Workshop
"Sub-seasonal to Seasonal Prediction"
Met Office, Exeter (1 to 3 December 2010)

REPORT AND RECOMMENDATIONS

1. Introduction

At its 15th session (November 2009), the WMO Commission of Atmospheric Sciences (CAS) requested 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) to set up an appropriate collaborative structure to carry out an international research initiative on sub-seasonal to seasonal forecasting. It recommended that such a research initiative is closely coordinated with the present existing WMO Commission on Basic Systems (CBS) infrastructure for long-range forecasting (with centres producing long-range forecasts and regional climate centres) and with the future developments in WMO climate service delivery and the Global Framework for Climate Services called for in the High-Level Declaration of the World Climate Conference 3 (WCC-3).

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 Workshop Agenda may be found in Annex I.

The main outcomes from this Workshop were:

- Review of the current capabilities in sub-seasonal to seasonal prediction and the identification of high-priority problems which if addressed successfully would lead to improvements in predictions

- Proposals for operational collaboration in sub-seasonal prediction

- Recommendations for the establishment of an international research project on sub-seasonal prediction

The Workshop presentations may be found on the following web sites http://www.wmo.int/pages/prog/arep/wwrp/new/thorpex_new.html .

2. Capabilities in sub-seasonal to seasonal prediction

This section on capabilities in "Sub-seasonal to Seasonal Prediction" is based on the review paper prepared by Dr. David Anderson, in collaboration with many of the Workshop's participants – the review paper forms an essential element of the outcome of this Workshop.

2.1 Experiences with TIGGE

THORPEX has been successful in establishing a data base of ensembles of operational medium-range global predictions (THORPEX Integrated Global Grand Ensemble (TIGGE)) from which methods of post-processing model forecasts to improve prediction skill can be tested. A multi-model (MM) approach has been tested, and if only the better models in TIGGE are used, then the MM forecasts are preferable to those from any single uncalibrated model. Model Output Statistics (MOS) and other methods to correct for model error have also been tested. While these latter work well for the shorter range they are less appropriate as the forecast lead time increases. The spread of a single forecast model is invariably too small since a single model does not represent all the uncertainty in a forecast, leading to forecasts which are overconfident. However, if a reforecast set spanning many years is available then model drift can be removed and the spread calibrated, such that the skill of a single model can match that of the MM, at a given location. Indeed calibration can partially take into account downscaling in regions of complex terrain. There is a loss of temporal and spatial cohesion, however, but calibration could be useful for applications. In a seamless system, in principle the verisimilitude of models at one time range can be used to calibrate them at another range.

2.2 Longer-range prediction

Extending the medium range to say 30 days, could be done without coupling to an ocean. Although atmosphere ocean interaction might influence the MJO to some extent, having an active ocean model as part of the forecast system is probably not essential. This is probably true for the ENSO/IOD variability also, another major source of predictability on the monthly timescale. If an ocean is included then good resolution near the top surface of the ocean is desirable. For forecast range beyond 30 days, however, it is important to have an ocean module. It is feasible, though not desirable, to use a two-tier system whereby the ocean SSTs are obtained from another forecast system, but a fully-coupled atmosphere-ocean model is the preferred option.

Whereas for medium range forecasting, model error is usually not dominant and a reforecast set for bias and skill evaluation is not generally performed, this is less acceptable the longer the forecast range. It is necessary for extreme weather forecasting, even in the medium-range, however, since the model PDF is not in general the same as nature making it necessary to reference any forecast to the model PDF. By monthly timescales, reforecasts are essential as model error not be ignored at this range. Indeed for monthly and seasonal prediction biases could be as large as the signal one seeks to predict, and hence, anomalies cannot be computed from the observed climatology.

Prediction of tropical cyclone frequency and landfall seems to follow the observed relationship with ENSO and the MJO giving some support to the idea that some aspects of extreme weather related to tropical cyclones might be predictable. Further studies show that other extreme events, particularly for temperature show similar levels of skill to forecasts of mean climate

For seasonal forecasting, as long a reforecast set with as many ensemble members as possible is preferable, typically 25 years with 10-15 ensemble members. This allows drift to be evaluated as a function of lead time and starting date and some evaluation of skill although there are issues with skill changing over time so that hindcasts may not always give good indication of forecast skill.

2.3 Importance of the MJO and tele-connections

An important source of predictability on the extended range comes from representing the MJO well as well as getting the ENSO, Indian Ocean Dipole (IOD), the Northern and Southern Annular Modes (NAM and SAM) and their tele-connections right. A poor representation of the MJO is likely to degrade forecasts not only in the tropics but also in mid-latitudes. No model has a completely acceptable representation of the MJO and its tele-connections though there has been considerable progress over the last few years at some centres and improvements in the propagation and characteristics of the MJO are leading to improved skill in the intra-seasonal range. Although predictability in the extra-tropics is modest there also appears to be an extra-tropical tele-connection from ENSO to the North Atlantic Oscillation (NAO) which offers the possibility of improved predictability during some winters. Parameterisation of convection seems to be important in representing the MJO, the ENSO/IOD and the mean tropical state. Horizontal resolution by itself is not sufficient, however, even up to 10 km.

Tele-connections are a primary problem as is bias in the ENSO/IOD mode. The tele-connections stem from variations in tropical convection, which depends on getting both the mean state and variability right. For example, if the mean convection is too low in the eastern Indian Ocean, proper anomalies of reduced convection will not be made, and hence sufficiently strong tele-connections that are driven by reduced convection will not result. Representing monsoons well and predicting active and break periods is still a problem. The West African Monsoon (WAM) is a system where land convection and precipitation are also very important. Apart from the WAM precipitation being wrong in most of the models from the first week of forecast, there are some studies that point at the tele-connection with the summer climate over the Mediterranean region, in particular the eastern Mediterranean.

2.4 Parametrization of physical processes

Parameterisation of physical processes is a very important component of model development. Errors in the representation of fast physical processes remain a key limiting factor in the skill of our models across all timescales from short to sub-seasonal to seasonal timescales. Efforts to develop these representations are therefore of crucial importance for many applications. Increasingly, parameterization has a stochastic component to it. Several ways of including stochastic processes are being tested, generally with positive results. More complex forms such as cellular automata have the potential to allow nonlocal processes which might be important in representing for example the MJO.

Insufficient blocking is a major problem of many models and can affect forecasts on all timescales. The frequency of occurrence of blocking is somehow improved to a level commensurate with that estimated from ERA-40, through increased orographic drag, the revised convection scheme of Bechtold et al 2008 for Euro-Atlantic blocking, and by the convection scheme in the case of North Pacific. Improvements in blocking have also been associated with improvements in the mean state of a model used for seasonal forecasting at the UK Met Office. Improvements in both resolution and parametrization schemes can produce such improvements.

Land conditions such as snow cover and soil moisture can give useful extended range predictability and therefore land should be initialised as well as possible. In the absence of an appropriate land reanalysis, nudging schemes such as ALI might work well and be cost effective.

Relaxation experiments can be used to identify remote origins of extended range prediction and give an idea of how much skill could be gained by reducing forecast error in these regions such as the tropics or the stratosphere. There is some evidence for significant benefits from better stratospheric representation. This will be further quantified by a CLIVAR-lead model study (SHFP) which is in progress to evaluate the importance of the stratosphere for extended range prediction. Further, operational models are now starting to resolve the stratosphere as part of their model development.

2.5 Treatment of the oceans

No operational model has a fully comprehensive upper ocean model interacting with the atmospheric model through the wave field. Some models do have a wave model built-in and the physics of coupling the atmospheric and oceanic models is being made more comprehensive, but much more research work is needed to quantify the importance of improved upper ocean physics for sub-seasonal prediction.

Presently the atmosphere and ocean components are analysed and initialised separately. Quite sophisticated schemes are generally used to analyse the atmospheric state such 4D-Var or Ensemble Kalman Filtering (EnKF). Ocean analysis techniques tend to be less sophisticated than their atmospheric counterparts but EnKF and EnOI techniques are being developed as are 3D-VAR techniques. Whereas a few years ago some schemes were uni-variate - analysing temperature but letting salinity wander, this is much less the case today and any useful scheme would be multi-variate.. Coupled data assimilation is frequently raised as an objective. Weak coupling is already being developed, whereby the first guess for the assimilation process is provided by the coupled model. Strongly coupled 4D-VARr assimilation in an operational setting still seems some way off but schemes which estimate cross covariances between atmosphere and ocean are being developed. Despite the fact that some data assimilation systems include a bias correction term in the atmospheric and oceanic data assimilation systems, this bias is not usually used in the forecast. At the start of the forecast the bias term is switched off.

2.6 User feedback

In the Workshop, three regional projects are mentioned, for South Asia, Africa and South America. Assuming that these projects have to deal with applications to, for example, hydrology, agriculture or disease prevention then most will use rainfall forecasts from monthly and/or seasonal prediction systems. It would be very useful if these regional projects could give a feedback to the modelling community about the "quality" of rainfall simulations over the respective regions. This may be done by establishing a small coordination group, who should ensure some consistency among the modelling input to these projects, as well as common verification tools and metrics. The goal of this exercise is to evaluate how different models/ensemble systems behave in terms of simulating convective rainfall over various tropical regions, both in terms of climatological properties (mean and variability) and in terms of forecast reliability (e.g. realistic spread-error relationship). The coordination group may also take care of interactions with the three CLIVAR monsoon panels. This project links model development with applications. The project could be broadened to tele-connections driven by tropical convection: this is the main source of seasonal predictability and clearly challenges most forecast systems. The importance of ENSO/IOD and its flavours is strong, yet every system still has strong ENSO/IOD biases.

Applications of extended-range and seasonal forecasts are still being developed. An example of malaria prediction is given, but there are other examples such as the Ganges river discharge and wheat production forecasts developed in Australia. Adapting the application model to run smoothly off model output at model scales is non-trivial. Recalibration might be useful.

3. Data bases of multi-model ensembles of operational seasonal predictions

3.1 The CBS Lead Centres for seasonal prediction

The WMO Commission for Basic Systems (CBS) has established a mechanism for collecting a sub-set of operational seasonal forecast products from twelve WMO designated Global

Prediction Centres (GPCs). Two Lead Centres (the Lead Centre for Long-range Forecast Multi-model Ensembles (LC-LRFMME) and the Lead Centre for the Standard Verification System for Long-range Forecasts (LC-SVSLRF) facilitate access to these products. A main aim of these efforts is to improve access and usability of global long range forecast products to aid the production of operational regional/national climate services.

As with the TIGGE project, the twelve centres provide a standard set of products (the minimum set being 2m temperatures, precipitation, and SST and forecast quality measures). The core product set consists of monthly mean anomalies with the option of providing hindcasts and forecasts.

The forecast and verification products are made available to Regional Climate Centres (RCCs) National Meteorological and Hydrological Services (NMHSs) and Regional Climate Outlook Forums (RCOFs). The two Lead Centres will play a key role in WMO Global Seasonal Climate Updates (monitoring and outlook) and can be regarded as part of the Global Framework for Climate Services (GFCS) vision.

Key plans for the WMO Lead Centres (guided by the Expert Team for Extended and Long-range Forecasts) include:

- Development of probability forecast products
- Extension of the prediction range (to ~6 months)
- Verification of multi-model products
- Centralisation of the verification process – currently the contributing centres verify their own forecasts
- Standardisation of the production of hindcasts

During the workshop, the chair of the Expert Team on Long Range Forecasting agreed to investigate the possibility that monthly forecasts might be provided via the lead centre at KMA by simply extending the timescales to include monthly forecasts as this would represent a simple extension of their current capability, at least for basic surface fields.

"The WMO Lead Centres appear to work well for seasonal prediction, but, currently, they are not set up to provide sub-seasonal forecasts. A monthly-mean archive is not adequate to provide support for a research programme on sub-seasonal prediction, for example studies of the MJO; however monthly-mean data may provide useful information for some applications. It is therefore recommended that the Lead Centres should be requested to consider archiving and making available real time monthly surface data to users to complement the research databases already available"

3.2 EUROSIP

The EUROSIP multi-model seasonal forecasting system consists of three independent coupled systems: ECMWF, Met Office and Météo-France; all integrated in a common framework. NCEP has become an associated partner but is yet to be fully integrated into the system.

The reason for creating a multi-model forecasting system is that research has consistently shown that better and more reliable seasonal forecasts can be created by combining the output from several models, rather than taking just one model. In most cases, the multi-model combination is better than the best single model. The value of multi-model forecasting has in particular been explored in the DEMETER and ENSEMBLES projects.

The fundamental reason for the benefit of a multi-model approach is that all models have errors which are large enough to significantly degrade forecasts made on a seasonal timescale. Compared to medium-range forecasting, the predicted signals are much smaller and the time over which model errors accumulate are longer, so the importance of model error is much, much higher. Although we are working hard to reduce model error, the requirements of seasonal forecasts are so exacting that we expect model error to be a critical problem for many years to come. Although all models have errors, these errors and the impact they have on a given forecast vary between models. By averaging across a number of models, a significant part of the model error can be reduced, resulting in better forecasts. It is unfortunate that some errors tend to be common between models, so averaging is neither a panacea nor a replacement for model development. Nonetheless, averaging across models is a very useful tool, and is likely to remain so for many years.

Data from all three models is archived at ECMWF, and can be accessed subject to the terms of the EUROSIP data policy. ECMWF produces a number of multi-model products which are created from the integrated output of the component models. These multi-model products can be accessed just like any other ECMWF products. A user guide outlines what is available, how the products are created, and how they can be accessed.

4. Research Data Bases

4.1 The THORPEX International Grand Global Ensemble

THORPEX is an international research programme to accelerate improvements in the accuracy and utility of high-impact weather forecasts up to two weeks ahead. THORPEX was established in 2003 by the Fourteenth World Meteorological Congress. THORPEX is part of the World Weather Research Programme, under the auspices of the WMO Commission for Atmospheric Sciences (CAS), and is a key research component of the WMO Natural Disaster Reduction and Mitigation Programme.

The THORPEX Interactive Grand Global Ensemble (TIGGE) provides a data base of ensemble predictions from the leading global NWP centres, for scientific research on predictability and development of probabilistic weather forecasting methods http://tigge.ecmwf.int - the focus being medium-range weather prediction.

Ensemble forecasts are collected in near-real time using a common format at three data archive and distribution centres: China Meteorological Administration (CMA), European Centre for Medium-range Weather Forecasts (ECMWF) and US National Centre for Atmospheric Research (NCAR).

The TIGGE data are available for research and education after a simple electronic registration process. Access is normally provided with a 48-hour delay after the initial time of the forecast. Access to data as soon as it becomes available may be granted for field experiments and projects of special interest to THORPEX. Registration for real-time access is handled via the THORPEX International Programme Office.

The TIGGE data set is seen as an enviable standard for databases and it has become a major resource for research and development for weather prediction, including:

- Calibration of ensemble forecasts, including bias correction and downscaling
- Combination of ensembles produced by multiple models
- Development of probabilistic forecast products
- Predictability and dynamical processes
- Hydrological applications

4.3 Climate Historical Forecast Project (CHFP)

The Climate Historical Forecast Project (CHFP) is a multi-model and multi-institutional experimental framework for sub-seasonal to decadal complete physical climate system prediction
http://www.clivar.org/organization/wgsip/chfp/chfp.php .

The expected outcomes of the experiments carried out within the CHFP framework will provide

- A baseline assessment of seasonal prediction capabilities using the best available models of the climate system and data for initialisation
- A framework for assessing of current and planned observing systems, and a test bed for integrating process studies and field campaigns into model improvements
- An experimental framework for focused research on how various components of the climate system interact and affect one another
- A test bed for evaluating IPCC class models in seasonal prediction mode

The core experiment is an 'Interactive Atmosphere-Ocean-Land-Ice Prediction Experiment' emphasizing the use of comprehensive coupled general circulation models, which includes realistic interactions among the component models. The experiment is to perform seven-month lead ensemble (10-members) predictions of the total climate system. If possible longer leads and larger ensembles are encouraged. The initialization strategy is to use the best available observations of all the components of the climate system.

While the emphasis in on comprehensive coupled general circulation models, uncoupled component, intermediate, simplified and statistical models are encouraged to participate where appropriate. The fundamental experimental design is to mimic real prediction in the sense that no “future” information can be used after the forecast is initialized.

The component models should be interactive, but this is left open to accomplish a wider participation, e.g. for groups without sea-ice or vegetation model. The only requirement is that no “future” information is used once the prediction is initialized. This requirement necessarily includes any tuning or training either the component models or the development of statistical prediction schemes.

Atmospheric initial states are to be taken from NCEP (or ECMWF) reanalysis each February, May, August and November of each year from 1979-present.

- Oceanic initial states (if appropriate) should be taken from most appropriate ocean data assimilation system
- Sea Ice initial states: (if appropriate) to be taken from best available observational data
- Land initial states: (if appropriate) to be taken from most appropriate land data assimilation system or consistent offline analyses driven by observed meteorology (i.e., GSWP; GLACE2)

4.3.1 CHFP – associated projects

In addition to the core experiment, a number of associated experiments/projects have been proposed and brief descriptions of three of these projects are given below.

Global Land Atmosphere Coupling Experiment (GLACE-2)

The 2nd phase of the Global Land Atmosphere Coupling Experiment (GLACE-2) is aimed at quantifying, across a broad range of state-of-the-art forecast models, the sub-seasonal forecast skill associated with the initialization of land surface state variables. The design of GLACE-2 is based on a successful pilot experiment and is built around a comprehensive suite of 60-day forecasts that are evaluated against observed precipitation and air temperature fields.

Stratosphere resolving Historical Forecast Project (SHFP)

The purpose of the Stratosphere resolving Historical Forecast Project (SHFP) is to:

- Quantify improvements in actual predictability by initialising and resolving the stratosphere in seasonal forecast systems
- Compare with existing seasonal to inter-annual forecast skill and to provide a hindcast data set that may be used to:
  - Demonstrate improvements in currently achievable season forecast skill for a range of variables and lead times
  - Understand improvements under particular scenarios such as El Nino and years with an active stratosphere
  - Justify changes in operational seasonal forecast approaches and methods as a subproject of the CHFP

Sea Ice Historical Forecast Project (SiHFP)

The purpose of the Sea Ice Historical Forecast Project (SiHFP) is to employ a concise set of multi-model sensitivity experiments to examine the effects of sea ice initialization in seasonal prediction systems. The experiments are a simple test of initializing sea ice conditions with the observed sea ice state versus initializing with climatology. All other components of the seasonal prediction system would be initialized identically across the two experiments. No use of any future information should be allowed in any of the system components. Although the scope of this project favours the use of interactive ice models, it should not be seen as excluding simplistic statistical modelling of ice - for instance the influence of prescribing persisted sea ice anomalies versus prescribing climatology. The primary goal of the study is to demonstrate the influence of “proper” initialization of sea ice on atmospheric circulation.

4.4 Year of Tropical Convection (YOTC)

Coordinated jointly by the World Climate Research Programme (WCRP) and the World Weather Research Programme (WWRP)-THORPEX and involving numerous institutions, research groups and individuals world-wide, the YOTC project addresses key strategic problems at the intersection of weather and climate (seamless prediction). The emphasis is tropical convection, its multi-scale organization and its interaction with the global circulation and role in the global water cycle. Research highlights includes the Madden-Julian Oscillation (MJO), convectively-coupled equatorial waves, the monsoons, easterly waves and tropical cyclones, tropical-extra-tropical interaction, and the diurnal cycle. All these phenomena severely challenge the global models used for both weather prediction and climate simulation. The YOTC Science and Implementation Plans may be found on the YOTC web site (www.ucar.edu/yotc).

The satellite data sets and associated archiving and dissemination system have been identified. High resolution analyses and deterministic forecasts, with diabatic and other process-oriented fields, are being archived - ECMWF at T799 (a horizontal resolution of about 25km), NASA/GMAO GEOS5 (a horizontal resolution of a ¼ degree), and NCEP (a horizontal resolution of about 35km). NASA supports the development of a unique satellite data analysis facility and dissemination framework (YOTC-Giovanni). The YOTC Implementation Plan identifies a number of periods of interest for modelling and analysis work. The YOTC-ECMWF archiving period (May 2008-April 2010) has been completed. This entire dataset (analysis, forecasts and special process-oriented diagnostics) have been stored at NCAR, where it will be made available to researchers via a new efficient web-based interface.

The "year" includes El Nino, La Nina, and Arctic Oscillation conditions, giving unique information on short-term climate variability.

Collaborative work within the YOTC project includes;

- Multi-model transpose-AMIP experiments (that is climate models run in weather mode) addressing critical issues challenging weather and climate models involving 5-day initialized forecasts for the YOTC period
- Global cloud-system resolving model experiments focused on YOTC periods of interest involving Japan NICAM, UK Cascade, NASA GMAO, and NCAR models.
- Tropical intra-seasonal multi-model (~15 models) 20-year hindcast experiments with additional output and analysis focused on the YOTC period, in association with CLIVAR Asian-Australian Monsoon Panel (AAMP) and Asian Monsoon Years (AMY).
- Extension of the GEWEX Cloud System Study (GCSS) Pacific Cross-section Inter-comparison (GPCI) for the June-August 2008 period during the YOTC "year"
- Synergistic forecast and analysis study in the Atlantic sector of easterly waves, tropical cyclones and their modulation by intra-seasonal variability
- Tropical-extra-tropical interaction studies focused on summer and winter T-PARC including the life cycle and impacts of tropical convection on the prediction and predictability of mid-latitude weather variability, e.g., extra-tropical-transition effects on storm tracks

5. Operational sub-seasonal predictions

The sub-seasonal forecast range is a range that some national meteorological services are beginning to look at with more interest and plans from six operational centres are briefly described below.

5.1 Operational systems and plans

ECMWF

The ECMWF monthly forecast system employs a T319L62 system and there are plans to extend the forecast range to 45 days and to increase the frequency of forecast generation from once per week to twice per week. On the seasonal timescale, a new system, System-4, will be introduced into operational use in 2011. Inter alia this will include a new ocean model (NEMO) with variational assimilation (NEMOVAR). The horizontal and vertical resolutions in both atmosphere and ocean will likely be increased. Since it is five years since the last update, substantial changes in the atmospheric model have been included, including the changes to convective parameterisation which greatly improved the model simulation of the MJO. The monthly (and the planned 45-day) system will include a new ocean model (NEMO) with variational data assimilation (NEMOVAR).

Japanese Meteorological Agency

The JMA issues operationally, monthly forecasts every week and the characteristics of their system are very similar to the ECMWF monthly system, though the resolution is less (T159L60), compared to (T319L62).

UK Met Office

The Met Office is planning to start testing a monthly forecast system in spring 2011. It will be based on their new seasonal forecasting system Glosea-4 with high vertical resolution in both the atmosphere and ocean, extending well through the stratosphere. The atmospheric horizontal resolution is N96, the ocean resolution is 1 degree with equatorial refinement. It will be run weekly with 28 members. The seasonal forecast has also recently been upgraded to include initialisation and evolution of both the sea-ice and the stratospheric state.

NCEP

Starting in early 2011, National Centres for Environmental Prediction (NCEP) will also be initiating a monthly prediction system. In real-time the NCEP monthly prediction system will be based on 16 forecasts each day and each forecast will be for 45-days. Forecasts will be made using a coupled system with a T126L62 atmospheric model. Real-time forecasts will be accompanied with a set of hindcasts for 1999-2010 with 4 runs each day. All the components of the forecast system will be initialized from the recently completed Climate Forecast System Reanalysis.

Environment Canada

Canadian plans for the monthly forecast system are to base the monthly forecast system on the Canadian global EPS. This system is currently providing 16-day operational forecasts twice daily. It is planned to extend the range to 35 days, three times per month to obtain monthly forecasts. This approach will be transferred to operations in two stages. The first one (2011) will use persisted SST anomalies obtained from the CMC SST analyses. In the second stage (2013-2014?), the GEM model will be coupled to an ocean-ice system based on the NEMO ocean model. It has been demonstrated that phase one will significantly improve on the current operational monthly forecast system by about 10 days.

The short term strategy for the Canadian (EC) seasonal forecasting system is to use a two-model ensemble coupled climate prediction system that makes use of data assimilation to initialize the atmosphere, ocean, sea-ice and land surface components. This system has been extensively evaluated in the context of the Coupled System Historical Forecast Project (CHFP2) produces forecasts out to 12 month lead that are superior to the current 2-tier, 4-model operational system, and compares favourably to other coupled systems being used elsewhere. Discussions are currently underway to begin operational implementation.

Bureau of Meteorology (Australia)

In Australia, the Bureau of Meteorology is currently experimenting with a monthly forecast system. The atmosphere and ocean are the same as those used for seasonal forecasting but the ocean analysis has been upgraded to an EnKF. In addition bred vectors are calculated and used in the generation of the ensemble. An ensemble of 30, ten from each of three versions of the model, is used, and an extensive set of hindcasts is also planned starting from 1982.

5.2 Standardization between data producers

In contrast to operational medium-range prediction, standardization across operational centres carrying out seasonal and monthly predictions is poor thus making it difficult to use operational predictions at these ranges for research. Forecasts are run on daily, weekly or monthly basis, the hindcasts employed differ considerably and data exchange is not sufficiently wide-spread. In addition, common verification data sets are required as is a standard framework for verification. The standardization achieved with the TIGGE data base is exemplary and its growing use for research underlines what can be achieved from a consistent coordinated approach.

The Workshop participants from the six operational centres mentioned above agreed that aligning the characteristics of the operational sub-seasonal procedures that are followed at each centre would enable more effective collaboration and would provide excellent data for research. Whilst it might be difficult, or unrealistic, to emulate the full TIGGE approach for sub-seasonal prediction, it was agreed that standardization of procedures and data exchange, primarily for research, between these operational centres is highly desirable.

6. The Societal and Economic requirements for sub-seasonal prediction

There is a growing, and urgent, requirement for the employment of sub-seasonal predictions for a wide range of societal and economic applications which include

- Warnings of the likelihood of severe high impact weather (droughts, flooding, wind storms etc.) to help protect life and property
- Humanitarian Planning and Response to disasters
- ICSU-IRDR case studies
- Agriculture particularly in Least Developed Countries – wheat and rice production are important examples
- Disease planning/control - for malaria and meningitis for example
- River-flow and river-discharge – for flood prediction, hydroelectric power generation and reservoir management for example
- Landslip
- Coastal inundation
- Transport
- Power generation
- Insurance

Many of these applications require seamless prediction from a few days ahead through to the seasonal time-scale. For example, farming in developing countries typically needs to manage the irrigation of crops throughout the whole growing season which requires continual weather predictions for water and power management from planting to harvest and seasonal prediction to help determine the optimal planting strategy. Similarly, the prediction and of last year's floods in Australia needed forecasts from hours ahead to time-scale of the La Nina event that influenced the large-scale atmospheric conditions for such a long period.

In addition to the workshop's opening presentation on "The societal requirements for sub-seasonal to seasonal prediction" (in which examples of a number of the applications listed above were described), three applications were presented.

- South American Demonstration Project for the La Plata basin
- South Asian Demonstration Project for tropical cyclone and flood forecasting in Bangladesh
- An Insurance Project aimed at reducing financial exposure

For some applications some “raw” forecast parameters can directly inform disaster mitigation decision making – examples are typhoon track, intensity and landfall probabilities, whereas for many applications, “raw” parameters have to be fed into application models – river-flow models are a well know example, but 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 which is 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.

Success, even where there is already a measure of predictive skill, will depend crucially on the willing involvement of the community and regional centres. 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.

The breadth and variety of the applications raises the need for

- The development of an inventory of societal applications of prediction/decision support
- An annotated bibliography and bibliometric analysis to identify research gaps and priority topics
- Consultation with WMO members (NMHSs) to identify past, on-going, planned services
- A 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
- Evaluation across the decision chain

7. Summary and recommendations

Considerable progress has been made in improving the skill of medium range weather forecasts and in developing operational seasonal forecasting. Forecasting in the intermediate range between medium range and seasonal is difficult as the importance of the initial conditions wanes, and the importance of slower boundary conditions such as sea surface temperature increases but has only a modest influence on the weather and climate, especially away from the tropical regions. Tropical sea surface temperatures play an important role not only in controlling the weather/climate in the tropics but in the extra-tropics also, through various tele-connections. The El Nino Southern Oscillation (ENSO) is the best-known long-lived source of predictability in the tropics but changes in SST in the Indian Ocean are also significant, though the forecast horizon is likely to be shorter than for ENSO. Predicting changes in the equatorial Atlantic SSTs has been less successful.

As discussed at the Workshop, recent results suggest that there is potentially useful predictability at sub-seasonal timescales, intermediate between NWP and seasonal timescales, and it is worth exploring this further and despite the difficulties in forecasting for this range it is worthwhile developing a research strategy to explore and exploit this potential.

The contribution that successful sub-seasonal predictions can make to the developing programme for Global Framework for Climate Services will be valuable in that

- All countries would benefit, but priority should be given to the needs of climate-vulnerable poor countries
- The primary focus must be greater access and use of climate information by users
- Framework activities should address three spatial scales: global, regional and national
- Climate information is primarily a public good and should be made widely available
- The Framework should respect national and international data policies while encouraging global, free and open exchange of climate-relevant data

In order to improve predictions at these ranges it is necessary to develop a seamless approach to weather and seasonal prediction. Similarly, it is also necessary to promote a seamless approach to the application of sub-seasonal predictions through physical and social science researchers, service providers and users and leveraging the work of existing programmes and such a collaborative initiative should be focussed (section 2 of this report) on

- Coupled global modelling
- Coupled data assimilation
- MJO and organised tropical convection
- Polar processes
- Surface-atmosphere interactions
- Stratosphere-troposphere interactions
- Ensemble prediction systems (EPS)
- Data bases for research
- Forecasting system design
- Societal and economic benefits from improved sub-seasonal to seasonal prediction

And, the utilization of these predictions will require

- Understanding how information at the weather/climate interface, including uncertainty, connects with decision-making and risk management
- User-oriented products

Recommendation

The major Workshop recommendation is that a Panel/Project for Sub-seasonal prediction research should be established. Panel members should include representatives from WWRP-THORPEX, WCRP, CBS and CCI and their relevant programme bodies. The first task for the Panel should be the preparation of an Implementation Plan which is consistent with the contents of this Workshop report.

The Implementation Plan should give high priority to:

- Sponsorship of a few international research activities

- The establishment of collaboration and co-ordination between operational centres undertaking sub-seasonal prediction to

    - ensure, where possible, consistency between operational approaches to enable the production of data bases of operational sub-seasonal 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 for research

- The establishment of a series of regular Workshops on sub-seasonal prediction

In a separate plan, or as part of the Implementation Plan, the WWRP/SERA Working Group and the WCRP should outline plans for a number of regional projects.

Workshop
"Sub-seasonal to Seasonal Prediction"
Met Office, Exeter –1 to 3 December 2010

AGENDA AND PARTICIPATION

Wednesday 1 December			
	08:00-09:00	**Registration**	
	09:00-09:15	Welcome and scope of the workshop	Julia Slingo (WCRP/JSC) and David Burridge (WMO)
Session 1: Setting the scene		**Chair: Julia Slingo**	
	09:15-09:45	Sub-seasonal to seasonal prediction (1-90 days) – A seamless approach	Gilbert Brunet (WWRP/JSC Chair)
	09:45-10:15	The societal requirements for sub-seasonal to seasonal prediction	Andy Robertson(IRI)
	10:15-10.45	Global Framework for Climate Services	Len Barrie (WMO) and Ghassem Asrar (WMO)
	10:45-11:15	**Coffee break**	
Session 2: Operational systems		**Chair: Arun Kumar (NCEP)**	**Rapporteur:**Michele Rienecker (NASA)
	11:15-11:45	Operational centre - JMA	Yuhei Takaya (JMA)
	11:45-12:15	Operational centre - ECMWF	Tim Stockdale (ECMWF)
	12:15-12:45	WMO Lead-centres for verification and archiving	Richard Graham (UK Met Office) and Won-Tae Yun (KMA)
	12:45-13:15	Discussion – status of operational capabilities	Chair
	13.15-14.00	**Lunch break**	
Session 3: Major scientific modelling problems and their diagnosis		**Chair: Franco Molteni**	**Rapporteurs:** Ben Kirtman (WGSIP) and Andy Brown (WGNE)
	14:00-14:30	The Atlantic – the NAO, AO and the MJO	Hai Lin (EC) presented by Frederic Vitart (ECMWF)
	14:30-15:00	Tropical modes in the Indian and Pacific Oceans	Harry Hendon (BoM)
	15.00-15.30	El Nino and its global tele-connections	Eric Guilyardi (IPSL)
	15.30-16.00	**Coffee**	
	16:00-16:30	Blocking and regime transitions	Tim Woollings (Uni. Reading)
	16.30-17.00	Stratospheric influences on the troposphere	Adam Scaife (WGSIP)
	17.00-17.30	Land surface processes and land-atmosphere interactions	Herve Douville (MF)
	17.30-18.00	Discussion – identification of major modelling problems	Chair
	18.00	**Reception**	

Workshop
"Sub-seasonal to Seasonal Prediction"

AGENDA continued

Thursday 2 December			
Session 4: Data assimilation and EPS		**Chair: Andrew Lorenc**	**Rapporteur:**Olivier Talagrand (LMD)
	08:30-09:00	Coupled data assimilation	Michele Rienecker (NASA)
	09:00-09:30	Ensemble data assimilation	Dale Barker (UKMO)
	09:30-10:00	Monthly forecasting with ensembles	Frederic.Vitart (ECMWF)
	10:00-10:30	**Coffee break**	
	10:30-11:00	Representing model uncertainty on seasonal time scales	Paco Doblas-Reyes (IC3)
	11:00-11:30	Discussion – identification of major initialization and EPS problems	Chair
Session 5: **Data bases and observations**		**Chair: Harry Hendon**	**Rapporteur:**Laurie Wilson (TIGGE WG)
	11:30-11.45	The MJO Task Force	Harry Hendon (BoM)
	11:45-12:15	TIGGE	Richard Swinbank (TIGGE WG)
	12:15-12:45	The CHFP	Ben Kirtman (WGSIP)
	12:45-13:45	**Lunch break**	
	13.45-14.15	The YOTC	Mitch Moncrieff (NCAR, YOTC)
	14:15-14:30	The NCEP prediction system	Glenn White (NCEP)
	14.30-15.00	Discussion – requirements for data bases	Chair
Session 6: **Societal and economic benefits**		**Chair: Brian Mills (WWRP/SERA)**	**Rapporteur:**Joanne Robbins (UKMO)
	14.45-15:15	A South American demonstration project	Celeste Saulo (CIMA)
	15:15-15:45	A South Asian demonstration project	Violeta Toma (GIT)
	15:45-16:15	**Coffee break**	
	16:15-16:45	An Insurance project	Matthew Foote (Willis)
	16:45-17:15	Discussion – identification of a few demonstration projects	Chair

Friday 3 December			
Session 7: Summaries of discussions		**Chairs:**Julia Slingo, Gilbert Brunet and David Anderson	
	09:00-10:30	Summaries	David Anderson and Rapporteurs
	10:30-11:00	**Coffee break**	
	11:00-12:30	Summaries continued	David Anderson and Rapporteurs
	12.30-13.30	**Lunch break**	
Session 8: International cooperation/project			
	13:30-15:00	Discussion lead by Chairs	

ADDITIONAL PARTICIPANTS

Michel Beland (President of CAS
Jim Caughey (WMO)
Melinda Peng (NRL, USA)
Olivier Talagrand (LMD; THORPEX PDP WG)
Dieter Peters (Leibniz-Institute of Atmospheric Physics, Germany)
Jean-François Gueremy (Météo-France)
Barbara Früh (DWD, Germany)
Glenn White (EMC, USA)
Jorge-Luis Vazquez-Aguirre (UEA, UK)
Randall Dole (NOAA, USA)
Tetsuo Nakazawa (WMO)
Roberto Buizza (ECMWF)
Magdalena Alonso Balmaseda (ECMWF)

Alberto Arribas (UKMO)
Sean milton (UKMO)
Tim Johns (UKMO)
Ann Shelly (UKMO)
Matt Palmer (UKMO)
John Siddorn (UKMO)
Matt Martin (UKMO)
Dan Lea (UKMO)
Catherine Guiavarch (UKMO)
Alex Arnold (UKMO)
Mike Bell (UKMO)
Bernd Becker (UKMO)
James Murphy (UKMO)