Regional Differences in the Human Toll from Tornadoes: A New Look at an Old Idea

MATTHEW D. BIDDLE,[a,f] RYAN P. BROWN,[b] CHARLES A. DOSWELL III,[c] AND DAVID R. LEGATES[d,e]

[a] *Police Department, University of Oklahoma, Norman, Oklahoma;* [b] *Doerr Institute for New Leaders, Rice University, Houston, Texas;* [c] *Doswell Scientific Consulting, Norman, Oklahoma;* [d] *Department of Geography and Spatial Sciences, University of Delaware, Newark, Delaware;* [e] *Department of Applied Economics and Statistics, University of Delaware, Newark, Delaware*

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ABSTRACT: Previously published claims of large regional (northern vs southern states) differences in risks of fatality associated with tornadoes in the United States are reexamined. This new study extends earlier claims to include 1) data from a much longer time frame, 2) injuries as well as fatalities, and 3) more precise estimates of meteorological features of tornado events (specifically, a precise calculation of daytime vs nighttime and pathlength). The current study also includes formal mediation analyses involving variables that might explain regional differences. Results indicate that significant increases in the risk of fatality and injury do occur in southern states as compared with northern states. Mediation models show that these regional differences remain significant when meteorological factors of nocturnal occurrence and pathlength are included. Thus, these meteorological factors cannot explain regional differences in risk of fatality and injury, a failure that is unlikely to reflect a lack of data or a lack of precision in the measurement of potential mediators.

KEYWORDS: Social Science; North America; Reanalysis data; Regional models

1. Introduction

In 1972, Sims and Baumann (1972) claimed that an "enormous difference" existed in the fatality risk of tornadoes in the southern versus northern United States. After excluding simple explanations such as time of day, prevalence of warning systems, quality of housing construction, and tornado strength, they concluded that sociocultural factors might account for the regional disparity in human casualties. Sims and Baumann then presented survey evidence in support of a sociocultural explanation of "southern fatalism," which, they argued, leads southerners to behave irrationally in the face of a tornado threat.

Evidence presented by Sims and Baumann (1972) exhibited a number of serious shortcomings. First, their assertion of an elevated southern risk of death from tornadoes was based on either very old (and arguably unreliable) data (Linehan 1957), or such a small number of events (between 1953 and 1964) as to make any analysis of tornado fatalities dubious. Evidence Sims and Baumann presented for "southern fatalism" reflected the survey responses of only 57 respondents, all white women, from either Illinois or Alabama—unlikely to be a representative sample of their respective regions. Subsequent studies were much less supportive of an elevated risk attributable to sociocultural factors (Kessler and Lee 1978), and examinations of larger datasets from southern and northern states failed to find significant regional differences in fatalism (Cohen and Nisbett 1998).

The goals of the current study are 1) to establish whether a regional difference in risk associated with tornadoes exists and 2) if a regional difference does exist, to examine whether simple meteorological explanations for any such risk might be sufficient to account for it. To improve the reliability of the conclusions, analyses will focus on tornadoes occurring between 1950 and 2018 in the five southern and five northern states on which Sims and Baumann focused their analyses, as well as across *all* southern and northern states (according to the U.S. Census Bureau; https://www2.census.gov/geo/pdfs/maps-data/maps/reference/us_regdiv.pdf), thus increasing the number of observations substantially over what was available to Sims and Baumann. Both fatalities and injuries were examined to expand the range of outcomes. Motivation for this research lies, in part, on the availability of a considerably larger and more comprehensive database on tornadoes than that available to Sims and Baumann (1972).

Although other researchers have examined regional differences in risk from tornadoes (with "regions" defined in a variety of ways across studies), as well as various meteorological factors that might be related to this risk, none of the studies conducted in the literature to date take this work the final step by conducting mediation tests to determine whether any such variables or combinations of variables can effectively account for regional differences. In the absence of such mediation tests, we are left with little more than descriptive differences between states or regions and assertions about the likelihood that such variables might be able to account for regional differences. However, the volume and quality of data available for examination since the time of Sims and Baumann (1972) make such mediation modeling both feasible and relatively easy, allowing us to test regional differences at multiple levels of analysis and to examine a diverse set of explanatory factors.

2. Factors associated with tornado fatalities

Without doubt, tornadoes present a significant fatality risk, particularly in the eastern two-thirds of the continental United States. Sims and Baumann (1972, p. 1386) noted that "the number of tornado-caused deaths in the South is strikingly

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[f] Deceased.

Corresponding author: Ryan P. Brown, ryan.p.brown@rice.edu

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higher than it is in the remainder of the nation.'' They note, however, that their *tornado death index* (TDI), given by

$$\mathrm{TDI} = 100\,\frac{D}{TP}, \qquad (1)$$

where D is the tornado death rate (per unit area), T is the tornado occurrence rate (per unit area), and P is the population density, is far greater in the southern United States than in the northern United States. Mathematically, this index is equivalent to the tornado fatality rate (per occurrence) divided by the population density, or alternatively the fatality per capita rate divided by the density of tornadoes (per square mile). Either way it is construed, this index is a strange way to account for the frequency of tornado occurrences and population statistics simultaneously. We will argue that there are better ways to account for these elements that were not feasible for Sims and Baumann, given their limited focus on just a small number of states.

To determine why a regional difference exists, Sims and Baumann (1972) posited several viable hypotheses and evaluated each in turn. Their first hypothesis speculates that the South has either a higher frequency of tornadic activity or a higher population density, either of which would increase the potential for loss of life due to tornadoes. They cite Sadowski (1965) to show that the highest *potential* for loss of life lies, in fact, with northern states, owing to a higher population density and a higher frequency of tornadoes. However, the second part of this assertion is contradicted by several more recent studies that have identified southern states as having a higher tornado frequency than northern states (Boruff et al. 2003; Brooks et al. 2003; Ashley 2007; Dixon et al. 2011; Coleman and Dixon 2014; Agee et al. 2016; Stokes and Senkbeil 2017; Strader et al. 2017a,b; Anderson-Frey and Brooks 2019; Strader et al. 2019), in part owing to characteristics such as increasing urbanization (Ashley et al. 2014; Strader et al. 2017a,b; Strader et al. 2018) and complex topography that causes lower lifting condensation levels (Lyza and Knupp 2018). Tornadoes in the southern region of the United States generally are more difficult to forecast owing to baroclinicity (Boruff et al. 2003; Dixon et al. 2011), their high-shear low-CAPE characteristics (Anderson-Frey et al. 2019), and their association with hurricanes (Schultz and Cecil 2009; Moore and Dixon 2011a,b). With regard to population density, Aguirre et al. (1993a,b, 1994) found that tornado occurrence increases in urban areas, although Elsner et al. (2013) clarify that, at least for the central plains, population bias is virtually nonexistent for F1 and stronger tornadoes and that the bias for F0 tornadoes has decreased over time. Anderson et al. (2007) concur, although they remark that Oklahoma is a notable exception due possibly to misclassification of weak tornadoes on the Fujita scale.

Research also has found that the U.S. tornado climatology has shifted in recent years. Specifically, locations of the most violent tornadoes (i.e., those which are most likely to create fatalities) have shifted from Texas and Oklahoma prior to 1984 (i.e., the period covered by Sims and Baumann 1972) to Tennessee and Alabama (Agee et al. 2016). Dixon et al. (2011) agree, noting that some parts of the southern United States are the most tornado-prone areas in the nation—Smith County, Mississippi (south-central Mississippi) emerges as the national hotspot, with the greatest average annual number of tornado days (1.38) and the greatest average annual number of tornadoes (1.48) occurring within 40 km (25 mi). Brooks et al. (2014) further argue that since the 1970s, tornado variability has increased due to a decrease in the number of tornado days per year but an increase in the number of tornadoes on any given day with tornado occurrence.

Next, Sims and Baumann (1972) suggest that southern states may exhibit a higher frequency of *nocturnal* tornadoes, thereby catching the population off guard as they sleep. Their data showed, however, a trivial difference between the proportions of nocturnal tornadoes in northern versus southern states. More recent research has evaluated the meteorology of nocturnal tornadoes (e.g., Bunker et al. 2019; Merrell et al. 2005), and analyses now indicate that southern states have a significantly higher nocturnal tornado risk (Ashley 2007; Ashley et al. 2008; Brooks et al. 2003) owing to their higher frequency outside of the summer months when day length is shorter. Specifically, Ashley (2007) noted that nocturnal tornadoes are responsible for a much greater proportion of tornado fatalities in southern states (42.5%) than in the United States in general (25.8%). Warnings, too, are more difficult to disseminate at night, which exacerbates the fatality risk associated with nocturnal tornadoes (Mason et al. 2018).

Sims and Baumann (1972) then hypothesized that tornadoes may last longer (i.e., have a longer pathlength) in the South, which would possibly explain why southern states exhibit more fatalities. They evaluated data from the National Weather Service and concluded that tornadoes in southern states did *not* have a longer pathlength. Sims and Baumann noted that, for example, the average pathlength in Alabama between 1959 and 1968 was 13.1 km (8.2 mi), whereas it was 14.9 km (9.3 mi) in Illinois. Thus, they concluded that tornadoes were *not* more severe in southern states (based on average pathlength for tornadoes in just two states, Alabama and Illinois). This view relating tornado intensity to pathlength is corroborated by Brooks (2004), who found that pathlength is proportional to Fujita rating, and by Malamud and Turcotte (2012), who demonstrated that a strong relationship exists between the number of significant tornadoes in a year and their total pathlength. However, Broyles and Crosbie (2004) provide a map of the frequency of F3–F5 tornadoes with at least a 25-mi pathlength over a 124-yr period (1880–2003). While these researchers suggest that strong tornadoes (which are more likely to cause fatalities) are more prevalent in southern states, the Broyles and Crosbie map exhibits considerable spatial variability, with many ''pockets'' of increased pathlength surrounded by areas of lesser pathlength. Despite the long time period, the relatively infrequent occurrence of significant tornadoes makes it difficult to argue that increased tornado intensity, brought on by an increase in tornado pathlength, is a major cause for an increase in tornado fatalities in southern states.

As a result of their assessment of these meteorological characteristics, Sims and Baumann (1972) subsequently concluded that variations in tornado characteristics do *not* lead to differences in fatalities between the northern and southern states; rather, the regional difference must be due to variations in human behavior. They then postulated that housing quality may be lower in southern states, and they rely on Flora (1954) and Hartman and Hook (1956) to suggest that building construction in southern states is not commensurate with construction in northern states, owing to the colder temperatures in the latter, which require thicker walls. Specifically, Sims and Baumann cite Bigler (1960), who argues that the pressure difference between the storm and the air remaining inside the home causes masonry buildings to collapse, but frame homes exhibited more flexible walls and ventilation, which allow for equalization of pressure. They do, however, note that Fujita (1970) argues that generalization of tornado damage to building design is not straightforward as a result of variations within tornadoes (e.g., ''suction spots'').

This latter issue regarding building construction has been more extensively researched since the Sims and Baumann (1972) analysis. Most notably, mobile homes have been identified as a major contributor to tornado fatalities, owing to their susceptibility to the high winds of a tornado (e.g., Ashley and Strader 2016; Schmidlin and King 1995; Simmons and Sutter 2008; Chaney and Weaver 2010; Liu et al. 2019a; Strader et al. 2019; Sutter and Simmons 2010). Lim et al. (2017) argue that tornado deaths are inversely proportional to per capita income, which is manifest particularly in housing quality and in the use of mobile homes, specifically. Strader and Ashley (2018) note that mobile homes are 350% more susceptible to tornado damage in Alabama relative to Kansas owing to a more widespread use of mobile homes in southern states. Ash (2017) argues that mobile homes make up approximately 15% of the homes in use in the southern United States, while Simmons and Sutter (2007a,b) note that over 40% of tornado fatalities occur in mobile homes. Moreover, mobile home residents are less likely to take shelter or to follow emergency response plans (Schmidlin et al. 2009; Chaney and Weaver 2010).

Sims and Baumann (1972) further suggest that the relative efficacy of warning systems may be lacking in southern states. They dismiss this possibility, however, by noting that a nationwide warning system was not in place prior to 1952, when southern states exhibited a greater frequency of tornado-induced fatalities, and that a change did not occur when nationwide warnings were instituted in 1953. Sims and Baumann argue, however, that it is not the presence (or absence) of a warning system, but rather, *how the population responds* to warnings that are given. They cite Brouillette (1956) and Adams (1965) to contend that a prevalence of tornado warnings and complacency resulting from a belief that one is safe lead to a failure to heed tornado warnings when they are given.

Presuming to have eliminated physical and demographic characteristics as possible reasons for the disparate tornado fatality rates between northern and southern states, Sims and Baumann (1972) proceeded to determine if human *responses* to a possible tornado threat differ between the two regions. Again, numerous studies have since investigated the impact of demographic and personal differences on the response to tornado risk. For example, studies have focused on age (Schmidlin and King 1995; Chaney et al. 2013), gender (Silver and Andrey 2014), race (Senkbeil et al. 2014), activity/location at the time the tornado occurs (Schmidlin and King 1995; Niederkrotenthaler et al. 2013; Paulikas and Schmidlin 2017), trust in authority (Shupp et al. 2017), or simply the understanding or misunderstanding of the actual risk that tornadoes pose (Chaney et al. 2013; Klockow et al. 2014; Silver and Andrey 2014; Shupp et al. 2017; Demuth 2018; Ellis et al. 2018; Mason et al. 2018; Schumann et al. 2018), although other demographic factors appear to be insignificant (Schmidlin and King 1995).

Given the historical importance of Sims and Baumann (1972) and the possibility that their research might be based on assumptions that were erroneous at the time or have since become invalidated due to a changing tornado climate and human behavior, this paper will reexamine the Sims and Baumann analyses, using a more extensive and accurate set of events and their associated characteristics, as well as an extended set of outcome metrics. Moreover, complementing numerous studies on fatality risks over the last several decades, we take the additional step that is missing from these more recent studies of conducting event-level mediation tests (a type of causal modeling). While researchers such as Ashley (2007) and Ashley and Strader (2016) have investigated factors such as the extent and type of land development across states in the United States at an exceptional level of granularity, alongside meteorological factors such as tornado frequency and intensity, no studies to date in this literature have conducted mediation tests to determine whether, or to what extent, such factors are capable of *explaining* regional differences, no matter how researchers define the boundaries of the regions of interest. Without formal mediation tests, we can conclude with great confidence, for example, that tornadoes kill more people in southern than in northern states, that nocturnal tornadoes are associated with enhanced vulnerability to tornadoes, and that nocturnal tornadoes are significantly more prevalent in southern states compared to northern states. These descriptive differences, however, do not establish whether a factor such as prevalence of nocturnal tornadoes can mediate (fully or partially) fatality differences between southern and northern states. Only a mediation test can do so. If meteorological (e.g., nocturnal occurrence) factors are significantly associated with regional differences, it remains important to know whether such factors are capable of fully or partially mediating regional differences in casualties from tornadoes. If they are not sufficient, then we know we need to keep searching for variables that enable us to explain any regional differences we might observe.

3. Analysis of tornado events: 1950 to 2018

Tornado data from 1950 to 2018 were obtained from the Storm Prediction Center (SPC) in Norman, Oklahoma (https://www.spc.noaa.gov/wcm/data/1950-2018_all_tornadoes.csv). Most reported tornadoes (77.7% between 1950 and 2018) are low-intensity events, recorded only as F0 or F1 (or EF0 or EF1) tornadoes with extremely low fatality and injury rates. In fact, less than 1% of these low-intensity tornadoes produced *any* fatalities in almost 70 years. Thus, our study was confined to *significant* tornadoes, rated as F2 (or EF2) or higher (Davies-Jones et al. 1973), with 12 286 significant tornadoes occurring nationwide during this time period. Sims and Baumann (1972)

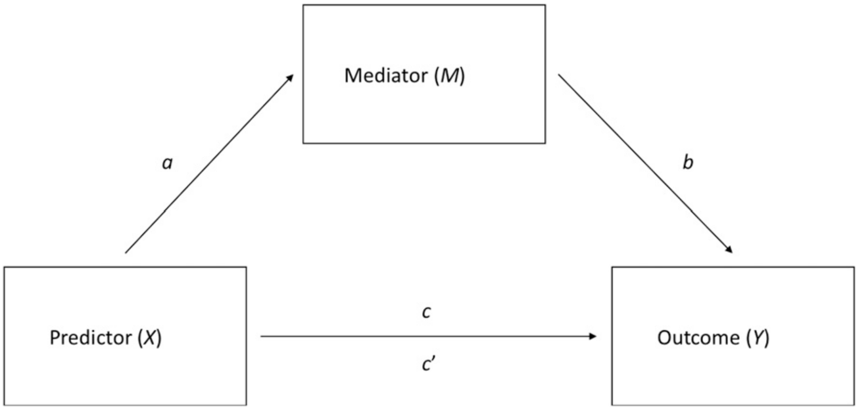

FIG. 1. Illustration of a standard mediation model.

considered only five southern states (Alabama, Arkansas, Georgia, Louisiana, and Mississippi) and five northern states (Illinois, Indiana, Iowa, Missouri, and Ohio) in their analysis. Within these 10 states alone, 4890 significant tornadoes were documented from 1950 to 2018.

Between 1950 and 2018, nearly 78% of all fatal tornadoes produced only three or fewer fatalities (although three tornadoes during this time resulted in more than 100 fatalities), highlighting the highly skewed nature of the distribution when considering only the raw number of fatalities (or injuries). The extreme skew in the distribution of fatalities and injuries by a tornado was addressed in the present study by creating two dichotomous variables—whether a tornado *did* or *did not* produce 1) any fatalities or 2) any injuries. This type of outcome metric is superior to the fatality rate that Sims and Baumann used in their tornado death index, which is highly susceptible to a small number of extreme outliers. This outcome metric also enables us to sidestep the question of whether a higher *number* of fatalities or injuries in the South might simply be due to a higher *frequency* of significant tornadoes occurring in the South, a relatively straightforward question that has already been addressed by other researchers (e.g., Brooks et al. 2003; Ashley 2007). The present study also examines casualties (both injuries and fatalities together) from tornadoes at two levels: the level of the tornado event, and the level of the state, the latter aggregating tornado events over the almost 70-yr time period to provide the percentage of tornadoes in each state that caused any human casualties. Models at the state level of analysis allow for further investigation of regional variables that might help to explain any differences in casualty rates between northern and southern states, such as population density, density of mobile homes, and others (described later). Rather than including such state-level variables in the casualty metric itself, however, we include these factors as independent predictors in our models.

Because these fatality and injury outcomes were dichotomous, logistic regression was used to analyze a dichotomous outcome using both categorical and continuous predictor variables. In the logistic regression results reported below, the primary statistics are 1) the odds ratio (OR), which indicates the *relative odds* of an event occurring (in this case, at least one fatality or injury) with a one unit increase in a predictor variable; 2) the Wald statistic, which is the chi-square test of the statistical significance of the OR, computed as the ratio of the square of the regression coefficient (the log of the OR) to the square of the standard error of this coefficient; and 3) a P value, which is the computed probability of obtaining an OR as large as was obtained in the study under the assumption that the null hypothesis is true (i.e., an obtained P value < 0.05 would lead to the rejection of the null hypothesis). In this study, the null hypothesis is that tornadoes were neither more nor less likely to result in fatalities (or injuries) in southern states than they were in northern states, an outcome that would be consistent with an OR of 1.0. Because southern tornadoes were coded as 1 and northern tornadoes were coded as 0, an OR greater than 1.0 would be obtained if southern tornadoes were *more likely* to result in fatalities (or injuries) than were northern tornadoes, whereas an OR less than 1.0 would be obtained if the reverse were true.

For comparisons of continuous variables as a function of region—such as the mean tornado pathlength—a two-sample t test is used, in which the T statistic is computed as the mean difference divided by the standard error of the difference (Blalock 1972). In the results reported below, N represents a sample size, $\overline{X}$ represents a sample mean, and s represents a standard deviation.

Mediation models, which are common throughout the social sciences, are rarely utilized in meteorology research. Although the original conceptualization of mediation placed it squarely within the realm of causal modeling for experimental research designs (e.g., Baron and Kenny 1986), neither the logic nor the computation of mediation actually requires data from a controlled experiment. All that is conceptually required is that there be a set of three (or more, in the case of multiple mediators) statistical relationships, and that a potential mediator of a primary association be specified. Figure 1 presents a generic diagram of such a conceptual model.

In this model, the primary association between a predictor variable X and an outcome variable Y is depicted by path c. This association can be positive or negative, but for simplicity, assume this association is positive. A mediator variable M is associated with both the predictor variable (through path a)

and the outcome variable (through path b). For illustration purposes, assume these associations are also positive. The formal test of mediation occurs when the indirect path from X to Y through M is examined by adding variable M to the primary model. If variable M fully mediates the association between X and Y, then the new association between X and Y (through path c') will no longer be statistically significant when M is added to the model, but the association between M and Y (through path b) will remain significant. To be considered complete, however, a further test of the *reduction* in path coefficients from c to c' must also be statistically significant (Baron and Kenny 1986). Partial mediation occurs when all of these conditions have been met with one exception—the direct path from X to Y (c') remains significant in the presence of the mediator, although c must still be significantly greater than 0. When the number of observations is small, bootstrapping models can be a powerful and effective way of testing mediation (Hayes 2018). We should note as well that multiple mediators can be tested in these models, although strong associations among mediators can create multicollinearity problems.

In this illustration, all paths (a, b, and c) are positive. A statistical suppressor variable acts in a complementary way to mediation. When either path a or b is negative, for instance, but path c is positive, then the inclusion of variable M will not reduce path c but will, instead, *increase* path c (such that $c' - c > 0$). Thus, when variable M is a suppressor rather than a mediator variable, path c' will be greater than path c. In our study, we used a mediation model to examine whether the meteorological variables of nocturnal occurrence or tornado pathlength might be capable of mediating regional differences in rates of fatalities and injuries from tornadoes.

4. A reevaluation of tornadoes in the United States

Sims and Baumann (1972) contended that tornadoes in southern states cause strikingly more deaths than do tornadoes in the northern states. Sims and Baumann's analysis of fatalities, based on their own ''tornado death index,'' used events occurring between 1953 and 1964. Considering the much larger and more precise dataset available now, the present study first considers whether any evidence exists for an increased risk of fatalities from significant tornadoes in southern states compared to northern states. This study also extends the analysis of risk by Sims and Baumann (1972) by including injuries as well as fatalities.

Our first analysis is limited to the five southern states (Alabama, Arkansas, Georgia, Louisiana, and Mississippi) and the five northern states (Illinois, Indiana, Iowa, Missouri, and Ohio) considered by Sims and Baumann. For these states, a significant difference in fatality risk by region was found, such that significant tornadoes in southern states resulted in fatalities 14.7% of the time, as compared with 10.9% of the time in northern states (OR = 1.41, Wald = 15.34, and $P < 0.001$); the OR indicates that the odds of significant tornadoes causing fatalities in southern states were 1.41 times the odds of significant tornadoes causing fatalities in northern states. Likewise, significant tornadoes in southern states caused injuries 50.0% of the time, as compared with 39.8% of the time in northern states (OR = 1.52, Wald = 51.56, and $P < 0.001$). Although these results support Sims and Baumann's underlying contention that tornadoes in southern states are more likely to cause harm to humans, the characterization of this increased risk as ''strikingly higher'' by Sims and Baumann appears to be somewhat overstated.

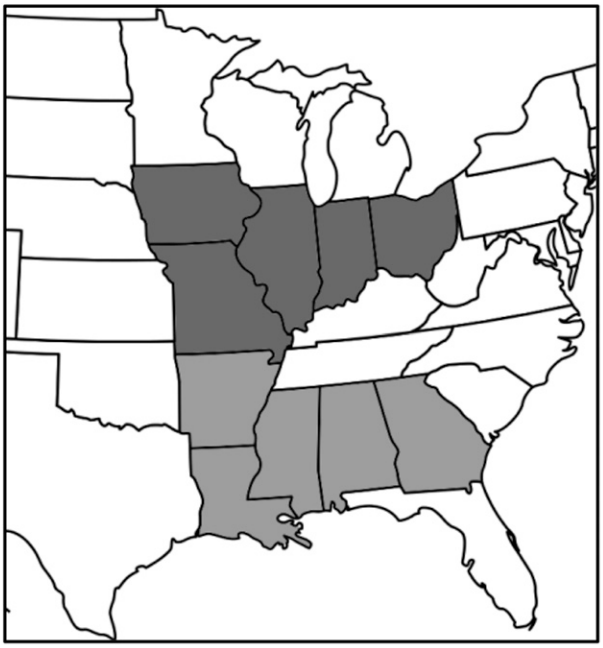

FIG. 2. States used by Sims and Baumann (1972) to delineate the southern states (lighter gray) from the northern states (darker gray).

Nocturnal tornadoes are more likely to produce fatalities than daytime tornadoes (Mason et al. 2018). In part, this is due to the more likely receipt of tornado warnings during the day. Belief that ''luck'' is an important factor to tornado survival is also negatively correlated with nighttime warning receipt (Ashley et al. 2008; Mason et al. 2018). Based on a comparison of diurnal distributions across the five northern and five southern states between 1916 and 1961, Sims and Baumann (1972) argued that the relative frequencies of nocturnal events cannot account for the regional difference in the likelihood of casualties. They concluded that no significant difference in the frequency of nocturnal events existed by region (specifically, only a 3.1% difference in the proportion of all events that were nocturnal).

For our study, a reexamination of the percentage of nocturnal tornadoes in each state examined by Sims and Baumann (see Fig. 2) was based on more precise calculations—specifically, locally derived calculations of daily twilight hours (as in Ashley et al. 2008).[1] Our estimates of nocturnal occurrence, which

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[1] We classified an event as having occurred at night if it occurred between 20 min after local sunset (post ''twilight'') and 20 min before local sunrise. This coding system was much more precise than that of Sims and Baumann (1972), who simply categorized events as nocturnal if they occurred between 2000 and 0700 LT.

TABLE 1. Estimates of the percentage of tornadoes occurring at night in each state included in Sims and Baumann (1972; see Fig. 2) and in our study. "Significant tornadoes" are those rated F2/EF2 and above, which are responsible for almost all (>99%) human deaths from tornadoes.

	Percent nocturnal from Sims and Baumann: all tornadoes	Percent nocturnal from new estimates	
		Significant tornadoes	All tornadoes
Northern states			
Illinois	27%	38%	26%
Indiana	34%	37%	30%
Iowa	27%	27%	24%
Missouri	35%	42%	37%
Ohio	29%	29%	23%
Southern states			
Alabama	37%	39%	36%
Arkansas	37%	44%	41%
Georgia	30%	39%	32%
Louisiana	34%	45%	35%
Mississippi	31%	45%	38%

were more precise and were based on a much larger number of events than were the estimates of Sims and Baumann (Table 1), revealed that nocturnal tornadoes were significantly more frequent in southern states. Specifically, 42.5% of significant tornadoes in these five southern states occurred at night, which was significantly higher than the 34.5% of significant tornadoes occurring at night in the five northern states (OR = 1.40, Wald = 32.60, and $P < 0.001$). This difference suggests that nocturnal occurrence might function as a statistical mediator of the association between region and casualty risk.

Because the Fujita (F) scale did not yet exist, Sims and Baumann (1972) used length of tornado pathlength to estimate tornado strength. Comparing events in just Alabama and Illinois between 1959 and 1968 and speculating on tornado pathlengths for some storms because of incomplete data, they concluded that the mean tornado pathlengths were, in fact, *shorter* in the South.

Using all 10 states from Sims and Baumann and data from the SPC database, this conclusion of shorter tornado pathlengths in the South was not supported. In fact, on average tornadoes in the five southern states ($\overline{X} = 11.69$ km, $s = 17.76$ km, and $N = 2611$) were significantly *longer* than tornadoes in the five northern states ($\overline{X} = 10.49$ km, $s = 15.39$ km, and $N = 2279$) [$T(1, 4888) = 2.30$, with $P = 0.021$]. A similar analysis of mean F-scale ratings, which were not available to Sims and Baumann (1972), revealed no difference between these five southern states ($\overline{X} = 2.32$; $s = 0.57$) and five northern states ($\overline{X} = 2.34$; $s = 0.62$) [$T(1, 4888) = 1.19$, with $P > 0.23$].

These analyses suggest that, at least for these 10 states, two meteorological qualities—nocturnal tornado occurrence and tornado pathlength—*might*, in fact, mediate differences in fatality and injury rates across regions. What would be required for mediation through either of these variables is that each one is significantly (and positively) associated with the likelihood of fatalities and injuries. A logistic regression analysis revealed that a greater proportion of nighttime tornadoes (14.2%) did, in fact, result in fatalities compared to the proportion of daytime tornadoes that did so (12.2%), (OR = 1.20, Wald = 4.29, and $P < 0.04$); similarly, a greater proportion of nighttime tornadoes (47.7%) resulted in injuries compared to the proportion of daytime tornadoes that did so (43.7%), (OR = 1.18, Wald = 7.61, and $P < 0.01$). Likewise, pathlength was significantly associated with the likelihood of fatalities (OR = 1.04, Wald = 286.16, and $P < 0.001$) and with the likelihood of injuries (OR = 1.04, Wald = 243.02, and $P < 0.001$). Thus, nocturnal occurrence and pathlength might well serve as statistical mediators of regional differences in casualty risks. Because the association between nocturnal occurrence and pathlength was significant but modest in magnitude ($T = 3.28$; $P < 0.001$), with an effect size estimated by Cohen's d of 0.094, multicollinearity among predictors was not a risk in any models reported here that included both potential mediators.

A model that controlled statistically for these two meteorological factors in separate analyses of fatality and injury rates for significant tornadoes showed that regional differences in fatality and injury rates were *not* explained by these potential mediators. Indeed, including each tornado's nocturnal classification and pathlength in the regression models only decreases *slightly* the regional association with both fatalities and injuries (see Table 2 for details), and region remained statistically significant in both cases.

This pattern of results changes if tornadoes from *all* northern and southern states, as defined by the U.S. Census Bureau, are included (Table 3; Fig. 3). For the 11 895 significant tornadoes rated F2 (or EF2) and above in the database, a significant association exists between region and likelihood of fatalities (OR = 1.42, Wald = 33.91, and $P < 0.001$), with significant tornadoes in southern states producing fatalities 12.5% of the time, as compared with 9.1% of the time in northern states. When variables representing nocturnal occurrence and tornado pathlength were included in the model, the association between region and fatalities actually *increased* slightly (OR = 1.50, Wald = 39.07, and $P < 0.001$), indicating a statistical suppressor effect of these variables on regional differences in fatality risk. Likewise, southern tornadoes were also more likely to produce injuries than were northern tornadoes (OR = 1.49, Wald = 106.99, and $P < 0.001$), with significant tornadoes

TABLE 2. Logistic regression results for fatalities and injuries in the 10 states analyzed by Sims and Baumann (1972; see Fig. 2); B = unstandardized regression weight, SE = standard error of the regression weight, Wald = the Wald statistic, which is a chi-square-based inferential test of the regression weight, P = P value, and OR = odds ratio, or the relative odds of an event (e.g., a fatality) occurring at each level of the predictor variable (e.g., in northern vs southern states).

	B	SE	Wald	P	OR
			Fatalities		
Step 1					
Region	0.341	0.087	15.34	0.001	1.406
Step 2					
Region	0.298	0.092	10.43	0.001	1.348
Nocturnal	0.276	0.092	9.01	0.003	1.318
Length	0.043	0.003	289.64	0.000	1.044
			Injuries		
Step 1					
Region	0.416	0.058	51.56	0.001	1.517
Step 2					
Region	0.395	0.060	43.06	0.001	1.484
Nocturnal	0.189	0.061	9.47	0.002	1.208
Length	0.042	0.003	243.44	0.000	1.043

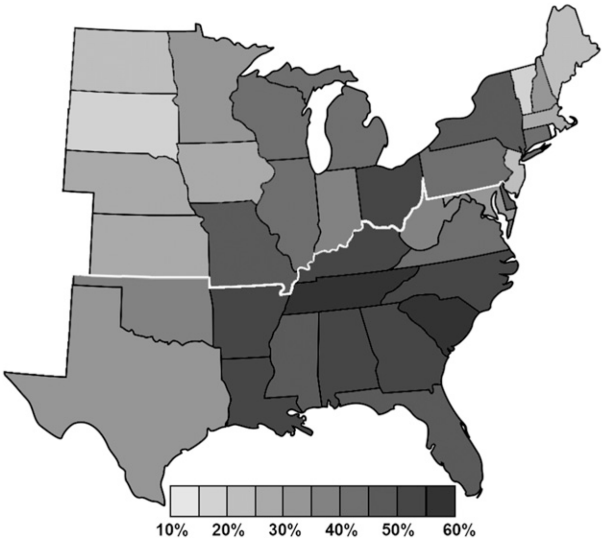

FIG. 3. Percentage of significant (F2+) tornadoes producing casualties (fatalities and/or injuries). The bright white line demarcates southern states from northern states. One state (Rhode Island, unshaded) did not experience enough significant tornadoes to calculate casualty percentages.

in southern states producing injuries 44.0% of the time, as compared with just 34.6% of the time in northern states. As with fatalities, the association between region and risk of injury also *increased* slightly when nocturnal occurrence and pathlength were included in the model (see Table 3).

These increased associations between region and likelihood of casualties appear to be due to the fact that when *all* southern and northern states were examined, rather than just those from the 10 states included by Sims and Baumann (1972), the mean tornado pathlength is significantly *shorter* in southern states (mean M = 9.45; standard deviation SD = 15.22) in comparison with the average length in northern states [M = 10.34; SD = 15.44; $T(1, 11\,893)$ = 3.14, with P = 0.002]—in other words, pathlength serves as a suppressor variable rather than as a mediator. Thus, conclusions about regional differences in tornado risk are not limited to just the 10 states on which Sims and Baumann focused—significant regional differences in the likelihood of harm to humans do, indeed, occur (see Table 4 for a summary of differences by region). Meteorological factors examined here (nighttime occurrence and pathlength), however, are unable to explain regional differences in casualty rates, and *how* meteorological factors affect regional differences depends on whether *only* the states from Sims and Baumann were examined or whether *all* southern and northern states were considered.

TABLE 3. As in Table 2, but for *all* southern and northern states.

	B	SE	Wald	P	OR
			Fatalities		
Step 1 (pseudo R^2 = 0.006)					
Region	0.354	0.061	33.91	0.000	1.424
Step 2 (pseudo R^2 = 0.117)					
Region	0.402	0.064	39.07	0.000	1.495
Nocturnal	0.365	0.063	33.43	0.000	1.440
Length	0.040	0.002	574.97	0.000	1.041
			Injuries		
Step 1 (pseudo R^2 = 0.012)					
Region	0.395	0.038	106.99	0.000	1.485
Step 2 (pseudo R^2 = 0.100)					
Region	0.437	0.040	119.92	0.000	1.548
Nocturnal	0.258	0.041	39.44	0.000	1.294
Length	0.042	0.002	574.27	0.000	1.043

5. Discussion

Data used by Sims and Baumann (1972) to establish the elevated risk of casualties from tornadoes in the southern United States were not highly reliable, and they appear to have overstated the degree of elevated risk associated with southern states. Nonetheless, their basic contention was supported by our analysis, which used an updated and more extensive database, examined additional southern and northern states beyond the 10 states that Sims and Baumann examined, and included injuries alongside fatalities. Whether we examined the small number of northern and southern states included by Sims and Baumann (1972) or all states defined by the U.S. Census Bureau as northern and southern, a significantly elevated risk of casualties from tornadoes was observed.

Although the meteorological factors of nocturnal occurrence and tornado pathlength were useful in predicting casualty rates, an examination of tornadoes in all northern and southern states showed that these meteorological factors actually *suppressed regional differences* in casualty rates rather than mediating them. This finding is at odds with recent arguments (e.g., Ashley 2007; Strader et al. 2017a) suggesting that nocturnal occurrence rates might mediate regional differences in casualties from tornadoes, and it underscores the

TABLE 4. Descriptive statistics for the 10 states analyzed by Sims and Baumann (1972) [labeled S and B (1972)] and all northern (N) and southern (S) states, as a function of region, during the time period 1950–2018. One state (Rhode Island) did not have enough (at least 10) significant tornadoes to compute casualty statistics reliably. Pathlength (mean across states) is expressed in kilometers.

	S and B (1972): original		S and B (1972): updated		All states in regions: updated	
	N	S	N	S	N	S
No. of tornadoes			2279	2611	5140	6755
Percent nocturnal	30.6	33.7	34.5	42.5	27.8	37.9
Pathlength (km)			10.6	11.7	10.3	9.4
Percent causing fatalities			10.9	14.7	9.1	12.5
Percent causing injuries			39.8	50.0	34.6	44.0

importance of conducting formal tests of mediation for questions like this. The failure of these basic meteorological factors to mediate regional differences indicates that more research is needed to examine other variables that might account for the elevated risk of casualties associated with southern states. Indeed, Sims and Baumann (1972) argued that ‘‘southern fatalism’’ might account for regional differences in risk of fatalities, but later research failed to support the contention that a regional difference in fatalism even exists (Cohen and Nisbett 1998), much less that it could explain the regional difference in casualties from tornadoes.

Numerous studies have examined the efficacy of tornado warning systems in alleviating tornado fatalities. Comparisons between studies in northern and southern states indicate that responses to such warnings are similar, although details associated with individual tornado events make regional comparisons difficult (Schmidlin and King 1995; Liu et al. 1996; Legates and Biddle 1999; Balluz et al. 2000; Biddle 2000; Mullins et al. 2012; Nagele and Trainor 2012; Sherman-Morris and Brown 2012; Plotnick et al. 2012; Senkbeil et al. 2012; Biddle and Legates 2013; Brown 2013; Senkbeil et al. 2014; Chaney et al. 2013; Niederkrotenthaler et al. 2013; Stokes 2013; Mason and Senkbeil 2014; Paul et al. 2015). These studies include factors such as people’s responses to false warnings and whether these warnings are perceived as being accurate, which might differ in southern relative to northern states (Simmons and Sutter 2009; Schultz et al. 2010; Ripberger et al. 2015; Trainor et al. 2015; Lim et al. 2019).

Variations in temporal patterns suggest that recent changes in tornado activity could exacerbate the tornado risk in southern states, which makes understanding the underlying causes of regional differences all the more important. For example, Agee et al. (2016) argue that the period from 1954 to 2013 exhibits a shift in the center of tornadic activity from Oklahoma and Texas to Alabama and Tennessee in 1983/84, a pattern that is also observed by Gensini and Brooks (2018). This may have affected some of the assessments here regarding Sims and Baumann (1972), although the observed temporal increase in autumnal tornado counts (both for all tornadoes and severe tornadoes) encompasses northern as well as southern states (Indiana south to Mississippi) (Agee et al. 2016).

Note that our study used two event-specific factors, nocturnal occurrence and tornado intensity, in an attempt to mediate regional differences in tornado casualties. Other factors, however, might be explored in future research to try to understand why tornadoes in southern states produce more fatalities and injuries than do tornadoes in northern states. For example, rather than using pathlength as an indicator of tornado intensity, we could have used ratings of tornado intensity using the F scale/EF scale. Doing so would probably require that we not include events as far back in time as those included by Sims and Baumann (1972) and the present extension of their study, as such ratings are not likely to be as accurate for older tornadoes. Likewise, we could have used the overall damage footprint produced by each tornado in the database by multiplying the pathlength by the width of each event (e.g., Ashley and Strader 2016). Although width data are included in the event database, these data appear to be in ‘‘fixed’’ widths (e.g., factors of 10, and some are zero width, implying missing data). Because tornado width is more difficult to ascertain and probably varies along the pathlength, this factor seems much less reliable than length alone. Indeed, when we created a ‘‘footprint’’ variable out of the product of length and width, this new variable did not add any significant explanatory strength to any of the models that we tested.

Another potential factor that was not examined in our study is tree cover (Ashley 2007). While we agree that tree density can be a factor in reducing the visibility of tornadoes, it is difficult to quantify the degree to which trees obscured a given tornadic event and to specify the functional relationship between tree density and tornado obscurity. Time of day also plays a significant role as nocturnal tornadoes are less likely to be obscured by tree density effects. Moreover, Ashley (2007, 1224–1225) notes that, despite a decrease in both tree cover and a noted lack of topographical variability, the southern Mississippi River Delta exhibits ‘‘a number of high killer tornado event[s].’’ This leads to the conclusion that tree cover ‘‘may not explain completely the enhanced vulnerability occurring in the Southeast.’’ Given the difficulty in quantifying its impact and the limitations of tree density as an explanatory variable, we chose not to include it in the current study.

Despite these limitations, policy makers, emergency management agencies, and even weather forecasters would do well to heed the message provided by the present data. Although Sims and Baumann (1972) might have been wrong about *why* an elevated risk of casualties from tornadoes occurs in southern states, their conclusion that such a risk exists was supported by the present study. The risk of both fatalities and injuries by tornadoes is greater in southern than in northern states, and this risk difference cannot be attributed merely to meteorological elements of the tornadoes themselves, such as their intensity or whether they occur at night. Further mediation models involving factors that might be able to explain these regional differences is warranted in order to protect people from some of nature's most powerful storms.

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