Numerous statistical and dynamical model simulations have been developed for predicting precipitation. However, both types of models offer limited seasonal predictability. This study outlines a hybrid statistical-dynamical modeling framework for predicting seasonal precipitation. The dynamical component relies on the physically based North American Multi-Model Ensemble (NMME) model simulations (99 ensemble members). The statistical component relies on a multivariate Bayesian-based model that relates precipitation to atmosphere-ocean teleconnections (also known as an analog-year statistical model). Here, the Pacific Decadal Oscillation (PDO), Multivariate ENSO Index (MEI), and Atlantic Multi-decadal Oscillation (AMO) are used in the statistical component. The dynamical and statistical predictions are linked using the so-called Expert Advice algorithm, which offers an ensemble response (as an alternative to the ensemble mean). The latter part leads to the best precipitation prediction based on contributing statistical and dynamical ensembles. It combines the strength of physically based dynamical simulations and the capability of an analog-year model. An application of the framework in the southwestern United States, which has suffered from major droughts over the past decades, improves seasonal precipitation predictions (3- to 5-month lead time) by 5-60 percent relative to the NMME simulations. Overall, the hybrid framework performs better in predicting negative precipitation anomalies (10-60% improvement over NMME) than positive precipitation anomalies (5-25% improvement over NMME). The results indicate that the framework would likely improve our ability to predict droughts such as the 2012-2014 event in the western United States that resulted in significant socio-economic impacts.

Methodology

The proposed hybrid approach benefits from the predictability of an analog-year model based on teleconnection indices. We propose a Bayesian model based on copula functions to represent the joint distribution of teleconnection indices and seasonal precipitation:

\[
P(x_1, x_2, ..., x_n) = P(Y_1 = y_1, Y_2 = y_2, ..., Y_n = y_n) = P(Y_1 = y_1 | x_1) \cdot P(Y_2 = y_2 | x_2) \cdot \ldots \cdot P(Y_n = y_n | x_n)
\]

where, C is the Cumulative Distribution Function (CDF) of the copula, and \(P(x_i)\) is the marginal distribution of \(x_i\) being uniform on the interval [0,1], which is also denoted by \(u_i\). We use the conditional probability distribution function based on copulas to estimate the predictive distribution of precipitation given the joint status of the teleconnection indices:

\[
P(x_1 | x_2, ..., x_n) = \frac{P(x_1, x_2, ..., x_n)}{P(x_2, ..., x_n)}
\]

where, \(p(x_1 | x_2, ..., x_n)\) is the conditional distribution of the random variable \(x_1\) given the set \(x_2, ..., x_n\) of random variables; \(p(x_2, ..., x_n)\) is the PDF of the continuous copula function; and \(p(x_1)\) is the PDF of the \(i^{th}\) random variable. The conditional probability of bivariate and trivariate cases are expressed as follows:

\[
P(x_1, x_2) = c(u_1, u_2) = \int_{-\infty}^{\infty} c(u_1, u_2 | u_3) f(u_3) du_3
\]

We estimate the conditional probability of precipitation at each grid cell in the study area (denoted by \(x_j\)) given multiple teleconnection indices such as PDO, MEI, and AMO (denoted by \(x_1, x_2, \ldots, x_j\)) that have been observed in the preceding months/seasons.

CONCLUSIONS

The proposed hybrid method aims to improve drought prediction by combining these two fundamentally different seasonal precipitation prediction methods. The hybrid model combines dynamical model forecasts from the NMME with Bayesian statistical forecasts using teleconnections indices (PDO, MEI, and AMO). The hybrid model utilizes the EA algorithm to merge the dynamical model forecasts and statistical model predictions. The results indicate that although the dynamical model simulations capture some of the recent droughts, they do not offer high predictability. The integration of the statistical and dynamical methods appears to improve the prediction of seasonal precipitation in this case study. The predictability of seasonal precipitation increases by 5-60% after application of hybrid model. Overall, the hybrid framework performs better in predicting below-normal precipitation than above-normal precipitation. We acknowledge that several issues such as the relatively short record, uncertainty in the observed dependencies, and model parameterization may have affected predictions of wet and drought anomalies. More efforts and evaluations of the proposed model are required before this model can be used in water resources management.