Statistical Analysis and Verification of Dynamically Downscaled Seasonal Reforecasts for the North American Monsoon Region

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Background: Operational Seasonal Forecast Products in the United States

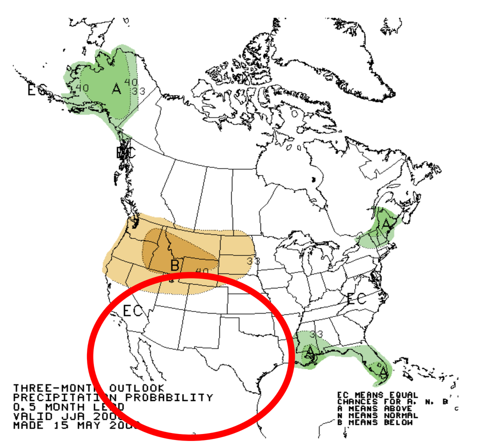


Figure 1: The official Climate Prediction Center forecast for summer 2008 that shows equal chances of precipitation probability for Southwest U.S. (from NCEP website).

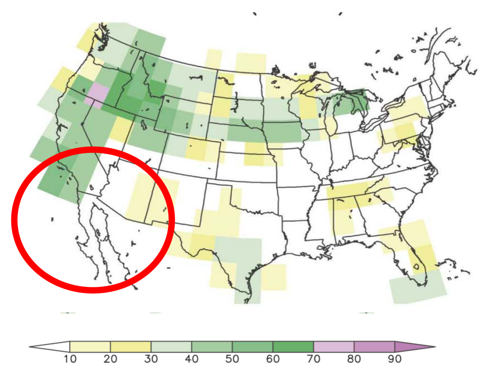


Figure 2: Spatial distribution of retrospective CFS model forecast skill (% anomaly correlation) of the 15 member ensemble forecasts of JJA. (Saha et al. 2006).

Official U.S. Seasonal Forecast Products: These are issued by the National Center for Environmental Prediction (NCEP), Climate Prediction Center (CPC) within the National Oceanic and Atmospheric Administration (NOAA). The CPC forecast qualitatively incorporates the combination of the global Climate Forecast System (CFS) model output, ENSO composite analysis, and statistical prediction of temperature, precipitation, and soil moisture. These seasonal forecasts have become an increasingly important factor in natural resource decision making within the United States. Much progress has been made in producing skillful seasonal forecasts for the cool season in recent decades, largely because climate interannual variability tied to atmospheric teleconnection responses of ENSO and Pacific decadal variability can resolved by a global model and are present in the recent historical record as statistically robust features. However, producing skillful operational seasonal forecasts for the warm season and its principal climatological feature, the North American Monsoon System (NAMS), has been more challenging. Figure 1 is the example of the CPC JJA 2008 precipitation forecast that indicated "equal chances" of precipitation being above or below normal for Southwest U.S. However, the global CFS model has very limited ability to forecast the precipitation in Arizona and Mexico (Fig. 2). The actual observed precipitation shows much above normal precipitation associated with a wet and early monsoon—a characteristically poor forecast result for this region that demonstrates the present ineffectiveness of these products for decision making purposes (Fig. 3).

NAME Forecast Forum: As part of the recent North American Monsoon Experiment (NAME), NCEP developed the online NAME Forecast Forum, for the posting, distribution, monitoring and synthesis of experimental intra-seasonal and seasonal precipitation forecasts of the North American Monsoon. Fig. 4 indicates the locations of NAME sub-regional domain. As an example, shown in Fig. 5 is the multi-model forecast precipitation for Arizona during the summer of 2008, using ensemble simulation products from multiple GCMs, including the CFS model. Most current operational global climate models fail to correctly forecast warm season precipitation in the NAM region, particularly in the Southwest U.S. and have a very poor model climatology. Dynamically downscaling the CFS model with a regional climate model for a historical reforecast period dramatically improves the representation of summer precipitation (Fig. 6) Much of this improvement is accounted for by the better representation of the diurnal cycle of convection in the regional climate model.

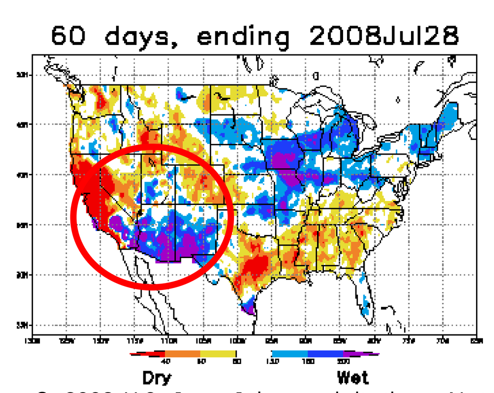


Figure 3: 2008 U.S. June-July precipitation. Note the substantially above average precipitation in Southwest U.S. (NOAA Climate Diagnostic Center).

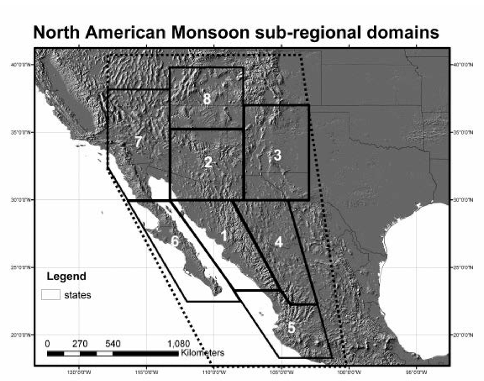


Figure 4: NAME precipitation regions for forecast and research purposes..

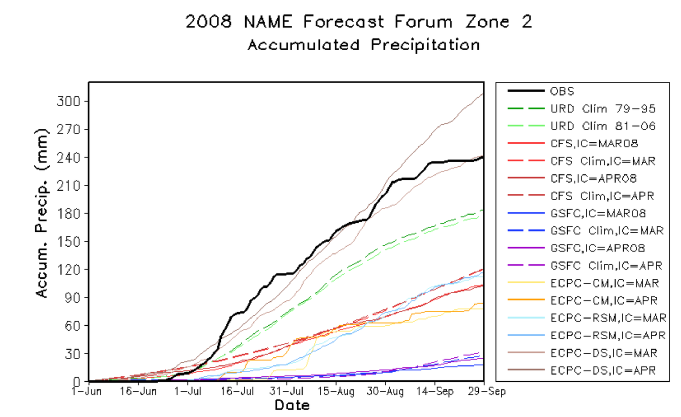


Figure 5: 2008 JAS accumulated precipitation for zone 2 (southern Arizona and Northern Sonora). Current operational GCMs have limited ability to correctly simulate precipitation in Southwest U.S.

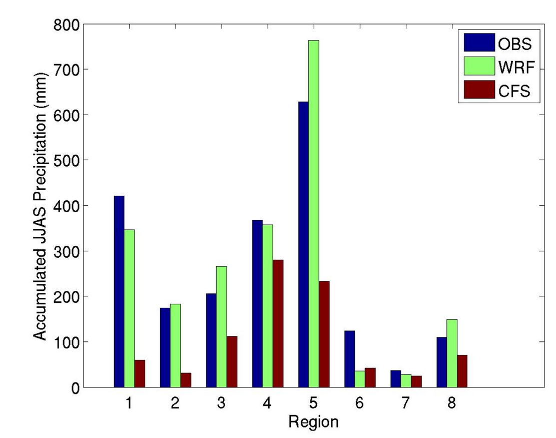
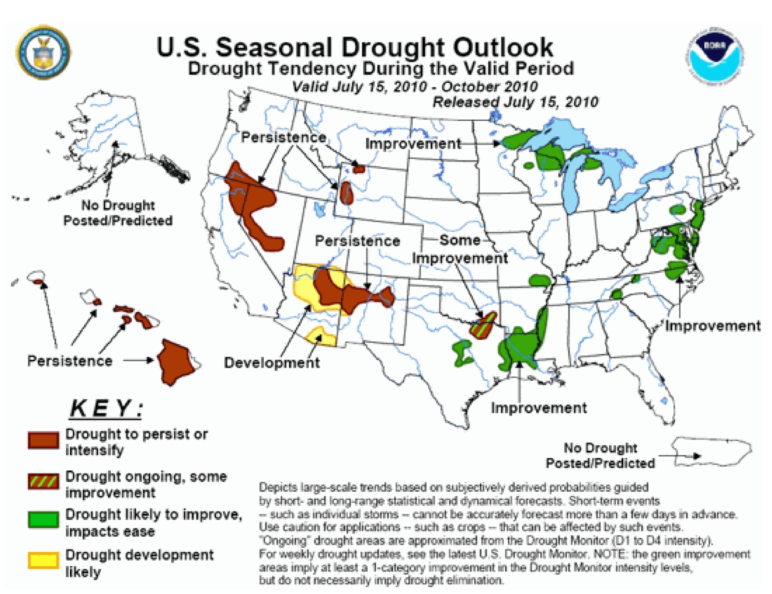


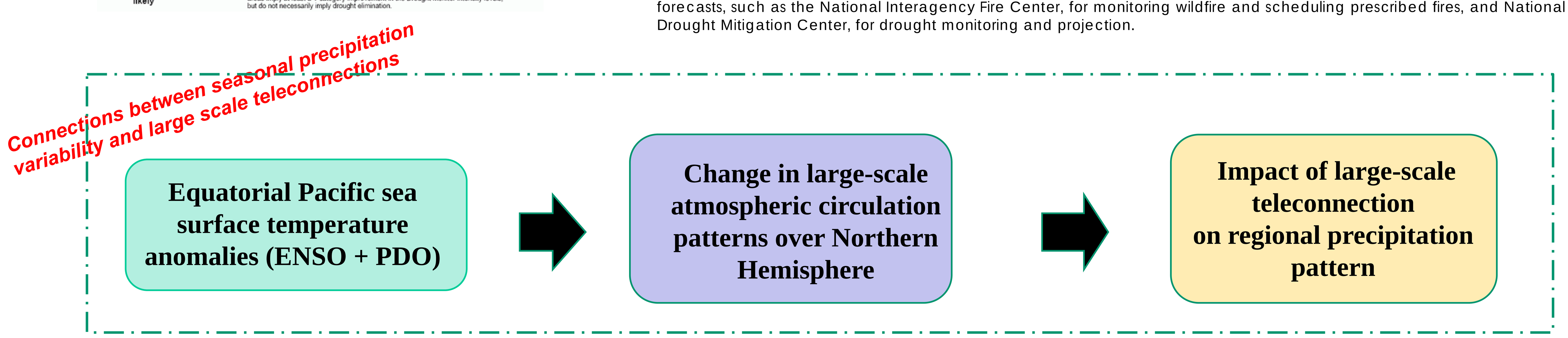
Figure 6: Total precipitation (mm) comparison between gauge-based observations, CFS and WRF-CFS simulations (shown in NAM zones) for the period of CFS reforecasts 1982-2000.

Motivation: Improve seasonal forecasts of North American Monsoon by dynamically downscaling GCM data with a regional climate model



Research Methodology: This study evaluates the use of the Weather Research and Forecasting (WRF) as a regional climate model to dynamically downscale CFS ensemble reforecast data for the period 1982-2000, as described in Saha et al. (2006). Nine CFS ensemble members are downscaled per year, starting from different monthly initializations from April through June. To evaluate the performance of WRF with "perfect" lateral boundary forcing, the corresponding NCEP/NCAR global reanalysis data were also dynamically downscaled. Further details on the WRF model experimental design are included on our companion poster. The primary objective is to demonstrate the potential for improved seasonal forecast capability of the NAMS during the warm season, addressing one of the major goals of North American Monsoon Experiment (NAME). Much of our present effort in the analysis of these simulations has focused on influence of large scale driving forces on the NAM warm season climate to verify these are consistent with those in nature (see below). We ultimately seek to improved seasonal forecast information at a spatial scale that will be more useful for decision making purposes.

Public Importance: The main interests for natural resource decision makers and the general public concerning the summer climate in the western U.S. are drought predictability, severe weather, wildfire outbreaks related to dry lightning, water demand, and water supply (see our companion poster). This is especially true for the rapidly growing, arid southwest U.S., our main geographic area of concern, as it is particularly sensitive to climate variability. Various government agencies and private utility companies have ongoing forecast and monitoring tools that would benefit from improved summer seasonal forecasts, such as the National Interagency Fire Center, for monitoring wildfire and scheduling prescribed fires, and National Drought Mitigation Center, for drought monitoring and projection.



Results: Representation of Monsoon Climatology and Interannual Variability

Statistical Tools for Analysis of Post-processed Model Data

Standard Precipitation Index (SPI): Designed to determine the rarity of a drought or anomalously wet conditions using a given precipitation record fit to a gamma distribution function (McKee et al. 1993).

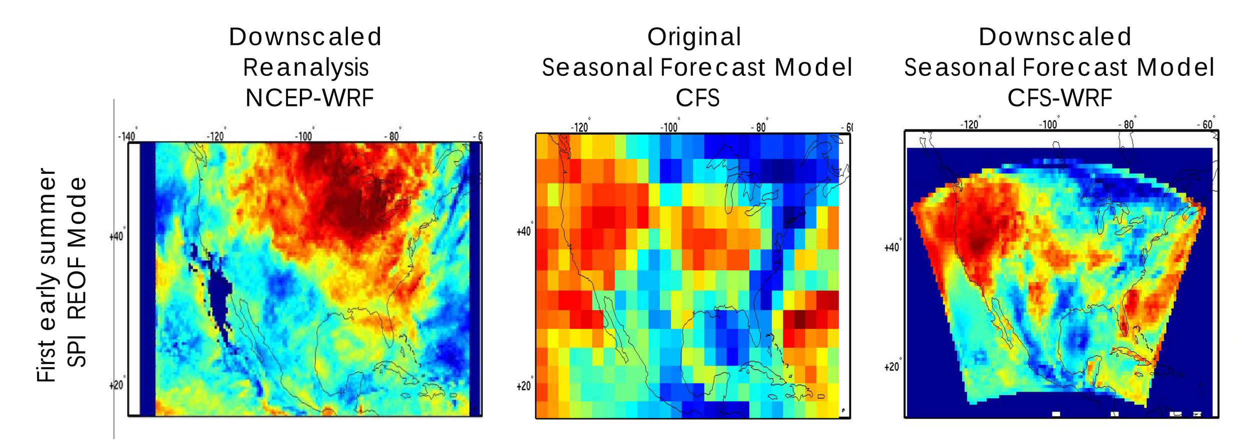
Rotated Empirical Orthogonal Function (REOF) analysis: Uses singular value decomposition (SVD) to pull out the dominant spatial patterns, or EOFs, and time series associated with those patterns, or principal components. The first few dominant EOF modes are then rotated using the Varimax Rotation method, which relaxes the orthogonality constraint on the EOFs and allows for a better representation of more regionalized patterns.

Regression Analysis: After the dominant modes of spatial variability for SPI are determined on SPI, the dominant PCs are regressed on to the time coincident large-scale climate forcing indicators of 500mb geopotential height and sea surface temperature. The early summer (June-July) and late summer (August-September) periods are considered separately to account for the decaying influence of Pacific SSTs on the atmospheric teleconnections.

Dominant Mode of Early Warm Season (June-July) SPI: The corresponding spatial loading patterns are shown on the left side of Fig. 8 for WRF-NCEP downscaled, original CFS, and WRF-CFS. This mode explains approximately 14-16% of SPI variance. The WRF model simulations show a sharp contrast in the sign of the SPI spatial loading between the central U.S. and the Southwest U.S., and the WRF-NCEP simulation is nearly consistent with the results from analysis of the very high resolution PRISM precipitation dataset (not shown). The most positive SPI spatial loadings occur more in the Pacific Northwest with WRF-CFS rather than the central U.S. due to the difference in the position of the center of action of the 500-mb height anomaly (upper right panels of Fig. 8). For the dynamically downscaled data in the NAMS region, the highest SPI spatial loadings are clearly tied to the terrain features, the Sierra Madres in Mexico and the Mogollon Rim in Arizona, due to their large influence on the generation of convective precipitation. The corresponding SPI spatial loading of CFS shows a much more muted contrast in precipitation between the Southwest U.S. and Central U.S., with little to no signal in the core monsoon region, and does not reflect any substantial terrain influence on precipitation.

Large-Scale Driving Forces of North American Warm Season Climate Variabilty: Sea surface temperatures in the Pacific Ocean are probably the most important large-scale driving force of interannual variability of North American warm season climate. Like the winter season, anomalous convection associated with ENSO and Pacific Decadal variability cause quasi-stationary Rossby wave trains that affect the upper-level circulation and precipitation patterns on a continental scale. Namely, ENSO-PDV is associated with the opposite relationship in precipitation between the central and southwest U.S., and this is the dominant continental-scale mode of warm season precipitation variability (e.g. Castro et al. 2007). A second mode of continental-scale precipitation variability is caused by the Circumglobal Teleconnection, another Rossby wave train characterized a series of coherent height anomalies across the entire Northern Hemisphere with a zonal wavenumber 5 structure (Ding and Wang 2005). This teleconnection affects summer precipitation primarily in the central and southern Great Plains and is more likely related to Indian monsoon convection and/or barotropic instability of the mid-latitude westerly jet in the North Atlantic. Interestingly, the latter possible mechanism for the Circumglobal Teleconnection may also explain some of the statistically significant relationships found between central U.S. summer precipitation and Atlantic SSTs.

Regression of Dominant Early Warm Season SPI on Climate Indicators: The corresponding regressions of the dominant early warm season SPI patterns onto normalized SST and 500-mb height anomalies are shown in the two right panels of Fig. 8. The center of action of the geopotential height anomaly in the NCEP reanalysis is located over the central Rockies, reflecting the constructive interference of ENSO and PDV-associated height anomalies. This center of action is displaced slightly westward in the CFS model, but the geopotential height anomaly signs are consistent with the NCEP reanalysis. Even though the same teleconnection pattern appears with dominant SPI modes in CFS and WRF-CFS, dynamical downscaling adds substantial value to the driving global model because it captures the correct regional response in convective rainfall tied to the local land surface forcing—that is totally absent in the precipitation from CFS. The WRF-CFS shows a much stronger ENSO-PDV signal in than the CFS regression map for SST, that is nearly identical to the NCEP Reanalysis.



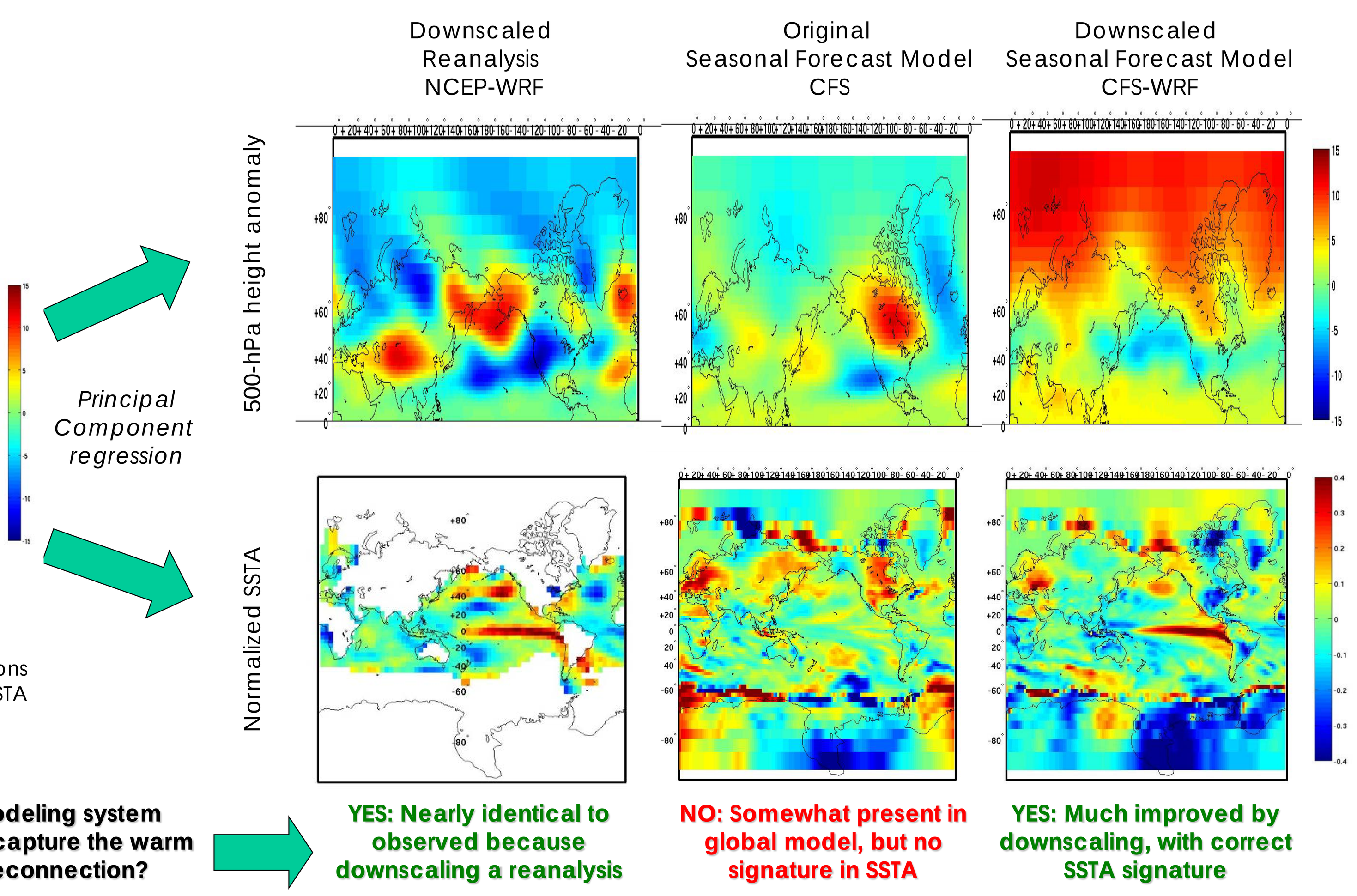


Figure 8: Left: Dominant REOF of early JJ two month SPI from WRF-NCEP, CFS, and WRF-CFS simulations (unitless). Right: Corresponding regression of PC on 500-mb height (m) (top) and normalized SSTA (bottom).

Research Conclusions and Operational Transferability

NEED FOR IMPROVEMENT IN MONSOON FORECASTS: The current global model used for warm season forecasts in the United States, the NCEP CFS, is inadequate to skillfully resolve the North American Monsoon as a salient feature. This is mainly due to the inability of the global model to simulate convective precipitation.

PRESENCE OF LARGE-SCALE FORCING IN DRIVING GLOBAL MODEL: In spite of its inability to resolve monsoon convective precipitation, CFS performs reasonably well in capturing the dominant large-scale teleconnections in the warm season related to Pacific SST forcing. Thus is provides good boundary forcing to a finer resolution regional model.

REGIONAL MODEL DYNAMICAL DOWSCALING ADDS VALUE: Use of the WRF model to dynamically downscale retrospective CFS reforecasts for the warm season demonstrates that a regional model with a grid spacing of 10s of km, or equivalent spatial scale within a global model, is necessary to resolve the monsoon as a climatological feature and substantially improves its representation of interannual variability.

INCORPORATION OF REGIONAL MODEL DATA IN OPERATIONAL FORECASTS: More work is needed to formally demonstrate the utility of these regional model data for official operational forecast purposes. Ultimately we intend to provide experimental operational real-time monsoon forecasts from the University of Arizona through the existing NAME Forecast Forum and work with NCEP to incorporate these products into their seasonal forecast methodologies.

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Acknowledgements

This work is supported by federal government of the United States under National Science Foundation grant ATM-813656. We acknowledge Dr. Jae Kyung Schemm from the National Center for Environmental Prediction, Climate Prediction Center for providing CFS reforecast data and Mr. Matthew Switanek for his assistance in archival of these data.