ASSESSING THE PREPAREDNESS AND MITIGATION RESEARCH ON TORNADOES: CLARIFYING RISK PERCEPTIONS AND IDENTIFYING CONTRADICTIONS

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Assessing the Preparedness and Mitigation Research on Tornadoes:
Clarifying Risk Perceptions and Identifying Contradictions

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The Supervisory Committee certifies that this ***disquisition*** complies with

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ABSTRACT

This paper examines literature from various disciplines contributing to the objective of saving lives and reducing damages from tornadoes. Specific topics include changes in tornado incidence, the genesis of tornadoes, and alterations in geographical distributions of tornadoes. I also review data on damages, casualties and deaths along with associated housing type vulnerability and atypical nocturnal tornado events. Literature associated with predictions including historical data and forecasting is addressed. Further data was presented regarding false alarms, warnings, watches and response behavior. Finally, mitigation issues regarding policy and planning, building practices and sheltering is reviewed. While reviewing the data, several contradictions were found regarding density, lead time expectations, vehicular use and actual increases in events and damages. Perception of risk may be dependent on factors of cultural geography and societal memory. Improved understanding of warning times, effective education, outreach and removing the human factor in tornadoes are points that need further study.

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CHAPTER 1. INTRODUCTION

Each year the recorded number of tornadoes across the United States (U.S.) has consistently increased beyond previously reported averages. According to the National Oceanic and Atmospheric Administration (NOAA), there were 1,400 recorded tornadoes in 2010. This is in contrast to the annual average of 1,077 since the onset of tornado data documentation in 1950 (NOAA, 2012). To the casual observer, U.S. tornado data shows a trend towards increasing events per year as well as increasing damages. While the raw data shows these increases, the rationale for the increase is complex. For this reason it is important to look at the variables behind the data. From 1950, the average annual property damage loss, according to NOAA, is approximately $400 million. Injuries and deaths over this same period do not follow the same pattern as the recorded damages and total number of events. In reviewing data for deaths caused by tornadoes, it is observed that the annual number of deaths has remained relatively constant over the past 30 years (approximately 57 deaths) opposed to the annual average of 81 since 1950. However, over the last 60 years the annual downward trend seems to be consistent. I wanted to review the research, specifically historical trends, predictions as well as, preparedness and mitigation research to shed light on these seemingly interesting trends. I found several contradictions in the literature and many other consistent points approached from differing avenues of research. As an emergency manager it is important to understand all the potential sources of information and how they impact and add to our discipline.

Considering the population increases, progress in efforts to reduce deaths seems to be effective. In the last 30 years, annual injuries remained relatively unchanged, as have deaths due to tornadoes. But unlike deaths, from 1950 to 1980, injuries increased, and then drastically dropped in the following years. Annual average deaths due to tornadoes have stayed the same despite the advancements in tornado understanding and detection. In theory, through our efforts in prediction, preparedness and mitigation, these numbers should be on the downward trend, yet in 2011 numerous lives were lost in Joplin, Missouri. While the use of warning systems has been valuable, the technology of recognizing high risk weather patterns has increased lead times in warnings. The same is also true for how we have been mitigating the effects of tornadoes. While we may know that tornadoes are destructive we need to understand the details involved such as, how they destroy property, how people react to warnings and what measures we can take to save lives. There is evidence to guide emergency managers towards informed decisions about tornadoes and their impacts.

Is current literature adequately guiding emergency managers through the trends and directions that result in reductions of overall deaths, injuries, and losses? The purpose of this review is to examine and synthesize literature on tornadoes, predictions, preparedness and mitigation to understand the existing research, contradictions such as planning issues, clarifications on the raw tornado data, a shifting historical "tornado alley" and possible gaps such as nocturnal tornadogenesis. The articles reviewed are those that focus on tornado research in the U.S. The aim is to aggregate that research literature aiding our understanding in the area of tornadoes and emergency management today. I have elected not to discuss response and recovery, as these two phases of emergency management focus on reactionary principles to events, and the topics outlined above focus more on a proactive approach. The following sections begin by examining the relevant facts regarding tornadoes specific to the U.S., focusing on the damages, deaths and injuries. After establishing the prevalence and severity of tornadoes in the U.S., I will provide an overview of the current research regarding tornado predictions. My focus in this section is on the technology used in identifying tornadoes and meteorological patterns that can create tornadic events. It is important to understand this issue because it underlies the basis for preparedness and warnings are of the most critical actions in towards mitigation. The last two sections will focus on preparedness and mitigation specific to tornadoes in the U.S. In conclusion, this review will provide an understanding of the literature concerning tornadoes and the findings specific to those three areas mentioned. Contradictions and important insights will be presented throughout the review and summarized in the conclusions. Overall, tornadoes are only understood to the depth of what has been provided in the literature. To understand one issue it is important as emergency managers to inform ourselves in all the facets of the hazards.

CHAPTER 2. TORNADOES

Currently, the U.S. is encountering high incidences of tornadoes in areas beyond the traditionally defined "tornado alley." For tornadoes, 2011 was a year of record setting events for annual damages, total number per day, total per month and second to 2004 in total number of events per year. As technology improves and warning lead time increases, it is important to call attention to the issues involved with advancing technology and warning. It is also relevant to bring to light the potential issues in mitigation in an area where limited options are available. Historically, "tornado alley" has been attributed to central Midwest region, but the impacts of tornadoes go beyond this area and research shows increased vulnerability regarding deaths, injuries and damages. Understanding this literature is critical at a time when tornadoes are impacting communities that have not typically experienced this natural hazard.

Incidences, Genesis and "Alleys"

Tornadoes have been reported in all fifty states; no matter where one lives, the probability of a tornado exists (Ashley 2007). Mileti (1999) stated that the U.S. has the most tornadoes of any place on earth and tornadoes are the number one cause of injuries from natural hazards. However, research shows that heat waves killed more people overall in the U.S. during the period of 1970-2004 (Borden and Cuttter, 2008). Although it is not a "killer" it impacts the U.S. significantly. The National Weather Service (NWS) has tracked tornadoes since the 1950s, and subsequently there have been almost 60,000 total tornadoes, directly causing 5,600 deaths. Earlier records on average show there were approximately 600 tornadic events a year, although there is research that disputes that average, and suggests there are 60 more tornadoes per hundred reported across the U.S. Recently the reported number of annual tornadoes has been above 1,300. Mitchell and Thomas (2001) observed this upward trend and predicted that the trend would not decrease. Their observations and predictions have been accurate thus far, but nuances with the data need to be explored.

Tornadoes are not fully understood from a meteorological standpoint, although certain components are accepted as theory. A tornadic event begins as air rushes inward centrally toward a low pressure area. It then drives upward in a spiraling fashion centrifuging heavier matter to the outside. This vortex is termed “the mesocyclone” coined by Ted Fujita. Although that description sounds simple, there are mechanics and physics involved specific to tornadogenesis. Tornadoes are hypothesized to develop according to Figure 1: a horizontal rotational airflow (a wall cloud) resembling a tube rolling parallel to the ground surface gets pulled up on end as it encounters an updraft due to ground or surface heating. This creates the visual anvil as it pulls hot air into the upper atmosphere. As this tube gets stretched it increases in rotation due to the physics of angular momentum. The moist, heated air rises and tilts the formation forward releasing moisture in a downdraft as rain. Rain, although not always associated with tornadoes, and cooler air spread out in front of the supercell. From here the process of downdrafts, front and rear, and the shifting of the mesocyclone to the rear of the supercell, away from the updraft column is all theory and not well understood. These events are complex meteorologically, and due to the complexity, no two storms are the same nor are the

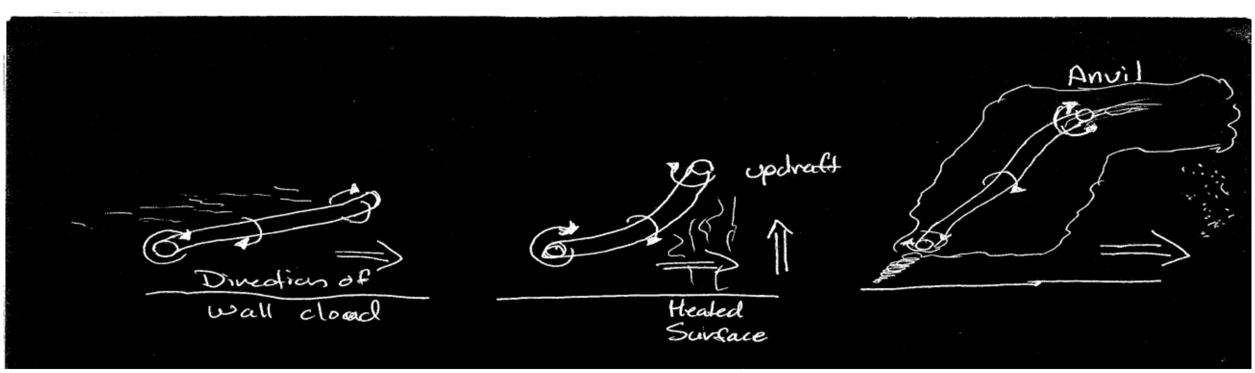

Figure 1. Tornadogenesis (Source, Freeman sketch 2012 –based on reproduction of figures from the NWS Pamphlet # NOAA/PA 201051).

conditions identical for the creation of the tornado. Both the National Weather Service and the Storm Prediction Center concur that neither organization understands the exact manner of how tornadoes develop.

Tornadoes span a distance as narrow as a few yards to as wide as a couple of miles. The widest tornado on record was two and a half miles wide in the May 3rd, 1999 Oklahoma outbreak. Wind speeds have reached as high as 315 miles per hour, as was recorded in a 2004 Nebraska tornado. Tornadoes occur most often in the central U.S. in an area traditionally classified as "tornado alley" (Figure 2). However, there have been more tornadoes occurring in areas to the east, challenging previously held perceptions of where the higher risk of tornadoes is centered (Concannon, Brooks & Doswell, 2000). Concannon, Brooks & Doswell (2000) reviewed data on tornadoes to evaluate the risk across the U.S., and found that the frequency forms an "L" shape extending up to the Dakotas, down to Oklahoma and across to Georgia. Based on these results, it has become common practice to accept this more modern description of the activity of the tornadoes across the U.S. Boruff et al (2003) looked at all tornado events from 1950 – 2010 and also found a shift in the alley to the south and east (Figure 3). Boruff et. al.

Figure 2. Traditional tornado alley (Source Keli Tarp, National Weather Service, 2001).

(2003) also showed that the increase in damages due to tornadoes in the recent years reflects the increase in population in the areas of higher tornado risk.   This follows the new alleys as they tend to be in higher populated areas. Demonstrated by the most recent activity in 2011, tornadoes have failed to follow or remain within the boundaries of the traditional alley. Without the accessibility to long term data, spanning hundreds of years, we cannot make specific conclusions regarding pattern changes or typical weather patterns across the U.S. Brooks, Doswell & Kay (2003) reviewed data on daily tornado activity in the U.S. and found the probability of daily tornadoes is higher than initially understood. In this study they isolated tornadic activity, excluding severe thunderstorms. Excluding the thunderstorm data had not been done before. By doing so the data was specific to tornadoes providing a clearer picture of tornado behavior.   More importantly, in this study they were able to show that as the season progresses, the activity shifts to the north and east. The results of these studies should increase

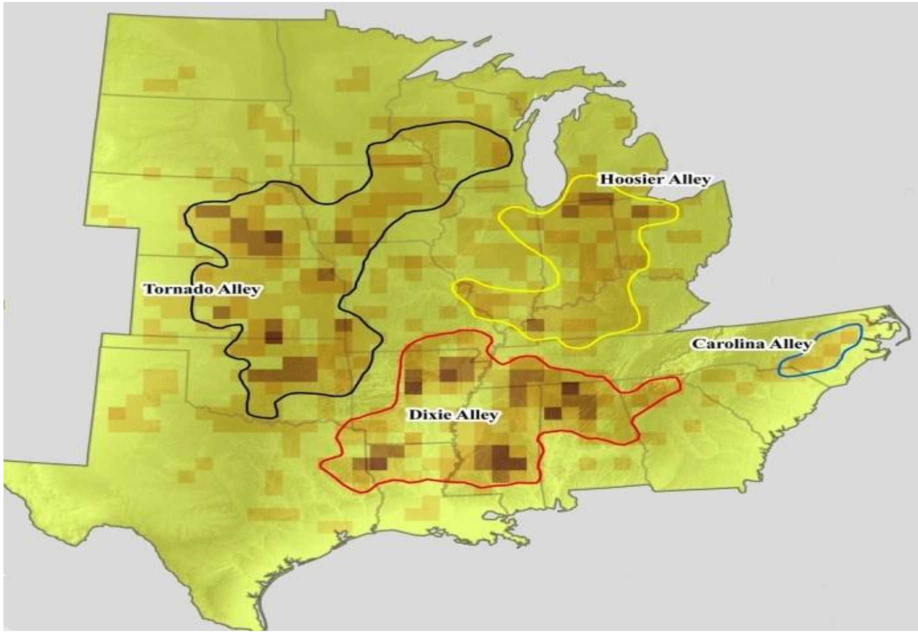

Figure 3. Modern tornado alleys (Source, Michael Frates, University of Akron).

awareness for the emergency management administrators in the north and to the east to assess their risks differently as the tornado season proceeds.

Aquirre, et al. (1993) demonstrated that counties with high numbers of previous tornadoes have a higher probability of tornado occurrences. This was also established by Donner 2007), stating that "most tornadoes occur within twenty-five miles of previously occurring events." These two results support findings by Graves and Brensock (1985) who reported that tornadoes are not random hazards, and in fact, we should prepare for subsequent events immediately after a tornado occurs. Data from 1998, 1999 and 2003 found at the National Climatology Data Center (NCDC) and the news releases of the Oklahoma outbreaks from the Federal Emergency Management Agency (FEMA), support the results of Graves and Brensock's (1985) studies. In those years, Oklahoma saw events that took 36 lives and damaged property to a sum of over $1.4 billion combined. Lives were saved after the first two storms due to the community's action to mitigate potential future and subsequent threats. It is not the geographic factor of tornadoes we need to concern ourselves, but also the time of day.

The period between late spring and early fall has been identified as the tornado season. However, tornadoes will occur all year depending on weather and conditions. As the seasons progress, the weather patterns change, and the tornado threat geographically moves north and east (Concannon, Brooks & Doswell 2000). For most people it is understood that during the course of the day, tornadoes occur more frequently in the afternoons and evenings. Even though data shows tornadoes occur more frequently during the evening hours, nighttime or nocturnal tornadoes are of eminent risk. Nocturnal tornadoes have the highest risk of casualties due to the inability of spotters to adequately recognize a tornado and because of the slow reaction time of a sleeping community. This type is more prevalent in the southern and eastern states where understanding and awareness of tornado risks are lacking (Concannon, Brooks & Doswell 2000).

Nocturnal Events

Nocturnal tornadoes are hard to spot, and due to the vulnerability of a sleeping population, account for almost 40 percent of all fatalities (Ashley, Kremenic & Schwantes, 2008). Ashley, Kremenic & Schwantes (2008) analyzed tornado vulnerability and found that nocturnal events are two and half times more deadly than daytime tornadoes. Even though nocturnal tornadoes only account for a quarter of all tornadoes, they result in a high percentage of deaths (Ashley, 2007). More importantly, the common meteorological tornadic theories used for all tornadoes may not be accurate for nocturnal tornadoes; this area needs more study and attention to the entire range of meteorological and environmental variables (Kis & Straka, 2010). Ashley (2007) and Ashley, Kremenic & Schwantes (2008) also found that the south is more likely to have nocturnal tornadoes than the upper Midwest. Davies and Fischer (2009) provided the meteorological explanation for that conclusion, it simply takes more energy due to differing forces in the layers of the atmosphere in the north to overcome inhibiting factors that do not exist in the southern air masses. This is mostly a result of the jet stream and how the drier air flows from the west and does not track to the south but rather into the upper Midwest. Exactly why the nocturnal tornado death rate is higher is not fully understood, but may be due to a lack of awareness by the communities where they occurred and because verification methods are difficult at night, resulting in individuals not seeking proper shelter or receiving adequate warnings. This area needs to be explored more deeply.

Damages

From 1950 to 2011, tornadoes caused over $21 trillion in damages. This figure does not account for inflation (NCDC, 2011). Reviewing the data from the 1950s to 1999, Brooks and Doswell (2000) evaluated the reasons for increased damage, and found that wealth and more abundant accumulation of goods were the cause for the increases in damage, which was later supported in further research by Brooks (2006). Frequently we see articles and presenters stating that weather is become more severe and frequently. Unfortunately that data is not there to support those claims (Schiermeier, 2012). Tornadoes are not necessarily causing more damage due to their increased number or intensity, rather as a country we have more possessions (cars per household, boats, real estate, and other personal assets) to damage when tornadoes come into contact with our communities. Insured values have gone up even more, to almost double the losses officially reported by government agencies (Changnon, 2009). The reason for the variance in numbers is that governmental figures are estimates, whereas actual insured losses are calculated based on real loss values reported or paid. Changnon et al. (2000) echoed the prior study result. They cite two factors for increased losses: increasing population growth (demographic shifts where people are moving to areas of high risk), and increasing urbanization and wealth. All these losses are replaceable, but injuries and loss of lives are more significant and have other implications to our communities.

Casualties

According to the NOAA, tornadoes have killed approximately 5,600 people in the U.S. since 1950, 90 people per year on average from 1950-2011 (Table 1). The number of people killed in any given year ranges from a low of 15 to a high of 580. The range is staggering, and should heighten our awareness of the risk tornadoes present as an unpredictable event, due to their frequent and regular occurrences. Similar figures reported in a 23 year period from 1975 to 1998, showed 58 annual deaths due to tornadoes (Mitchell & Thomas, 2001). In 2010 and 2011, the recorded tornado related deaths show the total has surpassed all prior decades going back to 1950. The data shows injuries surpass those in the same recorded periods. If the trend holds true, the total number of recorded tornadoes could easily pass the previous sixty year record, but more importantly continue the trend of increasing observed and recorded occurrences across the U.S.

A reasonable prediction of tornado outcomes is that the bigger the tornado, the greater the casualties. Donner (2007) demonstrated in a study that in fact this may be the case in relationship to area covered, not size of the tornado itself. The larger the area covered by the tornado, the greater the number of deaths. Brooks and Doswell (2002) suggest that what seems like a large number of deaths today (e.g. the 1999 Oklahoma tornado event) would have been a common or normal number of deaths in the 1920s, which shows that our acceptable level, or expected death toll, has been reduced.

The violent nature of tornadoes causes injuries due to debris, and the failure of structures and vegetation. Most injuries occur when the tornado reaches significant enhanced Fujita rating

Table 1

Total number of tornadoes occurring per 10 year period.

Year	Tornados	Deaths	Injuries
1950-59	5232	1419	14469
1960-69	7305	942	17265
1970-79	9362	997	21567
1980-89	9003	517	11237
1990-99	12061	586	11392
2000-09	13893	557	8214
2010-11	3141	580	5991

levels of EF3 or higher (Table 2). In a 20 year period from 1975 to 1994, approximately 23,000 people were injured (Mileti, 1999). Data from NCDC (2011) shows total injuries due to tornadoes at 90,000 since 1950, and 1,400 annually. When considered annually, tornadoes are periodically occurring events with injuries routinely exceeding any other natural hazard in the U.S. Little research has been conducted on injuries alone, and most of that research focuses specifically on deaths. The lack of specific injury research is because what causes injuries is also the main cause of deaths, debris. The most common cause of deaths and injuries is due to soft tissue impacts from flying debris termed missiles or projectiles (Carter, Millson & Allen, 1989, Bohonos & Hogan, 1999). It has also been noted that deaths and injuries can occur from people themselves "flying" (Legates & Biddle, 1999) into solid objects (Carter, Millson, and Allen, 1989). Comparably deaths have a greater emotional impact. Although injuries don't rise to the same emotional level as a death, they have significant consequences unseen during the recovery periods. Although injuries and deaths occur in the same manner during tornadoes, injuries occur more frequently, reducing productivity and recovery capabilities in the aftermath increasing health costs. The result is that the high number of annual injuries increases the cost of tornadoes, yet injuries are not reviewed specifically in the literature nor typically calculated.

Table 2

Enhanced Fujita scale.

Scale	**Wind Speed (mph)**	**Possible Damage**
EF0	65-85	branches broken
EF1	86-110	mobile home pushed off foundation
EF2	111-135	strong built homes unroofed
EF3	136-165	trains overturned
EF4	166-200	houses leveled
EF5	>200	automobile sized missiles generated

(Source NOAA Storm Prediction Center)

Several studies have tried to identify factors that are correlated to deaths and injuries. Each of these studies identified similar variables. Age (70+ years) for example seems to be one factor, depending on the study and location of the tornado (Cater, Millson, & Allen, 1989, Hanson, Vitek, Hanson, 1979). The devastating effects are evident when debris becomes enveloped in a tornado. Small items as well as larger ones can travel at incredible speed and on impact the projectiles can penetrate brick walls increasing the potential for fatalities (Figure 4). Structures or large trees falling on people are equally deadly. Schmidlin (2009) identified 407 deaths across the U.S. in a 12 year period ranging from 1995 to 2007 due to wind related tree failures. Of interest in this study, which included both tornadoes and cyclones, the largest number of fatalities occurred inside homes, followed by those in vehicles, then those occurring outside. The range over all three locations was 42 to 25 percent, which shows little variation or that one is substantially at higher risk indoors or outdoors comparatively. It seems however that trees have a deadly effect in all locations, which may be counterintuitive. Safety concerns

Figure 4. Projectile penetrating tire (Source NOAA, 2012).

should be considered for lot size tree placement as well as boulevard and highway tree size, set back, and placement.

During the 1999 tornado event in Oklahoma the most common injury was soft tissue damage (Brown, Archer, Kruger & Mallonee, 2002). Although most of the injuries and deaths were directly due to the event itself, others occurred during the preparation and clean up. Interestingly enough, some records do not separate out cause of deaths where others do. The argument is that the tornado must be the direct cause of death. However, if the tornado had not occurred, additional deaths would not have resulted, thus they should be included in the total deaths related to the tornado. In the Brown, et al (2002) study, it was determined that 30 percent of the individuals who died were in recommended safe areas during tornadoes. Location within a building seemed to be a factor as to whether an individual sustained a simple injury or fatal injury. Basements and interior rooms were the second best location only to an approved storm shelter. Vehicles are a hazardous place to shelter, as they provide no protection from debris, and they can become debris (Cater, Millson, & Allen, 1989). However, Hammer and Schmidlin et al. (2002) pointed out that during the May 1999 Oklahoma event many people fled the storm's path in vehicles, and none died as a result of evacuating in this manner. This event had a long lead time, and residents could put considerable distance between themselves and the path of the tornado. These results are not typical, and should not be taken as evidence that being in a vehicle is safe. Farley (2007) reviewed many tornado related damages and injuries, and sought to understand the safety behind advising people to shelter in ditches or in cars. His overall evaluation depends on the geographical location. If you live in the open prairie and you can see the tornado, determine the track's direction, and have ample time to get out of the way, you should drive in a car to safety. However, if you live in the eastern part of the U.S., you may not see the tornado nor do you have straight roads that travel in one direction. A better choice in this case is to abandon the vehicle, distance yourself from the vehicle, and lie in a low level area or seek shelter in a solid structure. More notable is research by Schmidlin, et al, (2002) who studied the safety of vehicles compared to mobile homes during tornadoes. They discovered that in most cases the vehicle was safer than originally thought. Vehicles sit low to the ground, and have few surfaces for the winds to act upon, leaving them in some cases virtually untouched. When it comes to significant tornadoes (EF-4 and higher), no place is safer than a shelter. Although emergency managers and safety experts do not advise seeking shelter in vehicles, mobile home residents should seek shelter via evacuation by vehicle.

Housing Types

The type of housing occupied during a tornado can potentially increase the probability of injuries and deaths. Mobile homes are particularly vulnerable during a tornado (Ashley, 2007, Chaney & Weaver, 2010, Sutter & Simmons, 2010, Mcpeak & Ertas, 2012). In these recent studies, a disproportionate number of deaths are occurring in the southeast. Most of these victums are residents of mobile homes (48 percent). More importantly, the deaths are due to low Fujita rated tornadoes occurring at night (Sutter & Simmons, 2010, Ashley, Kremenec, & Schwantes, 2008). Sutter and Simmons (2010) showed that fatality rates are ten times higher for those in mobile homes. Lower intensity events (EF1-3) kill more mobile home residents than those in permanent structures. Occupants of permanent housing are killed during higher level (EF4-5) tornadoes. However, there are by far more low intensity tornadoes, which present mobile home residents with a higher potential for death and injuries.

As stated earlier, tornadoes are the number one natural hazard in the U.S. when you look at the annual injuries and deaths. Some areas of the U.S. have greater meteorological probability for occurrences of tornadoes and some have unique societal vulnerabilities with respect to injuries and deaths. Historically, the U.S. has dealt with many tornadoes and in our most recent history, has made improvements and advancements in our abilities to address the rapid onset, low probability, high consequence, but frequent natural hazard. Contradicting data on vehicle use should be noted as well as mobile home vulnerability. Injury impacts should be explored more thoroughly to better quantify the impacts economically and behaviorally. To address education and community understanding better the emergency manager should have a heightened awareness of specific hazards in their jurisdiction.

CHAPTER 3. PREDICTIONS

Unlike run-up floods, hurricanes, droughts or volcanic activity, a tornado is an event that develops and is over in a split second. Meteorologists attempt to anticipate tornadoes by examining weather patterns and radar, but in reality tornadoes provide few visible or obvious clues to clearly predict their occurrence based on the energy in the atmosphere (NOAA, 2011). To study a tornado, one has to be in the right place at the right time. Teams of storm chasers with equipment follow storms hoping for that one chance to witness and collect data on an actual tornado. Unlike fluid dynamics and material testing, you cannot recreate a tornado in a lab, which makes accurate data collection difficult.

History

Over the years tornado studies have helped us identify the true nature of tornadoes, such as track length and intensity correlations (Schaefer, Schneider and Kay, 2002). Since the advent of radar in 1948, and its subsequent first time use forecasting a warning by the Air Force in Oklahoma, forecasting storms has improved. In 1953 at Willard Air Force Base in Illinois, the first recognizable hook pattern associated with tornadoes was observed, giving forecasters an edge in predicting tornadoes (Whiton, Smith, Bigler, Wilk & Harbuck, 1998) (Figure 5).

Figure 5. Hook pattern in radar echo (Source Wunderground, Jeff Masters)

Yet radar use for detection of these storms has limits. It has to have some mass or object to reflect a signal back. Clouds have moisture, droplets of rain or ice which reflect the radar signal. Strong wind occurrences do not reflect radar waves unless they include debris such as dust or moisture. As with strong wind events, tornadoes are usually observed on radar by the reflectivity of debris and moisture contained in them. However, by the time a tornado is detected using these techniques, it is generally too late to broadcast effective warnings and are only effective to downstream communities.

Since the early 1980s there has been an increase in tornado reports. Although more tornadoes are being reported, that does not necessarily mean more tornadoes are occurring. It is possible that the increased ability to detect and identify storms accounts for the apparently higher numbers. The increase has several causes: the advancement of more sophisticated radar, the population expansion into rural areas, and the ability to recognize the signs and characteristics of tornadoes (Verbout, Brooks, Leslie, & Schultz, 2006). The number of reported tornadoes annually in the U.S. has increased to more than double compared to reports sixty years ago (NCDC, 2011).   When the data is reviewed, we see that the increases are mainly in lower level events (EF0-1) (Verbout, Brooks, Leslie, & Schultz, 2005, Schaffer, Schneider, Kay, 2002). However, urban sprawl and rural development increases the probability of a tornado impacting property and lives (Brooks & Doswell, 2000, Aquirre, Saenx, Edmiston, Yang, Agramonte & Stuart, 1993). Not only that, but it also increased the probability of detection. We have seen that the increases are not just due to weather patterns changing but rather we know now that the methods of tracking, observing and the expansion of the population will impact how we forecast and prepare for such events.

Forecast

Tornado predictions have become routine for most parts of the U.S. Until recently, these were typically a warning for an entire county or larger region, leaving many wondering about the reason for issuing a warning, a potential cry wolf scenario. Not only was the warning non-specific but there was no indication of probability. In the later part of the 2000s the Storm Prediction Center (SPC) developed and provided a probability factor for each potential tornado in a well defined warning area rather than suggesting only that a tornado may occur in that general area (Vescio & Thompson, 2001). This research showed that accurately predicting the probability was difficult. The probability of intensity was predicted at a lower level than the actual event. In time, an increased understanding of tornadoes as a whole improved the forecast. Research by Dotzek, Grieser & Brooks (2003) brought both the European and U.S. meteorological communities together to formulate intensity distributions. The study provided a method and formula to predict intensity more accurately. They were able to show that using the lower end and a negative EF scale including 0 wind speed allows for improved sensitivity of the lower and upper level of tornado predictions. In addition, this new scaling and distribution of scale fit existing predictions in the databases making predictions more accurate. This is critical because those areas that have few but violent or frequent lower intensity tornadoes can use this formula to facilitate preparing a more accurate picture of their risk and vulnerability.

More recent research on the interaction of near surface vortex and frontal boundaries and supercells are revealing oddities in tornadoes that were not previously understood, such as corner flow collapse where low intensity storms can create intense storms that brew from the near surface level (Lewellen & Lewellen, 2007). In theory, most storms advance along a boundary that pulls moist air from the Gulf of Mexico into the jet stream, and mixes with cool air from the northwest along with dry hot air from the southwest. However, there have been cases (e.g. Oklahoma, 1995), where tornadoes advance to a front, retreat into the cold air mass and then draw in the southern front, causing the storm to back track to its origin (Blanchard, 2008). Multivortex tornadoes present greater risk due to the increased wind loads on the right side of the path, as the outer vortices accelerate the debris on the outer sides. The probability of being hit by the outer vortices has been calculated. Through these calculations it was shown that with multivoritces the initial path may not be the highest risk. In reality the outer path of the parent tornado may, in fact be at higher risk for impact and damage (Twisdale & Dunn, 1983, McPeak & Ertas, 2012) (Figure 6). A basic calculation is as follows; 30 mph tornado track, outer vortices rotating at 10mph around the center of the event, along the right side it now is travelling at a speed of 40 mph. So if the outer vortices had a rotationally speed (not track speed) of 170 mph, as it travels around the center on the right side the wind speeds are now at 210 mph. This is significantly faster than the left side and may mislead the observer as to where the true center of the event had occurred based on wind damage.

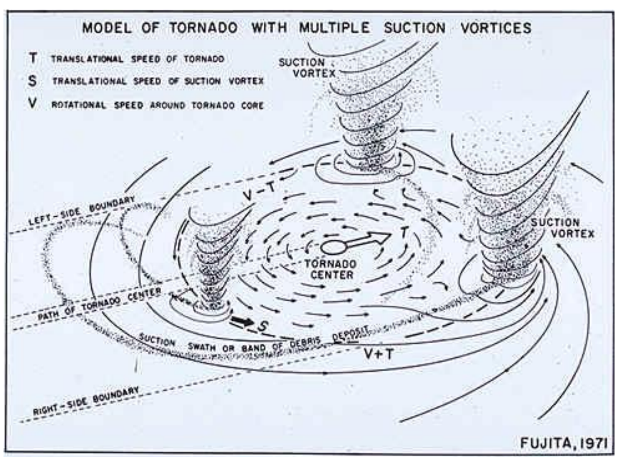

Figure 6. Multiple vortices (Source Fujita 1971).

The use of mobile Doppler units expanded the growing body of knowledge of tornadic wind speeds aloft and on the ground (Wurman & Gill, 2000). The technologies such as Enhanced Resolution Radar or polarimetric radar, has been tested to improve radar resolution to view tornadic vortices (Brown, Wood & Sirmans, 2002, Palmer et al., 2011). Polarimetric radar is a method that, similar to regular Doppler provides both lateral and vertical scan views. This method has shown to be highly accurate in measuring inflow debris, giving meteorologists an advantage in identifying tornadoes (Ryzhkov, Schuur, Burgess & Zrnic, (2005). Specific tornadoes were studied using mobile radar Doppler readings which provided insight into their multiple vortices and tornadogensis. Using that data, researchers were also able to superimpose photographic evidence along with surveyed damage data from meteorological data sets which proved to be valuable. These results provided clues into the oddities of tornadic paths and generation, such as the strong right side wind patterns leading observers to believe the tornado was actually further to the right of the actual vortex center (Bluestein, Lee, Bell, Weiss & Pazmany, 2003, Bluestein, Weiss & Pazmany, 2003, Speheger, Doswell & Stumpf, 2002, Wakimoto, Murphey, Dowell & Bleustein, 2003). Research confirms the ability of satellite imagery to indentify tornado events down to an EF-1 in rural areas, due to denuded vegetation (Yaun, Dickins-Micozzi & Magsig, 2002). These studies, along with newer methods to view meteorological events, will greatly improve the ability to prepare for tornadoes (Casati et al, 2008).

As we have moved further into technology we have improved forecasting and awareness. With these bases we should be able to begin to make meaningful advances in preparedness and mitigation activities. Continuous advancement in our basic understanding of the basics and details of tornadoes can only lead us into a safer environment for our communities.

CHAPTER 4. PREPAREDNESS

In preparation for a storm, back stage activities such as forecasting and storm chasing are occurring but not recognized by the casual community member. One of these activities is the meteorological monitoring of storms and weather in order to provide adequate watches and warnings. Many weather enthusiasts watch and provide information on cloud formations and on-site weather readings, such as wind speed, direction and barometric pressure. More importantly, the public behavioral response to warnings to shelter or evacuate is based on their knowledge and understanding of this information. It is their response to warnings that based on those assisting NOAA that will have a significant impact on safety. Response is based on the perception of risk and what can be reasonably understood about safety or the hazard. Understanding the language and terminology used by the scientific community such as meteorologist, that improves risk perception. Warnings and watches are the two most significant terms to be understood but the research conclusions that shed insightful rays of light on the matter.

Warnings and Watches

Tornado warnings have been identified as a method to reduce injuries and deaths since the turn of the 19th century (Finley, 1884, Bradford, 1999, Corfidi, 1999, Galway, 1985). The first warnings given by the U.S. Army signal corp. were to protect commerce (Bradford, 1999, Corfidi, 1999, Galway, 1985). The original system used in 1883 to notify the public was developed by Edward Holden using the existing telegraph infrastructure (Coleman & Pence, 2009,). A national warning system was initially proposed in 1883 but the government did not want warnings passed on to the public because it was feared the word “tornado” would cause more harm and panic (Corfidi, 1999). It was not until the mid 1900s that the government lifted the ban on warnings to the public about pending violent storms (Coleman, Knupp, Spann, Elliot, & Peters, 2011). Modern warning systems would not have been possible without the advancements in technology with the telegraph system and later radar development. Due to the technology advancement of NOAA's ability to recognize and detect potentially violent storms, NOAA has improved warnings up to thirty minutes in advance of a tornado. The advent and implementation of Doppler radar in the 1990s increased warning periods significantly, resulting in reductions of casualties due to tornadoes (Simmons and Sutter, 2005). More recent progress in radar shows promising improvements in identifying threatening weather patterns. These may improve warning time beyond the typical thirteen minute time frame. However, the increase in lead time, some research has shown, does not always result in a reduction in injuries and deaths (Simmons & Sutter, 2008a).

Since the 1980s, tornado forecasting has improved, but it is not clear what caused the reduction in injuries (Brooks, 2004, Glahn, 2005). The question is was it from warning times or improved awareness by the community? The WSR-88D radar system commonly known as Doppler, showed initial gains in probability of detection of at least 15 percent which was further increased once the system was in full operation with trained meteorologists (Bieringer & Ray, 1996). Glahn (2005) admits and echoes Brooks' (2004) conclusions that without the technological advancements implemented in the 1990s, agencies would be less likely to have improved forecasting to the level they do today. Although these warnings have often been broadcast at approximately 30 minutes or more ahead of storms, some warnings only occur as the storm arrives and sometimes not at all. The average warning time is 11 minutes (Simmons & Sutter, 2008a) or up to 13 minutes, depending on the research (Brotzge & Erickson, 2009). The amount of lead time varies with the accuracy of Doppler radar and the level of education and advanced training within NOAA who provides the warning. In a recent study, lead time has been shown to reduce injuries and fatalities by over 40 percent (Simmons & Sutter, 2008a). This is significant and still may be argued was the impudence of reducing deaths.

In 1990 Hales (1990) looked at the critical role the tornado watch played in producing a warning for significant tornadoes. He suggested that meteorologists should rely on atmospheric clues and not exclusively on sightings is contrary to the push to implement spotter programs. His study concluded that the data was more accurate if the software was able to produce the warning. However increases should be made in the overall number of spotter networks. Doswell, Moller & Brooks (1999) looked into the decrease in deaths in the 1950s and they concluded that the reduction is attributed largely to the improvement of the publics tornado knowledge, awareness of determining a sighting and the role as spotters. Furthermore, the improvement in the 1980s in accuracy of tornado watches comes with improvements in training spotters (Moller, 1978). Increased and heightened involvement in the spotter program can be achieved by using a framework of spotters' perceived risk and conceptualized spotting activities (Reibestein, 2008). Overall, the ability to provide watches that activate highly trained spotters will improve the warning capabilities of NOAA, resulting in improved accuracy and reduced deaths and injuries. The opposite is seen in Canada, where spotters in rural areas are not available. In this situation, rural tornadoes and any subsequent warnings are less accurate and most tornadoes go undetected because there is less radars, fewer spotters and more rural (Durage, Wirasinghe & Ruwanpura, 2012). Accuracy of warnings is important to reduce death and injuries, and for the public's confidence in the system to make better choices for safety.

An increase in warning lead time and the reduction in fatalities cannot be directly correlated. Depending on the research, the results are mixed. According to Donner (2007) lead time has a positive effect on fatalities, but with lead times longer than 28 minutes, fatalities increase. Simmons and Sutter (2008a) show that lead times over 17 minutes were associated with a rise in deaths. This is counter intuitive. Longer lead times should provide residents more time to evacuate and seek shelter knowing a violent storm is approaching. However, longer lead time may leave residents wondering if a storm is really coming and may lead them to satisfy their curiosity by going outside or to windows to see or assess for themselves the risks and observable weather (Drabek & Stevenson, 1971). Perhaps over time the public will have more confidence in the credibility and urgency of warnings and heed them accordingly.

In some cases there is no lead time for a tornado, or even a negative lead time when the warning is simultaneous with the storm. Brotzge & Erickson (2009) outlined several findings in zero and negative lead times. Studies suggested that the first storm of the day will more than likely have less warning or lead time than storms that occur later in the day. The month of May had a significantly lower lead time average compared to the rest of the calendar months. A discovery in this same study by Brotzge & Erickson, (2009) found that the more storms that occurred in the same day increased lead time significantly. This suggests that as the forecasters are following many storms, they are more aware of the potential for future storms and more confident in meteorological clues of impending violent storms.

Interestingly, zero or negative lead times for tornadoes greater than EF-2, only account for 8.5 percent of all fatalities. In following work of their earlier study, Brotzge and Erickson (2010) found that the westernmost states had a higher percentage of events occurring without warnings; January had fewer warnings, and May had the most tornado events and the least warned events. Most interesting is that in areas of higher population, tornadoes with no warning also increased. It would seem that rural areas may get more warnings than areas with higher populations. This result does not hold in the higher (EF2-EF4) rated tornadic events. In the conclusion of Brotzge and Erickson's (2010) article, they showed that the longer the track, the higher the probability of a warning. Also, the distance from tornado to radar site had little effect on lead time, but had a significant effect on whether a warning was issued. Of note is that the greater the distance, the less likely a warning and concluded that there were more tornadoes the closer you were to a radar site. According to further research however, tornadoes do not occur more often near radar sites or nearer to higher density areas (Ray, Bieringer, Niu and Whisel, 2003) contradicting the prior results.

Many challenges have been researched by scientists that have and will result in improvements to tornado predictions and warnings. Examples include, improvements in spotter networks and radar scanning abilities beyond the current radar systems' capabilities. Current discussion includes making the NWS fully automated and eliminating forecasters. It has been argued that the automated system will remove the biases and uncertainty of the human factor. This would potentially also eliminate the error seen in the first months of tornadoes and in the first storm occurrences within a day (Lakshmanan, Smith, Stumpf & Hondl, 2007). The usefulness of the automated system has been argued by forecasters. Forecasters suggest the relevant local experience of geography, vegetation and topography will be lost as well as and also the human gut feeling of a storm. However unpopular the decision to replace the forecaster, cost reduction for the agency may be the big factor and the data supports the claim that the rate of false alarms will improve if fully automated.

False Alarms

As part of the warning system it can be reasonably expected that some false alarms will be issued along with accurate predictions and warnings. The NWS has a false alarm rate that is acceptable at 70 percent (Brotzge, Erickson & Brooks, 2011). A false alarm is one where a warning was issued, but the event could not be verified and never occurred. These false alarms are the ratio of potential tornadoes to actually occurring tornadoes. However, as noted above the false alarm rate could be impacted by the fact that there are 60 percent more tornadoes occurring than reported (Ray, Bieringer, Niu, & Whissel, 2003). Findings suggest that most research on false alarm rates does not take this into account and thus, the findings may be skewed. False alarms affect the public's confidence in the warnings (Simmons & Sutter, 2009, Donner, Rodriguez & Diaz, 2007). After many false alarms a community can develop a normalcy bias (Donner, Rodriguez & Diaz, 2007). A normalcy bias is where a recurring event does not elicit the desired response, but rather will be part of the norm in society, desensitizing the public. Donner, Rodriguez & Diaz (2007) noted that education is a key component of the false alarm societal problem. They suggested that the lack of knowledge by the public in distinguishing between watches, warnings, and false alarms go unrecognized by those giving this information. The public tends to confuse these, and consequently over estimates the amount of false alarms. This may have an effect on the compliance of the public with warnings and watches. Simmons and Sutter (2009) suggested that the areas with higher rates of false alarms are at higher risk of fatalities than those with a lower ratio of false alarms and probability of detection. It was also concluded that the higher the rate of false alarms produced a higher rate of casualty. Barnes, Gruntfest, Hayden, Schultz & Benight (2007) reviewed literature on this topic and determined that although research on false alarms did lead to complacency in traditional settings, research labs testing the "*cry wolf syndrome*", in the case of natural hazards, did not. It was found that when information on hazards is supported through several sources that are credible, the perception of risk increases, which leads to action for safety.

Although false alarms can effect decisions, an individual's behaviors and actions are based on several factors as they react to pending storms. Dash and Gladwin (2007) noted that warnings themselves do not elicit a response; individuals must perceive the risk. Demographics will also dictate how one perceives risks, as well as prior experiences with hazards. The increased risk perception is key in the decision making process in that this perception will have a greater effect on our response than just hearing a warning. A potential research question is, are false alarms creating a higher rate of casualties because of a need to confirm tornados by the public? There are negative impacts to false alarms no matter which side of the research you are on. One of these is time spent on false alarm warnings for tornadoes alone, costing the U.S. approximately $2.7 billion a year for communities reacting to the warnings (Erickson, 2006, Sutter & Erickson, 2010). Although this seems immense, the cost of not warning may be greater in lives, injuries and property damage.

Societal Behavior

A community's collective memory is essential when it comes to how it will perceive, and thus react to a hazard (Concannon, Brooks and Doswell, 2002, Comstock & Mallanee, 2005). When communities have a memory of hazards over generations it solidifies the attitudes and understanding of the risks. Hanson, Vitek and Hanson (1979) reported that according to prior research reviewed, prior exposure was significant in how individuals respond to tornado warnings. They discovered that exposure and how the previous events affected the individual personally contributed to a person's ability to evaluate the danger. In one study, those who remembered the 1953 Flint Michigan Tornado recognized the threat of tornadoes better than those who had not been impacted or who did not remember the event. Just like that generation that lived through the great depression, who learned to save and be thrifty. The same can be said about disaster, people move out of harm's way through preparedness and other means. Although memory can be a powerful force, there are other factors that influence behavior.

Are there factors other than prior memory that will drive residents to shelter? Research has shown that there are many factors that will cause people to shelter including having two sources for the warning, hearing it on TV and hearing warning sirens. Balluz (2002) showed that one quarter of the respondents to his study sheltered because of four predominant factors. If respondents had a basement, had an existing household sheltering plan in place, heard a siren and were a graduate of high school, then they sought shelter within five minutes of hearing the warning. Bullaz (2002) concluded that preparedness through devising a plan to shelter and exercising the plan as a household has the greatest impact if emphasized by emergency managers. Emergency managers tend to emphasis the training and exercising in our municipal preparedness but less is spent on individual preparedness. This may be because inserting basements or increasing the student graduation rates may be difficult and out of the control of the emergency management discipline. However, emergency managers can do a better job at educating and emphasizing planning on a household level. A whole set of literature is devoted to the societal aspects of improving our communities. Topics dealing with economics, housing, education and health that is far outside of the purview of the emergency manager's capabilities.

However, the way data is presented will improve perception of risk. Yamagishi (1997) conducted a study to determine whether risk would be perceived differently pending the way it is presented. What he concluded is that if the subject is presented with a hazard and a specific number such as 1,242 out of 10,000 the subject would perceive that as riskier than a higher percentage. In the end people will overestimate risk or payoffs such as those who gamble. The payoff is greater and thus they anchor to that high payoff rather than the cost. In hazard risk perception people will see the risk as the anchoring point and this may be due to the deep impacts it has on each person.

Durkheim's classical theory of "anomie" is based in the subject's trigger of a bad event such as divorce or unemployment resulting in a sense of hopelessness (Boholm, 1998). Based partly on this theory Boholm (1998) reviewed literature and found in the studies he reviewed that if one has to struggle on a daily basis that factor was correlated with increased risk perception. One of the key factors was poverty. As wealth increases in a household the risk for lose is lessened. This significantly alters ones perception of risk overall. Potentially those with less money feel they have less control or fewer resources to protect their assets and safety. Hanson Vitek & Hanson (1979) conducted studies to evaluate the question of how self control influenced the ability to protect themselves in hazards. Their results concluded that those who felt in control of the circumstances and outcomes had more positive response patterns than those who felt they had no control. Seeking shelter is a learned behavior based on an understanding of the risks. However, despite the depth of understanding risks, not everyone feels control over the situation or what happens in their lives. Bohona and Hogan (1999) indicated that an attitude of fatalism increases the risk of injury, failure to seek adequate shelter, or act on warnings. Mulilis and Duval (1997) supported the Bohona and Hogan's 1999 study reiterating self determination. Mulilis and Duval (1997) reported that people who felt control over their preparedness capabilities planned better than those who felt little control, for which they relied on external resources or agencies for preparedness. On those same lines Siegrist and Cvkovich (2000) conducted research that identified that most will rely on social trust to make the judgment of risk when their knowledge and ability to process the information is low. While reviewing the factors in these reviews it was easy to see that those in lower economic situations, in poverty, had less education and having to rely on others will increase their perception of risk which can be easily influenced if the data is presented accordingly.

Research that evaluated the different coping styles between the northern U.S. states and the southern states supports the previous studies. In the Sims and Baumann (1972) study Southerners were more likely to leave the outcomes up to fate, declaring that no matter the preparation, fate will prevail. Southerners felt the event was between themselves and nature, and their confidence as participants in disasters was nonexistent. Contrary to this train of thought, the Northerner's response to the survey demonstrated their autonomy and responsibility for directing their own preparedness. A follow up question is to determine if, in fact Northerners are more prepared, in such he self report being prepared, but are they prepared for all hazards etc.

Mobile home residents were surveyed to assess their tornado shelter seeking behavior, and it was found they did not seek adequate shelter when warnings were provided, with more than half failing to do so (Schmidlin, Hammer, Ono and King, 2009). To put this into perspective, the South contains more mobile homes than in the North, not only in parks, but also spread out in rural communities. The Schmidlin, Hammer, Ono, King (2009) study reports that although mobile home residents had options none were good options for shelter. More importantly, the adequate options available, to mobile home residents, such as permanent homes within 200 meters, were underutilized. Mobile home parks are infrequently equipped with shelters; only 33 percent of all mobile home parks in the U.S. have shelters. Despite the number of shelters in mobile home parks the rural manufactured/mobile homes have no shelters and comprise a large segment of housing. Taken together the risk to mobile home residents is very high. Without proper shelters in which to evacuate, mobile home residents have few options.

Tornado warnings, as noted earlier originated by the telegraph system in 1883. Warnings have evolved into the current system predominately by way of radio, television, public announcements, or sirens and are administered by the NWS, news outlets and municipal agencies. A recent study on a university campus by Sherman-Morris (2010) studied a midday tornado event and observed that TV, albeit a less effective media than social media and cell phones, was a highly utilized and trusted source for university residents and staff. Students reported alerts were first received via cell phone, and faculty and other employees received alerts via instant messaging on their computer. There has been an emphasis to use social media as a source for emergency information, but that source alone will not be effective. People who were surveyed in the 1999 tornado in Oklahoma took shelter following the warning on TV, but this was not their only source of information (Hammer & Schmidlin, 2002). Hammer and Schmidlin's (2002) survey results support prior research by Sorensen (2000) and Sorensen and Mileti (1988) that the residents in the May 1999 Oklahoma event had contact with friends and neighbors in addition to the initial media sources for the warning. In these prior studies and review of research alike, it has been suggested that people need more than one source of information, or confirmation by reliable sources in order to react to the initial warnings. Current results support past research and strengthen the case for multiple source warnings in emergency management situations.

Overall preparedness for tornadoes needs to be explored in terms of getting the information out to the public. We know it takes several sources to make the public react to the warnings. We also know that false alarms are going to be problematic for emergency managers trying to motivate their communities to action. If preparedness is proving to be challenging can we handle the risks through mitigation?

CHAPTER 5. MITIGATION

Successful mitigation practices can be categorized into two types, structural and nonstructural. Nonstructural practices include storm spotters, sirens, radar, building code regulations, policy and planning, and land use. Structural types include tying framing down to foundations, retrofits, shelters and safe rooms. Both types of activities result in decreases in damages and deaths. However, if residents don't have access to these mitigated structures, injuries and deaths will occur during a tornado. Resulting casualties can be reduced when applications in modern building codes are implemented within communities publically and in the private sectors (Glass & Noji, 1992).

A common mitigation method commonly used is to provide warnings with a siren system administered by the municipality to ensure people are alerted. Lui, Quenemoen, Malilay, Noji, Sinks & Mendlein (1996) found that residents that did not have a siren nearby or in their community received the warning via radio or TV. This study showed that the use of sirens resulted in a two-fold increase in warning notification to the residents. It stands to reason that not everyone has a TV or radio on but a community siren will be one for everyone. Thus, those who do not have sirens within the community are two times less likely to receive a tornado warning via other sources. Sirens usually exist in higher density locations but not in rural communities, which may put the rural communities at a disadvantage. Specific communities have studied their needs for sirens and placement (Chaney, 2003) and noted that sirens serve not only to warn of tornado hazards, but hazards of any nature (Current & O'Kelly, 1992). The results echo and support an all hazards approach. It was also noted that the expense and overall benefits to the population are considerations for proper placement of sirens.

Stimers (2006) also studied siren use and placement and concluded that initial placement based on old standards may be inadequate. Utilization of improved assessment tools, like GIS, can provide better placement. With GIS functions, one can input multiple variables such as housing density, typical wind directions, vegetation, and siren height to help assess geographic siren placement effectiveness saving money, time, and lives. Benefits from technology are abundant; however, sometimes the benefits entail long term costs and unforeseen future risks. For years the answer to flooding was damming rivers, however ecological damage is irreplaceable. Our short term perceived risk, usually a reaction to a current hazard leaves us blind to actual long term hazards.

For centuries, humans have devised ways to address consequences of hazards. In recent history, the U.S. developed vaccines for viruses, saving lives and eradicating diseases in entire countries or regions. Communities have dammed rivers and set channel walls to contain rising waters, which preserved lives and property while controlling water resources for recreation and commerce. Housing materials and building practices strengthened dwellings and gathering places saving lives and reducing the impacts of minor intensity hazards. As humans we tend to react to nature, not take proactive measures to what may come. Implementing long term measures that are also cost effective reduces losses to life and property from violent hazards. Long term planning is one method to ensure that communities stay vital but presents hurdles along with demonstrated benefits.

Hazard mitigation efforts received a major boost in 2000 when the executive branch of the U.S. government implemented the Disaster Mitigation Act (DMA). It requires that local planning be proactive in order to be eligible for funding. According to the DMA requirements each community has to have mitigation goals based on their local hazards. However, the public and policy makers had difficulties admitting risks and approving actions that were meaningful (Drabek & Hoetner, 1991). Implementation of any plan also encounters the hurdle of cost. The benefits to incurring the cost are increased safety, and few towns have the chance to start anew with complete business and residential support. To bring stakeholders together the hazards have to be real, meaningful and of significant risk. Planning and policy outcomes will get minimal traction if the risks of hazards don't meet those factors of being meaningful and significant for all.

Policy and Planning

Devising policies to mitigate disasters requires all stakeholders to be vested. These policies may dictate planning. While we can all see the benefit of taking actions to mitigate the hazards, not all plans and policies will directly impact saving lives and property especially in the short term. Greensburg, Kansas, openly decided and implemented plans, after being completely destroyed in 2007, which would lead to the city going completely "green" (Paul & Che, 2011). Greensburg's problems have been cost barriers in achieving LEED certifications, and retaining residents and businesses in a community that had 95 percent of its residential and business structures damaged (Figure 7). A continued effort is still required, along with economic development (Paul & Che, 2011). Because the entire community was impacted, long term planning is needed as the community continues to develop and plan. They will have to bring the stakeholders together to discuss reviewing current actions and future plans to reduce hazards in order to save lives and property in the future. The event in Greensburg is important as a less or model for future communities to assess recovery and mitigation avenues proceeding disasters.

Focusing events are those that dramatically shift the political and sociological behavior after a disaster (Birkland, 2006). Some events do not reach this magnitude, and thus the resulting communities do not improve or advance. As Birkland (2006) defines focusing events, it takes both the community and its administrators to feel that the event was rare, sudden and could cause future harm to their geographic area. Birkland (2006) demonstrates that as far as natural disasters go, earthquakes have generated not only local but also national change, whereas hurricanes, at the time of this writing, have not. The current east coast "Hurricane Sandy" event could change that. Tornadoes still have not reached the level of hurricanes and earthquakes at the national level but continue to impact many local communities annually. It is because they impact smaller areas they will more than likely achieve local rather than national change.

Planning for disasters benefits communities but also possess many problems. In the planning process strengths and weaknesses can be found, and issues that might not have been

Figure 7. Greensburg Kansas damaged (Source FEMA, 2012 http://www.photolibrary.fema.gov/photodata/original/30066.jpg).

addressed or seen can be brought forward. New technology will be introduced, and it is important to review plans often to make sure new ideas and inventions can be considered and are relevant. However, these new technologies may not always be good. Historically, we have produced products, like can liners for pop that are linked to increases in cancer rates. Better construction materials and methods may lead to a false sense of security, encouraging homeowners to live in hazardous areas (Burby et al 1999). The same idea was echoed by Burby and Dalton (1994) that showed a reliance on building codes alone that give the consumer a false sense of security leading them to occupy areas that are inherently unsafe. The mere idea that hazards are mitigated by new technologies only increases our risk. The problem arises when we build in hazardous areas where we mitigated the prior disasters, not the new ones. What contributes to our failure to learn from our mistakes and experience as we continue administering previous policies is the lack of consensus amongst stakeholders (White, 1996). The same can be said on a local level.

According to other hazard literature, when local governments spend resources on policies, mitigation and education, the risk is lowered and so are real damages during events (Burby, French & Nelson, 1998). Do state mandated comprehensive plans incorporating natural hazards have a positive effect on disaster losses? According to Burby (2005), the insured losses for states that had comprehensive plans addressing natural hazards were significantly lower than those that did not. If this study had been done across all states, Burby (2005) concluded there would have been a significant reduction in losses for residential property over the period studied. With total losses from tornadoes averaging more than most other hazards, a reduction in damage losses through actions such as increased building codes to an EF-4 standard would have lessened insured losses significantly. Planning for disasters theoretically is wise and it has been shown practically to be penny wise as well.

Nelson and French (2002) demonstrated that high quality planning, especially in land use, reduced damages to natural hazards, specifically demonstrating that high investment by local governments in the mitigation process reaps benefits. Hall and Ashley (2008) studied the 1990 Plainfield, Illinois tornado event reviewing several scenarios as if they were to occur presently. They discovered that, due to urban sprawl and increased personal wealth in just a ten year period, a fifty percent increase in damages would occur. The sprawl in the fringe areas of a metropolis/urban center is the focus of the Hall and Ashley (2005) study, showing that sprawl may be contributing to increased hazard vulnerability and risk. What can we do to counter sprawl? Some planners have been implementing what is called “New Urban” designs. New urban design is the melding of residential and commercial uses into one structure within communities. These designs reduce sprawl while combining real estate uses into. The idea is to reduce and harden infrastructure and limit the reason for movement by providing more essential needs within a neighborhood. For example, having grocery stores and hygiene stores next to housing so people can walk to obtain basic needs reducing gas consumption and need for parking. Are these new designs advantageous? It turns out that research may be proving the designs contribute to increased risk and vulnerability (Berke, Song & Stevens, 2009, De Silva, Kruse & Wang, 2008). The increased density exposes more property and individuals to hazards. In the event of tornado mitigation, the amount of structural requirements prove to be too costly, thus increasing the risk overall by low quality construction and high density populations in higher prone areas to hazards.

A theory to reduce damages and deaths is to reduce the density. However, this goes against the planning trends to bring residential and commercial activities closer together that reducing infrastructure and resources and hardening them through designs. However, as for tornado safety it has been proven that population density is not a factor alone in reducing deaths (Donner, 2007). In these same studies, it was shown that living in rural areas decreases the probability of fatalities. So, even though density has no relationship, living in rural areas decreases fatality rates. Cities are complex organisms; each one is presented with unique challenges and opportunities and is subject to various stressors not necessarily experienced among all. Goldschalk (2003) suggests that collaboration among government and the private sector or professional groups will improve mitigation at the municipal level. A combination of methods such as education, land use planning, building codes and practices ultimately will reduce damages and deaths due to tornadoes.

Another event that resulted in a case study is the Hoisington Kansas tornado that impacted 45 percent of the community (Brock & Paul, 2003). The resulting outcome was that the community became more aware of the risk, and consequently implemented new codes and standards for buildings and land use. City blocks could no longer house eight homes, rather only contain four residential units. The density was decreased in hopes of reducing future damages and possibly reducing risks. Construction improved, while 90 percent of the new construction met higher standards to mitigate tornado winds. Reducing density has advantages. Research suggests that if a tornado was to impact higher density urban areas, the results would be catastrophic. Wurman, Alexander, Robinson and Richardson (2007) researched what might occur if a tornado struck Chicago, Illinois. They suggest that due to the density, the results at a one percent impact would be 1300 deaths and 40 billion in damages. The one percent is based on adequate warnings, improved shelters and efficient public response. If none of these things occurred, the most significant tornado (EF-5) would result in upwards of 45,000 potential deaths. Unfortunately you cannot reduce the density in a city like Chicago, nor would an area such as Chicago, based on the literature reviewed here, with low frequency be properly prepared.

Building Practices

While density of land use has been studied and considered in reducing losses, the same is true for residential housing construction and commercial building/environmental interactions. Wind profiles and loads on structures, and the fluid dynamics of wind storm force were studied regarding the interaction of tall buildings, debris fields, and risk assessments (Chen, 2008, Dagnew, Bitsuamalk, Merrick, 2009). The results of these studies have lead to improvements in building materials on taller structures as well as a better understanding of risk potential to adjacent buildings. Tall buildings next to other buildings have increased risks at the lower floors. The risk of damage and injury to persons inside the buildings is reduced at the floors above the nearest adjacent building due to the debris fields, velocities of debris and increased pressures between buildings. Implications would be where to shelter, risk assessments for occupants at the lower levels and building materials needed for safety at the lower levels. These conclusions and implications do not carry over to the typical residential developments, and different avenues must be sought when addressing risks across a larger metropolitan area.

Case studies done on tornadoes and specific cities that were impacted have resulted in dissemination of lessons learned and knowledge to impact mitigation efforts and planning. In a particular study utilizing a building performance assessment team (BPAT) to assess the damage after the 1999 Oklahoma tornado outbreak, several conclusions were made (Doswell & Brooks, 2002). An unexpected discovery was that regardless of how safe your home is, if your neighbor's home quality is poor, nearby homes and lives are at risk from debris fields. Doswell and Brooks (2002) concluded that homes rarely survive EF4-5 events, and most are only able to withstand an EF3 tornado. However, if structures are incapable of withstanding even an EF1 event, debris may be brought into the higher wind zones and compromise more capable structures (Figure 8). The BPAT showed that weather radios were underutilized in a significant number of homes and businesses. As well it was seen that there were very few acceptable shelters for people. Moreover, mobile homes, schools and other public buildings need to consider constructing appropriate shelters (Doswell & Brooks, 2002). Similar conclusions were supported by Marshall (2002) and in a follow up to an initial survey, it was found that new housing stock and replacement housing in tornado impacted areas were not constructed with higher safety standards. Governmental approval of building codes, such as those that define standards for shingle installation to withstand specific wind speeds and specific framing designs that attach to the foundations of homes has clear benefits in reducing property losses, damages and deaths (Figure 9). With each dollar spent on mitigating the effects of tornadoes, the drawback results in less household financial resources. The health impact to a household is

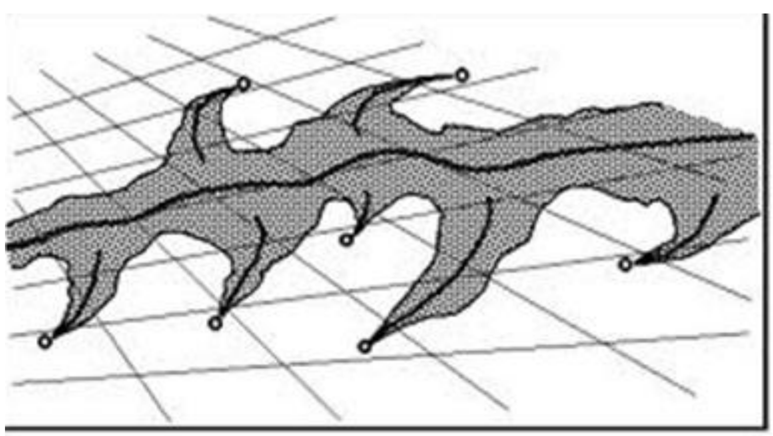

Figure 8. Debris fields pulling material into the center of the vortex (Source Doswell and Brooks, 2001).

significant as the building cost of a home increases (Hammit, Belsky, Levy & Graham, 1999). It has been shown that as the building cost increases such as reinforcing walls and additional improvements to withstand higher rated tornadoes, the increase in cost decreases the available resources for health care, nutrition and basic needs. In this risk assessment, one has to compare the benefits, probability and cost to other variables.

Construction practices in residential and low rise buildings are more important because most people who die in tornadoes live in single family homes and mobile homes. Recent research found that current building standards are below the standards needed. Haan, Balaramudu & Sarkar (2010) found that wind load coefficients in laboratory settings showed that straight line winds are greater than originally predicted and that in tornado alley, single family homes are not properly designed for those winds. Similar research assesses the ability of wood framed structures to withstand high winds and windborne debris that penetrates buildings (Minor, 1994, Sparks, Hessig, Murden & Sill, 1988, Sherman, 1973, Lui, Gopalalratnam &

Figure 9. Hurricane strapping holding framing to foundation (Source Journal of Light Construction, 1997).

Nateghi, 1990). These studies review practices such as toe nailing framing and the envelope protection during high wind events. Their conclusions demonstrated weak code and practices subject occupants to windborne hazards.

Where emergency management or hazard studies literature falls short, the engineering profession provides technical information needed to make appropriate decisions in policy and safety. Many studies show insight in the technical abilities of structures and how materials withstand debris impacts (McDonald, 1990, Hhoemaker & Womack, 1990). Specific studies examined the impact resistance of unreinforced masonry walls with carbon fiber reinforced polymer strips. Cheng and McComb (2010) used a pendulum system to test walls, and found that reinforcement specific epoxies woven across the walls drastically increase the strength of the walls and reduces the effects from impacts. A recent study by Moradi, Davidson and Dinan (2008) showed that reinforcing walls with membranes or steel sheets made a significant improvement in high impact forces. Although these results were meant for the military applications and further testing needs to be done for wind loads, commercial applications would also benefit. Commercial applications of these materials may be implemented at a reasonable cost to consumers in the private sector. Construction quality and building codes have been blamed time and time again for property loss and deaths. Although the research is bountiful regarding materials, structure and design the same cannot be said for research specific to mitigation and tornadoes. However, despite the abundance of research from other disciplines and their recommendations based on the results, very little has been implemented into codes and common practices for tornadoes.

Mobile Home Threat

During a tornado, mobile home occupants account for a high number of deaths (Brooks and Doswell, 2002, Daley et al. 2005). Overall, mobile homes prove unsafe during tornadoes. They provide little protection from flying debris, are not anchored to the ground or solid foundations to withstand high winds and will become a hazard when lifted and moved off their foundations during EF1-3 or greater events. Simmons and Sutter (2007a) reviewed as a case study, the 2003 Groundhog's Day tornadoes in Florida and found that the earlier Housing and Urban Development (HUD) requirements had a significantly positive impact on lives saved. The event was one that struck at night, in a region not geographically known for tornadoes, during the off peak season, and largely in an area populated with mobile/manufactured homes. All the deaths occurred in mobile homes. The newer homes built after the 1998 HUD requirements, were 60 % less likely to be damaged. Further studies by Simmons and Sutter (2008b) showed that even prior regulations (1976) for wind loads on manufactured homes had a 68 percent improvement in safety to mobile homes. Although mobile homes are comparatively unsafe, simple tie down and construction techniques can reduce those risks substantially.

If a homeowner is not able to absorb the cost of mitigating against tornadoes upon new construction or retrofitting old housing stock, can the park owners improve safety with shelters? Again Simmons and Sutter (2007b) assessed the cost to benefit ratio for creating mobile home park shelters provided by the owner of the park, and absorbed through rental space fees. They found rental space costs higher for parks with shelters, but that is not a feasible option for mobile home owners as most, about 35 percent in Oklahoma for example, are not in parks. They also found that in tornado prone areas like Oklahoma, renters prefer not to live in mobile home parks. As a result, park owners are taking more steps to create a safer environment with better shelter options to attract renters. This is encouraging and challenging because in the current economy, mobile home housing stock may be increasing. Most mobile homes are purchased by older individuals and placed in rural areas. These homes have fewer shelter options which may add to the vulnerability for communities. Because of the higher vulnerability, those communities may have to assess cost versus benefits for safety options differently than before. Merrel, Simmons & Sutter (2005) reviewed the cost effectiveness of these shelters and found mobile home parks providing shelters to be cost effective. The study was conducted in Oklahoma, and they admitted that due to the high frequency of tornadoes in this area, the shelter construction was cost effective per life saved. However, in the areas that have low probability, high impact tornadoes outside of the traditional alley but have out of season events, potential future studies may conclude that the risk for southern states may outweigh the cost from shelter construction too.

Sheltering

Since the inception of modern warning systems, such as sirens or broadcast of storm information to the communities via radio and television, we have seen improvements in the number of people who seek shelter before an impending tornado (Coleman, Knupp, Spann, Elliott & Peters, 2011). Liu, Quenenmoen, Malilay, Noji, Sinks & Mendlein (1996) reviewed the response to warnings during tornadoes in Alabama, and found that individuals sought shelter more often when adequate facilities were available. They concluded that education was necessary in regard to actions to take during warnings and watches, specifically for those individuals with less than a high school education. Television, despite siren use, was a major source of information during storms and warnings. Lastly, a majority of respondents reported that they did not have access to adequate sheltering options. Adequate shelter overall in public buildings and private residences is a factor that needs to be emphasized in every community where tornadoes are a risk factor, despite the low probability. Emergency managers need to focus education on adequate shelter during tornadoes because it is crucial to saving lives.

Building practices in residential and commercial structures are one of the many mitigation practices that afford overall safety in a community. While reducing the possibility of structure failure during high wind events, shelters in public buildings are needed to provide safety to citizens outside their residences. Most lives are lost in residential homes, where people feel they should stay, as they cling to news and warnings. To ensure safety within a residential structure, safe rooms and retrofits should be considered.

Mitigation reduces the loss from future hazards but this comes with upfront cost and must be justified. FEMA has reviewed cost/benefit analysis of their hazard mitigation grants and found that the benefits significantly reduce the possible losses to hazards (Rose et al., 2007). Rose et al. (2007) found wind hazards cost $1 for every $4.7 saved. However, the greatest benefit was to the utilities infrastructure, not to residential built environments. Even though the utilities gain the most per dollar spent, the overall benefit across all hazards is four to one. Having hardened utility infrastructures ultimately benefits the home owner indirectly by providing power to maintain heat or storage of food. Policies set in place by federal administrators for many common consumer products were reviewed against tornado shelters. Merrell, Simmons and Sutter (2002) found that half the regulations for consumer products e.g. seatbelts, Clean Air Act, scored higher in cost per life saved than tornado shelters. However, the benefits to preserving property and maintaining a workforce after an event are better than most regulations and could easily be argued in a discussion on policy. Shelters do not attract a lot of political discussion, but we need this discussion to realize the true cost of lives lost and rebuilding cost to fully perceive the benefits.

Buckley (2001) describes the benefits and the potential cost of building the highest safety rated shelter in a school. The level of safety parents demand is high and even one child lost is one too many. Unfortunately, with time hazard memory and concern from a tornado event fades reducing the desire to build and the cost hurdle higher. Looking at shelter cost from a manufacturing point of view, business is good when the experience of a tornado is fresh in their mind. Miller, Morgan and Womack (2002) found that when the memory of a tornado is fresh, such as currently experiencing one or near a community where a person lives the desire and inquiries for tornado shelters increases. However, the inquiries to builders quickly fall, and incentives are needed to encourage construction of tornado shelters within months after an event. Follow up research by Merrell, Simmons and Sutter (2005) revealed that residents see low probability as no probability thus will not commit to safety measures even if there are high consequences. In the above research it was again noted that cost effectiveness is greater for mobile home, not for permanent homes (Merrell, Simmons & Sutter, 2005, Simmons & Sutter 2006). However you look at it those who can afford effective measures are already in the safer homes. This may be more of an issue of recognizing where benefits are most cost effective than simply preparedness.

The tools accessible to emergency managers to assess risk are abundant. Whalen, Gopal and Abraham (2004) developed a model to help assess the cost/benefit of constructing shelters in communities. The model will greatly benefit the emergency manager to continue to assess safety within their areas of responsibilities. FEMA has a Benefit Cost Analysis tool and readily accessible on its website. This tool, although not specific to tornadoes, gives the ability to emergency managers to assess assets and evaluate the impacts in certain hazards and events. There are many useful life saving tools available to emergency managers and communities. How we use them to predict, warn, prepare or mitigate hazards determines the level of safety we can achieve.

CHAPTER 6. CONCLUSIONS

The number of tornadoes reported is increasing, but there is little evidence that tornadoes are more numerous or intense than in the past. Most data suggests that reports are increasing due to heightened community awareness and improved technology aiding identification of tornadoes between F0 and F2. These factors have improved our abilities to identify tornadoes in areas not observed in the past (Anderson, Wikle, Zhou & Royle, 2007). Tornadoes are not increasing in intensity, and the link to damages is only due to the community's increased wealth. The problem is those who have not dug into the research will only see the raw data indicating an increase of tornadoes and damages per year. This is misleading as those numbers do not represent all the variables we have discussed in this review. Without a thorough knowledge and review of the underlying variables it becomes impossible to arrive at reasonable assumptions why tornado occurrences are increasing.

The research shows that there is an increase risk overall outside the typical or traditional tornado alley. This is important because these areas receive the least education and preparedness efforts needed to save lives. The risk due to factors such as lack of knowledge, ability to provide warnings, building practices and atypical events needs to be considered by emergency managers. Nocturnal tornadoes need to be studied further and nighttime events need to be monitored more closely as they are the most deadly. The need to generalize results across populations is a real problem. Tailored preparedness must be conducted to provide messages for dwelling types specific to regions. Addressing the North/South differences by emergency managers with specific messages and assessments should be done based on these research results. Improvement in awareness will also be achieved with education which will lead to mitigating hazards and risks associated with tornadoes.

The traditional risk of the alley in our current period has to be thrown out and as emergency managers our perception of the risk has to be tailored more specifically to our locality. Belief in a warning system alone is not good enough and more has to be involved to keep our communities safe. A comprehensive attack has to be made with public warning, individual knowledge, technical advancement and socio-economic improvements.

The ability to predict tornadoes is increasing and efforts to identify potentially high risk storms have been improved. However, a tornado may occur anytime and develop in many unpredictable ways. What we do know is our prediction abilities are less sensitive in the first month of the season and the first storm cell of the day. That lack of sensitivity increases our risk, and has been argued it would be eliminated with the implementation of the automated warning systems. However, those same systems remove experience and the intuition of the person who knows the area, weather patterns, and the history of the area. It was also noted that meteorologist should rely on equipment and less on visual verification, which may improve warnings for nocturnal events. However, as part of the comprehensive method of improving tornado safety individual knowledge is critical and why we use spotters. If we are expected to rely on the technical data and modeling of the forecasters computer programs we would inherently dismiss the local spotters. The data I reviewed seems to contradict itself and although the improvement of software has improved forecasting, teasing out the conclusions, spotters and increased education in our communities about tornadoes is a must.

More education geared towards the public on prediction terminology is needed. The public gets terminology confused and consequently reacts poorly to warnings, watches and sightings. Improving understanding of terminology by the public will save lives by reducing complacency brought about by overly long lead times. By understanding and trusting the warnings, the public will likely stay sheltered and be patient for events to pass. As some of the research pointed out, if the public is less education and relies on the social trust for risk perception the message has to be simple and clear. It must also be noted that most research identified a need but none was found on how to specifically address this issue.

Unfortunately, there are conflicting results on sprawl and density of planning. Research has shown that after a high impact event, improvements in construction do not occur. The tradeoff between safety and acceptable risk is a discussion that will continue. We cannot be fooled into believing that technology will save or improve safety in high risk areas while ignoring unanticipated future hazards and events. Consequently, we adapt to what has occurred and hope that we have seen the worst of what is to come. Planning and policy making has to be specific to the region for which you're planning. High density may work for flooding, heat waves, or drought areas, but the infrastructure issues involved with tornadoes, earthquakes may not be reasonable. The economic bases for new urban designs make sense and have been successful in areas like Portland Oregon; however in rural North Dakota the main street ideal is much different and less feasible. The benefit cost ration in this matter is again specific to a community and again socio-economic factors have to be considered.

The idea of mitigation is to reduce the impacts of hazards. Birkland (2006) provided a realistic approach to the hazard problem. Birkland concludes that preparing and mitigating the hazard impacts, we will routinize the events. Our natural environment cannot be controlled nor dictated. Consequently, communities need to modify their actions and understanding to adapt to the environment. We have to live with the hazards because we cannot and will never eliminate them. Continued population growth and its secondary and tertiary impacts increase the interaction between the natural environment and the built environment. Given this continuous expansion, frequent interactions with hazards require routinized response to typical disasters (Birkland, 2006). As we move forward and time passes it is not enough to just consider one factor or one variable. Perception of hazards is done best when it considers the thousand points of light. It is not our role as emergency managers to address all aspects of the disasters such as socio-economical hazards but we must consider and understand them in order to serve our communities and regions. We need to not only be aware of the environmental risk, but also the economical, technological, societal, and global factors that impact our communities and how those impacts outside our communities as well. This review only brushes lightly on factors involved in tornadoes, their impacts, research gaps and contradictions. It may however allow a reader to understand the history of tornadoes in the U.S., our predictive abilities, shortcomings and the preparedness and mitigation issues to be considered. It should be noted that overall the literature on tornadoes is far less abundant than that on floods, earthquakes and hurricanes. This is an area that would benefit in bringing together multidiscipline approaches to research and information dissemination. For tornadoes to be understood it is necessary to go beyond emergency management literature and into accompanying disciplines to capture all the details related to this low frequency high impact hazard.

REFERENCES

Anderson, C. J., Wikle, C. K., Zhou, Q. & Royle, J.A. (2007). Population Influences on Tornado Reports in the United States. *Weather and Forecasting*, *22,* 571-579.

Ashley, W. (2007). Spatial and Temporal Analysis of Tornado Fatalities in the United States: 1880-2005. *Weather and Forecasting*, *22*, 1214-1228.

Ashley, W., Kremenec, A. & Schwantes, R. (2008). Vulnerability Due to Nocturnal Tornadoes. *Weather and Forecasting*, *23*, 795-807.

Aquirre, B. E., Saenz, R., Edminston, J., Ynag, N., Argamonte, E. & Stuart, D. L. (1993). The Human Ecology of Tornadoes. *Demography*, *30*(4), 623-633.

Balluz, L., Schieve, L., Holmes, T., Kiezak, S. & Malley, J. (2002). Predictors for People's Response to a Tornado Warning: Arkansas, 1 March 1997. *Disasters*, *24*(1), 71-77.

Barnes, L. R., Gruntfest, E. C., Hayden, M. H., Schultz, D. M. & Benight, C. (2007). False Alarms and Close Calls: A Conceptual Model of Warning Accuracy. *Weather and Forecast*, *22*, 1140-1454.

Beiringer, P. & Ray. P. (1996). A Comparison of Tornado Warning Lead Times With and Without Nexrad Doppler Radar. *Bulletin American Meteorological Society*, *11*, 47-52.

Berke, P. R., Song, Y & Stevens, M. (2009). Integrating Hazard Mitigation into New Urban and Conventional Developments. *Journal of Planning Education and Research*, *28*, 441-455.

Birkland, T. (2006). *Lessons of disaster: Policy change after catastrophic events*. Georgetown University Press, Washington, DC.

Birkland, T. (1997). *After disaster, agenda setting, public policy, and focusing events*. Georgetown University Press, Washington, DC.

Blanchard, D. O. (2008). Interactions Between a Supercell and a Quasi-Stationary Frontal Boundary. *Monthly Weather Review, 136*(12), 5199-5210.

Bluestein, H., Weiss, C. & Pazmany, A. (2003). Mobile Doppler Radar Observations of a Tornado in a Supercell Near Bassett, Nebraska on 5 June 1999 Part I: Tornadogensis. *Monthly Weather review, 131*, 2954-2967.

Bluestein H. B., Lee, W. C., Bell, M., Weiss, C. C. & Pazmany, A. L. (2003). Mobile Doppler Radar Observations of a Tornado in a Supercell Near Bassett, Nebraska on 5 June 1999. Part II: Tornado-Vortex Structure. *Monthly Weather Review, 131*, 2968-2984.

Boholm, A. (1998). Comparative Studies of Risk Perception: A Review of Twenty Years of Research. *Journal of Risk Research, 1*(2), 135-163.

Bohonos, J. J & Hogan, D. E. (1999). The Medical Impact of Tornadoes in North America. *The Journal of Emergency Medicine, 17*(1), 67-73.

Borden, K. and Cutter, S. "Spatial Patterns of Natural Hazards Mortality in the United States," *International Journal of Health Geographic's, 7*(46) (2008), accessed at www.ij-healthgeographics.com/content/7/1/64, on Nov. 23, 2012.

Boruff, B. J., Easoz, J. A., Jones, S. D., Landry, H. R., Mitchem, J. D. & Cutter, S. L. (2003). Tornado Hazards in the United States. *Climate Research, 24*, 103-117.

Bradford, M. (1999). Historical Roots of Modern Tornado Forecast and Warnings. *Weather and Forecasting, 14*, 484-491.

Brocks, V. T. & Paul, B. K. (2003). Public Response to a Tornado Disaster, the Case of Hoisington, Kansas. *Papers of the Applied Geography Conferences, 26,* 3436-351.

Brooks, H. (2004). Tornado-Warning Performance in The Past And Future. *Bulletin American Meteorological Society*, June, 837-843.

Brooks, H. (2006). Climate Change and Disaster Losses: Understanding and Attributing Trends and Projections. *Tornado and severe thunderstorm damage*. White paper presented at the workshop on, 25-26 May 2006, Hohemkammer, Germany.

Brooks, H. & Doswell, C. (2000). Normalizing Damage from Major Tornadoes in the United States: 1890-1999. *Weather and Forecasting, 16*, 168-176.

Brooks, H. & Doswell, C. (2001). A Brief History of Deaths from Tornadoes in the United States. *Weather and Forecasting*, January, 1-9.

Brooks, H. & Doswell, C. (2002). Deaths in the 3 May 1999 Oklahoma City Tornado from a Historical Perspective. *Weather and Forecasting, 17*, 354-361.

Brooks, H., Doswell, C. & Kay, M. P. (2003). Climatology Estimates of Local Daily Tornado Probability for the United States. *Weather and Forecasting*, *18*, 626-640.

Brown, R. A., Wood, V. T. & Sirmans, D. (2002). Improved Tornado Detection Using Simulated and Actual WSR-88d Data with Enhanced Resolution. *Journal of Atmospheric and Oceanic Technology, 19*, 1759-1771.

Brown, S., Archer, P., Kruger, E. & Mallonee, S. (2002). Tornado-Related Deaths and Injuries in Oklahoma Due to the 3 May 1999 Tornado. *Bulletin American Meteorological Society*, *17*, 343-353.

Brotzge J. & Erickson, S. (2009). NWS Tornado Warnings with Zero of Negative Lead Times. *Weather and Forecasting, 24*, 140-154.

Brotzge J. & Erickson, S. (2010). Tornadoes without NWS Warning. *Weather and Forecasting, 24*, 140-154.

Brotzge, J., Erickson, S. & Brooks. H. (2011). A 5yr Climatology of Tornado False Alarms. *Weather and Forecasting, 26*, 534-544.

Buckley, J. (2002). After the Storm: Building a Safe Room for the Shelter for School Children of Mulhall Oklahoma. *Weather and Forecasting, 25*, 159-172.

Burby R. J. (2005). Have State Comprehensive Planning Mandates Reduced Insured Losses From Natural Hazards? *Natural Hazards Review, 6*(2), 67-81.

Burby, R. J. & Dalton, L.C. (1994). Plans Can Matter! The Role of Land Use Plans and State Planning Mandates in Limiting the Development of Hazardous Areas. *Public Administration Review, 54*, 229-238.

Burby, R., French, S. & Nelson, A. (1998). Plans, Code Enforcement, and Damage Reduction: Evidence from the Northridge Earthquake. *Earthquake Spectra, 14*(1), 59-74.

Burby, R. J., Beatley, T. Berke, P. R., Deyle, R. E., French, S. P., Godschalk, D. R., … Platt, R. H. (1999). Unleashing the Power of Planning to Create Disaster-Resistant Communities. *Journal of American Planning Association, 65*(3), 247-258.

Carter, A., Millson, M. & Allen, D. (1989). Epidemiologic Study of Deaths and Injuries Due to Tornadoes. *American Journal of Epidemiology, 130*(6), 1209-1218.

Casati, B., Wilson, L. J., Stephenson, D. B., Nurmi, P., Ghelli, A. Pocernich, M., … Masonh, S. (2008). Forecast Verification: Current Status and Future Directions. *Meteorological Application, 15*, 3–18.

Chaney, P. L. (2003). Tornado Warning Siren Coverage in Lee County, Alabama: A GIS Analysis Case Study. *Journal of the Applied Geography Conference, 26*, 352-360.

Chaney, P. & Weaver, G. (2010). The Vulnerability of Mobile Home Residents in Tornado Disasters: The 2008 Super Tuesday Tornado in Macon, County, Tennessee. *Weather, Climate and Society, 2*, 190-199.

Changnon, S. (2009). Tornado Losses in the United States. *Natural Hazards Review*, 10(4), 145-150.

Changnon, S., Plelke, R., Changnon, D., Sylves, R. & Pulwarty, R. (2000). Human Factors Explain the Increased Losses from Weather and Climate Extremes. *Bulletin American Meteorological Society, 81*(3), 437-442.

Changnon, S. & Semonin, R. (1966). A Great Tornado Disaster in Retrospect. *Weatherwise*, *19*(2), 56-65.

Chen, X. (2008). Analysis of Alongwind Tall Building Response to Transient Non-Stationary Winds. *Journal of Structural Engineering*, *134*(5), 782-791.

Cheng, L. & McComb, A. M. (2010). Unreinforced Concrete Masonry Walls Strengthened with Cfrp Sheets and Strips Under Pendulum Impact. *Journal of Composites for Construction*, *14*(6), 775-782.

Coleman, T. A., Knupp, K. R., Spann, J., Elliott, J. B. & Peters, B. E. (2011). The History (and Future) of Tornado Warning Dissemination in the United States. *Bulletin American Meteorological Society*, May, 567-582.

Coleman, T. A. & Pence K. J. (2009). The Proposed 1883 Holden Tornado Warning System. *Bulletin American Meteorological Society*, December 1789-1796.

Comstock, D. & Mallonee, S. (2005). Comparing Reactions to Two Severe Tornadoes in One Oklahoma Community. *Disasters*, *29*(3), 277-287.

Concannon, P., Brooks, H. & Doswell, C. (2000). Climatologically Risk of Strong and Violent Tornadoes in the United States. *Bulletin American Meteorological Society*, *8*(12) 212-219.

Corfidi, S. F. (1999). The Birth and Early Years of the Storm Prediction Center. *Weather and Forecasting, 14*, 507-525.

Current, J. & O'Kelly, M. (1992). Locating Emergency Warning Sirens. *Decision Sciences, 23*(1), 221-234.

Dagnew, A. K., Bitsuamalk, G. T. & Merrick, R. (2009). 11th Annual Conference on Wind Engineering. *Computational evaluation of wind pressures on tall buildings.* San Juan, Puerto Rico.

Daley, R., Brown, S., Archer, P., Kruger, E., Jordan, F., Batts, D. & Mallonee, S. (2005). Risk of Tornado–Related Deaths and Injury in Oklahoma, May 3, 1999. *American Journal of Epidemiology, 161*(12), 1144-1150.

Dash, N. & Gladwin, H. (2007). Evacuation Decision Making and Behavioral Responses: Individual and Household. *Natural Hazards Review*, August, 69-77.

Davies, J. M. & Fischer, A. (2009). Environmental Characteristics Associated with Nighttime Tornadoes. *Electronic Journal of Operational Meteorology, EJ3*, 1-24.

De Silva, D. G., Kruse, J. B. & Wang, Y. (2008). Spatial Dependencies in Wind-Related Housing Damage. *Natural Hazards, 47*, 317-330.

Donner, W. (2007). The Political Ecology of Disaster: An Analysis of Factors Influencing U.S. Tornado Fatalities and Injuries, 1998-2000. *Demography, 44*(3), 669-685.

Donner, W. R., Rodriguez, H., & Diaz, W. (2007). 87th AMS Annual Meeting. *Public warning response following Tornadoes in New Orleans, LA, and Springfield, MO: A sociological analysis*. Retrieved December 1st from http://www.scopus.com/inward/record.url?eid=2-s2.0-77949298018&partnerID=40&md5=f64d23c067a276e0cb589343d411839d.

Doswell, C. & Brooks.H. (2002). Lessons Learned From the Damage Produced by the Tornadoes of 3 May 1999. Bulletin *American Meteorological Society, 17*, 611-618.

Doswell, C., Moller, A. R. & Brooks, H. (1999). Storm Spotting and Public Awareness Since the First Tornado Forecast of 1948. *Weather and Forecasting, 14*, 544-557.

Dotzek, N. Grieser, J & Brooks, H. (2003). Statistical Modeling of Tornado Intensity Distributions. *Atmospheric Research, 67-68*, 163-187.

Drabek, T.E. & Stevenson, S. (1971). When Disaster Strikes. *Journal of Applied Social Psychology, 2*, 187-203.

Drabek, T. E. & Hoetner, G. (1991). *The evolution of emergency management. Emergency management: Principles and practices for local government*. Drabek and Hoetner (eds), International City Management Association, Washington D.C. pgs 3-29.

Durage, S. W., Wirasinghe, S. C. & Ruwanpura, J. (2012). Comparison of the Canadian and U.S. Tornado Detection and Warning System. *Natural Hazards*, April, Retrieved December 1, 2012, from http://download.springer.com/static/pdf/10/art%253A10.1007%252Fs11069-012-0168-7.pdf?auth66=1354672527_4876f4b8ed089469a3933fc9072ad2f4&ext=.pdf

Erickson, S. (2006). 23rd Conference on Severe Local Storms, Session 11. *Lead time and time under tornado warnings: 1986-2004*. November 8th 2006 St Louis AB

Farley, J. (2007). Call-to-action statements in tornado warnings: Do They Reflect Recent Developments in Tornado-Safety Research. *International Journal of Mass Emergencies and Disasters, 25*(1), 1-36.

Fujita, T.T., (1971): Proposed characterization of tornadoes and hurricanes by area and intensity, SMRP No. 91, the University of Chicago.

Finley, J. P. (1884). *Character of Six Hundred Tornadoes*, Professional Paper # 7, U.S. Signal Service,

Frates, M., Web, 11/23/2012, http://news14weather.blogspot.com/2010/04/tornado-alley-in-carolinas.html

Galway, J. G. (1985). J. P. Finley: The First Severe Storms Forecaster. *Bulletin American Meteorological Society*, *66*(11), 1389-1395.

Glahn, B. (2005). Tornado Warning Performance on the Past and Future: Another Perspective. *Bulletin American Meteorological Society*, August, 1135-1141.

Glass, R. &Noji, E. (1992). *Epidemiologic surveillance following disasters. public health surveillance.* New York: Van Nostro and Reinhold, pgs. 195-205.

Godschalk, D. R. (2003). Urban Hazard Mitigation: Creating Resilient Cities. *Natural Hazards Review, 4*(3), 136-143.

Graves, P. E. & Bresnock A. E. (1985). Are Natural Hazards Temporally Random? *Applied Geography*, 5, 5-12.

Hales, J. E. (1990). The Critical Role of Tornado Watches in the Issuance of Warnings for Significant Tornadoes. *National Weather Digest*, *15*(4), 30-36.

Hall, S. G. & Ashley, W. S. (2008). Effects of Urban Sprawl on the Vulnerability to a Significant Tornado Impact in Northeastern Illinois. *Natural Hazards Review, 9*(4), 209-219.

Hammer, B. & Schmidlin, T. (2002). Response to Warnings During The 3 May 1999 Oklahoma City Tornado: Reasons and Relative Injury Rates. *Bulletin American Meteorological Society*, *17*, 577-581.

Hammit, J. K., Belsky, E. S., Levy, J. I. & Graham, J. D. (1999). Residential Building Codes, Affordability and Health Protection: A Risk-Tradeoff Approach. *Risk Analysis*, *19*(6), 1037-1058.

Haan, F. L., Balaramudu, V. K. & Sarkar, P. P. (2010). Tornado-Induced Wind Loads on a Low-Rise Building. *Journal of Structural Engineering, 136*(1), 106-116.

Hanson, S., Vitek, J.D. & Hanson, P. O. (1979). Natural Disaster: Long Range Impact on Human Responses to Future Disaster Threats. *Environment and Behavior, 11*, 268-284.

Hhoemaker, W. L. & Womack, A. S. (1990). Masonry Walls Subjected to Wind-Induced Lateral Loads and Uplift. *Journal of Wind Engineering and Industrial Aerodynamics*, *26*(2), 709-716.

Kis, A. K. & Straka, J. M. (2010). Nocturnal Tornado Climatology. *Weather and Forecasting, 25*, 545-561.

Lagates, D. R. & Biddle, M. D. (1999). Warning Response and Risk Behavior in the Oak Grove Birmingham, Alabama, Tornado of 08 April 1998. Quick Response Report #16.

Lakshmanan, V., Smith, T., Stumpf, G. & Hondl, K. (2007). The Warning Decision Support System-Integrated Information. *Weather and Forecasting, 22*(3), 596-612.

Lewellen D. C. & Lewellen, W. S. (2007). Near Surface Intensification of Tornado Vortices. *Journal of the Atmospheric Sciences*, *64*(7), 2176-2194.

Liu, H., Gopalaratnam, V. S. & Nateghi, F. (1990). Improving Wind Resistance of Wood-Frame Houses. *Journal of Wind Engineering and Industrial Aerodynamics, 36*(2), 699-707.

Liu, S., Quenenmoen, L., Malilay, J., Noji, E., Sinks, T. & Mendlein, J. (1996). Assessment of a Severe-Weather Warning System and Disaster Preparedness, Calhoun County, Alabama, 1994. *American Journal of Public Health*, *86*(1), 87-98.

Marshall, T. (2002). Tornado Damage Survey at Moore, Oklahoma. *Weather and Forecasting, 17,* 582-598.

Masters, J. Radar hook pattern, retrieved Novermber 29, 2012 the Wunderground website (http://www.wunderground.com/blog/JeffMasters/comment.html?entrynum=2111.

McDonald, J. R. (1990). Impact Resistance of Common Building Materials to Tornado Missiles. *Journal of Wind Engineering and Industrial Aerodynamics, 36*(2), 717-724.

McPeak, B. G. & Ertas, A. (2012). The Good, the Bad, and the Ugly Facts of Tornado Survival. *Natural Hazards, 60*, 915-955.

Merrell, D., Simmons, K., & Sutter, D. (2002). Taking Shelter: Estimating the Safety Benefits of Tornado Safe Rooms. *Bulletin American Meteorological Society, 17*, 619-625.

Merrell, D., Simmons, K., & Sutter, D. (2005). The Determinants of Tornado Casualties and the Benefits of Tornado Shelters. *Land Economics*, *81*(1), 87-99.

Mileti, D. (1999). *Losses, Costs, and impacts, disasters by design: a reassessment of natural hazards in the United States.* Joseph Henry Press, Washington DC.

Miller, D., Morgan, D. & Womack, C. (2002). Buying Tornado Safety: What Will It Cost? *Southwest Economic Proceedings*, *29*(1), 35-44.

Minor, J. (1994). Windborne Debris and the Building Envelope. *Journal of Wind Engineering and Industrial Aerodynamics*, *53*(1-2), 207-227.

Mitchell, T & Thomas, K. (2001). *Trends in disaster losses, American Hazardscapes,* Editor Susan Cutter, Joseph Henry Press, Washington DC.

Moller, A. R. (1978). The Improved NWS Storm Spotters Training Program at Ft. Worth Texas. *Bulletin American Meteorological Society, 39*(12), 1574-1582.

Moradi, L. G., Davidson, J. S. & Dinan, R. J. (2008). Resistance to Membrane Retrofit Concrete Masonry Walls to Lateral Pressures. *Journal of Performance of Construction Facilities, 22*(3), 131-142.

Mulilis, J. P. & Duval, T. S. (1997). The Pre Model of Coping and Tornado Preparedness: Moderating Effects of Responsibility. *Journal of Applied Social Psychology, 27(19)*, 1750-1768.

National Climatology Data Center (NCDC), 2012, Web, January, 2011, http://www.ncdc.noaa.gov/

Nelson, C. & French, S. (2002). Plan Quality and Mitigation Damage from Natural Disasters: A Case Study of the Northridge Earthquake with Planning Policy Considerations. *American Planning Association, 68*(2), 194-207.

NOAA, *EF4 Tornado Event of November 29th, 2010 in Central Louisiana*. 2011, Web, 11/23/2012, http://www.srh.noaa.gov/shv/events/select.php?date=11292010_1

Palmer, R.D., Bodine, D., Kumjian, M., Cheong, B., Zhang, G., Coa, Q., … Wang, Y. (2011). Observations of the 10 May 2010 Tornado Outbreak Using Ou-Prime. *Bulletin American Meteorological Society, 92*(7), 871-891.

Paul, B. K. & Che, D. (2011). Opportunities and Challenges in Rebuilding Tornado-Impacted Greensburg, Kansas as “Stronger, Better, and Greener.” *Geojournal, 76*, 93-108.

Ray, P.S., Bieringer, P., Niu, Xufeng, & Whisel, B. (2003). An Empirical Estimate of Tornado Occurances in the Central Plains of the United States. *Monthly Weather Review, 131*, 1026-1031.

Reibestein, J. L. (2008). Eyes to the sky: A Qualitative Study of Storm Spotters. Unpublished Master’s Thesis, North Dakota State University.

Rose, A., Porter, K., Dash, N., Bouabid, J., Huyck, C., Whitehead, J. ,… West, C. (2007). Benefit–Cost Analysis of FEMA Hazard Mitigation Grants. *Natural Hazards Review, 8*(4), 97-112.

Ryzhkov, A. V., Schuur, T. J. burgess, D. W. & Zrnic, D. S. (2005). Polarimetric Tornado Detection. *Journal of Applied Meteorology, 44,* 557-570.

Schafer, J., Schneider, R. & Kay, M. (2002). 3rd Symposium on Environmental Applications: Facilitating the Use of Environmental Information. *The Robustness of Tornado Hazard Estimates*. American Meteorological Society, Orlando, FL.

Schiermeier, Q. (2012). Disaster toll tallied: The soaring cost of natural catastrophes is due more to socio-economic than climatic factors. *Nature, 481*(7380), 124-125.

Schmidlin, T. W. (2009). Human Fatalities from Wind-Related Tree Failures in the United States, 1995-2007. *Natural Hazards, 50*, 13-25.

Schmidlin, T. W., Hammer, B. O., Ono, Y. & King, P. S. (2009). Tornado Shelter-Seeking Behavior and Tornado Shelter Options among Mobile Home Residents in the United States. *Natural Hazards, 48,* 191-201.

Schmidlin, T. W., Hammer, B. O., King, P. S., Ono, Y., Miller L. S. & Thuman, G. (2002). Unsafe at Any (Wind) Speed? Testing the Stability of Motor Vehicles in Severe Winds. *Bulletin American Meteorological Society, 83,* 1821-1830.

Scoggins, J. (1997). Tying Down the House: Properly Installed Hold-Down Hardware Can Keep a House from Shaking or Blowing Apart. *Journal of Light Construction*, *September*, 1-6

Sherman, Z. (1973). Residential Buildings Engineered to Resist Tornadoes. *Journal of the Structural Division*, *99*(4), 701-714.

Sherman-Morris, K. (2010). Tornado Warning Dissemination and Response at a University Campus. *Natural Hazards, 52*, 628-638.

Siegrist, M. & Cvetkovich, G. (2000). Perception of Hazards: The Role of Social Trust and Knowledge. *Risk Analysis, 20*(5), 713-719.

Simmons, K. & Sutter, D. (2005). WSR-88D Radar, Tornado Warnings and Tornado Casualties. *Bulletin American Meteorological Society*, *20,* 301-310.

Simmons, K. & Sutter, D. (2006). Direct Estimation of the Cost Effectiveness of Tornado Shelters. *Risk Analysis*, *26*(4), 945-954.

Simmons, K. & Sutter, D. (2007A). *The groundhog day florida tornadoes: A case study of high-vulnerability tornadoes.* Quick response Report Number 193, June.

Simmons, K. & Sutter, D. (2007B). Tornado Shelters and the Manufactured Home Parks. *Natural Hazards, 43*, 365-378.

Simmons, K. & Sutter, D. (2008A). Tornado Warnings, Lead Times and Tornado Casualties: An Empirical Investigation. *Weather and Forecasting*, *23*(2), 246-258.

Simmons, K. & Sutter, D. (2008B). Manufactured Home a Building Regulations and the February 2 2007 Florida Tornadoes. *Natural Hazards*, *46*, 415-425.

Simmons, K. & Sutter, D. (2009). False Alarms, Tornado Warnings, and Tornado Casualties. *Weather Climate and Society*, *October* (1), 38-53.

Sims, H. H. & Baumann, D. D. (1972). The Tornado Threat: Coping Styles of the North and South. *Science*, *176*, 1386-1392.

Sorenson J. M. (2000). Hazard Warning Systems: Review of 20 Years of Research. *Natural Hazards Review, 1*, 119-125.

Sorenson J. M. & Mileti, D, (1988). Warning and Evacuation: Answering Some Basic Questions. *Industrial Crisis Quarterly*, *2*, 195-209.

Sparks, P., Hessing, M., Murden, J. & Sill, B. (1988). On the Failure of Single-Story Wood-Framed Houses in Severe Storms. *Journal of Wind Engineering and Industrial Aerodynamics*, *29*(1-3), 245-252.

Speheger, D. A., Doswell, C. A. & Stumpf, G. (2002). The Tornado of 3 May 1999: Event Verification in Central Oklahoma and Related Issues. *Weather and Forecasting, 17*, 362-381.

Stimers, M. J. (2006). A GIS-Based Approach to Analyzing Warning Siren Networks: An Analysis of Riley and Wabaunsee Counties, Kansas. *Journal of the Applied Geography Conference*, *29*,186-195.

Sutter, D. & Erickson, S. (2010). The Time Cost of Tornado and the Savings with Storm-Based Warnings. *Weather, Climate and Sociology*, *2*, 103-112.

Sutter, D. & Simmons, K. (2010). Tornado Fatalities and Mobile Homes in the United States. *Natural Hazards, 53*, 125-137.

Tarp, K., *Clues from climatology: When and where do tornadoes occur?* National Weather Service, October 8th 2001, retrieved on, 11/23/2012, from the website of http://www.oar.noaa.gov/spotlite/archive/spot_climatology.html

Twisdale, L. A. & Dunn, W. L. (1983). Wind Loading Risks from Multivortex Tornadoes. *Journal of Structural Engineering, 109*(8), 2016-2022.

Verbout, S. Brooks, H., Leslie, L. & Schultz, D. (2006). Evolution of the U.S. Tornado Database: 1954-2003. *Weather and Forecasting*, *21*, 86-93.

Vescio, M. D. & Thompson, R. L. (2001). Subjective Tornado Probability Forecasts in Severe Weather Watches. *Weather and Forecasting*, *16,* 192-195

Wakimoto, R. M., Murphey, H. V., Dowell, D. C. & Bluestein, H. B. (2003). The Kellerville Tornado During VORTEX: Damage Survey and Doppler Radar Analysis. *Monthly Weather Review*, *131*, 2197-2221.

Whalen, T., Gopal, S. & Abraham, D. (2004). Cost-Benefit Model for Construction of Tornado Shelters. *Journal of Construction Engineering and Management*, *130*(6), 772-779.

White, G. F. (1996). Emerging Issues in Global Environmental Policy. *Ambio, 25*(1), 58-60.

Whiton, R. C., Smith, P. L., Bigler, S. G., Wilk, K. E. & Harbuck, A. C. (1998). History of Operational Use of Weather Radar by U.S. Weather Services. Part I: The Pre-NEXRAD Era. *Weather and Forecasting*, *13*, 219–243.

Wurnman, J. Alexander, C., Robinson, P. & Richardson, Y. (2007). Low-Level Winds in Tornadoes and Potential Catastrophic Tornado Impacts in Urban Areas. *Bulletin American Meteorological Society, July,* 31-46.

Wurman, J. & Gill, S. (2000). Finescale Radar Observations of the Dimmitt, Texas (2 June 1995), Tornado. *Monthly Weather Review*, *128*, 2135-2164.

Yamagishi, K. (1997). When a 12.89% Mortality is More Dangerous Than 24.14% Implications for Risk Communication. *Applied Cognitive Psychology, 11,* 495-506.

Yuan, M., Dickins-Micozzi, M. & Magsig, M. A. (2002). Analysis of Tornado Damage Tracks From the 3 May Tornado Outbreak Using Multispectral Satellite Imagery. *Weather and Forecasting, 17,* 382-398.