Abstract

This report describes exploratory research that followed the Southeastern U.S. tornado outbreak of April 27, 2011. The goal of the research was to advance discourse on tornado warning response by examining event details from a new perspective. Previous research has identified the types of information sources that individuals consult during tornadoes, and has demonstrated that multiple sources of information are needed to promote warning response. The present research builds on this existing knowledge, and examines how information received before and during a tornado outbreak can shape judgments about risk in time. Given the link between space and time in dynamic decision-making events, this paper also includes some discussion about individual geospatial awareness and spatial concept building skills. Several themes emerged during the research process that comprise the contents of this report. Given the magnitude of the data, the present report is based on interview notes and not full transcriptions. As such, these findings should be considered preliminary.

1. Introduction and Event Summary

Years of research have revealed a great deal about the design and dissemination of effective hazard warnings, as well as the types of information that people access during an event. For a given hazard warning to be effective, it should include the nature, location, and source of the hazard or risk, as well as message specificity, consistency, accuracy, and clarity (Sorenson and Mileti 1989, Vogt and Sorenson 1992). Myriad studies have been conducted after tornadoes to assess the mechanisms through which individuals receive warning information as well as to document problems with warning information dissemination (e.g., Gruntfest 1987, National Oceanic and Atmospheric Administration 2007, National Oceanic and Atmospheric Administration 2008). For tornadoes, this has revealed that most people receive information from television, followed by radio, social contacts, sirens, and Web sites. Having access to many sources of information bolsters individual resilience. Additionally, recent work by Simmons and Sutter (2007) has shown that increasing tornado warning lead time saves lives and reduces mortality. After a certain amount of time, however, mortality and morbidity rates increase. The reasons for this are not fully understood given the aggregate statistical approach to the study. To improve our understanding of outcomes following tornado events, we need to understand not only what information sources are being used and how much warning time seems optimal, but also how individuals use information over time to make judgments and decisions about tornado risk within a given event.

For an individual to make judgments about tornado risk, they must understand to some degree what is happening in their environment, and how their location relates to the hazard's position, trajectory, and scale. Thus, the way people interpret hazard warnings should be a function of geospatial awareness (e.g., how well individuals understand the area around them) and geospatial constructs regarding the hazard's position and movement (e.g., how tornadoes move, how large tornadoes behave, if an individual believes they favor certain tracks, etc.). Individuals differ in spatial reasoning abilities, including the ability to orient themselves, visualize space, and relate to objects in space (Hegarty and Waller 2006). Further, understanding a tornado's dynamic motion requires a reasoning ability that differs from that for static motion (Hunt et al. 1988). It may thus be a particular challenge to reason about what is happening dynamically in one's environment, and static weather risk images may not be as useful for evaluating personal risk. It is thus important to reveal what, if any, media information tends to be preferred by individuals during severe weather events. Particularly, identifying patterns in the types of information people seek (and not just passively receive) could reveal a great deal about what they need to adequately understand their tornado risk.

In the April 27, 2011, tornado outbreak, the ability to make sense of a dynamic and complex risk was potentially essential for survival. April 27, 2011, came at the end of a three-day tornado outbreak that ultimately killed 321 people across the southeast U.S. (National Oceanic and Atmospheric Administration 2011). Around 2 a.m. local time on April 27, a quasi-linear convective system (QLCS) that had formed as a result of daytime severe convection in Arkansas and western Mississippi made its way to eastern Mississippi, and moved through north-central Alabama between 4 and 6 a.m. This QLCS produced a number of tornadoes across the area, some rated as damaging as EF3. Around 2 p.m., a new line of convection moved into northeastern Mississippi and western Alabama. Numerous fast-moving supercells produced tornadoes throughout the afternoon in waves of storm activity. Storm speeds were generally around 60 mph, which is among the fastest ground speeds observed for tornadoes. Local forecast offices provided above-average lead times for many of the storms. Figure 1 shows the cumulative warning polygons issued that day. Several locations received more than a dozen individual warnings, particularly in the Huntsville County warning area. This day proved challenging for broadcasters, as they maintained ongoing coverage of existing tornadoes while forecasting storm trajectories and communicating appropriate levels of uncertainty for communities at risk. People in the areas of potential impact often had to evaluate their level of risk several times that day, and many tornadoes passed in close proximity (some within less than 10 miles of each other). A case study for such a complex day, complete with time pressure, could reveal a great deal about the ways in which information is or is not helpful to those making judgments and decisions about risk over time and space.

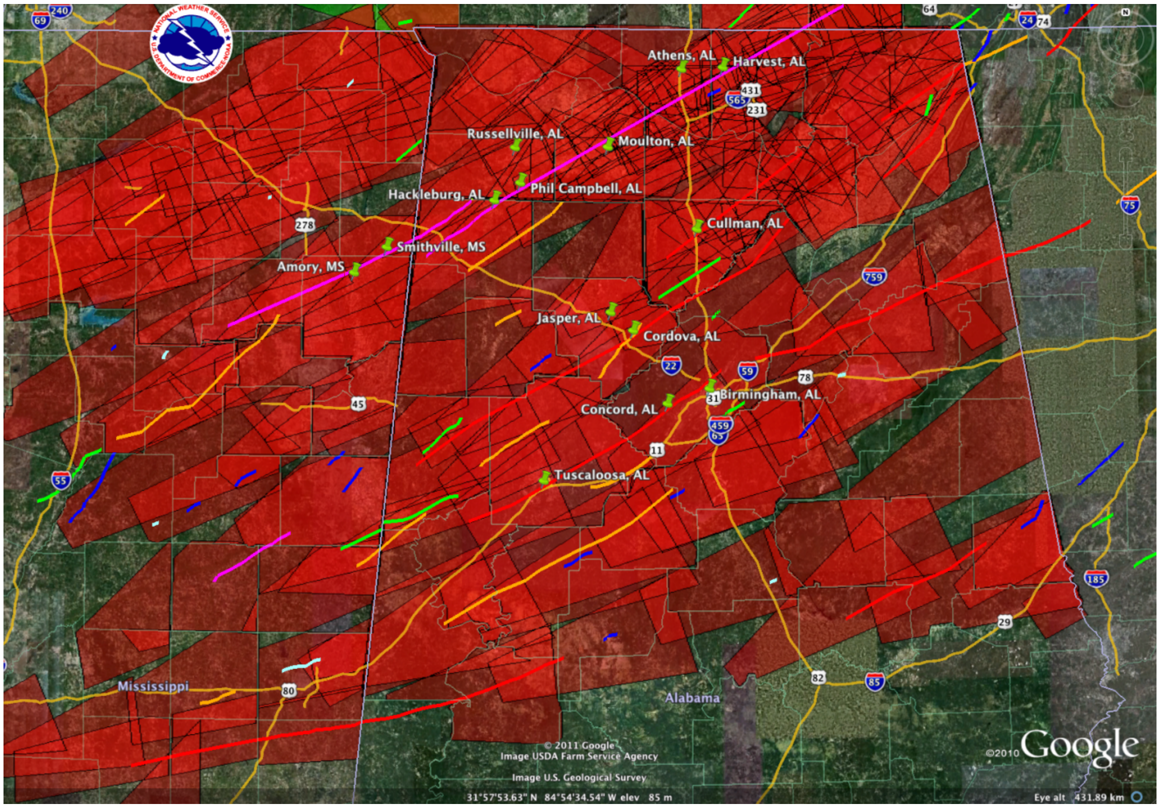

Fig 1: Tornado warnings and tornado tracks for April 27, 2011, in the Memphis, Tennessee; Jackson, Mississippi; and the Huntsville and Birmingham, Alabama county warning areas.

The events of April 27 were examined according to the following research question(s):

(1) How did different information sources (e.g., television, radio, monitoring of the environment) influence the geospatial constructs generated by individuals regarding this event?
(2) How was individual response to the presence of severe weather (sheltering, fleeing, monitoring, social activities such as calling and texting, etc.) shaped by the uncertainty they had regarding their relationship to the storms in space and through time?

2. Interview Design and Sampling

To get the most realistic representation of response behaviors, as well as a deep understanding of how different communication media were influential over time, a case study approach was chosen. Highly structured interviews were too limiting in this case, leaving little or no flexibility for the discovery of new information—a severe limitation for this somewhat exploratory research. Conversely, completely unstructured interviews would make comparisons between individuals extremely difficult. Thus, an in-depth interview method was selected. In-depth interviews, otherwise known as semi-structured interviews, blend a degree of structure with interviewer flexibility. As described by Bernard (1988), interviewers have a set list of topics to cover (following an "interview guide"), but have the flexibility to ask probing follow-up questions. This provides for directly comparable data among interviewees, but also allows for the generation of new hypotheses or insights during the research process. While this analysis process has not yet been completed due to the length of time needed to do full transcriptions, useful comparisons can still be made based on interview notes.

Based on background literature described above, as well as input from other researchers in this area, an interview guide was designed that covered tornado preparedness and experience, general severe weather awareness on the day of the event and others, communication sources accessed, interpretation of communicated information, geospatial awareness throughout the event, thoughts and decisions during the event, and demographic information. A snowball sampling methodology was employed to approach people for interviews. Snowball sampling is a reference-chain methodology whereby each contact leads to the next one or few contacts, and strings build. Such an approach may be ideal in situations where people are difficult to locate (Heckathorn 2002), and this was certainly the case with displaced tornado survivors. The strength of snowball sampling and its use of social connections is also a disadvantage, because the researcher is likely to sample individuals with similar characteristics and/or people that are more socially connected. For this reason, a non-targeted and random sampling supplemented the snowball sample to improve the representativeness of research findings. Sampling progressed until the point where the interviewer gained little insight from each additional interview.

Contacts at the National Weather Service Forecast Offices in Memphis, Huntsville, and Birmingham began several reference chains. The broad guidelines they were provided for this task, namely that a given town should have been under multiple warnings on April 27 and had one or more tornadoes pass within 20 miles, proved so broad as to include large fractions of the forecast areas. Additional reference chains were initiated by personal contacts living in Alabama. In sum, 71 individuals between ages 18 and 82 were interviewed. Interviews totaled 26 hours of recorded material, and the average interview lasted 21.9 minutes. Several people were interviewed in small groups of two to three, and the interview time for a given session was about 30 minutes. The mean age of interviewees was 44 with a standard deviation of 18 years. Income levels ranged from about $10,000 per year to $100,000 per year (incomes were approximate). The median income was $35,000, and 35.2 percent of the sample had an income below $30,000 per year while 16.9 percent had an annual income of $60,000 or greater. Alabama and Mississippi have median incomes of approximately $42,000 per year and $36,000 per year but less than 10 percent of their populations make over $60,000 per year (2010 U.S. Census). Thus, the median wealth level of the sample falls just below median incomes for the areas included in this study. Additionally, this study may have slightly oversampled individuals with the highest incomes. Individuals both in and around areas of impact were sought in order to understand how different environmental cues played into warning response (Figure 2).

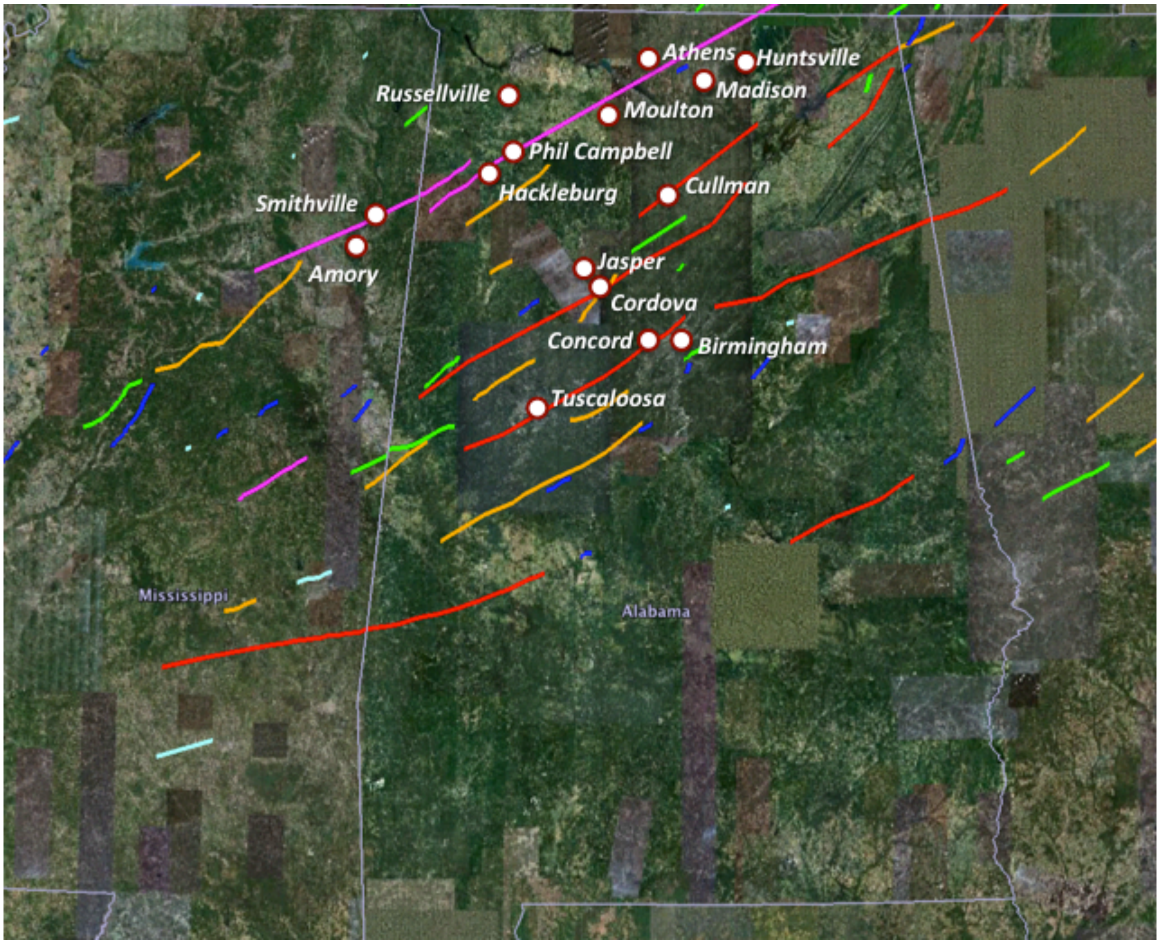

Figure 2: Tornado tracks from the April 27 event in Alabama and Missisippi (NOAA 2011) with locations of interviews. Purple tracks denote EF5 tornadoes, red tracks denote EF4 tornadoes, yellow EF3 tornadoes.

Interview responses are currently in the process of transcription. Thus, a detailed analysis of the interviews has not yet begun. However, points of consensus among individual perceptions and actions on April 27 were noted while in the field. Subsequent review of interview tapes provided additional content sufficient for a general analysis of findings that comprise the remainder of this report.

3. General findings

3.1. Information Transmitted, Received and Interpreted Over Time

3.1.1 Pre-Event Awareness

In the days leading up to Wednesday, April 27, local media outlets began to broadcast increasingly detailed and dire messages about the events that were likely to unfold. Two broadcast meteorologists interviewed for this study, one in

Huntsville and one in Birmingham, noted that they began alerting their viewers about potential tornado outbreaks on Saturday, April 23. At that time, they described a potentially widespread outbreak that could contain strong tornadoes. By Sunday and Monday, forecasters began to compare the potential upcoming outbreak with April 3, 1974—a very significant day for Alabamans when several deadly, long-track tornadoes killed 77 people in north-central Alabama. Since 1974, Alabama had not experienced tornadoes with that level of severity or fatality. Several people in Mississippi also reported hearing the event would be similar to April 3, 1974, even though Mississippi was largely unaffected that day. This comparison was intended to invoke a critical sense about what was to come—tornadoes could be large, numerous, and lethal.

Most of the interviewees (5-10) had heard about the potential for severe weather at least one day before the event. Most of those queried heard the reports on television, but some reported hearing about the threat from family, friends, or co-workers. Social reinforcement had the apparent effect of *assuring* that those individuals were attentive to events as they unfolded on the day of the outbreak. Approximately half of the sample reported hearing about the numerous damaging tornadoes that had occurred the day before (Tuesday) to the west and took that as verification that they should expect tornadoes in Mississippi or Alabama on Wednesday.

While people seemed generally aware of the threat, most people had not internalized the potential severity of the events before the morning of April 27. This was true even for many people who had heard the day would be like April 3, 1974. Some people felt that the forecasts were overhyped and actively discounted the anticipated risk. These individuals didn't believe the storms would be so numerous, so large, or so destructive. While mistrust in the forecast was a reason for some to discount the potential severity, others indicated that they didn't think the forecast had been that dire. The nature of the forecast is impossible to verify without checking network records, but this could mean that individuals receiving information before the event didn't fully interpret information presented to them in the way the broadcasters intended.

3.1.2 Awareness, Comprehension, and the Perception of Risk During the Event

Most people began the day began by going about their normal business—work, school, travel, chores, etc. (decisions to go about normal business will be discussed in section 3.3). This influenced the type and amount of information that people were likely to receive in the morning. Those who were at places of business noted that they had access to radio (National Oceanic and Atmospheric Administration (NOAA) weather radios and police scanners were common, particularly police scanners for those with municipal jobs), and frequently, television. Most groups and institutions had a mutual understanding that the day's events warranted monitoring. Many people at work were not monitoring information continually. Instead, they received infrequent updates until they decided that a hazard might be relevant for them (described further in section 3.2.1). Some people paused to get more in-depth updates on tornadoes that were hitting distant areas. A few (3-5) individuals reported that they heard nothing about what was happening during the day, and they sought shelter when someone in charge of their facility deemed it necessary. Those who were preoccupied with non-work activities reported similarly infrequent exposure to news updates, meaning that the information was not received continuously, and some individuals (15-20) reported more frequent,or continuous exposure. These individuals were able to seek out more information because they had more free time and a greater anxiety or concern about unfolding events. All information access was subject to a significant caveat—the influence of morning storms on power, broadcast systems, and other communication infrastructure.

Most individuals interviewed received convection in the morning. For those in northwest Mississippi this was around 2 to 3 a.m., and for those in north and central Alabama 4 to 6 a.m. Morning convection came as a surprise to a large majority of the sample, with only a few individuals recalling that they'd heard it was possible the night before. The morning convection incited tornado warnings in several areas, and resulted in a few tornadoes in the EF0 to EF3 range. In some rural areas this caused power outages, some of which persisted throughout the afternoon (this was the case particularly in Cordova, Alabama, which was hit by a stronger tornado again in the afternoon).

Additionally, a few people reported losing the NOAA weather radio signal from the morning convection. Most people interviewed had either no power outage or only a brief outage, with the exception of people in Cordova. A few (5-10) respondents reported that work or school was delayed due to the impacts of morning convection and power outage problems. As a result of the morning convection, most people reported increased concern about how events would unfold throughout the the day. Many individuals repeated lessons they learned from broadcasters previously, namely that afternoon heating fuels severe weather.[1] This did not apply to everyone, however, as a few (3-5) individuals thought the morning convection was "the event." Overall, morning convection promoted information-seeking behaviors throughout the day, but did not do so when individuals didn't understand the relationship between morning convection and the broader event.

3.2.1 Information Preferences, Geospatial Awareness, and Ways in Which Preferred Information Supported Geospatial Awareness

Throughout the day, people consulted several sources of information to stay updated and to estimate their risk. People primarily consulted television when it was available. If it wasn't readily available early in the day, they watched it at home after work and school. A vast majority of people watched a favorite broadcast meteorologist that they trusted. Those unable to watch television turned to radio broadcasts coming from a television station, police scanners, NOAA radios, and family, friends, and coworkers. Additionally, some people sought information on the

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[1] This is broadly an example of "folk science," or observed personal understandings of the science of meteorology, and will be explained in more detail in section 3.3.

Internet (weather information directly, not social networking). They reported doing so for a few reasons, but chief among them was their inability to estimate personal risk, or generate a timeline for their personal risk from other broadcast information.

Many individuals who were watching television reported confusion in determining personal risk. Some people noted, for example, that broadcasters showed live tornado footage (which helped to convey serious risk), but did not provide maps, or information about the relative location of the tornado. Some people that remembered seeing maps, however, had difficulty interpreting map scale, or recognizing familiar locations on the maps shown. These same individuals responded enthusiastically when asked if an inset map would have been a helpful addition. Additionally, many people had trouble inferring storm trajectory, because broadcasters were not showing loops of radar imagery, or were showing loops that were too short (incidentally, people with Internet access were able to find longer radar loops online—through both public and private vendors—and they found this helpful for inferring storm trajectory). Some broadcasters attempted to supplement radar loops with trajectory cones and estimated arrival times within 30 minutes to one hour. Many people appreciated the trajectory cones, and most interviewees expressed extreme and unwarranted levels of trust in the accuracy of arrival time projections.

Problems also mounted for those listening to radio broadcasts. Several people were relegated to listening to radio simulcasts because of power outages, particularly for in and near Huntsville. Listeners reported difficulty understanding their temporal and spatial relationship to tornado hazards. Often, areas at risk were not named because broadcasters would make gestures that were only visible to a viewing audience. Additionally, some people did not know the locations of small towns mentioned in the broadcasts, and the numerous ongoing storms were confusing to keep track of without a map. Combating these issues, some people (10-15) turned to local radio broadcasts, particularly police scanners. Those able to access this information liked listening to it because they knew the areas mentioned, they were receiving continual live reports for their local area, and they trusted the information.

The majority of people interviewed preferred to view information on a countywide scale. For about half of those people, the boundary of their own county was the point at which they became concerned. Almost all of these people were able to locate the area of the county in which they lived, and noted that tornadoes passing in another portion would not alarm them at all. A few people indicated that they could identify their county on a map, and knew to look west, south, or southwest for imminent storms and tornadoes. A minority of people (only 3-5) did not know their county's name, and none of those people were native to Alabama or Mississippi. In addition to county-level information, about half of the sample reported that perception of risk increased when tornadoes passed through familiar towns and cities. Again, most people talked about towns to the south and west and correctly identified the directions from which storms most frequently travel. In sum, most people started personalizing risk when the tornado was within 5-10 miles and hitting familiar locations nearby. Before that point, uncertainty was too great.

In addition to political markers and boundaries such as counties and cities or towns, some people noted that landmarks were useful in understanding hazard location and also personalizing risk more strongly. The landmarks that were used differed by person and information source, but the most commonly cited landmarks included roads, waterways, and businesses. People were alerted by broadcast meteorologists, friends, family, and others when tornadoes hit these landmarks. As such, landmarks were used less for forecasting purposes and more for up-to-the-minute reporting. This highly specific information was valued greatly by individuals who were making sheltering decisions at the last minute (discussed further in section 3.3). Broadcasters must be careful with this reporting, however. Similar to the problem with providing deterministic time-of-arrival estimates, people trusted landmark reports almost without question but they didn't know that the broadcasters weren't necessarily receiving reports of those landmarks getting hit. Instead, they used radar imagery (with significant scale biases) and local knowledge to simply name nearby landmarks, regardless of actual damage. Several individuals interviewed in Tuscaloosa noted confusion as a result.

Regardless, there is clearly a demand for landmark information, because at least half of the sample noted that they navigate by landmarks rather than political boundaries or cardinal directions. The way landmarks are used, however, must be considered carefully. The use of landmarks in advisory information could support trajectory forecasts and strengthen personalization of risk, but the uncertainty must be communicated clearly. This could be very difficult for broadcasters that are handling several ongoing storms at once.

Scale is a key issue to consider when determining the value of information provided in tornado forecasts. This has been discussed implicitly thus far, but scale concepts are critical in understanding how people perceive, and ultimately respond to nearby risks. Generally speaking, the larger the scale of concern, the more time individuals can spend personalizing the threat. This is analogous, from signal detection theory, to those individuals setting a more liberal criterion for concern (Ashby 1992), thus leaving themselves open to the potential for a greater space of false alarm. The present work makes the distinction between concern and response in that concern does not necessarily lead to shelter-seeking, but liberal inclusion of spaces of concern may provide a longer amount of time for which these individuals are alarmed and motivated to stay informed. When considering the value of leadtime, this is an important consideration. For those individuals who became concerned for their personal safety when storms were a full county (20-30 miles) away, the time spent preparing to respond was generally greater than with a city/town scale criterion of five miles or less. A vast majority of individuals in this study (50-60) reported their threshold for concern to be a location within 5-10 miles. This included specific portions of certain counties, towns, and landmarks.

Even with pre-event awareness, possibly hours of monitoring, and five or more minutes of detecting a highly personalized threat, environmental signals such as high winds, dark skies, bent and/or snapping trees, debris and even a tornado sighting were the most critical for inciting belief that a tornado could actually strike. With the exception of the severely risk averse (3-5 individuals), everyone interviewed made a statement to the effect that they "just didn't believe it would happen to them." Thus, interpretation of environmental signals was critical and everyone used information from broadcasts, friends, family, and others to understand the situation, personalize the threat, and ultimately believe whether or not it could happen to them.

One key scale-related problem existed on April 27— people didn't understand the scale of the tornadoes. This meant that they didn't know what a large (~1 mile wide) tornado would look like, particularly with the high ground speed for tornadoes that day. That in turn played a role in the confusion of,many and ultimately reduced the reduced the response time (responses discussed further in section 3.3). Even people who had seen tornadic storms in the past reported scale confusion. The information they were receiving lead them to generate the spatial concept that a tornado would likely be hitting one landmark or building at a time, or crossing a small section of a roadway. They didn't understand that the tornadoes were hitting many buildings at once and covered the distance between two rural roads or possibly multiple parallel streets. This problem was even greater for those who weren't given visual information. Effective communication about tornado scale should be a focus for those providing tornado advisory information in the future, especially given how critical the local scale was for individual assessments of risk in this study.

One final source of information is sirens. This was the last thing most people mentioned when they told their stories and most of the time the interviewer explicitly asked about sirens. Almost everyone interviewed heard sirens multiple times throughout the day. Many credited the sirens with alerting them to the danger of the morning convection. However, the first reaction when asked if they'd heard sirens was to either laugh or balk and note a "cry wolf effect," or that sirens "go off all the time," etc. When queried further, almost everyone knew that sirens were sounded on a county-based system. Thus, for the problem people were focused on—inferring storm trajectory—sirens were not ideal. The overarching opinion was that sirens likely meant nothing about tornado locations, which is probably a correct assessment. A few people noted confusion with interpreting the sirens and a large variety of siren policies were observed in counties and towns. This issue did not seem as irksome to people as the county-based issuance of the alarm. When asked what they did after hearing the sirens throughout the day, however, almost no one completely disregarded them. People reported turning on the television, looking outside, or using some other means to seek further information about the threat. While the scale was too imprecise to alarm people much, sirens still served as the first notification of an incoming storm for approximately half of the individuals interviewed. When asked what people typically do when sirens go off, they claimed to have the same behaviors as they did on April 27.

3.3 Actions and Decisions Through Time

While most people were aware that a tornado outbreak was expected, a majority of those sampled began the day by going to work, school, or other planned activities unless morning convection and/or power outages caused delays. Two individuals interviewed were driving from Tennessee down to portions of north-central Alabama, and one individual was driving from Huntsville to Russellville. The decision to hold school in Alabama that day seems peculiar—since the 2007 Enterprise tornado, the state has sent students home whenever tornado watches are issued. A tornado watch was in effect for the morning convection with another to follow shortly for the afternoon, yet students were sent to school, often dodging waves of storms. Many parents reported that this was done because there had been numerous snow days that winter and school districts were already holding classes on Saturdays and extending the school year by a few days. If students were sent to school and then sent home early, this would still count toward their required number of school days, so most schools stayed open. Many schools and businesses began to close in the early afternoon as convection appeared, and at this point, some people began to gather at places of relative safety.

When put under tornado warnings, a vast majority of people employed a similar strategy for deciding when to take shelter. Situations were of course somewhat complex and varied, but with the exception of the few individuals who discounted warnings and/or sirens, or did not hear sirens due to power outages (as in Cordova, AL and some areas near Huntsville), most people began to make preparations to take shelter when the information they were receiving identified their location as a point of concern. Preparations included discussing sheltering options, identifying shelter, moving to safer structures, bringing flashlights and other supplies to sheltering places, and more. For most people, preparations required 5-10 minutes. Once sheltered, most people continuously monitored the outdoors and other sources of information such as television, radio and social contacts. Those with less experience with tornadoes did not make preparations to seek shelter right away. A few business owners originally from New Jersey but now living in Alabama prepared for the possible loss of power (something they had experienced before), believing this threat to be greater than the tornado threat. A few other business owners hailing from India did nothing. Some University of Alabama students from less tornado prone areas followed their friends into dorm hallways and monitored web news feeds, but they noted that they felt silly sheltering when the sirens had sounded while the sky was visible. When tornadoes drew near enough for there to be significant environmental signals, those who had been preparing to shelter ran to it immediately. Some of these people were caught off guard by the speed of the storms and did not reach their sheltering place completely when the tornado struck, but most people were in the safest spot in their home or structure. Most people did not think to flee the storms, favoring a strategy whereby they would wait to see if they would actually be in danger, at which point they would be ready to take shelter at the last minute.

Nearly everyone interviewed explained the choice to shelter in the last two minutes or less by saying, "I just didn't think it could happen to me," or something similar. After years of observation, many people believed that local phenomena prevented tornadoes from occurring, even though they admitted they had been taught otherwise. The tendency to believe conclusions derived from personal observation or local rumor often superseded knowledge learned elsewhere when it came to personalization and belief in the threat. In one town, for example, many people noted that tornadoes never crossed the southwest-northeast-oriented waterway to the west (which it did on April 27). As such, most townspeople did not seek shelter until just moments before the tornado struck. Additionally, there was a common belief that tornadoes do not breach hills, and most people believed that since tornadoes had not hit their location before, they never would. This reveals a common underlying belief that tornadoes track in systematic ways rather than random paths determined by larger-scale flow. Whether this belief is grounded in normalcy bias (people searching for a way to believe that they will not be struck), a fundamental lack of understanding, or some other explanation beyond the scope of this study, but this belief system might have played a role in some of the fatalities that occurred on April 27. Many of the individuals interviewed might not have survived given how long they waited to take shelter.

4. Conclusions

RQ 1*: How did different information sources (e.g., television, radio, monitoring of the environment) influence the geospatial constructs generated by individuals regarding this event?*

April 27, 2011 presented a challenge for those communicating risk and those interpreting the information they were receiving. Ultimately, several things went well that day: most people were aware of the threat ahead of time, and awareness throughout the day was generally high. This initial awareness motivated people to be attentive, and to monitor storms throughout the day For most people, a storm had to be within 10-15 miles before they took shelter.

Several recommendations for warning communication are contained in this report. First, still radar images do not allow people to infer tornadoes' trajectories with confidence, and so long radar loops and trajectory cones are preferred. It's worth noting, however, that people expressed an unwarranted level of trust in the trajectory cones' estimated paths and arrival times. Second, even though most people agreed that sirens are not trusted sources of warning information, sirens prompted almost everyone on April 27 to seek further information. The notion that "sirens need to be fixed," however, (so that they're more location specific) was popular. Third, live tornado footage helped people to believe and personalize risk, but without accompanying maps that showed tornado location, people were not able to make sheltering decisions. A similar problem was noted for radar images that were zoomed in on a particular storm: if there was no inset map referencing the broader area, people were easily lost and didn't know where the tornado was located. Lastly, problems with spatial comprehension mounted for those who were only listening to broadcast information and unable to view maps.

RQ 2: *How did individuals' uncertainty about their spatial and temporal relationships to storms influence their sheltering responses?*

Regardless of individuals' level of meteorological knowledge (as well as any other factor), almost everyone required strong environmental evidence to ultimately seek shelter. Sheltering thus occurred in the last few minutes – moments before impact for almost everyone. Most people were surprised by the appearance of the tornado when they saw it (or evidence of it), particularly its size and speed, and some people actually waited to shelter because they took time to process what they were seeing. As such, helping people to understand visual cues might improve the time people will spend sheltering. This is a role that storm spotters, working closely with broadcasters, could possibly fill. Finally, almost everyone interviewed was aware that they were *supposed* to start sheltering earlier than they did. Since nobody behaves in this idealized way, however, it might be beneficial to provide people with information that is useful for last minute sheltering.

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