IMPROVING AND PROMOTING SUBSEASONAL TO SEASONAL PREDICTION

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There is growing interest in the scientific, operational, and applications communities in developing forecasts that fill the gap between medium-range weather forecasts (up to 2 weeks) and long-range or seasonal ones (3–6 months). A new World Weather Research Programme/World Climate Research Programme (WWRP/WCRP initiative on subseasonal to seasonal (S2S) prediction has recently been launched to foster collaboration and research in the weather and climate communities, with the goals of improving forecast skill and physical understanding, promoting forecast uptake by operational centers, and exploitation by the applications community. A key component of the project is to create an archive of S2S operational forecasts from EPSs (see Table 1 for project and model acronyms) that will become available in 2015. The meeting was the first scientific conference organized by the World Meteorological Organization (WMO)'s S2S steering group and U.S. THORPEX members, and it aimed to bring together the research and applications communities with operational centers interested in S2S prediction.

INTERNATIONAL CONFERENCE ON SUBSEASONAL TO SEASONAL PREDICTION

WHAT: More than 150 scientists from 16 countries met to review and discuss the status and prospects for subseasonal to seasonal (S2S) prediction.
WHEN: 10–13 February 2014
WHERE: College Park, Maryland

The conference clearly indicated the growing interest of subseasonal predictions. Although currently most of the focus is on the 15–30-day window, when skill is detectable in a number of subseasonal forecast systems, it was shown that specific phenomena [such as the Madden–Julian oscillation (MJO) or certain flow regimes] have the potential for skillful prediction 40–50 days in advance. The conference, which was held at the National Oceanic and Atmospheric Administration (NOAA)'s Center for Weather and Climate Prediction, was organized into five themes briefly summarized below, with 6 invited talks, 60 oral contributed talks, and 80 posters. Unfortunately, the discussion sessions had to be cancelled due to a major snowstorm, which was nonetheless well forecasted by the National Centers for Environmental Prediction (NCEP) GFS system several days in advance, allowing the program to be reorganized albeit at rather short notice! The conference web page (www.emc.ncep.noaa.gov/gmb/ens/s2s/) is archived at NCEP, where most of the presentations can be accessed.

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Introductory comments by representatives of U.S. agencies emphasized the importance of the weather–climate linkage, which S2S forecasts target, addressing the challenge of "end to end" forecasts for operations, applications, and climate services, and the efficacy of multimodel ensemble efforts and databases to foster collaborations internationally and between operational centers and academia. The introductory talks showed that S2S prediction is integral to several initiatives in the United States, including the NMME seasonal forecast project funded by NOAA. The second phase of NMME will start soon and will include ensembles of subseasonal forecasts. There are also efforts underway in the United States to enhance collaboration between agencies [the U.S. Navy, NOAA, the National Aeronautics and Space Administration (NASA), the National Science Foundation] to develop and implement improved Earth system predictions on time scales from a few days to weeks, months, seasons, and beyond.

Table 1. Project and model acronyms.

ABOM1	Australian Bureau of Meteorology Coupled Model, version 1
ABOM2	Australian Bureau of Meteorology Coupled Model, version 2
ACMAD	African Center of Meteorological Application for Development
AGRHYMET	Centre Regional de Formation et d'Application en Agrométéorologie et Hydrologie Opérationnelle
CFSv1	Climate Forecast System, version 1
CFSv2	Climate Forecast System, version 2
CHFP	Climate Historical Forecast Project
CMCC	Centro Euro-Mediterraneo per I Cambiamenti Climatici
DYNAMO	Dynamics of the MJO
ECMWF	European Centre for Medium-Range Weather Forecasts
EPS	Ensemble Prediction System
EUROSIP	European Seasonal to Interannual Prediction
FIM	Flow-Following Finite-Volume Icosahedral Model
GFS	Global Forecast System
HYCOM	Hybrid Coordinate Ocean Model
ISHVE	Intraseasonal Variability Hindcast Experiment
JMAC	Japan Meteorological Agency (JMA) Coupled Model
NMME	North American Multimodel Ensemble
POAMA	Predictive Ocean Atmosphere Model for Australia
SNUC	Seoul National University (SNU) Coupled Model
SVSLRF	Standardized Verification System for Long-Range Forecasts
THORPEX	The Observing System Research and Predictability Experiment
TIGGE	THORPEX Interactive Grand Global Ensemble

PREDICTABILITY AND RELEVANT PHENOMENA FOR S2S PREDICTION. The contributions in this session provided grounds for optimism that the skill of S2S forecasts can be substantially increased but many modeling challenges remain. The MJO is the most important source of skill on the subseasonal time scale, at least in the tropics, and was the topic of several presentations. Some models evaluated within the recent ISHVE show predictive skill up to 20–30 days and potential predictability between 31 and 45 days (Fig. 1). Thus, while MJO forecast skill has increased considerably over the last decade, there is room for further improvement. Most models have too little ensemble spread, resulting in overconfidence in forecasts. Tuning the rate of entrainment and mixing detrainment for deep and midlevel convection was shown to improve the representation of the MJO in one model, especially in terms of its propagation over the Maritime Continent (region of Southeast Asia that comprises, among other countries, Indonesia, the Philippines, and Papua New Guinea), though with undesirable side effects. Very high-horizontal-resolution experiments performed as part of the Minerva Project, which is a seamless high-resolution climate prediction system, did not improve the propagation of the MJO, although the amplitude and spread of the MJO forecasts increased significantly when the model's horizontal resolution is increased from T319 to T639 (about 64–32-km grid size), and remain constant from T639 to T1279 (about 32–16 km). Stochastic physics in the ECMWF System 4 model also enhanced the amplitude of the MJO. Problems with the propagation of the MJO over the Maritime Continent were an issue shared by many models during the DYNAMO experiment, while the impact of ocean coupling on the forecast skill was high during one MJO case, it was insignificant in another.

Sudden stratospheric warmings (SSWs) are another source of predictability in the S2S range. The

Stratospheric Network for the Assessment of Predictability (SNAP) has started an intercomparison to assess the predictive skill up to 20 days for 10 sudden stratospheric warmings. The SSW on 7 January 2013 was presented as a case study; models were able to predict it at a 10-day lead but not at 20 days. However, even with a 0-day lead, only one out of three models could sustain the vortex. Two speakers discussed the role of land initial conditions and land–atmosphere coupling for S2S prediction; both concluding that land–atmosphere coupling was not well simulated (e.g., due to biases in root depth of vegetation represented in land surface models), which may reduce S2S prediction skill.

The Arctic Oscillation (AO) was discussed in two talks, the first showing high seasonal prediction skill for the winter AO yet paradoxically a very low signal-to-noise (*S*/*N*) ratio, with an indication that atmospheric initial conditions may play an important role, even at the seasonal time scale. This represents an example of the S2S unifying concept because the usual distinction between the importance of atmospheric initial conditions for subseasonal scales and boundary conditions for the seasonal scale does not seem to apply. The second talk showed that negative-phase events of the Arctic Oscillation (or North Atlantic Oscillation) are an opportunity for subseasonal forecasting.

Important sources of S2S predictability include both El Niño–Southern Oscillation (ENSO) and the MJO, and an empirical coupled linear inverse model was shown to isolate well their respective contributions to the model's skill, which was demonstrated to be similar to that of a full global climate model (GCM). Thus, empirical models are important not only as benchmarks for EPSs, but also as tools to better understand the sources of S2S predictability. Such models may also help to identify, in advance, windows of opportunity with higher forecast skill where multiple mechanisms interact constructively.

PREDICTION OF EXTREMES. Extremes are an area of common interest to the climate, weather, and user communities, for both climate attribution and developing real-time early warning capability. The extremely warm March of 2012 in the United States was used as an example to show how conditional

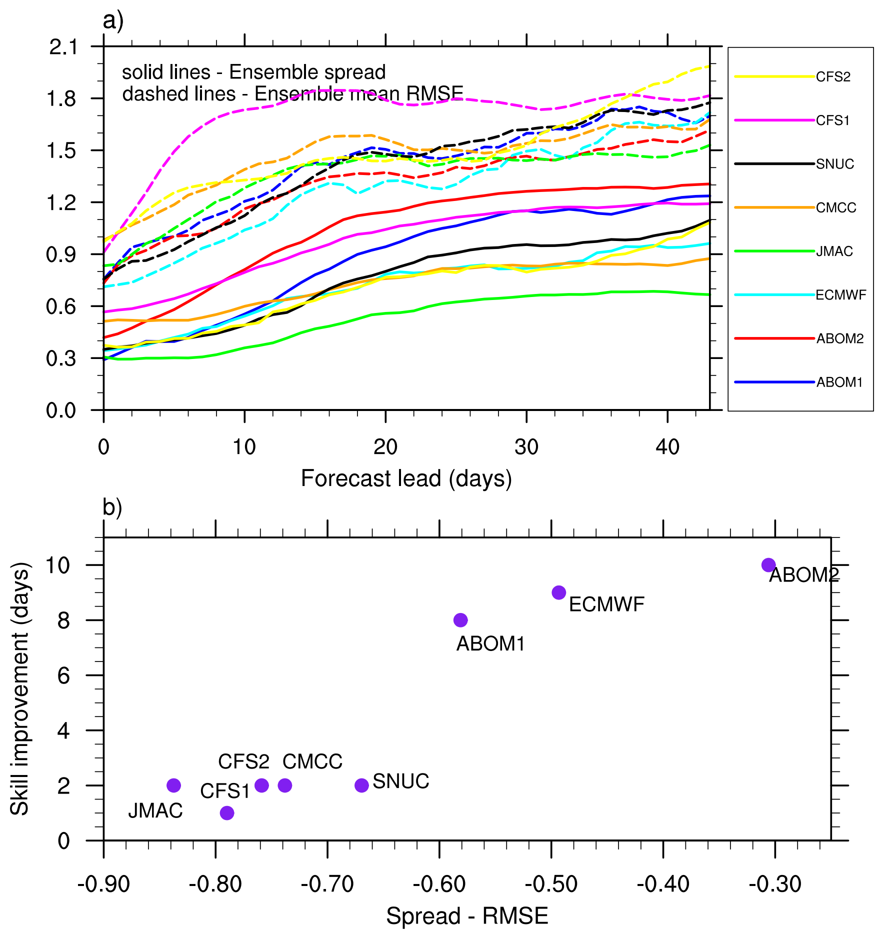

Fig. 1. Together, the two panels show how the fidelity of the ensemble spread relates to the improvement it provides to an MJO prediction system (see Table 1 for model acronyms). (a) The ensemble spread (solid lines) and the ensemble-mean root-mean-square error (RMSE; dashed lines) of the MJO in hindcasts produced by eight EPSs. Note that in a statistically consistent ensemble, the RMS forecast error of the ensemble mean (dashed lines) should match the ensemble spread (solid lines), and thus the systems with lower values of the spread compared to their mean RMSE indicate underdispersion of the EPSs for the MJO. (b) Scatterplot showing the improvement in skill (in days of lead time) provided by the EPSs over single deterministic forecasts from the same system on the *y* axis and the ensemble spread minus ensemble-mean RMSE computed from (a) on the *x* axis. [From Mani et al. 2014.]

information on different time scales enters into the prediction problem. The probability for exceptional warmth evolved dynamically as different phenomena became predictable across time scales from climate [Pacific decadal oscillation (PDO) and ENSO)] to the MJO and weather, necessitating a seamless approach. Over Australia, it was found that increased skill of the POAMA S2S coupled model to predict extreme heat over northern Australia came mainly from La Niña periods and over eastern and southeastern Australia from El Niño, highlighting the impact of ENSO even for subseasonal forecasts. Blocking diagnosis and the use of daily circulation regimes in forecasts and observations were discussed in several talks as important for understanding S2S predictability of weather extremes in the midlatitudes through tropical–extratropical teleconnections, as well as flow-dependent predictability. The ECMWF system exhibits flow-dependent predictability over the Euro-Atlantic sector with some skill up to 15–21 days. Prediction systems with demonstrated skill can help diagnose causes for extreme events with implications for climate change attribution. Initialized predictions of global hurricane activity by the Geophysical Fluid Dynamics Laboratory (GFDL) model was found to have skill on regional scales comparable to the skill on basinwide scales, suggesting that regional seasonal tropical cyclone (TC) predictions may be a feasible target.

INITIALIZATION AND PERTURBATION METHODS AND DESIGN OF FORECAST SYSTEMS. Several innovations in initialization methods and forecast system design were presented. The recently upgraded ensemble generation scheme of the Australian Bureau of Meteorology, used in POAMA, is based on a coupled breeding approach and produces an ensemble of perturbed atmosphere and ocean initial states. The resulting improvement in forecast performance is primarily reflected in improved reliability in the first month of the forecasts, but there is also higher skill in predicting important drivers of intraseasonal climate variability, namely, the MJO and the southern annular mode. The NCEP EPS (CFSv2) exhibits extratropical skill dependence on the MJO. The impact of accurate snow initialization on subseasonal forecasts may also be important in the extratropics. Detectable effects were shown by swapping snow-cover conditions from early and late autumn; this is a bigger perturbation than is realistic, but it makes detecting signals with ordinary-sized ensembles easier.

The new coupled atmosphere–ocean model for seasonal and climate forecast applications at NOAA's Earth System Research Laboratory uses atmospheric (FIM) and oceanic (HYCOM) models on the same icosahedral grid, allowing the ocean and atmosphere to be coupled directly without requiring a flux coupler. Changes to the parameterizations that help reduce biases in cloud cover were discussed. The stochastic physics parameterization scheme used in the operational seasonal forecasts at ECMWF reduces the overly active tropical convection, improves the MJO statistics of the model in terms of frequency and amplitude, and leads to increased skill in ENSO forecasts, especially for the tropical western Pacific.

APPROACHES TO INTEGRATE S2S FORECASTS INTO APPLICATIONS. Weeks 3 and 4 are the new frontier for predictability research and the conference witnessed a broad range of efforts that are underway to operationalize aspects of S2S forecasts and to develop and demonstrate the potential value of applications-relevant information. S2S forecast information in the Climate Prediction Center (CPC) operational outlook includes the use of MJO indices, displayed in real time from various operational centers. The CPC issues a Global Tropics Hazards and Benefits Outlook that currently uses MJO indices as predictors (e.g., certain phases of the MJO are known to increase or decrease the risk of tropical cyclone activity over some basins), and there are plans to use the direct outputs of the NCEP subseasonal forecasts to produce these maps in the future. Global impacts of MJO phase on flood and wildfire occurrence were shown.

African stakeholders at national meteorological and hydrological services and regional climate centers (AGRHYMET, ACMAD, etc.) would benefit from extended range forecasts of subseasonal evolution of the rainy season. Following an assessment of the forecast skill for the timing of the onset of the rainy season, trial forecasts of onset (phrased in terms of tercile probabilities for the onset being before, around, and later than average) in West, East, and southern Africa have been developed. Another attractive target for user-oriented S2S forecasts is daily rainfall frequency, which in the tropics tends to be more spatially coherent than seasonal total rainfall and thus more potentially predictable, as well as being more directly relevant to rain-fed agriculture. In the midlatitudes, the weather regime formalism is being used by investment companies to quantify state-dependent predictability; weekly mean wind speeds do exhibit skill in EPSs over areas of Europe at lead times of 2 weeks or more. The potential stakeholders for S2S forecasts are broad and their breadth is certain to increase.

Verification is a critical component of making forecasts useful to applications, and seamless verification will be important on the S2S scale. For instance, the time windows for verifying short-range forecasts are not the same as for seasonal forecasts, and a time-averaging window equal to the forecast lead time has been suggested as a possible approach (e.g., weekly means to verify forecasts at day 7, and 2-week means for forecasts at day 14). There is a need to unify the verification methodology used for medium-range databases (TIGGE) and seasonal databases (CHFP, EUROSIP, WMO SVSLRF), and this is an area where the S2S project can play a role.

CLOSING REMARKS. A large number of relevant discussions took place during the poster sessions. The NMME project is launching an MJO intercomparison assessment of contributing numerical models. Likewise, the Minerva Project is currently being evaluated by the Center for Ocean–Land–Atmosphere Studies (COLA) in collaboration with European centers. The conference also permitted a face-to-face meeting of the S2S Steering Committee.

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