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

FINAL REPORT

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This report summarizes work at the University of Washington (this was a joint project with the University of Arizona, which reports separately). The primary activities conducted by the University of Washington over the course of the project are summarized below.

Task 1: Selection of test sites, observation data and comparison to NARCCAP (UW Lead)

We proposed to identify a set of about 10 urban areas across the western U.S., and hourly precipitation data within each of these areas, which were extracted from the NCDC TD 3240. We also proposed to analyze the annual maximum series of precipitation extremes simulated for NARCCAP (using Reanalysis boundary forcing) for the grid cells close to station data, and to compare the distributions of annual maximum precipitation for accumulation intervals ranging from one to 28 hours. Recognizing that there may inevitably be differences between the station data and RCM grid cell values, we proposed to examine the scale dependence in the distributions of extremes.

Status:
We identified 20 major urban areas in the western U.S. (Mishra et al., 2012a) and obtained hourly precipitation data (TD-3240) for precipitation stations located in vicinity of each of them from the National Climatic Data Center (NCDC). We extracted data for stations within the 20 areas so defined for which records for the period 1950-2009 had minimal gaps. Years with more than 10% missing data were removed from the analysis. We focused our attention on relatively short accumulation durations (1, 2, 3, 9, 12,and 24 hours) as these are the durations that are most likely to lead to urban flooding, given the relatively small size of most urban drainage basins. Moreover, these short duration events that may generate the largest peaks in urban regions with short-response time.

We estimated trends and their statistical significance for each of the selected precipitation stations around major urban areas in the Western U.S. The results show substantial spatial variability in patterns of increasing and decreasing trends. For instance, urban areas such as Seattle, Portland, Salem, and Salt Lake City had stations with both statistically significant upward and downward trends in hourly annual maxima for 1 to 24 hour durations. Albuquerque, Casper, Los Angeles, and San Diego had significantly upward trends for at least one of the selected precipitation stations at various precipitation durations (1-24 hours). On the other hand, Phoenix had significant declines in 1-9 hour annual maximum precipitation.

We also found that the fraction of stations (out of total 96 analyzed in this study) showing statistically significant increasing trends were substantially higher (about three times) than those with downward trends. Furthermore, the number of stations with significant increases was higher for short (1 and 2 hour) and long (12-24 hour) durations than those of for 3 or 9-hour durations. These results reflect the general tendency of increasing annual maximum precipitation in urban areas in the Western U.S.

The major result however was that the NARCAP RCMs all have difficulties in reproducing properly the season during which the annual maxima occur. In the observations, the annual maximum 24 hour precipitation occurs in winter at almost all sites; however the annual maximum hourly precipitation occurs in summer at the inland sites, but in winter at the coastal sites. The RCMs, on the other hand, simulated annual maximum hourly values in winter, for both coastal and inland sites. This is the case regardless of whether the RCM boundary conditions are provided by the NCEP/NCAR reanalysis, or by current climate

Regional Model Evaluations from NARCCAP:

Because the station data essentially represent points, whereas RCM output is representative of areal averages, we used an areal reduction factor (ARF) approach ([*Asquith*, 1999]) to convert point precipitation estimates from the stations to areal precipitation that can be compared to precipitation maxima obtained from the RCMs output. To estimate ARF, we used the method of *Leclerc and Schaake* [1972] as described in equation (1):

$$ARF = \frac{Z_E}{Z_T} = 1 - e^{-1.1t^{0.25}} + e^{(-1.1t^{0.25} - 0.01A)} \qquad (1)$$

Where ARF is the Areal Reduction Factor (dimensionless), Z_E is effective precipitation over an area (mm), Z_T is point (station) precipitation (mm) at recurrence interval T years, t is duration of time in hours, and A is area (NARCCAP grid size in our case, or 50 km). We also considered the approach of Rodriguez-Iturbe and Mejía [1974] that is based on spatial correlations between points at the expected distance between two randomly chosen points (stations) in an area. We were limited in application of this method by the fact that some of our urban areas have only one station, hence precluding the estimation of the correlation distance was not possible. Moreover, *Asquith* [1999] found that despite the variations in various approaches to estimate ARF, the ARF values from various sources show similar behavior. Therefore, we decided to use equation (1).

In Mishra et al. [2011] we evaluated bias for each urban area relative to ensemble mean precipitation maxima at the selected precipitation durations simulated by the NARCCAP RCMs with GCM and NCEP boundary conditions. For most of the urban areas (15), RCM-simulated ensemble 3-hourly annual precipitation maxima showed high negative bias (0 to -70%). However, RCM-simulated ensemble 3-hourly annual precipitation maxima showed high positive bias (~ 100%) for a few urban areas (Spokane, Boise, Salt Lake City, and Casper). 3- hourly precipitation maxima for winter and summer seasons were also underestimated by the RCMs for most of the urban areas. RCMs simulated precipitation maxima showed negative bias for the majority of urban areas (13) in 9-hourly annual precipitation maxima. However, positive bias (0-200%) in 9-hourly annual and winter precipitation maxima was substantially higher for Spokane, Boise, Salt Lake City, and Casper. Similar to short-duration precipitation maxima, majority of urban areas showed negative bias for 12 and 24-hourly annual precipitation maxima. Urban areas such as Spokane, Boise, Salt Lake City, and Casper showed consistent high positive bias in RCM simulations for all the selected durations for annual and winter precipitation maxima.
The percentage biases in annual and seasonal precipitation maxima simulated by the RCMs with NCEP boundary conditions were also estimated. In general, RCM performance with NCEP boundary condition was similar to the RCMs with GCM boundary condition. For instance, most (16) of the urban areas showed high negative bias (0-70%) in 3-hourly annual precipitation maxima simulated by the RCMs. For the urban areas (e.g. Spokane, Salt Lake City, and Casper) that showed positive bias, bias increased with precipitation duration. Spokane, Boise, Salt Lake City, and Casper consistently showed high positive bias at all the selected precipitation maxima durations (e.g. 3, 9, 12, and 24 hours) for annual as well as winter season. On the other hand,

Phoenix, Seattle, and San Diego showed consistent negative bias at all the precipitation maxima durations

Task 3: Sensitivity of extreme precipitation prediction to RCM spatial resolution (UW Lead)

In order to provide high-resolution land surface conditions to initialize high-resolution WRF runs, we proposed to perform off-line simulations with the Noah land surface scheme used in WRF. From the list of the hourly and 24-hourly annual maximum precipitation events at the target stations identified in task 2, we proposed to construct a composite set of dates representing a number (to be determined, but probably 25-50) of the maxima across the stations. While we do not intend to target all of the maxima at all of the stations, we will select a sequence of dates that capture maxima from each of the three major climatic types (winter dominant, summer dominant, and mixed) across the region.

Status:
As the project progressed, we decided that this task was better suited to the capabilities of co-I Dominguez and her group, and in fact the issue of spatial resolution is addressed in Tripathi and Dominguez [2013]. Instead, we focused our efforts on understanding the relationship between precipitation extremes and daily air temperature in the historical record. As reported in Mishra et al. [2012b], we analyzed the relationship between hourly precipitation exceeding the 99th percentile of non-zero hours and the corresponding daily average air temperature at over 1000 stations across the continental U.S. for the period 1950-2009. We found that at most (about 80%) of the stations, regression slopes between hourly extreme precipitation and daily mean temperatures are higher than the Clausius-Clapyron (CC) rate. Stations located in the western coastal region exhibited the lowest regression slopes, which were considerably lower than the CC rate, while stations in the northern tier of the continental U.S. had the highest regression slopes (median > 16 %). More stations (75%) had super-CC slopes in summer than in winter. Stations in the southern U.S. and stations in the northern U.S. had higher slopes in summer than winter, while this was reversed for stations in the southern U.S... We argued that it is physically implausible that the intensity of extreme rainfall events could be as sensitive to local temperature as reflected by the regression slopes, and that the largest inferred sensitivity values must be at least partially a consequence of factors relating to temperature gradients as opposed to temperature in its own right.

Publications:

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