The State of the Art of Seasonal Prediction

Outcomes and Recommendations from the First World Climate Research Program Workshop on Seasonal Prediction

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Our ability to predict the seasonal variations of the Earth's tropical climate dramatically improved from the early 1980s to the late 1990s. This period was bracketed by two of the largest El Niño events on record: the 1982–83 event, which went unrecognized until many months after its onset; and the 1997–98 event, which was well monitored from its earliest stages and predicted to a moderate degree by a number of models several months in advance. This improvement was due to the convergence of multiple factors, including a concerted international effort to observe, understand, and predict tropical climate variability; the application of theoretical understanding of coupled ocean–atmosphere dynamics; and the development and application of models that simulate the observed variability. The international WCRP Tropical Ocean Global Atmosphere (TOGA) program (1985–94) successfully demonstrated this potential predictability as well as the societal benefit of seasonal prediction.

After the late 1990s, our ability to predict tropical climate fluctuations reached a plateau with little subsequent improvement in quality except for the provision of probabilistic information. Was this a result of a fundamental change in the predictability of the climate system due to either natural or anthropogenic forcing, or the emergence of a critical failing in the models used to make predictions, or merely a sampling effect? Have we accounted for all of the critical interactions among all the elements of the climate system (ocean–atmosphere–biosphere–cryosphere)? Are the observations adequately blended with the models to make the best possible forecasts?

To gain consensus and address these concerns, the First WCRP Seasonal Prediction Workshop[1] was convened in Spain in 2007. It brought together researchers with the four core projects of the World Climate Research Programme (WCRP–CLIVAR, CliC, GEWEX, and SPARC[2]), as well as the World Climate Programme (WCP) through its WCASP/CLIPS[3] project, to focus on two overarching questions:

1) What factors are limiting our ability to improve seasonal predictions for societal benefit?
2) What factors are limiting the application of our seasonal predictions for societal benefit?

With a substantial fraction of the world's population living in countries influenced significantly by climate anomalies, pursuing such commonality on these issues is important. Many of these countries have economies that are largely dependent upon their agricultural and fishery sectors. The climate forecast successes of the 1980s and 1990s brought great prom-

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DOI:10.1175/2008BAMS2707.1

[1] The First WCRP Seasonal Prediction Workshop was held on 4–7 June 2007 in Barcelona, Spain. Approximately 180 people from more than 30 countries in WMO Regions I–IV (Africa, Asia, Europe, the Southwest Pacific, and North, Central, and South America) attended.

[2] CLIVAR—Climate Variability and Predictability; CliC—Climate and Chryosphere; GEWEX—Global Energy and Water Cycle Experiment; SPARC—Stratospheric Processes and Their Role in Climate

[3] WCASP/CLIPS—World Climate Applications and Services Programme/Climate Information and Prediction Services

BEST PRACTICES IN SEASONAL FORECASTING

The following requirements for producing, using, and assessing seasonal forecasts were agreed upon during and in discussions subsequent to the First WCRP Workshop on Seasonal Prediction.

- Forecast error must be addressed by appropriately quantifying dynamical model uncertainty;
- Model output should be recalibrated based on historical model performance;
- Probabilistic forecast information should be issued;
- A description of the forecast process should be made available;
- In retrospective forecast mode, no information about the future should be used;
- Forecast quality information should be provided, including several metrics of quality;
- Regional climate service providers need to work with both the forecasting and application communities to develop tailored downscaled products;
- Users must be encouraged to use all the ensemble members to quantify forecast uncertainty;
- Web-based tools need to be developed to allow users to tailor forecast information;
- Regional mechanisms like Regional Climate Outlook Forums (RCOFs) should be used to develop regional climate outlooks based on the consensus and objective scientific assessment of multiple-prediction outcomes;
- Liaison with users should be promoted to understand their climate information needs in decision making and also to raise their awareness of the uncertainty aspects of seasonal forecasting;
- Regional/national ownership of seasonal forecasts should be promoted through effective and sustained capacity building and infrastructural support.

ise for societal benefit in the use and application of seasonal forecast information. However, this promise has not been fully realized, partly because there have not been adequate interactions among the physical scientists involved in seasonal prediction research and production, applications scientists, decision makers, and operational seasonal prediction providers. The issues and problems go beyond merely improving forecast quality and making forecasts readily available. Physical scientists need to actively engage users to understand and meet their requirements in order to provide improved climate information and prediction products and services, thereby increasing the applicability of forecasts. Users also have to maintain an active dialogue with the physical scientists and forecast providers so that their climate information needs are taken into account.

This article summarizes the workshop's core findings and recommendations, which have been published as a WCRP Position Paper on Seasonal Prediction.[4] The recommendations and overarching consensus statements bear the weight of the diverse seasonal prediction community that this workshop assembled. This included researchers of the physical climate system and forecast methodology, operational forecast providers, and forecast application experts. Representatives from all the major operational seasonal prediction centers and U.S. scientific funding agencies were in attendance.

A COMMON LANGUAGE FOR ASSESSING SEASONAL PREDICTION. There is a clear need for the seasonal prediction community to develop a common language for the assessment of seasonal prediction skill. This would benefit forecasters and forecast users. Given the steadily widening reach and use of seasonal forecasts, the need is urgent for an assessment that covers all types of models used in seasonal forecasts that can be understood by a wide audience.

The term "skill" covers a complex array of issues; just two are discussed in the WCRP Seasonal Prediction Position Paper: *quality* and *value*.

1) *Quality* refers to the technical measurement of forecast performance; quality is of prime concern to scientists and is often pertinent for users.
2) *Value* relates to the practical benefits achieved through decision-making based on forecast information, usually in conjunction with other information, and, while of fundamental concern to

[4] This paper should be viewed as an evolving or "living" document that will be periodically updated and reviewed as progress in seasonal prediction is regularly and comprehensively assessed. It is available from the WCRP and online at www.clivar.org/organization/wgsip/spw/spw_position.php.

the user, should also stimulate seasonal prediction scientists.

The WMO currently provides a standardized assessment of seasonal prediction quality through the Standard Verification System of Long Range Forecasts (hereafter referred to as the Standard Verification System), in which nine meteorological agencies currently participate. Several issues nonetheless continue to limit what needs to be a community-wide authoritative assessment, primarily because the Standard Verification System does not assess all the seasonal forecast products that are available.

The importance of a comprehensive and authoritative assessment lies not only in its usefulness for the seasonal prediction community but also in its ability to communicate the uncertainty, reliability, and applicability of the forecast products to the user community. Not enough seasonal forecasts have been made to date to provide a long enough record for reliable estimates of skill. Predictability has also been found to depend on variations in SST in the tropical Pacific, and so varies from year to year. These factors, combined with the limited production of seasonal forecasts to just a few times a year, restrict the sample size available for quality assessment. In addition, most metrics of forecast quality, including those used in the Standard Verification System, and particularly in the case of probabilistic forecasts, are technical in nature and difficult to use by audiences outside the forecast community.

Despite these problems, some broad statements on forecast quality can nonetheless be made, as outlined below. The same cannot be said for forecast value. Value depends on a complex interplay of multiple factors, of which forecast quality is but one. The direct link between forecast quality and value is difficult to determine, as is quantifying forecast value as part of a decision process where climate and forecast quality are often just one consideration among many. It is important to realize that effective communication of forecast quality, together with forecast uncertainty and an improved knowledge of climate variability, has direct bearing on the realized value.

OVERARCHING CONSENSUS STATEMENTS ON THE STATE OF SEASONAL PREDICTION. The maximum predictability of the climate system has yet to be achieved in operational seasonal forecasting. Model error continues to limit forecasting skill and since not all interactions in the climate system—land–atmosphere interactions, for example—are currently fully resolved, there may still be untapped sources of predictability. Multimodel methodologies can be used to quantify uncertainty due to model formulation. Forecast initialization with ocean data assimilation can improve forecast quality. Dynamical model forecasts can also be improved by synergistic use of empirical techniques.

Seasonal prediction skill should be assessed using a community-wide common language—which remains to be developed—that is critical to documenting future improvement; adherence to the existing Standard Verification System assessment framework is recommended. Retrospective hindcast experiments that are used to increase the sample size of seasonal forecasts need to take into account the nonstationarity of the climate system, and seasonal prediction must be addressed in the context of a changing climate. The wider seasonal prediction community needs to frequently review the agreed upon set of "core" metrics, including the best practices in forecasting and techniques for validation and verification. The sidebar with this article lists best practices for producing, using, and assessing seasonal forecasts.

ASSESSING SEASONAL PREDICTION QUALITY. The Standard Verification System assessment provides a well-established set of skill scores. For example, the mean squared skill score (MSSS) against climatology is a good measure of the deterministic skill of the evolution of SST related to ENSO. In particular, it gives a measure of forecast error scaled by the signal, which is forcing the atmosphere (i.e., it shows us the error relative to the signal strength). State-of-the-art MSSS for Nino 3.4 SST at 5 months lead time is about 0.7 for the best single models and 0.75 for multimodel combinations. ENSO SST forecasts are expected to continue to improve since the growth of errors in current operational systems continues to exceed that expected from current limit-of-predictability estimates. The use of multimodel ensembles techniques improves skill, though the optimal way to combine models has yet to be established. At the moment, forecast errors are still dominated by model error, and the relationship of forecast error to model ensemble spread is weak.

The workshop and the WCRP position paper also addressed the seasonal forecast skill for terrestrial temperature and rainfall. It is clear that 2-m temperature over land is more reliably predicted than rainfall regardless of the season. Tropical regions generally show more temperature reliability, while models have significant difficulty in capturing the rainfall variability over land regions. In addition to surface air temperature, precipitation, and SST, well-known climate indices representing major climatic features such as the North Atlantic Oscillation (NAO), ENSO, etc., are also predictable, and can be used to estimate associated regional impacts.

ASSESSING SEASONAL PREDICTION VALUE. Successfully communicating uncertainty and the limitations of seasonal forecasts is critical for achieving seasonal forecast value. While decision makers should not omit seasonal forecast information, it should be recognized that users have difficulty in making explicit use of forecasts, especially when only maps are offered instead of data. In some cases, the best forecast may be climatology, so the availability of this and access to hindcast data is essential to help users in assessing model performance and the potential benefit of the forecasts. The resolution of data stored from global models is generally too coarse for many decision makers, and it should be noted that downscaling this coarse information requires great care.

SUMMARY COMMENTS. During the 1990s, seasonal prediction matured to achieve notable successes—in particular, reaching a high level of quality in predictions of SST and ENSO variability in the tropical Pacific. Model error and forecast initialization nonetheless continue to limit forecast quality, and the predictability limit has not been reached. For example, while multimodel techniques improve forecast quality, they are still far from being applied to their full potential. There may be untapped predictability due to interactions between the components of the total climate system that are not fully accounted for in seasonal forecasts. The CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP) will provide the coordination for the Climate-system Historical Forecast Project (CHFP[5]), a multimodel and multi-institutional experimental framework to evaluate subseasonal-to-decadal physical climate system prediction.

The effective communication of forecast skill, including forecast uncertainty, is crucial to evaluate progress in quality and to attain forecast value through its application. A common language needs to be developed for the assessment of forecast quality, establishing a process by which the seasonal prediction community can regularly evaluate progress in both forecast quality and value, of which the WCRP Seasonal Prediction Paper is the starting point.

It is clear that there are challenges that still face the community in terms of predicting land surface temperature and rainfall and in the use of seasonal prediction information for societal benefit, and thus in yielding forecast value. The use of seasonal prediction information is partially hampered by forecast quality that needs to be increased and the difficulty in successfully communicating uncertainty and the limitations of seasonal forecasts. The seasonal prediction community is also only in the early stages of interacting with the climate change community; indeed, the use of forecast information for societal benefit will ultimately know no boundaries between seasonal prediction and climate change.

ACKNOWLEDGMENTS. The authors would like to thank the participants of the WCRP Workshop on Seasonal Prediction for making the meeting a success and for their work in producing the WCRP Position Paper on Seasonal Prediction, of which this article is a summary. The organizers of the Workshop are also grateful for the generous support of its sponsors, allowing us, in particular, to support the attendance of young scientists from all over the world. The Workshop was hosted by the Servei Meteorològic de Catalunya. It was also co-sponsored by the World Climate Research Programme, the Climate Information and Prediction Services Project of the WMO World Climate Programme, the European Science Foundation, the Spanish Ministry of Science, the School of Physics of the University of Barcelona, the Catalan Water Agency, U.S. CLIVAR, the U.S. National Science Foundation, NASA, and NOAA.

[5] www.clivar.org/organization/wgsip/chfp/chfp.php