

# A two-stage hybrid method for seasonal prediction of snow water equivalent, precipitation, and temperature

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## ***Seasonal forecast 101***

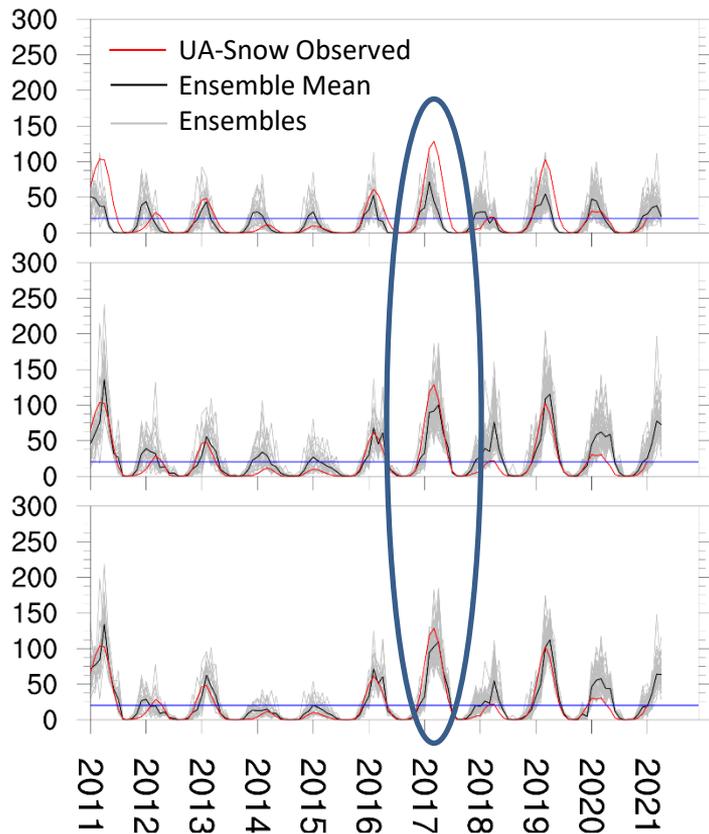
- Input: Observational data or global forecasting model output usually with 10-60 ensemble members
- Approach: statistics, machine learning
- Output: relevant variables (usually T and P)
- Assessment metrics:
  - deterministic: e.g., correlation (zero for default: using climatology)
  - probabilistic: e.g., Ranked Probability Skill Score (RPSS) for prediction of three categories (below, near, and above normal) (zero for default: equal probability for each category)

*We combine four ensemble forecasts into Super-Ensemble, leveraging skill of each ensemble forecast.*

- Two-stage adjustment using two dynamic models:
  - US (CFS) ensemble forecasts (32 members)
  - European (ECMWF/SEAS5) ensemble forecasts (51 members)
- Two empirical ensemble forecasts:
  - Empirical2: Stage 2 but only using observations (51 members).
  - EnsAnalog: weighted towards years with most similar teleconnections (51 members).

# UA's super-ensemble seasonal forecast system

## Two-stage adjustment of December forecast of JFM SWE



Original model  
forecast

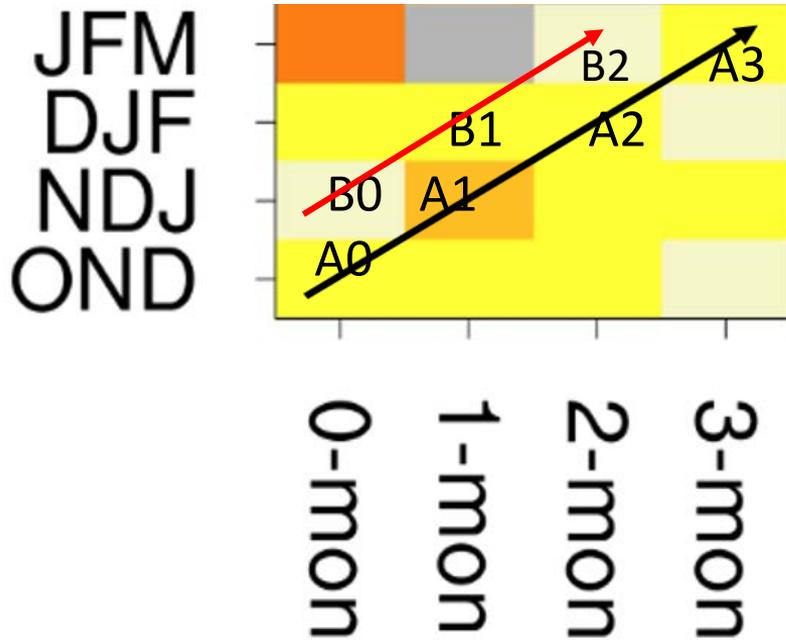
Stage 1: Distribution  
Matching

Stage 2:  
Teleconnections  
Adjustment  
(ENSO, PDO,  
persistence, etc.)

*We combine four ensemble forecasts into Super-Ensemble, leveraging skill of each ensemble forecast.*

- Two-stage adjustment using two dynamic models:
  - US (CFS) ensemble forecasts (32 members)
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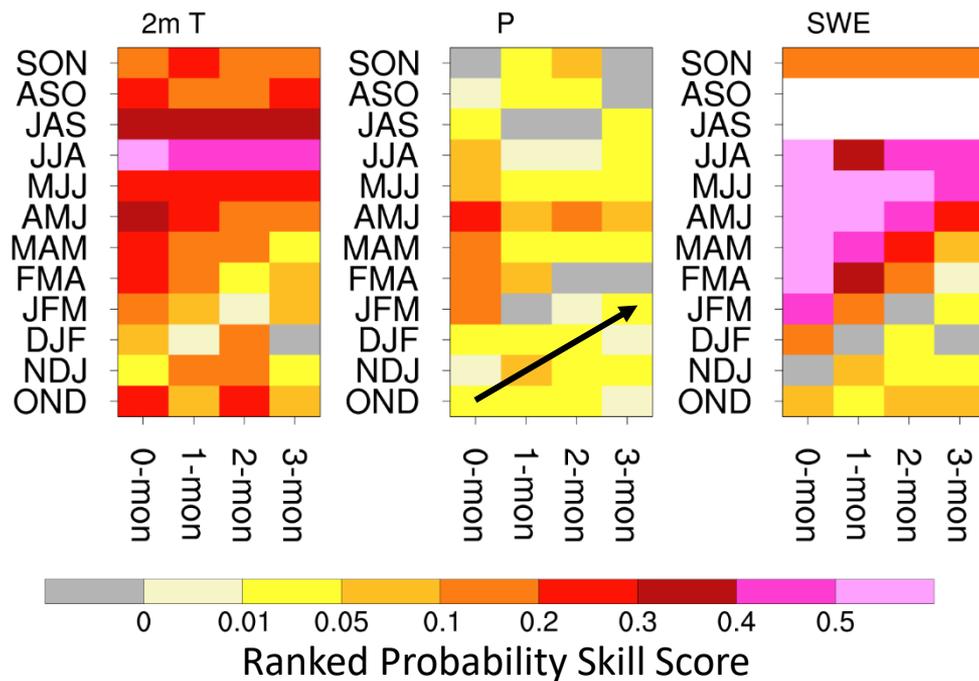
# Forecast performance throughout the year at different lead times



- A0: Early Oct predict of Oct-Dec (0-month lead time)
- A1: Early Oct predict of Nov-Jan (1-month lead time)
- A2: Early Oct predict of Dev-Feb
- A3: Early Oct predict of Jan-Mar
  
- B0: Early Nov predict of Nov-Jan (0-month lead time)
- B1: Early Nov predict of Dec-Feb

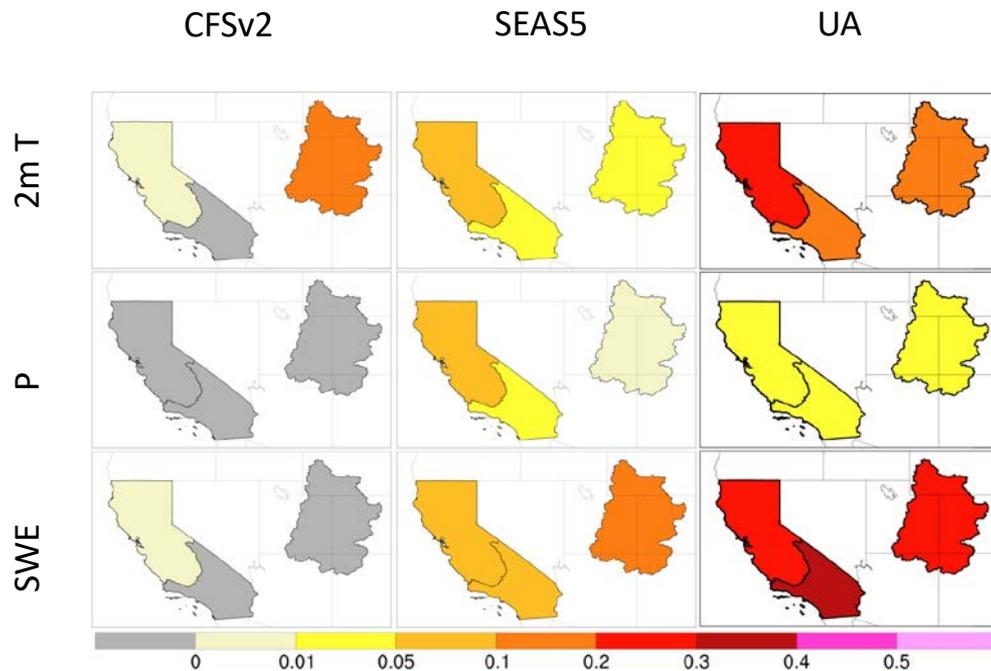
# Forecast performance throughout the year at different lead times

Super-ensemble skill > 0 (validation period: 2011-2020)  
for all seasons and leads, and averaged over N.  
California, S. California, and upper Colorado River Basin



- Prediction skill is higher for SWE, followed by T2m, with P showing the lowest skill.
- The best skill is seen from late winter through early summer.

# Performance compared to raw model forecast at 1 month lead time



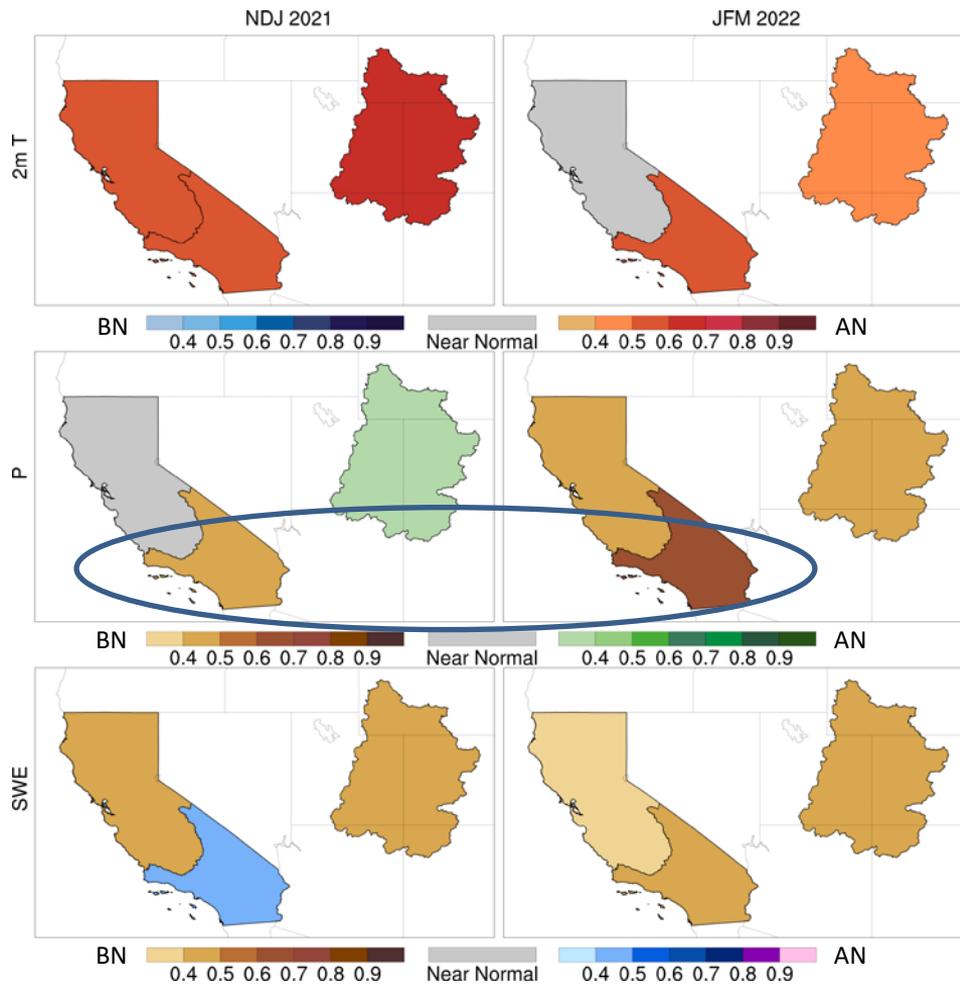
RPSS (relative to climatology) validated 2011-2020

RPSS of UA forecast exceeds raw forecast as biases in raw forecast push down skill.

SWE has the highest skill, followed by 2m, with only marginal skill for P.

SEAS5 performs better than CFSv2 for P and SWE, with similar skill for 2m T.

# 2021-22 forecast for NDJ and JFM initialized November



For Nov-Jan prediction

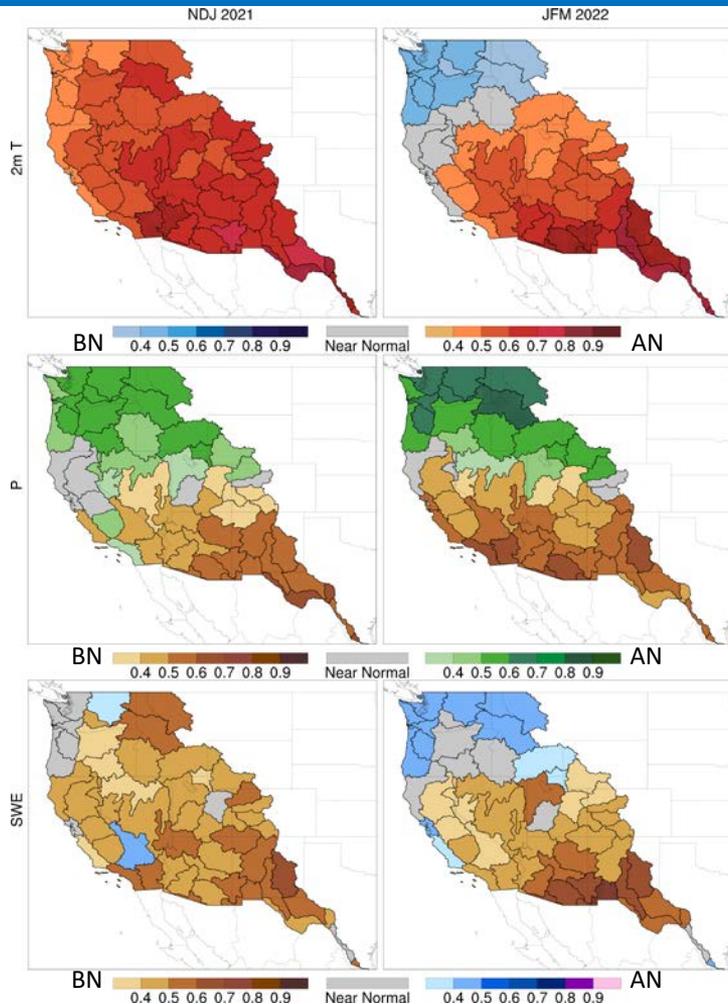
- Warmer temperatures are generally favored.
- Upper CO River slightly favors wetter than normal condition, Northern CA favors near-normal condition, and Southern CA slightly favors drier than normal condition.
- Northern CA and Upper CO River favor below normal SWE, and Southern CA weakly favors above normal SWE.

The value in each category refers to the probability for that category; e.g., for P prediction in Southern CA:

NDJ: 40-50% chance below normal

JFM: 70-80% chance below normal

# 2021-22 forecast for NDJ and JFM initialized November (western U.S.)



- Most of west warmer than average for NDJ, transitioning to the dipole pattern for JFM
- Dipole pattern in precipitation with wetter NW, drier SW. This pattern amplifies in JFM.
- The SWE forecast also shows this dipole pattern, particularly for JFM.
- Forecast is similar to last year and consistent with another La Niña year.

# Summary

- Developed a preliminary two-stage hybrid method for seasonal forecasts of snow mass, temperature, and precipitation over western U.S., including the three regions identified by the DWR.
- SWE has the highest skill, followed by 2m T, with only marginal skill for P.
- For our Nov-Jan precipitation prediction, initialized November 2021,
  - Upper Colorado River slightly favors wetter than normal condition,
  - Northern CA favors near-normal condition, and
  - Southern CA slightly favors drier than normal condition.