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Uncertainties In Future Projections Of Extreme Rainfall: The Role Of Climate Model, Emission Scenario And Randomness

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UNCERTAINTIES IN FUTURE PROJECTIONS OF EXTREME RAINFALL AT FINE SCALES: THE ROLE OF VARIOUS SOURCES

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INTRODUCTION AND PROBLEM DEFINITION

Globally, climate change has resulted in substantial variations in annual extreme rainfall quantiles across different durations and return periods. Current predictions, however, exhibit large uncertainties and the community tends to use multi-model ensemble projections to characterize the potential changes in future extremes. Nonetheless, little attention has been given to address and quantify various sources of uncertainty that are embedded in multi-model ensembles. We argue that the uncertainty in future projections of extreme rainfall stems from multiple sources, and thereby, there is a crucial need to address and quantify the uncertainties contributed from different modeling steps, particularly at finer temporal resolutions and local scales, where climate models' outputs are not currently available. We propose a simulation-based approach to identify various sources of uncertainty and demonstrate its application for analyzing the extreme rainfall predictions in Saskatoon, Saskatchewan, Canada.

METHODS AND DATA

We built up a combined stochastic-deterministic scheme for downscaling-disaggregating future rainfall projections obtained from Global Climate Models (GCMs). The scheme uses a sequential approach to (1) spatially downscale the future daily GCM projections using a stochastic rainfall generator; (2) temporally downscale the projected daily realizations to hourly sequences using a deterministic K-Nearest Neighbors (KNN) algorithm; and finally (3) quantify the changes in the Annual Maximum Precipitation (AMPs) quantiles based on Generalized Extreme Value (GEV) distribution. The stochastic spatial downscaling is based on acclaimed LARS-WG model, which uses a set of parameters for probability distributions of rainfall patterns to generate synthetic rainfall time series of arbitrary length by randomly selecting values from the appropriate distributions (Semenov and Stratonovitch [1]). For future projections, the GCM simulations are used to infer the so-called change factors that characterize the relative expected changes in weather variables at the GCM scale (Nazemi *et al.* [2]), Chun *et al.* [3]). Our deterministic KNN disaggregation uses the observed hourly rainfall profiles at the neighboring baseline days to break the simulated daily rainfall into hourly resolution

(Prodanovic and Simonovic [4]). The disaggregated hourly sequences are then analyzed across various resolutions to identify the corresponding AMPs, which are consequently used to characterize the extreme quantiles of various return periods using GEV distribution (Hassanzadeh *et al.* [5]).

We applied this model to generate large ensemble of spring and summer rainfall in Saskatoon, Canada, where the climate is largely variable and most intense annual rainfall events occur in the summer in the form of convective storms over small areas. The hourly precipitation data during the baseline period (1961-1990) were used to calibrate and validate the LARS-WG parameters and identify the optimum window size for KNN disaggregation (i.e. K=5). The parameters of the LARS-WG model were further perturbed based on the change factors calculated from the recently released CMIP5 data (http://cmip-pcmdi.llnl.gov/cmip5/). The 21st century (2011-2100) projections of the Canadian GCM (CGCM) and UK's Hadley model (HadCM), forced with the three frequently used Representative Concentration Pathways (RCPs); i.e., RCP2.6, RCP4.5 and RCP8.5 provided six different sets of monthly change factors to characterize future daily rainfall in Saskatoon. In order to have a consistent change factors with 30 years baseline data, we calculated the change factors in three-30 years slices related to short-term (2011-2040), middle-term (2041-2070) and long-term (2071-2100) GCM/RCP projections. For each GCM/RCP combination, we generated 1000 realizations of daily rainfall for each future segment with the length of 30 years and used the calibrated KNN model to disaggregate the future rainfall series into hourly segments.

RESULTS AND DISCUSSION

To address the uncertainty contributed from GEV quantifications, we fitted the GEV parameters using the Maximum Likelihood Estimator and characterized the lower and upper parametric bounds, given the uncertainty in the baseline AMPs at different durations. We noticed that GEV can include the observed AMPs within 95% confidence intervals; however, expected GEV quantiles can have some deviations from observed AMPs, particularly at shorter durations and larger return periods, where upper tails are extrapolated.

To address the uncertainty contributed from LARS-WG, we generated 1000 daily realizations for baseline period and characterized the AMP quantiles related to each realization at various return periods. The expected and 95% confidence intervals obtained from stochastic simulation were compared with corresponding theoretical quantiles derived from fitting the GEV distribution to the observed AMPs. We noted that the simulated confidence intervals systematically underestimate the theoretical 95% limits but overestimate the expected theoretical quantiles, particularly at large return periods, where the uncertainty in simulated AMPs are intensified by GEV extrapolation at upper tails.

To analyze the uncertainty contributed from the KNN-disaggregation step, we provided the algorithm with the observed daily series during the baseline, and disaggregated it into an hourly sequence. The disaggregated series was used to extract the simulated AMPs, which were further fitted to a GEV distribution to characterize the disaggregated extreme quantiles and their corresponding 95% limits. We noted that the KNN-based quantiles have a tendency to underestimate the expected quantiles and the corresponding upper bounds obtained by fitting the GEV fit to the observed AMPs at shorter durations as well as larger return periods.

Apart from uncertainties contributed from extreme quantification, downscaling and disaggregation, future fine-scale projections contain additional uncertainty related to large-scale climate predictions. These uncertainties are related to limitations in identifying local scale climate variability based on GCMs large-scales outputs as well as differences in projected large-scale climate change obtained across GCMs and RCPs. Most results are not shown here for brevity.

As noted above, LARS-WG uses change factors that are obtained at GCM scale to characterize future changes in mean monthly rainfall amount as well as durations of wet and dry spells at the local scale. We calculated the change factors for each GCM/RCP combination twice, either with or without considering the changes in wet and dry spells and compared the simulated daily extreme quantiles with those obtained for the baseline periods with no change in monthly rainfall properties. Figure 1 summarizes our analysis. We noted that the main contributor of change in daily AMPs is relative changes in monthly expected values; however, changes in the dry and wet spells can significantly affect quantifications at larger return periods, which in some occasion can result in uncertainty in determining the sign of change in extreme quantiles. Comparing the results across various GCMs, RCPs and time slices, we noted that the simulated changes can dramatically change based on different GCM/RCP projections and time horizons, however uncertainty in RCPs seems to have more contribution in the total uncertainty in determining the sign and magnitude of future change in the AMP quantiles.

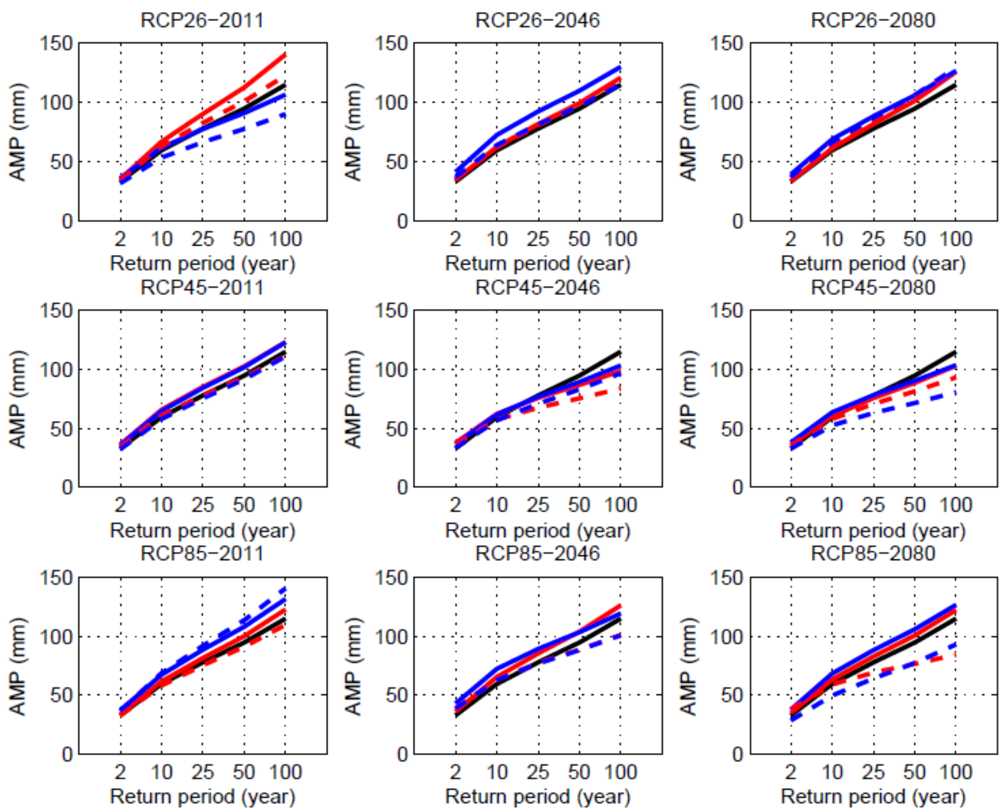

Figure 1. Uncertainties in future projections of daily AMP quantiles in the city of Saskatoon according to HadCM (blue) and CGCM (red) forced with three RCPs. Future projections are obtained using LARS-WG model in which the baseline parameters are perturbed using 2 sets of change factors, i.e. with considering variations in wet and dry spells at the large-scales (solid lines) and without considering those variations (dashed lines). The corresponding quantiles during baseline period are also shown in black.

CONCLUSION AND OUTLOOK

Our study provides an improved empirical understanding of various sources of uncertainty in future projections of extreme rainfall quantiles. Such a systematic diagnosis needs to be extended into other downscaling/disaggregation schemes and repeated in different geographic regions and/or with other GCMs and RCPs to provide a comprehensive view of current uncertainties in future projections of extreme rainfall quantiles at finer time-space resolutions.

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