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Considerations for the use of radar-derived precipitation estimates in determining return intervals for extreme areal precipitation amounts

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Abstract

To explore the feasibility of radar-based extreme precipitation climatologies, prototype radar areal reduction factor (ARF) curves are developed and compared to those based on traditional rain gauge networks. For both the radar and gauge data, increasing the spatial density of observations has little influence on the ARF relationship. However, independently, considerable differences between radar ARF and gauge ARF exist. Radar ARF decays at a faster rate (with increasing area) than gauge ARF. For a basin size of 20,000 km^2, the percent difference between radar ARF and gauge ARF ranges from 11 to 32%. This implies that radar-derived estimates of extreme point precipitation are disproportionately larger than radar-derived estimates of extreme areal precipitation, as compared to the corresponding relationship based on rain gauges.

Between-station variance of same-day extreme precipitation, as well as the coefficient of variation tends to be larger for the radar-derived areal extreme events, favoring a smaller radar areal precipitation. Smaller radar ARF is also favored because, on average, a higher percentage of gauges have coincident annual maxima than do the radar pixels that correspond to these gauges. Radar ARF curves computed based on gauge-calibrated radar data decay at an even faster rate than the unadjusted radar ARF. The accuracy of the calibrated radar data for these extreme events is suspect, however.

Areal precipitation amounts for the 2-, 5- and 10-year return period were computed by fitting an extreme value distribution to the areal radar, (and separately gauge), maxima from 5 years of available data. In one study area, the radar estimates tend to exceed those based on the gauge, whereas in a different region the gauge estimates tend to exceed those based on the radar. These results emphasize that a smaller radar ARF does not necessarily imply a lower radar mean areal precipitation.

Keywords: Radar rainfall; Areal reduction factors; Extreme value analysis; Raingauge; Rainfall estimates

1. Introduction

Contemporary US National Weather Service (NWS) radars are capable of providing precipitation

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estimates at spatial and temporal resolutions unmatched by conventional rain gauge networks. It is feasible these data could transform the procedures by which extreme areal precipitation return periods are currently computed, once an adequate historical record of radar-based precipitation observations becomes available. Each radar umbrella is essentially a dense measuring network with large areal coverage ($>50{,}000\ \mathrm{km}^2$), as well as high spatial ($\sim 2\ \mathrm{km}^2$) and temporal (15–30 min) resolution.

Given the limited sample of historical radar data, few studies have explored the potential of using radar-derived precipitation estimates to construct extreme precipitation climatologies. In the United States, Frederick et al. (1977) used the (now outmoded) WSR-57 radar to develop area-depth curves. Area-depth curves have been traditionally used as a means of converting point (i.e. station) rainfall extremes to values representative of larger geographic areas, such as river basins. US Weather Bureau Technical Publication 29 provides a set of these areal reduction factor (ARF) curves (based on rain gauge data) for the contiguous US (USWB, 1957). Allen and DeGaetano (2005) review the TP-29 methodology and assess several of the assumptions used in this publication.

In Frederick et al.'s approach, radar reflectivity is subsequently converted to rainfall rate, R in mm h^{-1}, by the following Z–R relationship:

$$Z = 55R^{1.6}. \tag{1}$$

Using four 'large' storms (at least one grid point with ≥ 25 mm of precipitation in 1 h) near Norman, Oklahoma, prototype ARF curves were developed for watershed areas up to 1500 km^2 and accumulation periods ≤ 1 h. Substantial differences between Frederick's radar ARF curves and those given in TP-29 were noted. The 30-min radar ARF was considerably larger than that derived from the gauges over all basin sizes. Beyond an area of ~ 690 km^2, the slope of the TP-29 ARF curves approaches zero, while the radar ARFs continued to decay.

Similarly, Stewart (1989) exploited the high temporal (and spatial) resolution of radar data to develop hybrid raingauge-radar ARF relationships for Northwest England. Limited by the small amount of radar data available (98 days), the analysis focused on the relationship between short duration (≤ 12-h) and 24-h areal rainfalls. For each heavy rainfall event, the ratio of the maximum areal short duration rainfall to the corresponding daily areal rainfall total was calculated and ultimately an average ratio over all events obtained. Using these ratios, ARF-area curves based on daily rain gauge data were modified to sub-daily ARF-area curves.

Despite the uncertainties inherent to radar precipitation estimation, as radar and computational technology continues to evolve, radar data has the potential to become the preferred source of high-resolution rainfall data. Current US National Weather Service Weather Surveillance Doppler Radars (WSR-88D) provide nearly complete coverage of the contiguous United States at 10,000 feet (3.05 km) above site level (Klazura and Imy, 1993). It is unclear as to whether this data can be exploited to improve current estimates of extreme areal precipitation events. When based on in situ rain gauge observations, these precipitation extremes are fraught with uncertainties related to spatial interpolation based on a widely spaced observation network. Conceivably the use of radar data will eliminate the need for spatial interpolation. However, the veracity of the radar rainfall estimates, particularly in terms of extreme events, may compromise the use of these data in developing extreme areal rainfall climatologies.

In this study a set of prototype radar ARF curves are developed (since only 5 years of data are currently available) and compared with those obtained using a relatively high-density rain gauge network. Although it is questionable that the ARF methodology will be preferred once an adequate record of radar data exists, this approach offers a convenient means of comparing the radar and gauge data in the context of an established method of areal extreme rainfall estimation. Furthermore, it identifies several potential sources of discontinuity between existing gauge and future radar-based climatologies. Two geographic regions are evaluated to isolate the effect of moderate differences in topography. Our data and methodology, including a brief discussion of the techniques to calibrate the radar estimates using gauge data, are described in Section 2. In Section 3, several analyses are presented to explain the observed differences between the radar and gauge areal extremes.