Hydrologic Extremes in a changing climate: how much information can regional climate models provide?

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The **overarching science question** we propose to address is: Can regional climate models reproduce observed extreme historical hydrologic events and provide useful information about future hydrologic extremes?

Subsidiary Science Questions

1. To what extent do the RCM internal dynamics, relative to boundary forcing, influence its ability to reproduce the observed probability of precipitation extremes?
2. How will future extremes change under a warmer climate, and what information can we provide for the adaptation of urban hydraulic structures?

Motivation

Observational evidence suggests that a warmer atmosphere is causing an intensification of the global hydrologic cycle and an increase in extreme precipitation events for most of the extratropical regions (Huntington 2006, Groissman, 2005). Increase in extremes, have implications for the hydrologic infrastructure, such as flood control and stormwater management systems, designed to protect life and property.

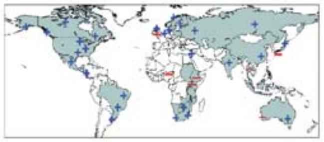

Figure 1: Regions where disproportionate changes in heavy and very heavy precipitation during the past decades were documented as either an increase (+) or decrese (-) compared to the change in the annual and/or seasonal precipitation (updated from Groisman et al, 2005), taken from Trenberth et al. (2007)

The spatial resolution of GCMs is much too coarse to resolve the processes that control the generation of precipitation extremes relevant to urban stormwater infrastructure. Regional climate models (RCMs), which can be used to downscale GCM output, have the potential to match, at least roughly, the spatial scales at which information is needed. This is particularly important for mountainous regions such as the western U.S. where RCM-based downscaling of future climate scenarios has been shown to provide more realistic estimates of hydrologic variables such as precipitation (See Figure). More importantly, there is a potential for amplification of hydroclimatologic extremes due to feedbacks that are not represented in GCMs.

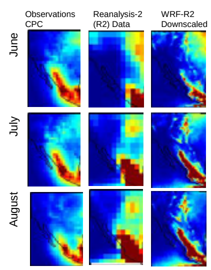

Figure 2: 1979-2000 June, July and August climatology of monthly precipitation over the Southwestern United States for CPC Observations (left), raw Reanalysis 2 (R2) (middle) and WRF-downscaled R2 (right).

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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Ancillary Science Questions

Can WRF reproduce observed probability of precipitation extremes in the Southwestern United States?

Methodology: We use WRF with spectral nudging to downscale 22 (1979-2000) years of Reanalysis-2 data (R2). The goal is to evaluate how WRF-downscaling reproduces heavy (95 percentile) and very heavy (99 percentile) precipitation. Our initial analysis focuses on the city of Tucson, Arizona.

Analysis of Precipitation Events in Tucson, AZ

Total amount of precipitation over Tucson has decreased over the past two decades (Figure 3, red shows observations). Both R2 (blue) and D-R2 (red) show this decrease in total precipitation. However, the raw R2 data seems to underestimate precipitation in the region, while D-R2 is much closer to observations.

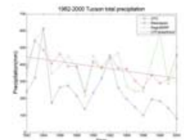
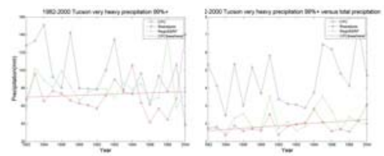


Figure 3: Total annual precipitation falling over Tucson, AZ from 1982-2000 from CPC Observations (red), raw Reanalysis 2 (blue) and WRF-downscaled (green).

Despite the decrease of total precipitation, heavy and very heavy events has remained constant, or slightly increased. The amount of total precipitation coming from heavy and very heavy precipitation has increased in the past two decades.



When compared to the R-2 data, the downscaled product (D-R2) has a more realistic representation of the intensity of heavy and very heavy precipitation and of the ratio of heavy and very heavy precipitation to total precipitation.

Bottom-up Approach. Letting the River Guide Us

We select the events that led to extreme flooding in the Santa Cruz river basin (Tucson). We then evaluate the upper-level circulation that led to these events and how WRF simulated these patterns, and the resulting precipitation. It is important to note that spectral nudging forces the WRF circulation to be equal to the driving model circulation. By analyzing the precipitation intensity and duration with respect to the atmospheric circulation, we can get an idea of the strengths and weaknesses of the WRF downscaling of these extreme events.

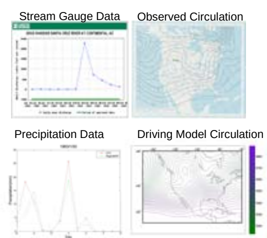


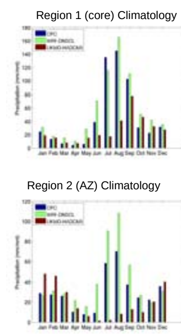
Figure 5: As an example of the methodology we present the flood that occurred on Feb 4, 1983 on the Santa Cruz River. The observed stream flow is on the upper left panel while the upper air pattern that led to the synoptic storm is seen on the upper right panel. The observed and modeled precipitation is on the lower left, while the WRF circulation is on the lower right.

How will precipitation extremes change under a warmer climate in the SW?

Methodology: We use WRF with spectral nudging to downscale 113 (1968-2081) years of UKMO-HadCM3 data. The goal is to evaluate how WRF-downscaled future climate data represents both 20th century and future extreme precipitation events. We begin by looking at the 20th century climatology, and focusing on the North American Monsoon Region.

Why did we choose the UKMO-HadCM3?

We chose to downscale the UKMO-HadCM3 from the suite of IPCC-AR4 models because it best represented the historical precipitation and temperature climatology in the Southwest and the upper atmosphere circulation patterns in the Northern Hemisphere. Furthermore, ENSO is realistically simulated with this model (Dominguez et al. 2009)



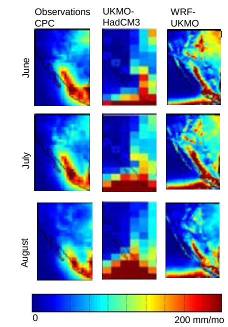


Figure 6: 1968-2000 monthly precipitation climatology for CPC observations (blue), WRF downscaled UKMO-HadCM3 data (green) and raw UKMO-HadCM3 data (red). Spatially averaged over the NAME Region 1 (Core) and Region 2 (Arizona).

Figure 7: 1968-2000 June July and August precipitation climatology for CPC observatiosn, WRF downscaled UKMO-HadCM3 data and raw UKMO-HadCM3 data.

Evaluation of Downscaled UKMO-HadCM3 Historical Climatology

Much like our analysis using WRF to downscale Reanalysis-2 data, we see that the regional model is better able to capture the spatial distribution of precipitation over the complex terrain of the North American Monsoon Region than the raw UKMO-HadCM3 data for the 20th century simulation. The GCM has trouble with the topographically induced convection, while WRF captures it and correctly extends the precipitation north into the Southwestern United States. Furthermore, when we look at the spatial average over the Core Monsoon Region and Arizona, we see that WRF clearly improves the monthly precipitation climatology by invigorating summer precipitation in both regions and decreasing winter precipitation in the Southwestern United States.

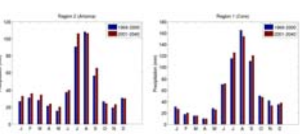


Figure 8: Historical (1968-200) and future (2001-2040) monthly precipitation climatology for the Core Monsoon and Arizona regions. We see a future increase in precipitation over Arizona, and roughly equal precipitation in the Core Monsoon region.

Conclusions

- When compared to the Reanalysis-2 data, WRF downscaled R2 is better able to capture the intensity and temporal variability of total precipitation and extreme precipitation events in the Tucson area.
- Our analysis of extreme events is guided by the stream flow response, preliminary results over Tucson shows that this will pinpoint the strengths and weaknesses in the WRF downscaling.
- The UKMO-HadCM3 model is currently being downscaled from 1968-2081. Preliminary results show WRF considerably improves the spatiotemporal variability of the precipitation climatology.

Future Work

- Continue the analysis of extreme precipitation in Tucson and extend it to other cities in the Western United States.
- Evaluate how future extreme precipitation events will change under a warmer climate.
- Evaluate what spatial resolution is necessary to reproduce the observed probability distribution of precipitation using high-resolution simulations over selected areas.
- Improve WRF parameterizations of convection and cloud microphysics based on these results.