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Tornado seasonality in the southeastern United States

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ABSTRACT

Tornadoes are among the most destructive natural events and occur most frequently in the United States. It is difficult to ascertain if the frequency of tornadoes in the U.S. is increasing because our ability to observe and report tornado occurrence has increased over time. Previous studies have demonstrated that tornado likelihood has shifted toward earlier dates across the south-central United States over the past seven decades, the region sometimes called "Tornado Alley", if it can be assumed that seasonal observation effort has not shifted over time. It is unclear if such shifts in tornado seasonality have also occurred elsewhere, including the region of the southeastern United States where tornado likelihood has a bimodal annual distribution. We use circular methods to demonstrate that the date of observed peak tornado occurrence during the early tornado season has not changed in the past seven decades. However, the date of peak tornado occurrence during the later tornado season has shifted toward earlier dates by more than a week. The influence of tropical storms had no effect on changes in late-season tornado seasonality. The conclusions are robust with respect to whether tornado counts or tornado days are used as the response variable. Results demonstrate the ongoing need to encourage tornado preparedness in the southeastern U.S., where tornadoes tend to have a higher impact on humans, and to understand the mechanisms that underlie trends in tornado seasonality.

1. Introduction

Tornadoes are among the most extreme weather events on Earth, often striking with devastating consequences. The United States experiences more tornadoes per year than any other country (Grazulis, 1990; Henson, 2003) because large portions of the central and eastern United States experience conditions favorable to tornadogenesis (Brooks et al., 2003; Mercer et al., 2009; Shafer et al., 2009; Sherburn et al., 2016). Seasonal tornado activity in the region of the U.S. where tornadoes occur most frequently - the Great Plains - is well-defined and most occur during spring (e.g., Brooks et al., 2003; Long and Stoy, 2014). Maximum, or peak, tornado activity occurs at progressively later dates for locations farther north and range from early May for Oklahoma and southeastern Texas to early July for North Dakota (Brooks et al., 2003). There is little variability in the length of this seasonal cycle, which lasts approximately 3.5 months. Recent work has determined that peak, or maximum, tornado activity in the Great Plains has shifted earlier in the year by an average of 7 days (Long and Stoy, 2014) and 12–13 days (Lu et al., 2015) relative to the 1950s. Observed shifts in the seasonality in the Great Plains are accompanied by corresponding trends in convective available potential energy (CAPE) and the fourth power of storm relative helicity (SRH^4), as well as their interaction, CAPE $\times$ SRH^4 (Lu et al., 2015).

Whereas the Great Plains have the most tornado occurrences, a region in the southeastern United States encompassing Arkansas, the northern and central portions of Louisiana, Mississippi, and Alabama, as well as portions of western Tennessee has the highest tornado risk (Coleman and Dixon, 2014) and the greatest concentration of tornado fatalities (Ashley, 2007). The delineation of this region, sometimes called "Dixie Alley" after the "Tornado Alley" of the central and southern Great Plains, varies slightly depending on the study (e.g., Ashley, 2007, Coleman and Dixon, 2014, Dixon et al., 2014, Deng et al., 2016). The seasonality of tornado activity in the southeastern United States is also more variable than the unimodal seasonality in the Great Plains. Namely, the southeastern states experience tornado activity throughout a substantially larger portion of the year with two periods of increased activity, one in spring and a second in autumn. The variation in the timing of these seasons is large, causing density plots of tornado activity in the southeastern United States to have broad peaks, which makes it difficult to assess where the maximum is located. Few studies to date have delineated tornado seasonality in the southeastern United

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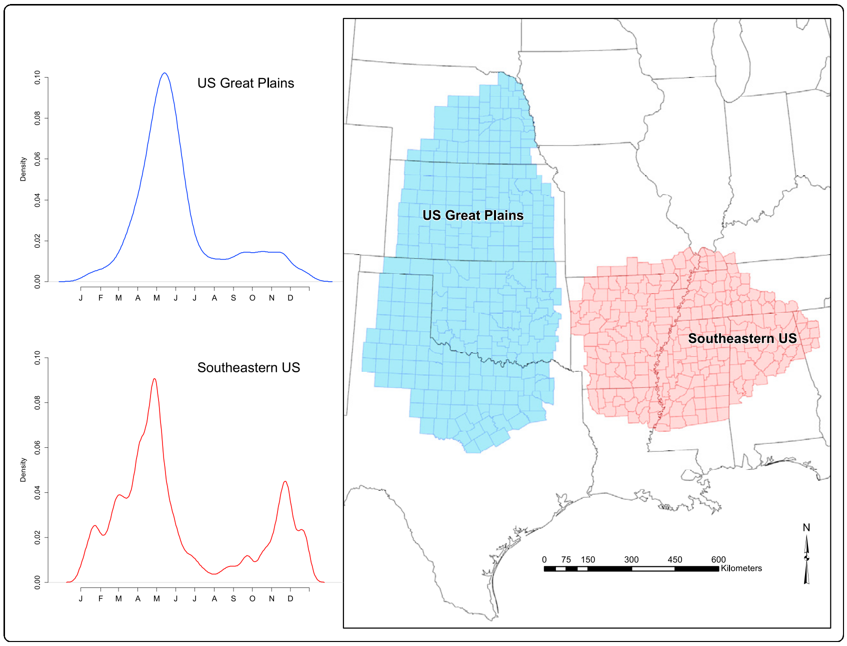

Fig. 1. Tornado activity in the Great Plains (blue) consists of a unimodal period of elevated activity during meteorological spring, whereas tornado activity in the southeastern United States (red) is bimodal with elevated periods of activity during spring and late autumn. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

States. Dixon et al. (2014) used K-means clustering to identify four seasons: winter (26 January–13 March), spring (14 March–7 May), summer (8 May–15 October) and fall (16 October–25 January), but this is for the tornado-prone regions of the entire United States. Tornado activity across the entire United States has a maximum in mid-June and a minimum in late December (Brooks et al., 2003), and the geographic region of maximum tornado activity in the United States changes throughout the year (Brooks et al., 2003; Tippett et al., 2014); thus, tornado seasonality is location-dependent. Brooks et al. (2003) examined the probability that a tornado day occurs at various locations in the contiguous United States, including several locations in the southeastern states and determined that the southeastern states face their biggest tornado risk in April. No studies to our knowledge have sought to identify any changes to tornado seasonality in the southeastern United States since the onset of systematic data collection.

The number of reported tornadoes in the southeastern United States has increased from an annual mean of 44 in the 1950s (1954–1959) to an annual mean of 97 during 2010–2015. Approximately 43% of the increase can be attributed to 2011, which had an unusually high number of tornadoes. It has also been widely reported that these increases are likely not "true" increases due to meteorological conditions, but instead reflect a variety of demographic factors such as better public awareness and reporting and increasing population trends, as well as technological improvements such as improved detection, better spotting techniques and the widespread implementation of Doppler radar (e.g., Verbout et al., 2006). We study trends in tornado seasonality rather than likelihood given known trends in reporting effort following Long and Stoy (2014). Furthermore, the increase in the number of reported tornadoes is primarily due to the increased reporting of weak tornadoes, (E)F0 and (E)F1 (e.g., Kunkel et al., 2013; Coleman and Dixon, 2014). Verbout et al. (2006) tested the stationarity of tornado frequency over a 50-year period and found that the number of annually reported tornadoes rated (E)F1 and greater was relatively constant over time, but the inclusion of (E)F0 tornadoes resulted in a non-stationary dataset. Consequently, researchers are divided with respect to whether or not (E)F0 events should be included in analyses, particularly those studies that look at trends over time. Others have reported a decrease in the number of days with at least one tornado (a tornado day), and a simultaneous increase in the number of days with many tornadoes (tornado outbreaks) (e.g., Brooks et al., 2014a; Elsner et al., 2015; Tippett et al., 2016). The use of tornado days as the response variable, rather than tornado frequency, is increasingly seen as a means to minimize the effect of tornado outbreaks on tornado accounting (e.g., Elsner et al., 2015).

The use of tornado days is of particular interest to the southeastern U.S. in part because tornadogenesis includes contributions from extreme weather events like landfalling tropical cyclones, which result in multiple tornado events. The majority of cyclones spawn tornadoes, typically weak, that tend to form in the outer rainbands and occur in outbreaks that may have wide spatial distribution (Gentry, 1983; Belanger et al., 2009).

The purpose of this study is to characterize the seasonality of tornadoes in the southeastern United States. Specifically we seek to: (1) delineate tornado seasonality in the southeastern United States to more accurately account for the bimodal nature of the observations; (2) determine whether the dates corresponding to peak tornado activity have changed since the 1950s using both tornado counts and tornado days; (3) assess whether including (E)F0 events in the analysis alters the results; and (4) assess the impact of tropical cyclones on tornado seasonality in the southeastern US.

2. Data and methodology

Tornado intensity varies greatly across events and is described using a classification scheme based on damaging effects from which wind speed is inferred. The original scale, the Fujita scale, was developed in 1971 and classified tornadoes on a scale from F0 to F5, in which F0 denotes tornadoes with the lightest winds that tend to cause the least amount of damage (Fujita, 1971). Well-known limitations with the Fujita scale led to the adoption of the enhanced Fujita scale (EF) (Potter, 2007). As in the original scale, the EF scale is graduated, with EF0 denoting the category with the lightest winds and damage, and EF5 denoting tornadoes with the strongest winds and the most extensive damage. To account for changes in tornado reporting over time, we use the abbreviation (E)Fx to denote a combined Fujita and enhanced Fujita scale where x varies from 0 to 5.