Three-Hour and Twenty-Four-Hour Rainstorm Ratios across the Southern United States

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Three-Hour and Twenty-Four-Hour Rainstorm Ratios across the Southern United States

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Abstract: Atlases of extreme rainfall were produced over the past 50 years (both nationally and regionally), for various applications. Quantile estimates—rainfall amounts for a given duration and return period—are often used in stormwater drainage and impoundment design, flood control, agricultural engineering, as well as in many other applications. The foundation for these atlases rests upon daily rainfall data. Past researchers determined relationships between daily rainfall frequency/magnitude relationships and 24-hour storm frequency/magnitude relationships, and then used ratios of 24-hour to shorter *n*-hour durations to determine storm magnitudes for durations of less than 24 hours. However, these ratios can vary geographically and the application of one averaged ratio over a large region may produce significant error into the quantile estimate maps. This research examines 14 hourly rainfall sites across the southern United States, thereby forming a transect from San Diego, to Jacksonville, Fla. Results show that the ratios between 3-hour and 24-hour rainstorms vary considerably from one climatic regime to another.

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Introduction

Frequency/magnitude relationships of extreme rainfall over all, or parts, of the United States have been used for stormwater drainage and impoundment design, flood control, agricultural engineering, and other applications. The document most often cited over recent decades is the *National Weather Bureau Technical Paper No. 40* (Hershfield 1961), which is national in scope. The early publication date of TP40 has contributed to a myriad of limitations with that report. These limitations include use of relatively short periods of record, low station density, and limited statistical analysis. As a result of these problems and others, several regional atlases have been produced, e.g., Huff and Angel (1992) in the midwest, Wilks and Cember (1993) in the northeast, and Faiers et al. (1997) in the south-central United States. Despite use of different methods to estimate frequency/magnitude relationships, each study was limited by the small number of quality hourly precipitation records, and each used a similar approach to overcome the problem. For example, Huff and Angel (1992) incorporated 55 hourly precipitation sites and 275 daily precipitation sites into their study. Faiers et al. (1997) used 27 hourly sites across the southern United States while finding 654 quality daily sites. The older nationwide study, by Hershfield (1961), used 200 hourly sites across the country while utilizing 5,000 daily rainfall locations.

Given that there are many more quality daily precipitation recording stations than there are quality hourly precipitation sites, daily data have become the foundation on which these atlases are designed. However, the discrete nature of daily rainfall recording even causes issues when attempting to understand 24-hour "moving window" totals of rainfall, not to mention durations shorter than 24 hours. For example, Hershfield (1961), Huff and Angel (1992), and Faiers et al. (1997) all found that daily extreme precipitation estimates needed to be increased by 13% to equal the magnitudes calculated using 24-hour moving windows.

To overcome the lack of quality hourly precipitation data across the country, the standard approach has been to determine ratios between 24-hour extreme rainfall magnitudes and the magnitudes of shorter durations using data from the limited number of quality hourly precipitation sites. Ratios for these stations are then average, and this mean ratio is then applied to all daily stations included in the study.

Ratios used in past research were all very similar. Huff and Angel (1992) used 0.87 (12-hour), 0.75 (6-hour), and 0.64 (3-hour) ratios while Faiers et al. (1997) employed ratios of 0.88 (12-hour), 0.74 (6-hour), and 0.62 (3-hour) ratios. Wilks and Cember (1993) noted that the Huff and Angel ratios were very similar to those used by Hershfield (1961). Hershfield's work is now being superseded by the National Weather Service Hydrometeorological Design Study Center (2006) publication Atlas 14. This atlas also employs use of ratios to determine daily to 24-hour relationships and relationships between adjusted daily storm magnitudes and magnitudes for storms of shorter durations.

To determine the 100-year, 24-hour rainstorm for a given location, for example, the daily rainfall record would be used, and the magnitude of this design storm would be determined. This value would then be increased by 13% to produce a 24-hour storm equivalent. Similarly, storm magnitudes for shorter-duration events, 3 hour for example, would then be determined by the ratio for that duration multiplied by the adjusted daily storm

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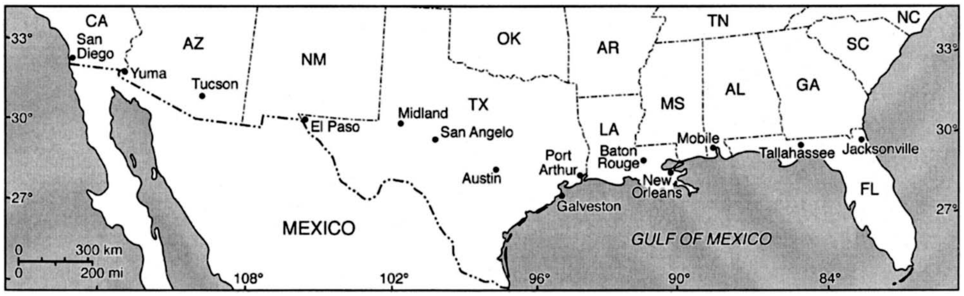

Fig. 1. Locations of the 14 National Weather Service observation sites along a transect across the southern United States

value. In the midwest, for example, if the adjusted 100-year, 24-hour storm for a given location was 203 mm, the 3-hour, 100-year storm would be 129.9 mm.

This approach to determining the magnitude of *n*-hour storms assumes low variability in ratios over space. It also assumes low variability in ratios between recurrence intervals. If significant and regionally identifiable variations in the ratios are expected, there will be locations where the sub-24-hour estimates will be inaccurate, either overestimated or underestimated. Therefore, this research illustrates the within-site and between-site variability of 3-hour/24-hour extreme rainfall ratios using a transect of quality hourly observation stations across the southern United States where rainfall regimes range from desert (Arizona) to subtropical along the U.S. Gulf Coast. This paper will thereby examine a transect from San Diego, to Jacksonville, Fla. (Fig. 1).

Methods

This research examines ratios of quantile estimates derived from 3-hour and 1-day partial duration series. The 3-hour duration was selected for comparison to the daily duration because it should provide a wide baseline for comparative purposes, especially given the varying synoptic regimes over the transect. Furthermore, since the data examined are recorded as discrete hourly observations, logged on the hour, use of 1-hour data would possess no "moving window" properties. Longer durations, such as 6 hour and 12 hour, would have larger ratios (closer to 1.0) at each site, while shorter durations (e.g., 1 hour) would be smaller than the ratios discussed in this paper. To illustrate the range of ratios between short duration (3-hour) and longer duration (24 hour) storms, a transect using hourly recorded rainfall from 14 National Weather Service (NWS) office data from San Diego, to Jacksonville, Fla. was selected (San Diego, Yuma, Ariz., Tucson, Ariz., El Paso, Tex., Midland, Tex., San Angelo, Tex., Austin, Tex., Galveston, Tex., Port Arthur, Tex., Baton Rouge, La., New Orleans, La., Mobile, Ala., Tallahassee, Fla., and Jacksonville). NWS sites generally have the most complete hourly precipitation data available. This transect crosses several climatic "boundaries" from the Mediterranean climate of coastal California through the desert sites of Yuma, Tucson, and El Paso, semiarid locations (San Angelo and Austin), and into the humid subtropical southeast. Each site used had a period of record from 1948–2003 (56 years).

Partial duration series (pds) of extreme events were extracted from the hourly data for 24-hour and 3-hour durations. In each series, independence was ensured by not allowing any given hour to be included in more than one "event." The beta-*p* distribution was then utilized to determine the storm quantile estimates (Wilks 1993; Keim 1998), and maximum likelihood (Levenberg-Marquardt) fitting procedures were implemented (Mielke and Johnson 1974). Ratios were then calculated for 3-hour and 24-hour storm magnitudes for 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. The ratios over these recurrence intervals were then averaged to determine the overall ratio for that site. The Friedman two-way nonparametric analysis of variance (ANOVA) test is employed to determine whether significant within-site and/or between-site variability existed (Gibbons 1992; Hogg and Lodolter 1987).

Results

Figs. 2(a and b) not only show the greater storm magnitudes along the U.S. Gulf Coast, but also how the differences between the 3-hour and 24-hour storm magnitudes vary, especially between El Paso, Tex. and Port Arthur, Tex. Noteworthy also is the larger differences between the 3-hour and the 24-hour storm magnitudes at the longer recurrence intervals.

In most instances, the ratios decrease with increasing recurrence interval (Table 1). Only at El Paso and Austin are the ratios larger for the 100-year storm than they were for the 2-year storm. In some cases, the degree of variability is quite impressive. For example, Yuma, San Angelo, Galveston, Port Arthur, and Pensacola had 20% or greater difference between the 2-year and 100-year storm ratios. Meanwhile, Tallahassee and Tucson showed a very slight difference in the ratios between the 3-hour and 24-hour storms across the different recurrence intervals. The general decrease in ratios from 2-year to 100-year storms results from single extremes (possibly outliers) within some of the pds data from which the probabilities were extracted. These extraordinary events tend to inflate the magnitudes of storms at the longer recurrence intervals, thereby creating a larger range of ratios between 2-year and 100-year ratios. In some other pds, the largest event was not much greater than the second largest storm total (creating a smaller range of ratios across recurrence intervals). When averaged for all sites, the ratios decrease from a high of 0.65 for 2-year storms to 0.55 for 100-year storms, with an overall average ratio of 0.59—slightly less than the ratios used in past atlases.

Differences in ratios between sites appear to be even greater than the within-site variability. The average ratios range from a high of 0.74 at Tucson to a low of 0.48 at Port Arthur (Fig. 3). It is clear that the more arid locations have higher ratios. This occurs because these sites tend not to have long-duration rainfall events. More typically, when heavy rainfall occurs in arid and semiarid regions, it occurs as thunderstorms over a short duration (Trewartha 1981; Adams and Comrie 1997; Faiers et al. 2005).

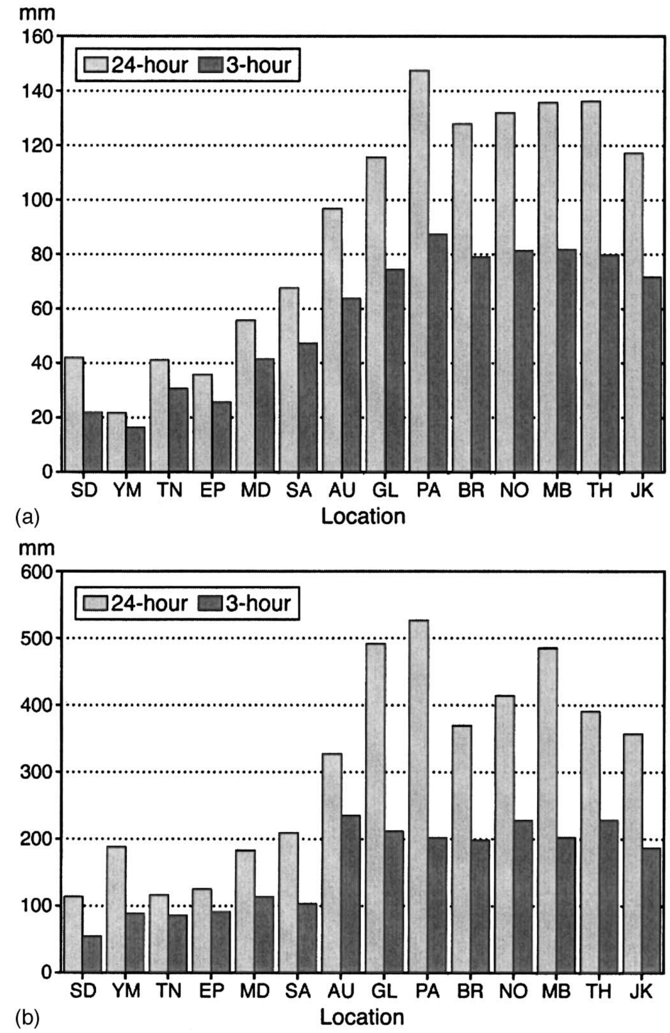

Fig. 2. Three-hour and 24-hour estimated storm magnitudes for each location, for (a) 2-year; (b) 100-year storms

Therefore, the differences between 3-hour and 24-hour storm magnitudes are not as great as they are at locations in the humid southeast, where extended periods of rainfall may be triggered by slow moving frontal boundaries or tropical systems that often persist for 24 hours or longer (Keim 1996), which are generally not experienced in the desert region of the southwestern United States. While not a location that experiences tropical storms or hurricanes, San Diego does experience extended periods of precipitation during winter as slow moving midlatitude cyclones

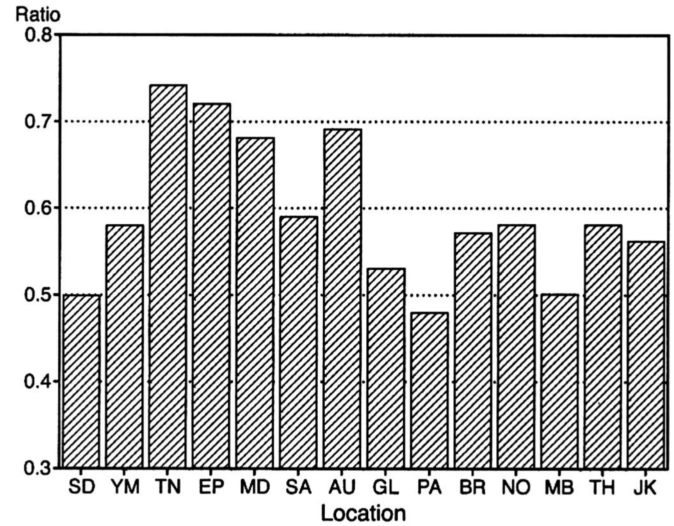

Fig. 3. Three to 24-hour quantile estimate ratios for each location

move into the area and entrain deep tropical moisture from the Pacific.

To determine whether the within-site and between-site differences are significant, the Friedman two way nonparametric ANOVA test was implemented (Hogg and Lodolter 1987). Within-site variance was found to be highly significant (.001) with a Friedman statistic of 30.54 (13 deg of freedom). This is not surprising, given that at the majority of the sites, there was a decrease in the ratios as the recurrence intervals increased. The between-site variance was even more significant with a Friedman statistic of 67.03 ($p < 0.001$).

Conclusions and Recommendations

This research shows clear differences in the 3-hour and 24-hour storm magnitude ratios by recurrence interval within sites and between locations. The tendency is for ratios to decrease as recurrence intervals increase (a function of the storm magnitudes through the partial duration series for each site) and for the ratios to be larger in arid and semiarid regions (closer to 1.0) and smaller in the more humid subtropical locations. The implication is that using traditional methods in which one average ratio is applied across all climate zones, extreme rainfall estimates for storm durations of under 24 hours have been underestimated in some regions (arid and semiarid especially) while others have been overestimated (humid climates). It also appears that the

Table 1. 3-Hour to 24-Hour Ratios by Recurrence Interval at the 14 Locations

RI	SD	YM	TN	EP	MD	SA	AU	GV	PA	BR	NO	MB	TH	JK	Average
2	0.52	0.72	0.75	0.71	0.75	0.70	0.66	0.64	0.59	0.62	0.61	0.60	0.58	0.61	**0.65**
5	0.51	0.65	0.74	0.72	0.71	0.64	0.67	0.58	0.53	0.60	0.60	0.55	0.59	0.59	**0.62**
10	0.51	0.60	0.74	0.72	0.69	0.60	0.68	0.54	0.49	0.58	0.59	0.52	0.59	0.57	**0.60**
25	0.50	0.55	0.74	0.73	0.66	0.56	0.70	0.50	0.45	0.56	0.57	0.47	0.58	0.55	**0.58**
50	0.49	0.51	0.74	0.73	0.64	0.52	0.71	0.46	0.41	0.55	0.56	0.44	0.58	0.54	**0.56**
100	0.48	0.47	0.74	0.73	0.62	0.49	0.72	0.43	0.38	0.53	0.55	0.42	0.58	0.52	**0.55**
Average	**0.50**	**0.58**	**0.74**	**0.72**	**0.68**	**0.59**	**0.69**	**0.53**	**0.48**	**0.57**	**0.58**	**0.50**	**0.58**	**0.56**	**0.59**

Note: San Diego (SD); Yuma (YM); Tucson (TN); El Paso (EP); Midland (MD); San Angelo (SA); Austin (AU); Galveston (GV); Port Arthur (PA); Baton Rouge (BR); New Orleans (NO); Mobile (MB); Tallahassee (TH); and Jacksonville (JK).

shorter recurrence interval storms have been underestimated, while longer recurrence interval estimates have been too large when applying one ratio across all recurrence intervals.

Future research into the spatial patterns of extreme rainfall frequency-magnitude relationships of durations of less than 24 hours should take these findings into account. This research suggests a 10% decrease in the ratios between 2-year and 100-year storms. Ratios should not be static between recurrence intervals if the within-site variance is significant. While differences are evident in the sign of this change and the degree of difference between the 2-year and 100-year ratios, there does not appear to be a climatic or geographic pattern to these within-site ratios.

If a particular study includes more than one climate region, researchers need to acknowledge that the relationship between 24-hour storm magnitudes and magnitudes of any shorter duration change as the precipitation climatology changes and that these changes may be statistically significant. For example, using Koeppen climate classification types (Hidore and Oliver 1993), the 14 sites in this study would fall into four distinct climate zones. San Diego would represent the warm summer Mediterranean type (Csa), Yuma, Tucson, and El Paso Desert (BWh), Midland and San Angelo Steppe (BSh), while the remaining sites to the east would classify as humid subtropical (Cfa). Other classifications could apply as well, for example using the Trewartha (1981) precipitation climate regions, these 14 sites would be divided into eight different zones. Regardless of which climatic regionalization was applied, analyses conducted at the regional or national scale would need to phase in such changes in ratios over space to avoid sudden changes in spatial pattern that are not realistic.

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