Historical evaluation of dynamically downscaled global climate model products for the warm season in North America

Carlos Carrillo, Hsin-I Chang, Christopher L. Castro, and Brittany Ciancarelli
Department of Atmospheric Sciences, University of Arizona, Tucson, Arizona, USA
Corresponding Author E-mail: carloscc@email.arizona.edu

Motivation: Improve warm season climate projections for water resource planning

Inadequacy of current climate change projections: Global climate model (GCM) projections of the Intergovernmental Panel on Climate Change (IPCC) are in broad agreement that subtropical regions, including the Southwest U.S., will generally become hotter and drier in the future. Though it is fairly certain that temperatures in recent decades have increases and will continue to do so, future projection of precipitation in the Southwest is highly uncertain due to the poor, parameterized representation of this process in current global climate models. How the North American monsoon will change is especially uncertain because global climate models do not resolve terrain-forced thunderstorms on the mesoscale and do not represent the monsoon as a salient feature. but they generally have a poor precipitation representation in the Southwest U.S. Since the data from the current suite of IPCC global climate models is inadequate for water resource projection in this regard, our approach is to dynamically downscale the GCM data, and create finer spatial and temporal resolution information using a regional climate model .

Research Objectives:

1. **Evaluate whether use of a regional climate model adds value in improving the climatology of the North American Monsoon in the Southwest U.S. and northwest Mexico during the summer, for purposes of seasonal forecasting and climate change.**
2. **Show how dominant modes of large-scale climate variability in North America for the warm season are represented in the regional climate model simulations, and compare to observations for our regional climate simulations.**
3. **Establish that the regional climate model demonstrates reasonable performance during recent historical period of the late twentieth century to increase confidence for its use as tool for climate projection and seasonal forecasting.**

Dynamical downscaling of global seasonal forecasts and climate change projections

Regional Climate Model : We use the Weather Research and Forecasting (WRF) model to dynamically downscale: 1) two well performing GCMs (HadCM3 and MPI-ECHAM5) from IPCC A2 emission scenario for historical simulations per the model performance evaluation of Dominguez et al. (2009); 2) retrospective Climate Forecast System (CFS) seasonal forecasts for the warm season, initialized in spring (1982-2000); and 3) the NCEP-NCAR atmospheric reanalysis. The RCM simulation domain covers all of the contiguous U.S. And Mexico at a grid spacing of 35 km. Model parameterization options conform to what is used for operational high-resolution WRF short-term forecasts at University of Arizona. Spectral nudging is employed in the RCM to retain the variability of large-scale atmospheric circulation patterns, such as ridges and troughs. The RCM then adds value over the GCM by an enhanced representation of dynamical processes on the mesoscale strongly tied to terrain forcing. The regional model substantially improves warm season precipitation, such that a well-defined North American Monsoon exists where none existed in the driving global models.

Observed JA precipitation — *MPI model JA precipitation* — *WRF-MPI downscaled JA precipitation*

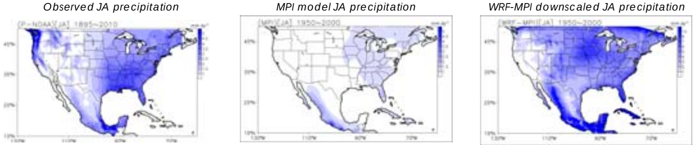

Figure 1: Precipitation climatology (mm day^{-1}) for July-August from a NOAA observational dataset (left), MPI global model (center) and downscaled WRF-MPI (right) for late 20th century.

Standard Precipitation Index (SPI): Defines anomalously wet or dry conditions using a given precipitation record fit to a gamma distribution function, and a common measure of drought in the western U.S. Here we use SPI to demonstrate the improved representation of interannual variability in the downscaled NCEP-NCAR atmospheric reanalysis and CFS warm season forecasts (Fig. 2). In particular, the downscaled CFS model is much more skillful in representing the interannual variability of the monsoon in Arizona and northwest Mexico, regions 1 and 2 of the North American Monsoon Experiment, respectively.

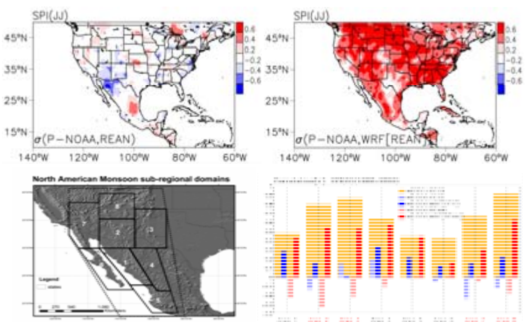

Figure 2: Upper panel: correlation of original NCEP-NCAR global reanalysis precipitation (left) and WRF reanalysis downscaled precipitation (right) against observed P-NOAA precipitation. Lower panel: NAME precipitation regions for research purposes (left) and correlation over each area for the suite of types of GCM and RCM model simulations as indicated (right). Regions within the United States highlighted in red.

Influence of large-scale atmospheric circulation variability forcing on model-simulated warm season precipitation

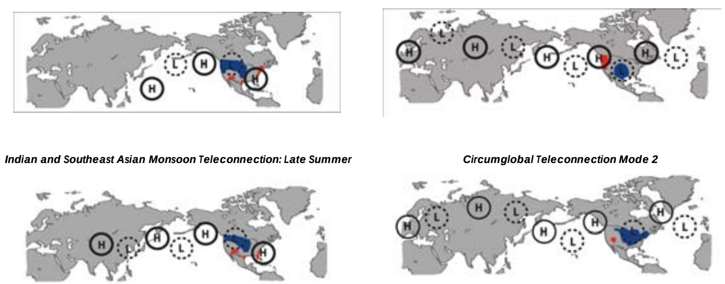

Figure 3: Dominant warm season teleconnection patterns that affect the continental scale distribution of precipitation in North America, as labeled. Approximate pattern of 500-mb geopotential height anomalies shown for the positive phases of the modes. Blue (red) indicates anomalously wet (dry) conditions (Ciancarelli et al. 2011, submitted).

Observed Dominant Warm Season Teleconnection Patterns: Using high resolution PRISM-derived SPI for the twentieth century, we have established the dominant modes of warm season precipitation variability in North America and their relationship to atmospheric forcing (Ciancarelli et al. 2011). Several atmospheric circulation teleconnection patterns are the first order factors in interannual variability of warm season precipitation (Fig. 3). The well-known anti-phase relationship in precipitation between the Southwest U.S. and central U.S. is related to forcing from the El Niño Southern Oscillation and Pacific Decadal Variability (ENSO-PDV), and the quasi-stationary Rossby wave for this pattern emanates from the western tropical Pacific in early summer (June, July) as shown in Castro et al. (2007). The forcing region for this teleconnection pattern shifts to the Indian and Southeast Asian monsoon region in late summer (July, August) and it becomes decoupled from Pacific SST forcing. The two phases circumglobal teleconnection pattern (CGT, Ding and Wang 2005) govern precipitation variability more in the central and eastern U.S. Though the CGT is not related to Pacific SST forcing, it may have a tie to the Atlantic or arise from pure stochastic forcing in the atmosphere. These are the dominant modes of atmospheric circulation we are looking for in our model simulation results.

Warm season teleconnections in the model simulations: A preliminary analysis indicates that these warm season teleconnection patterns and their associated precipitation responses (in JA SPI) are indeed present in the model simulations. Fig. 4 shows the dominant mode of precipitation and its relationship to global sea surface temperature anomalies in the CMAP product, the MPI global model and the WRF-MPI downscaled model for the late twentieth century. All three panels show a clear relationship of a wet and early monsoon to La Niña, low PDO conditions. Note that this relationship is even more pronounced in the dynamically downscaled precipitation (bottom panel). A clear quasi-stationary Rossby wave response corresponding to the ENSO-PDV and Indian, Southeast Asian monsoon teleconnection in Fig. 3 appears as one of the dominant modes in July and August. Very similar results are obtained when dynamically downscaled CFS and HadCM3 data are considered (not shown), and this likely accounts for the ability of the regional model to improve warm seasonal forecast skill as shown in Fig. 2 (lower right panel).

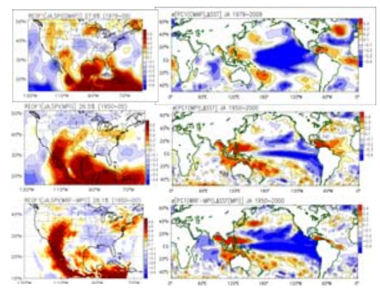

Figure 4: Left: Dominant rotated EOF of JA SPI for CMAP product (top), MPI global model (center), and WRF-MPI downscaled (bottom). Right: correlation of SST anomalies against the corresponding PC time series.

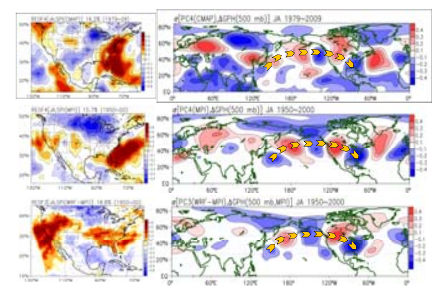

Figure 5: Left: Modes of JA SPI for CMAP product (top), MPI global model (center), and WRF-MPI downscaled (bottom). Right: correlation of geopotential height anomaly at 500-mb with the corresponding PC time series. Path of the quasi-stationary Rossby wavetrain indicated.

Conclusions

VALUE ADDED OF RCMs: Current GCMS have a very poor representation of warm season precipitation in the western U.S., which makes them inadequate for impacts assessment, such as water resource projection. This is especially the case when considering the North American monsoon. Regional climate models can add substantial value in this regard, as our WRF simulations have a reasonable representation of North American monsoon climatology and interannual variability.

IMPORTANCE OF NATURAL VARIABILITY: Well-performing GCMs do have an reasonable representation of atmospheric teleconnections that govern the continental-scale distribution of precipitation for the North American warm season. Therefore, a regional climate model should ensure that these large-scale teleconnections are preserved as to ensure the correct precipitation responses. A spectral nudging approach is most appropriate.

RELATION TO CLIMATE EXTREMES: It is important to distinguish the spatial modes of warm season precipitation variability according to their physical drivers, as this has bearing on climate predictability. Modes that have a strong dependence on sea surface temperature forcing should have some predictability at a seasonal timescale. Knowledge of how these forcing mechanisms, such as ENSO-PDV, change in the future is key to understand how climate change may synergistically interact with natural climate variability to intensify climate extremes.

SOCIETAL RELEVANCE: The Southwest U.S. urgently needs improved seasonal forecast and climate change projection at a fine enough spatial scale adequate for decision making purposes. We are demonstrating that a RCM as a dynamical downscaling tool is likely the better alternative to assess long-term water resource availability and basin-scale hydrology.

Selected References

Castro, C.L., R.A. Pielke, Sr., J.O. Adegoke, S.D Schubert, and P.J. Pegion, 2007. Investigation of the Summer Climate of the Contiguous U.S. and Mexico Using the Regional Atmospheric Modeling System (RAMS). Part II: Model Climate Variability. *J. Climate*, **20**, 3866-3887.

Ciancarelli, B., and co-authors., 2011. Influence of Large-scale teleconnections on Dominant Patterns of U.S. Warm Season Precipitation Variability in a Fine Resolution Observational Record (in preparation).

Ding , Q., B. Wang, 2005. Circumglobal teleconnection in the Northern Hemisphere summer. *J Climate*. **18**, 3483–3505

Dominguez, F., J. Cañon, and J. Valdes, 2009. IPCC-AR4 climate simulations for the southwestern U.S.: the importance of future ENSO projections. *Clim. Change*, DOI:10.1007/s10584-009-9672-5.

Saha, S., and coauthors, 2006. The NCEP Climate Forecast System. *J. Climate*, **15**, 3483-3517.

Acknowledgements

This research is supported by the National Science Foundation under grants AGS-0813656 and AGS-0823090 and the University of Arizona Water Sustainability Program (WSP). Carlos Carrillo has been additionally supported through a Graduate Incentives for Growth Award by the Graduate College of the University of Arizona. The authors acknowledge Dr. Francina Dominguez and Eric Rivera for their assistance with this project and Drs. Russ Vose and Ed Cook for their assistance in obtaining the P-NOAA precipitation dataset.