Section 2.4 Subseasonal Forecast - Research and Development

2.4.1 Overview

Demand for skillful forecasts of precipitation at longer lead times has been consistent for many decades across a variety of end user and applications communities, and in California is largely driven by its considerable year-to-year variation in annual precipitation (Dettinger et al. 2011). Recent advancements in forecasting models and innovative data analysis techniques have increased the potential for improved long-range prediction of physical quantities affecting water resource management over the western United States. The benefit and recent advancements of subseasonal-to-seasonal (S2S; 2-week to at least 2-month) forecasts was acknowledged in the PVA which recommended that research to support S2S forecasts become part of the FIRO effort because of the high value of such forecasts to reservoir management and other management decisions.

CW3E, in partnership with the NASA Jet Propulsion Laboratory, has conducted fundamental research with the ultimate goal of improving S2S lead-time forecasts of ARs and total precipitation and floods over California, including the Lake Mendocino watershed. Many of the S2S research efforts and associated online products that support FIRO leverage funding from the California Department of Water Resources.

For all of the target atmospheric variables mentioned above, the forecast skill of dynamical and/or statistical models is assessed at 2-week to at least 2-month lead times. Aggregate metrics of ARs, ridging, and precipitation throughout a week-long or several weeks-long lead windows are often used as opposed to predicting individual AR or precipitation events at S2S lead times. Quantitative benchmarks of forecast skill are developed for comparison to the performance of various experimental forecast products. The methods used by CW3E researchers to investigate S2S predictability of quantities relevant to water resource management over California are summarized in Figure 2.4.1 and serve as the scientific basis for developing experimental forecast products at S2S lead times.

S2S Methods at CW3E

Lead times investigated for S2S predictability of ARs, ridges/blocking, or precipitation/floods

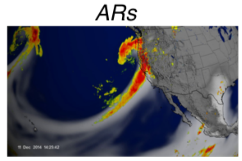
	A	B	C
6-12 months (water year/annual)		X	X
3-6 months (seasonal)		X	X
6-12 weeks (long-range subseasonal)	X	X	X
2-6 weeks (short-range subseasonal)	X		

S2S Methods

A = dynamical model approach
B = statistical model approach
C = machine learning approach

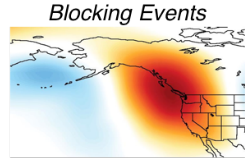
S2S quantities of interest (top label) and which S2S methods are used to investigate them (bottom label)

ARs



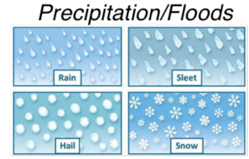
A, B

Blocking Events



A, B, C

Precipitation/Floods



A, B, C

Figure 2.4.1 Summary of S2S research and experimental product development at CW3E relevant to Lake Mendocino FIRO efforts. Lead times shown in the left column span from 2 weeks to 12 months, and each subsequent column denotes which S2S methods (dynamical models, statistical models, or machine learning methods) are being used at CW3E to investigate a particular lead time window. The bottom pictures summarize the three major quantities that CW3E S2S research focuses on (ARs, blocking events, and total precipitation/floods), with letters beneath each picture showing which S2S methods are used to investigate each process.

This task has produced the following accomplishments:

- Completed hindcast skill assessments at weeks 1-4 lead time for western U.S. AR occurrence and intensities (section 2.4.2).
- Identified forecast of opportunity at two-week lead time over Central California in hindcasts that were initialized during Madden-Julian Oscillation (MJO) phase 8 (section 2.4.2).
- Identified circulation regimes associated with increased AR activity, precipitation, and flooding over California (section 2.4.3).
- Created several S2S outlook products, listed below along with whether the product is public or internal as of the writing of this document (sections 2.4.3, 2.4.4):
    - Weeks 1-3 AR occurrence outlooks (DeFlorio et al. 2019b; public)
    - Weeks 3-4 AR intensity outlooks (Zhang et al. 2020 [in prep]; internal)
    - Weeks 1-6 circulation regimes outlook (Guirguis et al. 2020; product in development)
- Showed that ocean-atmosphere coupled models improve IVT forecasts at week-2 lead time, especially for ARs that cool the ocean (section 2.4.4).

2.4.2 Dynamical Model S2S Research and Product Development

AR occurrence and intensity are two key metrics that impact precipitation and water resource management over California. Accordingly, our team applied a suite of dynamical models from the S2S Project Database (Vitart et al. 2017) to investigate the model skill in predicting AR occurrence and intensity at subseasonal lead times (1-4 weeks; DeFlorio et al. 2019a,b, and Zhang et al. 2020 [in prep]). These skill assessments provide historical benchmarks for interpreting experimental S2S forecast products.

Research into S2S forecasts of opportunity (i.e., when large-scale climate conditions are particularly suited for more skillful S2S prediction) at week 1-4 lead times over the Central California region has shown the importance of the Madden-Julian Oscillation phase (from DeFlorio et al. 2019b) in modulating both AR activity and intensity, and AR prediction skill at S2S lead times. For example, a 15-20% reduction in false alarms of AR activity at week-2 lead time is seen in the ECMWF hindcast system when forecasts are initialized during MJO Phase 8 activity (Figure 2.4.2). The assessment of skill shown in Figure 2.4.2 is made over 5° x 5° box regions along the western U.S. coastline.

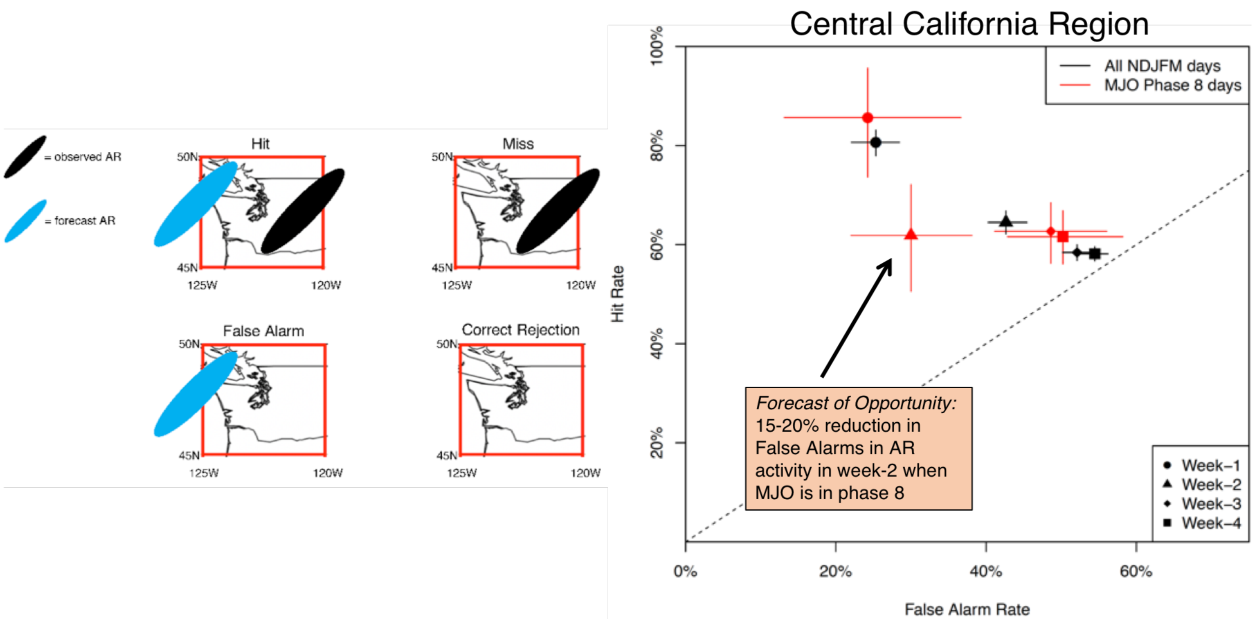


Figure 2.4.2 Example of "forecast of opportunity" of AR activity at week-2 lead time over the Central California region. From DeFlorio et al. 2019b. The left panel describes how hits, misses, false alarms, and correct rejections of AR occurrence are calculated over four 5° x 5° box regions along the western U.S. coastline. The right panel shows a ROC (Relative Operating Characteristic) Diagram of Hit Rate vs. False Alarm rate in the ECMWF hindcast system in predicting AR occurrence over a 5° x 5° box region in Central California, which includes the Lake Mendocino watershed. Black symbols show the average hit and false alarm rates as a function of lead time (denoted by the different symbol type) out to 1-month lead. The red symbols show the same metric, but only using hindcasts in the record that were initialized during MJO Phase 8 conditions.

Figure 2.4.3 shows an example of the CW3E-JPL week-3 AR occurrence outlook for the NCEP forecast system. This outlook was developed with direct input from a variety of potential users in the applications community (especially, from the California Department of Water Resources), and the hindcast skill assessment supporting its development is provided in DeFlorio et al. (2019b). The forecast shown was initialized on March 2, 2020, and the week-3 lead time period that it predicts is March 17-23, 2020. The top panel shows the number of AR days forecast to occur during that week-3 window. The middle panel shows the average AR conditions (climatology) in the NCEP model during March 17-23 periods from 1999-2010. The bottom panel is the top panel minus the middle panel, which shows the departure from normal AR conditions for the March 17-23, 2020 week-3 period. This product transitioned from an internal website to a public-facing CW3E website page in March 2020, as the first public S2S CW3E product. Release of products like this to the public are only allowed once a peer-reviewed hindcast skill assessment of the product (DeFlorio et al. 2019b) is published, and upon the approval by CW3E Director F. Martin Ralph, with close input and consultation from the CW3E-JPL S2S Advisory Panel. The panel is a team of experts at CW3E and JPL who contributed to the development of the product display and scrutinized closely the research supporting the product.

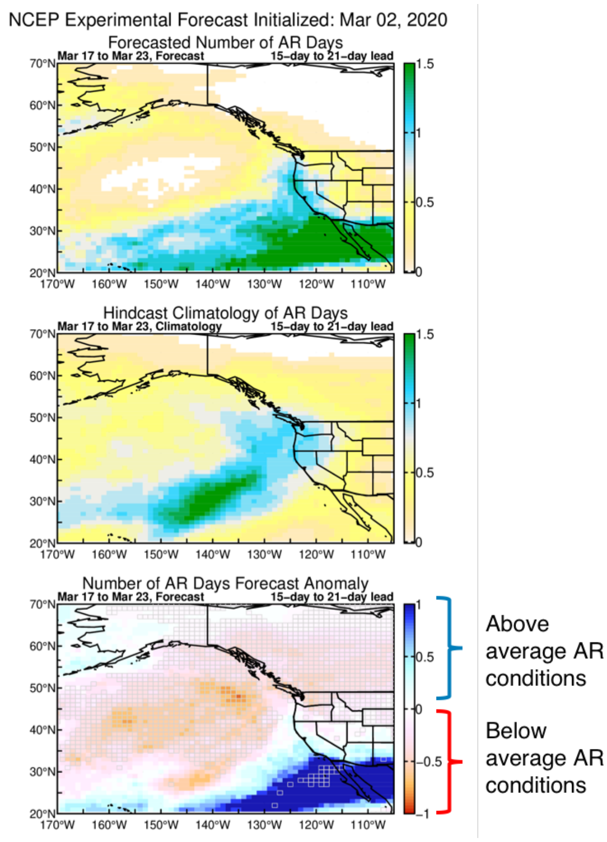


Figure 2.4.3 S2S week-3 AR occurrence outlook from Winter 2019-2020. Supporting hindcast skill assessment provided in DeFlorio et al. 2019b. Top panel shows the forecasted number of AR days during the March 17-23 2020 period in the NCEP model. Middle panel shows the average number of AR days per week during this same period in the NCEP hindcast record spanning 1999-2010. The bottom panel is the difference between the top and middle panel, representing the departure from normal AR conditions for the March 17-23, 2020 period relative to climatology. Blue shading represents more than normal AR occurrences, and red shading represents fewer than normal ARs. Grid cells are tiled in grey if greater than 75% of ensemble members in the NCEP forecast system agree on the sign of the weekly AR anomaly during this week-3 period, which can be interpreted as a measure of confidence across ensemble members. Grey tilings in the bottom panel indicate grid cells where >75% of ensemble members agree on the sign of the forecasted anomaly.

In addition to AR numbers, our team has investigated the skill of hindcast systems in the S2S Database at predicting period-averaged AR-related IVT. Figure 2.4.4 shows AR-related IVT hindcast skill for weeks 1-4 lead time (columns) in the NCEP, ECCC, ECMWF, and NASA GMAO hindcast systems (rows) (Zhang et al. 2020, in prep). Results from this skill assessment for AR intensities are guiding development of a new experimental weeks 3-4 S2S AR intensity outlook. Once it has fulfilled the requirements above, this product will be transitioned to the public CW3E website.

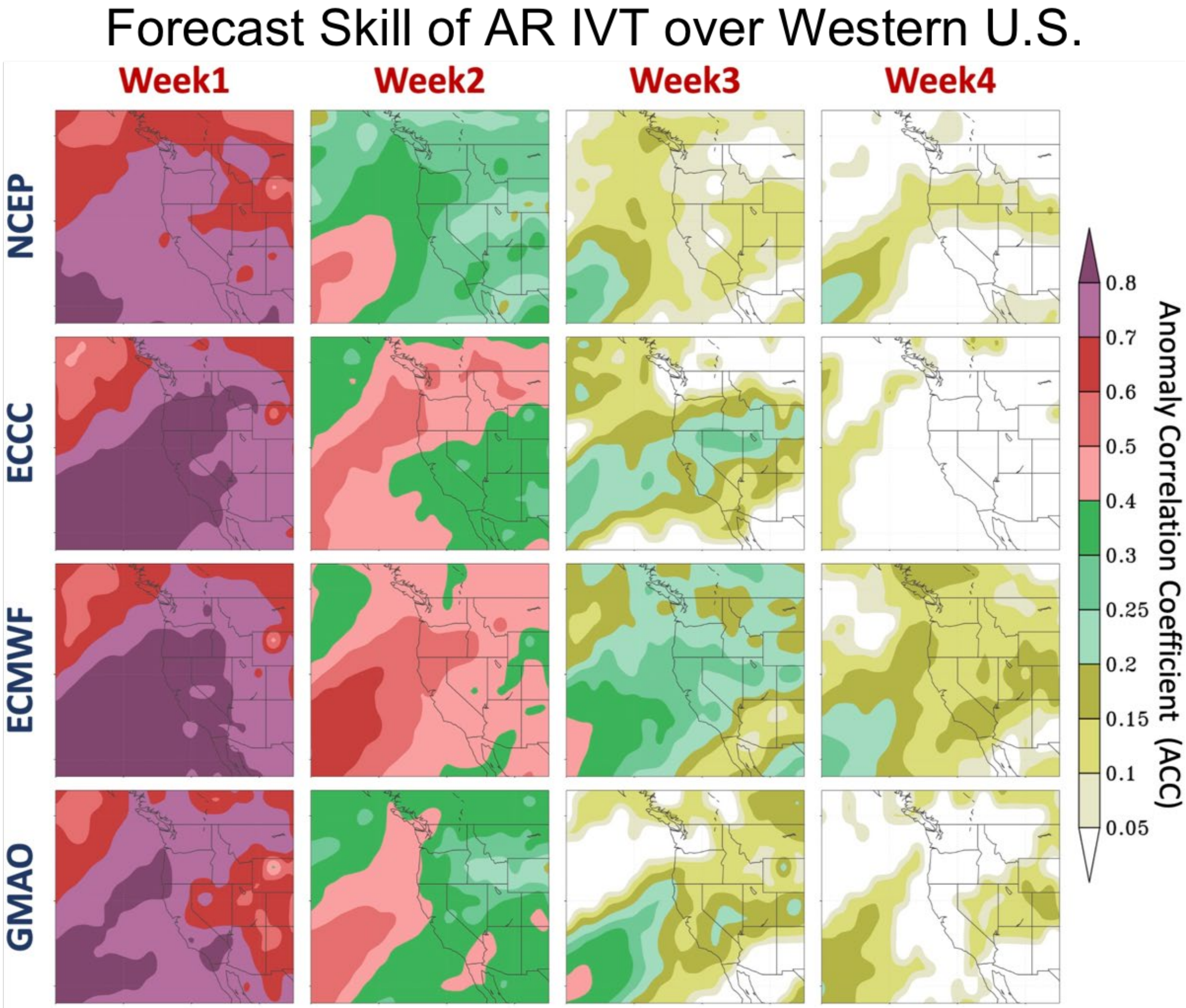


Figure 2.4.4 AR-related IVT S2S hindcast skill assessment at weeks 1-4 lead time (columns) in the NCEP, ECCC, ECMWF, and NASA GMAO hindcast systems (rows). Skill metric is the anomaly correlation coefficient (ACC) between forecast and observed AR-related IVT. From Zhang et al. 2020 (in prep).

2.4.3 Statistical Model S2S Research and Product Development

In addition to dynamical models addressed above, the S2S team has developed statistical approaches to S2S predictability and variability of precipitation, ARs, and circulation regimes over the North Pacific/western U.S. region (as described in, e.g., Guirguis et al. 2018 and Guirguis et al. 2020).

Figure 2.4.5 shows an example of a statistical model of seasonal variability of precipitation over the Lake Mendocino watershed region. When all of the atmospheric-circulation modes in the maps on the left side of the figure are in-phase and positive, AR landfall and precipitation are (on average) greatly enhanced over California. Indeed, behavior of the four circulation modes of circulation explains 37% of the seasonal variance of precipitation over Lake Mendocino. The predictability of the modes themselves on S2S timescales is being assessed now. This kind of model may allow predictions of California precipitation at seasonal lead times, which would be of considerable benefit since prediction skill for precipitation itself is limited beyond 2-week lead times (e.g., Pan et al. 2019) whereas circulation regimes may be more predictable at S2S lead times.

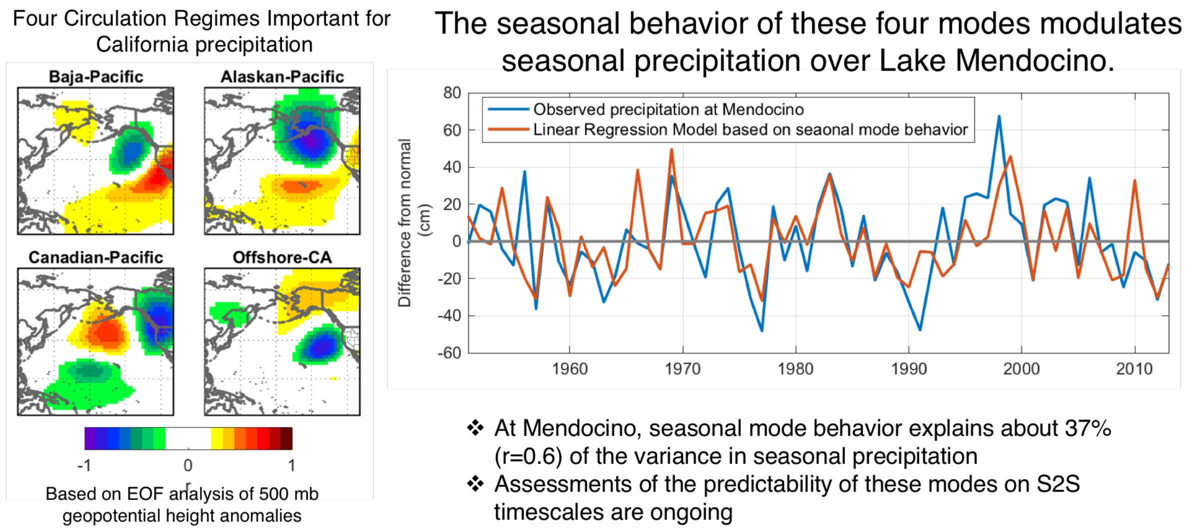


Figure 2.4.5 Four modes of circulation that are most important for California AR landfall and precipitation over the historical record based on rotated EOF analysis of 500 hPa geopotential height anomalies. The left panel shows four atmospheric circulation regimes, identified by a rotated EOF analysis of 500hPa geopotential height anomalies, that are most important for enhanced AR activity and precipitation over California. The color shading shows the correlation between the associated principal component time series of the rotated EOFs with local Z500 anomalies. The right panel shows the correlation between observed precipitation at Lake Mendocino and predicted precipitation at Lake Mendocino based only on the historical relationship between the phase of the four modes in the left panel and precipitation (right panel). Figure from Guirguis et al. 2020.

2.4.4 Role of Ocean-Atmosphere Coupling in S2S Prediction of ARs Over the Western U.S.

Air–sea interactions can impact ARs. Strong AR-induced surface winds are often associated with large pressure gradients between extratropical cyclones and anticyclones located on the southeast and northwest sides of ARs. Large air–sea fluxes of momentum, heat, and moisture often result and could affect the ocean surface and subsurface. The upper ocean response to the AR winds in turn can feed back up into the AR through sea surface temperature (SST) variations and air–sea fluxes (Shinoda et al. 2019) in ways that modify the evolution and intensity of the AR and AR precipitation once it reaches the West Coast.

These feedbacks and effects are not present in (uncoupled) atmosphere-only simulations and forecasts of ARs. To investigate their impacts on AR predictability, coupled and uncoupled simulations are being compared for AR events over the Northeast Pacific with 93 15-day hindcasts initialized each day from Jan 01 to Jan 31, 2018. The 93 hindcasts are of two types, allowed for by the coupled simulation: (1) ARs over a weakly cooling ocean, and (2) ARs over a strongly cooling ocean. A schematic description of the coupled model and more details are provided in Sun et al. (2019).

To investigate how much skill can be added by the coupled model in modeling ARs, Integrated Vapor Transport (IVT) and Integrated Water Vapor (IWV) in the simulations are compared to observations. Brier Skill Scores (BSS) for all simulations (93 simulations x 15 days/simulation) are plotted as a function of simulation lead time in Figure 2.4.6. This skill score measures improvements in skill of the coupled-model simulations relative to the uncoupled simulations. The figures show that coupled-model skill scores are better (more positive) than those for the uncoupled model. Strongly cooling AR events with their stronger air–sea interactions are predicted better than weakly cooling AR events (Sun et al., 2020).

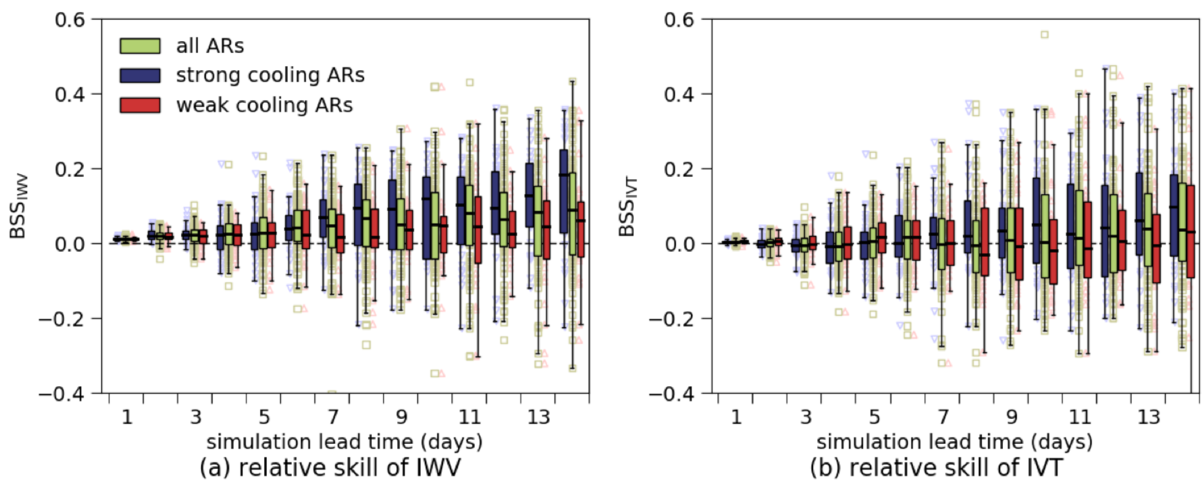


Figure 2.4.6 The relative Brier Skill Scores (BSSs) between Coupled and Atmosphere only runs plotted as a function of simulation lead time. Panel (a) and (b) shows the Brier Skill Scores for IWV and IVT, respectively. The markers show the averaged BSSs; the solid lines are showing one standard deviation.

2.4.5 Conclusions and Recommendations

Work by our S2S team is showing that skill for S2S "forecasts of opportunity" of AR occurrence exists and can be exploited over the Central California region (DeFlorio et al. 2019a,b). For example, the CW3E AR occurrence outlooks for weeks 1-3 were made public beginning in March 2020. Additionally, 35-40% of the seasonal variance in precipitation over Lake Mendocino has been shown to be predicted by four atmospheric-circulation modes over the North Pacific (Guirguis et al. 2020 and 2018). Research to assess S2S skill for aggregate AR intensity is now underway and may identify which dynamical ensemble systems have the most skill at weeks 1-4 lead times over the Lake Mendocino region (Zhang et al. 2020, in prep).

The following recommendations will benefit FIRO results:

- Assess the skill of forecasts of blocking events over the North Pacific/western U.S. at S2S lead times by various dynamical ensemble hindcast systems

- Explore combinations of dynamical and statistical methods to improve S2S skill of ARs, precipitation and blocking
- Apply ML algorithms to large ensemble systems to improve seasonal prediction of precipitation over the Western U.S.