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# Climate Risk Management: A Progress Report

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## Abstract

Climate risk management has emerged over the last decade as a distinct area of activity within the wider field of climatology. Its focus is on the provision of climate related information that will enhance the decision making process in a wide range of climate sensitive sectors of society, the economy and the environment. Given the burgeoning pure and applied climate science literature that addresses a range of climate risk management problems, the purpose of this progress report is to provide an overview of recent developments related to the risk assessment component of climate risk management. Necessarily, because of the vastness of the climate risk assessment literature, data rescue and climate data bases, hurricanes and droughts as examples of extreme climate events and seasonal climate forecasting are focused on in this report. The review of the literature finds that historical data rescue, climate reconstruction and the compilation of climate data bases has assisted immensely in understanding past climate events and increasing the information base for managing climate risk. Advances in the scientific understanding of the causes and the characterization of hurricanes and droughts has had clear benefits for managing these two extreme events while work focused on unravelling the nature of ocean-atmosphere interactions and associated climate impacts at the seasonal timescale has provided the basis for the possible seasonal forecasting of a range of climate events. The report also acknowledges that despite the potential of climate information to assist with managing climate risk its uptake by decision makers and users may well be contingent upon understanding a range of non-climate factors.

## I Introduction

Polemics aside related to climate determinism, it is clear that climate exerts a strong influence on a range of human activities and hence human development. Accordingly, there is now a demand from a variety of sectors for climate information that can be used across a range of decision making environments. In many ways the imperatives of disaster risk reduction, sustainability and resilience, resource development and management, building human capital and profitability in business have led to the emergence of climate risk management (CRM) as a distinct field of pure and applied research. A clear manifestation of the global recognition of the potential significance of climate information for risk management is the establishment of the World Meteorological Organization's Global Framework for Climate Services (GFCS) the overarching aim of which is "to enable society to manage better the risks and opportunities arising from climate variability and change, especially for those who are most vulnerable to climate-related hazards …… through developing and incorporating science-based climate information and prediction into planning, policy and practice" (WMO, 2014a). Given this, the purpose of this progress report is to focus on the science provision aspects related to the risk assessment component of climate risk management by summarizing recent literature on data rescue and climate data bases, extreme climate events and seasonal climate forecasting. Before proceeding, an attempt will be made to briefly define climate risk management.

As yet there is no formal dictionary style definition for climate risk management, as the term does not appear in a number of obvious places such as the glossaries of the American and Royal Meteorological Societies and major climate related encyclopedias. This situation most likely relates to the newness of CRM as a discipline as opposed to the contested nature of what CRM is. Conscious of this the World Meteorological Organisation's Task Team on Climate Risk Management (Rodriguez et al., 2012) has defined CRM "as a systematic and coordinated process in which climate information is used to reduce the risks associated with climate variability and change, and to take advantage of opportunities, in order to improve the resilience of social, economic and environmental systems”. This resonates well with the general conception of the nature of risk management as outlined in the International Organization for Standardizations “Guide on Risk Management Vocabulary” and “Principles and Guidelines of Risk Management” (ISO 2009a, 2009b). It also aligns with the views of how CRM is defined by the International Research Institute (IRI) for Climate and Society (Zebiak, 2010)), and UNDP’s Bureau for Crisis Prevention and Recovery (UNDP, 2014). In simple terms, these views of CRM emphasize the centrality of climate information for improving human livelihoods and lifestyles while ensuring ecosystem services are not compromised. Further, given that CRM deals with complex or ‘wicked’ climate related problems it is becoming by necessity an interdisciplinary science.

## II Historical Data Rescue, Climate Reconstruction and Development of Climate Data Sets

Because of the incompleteness of climate data in both space and time, efforts have been invested in historical climate data rescue and climate reconstruction, as well as the development of gridded climate products. Although not necessarily one of the “glamorous” aspects of climatology, these activities are of fundamental importance as they serve to support climate impact and risk as well as variability and change assessments, provide important historical weather observations that constrain climate modelling of the past and the future, extend the climate record for a single location or region allowing analysis of climate extremes, serve as inputs into climate reanalysis projects and calibration exercises for satellite and climate proxy data and provide context for early warning systems (Allan et al., 2011; Brohan et al., 2012). As noted by Brunet and Jones (2011) a number of data rescue efforts are underway at both national and international levels. Of particular note are the Mediterranean Data Rescue (MEDARE) (Brunet and Jones, 2011) and the Atmospheric Circulation Reconstructions over the Earth (ACRE) (Allan et al., 2011) initiatives. The discovery and rescue of instrumental records and their subsequent analysis alone, or in combination with other sources of climate information, continues to shed light on various aspects of climate system dynamics such as the long-term variability in the date of monsoon onset over western India (Adamson et al., 2013), climate periodicity and climate dynamics over Europe (Ludecke et al., 2013; Zorita et al., 2013) and specific weather events of climate importance (Dominguez-Castro et al., 2013).

Diaries, log books, expedition and other types of historical documents also provide a rich resource for assisting with climate reconstruction. For example Wilkinson et al (2011) have used logbooks of the Dutch and English East India Companies and the British Royal Navy in an effort to augment other historical sources of marine data. Brohan et al. (2010) and Wheeler (2010) have also used logbooks for Arctic and North Atlantic marine climate reconstruction respectively. Similarly using recordings in a private diary, Zhang et al. (2013) have built a picture of precipitation variations in Beijing for the period 1860-1897 while Hao et al., (2012) used historical documents of the Yu-Xue-Fen-Cun archive recorded during the Qing Dynasty (1644-1911) to build a climatology of winter snowfall for the middle and lower reaches of the Yangtze River. Further examples of how information contained in diaries has been used for reconstructing various aspects of climate include a reconstruction of mean sea level pressure for Paris and subsequently a time series of the North Atlantic Oscillation back to 1692 (Cornes et al., 2012; 2013), a record of atmospheric pressure changes in the Arctic from 1801 to 1920 (Przybylak et al., 2013) and a temperature reconstruction for North-Eastern Italy for the last millennium (Enzi et al., 2013).

Blending information from a variety of data sources is also yielding benefits for reconstructing climate conditions for areas where few if any instrumental records exist (Luterbacher et al., 2010). For example documentary information, hydrologic indicators, and rain gauge records have been compiled and combined into a semi-quantitative precipitation dataset that extends from 1801 to 1900 for Africa (Nicholson et al., 2012). For the Kingdom of Lesotho in southern Africa, Nash and Grab (2010) and Grab and Nash (2010) have reconstructed a record of rainfall variability and winter climate variability respectively based on unpublished English-, French- and Lesotho-language materials. Using similar sources, Nash and Endfield (2008) have presented an assessment of the historical association between El Nino and rainfall variability in the Kalahari for the period 1840-1900. Allied benefits of mining diaries and hitherto unpublished documents are insights into climate related impacts such that arising from the 1816 Tambora eruption (Bodenmann et al., 2011; Lee and MacKenzie, 2010) and understanding the complex relationship between climate, environmental change and epidemic disease "(re)emergence" in East Africa (Endfield et al., 2009).

Because there is increasing demand for data at fine space and time scales, the patchy coverage offered by data sets constructed from disparate and often qualitative documentary sources are not likely to fully satisfy the requirements of climate risk analysts. For this reason there is burgeoning investment in the development of a range of global climate data products (Chandler et al., 2012) many of which are gridded and cover at least 50 years. Further, in order to the maximize the utility of rescued data and newly constructed data sets and surmount issues related to data standards, digitization, exchange and sharing there has been a call for the global implementation of a set of climate data standards and protocols (WMO, 2014b; 2014c). Examples of recently developed data sets include a land surface specific humidity data product that has been used in the analysis of humidity trends (Willett, 2013), a near global gridded data set of temperature and precipitation extremes (Donat et al., 2013) applied to assessing trends in annual maximum daily precipitation (Westra et al., 2013) and a global monthly night marine air temperature data set (Kent et al., 2013). While such new and emerging data sets offer possibilities for a range of analyses for climate risk management, analyses based on existing well established data sets (Allan and Ansell, 2006; Huffman et al., 2009; Jones et al., 2012; Kennedy et al., 2011; Morice et al., 2012; Rayner et al., 2006) and third generation re-analysis products (Dee et al., 2011; Reinecker et al., 2011; Saha et al., 2010) continue to provide insights into a number of aspects of climate risk.

## III Seasonal Climate Forecasting

Until the latter part of the 20th century managers of climate sensitive resources and production systems relied on a blend of climatology and observed conditions to make decisions regarding climate related social and economic risks several months ahead. However, as the climate communities' understanding of the large scale mechanisms that influence climate has improved, seasonal to inter-annual to decadal climate forecasts have become a real prospect (Goddard et al., 2010), with some regions showing more promise than others. Understandably this has attracted much interest from a range of climate sensitive sectors such that outputs from seasonal climate forecasts (SCF) are beginning to be incorporated into the decision making processes related to managing risk in industries such as water (van Pelt et al., 2011), energy (Troccoli et al., 2010), agriculture (Crane et al., 2010) and insurance. Because of seasonal climate forecasting's rapid development as a science, there have been a number of recent reviews of its nature, current status and prospects (Brunet et al., 2010; Dobles-Reyes et al., 2013; Goddard et al; 2010; Smith et al., 2012; Stockdale et al., 2010). While these provide good coverage of statistical and dynamical seasonal climate forecast model developments (e.g. Stockdale et al., 2012), frameworks for assessing skill and predictability and factors that might influence these (Goddard et al. 2013; Sun and Wang, 2013) and challenges related to bridging timescales of prediction (Goddard et al., 2012; Hudson et al., 2011), less attention has been given to SCF based predictions of hydrometeorological extremes, applications of actual SCF in a range of sectors and the value or otherwise of these. Accordingly these aspects of seasonal climate forecasting will be emphasized here.

Hydrometeorological extremes that have been the subject of seasonal forecasting attempts include drought (Dutra et al., 2013; Sohn et al., 2013), fire (Khan, 2012; Road et al., 2010; Shabbar et al., 2011), tropical cyclones and hurricanes (Diamond et al., 2012; Kim and Webster, 2010; Liu et al., 2012; Vecchi et al., 2013); tornadoes (Tippet et al. 2012); floods, periods of high/low river flow and soil moisture (Shukla and Lettenmeier, 2011; Yuan et al., 2013), dust storms (Tao et al., 2010), ocean wave heights and variability (Colman et al., 2011; Hazeleger et al., 2013), windstorms (Renggli et al., 2011) and extreme temperatures (Barnston and Mason, 2011; Becker et al., 2013; Eade et al., 2012; Hamilton et al., 2012; Hanlon et al., 2013).

In many ways the true test of the utility of seasonal climate forecasting science and its products is its uptake by users. Encouragingly there is evidence that SCF are gaining traction within a number of sectors, an outcome closely aligned with the hopes of the World Meteorological Organisation's Global Framework for Climate Services (WMO, 2014a). For example SCF are being used for guiding decisions in the agricultural sector in the Sub-Saharan region of Africa (Hansen et al., 2011). For Zimbabwe, Unganai et al. (2013) have described how tailored forecasts have assisted with management of drought related risk in rain fed farming systems. Also for Zimbabwe, Zinyengere et al. (2011) describe the integral part that SCF and probabilistic rainfall forecasts have played in the development of a climate based maize production decision support tool. Other applications of SCF in the agricultural sector include the prediction of temperatures at the beginning of the growing season and killing frost frequency in Canada (Wu et al, 2013), the onset of the wet season in West Africa (Vellinga et al., 2013), managing mixed sheep-wheat farms in Western Australia (Asseng et al., 2012) and rice production in the Philippines (Koide et al., 2013).

In order to address the risk-averse behaviour of hydropower managers in the upper Blue Nile basin region of Ethiopia, Block (2011) has developed tailored SCF of rainfall for sequential ingestion into rainfall-runoff and hydropower models. When rainfall and eventually hydropower predictions are considered in the context of managerial risk preferences, SCF based predictions of hydropower are shown to produce superior benefits and reliability compared with risk-taking tendencies conditioned on climatology. Conscious of the need to dispel concerns about the predictability of heating-degree days (HDD), an important weather derivative (Zeng, 2000) traded daily in the energy sector, Brands (2013) shows how Eurasian snow cover extent in October can be used for making useful predictions of the so called 'strike', the pre-negotiated HDD standard deviation value above or below which an energy supplier will or will not receive an insurance payout. As season ahead forecasts of climate related health outcomes, such as vector borne disease (e.g. malaria and dengue), are likely to yield benefits for the health sector (McGregor, 2012) SCF are being applied in the development of malaria early warning systems (Jones and Morse, 2012; Thomson et al., 2006).

There is a burgeoning literature that addresses the value of SCF and associated barriers and limitations to the uptake of SCF products. Millner and Washington (2011) have provided a useful theoretical framework for considering the factors that might influence the perceived value of SCF. In a similar vein Coelho and Costa (2010), Marshall et al. (2012) and Lemos et al., (2012) address the challenges of integrating SCF into user applications, describe reasons relating to the reluctance of resource users to contemplate the potential benefits of SCF and consider strategies for narrowing the climate information gap between producers and consumers of climate information. Because science in general is being increasingly scrutinized in terms of its economic benefit and contribution to wealth generation, a number of recent studies have addressed evaluation strategies and presented estimates of the potential economic value of SCF (Emmanuel, et al., 2012; Kumar, 2010; Sultan et al., 2010). Lamb et al., (2011) also present an outline of the professional development requirements for capitalizing on the potential of SCF. Importantly, Jaeger et al. (2008) have suggested a methodology for calculating the fraction of attributable risk to climate related damages, which could be potentially managed provided information at sufficient lead times is available.

## IV Extreme Climate Events

Because of the vastness of the literature on extreme climate events this section necessarily is limited to two, namely meteorological drought and hurricanes. Further in keeping with the aims of this progress report the focus will be on the characteristics and causes of the selected extremes as opposed to the consequences of and responses to them. A comprehensive treatment of the impact of a range of climate extremes on natural and human systems and their management can be found in the IPCC's Special Report on Climate Extremes (IPCC, 2012) while an assessment of the evidence for trends in climate extremes and likely alterations to their climatology due to anthropogenic climate change can be found in the recently published IPCC Fifth Assessment Report (IPCC, 2013).

Unlike many other hydrometeorological hazards meteorological drought is pervasive in that its development is slow and not immediately visible; this also applies to hydrological and agricultural drought both of which have their origins in meteorological drought. Given this, the recent drought literature is replete with studies focused on the development and use of drought indices in drought characterization, risk assessment and forecasting, and analyses of the climate dynamics associated with drought occurrence.

Over the last several decades there has been an almost industrial scale production of drought indices, many of which have been produced without any specific end-user in mind; there are approximately 100. A number of attempts have been made to review the vast range of indices (Heim, 2002; Keyantash and Dracup, 2002; White and Walcott, 2009; Zagar et al., 2011), make inter-comparisons of them and draw conclusions concerning the suitability of particular indices for specific applications (Mo, 2008; Mo et al., 2011; Vicente-Serrano et al., 2010, 2012). While most indices are calculated using surface instrumental data a number of indices based on satellite derived climate products have materialized recently (AghaKouchak and Nakhjiri; 2012; Anderson et al., 2011; Gouveia et al., 2009; Mu et al., 2013; Naumann et al., 2012; Swain et al., 2007). Given the plethora of drought indices, understandably there has been a call for a universal index, with the standardized precipitation index (SPI) emerging as a likely candidate (Hayes et al., 2011). Similarly momentum is building for a global as opposed to a national/regional piecemeal approach to drought monitoring (Hein and Brewer; 2012; Pozzi et al., 2013).

Recent studies focused on the characterization of drought have applied a number of approaches. For Europe, Lloyd-Hughes et al. (2013) use a spatio-temporal structure-based approach finding little similarity between individual drought structures, irregularity in the temporal evolution of similar drought events and that geographically extensive droughts result from the coalescence of multiple small area short duration droughts suggesting that local land atmosphere feedbacks might play a role in the spatial aggregation process. Hannaford et al. (2011) and Parry et al. (2012) have noted that historical European droughts generally have distinctive signatures in their spatio-temporal development. Also focusing on Europe, Bonaccorso et al. (2013) suggest that in addition to the Euro-Mediterranean region, North Western and Central Eastern regions appear more drought prone than the rest of Europe based on an analysis of their respective marginal and multivariate probability conditional density function characteristics. Using spatial point process theory Yang et al. (2013) have considered the spatial characteristics of drought across China revealing a tendency for clustering of severe droughts in autumn and an inter-decadal change in the occurrence of clustering of extreme winter droughts. For the US central plains region, Logan et al (2010) find drought is confined to isolated regions of the West and North plains with little difference in drought frequency patterns across the region. At the global scale Perez et al. (2011) use non-contiguous and contiguous drought area analyses to consider the spatio-temporal characteristics of drought. They note the large spatial extent of the European 1976 drought and similarly the wide geographical impact of El Nino on drought.

A predominant theme in studies that explore the underlying atmosphere-ocean causes of drought has been the role of major modes of atmospheric variability and sea surface temperatures. In this regard El Nino Southern Oscillation (ENSO) has received considerable attention. At the global scale Vicente-Serrano et al. (2011) find varying sensitivity of drought severity and duration to El Nino and La Nina and intra-annual effects concerning the importance of ENSO for explaining drought variability. They also identify geographical variation of the ENSO effect on drought duration such that ENSO has its greatest visibility at the 1-3 month timescale across large areas of the US and eastern Europe at the beginning of ENSO events while the ENSO effect is more evident and longer lasting following its onset across South Africa, Australia and Southeast Asia. While such global scale analyses based on composites with a sole focus on El Nino tend to create the impression that this particular mode of atmospheric variability "dominates", recent regional or country scale analyses that consider the interactive effects of ENSO with other modes of atmospheric variability have begun to overturn some of the traditional thinking concerning drought causes. For example, Ummenhofer et al. (2009) have revealed Indian Ocean as opposed to Pacific Ocean variability and its impact on tropical moisture transport as an important player in the generation of Australia's worst droughts. Similarly for two principal droughts in the US, Hoerling et al. (2009) found that the 1946-1956 drought that dominated the Southern Plains and adjacent Southwest was principally due to La Nina effects while drought severity over the Northern Plains during 1932-1939 was likely triggered by random atmospheric variability, possibly related to land-atmosphere feedbacks (Cook et al., 2011). The role of regional factors related to possible land-atmosphere interactions and soil moisture effects in modulating large scale climate signals is also evident for multi-year droughts across Europe (Parry et al., 2012) and Korea (Rim et al., 2012).

That ENSO does not act as a "lone ranger" is evident for a number of regions. For monsoon Asia Ummenhofer et al. (2013) demonstrate the importance of ENSO - Indian Ocean Dipole interactive effects, Barriopedro et al. (2009) highlight the role of both ENSO and the Arctic Oscillation in the development of the severe 2009-10 drought in China, while Weng et al. (2011) and Karori et al. (2013) respectively describe the effects of the three coupled ocean-atmosphere phenomena of El Nino, El Nino Modoki and the Indian Ocean Dipole on summer climate and the asymmetric effects of two types of El Nino on drought in China. As for monsoon Asia, other major regions demonstrate a range of large scale climate forcings on drought. Shanahan et al. (2009) demonstrate the role of Atlantic Ocean forcing on West African drought while Munemoto and Tachibana (2012) show that the long-term variation of precipitation over Sahel is related to shifts in inter-hemispheric atmospheric circulation driven by contrasts and reversals in Northern Hemisphere and Southern Hemisphere sea surface temperature patterns in the Atlantic region. Over East Africa it appears that sea surface temperature variations in all global oceans have seasonally dependent impacts on drought (Omondi et al., 2013). These findings are partly corroborated by Elsanabary et al. (2013) who find the El Niño region and the northern Atlantic, west of the Sahara desert, to be particularly important for controlling dry periods over Ethiopia.

South America like Africa, which also sits between two major ocean basins, demonstrates climate and drought forcing effects from both the Pacific and Atlantic (Mo et al., 2011). Of particular interest has been the role of these ocean basins and associated atmospheric circulation anomalies in explaining the occurrence of severe drought in the Amazon. Based on an analysis of three severe drought events (1997–1998, 2004–2005 and 2009–2010 ) Coelho et al. (2012) conclude that drought in the Amazon is related to enhanced subsidence and associated inhibition of rainfall formation. This leads to a protracted dry season (Marengo et al., 2011) over the Amazon Basin due to a localized Walker Cell type circulation attributable to "cool" El Nino SST conditions in the Pacific and warm SST in the North Atlantic. While these region-wide forcing mechanisms and associated drought responses make sense, analyses of drought at smaller scales within the Amazon Basin and elsewhere in South America have been useful in adding clarity to the role of anomalous SST in the North Atlantic (Espinoza et al., 2011), complex terrain and the interplay between atmospheric processes at a range of nested spatial and temporal scales in determining the spatial heterogeneity of drought in the South American region (Cavalcanti and Fonesca2012; Bobba and Minetti, 2012; Houston, 2006)..

Hurricanes, tropical cyclones or typhoons are one of the most powerful natural hazards, which because of their associated effects, can have long lasting impacts on coastal and near coastal human and natural systems. In some ways they are unique amongst a range of hydrometeorological extremes in that they generate other extreme events such as intense rainfall, hail, tornadoes, fluvial and coastal flooding, mass movements, erosion and deposition and wind damage. A huge effort has been invested in quantifying hurricane risk, especially along the western margins of the North Atlantic and North and South Pacific Ocean basins where billions of dollars of coastal investment is exposed to the impacts of hurricanes. In comparison to the Atlantic and Pacific basins, regrettably there appears to be few studies in the mainstream journal literature on the Indian Ocean region especially in the vicinity of the Bay of Bengal where tropical cyclone risk is high and the human as opposed to the built environment consequences can be devastating.

A range of methods are applied in hurricane risk assessment including statistical analyses of hurricane intensity and frequency in the time and frequency domains as well as neural network and fuzzy approaches, dynamical models of hurricane structure and behaviour, hurricane disaster loss assessment based on scenario analysis and catastrophe modelling. Added to these are studies that contribute to understanding risk through revealing the factors that influence hurricane genesis and occurrence.

The main purposes of, and recent improvements in, hurricane hazard modelling based on numerical simulations have been outlined by Vickery et al. (2009a and 2009b). While acknowledging that modelling is an important tool for hurricane risk assessment, Levinosn et al. (2010) address some of the issues that may exacerbate sampling problems for accurate characterization of hurricane parameters for design and operational applications and Vickery et al. (2009c) discuss the uncertainty associated with hurricane wind speeds estimates for the US. Harper et al. (2012) and Cook and Nicholls (2012) also touch on the way in which assumptions about hurricane dynamics can influence hurricane wind hazard estimation while Pielke (2009) compares the value of climatology over predictions in relation to risk estimation. Notwithstanding some of the assumptions associated with hurricane risk assessment, a range of studies report on risk assessment methods or risk estimates from numerical or statistical based analyses of hurricane related hazards including hurricane related storm surge in New York (Lin et al. 2010) and risk to offshore wind turbines (Rose, 2012), US air force bases (Scheitlin et al., 2011) and the built environment in Florida (Hamid et al., 2011). Examples of methodological developments in hurricane risk assessment include the application of fuzzy mathematical and grey models (Liu et al., 2012), improved hurricane track simulations (Rumpf et al., 2009), the development of a risk calculator for estimating wind risk over a range of durations (Malmstadt et al., 2010), construction of a tropical cyclone potential impact index (Xiao et al., 2011), and the integration of a range of data in a GIS framework to produce hurricane risk maps (Poulos, 2010; Taramelli et al., 2010).

Of interest to the hurricane risk community are the large-scale climate mechanisms and factors associated with the inter-annual variation of hurricane occurrence as knowing these can inform the development of hurricane forecasting models for a range of time scales (Emmanuel et al., 2006; Klotzbach, 2011a; Slade et al., 2013; Veechi et al., 2013; Villarini et al., 2012; Villarini and Veechi, 2013). Of a range of factors, the role of regional and remote sea surface temperatures (Dailey et al., 2009; Jin et al., 2013; Rumpf et al., 2010; Wang et al., 2011) and large-scale modes of atmospheric or oceanic variability such as El Niño-Southern Oscillation, the Madden-Julian Oscillation and the Indian Ocean Dipole (Klotzbach, 2011b, 2012; Larson et al. 2012; Lin et al., 2012; Werner et al., 2012) have received attention. Of course, a fundamental requirement for robust hurricane risk assessment is the availability of quality assured homogenous tropical cyclone frequency, intensity and track data. Accordingly the compilation of tropical cyclone data bases has received much attention in the literature (Diamond et al., 2012; Knapp et al., 2010; Levinson et al., 2010b; Weinkle et al., 2012).

## V Synthesis

Climate risk management, which is broadly the use of climate information in risk related decision making in climate sensitive sectors and ecosystem services, is comprised of a number of steps of which assessing the risk associated with a particular aspect of the climate system is crucial. A range of methods and information have been applied to risk assessment, as part of the overall CRM process. However, there is still room for advances with respect to the use of structured information and transparent methodologies so as to add to the scientific rigour and reproducibility of risk assessments. Another area ripe for attention is the development of impact, as well as adaptation, indicators. The former are required to establish the link between impacts and associated weather and climate anomalies while the latter will assist in evaluating the efficacy of intervention strategies.

As climate risk assessment is dependent on the availability of high quality long term climate data and an understanding of the climate processes associated with generation of the physical hazards that precipitate risk, climate reconstruction using a range of historical records as well as the generation of global climate data sets constitute an important part of CRM. Likewise, understanding the ocean and atmospheric dynamics associated with the development of a range of hydrometerological hazards, such as drought and hurricanes, provides the scientific knowledge required for the development of statistical and dynamical seasonal climate forecast models and related products. Facilitating uptake of such science in climate related risk decision making may well be contingent upon understanding a range of non-climate factors. Therefore, for the sustainability of the "climate" component of climate risk management, it is probably necessary for climate risk management to develop over the next five to ten years as a truly interdisciplinary enterprise.

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