Improving Sub-seasonal to Seasonal Precipitation Forecasting Workshop
San Diego, California
May 7-9, 2025

Workshop Summary

On May 7-9, the WSWC and California Department of Water Resources (CDWR) co-hosted a workshop on Improving Subseasonal to Seasonal (S2S) Precipitation Forecasting. Tony Willardson, WSWC, and Jeanine Jones, CDWR, kicked off the meeting with opening remarks and provided the background for the annual workshop over the past ten years.

Jeanine Jones talked about S2S Coalition activities, Congressional appropriations, and Weather Act reauthorization. She highlighted the "Godzilla El Nino" of 2016 and water year 2023 as examples of poor forecasting. She stressed the importance of lead time in water management application such as forecast informed reservoir operations (FIRO). She talked about congressional efforts to include S2S in the original Weather Research and Forecasting Innovation Act. The 2020 NOAA report to Congress recommended pilot projects such as arctic sea ice, hurricanes, and precipitation forecasting for agriculture and water management. The reauthorization bill in the House included pilot projects, but it stalled in the Senate. She said the formation of the S2S Forecasting Coalition, supported by lobbying resources, has been crucial in advancing the cause. She noted the lack of NOAA implementation of the 2020 report and the need for new funding for research on S2S. The current fiscal year (FY 25) has seen significant staffing cuts in NOAA, affecting the Weather Service and research side. She highlighted concerns about the potential elimination of the Office of Atmospheric Research (OAR) within NOAA. She also discussed the impact of staffing shortages on regional river forecast centers (RFCs), with specific examples of high vacancy rates and operational challenges. She outlined the current federal budget cycle, with the President's budget proposal and large proposed cuts in research. The potential elimination of the Office of Atmospheric Research (OAR) within NOAA is a significant threat to S2S efforts. There is a possibility of state involvement in California for taking over some RFC products. She discussed the limitations of private sector forecasting, which typically repackages National Weather Service information, but can’t make the business case for investing in the research needed for improving S2S forecasting. There is growing interest in AI and machine learning in forecasting, but there are challenges in applying these technologies to Western precipitation forecasting.

Amanda Sheffield from the National Integrated Drought Information System (NIDIS) presented on NIDIS S2S activities. She provided an overview of the National Drought Mitigation Center (NDMC) and its role in drought monitoring, forecasting, and planning. She highlighted the development of new drought forecast products, including probabilistic outlooks. Collaboration with the National Water Center and other federal agencies improves NIDIS drought products.

Mike DeFlorio of UC San Diego followed with a virtual review of Scripps Subseasonal Forecasts for WY 2024. The Center for Western Weather and Water Extremes (CW3) at Scripps Institution of Oceanography prepares experimental subseasonal forecasts atmospheric rivers and extreme precipitation. He explained how the Subseasonal and Seasonal Advisory Panel vets forecast products and highlighted their use during WY 2022-2023, including the California historic winter storms. Atmospheric rivers have a significant role in reversing multi-year drought conditions. He emphasized the importance of regime shifts in forecasting and the challenges of predicting the duration of wet or dry conditions. He mentioned development of new forecast products, including hybrid statistical-dynamical forecasts for Santa Ana winds, and new prediction systems, including machine learning models. He talked about the lack of prediction skill of ENSO on precipitation in western areas, and the need to consider other predictor fields, such as deep tropical convection and Pacific SST patterns. He talked about the concept of "forecasts of opportunity" for periods when forecast skill is enhanced. He reiterated the need for continued research and collaboration to improve the skill of seasonal forecasts. Workshop participants discussed the challenges of communicating the degree of confidence in the skill of S2S forecasts to users, which can vary. There was some discussion about the technical jargon and developing simplified materials to show water managers the updates to long-term aggregate skills in a meaningful way.

Jiabao Wang from UCSD discussed investigating potential S2S predictability from the Madden-Julian Oscillation (MJO) in the Pacific. The MJO is a unique convection circulation system with a 30-60 day life cycle, making it useful for S2S predictions. It has significant impacts on global climate patterns and modulating precipitation extremes. She discussed the spatial distribution of the MJO for different phases, highlighting the intensity of convection in various regions, and demonstrating the impact of MJO on ARs and recent weather conditions in CA. MJO prediction skills have improved over the past decade, with current models suggesting a potential lead time of 5-7 weeks. Workshop participants discussed the differences between fully coupled and partially coupled models, and the complexity of the relationship between MJO activity and drought conditions. The potential benefits of a similar study for the Colorado River Basin were discussed.

Rosy Luna Nino, UCSD, presented on the ways that Atmospheric Rivers (ARs) act as disruptors or amplifiers of expected ENSO precipitation anomalies. She noted that the western US experiences high interannual precipitation variability compared to the east. California experiences the greatest variability, where a few large storms (mostly ARs) cause yearly fluctuations of about half of the average annual total. She studied the influence of ENSO and ARs during water years that brought opposite precipitation anomalies from the expected canonical ENSO signal, and found that ARs introduce wild cards for seasonal precipitation prediction. The highest correlations of ENSO and AR precipitation are found over the Sonoran, Arizona, and New Mexico deserts. These regions are highly dependent on the landfalling ARs in Baja California that penetrate into the interior Southwest and are somewhat reliably synchronized with contemporaneous ENSO activity. A new S2S prediction framework needs to be developed to merge seasonal Pacific SST conditions with subseasonal information related to ARs.

Kevin He, CDWR, presented on machine learning to improve evapotranspiration forecasts, as well as a new approach to ET forecasting using deep learning and multi-model ensembles. He discussed the potential benefits of improving ET accuracy for water management, drought prediction, and crop productivity. He presented two case studies. The first analyzed the accuracy, complexity, and data efficiency of reference ET for forecasting at one, three, and six months. The deep learning models handled large data input and were able to outperform the simpler statistical models. The second case study developed a globally-learned deep learning model to forecast monthly reference ET for up to one year in Central Valley, California. They used data from 55 CIMIS stations around the Central Valley, with more than six consecutive years of data. They used 47 stations and the training set, and 8 stations as the test set. They found that the globally trained deep learning models had a smaller bias.

Cenlin He, National Center for Atmospheric Research (NCAR), presented on S2S predictability as the first focus area of NCAR's Earth System Predictability Across Timescales (ESPAT) Initiative. There is an urgent need to accelerate research in earth system predictability and develop tools for community resilience. He outlined three major challenges: understanding interactions across Earth system components, scale interactions from short- to long-term projections, and Earth system variability. He talked about integrating physics-based modeling, data simulation, and machine learning and AI techniques to develop a convergent research framework. They are collecting information from the community, integrating and leveraging existing programs, and building dedicated community working groups to accelerate progress. S2S research priorities include land-atmosphere interaction, ocean-atmosphere interaction, model resolution analysis, data assimilation, tropical interactions, and convection representation. He talked about the impact of soil moisture feedback on S2S predictions, post-wildfire streamflow in watersheds, and changes in the water-energy nexus. In response to an audience question he replied that ESPAT was not connected to NOAA's proposed Precipitation Prediction Grand Challenge (PPCG) effort.

Alex Weixel, House Committee on Science, Space, and Technology, discussed the Weather Act Reauthorization Act from the 118th Congress. The bill passed the House with 394 votes but was not taken up by the Senate and did not become law. Plans are underway to reintroduce it. The comprehensive package includes NIDIS, weather forecasting modernization, and addressing aging observing system infrastructure. He emphasized that this is a bipartisan issue, as weather disasters affect everyone. He discussed the legislative strategy of members introducing individual bills that can then be packaged together. Jordan Smith, Van Ness Feldman, followed up with a congressional outlook and recent S2S lobbying efforts, including both authorization and appropriations. He noted that there is bipartisan support in both chambers and language supporting pilot projects for S2S forecasting improvements. He specifically called out Senator Jacky Rosen's (D-NV) bill, the Smarter Weather Forecasting for Water Management, Farming, and Ranching Act (S.324), which directed NOAA to establish an S2S pilot project for the western United States in the prior Congress. He noted that with the current Administration, the focus may shift to the cost savings of having better predictions. Participants discussed the importance of stakeholder support for Weather Act reauthorization, particularly from industry and agriculture, including anecdotes and direct links between reliable forecasting and business practices. Improving forecasting so farmers can make decisions six months out is significant, and there is often a disconnect between the forecast developers and the end users of forecast products that needs improvement as well. They also discussed the need for outreach and education to new members of Congress and their staff.

Emerson LaJoie, NWS Climate Prediction Center (CPC), noted that the CPC is going to be absorbed by the Weather Prediction Center sometime this summer. She provided a review of the extended and seasonal winter outlooks (both experimental and operational) and the experimental regime change prognostic tool. She discussed the extended forecast system and its adaptation of the operational sequential dynamic model suite. She showed a comparison of observed anomalies to model performance, which indicated mixed results across the US. She noted that forecasts in some distinct regions become more skillful depending on the lag times and modes selected. She said the new tools they have been developing are enabling optimization for any region, potentially engaging more Midwest stakeholders on pilot projects proposed in the 2020 NOAA report. She provided case studies with histograms where indications of abrupt, extreme changes in temperature or precipitation patterns may become visible more than two weeks out.

Mark Olsen, OAR WPO provided a virtual update on OAR Weather Prediction Office activities. Their primary goals are improving S2S model skill, improving precipitation and drought hydrology, with significant efforts on model improvements and data assimilation. He talked about the PPCG and its multi-faceted approach, aiming to improve forecasts of precipitation extremes across time scales, leveraging AI and strengthening observations. Ongoing activities include addressing model errors and improving operational data assimilation. The goal is to provide actionable information for decision-makers, including improved products and applications. He discussed the Water in the West program, a congressional add-on. Activities include developing nested global research prototype domains and regional AR forecast systems. Collaborative work includes improving snowpack predictions and hydrologic modeling. He provided an update on the development of the Seasonal Forecast System (SFS), designed to replace the long-outdated climate forecast system model, addressing common errors such as MJO propagation and temperature forecasts. The system is being designed as a fully coupled system, including atmosphere, aerosol, land, ocean, and sea ice modules.

Gudrun Magnusdottir, UC Irvine, discussed recent work on the challenges of predicting North Pacific (NPAC) wind anomalies and their impact on seasonal forecasts. Winter 2016-17 was marked by significant precipitation and highlighted model limitations, particularly in capturing zonal wave trains. Tropical variability impacts the initial conditions of the wave train. She showed heat maps to visualize how well forecast models correlated to observations over time. Models like ECMWF and NVIDIA showed improved skill, with NVIDIA's huge ensemble model outperforming traditional models. The analysis revealed higher skill in winter months, especially February and March, with ECWMF generally performing best. AI models exhibited less bias and better ensemble generation, enhancing predictability and demonstrating the ability to generate large ensembles quickly and inexpensively. She noted the intriguing changes to MJO predictability over different periods: the 1980-1998 period shows less predictable mean wet periods compared to the 1999-2015 period. Participants discussed the need for further research into long-term changes in MJO predictability and the implications.

Maria Janeth Molina, University of Maryland, explained her research on using large-scale weather patterns, or weather regimes, to improve predictions at S2S lead times. She noted the skill of current models in predicting temperature and precipitation, particularly for lead times of five to six weeks. Her team used machine learning and 500 hectopascal geopotential height anomaly fields to identify North American weather regimes, including the West Coast High, Pacific Trough (associated with ENSO), Alaskan Ridge, and Greenland High. They found that, unlike the typical increase in forecast uncertainty over time, ensemble results were realigning around four weeks out. This suggests a potential for improved prediction skill during certain periods. She noted that assessing weather skill is complex as it varies by atmospheric, land, and ocean influences, as well as by season, with the highest skill typically seen in Fall and Winter. One concerning signal related to climate trends is the increase in the Pacific Trough frequency and location, with implications for the Western US. They also used self-organizing maps (SOMs) to characterize weather regime diversity, using a hexagonal topology to avoid four-corner biases.

Lisa Bengtsson, NOAA OAR Physical Sciences Laboratory (PSL), presented on improving NOAA's Unified Forecasting System (UFS) Model. She explained the components of the UFS, which is a system of models for atmosphere, ocean, land, etc., with a common community physics package and coupling improvements. She highlighted the importance of tropical processes, particularly MJO, as a key driver for predictive skill in mid-latitude forecasts. The lab used the ECMWF convection scheme in the NOAA Global Forecast System (GFS). The experiment showed enhanced tropical variability and improved coherence with precipitation. She noted long-standing issues in weather and climate prediction regarding propagation and organization of convection. She explained that this is partly because of how convection is parameterized. She introduced a prognostic equation for the convection closure, incorporating moisture flux convergence, and its impact on MJO phase diagrams. Lisa provided an overview of the seasonal forecast system (SFS), which is currently being developed under the UFS infrastructure. They aim to launch operational implementation in 2028.

Bo Svoma, Salt River Project, highlighted central Arizona's high elevations, which represent the first major mountain barrier after the coastal range of Southern California. The Salt and Verde Rivers are the single largest providers of water to the Phoenix metropolitan area. The Verde River is characterized more by rainfall and flashy runoff, while the Salt River is influenced more by runoff from high elevation land and stable winter snowpack. Managing reservoirs presents challenges, including the need to release water during wet winters to prevent spillage. Arizona has two wet seasons, the summer monsoon (which is not a significant contributor to stream flow) and the winter season. Statistical models indicate that Salt-Verde stream flow is relatively insensitive to warming in these rivers compared to the Colorado River (with a 1-2% decrease per degree Celsius of warming), making winter precipitation a very important indicator. Svoma presented findings that the Pacific Ocean contributes significantly to winter precipitation, but the sources of moisture from the Pacific Ocean are surprisingly variable. Without a clear predictable source from the Pacific, the climate predictions are too uncertain for making long-term decisions about water management. Some models predict more and some less precipitation, indicating a need for improved forecasting skill at S2S lead times.

Andy Hoell, NOAA OAR PSL, focused on flash droughts in the Great Plains, noting their rapid onset and severe impacts, particularly for agriculture, livestock, and wildfires. He explained that flash droughts are compound weather events involving low precipitation, extreme warm temperatures, atmospheric circulation, land-atmosphere interactions, soil moisture, and increased evapotranspiration. These factors converge over several weeks and lead to a rapid intensification of drought. He distinguished them from abnormally dry periods, which may last several weeks without the same intensity of impact. The community is interested in flash drought warnings and how water users respond to them. Contributing causes differ across different regions, such as the Great Plains and the far West. He noted the lack of standardized metrics for flash droughts, partly because they haven't been common enough to generalize their behavior. He showed Northern Great Plains 2017 precipitation anomalies in the ECMWF relative to the record going back to 1982, and showed different forecasting models they studied to try to understand what might have predicted the drought at three to four weeks lead time. The GEOSS model was the only one that forecasted any sort of drought, and forecasters would not have relied on that with any confidence. He emphasized the importance of investing in better tools, and going back to revisit the data from flash droughts with new models.

Isabella Velicogna, UC Irvine presented on a recent UC-funded project for NMME Fusion aimed at improving S2S forecasting through a transdisciplinary approach, involving experts in remote sensing, modeling, AI, and social sciences. They are developing a user-driven approach to improve S2S forecasting, tailoring it to local and end-user needs. They are building a global model that can be repurposed for regional scales and using a benchmark to test skill. They are also using a machine learning model trained on smaller datasets, that integrates physical modeling, observational data, temporal relationships, and time-dependent variables. She explained the challenges of reducing cumulative error during autoregressive rollout forecasts, and the potential of creating an ensemble forecast by predicting multiple trajectories. The project also involves ensuring the scalability of the models and the ability to handle large datasets for real-time forecasting. The model prediction is based on events that occurred 30 hours, 24 hours, and 18 hours ago, with each point on the global map indicating model attention to specific locations. The research team plans to study regional anomalies and look for target opportunities, working within computational and cost limitations.

Candice Hasenyager, Utah Division of Water Resources, discussed Utah's water management needs and potential S2S applications, emphasizing the critical role of snowpack and spring runoff in supplying 95% of the State's water. The typical wet season is October to May, but peak snow accumulation has shifted to occur earlier in March or April. This shift affects stream flow, soil moisture, reservoir operations, and irrigation water for agriculture. The State uses data from the NRCS snow surveys, SNOTEL, and NWS River Forecast Centers to help guide reservoir operations. Drought management is crucial, with a recent drought declaration affecting 17 out of 29 counties. She touched on the challenges of forecasting with Utah's mountains, the lack of accounting for the effects of dust on snow, and the need for better data and models to inform water management decisions. The Great Salt Lake's water levels are influenced by snowpack and runoff, and she talked about recent efforts to conserve water and reduce evaporation. She noted that there is hesitation to release reservoir water that could flow to the Great Salt Lake due to uncertainty about whether upcoming seasonal precipitation will be sufficient to refill the reservoirs. Participants discussed the current sources of forecasting data that are available to water managers, and the high degree of uncertainty for decision making, especially when it comes to anticipating future precipitation.

Matthew Sittel, Kansas State University presented on the importance of summer precipitation to meet agriculture needs, and focused on the current tools available to support decision making. He talked about the Kansas Mesonet established in 1985, which has 91 stations measuring temperature, humidity, wind speed, solar radiation, and precipitation. They also have a robust citizen-based observer program that expands the network in data-scarce areas. He highlighted the importance of soil moisture data, including at different depths, and the significant impacts of heat waves and precipitation events on crops and cattle. He proposed a multi-factor agricultural index to integrate various environmental factors affecting crop growth. The index would help farmers anticipate and mitigate risks, with early warnings of heat waves and droughts. Participants discussed the challenges of implementing such an index and the need for better communication and education among farmers. They also discussed NOAA's announcement that they plan to stop producing their million-dollar disasters report, which in the past has highlighted significant disasters like drought and their impacts on agriculture. These reports have provided valuable justification for funding to improve forecasting and support agriculture.

Cary Talbot, USACE ERDC, provided an update on the forecast-informed reservoir operations (FIRO) pilot project at Lake Mendocino, noting that the updated water control manual is expected to be finalized soon. He talked about the Yuba Water Agency's new spillway, called the ARC spillway, designed to control water release ahead of atmospheric rivers. A May 2016 update to the USACE's regulations, first used for Folsom Dam in California, allowed for planning future operations based on forecasted conditions, opening the door for more flexible water management. Congress mandated the incorporation of FIRO into water control manuals in the 2024 Water Resources Development Act. The U.S. Army Corps of Engineers (USACE) is engaging in a screening process to determine which water control manuals can incorporate FIRO, focusing on forecast skill improvements. The screening process involves three stages: an initial survey, a detailed evaluation, and stakeholder engagement. Forecast skill varies widely across the country, with the West Coast enjoying the best forecast skill, followed by New England. The screening process aims to identify which dams would benefit most from FIRO implementation, considering both forecast skill and other operational factors. The screening process ensures that dams are assessed for FIRO suitability. The process includes a FIRO suitability index, which evaluates the effort-to-benefit ratio and forecast skill. The goal is to update water control manuals to incorporate FIRO, improving water management efficiency and flexibility. He highlighted an interactive map of federal and Section 7 reservoirs that are considered viable for FIRO, which is expected to be live within the year.

Nelun Fernando, Texas Water Development Board (TWDB), discussed a precipitation forecasting initiative to support FIRO in Texas in the Little River Watershed of the Brazos River Basin. Texas is considered a forecast desert region, and there are significant risks to using forecasts for water management. The initiative is a collaboration with state and federal partners, working to improve drought and flood predictability and bridge gaps between forecasters and reservoir operators. Preliminary results show some potential for forecast improvements, but significant challenges remain, including the need for higher resolution forecasts. They are exploring the use of higher resolution forecast systems, such as the HRRR and NAM. Some post-processing methods have yielded marginal improvements. Ensemble forecasts are important for improving the reliability of streamflow forecasts. They are developing a prototype to automate the parameter search and modify the reservoir operation model to incorporate ensemble forecasts.

Erin Towler, NOAA OAR PSL, presented on a recent project using weather types in forecasting, distinguishing them from weather regimes. Weather types, which are more commonly used in Europe, have a larger number of patterns, are less persistent, vary on shorter time scales, and are defined on smaller domains. Weather types are used in an operational multi-model ensemble tool that blends different models and offers predictions 45 days out. They developed a set of year-round weather types to be precipitation-relevant, and looked at how well forecast products predicted the seasonal frequency of the weather types, looking at large scale patterns and precipitation anomalies. They looked at retrospective forecasts over 27 years using an ensemble average. Seasonal forecast products can reproduce dominant weather patterns, and can capture frequency on average, but they struggle with year-to-year variability. Generally, ECMWF tended to do better at average pattern correlations, and the large-scale predictors are captured better than precipitation. They also looked at whether the skill improves with weather types developed for smaller geographic domains or sub-seasons, but found that the improved performance over the CONUS weather types wasn’t statistically significant.

Mike Anderson, CDWR, discussed the CDWR Roadmap to Seasonal Forecasting. He noted the variability in California's historical precipitation onset, with October in the north and November or February in the south. He highlighted the importance of temperature anomalies and soil moisture in predicting snowfall, and the impact of atmospheric rivers on annual precipitation. The variability in snowpack timing and magnitude is attributed to both natural variability and climate change. He explained the shift in water management strategies due to increased frequency of extreme events. Tropical systems influence precipitation patterns in the southern part of the state. He provided a visual comparison of historical and current climate normals, with an increasing range of outcomes and more time under extreme conditions. He discussed the need for new predictive models and the limitations of traditional water management rules. He addressed challenges in obtaining accurate and up-to-date ground-based measurements necessary for model inputs, the role of partnerships with various organizations and federal agencies in expanding observation and data collection, and the impact of federal staffing shortages. CDWR launched a new website several years ago, California Water Watch, to provide Californians with easy access to real-time information on local and statewide water conditions, including local hydrological conditions, forecasts, and water conditions down to the user's address or watershed. The website also allows users to compare data on local conditions by year and by region.

Wei Zhang, Utah State University, shared recent work using weather regimes to improve S2S forecasting. He discussed the identification of synoptic patterns and their impact on precipitation in the Midwest and Western US. They have seen significant decreasing trends in precipitation due to changes in weather patterns. He addressed the challenges of assigning forecast maps to weather regimes and talked about the development of a Gaussian mixture model to combine weather regimes in a probabilistic way. He shared the results of testing the methodology across different forecast models.

Finally, Sanjiv Kumar, Auburn University discussed the role of soil moisture and land surface processes in improving water management forecasts for droughts and flood risks. He presented the results of studies on predicting drought and stream flow using land surface initialization. He compared different forecasting models, discussed the challenges of predicting stream flow due to variable precipitation, and addressed the development of interactive forecasting tools to improve water predictability, including hybrid physics-AI models to combine physical and data-driven approaches. He discussed the challenges of integrating different data sources and the potential benefits of interactive forecasting.