ID# H53E-0988

Can Regional Climate Models Improve Warm Season Forecasts in the North American Monsoon Region?

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Our **goal** is to improve the seasonal forecasts in the North American Monsoon region by dynamically downscaling Climate Forecast System (CFS) global coupled ocean-atmosphere model seasonal forecasts (Saha et al. 2006) using the Weather Research Forecast (WRF) regional climate model.

Hypothesis

1. WRF should retain or enhance variability of larger-scale features provided by the driving global model (i.e. those on the synoptic scale)
2. WRF should also add information on the smaller scale because of increase in grid spacing, finer spatial scale data (e.g. terrain, landscape) and possibly differences in model parameterized physics.
3. WRF should add information that is actually of value, as demonstrated by comparing downscaled results with independent metrics

Background

Official U.S. seasonal climate forecasts by the National Oceanic and Atmospheric Administration (NOAA) are issued by the Climate Prediction Center (CPC), a branch of the National Center for Environmental Prediction (NCEP). CPC uses the Climate Forecast System (CFS) global coupled ocean-atmosphere model as the numerical modeling component of these forecasts. Recently, NCEP has produced a comprehensive long-term retrospective hindcast ensemble forecasts for the years 1980-2005, as described in Saha et al. (2006), for climate research purposes. For each hindcast year, an ensemble of approximately 10-15 members is produced, generated by different initializations by NCEP Reanalysis 2 at the beginning of each month.

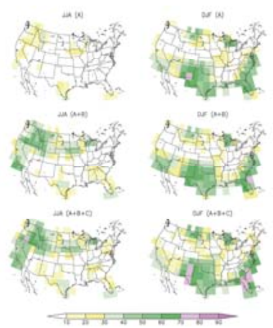

Figure 1: Spatial distribution of retrospective CFS model forecast skill (% anomaly correlation) of the ensemble forecasts of precipitation for JJA (left) and DJF (right). Forecasts made at 1 month lead. The number of ensemble members increases as shown in the panels (From Saha et al. 2006).

The CFS model demonstrates:

1. Greater skill when a greater number of ensembles members are used
2. An ability to forecast tropical Pacific SSTs and large-scale teleconnection patterns, at least as evaluated for the winter season
3. Greater skill in forecasting winter than summer climate.

Winter climate is largely dependent on synoptic-scale mid-latitude storms, while summer precipitation is more related to mesoscale processes, such as the diurnal cycle of convection, low-level moisture transport, propagation and organization of convection, and surface moisture recycling. In general, these are poorly represented in global atmospheric models

Spectral Nudging in WRF

RCMs loose synoptic scale variability from the driving GCM when forced only at its lateral boundaries. By using spectral nudging, in which selective nudging at only the largest scales takes place throughout the whole domain of the model for prognostic fields like geopotential height, winds, and temperature. The nudging is confined to the upper-levels of the atmosphere above the boundary layer. In this way, the variability of the synoptic scale circulation features may be maintained during the model integration, while allowing the RCM to still add value at the smaller scales. For this work, we use the spectral nudging technique in Miguez Macho et al. (2005) recently implemented in the WRF model.

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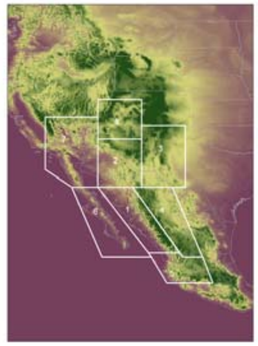


Figure 2: North American Monsoon region and the eight sub-regions delineated by the NAME, Region 1 and 2 are of particular interest in our study.

Results

RCMs, such as WRF, provide a more realistic representation of convective rainfall processes because they better resolve topography and the mesoscale circulation features tied to land surface forcing. Topographic forcing in the NAME region is particularly important and defines the spatial and temporal variability of rainfall.

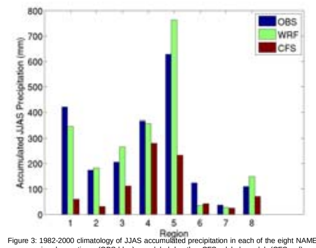


Figure 3: 1982-2000 climatology of JJAS accumulated precipitation in each of the eight NAME regions as seen in observations (OBS-blue), modeled by the CFS global model (CFS-red) and WRF-downscaled CFS (WRF-green). CFS and WRF are averaged over all 9 ensemble members.

Spatial and Temporal Variability of Precipitation

WRF simulations show more rainfall and are much closer to observations than precipitation from the CFS driving model (See Figure 3). The regional differences throughout NAME are accurately captured. Notably, rainfall in the core monsoon region and in Arizona is significantly improved in the downscaled estimates.

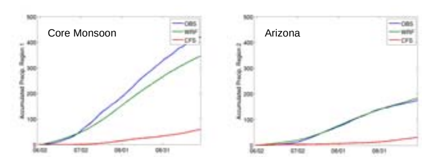
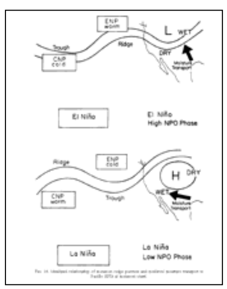


Figure 4: 1982-2000 climatology of JJAS seasonal precipitation variability in Region 1 (right) and Region 2 (right) as seen in observations (OBS-blue), modeled by the CFS global model (CFS-red) and WRF-downscaled CFS (WRF-green). CFS and WRF are averaged over all 9 ensemble members.

WRF-downscaled CFS simulations not only are better able to capture the total amount of precipitation falling during the NAM season, but also capture the seasonal evolution of the monsoon, particularly in the core monsoon region. The rapid ramp up in July and the decreased precipitation in September are well captured in the WRF simulations.



Interannual Variability of Precipitation

NAM rainfall is modulated in part by SSTs in the Pacific Ocean that in turn cause an atmospheric teleconnection response in the warm season. The Combined Pacific Variability Mode (CPVM) (Castro et al. 2007) is an index that relates well to this large-scale influence on monsoon rainfall.

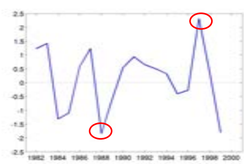


Figure 5: Cartoon explaining the teleconnection patterns that affect interannual NAM variability taken from Castro et al. 2001 (Left). Monsoon Index that shows the strength of the teleconnection patterns taken from Castro et al. 2008 (Right).

Funding
- NSF grant number 0813656, “Use of regional atmospheric modeling to improve short and long-term forecasting capability of the North American Monsoon System”. PI: C. Castro CoPI: F. Dominguez
- SAHRA (Sustainabil-ity of semi-Arid Hydrology and Riparian Areas) under the STC Program of the National Science Foundation, Agreement No. EAR-9876800 funded Francina Dominguez
- Science Foundation Arizona Grant number 431930 “ Using Regional Atmospheric Modeling to Investigate Heavy Monsoon Rainfall Events in Arizona and Socioeconomic Implications.”

Years of positive (negative) Monsoon Index, such as 1997 (1988), show anomalous low (high) precipitation in the NAM region and anomalous high (low) precipitation in the north-central part of the country. WRF-downscaled CFS accurately shows the precipitation anomalies in the NAM region with a slightly smaller spatial extent. The anomalies in the north-central part of the country are represented less accurately. We can also see these relationships by regressing the Monsoon Index against the anomalies of precipitation and 500mb geopotential height.

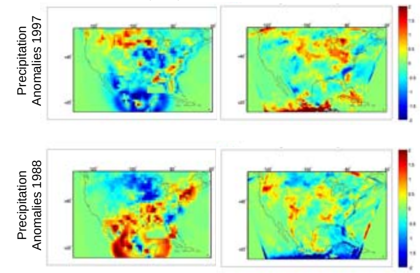
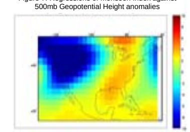


Figure 6: Precipitation anomalies for 1997 (Top) and 1988 (Bottom). These years respectively correspond to the positive and negative phase of the Monsoon Index. The maps correspond to CPC observations (Left) and WRF-downscaled CFS (Right). WRF simulations consist of 9 ensemble members.

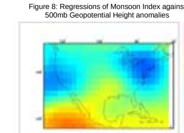
Observed (Reanalysis)

Figure 7: Regressions of Monsoon Index against 500mb Geopotential Height anomalies



Model CFS

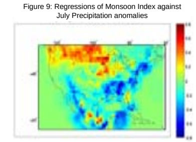
Figure 8: Regressions of Monsoon Index against 500mb Geopotential Height anomalies



The Geopotential height regressions show that the CFS data is accurately capturing the low pressure anomaly in the Western United States associated with lower monsoonal precipitation. Because of the spectral nudging, the 500mb heights in the WRF simulations are almost identical to the CFS ones.

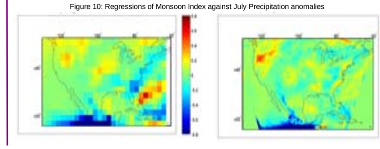
Observed (Reanalysis)

Figure 9: Regressions of Monsoon Index against July Precipitation anomalies



Model CFS **Model WRF**

Figure 10: Regressions of Monsoon Index against July Precipitation anomalies



The precipitation regressions show that the CFS and WRF data are accurately capturing the low precipitation anomaly in the NAM region. WRF anomalies show a more realistic spatial pattern as they extend further north than the CFS driving model. The positive anomalies in the northern part of the country are not as well captured. It is important to note that CFS model biases have not yet been corrected.

In **conclusion**, using the WRF regional climate model to dynamically downscale CFS global projections ***does*** improve the seasonal forecast in the NAM region because:

1. WRF is better able to capture the physical mechanisms that drive warm-season convective processes in the region - largely dominated by topographical controls.
2. While CFS underestimates precipitation throughout the region, WRF-downscaled CFS is much closer to observations both in total amount of rainfall falling during the NAM and the seasonal evolution of precipitation variability.
3. CFS shows some skill at capturing the circulation patterns that modulate summer monsoon rainfall in the NAM region.
4. Driven with a reasonable representation of large-scale circulation, WRF simulations show realistic interannual variability of monsoon rainfall.