alerts. There is a consequent need to enhance the local capacities to develop, establish and operate information and decision support systems that use climate related products but also sectoral information and simulation tools.

Effectively communicating climate information and embedding it in decision-making, planning and policies requires establishing “chains of information”. It is unrealistic to expect that an organization that provides seasonal climate forecasts, whether National Weather Services, Regional Climate Centers or Specialized Meteorological Centers, will be able to include experts in all the socioeconomic sectors that are relevant in any given country or region. A much more effective strategy consists of taking advantage of the structures and institutional arrangements that already exist in the different sectors (Meinke et al., 2001). For example, the agricultural sector of developed and developing countries includes technical advisers of NGOs, private companies and public institutions that continuously interact with farmers. The interaction with the farmer community is “holistic” in nature, i.e., advice is provided in issues that embrace the whole farming operation such as fertilizer use, crop and livestock management practices, pest control, markets, commercialization, etc. This holistic interaction forces advisers to learn and use adequate communication strategies and language, and results in establishing and enhancing their trust within the farmer communities. The communication of relevant climate information is therefore much more effective when it is carried out through these advisors. Consequently, efforts are needed to improve a two-way communication between the providers of climate information and this type of intermediary agents. Improving this communication includes developing the capacity of advisers to understand the climate information and products (including their limitations), and translating it into information and products that are understandable and usable for the farmers. It also includes improving the capacity of the climate service providers to better understand the types and formats of information and products that are relevant to the agricultural sector.

Similar two-way communication is needed between the climate science community and the seasonal climate providers (National Weather Services, Regional Climate Centers, or Specialized Meteorological Centers), as part of the "chain of information". Advancement in the ability to produce seasonal climate forecasts requires strong efforts in basic climate science research on for example, understanding the causes of climate variability. Such research is essential for providing a scientific basis for claiming predictability of seasonal climate. This type of research, as well as work targeted to create or improve coupled climate models is grounded in typical academic and scientific institutions, must be endorsed by publication of innovative methods in leading peer-reviewed scientific journals, and can be completely disconnected from the demands of socioeconomic sectors. However, in order to ensure the socioeconomic relevance of the scientific advances, there is a need for scientific groups (within the same institutions or beyond, see for example Miller, 2001) to capitalize on the scientific outcomes and develop applications and products that are helpful for intermediary organizations (climate service providers and/or boundary organizations directly linked to socioeconomic sectors). Here again, a two-way communication has proven to be effective in for example, shaping aspects of the research agendas in academic institutions to facilitate a smooth transition from basic science to applied research.

The ideal set of components of these "chains of information" varies for the different settings, regions, socioeconomic sectors, scales, etc. However, the successful cases always include strong two-way communications between the different components of the information chain, from the "end users", through a set of boundary organizations to the institutions conducting basic research.

The last few years have also witnessed increased awareness in the impacts of observed and expected changes in climate at longer time scales ("climate change"). Accordingly, there is a huge demand from stakeholders acting at different spatial scales (global, regional or local) and in different socioeconomic sectors (agriculture, food security, health, water, disasters) for climate information across a continuum of temporal scales: from days through seasons to decades. For example, the International Federation of the Red Cross/Red Crescent (IFRC) and the UN World Food Program (WFP) require seasonal climate forecasts to improve their planning and disaster risk management strategies, but they also need climate information at much shorter time scales (from monitoring current conditions to forecasting a few days ahead) to improve their immediate preparedness and response to climate related disasters. On the other hand, governments and development agencies (such as The World Bank and UNDP) are increasingly demanding information at longer time scales. In developing country context, the longer term climate information that is considered most actionable and therefore is being most intensively demanded is the information for the next one to three decades ("near term climate change").

Consequently, efforts to improve the provision, communication and effective applications of climate information and products at seasonal time scales, therefore, must be carried out in connection with the demands on other temporal scales. According to IPCC Working Group 2 (2007 p 137), adaptation assessments benefit from linking future changes in climate to past and present variability. The new seasonal climate forecast need to be conceived as part of the portfolio of climate relevant information that is increasingly needed by the stakeholders that act at different geographic scales (global, regional, local) and in the different socioeconomic sectors.

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Further Reading

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2. Confidence Builders: Evaluating Seasonal Climate Forecasts from User Perspectives By Holly C. Hartmann1, Thomas C. Pagano, S. Sorooshian, and R. Bales11. Department of Hydrology and Water Resources, The University of Arizona, Tucson, Arizona

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3. Is Information Enough? User Responses to Seasonal Climate Forecasts in Southern Africa: Report to the World Bank, AFTE1-ENVGC. Adaptation to Climate Change and Variability in Sub-Saharan Africa, Phase II (ISSN: 0804-4562) by *Karen O'Brien et al*

4. A. Troccoli et al. (eds.), *Seasonal Climate: Forecasting and Managing Risk.* 293© Springer Science+Business Media B.V. 2008

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6. Actionable climate knowledge: from analysis to synthesis By Holger Meinke et al (Climate Research, Vol. 33: 101–110, 2006)

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