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# Forecasting extreme events: making sense of noisy climate data in support of water resources planning

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## Abstract

Global climate model (GCM) projections are generally considered the best source of information for predicting future climate and hydrologic conditions in the face of a changing climate. Understanding and interpreting GCM projections is therefore critical for water resources planning. Unfortunately, this can be a challenging task as climate model data, particularly precipitation data, are notoriously noisy with large scatter and lacking in apparent patterns or trends. There is also usually large projection variability between models and model scenarios. This paper demonstrates a simple, practical method for synthesizing climate model data into more informative metrics using case studies of Atlanta, Georgia and Austin, Texas. Monthly and daily GCM projections, as well as historical observations, were translated into commonly used summary metrics for extreme event planning: peak 24-hour storm events and the Palmer Drought Severity Index (PDSI). Statistical trend analyses on these two metrics were used as a simple means to better understand the data. As expected, results identified significant, increasing, trends in projected 21st century temperatures for most GCM projections. Less expectedly, significant trends were also identified for projected future monthly and 24-hour maximum precipitation and drought severity. Implications of this work for water resources planning are discussed.

**Key words:** climate models, drought, planning, storms, trends

## INTRODUCTION

The scientific community, and much of the public, recognize that climate change is anthropogenically influenced and accelerating. Consequently, water resources planners must consider that recent climate history is not an adequate predictor of the future. Changing climate dictates the need for us to understand how climate and hydrology are changing, now and in the future, to be able to plan appropriately. We must assess variability, non-stationarity, and trends in climate data and incorporate these into resource planning studies. This is true whether planning focuses on typical conditions (e.g., in water availability studies), or on extreme conditions such as floods and droughts. Fortunately, a wealth of data now exists, including 20th century observations and 21st century climate model projections, to help us understand these dynamics. Such data, for case study cities of Atlanta (GA) and Austin (TX), are the focus of the study presented here.

Twentieth century climate trends have been noted in the literature for study regions across the US. There is evidence in the literature that air temperatures have increased in the southeast US over the past century, particularly over the past few decades (e.g., Wang *et al.* 2009; Patterson *et al.* 2012;

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Misra *et al.* 2012; Carter *et al.* 2014). Similar studies in the west have identified increasing temperature trends for the Texas-Gulf region (Grundstein & Dowd 2011; Kunkel *et al.* 2010), although others have found no trend for this region (Wang *et al.* 2009). Multiple recent studies have quantified statistically significant increasing trends in 20th century precipitation for the southeast region (Small *et al.* 2006; Pryor *et al.* 2009; McRoberts & Nielsen-Gammon 2011), including an increase in the frequency and intensity of extreme storm events (Wang & Zhang 2008; Li *et al.* 2011; Villarini *et al.* 2013; Wang *et al.* 2013). For the Texas-Gulf region, precipitation trend analyses for the area have been included in many recent studies, some of which have identified increasing trends in the region (Wang *et al.* 2009; Pryor *et al.* 2009; McRoberts & Nielsen-Gammon 2011) while others have identified mostly decreasing trends (Palecki *et al.* 2005). There is also evidence presented in the literature that extreme storms are occurring more frequently and more intensely now than in the past in the Texas-Gulf region (Brommer *et al.* 2007; Wang & Zhang 2008).

Droughts are of great interest to the water resources community due to their direct and often severe impact on communities and industry. Droughts are a function of both temperature, via evapotranspiration losses, and precipitation, which provides source water for soil moisture. Multiple metrics have been developed to quantify drought, including the standardized precipitation index (SPI), which is a function of precipitation only, and the Palmer Drought Severity Index (PDSI), calculated as a function of both precipitation and temperature (Palmer 1965). Trends in frequency and severity of droughts in the 20th century, in a study area inclusive of the southeast US, were the subject of recent studies by Chen *et al.* (2012) and Cook *et al.* (2014). While the first study failed to identify statistically significant trends in either frequency or intensity of 20th century droughts in the south and southeast (including both Georgia and Texas), the second, using tree ring data, identified a significant decline in the frequency of droughts for a 1,000-year study period.

In recognition of a changing climate, the use of global climate models (GCMs) to project future climate conditions has become commonplace. Water resources practitioners now depend on GCM projections to support long-term planning studies. In both the southeast and Texas-Gulf regions, 21st century temperature projections indicate large upward trends with average temperature increases of 2 to 6 °C projected for both areas by the end of the century (Liu *et al.* 2012; Carter *et al.* 2014). Even though consensus exists with respect to the *direction* of future temperature trends, the *magnitudes* of published projections varies significantly across studies based on the specific climate models used, the downscaling techniques employed, and the greenhouse gas emissions pathways assumed. For precipitation projections, the uncertainties are even greater. The large uncertainties and variability in GCM projections of future precipitation throughout the country are well documented. For the two study areas, there appears to be little consensus with respect to even the direction of future precipitation trends. For example, Liu *et al.* (2012) present multiple end-of-century projections for Austin, some increasing, others decreasing, depending on the selected GCM. For a study region inclusive of Georgia, Bastola (2013) presented 2070s' precipitation projections ranging from −50% to +50%, compared to a recent historical baseline. In each of these studies, only a relatively small subset of published GCM projections was used to support the presented analysis.

Several recent studies have focused on future projection of extreme events, including storms and droughts. For a 2090 planning horizon compared to the recent past, small increases in frequency and intensity of storm events for the southeast are presented by Tebaldi *et al.* (2006). Wang & Zhang (2008) project a significant increase (30 to 50%) in the recurrence of the 20-year, 24-hour storm event for a 2075 planning horizon in both the southeast, including Georgia, and the southwest, including Texas. These results are supported by the work of Gao *et al.* (2012) who presented projections of increases in the magnitude and frequency of 95th percentile storm events for the eastern US and a mid-century planning horizon. In the National Climate Assessment (Ojima *et al.* 2014), results are presented for the lower Great Plains regions, including Texas, that indicate small future increases in the number of heavy precipitation events, but also increases in the number of future consecutive dry days.

The recently released IPCC Working Group 5th Assessment Report on climate change (IPCC 2013) states that since the 1970s it is 'virtually certain' that the frequency and the intensity of storms in the North Atlantic have increased and that historical trends toward heavier precipitation events in North America are 'very likely'. Projecting forward, IPCC states that it is 'likely' that there will be increased risk of drought through the end of the century, particularly in areas such as the Southwest US that are already dry. This same modeling indicates that it is 'likely' to 'very likely' that the intensity and frequency of extreme precipitation events will increase in other parts of the world, including the eastern and central US, through the next century.

Precipitation data are known to be noisy, with large scatter and lacking in readily apparent patterns or trends. In general, large timescale patterns in the data are often difficult to decipher from more random small timescale variability in both historical observations and in GCM projections. Uncertainties associated with GCM future precipitation projections are also known to be high, as evidenced by the range of conclusions drawn in the literature. These characteristics can limit the utility of these data in water resources planning studies. Planners are often unsure how to use these projections in long-term water planning. Adding to the challenge is the fact that extreme precipitation events generally occur at a daily or sub-daily timescale, while downscaled GCM projections have, to date, only been readily and publicly available at a monthly timestep. Fortunately, a recently released set of daily timestep downscaled GCM projections, using the latest Coupled Model Intercomparison Project 5 (CMIP 5) data set and covering the entire continental US, has been made available to the public (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html). It has not yet been well demonstrated, however, how useful this new data set might be to water resources planners with respect to extreme event planning.

Given this background, the primary objectives of the work presented here were to:

1. Provide a template for future planning efforts, focused on extreme precipitation and drought forecasting, through the demonstrated methodology applied to two case study cities. Key to this methodology is the calculation of more informative summary metrics (drought index and peak 24-hour storm events) and trend analysis to identify patterns of projected change within large scatter data sets.
2. Gain a better understanding of the newly released daily precipitation projections with respect to short- and long-term variability, using the full suite of available data. This study assessed whether the data imply non-stationarity that reflects mechanistic features of the models themselves and should be considered in planning.
3. Investigate the implications of highly variable precipitation projections and known upward trending temperature on future drought forecasting.
4. Investigate climate trends in recent observed data to provide context for any identified future trends.

## METHODS

In this study, monthly and daily GCM projections, as well as historical observations, are translated into commonly used summary metrics for extreme event planning and evaluation: peak 24-hour storm event intensity and the Palmer Drought Severity Index (PDSI). A statistical trend analysis is then applied for these two metrics, and the underlying raw data, to gain further insight from the data and to support long-term forecasting. Two case study cities, Atlanta, Georgia and Austin, Texas, were used to demonstrate these methods. Both cities have faced recent challenges posed by extreme storm events (flooding) and regional drought conditions. Both are also centrally located within two distinct USGS two-digit hydrologic unit code (HUC) regions: HUC-3 (South-Atlantic Gulf) and HUC-12 (Texas Gulf), respectively, that provide for a useful comparison. The inclusion of additional cities was beyond the scope of the study. Further, the selected case study cities are intended only to provide for a demonstration of methods, which are the focus of this study. A summary of the methodology is provided in Figure 1. Each step in the methodology is described below and was applied for both case study cities.

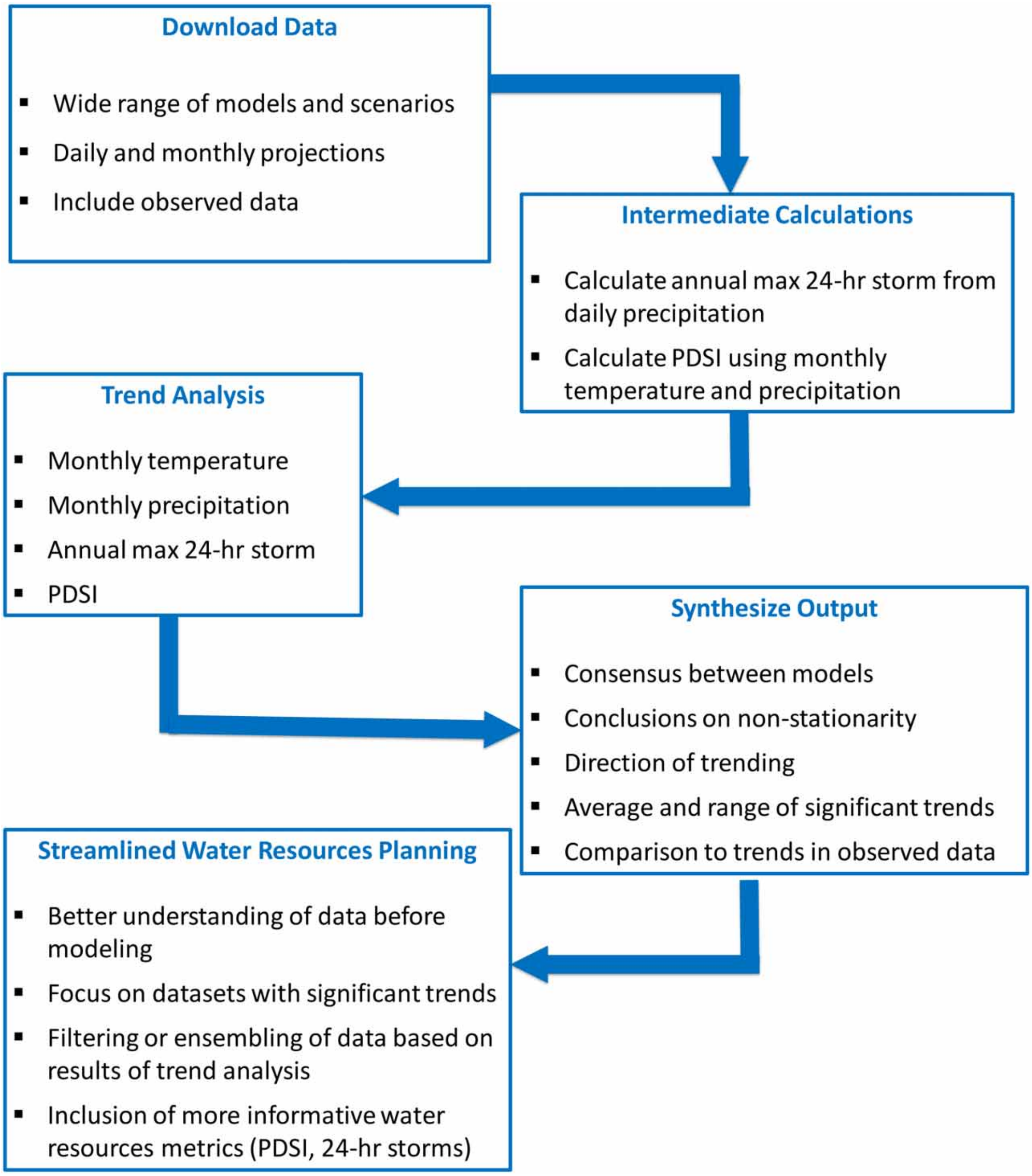

**Figure 1** | Methodology step summary.

Daily and monthly downscaled and bias-corrected GCM projections were obtained for each city from the U.S. Bureau of Reclamation data portal: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/. Projections were previously downscaled to a 1/8th degree latitude/longitude grid centered over each city (Figure 2). Downscaling was achieved using the bias correction with spatial disaggregation (BCSD) method (monthly) and the bias correction corrected analogues (BCCA) method (daily). For both cities, the single grid cells shown in Figure 1 were assumed adequate for climate representation of the city in the analysis performed here. The grid cells were selected to be generally representative of climate projections for the respective urban regions. For simplicity in the

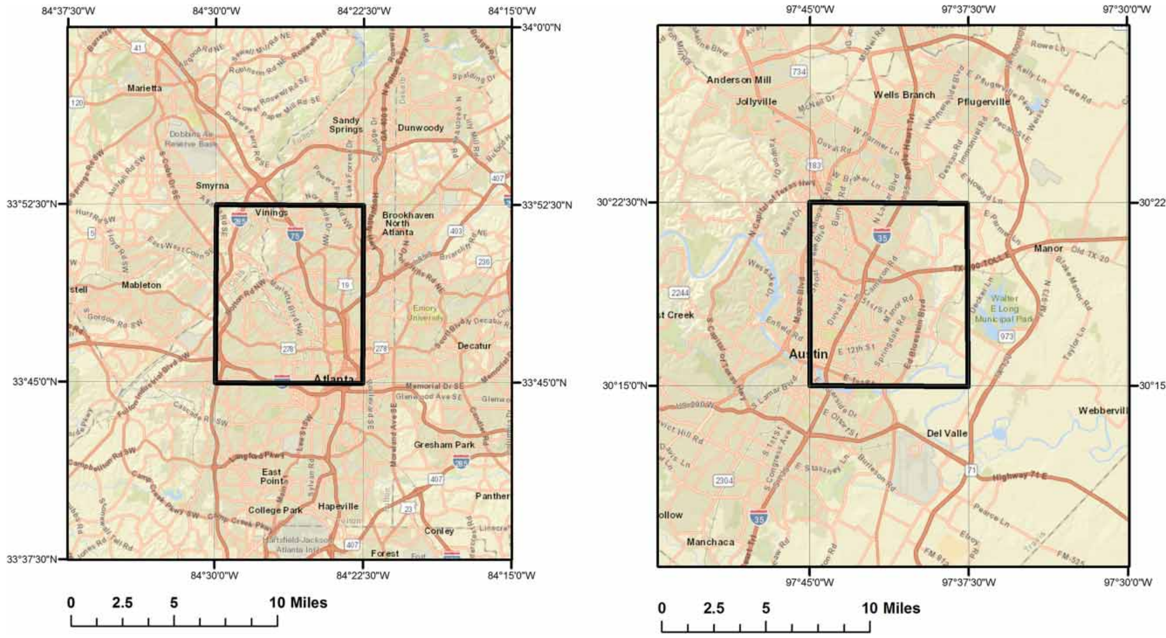

**Figure 2** | Study site and GCM grid cell locations.

demonstration of methods, single grid cells were used in the analysis. While the single cells do not strictly cover the entire respective urban regions, it should be noted that the focus of this paper is on the demonstration of methods, rather than providing a comprehensive description of the site-specific climate projections.

Only projections from the latest World Climate Research Programme's Coupled Model Intercomparison Project Release 5 (CMIP 5) were used in this study. A total of 66 different projections for each city, spanning the full range of available GCMs and assumed greenhouse gas emission scenarios, were used for the monthly timestep analysis described below. A total of 67 different projections for Atlanta and 69 projections for Austin were obtained and used for the daily timestep analysis. Each projection includes a model hindcasting 'overlap' period of 1950 to 1999 and a forecasting period of 2000 to 2100. Also included in the data set were gridded observed data (1950–1999) used here as a historical baseline reference and described in Maurer *et al.* (2002). For this study, no ensembling of projection data was performed. Each projection was included separately in the various analyses described below. No attempt was made to group projections according to projected climate changes or by representative concentration pathway (RCP) designation. For further information on this data set, the reader is referred to Reclamation (2013) and the website noted above.

Historical observed data (daily and monthly) were obtained from the National Climatic Data Center (NCDC) for the Austin Climate Division 4107 weather station and the Atlanta airport weather stations. Periods of record for the two were 1900 to 2014, except Atlanta precipitation which was only available from 1930 to 2013.

Statistical trend analysis was performed on both historical observed data and each of the GCM future projections. Mann–Kendall non-parametric tests, applied within the Excel add-in XLSTAT, were used for this task. Statistical significant levels were defined as $p < 0.1$. Trend analyses were performed on monthly climate data (total precipitation and mean temperature), broken out by calendar month and on calculated maximum annual 1-day precipitation events.

To assess drought conditions reflected by the climate data sets, the PDSI was calculated for each timestep in the monthly data sets. PDSI is a well-known metric for characterizing drought conditions and is based on a simplified soil moisture water balance model that considers timeseries information on both precipitation (source of soil moisture) and temperature (loss of soil moisture via evapotranspiration) (Palmer 1965). Positive PDSI values indicate a soil moisture surplus while negative values indicate a deficit. The more negative the PDSI value, the worse the drought conditions, with various drought threshold PDSI values defined in the literature. A customized version of NOAA's NCDC PDSI calculator (FORTRAN) was used for these calculations. PDSI values were calculated for both the historical data set (e.g., 1930–2000) and each of the GCM projection traces (2000–2100). Mann–Kendall trend analysis was then performed on each of the calculated PDSI data sets.

Lastly, daily precipitation projections were used to calculate new 24-hour design storm magnitudes, for multiple recurrence intervals, as predicted by the various GCM traces. Only those projections with statistically significant trends in annual maximum 24-hour events were used for this exercise. For those projections without trends, it is assumed that any differences in calculated design storms can be attributed to random variability within the sampling periods, rather than relevant and significant changes in the projected climate. Three different 50-year sampling periods were used to calculate design storms: 1950–1999 (historical overlap period), 2026–2075 (mid-century), and 2050–2099 (late century). Maximum annual 24-hour precipitation data for each sampling period were used to calculate design storms with 2, 5, 10, 25, 50, and 100-year recurrence intervals. The water resources software NetStorm (Heineman 2004) was used for this analysis. In this program, return periods are calculated using ranked precipitation depths fitted to a generalized extreme value (GEV) distribution following the method of L moments, as described by Hosking (1990).

## RESULTS AND DISCUSSION

Monthly trend analysis results for the historical observed data are summarized in Figure 3. Significant increasing trends in historical monthly air temperature were identified for nine of the twelve calendar months for Atlanta (1900–2013) and three of the twelve months for Austin (1900–2013). For neither city were any significant decreasing trends in temperature identified. In terms of Atlanta precipitation, only two months in the available data set exhibited statistically significant trends over the historical period. One of these (April) exhibited a decreasing precipitation trend, while the other (November) exhibited an increasing trend. For Austin, the results are similarly mixed. Five of the calendar months exhibit statistically significant precipitation trends, scattered throughout the year. Two of

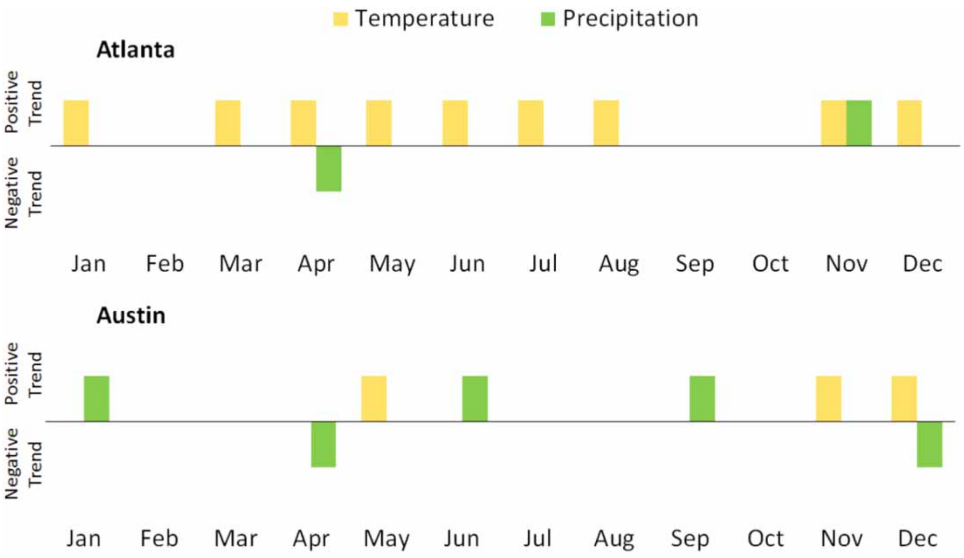

**Figure 3** | Results of historical climate data analyses: statistically significant ($p \leq 0.1$) trends (1900–2013) (note: no significant trends were identified for PDSI or 24-hr maximum storm events).

these are decreasing trends, while the others are increasing trends. Not shown in this figure are the results of the trend analyses performed on the annual maximum 1-day (24-hour) precipitation events and the calculated PDSI values. No statistically significant trends were observed in either the annual maximum 1-day (24-hour) precipitation events or the calculated PDSI values for either city. This indicates that neither the frequency nor intensity of droughts have changed significantly over the past century in either city, nor the frequency or intensity of 24-hour storm events. This deviates from other parts of the country, as described in the literature.

Climate model projections indicate a high level of consensus with respect to general future trending of air temperatures in both cities (Figure 4). Most of the projections exhibit statistically significant upward (positive) trends in monthly average air temperature through the end of the 21st century, at average rates of 0.034 and 0.035 °C per year for Atlanta and Austin, respectively. As expected, precipitation projections are more equivocal. However, significant trends have been identified in many of the precipitation data sets; 36% of the Atlanta projections and 39% of the Austin projections exhibit statistically significant trends in monthly precipitation through the end of the 21st century. There is, however, divergence in the two cities with respect to the direction of these trends. For Atlanta, most of these trends are positive (increasing precipitation); while for Austin the trends are primarily negative (decreasing precipitation).

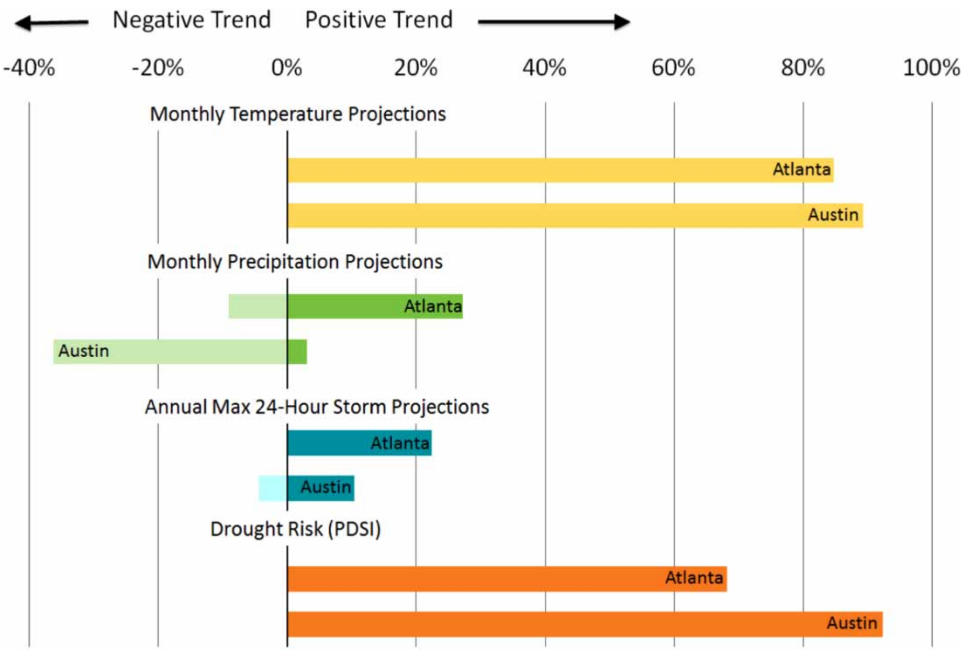

**Figure 4** | Percentage of 21st century model projections with a statistically significant ($p \leq 0.1$) trend.

In terms of extreme storm events, approximately 20% of the Atlanta projections display a statistically significant upward trend in annual maximum 24-hour precipitation through the end of the 21st century (Figure 4). None of the analyzed GCM projections for Atlanta indicate a decreasing trend in 24-hour storm events. In other words, Atlanta storms are predicted, albeit at a relatively low level of consensus, to increase in both frequency and intensity throughout the century. The average rate of increase of these storm events, across trending projections, is approximately 0.1 mm per year. Austin climate projections offer a lower consensus on future storm trending. Of the sixty-nine GCM projections analyzed, only eight (12%) displayed a statistically significant increasing trend in 24-hour storm magnitude (average = 2 mm per year), while two displayed a significant decreasing trend (average = –2 mm per year). Future projected PDSI values, calculated as a function of projected monthly temperature and precipitation, show statistically significant decreasing trends for most of both Atlanta and Austin GCM projections for 2000 to 2100 (Figure 4). In other words, droughts are projected to be more frequent and more intense in the future compared to the past.

Magnitude changes in 24-hour design storm magnitude, as projected by the climate models, are summarized in Figure 5, for both cities using the late century results. Results are presented as percentage 'delta' values, representing changes in magnitude relative to GCM hindcast results (the 1950–1999 'overlap' period). As can be seen, results are mixed and vary widely across GCM projections. As an example, calculated changes in the 50-year design storm magnitude for late century Atlanta projections range from an increase of 43% to a decrease of 20%. Even though all the Atlanta projections shown in these tables exhibit a statistically significant increasing trend in maximum annual 24-hour precipitation totals, many of the calculated design storms are smaller for the 21st century projections compared to the historical baseline. This is particularly true for the larger storm events (50- and 100-year events). This appears to highlight the fact that, although 'typical' max 24-hour storms are projected to increase, the largest of these are not necessarily projected to increase. Consequently, fitted recurrence distributions may result in calculated decreases in the large events. Averaged across the sample of GCM projections, Atlanta design storm magnitudes are all projected to increase (0 to 12% for mid-century and 4 to 18% for late century). For Austin, results are similarly mixed, but with an even greater number of projected decreases in storm size. Averaged across GCMs, however, projected changes are nearly all positive (−1 to 13% for mid-century and 1 to 14% for late century).

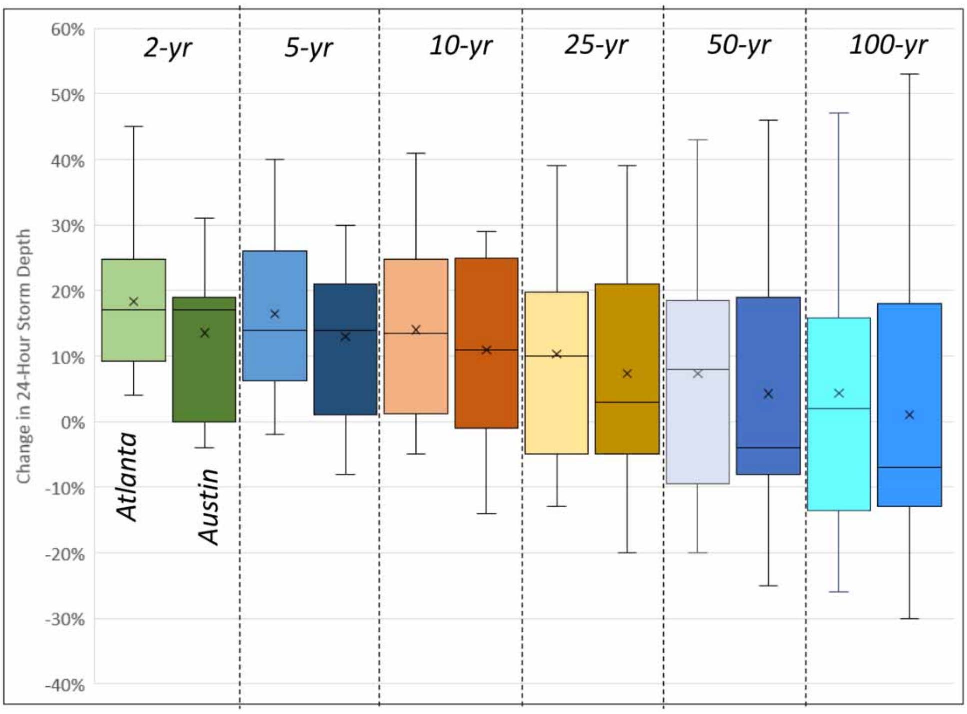

**Figure 5** | Summary of projected change (2050–2100 vs. 1950–1999) in 24-hour design storm depth for models with a statistically significant trend.

The magnitudes of projected changes in PDSI are highlighted in Figure 6, again for a late 21st century planning horizon. Results are included for each GCM projection and each city. Along the bottom of this figure are the descriptions of the drought categories associated with each average PDSI value, as defined by Palmer (1965). For reference, the late 20th century average PDSI value, calculated from GCM hindcast data, is also included. Multiple projections predict both cities to be in a state of severe

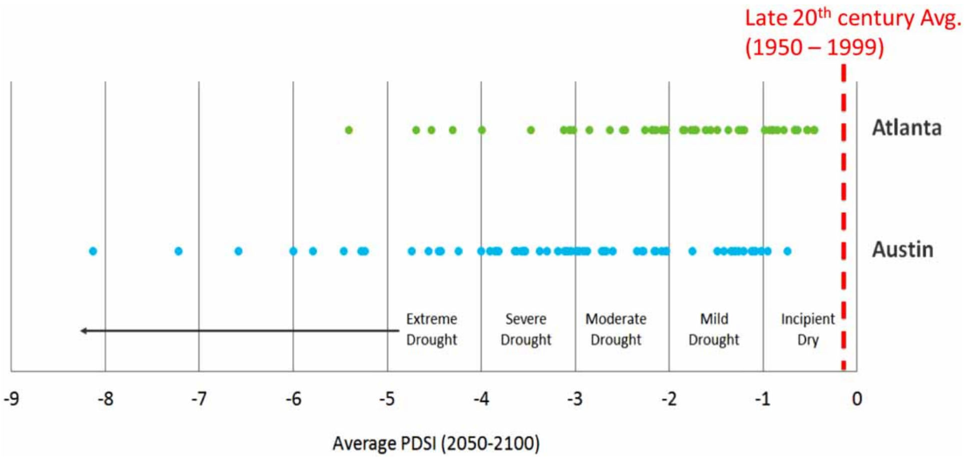

**Figure 6** | Summary of projected average PDSI values (2050–2100).

to extreme drought, as an average or typical condition for the second half of the 21st century, compared to essentially neutral conditions (PDSI ~ 0) calculated for the GCM overlap period (1950–1999). This is especially true for Austin in the latter half of the century. For Atlanta, the drought trends occur even though precipitation is generally projected to increase, rather than decrease. This result suggests that temperature and ET changes outweigh projected precipitation changes with respect to soil moisture levels.

Key to this work is the general methodology presented. The presented methods are intended to provide for a better understanding of, and deriving utility from, climate model projections as they relate to forecasting extreme events. The methodology is designed to answer the questions of: (a) do the projections suggest a ‘change’ in the nature of future extreme events; (b) how many of the available projections suggest such a change (i.e., what is the level of consensus among the models); and (c) if such a change exists, what is the magnitude of change with respect to intensity and frequency of occurrence? While there are a number of statistical methods that could be employed to help answer these questions, a simple and efficient method is presented based on non-parametric trend analysis, that can easily be applied for planning purposes. Implicit in the methodology is the assumption that significant trends in output data suggest a mechanism inherent in the specific model that captures such changes. In other words, it is assumed that the identified trends are not random but rather are the product of intentional, and science-based, features of the model design.

In addition to the trend analyses, summary metrics were calculated that may be more directly relevant to water resources planning, with respect to extreme events, and which provide more projection insight, compared to the raw data alone. The summary metrics calculated here were a drought severity index and annual maximum 24-hour storm events.

The steps followed here include:

1. Download readily available downscaled (and bias corrected) monthly and daily 21st century GCM projections, for a large suite of models and emissions scenarios, e.g., from: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html.
2. Include the historical ‘overlap’ period of model hindcasting (1950–1999), and the single set of available ‘gridded’ observed data (1950–1999) in the download from the same location.
3. Perform Mann–Kendall (non-parametric) statistical trend analysis on monthly climate projections of temperature and precipitation to identify statistically significant projected changes and non-stationarity in mean climate conditions and levels of consensus across models.
4. Use daily precipitation projections to calculate annual maximum 24-hour storm event totals for the full projection period and to calculate design storm magnitudes for standard recurrence intervals.

5. Perform trend analysis on annual maximum 24-hour storm event intensities for all projections to identify statistically significant changes in 21st century storm intensity and levels of consensus associated with these projected changes.
6. Characterize drought conditions associated with GCM projections using the Palmer Drought Severity Index (PDSI), calculated as a function of monthly temperature and precipitation, to provide a well-known metric of drought that captures coupled temperature and precipitation dynamics.
7. Perform trend analysis on calculated PDSI projections to understand whether projected changes in temperature and/or precipitation translate into changes in drought conditions and to ascertain levels of modeling consensus.
8. As a useful reference, perform similar trend analyses using historical observed data.

The result of this process should provide answers to the questions posed above. This enhanced understanding of the climate projections will then allow for improved and more efficient use of the data within a water resources planning study. For example, in this study, we present design storm projection results only for those projections that exhibit statistically significant changes through the 21st century. We reason that those projections without statistically significant trends can be viewed as essentially equivalent to historical observed data (sampled from the same distribution) and lacking in an underlying model mechanism for simulating such change (discussed above). We therefore might exclude these data from subsequent planning analysis, thereby streamlining the process. Further, the significant trends identified in this process could be used in planning studies as simplified predictive models themselves. The trend line slopes could be used to project changes in climate (e.g., storm event magnitude or drought conditions) associated with a specific planning horizon. The projected changes might then be used within a 'delta method' to adjust historical data to better reflect potential future climate scenarios.

Results specific to the case study cities of Atlanta and Austin provide evidence that both cities have been getting hotter through the 20th century, or at least part of the 20th century. Most calendar months appear to be getting hotter in Atlanta, while a minority exhibited statistically significant increases in Austin. This result agrees with results reported elsewhere for other parts of the country and supports the hypothesis that warming is already occurring, and has been, for multiple decades. The fact that results for historical precipitation are mixed (fewer significant trends, some increasing, some decreasing) highlights the uncertainty associated with climate change impacts on precipitation. Lastly, no evidence was identified that the frequency or intensity of droughts or 24-hour storm events have changed significantly over the past century. This appears to be contrary to popular opinion which is likely based more on the anecdotal evidence from the recent past (e.g., ten years) rather than long-term records.

As expected, climate model projections of 21st century air temperatures generally concur in their depiction of a significantly hotter future for both cities. This is not surprising. The identified trends in projected 21st century monthly precipitation may be more surprising. More than a third of the available GCM projections for both cities exhibit statistically significant trends. These results imply an underlying mechanism driving changes in precipitation as an aspect of climate change, simulated in at least a portion of the climate models. For Atlanta, most of the trends are positive; while for Austin the majority are negative. This agrees with the general literature consensus of projected wetter future conditions in the east and projected drier conditions in the west (Carter *et al.* 2014; Ojima *et al.* 2014).

Our analysis of projected maximum 24-hour storm events similarly provides evidence of a mechanistic coupling between short duration precipitation extremes and climate change processes as represented in (at least some of) the climate models. While the accuracy of such projections is certainly unknown, there is value in knowing that such coupling may exist in the models and should be a consideration in water resources planning. Where trends exist, they indicate a potential increase in both the frequency and intensity of 24-hour storm events in Atlanta, and to a lesser extent Austin, through the 21st century. Somewhat counter-intuitively, these results do not translate into consistent increases in design storm projections, particularly at the high end (e.g. 25-, 50-, and 100-year storms). This appears to be attributable to the fact that while trend analyses are focused on changes in *mean* values (typical maximum annual 24-hour events), design storm calculations are focused on the high percentile extreme values. Our results suggest that the largest of the projected 21st century 24-hour storms are not consistently larger than the largest of the hindcast (1950–1999) storms.

We focused on projected *changes* in design storm magnitude (modeled future vs. modeled past), due, in part, to an additional finding that the daily GCMs are not well 'trained' to historical observations (as part of the downscaling process) with respect to extreme storm events. Although not presented here, calculated design storm magnitudes for the historical overlap period vary widely across models and do not agree well with published values calculated from observed data. This finding appears to reduce confidence in model projections of future design storm magnitudes and suggest the need for a 'delta method' approach.

Droughts are projected to become more frequent and more intense through the 21st century in both case study cities. Statistically significant decreasing trends in PDSI were quantified for the majority of GCM projections for both cities. Clearly, this is driven primarily by the projected temperature increases, which will increase evapotranspiration (ET) losses, rather than changes in precipitation. Indeed, the fact that droughts are projected to worsen for Atlanta, despite generally increasing precipitation, suggests that temperature and ET changes outweigh projected precipitation changes with respect to soil moisture levels.

## CONCLUSIONS

Global climate models have proved to be highly useful in water resources planning studies. To date, this utility has primarily been derived from their projections of increasing temperatures, often associated with specific greenhouse gas emissions' assumptions, and in their projections of wide, and potentially expanded, variability in monthly and annual precipitation. A challenge to water resources practitioners, however, has been in understanding the extent, if any, of projected changes in 21st century precipitation. This is due primarily to the large scatter and 'noise' in the precipitation projection data that makes it difficult to identify patterns or evidence of whole-scale change. There is a need to differentiate random variability in precipitation from variability that implies an underlying mechanistic change in climate. This understanding is critical to the question of how planners should use GCM precipitation projections; or whether they should be used at all. If future precipitation projections are not significantly different than historical observations, then the use of historical data should suffice for future planning. If there are significant differences however, and the underlying model mechanisms for projecting these changes can be trusted, then it appears advisable to include GCM projections in a suite of potential climate futures used for planning. Of particular interest to water resources planners is the potential for changes in the intensity and frequency of storm events and droughts, which can be more directly analyzed by translating climate model projections into useful summary metrics (e.g., the Palmer Drought Severity Index and annual maximum 24-hour storm events).

In conclusion, a new and practical approach for gleaning insight from high scatter climate projection data has been presented, particularly with respect to the implications of highly variable precipitation projections. A key initial step is the translation of large volumes of climate model projections into more informative summary water resources metrics – in this case, drought severity indices and design storms with standard recurrence intervals. Applying simple time trend analyses, for both the raw climate projections and the calculated water resources metrics, identifies non-stationarity (or lack thereof) in the climate model projections and implies the presence (or absence) of underlying mechanisms of change in modeled scenarios. The methodology presented here could serve as a useful, and low cost, initial step in a long-term planning study targeting these types of metrics. It is intended to provide for both a better understanding of the data and improved efficiency in subsequent analysis steps. Developing subsequent methods for such a planning study is left to future investigations.

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