Subseasonal to Seasonal Prediction Project: Bridging the gap between weather and climate

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Great progress has been made in recent decades on development and applications of medium-range weather forecasts and seasonal climate predictions. The subseasonal to seasonal project will bring the weather and climate communities together to tackle the intervening time range, harnessing shared and complementary experience and expertise in forecasting, research and applications, toward more seamless weather/climate prediction systems and more integrated weather and climate services.

From the societal perspective, many management decisions in agriculture and food security, water, disaster risk reduction and health fall into the subseasonal to seasonal time range. However, this time scale has long been considered a "predictability desert", and forecasting for this range has received much less attention than medium-range and seasonal prediction. Recently, research has indicated important potential sources of predictability in this time range through better understanding and representation of atmospheric phenomena such as the Madden–Julian Oscillation, improved coupling with, and initialization of, the land–ocean–cryosphere and stratosphere, new model developments, more comprehensive and reliable observational networks, enhanced data assimilation techniques and increasing computing resources. These improvements are expected to translate into more accurate forecasts.

A number of recent publications (e.g. Brunet 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. At its fifteenth session in November 2009, the WMO Commission for Atmospheric Sciences (CAS) requested that the Joint Scientific Committees of the World Weather Research Programme (WWRP) and the World Climate Research Programme (WCRP) and the THORPEX[3] International Core Steering Committee set up an appropriate collaborative structure to carry out an international research initiative on this topic and recommended that it be coordinated with future developments in the Global Framework for Climate Services. An Implementation Plan[4] has been written-up on which this article is based.

Needs from applications

Weather and climate events continue to exact a toll on society despite the tremendous advances and investment in prediction science and operational forecasting over the past century. Weather-related hazards, including early/late 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. From the end-user perspective, the sub-seasonal time scale is important because it lies between the well-established and routine application of weather forecasts in diverse user sectors on the one hand, and the increasing use of seasonal forecasts on the other. Many management decisions, such as in agriculture, fall into the intervening two-weekly 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 regarded as a significant contribution of

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3 THe Observing system Research and Predictability EXperiment (THORPEX)
4 http://www.wmo.int/pages/prog/arep/wwrp/new/documents/Implementation_plan_V6.4_nolinenos.pdf

both WCRP and WWRP to the Global Framework for Climate Services.

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 a seasonal forecast, which might inform a crop-planting choice, a sub-seasonal forecast could help optimize the irrigation scheduling and pesticide/fertilizer application with collateral benefits for the environment. In situations where seasonal forecasts are already in use, sub-seasonal ones could be used as updates, such as for estimating end-of-season crop yields. Extending upward from user-applications of numerical weather predictions, there is a potential opportunity, for example, 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's International Research Institute for Climate and Society (IRI) have proposed a "Ready-Set-Go" concept for making use of forecasts from weather for seasonal forecasts. It uses seasonal forecasts to begin monitoring of sub-seasonal and short-range forecasts, update contingency plans, train volunteers, and enable early warning systems ("Ready"); sub-monthly forecasts are used to alert volunteers, and alert communities ("Set"); weather forecasts are then used to issue warnings, activate volunteers, distribute instructions to communities, and evacuate if needed ("Go").

Success, even where there is already a measure of predictive skill, will depend crucially on the active involvement of the climate and applications communities, and co-development with stakeholders. Important topical areas will include the evaluation of past and current experience, and the demonstration of applications with emphasis on communication and evaluation, including building upon on-going applications activities at operational centres.

Research priorities

The subseasonal to seasonal prediction initiative will give high priority to the following research activities:

- Understanding the mechanisms of subseasonal to seasonal predictability.

- Evaluating the skill of subseasonal forecasts, including identifying windows of opportunity for increased forecast skill, with special emphasis on the associated high-impact weather events.

- Understanding model physics and how well the important interaction processes in the Earth system are represented.

- Comparing, verifying and testing multi-model combinations from these forecasts and quantifying their uncertainty.

- Understanding systematic errors and biases in the subseasonal to seasonal forecast range.

- Developing and evaluating approaches to integrate subseasonal to seasonal forecasts into applications.

Forecasting 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 inter-annual range, in contrast, depends strongly on slowly-evolving components of the Earth system, especially the sea-surface temperatures (SST). In between these two time scales is subseasonal variability, which is defined here as the time range between two weeks and two months. Subseasonal to seasonal forecasting is at a relatively early stage of development. Many issues remain to be resolved and procedures improved before the full potential of sub-seasonal prediction can be realized. There are glimpses of potential predictability well beyond the range of normal numerical weather prediction (~10 days), but the range of processes involved is not well understood (Hoskins 2012a,b). Sources of subseasonal to seasonal predictability come from various processes in the atmosphere, ocean and land. A few examples of such processes are:

- The Madden-Julian Oscillation: as the dominant mode of intraseasonal variability in the tropics that modulates organized convective activity, the Madden-Julian Oscillation 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);

- Soil moisture: inertial 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);

  Snow cover: The radiative and thermal properties of widespread snow cover anomalies have the potential to modulate local and remote climate variability over monthly to seasonal time scales (e.g. Sobolowski et al. 2010);

- 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); and

- Ocean conditions: anomalies in upper-ocean thermal structure, in particular sea-surface temperature, lead to changes in air-sea heat flux and convection, which affect atmospheric circulation. The tropical intraseasonal variability forecast skill is improved when a coupled model is used (e.g. Woolnough et al. 2007), while coupled modes of ocean-atmosphere interaction, including the El Niño–Southern Oscillation in particular, can yield substantial forecast skill even within the first month.

In addition to the above, the topics of teleconnections, monsoon variability, tropical storms, polar prediction and sea ice have high relevance in the subseasonal to seasonal range, and linkages with the respective research communities will be emphasised by the project. It is likely that predictive skill will be higher in certain "windows of opportunity", for example where strong signals from several of these processes interact constructively, but exactly how this occurs and what these windows are, or how to recognize them, is still unclear.

Major issues from a climate perspective include the occurrence of extreme events, from heatwaves to hurricanes, how seasonal-to-interannual variability affects their probability of occurrence, and whether such climatic variations are usefully predictable. Many of the extreme events with the largest impacts have a strong subseasonal/weather character, reinforcing the importance of subseasonal time scales for advancing both understanding and predictions of extreme events in a variable and changing climate. Assessing how subseasonal to seasonal variations may alter the frequencies, intensity and locations of high impact events will be a high priority area of research from the societal decision-making perspective.

The probabilistic nature of weather and climate, and extreme events in particular, makes the development and use of ensemble-based modelling a requirement to improve estimates of the likelihood of high-impact events. In general, an ensemble prediction system (EPS) based on several models, rather than a single model, a so-called multi-model ensemble prediction system (MEPS) approach, provides more useful probability density functions than those obtained from a single EPS when using models of comparable skill (e.g. Hagendorn 2010). The majority of the current subseasonal to seasonal operational forecasting systems are based on ensembles of coupled ocean-atmosphere integrations because realistic representation of ocean-atmosphere coupling is likely to be important on the subseasonal to seasonal time range. However, several important modelling issues still need to be addressed:

- What is the optimal way to initialize a coupled ocean-atmosphere system for successful subseasonal to seasonal prediction?

- What is the best forecast system configuration for representing uncertainty to achieve successful subseasonal to seasonal forecasts?

- What is the impact of increasing horizontal or vertical atmospheric and oceanic resolution?

- What are the main sources of systematic errors at this time range?

- What is the impact of coupling the atmosphere to an ocean, land surface and cryosphere model?

- What is the spread-skill relationship at this time range?

- What is the benefit of multi-model combinations?

Forecast verification activities will be crucial and 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

Australian flood of 2011

the subseasonal prediction systems such as land data assimilation system impacts, the ability to predict the Madden-Julian Oscillation and other subseasonal phenomena (e.g. blocking, storm track variations, etc.), and the dependence on the El Niño–Southern Oscillation; (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 skill estimates for decision making).

Research activities will also focus on some specific extreme event case studies, to demonstrate that using subseasonal predictions could be of benefit to society. The case studies will be chosen for their high societal impact, but should also represent important research topics, for instance, the Russian heatwave of 2010, the floods in Pakistan in 2010 and Australia in 2011, or the European cold spell of 2012. An important outcome of these demonstration projects would be a better understanding of the causes of some extreme events. Some recent subseasonal to seasonal forecasts have already shown promise in predicting some of these high-impact extreme events. For instance, some seasonal forecasting systems have been successful in predicting higher precipitation over north-west Australia during the Southern Hemisphere summer of 2010-2011 (See example in Figure 1). Another example is the prediction by some extended range forecasts of the heat wave over the United States of America in July 2012 (See example in Figure 2). Therefore, it is timely to evaluate the ability of the state-of-the-art extended range forecasting systems to predict high-impact 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.

Implementation

Over the past years, a few multi-model ensemble prediction systems have been set up for medium-range weather and seasonal forecasting: the THORPEX Interactive Grand Global Ensemble (TIGGE) for forecasts up to two 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 goal of this project is to produce a MEPS database from the current operational subseasonal forecasts (most of the Global Producing Centres are now producing operational subseasonal to seasonal forecasts). The multi-model database will consist of ensembles of subseasonal (up to 60 days) forecasts, and will follow the TIGGE protocols, to capitalize on the existing infrastructure.

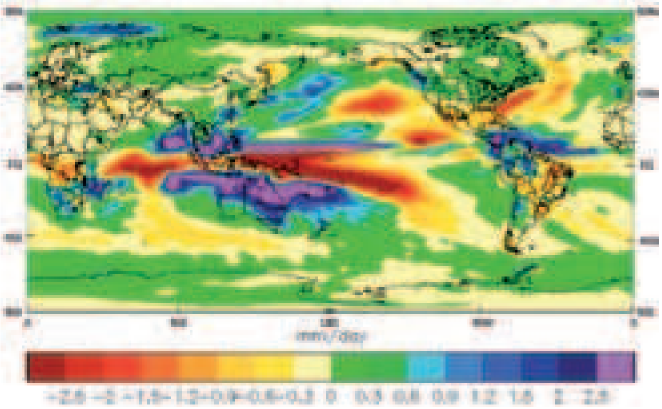

Figure 1 – Seasonal forecast of precipitation for December 2010 and January and February 2011 issued by the UK Met Office in September 2010. The purple region over Australia indicates increased rainfall.

The proposed database will provide a powerful community resource for investigating the mechanisms of subseasonal to seasonal predictability, and assessing their skill and the usefulness of state-of-the-art subseasonal forecasts for applications. Seasonal forecast practice and the TIGGE project have both recognized that the calibration of ensemble forecasts, correcting for model biases in the ensemble mean and spread and allowing downscaling, can provide an important complement to multi-model ensembling in improving the probabilistic reliability and skill of forecasts. 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, while constructing a multi-model ensemble of calibrated forecasts has been shown to improve overall skill of seasonal forecasts (e.g. Robertson et al. 2004). For numerical weather prediction forecasts, model error is not usually so large 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 a sizeable number of years is needed to calculate model bias, which in some cases can also be used to evaluate skill.

An important aspect will be to promote use of these forecasts and their uncertainty estimates by the applications community. 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 used to build statistical models to tailor climate forecasts for use in sector specific applications. However, the fact that some of the reforecasts are produced on the fly and include only a limited number of years may be an issue for some applications.

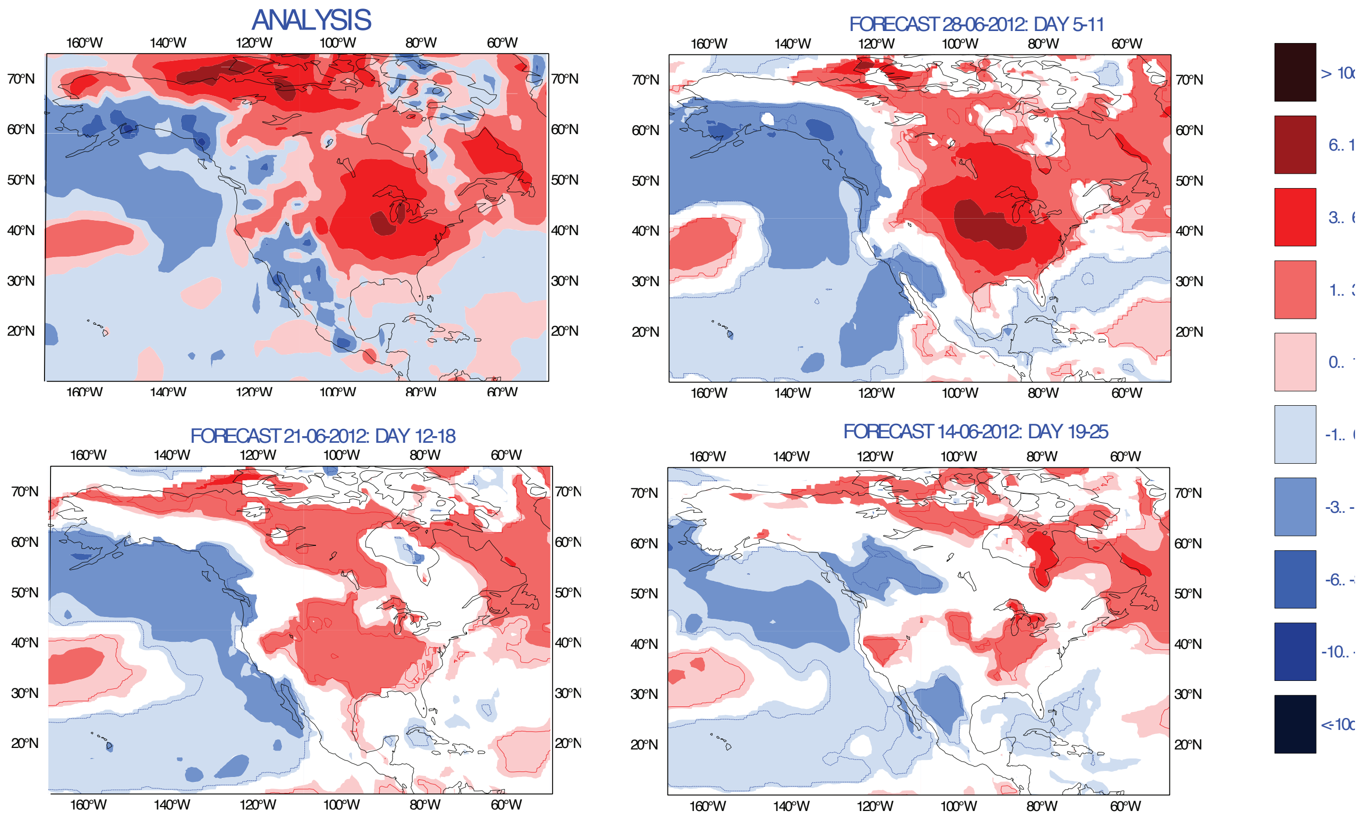

Figure 2 – 3-metre temperature anomalies averaged over the week 2 July–8 July 2012 and relative to the past 18 years climate. The top left panel shows the analysis from the European Centre for Medium-Range Weather Forecasts (ECMWF). The other panels show the 2-metre temperature anomaly forecasts for the ECMWF ensemble prediction system starting on 28 June (top right panel), 21 June (bottom left panel) and 14 June 2012 (bottom right panel) and verifying the same week as the analysis in the top left panel. Therefore, the time ranges of the forecasts are respectively: day 5 – 11, day 12 – 18 and day 19 – 25.

In order to attract a maximum number of applications and users of the database, it is desirable to release the forecasts as close as possible to real-time. However, this conflicts with the data policy of some operational centres. It is, therefore, proposed to start with a forecast release date that is a few weeks behind real-time. However, for some demonstration projects, it may be possible to allow near real-time access for a limited amount of time to the research and application communities, possibly including archiving a larger set of variables and at a higher resolution.

Open access to forecast data and user-friendly databases are important requirements for broad community uptake. The database will underpin the research that can shape the scope of developing operational products to be provided by the WMO Global Producing Centres as coordinated by the Commission for Basis Systems (CBS). The demonstration projects will provide an important mechanism to promote the use of subseasonal prediction by application users and foster relationships with partners and provide common focussed objectives. More details on the proposed database can be found in the implementation plan.

Linkages

The subseasonal to seasonal time range falls within the remit of the Global Framework for Climate Services and the output from this project aims to provide an important contribution to its first (near-term) phase. Collaborations and linkages will be established with other WMO working groups.

Through the intersection with disaster risk management, food security and markets, the subseasonal timescale is of relevance to development agencies such as the World Bank, USAID, UK Department for International Development, and food security organizations such as the World Food Programme, and the Consultative Group on International Agricultural Research's Program on Climate Change, Agriculture and Food Security. 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 for Climate Services.

Usefulness to society

Subseasonal forecasting has not received as much attention as weather forecasting or seasonal forecasting because it was thought to be a difficult time range that is not as well defined as weather and seasonal forecasting. However, there are reasons to think that there are opportunities for making forecasts for this time range that would be very useful to society.

To achieve success will require considerable improvement in scientific understanding of sources of predictability, together with the development of improved high resolution coupled atmosphere ocean ice models, improved initialization strategies of the coupled system and representation of longer-lived atmospheric phenomena such as the Madden-Julian Oscillation. Several operational weather centres are now either making, or planning to make, forecasts for the subseasonal range, and some climate models could also be brought to bear on this time range, opening the opportunity to compare model forecasts, to understand which processes are robust and which not, as well as to develop strategies for combining the various model forecasts.

This could include multi-model forecasts, but other approaches are possible. Such rigorous analysis and assessment of the forecast will offer greater confidence to the users of such information for decisions relating to agriculture and food production, water resources management, energy and transportation, etc. Establishing an effective feedback mechanism on adequacy and efficacy of the resulting information by the users will also ensure greater focus on improving such forecasts based on the users' perspective.

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