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Preliminary investigation of the contribution of supercell thunderstorms to the climatology of heavy and extreme precipitation in the United States

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ABSTRACT

The hazards attributed to supercell thunderstorms are primarily considered to be tornadoes, large hail, and damaging winds, but flooding from heavy and extreme rainfall is not as often considered with these storms. As a result there has been little research on the role that supercells play in the production of heavy and extreme rainfall events. In order to assess the contribution of supercells to the climatology of short-duration precipitation extremes the present study uses the Warning Decision Support System — Integrated Information to objectively identify supercell thunderstorms from mosaicked radar data during the year 2009 and associate them with high-resolution, accurate multisensor precipitation estimates at time scales of one hour. Supercells are found to be more likely than non-supercells to produce extreme and heavy precipitation, and comparisons are also made between storm types according to month.

1. Introduction

In the United States the hazards most commonly attributed to supercell thunderstorms are tornadoes, large hail, and damaging winds, but heavy precipitation is often overlooked. Duda and Gallus (2010) found that in the Midwestern United States supercells produce severe weather more frequently and at higher intensities than other storm morphologies, but only considered flooding events rather than rainfall accumulations. In their description of the spectrum of supercell-type thunderstorms Moller et al. (1994) identified so-called "high-precipitation" supercells, noting that these storms are likely the dominant form of supercells in the country. These authors also warn that high-precipitation supercells "pose a significant flash flood threat in addition to the severe weather risk." From a forecasting perspective the threat of flash flooding (i.e. heavy precipitation) from supercell thunderstorms is typically hindered by environmental conditions that reduce precipitation efficiency, but is overcome by the strong updrafts associated with supercells in combination with high amounts of low-level moisture (Doswell et al., 1996). Another limiting factor for flooding is storm motion, such that fast-moving storms allow little time for rainfall to accumulate at a particular location. The slow-moving storm described in Belville et al. (1980) is an example of the opposite effect. On more than one occasion Doswell (1994, 1999) has specifically addressed supercell thunderstorms as potential producers of heavy rainfall. This study will assess the contribution of supercell rainfall to the climatology of heavy and extreme precipitation.

Previous studies have examined individual cases of heavy and extreme precipitation produced by supercell thunderstorms. For instance, Smith et al. (2001) analyzed four instances of supercells resulting in extreme rainfall and flooding, noting that the most exceptional rainfall rates occurred at time intervals of 60-min and less. These authors suggested that supercell thunderstorms play a significant role in the occurrence patterns of extreme rainfall rates, but new analysis procedures are needed to adequately assess the contribution of these storms. Further, Rogash and Smith (2000) examined an outbreak of violent tornadoes with associated flash flooding. This case study illustrated the importance of a moisture-rich lower troposphere and strong supercell updrafts in the

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production of high rainfall rates. The absence of a dry layer in the mid-levels was also noted, suggesting that little entrainment or evaporation acted to reduce precipitation efficiency in the storm. Additional research by Rogash and Racy (2002) identified 31 more occurrences of flash flooding associated with significant tornado events.

The goal of this study is to objectively identify and classify convective storms, using this information to assess the contribution of supercell thunderstorms to the climatology of heavy and extreme precipitation in the United States. Convective storms are classified as either supercells or non-supercells using an automated, feature-based approach, and rainfall is associated with these storms using high-quality precipitation data. Similar studies have used a feature-based approach to evaluate precipitation extremes (Hitchens et al., 2010, 2012), finding that smaller-sized storm systems are not uncommon among the producers of extreme rainfall occurrences. This research, in conjunction with case studies of supercell thunderstorms producing heavy and extreme rainfall, suggests that a thorough investigation of the role of these storms as producers of heavy rainfall is necessary.

2. Data and methods

The storm type data used in this study were generated using an algorithm (Lakshmanan and Smith, 2009; Kolodziej and Lakshmanan, 2010) from the Warning Decision Support System — Integrated Information (WDSS-II; Lakshmanan et al., 2007). This algorithm uses *k*-means clustering and watershed segmentation techniques on a 200 km^2 spatial scale to identify individual storms, classifying each as a supercell or non-supercell based on three-dimensional mosaicked radar reflectivity, velocity, and derived data (Lakshmanan et al., 2006) using a decision tree. Storm type data were available at 5-minute intervals with $0.01° \times 0.01°$ horizontal grid spacing across the contiguous United States. Due to the high computational expense required to run the storm typing algorithm, an existing dataset of storm types generated using WDSS-II (Cintineo, 2011) covering 164 days during the year 2009 (Fig. 1) was used.

The next-generation quantitative precipitation estimate (QPE) (Q2; Vasiloff et al., 2007) hourly gauge-adjusted radar product, part of the National Mosaic and Multi-Sensor QPE System (Zhang et al., 2011), was used to associate rainfall amounts with supercell thunderstorms. The Q2 data have the same horizontal grid spacing as the storm type data, and encompass the domain of the storm type data, allowing for a direct match between the two grids. Since the storm typing algorithm assigns a unique identification number to each storm and tracks storms between radar scans, a single storm could be classified up to 12 times during a given hour. For this study if a storm was classified as a supercell at least once during an hour the rainfall associated with that storm is considered supercellular. Non-supercell rainfall is only considered for storms that are identified at least 10 times during an hour as a non-supercellular thunderstorm. As a result 17,212 instances of supercell thunderstorms and 66,855 instances of non-supercell thunderstorms were identified.

3. Results and discussion

Hourly rainfall accumulations were collected for each grid box associated with each identified storm and the rainfall values attributed to supercell thunderstorms were compared to the values attributed to non-supercells. The probability of rainfall exceeding a particular threshold is calculated by summing the number of precipitation values exceeding that threshold and dividing by the total number of values. In Fig. 2 it is seen that the probability of exceedance of any rainfall threshold is greater for supercells than non-supercells, with the difference between the two reaching an order of magnitude at the 34 mm threshold. For example, 1.32% of supercells produce rainfall exceeding 34 mm, while only 0.13% of non-supercell storms produce rainfall exceeding this threshold. Expectedly, the curves for both storm types in Fig. 2 are log-linear as shown previously in Brooks and Stensrud (2000). The approximate 95% confidence interval for each curve is constructed from 100 trials with random samples without replacement sized at 10% and 1% of supercellular and non-supercellular rainfall, respectively. These confidence intervals show that the two distributions are well separated. Similarly, the probability of a certain storm type is calculated by dividing the sum of the precipitation above a threshold for one storm type by the total precipitation above the threshold for all storms. It is seen that 89% of convective rainfall is not produced by supercells (Fig. 3) and, based on precipitation thresholds, non-supercellular storms are most likely for thresholds less than 30 mm, but by 48 mm two-thirds of rainfall exceeding

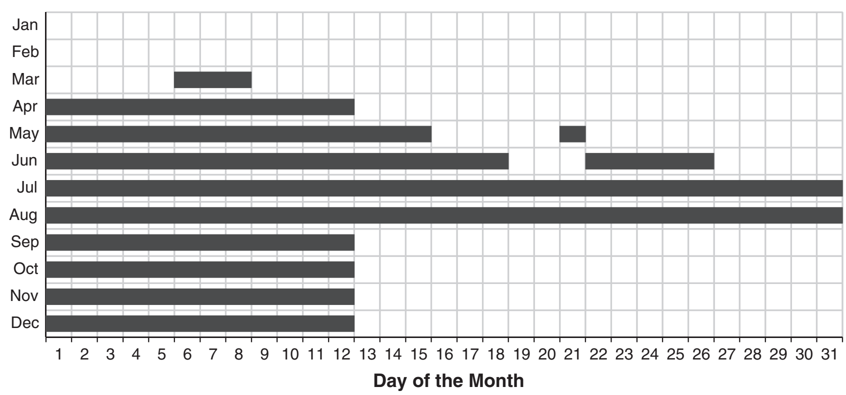

Fig. 1. Data availability during the year 2009 from Cintineo (2011).