Geographic Specificity, Tornadoes, and Protective Action

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ABSTRACT

In 2007, the National Weather Service (NWS) began using storm-based warnings (SBWs) rather than countywide warnings. Some analysts have examined the effects of this change, but little empirical research has yet to focus on the public response. Using a random digit dialing sample and a computer-assisted telephone interviewing (CATI) system, data were collected that focused on protective action decision making in counties that were affected by a severe storm or tornado warning. Based on those data, the following paper examines the influence of these new storm-based warnings on protective action decision making by the public. While a significant relationship between being inside the warning polygon and taking protective action was not found, the authors were able to conclude that polygon size is an important factor. Given these mixed results, it is suggested that future work on storm-based warnings focus on the warnings' dissemination and reception, as well as the optimization of the polygons themselves. It is suggested that the complexities associated with communicating with these risk areas complicate the dissemination process and create difficulties in the public understanding of the warning. The possible need for optimization is reinforced by the significance of the track proximity and polygon-sized variables. In addition, a smaller polygon resulted in protective action, in particular, sheltering. With regard to the preparedness and sociodemographic variables, the study's results agreed with previous findings on the importance of a family emergency plan. Unlike earlier research this study did not find past experience or education level significant within the regression model and showed mixed results of gender.

1. Introduction

In recent years, there have been continued improvements in the meteorological understanding of tornadoes, radar technologies, and severe weather forecasting. As a result, it is possible to more accurately predict the location and movement of tornadoes. These predictive advances have been, to varying degrees, translated into operational changes in warning systems. In particular, the National Weather Service (NWS) has placed attention on the geographic precision of tornado warnings. Even so, the 2011 and early 2012 tornado seasons remind us that as a nation, we have significant work yet to do. Part of that work needs to be focused on developing stronger linkages between the warning system policies and our understanding of public response to these warnings. This analysis is thus part of a larger effort to better understand how key advances in atmospheric and social sciences influence public response to tornadoes. In particular, it focuses on the geographic dimensions of present-day warnings. More specifically, it examines the relationship between warning polygons, storm tracks, household location, sociodemographics, and protective action decisions.

2. Background

Until 2007 the NWS issued tornado warnings by county. If a storm capable of producing a tornado was observed or detected, the county within which it was located would be warned. Over the years, many have suggested that this method was less than ideal because it alerts/warns people that are not actually at risk. For example, in the case where a tornado is observed in one corner of a large county, under the old system, the whole county would be placed under a warning when in reality a vast majority of the households were actually quite unlikely to see a tornado (NWS 2007). Needlessly alerting large areas is more than a matter of inconvenience, particularly when one considers research that estimates the high costs of taking protective action in terms of lost productivity and

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leisure (see Sutter and Erickson 2010), the importance of being precise becomes more apparent. Given this information, in 2007 the NWS began using a new warning method called storm-based warnings (SBWs). The SBW method attempts to add geographic specificity by issuing warnings that are not specifically restricted to geopolitical boundaries (NWS 2007). These polygons are constructed based on the storm motion and the location of the main updraft. While there is no set method for determining the boundaries for the polygon, according to some, this method may reduce the areas under warning by as much as 75% (NWS 2007). Furthermore, Sutter and Erickson (2010) estimate that this approach may reduce the time under warnings by 66 million person-hours per year, leading to a savings exceeding $100 million (U.S. dollars). Preliminary tests of the new method showed user benefits as well. Store franchises in areas warned by polygons could more easily determine which stores needed to activate tornado procedures and for how long. Also, emergency managers were better able to focus their resources and make preparations in the correct areas (NWS 2007).

Despite these improvements, until now little has been done to understand how SBWs affect public response behaviors. Building on previous empirical research, this study examines the effect of these polygons on public response. Given that saving lives is the major goal of the severe weather warning program, it is important that we not only understand the potential economic but also the life safety effects of this change to the warning system.

3. Literature review

Years of research have produced a wealth of knowledge regarding how people respond to warnings. So much so that multiple annotated bibliographies and published literature reviews (e.g., Mileti 1975; Drabek 1986; Fitzpatrick and Mileti 1991; Drabek 1999; Mileti and Peek 2000; Sorensen 2000; Tierney et al. 2001; Mileti et al. 2006; Sorensen and Sorensen 2006; Lindell 2012) have documented factors that influence protective action decision making. Two general warning models dominate these empirical analyses and provide much of the logical and theoretical foundation for most modern empirical works. The first model was developed by Mileti and Sorensen (1990) inductively, as part of an extensive review of the state of knowledge related to warnings. The second model, called the Protective Action Decision Model (PADM), was developed around the same time by Michael Lindell and Ronald Perry, who extended the logic of collective behavior, risk, and decision models to the context of hazard decision making (see Lindell and Perry 1992, 2004, 2011). These models capture much of what is known about how people respond to severe weather risks across hazards. In looking more specifically for research on behavioral responses to tornadoes it was found that while there is significant literature few focus directly on decision making (see Lindell 2012). Instead, much of the research comes from an epidemiological perspective and attempts to identify the predictors of morbidity or mortality. While such studies often address warnings and decision making, they rarely consider the decision process as the focal analytical element. Even so there are several identifiable patterns in the findings, many of which we can further support by extending patterns found in research on other types of hazards. Here we briefly review these patterns.

First and foremost, the research suggests that those who do not receive a warning are significantly less likely to take protective action (Balluz et al. 2000; Blanchard-Boehm and Cook 2004). This is the case regardless whether the cause was due to technical failure, such as power outages (Mitchem 2003), or situational circumstances, such as being in transit during a warning (Glass et al. 1980; Mitchem 2003), the storm happening at nighttime (Schmidlin et al. 1998), or the presence of a language barrier (Aguirre 1988). Lack of warning receipt has been found time and again by numerous studies to be an influential decision factor. As a result, our analysis will only consider the decision process for those who received some type of warning or alert from an official or unofficial source; all others are considered ineligible. Second, disaster experience has also been found to influence protective action during tornadoes. Hodler (1982) found that personal experience with a past event made people more likely to believe and to respond to tornado warnings. Others have found that experience also increases the likeliness of people to prepare (Blanchard-Boehm and Cook 2004) as well as their desire to react more proactively in future events (Simmons and Sutter 2007). The precise effect and duration of influence from an experience is, however, unclear. For example, Hanson et al.'s (1979) study found that awareness of a major historical event was more compelling than personal experience. Third, level of education has also been found to affect protective action. Being a high school graduate increases the likelihood of a person responding to a warning message (Balluz et al. 2000; Blanchard-Boehm and Cook 2004) and conversely, being less educated reduced the likelihood of responding to a warning message (Liu et al. 1996.) Finally, having a plan (Balluz et al. 2000) and feeling prepared (Blanchard-Boehm and Cook 2004) have also been found to increase protective action taking. The influence of other factors is less well known. For example, some note that greater lead time increases response (Hammer and Schmidlin 2002), while other studies have suggested that greater lead times make a person less likely to believe a warning message (Schmidlin and King 1995). Another important but controversial finding by Sims and Baumann (1972) suggested that if people feels more personal efficacy, they are more likely to respond to a warning message. Finally, one study suggested that females were more likely to shelter in safe locations than males (Comstock and Mallonee 2005). Fothergill (1996) also notes that women are more likely to hear a warning message due to larger social networks and in turn more likely to accept and personalize them. Furthermore, women are more likely to respond to a warning message in general (Fothergill 1996). Given these findings and the variables we have available in our analysis, in addition to the geographic specificity variables discussed below, our study will control for education, prior tornado experience, preparedness, and gender. In addition, we will also include controls for race and age, neither of which appears to have been tested in prior analyses of tornado response.

4. Geographic specificity

Theory can provide some insights into the likely effect that the increased geographic specificity that polygon warning might have on protective action decisions. Teigen's (2005) theory of ''proximity heuristic'' suggests that people have a tendency to judge threat probabilities by monitoring their spatial, temporal, and conceptual distance to a target. He claims that this ''proximity heuristic influences . . . how [people] prepare to avoid a disastrous outcome'' (Teigen 2005, p. 423). Given that SBWs offer people more detailed information about hazard location and timing, it is possible to hypothesize that they would have a favorable effect on public response. This notion is further supported by findings from other hazards, that for people to see a need for protective action, they must first identify a risk as real and assess that there are personal consequences associated with the risk. In focusing specifically on the importance of communicating geography during tornado warnings, Aguirre et al.'s (1991) publication, focused on the Saragosa, Texas, tornado, is one of only a few available empirical examinations of how geographic specificity in tornado warning messages influence public perceptions and responses. A review of their findings, developed from qualitative postevent interviews, suggests that ''broad geographic locations used in the emergency weather announcements were difficult to interpret'' (p. 10) by the population threatened by the storm. They go on to suggest that in this case, the county warned was very large and the residents could not understand whether their town was in danger. The authors commented that it would have been useful if the warnings included names of towns or other references (Aguirre et al. 1991). The implicit logic of their analysis could be extended into two potential recommendations: one, that the storm-based warning approach embraces; and the other, that it ignores. Namely, SBWs provide increased specificity when compared to the old county-based warnings, but they also detach the warnings from identifiable political boundaries. On one hand, prior findings would support the increased specificity. For example, Mileti and Sorensen (1990) recommend that agencies be clear and detailed about location to motivate behavioral compliance. Lindell and Perry (2004) do as well, in suggesting that when content is specific about location, time, and severity warning, recipients are more likely to believe that there is a real threat and to personalize the risk and thus establish protection motivation. On the other hand, the SBW practice detaches these warnings from recognizable geopolitical boundaries. Prior studies of other hazards (Arlikatti et al. 2006; Zhang et al. 2004) would agree with Aguirre et al.'s suggestion that this may be a poor decision, since these kinds of risk areas are difficult to communicate to the public. Given this contradiction, it is difficult to predict how such a system might influence behavior. Given opposing possibilities, our hypothesis adopts and empirically tests the official position of the NWS as follows:

H1: Having a home located inside the warning polygon will increase the likelihood of taking some type of protective action.
H2: More specifically, having a home located inside the warning polygons will increase the likelihood of taking shelter.
H3: Warning polygons that are relatively smaller than the county within which they are embedded will lead to households that are more likely to take protective action and, in particular, are more likely to take shelter.

Taking shelter is not the only important element in protective action decision making. To the contrary, most literature recognizes that information seeking and risk processing are also important. Further, these works have implied that increased warning specificity can reduce this behavior and aid the transition to action taking. For example, Mileti and Sorensen (1990) have suggested that confirmation is a negative function of the level of specificity in the original warning received. Presumably, the assumption is that more specific messages result in less of a need for people to seek more information. Lindell and Perry (2004) also note that information seeking is more likely to happen when there is uncertainty regarding the information conveyed in the message. Here again, the assumption is that one of the reasons people fail to take protective action is because they do not believe there is enough information about the hazard to warrant the time and energy costs of taking action. The abovementioned conclusions suggest that less specific information in the warning message is one of the reasons people seek information rather than taking action. Since SBWs give more specific information, there should be a lesser need to delay protective action by seeking further information about the threat. Therefore, the following hypothesis is tested:

> H4: Being inside the warning polygon will reduce the likelihood of seeking information.
>
> H5: When the warning polygon is smaller, people will be less likely to seek more information.

In addition to looking at warning specificity, we are also interested in whether a respondent's proximity to the actual tornado affects protective action as well. The logic builds on a number of previous studies that address the effect of proximity to the hazard (Dynes et al. 1979; Flynn and Chalmers 1980; Houts et al. 1984; Bourque et al. 1973), all of which have found that the closer people are to the hazard, the more likely they are to respond and to do so quickly. While the exact function of proximity is difficult to disentangle, it is possible to assume that closeness allows for greater personalization of risk and provides an opportunity to visually confirm the presence of a threat. People in close proximity are both more likely to see the tornado and experience signs of it, such as high winds, hail, or heavy rain, and are more likely to believe that these pose a risk. The latter may be particularly important given that many studies have found that confirmation of the disaster makes people more likely to believe and respond to a warning message (Hodler 1982). In fact, we know that a majority of individuals attempt visual confirmation and some even require it before acting (Comstock and Mallonee 2005). Conversely, the absence of such cues may lead to people missing the opportunity to protect themselves. Aguirre et al. (1991) found that following the Saragosa tornado warning, residents went about their normal business because they saw no signs of rain or dark clouds. Further support for this proposition comes from other hazards. Perry's (1983) analysis of flood survivors found that a large proportion responded only after seeing evidence of the threat. Similarly, Gruntfest et al. (1978) found that residents hesitated to evacuate when warned of a flood when skies were ''clear all day'' and/or there was no evidence of rain. The pattern holds even for technological events. Cutter (1987) examined the evacuation process of four man-made disasters. During two of these events, environmental cues played a part in the success of the evacuation. Specifically, many of the residents left the area after seeing, hearing, or smelling the gas leak and explosion. Based on these findings, we propose that being close to the tornado track should allow households to observe the tornado and as a result should lead to protective action:

> H6: There will be a positive relationship between being close to the tornado and taking shelter.

5. Methodology

This analysis was developed using a quantitative dataset created at the University of Delaware's Disaster Research Center (DRC) as part of the National Science Foundation (NSF)-funded Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere (CASA). The data were collected by telephone interviews with an instrument that aimed to better understand public response to tornado and severe storm warnings by bringing together knowledge from social science insights on weather warnings. The major topics the survey addressed included 1) receipt of warnings and alerts; 2) severe storm/tornado impacts; 3) confirmation/verification behavior; 4) access, use, and familiarity with specific sources of information; 5) multiple types of protective actions; 6) damage to property; 7) insurance coverage; 8) lead time, watch, warnings, and false alarms; 9) experience with previous hazards; 10) preparedness activities, 11) demographics; and 12) socioeconomic variables. The final instrument included 120 questions and took respondents between 15 and 45 min depending on their path through the skip patterns. The mean time to completion was approximately 30 min. The survey was administered as a telephone interview using a computer-assisted telephone interviewing (CATI) system in operation at the Disaster Research Center. In evaluating these data, it should be noted that we did not focus on a single severe weather event. Instead, we developed a method to collect data from multiple tornado events using a set of fixed methodological conventions. Over the course of the data collection, we put in place systematic procedures that improved the reliability and validity of the information we collected, each of which will be discussed in detail below.

a. Sampling

Data collection occurred during 2008–10. The first year we started data collection in June as soon as the survey system was readied and continued until August. For subsequent years we began searching for storms mid-February and ended around August. The only exception to this pattern was one major event in February 2009, when the system was deployed early due to an unusual tornado that was relevant to the larger CASA

TABLE 1. Summary of weather events.

State	County sampled	Date of event	Event type
OK	Tulsa	5 Jun 2008	False alarm
KS	Riley	11 Jun 2008	EF4
MN	Kandiyohi	11 Jul 2008	EF3
IL	DuPage	4 Aug 2008	EF1
OK	Oklahoma	10 Feb 2009	Two tornadoes (EF1, EF2)
OK	Carter	10 Feb 2009	EF4
MS	Jasper	26 Mar 2009	EF1
AL	Jefferson	3 May 2009	EF1
OK	Caddo	13 May 2009	EF2
TN	Shelby	12 Jun 2009	EF1
CO	Denver	20 Jul 2009	False alarm
OK	Rush Springs (ZIP code)	2 Apr 2010	Severe thunderstorm
MS	Yazoo	24 Apr 2010	Multiple tornadoes up to EF4
OK	Pottawatomie	10 May 2010	Three tornadoes (EF1, EF3, EF3)
MI	Monroe	6 Jun 2010	Two tornadoes (EF1, EF2)
SC	Lancaster	12 Jul 2010	Two tornadoes (EF0, EF0)
NY	Bronx	25 Jul 2010	EF1 (missed event)

project. This data collection period covers the months when most tornado events occur in the United States.

Our sampling approach can be described as a two-stage process. Stage 1 involved the selection of geographic areas where households were likely to have encountered the need to make protective action decisions. For this stage we choose to select counties where severe weather events either occurred or were predicted to occur. In stage 2, households were randomly selected from the county identified in stage 1. More details are provided below. This first stage of our sampling process identified significant weather or warning events that occurred in the United States. Because there is no national sampling frame or "population" of people who make protective action decisions, we collected data from selected counties in which tornado events or warnings occurred. Since it was not possible to survey every tornado in these years, we employed theoretical replication logic, an approach common in multiple-case-study research [see Yin (2009) for a more detailed description]. In total we collected data from households for 17 weather events over the 3-yr period, as summarized in Table 1.

During stage 2 of our sampling process, telephone numbers from each of the counties listed in Table 1 were obtained by purchasing a sample from Genesys, a third-party sample provider. The Genesys system generates random phone numbers based on the set of all telephone exchanges with area codes and zip code combinations matching the counties identified in Table 1 using random digit dialing (RDD) procedures. In each case 1000 RDD numbers were requested. After obtaining the initial 1000 numbers, we had Genesys purge business and disconnected numbers from the initial sample. To purge the business numbers, a database composed of nonresidential Yellow Page businesses was utilized. The distinction of *nonresidential* is important because over one million households nationwide use their residential phone number for business purposes as well. The generated sample was compared to this database, and any matching telephone numbers were purged from the sample. The remaining numbers that were not purged from the sample were then examined to determine if they are disconnected. Finally, a list of telephone numbers was provided for each county; it served as the sample for each event.

b. *Calling process and response rates*

Given our focus on choices made during multiple severe weather events, it was necessary to adopt a process for identifying, selecting, and transitioning between events. Our data collection process relied on a 3-week cycle. During week 1 a "storm searcher" developed a list of candidate events and counties associated with each event. Census data were obtained for each county and a case was selected. During weeks 2 and 3, our call center was activated at different times of the day with a focus on calling from Monday to Thursday between 1800 and 2100 LT and on Saturdays between 1200 and 1600 LT. After 2 weeks of calling, we would terminate data collection for that event and would start the cycle again as soon as a suitable next case was identified. This process optimized the timeliness of our calling by ensuring that we did not call more than a few weeks after an event occurred, greatly reducing retrospective bias. It did so, however, at the expense of not fully exhausting our samples. Each phone number was called up to 4 times to make contact with the residence and to attempt the interview. Our cooperation rates and refusal rates are within acceptable ranges, but the responses rates are lower than typically expected with a range of 4%–17% and an average of 11%. Contact rates (average 37%)[1] to some degree clarify the discrepancy between good cooperation rates (average 34%)[2] and refusal rates (average 10%)[3] but low response rates. We believe that this pattern reflects the consequences of only calling each number 2–4 times.

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[1] Contact rates measure the number of phone numbers that we were able to determine were eligible or ineligible for participation.

[2] Cooperation rates measure the percentage of eligible households that agreed to participate in the survey.

[3] Refusal rates measure the percentage of eligible households that refused to participate.

6. Dependent variables

a. Detailed protective action variable

To examine protective action in detail, we used a dependent variable that described the type of protective action taken if any. Specifically, the question asked was, after receiving the warning or notification, what did you do? This variable was coded into four categories for the purpose of this study: 0 = nothing; 1 = increase awareness, seek or distribute information; 2 = prepare/protect property; 3 = shelter/shelter and do other activities.

b. Simple protective action variable

We also simplified the above-mentioned detailed variable to a binary variable of 0 (nothing) and 1 (seek more information, protect property, or shelter) to determine the impact on taking any protective action at all.

7. Independent variables

a. Polygon variable

To determine whether a household was inside or outside the SBW polygon, we used a geographical information system (GIS) to overlay household and warning locations. The warning location shape files were obtained via the National Oceanic and Atmospheric Administration (NOAA) website. To determine household locations, we gathered the latitude and longitude coordinates associated with the respondents whose addresses were available. We then plotted these in GIS and overlaid the warning polygon for the specific event. Thirteen of the 17 events sampled had tornado warnings associated with them, and 645 of the total 1038 respondents had usable addresses. By using the select by location tool in GIS, we labeled each respondent with 0 for being outside the warning or 1 for being inside the warning. This information was then added to the dataset as a new independent variable.

b. Track variable

The track variable provided specific information on the location of the respondent relative to the tornado track. We used GIS in the same manner as stated above but overlaid household locations with tornado track locations. The tornado track shape files were also obtained from the NOAA website. The select by location tool was used again to label respondents depending on their distance from the track. For the purpose of this study, this variable was coded into two categories: 0 (beyond 5 mi of the track) and 1 (within 5 mi from the track). Those households within 5 mi of the track are more likely to see the tornado itself or experience signs of it, such as high winds, hail, or heavy rain. These important visual signs should aid in threat processing and decision making. Beyond 5 mi from the tornado, it is less likely that households would experience these cues, as they would no longer be directly under the storm. At such a distance, it is also more likely that the person's line of sight to the tornado itself would be obscured by buildings, trees, or clouds.

c. Polygon/county ratio variable

The polygon/county ratio variable provided information on the physical size of the warning polygon relative to the county, since respondents were sampled by county. It was calculated by dividing the polygon area by the county area. Each of the events in which a tornado warning was issued was then associated with its respective ratio.

d. Control variables

Based on the literature review above, several additional sociodemographic variables were included as controls. Age was used as a continuous variable in the regressions and simplified into a binary variable (0 = greater than or equal to 65 and 1 = less than 65) in the correlation matrix. Race was simplified into 0 (white) and 1 (nonwhite). Gender was a natural dichotomy (male = 0 and female = 1). Education was simplified into 0 (high school degree or less) and 1 (beyond high school).

We also included a variable that determined the existence of a family emergency plan. Specifically, the question asked was, have you developed a family emergency response plan? It was coded as 0 (no) or 1 (yes). Finally, a variable addressing past experiences with tornadoes was included as well. This question asked, how many tornadoes have you experienced in all? It was simplified into a binary variable of 0 (no experience) and 1 (at least one experience).

All variables were coded using Statistical Package for the Social Sciences (SPSS). SPSS was also used for the data analysis. A multinomial logistic regression was performed to determine the relationship between the dependent variables and the independent variable.

8. Results

Table 2 shows a correlation matrix of all independent and dependent variables. This matrix provides support for many but not all of our hypothesized relationships, as detailed below.

Our results fail to support H1. Looking at the polygon in/out variable, we would expect to see a significant negative correlation between this variable and doing nothing but that relationship is not apparent. In support

TABLE 2. Correlation matrix.

	%	Do nothing	Seek more information	Protect property	Shelter	Warning polygon in/out	Polygon country ratio	Track proximity	Age	Race	Gender	Education	Family plan	Past tornado experience
Do nothing	15.67	1	−0.340**	−0.134**	−0.331**	−0.003	−0.130**	−0.077	0.050	0.012	−0.027	0.044	−0.145*	−0.028
Seek more information	38.38	−0.340**	1	−0.245**	−0.607**	−0.175**	0.023	−0.165**	−0.054	−0.039	−0.051	−0.023	0.02	−0.029
Protect property	8.80	−0.134**	−0.245**	1	−0.239**	0.083	−0.098*	−0.009	0.015	0.016	−0.065	−0.03	0.084*	−0.012
Shelter	37.15	−0.331**	−0.607**	−0.239**	1	0.130**	0.124**	0.224**	0.008	0.021	0.110**	0.008	0.038	0.057
Warning polygon in/out	65.00	−0.003	−0.175**	0.083	0.130**	1	−0.156**	0.615**	0.066	0.082	−0.056	−0.009	0.011	0.007
Polygon/country ratio	65.05	−0.130**	0.023	−0.098*	0.124**	−0.156**	1	0.035	0.030	−0.202**	0.056	0.05	0.124**	0.06
Track proximity	48.00	−0.077	−0.165**	−0.009	0.224**	0.615**	0.035	1	0.006	0	0.006	−0.041	−0.002	−0.01
Age	30.64	0.05	−0.054	0.015	0.008	0.006	0.03	0.006	1	−0.132**	0.049	−0.146**	−0.106**	−0.082*
Race	20.81	0.012	−0.039	0.016	0.021	0.082	−0.202**	0	−0.132**	1	0.043	−0.128**	−0.072*	−0.005
Gender	66.50	−0.027	−0.051	−0.065	0.110**	−0.056	0.056	0.006	0.049	0.043	1	−0.129**	−0.052	−0.006
Eduation	59.10	0.044	−0.023	0.03	0.008	−0.009	0.05	−0.041	−0.146**	−0.128**	−0.129**	1	0.052	0.055
Family plan	50.20	−0.145**	0.022	0.084*	0.038	0.011	0.124**	−0.002	−0.106**	−0.072*	−0.052	0.052	1	0.089*
Past tornado experience	57.79	−0.028	−0.029	−0.012	0.057	0.007	0.06	−0.01	−0.082*	−0.0052	−0.006	0.055	0.089*	1

* Correlation is significant at the 0.05 level (two tailed).

** Correlation is significant at the 0.01 level (two tailed).

of H2 being inside the polygon, H2 is significantly correlated with sheltering ($R = 0.13$). In support of H3, a warning polygon covering less than 50% of the county was negatively correlated with taking no action ($R = -0.13$) and positively correlated with increased sheltering ($R = 0.12$). Results also support H4, in that those inside the polygon are less likely to seek information ($R = -0.18$). Results fail to support H5; there was no significant correlation between those in polygons covering less than 50% of the counties and seeking further information. Finally, results support H6, in that being closer to the tornado track is positively correlated with sheltering ($R = 0.22$).

To explore these hypotheses in more depth, we also ran a logistic regression using the simplified protective action variable as well as the geographic and sociodemographic variables. First, the polygon/county ratio variable was added to the regression as a continuous variable; then; as a categorical variable split into quartiles; and finally, as a binary variable split by polygons that took up 50% or more of the county and those that took up less than 50%. The parameters were of comparable direction and strength each time, but the variable was only significant when using the 50% split version. As a result, for the purpose of this study, the variable was simplified to 0 (greater than or equal to 50%) and 1 (less than 50%). Table 3 provides the frequency of responses for the variables in the regressions as well as the sample size and number of missing observations. There are a couple reasons for the large number of missing observations. Respondents were first asked whether they were present at the time of the event; those that answered no were not given the remainder of the survey. The geographical variables also eliminated some observations. Many respondents were unwilling to provide addresses. Without these locations, we could not determine the distance from the track or the location relative to the warning polygon and in turn these observations were missing from the regression.

As hypothesized in H3, the results do show a significant negative relationship between a larger warning polygon and taking protective action ($B = -0.69$, Sig. = 0.03). Having a family plan was the only other significant variable in the model. Having no family plan has a significant negative relationship with taking protective action ($B = -0.94$, Sig. = 0.00). The chi-square value for the model was highly significant, but the pseudo-R-square values were quite low (Table 4).

We also ran a multinomial logistic regression between the more complex protective action variable, the geographic variables, and the sociodemographics variables. Table 5 shows the results of this regression as well as the chi-square and pseudo-R-square values for the model.

TABLE 3. Variable descriptives and sample size.

		N
Any protective action	Do nothing	51
	Did something	343
Type of protective action	Nothing	51
	Seek more information	152
	Protect property	33
	Shelter	158
Warning polygon	Outside warning polygon	136
Polygon/county ratio	>50%	135
Track proximity	Beyond 5 mi	207
Race	White	327
Gender	Male	127
Education	High school or less	160
Family plan	No	200
Past tornado experience	None	168
Valid		394
Missing		644
Total		1038

TABLE 4. Protective action simple regression parameters.

Any protective action[a,b,c]		B	Error	Sig.
Did something	Intercept	3.316	0.692	0.000
	Age	−0.007	0.010	0.463
	Outside warning polygon	0.314	0.401	0.433
	Polygon >= 50% of the county	−0.687[d]	0.322	0.033
	Beyond 5 mi	−0.627	0.385	0.104
	White	0.259	0.401	0.519
	Male	0.245	0.350	0.485
	High school or less	0.232	0.331	0.483
	No family plan	−0.944[e]	0.335	0.005
	No past tornado experience	−0.052	0.315	0.869

[a] The reference category is do nothing.

[b] Chi-square value of 20.185; Sig. of 0.017.

[c] Pseudo-R-square—Cox and Snell: 0.050, McFadden: 0.066, Nagelkerke: 0.093.

[d] Coefficient is significant at the 0.05 level (two tailed).

[e] Coefficient is significant at the 0.01 level (two tailed).

The chi-square value was highly significant and the pseudo-R-square values were respectable, while not ideal.

In agreement with the correlation in Table 2, our regression did show a positive relationship between being inside the warning polygon and taking shelter, but it was not significant. With this in mind, we are not able to conclusively support H2. As with the correlation matrix, our regression also showed a negative relationship between being inside the warning polygon and seeking more information, but again it was not significant. Given this nonsignificance, we must reject H4. In contrast, the size of the polygon and the proximity to the track seemed to be more significant factors. In agreement with H3, a larger polygon made people less likely to take shelter ($B = -0.89$, Sig. = 0.01). Conversely, the regression results rejected H5. Those in polygons covering more than 50% of the county were actually less likely to seek more information, but it was only marginally significant ($B = -0.65$, Sig. = 0.06). These results combined with those seen in the correlation matrix suggest that the geographic specificity of the warning does lead to sheltering behavior, but it does not necessarily eliminate the need for information seeking. To test H6, we examined what kind of protective action was taken by those within and beyond 5 mi of the tornado track. In agreement with H6, those beyond 5 mi were much less likely to take shelter ($B = -1.08$, Sig. = 0.01). This supports the correlation shown in Table 2 and suggests that being closer to the tornado does indeed lead to sheltering behavior. In terms of control variables our regression results showed only one other significant variable in the model, the existence of a family emergency plan. Those who had a family plan were less likely to do nothing and more likely to seek more information, protect their property, and shelter. Given these results, along with the correlation shown in Table 2, we can reasonably assume that a family emergency plan leads to greater protective actions. In constrast, the correlation between gender and protective action was not supported by our regression. The results showed that males were more likely to seek more information and protect their property but were less likely to shelter; these relationships were not significant though.

9. Conclusions and discussion

Our analysis shows mixed results on the importance of storm-based warnings. On the one hand, we were not able to find a significant relationship between being inside the warning polygon and taking protective action. On the other hand, we did find considerable support for the notion that in events where the polygons were smaller than 50% of the county, people were more likely to take action, in particular, sheltering. While our data cannot provide a definitive explanation for this apparent paradox, it does point to the complexity of administering and receiving storm-based warnings. While one could interpret the nonsignificance as an indicator that storm-based warnings are not useful, we would caution against such a judgment. Instead, we recommend that more detailed and focused analyses be conducted. In light of that work, this study should eventually be seen as a rough first attempt at understanding how storm-based warnings influence behavioral response. In particular we want to note two important areas where future research should focus.

TABLE 5. Protective action complex regression parameters.

Type of protective action[a,b,c]		*B*	Error	Sig.
Seek more information	Intercept	2.332	0.740	0.002
	Age	−0.012	0.011	0.251
	Beyond 5 mi	−0.272	0.419	0.516
	Outside polygon	0.524	0.430	0.223
	Polygon >= 50% of county	−0.652	0.349	0.062
	White	0.352	0.441	0.426
	Male	0.452	0.372	0.224
	High school or less	0.417	0.356	0.241
	No family plan	−0.924[d]	0.357	0.010
	No past tornado experience	−0.035	0.339	0.917
Protect Property	Intercept	0.060	1.011	0.953
	Age	−0.002	0.015	0.885
	Beyond 5 mi	−0.185	0.541	0.732
	Outside polygon	−0.277	0.605	0.647
	Polygon >= 50% of county	0.055	0.473	0.908
	White	0.520	0.633	0.411
	Male	0.576	0.488	0.238
	High school or less	0.248	0.484	0.609
	No family plan	−1.138[d]	0.475	0.017
	No past tornado experience	0.463	0.463	0.317
Shelter	Intercept	2.815	0.742	0.000
	Age	−0.004	0.011	0.742
	Beyond 5 mi	−1.080[d]	0.423	0.011
	Outside polygon	0.245	0.448	0.584
	Polygon >= 50% of county	−0.888[d]	0.353	0.012
	White	0.091	0.440	0.836
	Male	−0.091	0.382	0.811
	High school or less	0.030	0.358	0.933
	No family plan	−0.919[d]	0.358	0.010
	No past tornado experience	−0.196	0.340	0.565

[a] The reference category is do nothing.

[b] Chi-square value of 58.570; Sig. of 0.000.

[c] Pseudo-*R*-Square—Cox and Snell: 0.138, McFadden: 0.062, Nagelkerke: 0.152.

[d] Coefficient is significant at the 0.01 level (two tailed).

First, future work should give greater attention to dissemination and reception of SBWs. Our data did not include specific information on the degree to which end users actually saw or processed polygons. It is important to focus on that reality. Earlier research has documented that advances in science are not always transmitted effectively in dissemination systems (Sorensen 2000). As discussed in an earlier section, the SBW approach to warning increases specificity but also detaches the warnings from identifiable political boundaries. Prior studies (Arlikatti et al. 2006; Zhang et al. 2004; Aguirre et al. 1991) have suggested that due to the complex nature of the risk area, it may be unwise to do this, since people may have a difficult time deciding if they are in the threatened areas. One could hypothesize that significant limits still exist in our ability to disseminate SBWs effectively to the public. Further, a warning polygon not bounded by political boundaries or linked to local communities and landmarks is innately difficult to convey over the radio and even TV. Even though TV is able to utilize visual elements, dissemination issues still occur. TV stations generally use "crawls" or "bugs" to alert viewers that there is a warning in their area. Further, some simply list the counties the warning is located in, negating the value of increased geographic specificity. Some stations use reference maps, but these maps tend to highlight all the counties that the warning polygon is included in, thus defeating the purpose of SBWs. However, there are undoubtedly some stations throughout the country that have overcome these issues and are able to effectively disseminate polygons. Even so, it is likely that there is still an overall difficulty in harnessing the geographic specificity in a way that makes a difference to the public.

Second, it is possible that while SBWs are a good start, the polygons need to be optimized to generate the desired effect. For example, maybe a tighter polygon is needed to elicit greater sheltering. In other words, perhaps these warnings are still not specific enough. This explanation seems to have some explanatory power, given the significance of our polygon size variable as well as our track proximity variable. While a warning polygon that was relatively smaller than the county did not seem to affect information-seeking behavior, it did lead to taking some protective action, in particular, sheltering. Similarly, the proximity to the track also had a highly significant relationship with sheltering. Being within 5 mi of the tornado track made people much more likely to take shelter as opposed to doing nothing. As past research (Dynes et al. 1979; Flynn and Chalmers 1980; Houts et al. 1984; Bourque et al. 1973) has suggested, our results show that proximity to the threat does matter. It is possible that the closeness allows for greater personalization of risk or that it simply provides an opportunity to visually confirm the presence of a threat. With our current dataset, we are unable to provide a definitive answer. Further analysis will be needed to fully understand the reason for the strong relationship between hazard proximity and protective action. Simply stated: we need more information to determine just how close/specific a warning needs to be to illicit action. Similarly, future analysis could address a possible gap between how the meteorologists and the public view the warning polygons. Viewers may interpret the polygon boundaries differently than how the meteorologists intended.

It is also important to note the performance of our sociodemographic and control variables. In opposition to several studies that have found that previous experience with the hazard made people more likely to believe and respond to the warnings (Hodler 1982; Blanchard-Boehm and Cook 2004; Simmons and Sutter 2007), we found that having at least one previous experience with a tornado had no significant relationship with taking protective action. Similarly, our results also run counter to those that suggest a lower education level reduces the likelihood of responding to a warning message (Balluz et al. 2000; Blanchard-Boehm and Cook 2004; Liu et al. 1996). While our results should not be used to discount the importance of education or experience, they do suggest that these variables need more thorough investigation in the future. However, our results did confirm some prior research that suggested having family emergency plans makes people more likely to take protective action and shelter (Balluz et al. 2000; Blanchard-Boehm and Cook 2004). Similarly our work also provided some degree of concurrence with the other studies of gendered effects in tornado response (Comstock and Mallonee 2005) in their findings that females are more likely to shelter than males. Within our correlation matrix, gender was significantly correlated with sheltering, but when included in our regression model, the variable was no longer significant. Given the lack of considerable previous research and our mixed results, we reinforce other studies' calls for a greater focus on the effects that gender has on disaster context (Fothergill 1996.) Since race and age have not yet been directly addressed in the context of tornado warning decision making, our analysis may provide some of the first results on these variables. With that said, we were unable to find any significant relationship between race or age and protective action taken. Future analyses should further test these relationships. Further depth could also be added to our analysis with the inclusion of risk perception variables, such as the degree of belief in hazard occurrence and damage potential. These variables may have a significant effect on protective action that we were not able to capture in this particular study. For a more complete understanding of protective action decision making, risk perception should be taken into account in future analyses. In addition, future research should also consider the merits of a raw polygon-size variable relative to the polygon/county ratio variable we constructed. While both approximate size, the relative strengths and weaknesses of these approaches should be considered more fully.

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