A Tornado Watch Scale to Improve Public Response*

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ABSTRACT

A tornado refuge rubric was revised into a six-level, hierarchical Tornado Watch Scale (TWS) from level 0 to level 5 based on the likelihood of high or low-impact tornadic events. Levels correspond to an estimate of the maximum potential tornado intensity for a given day and include refuge/shelter categories of ''adequate,'' ''questionable,'' or ''inadequate,'' which encompass a range of refuge/shelter locations taken from the Enhanced Fujita scale. Ratings are based on a conservative estimate of damage indicators in high winds and the safety of a person taking refuge inside buildings of varying structural design. Audio recordings similar to those used in current NOAA weather radio communications were developed for each TWS intensity level. Recordings representing an existing tornado watch, existing particularly dangerous situation (PDS) tornado watch, and three proposed levels from the TWS were then used in interviews with Alabama residents to determine how changes to the information contained in the watch statements would affect each participant's tornado safety actions and risk perception. Participants were also questioned about their knowledge and past experience with tornado hazards and their preference between the existing NWS tornado watches and the TWS. Results indicate a strong preference for the TWS when compared to existing products. The TWS was favored for providing additional information, containing descriptions of expected severity, and being easy to understand. The TWS also elicits more adequate safety decisions and more appropriate risk perception when compared to existing products, and these increases in safety were statistically significant.

1. Introduction

The Saffir–Simpson hurricane scale (SSHS) was institutionalized in 1973 in the aftermath of Hurricane Camille as a way of communicating storm intensity prior to landfall. Therefore, it is technically a watch scale, and despite its shortcomings (Kantha 2006; Senkbeil and Sheridan 2006), it has been retained in operational practice, with a modification of dropping storm surge in 2009 after anomalous values in several storms, notably, Hurricane Ike. Highly destructive events cause us to reconsider the efficacy of risk communication. With numerous fatalities resulting from violent tornadoes in the last 4 years, is it time to evaluate the possibility of a preevent scale for tornado outbreak potential? No current scale is widely advertised for this explicit purpose for tornadoes, although the Storm Prediction Center (SPC) has been communicating tornado risk categorically in the form of slight, moderate, and high risk days and also in probabilistic format. SPC products are explained in more detail in the following section. The objective of this research is to incorporate the basic principles of risk levels for tornado outbreaks in a format similar to the SSHS and to create a platform by which risk is more effectively communicated to the public.

Based on a system of rating tornado shelter/refuge adequacy (Mason and Senkbeil 2014), the focus of this manuscript is on transforming a tornado refuge rubric (TRR) into a Tornado Watch Scale (TWS). The crux of the TWS is a hierarchical classification system to communicate expected tornado intensity to the public. Based on the commendable performance of the SPC in tornado forecasts, this manuscript will not attempt to develop an additional or alternative method of forecasting tornado potential. Instead, the objective of this research is to communicate the risk associated with tornado watches in an entirely new format. An explanation of the TWS is presented along with an analysis

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of its safety value and favorability among participants in interviews.

There is a dearth of published literature on tornado watch risk perception; however, literature on tornado warning behavior and risk perception is abundant. Warning communication (Balluz et al. 2000; Sorensen 2000; Hammer and Schmidlin 2002; Paul et al. 2003; Farley 2007; Brotzge and Erickson 2009; Coleman et al. 2011; League et al. 2010; Schumacher et al. 2010; Sherman-Morris 2010; Hoekstra et al. 2011), false alarm rates (Barnes et al. 2007a,b; Simmons and Sutter 2009; Brotzge et al. 2011), probability of detection (Simmons and Sutter 2011; Brotzge et al. 2013), warning lead time, and possible improvements of the current watch system (Erickson and Brooks 2006; Simmons and Sutter 2008; Hoekstra et al. 2011) have all been discussed in recent literature. The goal of the TWS is to provide residents with a simple forecast of expected severity and corresponding precautionary actions in ample time for those who do not have a storm shelter or safe room readily available to travel to substantial shelter based on the forecast recommendations. Two brief sections explaining comparable and existing products and development of the TWS follow the introduction before proceeding to methods, results and discussion, and conclusions.

2. Comparable and existing products

The forecasting of tornado likelihood is currently addressed by multiple products, one example being the convective outlooks issued by the Storm Prediction Center. Risk levels are outlined up to 8 days in advance of an event and can contain the following levels: general or nonsevere thunderstorms (TSTM), which defines an area with a probability of thunderstorms of 10% or greater; marginal risk (MRGL), which is used to show "an area of severe storms of either limited organization and longevity, or very low coverage and marginal intensity"; slight risk (SLGT), showing a more organized area of severe storms which is low in coverage and varying in intensity; enhanced risk (ENH), implying an area with greater severe storm coverage than a slight risk, but still with varying levels of intensity; moderate risk (MDT), which implies a greater concentration and/or magnitude than an enhanced risk, including "days with several supercells producing intense tornadoes and/or very large hail, or an intense squall line widespread damaging winds" (National Weather Service 2015). The highest risk level shown in convective outlooks is HIGH, implying a high degree of certainty in a major severe weather outbreak, "from either numerous intense and long-tracked tornadoes or a long-lived derecho-producing thunderstorm complex that produces hurricane-force wind gusts and widespread damage" (National Weather Service 2015).

There are several other SPC products with similar objectives. In addition to the categorical convective outlooks discussed above, the SPC also issues probabilistic convectional outlooks up to 3 days in advance of an event. These are more descriptive of individual severe weather hazards (hail, winds, and tornadoes) and are used to address expectations for each hazard while including the forecaster's confidence in the event (www.spc.noaa.gov/products/outlook/probinfo.html). Also in use by the SPC are products known as public severe weather outlooks (PWOs). While the previously mentioned outlooks provide more detailed information up to several days in advance of an event, a PWO is typically issued 12–24 h in advance of an event. These outlooks are used when a high risk is issued for tornadoes or widespread significant wind damage, or when areas within a moderate risk category contain at least a 15% probability of tornadoes or 45% probability of damaging winds. In contrast to the convective outlooks and probabilistic convective outlooks, the PWOs incorporate a plain-language forecast for use by the general public (www.spc.noaa.gov/misc/about.html#PWO). Yet another source for information before an event is generated by the SPC when a tornado watch is issued and can be found on the tornado watch web page in a section addressing the likelihood of certain hazards (e.g., http://www.spc.noaa.gov/products/watch/2013/ww0033_prob.html). These include probabilities for multiple tornadoes and for tornadoes that are EF2 or stronger on the Enhanced Fujita (EF) scale, along with other associated severe weather hazards.

While the combined effect of these products is valuable to the weather community, particularly meteorological professionals, use of the TWS could simplify communication of only tornado risk to the general public. As such, this manuscript contains only a recommendation for the final product as delivered to consumers, leaving the actual conversion methods and forecasting decisions to be decided on by other parties.

Another product with similar objectives to the TWS is the experimental Impact Based Warning system, which was tested by the NWS in Kansas and Missouri in 2012 and expanded to the entire central United States during 2013 (www.crh.noaa.gov/crh/?n=2013_ibw_info). These warnings are meant to provide more information to the public in order to facilitate improved response to a tornado warning (Harrison et al. 2014). These warnings include explicit information on storm characteristics, such as presence of a tornado, potential tornado damage, and hail size in an attempt to elicit urgent protective actions from listeners. While the goals of this system mirror those of the TWS, the objective of the TWS is to redesign

TORNADO WATCH SCALE

LEVEL	EVENT TYPE	ADEQUATE SHELTER	QUESTIONABLE SHELTER	INADEQUATE SHELTER
LEVEL 0 LEVEL 1	Weak EF0-EF1	Storm Shelter/Safe Room One- or Two-Family Home Apartments, Condos, Townhouses[1] Small Retail Building Small Professional Building Strip Mall Large Shopping Mall Large, Isolated Retail Building Elem., Jr., or Sr. High School Low-, Mid-, or High-Rise Building Institutional Building Motel Fully Underground Basement Partially Underground Basement	Vehicle (to evacuate during tornado watch)[2]	Mobile/Manufactured Home Farm Outbuilding Automobile Showroom Automobile Service Building Metal Building System Service Station Canopy Warehouse Building
LEVEL 2 LEVEL 3	Strong EF2-EF3	Storm Shelter/Safe Room	One- or Two-Family Home Apartments, Condos, Townhouses[1] Institutional Building Partially Underground Basement Fully Underground Basement Vehicle (to evacuate during tornado watch)[2]	Mobile/Manufactured Home Farm Outbuilding Motel Small Retail Building Small Professional Building Strip Mall Large Shopping Mall Large, Isolated Retail Building Automobile Showroom Automobile Service Building Elem., Jr., or Sr. High School Low-, Mid-, or High-Rise Building Metal Building System Service Station Canopy Warehouse Building
LEVEL 4 LEVEL 5	Violent EF4-EF5	Storm Shelter/Safe Room	Vehicle (to evacuate during tornado watch)[2] Fully Underground Basement	One- or Two-Family Home Mobile/Manufactured Home Apartments, Condos, Townhouses[1] Farm Outbuilding Motel Small Retail Building Small Professional Building Strip Mall Large Shopping Mall Partially Underground Basement Large, Isolated Retail Building Automobile Showroom Automobile Service Building Elem., Jr., or Sr. High School Low-, Mid-, or High-Rise Building Institutional Building Metal Building System Service Station Canopy Warehouse Building

All refuge locations should be in an interior room on the lowest level of the structure, away from windows.

[1]Apartments, condos and townhouses three stories or less

[2]Evacuation should be done during a tornado watch, out of the watch area, before a tornado warning is issued and the evacuee should remain alert of changing weather conditions

FIG. 1. The TWS, revised from the tornado refuge rubric (Mason and Senkbeil 2014) to include tornado watch levels.

tornado watch statements to provide this information to a more generalized area in the hours before an event.

In addition to these communication products, NWS weather forecast offices (WFOs) will also use multimedia impact briefings, hazardous weather outlooks, and graphics illustrating relative threat levels for different (National Weather Service 2015) hazards (e.g., www.srh.noaa.gov/bmx/?n=HWO) to communicate forecasts of tornado risk. While these products provide weather hazard information in a simple format, easily disseminated on social media to increase the viewing audience, they do not address the issue of appropriate tornado refuge/safety locations in advance of an event, particularly those days when violent tornadoes are possible.

Communicating tornado risk has also been addressed by private weather entities, such as the tornado condition (TOR:CON) index used by The Weather Channel. These proprietary scales and indices may provide benefits by increasing awareness of a severe weather threat. It may also add an element of confusion if a person is presented with different systems and different levels of risk from different information providers. Because of this potential problem, the TWS was developed as a product for use across the entire weather communication enterprise, including the SPC and NWS, Internet weather information services, local and national broadcast meteorologists, highway information signs, billboards, and cell phone weather alerts as a uniform method of communicating risk levels and recommended actions to the public hours in advance of an event.

3. Development of the TWS

The first step in the transformation of the TRR (Mason and Senkbeil 2014) into the TWS was to develop a way of communicating these appropriate shelter/refuge locations to people in enough time to make decisions or alter their daily routines. This need is particularly important on days with an elevated risk of strong or violent tornadoes. On days with elevated risk, seeking refuge in an interior room on the lowest level of a sturdy building is not a guarantee of safety.

Because this system is designed to motivate the public to seek substantial shelter, such as a storm shelter or safe room, it is imperative that listeners or viewers are given sufficient time to process the information, discuss a shelter location, make a decision, and travel to the destination before a tornado arrives (Lindell and Perry 2012). Because of this possible increase in required travel time when compared to the availability of typical residential structures, the average tornado warning lead time of 13 min (Hoekstra et al. 2011) may be insufficient for some who must travel from their home, workplace, or school to a storm shelter or safe room.

Using the TRR as a basis, two levels were added to each of the existing tornado intensity classes (weak, strong, and violent) to form a level 0 to level 5 scale (Fig. 1). For example, a level 0 tornado watch would be issued for a low-end event with the possibility of weak tornadoes, such as a marginal squall line, mesoscale convective system, or quasi-linear convective system. A level 1 tornado watch would be issued for a slightly more intense event, perhaps tornadoes associated with deteriorating tropical cyclones in favorable environments (Schultz and Cecil 2009; Rhodes and Senkbeil 2014). This hierarchy continues with level 2 and level 3 tornado watches representing low-end and high-end events with the possibility of strong tornadoes. Level 4 and level 5 tornado watches would be reserved for days in which atmospheric conditions indicate the possibility of supercells with violent tornadoes. These highest-level watches are similar in form and function to the current particularly dangerous situation (PDS) tornado watch, albeit with a slightly different design. In short, the TWS modifies the existing tornado watch structure by defining and transforming the forecast levels from tornado watch and PDS tornado watch into six levels and providing a section for accompanying shelter/refuge locations for each level (see Fig. 1). In addition to text and audio tornado watch statements, the graphical representation of the TWS makes use of colors to symbolize the different hazard levels. Each of the three intensity categories is represented by its own color: weak is yellow, strong is orange, and violent is red. Prior research has shown the color red to elicit the highest feelings of severity, intensity, danger, or hazard, followed by orange and yellow (Ryan 1991; Braun et al. 1994; Chapanis 1994; Smith-Jackson and Wogalter 2000).

4. Methods

a. Overview and procedures

An audio interview was adapted to iPad and used with a sample of 38 Alabama residents to gather both quantitative and qualitative data for analysis of the efficacy of the TWS, along with tornado hazard knowledge and understanding. Interviews were administered face-to-face, resulting in a 90% response rate. Each interview lasted approximately 20 min and consisted of both open and closed questions, including classification, behavioral, knowledge, and perception question types (Bird 2009). Some questions contained multiple parts, such as ‘‘Do you have children at home? If so, how many?’’ and ‘‘Do you have a tornado safety plan for your home? If so, what is the plan?’’

The primary focus of this research was to collect data on how the TWS influenced understanding of the tornado hazard being communicated, tornado safety decisions, and preferences between the current NWS tornado watches and the proposed TWS watches. This was accomplished by presenting each participant with audio recordings of tornado watch statements. Each audio statement was followed by questions used to gather information on

1) what actions he/she would take after hearing the previous tornado watch statement;
2) what actions he/she would take if a tornado warning was issued for his/her home after hearing that particular watch statement on their television, radio, or NOAA weather radio the morning of the event; and
3) perceived danger to the participant associated with the tornado watch statement on a 1–10 scale, with 1 being the least dangerous and 10 being the most dangerous.

It is important to note the question asking participants about their actions after being presented with a tornado warning for their home was phrased as ‘‘What *would* you do. . .?’’ instead of ‘‘What *should* you do. . .?’’ The question was purposely constructed in this way to gather more accurate data on the likely behaviors of the participants, given their available resources, rather than simply assessing if they understood what actions would be best in the given situation. For this reason, the responses for safety actions following each hypothetical scenario likely represent a low-end estimate of statement efficacy in communicating risk because of some participants not having reasonable access to optimal shelter.

The texts from these statements were modified from SPC tornado watch statements issued for northern and central Alabama during the spring of 2011. Interviewer bias was minimized by using audio recordings for each hypothetical tornado watch statement, avoiding possible inconsistencies incurred by reading each statement. The recording mimicked the way participants would receive the information if heard over broadcast radio, NOAA weather radio, or television. An example of excerpts from audio statements is provided in Table 1 for the three TWS levels. Care was also taken not to identify the interviewer as being associated with development of the TWS throughout any portion of the interview. The authors made use of a spatial sampling technique, selecting participants congregated at parks, public buildings, and sporting events in central and northern Alabama (Patton 1990). The interview questions are included in online supplementary material along with full transcripts from the watch statement recordings.

Closed interview questions were developed to gather demographic information from respondents for analysis of differences in tornado hazard knowledge attributable to age, race/ethnicity, gender, education level, marital status, type of home, number of children in the home, and size of the group in which they normally make tornado safety decisions. There were also questions aimed at collecting information on participants’ tornado hazard knowledge, including whether the participant has had any meteorological or storm-spotter training, along with

TABLE 1. Examples of excerpts from TWS level 1, level 3, and level 5 audio statements.

Level 1 tornado watch
Level 1 tornado watch. . .Weak tornadoes. . .EF0 and EF1 tornadoes likely. . .Hail up to 2 inches in diameter. . .Thunderstorm wind gusts greater than 70 mph. . .And dangerous lightning are possible in these areas.
Shelter options. . .Unsafe shelter for a level 1 tornado watch includes mobile homes, warehouse buildings, and farm outbuildings. Residents in the watch area should not shelter in these structures if a tornado warning is issued for their area. Refer to the Tornado Watch Scale for additional shelter options.
If inside a mobile home and these shelter options are not available. . .Residents may evacuate the tornado watch polygon to safety. This should only be considered if the resident has no other adequate shelter available and can access storm information during evacuation.
Level 3 tornado watch
Level 3 tornado watch. . .Strong tornadoes. . .EF2 and EF3 likely. . .Hail up to 3 inches in diameter. . .Thunderstorm wind gusts greater than 80 mph. . .And dangerous lightning are possible in these areas.
Shelter options. . .Adequate shelter for a level 3 tornado watch is either a storm shelter or fully underground basement. . .Small, interior, windowless rooms of permanent homes. . .Apartments. . .And institutional buildings provide only questionable shelter for tornadoes of this strength. Residents in the watch area should make plans to have a storm shelter quickly available if a tornado warning is issued for their area. Refer to the Tornado Watch Scale for additional shelter options.
If these shelter options are not available. . .Residents may evacuate the tornado watch polygon to safety. This should only be considered if the resident has no other adequate shelter available and can access storm information during evacuation.
Level 5 tornado watch
Level 5 tornado watch. . .Violent tornadoes. . .EF4 and EF5 tornadoes likely. . .These have the potential to be devastating long-track tornadoes. Hail up to 4 inches in diameter. . .Thunderstorm wind gusts greater than 80 mph. . .And dangerous lightning are possible in these areas.
Shelter options. . .The only adequate shelter for a level 5 tornado watch is a certified storm shelter or safe room. Permanent homes, mobile homes, and apartment complexes can be completely destroyed by EF5 tornadoes. These locations provide no safe shelter. Residents in the watch area should make plans to have a certified storm shelter or safe room quickly available if a tornado warning is issued for their area.
If these shelter options are not available. . .Residents may evacuate the tornado watch polygon to safety. This should only be considered if the resident has no other adequate shelter available and can access storm information during evacuation.

open-ended definitional questions for common terms used in tornado hazard communication such as, "tornado watch," "tornado warning," "PDS tornado watch," "tornado emergency," and "warning polygon." Also, in an attempt to gather information on tornado experience, participants were asked if they had ever been in a tornado watch, tornado warning, PDS tornado watch, or a tornado emergency.

To obtain data as a basis for comparison, participants were asked if they currently had a tornado safety plan for their home, and if applicable, where they shelter and how long it takes them to travel there. This information was compared against responses given for refuge/shelter location after hearing each tornado watch statement. Participants were also questioned about tornado safety plans for their workplace and vehicle, though they were not asked if these plans would change after hearing any of the hypothetical watch statements. The interview also included questions on what the participant considered adequate shelter during a tornado, what he/she would consider to be the ideal lead time for a tornado warning, if he/she owns a NOAA weather radio, and how he/she receives his/her weather warning information.

Participants were instructed to listen to audio recordings for each hypothetical event to create the most realistic scenario. The goal of the authors was to assess participant understanding, decision-making, and preferences when the respondents were given only minimal information without being able to reference a graphical illustration of the TWS (see Fig. 1). Following these recordings, the participants were asked for their preference between the current NWS tornado watch system and the proposed TWS system and to provide their reason for this preference.

After recording responses from each of the five scenarios and participant preference between the current tornado watch system and the TWS, participants were allowed to examine a graphical illustration of the TWS and asked what actions they would take if a tornado warning was issued for their home while under a level 1, level 3, or level 5 tornado watch.

Participants were also asked if they would be willing to participate in a postevent survey if a tornado warning was issued for their zip code. Of the 38 respondents in the preliminary study, 37 consented to being contacted for the follow-up survey by phone. This information was intended to be used to compare participants' hypothetical decisions with those decisions made during an actual event. However, at the time of Institutional Review Board (IRB) expiration of the study there had been no tornado warnings affecting any of their zip codes.

b. *Statistical analysis*

Perhaps the most important part of this research was ascertaining how each participant's safety decisions changed based on the information presented. If the TWS was effective, participants would increase their relative safety as risk increased. The response following one scenario was compared with the same participant's response after hearing each of the other scenarios to determine if the participant's actions would result in an increase in safety, no change in safety, or a decrease in safety from one scenario to another. As an example, if a participant indicated he/she would seek refuge in a lowest-level interior room after hearing a current PDS tornado watch, then in a storm shelter after hearing a level 5 tornado watch, this was classified as an increase in safety. Conversely, if a participant chose a storm shelter after hearing a current tornado watch, then a lowest-level interior room after hearing a level 3 tornado watch, this was classified as a decrease in safety. The order in which the scenarios were presented was as follows: current watch, level 1, PDS, level 5, and level 3. This order was chosen to allow for each participant to hear similar scenarios in pairs and counteract potential ordering impacts by presenting scenarios always increasing in severity.

To allow for a more direct comparison when classifying responses for the participant's current home plan, or after hearing a current tornado watch or PDS tornado watch, these refuge/shelter locations were graded using the adequacy ratings from the Tornado Watch Scale corresponding to the tornado watch level being used for comparison. For example, if responses following a current tornado watch are being compared to those following a level 3 tornado watch, the adequacy of the locations cited for the current watch are graded using the adequacy ratings corresponding to a level 3 tornado watch in the TWS. An additional classification, "optimal," was used to group participants who chose a storm shelter or safe room for both scenarios.

Cochran's Q was used to determine if there were statistically significant differences in the number of participants choosing safer shelter for each scenario when compared to their existing home shelter plans. Following Cochran's Q, McNemar's test was used to determine if there were statistically significant increases in safer shelter selection using paired scenarios. For example, did the number of participants choosing safer shelter options significantly increase after hearing a level 5 tornado watch when compared to a PDS watch? McNemar's test is appropriate to use for paired comparisons following a significant Cochran's Q test (Rovai et al. 2014).

5. Results and discussion

a. Demographics

The demographic information for the interview participants reasonably approximates a representative sample of the state of Alabama according to the U.S. Census Bureau in most categories (U.S. Census Bureau 2014). State estimates represent U.S. Census Bureau percentages applied to our sample size of 38 respondents. For example, the U.S. Census Bureau estimates the population of Alabama to be 52% female, indicating a representative sample of 38 would include 20 female participants. Despite each person who declined to participate in the study being male, the distribution of gender for the sample is still representative of the state. Race/ethnicity is also representative of the state, with each sample category equaling the expected estimate. Because of the nature of the sampling technique, the youngest and oldest age groups are less representative than the middle-age categories. This is due to an increased number of participants 19–24 and decreased number of participants 55 and older at the sampling locations—typically parks, sporting events, and public buildings. Mobile home and apartment residents also appear to be slightly oversampled, which is likely related to the increased number of younger people in the sample. Also related to this age discrepancy is the increase in the number of participants indicating "some college" as their education.

In addition to the above demographic characteristics, participants were also asked to indicate their marital status and how many children they had living at home. Of the 38 participants, 19 indicated they were not married, 15 indicated they were married and 4 indicated they were divorced. Also, 21 of the respondents were without children, while the remaining 17 averaged 1.9 children per home. Care was also taken to ensure that no two people from the same household were interviewed.

b. Hazard awareness

The next section of the study focused on participant knowledge and experience with tornado hazards. This consisted of open and closed questions assessing 1) how the participants made safety decisions; 2) how they understood terms associated with tornado hazard communication; 3) if they had prior experience with tornado events; 4) if they had previous severe weather training; 5) if they had established current tornado safety plans for their home, vehicle, or workplace; 6) the preferred tornado warning lead time; and 7) what the participants considered "safe" shelter during a tornado.

Participants were asked to define, in their own words, a series of terms related to tornado hazard communication. The NWS definitions provided for the terms tornado watch, tornado warning, PDS tornado watch, tornado emergency, and warning polygon were then assembled into categories and graded by their accuracy into groups of correct or partially correct responses and

TABLE 2. Classified responses to tornado hazard term definitions from interview participants.

Term		Response	Count
Tornado watch	Correct/partially correct	Indicated tornado formation possible	25
	Incorrect	Confused with tornado warning	8
		Incorrect/too vague/unknown	5
PDS tornado watch	Correct/partially correct	Particularly dangerous situation	2
	Incorrect	Indicated elevated risk of tornadoes	2
		Incorrect/too vague/unknown	29
		Confused with a tornado watch	5
Tornado warning	Correct/partially correct	Positive sighting of a tornado	18
	Incorrect	Possibility of a tornado	3
		Radar indicates possible tornado	1
		Incorrect/too vague/unknown	12
		Confused with a tornado watch	4
Tornado emergency	Correct/partially correct	Elevated urgency, tornado on the ground	5
	Incorrect	Tornado has been spotted	4
		Incorrect/too vague/unknown	27
		After a tornado	1
		Confused with a tornado watch	1
Warning polygon	Correct/partially correct	Shows area where the tornado could go	10
	Incorrect	Incorrect/too vague/unknown	27
		Eight tornadoes on the ground	1

incorrect responses. Credit was given for partially correct responses to allow for participants who could communicate the general idea of a term, even if part of the NWS definition was omitted.

The results of this classification are presented in Table 2, which shows 25 respondents were able to provide a correct or partially correct definition for a tornado watch, the majority of which were quoted as saying "conditions are favorable for tornadoes," while eight participants provided a description of a tornado warning instead. The other five participants stated that they did not know what a tornado watch was, and their responses were grouped into the category "incorrect/too vague/unknown." The next term with the highest count of correct or partially correct responses was tornado warning. Of the 38 responses, 22 included descriptions indicating that a tornado has been spotted, was on the ground, or was indicated by radar. The remaining 16 responses were incorrect, with four confusing a tornado warning with a tornado watch. Ten of the respondents correctly described the general idea of a warning polygon as the area where a tornado could go, while 28 responses were incorrect, with one of those participants stating a warning polygon was used to indicate that eight tornadoes were on the ground.

To assess the preference on tornado warning lead time, each participant was asked the question, "What would you consider to be the ideal lead time for a tornado warning?" Though the exact number was not recorded, several respondents were not sure what this question was asking, requiring clarification along the lines of, "How many minutes would you like to have between a tornado warning being issued and the tornado arriving at your location?" Because one participant indicated she would like a week of lead time (10 080 min) for a tornado warning, the average ideal lead time for the entire sample set was 302 min. When excluding this outlier, the average for the rest of the sample ($n = 37$) was 37 min. This agrees with findings from Hoekstra et al. (2011), who reported a preferred tornado warning lead time of 34 min when surveying 320 visitors to the National Weather Center in Norman, Oklahoma, during the summer and fall of 2009. Excluding the outlier, the maximum preferred lead time was 180 min and the minimum lead time was 5 min, with 10 participants choosing 30 min.

Participants who provided a refuge or shelter location for their home were asked to estimate how long it would take to travel to their home refuge/shelter location after receiving a tornado warning. Of the 29 participants with tornado safety plans for their home, the average estimated time to reach that location was 2 min, with a minimum value of 1 min and maximum value of 15 min. Several people indicated their travel time would be "less than a minute," but these responses were rounded up to one to facilitate analysis. Those participants living in apartments ($n = 6$) reported the least travel time, with an average of 1.0 min, while those in permanent homes (18) averaged 1.2 min. Interview participants who reported living in mobile homes (5) had a substantially higher average travel time of 6.2 min.

To develop an understanding of what the participants viewed as a safe structure during a tornado, each was asked, "What do you consider safe shelter during

TABLE 3. Refuge/shelter locations reported by interview participants when asked if they had a tornado safety plan for their home (current home tornado safety plan) and what actions they would take if a tornado warning was issued for their home after hearing the preceding tornado watch statement (current tornado watch statement through level 5 tornado watch statement).

What safety actions would you take if a tornado warning was issued for your home?	Storm shelter	Fully underground basement	Partially underground basement	Lowest-level interior room	Institutional building	Evacuate	Second-floor interior room	No shelter
Current home tornado safety plan	6	2	3	16	—	—	2	9
Current tornado watch statement	7	4	4	20	1	—	1	1
Current PDS tornado watch statement	8	4	4	18	1	3	—	—
Level 1 tornado watch statement	6	4	3	22	1	1	1	—
Level 3 tornado watch statement	11	6	4	13	1	3	—	—
Level 5 tornado watch statement	15	3	4	10	1	5	—	—

a tornado?'' The most common response chosen, a lowest-level interior room, corresponds to the language used in typical tornado warning statements from the NWS. Almost half ($n = 16$) of the respondents indicated they perceived this as safe shelter during a tornado, followed by 12 who stated they only consider areas underground to be safe, while six chose a storm shelter or safe room and four chose other responses. These other responses included, ''somewhere I don't get killed,'' ''anything that's not moveable,'' ''under something heavy,'' and ''out of the path of the tornado.''

c. *TWS evaluation and preferences*

The first statement presented was that of a typical NWS SPC tornado watch, the basis of which was taken from Tornado Watch Number 140 issued at 1235 UTC 15 April 2011 for portions of northern and central Alabama, eastern Louisiana, and central and southern Mississippi. The date and time of the statement were amended in the interview in an attempt to disassociate the statement from that particular event. The detailed location description was omitted from each statement to expedite the interview process. The full transcript of the audio statement is included in supplementary material.

When asked what actions they would take if a tornado warning was issued for their home after hearing this message earlier that morning, 20 participants said they would go to a lowest-level interior room for shelter (Table 3). These locations included bathrooms, closets, hallways, and under stairwells. This was followed by seven who would go to a storm shelter, four to a fully underground basement, and four to a partially underground basement. An institutional building, a second-floor bathroom, and no action were each chosen once. This change in behavior was noticeably different from simply asking the participants if they had a tornado safety plan for their home, nine of which did not.

When asked the same question after hearing an audio statement describing a PDS tornado watch, modeled after Tornado Watch Number 235, issued at 1845 UTC 27 April 2011 for portions of Alabama, Georgia, Mississippi, and Tennessee, the number of participants choosing a lowest-level interior room for shelter dropped to 18, while the number using a storm shelter increased to eight (Table 3). One participant still selected an institutional building, while no participant chose a second-floor bathroom or no shelter after hearing the PDS tornado watch statement. The largest change was seen in the number of participants who reported that they would evacuate after hearing the tornado warning. This increased from zero after hearing a standard tornado watch to three after hearing a PDS tornado watch.

Participants were also presented with hypothetical scenarios for three levels of the Tornado Watch Scale. These statements were also modeled after the same statements from the NWS SPC, with the addition of a section describing the corresponding common refuge/shelter options recommended in the TWS. The full transcripts of these hypothetical statements are also available in the supplementary material, with excerpts shown in Table 1.

When presented with a hypothetical level 1 tornado watch statement and asked what actions they would take if a tornado warning was issued for their home later that day, 22 participants chose a lowest-level interior room, while six chose a storm shelter, four chose a fully underground basement, three chose a partially underground basement, and one participant each indicated he/she would take refuge in an institutional building, a second-floor interior room, or evacuate (Table 3). An important difference in evacuation as recommended by the Tornado Watch Scale and included in the audio recording of the hypothetical TWS statements is that evacuation is only recommended if adequate shelter is unavailable, if the person evacuates the tornado watch area *before* a tornado warning is issued, and if the person is familiar with the area and has access to storm information during evacuation.

TABLE 4. Results of McNemar's test for statistical significance of change in relative safety of stated tornado shelter locations by scenario. Significant results at the 0.05 (0.01) level are italicized (bold italicized).

From		To current PDS watch			To level 1 watch			To level 3 watch			To level 5 watch		
		Safe	Unsafe	*p*	Safe	Unsafe	*p*	Safe	Unsafe	*p*	Safe	Unsafe	*p*
Current watch	Safe	7	0		6	0		7	0		7	0	
	Unsafe	3	28	0.13	1	31	0.5	7	24	<***0.01***	13	18	<***0.01***
					Safe	Unsafe	*p*	Safe	Unsafe	*p*	Safe	Unsafe	*p*
Current PDS				Safe	6	1		8	0		8	0	
				Unsafe	0	31	0.5	5	25	*0.03*	9	21	<***0.01***
								Safe	Unsafe	*p*	Safe	Unsafe	*p*
Level 1 watch							Safe	6	0		6	0	
							Unsafe	8	24	<***0.01***	14	18	<***0.01***
											Safe	Unsafe	*p*
Level 3 watch										Safe	10	0	
										Unsafe	7	21	<***0.01***

After hearing a hypothetical level 3 tornado watch statement, the number of participants indicating they would go to a lowest-level interior room fell to 13, while the number who chose a storm shelter or safe room rose to 11 (Table 3). In this scenario, six participants indicated they would go to a fully underground basement, four to a partially underground basement, and one to an institutional building. Additionally, three indicated they would evacuate the area before a tornado warning was issued.

The greatest divergence from the current home tornado safety plan was seen when participants listened to the level 5 tornado watch statement and were then asked what actions they would take if a tornado warning was issued for their home later in the day. This set of responses saw the number of participants who chose a lowest-level interior room drop to 10, while the number indicating they would seek out a storm shelter or safe room rose to 15 (Table 3). Four participants chose a partially underground basement for this scenario, while three chose a fully underground basement and one chose an institutional building. Also, five participants indicated they would evacuate if a level 5 tornado watch was issued for their area.

Cochran's Q was used to determine if there was a statistically significant difference in the number of participants choosing safer shelter options for each scenario when compared to that resident's existing home plan. The sample size was 32 for this test because of six participants who indicated they would use a storm shelter or safe room for their existing home plan. The Cochran's Q test statistic was 30.8 ($p < 0.01$) with 4 degrees of freedom. Of the 32 participants, a total of 9 chose safer shelter for a current watch, 10 for level 1, 12 for PDS, 20 for level 5, and 17 for level 3. Thus, only level 3 and level 5 appear to have persuaded more than half of the participants toward safer shelter options.

Following the Cochran's Q test, McNemar's test was used to determine the statistical significance of change in each pair of scenarios (Rovai et al. 2014; Table 4). There were numerous pairs with statistically significant increases in safety. A level 3 watch ($p < 0.01$) and a level 5 watch ($p < 0.01$) both resulted in statistically safer actions when compared to a current NWS tornado watch. A level 1 watch ($p = 0.50$) and an NWS PDS watch ($p = 0.13$) did not result in an increase in safety compared to an NWS tornado watch. This suggests that the current NWS PDS tornado watch may not be particularly useful in eliciting safer shelter actions, while a level 1 watch is essentially the same as a current NWS tornado watch. Furthermore, a PDS watch had the same result as a current NWS tornado watch ($p = 0.50$) when compared to a level 1 watch. All other comparisons resulted in statistically significant increases in safety with alpha at 1%, with the exception of a PDS watch compared to a level 3 TWS watch ($p = 0.03$). These results suggest that the TWS is especially effective at stimulating safer decision-making when compared to current tornado watch statements. Because these results only represent response findings after hearing audio recordings, they are likely a conservative estimate of efficacy. These results would likely be even stronger if respondents had been allowed to view the TWS graphic as they were listening to the audio statements, or if the question had been framed to assess participant understanding instead of change in intended actions.

d. Does viewing the TWS graphic result in further safety increase?

After completing all of the previously discussed questions following audio-only statements, participants were then presented with a graphical depiction of the Tornado Watch Scale (see Fig. 1). After allowing time for each participant to become familiar with the graphic,

TABLE 5. Comparison of relative safety when participants' responses for their tornado safety actions following the audio tornado watch statements are compared to their tornado safety actions after viewing the graphical representation of the TWS.

	Optimal	Increase	No change	Decrease
Level 1 tornado watch	4	1	33	0
Level 3 tornado watch	10	4	23	1
Level 5 tornado watch	15	4	19	0

he/she was asked a series of three questions involving each of the three previously used levels. For example, "If you are at home under a level 1 tornado watch and a tornado warning is issued for your location, what actions do you take?" These responses were then compared against the participant's response for the corresponding level following the audio statement.

For a level 1 tornado watch, 33 participants saw no change in their relative safety when using the graphical illustration instead of the audio statements, while four chose optimal shelter and one increased their relative safety after using the TWS graphic (Table 5). Of the 33 who saw no change in safety, two of these originally chose a storm shelter following the audio statement, but then chose a first-floor interior room when using the graphic. Because both of these are considered "adequate" shelter for a level 1 tornado watch, they were classified as "no change" in relative safety.

Using a level 3 tornado watch, 23 participants saw no change in their safety, while 10 chose a storm shelter or safe room, four participants increased their safety, and one decreased after using the TWS graphic (Table 5). The decrease came from a participant who initially chose a storm shelter following the audio statement, which is considered adequate shelter using the TWS, then chose a partially underground basement using the graphic, which is considered "questionable" shelter by the TWS.

Last, for a level 5 tornado watch, 19 participants' responses saw no change in relative safety between audio and graphical methods, while 15 chose optimal shelter and four increased their relative safety (Table 5). These increases were accounted for by participants who chose a storm shelter or safe room after viewing the TWS graphic. Previously, these four participants had chosen first-floor interior rooms, partially underground basements, or evacuation as their safety actions after hearing the level 5 TWS statement. Ultimately, after being presented with the TWS graphic, 19 participants indicated they would use a storm shelter or safe room as their shelter area if presented with a tornado warning while under a level 5 tornado watch, up from seven who chose a storm shelter or safe room after hearing the current tornado watch statement. As was the case with the audio statements, these results likely underestimate participants' ability to use the TWS scale correctly because of the syntax of the question asking respondents what actions they would take, instead of what actions they should take.

e. Ranking each category on an ordinal scale

Following each audio statement, participants were also asked to rate the danger they felt associated with each watch statement on a 1–10 scale, with 10 being the most dangerous. After averaging all participant responses, the danger associated with each statement was ranked as expected, with a PDS tornado watch being rated as more dangerous than a standard tornado watch and the average danger rating for each level of the TWS scale presented to the participants being rated successively. These responses resulted in a PDS tornado watch receiving a rating of 7.68 out of 10, while a standard tornado watch received a 5.76. As expected, the results show participants' perceived danger from the current tornado watch statement (5.76) as comparable to the level 1 tornado watch statement (6.55). Participants also felt similar levels of danger associated with a PDS tornado watch (7.68) and a level 3 tornado watch (7.45). Participants rated the level 5 tornado watch as a 9.25, with 26 of the 38 participants rating their perceived danger as a 10.

f. Comments

Likely the most important question related to the proposed TWS was asking participants directly, "Of the two communication methods you just heard, the current National Weather Service tornado watch system, which used a tornado watch and a PDS tornado watch, and the Tornado Watch Scale, which used level 1, level 3, and level 5 tornado watches, which method did you prefer, and why?" Of the 38 participants in this study, 37 said they preferred the Tornado Watch Scale communications, while 1 chose the current NWS tornado watch system (Table 6). When asked for the reasoning behind this preference, the one person who chose the current system said, "Because it's more readily available." It is unclear if this participant, a 74-yr-old male, fully understood the question being asked, as he asked for clarification three times. Of those who preferred the TWS, the most common reasons for this choice included more information/more detail, easier to understand, describes severity, more explanation, and the numerical rating scale.

After completion of the interview questions, participants were given a chance to add their own questions, comments, or suggestions. Three participants took

TABLE 6. Participant responses when asked for their preference between the current NWS tornado watch and PDS tornado watch communication statements vs the TWS statements.

Current NWS watch statements (n = 1)	TWS statements (n = 37)
More readily available.	No response.
	To know severity of the weather conditions.
	Provides information on different levels of danger.
	It gives you more information on how strong the storms may be.
	Because I know what it's talking about.
	More detailed, more informative.
	Far more detailed and shows me that some things I thought were safe are not as safe as I thought they were.
	Gave more information.
	It gives me a better idea of what to expect throughout the day.
	It seems like it gives you more information.
	It tells the severity with the different types of shelters.
	It just makes more sense. Not everybody knows what a PDS thing is.
	You would have an idea of how dangerous the expected tornadoes are.
	It tells you more about what's going on.
	It gives you a code of reference to understand what is more dangerous.
	It is easier to understand.
	It breaks it up and gives a better idea of how bad it's really going to be.
	Because you can understand it better.
	Because it broke it down like that, a lot of people do not understand the PDS.
	That lets me know what to be expecting.
	It's just easier for me to think about.
	It makes me get ready because you already know the damage of those tornadoes.
	What really got my mind when I got into it was it gave you a choice.
	Because it gives you an indication of the severity.
	It was very specific and gave more information. I just like that better.
	Because it explained more.
	Because it had more information in it.
	It gives me a sense of the severity and potential conditions.
	Because I think it makes you more aware of what could be coming, versus just saying "PDS."
	Because it gave more information.
	I liked it because with a rating scale, you know 5 is something serious. That way you do not get confused because numbers are a little bit easier.
	It lets you know the severity.
	It is more specific.
	I like the levels because there's just something about it.
	I liked the levels because it tells about what kind of storms you're going to have so you get prepared better.
	Because it told me whether I could stay inside the house or if I needed to go to a storm shelter.
	It gives you a chance to get yourself really prepared.

advantage of this opportunity, the first providing insight into the need for better advertisement of public storm shelters, saying, "I would give more alternative places to go and tell where storm shelters are located. I'm seeing storm shelter, but I don't know where they are for real." Another participant, an elementary school principal, remarked, "As a school principal, I would find this system helpful in understanding the severity of an event." Last, one participant's response encapsulated this study's primary objective, which is motivating the public to choose adequate shelter by better communication of enhanced tornado risk saying, "I've got one shelter for everything now, but that level 5 made me think about getting something more substantial."

6. Limitations

The concept of the TWS is still evolving, and this research represents an initial presentation of the idea and discussion of its potential value based on strong results in northern and central Alabama. Our study area has recently been impacted by several violent tornadoes in the last 5 years, and the TWS may have resonated more in the minds of our small sample of participants when compared to a less active region. Furthermore, our spatial sampling technique was not random and we may have had participants with more interest in weather than the general population. In future research we hope to continue to evaluate the efficacy of the TWS on a broader scale with a large random sample.

Potential implementation of the TWS as a functional operational product is plagued by the same concerns that all warning and watch scales and weather forecasts share (Barnes et al. 2007b). On the conceptual model of warning accuracy from Barnes et al. (2007b), weather forecasts ideally need to always be correct, but that will never be true. Forecasts need to be reasonably accurate because error reduces credibility and perception of the accuracy of warning systems (Ripberger et al. 2014). What if there is a reduction in credibility after a series of level 3, level 4, and level 5 tornado watches are issued with consistent overforecasting? What if a level 1 watch is issued, then 12 h later unexpected atmospheric developments result in several tornadoes in the EF3 intensity range? Just as tornado watches are currently issued and some are upgraded to PDS status, a TWS watch could also be upgraded or downgraded depending on changing conditions. Similarly, hurricane intensity forecasts are updated every 6 h as a storm prepares to make landfall.

One possible solution to deterministic forecasting is using uncertainty. In current research, we are attempting to incorporate uncertainty into the TWS so that users would be given a confidence interval for potential intensity that can possibly span across more than one TWS level. We preliminarily piloted this idea using a private sample of 70 followers in Tuscaloosa for an October 2014 severe weather event. We forecasted a confidence interval of 0.7–1.7 on the TWS (Fig. 1) for that event, placing the entire forecast within the ''weak'' category. Despite what we considered narrow uncertainty, some of our followers new to the region thought the information was overwhelming and somewhat confusing preevent, but later indicated that they understood postevent. Long-term residents almost universally supported the incorporation of uncertainty. If our confidence interval had spanned the weak and strong categories, our preliminary feedback may have been less positive. We will continue to explore using the TWS with and without uncertainty.

7. Conclusions

The Tornado Watch Scale was developed as a conversion of current probabilistic SPC products to a categorical forecast product in the 24 h prior to an expected tornado event. It is intended to be used in the temporal transition period from convective outlooks to tornado warnings by providing individuals with additional information on expected tornado intensity in the forecast area.

Through our preliminary study, it is evident the TWS was adequately understood when participants were given only an audio tornado watch statement on which to base their tornado safety decisions. This response was further improved after participants were presented with a graphical illustration (Fig. 1), particularly for the most intense classification. Results likely would have been stronger if the study had focused on participants choosing the correct recommended action instead of examining their intended safety actions, because of the limited availability of storm shelters and safe rooms. Based on these results, the TWS was effective in accomplishing its objective of providing tornado hazard communication information meant to stimulate appropriate life-saving protective action through more specific and descriptive tornado watch statements. Since the participants almost unanimously indicated preference for the Tornado Watch Scale communication statements, it is hoped that this system will be considered and modified for use as an experimental forecast product to determine its efficacy on a larger scale.

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