Resilience to Extreme Rainfall Starts with Science

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Abstract:

Intensification of extreme rainfall due to climate change means that federally-published rainfall metrics such as the “100-year storm” are outdated throughout much of the United States. Given their central role in a wide range of infrastructure designs and risk management decisions, updating these metrics to reflect recent and future changes is essential to protect communities. There have been considerable advances in recent years in data collection, statistical methods, and climate modeling that can now be brought to bear on the problem. Scientists must take a lead in this updating process, which should be open, inclusive, and leverage recent scientific advances.

Capsule:

Updating extreme rainfall information in a changing climate is essential for communities and infrastructure and requires an inclusive, science-driven process.

Extreme rainfall statistics produced by Federal agencies, such as the so-called “100-year storm,” help protect the health, safety, and productivity of every community throughout the United States. These statistics are used for a wide range of applications from designing bridges, culverts, and storm drains to relicensing dams and levees to delineating floodplains. But the 100-year storm is not what it used to be, and our extreme rainfall statistics are not keeping up. The first systematic nationwide release of these statistics, titled *Technical Paper 40*, was published by the U.S. Weather Bureau in 1961 (Hershfield 1961). Its successor, *Atlas 14*, has been rolled out on a regional basis by the National Oceanic and Atmospheric Administration (NOAA) since 2004, and is now nearly complete (Perica et al. 2018). Atlas 14 analyzes historical data to provide rainfall amounts for storms up to the 1,000-year recurrence interval (i.e. a 0.1% annual likelihood or the 1,000-year storm), along with confidence intervals that reflect associated statistical uncertainties. The more than forty years between these analyses saw many major rainstorms that redefined our understanding of the likelihood of extreme storms throughout much of the country (Lopez-Cantu and Samaras 2018), leaving an overwhelming majority of infrastructure unprepared to meet the real-world conditions that face the communities they are intended to protect (Wright et al. 2019). Consider Texas as an example. Using rainfall records that ended in 1958, the 100-year 24-hour rainfall for Houston from Technical Paper 40 was estimated to be 330 mm. This value, supplemented by results of two later state-level analyses for Texas (Asquith and Roussel 2004), was used in planning and design decisions over the following fifty years. With the release of Atlas 14, this estimate was revised upward to 432 mm using rainfall records extending through 2018 (Fig. 1A), as a direct consequence of recent extreme rainfall conditions (Perica et al. 2018) and improved sampling of rain events. And all of this is before considering the future effects of continued climate change on extreme rainfall patterns and resulting statistics.

Rainfall extremes in many regions have continued to intensify due to global warming: recent research has shown that both Technical Paper 40 and Atlas 14 are already out-of-date over much of the country (Fig. 1A-B) and thus can seriously understate current levels of extreme rainfall hazard (Wright et al. 2019). Most of the infrastructure systems in place today were designed for the climate of the 20th century, and since infrastructure often lasts for five decades or more, these systems will have to perform under the climate of the mid-to-late 21st century and beyond. The combination of long infrastructure lifetimes and projected further intensification of rainfall (Melillo et al. 2014) means that much of our existing infrastructure will fail to meet intended levels of safety, while without updates to extreme rainfall statistics, future projects could be obsolete before even being constructed. Although local conditions and historical design choices have influenced how robust existing infrastructure will be under climate change, it is clear that new approaches—including scientific ones—are needed to keep infrastructure reliable now and in the future.

Remedying this situation will be difficult, not least because infrastructure development involves competing public, private, and environmental interests and lies within a jumble of municipal, state, and federal jurisdictions. Design standards are often piecemeal—for example, addressing water quality and erosion but not flooding, or not fully considering downstream consequences. Furthermore, many ordinances mandate the usage of the very same federally-published rainfall statistics that are badly out-of-date.

As difficult as updating regulations and practices to reflect recent and future change will be, it will likely prove impossible if scientists do not take the first step of providing better extreme rainfall information. Hence scientists have a central and urgent role in preparing communities for climate change. This fundamentally requires three things. First, scientists must focus their work on the metrics that are most relevant for engineering and communities: for example, researchers often define "heavy" daily rainfall as above the 90^{th} or 95^{th} percentile, while the 10-year storm used in stormwater design is well beyond the 99.9^{th} percentile. Second, while it will be challenging and contentious, it is critical that scientists provide results that consider both recent post-Atlas 14 observations and future conditions from multiple climate projections. Third, scientists must strike a balance between ease-of-use and proper acknowledgement of the uncertainties inherent in both extreme event statistics and climate projections.

A range of barriers still exist to producing updated rainfall statistics for the nation. On one end of the spectrum is a national funding landscape that does not readily support and sustain research-to-operations efforts; on the other, modeling extreme precipitation remains highly uncertain despite decades of progress, with large discrepancies between various projections in the magnitude and spatial distribution of extreme rainfall changes throughout the country and in individual states (Lopez-Cantu et al. 2020; Fig. 1B). The current Atlas 14 funding model—in which one or more states must provide the necessary financial resources to NOAA to conduct a regional analysis—likely poses a hurdle to timely and cost-effective updating. Furthermore, while NOAA has collaborated with academic researchers on the issue of climate impacts on rainfall statistics (Wu et al. 2019), it remains to be seen how this and other research findings may find their way into updated official statistics and standards. In the absence of updated Federal rainfall statistics, researchers, organizations, and consultants have conducted studies to update local or state-level rainfall data (e.g. Angel et al. 2020; Mahoney et al. 2018; WICCI 2011; Koy et al. 2011) and to develop methods for infrastructure decision-making under climate-induced precipitation uncertainty (e.g. Ragno et al. 2018; Cook et al. 2020; Mailhot and Duchesne 2010; Kilgore et al. 2019). Though innovative, these smaller-scale actions lack the economies of scale of a nationwide effort and will can lead to spatial inconsistencies in methods, input data, and results. Federal leadership, on the other hand, can ensure a consistent and transparent process that improves trust and adoption of updated information.

Fortunately, many of the previous bottom-up analyses have resulted in considerable data and methodological advances in recent years, which could be employed by larger Federal analyses. These include both nonstationary extreme value analysis (Ragno et al. 2019), "storm-based" approaches that leverage newer data sources such as weather radar (Wright et al. 2017), and improved methods for both high-resolution climate modeling (Mearns et al. 2017; Liu et al. 2017; Prein et al. 2016) and downscaling of climate model projections (Wu et al. 2019). The growing diversity of tools and data presents opportunities, including to a chance to rethink how to characterize and manage uncertainty: unlike the confidence intervals from Atlas 14, which reflect only the statistical uncertainty associated with a single methodology; a multi-model, multi-dataset approach would allow a "preponderance of evidence" approach which promises to be more informative than any individual methodology or data source (Switzman et al. 2017; Fig. 1A). With its longstanding use of multiple models, datasets, and assumptions, the climate science community already has examples of such approaches to uncertainty. Scientists are also well-positioned to help decision-makers analyze context-specific uncertainties, which could help to identify appropriate resilience decisions depending on varying risk tolerances associated with different infrastructure systems.

Any new analysis paradigm must be low cost and easy to update: given the rates of change in both rainfall extremes and advances in climate modeling, the time between updates should be measured in years rather than decades. Transparency, reproducibility, accessibility, and usability by stakeholders should be key aims, and there should be room for non-federal researchers and end users to contribute their expertise, ideas, and peer-reviewed results. The merits of recent local and regional updates should be considered, while NOAA Regional Integrated Sciences and Assessments centers or U.S. Geological Survey Climate Science Adaptation Centers could coordinate and collate regional expertise to experiment, generate lessons learned, and produce localized, usable, nationally consistent and usable, updated information about current and future rainfall conditions at a national scale. A sustained climate assessment is urgently needed (Moss et al. 2019), and Federal leadership on updating rainfall statistics coupled with existing efforts could provide the foundational infrastructure of a sustained assessment. Furthermore, because climate impacts fall disproportionally on vulnerable communities, and since climate resilience planning has the potential to exclude vulnerable populations, broadening participation in infrastructure resilience planning is essential (Shi et al. 2016; Siders et al. 2019). Open, up-to-date, and easy-to-use information about current and future extreme rainfall conditions can facilitate dialogue and collaboration between the public, the engineering community, and other stakeholders to ensure that equity and social justice are front and center in future infrastructure planning. Air pollution vulnerability mapping using CalEnviroScreen (Faust et al. 2017) in California provides a useful example of how up-to-date and easily-accessible scientific data can facilitate equitable and inclusive decision-making.

Our own experiences with practicing engineers and the public have revealed widespread recognition of the shortcomings of existing extreme rainfall statistics, as well as a desire for scientists to step forward with information and guidance. The effort should be nationwide, implying continued, and indeed elevated, Federal leadership—but at the head of a more inclusive and participative process. This could be led by the NOAA Administrator with explicit support from the Secretary of Commerce and The President. Methods could be either reviewed or developed by a National Academies of Sciences, Engineering, and Medicine committee. Armed with updated rainfall statistics, the Federal government could require their use for all Federal infrastructure decision-making and could incentivize their use by state and local governments. Finally, Congress could authorize and appropriate the sustained resources for mandated periodic updates and reviews on a predictable timeline. Done right, such an effort would provide more accurate, timely, and trustworthy results at lower cost—and any investment would be repaid in full by fewer rainfall-related fatalities and reduced economic and environmental damage. Given the critical role of rainfall statistics in the infrastructure that will serve communities for decades to come, waiting another fifty years for better answers is not an option.

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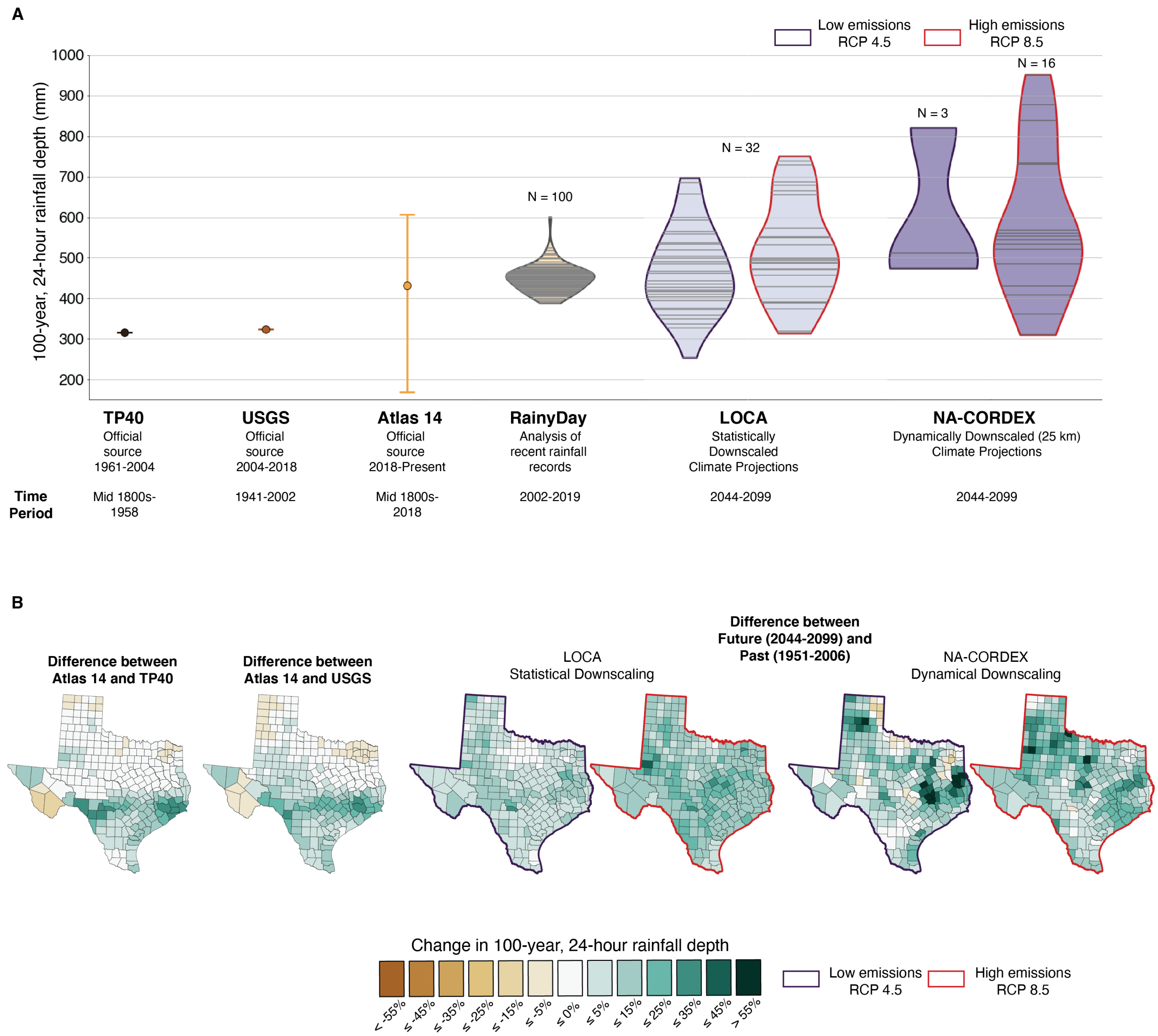

Fig. 1: Federal rainfall statistics are outdated and updates should consider multiple data sources and methods. (A) historical and future 100-year, 24-hour rainfall depths for Houston, Texas. Differences between TP40, USGS (Asquith and Roussel 2004), and Atlas 14 are due to longer station records, improved statistical methods, and recent major storms. RainyDay is a "storm-based" method based on recent radar rainfall observations (Wright et al. 2017); violin plot shows ensemble spread from 100 members (N=100). Other violin plots show projected depths over the 2044-2099 period under the Representative Concentration Pathways (RCP) 4.5 and 8.5 at

the Houston International Airport station estimated using the change signal between future (2044-2099) and historical (1951-2006) periods from two sources of climate projections, LOCA (Pierce et al. 2014) and NA-CORDEX (Mearns et al. 2017). These sources differ in resolution, downscaling method, and selected climate models. (B) three cases of county-level changes in 100-year, 24-hour rainfall for Texas. Maps on the left show the changes between Atlas 14 and TP40 and USGS; results imply that infrastructure in green-colored counties is under-designed with respect to Atlas 14. The remaining maps show projected changes between Atlas 14 and the medians of LOCA and NA-CORDEX. Future projections vary spatially, suggesting highly variable increases in climate vulnerability compared with present conditions.