SUBSEASONAL TO SEASONAL PREDICTION

RESEARCH IMPLEMENTATION PLAN

22 June 2012

“Subseasonal to Seasonal Prediction Project”

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Executive Summary

The subseasonal to seasonal timescale provides a unique opportunity to capitalise on the expertise of the weather and climate research communities, and to bring them together to improve predictions on a timescale of particular relevance to the Global Framework for Climate Services (GFCS). A planning group which included representatives from WWRP/THORPEX, WCRP, CBS and CCl drafted the implementation plan, giving high priority to establishing collaboration and co-ordination between operational centres and the research community involved in subseasonal to seasonal prediction, and to sponsorship of key international research activities.

From the end-user perspective, the subseasonal to seasonal time range is a very important one, as many management decisions in agriculture and food security, water, disaster risk reduction and health fall into this range. Improved weather-to-climate forecasts promise to be of significant social and economic value. An integrated decisional framework such as the READY, SET, GO being developed by the Red Cross and IRI, where seasonal forecast provide READY information, subseasonal the SET and weather forecasts the GO stage illustrates the potential benefit of a more seamless approach to predictions.

Forecasting for the subseasonal time range has so far received much less attention than medium-range and seasonal prediction as it has long been considered as a `predictability desert`. However, recent research has indicated important potential sources of predictability for this time range which can be realized through better representation of atmospheric phenomena such as the Madden Julian Oscillation (MJO) and improved coupling with, and initialisation of, the land-ocean-cryosphere and stratosphere. Better understanding of these potential sources of predictability together with improvements in model development, data assimilation and computing resources should result in more accurate forecasts. In particular, the representation of the MJO in models has improved substantially in recent years and some models now have skill beyond 20 days. This has important implications globally due to links between this tropical phenomenon and major modes of variability such as El Nino-Southern Oscillation and the North Atlantic Oscillation. Models are beginning to represent these links and processes better but there is still a need for further improvement. In addition, identifying windows of opportunity with increased forecast skill could be the basis for enhanced, actionable forecasts. However, much more research is needed to explore all the potential sources of predictability and model development is needed to subsequently exploit this potential predictability.

The main goal of the proposed WWRP/THORPEX-WCRP joint research project is to improve forecast skill and understanding on the subseasonal to seasonal timescale, and promote its uptake by operational centres and exploitation by the applications community. Specific attention will be paid to the risk of extreme weather, including tropical cyclones, droughts, floods, heat waves and the waxing and waning of monsoon precipitation. Work will be guided by a steering group that will work in conjunction with appropriate WMO bodies and other relevant structures.

To achieve many of these goals the planning group advocates the establishment of an extensive data base of subseasonal (up to 60 days) forecasts and reforecasts (sometimes known as hindcasts), modelled in part on the THORPEX Interactive Grand Global Ensemble (TIGGE) database for medium range forecasts (up to 15 days) and the Climate-System Historical Forecast project (CHFP) for seasonal forecasts. Developing an extensive data base for the subseasonal time scale will be a challenging task since consensus still needs to be reached on how to produce these forecasts (start dates, length of the forecasts, averaging periods, update frequency of the forecasts). For NWP forecasts, model error is not usually so dominant that a reforecast set is needed but for the subseasonal to seasonal range model error is too large to be ignored. Therefore an extensive reforecast set spanning several years is needed to calculate model bias, which in some cases can also be used to evaluate skill.

Careful calibration and judicious combination of ensembles of forecasts from different models into a larger ensemble can give higher skill than that from any single model. Comparing, verifying and testing multi-model combinations from these forecasts, quantifying their uncertainty as well as the handling of such a massive dataset will nevertheless be challenging.

An important aspect will be to promote use of these forecasts and their uncertainty estimates by the applications community. The project will focus on some specific case studies, such as the Russian heat wave of 2010, the Pakistan floods in 2010, Australian floods of 2011, European cold spell in 2012, as demonstration projects. These examples can also provide the basis to better quantify benefits through links with the WWRP Societal and Economic Research and Applications (SERA) working group and relevant WCRP activities. Truly actionable science for a wide range of decision makers will require inter-disciplinary researchers engaged in developing risk-management strategies and tools for establishing climate services. Extensive multi-model reforecast sets will also be needed to build statistical models which are used to tailor climate forecasts for use in sector- specific applications on the seasonal scale.

Open access to forecast data and user-friendly data bases are important requirements for broad community uptake. The data base will underpin the research that can shape the scope of developing operational products to be provided by the WMO Global Producing Centres and eventually to serve real time forecasts via the WMO Lead Centres for Long Range Forecast Multi Model Ensembles as coordinated by CBS.

The proposed WWRP/THORPEX-WCRP joint research project to improve forecast skill and understanding on the subseasonal to seasonal timescale will require:

- The establishment of a project Steering Group representing both the research and operational weather and climate communities. The steering group will be responsible for the implementation of the project;
- The establishment of a project office to coordinate the day to day activities of the project and manage the logistics of workshops and meetings;
- The establishment of a multi-model data base consisting of ensembles of subseasonal (up to 60 days) forecasts and supplemented with an extensive set of reforecasts following TIGGE protocols. A workshop will be necessary to address technical issues related to the data base;
- A major research activity on evaluating the potential predictability of subseasonal events, including identifying windows of opportunity for increased forecast skill with a special emphasis on events that have high societal or economic impacts. Attention will also be given to the prediction of intraseasonal characteristics of the rainy season that are relevant to agriculture and food security in developing countries.
- A series of science workshops on subseasonal to seasonal prediction. The first topic identified is "Sources of predictability at the subseasonal timescale- windows of opportunity for applications";
- Appropriate demonstration projects based on some recent extreme events and their impacts, in conjunction with the WWRP SERA

This challenging project will require 5 years, after which the opportunity for a 5 year extension will be considered.

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1. Introduction

This document describes the scientific issues as well as the implementation actions identified by the Subseasonal to Seasonal Prediction planning group**.**

1.1 History

A number of recent publications (Brunet et al 2010, Hurrell et al 2009, Shapiro et al 2010, Shukla et al 2010) have stressed the importance of and need for collaboration between the weather and climate communities to better tackle shared critical issues, and most especially to advance subseasonal to seasonal prediction. Such an initiative would help bridge the gap between the numerical weather and short-term climate communities and be an important step towards a seamless weather/climate prediction system. These recent studies also promoted the fact that weather, climate, and Earth-system prediction services would greatly benefit from this joint effort.

Based on this proposal and on the potential for improved forecast skill at the subseasonal to seasonal time range, the WMO Commission of Atmospheric Sciences (CAS) requested at its 15th session (November 2009) that the Joint Scientific Committees of the World Weather Research Programme (WWRP) and the World Climate Research Programme (WCRP) and also the THORPEX international Core Steering Committee (ICSC) set up an appropriate collaborative structure to carry out an international research initiative on this time range and recommended that this initiative be coordinated with future developments in the Global Framework for Climate Services (GFCS). This effort should be a significant contribution of the WCRP/WWRP to the Global Framework for Climate Services. The initial response to this request was to convene a joint WWRP/THORPEX/WCRP Workshop which was held at the UK Met Office (1 to 3 December 2010). The Reports from the Workshop on “Subseasonal to Seasonal Prediction” (Met Office, Exeter 1 to 3 December 2010) are on the web:
http://www.wmo.int/pages/prog/arep/wwrp/new/documents/recommendations_final.pdf
and
http://www.wmo.int/pages/prog/arep/wwrp/new/documents/CAPABILITIES_IN_SUB_SEASONAL_TO_SEASONAL_PREDICTION_FINAL.pdf.

The major Workshop recommendation was that a Panel for Subseasonal prediction research should be established and that members should include representatives from WWRP-THORPEX, WCRP, CBS and CCl and their relevant programme bodies. With the approval of the Chairs of the WWRP/JSC and the WCRP/JSC, the subseasonal to seasonal prediction planning group was established. The membership is given in Annex 1. The Panel was tasked with preparing an Implementation Plan, consistent with the contents of the Workshop Report and Recommendations. A kick-off meeting of the planning group took place on 2-3 December 2011 in Geneva to begin preparation of the implementation plan which is discussed in the present document.

1.2. Motivation

From the end-user perspective, the subseasonal time scale is a very important one, because it lies between the well-established and routine use of weather forecasts in diverse areas on the one hand, and the developing use of seasonal forecasts on the other. Many management decisions, such as in agriculture, fall into the intervening sub-monthly scale, so the development of more seamless weather-to-climate forecasts promises to be of great societal value. The Pakistan floods (2010), concurrent with the Russian heat wave, were two extreme events with very high societal impact which exhibited some associations with tropical-extratropical interactions. Reliable and skilful subseasonal forecasts for this period could have been of considerable value.

Forecasting the day-to-day weather is primarily an atmospheric initial condition problem, although there can be an influence from ocean and land conditions. Forecasting at the seasonal to multi-annual range depends strongly on the slowly-evolving component of the earth system such as the sea surface temperature. In between these two time scales is subseasonal variability (defined in the present document as the time range between 2 weeks and 2 months). Forecasting for this time range has so far received much less attention than medium-range and seasonal prediction despite the considerable socio-economic value that could be derived from such forecasts. This timescale is critical to proactive disaster mitigation. It is considered a difficult time range since the lead time is sufficiently long that much of the memory of the atmospheric initial conditions is lost and it is too short a time range for the variability of the ocean to have a strong influence. However, recent research has indicated important potential sources of predictability for this time range such as from the Madden Julian Oscillation, stratospheric initial conditions, land/ice/snow initial conditions, sea surface temperatures. Recent improvements in computing resources and model development may make it possible to develop a better representation of these sources of subseasonal predictability. An example of such improvement is the substantial progress in the representation of the Madden Julian Oscillation in some models. Thanks to these improvements, a few operational centres are now producing operational subseasonal forecasts. The joint and collaborative effort on subseasonal to seasonal prediction planned here between WWRP/THORPEX and WCRP brings together WWRP/THORPEX expertise needed to build from weather time scales outward, with WCRP building the bridge inward from seasonal-to-interannual scales inward. The subseasonal scale is the critical interface where weather and climate services also come together, providing a natural operational bridge.

One of the largest issues from a climate perspective is how extreme events may change under human-induced climate change; how seasonal-to-interannual variability affects the probability of extreme events, from heat waves to hurricanes, is also a key issue. Many of the extreme events with the largest impacts have a strong sub-seasonal/weather character, reinforcing the importance of subseasonal time scales for advancing both understanding and predictions of extreme events in a variable and changing climate. Scientific approaches are needed that will progressively stage information down time scales from decades to days, adding specificity on risks of events as we move toward shorter lead times. It is highly plausible that probabilistic predictions of weather/climate risks can be sharpened by considering joint conditions, e.g., how climate change + ENSO + MJO alters the risk of extreme events in a given region and time. From a societal benefits perspective, “forecasts of opportunity” constructed from such joint probabilities on subseasonal time scales may aid in planning and preparedness for high-impact events for many applications, e.g., in advancing lead times for agriculture planning or anticipating and mitigating impacts on local or global food supplies due to persistent large-scale weather extremes like heat waves or subseasonal dry spells or droughts.

Assessing how subseasonal-to-seasonal variations may alter the frequencies, intensity and locations of high impact events is a high priority for decision making. This makes the development and use of ensemble-based modelling a requirement to improve estimates of the likelihood of high-impact events a central scientific issue. In general, a multi-model ensemble prediction system (MEPS) approach provides more useful probability density functions (PDFs) than those obtained from a single EPS when using EPSs of comparable skill. Over the past years, a few MEPS have been set up for medium-range weather and seasonal forecasting: the THORPEX Interactive Grand Global Ensemble (TIGGE) for forecasts up to 2 weeks, the WMO lead centre for long-range forecasts and the Climate-System Historical Forecast Project (CHFP) for seasonal forecasts. However, these databases were not designed to study subseasonal prediction. Therefore an important motivation for the subseasonal to seasonal prediction project is to produce a MEPS database from the current operational subseasonal forecasts. Such a database would be a useful tool to investigate predictability at the subseasonal to seasonal time range and study the usefulness of these forecasts for a wide range of applications. MEPS is not the only way of improving, a posteriori, the reliability or the skill of forecasts. Using the TIGGE data base it has been shown that calibration can also be beneficial, and development of other methods is likely. See Anderson 2011.

1.3. Main objectives

The main goal of this project is to develop coordination among operational centres to improve forecast skill and applications on the sub-seasonal timescale by filling the gap between medium-range and seasonal forecasting and linking the activities of WCRP and WWRP. For that purpose, the WWRP/THORPEX/WCRP Workshop which was held at the UK Met Office (1 to 3 December 2010) recommended the following objectives for the subseasonal-to-seasonal prediction project:

- Sponsorship of a few international research activities
- The establishment of collaboration and co-ordination between operational centres undertaking subseasonal prediction to ensure, where possible, consistency between operational approaches to enable the production of data bases of operational subseasonal predictions to support the application of standard verification procedures and a wide-ranging programme of research.
- Facilitating the wide-spread research use of the data collected for the CHFP (and its associate projects), TIGGE and YOTC[1]for research
- The establishment of a series of regular Workshops on subseasonal prediction

1.4 Parent Organizations

Three main parent organizations are supporting this initiative: The World Weather Research Programme (WWRP), The Observing System Research and Predictability Experiment (THORPEX) – a programme of WWRP, and the World Climate Research Programme (WCRP).

The motivation for the WWRP is to meet the needs of WMO Members by providing research to advance both the prediction of high-impact weather and the utilization of weather products for the benefit of society, the economy and the environment. The activities of the WWRP span nowcasting, mesoscale meteorology, global numerical weather prediction, tropical meteorology, forecast verification, weather modification assessment, and societal and economic research and applications. Given the breadth of the WWRP, scientific Working Groups have been set up to initiate and guide the activities in each of these areas. WWRP Working Groups are composed of international leaders in weather research, operational weather prediction and the usage of weather information. The Working Groups report to a Joint Scientific Committee (JSC) of WWRP. In the case of global numerical weather prediction, the Working Groups in the major areas of research have been focused into a single programme called THORPEX with its own internal organizational structure and a budget provided through donor contributions to a Trust Fund at the WMO. The intent of creating a single programme for this research area was driven largely by unmet research challenges, since there has not been a broad international research programme aimed at global weather prediction since the GARP effort of the late 1960s and early 1970s.

Similarly, the motivation for the WCRP is to meet the needs of WMO, IOC and ICSU Members by facilitating the analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society. This endeavor is organized around two overarching objectives: to determine the predictability of climate and to determine the effect of human activities on climate. The WCRP is organized around 4 core projects, to deal with the main components of the earth system (atmosphere, ocean, land and cryosphere), and a number of cross-cutting activities in modeling (e.g., numerical experiments, coupled modeling, seasonal to interannual predictions, regional climate), observations (e.g., reanalyses, data assimilation) and capacity building (e.g. adaptation, impact studies). Progress in understanding climate system variability and change, to improve climate predictability and the use of this predictive knowledge in developing adaptation and mitigation strategies are important objectives. Such strategies assist the global communities in responding to the impacts of climate variability and change on major social and economic sectors including food security, energy and transport, environment, health and water resources. Given the breadth of the WCRP work, scientific Working Groups have been set up to initiate and guide the activities in each of these areas and they report to a Joint Scientific Committee (JSC) of WCRP.

The main criterion for WWRP and WCRP research activities is whether research advances would result from an orchestrated international collaboration and which would address a specific socio-economic need. In selecting priority areas and future tasks, the WWRP and WCRP consider advances in scientific knowledge and growing technical capabilities in both research and applications, such as operational predictions and climate services respectively.

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[1] Year of Tropical Convection See Waliser and Moncrieff (2008)

One of these emerging priorities is to improve subseasonal-to-seasonal predictions via a joint WWRP-WCRP partnership with a strong THORPEX legacy. Motivation for this priority, in part, is driven by recent work that reveals that some of the important biases in climate modelling are already evident in 3 to 5 day weather forecasts. The WWRP and WCRP have also already identified a number of areas of collaborative research for the improvement of subseasonal-to-seasonal predictions: These include the development of seamless weather/climate predictions including Ensemble Prediction Systems (EPSs), multi-scale organization of tropical convection and its two-way interaction with the global circulation (e.g. Year of Tropical Convection- YOTC), data assimilation for coupled models as a prediction and validation tool for weather and climate research, and utilization of subseasonal to seasonal predictions for socioeconomic applications.

The WCRP Working Group on Seasonal to Interannual Predictions (WGSIP) is a valuable key stakeholder to the subseasonal to seasonal research project. It aims at developing a programme of numerical experimentation for seasonal-to-interannual variability and predictability, paying special attention to assessing and improving predictions by developing appropriate data assimilation, model initialization and forecasting procedures, considering such factors as observing system evaluation, use of ensemble and probabilistic methods, statistical and empirical enhancements, and measures of forecast skill.

The CBS Expert Team on Extended- and Long-Range Forecasting (ET-ELRF) is a valuable key stakeholder to the subseasonal to seasonal research project. The ET-ELRF provides guidance to the production verification, access, dissemination, exchange and use of long-range forecasts through the identified WMO Lead Centres and Global Producing Centres. It is foreseen that there will be close cooperation and exchange between these two initiatives to ensure alignment of the research effort to the needs of users of forecasts on the subseasonal to seasonal time scales.

1.5 Structure of the document

The potential applications of subseasonal-to-seasonal forecasts are discussed in Sect. 2, followed in sections 3 and 4 by research and modelling issues relevant to the improvement in reliability and skill of subseasonal to seasonal forecasts. One of the main tasks in the panel's terms of reference was the construction of a multimodel data base. A summary of current activities relevant to this is presented in sec 5 and a proposal for a multi-model data base is given in section 6. Specific demonstration projects, showing potential skill in forecasts including a link through to applications are discussed in section 7. The subseasonal to seasonal forecast project should seek to develop links with already on-going or planned activities, and with panels already established by WWRP and WCRP. Some potential links are given throughout the document as well as listed in section 8. Finally in section 9 the next steps needed to improve the understanding and prediction of subseasonal to seasonal forecasts are discussed.

2. Needs and Applications

Weather and climate events continue to exact a toll on society despite the tremendous success and investment in prediction science and operational forecasting over the past century. Weather-related hazards, including slow onset of rainy seasons and chronic events such as drought and extended periods of extreme cold or heat, trigger and account for a great proportion of disaster losses, even during years with other very large geophysical events (e.g., Haitian and Chilean earthquakes). While many end-users have benefited by applying weather and climate forecasts in their decision-making, there remains ample evidence to suggest that such information is underutilized across a wide range of economic sectors (e.g., Morss et al., 2008; Rayner et al., 2005; O'Connor et al., 2005; Pielke and Carbone, 2002; Hansen, 2002). This may be explained partly by the presence of 'gaps' in forecasting capabilities, for example at the subseasonal scale of prediction, and partly by a lack of understanding and appreciation of the complex processes and numerous facets involved in decision making.

The subseasonal to seasonal scale is especially interesting as it bridges applications at much shorter (hourly through weekly) and much longer (seasonal through decadal) scales where considerably more societal and economic research has been conducted (e.g., decision and economic valuation studies, climate change impact and adaptation studies). It is therefore an ideal scale to improve forecasts and to evaluate the development, use, and value of predictive information in decision-making.

In principle, advanced notification, on the order of two to several weeks, of tropical storms, severe cold outbreaks, the onset or uncharacteristic behaviour of the monsoonal rains, and other potentially high impact events, could yield substantial benefits through reductions in mortality and morbidity and economic efficiencies across a broad range of sectors. Realization of the potential value of such information is, however, a function of several variables, including: the sensitivity of an individual, group, enterprise or organization (or something they value) to particular weather events; the extent and qualities of their exposure to the hazard; their capacity to act to mitigate or manage the impacts such that losses are avoided and benefits are enhanced; and the ability of predictive information to influence their decisions to take action. Unlocking value therefore involves much more than creating a new or more accurate prediction, product, or better service.

From the end-user perspective, the subseasonal time scale is a very important one, because it lies between the well-established and routine application of weather forecasts in diverse areas on the one hand, and the developing use of seasonal forecasts on the other. Many management decisions, such as in agriculture, fall into the intervening sub-monthly to two-monthly time scale, so the development of more seamless weather-to-climate forecasts promises to be of significant societal value, and will augment the regions/situations where there is actionable forecast information. As such, this activity is envisioned as a significant contribution of the WCRP/WWRP to the Global Framework for Climate Services (GFCS).

Weather and climate span a continuum of time scales, and forecast information with different lead times is relevant to different sorts of decisions and early-warning. Extending downward from the seasonal scale, a seasonal forecast might inform a crop-planting choice, while sub-monthly forecasts could help irrigation scheduling and pesticide/fertilizer application, by making the cropping calendar a function of the subseasonal-to-seasonal forecast, and thus dynamic in time. In situations where seasonal forecasts are already in use, subseasonal ones could be used as updates, such as for estimating end-of-season crop yields. Subseasonal forecasts may play an especially important role where initial conditions and intraseasonal oscillation yield strong subseasonal predictability, while seasonal predictability is weak, such as in the case of the Indian summer monsoon. Extending upward from application of NWP, which is much more mature, there is a potential opportunity to extend flood forecasting with rainfall-runoff hydraulic models to longer lead times. In the context of humanitarian aid and disaster preparedness, the Red Cross Climate Centre/IRI have proposed a “Ready-Set-Go” concept for making use of forecasts from weather to seasonal, in which seasonal forecasts are used to begin monitoring of subseasonal and short-range forecasts, update contingency plans, train volunteers, and enable early warning systems (“Ready”); sub-monthly forecasts are used to alert volunteers, warn communities (“Set’); and, weather forecasts are then used to activate volunteers, distribute instructions to communities, and evacuate if needed (“Go”). This paradigm could be useful in other sectors as well, as a means to frame the contribution of subseasonal forecasts to climate service development within GFCS.

Examples of possible applications/users include: warnings of the likelihood of severe high impact weather (droughts, flooding, tropical and extratropical cyclones etc.) to help protect life and property; humanitarian planning and response to disasters; agriculture and disease planning/control (e.g., malaria and meningitis), particularly in developing countries; river-flow and river-discharge for flood prediction, hydroelectric power generation and reservoir management; landslides; coastal inundation; transport; power generation; insurance.

For some applications certain “raw” forecast parameters may be directly useable to inform disaster mitigation decision making, for example, parameters such as typhoon track, intensity and landfall probabilities, or monsoon onset date and rainday-frequency within the rainy season could be useful in this context. However, in general a process of calibration is required to remove model biases, and for downscaling, or more general “tailoring” of the forecasts may be required to target user-specific needs. This process of tailoring may involve empirical models or applications-specific models, such as river-flow or crop-growth models; recent disasters point up the urgency of developing landslip and coastal inundation models. However, adapting the application model to run smoothly off model output at model scales is often a difficult problem and resources required are frequently underestimated. Here, determining how much intricacy is required for the end user to make actionable decisions is an important element of the application model.

In the seasonal forecasting context, the tailoring of the forecasts to decision-relevant quantities is often statistical, and can be framed as an extension of the model-output calibration process that is used to re-calibrate forecast output in terms of observed meteorological variables (e.g., precipitation) through the use of statistical models, or through physically-based sectoral dynamical models, or some combination of the two. This general process can be interpreted as a forecast assimilation process, whereby the forecast is assimilated into the decision making context. Tailoring of seasonal forecasts hinges on reforecast (sometimes called hindcast or retrospective forecast) sets with matching characteristics to the real-time system, using the “MOS” (Model Output Statistics) approach. These reforecast sets allow (1) the statistical MOS transformations (usually regression based) to be constructed, and (2) the skill of the tailored forecast system to be quantified, typically by means of cross-validation. The second step is recognized as being of central importance to providing forecasts that are actionable, since users are often risk-averse and need to have confidence in the forecast information. For this to be the case, forecasts need to be probabilistic and reliable, so that the forecast distribution of the outcome only deviates from the climatological expectations where and when there is predictability.

An important question concerns how the different applications experiences/communities in weather vs. seasonal forecasting can be exploited/capitalized for the intermediate time scale. Applications of the subseasonal forecasts lie beyond the deterministic predictability limit of weather and forecasts and so need to be probabilistic, and thus may profit from methodologies developed for applications of seasonal forecasts. On the other hand, long and large reforecast sets are unlikely to be as readily available as they are for seasonal forecasts, while ensemble-spread skill relationships may be stronger at subseasonal leads.

Success, even where there is already a measure of predictive skill, will depend crucially on the willing involvement of the community and regional centres, and co-development with stakeholder involvement. This will require, amongst other things, communication with the users to understand requirements, appropriate methods of dissemination and the development of understanding and use of probabilistic forecasts for decision making.

Supported by a partial, in-progress literature review (Silver and Mills 2012) it is possible to distinguish three general categories of applications: 1) Monthly and seasonal forecasts available to the public and typically funded and delivered through National Meteorological and Hydrometeorological Service organizations; 2) Sector, issue or organization-specific applications that may either be operational or piloted as a research demonstration activity but where detailed methods and results are typically reported in the peer-reviewed literature or government publications; and 3) Proprietary applications in specialized industrial sectors (e.g., insurance, financial trading) or government operations (e.g., military). Drawing from this array of experience, as well as the larger meteorological applications and decision support literature, two primary societal research and application activities are recommended:

1) Evaluation of past and current experience

The key question within this topic is how have existing application needs been identified, decision support systems designed and implemented, evaluations conducted, and benefits realized? An outcome should be a preliminary list of ‘better practices’ measured against a set of well-defined criteria derived from the literature. Such an exercise would benefit from the development of an inventory of societal applications of prediction/decision support at the subseasonal to seasonal scale; an annotated bibliography and bibliometric analysis to identify research gaps and priority topics; and consultation, through a survey and follow-up interviews, with WMO members (NMHSs) to identify past, on-going, and planned services.

2) Demonstration applications with emphasis on communication and valuation

Even in the absence of a thorough literature review, it can be assumed that ‘communication’ will be an important theme (Morss et al., 2008). A key objective is to understand how the nature of the message content (e.g., raw meteorological element, impact expectations, suggested actions; explicit uncertainty; precision; use of analogues and societally-relevant verification measures), media (e.g., conversation, Internet, mobile device, video, radio, print, etc.), format (e.g., text, numeric, narrative; audio, visual), frequency, timing, and source (e.g., trust, credibility factors), in relation to the decision problem(s), interacts with situational variables (e.g., institutional, technical, political, social, cultural, and economic factors) to influence individual and collective perception, attitudes and decision-making behaviour? Since the quality of subseasonal forecasts is highly variable in time, being dependent upon the presence of strong atmosphere-ocean teleconnections, there is the potential to experiment with new and innovative approaches to communicating forecast (and impact) uncertainty that may have implications for decision tendencies and actions.

Societal (including economic) valuation is a logical extension from communication as it depends on understanding decision choices, actions and their consequences. An indication of the absolute value of subseasonal to seasonal forecasts, for at least a few sectors/activities, would be an important outcome. More useful would be the comparison of different methods used to determine value (e.g., prescribed or top-down assumptions regarding information use; stated preference values derived from surveys; analysis of actual behaviour in experimental and real-world settings).

These activities would be pursued through the development of demonstration applications, most likely extensions of existing projects, for example those presented at the initial December 2011 workshop (identify examples/sources). Given limited resources, it would be favourable to treat 1-3 application areas (e.g., emergency management, power generation and distribution, humanitarian aid, insurance) in-depth in multiple places/contexts (e.g.., developing/developed nation; urban/rural; frequent/infrequent weather events) than just a low-level analysis or broadbrush of many sectors. Flexibility should be retained to address other issues and gaps that result from the first, evaluative activity.

The breadth and variety of the applications raises the need for:

- Archiving all reasonable variables needed for applications
- Attention to reforecast sets from the sectoral modelling perspective
- Focused metrics or indices, in addition to the "popular" skill scores employed by modellers, related to the skill of the decision-making
- A focused evaluation of decisions and corresponding weather or climate risks/sensitivities and information needs for one type of user in multiple social, economic, environmental, political and cultural settings (for example emergency management and power generation and distribution
- Promotion of subseasonal forecast archives and demonstrations of successful application projects on this time scale

A partial list of on-going applications activities at operational centres is given in Annex 6.

3. Research Issues

As indicated in section 1, subseasonal forecasting is at a relatively early stage of development. Many issues remain to be resolved and procedures improved before the full potential of subseasonal prediction can be realised. There are glimpses of potential predictability well beyond the range of normal numerical weather prediction (NWP) (~10 days), but the range of processes involved is not well understood. It is likely that predictive skill will be higher in certain windows of opportunity but exactly what these are or how to recognise them is still unclear. For that reason relevant science issues that need to be addressed will be reviewed in section 3 and modelling issues in section 4.

3.1 Predictability

Short to medium-range weather prediction is considered to be mainly an atmospheric initial value problem. The estimated limit for making skilful forecasts of mid-latitude weather systems is about two weeks, largely due to the sensitivity of forecasts to the atmospheric initial conditions (Lorenz 1965; 1969). Subseasonal predictions, on the other hand, benefit from both atmospheric initial conditions and factors external to the atmosphere, such as the state of the ocean, land, and cryosphere. Processes internal to the atmosphere including the Madden-Julian Oscillation (MJO) and low-frequency atmospheric patterns of variability also contribute significantly to the predictability (Nat Acad. Sci. 2010). Furthermore, in a subseasonal forecast, some kind of time average (e.g. weekly or pentad mean) is usually used, which removes part of the weather noise. Therefore, it is reasonable to expect subseasonal forecasts i.e. beyond the traditional weather forecast limit of two weeks, to have useful skill. At this time range the forecasts have to be probabilistic.

Sources of subseasonal predictability come from various processes in the atmosphere, ocean and land, although they are not yet fully understood. A few examples of such processes are:

1) The MJO: as the dominant mode of intraseasonal variability in the tropics that couples with organized convective activity, the MJO has a considerable impact not only in the tropics, but also in the middle and high latitudes, and is considered as a major source of global predictability on the subseasonal time scale (e.g. Waliser 2011);
2) Soil moisture: memory in soil moisture can last several weeks which can influence the atmosphere through changes in evaporation and surface energy budget and can affect the forecast of air temperature and precipitation in certain areas during certain times of the year on intraseasonal time scales (e.g., Koster et al., 2010);
3) Snow cover: The radiative and thermal properties of widespread snow cover anomalies have the potential to modulate local and remote climate over monthly to seasonal time scales (e.g., Sobolowski et al., 2010; Lin and Wu 2011);

4) Stratosphere-troposphere interaction: signals of changes in the polar vortex and the Northern Annular Mode/Arctic Oscillation (NAM/AO) are often seen to come from the stratosphere, with the anomalous tropospheric flow lasting up to about two months (Baldwin et al., 2003);
5) Ocean conditions: anomalies in SST lead to changes in air-sea heat flux and convection which affect atmospheric circulation. The tropical intraseasonal variability (ISV) forecast skill is found to be improved when a coupled model is used (e.g., Woolnough et al. 2007; Fu et al. 2007).

Great efforts have been made on the prediction of the tropical ISV, specifically the MJO. This reflects the expectation of a possible substantial gain of global subseasonal forecast skill from an improved forecast of the MJO. To assess the potential predictability of the MJO, the "perfect model" approach is usually used, where one member of the model forecast is verified against the ensemble of other members (e.g., Waliser et al. 2003; Reichler and Roads 2005; Pegion and Kirtman 2008; Rashid et al. 2010). The estimated limit of potential predictability of the MJO ranges from 20 to 40 days, which is model-dependent. Different empirical and statistical models have been developed to predict the MJO (e.g., Waliser et al. 1999; Lo and Hendon 2000; Wheeler and Weickmann 2001; Mo 2001; Jones et al. 2004; Maharaj and Wheeler 2005; Jiang et al. 2008). The useful predictive skill of the MJO from these empirical models can usually reach a lead time of about 15-20 days. For the dynamical models, the MJO forecast skill has displayed remarkable improvements in recent years. About 10 years ago, the actual forecast skill of the MJO by all the dynamical models was considerably lower than that of the empirical models (e.g., Chen and Alpert 1990; Jones et al. 2000; Hendon et al. 2000). In general these studies using dynamical models found some MJO skill only out to about 7–10 days. Recently, skilful MJO forecasts are reported to go beyond 20 days (e.g., Kang and Kim 2010; Rashid et al. 2010; Vitart and Molteni 2010). The progress can be related to model improvement and better initial conditions, as well as the availability of historical reforecasts to calibrate the forecast.

There have been studies on subseasonal prediction and predictability of other individual systems. For example, Webster and Hoyos (2004) have developed an empirical model for predicting ISV in Indian rainfall based on predictors from the composite structure of the boreal summer ISO. The model illustrates skill out to 20-25 days. Subseasonal forecasts of tropical storms in the Southern Hemisphere are found to be useful up to week 3 (Vitart et al. 2010). Johansson (2007) estimated the prediction skill of the PNA and NAO in the operational forecasting models of NCEP and ECMWF. The correlation skill drops to the 0.50 level at about 10-day lead time, which is slightly more skilful than that for the Northern Hemisphere extratropical flow as a whole due to the large-scale and low-frequency nature of the PNA and NAO. The skill of the NAO forecast is found to be influenced by the existence of the MJO signal in the initial condition (Lin et al. 2010b). Subseasonal predictability of extreme weather is of great interest. There have been several recent predictability studies on the 2010 Russian heat wave (Matsueda 2011; Schultz 2011; Dole et al. 2011) and the 2010 Pakistan floods (Webster et al. 2011; Lau and Kim 2011). It was suggested that the 2010 Russian heat wave is predictable up to 9 days in advance (Matsueda 2011), and the Pakistan rainfall is predictable out to 6–8 days (Webster et al. 2011). Both of the extreme events are related to an extraordinary strong and prolonged extratropical atmospheric blocking event, and excitation of a large-scale atmospheric Rossby wavetrain spanning western Russia, Kazakhstan, and north western China/Tibetan Plateau region. A connection with the monsoonal intraseasonal oscillation was also found (Lau and Kim 2011).

Model uncertainty prevents one from having a reliable estimate of subseasonal predictability. Forecast skill against observations provides a lower bound for predictability, which measures the performance of individual models. The potential predictability resulting from the "perfect model" approach is also highly model-dependent. What can be achieved is unclear. Uncertainty due to model formulation can be improved by multi-model methodologies. Questions that can be explored using a multi-model approach include those related to the upper limit of subseasonal predictability and possible skill improvement.

There is still much to learn on sources of predictability. Since not all the processes and interactions are resolved in numerical models, there may still be untapped sources of predictability. It is important to know the relative importance of different sources. Their combination may not be linear, and how the sources interact with each other is not well understood. Other questions related to source of predictability can also be investigated. For example, it is still unclear how the models agree on the contribution of the MJO to the forecast skill of surface air temperature and precipitation in extratropical regions. Further studies are needed on models' fidelity in representing global teleconnections and how that influences the forecast skill.

It is necessary to have some common methodologies to quantitatively estimate prediction skill, validate models and verify forecasts. This will facilitate an objective comparison across different models.

3.2 Madden Julian Oscillation (MJO) or Intraseasonal Oscillation (ISO)

Given the great importance of the MJO highlighted in the previous section, it is not surprising that there is already an active task force focussed on the MJO. Some relevant work on-going or needed is outlined here.

The framework for the discussion on the MJO takes the following approach: 1) Describe the main focus areas, including motivation and activities, of the work being done by the WCRP-WWRP/THORPEX MJO Task Force, 2) Describe how the planned work by the project could benefit the MJO Task Force and vice versa, and 3) Discuss some general recommendations on high priority areas from the perspective of the MJO Task Force. For reference, please see www.ucar.edu/yotc/mjo.html.

3.2.1 Work being done by the MJO Task Force (MJOTF).

The work by the task force can be organized into four subprojects. These include;

1) Process-Oriented Diagnostics/Metrics for MJO Simulation
2) MJO Metrics for WGNE/WGCM Climate Metrics Panel
3) Boreal Summer Forecast and Monitoring Metrics
4) Vertical Structure and Diabatic Processes of the MJO

Subproject 1) continues the development and application of MJO simulations diagnostics work [Kim et al. 2009; Waliser et al. 2009] started by the limited lifetime CLIVAR MJO Working Group (MJOWG; www.usclivar.org/mjo.php). These initial diagnostics (climate.snu.ac.kr/mjo_diagnostics/index.htm) were designed to provide quantitative measures of MJO simulation fidelity. The new work by the MJOTF is focused on providing more process-oriented insight into the model behaviour so that a more obvious pathway for model improvement is afforded.

Subproject 2) is a corollary to this diagnostic and metric research. The objective is to respond to a request from the WGNE/WGCM Climate Metrics Panel to recommend one or more very simple MJO metrics that can be used to assess the fidelity of simulations contributed to the Coupled Model Intercomparison Project(s) (e.g. CMIP5).

Subproject 3) continues the development and application of MJO monitoring and forecasting work also started by the CLIVAR MJOWG [Gottschalck et al. 2010]. That effort resulted in a joint invitation by the MJOWG and WGNE for operational centres to contribute the needed fields (u200, u850 and OLR) to compute the Wheeler and Hendon [Wheeler and Hendon 2004] based MJO monitoring and forecast metric. These MJO forecast metrics are now available and presented via CPC/NCEP/NOAA in quasi-operational mode (www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/CLIVAR/clivar_wh.shtml). The objective of this subproject is to develop analogous metrics that are more finely targeted toward boreal summer season and/or northward propagating intraseasonal variability.

Subproject 4) is jointly sponsored with the GEWEX Global Atmospheric System Study programme and involves the development and analysis of a multi-model experiment focused on the vertical structure of the MJO, in particular the heating and moistening processes (www.ucar.edu/yotc/mjodiab.html). There are three components to the experimental framework: a) climatological simulation, b) two-day reforecasts for two YOTC and one DYNAMO (TBD) MJO event with intensive time-step level output over the Indo-Pacific warm pool region, c) same as b) but for 20-day reforecasts and global output.

3.2.2 Mutual benefits and recommendations

Based on the MJOTF activities described above, there are several synergistic activities that can be developed that would contribute to improving subseasonal forecasting. These include:

1) The ability to develop and apply more monitoring and forecasting metrics for the subseasonal variability. For example, to fully implement Subproject 3) above, it will be necessary to obtain additional fields from the operational centres. This could be done readily with the forecast database being planned in sec 6. Moreover, refinements and improvements in the metrics could be explored that might target other regions or applications of notable interest.
2) In conjunction with an evaluation of forecast skill by the models contributing to the database, the outcomes of Subproject 1) could be used to help pinpoint model weaknesses and guide model developments leading to improved subseasonal forecasts. Similarly, the results and methodologies developed in conjunction with Subproject 4) could also be used to guide and hasten forecast model improvements.
3) The MJOTF has considered and discussed starting an activity to better understand the relationships between the MJO (and related ISV) and the initiation and modulation of tropical cyclones (TCs). There is perceived to be significant forecast potential afforded by this relationship. However, at present there is no viable reforecast/forecast database suitable for undertaking such studies except

through the examination of a select few research (e.g. GFDL HIRAM) and operational models (e.g. ECMWF). The planned forecast database would provide an excellent resource for exploring MJO/ISV-TC relationships.

4) There is keen interest in exploring the utility of MJO and related ISV forecasts to application and decision support areas. There are numerous studies in the literature in recent years highlighting the modulation of the MJO/ISV of a number of quantities closely related to application and decision support. Given a skilful multi-day/week prediction based on the MJO for example, considerable societal benefit could be afforded. Apart from TCs just mentioned, these include quantities such as ocean chlorophyll, river discharge, aerosol, ozone, snowpack, etc. [Webster and Hoyos 2004; Waliser et al. 2005; Tian et al. 2007; Tian et al. 2008; Guan et al. 2011; Tian and Waliser 2011; Tian et al. 2011].

3.3 Teleconnections- Forecasts of opportunity

Extratropical weather is frequently influenced by recurring circulation patterns, usually referred to as flow regimes or modes of variability. Examples of such circulation patterns include the Pacific-North American pattern (PNA), the North Atlantic Oscillation (NAO)/Arctic Oscillation (AO), the East Atlantic (EA), the West Pacific (WP), and the tropical/Northern Hemisphere (TNH). The circulation patterns are usually associated with global teleconnections as in many cases propagation of Rossby wave trains is involved and the atmospheric variability in one place is related to a forcing in another (e.g., Wallace and Gutzler 1981). Because of their large scale and low-frequency nature, the circulation patterns contribute greatly to the atmospheric predictability on the subseasonal time scale.

Of particular interest are the teleconnections associated with tropical organized convection. The variability of tropical organized convection associated with the MJO has a considerable global influence (e.g., Higgins et al. 2000; Mo and Higgins 1998; Vecchi and Bond 2004; Donald et al. 2006; Lin and Brunet 2009; Lin et al. 2010a). As the atmospheric response to tropical heating, a Rossby wave train is generated that propagates poleward and eastward, and the extratropical response pattern is established in about two weeks (Jin and Hoskins 1995; Matthews et al. 2004). A dipole tropical forcing associated with an above (below) normal convection in the Indian Ocean and a below (above) normal convection in the western Pacific, which corresponds to MJO phase 3 (7) according to the definition of Wheeler and Hendon (2004), is found to be the most effective in exciting extratropical circulation anomalies (e.g., Lin et al. 2010a). Observational studies show a robust lagged connection between the MJO and NAO (Cassou 2008; Lin et al. 2009). A significant increase of probability of a positive (negative) NAO happens about 2-3 pentads after the occurrence of MJO phase 3 (7). The MJO is also found to be influencing the PNA (e.g., Mori and Watanabe 2008) and AO (e.g., L'Heureux and Higgins 2008).

Vitart and Molteni (2010) found that their monthly forecast model is able to capture the increase in probability of a positive (negative) NAO following an MJO Phase 3 (7). Their results indicate that the MJO simulated by the model has a statistically significant impact on weekly mean probabilistic skill scores in the Northern Extratropics, particularly at the time range 19-25 days. Lin et al. (2010b) analysed the reforecast experiment conducted with the Global Environmental Multiscale (GEM) model, and demonstrated that with a lead time up to about one month the NAO forecast skill is significantly influenced by the existence of the MJO signal in the initial condition. A strong MJO leads to a better NAO forecast skill than a weak MJO. An initial state with an MJO phase corresponding to a dipole tropical convection anomaly in the eastern Indian Ocean and western Pacific favours a more skilful NAO forecast than other MJO phases. These results indicate that it is possible to improve the skill of the NAO and the subseasonal forecast in the Northern Extratropics with an improved tropical initialization, a better prediction of the tropical MJO and a better representation of the tropical-extratropical interaction in dynamical models.

The association between the extratropical atmosphere and the tropical organized convection is not just a one-way influence from the tropics to the extratropics. Instead, it is a two-way interaction. Understanding the two-way tropical-extratropical interaction is important, as it helps not only to identify the tropical influence on the middle- and high latitude weather, but also to explain and predict the tropical low-frequency variability, which in turn provides useful signals for the extratropical weather. Some earlier studies found coherent circulation anomalies across the tropical and extratropical regions (e.g., Lau and Phililips 1986) and suggested a global view of intraseasonal variability (e.g., Hsu 1996). This is supported by the instability theory of Frederiksen (2002), who found that one of the unstable modes couples the extratropics with a tropical 40-60 day disturbance, which is similar to the MJO. Using a dry atmospheric model, Lin et al. (2007) showed that a tropical MJO-like wave can be generated through tropical-extratropical interactions, and there is coherent circulation variability between the tropical and extratropical regions in the model atmosphere. Generation of MJO-like signals by extratropical forcing was also found by Ray and Zhang (2010) using a dry-channel model. The two-way interaction between the MJO and NAO was studied using observational data (Lin et al. 2009). The MJO with its organized convection induces extratropical Rossby waves, which propagate into the North Atlantic and interact with synoptic-scale transients and lead to an NAO anomaly. The changed NAO, through a southward wave activity flux in the North Atlantic, generates tropical zonal wind anomalies which help to trigger an MJO development in the Indian Ocean. The GEM model appears to be able to capture the extratropical influence of the MJO, as it was found that a strong NAO leads to a better MJO forecast skill than a weak NAO (Lin and Brunet 2011).

There is great potential gain in subseasonal forecast skill if the model can capture the atmospheric teleconnections. However, many scientific questions remain to be answered. For example, what is the relative importance of tropical convection in generating teleconnections in comparison to other dynamical processes such as interactions with synoptic-scale eddies? What are the processes involved in the initiation of tropical convection by Rossby wave-trains propagating from the extratropics into the tropics? There has not been a systematic assessment of how the current models perform in simulating global teleconnections on the subseasonal time scale, especially for those related to tropical-extratropical interactions. How the models differ and what determines a model’s ability to capture the teleconnections are also unclear.

The strength of planetary-scale teleconnections with both ENSO and the MJO and other sources of subseasonal and seasonal predictability raise the possibility of important windows of opportunity for skilful subseasonal to seasonal forecasts when and where these teleconnections are active and interacting. For example Hudson et al. (2011) found that subseasonal forecast skill of the POAMA seasonal was enhanced over Australia when ENSO, the Indian Ocean Dipole and the Southern Annular Mode are active, while the MJO was not found to contribute skill in that case. Such targeted “forecasts of opportunity” would represent a departure from the usual practice in seasonal forecasting where skill levels are averaged across all reforecasts for a particular season and start date, and might spawn a substantial research effort needed to properly represent and convey the conditional skill of such forecasts, perhaps in terms of spread-skill relationships.

It is necessary to have some common methodologies and simple metrics to evaluate the model performance in simulating and predicting the teleconnections. This will facilitate an objective comparison across different models.

3.4 Monsoons

The monsoon precipitation is a principal atmospheric phenomenon that drives tropical and extratropical circulation and subseasonal-to-seasonal forecasts could have profound impacts on agricultural planning, water resource management and other socio-economic activities. Waxing and waning of monsoon precipitation during local summer is a major challenge in subseasonal-to-seasonal climate prediction. Although the El Niño and Southern Oscillation (ENSO), a dominant predictability source of global climate, is reasonably well predicted owing to the ground-breaking progress of global climate modelling in the past few decades (Wang et al. 2009; Jin et al. 2008), the monsoon prediction is very poor, particularly during local summer over land on the seasonal time scale (Wang et al. 2007, 2008; Chowdary et al. 2010; Lee et al. 2010, 2011a,b; Sohn et al. 2012) as well as on the subseasonal time scale (Fu et al., 2009, 2011).

On the seasonal time scale, coupled models have difficulty in predicting summer mean precipitation anomalies, particularly over the Asian-Australian monsoon (A-AM) region even for a zero-month lead forecast, but they are capable of predicting zonal wind anomalies at 850-hPa over the region of interest several months ahead (Lee et al. 2011b). The prediction skills for monsoon precipitation are highly dependent on the strength and phase of ENSO. Although a multi-model ensemble can only capture a moderate portion of the monsoon precipitation variability, it can reproduce well the observed anomalies of circulation and rainfall with Tropical Indian Ocean (TIO) and South China Sea warming and cooling over the southeastern flank of the surface anticyclone in boreal summers after the mature phase of ENSO. Local air-sea interaction (Wang et al. 2000, 2009) and remote forcing by TIO SST variability (Xie et al. 2010) play an important role in predicting the Western North Pacific-East Asia (WNP-EA) climate during the summers (Chowdary et al. 2010; Lee et al. 2011b; Sohn et al. 2012). Improvement of models is essential and remains a long-term goal to advance monsoon prediction. In particular, correction of the inherent bias in the mean state and annual cycle is critical for improving the long-lead seasonal prediction of precipitation (Lee et al. 2010). Continuing improvement to the models’ representation of the slow coupled dynamics (e.g., properties of the coupled ENSO mode) is essential for improving ENSO and long-lead precipitation prediction. There is an urgent need to determine to what extent the intrinsic internal variability of monsoon limits its predictability, and to what extent improved land processes can contribute to improved predictive skill. The poor performance over the continental monsoon region may be partially due to poor quality of the land surface initial conditions and the models' deficiencies in the representation of atmosphere-land interaction. Global land surface data assimilation is an urgent need (Wang et al. 2009).

The Boreal summer monsoon intraseasonal oscillation (MISO) is one of the dominant short-term climate processes inducing variability in the global monsoon system (Webster et al. 1998; Wang 2006) with quasi-oscillating periods of 10-20 day and 30-60 day (Yasunari 1979, 1980; Kajikawa and Yasunari 2005).The MISO is more complex in nature than the Madden-Julian Oscillation (MJO) due to intrinsic monsoon variability as well as the interaction between the basic monsoon circulation and MJO (Webster et al. 1998; Lau and Waliser 2005; Wang 2006). The MISO is known to affect summer monsoon onsets, the active/break phases and the seasonal means of summer monsoons. The wet and dry spells of the MISO strongly influence the extreme hydro-meteorological events, which are responsible for about 80% of natural disasters in that region and thus have important socio-economic consequences in the World's most populous monsoon region.

The predictability of weather and the seasonal mean climate has been extensively studied. MISO falls between the daily weather and the seasonal mean climate. MISO is largely governed by internal dynamics (Palmer 1994; Waliser 2006) and is therefore, to a large extent, chaotic in nature and unpredictable. Previous studies have shown that air-sea coupling may extend MISO and MJO predictability (Fu et al. 2008a, b; Woolnough et al. 2007; Vitart and Molteni 2009), suggesting that atmosphere-ocean interaction may be a source of predictability for the MISO. It is also worth mentioning that the models which simulate the seasonal mean tend to make a better prediction of intraseasonal activity, indicating the seasonal mean is somewhat related to the intraseasonal activity over the season, particularly in the Monsoon region (Sperber et al. 2000, Kim et al. 2008). There are still great uncertainties regarding the level of predictability that can be ascribed to the MISO, other subseasonal phenomena, and weather/climate components that they interact with and influence. It is also important to determine MISO's modulation of extreme hydrological events and its contribution to seasonal and interannual climate variation. Development and analysis of a multi-model ensemble reforecast and real-time forecast experiments are needed to address the above questions and challenges in addition to producing lead-dependent model climatologies to properly quantify and combine the independent skill of each model as a function of lead-time and season.

On a global basis, during the boreal summer, the MJO also influences the monsoons over West Africa (Maloney and Shaman 2008; Lavender and Matthews 2009) and North America (Lorenz and Hartmann 2006); intraseasonal teleconnections between the North American and Western North Pacific Monsoons with a 20-Day time scale have also been documented (Jiang and Lau 2008). During the austral summer, active and break phases in the South American Monsoon System have been linked to intraseasonal oscillations that may have an MJO component, besides an extratropical one (Jones and Carvalho 2002).

Another factor that may influence the sub-seasonal to seasonal predictability of the Asian and East Asian monsoons is the Tibetan Plateau. For example, the duration of snow cover over the Tibetan Plateau affects the train of Rossby waves and the migration and intensity of the East Asian monsoon.

3.5 Rainfall variability and extreme events

3.5.1 Tropical rainfall variability

Rainfall in the tropics is dominated by the monsoons, and predictability on seasonal and subseasonal variability is often low, as discussed in the previous sub-section. However, the onset date of monsoonal rainfall has been shown to exhibit higher seasonal predictability over Indonesia (Moron et al. 2009a; Robertson et al. 2009) and the Philippines (Moron et al. 2009b), as well as over West Africa. A similar finding has been reported over the Amazon basin (Liebmann et al. 2007), and in both Indonesia (Hendon 2003) and the Amazon (Liebmann and Marengo 2001), seasonal rainfall predictability is higher in the "dry" and dry-to-wet transition seasons. In a recent paper, Jones et al. (2012) document seasonal forecast skill of the NCEP CFSv2 in monsoon onset date reforecast for the South American Monsoon system more generally. Since all of these monsoon regions are also influenced by intraseasonal oscillations, there is reason to believe that such monsoon onset date forecasts could be enhanced at sub-monthly lead times.

Despite the lower seasonal predictability over land in the tropics, it is now quite well established that rain-day frequency is more potentially predictable than mean rain intensities and seasonal rainfall totals (Liebmann et al.

2007, Moron et al. 2007). Since rainfall occurrence is related to drought, this finding also has potential agricultural significance.

The High-Level Task Force towards the Global Framework for Climate Services (GFCS) has stated that, in development of the GFCS, priority should be given to meeting the needs of developing countries, particularly African countries. In much of Africa, national economies and livelihoods are dependent on rain-fed agriculture, and reliable forecasts of the subseasonal distribution of rainfall (e.g. timing of season onset and cessation, dry spells within the season), if exploited, would enhance abilities to adapt to variability, provide input to food security early warning systems and help maximise agricultural output. As part of the subseasonal to seasonal research programme, activities to predict season onset, season cessation and dry spells within a season should be encouraged. A regional focus for such investigations will likely be necessary and will be decided by the steering group.

Results from DFID-Met Office Climate Science Research Partnership (CSRP) demonstrate the requirement and potential for such studies. (DFID- Department For International Development, a UK Government Agency). As part of an initial consultation with African stakeholders conducted by the CSRP, a questionnaire on priorities for new prediction products was fielded to 9 climate service providers (regional centres and NMSs). Respondents were asked to rank in order of importance four options for developing/extending existing dynamical seasonal forecast products (i.e. the typical probability forecast products for tercile categories of 3-month rainfall total). The options given were:
1) Finer geographical detail, through downscaling;
2) Information on the temporal distribution of rainfall (e.g. onset and cessation of rainy season);
3) Information on the likely frequency of 'extreme' daily events within the 3-month season;
4) Extension of the prediction range to cover interannual- to decadal -range predictions.

Predictions of the temporal distribution of rainfall were given by far the highest priority, with information on downscaling and the frequency of extreme rainfall events approximately equal in second place. Interannual to decadal predictions were seen as important to develop, but of lower priority than developing reliable and useful predictions on seasonal timescales. The high priority given to the need for predictions of the temporal distribution of rainfall is in accord with the findings of Ingram et al (2002)

Research conducted under the CSRP programme has found promising potential for predicting the timing of season onset (Vellinga et al. 2012). The methodology uses an index of onset defined as the date on which 20% of the long-term seasonal average is received. Probability forecasts with the GloSea4 seasonal forecast system gave good guidance for the onset of the 2011 short-rains season in the Horn of Africa: a high probability of early onset was predicted – and early onset was observed. Evaluation over retrospective forecasts suggests similar levels of success in ~70% of years over much of East Africa. Skill is also found in other regions of the continent. These results with a seasonal forecast system suggest there is good potential for enhanced skill (at shorter 10-30 day range), with dedicated subseasonal prediction systems, opening up possibilities of 'seamless' prediction for such events (and windows for forecasts of opportunity)– and evaluation of this potential will be part of the research programme.

3.5.2 Prediction of heat waves and cold waves

Heat waves and cold waves are amongst the weather events which have the strongest societal impact. This is particularly true for the heat waves during the warm season and the cold waves during the cold seasons. For instance, the 2003 summer heat wave over Europe was particularly intense. Its overall impact on society has been exceptional, with severe disruption of activities and heavy loss of life in many European countries. Health authorities estimated that, because of the soaring temperatures, about 14,000 died in France alone, and thousands more casualties were reported in other countries. The prediction of the evolution of such an extreme event (onset, maintenance, decay) a few weeks in advance would be particularly useful. Therefore the evaluation of the skill of the models which are part of the database to predict this type of event with a high societal impact should be a high priority. At the subseasonal-to-seasonal time scale, the models are not expected to have skill to predict the day-to-day variability of the weather, but heat waves and cold waves which can last more than a week could be the type of weather events the subseasonal prediction systems can predict. Vitart (2005) showed that the monthly forecasting system had some skill in predicting the maintenance of the heat wave during the 2003 summer, but this model had more difficultly in predicting its onset and its decay. It seems that this model had a tendency to be overly persistent. Therefore, the prediction of regime changes which can lead to such extreme events should be investigated more closely and the database (see sec 6) would be a very useful tool for this investigation.

One issue within this topic will be how to define a heat wave and cold wave. The criteria (duration, intensity, return period...) to define a heat wave or a cold wave will need to be agreed. In the model, such extreme events can also be defined using the Extreme Forecast Index (EFI) (Lalaurette et al, 2003) approach in which the ensemble distribution of the real-time forecasts is compared to the ensemble distribution of the re-forecasts. This approach which is used for medium-range could be extended to the subseasonal to seasonal time range. The possibility of using weather regime classification could also be explored. The verification of such extreme events will also be challenging since significant heat waves and cold waves are relatively rare, and it will be difficult to have a dataset large enough to produce meaningful statistics.

Since these events are by definition rare, it is recommended that at least one of the special case studies (see Section 7) includes a heat wave or a cold wave that occurred in the past few years, like for instance the Russian heat wave in summer 2010. In addition to these past cases, it will also be important to evaluate the capacity of current sub-seasonal to seasonal forecasting systems to predict extreme events in near real-time. A period of time limited to a one or two seasons should be defined for that purpose. It is recommended to collaborate with the appropriate structure on a definition of heat waves and cold waves which could be used to detect them objectively in observations and in the model integrations. Finally, it will be important to liaise with application and health organizations to measure how useful the present subseasonal to seasonal forecasting systems are in predicting these extreme events. The fact that day-to-day weather variability may not be predictable beyond two weeks does not necessarily mean that the extended-range predictability of extreme or severe events is limited to large scale long-lasting events like heat wave or cold waves. Changes in large-scale circulation which can be predicted more than 2 weeks in advance can impact the probability of synoptic scale extreme events. The following section will discuss the predictability of tropical cyclones, as an example.

3.5.3 Prediction of tropical storms

Medium-range and seasonal forecasts of tropical storms have been available for a few decades. However, it is only recently that statistical or dynamical models have been developed to predict the genesis or occurrence of tropical cyclones (TCs) at the intraseasonal time range (Leroy et al. 2004; Frank and Roundy 2006; Leroy and Wheeler 2008, Vitart et al. 2010). It is the impact of the Madden Julian Oscillation (MJO) (Madden and Julian 1971) on tropical cyclone activity (Nakazawa 1986; Hall et al. 2001; Bessafi and Wheeler 2006; Ho et al. 2006) that has triggered the recent interest in subseasonal TC prediction. The modulation of TC numbers by the phase of the MJO has been quoted to be as high as 4:1 in some locations (e.g., Hall et al. 2001; Maloney and Hartmann 2000a). SST anomalies can also be an important source of tropical storm predictability at the subseasonal time scale. For instance, the probability of higher than normal TC activity in the central Pacific during an El-Niño event extends down to the multi-week time scale as well (Leroy and Wheeler 2008). Other sources of predictability at the intra-seasonal time scale include equatorial Rossby (ER) waves, mixed Rossby gravity (MRG) waves, easterly waves, extratropical waves, and equatorial Kelvin waves (Frank and Roundy 2006).

A few case studies have shown that a numerical model can simulate the impact of an MJO event on tropical cyclogenesis (e.g. Aiyer and Molinari 2008, Fudeyasu et al. 2008). Using a very large set of reforecasts, Vitart (2009) showed that a state-of-the art subseasonal prediction system can reproduce well the modulation of tropical storm activity by the MJO over all the ocean basins. This paper also showed that a NWP model is able to simulate the impact of the MJO on the probability of TC landfall, suggesting that it should be possible to issue subseasonal forecasts of tropical storms with NWP models.

Statistical and dynamical models have been developed to predict the genesis or occurrence of tropical cyclones (TCs) at the intraseasonal time range (Leroy et al. 2004; Frank and Roundy 2006; Leroy and Wheeler 2008, Vitart 2010). Recently, the skill of the ECMWF monthly forecasting system for predicting tropical storm modulation of TC activity has been demonstrated, prompting a comparison of the skill and reliability of the statistical and dynamical models (Vitart et al. 2010). Calibrated forecasts were found to display higher Brier Skill scores than the statistical model during the first 3 weeks, but the statistical model is more reliable. Elsberry et al (2009) and Belanger et al. (2010) showed that the monthly forecasts had skill in predicting subseasonal tropical storm activity. Now, subseasonal forecasts of tropical storms are produced routinely at ECMWF.

Recent publications have shown that a state-of-the-art NWP model can produce skilful subseasonal forecasts of tropical storms. Some tropical storms can display a predictability exceeding 2 weeks (Elsberry et al, 2009). The subseasonal forecast database discussed in sec 6 would be very valuable for evaluating the skill of the other subseasonal forecasting systems to predict tropical storms and exploring the possibility of producing multi-model subseasonal forecasts of tropical storms, which could end up being a very useful end-product. This dataset would also be very useful for investigating the various sources of tropical storm predictability and help identify the tropical storm geneses which are more predictable that others.

The tracking of tropical storms in the different models will be an important issue. The proposed archiving (see sec 6) will be at a relatively low resolution which will make the identification of the model tropical storms more difficult. However some trackers can be used on different resolutions (Vitart et al 1997) and has already been applied successfully on resolutions coarser than 1.5 degree grid (Vitart et al. 2003). Another option would be to track the tropical storms in the native resolution in each operational centre and collect the tropical storm tracks afterwards.

Making the subseasonal prediction of tropical storms useful for applications will be an important issue. At the subseasonal time range, the models tend to be over-confident and produce too many false alarms. Calibrating the tropical storm probabilistic forecasts using re-forecasts is likely to be necessary. Research is under way to try to find large-scale criteria to identify unrealistic model tropical storm geneses to reduce the number of false alarms. The best way to display the forecast probabilities needs to be agreed. The most common way is to display the probabilities on a grid point map for a specific time period. Elsberry et al (2009) use a different technique, where model tropical storm tracks are clustered into an “ensemble track” which may be more useful for forecasters and applications. Finally a protocol for verifying these forecasts will need to be agreed so that the performances of the various subseasonal forecasting systems can be compared.

A proposal has already been submitted for a tropical formation and early track forecast demonstration project under WWRP /WWW Tropical Cyclone Programme and the WMO THORPEX Interactive Grand Global Ensemble (TIGGE). The objective of this project is to develop and test a multi-model ensemble prediction system for probabilistic forecasts of western North Pacific tropical cyclone formations and tracks on time scales of 5-30 days. It is therefore recommended to establish strong links with this initiative, most especially through the creation of a subseasonal forecast database. It is also recommended to collaborate with the working group on verification to define a verification protocol and with SERA to evaluate the possible use of these subseasonal forecasts for applications. In that regard, it would be useful to produce these forecasts as close as possible to real-time for one of the case studies which will be discussed later or during a past period like the THORPEX - Pacific-Asian Regional campaign (T-PARC) period. Because of its high predictability and potentially important societal impacts (agriculture, hydrological applications, energy trading, emergency management and early warning for meteorological agencies), the subseasonal prediction of tropical storms should be a high-profile activity. Such activity, which would link the research and application communities, could be a key demonstration of the usefulness of the subseasonal forecasts.

3.6 Polar prediction and sea ice

The predictability of the climate system on subseasonal to seasonal time scales in polar regions is not well understood yet. This can be explained by the fact that the polar regions have not been routinely verified and that forecast skill was believed to reside primarily in the tropics (e.g. MJO and ENSO) affecting mid-latitude predictive skill indirectly through atmospheric teleconnections. Secondly, many forecasting systems do not capture processes and climate system components - neither during initialization nor during the course of the integration - that are key to the polar regions. Perhaps the most prominent example is sea ice, which is represented rather simplistically in most of the existing operational subseasonal to seasonal forecasting systems.

In general one can distinguish between local (i.e. polar) and remote (non-polar) sources of subseasonal and seasonal prediction skill in the polar regions. Local sources of extended-range forecast skill include the stratosphere (see below), sea ice, snow cover and the land surface including the hydrological cycle. There is also certainly some role to play for internal tropospheric dynamics which at times can produce quite persistent atmospheric flow anomalies (Jung et al. 2011). Furthermore, the length of extended-range predictions allows lower latitude phenomena such as the MJO or ENSO to affect the polar regions through atmospheric wave processes (e.g. Lin et al. 2010b).

An important characteristic of the polar regions is the presence of sea ice. In fact, sea ice cover could provide a source of memory that is not present at the lower latitudes. This may enable some predictive skill at longer time scales (Holland et al 2011). To degree to which sea ice anomalies influence the atmosphere locally and remotely in the mid-latitudes is not fully understood yet. Modelling results do suggest, however, that sea ice anomalies can influence the atmosphere, especially in the sea ice margin zones of the Labrador Seas and Greenland-Icelandic-Norwegian seas (Deser et al. 2007).

Progress in subseasonal to seasonal polar prediction hinges on significant improvements to the polar observing system, the way (coupled) models are initialized and the way key polar processes such as stable boundary layers and sea ice are represented in numerical models. A further challenge is the representation of initial and model uncertainty in the polar regions which might require modifications to the techniques which have been successfully used in the lower latitudes.

Observational data is particularly limited in polar regions, leading to a large reliance on satellite observations. While satellite observations provide a useful characterization of some atmosphere and sea ice conditions, they provide little information on the underlying ocean. Issues with observational data sparseness, incompleteness, and bias are a critical challenge in terms of adequately initializing coupled model forecasts. Furthermore, satellite data are usually not sufficient when it comes to improving models at the processes level.

Data assimilation for subseasonal and seasonal prediction in the polar regions needs to consider the coupled atmosphere-ocean-sea ice-land system. Relatively little is known at present about the role of sea ice initialization for subseasonal prediction. Some progress in this area can be expected through detailed analysis of the data set made available by WGSIP through the Sea Ice Historic Forecast Project (iceHFP, http://www.wcrp-climate.org/wgsip/chfp/iceHFP.shtml). Data assimilation in the polar regions is likely to lead to unique problems due to the presence of sea ice when sequential data assimilation techniques are used. The presence of model and/or observational biases, for example, will lead to systematic sea ice increments which change the salinity of the upper ocean and hence its static stability. This is especially problematic because of a lack of sufficient upper ocean data to constrain the analysis.

When it comes to modelling the polar regions the use of relatively high horizontal and vertical resolution becomes crucial. Both the polar atmosphere and the Arctic ocean are characterised by relatively shallow boundary layers, steep orography (e.g. Greenland and the overflow) and narrow straits as found, for example, in the Canadian Arctic Archipelago, all of which need to be adequately represented. Furthermore, the baroclinic Rossby radius of deformation reduces to approximately 5 km in the high-latitudes which has to be taken into account when setting up coupled model systems. The use of relatively high resolution may lead to the fact that some of the approximations successfully used at lower resolutions are no longer valid (e.g. plastic-viscous rheology), that is, the so-called ‘grey zone’ will be approached. The need for increased resolution might make it necessary to employ a new generation of sea ice-ocean models based on unstructured mesh approaches (e.g. finite elements) which allow a regionally increased resolution in an otherwise global and relatively coarse-resolution setup (Danilov et al. 2004, Timmermann 2009).

Ensemble predictions systems are used to predict the influence of initial and model uncertainty on forecast skill. In current subseasonal forecasting systems atmospheric initial perturbation are predominantly being generated using singular vectors or breeding. These methods tend to find growing directions in the major baroclinic zones. Whether either of those techniques is capable of characterizing growing directions in the polar regions and whether it is actually required to sample polar initial perturbation for subseasonal forecasts remains to be shown. Representation of model uncertainty in atmosphere, ocean, sea ice and land models is expected to be crucial to obtain reliable spread-skill characteristics. While it should be relatively straightforward to apply the multi-model concept in the polar regions extensive research will be necessary to formulate stochastic parameterization schemes, which in the past have focussed on the atmosphere in general and convection in particular, for all components of the climate system.

Some of the state-of-the-art subseasonal forecasting systems already have a sea-ice model and sea-ice initialization (UKMO for instance) while other systems will have a sea-ice component in the near future. Therefore, a database of subseasonal forecasts similar to TIGGE would be useful to assess the skill of the state-of-the-art numerical models to predict the evolution of sea-ice in the subseasonal time scale, even if there are still considerable uncertainties and difficulties in modelling sea-ice as mentioned above. This database which would contain a large set of reforecasts would also be useful to assess the impact of sea-ice anomalies on the subseasonal forecasts. These studies should be undertaken in collaboration with the WWRP polar prediction project. Experiments should be coordinated between both steering groups.

3.7 Stratospheric Processes

The importance of the stratosphere has not been fully assessed but many individual case studies now show a likely role for its influence on the extra-tropics. While the influence of the stratosphere on year round averaged skill scores may be modest, there is a good case for an impact on the NAO and the southern annular mode, especially during a sudden stratospheric warming and other times when the polar vortex is active. An international CLIVAR project run under the CLIVAR Working Group on Seasonal to Inter-annual Prediction (WGSIP) is now in progress to quantify the improvements in forecast skill resulting from proper inclusion of the stratosphere. Some centres (for example the UKMO) already run with a well-resolved stratosphere including such effects as the low frequency QBO and others plan to introduce similar improvements in the coming year.

Baldwin and Dunkerton (2001) showed strong apparent downward propagation of easterly and westerly anomalies from the stratosphere to the troposphere on monthly timescales. Importantly, this tends to be followed by easterly (negative NAO/AO) conditions in the troposphere. Perturbation experiments also reproduce negative NAO/AO in response to weakened stratospheric winds on both seasonal and longer timescales (for example Boville 1984, Norton et al 2003, Scaife et al 2005, Scaife and Knight 2008). Jung et al (2010) find that relaxation of the extra-tropical stratosphere to the observed state leads to forecast error reduction in the high latitude and European troposphere, but that the tropical stratosphere has no such impact. They caution the interpretation of these results, however, as the troposphere strongly influences the NH stratosphere and other studies suggest a role for the tropical QBO on the extra-tropical surface climate (Boer and Hamilton 2008, Marshall and Scaife 2010).

Scaife and Knight 2008 suggest that the stratospheric sudden warming in Jan 2006 contributed to the cold winter of 2005/6 in the NH and reproduced stronger surface NAO and cold European signals in simulations where stratospheric variability was imposed according to observations. The QBO was in a negative phase which could also have contributed. On the other hand, Jung et al (2010) suggest that the origins were in the tropical troposphere. While relaxation experiments can be used to suggest remote origins of anomalies in extended range prediction and give an idea of how much forecast skill could be gained by reducing forecast error in various regions such as the tropics, they are not definitive. Recent results from a prototype ECMWF S4 indicate improved results in seasonal forecasting by using an active stratosphere and Hendon et al (using the CAWCR model show a small reduction in RMSE some 15-20 days into the forecast over the polar cap by better resolving the stratosphere. This is a high latitude effect and limited to 5% reduction, leading the authors to question the need for an active stratosphere in the Australian monthly/seasonal forecast system.

Although the jury is still out on the exact level of improvement to be expected from including stratospheric processes, and the stratosphere is most likely to contribute in winter and under sudden stratospheric warming events, some modelling groups are starting to include the stratosphere in their extended range forecast models. The UKMO system now uses an 85 level model which includes a comprehensive representation of the stratosphere for seasonal forecasting, and ECMWF has 91 levels for their System-4. Many other current systems do not fully include the stratosphere.

In order to assess the impact of stratospheric processes on predictability and prediction, the WCRP CLIVAR core project has launched the Stratosphere resolving Historical Forecast Project (SHFP). Specifically, its purpose is: to quantify improvements in *actual* predictability by initialising and resolving the stratosphere in seasonal forecast systems; to compare with existing seasonal to inter-annual forecast skill and to provide a reforecast data set that may be used to demonstrate improvements in currently achievable season forecast skill for a range of variables and lead times; to understand improvements under particular scenarios such as El Nino and years with an active stratosphere; and to justify changes in operational seasonal forecast approaches and methods. For more details see http://www.wcrp-climate.org/wgsip/chfp/index.shtml. Collaboration between this activity and the subseasonal forecast group is to be encouraged. Observations, such as the space-based Global Positioning System data could also contribute to improve our understanding of the impact of stratosphere on the troposphere. Collaborations with COSMIC/UCAR could help produce better initialization and data assimilation of global models in the lower stratosphere and upper troposphere which would benefit sub-seasonal to seasonal predictions.

4. Modelling Issues

4.1 Initialisation

What is the best way to initialize the coupled system for successful subseasonal prediction? This question is largely unanswered. Traditional approaches for forecast initialisation used in both medium-range and seasonal forecasting have limitations for the subseasonal timescale. The approach for medium-range forecasting has been to use the most accurate initial conditions as possible for the atmosphere and to largely ignore the more slowly varying ocean conditions. For seasonal prediction, the initial conditions of the coupled system are important, particularly the upper ocean, and the rapidly varying components of the atmosphere are often less well predicted and initialised. The solution for the subseasonal timescale probably lies somewhere in-between. Forecasts in this timescale are influenced by initial conditions of both the fast (i.e. atmosphere) and slow (i.e. ocean and land) components of the coupled system. A major challenge for data assimilation and initialisation of subseasonal forecasts is addressing these different time and space scales of the atmosphere and ocean, and trying to exploit information from both the fast and slow components.

The most common approach is to analyse and initialise the atmosphere and ocean components separately. Quite sophisticated schemes are generally used to analyse the atmospheric state, such as 4d-var or EnKF. Ocean analysis techniques tend to be less sophisticated but EnKF and 4d-var techniques are being developed. However, it is not clear that uncoupled initialisation is optimal and coupled data assimilation is often mentioned as an objective, such that observed information in one component is used to correct fields in the other coupled components. Research and development for coupled data assimilation is still in relative infancy. There are no operational fully coupled data assimilation systems in existence, although weakly coupled schemes (e.g. assimilation into each component of the coupled model separately, but evolving the background states using the coupled model) are being developed or in the case of NCEP already implemented. Coupled assimilation should include land surface conditions and sea-ice, and thus provide a more balanced initial state for the whole coupled system. Research is required to:

- investigate how best to initialise the coupled modes of the climate system. Is a 4d-var approach, which requires the adjoint of the coupled system, appropriate? How would one deal with rapidly growing atmospheric perturbations in a coupled system with an assimilation window set by slow coupled or oceanic timescales? Are coupled ensemble Kalman Filtering approaches more feasible for a coupled system?
- examine the dynamics of error growth in the coupled system. The diagnosis of errors in data assimilation can also make a positive contribution to model development.
- increase our knowledge of state-dependent error covariances of the coupled system.
- develop metrics to assess the skill of a coupled data assimilation system.

Initialisation shock is manifested by most coupled modelling systems due to strong model drift. What are the best approaches to avoid spin-up issues? Key questions include:

- How much does initialisation shock compromise subseasonal forecast skill?
- Is there a distinction between the best initialisation and the best analysis in the face of imperfect models and strong model drift, i.e. what is the trade-off or balance between initialising a model close to reality versus close to the model attractor?
- Can current methods of uncoupled initialisation solve the problem of initialisation shock? Would coupled assimilation, such that the atmosphere and ocean are in balance with each other, reduce shock?
- Does high frequency assimilation for the atmosphere and ocean (e.g. 6-hourly intervals) ameliorate drift in coupled models?
- Should spin-up/shock be a worry when using analyses that were not generated by the forecast model? (As would be the case for the re-forecasts when reanalyses are used for initial conditions.)

Initial conditions are required not only for real-time forecasts, but also back in time (reanalyses e.g. ERA-Interim) for initialising the reforecasts needed for calibrating the real-time forecasts. This raises a number of issues:

- What observations of the coupled atmosphere-land–ocean system are needed for capturing details of the initial conditions for successful subseasonal predictions? For example, how important are correct stratospheric initial conditions?
- How important is it to have consistency between the initial conditions of the reforecasts and real-time forecasts?
- There are differences between reanalyses used to initialise reforecasts. How accurate are these reanalyses in describing subseasonal variability in the real-world? Are some reanalyses better than others?

The importance of land-surface initialisation for subseasonal prediction is still an open issue. For example for summer heat waves or the prediction of soil moisture for agriculture, preconditioning of land surface and vegetation could be important for changing the likelihood, rapidity of development, and intensity of heat waves. It is also not clear how best to initialise the land surface. There is a model consistency issue such that one cannot take the soil moisture from one model and put it in another. Various options are available, such as running the land-surface model offline; or adding appropriately scaled soil wetness anomalies from land reanalyses to the annual cycle of the model; or by allowing the model to develop its own soil moisture when nudged towards an atmospheric analysis as used by Hudson et al 2010.

Initialising subseasonal tropical convection (and associated circulations such as the MJO, which is presumedto be one of the key modes of subseasonal variability that is predictable and produces an impact both locally and remotely) is a primary challenge from both observational (do we have the data?) and model error perspectives (do we initialise the model's representation of the MJO or the real MJO?). An underlying question is how far subseasonal prediction can progress through improving initialisation if one has a poor model (e.g. with a poor MJO or an extremely biased ENSO). Essentially, progress in initialisation also requires progress in reducing model errors.

4.2 Ensemble generation

What is the best forecast system configuration for representing uncertainty to achieve successful subseasonal forecasts? The representation of uncertainty in initial conditions has been approached by using random sampling, singular vectors or breeding schemes, or lagged averaging. The representation of uncertainty in model formulation has been approached by using multi-model, stochastic physics or perturbed parameters ensembles (although the latter has mainly been used in climate change and multi-annual forecast experiments). In order to determine the appropriate approach for ensemble generation for subseasonal prediction, there are a number of research issues that need to be addressed:

- Model error may be a significant source of forecast error for subseasonal prediction (as for seasonal prediction) and properly sampling model error may be important. Optimal ways of representing model formulation uncertainty (e.g. multi-model approach, stochastic physics) should be explored for the subseasonal timescale.
- What are the optimal ways of sampling uncertainty in the initial conditions?
    a) A common approach for medium-range forecasting is to use singular vectors. Are singular vectors currently used for NWP appropriate for subseasonal forecasting (e.g. do they affect the spread enough in tropical latitudes)? What norms should be used for subseasonal timescales? Over what timescale should the singular vectors be calculated?
    b) Which is better: a lagged ensemble or a “burst” ensemble?
    c) Should we focus on optimal methods of perturbing the initial conditions, e.g. breeding methods that capture the leading modes of coupled model error growth?
    d) Should we focus on perturbing the slow modes of the coupled system, e.g. the MJO and annular modes?
- Do we need to capture uncertainty in the ocean and land as well as the atmosphere? Some seasonal forecasting systems address this issue for uncertainty in ocean initial conditions. Should stochastic parameterisation be extended to the ocean and land surface models to account for uncertainty in model formulation?
- Should we aim to provide coupled perturbations for the ensemble members?

<u>Recommendations</u>

A focus workshop and workgroup on initialisation and ensemble generation of the coupled ocean-land-atmosphere system is recommended. There is a strong need for an interdisciplinary research approach. This workshop and workgroup should therefore bring together experts from the NWP and climate data assimilation communities to outline the way forward for subseasonal prediction. The workshop could include:

- Proposals of specific OSE and OSSE experiments to answer questions of what observations of the coupled system are needed for capturing details of initial conditions for successful predictions in the subseasonal range. It is necessary to show demonstrated improvement in forecast skill through the use of atmosphere, land and ocean initial conditions.
- A focus on and plan for advancing coupled data assimilation.
- Proposals of specific experiments to determine the best approach for representing uncertainty of initial conditions and model formulation.

The proposed subseasonal research database is somewhat limited in answering questions regarding initialisation and ensemble generation since there are many differences between the systems from the different operational centres. However, the database can be used to examine certain issues, such as:

- The benefits of and best approach for creation of multi-model ensembles.

- Assessing the relative benefits of using a burst ensemble compared to a lag ensemble.
- Targeting specific case studies, which could then be re-run to answer specific research questions (e.g. re-run using another centre's analysis for the initial conditions and then examining the impact on initialisation shock).

There should be liaison with the WGSIP CHFP project's three major research themes, namely the treatment of sea-ice, the stratosphere and the land surface. Each project has experiments (Ice Historical Forecast Project; Stratospheric Historical Forecast Project and the GLACE experiment respectively) which could be analysed to inform about initialisation of these components of the coupled system for subseasonal prediction. There should also be liaison with the monthly mean output provided by GPCs via the WMO lead centre as part of the WMO's global framework for climate services. This is important to ensure a unified approach with seasonal and longer forecasts given the strong overlap. (See www.wmolc.org for information on the activities of the lead centres).

4.3 Role of resolution

There are two aspects that become obvious when analysing the importance of model resolution:
If we look at the existing operational systems around the world for subseasonal-to-seasonal prediction, there is a large range of model resolutions currently in use: from atmospheric models with horizontal resolutions of approximately 30 km (ECMWF) to others with resolutions of near 300 km (South African Weather Service); from systems with 91 vertical levels and a fully resolved stratosphere (Météo France) to others with only 17 levels (Australian Bureau of Meteorology). If we look at the last 30 years of history in Numerical Weather Prediction, it can be seen that increases in model resolution are clearly linked to improved forecast skill. The reason for this is that the higher the model resolution the more physical processes that can be simulated (or better resolved) by the model.

Although the previous statement is derived mainly from work using atmosphere-only models, it is applicable to coupled models. For example, resolution plays an important role with respect to tropical/extra-tropical teleconnections (Toniazzo and Scaife, 2006) and the response of surface and boundary layer fluxes to sea surface temperatures. However, coupled models may need to get down to the Rossby radius of deformation (a few 10s of km) in the ocean in order for the atmosphere to respond to ocean variability (Minobe et al., 2008).

One of the main attractions of the database to be created through this project is that it will contain forecast and reforecast datasets from many prediction systems using different model resolutions – resolutions that will be increased during the lifetime of the project. This will allow us to systematically investigate the role of resolution in forecast skill by comparing different systems.

Without trying to be prescriptive – undoubtedly, the understanding and analysis tools will improve in the next 10 years – it is recommended that a process-based approach be followed. The key questions to ask are:

- What processes are improved by increasing model resolution?
- What is the role of resolution in reducing mean biases?
- How are reductions in mean biases related to improved physical processes?
- Is there consistency across models; following the example below, do models with a high resolution ocean have a better representation of blocking?

A recent example of this kind of approach is Scaife et al 2011 who show that increasing the resolution of the ocean component of a coupled model (from 1 degree to 0.25 degree) substantially reduced the SST biases in the North Atlantic which, in turn, greatly improved the simulation of Atlantic winter blocking frequency in the coupled model. On the other hand, not all improvements come from resolution. The Athena project showed that even at very high resolution, the representation of the MJO was not improved. Advances require both resolution and parameterisation improvements.

4.4 Systematic error

Despite many years of effort devoted to model development, a number of persistent biases still exist in the CGCMs used for climate simulations in e.g. tropical precipitation, low cloud cover (e.g. Randall et al. 2007) and subseasonal and seasonal prediction. Some of these biases will arise solely from the errors in the component models and some may arise from misrepresentation of the coupling processes themselves. Furthermore the coupled feedbacks between the atmosphere and ocean may compound existing errors in individual components or generate new biases.

For many years WGNE and WGCM have addressed the issue of the systematic biases in climate models through model intercomparison projects such as AMIP and CMIP. These projects assess the climate statistics of long integrations to identify the systematic errors. However, whilst these projects are able to diagnose the biases in the simulations, it is difficult to identify the sources of the errors in these long simulations for two reasons. The first is that as the simulated climate departs from the observed climate the physical parameterizations are operating on a climate state far from reality and their behaviour in this regime, even if they themselves were perfect would be different from observed. Secondly, some of the errors will have developed not directly as a result of errors in the representation of the local process, but as a result of the response to remote errors.

Prediction systems from NWP to seasonal timescales also exhibit systematic biases; these systematic biases depend on forecast lead time. Whilst on NWP timescales the forecasts are traditionally presented in raw format without recourse to bias correction, on subseasonal and seasonal timescales forecasts are often presented bias-corrected, i.e. the prediction is presented relative to the time-dependant systematic bias of the model. Often at short lead times the systematic bias has a similar structure to the systematic biases of the climate simulation (see for example figure 1 of Martin et al. 2010).

A number of authors (e.g. Jakob 2003, Phillips et al. 2004) propose the use of initialized forecasts as a way to diagnose the development of systematic errors in models, both through the analysis of the very short range error growth using data assimilation increments, and through analysis of the time dependent growth of the initial error over the first few days of the forecast. To date much of this work has focused on atmospheric model development, making use of the regularly initialized operational forecasts, to provide a large database of the initial model error development. The increase in operational seasonal and subseasonal forecasting using coupled systems allows such an approach for coupled models and allows the impact of the coupling on the error development to be assessed.

As well as providing information on the time development of the error, the use of initialized forecasts also allows an analysis of the dependence of the error development on the initial state of the atmosphere, either for time in the seasonal cycle or particular phases of modes of variability, including both modes with timescales longer than the relevant prediction timescale (e.g. ENSO for subseasonal forecasting) and those of the relevant prediction timescale for the system in question, (e.g. the MJO for subseasonal forecasting). Vannière et al. (2012) analyse seasonal forecasts from the ENSEMBLES project and find that the evolution of the systematic biases in the Pacific cold tongue region depends on the phase of ENSO.

Most of the applications of this approach to date have focused on the analysis of a single modelling system; from the point of view of the group developing the model this approach is likely to be the most fruitful (e.g. Martin et al., 2010; Fu and Wang, 2009). However a multi-model database provides an excellent community resource for identifying common biases across models with likely common causes, or systematic relationships between different biases and physical parameterizations (e.g. Hannay et al, 2009; Vannière et al. 2012). Identification of these common biases will provide focus for community-wide process-based studies such as those carried out within GASS[1]and WGNE or new observational campaigns.

Issues

The identification of systematic errors requires a sufficiently large database of initialized forecasts to distinguish between random errors and systematic errors. Furthermore, if the analysis is of some flow-dependent error growth (but still systematic) then sufficient examples of this flow state are required. Such analysis for subseasonal forecasts is likely to rely more heavily on the reforecast dataset than the forecast dataset and the reforecast dataset will likely be a useful resource here providing it is long enough and/or the ensemble size is large enough. It is likely that not all Centres will fulfil these criteria.

Whilst the proposed database will be useful for identifying the systematic errors, it is unlikely that the archive will have sufficient information for the analysis of the source of these errors. Such an analysis is likely to require more substantial process diagnostics.

Recommendations

1) *Two workshops on the systematic errors in the coupled system.*

    A workshop in this area at an early stage of the project would highlight the availability of this dataset for use, and provide a forum for discussion of techniques and existing results in this area to stimulate the use of this dataset. A second workshop later in the project could be used to stimulate new research, additional forecasting experiments, process modelling or observational campaigns to tackle common systematic biases.

Involvement of the TIGGE community is recommended as this would allow for comparisons between short range error evolution in coupled and uncoupled systems to be evaluated. These workshops should be held in conjunction with the CHFP as many of the forecasting systems will be similar and the seasonal forecasts allow for longer time development of the errors to be assessed.

Strong engagement of the modelling community e.g. through GASS[2] will help to identify productive areas of research and design of additional experiments.

NB WGNE is organising a workshop in Exeter in 2013 on systematic errors.

2) *Datasets*

The reforecast datasets will likely be the most useful resource for this type of analysis and early availability of these datasets will facilitate this and other projects (e.g. predictability studies).

Some types of analysis will be limited by the length of the reforecast datasets; mechanisms to make longer datasets available from those centres which use short reforecasts should be sought.

The availability of additional diagnostics (e.g. physics tendencies) would allow a more thorough analysis of the source of model errors; mechanisms for making these available, either through the archive or directly from centres (possibly with a catalogue at the archive) should be provided.

4.5 Ocean–atmosphere coupling for subseasonal prediction

In the context of prediction of atmospheric and terrestrial quantities, design of a prediction system depends on the sources of predictability, which are generally from predictability inherent in the specification of initial conditions, or the predictability associated with the evolution of boundary conditions, e.g., sea surface temperatures (SSTs). These two sources of predictability are referred to as the predictability of first and second kind respectively.

For predictions targeting a particular time scale, knowing dominant sources of predictability has implications for the design of appropriate prediction systems that can lead to maximal realization of inherent predictability. For predictions up to 10-15 days information contained in the atmospheric initial state is the most important source of prediction skill, and current operational weather predictions are generated using the best possible atmospheric analysis and with forward integration of the atmospheric general circulation model (often uncoupled with the ocean playing a passive role). For prediction on the weather time scales, therefore, realism of ocean-atmosphere coupling is not maintained, and further, the relative contribution of realistic ocean-atmospheric coupling to prediction skill over the skill due to specification of initial conditions is assumed to be small.

For seasonal predictions, on the other hand, there is a contrasting situation for the role of ocean-atmosphere coupling. For long-range prediction of atmospheric and terrestrial quantities, atmospheric initial conditions may be a less-important factor for prediction skill, and since evolution of the slowly varying ocean state needs to be predicted, reliance is on the coupled ocean-atmosphere prediction systems that include a realistic representation of ocean-atmosphere coupling.

The time scale of subseasonal prediction is such that the influence of initial conditions on the predictability is on the wane while the contribution from slowly evolving oceanic conditions may be on the rise. For this intermediate range, realistic representation of ocean-atmosphere coupling can be important for at least two reasons. It is possible that as the contribution of atmospheric initial conditions on the prediction skill goes down, the relative contribution of including a realistic ocean-atmosphere coupling on prediction skill increases. However, the potential contribution of realistic ocean-atmosphere coupling on prediction skill relative to initial conditions, and how this contribution changes with lead time, has not been quantified. The answer to this question primarily depends on the role of ocean-atmosphere coupling in constraining the atmospheric variability. It is also conceivable that correct representation of ocean-atmosphere coupling may be important for some specific phenomena, e.g., prediction of intensity and tracks of hurricanes, Madden Julian Oscillation etc., while it may not be of importance for atmospheric variability in high latitudes, and questions like these can also

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be addressed. (If the atmospheric model resolution is not very high, coupling leads to weaker tropical cyclones as it tends to lead to reduced SSTs, in which case coupling can actually lead to worse results, because of model error i.e. unless the model resolution is very high, the model tropical cyclones are not strong enough and are weakened by coupling).

As some of the operational monthly prediction systems are uncoupled and some are coupled, the contribution of ocean-atmosphere coupling on monthly and subseasonal predictions, together with the role of ocean-atmospheric coupling on modifying atmospheric variability are two of the questions that can be addressed as part of this project. Answers to these questions will also provide guidance for the future design of operational monthly prediction systems.

Another facet of ocean-atmosphere coupling is its effect on the prediction of SST on monthly time-scale themselves. An implicit assumption for weather predictions based on atmospheric models alone is that because of the slow evolution of SSTs, the skill of persisting initial SST anomalies remains high (Jung and Vitart 2006). Whether this holds for the monthly time scales, and how the skill of persistence of SST forecasts compares with predictions based on coupled models remains an open question (Kumar et al. 2011). Further, to the extent improvements in SST prediction skill, because of the inclusion of realistic air-sea coupling, subsequently leads to improvements in prediction skill of atmospheric and terrestrial variables remains to be quantified (Chen et al. 2012).

A different issue where ocean-atmosphere coupling can play an important role is having consistent data assimilation for coupled forecast systems. If the experience gained from weather predictions is of any guidance, the consistency between data assimilation and the prediction system for improvement in prediction skill should also be an important requirement for monthly prediction systems. Whether this could be achieved via conventional ocean and atmosphere data assimilation systems run separately or comprehensive coupled data assimilation techniques where error statistics take ocean-atmosphere coupled interactions into account needs to be addressed. A consistency in assimilation and forecast system is also required to minimize initial shock, and its influence on SST prediction.

4.6 Spread/skill relationship

Ensemble prediction systems provide information about the forecast distribution, which is most basically characterized in terms of information about the ensemble mean and spread. In seasonal forecasting, sizable ensembles are used to provide better estimates of the forecast mean, while the ensemble spread of individual forecasts does not typically provide useful information about the uncertainty of the individual forecast, over and above what can be derived from average forecast spread across many forecasts (Kumar et al. 2000; Tippett et al. 2004). This contrasts with the situation in NWP where there is more evidence that spread-skill relationships can be used to estimate the forecast uncertainty as a function of particular forecasts—in other words to predict forecast skill (Palmer 2000; Scherrer et al. 2004). The proper quantification of forecast uncertainty is critical to the successful use and broad uptake of forecasts, and research will be needed to determine the information content of subseasonal forecast ensembles. This has important bearings on defining the most efficient trade-off between model resolution and ensemble size, as well as the ensemble size of reforecast sets. The latter are typically much smaller than those of the real-time forecasts (e.g., 5 vs. 51 members respectively, at ECMWF).

Tailoring of forecast information for a wide range of applications requires flexible formats for probabilistic information. While seasonal forecasts have typically been issued in terms of forecast probabilities of tercile categories defined with respect to the historical distribution, recent practice has sought to provide the full forecast distribution from which the exceedance probabilities of user-relevant quantiles or thresholds can be provided as needed. The forecast probability distribution function (PDF) can either be estimated empirically from the ensemble by “counting” ensemble members, or by fitting a parametric distribution by the method of moments. For the ensemble sizes and lengths of reforecasts sets typical of seasonal forecasting, the parametric method has been shown to be superior for estimating tercile category probabilities (Tippett et al. 2007). Research will be required to develop optimal methods for the subseasonal time scale.

4.7 Design of forecast systems

At present, the configuration of subseasonal prediction systems at operational centres is an amalgamation of various strategies. Regarding prediction systems themselves, some systems are run in an uncoupled mode while others in a coupled mode. Relative merits of coupled and uncoupled systems and role of ocean-atmosphere coupling on prediction skill, together with unsolved questions were discussed earlier.

Differences also exist in scheduling subseasonal forecasts, for example, some forecasts systems are run in a "burst mode" in that a large ensemble of forecasts is initiated on a particular day of the week or month, while other systems are run in a continuous mode with a small ensemble of forecasts run each day. Both of the scheduling strategies have advantages and disadvantages, and their influence on prediction skill is a question that needs to be understood.

Subseasonal forecast systems run in a continuous mode, because of a smaller ensemble, require lagged ensemble approach for generation of real-time predictions. Lagged ensemble technique has two opposing factors that can influence prediction skill: while an increase in ensemble size by including longer and longer lead forecasts can improve prediction skill and reliability (Kumar and Hoerling 2000), inclusion of longer lead predictions in lagged ensemble can also result to degradation in prediction skill (Kumar et al. 2011; Weigel et al. 2008). Because of two opposing factors, it is not clear if there is an "optimal lagged ensemble" for monthly and subseasonal predictions, and what is its dependence on variable, geographical location, and time-average for which the prediction is made.

An advantage of prediction systems run in a continuous mode may be a better sampling of ocean and atmosphere initial state, and the possibility that some of the fast transitions in the modes of variability that can affect climate for the subsequent month, can be better captured. However, at present we don't know whether a larger ensemble for predictions systems in a burst mode or a smaller ensemble, but spread over many different days for the continuous mode systems, offers a better strategy for sampling forecast uncertainty associated with initial conditions.

One potential disadvantage of continuous prediction systems, is that unless the associated reforecasts are run in a similar mode, construction of appropriate lead time, and initial time dependent climatologies becomes more complex. In summary, there are many forecast system configuration issues that can be addressed based on the data sets collected as part of this project, and answers will help develop future strategies, and improved coordination of monthly forecast systems among operational centres. It is worth noting that it is the standardization of weather forecasts across operational centres in terms of their scheduling that greatly facilitated exchange of forecast data and improvement in skill and reliability of products issued to the user community.

A contrast also exists in the generation of the reforecast set. A reference set is needed in order to allow correction for model error. This reforecast set should cover a sufficient number of years to allow calculation of the model climate pdf, but the number of ensemble members in the reforecast set varies between centres. A large ensemble set allows a better evaluation of skill and the training and testing of application models (see sec 2) but requires either a large increase in computing cost or a reduction in the model resolution used.

One could argue that many questions raised in the context of design of extended-range prediction systems are interim in nature and ultimately with advances in computing, and eventual development of coupled assimilation techniques, forecast for all time ranges will be just an extension of weather forecasts, which will be made using coupled prediction systems. Further, as every day a large enough ensemble (with an appropriate set of reforecasts can be generated), a differentiation between "burst" vs. "continuous" mode, in the context of their influence on prediction skill, will no longer be relevant questions. However, the question of how often a monthly prediction should run, and how often the information should be provided to the users, will ultimately depend on the decision making process that is affected by forecast information on this time scale.

4.8 Verification

Forecast verification activities will be an important aspect of the subseasonal to seasonal prediction effort and will serve numerous purposes, including (i) providing information and guidance regarding deficiencies and benefits associated with changes in subseasonal prediction systems, which can feed back into system improvements; (ii) evaluating the impacts of components of the subseasonal prediction systems such as land data assimilation system impacts, the ability to predict MJO and other sub-seasonal phenomena (e.g blocking, storm track variations, etc.), and the dependence on ENSO; (iii) evaluating the benefits of multi-model ensemble configurations; and (iv) providing linkages with users and applications of the predictions (e.g., to provide meaningful information for decision making). It will also be important to include the verification of user-relevant quantities or variables right from the start of the project. This may involve early meetings with user communities to better define needs. While verification of subseasonal predictions will share many characteristics with verification methods and approaches for both shorter-range and seasonal and long-range forecasts, certain attributes will require special treatment, and the approaches taken for each of the other time scales will contribute only partially to meet the needs for evaluation of subseasonal predications. For example, verification samples for short-range predictions typically are quite large, at least in comparison to the samples available for evaluation of seasonal and long-range predictions. Naturally, the sample sizes for subseasonal predictions will fall somewhere in the middle. In particular, sample size limitations for subseasonal predictions will not be nearly as great a limiting factor as for seasonal and long-range predictions since the forecasts are anticipated to be collected on a daily, twice weekly or weekly (as opposed to monthly or seasonal) time scale. Nevertheless, adequate samples (including reforecasts) will be needed to allow subsetting of data to provide meaningful verification information.

Before any detailed consideration can be given to the kinds of methods that will be utilized in the verification effort, it will be critical to carefully and precisely clarify the definitions of the variables being predicted. In particular, the temporal and spatial scales and physical definitions associated with each variable must be clearly specified. Secondarily, observations and analyses that are available for comparison to the forecasts must be identified. Where possible, either actual observations or model-independent analyses should be considered for use in evaluating the predictions in order to allow more meaningful (model-independent) evaluations, particularly for surface variables.

As has been done for seasonal and long-range forecasts, it will be desirable to establish a common set of metrics to apply to the subseasonal predictions. Since most Centres do not currently use the same set of metrics, it will likely take some effort to obtain agreement on the measures. Although many of the verification efforts will be undertaken by researchers, a centralized verification effort would be highly desirable and should be considered; a centralized effort would allow uniformity in the evaluation methods applied, and would lead to broader evaluation of the forecasts, but would also add significantly to the effort required for the subseasonal to seasonal prediction project. Verification approaches for ensemble forecasts and forecasts of extreme events will be particularly important; a focus on the distributional and probabilistic aspects of the ensemble forecasts, with potential implications for models with small ensemble size – as opposed to the ensemble mean forecast – will be most relevant for meeting the goals of the subseasonal to seasonal prediction effort and the needs of end-users. Advanced and user-relevant verification metrics should be considered, such as new probabilistic measures (e.g. Weigel et al. 2008, Weigel and Mason 2011) and spatial methods that provide meaningful performance information for forecasts with coherent structures (e.g., Gilleland et al. 2009). The latter approaches can also provide information regarding which scales are predictable (Gilleland et al. 2009). Where appropriate, a wide range of thresholds should be applied to probabilistic forecasts to provide verification information that is meaningful for a variety of forecast users. Evaluation of quantile forecasts may also be of considerable benefit. For many evaluations, long-term climatological information (quality controlled, for both stations and grids) will be required and should be included in any data archival system associated with the project. The use of confidence intervals should be strongly encouraged, to represent the sampling uncertainty associated with the verification measures and to provide statistically meaningful comparisons between forecasting systems.

Data collection, storage, and access should be designed to take into account the needs of verification and application efforts. For example, time series information for a particular location or region is often relevant for these activities. Easy access to data in this form will make it more likely that these kinds of activities will be undertaken. In addition to researchers, the data should be provided in a way that will encourage evaluation of the forecasts by the Centres. Verification efforts focused on intercomparing the subseasonal forecasting systems and different ensemble forecasting configurations should be encouraged, to evaluate the benefits of the multi-model ensemble approach. To facilitate these kinds of efforts, and to ensure that the verification methods are closely linked to user needs, the Steering Group for the WMO's subseasonal to seasonal prediction effort should include a verification expert and a member of the SERA working group.

4.9 Summary of some recommendations from sections 3 and 4.

- Define a set of common methodologies and metrics to validate models, estimate skill of subseasonal forecasts, and to evaluate model performance in simulating and predicting teleconnections.

- Identify potential sources of predictability and their representation in models

- Identify, represent and convey the conditional skill of forecasts during 'windows of opportunity' when predictability is enhanced

- Investigate the ability to predict the onset and cessation of the rainy season as well as dry/wet spells within a season, such as breaks and active phases of monsoons

- Investigate the predictability of sea-ice and the impact of sea-ice on subseasonal forecasts.

- Determine the modulation of extreme hydrological events by the MISO using both individual models and multi-model ensembles.

- Set up a demonstration project to assess the skill of extreme events such as a heat wave or a cold wave. (See later)

- Investigate how best to initialise models, to diagnose the growth of error with a view to model improvement, to quantify the degree to which initialisation shock degrades the subseasonal forecasts and to assess the extent to which coupled data assimilation can improve forecast skill.

- Identify what processes are improved by increased model resolution, and determine how resolution affects forecast skill, bias, and important processes such as blocking.

- Evaluate the degree to which coupling of the atmosphere and ocean impacts forecast skill.

- Evaluate the spread-skill relationship for the subseasonal range, and the impact of ensemble size on forecast skill

- Quantify the relative advantages and disadvantages of burst v lagged ensemble generation.

- Develop and compare existing methodologies for re-calibration of forecasts at the subseasonal range

- Quantify the relative skill of a multi-model ensemble compared to that from a single model.

A database of operational subseasonal forecasts similar to TIGGE for medium-range forecasts together with available reforecasts would be a useful tool to investigate the predictability of the subseasonal to seasonal time range and would help address most of the recommendations listed above. However, the database may not be sufficient to answer some of these scientific questions (e.g. what is the optimal way to initialize subseasonal forecasts). In these cases, targeted experiments would be needed. It is therefore recommended for the steering group to coordinate one or two experiments in addition to setting up the database. These experiments could be done on the special case studies, which are discussed in Section 7, and could also be done in coordination with other working groups.

5. Summary of current activities in operational subseasonal forecasting

A major recommendation of the subseasonal to seasonal prediction planning group is that a collaborative structure between WCRP and WWRP be set up to help improve prediction at the subseasonal to seasonal time scale. In order to improve numerical prediction, we need first to know how the state-of-the-art models perform and what their shortcomings are. For that purpose, the planning group recommends the building of a database for subseasonal to seasonal prediction similar to what TIGGE has done for medium-range forecasting or CHFP for seasonal forecasting. Such a database would be very valuable for assessing the skill and usefulness of state-of-the-art subseasonal forecasts for applications. The TIGGE project recognised that the calibration of ensemble forecasts, correcting for model biases and allowing downscaling was an interesting alternative to MEPS. Calibration can be made by removing drift and adjusting the spread of the ensemble. In TIGGE it was shown that a calibrated forecast from a single model could be as skilful as a multi-model ensemble of uncalibrated models. In principle, one could construct a multi-model ensemble of calibrated forecasts, but this seems not to have been done in the context of weather or subseasonal forecasting, but some work has been done in the context of seasonal forecasting. (see Anderson 2011). This database would help to assess the advantage of multi-model combination at the subseasonal time scale. Finally, this database would also be very valuable to answer important scientific questions, such as the identification of sources of predictability at the subseasonal to seasonal time scale and their representation in the state-of-the-art numerical models. This aspect has been discussed in more detail in earlier sections of this report. Before making a specific proposal for the construction of a comprehensive data base we review the characteristics of various operational subseasonal and seasonal forecast systems.

Ten years ago, only a couple of operational meteorological services were producing subseasonal forecasts. However in recent years, more operational forecasting systems dedicated to subseasonal prediction have been implemented and now the majority of the GPCs (9 out of 12) have a forecasting system designed to target specifically the subseasonal time range (more than 2 weeks and less than 2 months). In some GPCs, the subseasonal and seasonal forecasts are produced by the same forecasting system (e.g. UKMO, NCEP, CAWCR), whereas they are produced by two distinct forecasting systems in other centres (e.g. JMA, ECMWF, EC). Annexe 2 shows a summary of the subseasonal to seasonal prediction activities in the 12 Global Producing Centres of long-range forecasts (GPCs). In this table, the activities related to seasonal forecasting are indicated in red (all 12 GPCs produce operational seasonal forecasts). The activities specifically related to subseasonal prediction are indicated in blue.

During integration, the models tend to drift towards their own climatology which can be quite different to the observed climatology. At the subseasonal to seasonal time range, this model systematic error becomes too important to be ignored. One way to correct this error is to apply a bias correction during the model integrations. This method, sometimes called flux correction, as it originally applied as a heat flux correction at the surface, though in principle it could be a 3d field applied to any prognostic variable, is sometimes used in climate modelling, but is rarely used in subseasonal and seasonal forecasts. An alternative approach, used extensively in seasonal and subseasonal forecasting, is to correct the model systematic errors a-posteriori. In order to correct the bias, we need to estimate the model biases, which is done by integrating the models over a number of past dates and comparing these reforecasts to an analysis. This is the reason why most of the systems described in Annexe 2 include an extensive set of re-forecasts.

As for the real-time forecasts, the set-up of the re-forecast datasets can vary greatly from one centre to another. Sometimes, the re-forecasts are produced once and they are used to calibrate the real-time forecasts for a number of years. This is also the case for most seasonal forecast systems, which often use a frozen version of a model, which is changed only after a number of years. However, in the centres where the version of the model used to produce subseasonal forecasts changes several times a year, the re-forecasts are often produced on the fly. For instance, the re-forecasts that are used to calibrate a given real-time forecast can be produced the week preceding the production of the real-time forecast. This ensures that the real-time forecasts and the re-forecast use exactly the same model physics. Other differences between re-forecast sets include the ensemble size, model resolution, the frequency (daily, weekly or monthly) and also the number of years that are covered by the re-forecasts. In some models, the re-forecasts cover only 10 years whereas in other cases they cover more than 30 years.

As annexe 2 shows, there is much less consistency between the various subseasonal forecasting systems than there is amongst the various seasonal forecasting systems. Some subseasonal forecasts are produced on a weekly basis (once or twice a week), others are produced on a monthly basis (several times a month) and others are produced on a daily basis. Some models are coupled to an ocean model, others are based on atmospheric integrations forced by persisted sea surface temperatures or persisted sea surface temperature anomalies. The horizontal and vertical resolution of the models and the ensemble size varies greatly from one centre to another.

There is also a difference in the way the various centres perceive the use of re-forecasts: for some centres, the purpose of the re-forecasts is just to calibrate the real-time forecasts and therefore these re-forecasts have a small ensemble size in order to save computational time for the real-time forecasts. In other centres, the re-forecasts are also viewed as a key element to assess the skill of the real-time subseasonal forecasts, in addition to their use to calibrate the real-time forecasts. In these institutions, the size of the re-forecasts is generally large and spans a large number of years to allow skill assessment. This explains partially why there is such difference in the configuration of the various subseasonal re-forecasting systems displayed in Annexe 2. A large reforecast data set is advantageous for downstream applications, to be able to train and test application models.

In summary, the operational subseasonal forecasts produced by the GPCs exhibit very different configurations. Medium-range and seasonal forecasts display much more consistency; for example, all the GPCs issue seasonal forecasts once a month valid for the 1st of the month. The diversity of approaches used for subseasonal forecasting will make the creation of a subseasonal MEPS database particularly challenging.

6. Database proposal

Ensemble Prediction Systems (EPSs) are widely used for weather and environmental (e.g. hydrological services) prediction by operational services. Ensemble forecasts offer not only an estimate of the most probable future state of a system, but also a range of possible outcomes. Assessing how subseasonal–to-seasonal variations may alter the frequencies, intensities, and locations of high-impact events is a high priority for decision making. This makes the development and use of ensemble–based modelling a requirement for subseasonal to seasonal prediction. Therefore the Multimodel EPS (MEPS) approach (like for TIGGE and CHFP) is strongly recommended for this database. The data base can be used to assess many practical and scientific issues related to subseasonal forecasting and to application of these forecasts. It is not envisaged that the data base can be used to address all issues, however, but rather that it will be augmented with specific targeted experiments to address specific scientific issues.

Although the current operational subseasonal forecasting systems have very different set-ups as discussed above, most of these forecasting systems share enough common points to make model intercomparison and multi-model products feasible. For instance, 6 of these forecasting systems (JMA, ECMWF, EC, CAWCR, NCEP, and UKMO) can produce real-time subseasonal forecasts once a week (every Thursday) and some twice a week. This would be sufficient to study the advantages of multi-model combinations for subseasonal prediction. It is recommended that the dataset includes contributions from the 12 GPCs for long-range forecast, both to maximize the scope as well as to increase the potential level of community support. For the GPCs which have separate subseasonal and seasonal prediction systems, only their subseasonal forecasts will be included in the database since CHFP and ET-ELRF are already collecting their seasonal forecasts. For the GPCs which do not have a specific subseasonal forecasting system, the daily data of the first 2 months of their seasonal forecasts could be used. Annexe 2 shows a table of the models that could be included in the database.

It would of course be desirable to release the subseasonal to seasonal forecasts as close as possible to real-time to attract a maximum number of applications and users. However, this conflicts with the data policy of some of the GPCs. It is therefore proposed to start with a forecast release date that is at least 3 weeks behind real-time. This issue will be revisited after 1 year. For some special cases, the 3-week delay could be removed and near real-time access allowed for a limited amount of time.

Finding a centre willing to host this database will be crucial to the success of this proposal. So far, ECMWF, which already hosts the TIGGE dataset, has expressed an interest in archiving this dataset under several conditions: the dataset volume should be relatively small (less than 10% of the TIGGE dataset volume would be acceptable) and the amount of human resources needed to implement and monitor this dataset should be very limited or funded by external agencies. It is very likely that other potential hosts would have the same requests. Therefore it is very important to make the implementation of this database as efficient as possible in terms of volume and human resources.

In order to reduce the human resources needed to implement this database, it is strongly recommended that the same GRIB2 protocol be used to archive the data as was used for TIGGE. This would make additional use of the work already done for TIGGE and therefore would minimize the technical work needed to create and maintain the subseasonal prediction database. However, the database displays some characteristics which are not shared by TIGGE, such as the archiving of reforecasts. In particular, the archiving of reforecasts which are produced on the fly will need to be defined in GRIB2. Therefore the setup of this database will require some technical work, but this will be significantly less than that needed to set up the TIGGE data base. In addition, TIGGE has more than 1300 registered users on the TIGGE portal and more than 50 publications. See, for example, (http://tigge.ecmwf.int/references.html). Following the TIGGE protocol will also have the very important advantage of making the subseasonal prediction dataset easily accessible to the WWRP community which is already making use of the TIGGE database. Archiving the new database at the same locations as TIGGE would also help to encourage the use and evaluation of the subseasonal predictions by the TIGGE community. This new database could be seen as an extension of TIGGE to the subseasonal time range.

To reduce the volume of data, there are two options: either archive only a few variables at their native resolution which can be very high for some models or archive a large number of variables but at a fixed relatively low resolution. The last option is recommended since archiving a large number of variables will allow better diagnostics of model skill and failures and also will help diagnose various sources of predictability (stratosphere, ocean, land surface…). In addition, at the extended time-range the predictive signal has generally a relatively large scale, and having very high resolution inputs is not always that useful. Therefore it is recommended to archive the data on a fixed latitude-longitude grid (1.5x1.5 degree or closer to the native resolution for low-resolution models). This will have the advantage of reducing the volume of the database and also ensure that the database will not grow exponentially with time when new higher resolution forecasting systems are introduced. The choice of 1.5x1.5 degree grid may be a problem for some applications which may need much finer horizontal resolution, but it has the advantage of making the volume of the archive small enough to allow the archiving of a large number of variables. To limit the volume of data archived, it is also recommended to archive only daily forecasts and reforecasts. For most of the surface fields, daily data could be computed from outputs produced 4 times a day to avoid aliasing the diurnal cycle. For upper air-fields, instantaneous fields should be used, e.g. 00Z.

Annexe 3 shows the list of variables that are recommended to be archived. This list has been built from the list of variables for TIGGE, except that some TIGGE variables (convective inhibition, field capacity…) and pressure levels (700 hPa and 250 hPa) have been removed and a few pressure levels and a few surface variables have been added. The main difference with the list of variables for TIGGE is the inclusion of stratospheric levels and oceanic variables. The archiving of a few stratospheric levels is motivated by the potential importance of stratosphere-troposphere interaction at the subseasonal to seasonal time scale. The archiving of oceanic data is motivated by the fact that some of the models in Annex 2 have an oceanic component, unlike all the models used for TIGGE, and the upper-ocean variability is also an important source of predictability at the extended range. Overall, this represents 73 fields (9 ocean fields, 26 surface fields and 38 pressure level fields). As is the case for the TIGGE database, it is not expected that all the GPCs will provide all the variables. A survey amongst some of the GPCs shows that they can produce most of the surface and pressure level fields. For the ocean fields, there will be fewer GPCs able to produce them, since some subseasonal forecasting systems are still based on atmosphere-only integrations forced by prescribed SSTs or SST anomalies, and some of the GPCs which use a coupled ocean-atmosphere model do not archive ocean data.

The list of ocean variables in Annexe 3 does not allow the computation of the barrier layer, which can be a useful diagnostic of ocean processes at the subseasonal time scale. The barrier layer can be computed as the difference between the depth where the temperature differs from SST by a specific amount such as 0.5C and the depth of the mixed layer where the density differs from the surface density by a certain amount. However, there is currently no clear definition of what this amount should be, and different centres are archiving different values. Some of these values are relevant for the Tropics whereas others are relevant for the Extratropics. It would therefore be useful to have an agreement for some convention, which should be adopted by the relevant ocean community.

The table in Annexe 4 gives an estimate of the volume of data to be archived per year. Since reforecasts will be archived and some of the model reforecasts are produced once and for all, the volume of data to be archived will not be constant from one year to another. The first year will be the most costly, with about 15 Terabytes of data to archive, but the volume of archiving will drop significant in the following years, with only about 7 TB per year. This table assumed that all the 76 variables will be archived by all the models. This will not be the case since several of the models for instance do not have an ocean component as discussed above. Therefore the numbers in this table are an overestimation of the real cost. Since the volume of data archived for TIGGE is currently about 180 TB per year, even the archiving volume in the first year (15 TB) will be less than 10% of the volume of TIGGE data per year, and be less than 5% in the following years. This should be small enough to make it acceptable for some operational centres to host this subseasonal forecast dataset.

In addition to the daily data described in Annexe 3, it would be very useful for some users to archive some of the fields after calibration using the model reforecasts and averaged over a specific period of time (e.g. weekly or pentad means). This would make access to the dataset much easier for some users and reduce significantly the number of retrieval requests and also the complexity of creating calibrated fields due to the large inconsistency of the reforecasts. However, it is recommended to start archiving the daily fields and coordinate with ET-ELRF on the issue of calibration and time averaging. In addition these calibrated temporal means will need to be properly defined in GRIB2.

To encourage its use, it will be very important to make this subseasonal forecast database easily accessible to the WCRP community as well as to the WWRP community. However, the climate community uses the netcdf format rather than GRIB2. Therefore, an effort will be needed to make this dataset also available in netcdf. This may not be as straightforward as for other projects which used OpenDap, since the volume of data involved is too large. The IRI infrastructure (Data Library) could act as a second server of this database.. The potential use of the IRI Data Library would be contingent on adequate additional resourcing through the project. In addition, the GEOWOW FP7 project plans to develop an interface for the ECMWF TIGGE portal to enable people to get data in netcdf format (by converting it from GRIB2). This interface should also work for the subseasonal forecasts. Therefore it will be important to follow the progress made by this working group. A grib to netcdf conversion protocol is also currently available for the ECMWF reanalysis (ERA Interim). The data are stored in the database, but the retrieval of the data includes a script which automatically produces netcdf data. A similar procedure could be applied for the subseasonal dataset.

To achieve some of the goals of this implementation plan, a technical workshop is needed to review the technical aspects of the archiving and organize its implementation. Although many issues relative to the archiving in GRIB2 have already been sorted out for TIGGE, this workshop should also address other technical issues:

- Archiving of reforecasts produced on the fly
- Archiving of calibrated forecasts
- Archiving of temporal means
- Netcdf conversion

In order to strengthen the links between the sub-seasonal to seasonal prediction project and the seasonal (in particular WGSIP) and climate communities, it is also envisaged to invite some high resolution climate models to be part of this database. In general, these models are not run in real-time, but re-forecasts produced with these climate models could be archived in the sub-seasonal to seasonal project database using the same protocol. In addition, high resolution climate models could also participate to some of the demonstration projects which will be described in the next section. This would make it easier to assess and compare the sub-seasonal variability and predictability in state-of-the-art NWP and climate models.

The global models mentioned above, and which display sufficient skill to predict the large-scale circulation at the sub-seasonal to seasonal time scale, could be used to produce the boundary forcing of regional models, especially for selected case studies. High resolution regional or mesoscale models which have the advantage of better identifying severe convection can contribute to further improvement of extreme weather and climate prediction (e.g. frequency and intensity of tropical cyclones). The participation of regional models to this project would help establish stronger links with regional panels.

7. Demonstration projects

There are many potential advantages in setting up demonstration projects as part of this project. Demonstration projects could consist of several test cases where subseasonal forecasts from the various operational centres would be available close to real-time to the research and application communities, possibly including archiving a larger set of variables and at a higher resolution. The demonstration projects would be an important way to promote the use of subseasonal prediction by application users and foster relationships with partners and provide common focussed objectives.

At least two case studies are recommended. The main goal of these case studies will be to demonstrate that using subseasonal predictions could be of benefit to society. Therefore the case studies should be chosen for their high societal impact, but should also represent interesting research topics. The case studies should therefore focus on extreme events. Since the extreme events are by definition rare, one case study could be taken from the past. Other case studies for the demonstration project should be studied in real-time.

The Pakistan floods (2010), concurrent with the Russian heat wave, could be an excellent test case from the past. The amplitude of these two extreme events and the very high societal impact they had would make a focussed study on this period very valuable to the application communities. Furthermore, the Pakistan floods exhibited some associations with tropical-extratropical interactions, MJO events and a La-Nina event which makes it a very interesting test case for the scientific communities to better understand its causalities. The use of the subseasonal prediction database will be a very useful tool to see how this event was predicted by the models which have re-forecasts covering this period. For the other models which do not have re-forecasts for this period, running a specific re-forecast experiment could be suggested. Other possibilities could be the Australian floods of 2009, which happened during the YOTC period, or the Australian floods of 2011, and the European cold spell of 2012.

Other past case studies could be chosen for the scientific insight they could produce, or for the insight on the use of sub-seasonal to seasonal forecasts they could bring to the application community, and could be chosen in conjunction with other working groups. For instance, one of the demonstration projects could be one of the MJO events being undertaken in the MJO TF and GASS study (from October 2009 to January 2010); it would provide a wealth of augmentation in terms of YOTC data sets, analysis by the community on observations and the multi-model experiment that might be leveraged by the GPCs to examine and improve their models.

At least one of the demonstration projects should be a real-time case. This is often the best way to foster collaborations between the research and the application communities. For instance, a period of one or two seasons could be chosen for the subseasonal prediction database to be in real time and investigate the prediction of the extreme events during that period. The choice of the period could also be chosen to coincide with test bed studies from another project such as the Year of Polar Prediction to help understand the subseasonal predictability of sea-ice and the impact of polar processes on subseasonal forecasts, or new tropical field experiments (like YOTC, DYNAMO, T-PARC in the past). This could also be done in collaboration with a CLIVAR or GEWEX regional panel.

An important outcome of these demonstration projects would hopefully be a better understanding of the causalities of some extreme events. This would be of interest to the climate community for the attribution of extreme events to global warming or to natural low frequency variability and would help to generate additional coordination between the weather and climate communities. The WWRP Working group on Societal and Economic Research and Applications (SERA) should be an integral part of these demonstration projects. An application to Africa should be considered with SERA as suggested above.

8. Linkages

8.1 Global Framework for Climate Services (GFCS)

Within the Research Modelling and Prediction (RM&P) component of the Global Framework Climate Science, research focussed on delivery of climate information for decision making will consist of experimental and theoretical work aimed at improving the quality of forecasts on various timescales, including the subseasonal. The objectives of the RM&P component of the GFCS are to conduct the fundamental climate research aimed at deeper understanding of the functioning and predictability of the Earth climate. It should enhance the science readiness level to develop the core climate prediction tools and substantiated climate information products, and to maximize the societally relevant and useful climate information. This should be based on climate science by proactively targeting the research towards development and improvement of multiple practical applications and information products and satisfying the identified requirements of the users of climate information at the current science and technology readiness level.

Topics listed as being very important to GFCS are land, monsoons, floods, droughts etc. cyclones, sea level which are essentially the same products that the subseasonal to seasonal project is interested in. A high level task force has produced a view as to how the GFCS should operate. They envisage the RM&P feeding into a Climate Services Information System (CSIS) and then into a User Interface. Feedback would occur from the user community back to the research community through the CSIS.

The subseasonal to seasonal time-frame is very much within the remit of CFCS and the output from the Subseasonal to seasonal prediction project could be an important contribution to the first (near-term) phase of GFCS. Although the full structure for GFCS is unlikely to be in place before the project starts, it should be prepared to participate as the GFCS infrastructure is developed. For further information on the GFCS see Climate Knowledge for Action: A global framework for climate services- empowering the most vulnerable. 2011 WMO pub no 1065. ISBN 978-92-63-11065-7. P-WDS-101813.

8.2 CLIVAR and GEWEX including Regional panels and WGNE

The research required to improve subseasonal to seasonal prediction as well as the evaluation of forecasts should be conducted in close collaboration with the WCRP GEWEX AND CLIVAR core projects.

GEWEX is currently developing plans for the next 10 years, based around four grand challenges (GCs). GC1 involves developing improved data sets on precipitation and soil moisture and development of new products for improved understanding of atmosphere-ocean-land surface processes with a view to improved representation of precipitation and the hydrological cycle in models. GC2 and GC3 are concerned with droughts, floods and heat waves and seek to develop field programmes and process studies to improve representation of extreme events in models. These are examples, not exclusive, of areas of common interest between GEWEX and the subseasonal to seasonal prediction project and represent areas where collaboration would be mutually beneficial.

In the same spirit, CLIVAR has a number of panels dealing with issues relevant to subseasonal forecasting. The regional panels, AAMP, VACS and VAMOS have specific objectives to assess the variability and predictability of the Asian/Australian/ monsoon, the African climate system and the American Monsoon system. These three are focussed on the tropics but several of the regional projects within GEWEX have an extratropical focus. CLIVAR/GEWEX Endorsed projects such as that for the La Plata Basin illustrate projects that incorporate basic science, applications in agriculture and hydrology, with a strong component in capacity building. (CLIVAR Exchanges, no 57, Oct 2011, is specifically devoted to this type of activity.) Reference has already been made to several CLIVAR activities such as the one on assessing the importance of stratospheric processes. See also secs 3 and 4 where links to CLIVAR and GEWEX activities are made and sec 4 where collaboration with WGNE is envisaged.

There should be liaison with the WGSIP CHFP project's three major research themes, namely the treatment of sea-ice, the stratosphere and the land surface. Each project has experiments (Ice Historical Forecast Project; Stratospheric Historical Forecast Project and the GLACE experiment respectively) which could be analysed to inform about initialisation of these components of the coupled system for subseasonal prediction.

Although the remit of WGSIP is from seasons to longer timescales, there are likely to be many issues of common interest and so strong collaboration with this group is envisaged. The WCRP WGSIP work on the stratosphere (SHFP) will quantify improvements in predictability by initialising and resolving the stratosphere in seasonal forecast models. The data base (see sec 6) will allow such an assessment to be applied to the subseasonal range, and illustrates a potential link with CLIVAR. A possible joint project might consider a case study of a sudden warming and subsequent cold event over Europe, for example winter 2003/4, JAN/FEB2005/6, JAN/FEB2009 or JAN/FEB 2012.

There are several ways in which the MJOTF and the subseasonal to seasonal prediction project could collaborate. The data base being proposed by the TSPG will be very useful for the MJOTF to better understand the relationship between the MJO and ISV and initiation and modulation of tropical cyclones. The methodologies developed in MJOTF can be used to target boreal summer season and northward propagating ISV.

The CLIVAR SHFP (stratosphere) will quantify improvements in predictability by initialising and resolving the stratosphere in seasonal forecast models. The data base (see sec 6) will allow such an assessment to be applied to the subseasonal range, and illustrates a potential link with CLIVAR.

With respect to model bias, two workshops are recommended to address model bias. These would involve WGNE and GASS and could be used to advertise the availability of the data base. The TIGGE community should be involved, as the data base should be a simple extension of the TIGGE data base. In collaboration with TIGGE and GASS, there should be coordinated periods when addition information is archived. By involving TIGGE and GASS there is a link between error in the subseasonal time range and other time ranges including short term NWP.

The examples given above are neither prescriptive nor exhaustive.

N.B. WGNE is organising a workshop on model bias, scheduled for spring 2013 in Exeter.

8.3 Year of Tropical Convection

The Year of Tropical Convection (YOTC), jointly coordinated by the WMO's World Climate Research Programme (WCRP) and the World Weather Research Programme (WWRP)/THORPEX, exploits the vast pool of existing observations, high-resolution assimilation and modelling, and theoretical developments. The main objective is to advance capabilities in weather forecasting and climate prediction with a focus on tropical convection, its multiscale organization, and interactions up to the global scale. The YOTC Science Plan (Waliser and Moncrieff, 2008) describes the motivation and proposed science framework and Waliser et al (2012) and Moncrieff et al (2012a) describe the synoptic character of the YOTC period and proposed YOTC paradigm for global virtual field programmes, respectively. There are a number of linkages with YOTC data and resources that can support the objectives of the Subseasonal Prediction programme. This include the connections to the objectives and activities of the YOTC MJO Task Force which were highlighted in Section 3 (www.ucar.edu/yotc/mjo.html), specifically these include their development of process-oriented metrics to inform model development and MJO simulation/forecast metrics for monitoring and forecast uses. In addition, the MJO Diabatic Heating multi-model experiment that the YOTC and their MJO Task Force is sponsoring can be a useful research resource to examine the sensitivity of MJO simulation and forecast quality to model parameterization choices (www.ucar.edu/yotc/mjodiab.html). Moreover, there are a number of operational centres contributing to these experiments which provide a more direct way of making comparisons between the centres models and capabilities. This experiment, along with the Transpose AMIP http://www.metoffice.gov.uk/hadobs/tamip/ and DOE/CAPT activity at PCMDI, both rely on the YOTC ECMWF analyses data set for initial conditions. This data set, and associated strategy of using even very short term reforecasts can be a very useful strategy for continued model development and benchmarking - much the same as ECMWF has used the TOGA COARE period to check for and demonstrate continued model improvement. Finally, YOTC sponsors a number of community engagement activities such as their 1st Science Symposium (Moncrieff et al. 2012b) in May of 2011 and annual sessions at the Fall AGU meetings. These sorts of meetings and activities can be leveraged as there are common objectives between YOTC and the subseasonal to seasonal prediction activity.

8.4 Linking with commissions on agriculture/health/hydrology communities

The research programme will be conducted in close coordination with developing operational subseasonal activities coordinated under CBS.

Background to CBS operational seasonal and subseasonal activities
Supply of real-time, operational forecast information to WMO members is coordinated through the WMO's Commission for Basic Systems (CBS) - with infrastructure and procedures defined in the Manual on the Global Data Processing and Forecast System (GDPFS). In recent years, working through the CBS Expert Team on Extended and Long-range Forecasting (ET-ELRF), an operational system for coordinating seasonal forecast output from international prediction centres has been established and products from this system are now in widespread use (Graham et al. 2011). The infrastructure includes 12 Global Producing Centres for long-range forecasts (GPCs) and 2 Lead Centres to facilitate information flow to the users. The 2 Lead Centres (LCs) are the LC for Long-range Forecast Multi-Model Ensembles (LC-LRFMME) - which collects, processes and displays data from the GPCs, and the LC for the Standard Verification System of Long-Range Forecasts (LC-SVSLRF) - whose primary function is display of GPC reforecast verification information. The LC-LRFMME is jointly operated by KMA and NOAA NCEPs CPC. The LC-SVSLRF is jointly operated by CMC and BoM.

Development, within the GDPFS, of similar infrastructure and procedures to allow real-time operational exchange, processing, dissemination and display of subseasonal forecast information generated by international prediction centres is in the Terms of Reference of the CBS ET-ELRF. Noting that many centres are developing operational monthly forecast systems, WMO Congress XVI requested the LC-LRFMME to explore the possibility of extending its role to include exchange of extended-range predictions. In this context, all GPCs were invited to also provide data from their monthly forecast systems so that the LC-LRFMME would be able to provide subseasonal forecast products through the LC-LRFMME web pages.

Coordination of the research programme with CBS operational activities
Research into subseasonal predictability under the project will be conducted in close liaison with developing infrastructure and procedures for operational subseasonal prediction, alluded to above, as they develop under CBS. Data archiving and research themes will be aligned to support and help future operational activities. For example, data for operational exchange under CBS may be defined as a subset of that archived for research – allowing efficient servicing of both activities. Research activities conducted will include identification of the present prediction strengths and limitations at the subseasonal range – helping to shape the scope of developing operational products to be provided to the lead centres in due course.

Liaison between the project and CBS programmes will be achieved through nomination of specific individuals involved in both activities who will act as rapporteurs. Rapporteurs will be nominated at the next meeting of the implementation team. In addition to maintaining strong links between subseasonal research and CBS's operational activities it is also important that Regional Climate Centres (RCCs), developing under the CCl programme, are kept informed of developments in subseasonal research. RCCs form an important link between

GPCs and the NMSs and end users and can assist in prioritising research themes that will help address current gaps in information needed by users. In this context the research programme will liaise with the joint CCl/CBS Expert Team on Regional Climate Centres http://www.wmo.int/pages/prog/wcp/ccl/opace/opace3etRCC.php .

The steering group should also establish direct links with some agriculture/health/hydrology initiatives. For instance, links with the Meningitis Environmental Risk Information Technologies (MERIT) would help determine if subseasonal forecasts can be useful for the prevention of the meningitis, through the prediction of low-level winds over the Sahara.

8.5 Verification

The verification effort for the subseasonal forecasts will benefit greatly from connections with the Lead Centres for verification of long-range forecasts, making use of the Standardized Verification System for Long-range Forecasts (SVS-LRF), and with the Joint Working Group on Forecast Verification Research (JWGFVR), which is a working group under the World Weather Research Programme (WWRP) and the Working Group for Numerical Experimentation (WGNE). The SVS-LRF documents verification approaches that are appropriate for seasonal forecasts, and the Lead Centres make tools available for computing the verification measures that are prescribed (http://www.bom.gov.au/wmo/lrfvs/index.html). The JWGFVR provides guidance on verification methods for weather forecasts at a wide range of time and space scales and provides resources on verification methods (http://www.cawcr.gov.au/projects/verification/). The JWGFVR also provides outreach and education on verification topics and authors documents that provide guidance on the methods that should be applied to evaluate specific types of forecasts (examples include precipitation, cloud, and tropical cyclone forecasts; the latter two documents are in preparation). Since the subseasonal verification effort will be characterized by aspects of both the long-range and shorter-range forecast verification problems, linkages to both of these verification efforts will be critical. In addition, the subseasonal verification effort may benefit from linkages with the WGNE/WGCM Climate Metrics Panel (http://www-metrics-panel.llnl.gov/wiki). Although this group is focused on longer range projections, their experience and knowledge of data sources for model evaluation may be of some benefit for the subseasonal effort.

8.6 World Bank and development/food security organizations

The World Bank has recently created a web-based Climate Change Knowledge Portal (CCKP) http://sdwebx.worldbank.org as a means to communicate climate-related information, data, and tools to foster climate-resilient development in low-income and disaster-prone countries. It also hosts the Global Facility for Disaster Reduction and Recovery (GFDRR) http://www.gfdrr.org as a mean to enable high-risk, low income countries to understand and act on the hazards they face, helping them adapt to a changing climate. The World Bank is increasingly augmenting its data sets with environmental and climate data sets and fostering a new open data initiative http://data.worldbank.org/climate-change, bringing environmental, economic and development data to the web for the world to use.

The subseasonal timescale is of particular relevance to the World Bank and other large development (e.g. the US Agency for International Development, USAID, and the UK's Department For International Development, DFID) and food security (e.g. the World Food Programme, WFP, and the Consultative Group on International Agricultural Research (CGIAR) Research Program on Climate Change, Agriculture and Food Security, CCAFS) organizations through the intersection with disaster risk management and food security. Subseasonal weather variability has a major impact on food supply and markets. As mentioned in Sect 2, improved forecasts of extremes on this timescale have the potential to mitigate disasters, and thus improve resilience of vulnerable communities to climate shocks, and help them better adapt to climate change. Importantly, the two-way flow of information between development/food security organizations and the climate community will be crucial to the creation of meaningful climate services through the global framework.

9. Next steps

The implementation plan will be presented for approval to the WWRP JSC meeting in April 2012, the WCRP JSC meeting in July 2012 and the WMO Executive Council. Following approval by both JSCs, a steering group on subseasonal to seasonal prediction should be formed. The current composition of the implementation group seems appropriate and it is therefore recommended to keep the same membership. It could be also useful to add a few additional members for additional expertise and for a more complete representation of the operational centres (from the Chinese Meteorological Agency for instance).

The steering group should work on implementing the recommendations listed in the present document. The length of this subseasonal to seasonal project should be 5 years initially after which it should be reviewed with a view to a possible extension for a further 5 years. As mentioned in this document, a major task of the steering group will be to implement a subseasonal database. This will involve contacting potential archiving hosts and also contacting the operational centres that will provide the subseasonal forecast data. The steering group will also have to promote and coordinate some important research topics relative to subseasonal prediction. Research on the sources of predictability at the subseasonal time range should be a top priority. This will involve studying their representation in the models which will be part of the dataset and defining windows of predictability for applications. The steering group should also explore the problem of initializing subseasonal forecasts. Other research topics relevant to subseasonal prediction should be coordinated with other groups (MJO task force, GASS, polar prediction project, CHFP, …). The steering group should also explore the use of subseasonal forecasts with applications in coordination with SERA and other application groups. A few demonstration projects involving the diffusion of real-time subseasonal forecasts should help foster these collaborations by establishing close partnerships between researchers, intermediaries, and end users.

An important task of the steering group will be to organize a series of workshops dedicated to subseasonal to seasonal prediction. Ideally one workshop a year would be suitable. It is proposed to have a first workshop entitled "Sources of predictability at the subseasonal time scale- Windows of opportunities for applications". This workshop would fit well with "subseasonal predictability" being the main science topic for the steering group. An output of this workshop could be recommendations or guidance to the steering group on how to analyse the subseasonal predictability in the multi-model database that will be implemented by the steering group. This workshop would also involve the application community. The following workshops could alternate topics that are more research oriented with those that are more application oriented. Possible titles could include: "Predictability of rainy season onset, cessation and dry spell prediction: evaluation and strategies for improvement" and "Initialization of subseasonal forecasts". The first topic would be more application oriented and could benefit from the expertise in the CLIVAR regional panels (see sec 8.2) and the second one more research oriented. Other workshops could be organized in collaboration with other working groups. For instance, a workshop on model errors could involve GASS, WGNE, CHFP and the subseasonal to seasonal prediction steering group. Subseasonal prediction of the monsoon could also be organized with the monsoon CLIVAR panel. Coupled data assimilation is a larger topic than one specifically relevant to subseasonal forecasting. The steering group does not have the expertise on its own to deal with this, but might collaborate with other panels such as CLIVAR GSOP.

The steering group should also promote several domestic meetings as, for instance, TIGGE/THORPEX have done. These regional meetings would focus on forecast applications (agriculture, weather impacts, and solutions for damage prevention...) which can be different from one region to another. This activity could be crucial to promote the evaluation and use of subseasonal forecasts and enhance the collaboration between meteorological scientists and local research institutes in other disciplines. This should be done in coordination with the relevant structures (GEWEX CLIVAR regional panels for instance).

In Summary:

The proposed WWRP/THORPEX-WCRP joint research project to improve forecast skill and understanding on the subseasonal to seasonal timescale will require:

- The establishment of a project Steering Group representing both the research and operational weather and climate communities. The steering group will be responsible for the implementation of the project;
- The establishment of a project office to coordinate the day to day activities of the project and manage the logistics of workshops and meetings;
- The establishment of a multi-model data base consisting of ensembles of subseasonal (up to 60 days) forecasts and supplemented with an extensive set of reforecasts following TIGGE protocols. A workshop will be necessary to address technical issues related to the data base;
- A major research activity on evaluating the potential predictability of subseasonal events, including identifying windows of opportunity for increased forecast skill with a special emphasis on events that have high societal or economic impacts. Attention will also be given to the prediction of intraseasonal characteristics of the rainy season that are relevant to agriculture and food security in developing countries.
- A series of science workshops on subseasonal to seasonal prediction. The first topic identified is "Sources of predictability at the subseasonal timescale- windows of opportunity for applications";
- Appropriate demonstration projects based on some recent extreme events and their impacts, in conjunction with the WWRP SERA

This challenging project will require 5 years, after which the opportunity for a 5 year extension will be considered.

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Annexe 1 Membership of the planning group

With the approval of the Chairs of the WWRP/JSC and the WCRP/JSC, the subseasonal to seasonal prediction planning group has been set up with the following list of members:
Co-Chairs:

Frederic Vitart (ECMWF)
Andrew Robertson (IRI)

Members:
Arun Kumar (NCEP)
Harry Hendon (CAWCR)
Yuhei Takaya (JMA)
Hai Lin (EC)
Alberto Arribas (UKMO)
June-Yi Lee (U. Hawaii)
Duane Waliser (JPL NASA)
Ben Kirtman (UM RSMAS)
Hyun-Kyung Kim (KMA)

Liaison group:
Carolina Vera (WCRP JSC Liaison)
Richard Graham (UKMO, CBS)
Jean-Pierre Ceron (Météo-France, CCL)
Barbara Brown (SERA/Verification)
Steve Woolnough (GEWEX/ GASS)

David Anderson WMO consultant

The role of the liaison group is to ensure a good interaction between the planning group and other working groups.

Annexe 2: Characteristics of the forecast systems

Subseasonal and seasonal forecast systems, operational and under development at ECMWF, JMA, UKMO, Météo France, NCEP, MSC, BMRC, KMA, CMA, CPTEC, SAWS and Hydrometeorological Centre of Russia.

	Current systems spanning the subseasonal (blue) and seasonal (red) time ranges	**Known planned changes for 2011-12**
ECMWF:	• **d0-d32: ECMWF EPS/monthly (twice a week: every Mondays and Thursdays)** T_L639 (d0-10) v319 (d10-32) L62, TOA 5hPa, 50+1 members. Persisted SST up to d10 and coupled to HOPE (1:1/3 degree resolution, L40) ocean model from day 10. Initial uncertainties simulated using T_L399L91EDA- and T42L62SV-based perturbations Model uncertainties simulated using SPPT and BS stochastic schemes. Re-forecast suite with 5 members run on the fly once a week for 18 years. • **m0-7/13: ECMWF-S4** 51 members with T_L255L91 resolution, with coupled NEMO (ORCA1, i.e. 1-1/3 degree resolution, L42) ocean model. Frozen model cycle (cy36r4). Re-forecast: 15 ensemble members the 1st of each month 1981-2010.	• d0-d32: ECMWF-EPS Increase in vertical resolution to about L95 in 2012. Use of NEMO (ORCA1 with tripolar grid, i.e. 1:1/3 degree resolution, L42) instead of HOPE ocean model by the end of 2011.
JMA:	• **d0-34: JMA monthly system (once a week)** T_L159L60 resolution (AGCM) with 50 members runs 25 from Wed and 25 from Thu ICs. Supplemental 2-week forecasts with the same system, 50 members runs 25 from Sun. and 25 from Mon. ICs. Initial uncertainties simulated using bred vectors. Uncoupled. All reforecasts are done before system updates. Five-member runs start from 10th, 20th and the end of calendar month during more than 30 years (currently 1979-2009). http://ds.data.jma.go.jp/tcc/tcc/products/model/outline/index.html • **m0-3/6: JMA seasonal system (once a month to m3 and every semester to m7)** T_L95L40, 51 members run in lagged mode (9 members run every 5 days), with coupled JMA/MRI ocean model (1:0.3 degree horizontal resolution, L50, 75°N-75°S), with flux adjustment. http://ds.data.jma.go.jp/tcc/tcc/products/model/outline/longrange.html Initial perturbations for ocean and atmosphere with an atmospheric bred vector. (atmospheric perturbations are used for parallel ocean analysis.)	• d0-34: increase resolution to T_L319L100(L80?) in 2013. • m0-3/6: increase resolution to T_L159L60(L80?)coupled to a higher resolution 0.5-1 degree ocean (tripolar grid), L53. Coupling with sea-ice will be tested.

	Reforecast Five-member ensembles twice a month during 1979-2008.	
UKMO:	• **d0-60: UKMO monthly system (run daily - issued once a week)** It is part of the UKMO seasonal system. N96 (~120km resolution) L85 with coupled NEMO ocean model (ORCA1, i.e. 1:1/3 degree resolution, L75 resolution). 28 members run in lagged mode (4 members per day for the last 7 days). • **m0-7: UKMO seasonal system (run daily – issued once a week/month)** N96 (~120km resolution) L85 with coupled NEMO ocean model (ORCA1L75 resolution). 42 members run in lagged mode (2 members per day for the last 3 weeks). Reforecast suite with 42 members spanning 14 years (1989-2003) run in real time. Start dates 1st, 9th, 17th and 25th of each month.	• The configuration of the UKMO EPS and seasonal systems are under continuous development. • Monthly and Seasonal: increase resolution to N216 in 2012.
Météo France:	• **m0-7: MF seasonal system T63L91 (once a month)** Arpege (the atmospheric component) has 91 vertical levels and a spatial resolution of about 300Km. OPA with ORCA2 (with tripolar grid, i.e. 2:1/3 degree resolution, L42). The ocean initial conditions are prepared by MERCATOR in Toulouse. 41 members	
NCEP:	• **d0-45: NCEP monthly system** T126L64 resolution, 16 members run per day (4 members run four times a day at 00, 06, 12 and 18). Coupled ocean model. Re-forecast: 4 members/day from 1999 to 2010 • **m0-9: NCEP seasonal system (4 runs a day)** T126L64 atmosphere resolution, MOM4 (MOM is the Modular Ocean Model developed by GFLD) ocean model (0.5 to 0.25 degree resolution, L40), with interactive sea-ice model. Re-forecasts: 4 members run every fifth day for the past 29 years (1982-2010).	
EC:	• d0-30: MSC monthly (twice a month) The current operational monthly forecasting is the first month of the MSC multi-model seasonal system. • m0-4: MSC seasonal system (once a month) Multi-model system with 4 models: GEM 2°x2°L50, AGCM2 T32L10, AGCM3 T63L32 and SEF T95L27. 40 members (10 run with each model). Uncoupled (persisted SST anomaly).	• **d0-35: MSC GEPS (once a week)** GEM 0.6°x 0.6°L40 uncoupled (persisted SST anomaly). 21 member ensemble. Initialised with Kalman Filter. Re-Forecast of 4 members once a week on the fly over the past 15 years. In operation early 2012. • **m0-12: MSC seasonal system (once a month)** Multi-model system with 2 coupled models: CanCM3 T63L31 and CanCM4 T63L35. 20 members (10 run with each model). Re-forecast: 10 ensemble members for each model initialised on the 1st of

		each month 1981-2010. In operation by the end of 2011.
CAWCR:	• **d0-120: POAMA2 T47L17** multiweek **(once-a-week)** Based on the BMRC (old) spectral model (T47L17) coupled to MOM2 (2x0.5 tropical res). 33 member ensemble initialized on 00Z every Thu (3 model versions x 11 members each). Perturbations from a coupled breeding cycle based on nudging to a previously assimilated ocean and atmosphere analysis. Re-forecast: Monthly/multi-week set consisting of 33-member ensemble on 1st, 11th and 21st of the month from 1989 to 2010 run for 120 days. • **m0-9: POAMA2 T47L17** Seasonal **(twice-a-month)** Based on the BMRC (old) spectral model (T47L17) coupled to MOM2 (2x0.5 tropical res). 30-member ensemble initialized on 00Z the 1st and 15th of each month (3 model versions x 10 members each). Ocean perturbations only directly from ensemble ocean assimilation). Re-forecast: Seasonal set consisting of 30-member ensemble starting the 1st of each month from 1960 to 2010.	• Extend d0-120 POAMA2 multiweek re-forecast set back to 1980 • POAMA3 Experimental forecasts d0-45 by end 2012 using N144L80 (UM7) uncoupled. • POAMA3 Post 2012: d0-120 N144L80 (UM7) coupled to MOM4 (1x.3 tropical res). Initial conditions and perturbations from a coupled assimilation system.
KMA	• **d 0-30: GDAPS T106L21 (three times a month)** Same system as for seasonal forecasting. The atmospheric model runs 3 times a month (3rd, 13th and 23rd of each month) . The ensemble size is 20 members using a lagged average method with about a 15-day forecast lead time. The atmospheric model is forced by predicted SST anomalies. Re-forecast: Monthly set consisting of 20-member ensemble starting the 3rd, 13th and 23rd of the month from 1979 to 2010 run for 230 days • **m 0-3 (once a month) and m0-6 (4 times a year)** The atmospheric model runs for 3 months every 23rd of the month and for 6 months the 23rd of Feb/May/Aug/Nov with 20 ensemble members (lagged average method with about a 15-day forecast lead time). The atmospheric model is forced by predicted SST anomalies. Re-forecast: Seasonal/6 months set consisting of 20-member ensemble starting the 23rd of the month from 1979 to 2010 run for 230 days	• Replace this extended range forecasting system with UM based climate model (HadGEM3 or GloSea4) by 2013
CMA	• **D 0-45: BCC_AGCM1.0 (6 times a month)** The atmospheric model is integrated for 45 days at T63L16 resolution forced by persisted SST anomalies (persistence of the previous weekly SST anomalies). The starting dates are the 1st, 6th, 11th, 16th, 21th and 26th of each month. There are 40 ensemble members. Half of them are generated with lagged-average-forecast (LAF) method, the other half with singular-vector-decomposition (SVD) method.	• Use of the new generation BCC_CSM model at a T106 resolution. ocean resolution is about 1/3-1°. Intra-seasonal forecasts will use the atmosphere-only version of this model. This new system will be operational at the beginning of 2012.

	Re-Forecasts: 1982-now • **m 0-3: BCC_CGCM1 (once a month)** The coupled ocean-atmosphere model is integrated for 90 days at T63L16 resolution. There are 48 ensemble members. Re-Forecasts: 1982-now	
CPTEC	• **D 0-30: CGCM T126L28 (experimental)** The coupled ocean-atmosphere model is integrated for 30 days at T126L28 resolution. There is 1 ensemble member per day. No reforecasts • **m 0-7: AGCM T62L28 (once a month)** The atmospheric model is integrated for 7 months at T62L28 resolution forced by persisted SST anomalies from NCEP(Reynolds SST OI v2) of the previous month of lead 0. There are 15 ensemble members per month (lagged approach). Re-Forecasts: 1979-2001-10 members	
SAWS	• **m 0-5: T42L19 (once a month)** The atmospheric model is integrated for 5 months at T42L19 resolution forced by predicted SSTs. There are 6 ensemble members per month (lagged approach). Re-Forecasts: 1981-2001	
Hydro meteorological Centre of Russia	• **m 0-4: 1.1x1.4 L28 (once a month)** The atmospheric model is integrated for 4 months at 1.1x1.4 degree L28 resolution forced by persisted SST anomalies. There are 10 ensemble members per month (lagged approach). Re-Forecasts: 1979-2003	

Annexe 3: Forecasting systems which are recommended to be included in the subseasonal forecasting database.

	Time-range	Resolution	Ens. Size	Frequency	Hcsts	Hcst length	Hcst Freq	Hcst Size
ECMWF	d 0-32	T639/319L62	51	2/week	On the fly	Past 18y	weekly	5
UKMO	d 0-60	N96L85	4	daily	On the fly	1989-2003	4/month	3
NCEP	d 0-60	T126L64	16	daily	Fix	1999-2010	Once a day	4
EC (exp)	d 0-35	0.6x0.6 L40	21	weekly	On the fly	Past 15y	weekly	4
CAWCR	d 0-120	T47L17	33	weekly	Fix	1989-2010	3/month	33
JMA	d 0-34	T159L60	50	weekly	Fix	1979-2009	3/month	5
KMA	d 0-30	T106L21	20	3/month	Fix	1979-2010	3/month	10
CMA	d 0-45	T63L16	40	6/month	Fix	1982-now	monthly	48
CPTEC	d 0-30	T126L28	1	daily	No	-	-	-
Met-Fr	d 0-60	T63L91	41	monthly	Fix	1981-2005	monthly	11
SAWS	d 0-60	T42L19	6	monthly	Fix	1981-2001	monthly	6
HMCR	d 0-60	1.1x1.4 L28	10	monthly	Fix	1979-2003	monthly	10

Annexe 4: Proposed list of variables to be archived

1. Multi-level fields

	Unit	Abbrev.	Descript	1000	925	850	500	300	200	100	50	10
Geop. height	gpm	gh	Inst. 00Z	x	x	x	x	x	x	x	x	x
Spec. humidity	Kg/ kg	q	Inst. 00Z	x	x	x	x	x	x			
Temperature	K	t	Inst 00Z	x	x	x	x	x	x	x	x	x
U	m/s	u	Inst 00Z	x	x	x	x	x	x	x	x	x
V	m/s	v	Inst 00Z	x	x	x	x	x	x	x	x	x

2. Single-level fields

	Unit	Abbreviation	Description
Potential vorticity at 320K	$K\ m^2\ kg^{-1}\ s^{-1}$	pv	Inst 00Z
10 metre U	$m\ s^{-1}$	10u	Inst 00Z
10 metre V	$m\ s^{-1}$	10v	Inst 00Z
CAPE	$J\ kg^{-1}$	cape	Daily Av. 4x
Land-sea mask	Proportion	lsm	Once
Orography	gpm	orog	Once
Skin temperature	K	skt	Daily Av. 4x
Snow depth water equivalent	$kg\ m^{-2}$	sd	Daily Av. 4x
Snow fall water equivalent	$kg\ m^{-2}$	sf	Accumulated
Soil moisture	$kg\ m^{-3}$	sm	Daily Av. 4x
Surf. Air Max. Temp.	K	Mx2t6	Daily Max.
Surf. Air. Min. Temp.	K	Mn2t6	Daily Min.
Surf. Air. Temp.	K	2t	Daily Av. 4x
Surf. Pressure	Pa	Sp	Daily Av. 4x
Outgoing long-wave radia.	$W\ m^{-2}\ s$	ttr	Accumulated
Surface latent heat flux	$W\ m^{-2}\ s$	shlf	Accumulated
Surface net solar radiation	$W\ m^{-2}\ s$	ssr	Accumulated
Surface net thermal radia.	$W\ m^{-2}\ s$	str	Accumulated
Surface sensible heat flux	$W\ m^{-2}\ s$	sshf	Accumulated
Total cloud cover	%	tcc	Daily Av. 4x
Total column water	$kg\ m^{-2}$	tcw	Daily Av. 4x
Total precipitation	$kg\ m^{-2}$	tp	Accumulated
Convective Precipitation	$kg\ m^{-2}$	cp	Accumulated
North-South surface stress	$N\ m^{-2}\ s$	nsss	Accumulated
East-west surface stress	$N\ m^{-2}\ s$	ewss	Accumulated
Mean sea-level pressure	Pa	msl	Daily Av. 4x

3.Ocean fields

	Unit	Abbreviation	Description
Sea surface temperature	K	sstk	Daily Av. 4x
Sea surface salinity	psu	ssts	Daily Av. 4x
Depth of the 20 deg isoth.	m	20d	Daily Av. 4x
Sea ice cover	Proportion	ci	Daily Av. 4x
Heat content top 300m	Degrees C	tav300	Daily Av. 4x
Salinity in top 300m	psu	sav300	Daily Av. 4x
U surface current	m s^{-1}	u	Daily Av. 4x
V surface current	m s^{-1}	v	Daily Av. 4x
Sea surface height	m	sl	Daily Av. 4x

Annexe 5: Evaluation of the data volume

Hypothesis: 1.5x1.5 degree or less – 73 variables (59 kb /day/variable/ensemble member). The table shows an evaluation in TB/year for the real-time forecasts and reforecasts for each GPCs (see Annexe 2 for the model configurations). The numbers in red indicate the reforecasts which are produced once and are used for several years (referred to as fix in the table of Annexe 2).

	RT	HC	TOT
ECMWF	0.76	0.75	1.5
JMA	0.4	0.95	1.25
NCEP	1.1	3.5	4.6
UKMO	0.36	0.58	0.94
EC	0.17	0.49	0.66
CAWCR	0.07	1.09	1.16
KMA	0.08	2.4	2.5
CMA	0.16	0.8	0.96
CPTEC	0.014	-	0.014
Meteo-France	0.04	0.3	0.34
SAWS	0.002	0.05	0.052
HMCR	0.03	0.8	0.83

Form this table, the total cost for the first year is estimated to be around 15 TB (all the hindcsts will need to be archived) and about 7 TB per year for the following years (only the real-time forecasts and reforecasts which are produced on the fly will need to be archived).

Annexe 6: Ongoing Applications Activities at Operational Centres

Environment Canada:

Forecast of extreme agrometeorological indices across Canada. Right now, this is done using the 16-day ensemble forecasts. It is planned to use the monthly forecast system.

Hydrometeorological forecast for the Great Lakes. It is run in an experimental mode. One component is to use the monthly ensemble forecast to force the hydrological model.

ECMWF — 3 European projects:

SafeWind (wind ensemble forecasts for the energy sector). Medium-range focus, but interest in the subseasonal time scale.

Applications in hydrology and real-time flood forecasting, using ECMWF monthly forecasting system, demonstrated useful skill. Also use TIGGE.

Prediction of African rainfall and temperature for disease prevention (Malaria, Dengue, Yellow fever..) (QWECI).

CAWCR/BoM:

Prediction of heat waves, including understanding of the role of large-scale circulation as pre-cursor, ability forecast model to capture these larges scale drivers, and development of some experimental prediction products. Funded by an agricultural consortium.

UKMO:

Predictability of the temporal distribution of rainfall through the seasons, with specific reference to Africa (e.g. season onset, cessation, risk of in-season dry spells). Currently seasonal system; preliminary look at this in the ECMWF monthly system.

Frequency of daily temperature extremes & 'heatwaves' also of interest & rainfall extremes over Africa.

Reservoir inflow forecast for Ghana, on seasonal timescale.

Sudden stratospheric warmings also of interest for European winter cold spells.

NCEP:

MJO & Global Tropical Hazard
Prediction of consecutive days of extreme temperature
Prediction of Blocking and circulation indices
Prediction of Tropical storms and Atlantic Hurricanes
Prediction of onset dates of various monsoon systems
Prediction of Active/break phases of Indian monsoons
Prediction of sudden stratospheric warming events

JMA:

JMA is developing new products for heatwave and flood prediction on a subseasonal time scale adopting the Extreme Forecast Index(Lalaurette, 2003; Zsoter, 2006) together with so-called 'meteogram' to support early warnings of severe weather (e.g., heatwave, flood).

JMA also has a research project on applications in an agricultural sector incollaboration with National Agricultural Research Centre for Tohoku region (NARCT). This involves development of downscaling and application techniques for agricultural purposes.