Analysis of potential impacts of climate change on intensity–duration–frequency (IDF) relationships for six regions in the United States

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ABSTRACT

Potential changes in climate are expected to lead to future changes in the characteristics of precipitation events, including extreme rainfall intensity in most regions. In order for government agencies and design engineers to incorporate these trends and future changes into assessment and design processes, tools for planning and design should be capable of considering nonstationary climate conditions. In this work, potential changes are investigated in intensity–duration–frequency (IDF) curves, which are often used for assessment of extreme rainfall events, using historic data and future climate projections. An approach is proposed for calculating IDF curves that incorporates projected changes in rainfall intensity at a range of locations in the United States. The results elucidate strong regional patterns in projected changes in rainfall intensity, which are influenced by the rainfall characteristics of the region. Therefore, impacts of climate change on extreme hydrologic events will be highly regional and thus such assessments should be performed for specific project locations.

Key words | areal reduction factor, climate change, intensity–duration–frequency (IDF) relationships, North American Regional Climate Change Assessment Program

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ABBREVIATIONS

AOGCM	atmosphere-ocean general circulation model
ARF	areal reduction factor
EVI	extreme value type I
GCM	global climate model
GHG	greenhouse gases
HadCM3	Hadley Centre Coupled Model Version 3
HRM3	Hadley Regional Model 3
IDF	rainfall intensity–duration–frequency
IPCC	Intergovernmental Panel on Climate Change
NARCCAP	North American Regional Climate Change Assessment Program
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PCMDI	Program for Climate Model Diagnostics and Intercomparison
RCM	regional climate model

INTRODUCTION

The large number of extreme flood events that have been observed in recent years worldwide has put a focus on potential changes in extreme weather conditions due to climate change. Trends in recent decades indicate an increasing frequency of extreme events in many regions (e.g. Madsen *et al.* 2009). Further, changes in the characteristics of extreme precipitation events can have significant impacts on many sectors of society (Folwer & Kilsby 2003).

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Various regional studies have revealed evidence of significant changes in extreme precipitation at local scales (e.g. Haylock & Nicholls 2000; Fowler & Kilsby 2003; Schmidli & Frei 2005; Su *et al*. 2006). Adamowski & Bougadis (2003) analyzed annual maxima of rainfall intensities for durations between 5 min and 12 h from 44 rainfall stations in the province of Ontario, Canada. They found significant positive as well as negative trends in some regions, especially for short duration events. It has been reported that the frequency of extreme precipitation events has increased over most land areas in the late 20th century (IPCC 2007). However, Frich *et al*. (2002) analyzed daily precipitation records of a global data set and indicators based on daily precipitation records and revealed no clear patterns of trends.

The recent Intergovernmental Panel on Climate Change (IPCC) Assessment Report (IPCC 2007) utilized a number of global climate models (GCMs) to assess future climate given various emission scenarios, under the assumption that greenhouse gas emissions have driven and will continue to drive significant warming in the future. Based on climate model simulations with different emission scenarios it was concluded that it is 'very likely' that trends in extreme precipitation and hydrologic events will continue to increase. Other climate-based projections also suggest increasing precipitation intensity and variability in future decades (Endreny & Imbeah 2009).

Rainfall intensity–duration–frequency (IDF) curves are a probabilistic tool, which have proved useful in planning and design studies in water resources management and engineering. IDF curves enable assessment of the extreme characteristics of rainfall. These tools provide a simple means of communicating information about local extreme rainfall characteristics to enable assessment of flooding risk and design for other hydrologic purposes. IDF curves are used, for example, in design of hydraulic structures such as bridges and culverts. Urban drainage design is often based on the values provided through IDF curves (Guo 2006).

IDF curves consist of rainfall intensities for design storms of different frequency and duration (e.g. the 100-year, 6 h storm). There are different methods for determination of these intensities. The United States Government has issued various reports for methods of calculation of design storm depths/intensities for IDF curves. Recently Atlas 14 (Bonnin *et al*. 2004) has been issued by the National Oceanic and Atmospheric Administration (NOAA) for certain regions, and design storm depths can be obtained through an online interface for a range of durations and return periods enabling easy construction of IDF curves. Because of the location-specific nature of the extreme event rainfall, area-specific IDF curves are often calculated by local government agencies. Calculations of IDF curves are typically based on historic observations (e.g. Atlas 14).

Some research has indicated that because of anthropogenic forces, the Earth is now in a nonstationary climate (Milly *et al*. 2008; Brown 2010). If climates have indeed become 'nonstationary', then the definition of return period as used for design criteria must be revisited (Mailhot & Duschene 2010). Owing to this nonstationarity, planning and engineering design for future decades would benefit from calculating IDF intensities, especially in urban areas, not only from historic observations, but also taking into account expected changes in atmospheric conditions for the life of the target structure or area. Steps should be taken to address potential changes in IDF design depths to assist government agencies and private companies. Simple methods are needed to enable ease of use by agencies and design firms, and transposition of the method for different locations and purposes.

A few studies have been conducted recently to calculate IDF curves addressing assessment of climate change or climate trends. Some of these efforts have used gridded data from GCMs. Mailhot *et al*. (2007) calculated regional IDF curves from gridded climate data. Further, Madsen *et al*. (2009) updated IDF relationships in Denmark with rainfall data from a newer database. For the durations (30 min to 3 h) and return periods (~10 years), which are typical for most urban drainage designs, the increase in intensity was reported on the order of 10%. The analysis revealed that the changes are not statistically significant compared with the uncertainties of the model used, but the increased design intensities are large and thus have significant consequences for the cost of engineering design.

One of the core challenges in climate change impact assessments is dealing with the issues surrounding spatial scale. GCMs are the most frequently used tool in global climate modeling. GCM simulations are performed with elevated concentrations of anthropogenic greenhouse gases (GHGs) to assess potential changes in environmental processes due to climate change. The recent availability of higher spatial and temporal resolution climate data, as produced by regional climate models (RCMs), has facilitated impact assessments. Although the spatial resolution of recent GCMs/RCMs has greatly improved because of increased computational power, the grid size of all GCMs/RCMs (at least in tens of kilometers) is still much larger than the typical station-scale measurements such as those monitored using rain gauges and used for watershed studies. Therefore, the output from the GCMs/RCMs for each model grid is uniform and considered to be an average estimate within the individual model grid. On the other hand, historic data are typically provided at station or point spatial scales. Assessment of extreme precipitation events needs to be conducted at scales much smaller than that of most GCMs and RCMs, and classic design techniques typically utilize point station records. To assess potential climate change impacts, these spatial scales must be bridged.

A simple method for bridging spatial scales of precipitation is the use of delta change factors. In this approach, predicted changes at the gridded scale are transposed to the station scale. Use of the delta change method requires assumptions about station to areal relationships (Mailhot *et al.* 2007). This may involve the use of areal reduction factors (ARFs). In this study, ARFs are used to relate gridded and station spatial resolutions for climate impact assessments. For climate impact studies, station-to-areal relationships are often assumed to remain constant (Mailhot *et al.* 2007). That is, historically based areal relationships between gridded and station data are assumed to be equivalent to those in the future for the respective gridded data set.

The goal of this study is to explore potential impacts of projected climate change on extreme rainfall characteristics for various climatic regions across the United States. This goal was met by satisfying the following objectives: (1) investigate the use of ARFs for describing station-scale changes in rainfall characteristics for climate change assessments; (2) develop IDF curves under baseline and climate change scenarios at both grid and station scales; and (3) compare relative impacts of climate change on rainfall intensities for various climatic regions of the United States.

METHODOLOGY

To assess potential impacts of future climate change on extreme rainfall events, six locations in urban areas were selected encompassing a range of climates and locations in the continental United States. These six locations were: Seattle, WA; Las Vegas, NV; Omaha, NE; Dallas, TX; Newark, NJ; and Miami, FL. For each location, station-scale rainfall historic data were obtained from the National Climatic Data Center (NCDC) of the National Weather Service (NWS). Historic and projected future grid-scale rainfall data were obtained from the North American Regional Climate Change Assessment Program (NARCCAP). The respective 50 km climate model grids were selected to ensure that the locations of corresponding stations where historic rainfall data were extracted are within the grids.

Historic station data

Hourly rainfall historic data were acquired online from the NCDC (NCDC 2010). Record lengths varied by location. Information about the original station records is summarized in Table 1. First-order airport stations were favored because these locations tend to have the most complete records. The data sets have undergone quality control by

Table 1 | Rain gauge station locations and historic record length

NCDC Station	Latitude	Longitude	Start date	End date	Elevation (meters)	Years used
Dallas Airport, TX	32.85	−96.85	1 Jan 1941	31 Dec 2008	134	56
Las Vegas Airport, NV	36.07	−115.16	1 Jan 1950	31 Dec 2008	650	57
Miami Airport, FL	25.79	−80.32	1 Jan 1951	31 Dec 2008	9	58
Newark Airport, NJ	40.68	−74.17	1 Jan 1949	31 Dec 2008	2	60
Omaha Eppley Airfield, NE	41.31	−95.9	1 Jan 1949	31 Dec 2008	299	41
Seattle Tacoma Airport, WA	47.44	−122.31	1 Jan 1965	31 Dec 2008	113	44

the NCDC. Quality control flags in the data set indicate quality concerns, such as accumulation of snow. In this study, years containing more than two months with missing or flagged hourly values were removed before analysis. The last column in Table 1 indicates the number of years of data available after removing incomplete years.

Gridded climate data for historic and future climate runs

Gridded rainfall intensity data produced eight times daily (at 3 h intervals) is currently being made available for various combinations of RCMs and GCMs by the NARCCAP (NARCCAP 2010). These rainfall intensity data sets are provided at a 50 km resolution and simulated for historic (1971–2000) and future (2041–2070) 30-year time intervals.

NARCCAP was designed in part to encourage impact assessment of anticipated climatic changes in North America. The program is systematically investigating the uncertainties in future climate projections on the regional level by closely matching RCMs with multiple atmosphere-ocean general circulation models (AOGCMs). AOGCMs simulate the global atmosphere and ocean using prescribed boundary conditions (e.g. solar constant, atmospheric aerosols, sea-surface temperatures, etc.). AOGCMs being used in NARCCAP include the Hadley Centre HadCM3, National Center for Atmospheric Research (NCAR) CCSM, the Canadian CGCM3, and the GFDL model (NARCCAP 2010). The resulting climate model runs form the basis for multiple high-resolution climate scenarios that can be used in climate change impact assessments in North America.

The RCM/GCM combination used in this study (hereafter HH) was developed by the Hadley Centre for Climate Prediction and Research located in the United Kingdom. The GCM is the Hadley Centre Coupled Model Version 3 (HadCM3) and the RCM is the Hadley Regional Model 3 (HRM3). The HadCM3 model is currently being used in IPCC works and its performance has been assessed in various research efforts (e.g. Gordon *et al.* 2000; Pope *et al.* 2000). The model has an extensive record for simulating current and future climates. Model documentation for historic and future simulations is provided by the Program for Climate Model Diagnostics and Intercomparison (PCMDI 2010).

Since NARCCAP focuses on the uncertainty across different GCMs and RCMs, only one emissions scenario (i.e. SRES-A2) was used for all simulations. The SRES-A2 emissions scenario was selected because it is one of the six 'marker' scenarios developed through the IPCC and it was a common scenario at the time NARCCAP was being planned. The scenario was described in Nakicenovic & Swart (2000) in the Special Report on Emissions Scenarios (SRES) that was commissioned by the IPCC. The SRES scenarios were developed by considering various possible futures of world development in the 21st century, including such factors as economic development, technological development, energy use, population change, and land-use change. The A2 scenario is at the higher end of the SRES emissions scenarios, and this is preferred because, from an impact and adaptation point of view, if one can adapt to a larger climate change, then the smaller climate changes of the lower end scenarios can also be adapted to. Readers are referred to IPCC (2007) and Figure 3.1 therein in particular for detailed description of all six emission scenarios.

Development of IDF relationships

The rainfall values for IDF curves are typically calculated based on historic station measurements. In this study, IDF curves were also produced that incorporate climate change projections, which originated from large gridded data sets. Here, IDF curves were calculated for single station locations using areal reduction. The annual maximum series were calculated for durations of 3, 6, 9, 12, 18, 24, 48, and 96 h.

To determine design intensities, first, an algorithm was developed to calculate the annual maximum series, the largest X hour total for each year, from each data set. Annual maximum series have often been used in calculation of storm frequencies (e.g. Bonnin *et al.* 2004). HH data were in the form of three-hourly time series for each grid and model combination, while NCDC data were in the form of hourly series. The algorithm determined the largest X hour rainfall totals for each year using a moving window, which shifted incrementally across each three-hourly (or hourly) value. Since these totals were located in the extreme tail of the probability distributions from which they are drawn, their distribution was different from that of the whole population. There are three asymptotic forms of the distributions of extreme values: type I, type II, and type III. In this study, the extreme value type I (EVI) (Gumbel) probability distribution function was used (e.g. Chow *et al.* 1988; Stedinger *et al.* 1992):

$$F(x) = \exp\left[-\exp\left(-\frac{x-u}{a}\right)\right] \cdot -\infty \le x \le \infty \tag{1}$$

where u is the location parameter and a is the scale parameter. Note that other commonly used probability distributions (e.g. generalized extreme value distribution) can also be used in the same approach. The Gumbel distribution was selected for its simplicity. Considering the large uncertainties associated with climate models and short series (only 30 years), the Gumbel distribution may be considered as a good compromise. To fit a Gumbel distribution to each set of maximum series, the scale and location parameters were determined using probability weighted moments (Stedinger *et al.* 1992). Unbiased estimators were used to calculate the L-moments estimators for the location and scale parameters. The cumulative distribution functions were inverted to calculate quantiles, or values for specific return periods (Stedinger *et al.* 1992):

$$x_p = u - aln[-ln(p)] \tag{2}$$

where $p = 1$ – exceedance probability. Values were calculated for 2, 5, 10, 25, 50, and 100 year return periods. This procedure was repeated for all return periods, durations, and locations.

Areal reduction factors

Climate projections are available at various gridded spatial resolutions in NARCCAP. Analyses of station-scale rainfall impacts should be based on certain assumptions about relationships from the simulated grid-scale results. In this study, an assumption was adopted that would relate local station-scale rainfall intensity to model grid-scale rainfall intensity. The concept of the ARF is used to relate the maximum areal average gridded rainfall intensity to the maximum rainfall intensity estimated at a station (Allen & DeGaetano 2005). Osborn (1997) has examined the use of ARFs derived from past records to relate areal and station estimates in a future climate.

The average ARF values are defined as follows:

$$ARF(T,d) = \frac{I_{\mathrm{H}}^{(g)}(\tau,d)}{I_{\mathrm{H}}^{(s)}(\tau,d)} \tag{3}$$

where $I_{\mathrm{H}}^{(g)}(T,\ d)$ and $I_{\mathrm{H}}^{(s)}(T,\ d)$ are the rainfall intensity associated with events of duration d and return period T, at the grid-scale and the station-scale, respectively. The subscript 'H' indicates historic.

IDF curves are needed at station-scale and usually developed from site-specific records. However, the rainfall intensities at the station-scale for the future climate are not available. Available rainfall data to compute IDFs include historic observations at station-scale and climate model rainfall outputs at model grid-scale (both historic and future). Therefore, assumptions are required in order to estimate future rainfall intensities at the station-scale from the estimated values at the model grid-scale (both historic and future) and at the station-scale (historic). In this study, the assumption was adopted that climate model-simulated relative change between future and historic rainfall intensities at a given duration and return period (the delta term in Equation (4) below) could be applied to adjust the historic station-scale intensities to produce future station-scale values for the same duration and return period, namely:

$$I_{\mathrm{F}}^{(s)} = I_{\mathrm{H}}^{(s)}\left[1 + \Delta_{\mathrm{F-H}}^{(g)}(T,d)\right] \tag{4}$$

where subscript 'F' indicates future, and

$$\Delta_{\mathrm{F-H}}^{(g)}(T,d) = \frac{I_{\mathrm{F}}^{(g)}(\tau,d) - I_{\mathrm{H}}^{(g)}(\tau,d)}{I_{\mathrm{H}}^{(g)}(\tau,d)} \tag{5}$$

This formulation is equivalent to

$$I_{\mathrm{F}}^{(s)}(T,d) = I_{\mathrm{H}}^{(s)}(T,d)\frac{I_{\mathrm{F}}^{(g)}(\tau,d)}{I_{\mathrm{H}}^{(g)}(\tau,d)} \tag{6}$$

That is,

$$\frac{I_{\mathrm{F}}^{(g)}(\tau,d)}{I_{\mathrm{F}}^{(s)}(\tau,d)} = \frac{I_{\mathrm{H}}^{(g)}(\tau,d)}{I_{\mathrm{H}}^{(s)}(\tau,d)} \tag{7}$$

Or

$$\mathrm{ARF}_{\mathrm{future}} = \mathrm{ARF}_{\mathrm{historic}} \tag{8}$$

Equation (8) indicated that the adopted basic assumption is equivalent to assuming ARF for the future climate is equal to that for the historic data.

RESULTS AND DISCUSSION

To meet the objectives, the results were investigated from several perspectives. ARF values are first reported for the six study regions as a function of storm duration and return period. A comparison of historic and projected future rainfall intensities is then provided at each study region. Finally, changes in IDF curves produced at model grid- and station-scales are investigated.

Areal reduction factors

ARFs calculated from the data sets used in this work are indicative of the relationships between the spatial resolution of the gridded data set (2,500 km^2) and NCDC historic gauging station values. These results should not be viewed as classic ARF values because the HH output is a modeled historic value rather than an observed value. In general, ARFs tend to be less than 1.0 and decrease with shorter-duration storm events. Storm systems responsible for short-duration annual extremes in station records are commonly convective in nature (e.g. summer thunderstorms) and these localized storms have spatial scales much smaller than the extent of a typical grid cell. Rainfall depths generated by intense but spatially limited storm systems are therefore much lower when distributed over the 2,500 km^2 grid cell used in this study.

Meteorological systems responsible for longer duration annual extremes are larger in scale in space and time, often associated with synoptic fronts. These systems can last for longer periods, cover more areas, and thus lead to larger area averaged accumulations. These storms can potentially cover more than one grid cell. Longer duration intensities from station records are expected to be closer to gridded values. Osborn & Hulme (1997) showed that the characteristic scale of 24 h annual maxima in Western Europe is on the order of a few hundred kilometers. The relative contribution of convective versus synoptic rainfall processes varies widely between season and location.

From Figure 1, it can be seen that ARFs varied widely with storm duration, return period, and location. Except for Seattle, ARFs noticeably decreased for annual maxima of shorter durations (less than 12–24 h depending upon location). This is consistent with what is expected for small spatial-scale/high-intensity storms, which are uncommon in the Seattle area. As storm duration increases, ARF values for most locations increase and for durations equal to and greater than 24 h, are in the vicinity of 1.0. In this condition, time averaged station-scale storm intensity is similar to model grid-scale intensity. This may be indicative of rainfall characteristics where storm systems cover an area larger than the grid-scale for that duration.

Alternatively, ARF values near or exceeding unity may be attributed to the model's inability to properly represent the physical processes of some storm types. For some locations, ARFs exceeded 1.0, and this likely indicates overestimation of rainfall intensity by the model for these time spans. For instance, the ARF values at Las Vegas for durations of 2 and 4 days exceeded 1.8 for most return periods. Infrequent and intense storms in desert environments tend to be more difficult to simulate by grid-scale models and long-duration storms in this environment are extremely rare. Miami is the only location where no ARF exceeded 1.0, while Seattle and Newark only had one exceedance, occurring at 96 h with a 2-year return period for both locations. Las Vegas and Omaha both had multiple exceedances of 1.0.

There have been conflicting assessments of changes in ARFs as a function of return period, possibly because of geographic differences. For gridded data in Quebec, Canada, Mailhot *et al.* (2007) observed increasing ARF values as a function of return period. Allen & DeGaetano (2005) reported lower ARF values for higher return periods for 24 h events in New Jersey and North Carolina. Figure 1 reveals an increase in ARF values with an increase in return periods for all sites except Newark and Seattle. This trend suggests that the relative occurrence or absence of convective events may play an important role in the interaction between ARF values and return periods. Another

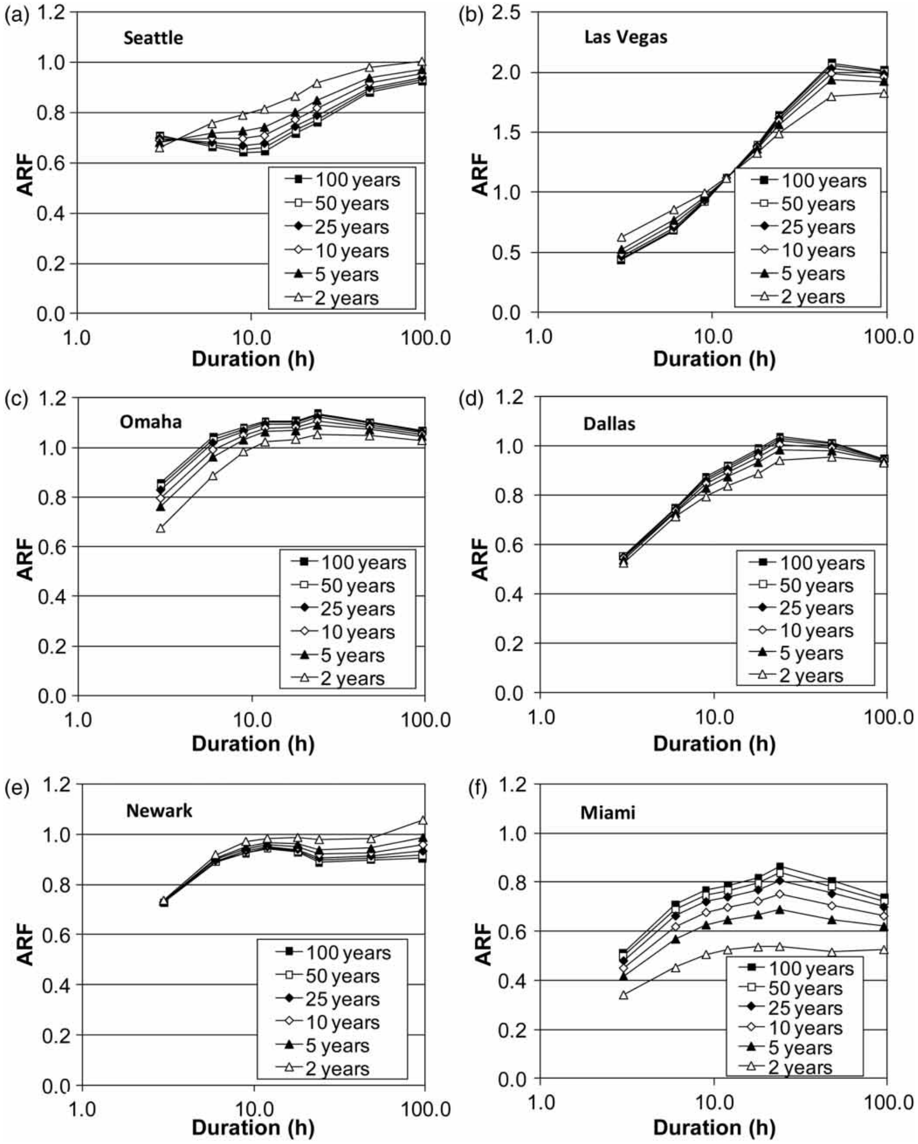

Figure 1 | Areal reduction factors (ARF) calculated based on Hadley Centre model historic simulations and NCDC historic data for: (a) Seattle, (b) Las Vegas, (c) Omaha, (d) Dallas, (e) Newark, and (f) Miami.

noteworthy observation is the wide variation in ARF values as a function of return period in Miami, whereas the distributions were much tighter for the other stations. This high degree of variation may be the result of the wide variety of storm types experienced in Miami. ARF values depend on the proportions of convective and stratiform rainfall and on the spatial scale of storm events, and these characteristics can change in future climates if the spatial scale of rainfall events changes (Osborn 1997). However, since these changes cannot be confirmed or quantified at this time, in this study it was assumed that ARF values will not change significantly in a future climate (Ekstrom *et al.* 2005; Fowler *et al.* 2005). This important issue could be further investigated as higher-resolution RCM simulations become available.

Projected change in rainfall intensity

Figure 2 provides a comparison between historic and projected future rainfall intensities from the gridded HH data

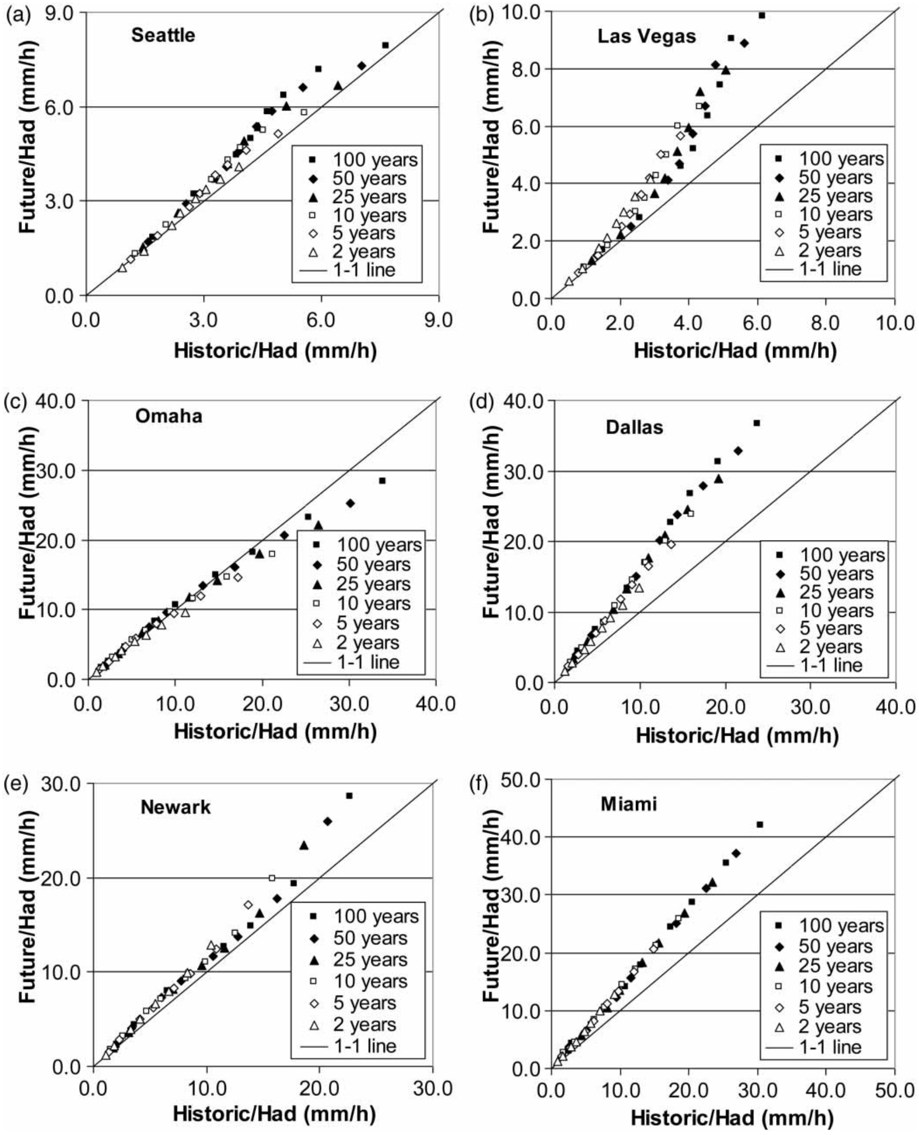

Figure 2 | Scatterplots of storm intensities calculated based on the Hadley Centre future runs (2041–2071) against Hadley Centre model historic runs (1971–2000) at selective locations across the USA for all durations and return periods.

sets at all six study sites. While the plots generally indicate a greater increase in magnitude at longer return periods, the percentage increase was similar for most return periods. Comparing the average percentage change for all conditions revealed substantial variability between locations. The largest average increase was for Dallas (52%) and intermediate gains were found for Las Vegas (35%) and Miami (36%). Seattle had an average increase of 13%, Newark had an increase of 16%, and Omaha showed an average percentage difference of 0%. Omaha was the only location with a projected decrease in rainfall intensity for multiple conditions. The sizeable variation between historic and future rainfall intensities for short-duration events supports the notion that rainfall intensity will be more severe in future decades (Endreny & Imbeah 2009).

Intensity–duration–frequency curves

Figures 3 and 4 include IDF curves for all stations for 2-year and 100-year return periods, respectively. When comparing

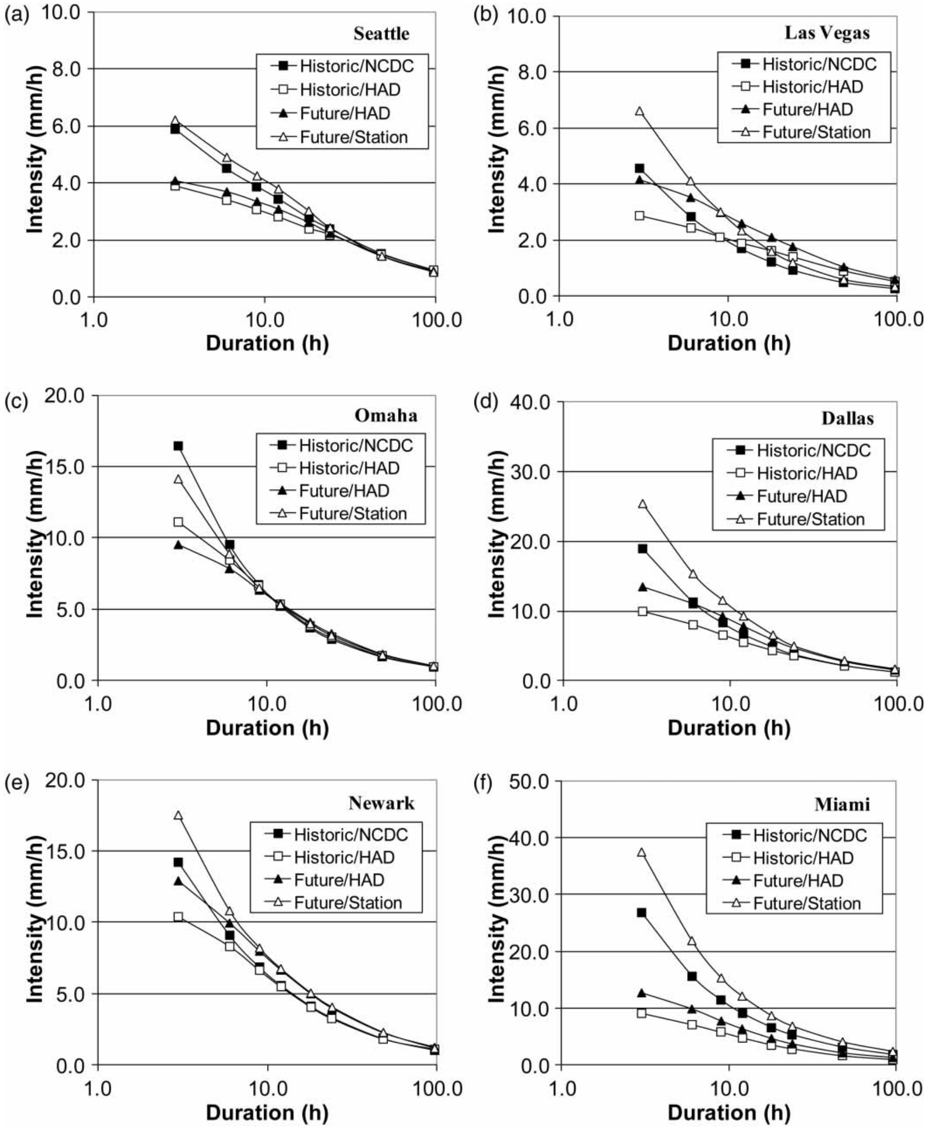

Figure 3 | Intensity–duration–frequency (IDF) curves of 2-year return period for: (a) Seattle, (b) Las Vegas, (c) Omaha, (d) Dallas, (e) Newark, and (f) Miami.

IDF curves between the locations for all return periods, a few trends are discernible. First, rainfall intensities for the grid-scale data sets (Future and Historic HH) were consistently lower than corresponding intensities for station-scale data (NCDC and Future Station). A few exceptions to this trend were observed in Las Vegas, Newark, Omaha, and Dallas. For both the 2-year and 100-year return periods, the rainfall intensities for storms of 9 h and greater duration revealed unusual trends. As described above, such storms are exceedingly rare in Las Vegas and the data in this range are considered to be unreliable. In Newark, the grid-scale data and station-scale data for both future and historic conditions converged for storms of 9 h duration and greater. The convergence was less pronounced for the 100-year return period when compared with the 2-year return period.

A second observable trend was that rainfall intensities for future conditions were consistently higher than historic conditions for a given spatial resolution (grid or station). A few exceptions were noted. In Omaha, for both the 2-year and 100-year return periods, the historic rainfall intensities

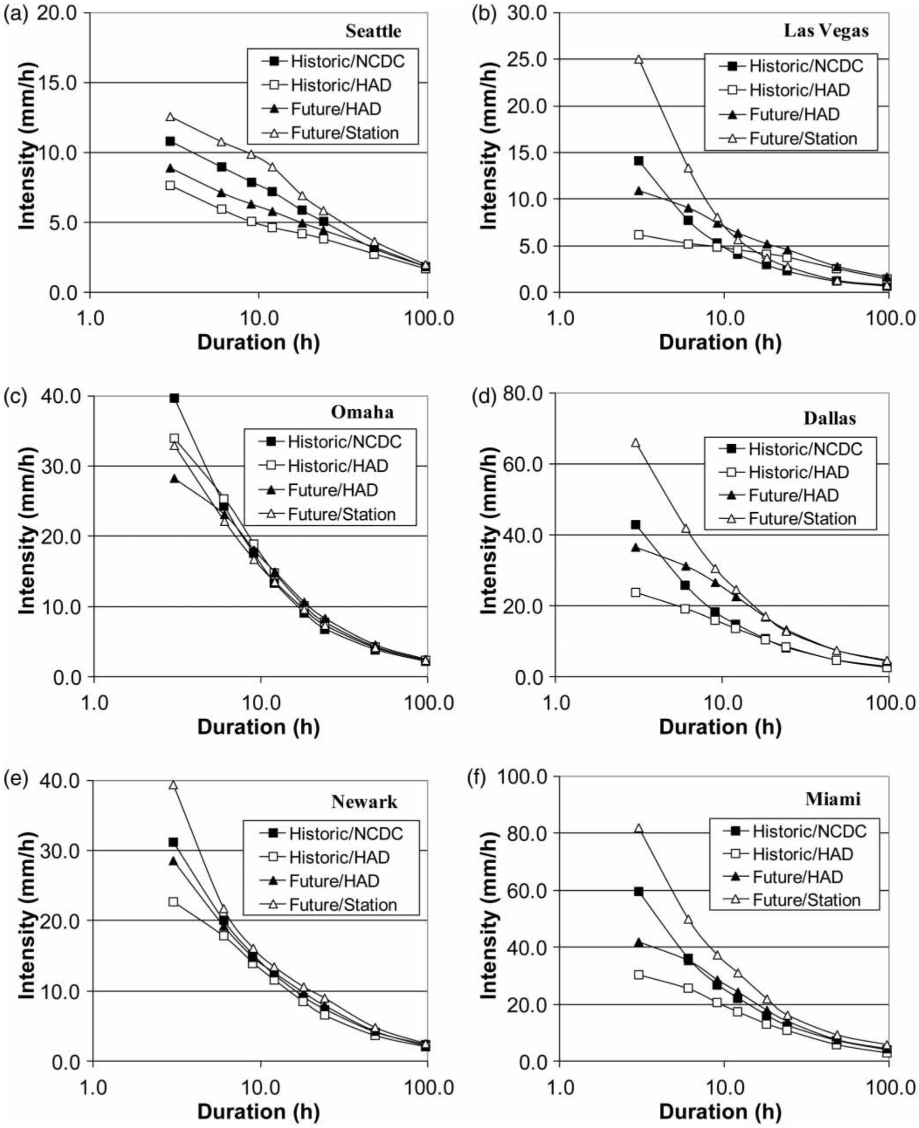

Figure 4 | Intensity–duration–frequency (IDF) curves of 100-year return period for: (a) Seattle, (b) Las Vegas, (c) Omaha, (d) Dallas, (e) Newark, and (f) Miami.

were higher than the future intensities for storms with durations of 9 h or less. The final general trend observed in the IDF curves was a convergence in the various IDF curves for a given station as the storm duration increased. The degree of variation among scenarios for shorter duration storms varied greatly between the six locations. Generally, variations between station and gridded data sources most likely relate to uncertainties associated with model scales whereas variations between historic and future scenarios are more likely related to the influence of projected climate change, but further research is needed to test this suggestion.

Finally, it should be pointed out that the results obtained in this study are model dependent and the use of the output of different models and climate change scenarios could lead to different results. The numerical values presented in this study should be viewed as a relative indication of potential future climate impacts. Future work should use multiple GCM/scenario combinations in a likelihood framework to more robustly assess potential impacts of future climates on IDF relationships for different regions. Frei *et al.* (2006) suggested that the formulation of RCMs contributes significantly to uncertainties in extreme rainfall assessment. Such uncertainties were not taken into consideration in this study since only one RCM simulation was analyzed. Clearly, multi-model ensemble systems need to be analyzed in order to quantify uncertainties. These multi-model ensemble systems must include the use of the output of different GCMs, as well as different RCMs to estimate how model structure can modify extremes in future climate.

CONCLUSIONS

In this study, potential impacts of projected climate change on rainfall characteristics across the United States were explored. For most of the study sites, future climate projections suggest an increase in the intensity of extreme storms for a given duration and return period with strong regional variations.

The results revealed the dependence of ARF values on return period and storm durations as related to the characteristic spatial scale of the systems generating extreme rainfalls. The six study regions represent a wide range of climatic conditions observed across the United States including desert, tropical, temperate, and continental climates, which are influenced by a range of storm types (e.g. synoptic and convective). As a result of these climatic variations between sites, ARF values responded differently to changes in storm duration and return interval from site to site. ARF values were relatively low for short-duration, high-intensity storms that are typical of small spatial scale and thus poorly captured at the model grid scale. ARF values were higher for long duration storms where storm scale is more commensurate with model grid scale.

Station-scale rainfall intensities were generally higher than the corresponding gridded values. However, these variations between data types and storm characteristics (duration and return period) were more pronounced for short-duration, high-intensity events than they were for long-duration, low-intensity events.

In summary, the impacts of climate change on severe storm characteristics were found to be highly local in nature and investigations should be carried out at the local level. The results suggest a stronger influence of climate change on rainfall intensities for short-duration, high-intensity events. The implication is that small, flashy watersheds will be more vulnerable to changes in rainfall intensity than larger basins.

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