BAMS
Meeting Summary

Celebrating 10 Years of the Subseasonal to Seasonal Prediction Project and Looking to the Future

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Subseasonal variability;
Forecast verification/skill

WWRP/WCRP S2S Summit 2023

What: More than 190 scientists from 29 countries met to celebrate 10 years of the Subseasonal to Seasonal (S2S) Prediction project and look to the future of S2S prediction.

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Where: University of Reading, United Kingdom

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The conference clearly demonstrated the increasing interest and growth of the scientific community working on the development and application of subseasonal to seasonal prediction since the start of the World Weather Research Programme (WWRP)/World Climate Research Programme (WCRP) Subseasonal to Seasonal (S2S) Prediction project in 2013. The conference, which was held at the University of Reading (United Kingdom), was organized into three main themes as briefly summarized below, with 11 invited talks, 74 oral contributed talks, and 101 posters. The conference also included a 2-h breakout session, wherein eight groups discussed the current state and prospect for S2S prediction, and an early-career researcher event. A summary of these discussions and recommendations is presented below. The conference web page (https://research.reading.ac.uk/s2s-summit2023/) is archived at the University of Reading.

Introductory comments by representatives of the World Meteorological Organization (WMO) WWRP and WCRP emphasized the importance of the weather–climate linkage, targeted by S2S forecasts (from 2 weeks to a season ahead), addressing the challenges of creating "end-to-end" forecasts that encompass the entire climate-services chain from the prediction science and forecast to the development and issuing of forecast products tailored to informing user decisions. They also emphasized the efficacy of multimodel ensemble efforts and databases to foster collaborations internationally and between operational centers and academia. Although the WWRP/WCRP S2S project comes to an end in 2023, S2S prediction will remain an important focus for WWRP and WCRP. In WWRP, a new project called Subseasonal to Seasonal Predictions for Agriculture and Environment (SAGE) will start in 2024. Another important legacy of the S2S project will be the maintenance of the S2S database (Vitart et al. 2017) and the establishment of a WMO Lead Centre for Sub-Seasonal Prediction Multi-Model Ensemble (LC-SSPMME), which will provide real-time multimodel S2S climate information.

In two keynote presentations, Prof. Brian Hoskins (University of Reading) and Dr. Gilbert Brunet (Australian Bureau of Meteorology) discussed the potential of S2S predictability and the ongoing journey for understanding and improving these predictions.

This conference was a sequel to the International Conference on Subseasonal to Seasonal Prediction (Robertson et al. 2015), which took place in College Park, Maryland (United States), in February 2014 to celebrate the start of the WWRP/WCRP S2S project, and to WCRP and WWRP conferences in Boulder, Colorado (United States), in 2018 (Merryfield et al. 2020). A significant development compared to the previous S2S conferences was the large number of presentations on research to operations (R2O) and S2S applications and on the use of artificial intelligence and machine learning (AI/ML) methods for S2S prediction. Some of these methods provide empirical S2S forecasts which are competitive with state-of-the-art dynamical models. Other presentations demonstrated that AI/ML can provide alternative calibration of dynamical model outputs to traditional methods. Several talks and posters highlighted the increasing use of AI/ML, including deep learning, in S2S forecast postprocessing and using AI to identify higher flow-dependent skill. Finally, some presentations demonstrated the value of AI/ML methods for a better understanding of S2S sources of predictability and attribution of extreme events.

Predictability and processes

This theme was organized around particular sources of predictability such as the Madden–Julian oscillation (MJO), the stratosphere, and land surface processes. However, across those some common topics emerged. One such topic was the interaction between different drivers—for example, the modulation of MJO teleconnections over North America and the North Atlantic by El Niño–Southern Oscillation (ENSO) or over East Africa by the land surface, and stratospheric pathways for MJO teleconnections to the Northern Hemisphere extratropics. This topic (interaction between different drivers), which emerged in recent years, represents a major advance in our understanding of S2S predictability. Variability in the predictability or prediction skill on S2S time scales is often associated with strong drivers, such as the MJO or the influence of stratospheric anomalies. On the other hand, sources of S2S predictability can sometimes reduce the predictive skill. For instance, one presentation showed how MJO activity can reduce the predictive skill associated with predictability from the Southern Annular Mode. Also, one presentation discussed the interaction of the jet stream and weather systems on mesoscales to synoptic scales for the onset of extratropical weather regimes that might limit S2S predictability intrinsically. The role of stratosphere–troposphere coupling for S2S prediction skill was discussed, particularly in association with extreme events of the stratospheric polar vortex such as sudden stratospheric warming and stratospheric wave reflection events. Several presentations highlighted the role of equatorial waves for high-impact weather, in particular heavy precipitation, but also as a precursor for tropical cyclones. Taken together, these sources of predictability offer various windows of opportunity for tropospheric forecasting.

Modeling

Several operational centers presented their latest model updates. Most S2S data providers have considerably enhanced their models since the start of the S2S project in 2013. However, there was a clear difference of strategy between centers, with some investing in greatly increased horizontal resolution (e.g., U.S. Naval Research Laboratory), others on model complexity (e.g., NASA Global Modeling and Assimilation Office), and still others on larger ensemble size (e.g., European Centre for Medium-Range Weather Forecasts). All these strategies have advantages, but there is not yet consensus on which one provides the best path for improved S2S forecast skill. Several talks highlighted the benefit of improved representation of land processes. Results from the European Union (EU) Consistent Representation of Temporal Variations of Boundary Forcings in Reanalyses and Seasonal Forecasts (CONFESS) project showed the benefits of time-varying vegetation and time-varying aerosols (most S2S models use prescribed climatological vegetation and aerosols).

Another emerging area of research was the use of dynamical models with smaller domains, forced by global S2S forecasts to produce high-resolution regional S2S forecasts. Preliminary results suggest that this approach can help improve S2S prediction of local extreme events (e.g., intense convective winter events over the west coast of Saudi Arabia). Several talks focused on the role of model systematic errors on S2S prediction, including the negative impact of errors in the representation of climate trends on S2S prediction.

Research to operations

The topic of calibrating and tailoring S2S forecasts to create forecast products that can be relied on for early warning and action, as well as for climate-informed societal decision-making, is one that received increasing interest during the span of the S2S project. The conference featured four R2O oral sessions focused on S2S forecasting of extremes, forecast verification, calibration and postprocessing methods, and on the use of S2S forecasts as part of climate services, together with a large number of posters on these themes. The establishment of the designation of Global Producing Centres (GPCs) for Sub-Seasonal Prediction and the associated Lead Centre for Sub-Seasonal Prediction Multi-Model Ensemble, under WMO technical regulations (which includes forecast and verification products), was highlighted as an important R2O outcome of the S2S project. The concept of temporally compounding extremes was highlighted, in which the potential utility of an S2S forecast of one kind of extreme (e.g., of heatwaves) is increased in the aftermath of another type of extreme (e.g., Hurricane Laura's landfall over Louisiana in 2021). S2S advance warning of extreme ocean events, including marine heatwaves, was also highlighted. Over Africa, state-dependent rainfall forecast skill was illustrated as a pathway toward identifying windows of opportunity for actionable forecasts. A new approach to skill-weighted S2S multimodel combination was proposed, one that involves computing a Wasserstein barycentre of the forecast probability distributions from individual models. A session was dedicated to the recent surge in the use of S2S forecasts as part of user-oriented weather–climate services toward managing the increasing risks in today's rapidly changing climate. Several examples from the developing world including Africa and Southeast Asia were presented, but presentations also discussed atmospheric rivers impacting the U.S. West Coast and the pricing of insurance in the private sector in Nordic countries. Some of the examples discussed were part of the S2S real-time pilot project which provided real-time access to S2S forecasts to 16 application projects. A few examples have clearly demonstrated the potential value of S2S forecast information for applications.

S2S Summit Early Career Researcher event

During the week, an Early Career Researcher (ECR) event took place, at which three speakers were invited to give their perspectives based on their own experiences. The speakers were chosen to represent a diverse set of research pathways, geographical locations, and experiences. Dr. Donaldi Permana, who is coordinator of the Climate Research Division at the Indonesia Agency for Meteorology, Climatology, and Geophysics (BMKG), shared insights from combining operations with research. Dr Kieran Hunt, who is a

National Environmental Research Council (NERC) research fellow at the University of Reading, covered aspects of career development within academia. Finally, Ms. Patricia Nying'uro, who is a principal meteorologist at the Kenya Meteorology Department, shared insights from her career in operations, particularly on engaging in research and policy, including the IPCC process. The event brought together over 50 ECRs who were attending the S2S Summit. Short talks were followed by a lively discussion with questions on how to discern which activities to prioritize and commit time to, the value of having good mentors, and the art of saying no. Overall, it was a successful event that provided the crucial space for peer-to-peer learning and a chance for ECRs to build on and develop their own international collaborative partnerships.

Breakout discussions

In the breakout discussions, it was recognized that some of the main achievements of the WWRP/WCRP S2S project (S2S) include the following:

- Bringing together a varied geographical and multidisciplinary community of scientists, spanning a wide range of regions and subjects.
- Creating a functional S2S database: a great resource for research exploration on predictability and impacts.
- Advancing understanding of predictability drivers, teleconnections, and model deficiencies on different processes and areas.
- Quantifying current skill and detection of windows of opportunity.
- Capacity building and training in the science and application of S2S forecasts
- Establishing links with the impact community and promoting practices for the use of the S2S forecasts. Uptake was particularly good in tropical regions, where the quality of current forecasts is better and thus more useful.

Several important remaining challenges were highlighted. For S2S predictability research, it is important to continue working on S2S process understanding and improving models in order to get a predictive skill closer to the theoretical predictability limit. In particular, we still lack an understanding of why MJO extratropical teleconnections are too weak in models. New metrics, diagnostics, and coordinated experiments, and verification methods are needed for a better understanding of diabatic processes and waves associated with the MJO and its teleconnections (e.g., diabatic heating in the MJO, precipitation, wave breaking, and variations along the subtropical jet). These new approaches should better account for and quantify flow-dependent predictability and windows of S2S forecast opportunity. Some breakout groups highlighted the value of nudging experiments as a powerful tool to diagnose the sources of model errors. The role of the stratosphere (processes and windows of opportunity), including the impact of the quasi-biennial oscillation on S2S time scale, also needs more research. Enhanced diagnostics including explainable AI and large ensembles offer potential to detect model deficiencies and windows of opportunity and provide indicators of forecast confidence specific to the current large-scale situation. The rise of competitive data-driven AI/ML forecasting methods for numerical weather prediction was also discussed. Such methods could also be applied at S2S time scales, but further research is required to understand the pros and cons of such approaches, including the representation of forecast uncertainty, the challenges of training AI/ML models for longer lead times, and the representation of physical processes that are particularly relevant for S2S lead times (e.g., tropospheric/stratospheric teleconnections and air–sea interactions).

Regarding modeling and observation requirements, more research is needed to investigate the role of land, aerosols, ocean–sea ice, and the stratosphere, as well as the impact of model resolution on S2S prediction, to formulate requirements for model development. These need specific coordinated experimentation and databases. We also need to find connections between errors in forecasts and the initial conditions to inform observing system development, and we need to explore ML strategies for modeling, including hybrid strategies.

To improve research exploration on impact on S2S time scales, there is a need to systematically define windows of opportunity while considering the needs of risk management. This is especially important and promising for the prediction of compound events. However, some impact models may require more output variables than are currently available through the S2S database. A breakout group also mentioned that the successful use of S2S forecasts requires expert knowledge. Therefore, improved meteorological training and acknowledging the need for daily interpretation by experts might advance the wider use of S2S forecasts.

There was a strong interest in maintaining and expanding the S2S database (e.g., more land and ocean variables, more stratospheric levels, vertically integrated atmospheric variables) for process diagnostics. Some breakout groups recommended the use of cloud computing facilities with basic toolboxes to access the S2S data and perform some basic postprocessing. This would avoid large-volume data transfers. There were several requests, mainly from the S2S real-time pilot projects, for real-time access to S2S data. Now that the real-time pilot initiative, which provided real-time access to 16 application projects, has ended, several projects in Africa would like to continue having access to these data but are prevented because of the 3-week delay in the S2S database and some bureaucratic barriers in Africa that prevent the purchasing of data in real time. The establishment of the LC-SSPMME will help overcome these barriers by providing free access to real-time forecasts from several operational centers. Some participants expressed the need for some managed cloud computing infrastructure to share data from coordinated experiments and to share diagnostics tools.

Closing remarks

A large number of useful discussions took place during the poster sessions and separate face-to-face meetings, including one for the S2S Steering Committee. This conference highlighted the progress in S2S prediction over the last 10 years. The S2S database and international coordination of S2S activities under WMO will continue under the new SAGE WWRP project. The establishment of a WMO Lead Centre for Sub-Seasonal Prediction Multi-Model Ensemble will be a major step toward real-time access to S2S climate information.

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