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WARNING RECEPTION, RESPONSE, AND RISK BEHAVIOR IN THE 3 MAY 1999 OKLAHOMA CITY LONG-TRACK VIOLENT TORNADO

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By

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WARNING RECEPTION, RESPONSE, AND RISK BEHAVIOR IN THE 3 MAY 1999 OKLAHOMA CITY LONG-TRACK VIOLENT TORNADO

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF GEOGRAPHY

BY

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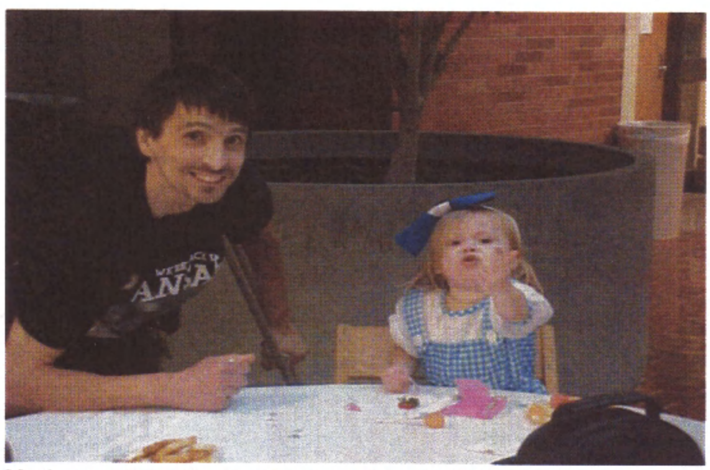
Dedication

This work is dedicated to the victims of the tornadoes of 3 May 1999, their families, the first responders, the weather service personnel, and all that were touched by the forces of Mother Nature that fateful Monday evening. The generous gifts of stories and photos, fears and tears, and observations and recommendations are of tremendous value if not only for history's sake, but with the hope of preventing similar disasters in the future.

Damaged Residence in Moore, 4 May 1999 - Todd Lindley - Copyright.

and

To my daughter - Faith Aleksondra Biddle (b. 2002) - who has been a source of immediate and continuous inspiration, is a source of incessant pride and joy, and will always be the focus of my deepest love. I could not have done this with out the help of many, but I likely would not have done this without Faith.



Matthew and Faith Biddle - c. October 2004 - Debi Ellis - Copyright

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Faith: I love you.

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Abstract

WARNING RECEPTION, RESPONSE, AND RISK BEHAVIOR IN THE 3 MAY 1999 OKLAHOMA CITY LONG-TRACK VIOLENT TORNADO

On 03 May 1999, a long-track violent tornado killed 40 people and injured ~800 in and near Oklahoma City, Oklahoma. Following the disaster, surveys were collected from persons residing or working within the damaged areas regarding their actions, and the actions of those in their care or company. Similar data were obtained for fatalities. The purpose of the field operations were to collect geographical, demographical, behavioral, and attitudinal information from a sample of survivors, and to the fullest extent possible, for all decedents. Respondent data were analyzed for patterns in warning access, source, compliance, and lead time, as well as for geographical and cultural variables such as shelter availability, tornado hazard perception, and opinions about warning systems. Goals were to catalog significant differences between survivor and decedent traits to identify successful warning operations and media practices; to delineate the warning environment as characterized by societal risk perception and response; and to compare these findings to previous research. Situational risk factors for death included: living in a mobile home or unincorporated area; living near the starting point of the tornado path; and being physically disabled, elderly, or of lower socioeconomic strata. Cognitive risk factors for death included misjudging the tornado path or severity in spite of receiving warnings; choosing inadequate shelter; and attempting to flee too late. Risk factors for survival included access to televised warnings and receiving warnings via telephone; sheltering below ground or fleeing the path; and general familiarity with weather information and local geography. Risk factors for survival did not substantially include warnings from siren systems or NOAA Weather Radio. The performance of tornado detection and surveillance systems, Integrated Emergency Management, and the timely dissemination of detailed warnings via electronic media were all important in holding the death toll down. Yet, none of these were able to completely mitigate the risk to certain highly vulnerable populations or individuals. Warning system efficacy for this extreme event, having occurred among a large population with relatively-high severe weather awareness is explored, along with some unusual findings regarding warning communication and evacuation behavior.

Keywords: Tornado; Warning; Natural Hazard; Disaster; Oklahoma; USA

WARNING RECEPTION, RESPONSE, AND RISK BEHAVIOR IN THE 3 MAY 1999 OKLAHOMA CITY LONG-TRACK VIOLENT TORNADO

1- INTRODUCTION

On Monday 3 May 1999, an outbreak of some 70 tornadoes in the Southern Plains killed 44 people in Oklahoma, and six people in Kansas. Forty Oklahoma deaths (80%) were directly due to a *long-track violent tornado*[A] that struck Oklahoma City, Oklahoma and portions of its southern and eastern suburbs. The 'Oklahoma City Tornado' (hereafter OCT) was exceptional not only for record-breaking damage and human trauma, but because it presented the rare convergence of a violent tornado with a large metropolitan area. The OCT injured ~800 (~ is approximately) and caused significant damage to ~8000 structures, nearly three times more than any other single tornado in United States (US) history (Henson 2000). Numerous assessments set total damages for this single tornado in excess of one billion US dollars (1B$), which is greater than the modern day national mean aggregate value for all annual tornado damage (ESIG c.2006). It is ranked by the *Storm Prediction Center (SPC)* as the 4th most damaging tornado in inflation-adjusted dollars (SPC c.2006). Grazulis (2001) has the OCT ranked 1st, also considering inflation. In addition, the event occurred in the heart of *Tornado Alley*[B] – a vernacular region of the Plains (see Figure 1.1) having the highest tornado frequency and intensity – that is home to a unique concentration of weather forecasting resources, research institutions, and electronic media, which all maintain very high profiles within the *modernized warning system*[C].

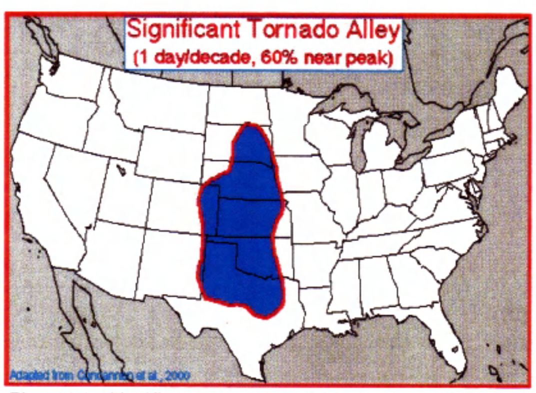

Figure 1.1 - Significant Tornado Alley. Map by Concannon et al. 2000. Copyright - Used with permission.

* *Letter denotes a glossary term*

Post-event data were collected from various agencies involved in the warning process, as well as from survivors regarding their observations, actions, and opinions. Previous research suggests that historically, Oklahomans have possessed relatively high levels of *public awareness*[D] about severe weather, and are well-prepared to deal with tornado risks (in the *Official Period*[E]) due to: 1) their personal, familial, and institutional experience with past tornadoes; 2) their familiarity with warning products and safety measures; and, 3) their heightened exposure to the aforementioned modernized warning technologies and interaction with weather, media, and *emergency management agencies*[F] *(EMA)*. Thus in theory, the OCT event provides a sort of benchmark event with regard to warning infrastructure and warning behavior for future events and in other regions (Biddle 2000; Hammer and Schmidlin 2002; Brown et al. 2002; Brooks and Doswell 2002; Daley et al. 2005).

There is general consensus that OCT warning dissemination functioned to nearly faultless levels (NOAA 1999; Biddle 2000; Quoetone et al. 2000; Hammer and Schmidlin 2002) leaving it challenging to address shortcomings and identify needs for the next wave of warning system improvements or to predict how similar tornado events would play out in other regions of the country. More importantly, what lessons can be learned about the spectrum of behaviors, risks, and technologies exemplifying the OCT *warnscape*[G] and how might these lessons be applied to future warning programs, public health and safety initiatives, and community mitigation policies? This dissertation is intended to be self-standing such that it includes a comprehensive literature review on relevant contemporary paradigms of natural hazards and vulnerability, as well as tornado risk behavior and modern warning systems. For this reason, the appendices are also extensive and include a variety of detailed background information. Where this is not practical or pertinent – such as for detailed meteorological information – readers are directed to the relevant literature or internet websites. The goal is to place the data from the field and subsequent statistical analyses in context with the conceptual framework of the human ecology of the modern tornado disaster.

1.1 - Key Research Questions

This study provides descriptions of the tornado event and the physical and cultural landscapes on which it occurred, in addition to forensic reports on the warnings, observations, and impacts. Some key questions include: What do survivors have to say about the information they used and where they got their information?

How do risk factors for survival differ from risk factors for death? (Risk is the probability of occurrence multiplied by vulnerability, and has consequences like uncertainty, the social values of acceptable risk, and perceived risk in its formula). What are the possible implications of the survey findings on future warning system efficacy and what has emerged as the key research gaps? This information leads to the following problem statements:

- Television (TV) was the most commonly used form of severe weather warning for the OCT. Of 147 of 164 (89.6 %) of those surveyed, used TV as their primary means of receiving weather warnings and advisories.
- A smaller number of the elderly did NOT evacuate (65 and over) relative to the median.
- A majority of juveniles (and their families) did evacuate relative to the median.
- Mobile homes and manufactured homes were the most dangerous places during severe weather.
- Approximately 25 % of the victims were disabled, which is higher than the national population of disabled.

How do the primary findings of this work compare to those of other similar works from recent tornadoes, including the handful of other works on this same tornado disaster? Ultimately, a goal of this work is to provide an accessible and tangible body of evidence that yields not only a 'snapshot' of the human ecology of the OCT, but also provides useful information to the *National Weather Service [NWS]* and EMA. Hurricanes Katrina and Rita exposed many shortcomings that most citizens would not have supposed existed. While tornadoes occur on spatial and temporal scales much smaller than hurricanes, earthquakes, wildfires, or floods, there are many lessons to take from other disasters. We will see major tornado disasters in the future, regardless of their recent infrequency (Grazulis et al. 1998).

1.2 – A Review of Natural Hazards Research and Warning Theory

'Natural hazards' are the perils to life and property resulting from the interaction of natural (environmental) systems and human agency (societal and cultural systems). A synthetic definition of natural hazards might be that they "are extreme geophysical events which exceed normal expectations of society in magnitude and frequency, to result in large-scale death, hardship, or capital loss" (Kirby 1990, p. 3). Of key importance is accepting that natural hazards cannot be considered independently from the people or property they affect (Burton et al. 1993). Gilbert F. White's pioneering work, along with that of a handful of other geographers (e.g., Burton, Kates) and sociologists (e.g., Drabek, Mileti, Sorensen) remains important, particularly in a

Western or developed societal context. The work provides the framework for integrating of the role of human agency in environmental hazards, and illustrates that societal and individual behavior are manifest in magnifying vulnerability to geophysical processes – which are by nature just that – natural. Post-structural scholars have criticized the earlier works of White and the 'Hazards School' for ignoring the way that social inequality and the broad workings of political economy produce human vulnerability to natural events. Watts (1983), for example, claims that the 'traditional Hazard Model' overlooks the ways that social systems increase human vulnerability by reducing social safety nets and weakening risk management strategies. During tornadoes, mobile and manufactured homes (MMH) residents tend to support Watts' claims because there is a correlation between vulnerability and socioeconomic status (which would have provided some shelter beyond MMH). These more recent natural hazards paradigms (Hewitt 1983) also place the role of human agency as that of causative force and stress that much of the choices involved in individual and community assumptions of, and adjustments to, risk. Risk is framed by forces that in fact severely constrain available choices (Steinberg 1999).

Disasters are still commonly seen by many scientists, mass media, and bureaucracies alike, as reflective of the costs of doing business on a perilous Earth. Popular media accounts continue to present disasters as 'freak events' or 'Acts-of-God' outside the realm of everyday life that fall through the cracks of accountability at individual, community, governmental, and societal levels. Steinberg (2000, p. 98) observes that "risk does not simply exist. It is produced. Risk is manufactured, and who bears its burden is one of the most important questions we can ask in exploring the history of natural disaster." Natural hazards such as tornadoes include more than their geophysical elements. They also include technological, sociological, psychological, and cultural components (White and Haas 1975). The inherent infrequency of extreme events provides few metrics by which to measure success or improvement. Incorporating change and upgrading mitigation strategies can be complicated, owing to the many jurisdictions involved, and the 'non-normal' aspects of the actual use of the systems. Multi-disciplinary perspectives in hazard studies have been an early and consistent theme. Mitchell (1989) proposed investigation of hazards as interactive phenomena having layered causes and consequences, encouraging interdisciplinary approaches to the research because methodologies must apply to infinite scenarios with humans viewed as the pre-eminent common risk variable. Others (Palm 1990; Showalter et al. 1993) have stressed contextual methodologies for 'real world' problems, which likewise demand multi-disciplinary examinations.

1.3 - Environmental Risk and Risk Perception

There are two basic categories of variables that frame public risk perception and subsequent risk behavior and response. They are the physical properties of the risk agent itself, and the societal characteristics of the community affected. While the role and dynamic of perceptual variables upon adjustment to hazards (and the evolution of mitigation programs) remain largely uncharted waters, a well-mapped concept is that public reactions to risk are governed more by perceptions than logic about the natural. Risk perceptions also become politicized and mitigation programs and policies are ultimately shaped by widespread risk perceptions, which may not reflect the science-of-the-day. Risk perceptions are thus reflected in risk communication. Mileti and Fitzpatrick (1991, p. 21) maintain that "behavior which results from risk communication is the consequence of [risk perceptions]." Risk communication research indicates that the heuristics and biases employed in human adjustment and response decision-making to hazards also vary greatly by hazard type. Information reception and mitigation choices do not always follow systemic or linear patterns. This makes modeling societal response frameworks problematic (Slovic 1991; Kates 1997). Compounding this is the fact that response options are dictated by a spectrum of variables that are not generally seen as rational choices. The information processing and problem-solving skills needed by the public to receive and comprehend risk messages come with no guarantees that said public has the ability or opportunity to take responsive action, because mitigation resources are unequally-distributed throughout society (Watts 1983). Societal and governmental bodies are under increasing pressure to seek tangible and rational strategies (including warning systems) to cope with extreme events (Tierney et al. 2001). As we move away from antiquated assumptions that disasters are merely acts-of-God beyond human intervention, greater emphasis is placed on the possibilities of acting rational in an irrational world (Kirby 1990).

Several methods are used to characterize the levels of risk posed by a natural hazard or activity. Among the most common are cost-benefit analyses – which simply weigh costs versus benefits of an (in)action; and decision analyses – which aim to control economic and environmental costs of hazards which are often latent and hidden to maximize long-term benefits by projecting the implications of various response scenarios (Smith 2001). Such assessments of capital and resources versus costs and vulnerabilities are political attempts to clarify waters muddied by the fact that humans – no matter their backgrounds or status – all perceive risks differently from each other, and from event to event. The policy ramifications of these psychological aspects of risk are enormous. Cost-benefit analysis, in theory, modifies or nullifies perceptual variance via statistical analysis. Good policy design requires that actual risk be as equal to perceived risk as possible, thus maximizing cost effective mitigation. However, this is seldom the situation. When perceived risk is significantly larger than actual risk, costly over-protection ensues. When the perceived risk is significantly smaller than the actual risk, under-protection may yield short-term savings, but usually by transferring costs to future generations. Who directs the cost-benefit analysis process politically, and how costs and losses are measured and valued often fail fully to characterize vulnerability. A common critique of cost-benefit analysis is that it is asocial, positivistic, authoritarian, bureaucratic, and beneficial to a select few with political and socio-economic stature (Tobin and Montz 1997). It also tends to over-emphasize benefits, which are of higher visibility and thus measured with greater ease than costs, which tend to be spread out over time, mis-allocated, or unquantifiable (Chiras 2001). Policy design and management decisions based on cost-benefit analyses, sustainable development programs, and meta-policies aimed at identical risks and societal structures, often result in markedly different programs that tend to serve certain interests over others (Cuny 1983).

The successful communication of acute risk from the scientific community to the public through responsible governmental authorities involves a wide variety of individual, societal, cultural, political, environmental, institutional, and organizational variables. In the US, this is generally manifested in a bipolar way. While individual responsibility is ingrained in the culture, there are disaster program expectations among many for a big government response in the rescue phases and large 'bail outs' in the recovery phases (Platt 1999). Most individuals are not experts in natural hazards. Thus, the role of government has evolved to process the scientific knowledge about a hazard, and to provide the logistical capacity and infrastructure to disseminate this knowledge to citizens. All aspects of community safety cannot rest extensively in the hands of scientists or governmental personnel, however. This makes the science of crafting mitigation and preparedness programs for low-probability, high-consequence, rapid-onset, extreme events much different from that of most other forms of risk communication – such as cancer prevention (e.g., often tied to certain behaviors), earthquake mitigation (e.g., often tied to certain locations), or seat belt use (e.g., often tied to the frequency of exposure). Risk communications for short-fuse hazards from scientific bodies or governmental authorities commonly take the form of warnings.

1.3.1 - *Communicating Risk Via Warnings*

Sociologists and psychologists have noted the human tendency to convert vague risk and its accompanying uneasiness into defined risk that carries a sense of control (Kirby 1990; Quarantelli 1998). Devising networks to share information regarding known hazards and developing risks are as old as smoke signals and posting look outs. The primary way to communicate acute danger effectively from short-fuse hazards is via warning systems. In general, according to Mileti and Sorensen (1990, p. 2-1), a warning system is a "means of communicating information about an occurring or impending hazard, aimed at eliciting successful mitigative response by people in danger from the hazard." Contemporary warning systems tend to be complex, inter-organizational, multi-jurisdictional, multi-tiered, multi-cultural, and technology-laden. Somewhat surprisingly, most warning systems are specialized and address a single hazard or risk mode (e.g., tornadoes, tsunami, chemical release), although often the communications networks and hardware may be used interchangeably for multiple hazards. There continues to be lobbying among emergency management associations and professionals for a unified and coordinated system (PPW 2002). We appear to be far from realizing such for a variety of logistical, economical, and political reasons. In order to motivate public mitigation activities, a warning system must meet two basic functions: assessment – the organizational activities associated with detecting the hazard and deciding a given risk threshold has been met to warrant a warning; and, dissemination – issuing and transmitting a warning message to the intended audience (Nigg 1995). Primary components of a warning system may be broken down to include detection, management, and response subsystems, with most warning systems currently in use designed to address hazards that present the following common traits (adapted from Mileti and Sorensen 1990):

- Low probability of occurrence, yet plausible evidence of potential to materialize (past history).
- Threat of large-scale damage, disruption, or mass casualties.
- Hazard agent is detectable / can be forecasted.
- Public response upon receipt of warning can mitigate the risk or damage.

However, there is little in the guidance that spells out how vulnerability is to be assessed, and less about how vulnerable populations are to be identified, engaged, and integrated into the warning process. There is considerable available insight into successful warning communication techniques, and much of the semantics on what works and what has generally failed is well documented, although some may be antiquated in light of the 'Age of the Internet' and rapidly occurring US demographic changes. The primary historical source is Mileti and colleagues (Mileti 1975; 1995; 1996; 1999; Mileti and Sorensen 1990; Mileti and Fitzpatrick 1991; and Mileti and O'Brien 1992). The typical successful warning process (reception and response) is summarized by the following characteristics or processes (adapted from Mileti and Sorensen 1990):

- **Reception** of the warning
- **Understanding** of warning
- **Belief** in validity
- **Confidence** in accuracy of warning
- **Credibility** afforded to warning agent(s)
- **Confirmation** (corroboration) of warning from alternative sources
- **Personalization** of risk associated with the warning
- **Spurs appropriate decisions** in warning response
- **Timely** response is possible
- **Frequent updates** of warning information
- **Message redundancy** in warnings received via other channels
- **Reason** for warning is clear
- **Suggestions** on mitigation options included
- **Time-frame** of warning is detailed
- **Geographical references** included in warning
- **Projected impacts** and magnitudes noted in warning
- **Uncertainty** of warning information expressed

1.3.1.1 - *Communicating Uncertainty* -

Uncertainty exists in most all environmental problems, and especially so with scientific information regarding risk. Such is the case with weather forecasts, which are a product of incomplete scientific knowledge, limited availability of environmental observations, imperfect computer models, dynamic variability tied to temporal and spatial scales, and finally, human interpretation. We need to cope with uncertainty, minimize it where possible, and most importantly, not deny its existence by failing to communicate about it accurately and honestly. As stated by Moore and Thomas (1976, p. 12), "a formal theory of decision-making must take uncertainty as its departure point, and regard precise knowledge of outcomes as an unobtainable ideal." And, Murphy (1993, p. 283) acknowledges this in stating "since forecasters' judgments necessarily contain an element of uncertainty, their forecasts must reflect this uncertainty accurately in order to satisfy the basic maxim of forecasting. In general, then, forecasts must be expressed in probabilistic terms. . . expressing forecasts in a non-probabilistic (i.e., categorical) format generally is a decidedly inferior strategy in terms of reaching high levels of consistency." Murphy further noted (p. 291) . . ."a basic maxim of forecasting is violated whenever forecasts do not correspond to judgments [of the forecaster]."

For a variety of complex reasons, probabilistic products have not been widely-deployed for short-fuse hazards such as tornadoes, at least not for the general public. The most commonly noted reason seems to be the well documented difficulties that many people – including professionals from within the meteorological community – have communicating about uncertainty in general, and in digesting and utilizing probabilistic expressions of uncertainty specifically. The academic discourse about the potential operational benefits and pitfalls and the considerable challenges in the eventual education and training of users to enable skilled use of probabilistic warning products remain hot topics (Eliá and Laprisè 2005). The potential for warnings clearly remains a frontier of sorts with untapped riches (Doswell 2006), yet many significant pitfalls exist (Mileti 1999). Warning agencies and forecasters, as well as stakeholders, would benefit from additional policy and program focus and continued communications and behavioral research in attempting to promote the eventual integration by *NWS* into the 'mainstream' suite of products. For now, the diversity of opinions regarding the value and limitations of probabilistic products and the varying interpretations of the very same warning information by myriad users continue to handicap its progression and usage.

1.4 - The Human Ecology of Weather Warnings and Vulnerability

The manner in which warning programs are designed, implemented, maintained, and utilized, varies from region-to-region, among organizations, and in particular, among individuals. Myriad personality traits and individual circumstances dictate that no two persons respond to risk, or warnings, in exactly the same manner. Likewise, few communities address warning programs exactly the same as their neighbors because institutional experiences and resources are highly variable. Still, for the purposes of communicating about policy-making, program design, and technical implementation of warning systems, it is necessary to speak in generalities regarding the broadest category of stakeholders – the "general public". The term, problematic in its vagueness, is useful when discussing the broadest spectrum of users. As placed in a warning systems context by Nigg (1995, p. 378), the term "the public" is frequently used as though it were a single homogeneous group of people, when in fact we should be talking about "various publics." Doswell et al. (1999) echoed the notion that, at least for severe weather warnings, the stakeholder population is not some 'monolith' with homogeneous needs or reactions. Thus, in order to optimize the societal benefit from warning programs (in terms of sound economic and institutional policy), efforts to characterize the heuristics of tornado risk need to be pursued as vigorously as the unsolved meteorology. The general public cannot be thought of as the demographic mean and must reflect different age groups, socio-economic classes, ethnic groups, and cultures. It always must be remembered that response to warnings of imminent disaster is a social process. That is, citizen interpretations of danger do not take place in a vacuum, nor should be thought of as having a taken-for-granted outcome. In this research then, the term 'general public' includes non-organizational, non-institutional, individual citizens that live within the jurisdiction of a given warning system, are targeted to be served as stakeholders by the service agencies involved (often by the authority granted to such agencies by the public via public funds), and constitute the spectrum of users that do not otherwise demand or require 'specialized' products or services in their day-to-day living.

A fundamental concept of disaster epidemiology (counting the people wounded and killed) is that morbidity and mortality occur in patterns (Lillibridge 1997). Tornadoes are not an exception, as geographic and demographic patterns emerge to implicate sectors of the public at greater risk than others. Such patterns may be delineated by era, region, state, as well as by various social and cultural characteristics. In turn, there is a small body of research – some epidemiological studies (e.g., Glass et al. 1980; Brenner and Noji, 1995) along with non-medical geography-based studies (e.g., Schmidlin and King 1997) – that have examined tornado risk, including warning system performance relative to human ecology. Such characteristics, combined with attitudes about warning systems, the technological and managerial make up of the systems, and the frequency of the use of the warnings, all play significant roles in public awareness and subsequent *warning compliance*[H].

Tornado disasters reflect, ultimately, failures in the social system. These failures include aspects of warning programs, in that impact is directly tied to relationships between the environment, and social and cultural attempts (or failures) to plan, respond, and recover. According to Aguirre (2000, p. 99) "there is considerable consensus among social scientists that it is useful to conceptualize the public's response to warnings as a function of the physical environment, population, technology, social relations, and culture. Moreover, it is necessary to differentiate between the warning message and the system which produces it." Substantial applied research examining the human ecology of weather warnings began in the 1970s (McLuckie 1970; Mileti 1975) and has struggled to keep pace with advancing warning and detection technology ever since. Most recent efforts have examined systems from holistic standpoints as foundations for warning policy (Mileti and Sorensen 1990; Nigg 1995; Gruntfest and Carsell 2000), while others have conducted forensic audits of specific events to focus on behavior and culture as response factors (e.g., Gruntfest 1987; Schmidlin and King 1995; Liu et al. 1996; Legates and Biddle 1999). The construction and delivery of warnings, and their reception leading to successful mitigation by stakeholders are complex scientific, political, and social processes. Sims and Baumann (1983, p.168) summed up these complexities with the highly-inconclusive conclusion that "warning information may lead to behavior change, under highly-specific conditions, if properly executed, and delivered specifically, to targeted recipients."

Currently, there is only limited contemporary insight in the human ecology of severe weather risk and warning systems, and the knowledge base is itself changing as rapidly as the technology and meteorological knowledge. Methodologies to address the implications of changing US demographics on warning system design and policy are underway in earnest. For instance, the US population in 2025 will be less rural, significantly older, and generally smaller in family size than 3.18 (Gruntfest 2002). It will reflect substantial ethnic and cultural change, such as a projected Hispanic population of ~13 %. Emergent technologies aimed at disseminating warnings to areally-discrete levels (e.g., household alarms, PDA, hand-held computers) highlight the incumbent need to characterize fully the environmental, cultural, and societal *status quo* among various public and communications subcultures. Improvements in technical systems should in theory yield equal benefits to all users in all regions prone to tornadoes, while catering to a technophilic, highly-mobile, and diverse society where entire families move from one region to another with significant regularity. Often, however, technological advancements are pushed on the public without substantial understanding of the needs of, or pull from stakeholders. Advances often are the result of efforts focused on product content and pathway, at the expense of attention to product content and target. Conversely, since the overall warning program is theoretically tailored to the overall general population that encompasses many groups, cultures, and individual needs, there is a sort of 'dumbing down' generalization that occurs to make products understandable to lower common denominators of society.

In earlier times, especially in Oklahoma, rural populations faced increased risk from tornadoes owing to their disconnection from media and communications networks that benefit their urban cousins. In the 1940s for instance, rural residents who spotted a tornado may not have had a means to pass on warnings. With the proliferation of the first telegraphs, then radio and telephones, to television, and now the Internet, the way that warnings are disseminated has resulted in more complete coverage nationally. There is some evidence that increased risk has passed from the rural population to those in metropolitan areas (Biddle 1996). People in cities are becoming more and more removed from the natural environment, and part of the 'rat race' that is too busy working, playing, or driving from point A to point B to notice weather conditions until such conditions literally confront them (Grazulis et al. 1998). Media networks now serve rural and urban populations more uniformly with regard to weather information. Delineating these trends remains problematic however, as there are ultimately many factors in play, including proximity to public safety services such as search and rescue and rapid access to medical care. Urban populations present greater opportunities for mass-casualty disasters by presenting targets of concentrated population, whereas rural populations suffer differing vulnerabilities related to housing and resource allocation. The aforementioned cultural changes (e.g., increases in foreign language populations), demographic shifts (e.g., aging, shrinking middle class), political trends (e.g., funding decisions), and housing (e.g., proliferation of mobile homes), coupled with any natural or anthropogenic climate changes, result in fluid regions of risk. For instance, even the possibility of future increases in storm frequency and magnitude (and any associated changes in tornado risk) that could be attributable to 'global warming' has generated enough concern to spur the insurance industry to commission numerous studies (Flavin 1994).

Regional differences in coping with risk are also hard to define and measure. Aside from familiarity with the look, character, and impacts of storms, as well as with warning system routines and how to get warning information, there do not appear to be any tangible differences in the way Oklahomans perceive tornado risk itself. Yet, there may be differences in the Oklahomans they cope. Often what is expressed in attitudinal surveys does not correspond well to what actual response behaviors are demonstrated. For instance, in spite of the high profile that religion takes in the 'Bible Belt', there is no evidence that Oklahomans are excessively fatalistic about dealing with weather risks (Biddle 1996). People may claim that "God will protect them," but these same people get in the storm shelter when the tornado approaches. All this may mean that it is the warning environment culture that differs, rather than the make up of society in general. Still, there clearly are cultural geographical patterns in increased risk factors – most notably poverty and education levels – which greatly alter abilities to access the warning products that are available. Additional challenges exist to serve the very young and elderly, the mobility, vision, and hearing impaired, and those in sub-standard housing such as mobile homes. It is an unsubstantiated assertion that the issues remain concerns in Oklahoma to the same extent as in Michigan, or Mississippi, or any other state. Likewise, key safety issues such as providing shelter access are in need of additional redress.

1.4.1 - *Warning Behavior and Coping Styles*

Attempts to characterize the behavior of disaster victims and survivors stress two primary sets of personal profiles (Drabek 1986; Tobin and Montz 1997). The first, 'cognitive factors' – are attitudinal variables and behavioral characteristics that influence risk perception – such as religious beliefs, political ideologies, and personality traits. Theoretically, these are the personality traits and personal choices available to individuals. The second, 'situational factors' – are physical and demographic variables that affect a persons range of choices and responses to the risk – such as shelter availability, parental responsibility, or personal mobility. Thus, these personality profiles are the circumstances that enable or limit the range of choices. An example of a cognitive factor influencing warning compliance is seen in the '*cry wolf effect*'[I] – where subjects ignore warnings after becoming conditioned owing to warned events of the past where no personal impact followed (Breznitz 1984). Examples of situational factors include cases where subjects are precluded from complying with a warning because of inability to afford shelter, or mental or physical impairments limiting ability to act on a warning. For instance, elderly persons are less likely to heed warnings as a consequence of compromised mobility, situational communication factors, and previous experience with the risk agent (Gruntfest 1987). Additional warning failure modes include: being completely unaware of the risk, owing to preformed attitudes about the hazard (cognitive); the inability to evacuate because one does not own a car (situational); failure to understand the warning owing to a language or physical barrier (situational); or beliefs that "it won't happen to me" or "God will protect us" and thus there is no purpose in mitigative action (cognitive). To elicit mitigative response, a warning must convey that the threat is real. If there is significant doubt about its validity, it will be ignored. If it is only given marginal credibility, it is likely to evoke 'confirmation behavior' – by which recipients seek other sources (such as often happens with tornadoes) – by dangerously venturing outside or to a window to look for the tornado (Drabek and Stevenson 1971).

Sims and Baumann (1972) suggested that regional 'coping styles' were partially responsible for differing tornado death rates between those living in differing regions of the US. They concluded after surveys that Southerners' interactions with nature (and tornado risk) were determined by external forces – attributable in a large part to religious convictions promoting an 'external locus of control' where individuals present with fatalistic attitudes regarding moderation of risk posed by 'Acts-of-God' – and manifested by a neglect of the benefits to be derived from government and technology, such as warning systems. Their premise was that there were significant cultural differences in the way various societal sectors accessed and utilized tornado warning systems, and their theories resonate in some of the contemporary hazard literature (e.g., Alexander 2002) despite limited applicability, insignificant sample sizes, and antiquated generalities (Biddle 1996; Etkin and Myers 2000). Ultimately, risk is not restricted to a lack of awareness among regions, the poor, disenfranchised, or elderly. For many people, the more common concerns of daily life overshadow consideration of some low probability event, no matter how catastrophic or lethal its potential. This is especially true if little control is perceived over its probability (Drabek 1986). Biddle (1996) found that most of Tornado Alley has similar access to warnings, and similar awareness of tornado risk. National watch and warning programs (WWP) are instituted in a generally homogeneous fashion. Local attention to storm risks and warning dissemination programs vary on the local level, but cultural behavior factors – if they existed on a regional basis to affect warning efficacy – have eroded or are now completely overshadowed by stronger local and situational characteristics. Today, other more basic demographical and environmental factors (e.g., population density, age, health factors, and especially socioeconomics) play much larger roles than ethnocultural traits. Nonetheless, despite a lack of contemporary supporting research, the idea that warning compliance and efficacy is significantly dictated by a multitude of cultural conditions is still a regularly cited concept. However, methodologies for investigating and confirming this paradigm remain absent. While warning systems have undergone major and frequent overhauls, both locally and nationally, so have the human ecological variables related to warnings, which are likewise dynamic. Thus, human ecological factors have never been fully researched, nor adequately incorporated into warning system planning. This greatly impedes ability to serve stakeholders, as well as to parameterize warning systems or to develop performance metrics.

A key to future warning system design and technological upgrade is investigating and cataloging various aspects of response, reception, and utility in contemporary events. Much of what was identified by the response literature produced at the dawn of formal weather warnings may no longer be valid, considering the many changes to both the system and stakeholder populations. Most assessments have been tied to and biased toward the era(s) considered (Grazulis et al. 1998). People in cities are becoming more and more disconnected and insulated from the natural environment. For instance, there appears to be conflicting evidence about tornado risk in rural populations versus those in metropolitan areas. In the past, rural communities were at increased risk by segregation from information sources. Today media networks tend to serve rural and urban populations more uniformly (Biddle 1996). Urban populations present greater opportunities for mass-casualty disasters by presenting targets of concentrated population, whereas rural populations suffer differing vulnerabilities related to housing and resource allocation (Grazulis 1996). Delineating these risks in any broad sense is difficult. Ultimately, many factors influence overall tornado risk, such as proximity to public safety resources and advanced medical care, as well as numerous situational factors and personality traits.

1.4.1.1 - *Confirmation Behavior* -

For most people, the initial reaction to warning is denial and disbelief (Drabek 1986). To elicit mitigative response, a warning must convey that the threat is real. If there is significant doubt about its validity, it will be ignored. Even when credibility of the warning source is not in doubt, the natural reaction is to search for corroborating information. This is known as *confirmation behavior*[3], also called 'normalcy bias' (Drabek and Stevenson 1971; Perry et al. 1981) – by which recipients seek other information – such as dangerously venturing outside or to a window to look for the tornado upon receiving a tornado warning. Confirmation behavior processes 'self-correct' receiver perceptions of risk to comfortable levels of reasonableness, attempting to overcome inertial feelings of disbelief, and is consistently identified in the literature as an inherent part of the warning process and human condition (Mileti and Fitzpatrick 1991; Mileti 1999). In general, when individuals receive a warning, they assess its significance to themselves and to others significant to them, based on a variety of factors. These factors include past interaction not only with the hazard agent involved, but also any warning systems, played against various elements of personality (ideologies, values, goals, responsibilities). Reinforcement of the message is sought by observing environmental cues (e.g., going outside to look at sky; hearing the wind), checking alternative warning sources of the message is commonly sought (e.g., polling multiple TV channels), and inquiring how peers perceive the impending risk (e.g., phoning neighbors). The common *sequelae* of actions subsequent to a warning can be described also as 'queuing' – where risk information is accumulated and mentally stored until a risk aversion threshold is reached – by environmental cues, additional warnings, or cognitive realizations. It is in essence a "queuing of cues," until a tipping point is reached to spur warning compliance and protective action. The confirmation process is so common that attempts to bypass or eliminate it have been fruitless. Instead, warning authorities must integrate this behavior into the planning process. This is attempted by increasing lead times, maintaining warning message consistency and source credibility, and continuously directing receivers with explicit instructions on how to respond with what is known as 'call-to-action' (CTA) statements.

Haas (1973) noted long ago the importance of environmental cues to inducing warning reaction. In the modern era, as especially indicated in recent tornado events, perception of environmental cues is now commonly achieved via TV. Images of the weather are less often derived by naked eye, but rather by live digital image. It is important to note that such images are still based on environmental cues (vision), only that they are not *in situ*. Tornado video in a warning situation is significantly different than receipt of the exact same information conveyed by a radio report or TV text 'crawl'. With regard to risk communication, "a picture may indeed be worth a thousand words." Biddle (2000) found that video broadcast live as a tornado approached a metropolitan area had a major impact on warning awareness and compliance among viewers and the folks that talked to them. There are numerous questions regarding the spatial aspects of such conveyances. For instance, does such video result in high numbers of viewers wrongly perceiving themselves to be in the path of a threatening tornado or within a valid warning? Might there be a large *de facto* false alarm component to video images that accompany verbal or text warning information that lacks geographic specificity? Lopes (1992) suggested people can become desensitized when exposed to actual disaster or damage images, possibly due to greater fears of the unknown and its imagined impacts. That was not the case for the OCT, because it was big in size when it was south of Amber (Figure 1.2). The impact of video is complex and involves a number of situational and contextual variables. Similar to the instant and emotional impact of imagery supplied by 'combat camera' in an ongoing war, the policy implications brought by exposure to live tornado video on individual and community perceptions can be virtually instant, yet may not be understood until well after, permanently altering the human ecological response for that event (Moeller 1989).

Figure 1.2 - OCT at 7 mi South of Amber, Ok. R. McPherson, Wolfinbarger, Reader, and Duvall, 1999, Oklahoma Climatological Survey. Used with permission. Copyright.

Given that previous studies (Hanson et al. 1979; Grazulis et al. 1998; Gruntfest 2002) indicate that past experience with weather risk is an important factor in response to subsequent risks, there is little doubt that real-time images of tornado events affect the warning process. Slovic (1987) suggests that the most likely impact is increasing acute awareness ('availability heuristic'). Video imagery also seems to increase overall (or chronic awareness) particularly during an event in areas climatologically most prone to tornadoes. By simply keeping the risk tangible and real, the result is a behavioral state known as 'hyper-vigilance.' However, the same imagery in less climatologically active areas may foster 'it doesn't happen here' attitudes ('affect heuristic'), decreasing awareness and preparedness (Slovic 1987). Every time a tornado warning is issued and the sirens do not wail, or that each time the sirens wail when there is NOT a tornado warning, there is a cost (Lindell 1987; Biddle 1996, Biddle 2000). Public response evolves as fast as the warning technology, and much faster than our ability to characterize these responses.

1.4.1.2 - *False Alarms, Close Calls, and Cry Wolf Syndrome* -

Cry wolf effects – the declining attention to, and lowered confidence in, community warning programs that emerges following a *false alarm*[K] (or series of false alarms) – is a cognitive factor of recurrent concern in the literature (Mileti 1975; Burnham 1992; Atwood and Major 1998). While detailed false alarm research regarding short-fuse weather hazards is sparse, some hazard literature has gone so far as to suggest that every cancelled warning produces a negative impact (Breznitz 1984). Other works have found that false alarm impacts are magnified by the media (Mileti and Fitzpatrick 1992), or that false alarms followed closely by official explanations can lessen the negative impact (Baker 1993). Emerging research suggests that the impacts of previous false alarms may not have negative impacts in all situations, particularly in high-consequence, short-fuse events. The implications of this remain a topic for further study, but ideas put forth by Gruntfest et al. (2002) indicate an inherent value to both warning networks and stakeholders in false alarm experiences where the predicted event did not fully materialize. These experiences are labeled '*close calls*'[L] or *near-miss events*[M] and are found in many situations to serve as learning experiences, tests of procedures and technological systems, and publicized incidents that remind people of the hazard and the functions of the warning systems themselves. Still, there is little doubt that some stakeholders can develop some level of conditioning if exposed to a significant number of false alarms. False alarms are most prevalent when warning systems are new, and magnified in situations where warnings are issued for large areas and long time-frames. The spatial and temporal size of a warning (in severe local storm scenarios) dictates that many recipients covered by warning will not experience any impact. Under formal *NWS* verification schemes, if the warned event does occur within the warned area (e.g., a county), no portion will be classified as a 'false alarm' – even a large portion of the area saw no impact. Also, the *NWS* will mark a tornado warning as valid even if there were high winds or hail in the storm, and it does not produce a tornado. Still, many people experiencing no personal impact could perceive the event as a false alarm. Thus, it is a practical goal of warning systems to make warnings as discrete in time and space as possible. Research from other hazards, such as flash floods, hurricane landfalls, and chemical spills, may not translate well in characterizing the warning ecology for severe local storms, as impacts vary significantly based on the frequency of events and local event impact histories (Dow and Cutter 1998). The false alarm dynamic remains an area ripe for further research, especially if plans for an 'all hazard warning system' materialize, as it would surely bring with it changes in false alarm ratios and perceptions of warning system utility and value.

1.4.2 - *Warning Message Content*

Key elements of warning compliance are related to warning message content. In its most basic form, a warning must convey the 'what, where, and when' of the risk, with some inclusion of the 'why' and regarding 'who' is at risk. Warning message content influences compliance directly (Carter 1980). The more consistent the message across several broadcasts and media, the more direct and timely is compliance (Mileti and Sorensen 1990). Reliability and 'officialness' of warning source(s), and observed actions of local authorities, are also important to compliance. This is because identical warning messages evoke differing responses among stakeholders. There has been a trend to streamline *NWS* warning formats (by *NWS*) to key bits of information ('bullet format' - NWS 2001) for short-fuse scenarios such as tornadoes. The claimed utility of such formats is to enhance and expedite understanding and compliance, but little aside from anecdotal evidence is available to support these claims.

1.4.2.1 - *Call-to-Action Statements* -

'Call-to-action' statements are bits of verbal information addressing recommended preparatory and response actions to be undertaken by users. They are short, direct, supplementary messages that advise people about specific threats in specific locations, aimed at spurring specific mitigative actions to protect personal safety. For example, if a storm is about to cross a lake, a CTA might focus on quick action to be taken by boaters in the path. If a tornado is known to be 'rain-wrapped and not visible,' a CTA could be used to remind people that they will likely not see the tornado coming, so they shouldn't wait for its appearance (Troutman et al. c.2003). Some CTA statements are remedial and seemingly obvious – such as "this is a dangerous storm, take cover now!" – but they may be important to streamlining the confirmation process, especially among highly-vulnerable personalities. Conversely, CTA can take up valuable time and bandwidth that could be utilized to communicate more detail about storm path and intensities, and a controversy for planning and for confirmation behavior ensues. The value of CTA statements have been lauded by *NWS* in recent tornado disasters in Oklahoma (1999), Texas (2000), and Alabama (2002), though there is some criticism of the CTA concept and *post hoc* assessments of their value (Doswell 2003).

1.4.2.2 - *Spatial and Temporal Information* -

There is a discrete, yet largely-uncharacterized 'window of opportunity' in time for a warning to capture public attention and spur mitigative response. Theoretically, the longer the lead time – or the more advanced the warning - the higher the efficiency and compliance. Surprisingly, this does not seem to be the situation, as it appears that the relationship between lead time and compliance is quite complicated, illogical, and non-linear. Some response research (Balluz et al. 1997) has indicated that, in spite of available lead time, most who have sought shelter in a warning situation did so within five min or less of reception. This suggests that even with clear understanding of the hazard and early reception of credible warning information, the confirmation process has not been extirpated with technological and programmatic advancements in the warning process resulting in the tangible mitigation improvements expected. It seems earlier and superior warning information is often lost in the period between the reception and reaction phases. Similar behavior has been noted in recent tornadoes in spite of very long average lead times (Biddle 2000). The ALT (Average Lead Time) for the OCT official warning was 18 min, with some areas having more than a 30 min lead time before tornadoes struck (Quoetone et al. 2000). This is explored in detail in the survey results below, as it has emerged as one of the key observations of this work.

Given that warning information has become more precise in time and space, the numbers of people spending hours in storm shelters has dropped in kind. Yet, this has brought new challenges to the EMA community. Not only do advances in ALT not always translate into higher compliance rates, increased ALT have made flight from a tornado path upon receipt of a tornado warning much more possible and common. This is essentially an evacuation, a concept not previously considered possible (or intended) for a short-fuse hazard such as tornadoes. ALT coupled with the nature of real-time tornado coverage on TV is resulting in ever-increasing examples of people choosing to take to the highways to flee the tornado (Hammer and Schmidlin 2002). Alexander (1993) noted that longer warning ALT can lead to situational apathy and distract from optimal response. Mileti (1999, p. 175) summarized the improvements of tornado warning ALT time over the past two decades: " In 1978 warnings were issued for 22 percent of tornadoes; the average lead time was three minutes. In 1995 the percentage had risen to 60 and the lead time to almost nine minutes" and further noted that "the nation is moving from 'detected' warnings to an era of 'predictive' tornado warnings." Were such ambitions to come to full fruition, they would likely turn the current paradigm of human ecology of tornado warnings (limited in definition as it is) on its face by dramatically altering views of the warning landscape in multiple ways. Warning lead time relationships with reception and compliance are important research gaps. With future ALT projected at ever-increasing durations, the supporting human ecology research is rendered purely theoretical. The implications of longer lead times on warning behavior and mitigation options demand careful and thorough examination (Gruntfest 2002; Doswell 2003), particularly with regard to impacts on flight from tornadoes in vehicles, and is also discussed at length below.

Technologies or forecasting skills that allow for more site-specific warnings are, in most instances, beneficial to the system and inherently result in smaller numbers of persons subjected to false alarms, minimize the cry wolf effect, and increase compliance over time (Mileti 1975; Drabek 1986; Nigg 1995). Conversely, there is a theoretical threshold minimum warning size imposed by the technological and logistical capabilities of the warning system. Logistically, it is not practical for authorities to warn each household with the proverbial knock at the door from a police officer. While technological innovations such as cell phones and Blackberry™ devices suggest personal warnings may eventually be possible, the availability of such systems to the bulk of society, particularly to some of the most vulnerable sectors, is years away. Thus, the size of a warning area and the population therein remain important factors for warning applications. Mileti (1997) noted that the areal extent of warnings presents significant logistical hurdles for the systems to overcome. Threats to larger areas involve warning more people and require working through more media and organizations. Similar threats to smaller areas facilitate localized warning efforts that are more readily coordinated cutting the number of people inaccurately or unnecessarily warned, and insuring that those not in areas 'under the gun' do not cease normal activities. Small areas are a logisitical challenge however.

Akin to the impact of increasing temporal warning precision, the response spectrum for scale changes and accompanied procedural changes are also purely speculative. It is unlikely that compliance continues to increase past certain temporal precision thresholds, but it would seem logical to assume response parameters are positively affected with spatial precision, assuming a reasonable false alarm ratio (FAR). Delineating these thresholds remains a major research gap. A system that seeks spatially and temporally smaller warnings allows customized responses, with stakeholder utilization commensurate with given activities and risk exposures. Such efforts might be automated with detailed mitigation plans in place, with warning systems calibrated to acceptable levels of probability of detection (POD), FAR, and ALT over a given test period. The use of probability-based warnings to better communicate the increased uncertainty that comes with more precise warning scales may eventually prove workable, but there are many unknowns with regard to changes in decision-making thresholds that might result in performance or utility trade-offs in FAR (i.e., Type I and Type II errors), and associated societal costs (Stewart and Bostrum 2002).

If you don't like the weather in Oklahoma, wait a minute and it'll change.
- Will Rogers -
Political Satirist and Native Oklahoman

The image of Man-Ka-Ih (tornado) - a great wild horse - roams the skies. It is violent. Kiowas speak to it, asking it to pass over as they enter storm shelters, that take the shape of the Earth.
- N. Scott Momaday -
THE WAY TO RAINY MOUNTAIN

2 - CONTEMPORARY TORNADO WARNING SYSTEMS

Severe convective storms and their progeny - most notably tornadoes - present significant risk to life and property. Mileti (1999) noted that tornadoes are the leading cause of injury from any natural hazard in the US, ranking 2nd in mean annual deaths, and 3rd in mean annual property loss. *Federal Emergency Management Agency [FEMA]* allocated in excess of $1B for presidentially-declared tornado disasters in the first-half of the 1990s (Mileti 1999) while again - the 1999 OCT alone carried a price tag in excess of $1B (Grazulis 2001). Yet, tornado casualties have shown significant and somewhat steady declines since the implementation of severe local storm warning systems over the last half-century. The severe weather forecasting and WWP as overseen by *NWS*, has operated in virtually the same manner since its inception beginning in the early 1950s. Exceptions to this have been primarily in infrastructure upgrades (Grazulis 1996) and include the proliferation of detection and communication technologies. However, it is important to note that the way warnings are disseminated and received has dramatically and consistently changed, and that these changes are reflected in the spectrum of human risk (Grazulis et al. 1998). Warning system modernization has often occurred in evolutionary spurts, with the rapid integration of the telegraph, radio, telephone, television, and now Internet and wireless messaging systems. A significant research gap exists within the overlap between what is technologically possible and what is socially feasible. Technological advancements are not the only factors, as Doswell et al. (1999) documented the evolution and importance of public awareness campaigns and storm spotter networks to the overall performance of severe weather warning programs. In addition there is a clear, but dynamic population bias in historical and contemporary observational data (Biddle 1996).

2.1 - Evolution of the Watch-Warning Program

While US thunderstorm and tornado fatalities have steadily dropped, damage totals have steadily increased. As extrapolated from Grazulis (1996) since 1680, about 20 000 deaths have been recorded from more than 4000 tornadoes. In the 'Official Period' of severe weather forecasting [1953-present], mean annual tornado deaths were 65.8 per annum (Grazulis 2001). Over the last decade [1996-2005], tornado deaths fell to 57.8 annually, and only twice in the last two decades have total annual deaths topped 100 – in 1984 and 1998 – with 122 and 132 deaths respectively (SPC c.2006). Grazulis et al. (1998) found that the *NWS* severe weather WWP has had a definitive impact on tornado casualties, saving at least 5800 lives since the program was initiated by the *US Weather Bureau* in 1953. Doswell et al. (1998) estimated more than twice this number of lives saved over the same period.

Successes of warning systems and mitigation programs aside, hubris in the face of the regular and still significant risk posed by tornadoes to society – in particular to certain vulnerable sectors – is foolish. There remains significant opportunity to see a 300-plus tornado fatality year or 100-plus fatality event if weather forecasting programs and warning networks fail to keep pace with an increasingly complex society and the dynamic human environment. Grazulis et al. (1998) noted that while casualties show signs of 'bottoming out', the potential for mass casualty events lingers. Large venue special events (e.g., stock car races, stadium events, outdoor festivals) are increasing both in frequency and total attendance per event. Edwards and Lemon (2002) caution that numerous tornado disasters have been narrowly averted, highlighting the currently very real risk of a mass casualty tornado to suggest that it is not a question of if such a catastrophe will occur, but when and where. It is easy to envision scenarios that involve tornadoes within the heart of an urban area or bumper-to-bumper rush hour traffic, particularly in regions on the margins of high tornado frequency where warning networks, personal experience, and public awareness may not be as advanced as the norm in Tornado Alley (Grazulis et al. 1998). It is also unknown how future climate change might alter the physical environment in such a way as to increase tornado frequency in certain areas, bringing with it concurrent increases in risk (Etkin and Myers 2000). All of the above seem to justify what little resources are currently extended to severe weather warning programs, and argue for continued research and development for all components of the warning system, including warning content, format, dissemination methods, and reception variables. Advancements in technology alone will not be enough to eliminate the risk to certain vulnerable sectors of society, and to increasingly large, mobile, and urban populations.

2.1.1 - *Brief History of NWS Warning Program*

In the early 1950s, the existence and benefits of the Department of Defense [DOD] program became increasingly known to the civilian population and the media, and political demands to establish a public program pushed the *US Weather Bureau* to establish a *Severe Weather Unit* in Kansas City, aimed at implementing a national program for severe weather forecasts delivered through local *Weather Bureau* offices. A watershed year was 1953 for tornado warning programs as it marked not only the first full year of centralized severe local storm prediction (Washington, DC), but also saw numerous intense tornadoes that killed 100-plus each in the widespread locations of Waco, Texas; Flint, Michigan; and Worcester, Massachusetts. In 1956, the *Weather Bureau* began to address public safety and warning program awareness with various pamphlets and documentary style TV programs. On Palm Sunday of 1965, a major Midwestern tornado outbreak killed 265 persons. This focused further attention and resources on warning dissemination issues and resulted in the creation of the Skywarn Spotter Program and NOAA Weather Radio (NWR).

In 1966, the *tornado watch*[N] was introduced by the *SEvere Local Storms [SELS]* unit in Kansas City. The WWP concept has generally remained conceptually the same since its inception. More recent developments to the history of warning programs include the 1988 completion of the NEXRAD Doppler radar program as part of a formal *NWS* Modernization and Restructuring (MAR) effort, and the moving and reorganization of the *SELS* to Norman, Oklahoma as the *Storm Prediction Center [SPC]*. For more detailed information on the history and evolution of US severe weather forecasting and warning programs see Galway 1982; Galway 1989; Ostby 1992, Grazulis 1993; Grice et al. 1999; and Bradford 2001.

2.2 - The US Tornado Problem

Historically (1953-1999 - Grazulis 1993), the US experiences an average of ~85 tornado-related fatalities per year. For 2000-2006, it was an average of 33.2 fatalities (SPC c.2007). If one compares the two time frames, it shows that deaths were roughly one-third the last seven years compared to the Official Period. Grazulis (2001) suggests the steady drop in tornado fatalities began in the 1930s - prior to the onset of organized warning and forecasting efforts - indicating that other societal forces are partially responsible. In noting that fatalities per capita have dropped in magnitudes incongruent to what could reasonably be attributed to warning programs alone, his hypotheses include: rural depopulation and migration to the West Coast early in the 20th Century; the proliferation of radio and then TV in the mid-century; increasing capabilities in emergency medical care; and institutionalized safety programs of the World War II manufacturing culture that persisted until recently with 'duck-and-cover' civil defense mind sets of the Cold War / Nuclear Era (Platt 1999). Nonetheless, the imprint in the historical record marking advancements in forecasting techniques, observing technologies, severe storm research, and IT applications and telecommunications, that combine as warning systems is well documented (Grazulis et al. 1998; Doswell et al. 1999; Grazulis 2001). Brooks and Doswell (2002) describe trends that clearly demarcate the impacts of the WWP on tornado morbidity and mortality, with death rates dropping since 1925.

The consistent decline in tornado fatalities in the modern era has greatly altered definitions and public perceptions of what constitute a '*tornado disaster*'[10] (Grazulis et al. 1998). The last single tornado to kill at least 50 persons was in 1971 in Mississippi, and the last one to kill at least 100 was in 1953 in Michigan (Grazulis 2001). Still, it is not unusual after a tornado event to see newspaper articles discussing a lack of warning (Daily Oklahoman 30 March 2007). However, usually with some investigation it is clear that, in most cases, there was in fact adequate warning available, and that it simply was not accessed or could not be acted upon. That the WWP has been available for some three generations and the system has by most measures improved with time, is by most accounts a success story. Baselines relative to alternatives that have not been employed, or for what may be tried in the future, are not currently evident (Brooks and Doswell 2002).

2.2.1 - *TORNADO CLIMATOLOGY AND THE GEOGRAPHY OF RISK*

Grazulis (2001, p. 269) identifies three primary ways to define tornado risk: 1) the risk of encountering some part of a tornado; 2) the risk to property; and 3) the risk to human life. For the most part, warning programs (and this research) are concerned with risk to human life. There are approximately 2.3M US deaths per annum from all causes, of which about 350 are due to natural hazards. Usually about one-fouth of these deaths are tornado-related. A 1995 study put the annual risk of death from tornadoes per million people at 0.5 (or 1 in 2M). For perspective, this compared to 1500 per million for health problems related to air pollution (Botkin and Keller 1995). Based on more recent statistics, tornado risk is now as low as 0.12 deaths per million persons per year, or less than one in 8.33M (Brooks and Doswell 2002). *Lifetime odds*[P] for a person born in 1999 to die from any form of 'cataclysmic storm' (including tornadoes) are 1: 27 573 (NSC c.2005). All things considered, the risk for death by storm generally, and death by tornado specifically, is relatively low and can be modified considerably by choice and behavior.

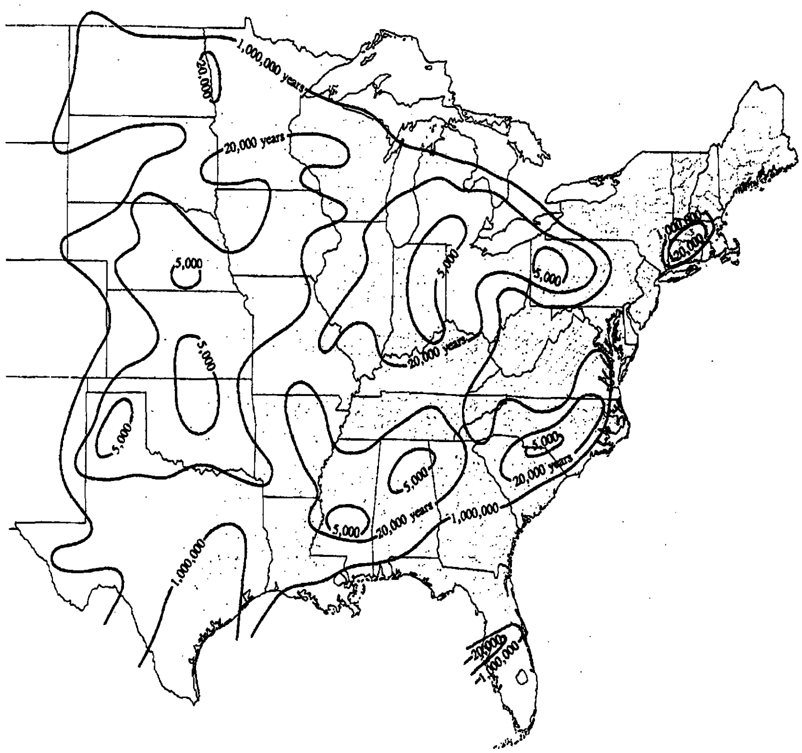

Figure 2.1 - Recurrence Interval of Tornadoes (east of Rocky Mtns). T. Grazulis, The Tornado: Nature's Ultimate Windstorm. Used with permission. Copyright.

While there is tornado risk in the majority of the US, most of the risk lies in the central portion. Tornado events have resulted in significant casualties in Massachusetts, Florida, Wyoming, and extreme southwest Texas, as well as many locations in between. However, certain areas of the Great Plains, Midwest, and the South have significantly higher *recurrence intervals*[Q] (RI) for *Significant Tornadoes*[R] (Figure 2.1) as compared to the national mean. Mitigation programs including warning systems tend to receive more attention and resources in these areas. Such programs are warranted throughout the eastern two-thirds of the US, where higher potential for mass casualty events exist. However, there is much variation in warning program implementation. Regional and local variation is considerable even in Tornado Alley, as one town may have little or no warning infrastructure while its neighboring town may have a 'cutting edge' system with all the modern 'bells and whistles.' Basic evidence of this is found by noting the varied numbers and organizational structures of *Skywarn Programs*[S] in given regions, as well as charting the locations of *Stormready*[T] certified communities (NOAA c.2007). Areas with lower RI often garner less than adequate attention, fostering complacency among the public as well as response agencies (Grazulis et al. 1998). For these reasons, it is stressed that while warning systems should be considered uniformly important in the majority of the US, most of the risk lies east of the Rocky Mountains. Tornado events have resulted in significant casualties in Massachusetts, Florida, Wyoming, extreme southwest Texas, as well as many locations in between. However, certain areas of the Great Plains, Midwest, and South have significant fatalities to the other areas of the US (Figure 2.2). Research and development of modernized technologies and techniques should aim to serve all jurisdictions in a uniform manner.

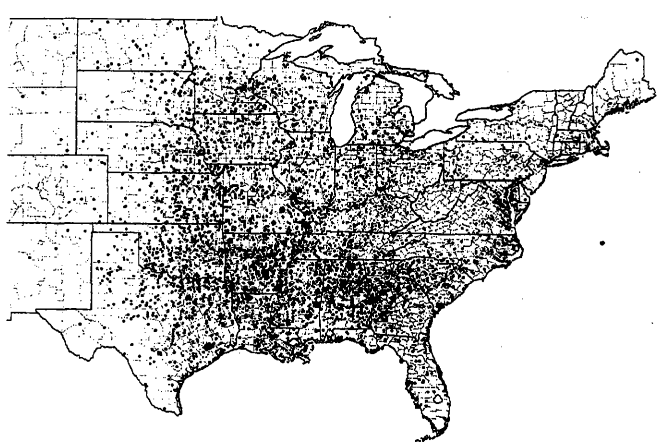

Figure 2.2 - Tornadoes With a Death (a point for at least one fatality). Matthew Biddle, The Tornado: Nature's Ultimate Windstorm. Through 1998. Copyright.

2.2.1.1 - *Tornado Epidemiology* -

Most tornado victims are killed by either by being struck by highly-energized flying debris, or when they are lifted, bounced, or sent airborne and subsequently strike the ground or some other static object. Most of these fatalities are generically classified as 'blunt force trauma', and commonly affects the head and spinal column, and 'major complex trauma', which includes major missile injuries, lacerations, internal hemorrhaging, and amputations. A smaller category is 'mechanical asphyxiation', which occurs when large debris, such as a wall or tree, falls on the victim, preventing expansion of lungs (Brenner and Noji 1995; Lillibridge 1997).

A non-physiological risk factor for death is the strength of the tornado. Simply, the stronger the winds, the more damage, and the more damage, the more morbidity and mortality. In fact, violent tornadoes [F4/F5 on the Fujita Scale] comprise about 1 % of all tornadoes, yet they regularly account for about ~70 % of all fatalities (Table 2.1). Also, as should be expected, nocturnal tornadoes cause more fatalities than their daylight counterparts. Night-time tornadoes are simply are less likely to be spotted, which can delay the confirmation process even if a warning has been issued. Since most of the population is asleep, available warnings fail to be accessed and may not reach those in the path, and there are fewer opportunities for people to communicate warnings in informal networks. Structures below ground or other engineered storm-proof structures clearly contribute to survivability; thus, a significant risk factor for death is a lack of available shelter (Marshall 2000).

Table 2.1 - Percent Occurrence and Fatality Rates of Tornadoes (Fujita Scale)

Weak Tornadoes (F0/F1)	**Strong Tornadoes (F2/F3)**	**Violent Tornadoes (F4/F5)**
88% of all tornadoes	11% of all tornadoes	**1% of all tornadoes**
Less than 2% of deaths	Nearly 28% of all deaths	**70% of all tornado deaths**
Lifetime: 1 to 10 minutes	Lifetime: 20 minutes or longer	Lifetime: 1 hour or longer
Winds less than 110 mph	Winds 111 mph to 205 mph	Winds greater than 206 mph

With regard to tornadoes, the mobile and manufactured home (MMH) population is known to exhibit such disproportionally-high vulnerability compared to those in regular frame houses than the mean population. With few limitations, there simply is no severe storm or tornado scenario where occupying a mobile home is safe (AMS 2004). 'Shelter-in-place' is not a viable option, as it has been shown that many mobile homes have been destroyed in winds significantly less than 150 km/h (<100 mph). The MMH population continues to grow as the popularity of the structures – traditional among the poor in particular – has increased and now includes mid- and upper-income groups seeking seasonal and retirement homes, especially in the 'Humid South'. The statistics tell the story: in recent years MMH accounted for between ¼ and ¾ of annual tornado deaths (Grazulis 2001); and, over the last two decades *half* of all tornado deaths have been among MMH (Golden c.2003).

A recent tornado disaster – a nocturnal November (2005) tornado near Evansville, Indiana – killed a total of 23 people, at least 19 of which were MMH occupants. According to Brooks and Doswell (2002, p. 355) the "mean (median) annual [MMH] death rate from 1975 to 2000 in was 1.23 (1.19) per million per year, whereas the mean (median) rate from 1985 to 2000 in permanent housing was 0.06 (0.04) per million per year. In short, the death rate is approximately 20 times as high in mobile homes as in permanent homes, and the [MMH] rate is about 70 % of the rate for the total US population prior to 1925." It is not serendipity that a disproportionate number of tornado fatalities come from the largely-poor MMH. It stands to reason that with roughly one-twelfth of the population accounting for half the tornado-related deaths that the equation is skewed by societal rather than natural forces. While much of the underlying causes for this situation can be traced directly to socio-economics (i.e., inability to afford permanent housing) and are tied less directly to warning issues, future warning programs should design new methods aimed at MMH populations with the problem addressed as what it is – a public health crisis.

Finally, as noted above, the existence of warning programs and the timely reception of warnings remarkably decrease tornado risk exposure. Warning systems and increased awareness have dramatically lowered tornado fatality rates, there may also be a small but significant medical advancement bias in the decrease. Deaths have dropped off in part due because medical treatment, search and rescue, and emergency transport capabilities have all undergone dramatic advancements. This is partly evident in the incidence of higher percentages of fatalities killed in the field, as compared to the historical tornado mortality (Grazulis 2001). Many forms of injury that were fatal in the past are less so today. Additional demographic shifts related to urbanization also alter perceptions of warning system impacts and can foster misrepresentations. These factors may augment data that champion "better warning" or "increased awareness," and care must be taken to note the changes in the data as well as comparing aggregates.

2.3 - Oklahoma Tornado Climatology

Central Oklahoma averages ~60 thunderstorm days a year with about half classified as "severe" (Kessler 1983), and ~21 tornado days per annum (OCS c.2006). "Tornado Season" for Oklahoma is roughly April through June, but significant events have occurred in every month. Oklahoma experiences ~50 Significant Tornadoes yearly, with about ½ between the hours of 4:00 pm and 8:00 pm (2100 and 0100 UTC - Grazulis 1996). Total Oklahoma tornado deaths over the last two centuries are about 1400 persons (Grazulis 1996; SPC c.2006), with an average rate over the last two decades of 3.75 persons per annum. By any measure, the OCT was one of the worst tornadoes in magnitude and intensity to ever strike Oklahoma, and at least in the contempary era to occur in the US. While it was the first 'violent tornado' (F4/F5) to hit within OKC, the city has a history that includes many tornadoes and tornado disasters. About 100 Significant Tornadoes have been recorded in Oklahoma County alone, with at least six notable disasters since 1930 (Branick 1994). Grazulis (1996; p. 16) reported "when the concentration of tornadoes, Significant Tornadoes, and violent tornadoes are calculated, Oklahoma is number one. Concentration per unit area is probably the truest measure of tornado risk." Using *NWS* Official Period data, portions of central Oklahoma yield RI of ~2000 yrs, among the shortest anywhere on Earth (Grazulis 2001). Assessment of tornado risk based on political subdivisions (such as states) is always problematic. Yet, it remains important to note that by virtually any scientific measure, Oklahoma is at or near the top of *all* important statistical categories for tornado frequency, magnitude, and risk (Stein and Hill 1993). There have been ~275 killer tornadoes in the history of the state for which there are reliable records (Grazulis 2001). When population density is considered, Oklahoma ranks 4th among states in tornado fatalities at 77 per million persons (NWS 2001), yet 36th in km^2 at 56 470 per million persons (USBC 2001). In average annual adjusted economic damages (1950-95), Oklahoma ranked 5th at ~\$23M (ESIG c.2006). By any data set, the high tornado frequency, high ratio of Significant Tornadoes, and the continued urbanization of greater OKC, all conspire to make it the most tornado-prone major city (Grazulis 1996).

In the public psyche, both inside and outside Oklahoma, it is quite clear in the vernacular that Oklahoma *IS* Tornado Alley. Oklahomans seem resigned to, and perhaps even proud of, their homeland's association with tornadoes. Likewise, national associations of Oklahoma with tornadoes are *pervasive*[U]. To the extent that these perceptions impact tornado risk generally, and how they may have molded the coping styles of those affected by the OCT specifically, pose a number of important questions. Previous studies (e.g., Hanson et al. 1979; Grazulis et al. 1998) indicate that past experience with tornado risk is an important factor in response to subsequent risks. Such would seem to be the case in Oklahoma, with the stature of intense media coverage of weather, and the proactive stance of the *NWS* and location of the *weather industry*[V] in the area. Indeed, the area is significantly tornado-prone to justify the placement of the first national center dedicated to the study of tornadoes – the *National Severe Storms Laboratory [NSSL]* – where it remains ~10 km (6.2 mi) from the OCT path. Oklahomans benefit to a degree simply by 'rubbing elbows' with personnel of these operations, as well via the incumbent public relations, educational, and media attention that surround the weather industry. While most warning system components and structures in the study area are similar to those found in majority of the US, some are unique to Oklahoma (Crawford and Morris 2000; Biddle 2000; Svenvold 2004). Regular confrontations with severe weather (and weather media) appear to augment abilities to reap the benefits of modernized warning systems (Doswell et al. 1999).

Norman, Oklahoma is currently home to numerous agencies of the *National Oceanic and Atmospheric Administration [NOAA]*, a division of the *U.S. Department of Commerce [DOC]*, including the Oklahoma City Area *Weather Forecast Office [WFO]* that serves all of central and western Oklahoma and a portion of north Texas with forecasts and warnings. This office was the prototype for contemporary severe weather operations nationally as a part of the *NWS* recent moderation and resturcturing (MAR) – that included an upgrading of technology agency-wide including the new WSR-88D Doppler radar – that was tested and developed at the OU North Base (Bluestein 1999). The emergence of Norman as a world center for research, monitoring, and prediction of tornadoes and severe local storms, began in 1948 at nearby *Tinker Air Force Base* where tornado forecasting was pioneered. This was followed by establishment of *NSSL* in Norman in 1964 where Doppler weather radar was pioneered and tested. In 1997, under other MAR initiatives, the *SPC* - responsible for the issuance of severe weather watches and hazardous weather guidance nationwide - relocated to Norman from Kansas City. Additional *NOAA* agencies including the *NEXRAD Radar Operational Center [ROC]*, and numerous federal and state atmospheric research institutes associated with *NSSL* and the *University of Oklahoma,* were placed under one cooperative umbrella in 1998 as the so-called *National Weather Center [NWC]*. The center, with emphasis in the development of numerical forecast models, environmental monitoring systems, tornado research, and severe weather forecasting, directly employs more than 600 people and injects over $60M annually into the economy (Biddle 2004a).

2.3.1 - *Previous OKC -Area Tornado Events of Importance*

The OCT was the 3rd Significant Tornado event to strike the OKC metro in less than a year (13 June and 4 October 1998). While minor in comparison (no fatalities), the media heavily covered both earlier events, forcing many people to reconsider tornado risk in their own 'backyard'. These events may have acted as antidote to any accumulated complacency as a result of a period of relative storm inactivity in the area over the previous decade. No cry wolf effect many feared had evolved from excessive exposure to warnings for non-significant events (Grazulis et al. 1998) materialized in OCT warning response. On 8 May 2003 and 9 May 2003, no fear of false alarms was found either (NOAA 2003). On 8 May 2003, what amounted to a Top 10 in *SPC* tornado damage (SPC c.2006) killed one person and was rated F4. There was less time to be warned for that tornado because of the time-of-day. Many were not back from work yet. The 1999 OCT entered Moore about 1915 CDT (0015 UTC), whereas the 2003 tornado entered Moore about 1649 CDT (2149 UTC). The difference in time was essential to enabling workers to get home and see warnings on TV (1999). In 2003, the tornado formed in Moore instead of upstream. On 8 May 2003, 75 % were warned by TV (Comstock and Mallonee 2005) which is a significant number compared to the baseline of this study.

2.4 - The Tornado Warning Process Under the Integrated Warning System

There are numerous threats to life and property from severe convective weather, most associated with supercell thunderstorms (for discussion of the meteorology, see Doswell 2001) - namely tornadoes, high winds, large hail, lightning, flash flooding - as well as miscellaneous threats to transportation activities such as wind shear, acute erosion, and compromised visibility (e.g., heavy rains or blowing dust). These phenomena are covered in forecasts and warning products for severe thunderstorms or severe convective weather - specifically *Severe Thunderstorm and Tornado Warnings* - and their associated *Convective Outlooks, Watches*, and *Nowcasts*. Outlooks and watches - issued by *SPC* on a national basis and warnings and, nowcasts – issued by *NWS* locally, form the nexus of the current national WWP (the history and evolution of which have been described elsewhere, see Galway 1989; Ostby 1992; Grazulis 1993; Bradford 2001). It is again stressed that with the exception of technological advancements, the program has remained in place roughly unchanged since its inception in the 1950s. It is important to note that the WWP came together as a function of the evolving meteorological technologies and techniques of the era, and the insight added by the personnel on hand to implement the program as political and public demand emerged. The program was not the result of an appreciable amount of sociological research, risk analyses, or policy investigations, and has been described as having 'evolved in a vacuum' (Doswell et al. 1999).

Moller et al. (1993) identify three primary groups of warning program users (stakeholders): the news media; the *IEMS ('Integrated Emergency Management System')* and EMA; and the general public. All three groups interact amid myriad independent and overlapping mitigation programs, dissemination networks, and coping mechanisms of greatly varying formality. The *NWS* is the governmental authority responsible for the issuance of severe weather warnings (NWS c.2005). Approximately 2700 tornado warnings are issued each year (Steinberg 2000). Once *NWS* issues a warning, information 'cascades' down through various stakeholder tiers - such as the mass media and EMA - to targeted end-users. In some instances, *NWS* disseminates warnings directly to the public (e.g., NWR). Doswell et al. (1999) noted the importance of warning processes proceeding within the general guidance of inter- and intra- jurisdictional *Integrated Warning Systems (IWS).* IWS is a warning system framework and subset of a broader

'Integrated Emergency Management System' to ensure four 'integrated elements of warning systems' - forecasting, detection, dissemination, and response (Mileti and Sorensen 1990) - are utilized as keys to mitigative success (Moller 2001). In the late 1980s, *NWS* adopted the IWS concept as procedural policy (NWS 2000) and it is among the most frequently utilized aspect of IEMS in the US. The *NWS* blueprint for the current warning program remains within the *NWS Family of Services*[W] *(FOS)*, a suite of severe weather forecasts, warning products, and dissemination routes that serve the *NWS mission*[X] to protect life and property (NWS c.2005). Ultimately, the goal is to have multiple media and sources disseminate the same warning information to targeted stakeholders (usually the general public) as expeditiously as possible.

When severe weather is observed, reported, or detected, *Warning Forecast Offices [WFO]* have responsibility for generating warnings. *WFOs* utilize an array of resources to accomplish this, including Doppler radar and ground-based reports from spotter networks. However, many other information sources contribute to forecaster decision-making and 'situation awareness' (e.g., satellite imagery, observational data, model output, personal experience) are involved in the warning process (Andra et al. 2002). When warnings are issued, they are relayed via numerous media of the *NWS*-FOS immediately and simultaneously. Network media include, but are not limited to: the Emergency Alert System (EAS), the National Warning System (NAWAS), NWR, and miscellaneous Internet and World Wide Web systems. Warnings are then re-disseminated by electronic mass media (local radio, TV), certain cable TV systems (e.g., *The Weather Channel*), vendor messaging systems (pagers, cell phones, alarm systems), and EMA warning networks (radio nets, sirens, loud speakers, etc.). In some instances, many warnings and nowcasts may be issued by a single *WFOs* in a very short time-frame. Active severe weather days present significant challenges to warning systems and forecasters alike. The more severe weather in a given area over a small period of time, the more logistical stress upon the entire IWS, including end users who must receive and act upon the information. In the 1999 OCT for instance, *NWS* personnel issued 70 Warnings and processed 100 field spotter reports over some 6 hr (McCarthy 2002).

Few changes in the actual information content of weather warnings themselves have occurred for most users. However, many new forms of 'value added' information have been developed for those users with specialized needs or interests. For instance, effort has been made at some *WFOs* to provide multiple formats of enhanced information to fit a variety of scenarios, rather than simply generating one or two standard forms of tornado warnings. The stated purpose is to increase effectiveness by providing specific information about the nature of the tornado threat (Smith and Piltz 1999). Such situational approaches allow forecasters to define tornado warnings - whether prompted by Doppler-generated or spotter reports - by their meteorological and geographical contexts (e.g., storm morphology: supercells vs. squall lines, environment: Great Plains vs. Florida, etc.). In addition, a variety of specific formats has been designed that include statements tailored to certain stakeholders (e.g., RV parks, boating areas, rural areas, highway overpasses), or certain storm climatologies (e.g., nocturnal events, coastlines, hurricane landfall events) that have molded *WFO* expertise (Troutman et al. c.2003). In some regions, specific warning programs for hearing impaired users have been implemented as well (Wood and Weisman 2003).

2.5 - DISSEMINATION

Subsequently, warning information is disseminated to EMA and the media for relay to the public for mitigative uses. Noted technological advancements have greatly added to the means and forms of warning dissemination. Warning systems include sirens, TV, public radio, NWR, and forms of warning using the telephone, PDA, cellular telephone, the Internet, and automated GPS warning transceiver. After the 2007 storm season, the *NWS* will stop using county-wide warnings and issue polygons (which will be given county or city boundaries).

2.5.1 - *SIRENS*

Sirens are generally dichotomous. They are sounded if there is a warning, and silent if there is no warning. In theory, polychotomous schemes for sirens could be designed, with differing auditory signals for differing warning thresholds. But the prospects of this are quite problematic, would require significant study, and require complex and expensive technology and hardware. Sirens were designed to alert special populations (e.g., outdoor workers, factory grounds, golf courses, etc.) and rarely intended as a primary source in this era. They are of high utility in certain situations, such as small towns or MMH. Sirens are difficult or impossible to hear in many locations, especially at night when insulated and air conditioned homes and buildings are sealed up. New siren placement does not always keep pace with housing development, and maintenance is inadequate in many locales. Changing political priorities and supervisory philosophies can result in lapses in funding and manpower to maintain siren systems in many communities. While sirens remain important tools and in high demand in many areas (especially rural communities), there are indications that their utility as primary or secondary warning sources has dropped with the proliferation of other electronic communications media, and they are for the most part, outside only (Biddle 2000).

2.5.2 - *Television*

TV has overwhelmingly become the most common source of warning reception, as was evident in recent major tornado events. Legates and Biddle (1999) found that 68 % of those surveyed in the damage path of the 1998 Birmingham, Alabama Tornado utilized TV as the primary warning source, with 17 % more using it as a secondary warning source for a total of 85 %. Similar data for the 1999 OCT with primary and secondary users at 69 % and 19 %, respectively for a total of 88 %, are discussed in detail in later chapters. Improvements in ALT over that last decade also are partially related to the utility and efficiency of TV-based dissemination. TV would also seem to be a primary medium for the dissemination of various advanced warning products, such as probability-based warnings, given the hypothesized graphical requirements of most of the products. It remains to be seen whether TV probability presentations directly to the public will result in higher quality information and higher compliance rates, versus the current verbal and lexical presentations of traditional warning formats. In any case, probability data might assist on air TV personnel in prioritizing which storms to give the most attention to in order to convey the most urgency. Under current county-based warning schemes, the efficiency and high dissemination rates for TV as a primary and secondary source cannot be denied. Any drastic changes to the system will be hard pressed to match current numbers in warning reception.

2.5.3 - *Radio*

AM / FM radio remains a popular and effective medium for communicating warnings, and is usually the most common secondary source of recent studies (Biddle 2000). One drawback to radio dissemination has always been the limitations to communicate spatial information verbally, such as probability contours or path projections overlain on local maps, over radio air waves absent the graphical capabilities of TV. However, radio is the medium commonly used by motorists. Local radio stations poll out to the TV stations when there is weather in the metro (tornado warnings in general). Basically, when there is a tornado warning for Oklahoma City metro area, the radio stations go to one of five TV stations for help and they broadcast in unison. This systems is better that nothing, but is less than adequate for the radio audience because of the lack of graphics and other visual information cues compared to what TV viewers see.

2.5.4 - *NOAA Weather Radio*

NWR is intended to disseminate information to the users of weather information, but the 'nowcasts' has been a failure even at *NWS-Norman*. Doswell (c.2005) writes "the nowcasts contain little or no real information about what is going on and the forecast aspects of the nowcasts sound more like a plain forecast, than one based on mesoscale information. *The Central Region Headquarter's [CRH]* standards in this regard are the absolute worst I have encountered. Their decisions on how to operate the NWR have been terrible, from my perspective. They give the users so little real information, it's hardly worth having. CRH apparently have programmed for the least common denominator and so have produced a broadcast that approaches being content-free". At the height of the outbreak (OCT) the use of NWR was less than 3 % of those surveyed.

2.5.5 - *Other Dissemination Systems*

Some of the greatest potential for future warning product development and dissemination methods is tied to the newest forms of dissemination media – in particular, the Internet. World Wide Web-based presentations not only have graphics capabilities, but easily can be personalized and locationally-specific such that detailed spatial data may be presented over base maps of users' exact locations. Probability thresholds, as well as temporal and spatial scales, can be defined by the receiver. The ability of such systems to ignore weather occurring outside the area of user concern brings with it an inherent capacity to lower potential FAR and reduce cry wolf effects. In addition, various wireless technologies with graphics capabilities (such as cell phones) may prove to be efficient platforms for visual presentations of probabilities. Probability-based information, including specific time and location data as well as forecast confidence intervals, are easily and commonly presented in a digital format. In theory, this allows for additional user-defined thresholds for alert protocols. Users may set various receiver devices to alert them only when certain warning thresholds of storm intensity, probability, and location are met. For instance, a motorist with a Global Positioning System (GPS-based) warning transceiver driving on the Interstate could enroll in a program whereby they set their reception of a warning alert predicated with their being physically in a warned area. Probabilities might facilitate high consequence users (e.g., school bus) to be alerted whenever there is for example, a tornado warning with a probability value of 10 % or higher within a 20 km (12.4 mi) radius, whereas a different user (e.g., a highway patrol cruiser) may choose to be alerted only for tornado warnings with a probability value of 50 % or higher within a 10 km (6.2 mi) radius.

"I don't think she's seen the sky,
since we got the satellite dish."
- James McMurtry -
Levelland
WHERE'D YOU HIDE THE BODY

"Video killed the radio star."
- Trevor Horn (The Buggles) -
Video Killed the Radio Star
THE AGE OF PLASTIC

3 - THE 3 MAY 1999 OUTBREAK: OVERVIEWS

3.1 - PHYSIOGRAPHY, LAND COVER, AND ENVIRONMENT

Storm A (the storm that produced the Oklahoma City tornado) entered the northern Grady County line from Caddo County on 3 May 1999, south of State Highway 92 west of Chickasha at approximately 1720 CDT (~2320 UTC) two km (1.24 mi) south-southwest of the town of Amber (~35.12° N, ~97.89° W). It dissipated at ~1949 CDT (~0049, 4 May 1999) in northwestern Midwest City in eastern Oklahoma County (~35.49° N, ~97.40° W). Over its ~1.5 hr life span, the OCT left a 62 km path (38.5 mi) along an azimuth of ~045 degrees (~015° last ~10 km) across portions of four counties - Grady, McClain, Cleveland, and Oklahoma (Figure 3.1). The OCT was rated F5 or "violent" on the *Fujita Scale*[Y] (see Grazulis 2001), and assessment teams noted that the extent of F4 to F5 damage was unusually great. Path width was up to a kilometer at times (>1 mi), and areal extent of significant damage was estimated to be ~25 km^2 (NWS 2001; see Figure 3.1 for path and Figure 3.2 for the deaths).

At ~1855 CDT (2355 UTC), the OCT crossed the Canadian River near I-44 (~35.30° N, ~97.56° W). This point in the path marked a general mid-point for the tornado: 37 of 62 km; 48 of 88 min on the ground; and 13 of 40 fatalities. As the OCT entered the city of Moore at ~1910, it remained highly visible (Figure 3.3) while it changed physiographic, demographic, and epidemiologic regimes. Because of these differences, these two different portions of the OCT path are used to characterize data. Thus, *SWPA* refers to the 'Southwest Path Area,' or the upstream portion south and west of the Canadian River. *NEPA* refers to the 'Northeast Path Area,' or the remaining downstream path north and east of the Canadian River. This tornado killed .449 persons per minute, and caused $14.1M / min of damage. In the SWPA, .351 persons were killed per km over a distance of 37 km. In the NEPA, .926 persons were killed per km over a distance of 25 km. The difference is the number of homes per unit area within the NEPA, much higher than mostly the rural SWPA. The average for the 62 km (38.5 mi) that the tornado killed on the ground is .645 killed per km (1.04 killed per mi).

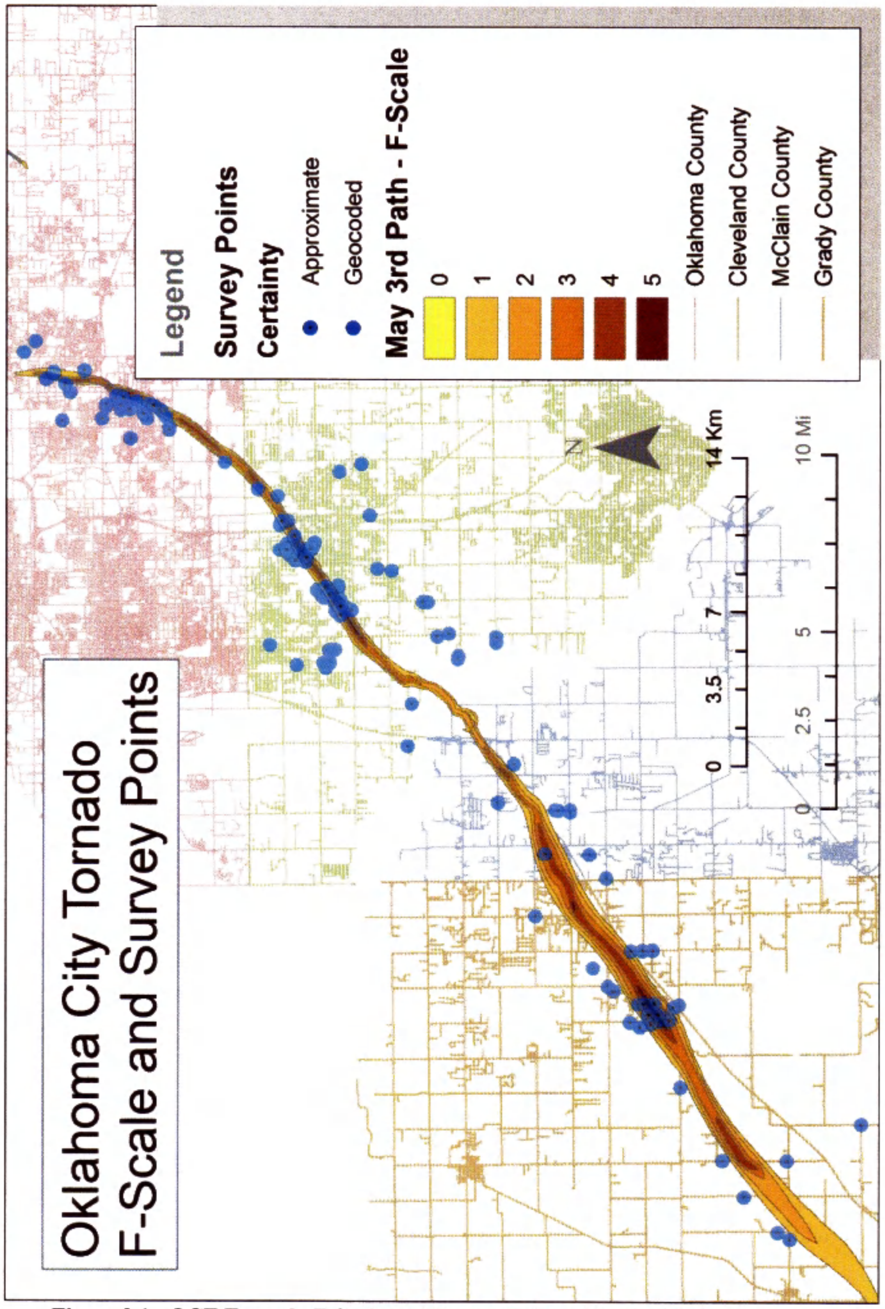

Figure 3.1 - OCT Tornado F-Scale and Survey Points. Map by M. Scott-Brown, M. Biddle, B. McPherson, and D. Howard. Copyright.

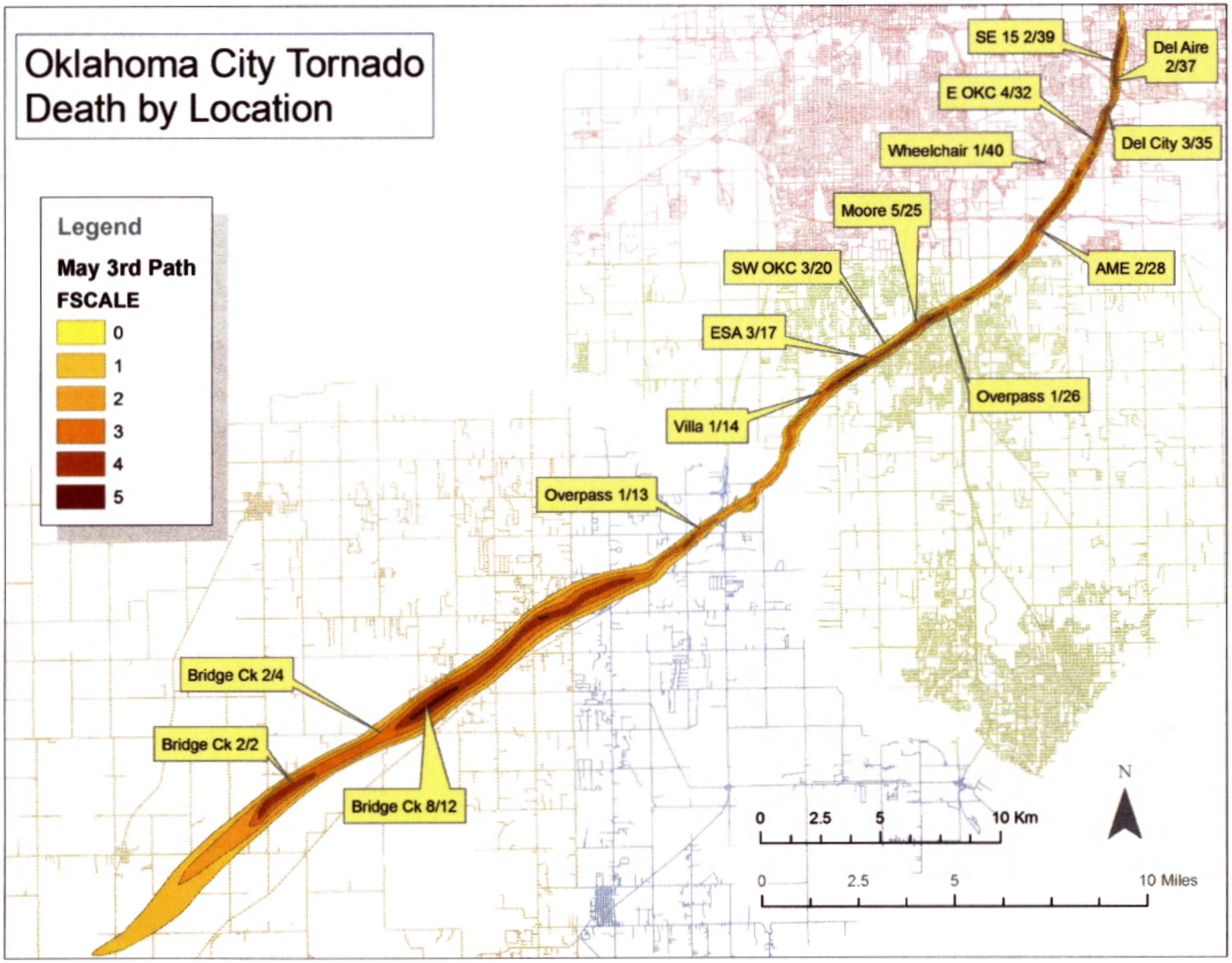

Figure 3.2 - OCT Deaths by Location. Map by B. McPherson, D. Howard, M. Biddle, and M. Scott-Brown. Copyright.

Figure 3.3 - OCT After it Crossed the Canadian River in Cleveland County (in rural Oklahoma City), 3 May 1999. Photograph by CA Doswell III, Copyright.

In the SWPA (particularly the Bridge Creek area), relief is more variable (~80 m) with north-south trending ridges that face east. Primary SWPA land cover is agricultural grasses and pastures, but small valleys in the area are moderately-vegetated with trees and riparian shrubbery. More SWPA residences tend to be in valleys than on ridge lines. In the NEPA, terrain is broadly more level and relief varies only by 50 m. Vegetation is typical of urban and suburban environments, with few dense areas of vegetation. Typically, visibility to the apparent horizon along the SWPA is good-to-poor (varying with the obstacles noted above), whereas NEPA line-of-sight is generally farther (excepting man-made obstacles). Housing in NEPA is less scattered, with clustered patterns having little regard to topography. Roads take on the common American urban-suburban grid pattern. The study area is physiographically-situated in the Osage Plains. Regional topography is "gently rolling southeastward-sloping plains of moderate slope, along tributaries of the Canadian" (USDA 1987). Most of the central portion of the state is either covered with Black Jack / Post Oak forest, or once was a tall grass prairie (Duck and Fletcher 1943).

3.2 - HUMAN ENVIRONMENT

The OCT caused significant-to-severe damage in one or more 'jurisdictional spheres' of the following communities: Amber, *Bridge Creek*[Z], Blanchard, Tuttle, The Chickasaw Nation, and Newcastle (all SWPA); and Moore, Oklahoma City, Del City, *Tinker Air Force Base (TAFB)*, Midwest City, and Spencer (all NEPA). The SWPA cut across the northern third of Grady County and a small sliver of northwestern McClain County. Population in the Oklahoma City Metropolitan Statistical Area is ~1 000 000 persons (USBC 2001). Most of central Oklahoma has undergone moderate population growth over the last decade, largely in 'bedroom communities' suburban to Oklahoma City and Norman (Selland et al. 1998). It is estimated by the survey that ~50 000 people lived directly in, or within two km either side of the center of the OCT path. As with physiography, the Canadian River marks a transition zone in settlement patterns. The SWPA is predominately rural, as indicated by Grady County's population density of ~100 persons per km^2. This compares to mostly suburban NEPA areas in northern Cleveland (~1000 persons/km^2) and southern Oklahoma Counties (~2300/km^2). SWPA land use is ~70 % agricultural, dropping to ~25 % in the NEPA (OCS 2001). Minority population in the SWPA is ~10 % and increases to ~25 % toward the urban-center portions of Oklahoma County. The projected 2000 aggregate percentage of all minority groups in central Oklahoma was ~10 % (USBC 2001), which mirrors the 90 % of decedents identified as "White" (OCME 1999). The OCT did not directly impact predominantly Hispanic and Black neighborhoods in south-central and northeast OKC, respectively. In general, no significance to OCT survey data was identified that correlated to race. Therefore, further demographic analyses or speculations based on race are omitted.

3.2.1 - *TRANSPORTATION AND INDUSTRIAL SETTINGS*

The OCT crossed four Interstate Highways (I-44, I-35, I-240, and I-40) and numerous heavily-traveled major thoroughfares. Total daytime traffic along the I-35 corridor in Moore is more than 75 000 vehicles per day. Estimated weekday rush hour traffic (~1800 CDT) for this location is 7200 vehicles per hour (ACOG pc.2001). A major rail line (Burlington Northern - Santa Fe) parallel to I-35 was crossed by the OCT in Moore. It carried ~22 trains per day in 1999 (ODOT pc.2001), including two Amtrak trains. Will

Rogers World Airport (~75 departures per day) is located ~10 km (6.2 mi) northwest of the OCT path (OCCVB 2001). There were no reports of incidents regarding trains or aircraft in transit, although there were train cars in the wreckage.

Significant lands zoned as commercial or industrial lay in the NEPA. Dense pockets of 'service industries' and market places are found in Moore and southern OKC, primarily between I-35 and I-240. While two fatalities occurred in this area - at a major commercial truck and warehouse facility (AMF) - population density is considerably lower than other portions of the NEPA, owing to the lack of residences in the section. Given the time frame of the OCT, most of these sites were vacant, as most workers had left for the day. The OCT passed ~four km (2.4 mi) southeast of *Crossroads Mall*, a major marketplace that hosts ~2500 shoppers daily (OCCVB 2001). Another densely-commercial area is found toward the end of the OCT path along I-40 near *TAFB*, where >1000 vehicles were destroyed in a concentrated area of car dealerships (~10 000 vehicles were "totaled" in the OCT). *TAFB* is an Air Force Logistics Center with personnel and resident populations comparable to a city of ~30 000 (USAF 2001). Numerous restaurants, hotels, and portions of *Rose State College* also were damaged or destroyed. Aerial photography and census tracts indicate that many opportunities for the release of hazardous materials were narrowly-averted along the OCT path. Surprisingly, environmental regulatory agencies reported no 'significant hazmat' releases that required specialized response associated with the OCT (OCFD pc.2000).

3.2.2 - *EMERGENCY RESPONSE AND MEDICAL CARE*

First responder search and rescue in the SWPA primarily consisted of small volunteer fire departments. NEPA responders were predominantly professional fire departments. Despite the rural setting in the SWPA, and the magnitude of the disaster in the NEPA, search and rescue was efficient and well-conducted in both sections (FEMA 1999). The coincidental location of the OCT to the Interstates allowed rapid transport of injured to hospitals. Injured were taken to either the only Level Three Trauma Center (University Hospital) or eight other "*Major Trauma Centers*"[AA] in metro OKC. An additional benefit of proximity to OKC was the rapid deployment of mutual aid equipment and manpower from neighboring jurisdictions, private heavy equipment contractors, and the Oklahoma National Guard. A helicopter paramedic-transport service based in OKC (Lifeflight) was also utilized (Hogan et al. 1999). Such geographical fortunes are moderating factors for death tolls in contemporary tornado disasters (Legates and Biddle 1999). Area EMA indicated that experience with recent minor tornado events, as well as mutual aid responses to the 1995 A.P. Murrah Federal Building bombing in OKC, increased coordination and overall response capability. While the scales of both disasters were very different, the recent experience of the bombing in the coordination of mutual aid response, inter-agency, multi-jurisdictional communications, and field triage and coordinated transport to multiple hospitals are particular examples (OCFD pc.2000).

3.2.3 - *Electronic Media*

Television weather coverage in the Southern Plains is extensive and highly-detailed. TV stations in OKC and Tulsa devote more resources to weather coverage than counterparts in such large markets as Los Angeles or Chicago (England 1996). In the OKC market, all major network affiliates take aggressive and competitive approaches to warning dissemination. Many of the TV weather innovations of recent years were developed or first employed in the OKC market. In fact the first televised tornado warning ever broadcast was in Oklahoma (Bradford 2001). Cable TV and satellite connections to national networks that broadcast some weather information are also common. Some locales (e.g., Moore) have the ability to interrupt cable programming regardless of what channel viewers are watching. However, usage rates for such technology is intermittent and inconsistent. Total TV access in the OKC metro was >600 000 households (USBC 2001). At least 25 radio stations serve the OKC metro area, of which about half report that they "regularly" broadcast weather warning information by the survey. Many area residents also have access to instant warning information via the Internet and wireless media such as cell phones or pagers. However, usage totals on these populations, while clearly growing rapidly, remains unknown. NWR is broadcast from a tall tower in OKC (WXK-85) and was receivable in most locations along the entire OCT path (NWS 2001).

3.3 - THE OKC TORNADO EVENT: FORECASTS AND WARNINGS

Chronology and geography for the OCT are noted above and indicated in Figure 3.1. Detailed meteorological data for the OCT are available on the *NWS-Norman* web site, and discussed elsewhere in this issue. Focus here is on the reception and impact of various forecast and warning products. Generally, the event was well forecast and given increased attention by warning networks as the day unfolded and risk magnified.

3.3.1 - *LONG-RANGE FORECASTS*

The *Convective Outlook*[BB] 'Day Two Severe Weather Outlook' (SWO – a regularly-issued forecast product; the glossary and acronyms have the definitions) from *SPC* – issued on 2 May 1999 (valid for 3 May), and the 3 May 1999, 0530 CDT (1130 UTC) 'Day One' SWO, both forecast a 'Slight Risk' for severe storms with tornadoes in the OKC area. The next issued SWO at 1115 CDT upgraded the same general region to a 'Moderate Risk'. At 1230 CDT, *NWS-Norman* issued the daily 'Hazardous Weather Outlook' (HWO) that also noted a 'Moderate Risk' with significant tornado potential. At 1549 CDT, *SPC* issued an SWO upgrading the area to a 'High Risk'. The nature with which risk was expressed in incrementally-increasing steps, generally resulted in kind with increasing awareness and preparedness among stakeholders, especially the media. Although the magnitude of severe weather potential was not obvious to *NWS* until late afternoon, *NWS* did express the possibility much earlier (Quoetone et al. 2000). Via the attention given to updated products, when severe weather began, it was highly-anticipated. It is believed that the steady "ratcheting up"(of the *NWS*) of tone regarding both storm likelihood and anticipated impacts was an important aspect of event awareness. This was corroborated by many anecdotal reports by the survey from the field.

3.3.2 - *WATCH CHRONOLOGY*

At 1645 CDT (2145 UTC) *SPC* issued tornado watch (hereafter WWT) #195 for most of Oklahoma. The first tornado warning (hereafter TOR) was issued at 1651 CDT for a small tornado in Comanche County in southwest Oklahoma. This tornado was the first of 14 associated with the cyclic supercell that spawned the

OCT. At 1859 CDT, *SPC* issued WWT (#198), replacing WWT #195. WWT #198 was a 'PDS' (Potentially Dangerous Situation), meaning it included "enhanced wording" with regard to violent tornado potential (Thompson and Edwards 2002).

3.3.3 - *Warning Chronology*

At 1721 CDT (2121 UTC), a TOR was issued for Grady County (SWPA) just west of Cyril, which was ~1 hr before the first OCT fatality. At 1755 CDT, a TOR was issued for Grady County for a tornado 3.2 km (2 mi) north of Laverty. It is important to note that this is ~29 min upstream and ~10 km (6.2 mi) from the first OCT fatality. Shortly thereafter, the storm produced numerous small tornadoes, as well as a very large tornado that passed into northern portions of the city of Chickasha. At 1819 CDT, *NWS-Norman* (OUN) issued a Severe Weather Statement (SVS) noting a tornado "on the north side of Chickasha, near the airport." Note that TOR were already in effect for Grady County – the point of origin for the OCT – *prior* to initial tornado touchdown.

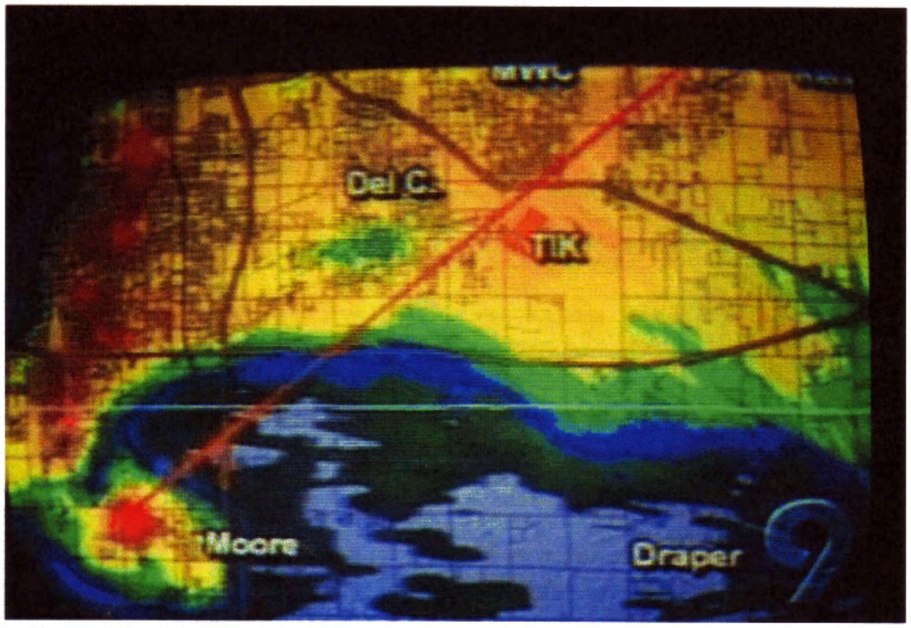

Figure 3.4: Doppler Radar Picture of KWTV When the OCT was in Moore, Ok. KWTV Television. Photography by Matthew Biddle, Copyright.

The first TOR specifically for the OCT was issued by *NWS-Norman* at 1826 CDT (2326 UTC), ~10 min prior to the first OCT fatality in Bridge Creek (Figure 1.2). As *NWS* TORs were continuously disseminated, TV showed live video of dramatic storm structure, as well as the damage (Figure 3.4). Much was made in warning communiques from all forms of media about the "*threat to life*" the storm presented as it approached Chickasha, aimed toward OKC. It is important to note that owing to logistical parameters associated with current warning systems, Bridge Creek (being an unincorporated area) was not specifically listed in TOR text, as were some neighboring towns (e.g., Amber, Newcastle). However, a TOR for Grady County (included the Willow Lake Estates, Southern Hills Edition, and Bridge Creek Estates in Bridge Creek where 12 deaths occurred), was *officially* in place for more than 30 min prior to the OCT.

McClain County was also included in a TOR issued at 1840 CDT (2340 UTC). At ~1857 CDT, the OCT crossed the river (and entered the NEPA). It continued to be tracked by spotters in direct contact with the *NWS*. The tornado was shown on TV from multiple perspectives, including ground teams, two helicopters, and numerous tower cams. In addition, various radar depictions were presented showing a textbook "hook echo." While many viewers may not be familiar with a hook echo, a significant number are and either way, the discussion on-air by the broadcast meteorologists of the dramatic radar returns acted to capture the moment and convey the ensuing reality that this was a serious storm and a real tornado with serious implications. As the OCT progressed northeast, it remained in full view of an increasingly large population of viewers, many advised to turn on TV by friends or relatives. Thus, the OCT existed under TOR until it dissipated at ~1949 CDT. The *minimum* official (*NWS*) TOR lead time for OCT was 13 min and the mean lead time for the entire event a remarkable 32 min, with some areas in excess of one hr (NOAA 1999).

3.3.4 - *The Tornado Emergency SVS*

At 1657 CDT (2357 UTC), *NWS-Norman* issued a Special Weather Statement (SVS) with the header – "*Tornado Emergency in South-Central Oklahoma City Metro Area.*" While no precedent for this nomenclature is known, and there has been some speculative concern in its use as a sort of 'augmented warning,' surveys indicated that this SVS had a *major* impact with the media. Upon receipt of this SVS, personnel at popular radio stations that did not normally broadcast warning information realized the gravity of the unfolding situation, and began relaying warning information in real time. A number of radio stations picked up the audio feeds of local TV coverage. The result was near continuity in broadcasts of warnings across the AM-FM dial, a factor that may have been critical in holding down the number of casualties among motorists. Included in the SVS was the statement "*...a large damaging tornado WILL enter the metro between 7:15 - 7:30* [0015 - 0030 UTC]. *Persons in Moore and South Oklahoma City should take tornado precautions..!* " (NOAA 1999). The interviews and surveys told of many who took that to mean 'turn on the TV,' and many called '3rd parties' to warn that the tornado was coming. At least six of those killed in the OCT had calls that warned them.

You need to be below ground if you want to survive this tornado!
Gary England, KWTV -

I got lost in a neighborhood I've driven around for 10 years because there's no landmarks anymore
- Del City Police Sargent Jody Suit -

It's just absolutely unprecedented. No one has ever heard of anything like this.
- Oklahoma Governor Frank Keating -

4 - Emerging Issues of Tornado Risk, Behavior, and Mitigation

4.1 - Field Methods

Beginning 4 May 1999, permission was obtained from various EMA authorities to access disaster sites for field interviews and data collection. Goals were to collect geographical, demographical, behavioral, and attitudinal information from a sample population affected by the tornado. More than 200 households in or within ~3 km of the damage path were contacted. Questionnaires similar to those from other contemporary tornado disasters (e.g., Schmidlin and King 1995; Legates and Biddle 1999 – see Appendix A) were used to poll the actions of respondents and of those in their company. Surveys were conducted as convenience samples in a 'shotgun-like' manner, as logistical and physical obstacles precluded organized and consistent access to portions of the disaster area. This was the best option, given the perishable nature of the recounted actions of traumatized and overwhelmed survivors. Additional data on fatalities were provided by the Oklahoma Office of the Chief Medical Examiner (OCME), and the Oklahoma State Department of Health, Office of the State Epidemiologist (OSDH), gleaned from newspaper reports, and from interviews with local officials, *NWS* personnel, and neighbors and relatives of decedents and survivors. Significant follow-up occurred intermittently through the end of 2000.

4.2 - Research Objectives

Data were analyzed for patterns in warning access, source, lead time, and compliance, as well as for respondent locations, actions, and observations. Additionally, attitudes toward tornado risk and performance of the warning system for this event were sought. This work seeks to complement rather than duplicate other research projects for the OCT that examined structural engineering and damage (e.g., Doswell and Brooks 2002; FEMA 1999), warning performance (Andra et al. 2002), or detailed epidemiology (Brown et al. 2002; Daley et al. 2005), by attempting to focus on the OCT human-environment interface, or the warnscape. In addition, comparisons to another work that in part assessed warning response for this event (Hammer and Schmidlin 2002) are examined. Presented below are findings about warning access and compliance, with brief comparisons to previous research of other contemporary tornadoes.

4.3 - Notes on Previous Studies

It must be noted that, while similar surveys have been undertaken for a number of tornado disasters, they are all systematically and statistically distinct. This relegates cross-comparisons to largely-empirical domains. For the purposes of data comparison to other studies of tornado events and warnings, unless otherwise noted, the following sources were used: Legates and Biddle (1999) for the 8 April 1998 tornado that killed 32 people in the Birmingham, Alabama area (BHM); Schmidlin (1998) for the 22-23 February 'Central Florida Outbreak' (FLO) that killed 42; Schmidlin (1997) for the 1 March 1997 'Arkansas Outbreak' that killed 26 (ARO); Schmidlin and King (1995) for the 27 March 1994 'Second Palm Sunday Outbreak' in the Southeastern US that killed 40 (PSO), Glass et al. (1980) for the Wichita Falls, Texas Tornado of 10 April 1979 that killed 56 (WFT); Hammer and Schmidlin (2002); Brown, Archer, Kruger, and Malonee (2002); and, Daley, Brown, Archer, Kruger, Jordan, Batts, and Mallonee (2005) for their study of the Oklahoma City Outbreak (of 3 May 1999).

It should also be acknowledged that there are limitations in comparing tornado disasters, aside from differing survey methodologies. There are significant differences in event character, and there are limits to the utility of comparing data from single tornado events with cumulative impacts of outbreak events. Obviously, with outbreaks, time-lines overlap in some cases, and warning information tends to become logistically-complex and cumbersome. In long-track violent events, persons along projected paths are often presented with higher-quality warning information, both temporally and spatially, and thus given better opportunity to make warning response decisions. Conversely, media-delivered warning information may be vague and confusing in outbreaks that occur among audiences in spatially-large areas (inter-regional).

Some of the events involve nocturnal storms, which are inherently more challenging to warn for, owing to darkness and higher percentages of sleeping populations.

4.4 - Sample Populations

The community demographics in central Oklahoma the citizenry on average is white (75.4 %) and female (50.7 %). At the low end, there are 2.61 persons per household in (McClain), and at the high end, there are 3.04 persons per household in Oklahoma City (Oklahoma). Median homes were listed as $41,100 in Blanchard and $62,600 in Newcastle (McClain County), and $51,200 in Moore (Cleveland County) and $42,686 in Oklahoma City (Oklahoma County). The MMH were not listed in Oklahoma County.

4.4.1 - *Community Demographics*

Table 4.1 - 1990 US Census Bureau listings for general population and housing characteristics -

			Population		**% Female**	**<5, 5 to 17, 18 to 44, 45 to 64, 65^**
BLANCHARD			1922		51.77	159, 380, 724, 350, 316
PPH			**MMH**		**Median (dollars)**	
2.61			45		41100	
White	**Black**	**NA**	**Hisp**	**Asian**	**Other**	
1806	3	97	21	4	12	
			Population		**% Female**	**<5, 5 to 17, 18 to 44, 45 to 64, 65^**
NEWCASTLE			4214		49.95	252, 984, 1671, 1006, 301
PPH			**Mobile Home**		**Median (dollars)**	
2.87			231		62600	
White	**Black**	**NA**	**Hisp**	**Asian**	**Other**	
3910	4	245	85	5	41	
			Population		**% Female**	**<5, 5 to 17, 18 to 44, 45 to 64, 65^**
MOORE			40318		51.11	3354, 9723, 18468, 6744, 2029
PPH			**Mobile Home**		**Median (dollars)**	
2.96			283		51200	
White	**Black**	**NA**	**Hisp**	**Asian**	**Other**	
36362	719	2136	1353	516	585	
			Population		**% Female**	**<5, 5 to 17, 18 to 44, 45 to 64, 65^**
OKLAHOMA CITY			506132		51.10	37194, 95579, 207661, 108603, 58098
PPH			**Mobile Home**		**Median (dollars)**	
3.04			N/A		42686	
White	**Black**	**NA**	**Hisp**	**Asian**	**Other**	
362788	83034	29001	51368	20165	32184	
			Population		**% Female**	**<5, 5 to 17, 18 to 44, 45 to 64, 65^**
DEL CITY			22128		52.26	1636, 4494, 4494, 7995, 4705, 3240
PPH			**Mobile Home**		**Median (dollars)**	
2.96			N/A		51400	
White	**Black**	**NA**	**Hisp**	**Asian**	**Other**	
17191	3315	1422	1043	511	579	

NA = Native American **Hisp = Hispanic** **PPH = Persons Per Household**

4.4.2 - *Warning Dissemination and Access*

Respondents are contacts made during the survey (164 total) that lived through it (the OCT) that made themselves available to the survey parties which were "shotgunned" about the area the first week (there was some follow up). Respondent access to *warnings*[CC] was evaluated, both for quantity and quality of sources for potential warning reception. Those with 'specialized' access to primary warning information, such as police and fire radios, scanners, or weather pagers, or who were otherwise made aware of the weather situation as a function of duty (e.g., storm spotters or TV personnel) received the highest ratings for warning access. Those that utilized multiple sources of primary and secondary official warnings (e.g., TV, radio, NWR) were rated high, and those with access to only one of these media were rated moderate. Persons relying on sirens or 3rd party notification were rated low. Those with no access to media or remote systems or no information, were rated the lowest.

TABLE 4.2 - WARNING SYSTEM RATINGS - (n=127/ 164)

Rating -	Number - Percentage -	
No Answer	37 / 29.1	
0 - No Warning	01 / .787	
1 - Poor	03 / 2.36	
2 - Inadequate	03 / 2.36	
3 - Adequate	10 / 7.87	
4 - Good	51 / 40.1	
5 - Excellent	59 / 46.4	
Median = 5	Mean = 4.23	4+ = 110 / 86.5 %

To the best of the authors knowledge, warning response in the OCT was the most successful in public warning reception, lead time, and overall compliance identified or documented in the history of organized warning systems. Data from 164 households indicated that TV played a major role as it does in general nationally, but for the OCT, in the highest percentages known. Total warning reception was 76.8 % (99.2 % of the available people), with TV as the primary source at 69 %. Third-party notification was the primary source for 18 % (12 % via telephone). Nearly 40 % indicated they informed neighbors or relatives of the approaching storm either in person or via the telephone.

Sirens or NWR as a primary warning source together amounted to only 3 % each among those surveyed. Sirens only amounted to ~1 % of those primarily and 18.7 % of those secondarily. Hammer and Schmidlin (2002) found similarly low NWR usage for the OCT. In the BHM, NWR use was ~14 %, and <2 % in the FLO (Baker and Troutman 2000). It is thought that in BHM, respondents were confused about what AM/FM radio and NWR radio is different. Even so, NWR remains seriously under-utilized. It is important to note that in the OCT, many of the TOR broadcast over AM-FM radio were live broadcasts of NWR transmissions (Quoetone et al. 2000), so its overall value is not fully reflected in the survey. It is noted though that sirens as a secondary confirmation existed in OCT.

4.4.3 - *Tornado Characteristics*

The time-of-day of the OCT (~1800 CDT - 1930 CDT) may have played a significant role in holding down the death toll, as most residents were home from work or school, with ready access to TV and radio. Few were asleep or stuck in rush hour traffic, which had largely subsided. Since the tornado occurred during *daylight*[DD], many were able to utilize sight as an environmental confirmation cue, because the storm structure allowed for relatively clear viewing of the tornado (Figure 1.2 and 3.4). Provided views to the horizon were not blocked by trees or buildings, the tornado was visible to both the naked eye and TV cameras along the entire path. It is suggested that environmental cues were also *major* factors in expediting the confirmation process, and in third-party warning relay, as well as in limiting vehicular deaths.

Additionally, OCT path orientation spared many populated neighborhoods, particularly to the east of I-35, and south of I-240. It is estimated that had the storm followed the same heading but occurred only a few km north, ~20 % more residences might have been struck, as well as a major shopping center. Historical records contain many examples of violent long-track tornadoes, but these are spread sparsely over large regions and many decades (Grazulis 1993). Thus, comparing them is difficult and even more challenging because they have not been uniformly subjected to carefully-designed surveys. Serendipity and luck were paramount in the OCT as they have been historically (Grazulis et al. 1998). Both the OKC Blazers (hockey) and OKC Redhawks (baseball) minor league teams were hosting games with >5000 persons (in two adjacent facilities) ~6 km west of the path. *Many* local schools, including some that were damaged, were hosting public assemblies associated with upcoming graduations and the end of the school year. At least 1500 people took cover in numerous school buildings along the path – especially at Westmoore and Del City High Schools.

4.4.3.1 - *Watch Utility* -

A surprising majority of respondents claimed to be aware of a WWT prior to a TOR for their location (Legates and Biddle 1999). Still, many did not utilize the WWT as a time to prepare. This period of time – usually at least half hr to as much as 6 hr in duration – is especially important for those who must go to an alternative location for adequate shelter. It is also an important trigger in many emergency plans, such as at moving patients at hospitals away from windows, activating spotter networks, or calling in additional police and fire personnel. Reported 'watch awareness' was high for the OCT at ~75 %, but less than for the BHM (86 %). It was much higher than for ARO where 61 % knew of the tornado after hearing or seeing it, or FLO where 68 % knew of it. These figures are thought to be largely a function of the time-frames of the events. Watches in the FLO were issued very late at night when most of the public was asleep. The higher reported watch awareness for BHM is not fully understood. It may be directly related to the shorter time-frame between the WWT issuance and the first TOR, such that the information reception was virtually concurrent. In other words, people were tuning in to the alert stage for the WWT and were still interfacing with the warning media when the first TOR was issued. Possible explanations are: survey bias or error; significant numbers of respondent confusion of watch with warning; the fact that the tornado occurred later in the evening when more persons were home for the night watching 'prime time TV'. In any case, the watch awareness can be considered very high for both the BHM and OCT events. Previous research has indicated that regardless of past usage, and despite common misconceptions to the contrary, *most* of the public understands the meaning of a tornado watch (Baker 1993; Legates and Biddle 1999). This appears exceptionally true in Oklahoma (see Biddle 1996) as shown in the OCT, and despite the short time period from WWT issuance to onset of severe weather. Although it might have been better to have had the WWT in effect with more lead time, the elapsed time during which the severe weather marched toward the OKC metro with its associated media coverage amounted to *de facto* watch preparation time.

4.5 - Warning Reception and Mode

Respondents were polled regarding their self-identified primary warning sources, as well as for all ancillary sources for warnings. As noted, TV was the primary source for the majority (69%). It was utilized as a information source in some way by 89 % of respondent households.

4.5.1 - *Television Coverage*

The experience and tenacity of the weather coverage of the OKC TV stations - thought to be a source of overactive annoyance to some residents - was, in this case, paramount in the high percentage of those who received warning. All major networks had multiple storm chase crews deployed, providing real-time information on simultaneous tornadoes. Captivating live video, including some from news helicopters, quickened confirmation response and moved many to closely monitor OCT progress. Interviews and surveys clearly indicated that, in addition to the dramatic video, the demeanor of the on-air TV personalities succinctly conveyed the exceptional risk and motivated mitigation (Figure 4.1). It also motivated many citizens to telephone others that they perceived to be in harm's way. Thus, warning information was re-disseminated in unofficial cascade-like networks.

Figure 4.1: OCT North of Chickasha, OK. KWTV Television, 3 May 1999. Matthew Biddle, Copyright.

Previous TV coverage of tornadoes associated with the OCT supercell, began more than an hour before OCT touchdown. In fact, at least three TV stations provided live video of the birth of the OCT near Amber (and actually the storm at Medicine Park). All major stations provided live feeds almost immediately thereafter, resulting in what became 'wall-to-wall' continuous broadcasts of warnings and storm information that continued through, and well after, the tornado. At one point midway through the event, *CNN* picked up the feed of one of the OKC TV stations, providing live national coverage of the tornado entering OKC. One aspect of the TV warning dissemination was the preponderance of confirmation activity exhibited by respondents, who continuously changed stations seeking information that was very viewer-specific. Approximately half of the respondents indicated they continuously changed channels while monitoring the OCT. Of the remaining half, one TV station was reported as the source of information by ~25 % of viewers, with two other major affiliates accounting for the remaining ~22 % of those who monitored a sole station for the event. Only 3 % reported using 'other' TV sources such as *The Weather Channel* or *CNN* for warnings.

TV was a key ingredient used by most of the respondents (89 %) to make decisions; notably, the decision to flee or to seek shelter in place. Thus 37.2 % of the respondents listing TV as a warning source fled, leaving 62.8 % who did not. *All* the people who fled, sometimes prior to any *official* warning (*NWS* warning) having been issued for them, listed TV as either the primary or a secondary warning source. For respondents using TV as a warning source, those accompanied by juveniles within their group were more likely to flee (41.3 %) than average. On the other hand, respondents using TV as a warning source accompanied by the elderly (age 65+) within their group were less likely to flee (9.6 % fled). Figure 4.2 is the map of evacuation by households and Figure 4.3 is the map of juveniles and of elderly households. Chi-square goodness of fit tests were performed on the survey data to analyze the hypotheses discussed above. The critical value for each question with a 95 % confidence level is 3.84. The observed chi-square value for each hypothesis was above this threshold – 4.1, 24.3, and 8.8 – respectively.

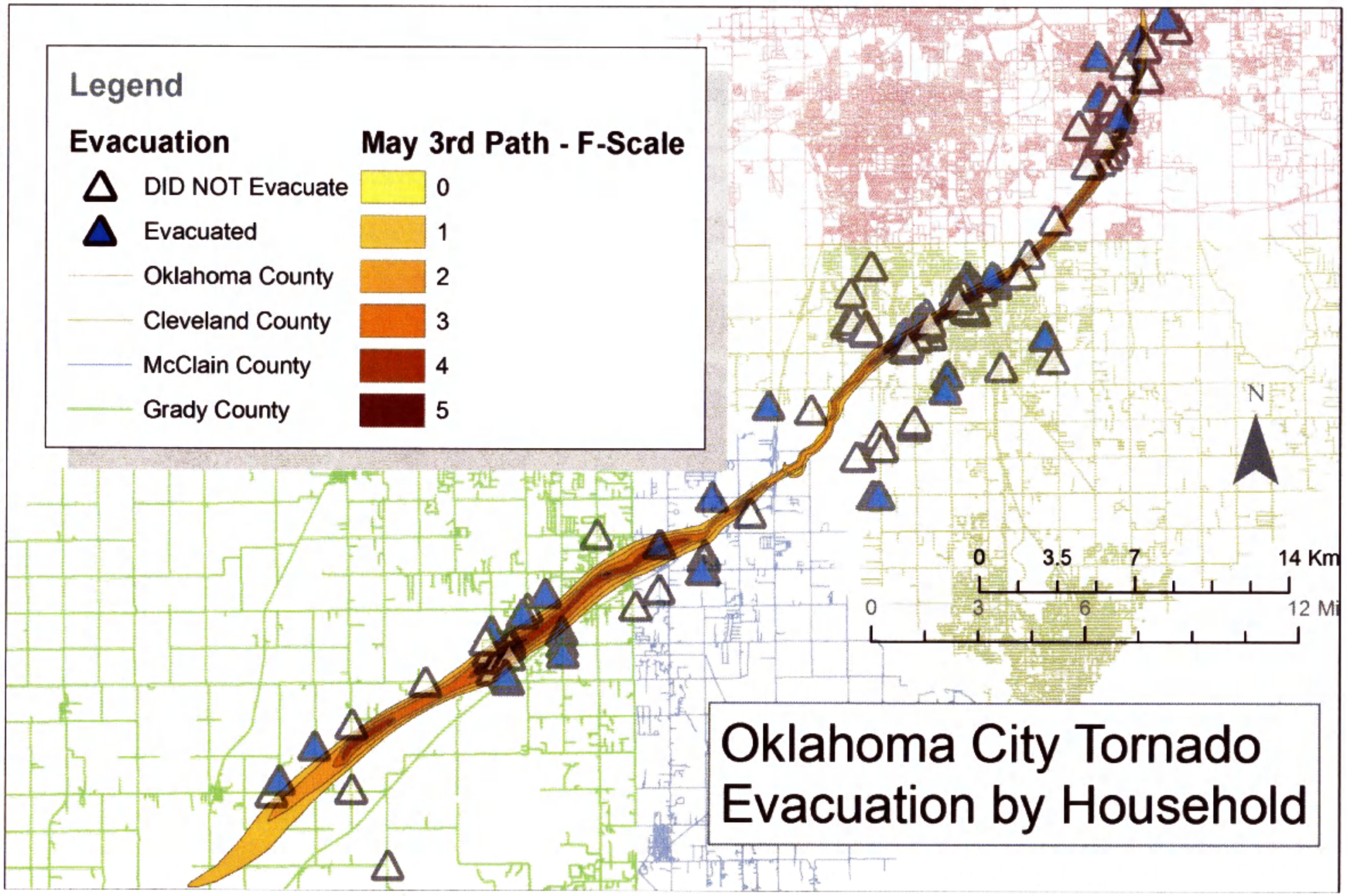

Figure 4.2 - OCT Evacuation by Household. Map by D. Howard, B. McPherson, M. Scott-Brown, and M. Biddle. Copyright.

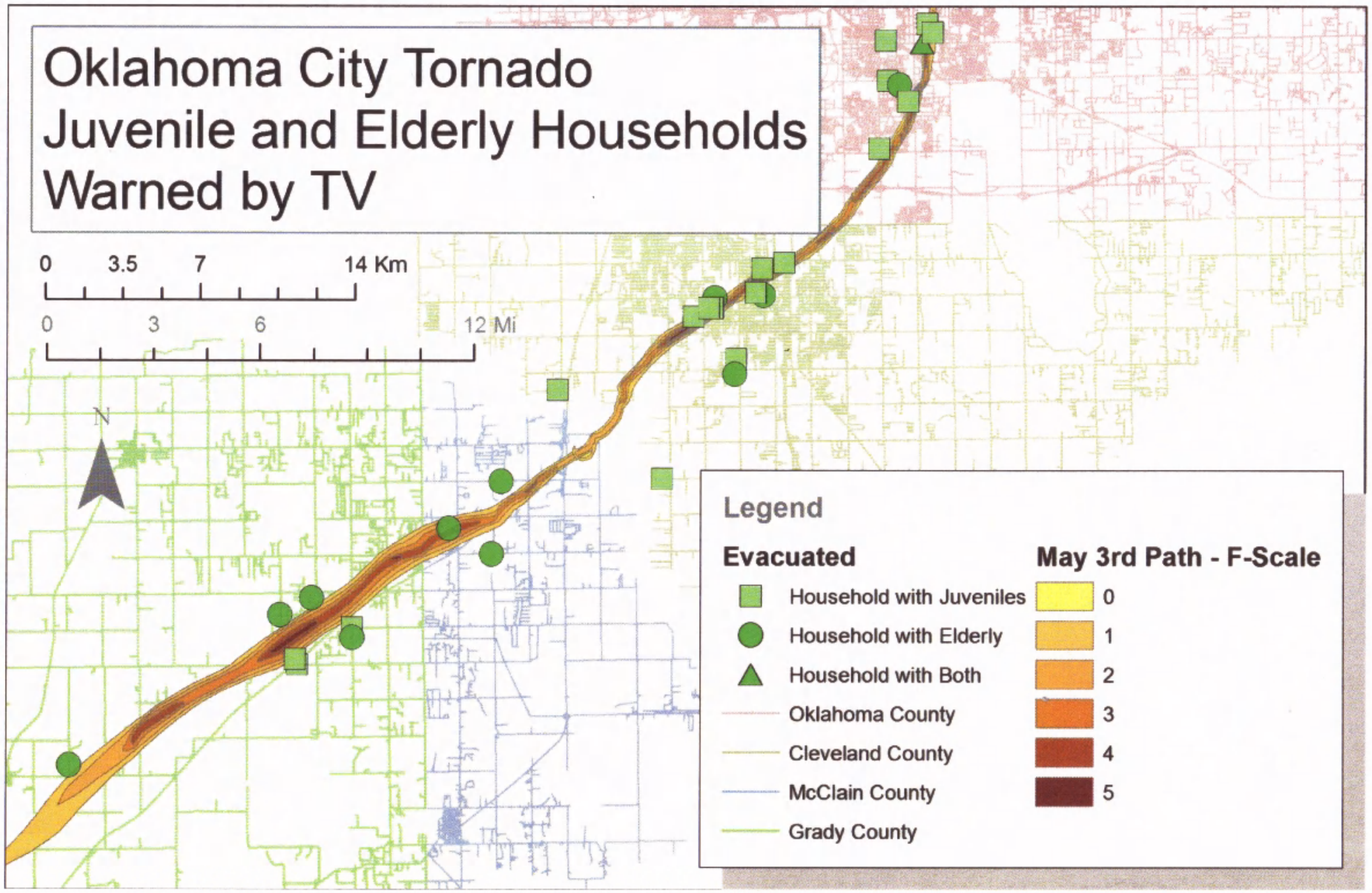

Figure 4.3 - OCT Juvenile and Elderly Households Warned by TV. Map by D. Howard, B. McPherson, M. Scott-Brown and M. Biddle. Copyright.

There are two different uses for the term "lead time" used here. In the official sense, as used by the *NWS*, lead time refers to the time interval between the time their official warning is issued for the warning area, and the time the warned-for event begins to affect the warning area. The *NWS* determines its own official warning lead times, but these have not been used in this study. Another type of lead time is used here (which might be called an *effective* lead time): the time that elapses between when the official warning was issued for the area in which the respondent was, and the time when the tornado struck the respondent's location (or was at its point of closest approach). The method for determining the effective lead time is described in the text and represents an approximate value, based on some simplifying assumptions, because it is not known precisely when the respondent's location was struck (or the tornado was at its point of closest approach). The response time is the time that elapsed between when a respondent first heard about the tornado and some action was taken to either flee or shelter-in-place. This information was part of the survey and was obtained only as rough estimates. Since someone might have heard about the tornado via TV well before the official warning was issued for their area, it is possible to have the seeming paradox of a long response time and a short lead time (the grouping indicated with an orange oval on the upper left side of Figure 4.4). There were 50 respondents with a lead time of less than 60 min and a response time of more than 30 min. These respondents are distributed all along the track (Figure 4.2). The gap in lead times seen in the middle of Figure 4.4, between about 60 min and around 100 min, is just a reflection of the order in which official warnings were issued.

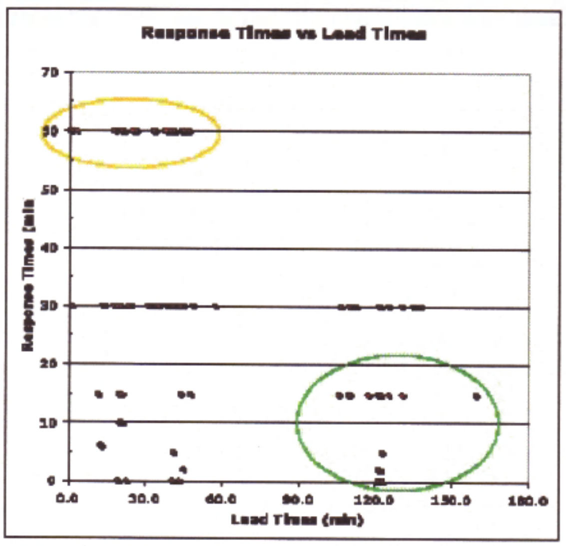

Figure 4.4 - Response Times Versus Lead Times - Copyright.

This is partly an artifact of the way the official warnings are issued – sometimes, warned areas are done individually as a storm approaches, whereas other times, several different areas are warned for at the same time. The long lead times generally result from the fact that the first tornado warning, issued at 1647 CDT included Grady County (in which the OCT began), was well downstream at the time of the first tornado in Comanche County that prompted the first warnings. In Grady County, tornado warnings were re-issued several times after that, lasting at least until 1930 CDT. There were 18 respondents with lead times of more than 100 min and response times of less than 30 min (indicated with the green oval on the lower right side of Figure 4.4). All of them but one were in Grady County, early in the OCT life cycle. Since this was a Monday, many people were just getting home from work and school and might not have tuned in their TV until they got home. Thus, the response times of 30 min or less for these long lead times are understandable.

Currently there is little literature regarding temporal and spatial details and scales that make warning products most useful to the public. According to survey accounts for this event, the *NWS* did an exceptional job in providing needed geographical and 'call-to-action' information in the warnings. TV stations likewise provided adequate detail, allowing most users to comprehend the magnitude of the risk and consider mitigative actions. Many respondents indicated that TV presentations of radar storm details – identified as subject to user error and presenter embellishment for marketing reasons (AMS 2001) – were not as important as path projections and verbal descriptions of local geography. A major research gap remains the delineation of the cognitive thresholds in play related to the comprehension of storm-related graphics, such as detailed Doppler radar. In spite of modern technologies and graphics, little more is understood about the geographical and spatial skill of various user groups identified long ago as critical to framing warning compliance and response (Haas 1973). In fact, public comprehension of most forms of warning information remains ill-defined, and presentations vary between networks, regions, and events.

4.5.2 - *Other Warning Pathways*

Not much was relayed under warning systems that were 'other warning pathways.' Only 3 % used NWR, which is not that much, and they then switched to TV and radio. The via scanner group – which is 4 % – also led to TV and radio. The Internet was silent on my surveys, but the author thinks there would be more computerized warning in 2007 because the Internet has aged eight years and more citizens have the World Wide Web on all the time during severe weather (NOAA 2003). The *NWS* has 24-hr information available under Hazardous Weather Outlooks, watches, and warnings (www.weather.gov), with the public warning in one min or less. Watches and warning are also available through certain vendors like the TV stations. Cell phones and pagers were not used like they are in 2007. In 1999, there were 86 047 003 cell phone users in the United States. In 2005, there were 207 896 198 in the US (The Wireless Association c.2007 - www.infoplease.com/ipa/A0933563/html). There are now ways to get weather warning and local radar on your cell phone if interested, and this number is more accessible now.

4.5.2.1 - *Third Party Notification* -

Neighborly behavior (third party notification) – especially the use of telephones to disseminate warnings – was the 2nd most important mode of warning transfer in the OCT, after TV. The importance to the warning system of stakeholder implemented *ad hoc* warning cascade networks, where warning information flows from the *NWS* to media to the public, and then to still more of the public, needs to be embraced by system policies. Significant numbers (~15 %) of people receiving telephone warnings were also noted in BHM. In both BHM and OCT, third-party notifications obviously saved lives. In fact, in the OCT, at least six decedents are known to have received phone notifications (all subsequently turned on TV), and at least two decedents were known to have telephoned relatives and neighbors to warn them of the approaching storm, acknowledging their awareness of the threat. Combinations of situational factors and tornado intensity made the notifications ineffective for survival.

4.5.2.2 - *Sirens* -

In the SWPA, sirens were not used extensively. There were sirens in Chickasha, Amber, Blanchard, Tuttle, and Bridge Creek, but they were local and only warned people within ~2 mi away. There could have been warning sirens at the Willow Lake Addition, Southern Hills Addition, and Bridge Creek Estates, but there were none because there is not a Bridge Creek siren system. There were sirens in the NEPA, but they were down on the list of warning sources, if and when they could be heard (they were unheard ~1 mi away). Basically, the residents were kept up to date by TV long before the warnings were issued for their counties, and evacuees were in their car, or even out of their car and in a position to deal with the tornado long before a siren sounded. Greater Moore knew about the tornado via TV, radio, and third party notification, but Gayland Kitch - Moore EMA - says "a siren speaks loudly when someone has 10 minutes or less to be ready." For the OCT population, sirens were the 2nd most prominent source among my surveys. But, this study the sirens were at 3 % of the primary warning source, and the 3 % turned on the TV. That did not do it justice, because it was a secondary or tertiary source. Brown et al. (2002) surveyed the OCT sirens and they were at 8 % of the warnings. Based on this study and Brown, sirens are for warning among those outside only, even though respondents said they were critical.

4.5.2.3 - *NOAA Weather Radio* -

For reasons not entirely clear, obstacles to presenting and marketing NWR have been persistent. In the OCT, NWR was a primary warning source for only ~3 %, with only ~12 % reporting owning a NWR in their homes. It is obvious that since the event, NWR ownership has gone up, partially due to major *NWS* and media-sponsored campaigns subsequent to the OCT. There can be few negatives in this, but in order for NWR to approach its full potential, many more need to use the service regularly, especially to access watch information and in situations where TV is not accessible. NWR is also of high value and utility in its ability to wake sleeping populations. There is little evidence that NWR use has risen as hoped, with the offering of Specific Area Message Encoding (SAME) technology, the primary aim of which is to allow warning more discrete populations based on geographical aspects of the warned event. However, this feature is of little value if few people use NWR in the first place. Confounding assessments of SAME are the undefined thresholds of geographic perception and spatial cognition, lead time issues, and confirmation behavior of stakeholders as related to warning compliance. In fact, any post-OCT increases in use of or attention to NWR by area residents, might be short-term responses (albeit positive) to the publicity surrounding the disaster and the subsequent marketing of NWR receivers by large discount department stores (e.g., WalMart, Target). However, by the Spring of 2001 it seemed that NWR was again by the wayside (NOAA 2003). Primary interest in NWR seems to be among those who cannot get a signal (and thus feel neglected by civil authorities). The controversy is 'we have no NWR' rather than 'we have no weather warning plan' or 'we need more weather information.' Once a transmitter is placed, there is no evidence that use rises above the 5 % level.

Mileti (1999) noted that the areal extent of warnings present significant logistical hurdles for the systems to overcome. In general, threats to larger areas require warning more people and working through more media and organizations. Similar threats to smaller areas facilitate more localized warning efforts that are more readily coordinated. However, akin to the impact of increasing spatial and temporal warning precision, the response spectrum to such products and major changes in procedure are purely speculative. It is unlikely that compliance continues to increase past certain time and space precision thresholds.

4.6 - Warning Lead Times

Warning lead time for survivors was exceptional, and respondent self-assessments of the performance of the overall warning system reflect this (Table 4.3).

Table 4.3 - OCT Warning Lead Times

Range	Primary (100)	Secondary (56)	Fatality (21)
1 hr +	12	0	0
1 hr	47	3	1
½ hr to >1 hr	32	10	6
15 min to >½ hr	6	18	7
5 min to >15 min	2	19	4
> 5 min	1	6	1
No Warning	---	---	1
Some	---	---	1

In BHM, 50 % of the respondents said they took 10 min to respond. In ARO, 50 % had little or no warning, while in PSO ~60 % they had little or no warning. This compares to FLA, when 68 % of those surveyed said they took cover "only by seeing/hearing". Other OCT surveys found similarly long TOR lead times as about a ½ hr or more, and hr or more.

As difficult as it is to comprehend, numerous respondents indicated that they felt that there could be such a thing as "too much warning" (Gruntfest 2002). At first perplexing, such feelings are possible when considering the decision-making thresholds of confirmation behavior that determine when to undertake mitigative action (e.g., seek shelter; flee). Survivors suggest that lead times in excess of 15 min play little role in motivations to undertake mitigative action (excluding telephone use), compared to detailed spatial information. There are many logistical and technological issues that need to be solved before more site-specific warnings may be technologically-feasible (Mileti and Sorensen 1990). Additional research regarding warning information content and graphical details versus lead time thresholds is warranted.

4.7 - Warning Compliance

All indications are that the percentages of those who received warnings, both among survivors and decedents, were at unprecedented and unforeseen high levels. No forensic studies in the literature present percentages for those who received warnings at levels approaching those found here. As previously noted, live video of the OCT and its upstream destruction, as well as the tenor of on-air TV personality advice ("if you are in X neighborhood take cover now"), played major roles in warning compliance. It is echoed in other literature that the 'wall-to-wall' TV coverage was a major factor in the decision-making behavior in all aspects of the warning system (Quoetone et al. 2000; Hammer and Schmidlin 2000).

4.7.1 - *Fatality Demographics*

Little of the morbidity data from this disaster is different from what would be projected for a violent tornado that encountered a major metropolitan area, with the possible exception of total deaths. The epidemiological 'footprint' closely followed the historical norm (Grazulis et al. 1998). Fatalities were clustered among the elderly, poor, handicapped, and *inexperienced*[EE], as well as skewed toward MMH or other structurally-weak dwellings. The recommended environmental response (not MMH) is not to attempt evacuation, but rather to shelter in the home (FEMA 2005b). However, in mobile home occupants, it is to find out whether a tornado watch (or warning) has been issued and move to a shelter in time. Among decedents, 60 % (24) were female. Decedent age ranged from 1mo to 94 yr, with a median age of 47 yr. More than half (52 %) were over 50 while 12 (30 %) were over 65, and five (12.5 %) were over 80 years of age. The deaths are cataloged in Daley et al. (2005) and Brown et al. (2002).

It is noted that no children between the ages of four and 18 were among the fatalities (OCME 1999). It certainly appears likely that the both the educational efforts of the *NWS* and local media, centered toward the elementary schools, have been effective (Brooks and Doswell 2002). And more acutely, warning messages directed specifically to "children home alone" that have been common on OKC TV (England 1996) might have contributed to low death tolls among school-aged children, and high levels of warning compliance among respondents with children in their company. Although England (KWTV-9) was adamant that you had to be below ground to live (in the OCT), many people above ground were not killed by the tornado. But even so, Daley et al. (2005) reported that "people who were in motor vehicles that were struck by tornado were at lower risk of death or injury than were outdoors or in mobile homes; differentiated in these risk estimates were striking, and most reached statistical significance," . . . [but] . . . "even when we combined all of these victims with those who were clearly fleeing the area, the risk of directly-related death and injury was higher among people remaining in homes." If you had to leave in a motor vehicle, perhaps 5 min or more to get to shelter was the minimum. If the roads are not congested and you can get clear of the tornado path or in a shelter without difficultly, you should go without hesitation.

Generally, the elderly are less likely to heed warnings, owing to compromised mobility and communication factors (Gruntfest 1987). Most victims over 65 suffered from some degree of compromised mobility or comprehension; one was legally blind, one used a walker to ambulate, two were recovering cardiac patients, one was wheelchair-bound, and one was hooked to renal dialysis machine at some point concurrent with the warning time-line. Similarly, three decedents were young children (two infants and one pre-schooler). Most victims were in their homes, with seven deaths outdoors and two were in a commercial building.

Among fatalities (insofar as can be reliably determined) at least 19 (47.5 %) had 'significant' warning of >5 min, and eight (20 %) of them had a ½ hr or more, and six (15 %) of them had 15 min to prepare. But the Bridge Creek victims had less time to get to shelter (which unfortunately was in MMH or outside), and all were in MMH. Warning details were unavailable for eight victims, although it was not determined that there were any decedents completely unaware of the tornado. Thus, at least 75 % of those killed were aware of the approaching tornado for some time before impact. Many decedents had time to speak to others in person or via telephone prior to tornado impact. Thus, survivor interviews indicated a third of decedents received TV warnings, 25 % were alerted by a neighbor, 20 % via telephone, and 12 % only by seeing or hearing the tornado without enough time to react. Most of the literature regarding past events with low warning reception involved rural locations or nocturnal events, factors not at issue for the majority in this study.

4.7.1.1 - *Flight and Vehicle Occupants* -

Perhaps the most significant exception in the OCT to currently understood 'norms' of contemporary tornado epidemiology involved the small number (two) of motorists killed, especially given the high number of potential vehicle-tornado encounters. The tornado crossed Interstates no less than four times, and spent at least a third of its life in densely-populated areas. Finding and surveying motorists that were in the OCT path who were not killed or seriously injured would be quite challenging, as their identities are elusive. Comparisons with other tornado events where significant numbers of vehicle fatalities have occurred are also problematic. Thus, comparing the OCT to the Wichita Falls, Texas tornado of 1979 (WFT) that killed 26 people in cars (Glass et al. 1980), or the Catoosa, Oklahoma tornado of 1993 where six of seven deaths were in vehicles (Biddle 1996), result in many difficulties related to vehicle engineering, warning technology, and even seat belt usage (Hammer and Schmidlin 2000). Tornado-related vehicle risk may be less related to the engineering, than to tornado time-of-day, traffic patterns, warning characteristics, and simple geography (e.g., hills, trees, urban, etc.). Schmidlin et al. (1998) reported that 15 % of all tornado fatalities from 1975-1995 were in vehicles. WFT yielded percentages of more than 60 % dead from vehicular fatalities.

In the OCT, four deaths were vehicle-related, though none were killed in vehicles. Four were killed outside their vehicles in the driveway of their residence, in belated attempts to flee (two each in a rural area and Del City). The remaining two (separate cases) died seeking shelter under highway overpasses. Neither were in vehicles with the intention of fleeing, but was simply traveling on an Interstate. It is not clear how or why either victim chose the overpass as shelter, nor on what sort of warning they were acting. Indications are that both decedents took cover at the suggestions or observations of other motorists doing the same. Likewise, it remains unclear what options or restrictions of options decedents had, nor how in either case only these two of the many seeking shelter under overpasses were killed. That more were not killed in these locations (there were numerous serious injuries) is fortuitous. In recent years, *NWS* and severe weather researchers have noted the increasing choice of highway overpasses (Figure 4.5) as shelters with significant concern (Miller 2001).

Figure 4.5 - A Car Hit by the 3 May 1999 Tornado (OCT).
The car was not occupied and was thrown about 1 mile.
M. Biddle. 4 May 1999. Copyright.

With regard to vulnerability, it is important to note that for the average citizen at their residence or place of work, and not in some increased risk situation (e.g., MMH, vehicle, outside, wide-span roofed structure, etc.), the risk of tornado injury can be mitigated even in direct impact scenarios (Brooks and Doswell 2002). This is because violent tornadoes – those that cause about ~70 % of the deaths – are rare and when they do occur the actual violent tornado wind speed exposure is a fraction of the tornado path area (Grazulis 2001). This means that shelter-in-place in substantial structures (e.g., interior room, bath, etc.) results in significant protection. Decisions about when to undertake shelter-in-place versus evacuating to an improved shelter cannot be made at the last second, for the risk of fleeing is substantial in its own right.

There were 24 injured in motor vehicle crashes in the OCT, but it is unknown if the storm was part of the accidents (Brown et al. 2005). Fleeing in a motor vehicle exposes one to not only a direct tornado encounter, but also to traffic accidents amid what may be panicked or snarled traffic in high winds and torrential rainfall, with no guarantees of arrival at shelter in time. Flight on foot exposes one to significant danger from flying debris, lightning, and other physical hazards. However, modern post-event surveys indicate as much as 70 % of the MMH has driven away from their homes in past tornado situations (Hammer and Schmidlin 2002). Something of a controversy has emerged regarding the mitigation actions that the MMH should take, including notions that, in many cases, a motor vehicle may be safer than an mobile home (Schmidlin et al. 2002). There is also increasing information that much of the non-MMH has or will 'evacuate' the path by car in future events. Those who must make shelter-in-place or flight decisions might benefit immensely from warning products that specifically include information required for such urgent decisions. Probability-based warnings could provide the added information required via decision thresholds – dependent on accuracy and lead time dynamics – or could alter the warning ecology in negative and unforeseen ways.

At least two people (Bridge Creek) were killed outside attempting to reach their vehicles to flee the tornado. Others were injured attempting to do the same. However, perhaps many more than ever measured successfully fled the tornado path in vehicles. Surveys indicated 61 (48 %) of respondents fled, and 54 used a vehicle (the ones on foot went to a neighbors). This compares to 45 % from a similar survey limited to those in the F4/F5 damage areas in the OCT (Hammer and Schmidlin 2002). Aside from concerns regarding shelter availability, traffic hazards, and a risk of a tornado encounter in the open, it is inconceivable under current warning system capabilities that evacuating large sectors of a population is a logistically-feasible scenario. Conversely, it is impossible to ignore the fact that significant numbers of people (approaching 25 % of all those in and near the path) fled from the tornado, and that a sizeable number could have been casualties. Neither the *NWS* nor EMA advocate vehicular flight in a tornado warning because of the imprecision of path forecasts, risks of chaotic and panicked traffic (Grazulis 2001), and the potential to find poor shelter options as a function of tornado-highway encounters. Flight, which is essentially an evacuation, appears to be a viable option only under conditions which are very situational and not always obvious to those facing the decision to flee or not. Only when there is enough time to clear the storm's path or get to shelter is it prudent. Incorporating traffic issues, including the potential for traffic jams and accidents, as well as downed trees and power lines, can make the prospect of flight something of a gamble. Even with increased warning lead times becoming more common, there appear to be tendencies among many stakeholders to spend significant amount of this time in the confirmation process, deciding what action to take. Thus, much of the lead time is lost. The value of tornado watches and the importance of understanding one's geographic location relative to the severe weather and warning products must be emphasized as critical to decision-making regarding flight.

There is no new research contradicting previous findings that have suggested persons attempting to flee tornadoes in vehicles are at higher risk (e.g. Glass 1980), or newer studies that suggest there may be limited protection afforded by vehicles in certain tornado scenarios (Schmidlin et al. 2000). Something of a challenging EMA dilemma is emerging as the EMA community stresses 'shelter-in-place.' This concept seems contradictory to other common advice given in current warning 'call-to-action' statements to NOT stay in mobile homes or in unhardened locations without shelters. The survey formats and warning landscapes of the different events (OCT and WFT) are too separate in time to make major policy conclusions. What is certain is that a significant population indicated that they fled the OCT. Most people returned to find their homes undamaged. However, some had major damage and it can be conservatively surmised that some, perhaps hundreds, escaped death or serious injury by fleeing (Sunday Oklahoman, 18 September 2005). It is unclear if the high numbers of those who fled the path is a behavioral phenomenon that is particular to this event or this region, perhaps as a result of the regional TV coverage and the overall attention to severe weather, or if it is some major behavioral shift that has occurred in other areas also as a function of the more general advancements in forecasting and increased warning lead times. There were numerous stories of families driving to and getting under overpasses and viaducts at least 30 min prior to OCT passage. Interviewees reported that they ventured down to Norman or up to Edmond to eat dinner at restaurants and wait out the storm. This behavior, concomitant with the lead times, does not fit previous or current models for flight behavior or warning compliance. It is premature and unwise to advocate in any sort of broad sense, evacuations by anyone, save the MMH. Most survivors who fled implicated real-time TV coverage as their confirmation that the situation was serious enough to induce them to flee. Some indicated that they do so on a regular basis when a tornado warning is issued. Many said they did not have a plan in place, did not have a particular shelter location in mind, and had never undertaken such action before. A few stated that they simply got in their cars and started driving in attempts to remove themselves from the storm's path! This poses something of a paradox in that countless stories of flight should have resulted in higher vehicle-related mortality. To this paradox, two explanations are offered. First, previous studies have failed to characterize those persons who successfully fled *post hoc*, by focusing on those who were casualties in the attempt. Second, the character of the live media coverage (and the explicit tornado video), the unusually-long lead times of *NWS* warnings, the diurnal time-frame, and the high visibility of the tornado were a unique combination of occurrences that combined to allow many people to flee. Flight seemed not to be part of most people's response plans (if they had any) and became more viable as a consequence of of the long warning lead times. The lead times allowed "contemplative" rather than "spontaneous" evacuations (see Hammer and Schmidlin 2000). The significant advance warning led to more flight, and in turn more survivors who fled. This illustrates the major rift that exists in our understanding of the impact of warning dissemination and lead time, versus warning behavior and warning message content.

4.7.1.2 - *Special Needs Demographics* -

As mentioned, certain demographic sectors consistently present more vulnerability to tornadoes. Among them the poor, elderly, very young, and disabled. The human ecology of risk for these groups may be traced in part to warning issues. The poor are less likely to have access to multiple media or certain technologies inhibiting reception of warnings. It is surmised that the elderly have tendencies to dismiss warnings in cognitive processes framed by situational factors, such as compromised mobility and media access (Gruntfest 1987). In the OCT, all fatalities over 65 yr of age suffered some degree of compromised mobility, communication, comprehension, or other compliance impairments (again, one was partially blind; one used a walker to ambulate; one each were recovering cardiac and stroke patients; one wheelchair bound; and one was evidently hooked to renal dialysis machine at the time of tornado impact). Similarly, three decedents were young children; two infants, and one pre-school age. Disabled persons tend to suffer from situational impediments to warning compliance. Some are not able to physically respond to warnings when received. In other cases they fail to perceive risk correctly even when warnings are received. Caregivers responsible for disabled persons may require more time to comply with warnings, or are pre-occupied with other life support issues to properly monitor weather news. Often these special needs groups are inter-related. Both the elderly and disabled are disproportionally poor, the elderly often disabled, and *vice versa*. There are costs involved with all mitigative responses to a warning for all users. Usually the costs are intangible and inconsequential (e.g. time, interruptions of activities). Costs tend to be higher among special needs groups, especially those with medical problems. Stress, even for false alarms is more dangerous, as are the physical demands of getting to shelter. An example is an indirect fatality that occurred in OCT. A wheelchair-bound elderly man was killed from a fall attempting to get to underground shelter, his home ultimately untouched by the tornado. In 2005, there were ~676 000 Oklahoman disabled persons (1999 population was ~3M). So, it's up to 25 % (the disabled in the OCT) from about 22 % statewide, and that 25% figure is severely disabled and not the walking partially-disabled that blends into the data. Future warning programs might be designed with these populations in mind, providing additional or tailored information to enhance mitigation.

4.7.1.3 - *Mobile Homes as a Risk Factor* -

Over the last two decades, as much as 70 % of all fatalities have been in the MMH in certain years (Grazulis 2001). MMH fatalities in the OCT were high (31%), though slightly less than the national aggregate average (~50%) in recent years (Brooks and Doswell 2002). All MMH deaths occurred in the early stages of the event in Bridge Creek (of the SWPA). Compounding the risks inherent to the MMH, rural SWPA victims had less potential warning lead time than those impacted downstream. While there was still considerable warning available, varying in the tens of minutes, residents of Bridge Creek had less time to notice sky, wind, or other environmental cues, as well as to receive telephone relays or notifications from neighbors or other third parties. And the bulk of the people were just getting home from work. Most importantly, they were less likely to receive TV warnings (SWPA) than the Cleveland and Oklahoma

County residents (NEPA). All these variables add up to less time to complete the confirmation process (which varies with each person and situation). This confirmation process has been identified in the literature in numerous studies from numerous eras and it appears to have been common and critical to OCT survivors in that most had a wealth of information and long lead times. Though likely related to the NEPA geography (i.e., luck) it is important to note that only a few of the ~6500 'mobile homes' in Oklahoma County were destroyed (OCTA 2001).

The rural nature of SWPA locations (and the bulk of the MMH) reduced the probability of the reception of siren alerts. Though many technological and societal factors reduce siren efficacy, a siren in these small but densely-settled mobile home plats may have saved some lives. As mentioned, terrain in this area limited storm viewing via naked eye to the west and southwest. According to survivors, it was difficult to see the tornado or gauge its movement until it was <1 km away. However, field investigations indicated that tornado visibility played limited roles in these fatalities. *None* of those killed in the Willow Lake Addition, Southern Hills Addition, and the Bridge Creek Estates in Bridge Creek had ready access to improved shelter.

4.7.1.4 - *Shelter as a Risk Factor* -

Interviews and epidemiological data (Brown et al. 2002) indicated that nearly all OCT deaths occurred among those with no improved shelter onsite or nearby. Only one victim died where underground shelter was available, which they failed to utilize. Twenty-four (61 %) deaths occurred in residences where no *significant* shelter was available (Figure 4.6). Fifteen victims (38 %) were killed in the best available shelter of their homes, such as in a closet, bathtub, or under a staircase. While such above ground shelter options are no match for F4/F5 wind speeds, the actual area of violent tornado damage is a small fraction of the total damage and many survivors did endure major damage while sheltered in baths or interior bedrooms to emerge with minor or no injuries. However, at least four fatalities in well-constructed homes occurred when large missiles (such as automobiles) were thrown onto residences where people had sought shelter in baths or closets. The three apartment fatalities involved occupants in upstream exposures (southern and western) of the outermost units of apartment complexes, with one on the ground and two on second floors. Four (possibly 6) people were killed outside in belated attempts to flee or reach shelter too late.

Shelter availability, especially for low income residents, rural populations, elderly, handicapped, and the MMH continue to be the most prominent emergent risk issue. While opinions regarding the feasibility of community shelters are quite varied, where they existed, many respondents indicated that they did not regularly utilize them, nor even knew their locations. Although the popularity of home-based shelters has increased substantially since the disaster, costs (usually >$2000) are beyond the means of many lower income residents. Studies on options to address these issues are needed to craft appropriate legislation (e.g., shelter tax credits, mandated shelters for MMH), building codes, or public education campaigns. Moreover, there are concerns about substandard shelter proliferation by companies that prey on the fears of survivors. There were nine contractors listed under 'storm shelters' in the *1996 OKC Yellow Pages*, whereas there were 38 in the 2000 phone book that manufactured shelters. There is 12 in the 2007 phone book.

Figure 4.6 - 4 May 1999 in Moore, Oklahoma.
Matthew Biddle, Copyright.

Similar concerns about reconstruction were noted in the quality of construction amid rebuilt housing developments (Marshall 2000). Structural policies (such as mandated building codes) are emphasized after a disaster seemingly at the expense of non-structural policies, such as EMA programs to identify vulnerable individuals or research to determine future warning, shelter, and evacuation trends. 'Shelter-in-place' concepts, currently common in EMA doctrines, provide a response framework for much of the public, with little erosion of EMA budgets. Such policies have little foreseeable negative impacts, but there appear to be broad assumptions that people: a) have a shelter to go to and know where it is; and b) choose to 'gamble' on survivability because of unawareness of the potential risks and in spite of publicized mitigative guidance (Figure 4.6).

The recommended public health response is to shelter in situ, *rather than attempt evacuation.*
- R. Dawn Comstock and Sue Mallonee -
DISASTERS 2005, 29 (3): 277-287.

Although the manufactured housing industry would have you believe that tornado disasters are the product of freak natural acts - equal opportunity killers roaring willy-nilly across the landscape - the figures suggest a less democratic, more class-based pattern.

- Ted Steinberg -
ACTS OF GOD: THE UNNATURAL HISTORY OF NATURAL DISASTER IN AMERICA

5 - POLICY ISSUES AND RECOMMENDATIONS

5.1 - OUTSTANDING ISSUES

Outstanding issues that need to be addressed are standardized post-event surveys, the 'Tornado Emergency', public assemblies, high-vulnerable populations, future of probability-based warnings, and the future of *NWS* programs. Addressing weaknesses in these areas could improve compliance and the overall safety of the general public.

5.1.1 - *STANDARDIZED POST-EVENT SURVEYS*

While there has been an increase in the number of tornado disasters forensically-studied, particularly by Schmidlin et al., many efforts (including this study) suffer from logistical and scale limitations. Cross-comparisons between disciplinary specialties are statistically and subjectively problematic. Research is piecemeal and episodic, and a much-larger percentage of events needs to be surveyed to expand the body of statistically-significant data. Better coordination is needed between epidemiologists, geographers, engineers, EMA, and the meteorological community. However, this seems to be a "broken record", as *every* major policy directive regarding tornado risk since the 1970s has advocated such collaborations. Such policy initiatives have not filtered down to the day-to-day activities at the local levels. The *NWS* should redouble efforts to become more involved in the "human factors" aspects of warning system policy. One of the major obstacles to characterizing warning response and storm impacts adequately is simply the perishable nature of the data. Response and clean up begins immediately and recovery soon after the event. Survivors and responders tend to scatter quickly and lose memory of certain details in the days following the event. Getting into the field immediately as a routine part of post-event assessments (such as *NWS* Service Assessments and *FEMA* Impact Reports) with experienced survey teams and standardized survey instruments would be a good start on building a foundation of human ecology data for tornadoes.

The *NWS* diversifying administrative 'Service Assessments' to include emergency managers, college professors, city managers, health professionals and other involved people would help (Speheger et al. 2002.) Currently the service assessments are self-maintained within the *NWS*. It should not be standard protocol for an agency to be in charge of its own quality assessment and standards compliance. The current setup does not allow for objective analysis. A lack of cross-jurisdictional commitment to emergency preparedness and warning was noted in surveying this disaster, though it is by no means unusual anywhere. Oklahoma County and the City of Moore appear to have benefitted from progressive and prepared EMA offices. Other nearby localities with identical tornado risk give EMA piecemeal or inadequate attention. Many communities have personnel with EMA authority, but provide essentially no resources or appreciable funding. Consistency of approach in EMA is important in achieving public preparedness and in maximizing the efficacy of the *NWS* FOS. Stakeholders benefit from uniform approaches and products in this era of the highly-mobile society, where people travel extensively, and live and work in different communities.

5.1.2 - *The Tornado Emergency*

It is appropriate to use 'Tornado Emergency' (an SVS from the local *NWS-OUN*) in cases where a large tornado is *known* to be on the ground and threatening a significantly populated area, as in the OCT. Since this event, however, the phrase has been used in rural areas in warnings disseminated for weak and brief tornadoes (e.g., Texas Panhandle). Much like the terminology confusion regarding PDS watches, the impact of such 'special' products remain largely conjecture. For the OCT, this innovative approach seems to have been quite beneficial in this CTA. However, *NWS* should consider a standard protocol (not necessarily a mandate) for the future use of such statements to avoid overuse and subsequent dilution of its meaning. Future warning system improvements must incorporate the fact that the identical terminology carries different meanings among stakeholders, especially when such terminology is new and usage not standardized. Until the warning system defines such terms and consistently dictates their meaning, their impact will likely be less than optimal. Conversely, it is very clear that the use of the phrase represents a sort of *de facto* increase in warning certainty. Thus, it anecdotally implies that the public does indeed respond to levels of (un)certainty in warning messages, and furthers the idea that cataloging different ways to express (un)certainty is critical.

'Tornado Emergency' was subsequently observed using a 'non-severe' tornado in the sparsely-populated Texas Panhandle in 2000 (Biddle 2000), and in what could have been a more obvious scenario in Indianapolis in 2002. In the former example, a small, brief, and weak tornado - well observed, reported, and tracked by spotters and research teams - lumbered outside a rural town (2000 population ~2300) in broad daylight. It is arguable whether a Tornado Emergency can exist in the connotation intended in that particular scenario. In the second example, a tornado was known to be on the ground in an urban area, and the words 'Tornado Emergency' were used (Mitchem 2003), but the phrase was buried in the text of a standard warning, and appeared to have little impact in and of itself. Tornado Emergency was again used in Oklahoma City for a damaging nocturnal tornado on the city's northern fringes (8 May 2003). But the tornado was not violent and the impact of the statement in this case is difficult to measure, given the intense media coverage afforded all tornadoes in the area since 3 May 1999. Is every tornado warning situation that occurs in greater Oklahoma City to prompt the use of Tornado Emergency? Is its use dictated by population densities, path length and persistence, or predicted or detected intensity? Until the warning program defines such terms and consistently dictates their meaning, their impact will likely be less than optimal.

5.1.3 - *Public Assembly*

While many facilities were well-prepared, numerous reports of certain school officials – "ushering children and assembly attendees to shelter as the storm began to hit the building" – were recounted. These are *not* stories of safe behavior, but rather, good luck. A 'Tornado Watch' had been in effect for some time and warnings had been ongoing upstream of these locations for tens of minutes. Organizers of mass assembly – particularly in a public school – should *never* carry on such activities without direct lines to warning information or designating someone to monitor the outside conditions, or preferably, *both*! In several instances, mass casualties were narrowly avoided by minutes or meters, which could have easily and dramatically increased the death toll (Grazulis et al. 1998; Edwards and Lemon 2002). More emphasis must be placed on the importance of weather watches with more training given to school, church, and public venue officials on planning for such instances.

The EMA community should consider mandatory minimum compliance standards for severe weather plans and shelter procedures for public facilities and other places of mass assembly (e.g., churches, malls, schools, etc.). Such standards could easily and economically be incorporated into the *Life Safety Codes* (promulgated by the *National Fire Protection Association*) and be administered locally by EMA or fire department personnel. Such standards might include NWR as an alert device, and could be seen as comparable to smoke detector regulations in basic fire codes (as is presently part of *NWS* Stormready certification). This is not to suggest one way or another, that shelters themselves be mandated, but that plans and postings be made available to the public regarding the severe weather plan for the facility, and that personnel at such locations be trained regarding the best available practice in the event of warnings or severe weather.

5.1.4 - *Siren Efficacy*

The siren system can only reach people in a certain radius and the competing noise factor is difficult to control. Another variable with a siren system is varying rules of regulation by each municipality controlling the sirens. The skill level of the individual sounding the sirens (or automatic systems) is not going to be uniform. You might be able to hear a tornado warning siren one time, and then the next time you will not be able to hear it because of wind patterns, environmental noise, etc. It is an outdoor warning system ONLY. The civil defense system of the 1950s warned the public of air raids (and there was less environmental noise) and they stayed around until the present. This variability makes the system ineffectual. The cost of NWR for all households is less than a working siren system. A siren system is not only more expensive, but reaches significantly fewer people. The NWR is more cost effective and has the capability to reach rural areas more reliably.

According to Comstock and Mallonee (2005) in the OCT the two most common warnings were television (92.8 %) and sirens (72.9 %). However, when you allow for multiple warning media, you are not doing justice to the primary source. For instance, that more people could hear the sirens does not mean they were moved by them or first alerted by them. The author stresses that the siren totals are only beneficial as an imminent danger alert sound at the warning for the county or city in reference. The TOR in live time on the TV allows for timely decision-making. This coverage was responsible for the prevention of additional injuries and fatalities and moved many to evacuate.

5.1.5 - *Highly-Vulnerable Populations*

The most vulnerable populations were the poor, the disabled, and elderly. Statistically, the poor respond less well to natural hazards, and with it weather reports, than the whole population does (Gruntfest 2002). The poor are too busy trying to survive from day-to-day. Their priorities do not include storm warnings when the stresses of everyday living are so great. The disabled presented with obvious navigation difficulties for getting to a safe place, especially those living alone without caregiver assistance. Caregivers are too busy assisting the patients with personal care issues to attend to weather warnings. Duties of caregivers need to include watching for weather warnings. Possibly the provision of NWR (where there are adequate radio signals) as basic safety equipment for the disabled and the caregivers would prevent isolation from warnings and give time to seek shelter. The elderly alike are the most-vulnerable because they are disabled, poor, or both among the population. The factors that interfere with warning recognition are poor hearing, vision, and cognitive skills (memory and problem solving). In addition to these possible deficits, they may also have physical limitations that prevent fast movements needed for seeking shelter or fleeing. If they're even aware of the need to act quickly, they might realize their limitations and take their chances by doing nothing. Many of the elderly do not drive and rely on others for transportation.

Safety of the young (< 16 yr) is directly related to the competency of the adults in charge of their care or the lessons learned in school. There were no deaths in the OCT between the ages of five and 23 yrs (OCME 1999). The decision thresholds crafted in response to probability-based warnings could aid such subgroups in warning response, given that they should not be subjected to as many warnings requiring mitigation compliance as is common under current categorical formats, and allow in theory. It is speculated that customized planning thresholds for activities that involved more complicated decisions and actions will be needed. We need to explore the 'push' concept where information is sent to certain receivers/computers based on need, locations, and risk, the cell phones would be a good start.

5.2 - THE SURVEY INSTRUMENT

The survey was developed hurriedly on the day of the field work (4 May 1999), but it was loosely based on similar post-tornado surveys by Schmidlin (1997) and Legates and Biddle (1999). This is not necessarily the ideal way to develop a survey instrument, and several inadequacies became apparent during data analysis (Appendix A). Thus, the survey was done with some pre-conceived issues in mind, based on previous experience by the author and on other surveys. There are two distinct issues associated with this survey: (1) If it were possible to redo the survey, what changes to the instrument would be beneficial? (2) If a survey were to be developed that would become a standard survey for tornadoes in the future, what elements should that survey contain?

It is felt that this survey, suitably modified as described in what follows, can serve as a prototype for survey instruments in future tornado:

> **1) RESPONSE TIMES.** These were estimated by the respondents and then sorted into categories (e.g., 60 min, 30 min, 15 min, etc.). Retrospectively, the original uncategorized estimates should have been saved or elicited.
>
> **2) RESPONDENT INFORMATION.** After reviewing the data, it was felt that it might be appropriate to go back and re-interview some of the respondents. However, there was not enough detailed information about their location and address (the two might be different) to go back to all of the respondents. In many cases, their location at the time of the tornado is known only approximately (within a few blocks). Having specific information would have made the analysis easier.
>
> **3) DEMOGRAPHICS.** It is unclear what value knowing marital status and ethnicity had in this study, because responses may not always be truthful or can be questionable (mixed racial ethnicity, for example).
>
> **4. UNASKED QUESTIONS.**
> a. Do they have a plan for what to do in case of (1) tornado watch, (2) tornado warning, (3) severe thunderstorm watch, (4) severe thunderstorm warning?
> b. If yes, was their actual response consistent with that plan?

c. If not, why not?
d. How far away (estimated) was the tornado when you first heard about it?
e. How far away (estimated) was the tornado when you took action regarding it?
f. The question "What would have made the warning better?" That was on the instrument, but actually was not asked of all the respondents. This question should have been asked of all respondents. Among those who were asked, it was observed that those who actually were hit by the tornado generally responded to this negatively (didn't suggest any way to improve the warning), while those who were not actually hit, offered suggestions. Rather than recording 'shorthand' descriptions of the responses to this question, detailed responses should have been documented.

The survey needs to be short enough that it can be completed within 10 min -15 min, since the contact with respondents typically occurs while they are in the process of cleaning up or otherwise dealing with the situation caused by the tornado. The respondents were selected in a "shotgun" manner within 3 km (1.9 mi) of the OCT. No doorbells were rung. With exceptions, respondents were dealt with in three days of the OCT. Respondents can be called after one month or so and asked further questions, if the need arises.

5.3 - Future of National Weather Service Warning Programs

Wernly and Ucellini (2002; p. 71) note that *NWS WFOs* have "the ultimate warning and forecast responsibility [that] includes producing and issuing all of the traditional critical information products, as well as working with all *NWS* partners in the warning process to coordinate preparedness planning efforts and hazard awareness activities." Still, there is very little in the literature, including from *NWS* sponsored works, that does much to specifically design 'critical information products.' There appear to be a number of forces, some of them seemingly in opposition, about what directions that society in general, and the *NWS* specifically, should develop with regard to severe local storm warning systems. Among the issues are the increasing advancements in technology, the evolution of the roles of private forecasting services versus public service aspects of data ownership and 'right-to-know' issues, and intra-*NWS* issues related to automation, centralization, and public outreach. It is very difficult to project what sort of institutional environment will exist in the next couple decades, making hypotheses about forecast and warning product evolution that much more challenging. According to the NRC (1999; p.55): "the principal future roles of the *NWS* in providing environmental information will be extensions of its current roles ... public forecasts and severe weather warnings will continue to be a government responsibility. The *NWS* will retain the lead role for issuing warnings and ensuring their dissemination. *NWS* will have to focus on saving their primary customers, defined as whomever immediately received their products. The primary customers of the *NWS* will often be other information providers, not end users."

There is reason to believe that continued advancements in IT, MOS performance, and other technological advancements will increasingly 'usurp the traditional role of weather forecasters' (Brooks et al. 1996; p. 1), and that competition for access to data could involve the public competing with various other governmental or corporate entities. Such organizational and manpower developments, coupled with the predicted expenditures for weather forecasting and warning programs that will fall (relative to inflation), must be cause for reflection about ultimate *NWS* motivations to increase the use of probability-based products. Currently, liability issues make it problematic for private and commercial sources to issue warnings (Klein and Pielke 2002), and public entities usually cannot finance duplicate services of those offered by *NWS* (NSTC 2000). However, as private vendor and subscriber warning services become increasingly common, warning programs could suffer if centralization and privatization of *NWS* responsibilities dilute local interactions and connections to stakeholders.

If private or local jurisdictions attempt to fill certain roles exclusively, the discontinuities that could emerge could likely doom any imagined 'seamlessness' in services. Services might become piecemeal, inconsistent, and lack the standardization and authority that has proven to be important to warning program access and compliance. *NWS* has professed (NRC 1999, p. 47) that "customers in 2025 will be considerably more knowledgeable about weather and environmental forces than their counterparts in 1998, and they will be more sophisticated in using this information in their professional and personal lives." Aside, the fact that it is unclear how knowledge is assessed here, it appears that to the 'agents-of-change', knowledge is synonymous with data access. However, research regarding such conclusions and examinations of the implications to the design and utility of future *NWS* products is curiously absent. *NWS* policy tends to reflect a mind set where technologies are solutions to problems, whereas the problems themselves have not been formally defined nor sufficiently studied (Brooks et al. 1996). *NWS* has a poor track record in this area, and its organizational propensity to institute programmatic policies and program revisions (such as major revisions of the watch-warning program) blindly must be moderated by customer research and policy discourse if change is ultimately to benefit both the *NWS* and its stakeholders alike (Doswell c.2003b).

5.3.1 - *Warning Policies*

Advances in low cost computer graphics and increasingly common access to Internet-based communications have given stakeholders a hand in the generation of misleading symbols and inappropriate projections (Monmonier 1996). The implications of this remain speculative, but as it stands, when weather information is disseminated via computer graphics, there are no assurances that the information is being projected as generated, transmitted as intended, nor communicated as designed (AMS 2001). There has been some research on how users understand graphical weather warning information, particularly that which has been disseminated via TV. Mroz and Raven (1993, p.426) concluded that televised weather information is "poorly understood, often misinterpreted, and at times, even manipulated by the public." Effectively utilizing graphic displays of weather data require knowledge of user's 'mental maps' of space and place, and how such representations are spatially, culturally, and environmentally situated (Curry 1996). And the urgency and available time to process spatial / graphic warning information mentally is a learned experience subject to breakdown under stress. An illustration is an incident (witnessed by the author) where a government tornado intercept team was directed by highly-qualified and experienced nowcaster support to make numerous wrong turns, such that the mission was compromised (by at least 50 km). The cause was misreading radar data overlain on county-base maps in the heat of battle (Rasmussen pc.2000).

Empirical reviews of TV weather radar in warning situations reveal a complex blend of useful technical information, and presentation-oriented 'eye candy' that often provides little useful information (Mroz and Raven 1993; McCarthy 2002). Survey data from OCT indicates that the combination of video images, statements made by on air meteorologists – and of critical importance, the tenor and emotion conveyed in these statements – were more important in stimulating response or achieving compliance than radar presentations. Surveys of radar comprehension and spatial cognition of weather radar displays are few and have proven difficult (Drabek 1986; England 1996; Biddle 1996; Golden and Adams 2000). Self-assessments and comments gleaned from survey respondents are problematic because there tends to be a large magnitude of biases in the responses. In other words, the fact that people claim to want radar images, or say they understand weather radar imagery, is not necessarily indicative of the role it plays in response nor indicative of what people really comprehend from such presentations. Considerable research in this area would be very beneficial to the overall warning ecology library, as well as to the media and vendors involved in crafting graphical warning products. The media can provide detailed information about the track of the tornado (NOTE: this does NOT include street names). This allows the public to make more informed decisions about evacuating. Many people evacuated in the OCT needlessly.

However, people process risk information primarily through a filter of existing experience and knowledge. Given this, the most efficient means to communicate short-fuse risk is to characterize and integrate what people already know (and do), and then develop warning strategies accordingly (Morgan 1993). Although many are familiar with certain aspects of a hazard risk impact, magnitude, or frequency, most are not fluent on statistical probabilities. This makes communication of uncertainty very challenging. Partially because of these common heuristics, and partially because of the evolution of the WWP – most warning products are dichotomous and applied at the county size. This dilutes a considerable amount of the forecaster's detail regarding uncertainty or confidence. Even when we are scientifically able to define the uncertainty quantitatively, perceptions of the uncertainty are often 'socially amplified' or attenuated, and reduced to biased qualitative attributes (Kasperson et al. 1988).

What, if anything, would have been different with more advanced technologies and even greater lead times? Most of the evidence suggests that very little would have been different absent significantly more lead time coupled with highly-accurate and reliable path forecasts (Lindell 1987; Legates and Biddle 1999; Hammer and Schmidlin 2002). Consistency in warning system procedures, and more uniformity in alternative media messages would provide more effective safety measures. Alternative warning modes are currently not controlled by any one vendor and are in need of consistency of warning systems procedures and more uniformity in alternate media messages. Pagers and cell phones, GIS systems, siren systems, reverse 911, and outdoor and highway signals are some of the alternative warning dissemination systems used.

5.3.2 - *Policy, Service, Marketing, and Transition*

Most of the limited human ecology research that has gone into *NWS* policy and product development has been through 'focus group' methods (e.g., NOAA c.2003; UCAR c.2003). Judgments and summaries of stakeholder attitudes via 'focus group' methods are wrought with accuracy and bias problems. Focus groups are often biased toward the motives of the investigators (either consciously or unconsciously). Conclusions about the focus of the group are often grossly simplified, smoothed toward the mean, and summarized in ways that do not reflect the diversity of behaviors or important notions regarding use of the given information. Survey data are equally prone to mishandling as self-assessments of user comprehension of graphical weather information for instance, can be highly-skewed owing to combinations of two forces: many people use such information with partial efficacy, and thus think they understand the information much better than they actually do; and, many people are loath to admit to survey administrators (or themselves) that there are technical issues in the information that they do not understand. Questions are often leading and discussions are often steered in specific directions. The more complicated and time-consuming the survey, the more likely that the population of those willing to complete it are those with either an enhanced personal interest in the survey topic, a personal interest in the agency or product being surveyed, or are otherwise 'cornered' in such a way as to not be typical of an unbiased sample population. The result is that we know little about how weather information is really used, and new products often come on-line and old ones are retired without it ever being well-established how they were used, and by whom.

Mileti (1975) suggests that many public education efforts to change warning response need improvement and that some portion of a population fails to take appropriate action regardless of the warning. Only with greater understanding of the likely responses of individuals and groups under disaster threat would it be possible to make beneficial refinements. In situations where warning systems can function to a large-scale loss-of-life and movable property, an integrated sociological and psychological all hazard project could refine present knowledge and expand on it. Community vulnerability is not only a function of the probability of impact, but also the degree to which the community can endure the impact.

5.3.3 - *Privatization: Commodification of Warnings*

The commodification of weather information – or the transformation of knowledge, observations, or data into products for sale – has revolutionized both government and private sector meteorology, particularly in areas related to technology transfer. Similar evolution has been observed in other environmental fields such as agriculture (Rivera 2000) and energy (Levin and Espeland 2001). The commodification of all types of weather information, including data critical to warning programs and in certain cases actual warning information itself, is a complex emerging issue that cannot be debated to any significant degree in this work. However, it bears noting that as more probability-based products become possible (largely because they are themselves commodities) via the IT revolution, increased privatization of weather warning information – traditionally the domain of government – is of relative concern. The research and development of investments, the body of intellectual and operational expertise, and the physical and technological infrastructure of the *NWS* is 'fruit from the publicly-subsidized tree.' Are prospects that the more basic and valued aspects of current warning programs and products become paid 'subscriber only' services segregated economically from large sectors of lower income society, and that the technological devices needed to receive modernized or value-added work annually, solely available to certain upper sections of socioeconomic strata?

5.3.4 - *Information Access and The 'Digital Divide'*

Although the use of the Internet is increasing rapidly, as are the use of Internet platforms (e.g., *NWS* sites or weather.com) to receive weather information – including warnings – there remains a sizeable portion of the population without regular access to computers (Dimaggio et al. 2001). As of 2003, the Pew Research Center (PRC) found that ~59 % of all adults in the US had 'regular access' to the Internet, with variability within regions from a high of ~67 % in the Middle Atlantic States to ~48 % in the Southern States (PRC c.2006). Also of note is the uneven Internet 'penetration' to certain community types (e.g., urban, suburban, rural, etc.) and stratification of access among various groups based on age, family size, ethnicity, education level, and income. PRC has specifically and thoroughly assessed these demographics and further note: "Anxiety about the divide centers on arguments that those who do not have access to the Internet are disadvantaged compared to Internet users for a number of reasons. The concern is that Internet non-users will have, among other things, less power as consumers and fewer economic opportunities, less access to high-quality health information, fewer options for dealing with government agencies, no chance to learn about their world from the millions of organizations and learning centers that have posted their material on the World Wide Web, and less opportunity to interact with others through email and instant messaging" (PRC c.2006; http://www.pewinternet.org/reports/reports.asp). It is a natural extension of these concerns to wonder what will be the implications to various societal groups if the Internet becomes either a primary sole-source for warning information, a source of warning information that scientifically or technologically of higher value, or that is better than other forms of public warning information. These are not questions to be answered in this research, but merely questions that those involved in any sort of warning product design in this era need to consider.

5.3.5 - *Information Overload*

From the early onset of the 'Electronics Age' (Broadherst 1958), concerns over increased data processing duties and volumes and their limitations on human logistical and cognitive capacities, emerged in what was colloquially called 'Fighter Pilot Syndrome'. This mental 'separating of the wheat from the chaff' with regard to human information processing is of most importance when the decision-making stakes are the highest and the time frames are the shortest. As noted by Wallace (1990; p. 265), "technological capabilities do not ensure more effective decision-making, particularly in disaster management. In fact, they seem to ensure the delivery of more data than can be processed effectively in crisis situations. We need to utilize technology to help alleviate the potential for information overload and, in addition, provide support for the cognitive processes of both individuals and groups involved in disaster management." Thus, 'Information Overload' concerns are applicable not only to the F-15 pilot in a dogfight, but to a Greyhound Bus driver monitoring weather warnings while driving through a thunderstorm on the Interstate.

5.3.6 - *Social Implications of Technology*

While the new technological capabilities that make probabilities possible, and their tremendous potential applications have made for much positive speculation regarding an era of 'predictive warnings' (Wernly and Uccellini 2000), the 'push' for such technologies from scientists, engineers, or policymakers, must be in response to a 'pull' from potential users and stakeholders (Walter and Quarantelli 1996). New systems require tangible relevance, economic gain (often profit), and societal benefit if innovations are to be adopted. Steinberg (2000) notes an interesting aspect of American policy culture and how it addresses (or fails to) hazard vulnerability; an affinity for 'clinical diagnoses' has become politically pervasive in attempts to impose scientific and technological ideas toward solving the 'natural hazard problem'. This mind set tends to drive policy further down the road toward the 'technofix' and away from humanistic mitigation policies and institutionally empathetic responses, drifting toward stratified, capricious, or spurious societal and environmental impacts. Technological 'fixes' do not always work.

Given that a significant reason for the decrease in tornado morbidity and mortality – in light of increasing population has been demonstrated to be the impact of warning programs already in place – it is a fair question to ask why (or *should*) we as a society continue to expend resources on tornado warning systems when there are so many other public health threats in the environment that pose greater risk? The most basic answer to this is that politically, most people in American society perceive tornado risk as significant and worthy of institutional engagement (Riebsame et al. 1986). Most want warning programs, are accustomed to them, expect them, and are willing to see at least some of their tax revenues allocated to developing and maintaining them (Steinberg 2000). Relatively speaking, the technology and scientific know-how exists at levels that enable significant mitigation of many risks with little cost and infrastructure. Often, this infrastructure exists for other purposes and serves multiple roles in various other areas of public service. The primary reason tornado warning programs exist then is largely due to their evolution as political and institutional responses to public demand (Steinberg 2000). However, it goes deeper than this. Social science research (Alexander 2002) has indicated that the public has substantially-more concern with (and more dread of) involuntary risks (e.g., nuclear accidents, tornadoes), as opposed to assumed risks (e.g., smoking, driving). While tornadoes remain relatively rare events, media coverage of them, coupled with the occasional significant tornado in one's own neighborhood are enough to convince most of the potential value of warning programs. It is also enough to result in public outcry when systems fail or discussions of cutbacks in service occur (Steinberg 2000).

There is a need for response studies to assess the importance of lead time and confidence and accuracy in relation to myriad response and mitigation needs. As detection and warning capabilities increase, response spectra eventually change to reflect this. The result can be that activities never before possible or practical are taken in response to certain types of warning products under certain lead time parameters. In theory, a person living in northeast Oklahoma City on 3 May 1999 would have had time to hand-dig a hole in the ground that would offer substantial protection, if they would have started digging when the first warning was issued for Oklahoma County. Although it is arguable as to how much protection such a foxhole would afford, it is conceivably more than that of a mobile home, those choosing to flee could have put many miles between themselves and the tornado. However, there were numerous dangerous storms ongoing, making options problematic on spontaneous determinations of routes and shelter available. This suggests that increasing lead times are resulting in the contemplation of a variety of forms of shelter decision-making. This is behavior that the current warning programs were never designed to address.

6 - Conclusions

Warning technology is dynamic, changing with time and circumstance. There is a significant gap in our understandings of the use of this technology. Many assumptions are made about the use of increased technological capabilities of detection and dissemination, and why they do not serve the use parameters of general society. There are limitations in comparing individual tornado disasters, aside from differing survey methodologies. There are significant differences in event character, and there are limits to the utility of comparing data from single tornado events with cumulative impacts of outbreak events. Obviously, with outbreaks, time-lines overlap in some cases and warning information tends to become logistically complex and cumbersome. In long-track violent events, persons along projected paths are often presented with good-quality warning information – both temporally and spatially – and thus given ample opportunity to make warning response decisions. Conversely, media delivered warning information may be vague and confusing in outbreaks that occur among audiences in spatially-large areas (inter-regional). The OCT outbreak was epic in TV coverage and warning, which was responsible for the prevention of additional injuries and fatalities and moved many to seek shelter or evacuate.

6.1 - Vulnerability and Risk Issues

Issues of vulnerability, both at individual and societal levels, are fundamental to both the public risk and its ability to utilize mitigation services or technologies to confront hazards. The disabled, elderly, dependent juveniles and MMH residents have shown disproportionate levels of vulnerability. While the details change through time and space relative to scientific knowledge, structural controls, or warning programs, the outcome generally stays the same. Disadvantaged or disenfranchised peoples are at inherently greater risk from all manner of direct and indirect effects of disasters, including tornadoes. In terms of equal access to mitigation programs and services (including warning systems), the poor are systematically displaced by societal pressures in the name of advancing development, capital benefits, or for political advantage. The social dynamics center on the accumulation of wealth (including warning technologies, shelter, etc.) and barriers to programs (including warning services, health care, etc.). This often deprives the poor of opportunity to utilize traditional common services, including warning systems that may be essential for survival. In short, people that are preoccupied with the basic aspects of survival on a daily basis (e.g., food, water, shelter, poor health, crime) are not likely to give much thought to low probability risks, no matter how catastrophic their potential impact.

Warnings that say that it is safer to stay in your home (unless it is MMH) need to be contested because of the uncertainty of the strength of tornadoes at any given time. Probability-based warnings would give the strength and they would be smaller than the contemporary warning systems now. Also instructions to flee are risky because of varying traffic conditions. So probability-based systems could fix this because they would significantly reduce the numbers of individuals on any given road related to fleeing a tornado.

The electronic media – a vital component of a warning system – are conversely major players in systematic misperception of risk frequency and magnitude. This matters on both tails of the response curve: at one end, hyper-vigilance causes undue stress on both the system and the public and, at the other end, complacency emerges among those overwhelmed by the messages, choosing to 'tune out' or deny the risk they are hearing of incessantly , amid the background noise of other risks competing for media attention. The survey responses on OCT were positive for warnings, and compliance was maximized by response time that allowed for adequate planning.

The percentage of respondents who received some warning for the OCT was amazingly high (< than 1 %), implicating to a large part, the violent nature of the tornado and the general lack of improved shelter available to most killed. While data collected in this work may not fully characterize the event, it seems logical to conclude that the high percentage of the population warned, the exceptional lead time of the warnings, and the extent of the media coverage for this event were critical in keeping casualties low relative to the number of residences destroyed. Today people know more about tornadoes and receive more exposure to warnings than ever before, but: 1) too often have no plan and no improved shelter to access, and; 2) still little is understood about what warning data and time-frames are required within the scope of the new technologies (that allow for warnings that are temporally and spatially becoming more-specific).

Still, there remains those with increased risk factors – most notably poverty, education levels, and disability – which greatly alter abilities to access the warning products that are available. Additional challenges exist to serve appropriately the very young and the very old, the mobility, sight, or hearing impaired, and those in substandard housing such as mobile homes and apartments. The 'fight or flight' issue – the newly-identified propensity for evacuation under tornado warnings and the way such affects both the warning system and the overall risk – has moved to the forefront.

Until these issues are fully addressed, simply decreasing false alarms and increasing lead times may be diluted advancements, with benefits that exist only on paper. In the 'Digital Age', social parameters appear even more elusive and in a state-of-flux. Thus, much of what little research there is on the human ecology of warnings and the tornado risk is seriously antiquated and of uncertain value. Finally, it is important to convey, that while the human ecology of the OCT event fits the current hazard models of what would be projected for such an event, the truth is we are no closer to defining the variability that itself defines pre-event warning landscapes, nor in maximizing the efficacy of our investments in warning systems. Increasing exposure of infrastructure and the costs of protecting, insuring, and rebuilding, has fostered added interest from all levels of government and the private sector in mitigation programs of all manner, including warning systems. Currently, the country has no comprehensive national warning policy or strategy that covers all hazards or all places. Efforts to develop such are gaining momentum, spurred on by increasing concerns over terrorism and weapons of mass destruction (NRC 2002). Not only are technological hazards a concern in their own right, but with their potential come prospects for 'hybrid hazard' or 'na-tech' events, large-scale incidents involving elements or combinations of both natural and technological agents. Many threats posed by natural and technological hazards are similar with regard to potential warning strategies. This is especially true with short-fuse hazards, and planning has ensued in earnest to design modern communications networks (using digitally codified 'Common Alerting Protocols') for a comprehensive and universal national 'All Hazards Warning System'.

6.2 – Key Points

The background investigation for this proposal indicates a dearth of contemporary studies in the human ecology of environmental warnings as defined by information processing in general, and assessments of short-fuse weather phenomena. A wide gulf exists between the physical science community (e.g., meteorology, physics) and the social science community (e.g., geography, sociology) for communicating about and understanding relationships of human ecology and weather hazards. These issues continue to impede multi-disciplinary initiatives to construct research dialogues. A prime directive of this work is to initiate efforts to find a common language that both sides are comfortable with and capable of fully exploiting. Continued improvements in warning processes and severe weather mitigation policy implore that the design and implementation of modernized warning systems include both the technological and human ends of the spectrum. Furthermore, in this age of rapidly changing emergency management priorities, it is worth noting that the products of this research – in particular, that which further delineates the human ecology of risk communication and warning procedures – may prove invaluable to all manner of emergency planning, risk behavior, and warning policy. The following are conclusions. The first five are backed with statistics from this study:

> **1)** Of those who responded to TV warnings, 37.2 % chose to evacuate. Although it is not possible herein to compare this figure from the OCT to other events, it is likely that this fraction is not typical in most major tornado events. During tornado events of the future, people will attempt evacuation more so as tornado warnings lead times increase (Figure 4.2). Even though many evacuated needlessly, it is likely that without that evacuation some percentage would have been killed.
>
> **2)** For those who had TV as a source of warning information, the presence of juveniles had a positive effect on their decision to flee or not, whereas the presence of elderly people had a negative effect. It is possible, but cannot be shown herein, that the elderly were reluctant to leave their location owing to mobility issues, whereas parents of juveniles wished to reduce the threat to their children by leaving their location (Figure 4.3 and 4.4).
>
> **3)** TV was the primary warning source for 69 % of the respondents, and 88 % listed TV as either their primary or secondary warning source (Figure 4.3). Third party warnings were 40 % (primary and secondary) for the OCT, which is second to TV among warning sources. NWR is not a significant factor as a warning source for this tornado).
>
> **4)** Of those who evacuated their location, apparently most were successful in not being harmed by the tornado, but it is not known what percentage, became casualties. Three people were killed on this date (two in the OCT) in underpasses, but they were not respondents, for obvious reasons – what information about them was available was included in the survey.

5) This study makes it very clear that the *official* lead time (as determined by the *NWS*) and the *effective* lead time (as observed by the respondents) can be very different. The source of this difference is directly attributable to TV. That is, even though respondents may have lived in counties far enough away from the tornado not to be included in an official warning, they were receiving TV-based information about events in other counties well in advance of the time when they finally were included in an official warning. Moreover, in some instances, a warning for a county was issued for an early tornado, but that county remained in tornado warnings more or less continuously for more than two hr, before the tornado affected some of the respondents (Chapter 5.2).

6) Although the term "Tornado Emergency" as a SVS was apparently effective in conveying the gravity of the threat associated with the OCT, its use in subsequent events is questionable, since it is not an officially-defined term, and criteria for its use have not been determined.

7) For public assemblies – such as the student event being held in *Westmoore High School* – those responsible should take steps to be prepared for tornadoes, such as designating spotters when the threat of severe weather is present. Had the tornado hit *Westmoore High School* directly instead of peripherally, more casualties likely would have resulted as they waited until 2 min before the OCT hit to tell the students and parents to take cover in the halls.

8) In the survey, ~1 % listed siren as a primary source, and 18.7 % listed it as a secondary source. There remain many concerns for the use of sirens – for example – increasing noise pollution makes them difficult to hear, they are generally not effective except for people outdoors. Sirens don't always work when needed and occasional testing may not reveal how they will perform when needed. After a tornado has occurred, it is common for a public outcry to install more sirens or for them to be fixed, and so on. This is understandable, but may not reflect the best use of limited resources.

9) Disabled persons constituted 25 % of the fatalities in the OCT. It is evident that the disabled need special assistance or facilities (such as shelters on-site). Know where they are and assist them! Elderly people need assistance too (check on them) and beware of the tornado watch because one can get them situated, as opposed to a tornado warning when there might not be enough time.

10) As has been demonstrated many times, mobile homes (manufactured homes, or homes that are ill-suited for sheltering) are unsuitable on location in the absence of a tornado shelter. Either shelters must be provided or plans made to evacuate to a suitable shelter in time (AMS 2004). Those living in mobile homes will necessarily have to take action at a lower perceived threat level, since sheltering on location is rarely a viable option. The tornado watch is critical for choosing your location for the storm, and getting there.

Mileti (1975, p.) wrote that: "evidence suggests that many public education efforts to change warning responses need improvement and that some portion of a population fails to take appropriate protection actions regardless of the warning." Only with greater understanding of the likely responses of individuals and groups under disaster threat would it be possible to make precise and beneficial refinements. In situations where warning systems can function to avert a large-scale loss-of-life and movable property, an integrated sociological and psychological all hazard project could refine present knowledge and expand upon it. Dramatic technological, environmental, and societal changes have rendered previous conceptions of the relationships between hazard warning systems and behavior inadequate. As noted, risk perception is inherently human and often described as irrational, skewed toward the exotic, dramatic, and intimate. This makes positivistic studies of risk and scientific formulation of mitigation policies difficult to synchronize in a dynamic society. The multi-organizational complexities of warning programs make assessments subject to *post hoc* fallacies regarding success. The most difficult aspects of warning program appraisal involve societal response. There are two basic hurdles that impede assessments of short-fuse products that are intended to produce actions or behaviors, especially if they involve significant risk to life and limb. First, opposed to most other sorts of forecasts that can be measured with regard to their economic impacts (e.g., crop yields, gate attendance), weather warnings are not easily characterized in degrees of value. This is because many of the 'pay offs' that exist among a vast array of potential responses are somewhat intangible. Secondly, warning behavior is difficult to model or predict. Surveys regarding user assessments of warning product performance are wrought with limitations and errors, tending to over-represent respondent perceptions of value, rather than their actual value. What people say they do, and what they actually do, can be very different and often not highly-correlated. Product designs that rely on surveys or focus groups tend to promote systems based on what stakeholders think they need, rather that what they most likely actually need. Regardless, in a general sense response surveys continue to form the bulk of 'stakeholder needs' assessments for warning program design.

We keep getting better on the technology, but some specific groups of people are still getting killed by tornadoes, especially in the last twenty years. The reduction of tornado casualties is dependent upon several variables that constitute the warning system: early and accurate detection of tornadoes by meteorologists; efficient and clear communication of warnings to the public via multiple media; and expedient and successful mitigation reactions among the warned community. Probability-based products are increasingly becoming technologically and organizationally plausible. They have immense potential to stabilize mitigation response curves for a variety of stakeholders. The author would like to test this among his studies next. For this to become a reality, details regarding efficacy and efficiency must be characterized, and the certain educational and marketing programs that will be required for the 'probability revolution' of the warning program will require a foundation of research that currently does not exist. Consequently, this research aims to provide insight on the nature of the relationship between human behavior and warning system characteristics that affect the capability, utility, and efficacy of warnings. A secondary impact will hopefully be the establishment of a foundation for routine investigations and dialogues of forecast and warning products that emphasize human ecology to be undertaken here in Norman, Oklahoma under the umbrella of the so-called *National Weather Center*.

In general terms, this study has demonstrated the crucial importance of the human ecology of warnings. Although primarily concerned with the findings from a very specific event (the OCT), this research has shown that the landscape of tornado warnings (the warnscape) from the human side is every bit as dynamic and complex as the scientific and technical sides, if not more so. Research into human risk perception, decision-making, and behavior is not something that likely ever will be considered complete. Nor can we conclude that communication of information is static, so that some ideal system can be determined once and for all time. The recipients of warning information are not some monolithic block, but represent the entire spectrum within any particular location, and that spectrum changes as the larger society outside changes. In addition, people move into and out of that particular location (or are traveling) and the infrastructure for producing effective tornado warnings might have to change as the population changes in order to remain effective. As we learn more about who becomes casualties and who does not, then procedures can be developed to target those particularly vulnerable, presumably without disrupting the processes shown to be effective for groups which are less vulnerable.

As the scientific and technical aspects of tornado warnings change, and they inevitably will, it is likely that the accuracy and specificity of tornado warnings will continue to improve. However, it is not likely that warning uncertainties will disappear any time soon – in fact – there is reason to believe that some uncertainty in tornado warnings is virtually inevitable. This implies that vulnerabilities will remain present and developing ways to address that changing pattern of vulnerability will have to evolve, both from the physical ecology (i.e., the science and technology), and from the human ecology. If warning technology is dynamic, changing with time and circumstance, then this results in significant gaps in our understanding of the use of this technology.

GLOSSARY

[A] *Long-Track Violent Tornado* is violent on the Fujita Scale (F4/F5) and while it has no separate distance (Grazulis 1993, p. 56) it is about 20 miles long or more.

[B] *Tornado Alley* is a vernacular region with no set boundaries. It generally includes many portions of the central third of the US. For our purposes, we mean the Southern Plains - home of the largest contiguous area of Significant Tornado frequency (See Grazulis 1996 and 2001). Figure. 1.1 shows a contemporary version of Tornado Alley from a map courtesy of *NSSL*. Note that the Tornado Alley of frequency is not necessarily highly-correlated to the areas of the highest fatality rates – which depending on the data base utilized would clearly include the Mississippi and Ohio Valleys – especially the states of Alabama, Mississippi, Georgia, and Tennessee.

[C] *Warning Systems* are *ALL* components of the warning process, both human and technological, from *NWS* to stakeholders (users). It includes, but is not limited to – Doppler Radar, NWR, TV and radio, sirens, storm spotters, elements of EMA and public safety agencies, and third party (public or business) – actions that encompass the entire spectrum of the warning process, for a given event or agent. They are generally formalized at least in part, however, many aspects may be informal, unofficial, and emergent (see Mileti and Sorensen 1990).

[D] *Public Awareness* implies general knowledge regarding tornado risk and safety, familiarity with warning processes, and attempts to secure 'warning access.' Public awareness may be gained through one's own perceptions, previous experience, via the attitudes of others, or by means of information, including public education campaigns and media exposure (See Doswell et al. 1999).

[E] *Official Period* refers to the period of data recording under *NWS* warning programs (1953) to the present (see Doswell et al. 1999). Modern era refers to the Post-Doppler Period of the last two decades.

[F] *Emergency Management Agencies* (EMA) – there is no set definition – it includes different sized agencies and organizations from place-to-place, but generally – those organizations charged with planning for, warning for, responding to, and mitigating potential disasters and mass casualty events. This may include federal, state, tribal, local, or private emergency management departments, civil defense authorities, public safety or police and fire departments, health or environmental departments, public works authorities, and para-military (e.g., *American Red Cross, US Coast Guard Auxiliary, Civil Air Patrol*), or military bodies such as *National Guard*. A modern EMA operates within the aegis of an IEMS - a State Emergency Response Plan, and/or The Federal Response Plan (FEMA c.2003). While size, manpower, and resources all vary widely, key characteristics of EMA are missions to plan for, and respond to, extreme events outside the scope of other normal day-to-day emergency services of the given jurisdiction (cf. Drabek and Hoetmer 1991).

[G] *Warnscape* is used to denote the association of agents and environments – both physical and cultural – that dictate human ecological circumstances and relationships of the specific event. They including warning systems and behavioral response in relation to environmental and situational factors such as tornado intensity and path, shelter, time-of-day, communications infrastructures, and population densities, as well as other aspects of the environment.

[H] *Warning Compliance* is the public reception of warning with subsequent attempts to undertake defensive action, within an array of mitigative intentions of a warning system. More simply, it is a person's *attempt* to seek shelter or lessen injury upon receipt of a valid official warning (see Mileti and Sorensen 1990).

[I] *Cry Wolf Effect* to a warning is a phrase from *Aesop's Fable* "The Shepherd Boy Who Cries Wolf," (Gruntfest and Carsell 2000) and is used to describe a lack of reception of warnings or efforts to comply with them owing to a desensitization from too many previous false alarms (See Breznitz 1984; Drabek 1986; Burnham 1992; Dow and Cutter 1998; Gruntfest and Carsell 2000).

[J] *Confirmation Behavior* is the cognitive heuristics employed in response to warnings that: overcome other ongoing activities and demands for attention; assess the credibility of the warning source(s); confirm a hazard exists; personalize the risk and determine others are heeding the warning; determine what mitigative actions to undertake (see Mileti 1999).

[K] *False Alarms* are instances when a warning for an event or hazard is issued and disseminated and said event or hazard does not occur at all, does not occur in the warned area, does not occur within the time frame of the warning, or does not occur to the magnitude predicted (Mileti and Sorensen 1990; Gruntfest and Carsell 2000).

[L] *Close Call Event* is a warning situation where the warned event did occur, only it failed to occur in the magnitude, location, or time specified in the warning. Example: a tornado warning for the northern half of county-X, whereas no tornado occurs in county-X, but a tornado does occur in the southern portion of county-Y immediately north of county-X. Technically this is a 'false alarm' for county-X, though research (Gruntfest and Carsell 2000) shows that such situations are not sociologically the same as a standard false alarm where no event whatsoever occurs.

[M] *Near-Miss Event* is a hazard event that occurs with no warning, very near a given location that does have a valid warning, or, very close in time to a valid warning for the same or an adjacent jurisdiction; or and event that does occur but of a magnitude much less than predicted in any warnings (Gruntfest and Carsell 2000).

[N] *Tornado Watch* is issued by the *SPC* when conditions are especially favorable for tornadoes. Watches encourage the general public to stay alert for changing weather conditions and possible warnings. For EMA, storm spotters, and the broadcast media, watches provide valuable lead time to gear up operations and increase staffing. Watch (one, two, three ... at the beginning of each year), and have a duration of about four to six hours, but may be canceled, replaced, or re-issued as required. A watch is not a warning, and should not be interpreted as a guarantee that there will be severe weather (SPC c.2003).

[O] *Tornado Disaster* - There is no set definition with regard to death tolls or damage figures. A tornado that damages one's neighborhood certainly constitutes a disaster to them. However, it is interesting to note that what is considered a tornado disaster today – whether the threshold is 10 deaths or 100 million dollars – is much lower in terms of deaths over the past century, and much higher in damages (even when corrected for inflation) than past eras (cf. Grazulis et al. 1998). For example, in 1925 deaths per million persons from tornadoes was 6.95. In 2000 with an approximate population of 300 million – we could expect to see 2085 tornado fatalities per year! A 100 death tornado event, in 1925 would be the equivalent of a 800 death event today, without the declines noted in historical death rate, and as a partial response to warning systems (cf. Brooks and Doswell 2002).

[P] *Lifetime Odds* (comparative relative to tornadoes) - For reference under the same formula, consider that lifetime odds are: 1:24 for all forms of external cause; 1:77 for any form of transportation accident; 1:328 for murder by firearm, 1:1008 for accidental drowning; 1:1062 for exposure to smoke, fire, or flames; and 1:2503 for falling down the stairs (NSC c.2003). It is easy to see, all things considered, the risk for death by storm generally, and death by tornado specifically, is relatively low and may be modified considerably by choice and behavior.

[Q] *Recurrence Interval (RI)* is the period of time elapsed (based on the mean historical data) at a given spot between tornado strikes. Or, the amount of time to completely cover a given area with a given RI value with tornado paths. For comparison, consider the RI of Kansas (2220 yrs), Illinois (3420), Texas (6990), and California (508000). The RI for the entire state of Oklahoma is ~2220 yrs (Grazulis 2001).

[R] *Significant Tornado* is a significant tornado is a tornado that rates F-2 of higher on the *Fujita Scale*; or has caused at least one fatality; or both. By eliminating weak tornadoes from the data base, much of the population bias and inaccuracies of the climatological data base are smoothed or removed (Grazulis 1993).

[S] *Skywarn Program* is a storm spotter program that "*is a concept developed in the early 1970s that was intended to promote a cooperative effort between the National Weather Service and communities. The emphasis of the effort is often focused on the storm spotter, an individual who takes a position near their community and reports wind gusts, hail size, rainfall, and cloud formations that could signal a developing tornado. Another part of SKYWARN is the receipt and effective distribution of National Weather Service information.*" (NWS c.2007).

[T] *Stormready Community* is a joint venture of *NWS* and various local *NWS* 'certified' communities where *NWS* "*helps arm America's communities with the communication and safety skills needed to save lives and property – before, during and after the event. Stormready helps community leaders and emergency managers strengthen local safety programs*" (NWS c.2007).

[U] *Pervasive* as the state tourism magazine proclaimed "*Will Rogers, Tornadoes, and Phillips 66 - it doesn't get anymore Oklahoman than that.*" (*OKLAHOMA TODAY* 51(1): 45). The Oklahoma State Board of Tourism promoted the premier of the movie *TWISTER* – set in, and largely filmed in – the State. It is likely that this movie, with its *many* inaccuracies and unscientific liberties, heightened public awareness toward the end of the 1990s, as the *WIZARD OF OZ* was speculated to have done by in the mid-20th Century by Grazulis (2001). Richard Pelton, in his best selling book, *THE WORLD'S MOST DANGEROUS PLACES* (Pelton 1999, p. 933), cites a study that indicated the OCT was the seventh most-closely followed news story in the US in 1999.

[V] *Weather Industry* in Oklahoma refers to the concentration of weather reporting media in the OKC Metro and, businesses, research institutions, and state and federal weather and climate agencies located in Norman. Among them are the *WFO*, the *NWS Operational Support Facility, NSSL, SPC, Oklahoma Climate Survey, the Cooperative Institute of Mesoscale Meteorological Studies, and a School of Meteorology, Department of Geography,* and the *Center for Spatial Analysis* at the *University of Oklahoma*; and the private companies (*Weathernews, Weather Detection Systems*, etc. (cf. Biddle 2004).

[W] *NWS Family of Services (FOS)* refers to services and products distributed by the in the fulfillment of its mission which is... "*[to] provide weather, hydrologic, and climate forecasts and warnings for the US, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy. NWS data and products form a national information database and infrastructure which can be used by other governmental agencies, the private sector, the public, and the global community*" (Golden and Adams 2002).

[X] *National Weather Service (NWS) Mission* - "[to] *provide weather, hydrologic, and climate forecasts and warnings for the US, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy. NWS data and products form a national information database and infrastructure which can be used by other governmental agencies, the private sector, the public, and the global community*" (NWS 2001).

[Y] *Fujita Scale* is a damage scale named after one of its developers – *TT Fujita, University of Chicago* – to classify tornado damage by inferred wind speeds. The *NWS* accepted the scale for use in 1973. Anything F2 or stronger, or causes one or more deaths, is'Significant' (Grazulis 1993):

F-0. Light damage. Wind up to 72 mph – "Weak"
F-1. Moderate damage. Wind 73 to 112 mph – "Weak"
F-2. Considerable damage. Wind 113 to 157 mph – "Strong"
F-3. Severe damage. Wind 158 to 206 mph – "Strong"
F-4. Devastating damage. Wind 207 to 260 mph – "Violent"
F-5. Incredible damage. Wind above 261 mph – "Violent"

[Z] *Bridge Creek* is an unincorporated rural community in northern Grady County that includes a school district and volunteer fire department. Most residents have post office addresses in Blanchard, Newcastle, or Tuttle, and work in the OKC metropolitan area or Chickasha.

[AA] *Major Trauma Center* as defined by OSDH (Brown et al. 2002). A "Level Three Trauma Center" is a certification from the American College of Emergency Physicians and used (in 1999) for University Hospital in OKC. There is NO Level One Trauma Center in Oklahoma (as of 2007) and the nearest one is Parkland Hospital in Dallas, Texas.

[BB] *Convective Outlook* has severe weather forecasted (in Day 1,2, and 3 formats) containing the area(s) of expected thunderstorm occurrence, and expected severity over the contiguous US, issued several times daily by the *SPC*. The terms *slight risk, moderate risk,* and *high risk,* are used to describe severe thunderstorm potential of 2 to 5, 5 to 10, and >10 % of the area (SPC c.2003).

[CC] *Warning* for reference, the AMERICAN HERITAGE DICTIONARY OF THE ENGLISH LANGUAGE (Houghton-Mifflin 2000) summarized definition is that a warning is *"An intimation, threat, or sign of impending danger or evil; Advice to beware; A cautionary or deterrent example; Something,such as a signal, that warns."* In the *NWS* and severe weather context, it refers to the products issued by a *WFO* for a threatening phenomena (e.g., tornado (TOR) or severe thunderstorm (SVR) when the phenomena is observed to be occurring, has been detected, or is expected to occur. They are intended to save lives and protect property and are usually valid for a county or portion of a county, and for 30 min to 60 min (NWS c.2003c).

[DD] *Sunset* for Moore (near the path mid-point) on 3 May 1999 was at 0017 UTC 4 May 1999 (2017 CDT 3 May 1999). The entire life of the OCT was during afternoon and evening daylight.

[EE] *Inexperienced* means that "the uninformed, misinformed, unconcerned, very young, very old, hearing-impaired, sight-impaired, immobile, inebriated, preoccupied and foolish will always be with us." (Grazulis et al. 1998)

ACRONYMS

x B – X billion
x M – X million
ACOG – Association of Central Oklahoma Governments
ALT – Average Lead Time (NWS)
AMS – American Meteorology Society
ARO – ARkansas Outbreak
BHM – BirmingHaM outbreak
CDT – Central Daylight Time
CRH – Central Region Headquarters (NWS)
CTA – Call-To-Action (NWS)
DOC – Department Of Commerce
DOD – Department Of Defense
EAS – Emergency Alert Systems
EMA – Emergency Management Agencies
FAR – False Alarm Ratio (NWS)
FEMA – Federal Emergency Management Agency
FLO – central FLorida Outbreak
FOS – Family Of Services (NWS)
GIS – Geographic Information System
GPS – Global Positioning System
HWO – Hazardous Warning Outlook (NWS)
IT – Information Technology
IEMS – Integrated Emergency Management System
IWS – Integrated Warning System
KWTV – KWTV channel 9, (OKC, OK).
MAR – Modernization And Restructuring (NWS)
MMH – Mobile and Manufactured Homes
MOS - Model Output Statistics
NAWAS – NAtional WArning System
NSC – National Safety Council
NEPA – NorthEast Path Area
NEXRAD – NEXt generation RADar (NWS)
NOAA – National Oceanic and Atmospheric Administration
NRC – National Research Council
NSSL – National Severe Storms Laboratory
NSTC – National Science and Technology Council
NWR – NOAA Weather Radio (NWS)
NWS – National Weather Service (NWS)
OCCVB – Oklahoma City Convention and Visitors Bureau
OCFD – Oklahoma City Fire Department
OCME – Office of the Chief Medical Examiner
OCS – Oklahoma Climatological Survey
OCT – Oklahoma City Tornado
OCTA – Oklahoma City Tax Assessor's office
ODOT – Oklahoma Department Of Transportation
OKC – OKlahoma City
OSDH – Oklahoma State Department of Health
OUN – Norman Weather Forecast Office (NWS)

PDS – Potentially Damaging Situation (SPC/NWS)
POD – Probability Of Detection (NWS)
PPW – Partnership for Public Warning
PRC – Pew Research Center
PSO – (2nd) Palm Sunday Outbreak
RI – Recurrence Interval
ROC – Radar Operational Center (NWS)
RV – Recreational Vehicle
SAME – Specific Area Message Encoding
SELS – SEvere Local Storm unit (NWS)
SPC – Storm Prediction Center (NWS)
SVS – Severe Weather Statement (NWS)
SWO – Severe Weather Outlook (SPC/NWS)
SWPA – SouthWest Path Area
TV – Television
TAFB – Tinker Air Force Base
TOR – TORnado warning (NWS)
UCAR – University Corporation of Atmospheric Research
US – United States
USAF – United States Air Force
USBC – United States Bureau of the Census
USDA – United States Department of Agriculture
UTC – Universal Time Corrected
WFO – Weather Forecast Office (NWS)
WFT – Wichita Falls, Texas outbreak
WSR-88D – Weather Service Radar 1988 D series (NWS)
WWT – Tornado Watch (SPC/NWS)
WWP – Watch and Warning Program (NWS)

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The University of Oklahoma

DEPARTMENT OF GEOGRAPHY

SURVEY FORM - 1999 OKLA OUTBREAK

Date__ - __Interviewer Boddle __CODE__________

PERSON INTERVIEWED ____________________

LOCATION____________________

STORM LOCATION (Address/Town Business/School/Other?)

____

GPS____________________PHONE____________________

Alternate Address/Contact____________________

OCCUPANTS ON IMPACT (Race/Age/Sex/Name)

____

BRIEF SUMMARY OF ACTIONS____________________

____

Location on impact: ____________________

STRUCTURE TYPE (Style/Floors/Roof/Construction/Shelter)

____

Injuries N/ Y / U / Fatalities N / Y (info)____________________**DAMAGE** 1 - none / 2 - missiles or shingles / 3 - minor roof or garage / 4 - major roof / 5 - roof gone / 6 - wall damage / 7 - major wall damage / 8 - collapsed / 9 - blown away / 0 - Other / U - unknown or cleared _____Est F-Scale__________

WARNING INFO____________________

WARNING Y / N / SOURCE: (CIRCLE ONE W ACCESS TO) 0 - none / 1 - heard/saw / 2 - siren / 3 - radio / 4 - NWR / 5 - scanner / 6 - 3rd person / 7 - phone / 8 - comp./pager / 9 - TV / 0 - other

PRIMARY WARNING SOURCE __________TIME__________

SECONDARY WARNING SOURCE __________ TIME __________

AWARE OF WATCH? Y / N - SELF ASSESSED WX AWARENESS (1-5)__________

SELF ASSESSED WARNING 9 (1-5)__________WHAT WOULD HAVE MADE WRN BETTER?____________________

100 East Boyd, SEC 684, Norman, Oklahoma 73019-1007 PHONE: (405) 325-5325 FAX: (405) 325-6090

APPENDIX B - IRB LETTER -

The University of Oklahoma

OFFICE FOR HUMAN RESEARCH PARTICIPANT PROTECTION

IRB Number: 11012
Category: 4
Approval Date: September 22, 2005

September 23, 2005

Matthew Biddle
Geography
100 E. Boyd Street, SEC 684D
Norman, OK 73019

Dear Mr. Biddle:

RE: Warning Reception, Response, and Risk in the 3 May 1999 Oklahoma City Long-Track Violent Tornado: Assessment from a Historical Perspective and Implications for Future Disasters and Mitigation Programs

On behalf of the Institutional Review Board (IRB), I have reviewed the above-referenced research project and determined that it meets the criteria in 45 CFR 46, as amended, for exemption from IRB review. You may proceed with the research as proposed. Please note that any changes in the protocol will need to be submitted to the IRB for review as changes could affect this determination of exempt status. Also note that you should notify the IRB office when this project is completed, so we can remove it from our files.

If you have any questions or need additional information, please do not hesitate to call the IRB office at (405) 325-8110 or send an email to irb@ou.edu.

Cordially,

E. Laurette Taylor, Ph.D.
Chair, Institutional Review Board

Ltr_Prot_Fappv_X

660 Parrington Oval, Suite 316, Norman, Oklahoma 73019-3085 PHONE (405) 325-8110 FAX (405) 325-2373

APPENDIX C - TORNADO WAYPOINT ANALYSIS -

The beginning and ending points along the track are given by (x_b, y_b) (x_e, y_e) . The equation of the straight line connecting them is given by

which can be rearranged to give
$$\frac{y - y_b}{x - x_b} = \frac{y_b - y_e}{x_b - x_e}$$

$$y = \left(\frac{y_b - y_e}{x_b - x_e}\right)x - \left[x_b\left(\frac{y_b - y_e}{x_b - x_e}\right)\right] + y_b = mx + b$$

$$m = \left(\frac{y_b - y_e}{x_b - x_e}\right)$$

$$b = -mx_b + y_b$$

We will use the latitude and longitude of the points as Cartesian coordinates – a fairly good approximation over the distances involved along this tornado track, but we'll move the "origin" of our Cartesian coordinate to the beginning point of the track. Hence, we will use the transformed coordinates:

$$x' = x - x_b, y' = y - y_b$$

such that

$$x'_b = x_b - x_b = 0, y'_b = y_b - y_b = 0$$

From here on, we'll drop the ()' notation, but it will be understood that this is the transformed Cartesian coordinate system.

As shown in Fig. A1, the points along the actual track can depart some distance from the simple straight line track connecting the beginning and end points. But if the point is to determine the approximate time when the tornado was closest to that survey participant's location, this simplified scheme should not be too much in error (no more than a few minutes), even in absolute terms. In relative terms – comparing one point to another – the errors are likely to be even smaller

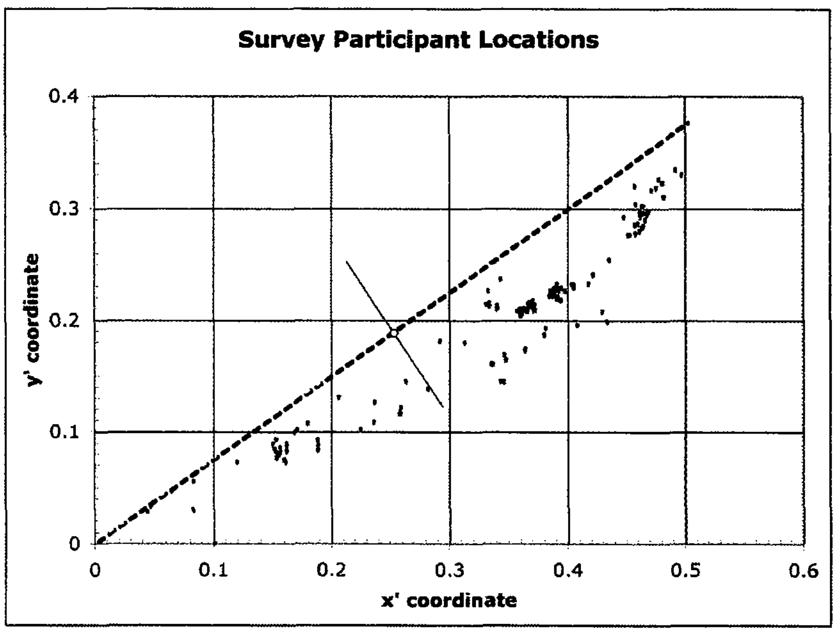


Figure A1. A plot of the survey participant locations in the (x',y') coordinate system. The dashed line is connects the beginning and ending points; the thin line is perpendicular to the track, passing through one of the waypoints, and the red circle locates the intersection, representing the time when the tornado was closest to that waypoint.

Assume that the tornado moves at a constant speed along the line connecting the beginning and ending points. That would be the *average* speed given by the distance traveled divided by the time to move from the beginning of the track to the end, **C**, which is given by

$$\mathbf{C} = \frac{\Delta \mathbf{X}}{\Delta t} = \frac{\left[(x_e - x_b)\mathbf{i} + (y_e - y_b)\mathbf{j}\right]}{(t_e - t_b)} = c_x\mathbf{i} + c_y\mathbf{j}$$

so the position as a function of time along the straight-line path is given by

$$\mathbf{X}(t) = \mathbf{X}(t_b) + \mathbf{C}(t - t_b)$$

We're given locations for the survey participants (our points) that do not generally lie along the line connecting the beginning and ending points – the actual tornado track was not a straight line. A detailed analysis of the actual tornado arrival times along the complicated track is not possible, so we're making some approximations, but as noted above, this method is sufficient for our purposes. Moreover, the points are not all within the damage path and many of them are known only approximately.

Given a particular waypoint (x_i,y_i), a line perpendicular to the simple line (our approximate track) connecting the beginning and ending points of the tornado, has a slope $\hat{m}$ given by the negative reciprocal of the approximate track's slo $-1/m$). The equation of a line with this slope passing through the point in question is

$$y = \hat{m}(x - x_i) + y_i = \hat{m}x + (y_i - \hat{m}x_i) \equiv \hat{m}x + \hat{b}$$

where $\hat{b} = y_i - \hat{m}x_i$. The point at which those two lines intersect must simultaneously satisfy the following:

$$y = mx + b \quad \text{and} \quad y = \hat{m}x + \hat{b}$$

Therefore, substitution from the first into the second gives

$$mx + b = \hat{m}x + \hat{b}$$

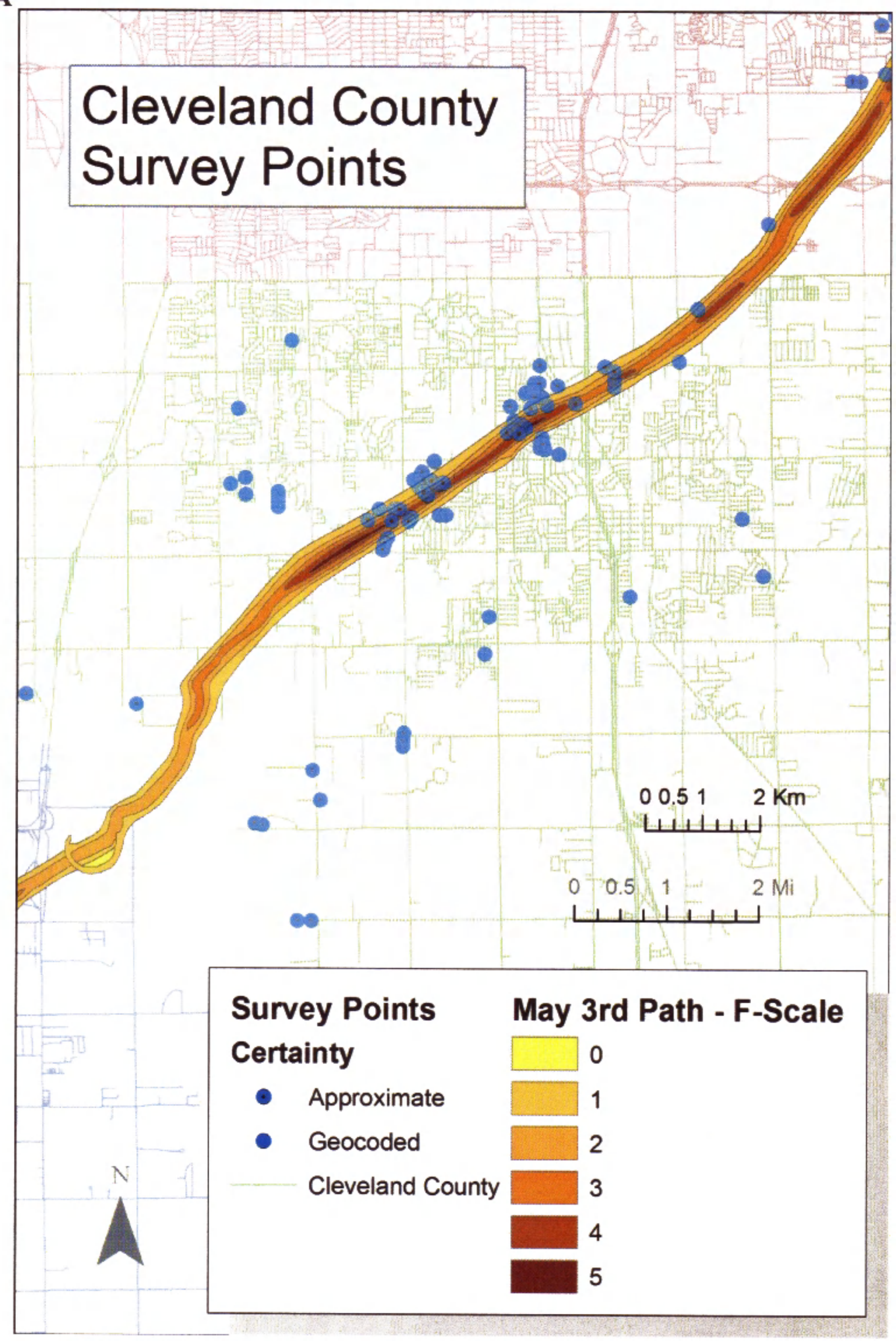
Solving for the x-coordinate gives

$$x = \left(\frac{\hat{b} - b}{m - \hat{m}}\right)$$

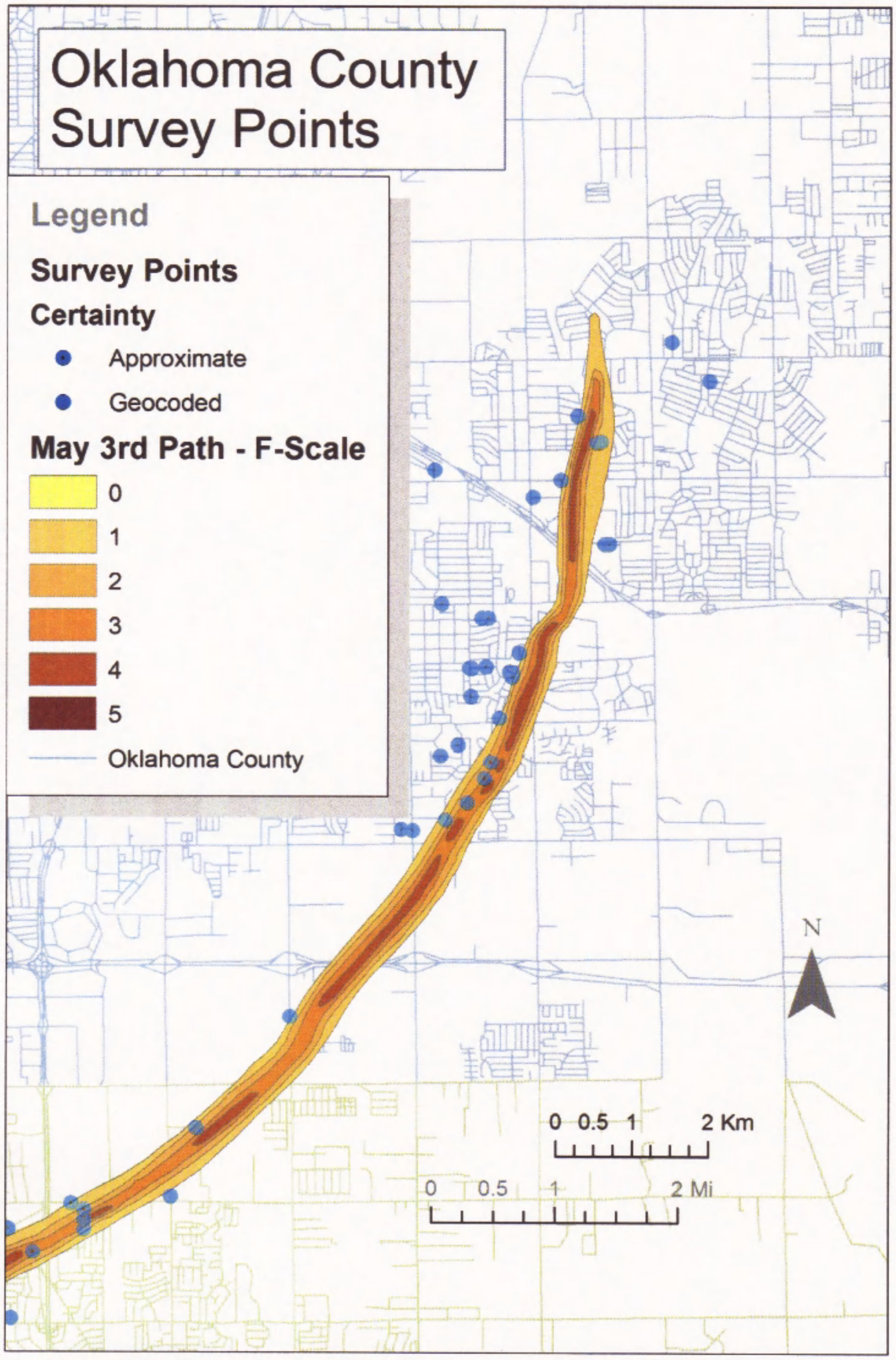
and the y-coordinate can be obtained by back-substitution into $y = mx + b$. This is the point on the approximate track that is "closest" to the location of the survey participant. However, for our purposes, we don't need *both* the coordinates. We can use only the x-coordinate average velocity to find the time to that point on the track according to the following procedure: given the coordinates of the point in question (x_i,y_i) and knowing the equation for the line in $y = mx + b$, we can det (x_l,y_l) e coordinates o where the line is closest to the point in question, using the formulae above. Using either of these coordinates, say x_l, we can find the time by solving the equation $x_l = x_b + c_x(t - t_b)$, which means that

$$t = \frac{x_l - x_b}{c_x} + t_b$$

A PPENDIX D - CLEVELAND COUNTY SURVEY POINTS -



Map of Cleveland County Survey Points. Map by D. Howard, B. McPherson, M. Biddle, and M. Scott-Brown. Copyright.



Map of Oklahoma County Survey Points. Map by D. Howard, B. McPherson, M. Biddle, and M. Scott-Brown. Copyright.

APPENDIX F - SPC AND NWS -OUN BULLETINS -

ZCZC MKCSWODY1 000
ACUS1 KMKC 021248
MKC AC 021247

CONVECTIVE OUTLOOK...REF AFOS NMCGPH94O.

VALID 021300Z - 031200Z

THERE IS A SLGT RISK OF SVR TSTMS TO THE RIGHT OF A LINE FROM
25 ESE CRP 35 WNW LRD ...CONT... DRT 65 NW ABI 60 SSW GAG
40 WNW GAG 40 NNW GCK 30 ENE GLD 25 SW MCK 35 NNW HLC 45 ENE HLC
35 NW HUT 10 ENE END 30 W ADM 30 SW FTW 30 WNW TPL 25 SSW TPL
40 S CLL 30 WSW HOU 35 ENE PSX 25 ESE PSX.

GEN TSTMS ARE FCST TO THE RIGHT OF A LINE FROM 40 WNW INL 45 E BRD
25 SE CID 35 E JEF 10 ENE UNO 50 SSW 7R4 ...CONT... 35 NW DRT
40 WNW CDS 55 NE AMA 25 W LBL 15 S 4LJ 45 SW PUB 45 NE DRO
35 E 4HV 15 SW DPG 60 N ENV 15 SSE SUN 35 SSE 27U 35 WNW DLN
35 SE HLN 25 ENE 3HT 70 SSW GGW 25 SE OLF 40 NW ISN 65 NNW ISN.

--- SYNOPSIS ---
OMEGA BLOCK WILL CONTINUE TO ERODE. WELL-DEFINED CYCLONE ALOFT AND ASSOCIATED SHORTWAVE TROUGH NOW MOVING ACROSS ERN CO/WRN OK/NW TX WILL DEAMPLIFY AS IT LIFTS NNEWD ACROSS CENTRAL PLAINS TODAY. STILL...BAND OF LARGE-SCALE DESTABILIZATION TO ITS ENE WILL RESULT IN SOMEWHAT STEEPENED LAPSE RATES AND ENHANCED SUPPORT FOR CONVECTION. SECONDARY SHORTWAVE TROUGH -- INDICATED BY MOISTURE CHANNEL IMAGERY OVER NWRN NM...APPEARS TO BE BEST RESOLVED BY AVN BUT IS ALSO EVIDENT IN ETA. THIS TROUGH IS FORECAST TO MOVE EWD ACROSS TX PANHANDLE AND PORTIONS NW TX...AGAIN INCREASING LARGE-SCALE ASCENT THIS AFTERNOON/EVENING OVER NW TX AND WRN OK.

AT SURFACE...DRYLINE IS NOW ANALYZED FROM SERN CO SEWD TO NERN TX PANHANDLE...THEN GENERALLY SSWWD ALONG CAPROCK TO E OF MAF AND W OF SJT. DIFFUSE WARM FRONT EXTENDS FROM JUST S SJT ESEWD TOWARD UPPER TX COAST...WHOSE BAROCLINICITY AND INSTABILITY GRADIENT ARE BEING AT LEAST TEMPORARILY REINFORCED BY SRN PORTION OF CONVECTIVE ARC ASSOCIATED WITH LEAD SHORTWAVE TROUGH. DRYLINE SHOULD MIX EWD SOMEWHAT OFF CAPROCK TOWARD 100W...WHILE FRONT MOVES NWD FASTER OVER CENTRAL TX THAN SE TX.

...SEVERE THUNDERSTORM FORECAST DISCUSSION...

--- S-CENTRAL PLAINS TO S TX ---
NARROW WEDGE OF RELATIVELY HIGH BOUNDARY LAYER THETAE IS INDICATED INVOF A MERIDIONAL AXIS S OF SJT. THETAE SHOULD ADVECT NWD TODAY ACROSS OUTLOOK AREA IN WAKE OF EARLY MORNING CONVECTION...HELPING TO DESTABILIZE AIR MASS IN A NARROW CORRIDOR FROM NW TX AT LEAST INTO SW OK...AND POSSIBLY INTO W-CENTRAL KS. RICHER MOISTURE RETURN AND ASSOCIATED HIGH MLCAPE BECOME LESS PROBABLE WITH NWD EXTENT...BECAUSE OF INFILTRATION OF COOLER TRAJECTORIES WITH LOWER MIXING RATIOS FROM ERN OK/ERN KS. CONVECTIVE DEBRIS CLOUDS SHOULD MOVE EWD ENOUGH SUCH THAT BOUNDARY LAYER SHOULD HAVE TIME TO HEAT WELL THROUGHOUT DAY OVER MOST OF SAME CORRIDOR.

THERE WILL BE SOME CAPPING AND SUBSIDENCE IN WAKE OF EARLY SHORT WAVE. HOWEVER...CIN IS NOT EXPECTED TO BE REINFORCED MUCH BY ELEVATED MIXED-LAYER AIR FROM THE HIGH PLAINS...SINCE THE SOURCE REGION HAS BEEN MOIST AND POORLY HEATED THE PAST COUPLE DAYS. 12Z MAF/AMA RAOBS SUPPORT THIS SCENARIO.

AFTERNOON SUPERCELL DEVELOPMENT POSSIBLE NEAR DRYLINE ESPECIALLY ACROSS OK/TX...WITH ORGANIZED MULTICELL HAILSTORM FORMATION EXPECTED FARTHER N. DAMAGING HAIL AND SEVERE GUSTS LIKELY WITH MOST SUPERCELLS. EXPECT MANY STORMS TO BECOME HEAVY-PRECIP IN CHARACTER AND OUTFLOW-DOMINANT RELATIVELY SOON IN THEIR LIFE CYCLES OWING TO WEAKNESSES IN SR ANVIL-LEVEL FLOW AND POTENTIAL FOR SEEDING BY UPSTREAM ACTIVITY. HOWEVER...THERE MAY BE A BRIEF WINDOW OF TORNADIC POTENTIAL WITH A FEW OF THE SUPERCELLS... PARTICULARLY INVOF DRYLINE/OUTFLOW OR DRYLINE/WARM FRONT INTERSECTIONS.

LATEST SURFACE ANALYSES AND SERIES OF FORECAST HODOGRAPHS INDICATES RELATIVE MAXIMUM IN TORNADO THREAT MAY DEVELOP OVER PORTIONS W-CENTRAL AND NW TX...BUT THERE ARE STILL TOO MANY MESOSCALE UNCERTAINTIES AND LIMITS TO PROGGED SR MID LEVEL FLOW FOR A MDT RISK. PROGGED LOW-MID LEVEL SR FLOW IS MAXIMIZED OVER THIS AREA N 18Z-00Z TIME FRAME...AND LOW LEVEL CONVERGENCE/INFLOW/VORTICITY MAY BE AUGMENTED BY FRONT/OUTFLOW.

ATTM...IT APPEARS THAT CONVECTION MAY EVOLVE AFTER DARK INTO TWO MAIN AREAS -- ONE MOVING EWD-NEWD ACROSS KS/OK/N-CENTRAL TX..AND ANOTHER ESEWD INVOF FRONT TOWARD TX COAST.

..EDWARDS.. 05/02/99

NNNN

ZCZC MKCSWODY2 000
ACUS2 KMKC 021704
MKC AC 021704

2ND DAY CONVECTIVE OUTLOOK...REF AFOS NMCGPH98O.

VALID 031200Z - 041200Z

THERE IS A SLGT RISK OF SVR TSTMS TO THE RIGHT OF A LINE FROM 35 NW HDO 45 N DRT 30 ESE BGS 20 WNW CSM 20 ESE RSL 35 SSW BIE 10 NW FLV 20 SE JLN 25 N TYR 30 E AUS 35 NW HDO.

GEN TSTMS ARE FCST TO THE RIGHT OF A LINE FROM 35 ESE INL 20 NNE MLI 25 NNE ALN 40 W UOX 35 SW HUM ...CONT... 20 E CRP 30 NW LRD ...CONT... 70 SW P07 35 NNW BGS 25 NNW CDS 20 ESE LBL 35 N CAO 30 SE 4SL 50 ESE PGA 25 NE U24 45 WNW PIH 35 NW BKE 10 NW AST.

UPPER LEVEL SHORTWAVE TROUGH CURRENTLY OVER THE SOUTHERN AND CENTRAL PLAINS WILL CONTINUE TO LIFT NORTHEASTWARD TODAY...WHILE ANOTHER TROUGH OVER THE PACIFIC NORTHWEST COAST DIGS SOUTHEAST INTO THE INTERMOUNTAIN REGION DURING THE DAY 2 PERIOD. A LONGWAVE TROUGH PATTERN IS FORECAST TO DEVELOP ACROSS THE WESTERN TWO-THIRDS

OF THE NATION BY LATE MONDAY AFTERNOON...WHILE A MAIN SHORTWAVE TROUGH IS EXPECTED TO MOVE THROUGH THE MEAN TROUGH INTO THE ROCKIES DURING THE LATTER HALF OF THE PERIOD. AT THE SURFACE...A WEAK AREA OF LOW PRESSURE IS EXPECTED TO REMAIN OVER PORTIONS OF SOUTH DAKOTA DURING THE ENTIRE PERIOD.

...SOUTHERN AND CENTRAL PLAINS...
A DRYLINE WILL LIKELY BECOME ESTABLISHED ACROSS THE PLAINS STATES FROM WESTERN NEBRASKA SOUTHWARD INTO THE BIG BEND REGION OF TEXAS. IN THE ABSENCE OF A STRONG SHORTWAVE TROUGH MOVING THROUGH THE PLAINS...THE DRYLINE SHOULD MIX EASTWARD DURING THE DAY...THEN RETREAT WESTWARD AT NIGHT. MID LEVEL FLOW IS EXPECTED TO BE SOMEWHAT WEAKER THAN THE PAST SEVERAL DAYS AS THE LOW THAT HAD BEEN OVER THE SOUTHWESTERN STATES MOVES INTO THE GREAT LAKES REGION. HOWEVER...FORECAST SOUNDINGS CONTINUE TO SHOW STRONGLY VEERING WINDS DESPITE THE SLIGHTLY WEAKER WINDS AT MID LEVELS. THE RESULTING WINDS SHOULD STILL BE FAVORABLE FOR SOME ROTATION AS STORMS DEVELOP DURING THE AFTERNOON HOURS.

THE GULF SHOULD BEGIN TO OPEN UP LATER TONIGHT...ALLOWING MOISTURE TO RETURN ACROSS THE SOUTHERN AND CENTRAL PLAINS. DEWPOINTS ARE LIKELY TO CLIMB INTO THE 60S POSSIBLY AS FAR NORTH AS SOUTHERN KANSAS BY LATE AFTERNOON. DEPENDING ON THE AMOUNT OF CLOUD DEBRIS FROM OVERNIGHT CONVECTION...SURFACE BASED CAPE VALUES WILL LIKELY REACH 3000 TO 3500 J/KG ACROSS SOUTHERN PORTIONS OF THE OUTLOOK AREA TO PERHAPS 2000 TO 3000 J/KG IN THE NORTH. THUNDERSTORMS WILL REDEVELOP IN THE VICINITY OF THE ADVANCING DRYLINE ACROSS WEST TEXAS...WESTERN OKLAHOMA...AND WESTERN KANSAS. THESE STORMS SHOULD MOVE EASTWARD OFF THE DRYLINE INTO CENTRAL AND PERHAPS EASTERN PORTIONS OF THE ABOVE MENTIONED STATES. WIND FIELDS SUGGEST THERE IS A LIKELIHOOD FOR ISOLATED SUPERCELLS FROM KANSAS INTO OKLAHOMA ...AND SCATTERED SUPERCELLS ACROSS TEXAS. LARGE HAIL...DAMAGING GUSTS...AND ISOLATED TORNADOES ARE ALL POSSIBLE WITH SOME OF THESE STORMS.

..REHBEIN.. 05/02/99

NNNN
O

ZCZC MKCSWODY1 000
ACUS1 KMKC 021933
DMKC AC 021933

CONVECTIVE OUTLOOK...REF AFOS NMCGPH94O.

VALID 022000Z - 031200Z

THERE IS A SLGT RISK OF SVR TSTMS TO THE RIGHT OF A LINE FROM 40 W END 25 SW DDC 50 NNE GCK 30 NE HLC 25 SW CNK 25 SW EMP 25 SW BVO 40 W END.

THERE IS A SLGT RISK OF SVR TSTMS TO THE RIGHT OF A LINE FROM 35 S SAT 50 SSW JCT 40 SW ABI 30 S LTS 45 WSW ADM 35 SSE DAL 30 ESE AUS 35 S SAT.

GEN TSTMS ARE FCST TO THE RIGHT OF A LINE FROM 40 WNW INL 25 SE CID 10 ENE UNO 20 SW 7R4 ...CONT... 35 ENE CRP 35 NW LRD ...CONT... DRT 15 NNW CDS 30 SE LBL 15 SW LHX 45 NE DRO 35 E 4HV 15 SW DPG 60 N ENV 35 SSE 27U 25 E LWT 50 NNW I8N.

EARLY AFTERNOON SURFACE ANALYSIS SHOWS A DRYLINE EXTENDING ACROSS PORTIONS OF WESTERN KANSAS...THROUGH EXTREME WESTERN OKLAHOMA... INTO THE BIG BEND AREA OF TEXAS. LATEST VISIBLE IMAGERY SHOWS EXTENSIVE CLOUDINESS WELL AHEAD OF THE DRYLINE FROM CENTRAL AND EASTERN KANSAS THROUGH EASTERN OKLAHOMA INTO CENTRAL TEXAS. THIS CLOUD COVER HAS SEVERELY LIMITED SURFACE HEATING AND DESTABILIZATION THROUGH EARLY AFTERNOON. SKIES BECOME PARTLY TO MOSTLY CLOUDY ACROSS WESTERN KANSAS AND WESTERN OKLAHOMA...AND NEARLY CLEAR ACROSS NORTHWEST TEXAS. SURFACE DEWPOINTS HAVE REMAINED IN THE LOW 60S ACROSS WESTERN AND CENTRAL OKLAHOMA AND TEXAS. WHERE THERE HAS BEEN CLEARING...THE ATMOSPHERE HAS BECOME VERY UNSTABLE. HOWEVER...THIS HAS BEEN A RATHER NARROW AXIS FROM THE BIG BEND AREA OF TEXAS TO NEAR ALTUS OKLAHOMA. SURFACE BASED CAPE VALUES IN THIS AREA ARE CURRENTLY RUNNING IN THE 1500 TO 3000 J/KG RANGE.

CUMULUS HAS BEGUN TO DEVELOP ALONG AND JUST AHEAD OF THE DRYLINE ACROSS SOUTHWEST KANSAS AND WESTERN OKLAHOMA. HOWEVER...THE DEVELOPMENT HAS BEEN RATHER SHALLOW...SUGGESTING THE AIRMASS IS STILL CAPPED. EARLY AFTERNOON SOUNDING FROM NORMAN CONFIRMS THE PRESENCE OF A CAPPING INVERSION. ADDITIONALLY...CONVERGENCE ALONG THE DRYLINE REMAINS RATHER LIMITED ACROSS THE SOUTHERN OUTLOOK AREA...BUT THE CAP IS SOMEWHAT WEAKER IN THIS AREA. IT APPEARS THAT THE GREATEST CONVERGENCE ALONG THE DRYLINE HAS BEEN CONFINED TO THE KANSAS AREA. AT THIS TIME...IT APPEARS THE GREATEST POTENTIAL FOR SEVERE THUNDERSTORM DEVELOPMENT WILL REMAIN ACROSS WESTERN AND CENTRAL KANSAS/NORTH CENTRAL AND NORTHWEST OKLAHOMA AS WELL AS PARTS OF WEST AND CENTRAL TEXAS. THE KANSAS AREA HAS THE GREATEST LOW TO MID LEVEL FORCING WHILE THE TEXAS AREA IS LESS CAPPED AND HAS GREATER INSTABILITY. IT APPEARS THE PRIMARY THREAT ACROSS KANSAS WILL LIKELY BE FROM LARGE HAIL. WIND FIELDS ACROSS THE TEXAS AREA EXHIBIT STRONG VEERING PROFILES...FAVORABLE FOR THE DEVELOPMENT OF SUPERCELLS. FOR THAT REASON...THE SOUTHERN AREA HAS POTENTIAL FOR LARGE HAIL...DAMAGING GUSTS...AND PERHAPS ISOLATED TORNADOES.

..REHBEIN.. 05/02/99

NNNN

ZCZC MKCSWODY1 000
ACUS1 KMKC 030045
MKC AC 030045

CONVECTIVE OUTLOOK...REF AFOS NMCGPH940.

VALID 030100Z - 031200Z

THERE IS A SLGT RISK OF SVR TSTMS TO THE RIGHT OF A LINE FROM
25 NE LNK 30 ENE MHK 15 E ICT 25 SE P28 50 S DDC 20 SW DDC
35 S RSL 25 W CNK BBW 30 E ANW 50 W YKN 30 NE OFK 25 NE LNK.

GEN TSTMS ARE FCST TO THE RIGHT OF A LINE FROM 35 SSW PSX 10 SW DAL
40 N ADM 15 ENE LBL PUB 15 E CAG 15 WSW COD LWT 60 NNE GGW
...CONT... 60 NNW DVL 30 W STC 25 SW OTM 15 NNE LIT 30 NNE ESF
20 SW 7R4.

...SEVERE THUNDERSTORM FORECAST DISCUSSION...
WEAKENING UPPER SYSTEM MOVING ACROSS NEB AT THIS TIME WILL CONTINUE
LIFTING NWD ACROSS THE NRN PLAINS TONIGHT...WHILE ANOTHER STRONGER
SYSTEM DIGS SEWD INTO THE INTERMOUNTAIN WEST. WEAKENING SYSTEM HAS
MAINTAINED SEVERE STORMS INCLUDING A FEW TORNADIC SUPERCELLS INTO
S-CENTRAL NEB OVER THE PAST FEW HOURS...WITHIN MARGINALLY UNSTABLE
AIR MASS. HOWEVER AS THE SUN SETS AND THE LOW LEVEL AIR MASS
STABILIZES...EXPECT SEVERE THREAT TO GRADUALLY END. UNTIL
THEN...EVENING SOUNDINGS AND VWPS YIELD SUFFICIENT DEEP LAYER SHEAR
AND LOW LEVEL VEERING FOR ISOLATED SUPERCELLS AND POSSIBLY ANOTHER
TORNADO OR TWO INTO PARTS OF CENTRAL NEB.

TAIL END OF THIS SHORTWAVE TROUGH APPEARED TO BE SUPPORTING
ISOLATED THUNDERSTORMS INTO SWRN KS RECENTLY...AND THIS FORCING
WILL SHIFT ENEWD INTO MID 50F SURFACE DEW POINTS OVER CENTRAL KS
OVER THE NEXT COUPLE OF HOURS. THEREFORE...ISOLATED SEVERE
HAIL/WIND MAY ACCOMPANY ANY STORMS WHICH DEVELOP INVOF DRY LINE/
SURFACE TROUGH INTO CENTRAL KS.

...GENERAL THUNDERSTORM FORECAST DISCUSSION...
ELSEWHERE...ISOLATED CONVECTION SHOULD CONTINUE THROUGH THE PERIOD
WITHIN REGION OF COLD MID LEVEL TEMPERATURES FROM THE ROCKIES INTO
THE NRN PLAINS. AS LOW LEVEL JET DEVELOPS ACROSS THE SRN PLAINS...
CONVECTION MAY ALSO FORM INTO PARTS OF ERN OK/MO/KS/WRN AR LATER
TONIGHT. CONVERGENCE ALONG DRY LINE HAS BEEN WEAK AND SHOULD
REMAIN WEAK OVERNIGHT WITH SLOW WWD MOVEMENT...WHICH WILL LIMIT
POTENTIAL FOR THUNDERSTORMS ALONG IT TONIGHT.

..EVANS.. 05/03/99

NNNN

ZCZC MKCSWODY1 000
ACUS1 KMKC 030555
MKC AC 030555

CONVECTIVE OUTLOOK...REF AFOS NMCGPH940.

VALID 031200Z - 041200Z

THERE IS A SLGT RISK OF SVR TSTMS TO THE RIGHT OF A LINE FROM SAT
40 WSW SJT 15 W CDS 20 NW DDC 40 NW CNK 20 NNW FNB 35 NE MKC
50 SSW SZL FSM GGG SAT.

THERE IS A SLGT RISK OF SVR TSTMS TO THE RIGHT OF A LINE FROM
40 SW 9V9 20 NW MHN 30 SE CDR 25 ENE RAP 20 ESE Y22 25 S BIS
40 WNW ABR 40 SW 9V9.

GEN TSTMS ARE FCST TO THE RIGHT OF A LINE FROM 35 ESE INL
20 NNE MLI 25 NNE ALN 40 W UOX 35 SW HUM ...CONT... 20 E CRP
30 NW LRD ...CONT... 50 ESE P07 20 ENE MAF 15 SSE PVW 25 NNE AMA
50 NW TCC 15 ENE ABQ 50 ESE PGA 10 WSW U24 35 SSE TWF 65 W 27U
90 ENE 63S.

...SEVERE THUNDERSTORM FORECAST DISCUSSION...
WEAKENING UPPER LOW WILL CONTINUE LIFTING NWD ACROSS THE NRN PLAINS EARLY IN THE PERIOD...AS DEEP TROUGHING ACROSS THE ROCKIES BECOMES THE DOMINANT FEATURE THROUGH THE PERIOD. MODELS CONSISTENT IN SHIFTING NOSE OF MID LEVEL SPEED MAX AND ASSOCIATED TROUGH AXIS INTO THE SRN PLAINS BY LATE IN THE PERIOD...WITH FAIRLY ILL-DEFINED SURFACE FEATURES THROUGH MUCH OF THE AFTERNOON.

...SRN PLAINS...
DRY LINE WAS ALREADY RETREATING WWD INTO WRN KS/ERN TX PANHANDLE... WITH DEEP BOUNDARY LAYER MOISTURE EAST OF THIS FROM TX INTO PARTS OF KS AT THIS TIME. GIVEN HEIGHT FALLS REMAINING OVER THE ROCKIES AHEAD OF UPPER TROUGH...THERE SHOULD BE LITTLE EWD MOVEMENT TO DRY LINE DURING THE AFTERNOON. PRIMARY CONVECTIVE POTENTIAL ACROSS MUCH OF THE SRN PLAINS SHOULD BE THROUGH THE EVENING/OVERNIGHT AS UPPER SYSTEM LIFTS EWD...AND LOW LEVEL CONVERGENCE INCREASES AS SURFACE TROUGH/DRY LINE MOVES INTO CENTRAL OK/TX. ISOLATED THUNDERSTORMS SHOULD BEGIN DEVELOPING TOWARDS 00Z/04 OVER FAR WRN OK/NWRN TX WITHIN VERY UNSTABLE AIR MASS...WHERE SURFACE-BASED CAPES MAY APPROACH 3000 J/KG. INITIAL ACTIVITY SHOULD BE SUPERCELLULAR GIVEN DEGREE OF CAPE AND INCREASING DEEP LAYER SHEAR ...THOUGH ACTIVITY WILL LIKELY EVOLVE INTO A SQUALL LINE LATER IN THE EVENING ACROSS CENTRAL/ERN KS...OK...CENTRAL/NERN TX.

...SD...
COLD FRONT ASSOCIATED WITH STRENGTHENING WRN U.S. TROUGH WILL MOVE SEWD INTO THE NRN HIGH PLAINS DURING THE DAY...IN THE WAKE OF UPPER LOW MOVING ACROSS THE DAKOTAS AT THIS TIME. LOW CENTER WILL LIKELY DEVELOP INVOF INTERSECTION OF COLD FRONT AND LEE TROUGH INVOF SWRN SD/WRN NEB AND INCREASE CONVERGENCE INTO THIS AREA. DEW POINTS IN THE LOWER TO MID 50S AND TEMPERATURES IN THE LOWER 70S...SHOULD SUPPORT SURFACE-BASED CAPES FROM 1000-1500 J/KG AND MAINTAIN A THREAT OF ISOLATED SEVERE HAIL WITH THIS ACTIVITY INTO THE EARLY EVENING.

..EVANS.. 05/03/99

ZCZC MKCSWODY1 000
ACUS1 KMKC 031246
□MKC AC 031246

CONVECTIVE OUTLOOK...REF AFOS NMCGPH94O.

VALID 031200Z - 041200Z

THERE IS A SLGT RISK OF SVR TSTMS TO THE RIGHT OF A LINE FROM
25 ENE RAP 35 SW Y22 15 N Y22 25 SW BIS 45 ESE BIS 35 W ABR
30 WSW 9V9 20 SSW VTN 40 ESE CDR 40 SE RAP 25 ENE RAP.

THERE IS A SLGT RISK OF SVR TSTMS TO THE RIGHT OF A LINE FROM
35 ESE BGS 60 NNW CDS 40 SE LBL 45 WSW HLC 45 NNE HLC 20 SSE HSI
35 SE BIE 25 ESE TOP 40 ENE CNU 20 WSW FYV 40 ESE PRX 55 SSW TYR
25 SSE CLL 50 SSE AUS 50 SSW JCT 55 NNW DRT 35 ESE BGS.

GEN TSTMS ARE FCST TO THE RIGHT OF A LINE FROM 35 E INL 10 ESE EAU
30 WNW PIA 20 E JBR 30 SW UOX 35 WNW MEI 10 N LUL 30 WNW GPT
15 S MSY 25 SSW 7R4 ...CONT... 10 ENE GLS 45 WNW VCT 30 N COT
20 WNW COT 25 NW LRD ...CONT... 35 WNW DRT 30 W CDS 60 WSW GAG
15 NW LBL 35 ESE 4LJ 35 SE LHX 45 NW CAO 50 SSE RTN 20 SW LVS
20 E GUP 55 E PGA 20 WNW DPG 35 NNW THF 50 SW 27U 50 NW 27U
25 SE 3TH 100 NE 63S.

--- SYNOPSIS ---
ROCKIES LONGWAVE TROUGH WILL AMPLIFY AS TROUGH NOW OVER SD EJECTS
NEWD...AND SHORTWAVE TROUGH EVIDENT ON MOISTURE CHANNEL IMAGERY
OVER WRN AZ MOVES E. MIDDLE-UPPER LEVEL WINDS ACROSS SWRN CONUS ON
BOTH SIDES OF THIS FEATURE WERE SIGNIFICANTLY UNDERFORECAST BY
00Z/03Z ETA...BASED ON LATEST RAOB DATA AND OBSERVATIONS FROM
REGIONAL VWP/ACARS. AVN WINDS/HEIGHTS ARE VERIFYING MUCH BETTER
THIS MORNING...AND SUGGEST MID/UPPER LEVEL FLOW MAY BE STRONGER
THAN FORECAST BY ETA OVER SRN PLAINS THIS EVENING. TROUGH SHOULD
REMAIN PROGRESSIVE BUT COULD BE SLIGHTLY MORE AMPLIFIED THAN
PROGGED AS IT MOVES ACROSS NERN AZ AND NM...REACHING TX PANHANDLE
THIS EVENING. SURFACE LOW N GCC SHOULD MOVE EWD ACROSS SD...WHILE
LEE TROUGH FARTHER S OVER SRN HIGH PLAINS STRENGTHENS THIS EVENING.

... SEVERE THUNDERSTORM FORECAST DISCUSSION ...

--- CENTRAL/SOUTHERN PLAINS ---
EXPECT GREATEST CONVECTIVE THREAT AFTER ABOUT 23Z...WHEN LARGE-
SCALE ASCENT ASSOCIATED WITH AZ SHORTWAVE TROUGH BEGINS TO IMPINGE
UPON DRYLINE REGION. SUBSIDENCE ASSOCIATED WITH FOREGOING
SHORTWAVE RIDGE SHOULD HELP TO REMOVE BOTH CLOUD COVER AND
CONVECTIVE THREAT IN THE MEANTIME...WHILE AIDING DIABATIC SURFACE
HEATING. ETA DESTABILIZATION N OF RED RIVER THRU EARLY
AFTERNOON...HOWEVER...IS OVERDONE BECAUSE OF HIGH DEW POINT
FORECASTS. LARGEST BUOYANCY SHOULD BE OVER N-CENTRAL/NWRN TX WHERE
MID/UPPER 60S DEW POINTS AND TEMPS MID 80S F WILL CONTRIBUTE TO
MLCAPE APPROACHING 3000 J/KG...SBCAPE TO 4500 J/KG. ZONE OF UPPER
LEVEL DIVERGENCE/ UVV IN ETA...ASSOCIATED WITH LEFT EXIT REGION OF
CYCLONICALLY CURVED SUBTROPICAL SPEED MAX OVER MEX/S TX...SHOULD
REMAIN BROAD AND WEAK -- NOT WITH SUDDEN INTENSIFYING EVIDENTLY
ASSOCIATED WITH ETA CONVECTIVE FEEDBACK.

UPPER LEVEL FLOW IS EXPECTED TO BACK DURING LATE AFTERNOON AND EVENING AS AZ SHORTWAVE TROUGH APPROACHES. THIS SHOULD HELP TO TREND STORM EVOLUTION TOWARD HP THEN LINEAR VIA TWO PRIMARY EFFECTS AT ANVIL LEVEL. THOUGH SR FLOW WILL NOT BE AS WEAK AS ETA PROGS...IT STILL SHOULD BE GENERALLY AOB 40 KT WITH PRECIP PARTICLE RECYCLING...AND FLOW DIRECTION SUGGESTS SEEDING FROM MERIDIONAL COALESCENCE OF ANVILS UP AND DOWN CONVECTIVE ZONE. BRIEF WINDOW OF TORNADO POTENTIAL MAY EXIST WITH A FEW STORMS BETWEEN ABOUT AN HOUR AFTER INITIATION...AND FULLY OUTFLOW-DOMINANT HP TRANSITION. HOWEVER...MAIN THREAT SHOULD BE LARGE HAIL FIRST FEW HOURS AFTER INITIATION...TRANSITIONING TO DAMAGING WIND.

LINE OF STRONG-SEVERE THUNDERSTORMS IS EXPECTED TO FORM FROM AFTERNOON/EARLY EVENING DEVELOPMENT...THEN MOVE EWD ACROSS MUCH OF CENTRAL/ERN KS...CENTRAL/ERN OK AND N-CENTRAL TX AFTER 6Z. EXPECT SOME LEWPS/BOWS WITH DAMAGING WIND...AND A MARGINAL THREAT OF EMBEDDED TORNADOES. SRN END OF BACKBUILDING LINE SOMEWHERE OVER CENTRAL TX WILL BE DICTATED BY CAPPING AT BASE OF ELEVATED MIXED LAYER ADVECTED OFF HIGH MEX PLATEAU...WHICH IS ALREADY EVIDENT ABOVE 750 MB IN 12Z DRT SOUNDING.

--- N-CENTRAL PLAINS ---
FOR MOST OF TODAY...SHORTWAVE RIDGING BEHIND CURRENT EJECTING SD SHORTWAVE TROUGH WILL SUPPRESS CONVECTION AND AID IN INSOLATION. BY MID/LATE AFTERNOON...ISALLOBARIC FORCING INVOF LOW LEVEL CYCLONE WILL RESULT IN BACKED BOUNDARY LAYER FLOW AND ENHANCED CONVERGENCE/LIFT ON MESO ALPHA SCALE. ETA PFC SOUNDINGS SHOW SMALL HODOGRAPHS WITH SRH AOB 100 J/KG...BUT REGIONAL ISALLOBARIC FORCING SHOULD STRENGTHEN NEAR-SURFACE FLOW MORE THAN PROGGED...INCREASING SR LOW LEVEL INFLOW.

EXPECT MLCAPE NEAR 1000 J/KG...SUPPORTING DEVELOPMENT OF WIDELY SCATTERED STRONG-SEVERE THUNDERSTORMS NEAR LOW AND ATTACHED SURFACE TROUGHS AND DRYLINE. A FEW STORMS SHOULD ROTATE...BUT WEAKNESSES IN LOW-MID LEVEL SR FLOW ABOVE THAT SUGGEST MAIN THREAT WILL BE LARGE HAIL...WITH ISOLATED DAMAGING WIND POSSIBLE. INSOLATION IS SUCH A MAJOR CONTRIBUTOR TO CAPE IN MODIFIED FORECAST SOUNDINGS THAT THREAT SHOULD DECREASE GREATLY AFTER DARK.

..EDWARDS.. 05/03/99

ZCZC MKCSWODY1 000
ACUS1 KMKC 031615
MKC AC 031615

CONVECTIVE OUTLOOK...REF AFOS NMCGPH94O.

VALID 031630Z - 041200Z

THERE IS A MDT RISK OF SVR TSTMS OVER NORTH CENTRAL TEXAS...MOST OF OKLAHOMA AND SOUTH CENTRAL KANSAS. THIS AREA IS TO THE RIGHT OF A LINE FROM 10 ESE CDS 55 WNW CSM 50 S DDC 45 SW RSL 30 NNW HUT EMP 25 N BVO 25 NNW MLC 45 WSW PRX 55 ENE ACT 25 ESE BWD 40 SSW ABI 65 NNW ABI 10 ESE CDS.

THERE IS A SLGT RISK OF SVR TSTMS TO THE RIGHT OF A LINE FROM 40 ENE Y22 50 SW JMS 25 S ABR 10 S SUX 20 SSW FLV 35 S JLN 20 S PGO 25 WNW GGG 35 ESE CLL 30 WSW AUS 50 SW JCT 45 ENE BGS 35 SSE LBL 45 E MCK 60 ENE CDR 40 ENE Y22.

GEN TSTMS ARE FCST TO THE RIGHT OF A LINE FROM 30 NNW ELO
25 NNE DBQ 10 ESE STL 20 WNW MEM 30 WNW MEI 30 WSW GPT 30 W HUM
20 NE GLS 35 WNW VCT 30 NW LRD 35 NW DRT 30 SSE 1K5 40 ENE 4LJ
25 ESE TAD 15 W LVS 20 NW GUP 30 SSW U17 35 N ENV 30 W SUN
45 NNW 27U 70 WNW FCA.

...SEVERE THUNDERSTORM FORECAST DISCUSSION...

...SYNOPSIS...
NEGATIVELY TILTED LONGWAVE TROUGH WILL PIVOT ENEWD THROUGH THE ROCKY MOUNTAINS INTO THE HIGH PLAINS THROUGH PERIOD. SHORT WAVE TROUGH...EVIDENT ON WATER VAPOR IMAGES...FORECASTED BY MODELS TO MOVE ACROSS TX PANHANDLE INTO WRN OK LATE THIS AFTERNOON AND LIFT NEWD INTO CENTRAL OK/SERN KS DURING THE EVENING. STRONGER VORT CENTER WILL MOVE ACROSS SRN ROCKIES INTO NWRN TX OVERNIGHT.

SURFACE TROUGH/DRY LINE EXTENDED FROM WRN ND TO WRN TX AT 14Z WHILE COLD FRONT TRAILED SWWD THROUGH WY INTO UT. TROUGH POSITION WILL REMAIN ALMOST STATIONARY THROUGH LATE AFTERNOON BUT AXIS SHOULD SHIFT SLOWLY EWD TONIGHT AS COLD FRONT ADVANCES INTO CENTRAL/SRN HIGH PLAINS. 40 TO 50 KT LOW LEVEL JET AXIS WILL MEANWHILE EXTEND FROM N CENTRAL TX THROUGH OK INTO CENTRAL/ERN KS AND ERN NEB THIS AFTERNOON AND TONIGHT WITH CONTINUED ADVECTION/INFLOW OF HIGHER THETAE AIR MASS THROUGH THE PLAINS.

...N CENTRAL TX/OK/SRN KS...
LOW LEVEL JET WILL MAINTAIN SIGNIFICANT INFLOW OF LOW LEVEL MOISTURE WITH SURFACE DEWPOINTS AROUND 65 F. CLEARING SKIES EVIDENT ON VISIBLE IMAGES WILL FURTHER CONTRIBUTE TO STRONG DESTABILIZATION OVER REGION WITH LATE AFTERNOON MUCAPES FORECASTED FROM 3500 TO 4500 J/KG OVER MDT RISK AREA. AS SHORT WAVE APPROACHES WRN OK/TX BORDER...LIFTING WILL DEEPEN NEAR/ALONG DRY LINE WITH THUNDERSTORMS INCREASING AS THEY MOVE EWD INTO INSTABILITY AXIS. 50 KT MID LEVEL SWLY FLOW SPREADING OVER LOW LEVEL JET AXIS WILL PROVIDE SUFFICIENT SHEAR FOR A FEW STRONG OR VIOLENT TORNADIC SUPERCELLS GIVEN THE ABUNDANT LOW LEVEL MOISTURE AND THE HIGH INSTABILITY. WET BULB ZERO HEIGHTS NEAR 8000 FT AND DRY AIR AT MID LEVELS ALSO INDICATE POTENTIAL FOR SCATTERED TO NUMEROUS HAIL AND WIND EVENTS.

...SD...NEB...NRN KS...
NRN PORTIONS OF LOW LEVEL JET WILL BRING INCREASING MOISTURE TO REGION WITH SURFACE DEWPOINTS POSSIBLY EXCEEDING 60 F AS FAR N AS NRN NEB BY LATE AFTERNOON. BREAKS IN CLOUD COVER WILL ALLOW AFTERNOON HIGHS NEAR 75 TO 80 RESULTING IN MUCAPES CLIMBING TO AROUND 2000 TO 3000 J/KG. TIMING OF CONVECTIVE INITIATION MAIN UNCERTAINTY BUT EXPECT CONVERGENCE ALONG SURFACE TROUGH AND INCREASING UPWARD MOTION ALOFT AHEAD OF UPPER TROUGH WILL INITIATE CONVECTION LATE THIS AFTERNOON AND THIS EVENING. WET BULB ZERO HEIGHTS NEAR 7000 FT AND DRY AIR AT MID LEVELS INDICATE AT LEAST SCATTERED WIND AND HAIL EVENTS. WHILE WEAKNESS IN THE MID LEVEL WIND SPEEDS ARE NOT FAVORABLE FOR TORNADOES...THE STRONG LOW LEVEL SHEAR NEAR LOW LEVEL JET AXIS MAY SUPPORT ISOLATED SUPERCELLS.

..ROGASH.. 05/03/99

NNNN
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ZCZC MKCSWOMCD ALL;334,0996 373,0979 353,0979 314,0996;
ACUS3 KMKC 032023
MKC MCD 032023
TXZ000-OKZ000-032300-

SPC MESOSCALE DISCUSSION #0345 FOR...SW OK/NW TX...
CONCERNING...SEVERE THUNDERSTORM POTENTIAL...

WATER VAPOR IMAGERY SHOWS A LEAD MID LEVEL SHORTWAVE TROUGH MOVING ENEWD OVER E/NE NM THIS AFTERNOON...AND THIS IS CONFIRMED BY PROFILER TIME SERIES FROM AZC/GDA/TCC/JTN. MID/UPPER 60 DEWPOINTS AND TEMPERATURES NEAR 80 ARE CONTRIBUTING TO SURFACE-BASED CAPE VALUES OF 3500-5000 J/KG OVER WRN OK AND NW TX TO THE E OF THE DRYLINE. CONVERGENCE ON THE DRYLINE IS NOT STRONG AND A CIRRUS SHIELD OVER THE TX PANHANDLE/NW TX/WRN OK SHOULD LIMIT ADDITIONAL SURFACE HEATING...BUT VISIBLE/RADAR IMAGERY HAS SHOWN THE FIRST ATTEMPTS AT TCU OVER FAR NW TX AS OF 20Z WITHIN A BREAK IN THE CIRRUS. MID LEVEL FLOW AND VERTICAL SHEAR WILL INCREASE OVER NW TX AND WRN OK THROUGH LATE AFTERNOON... WITH AN INCREASING THREAT OF SUPERCELLS NEAR THE DRYLINE FROM 00-03Z. THIS AREA IS BEING MONITORED FOR A POSSIBLE TORNADO WATCH LATER THIS AFTERNOON.

..THOMPSON.. 05/03/99

...PLEASE SEE WWW.SPC.NOAA.GOV/ FOR GRAPHIC PRODUCT...
NNNN

ZCZC MKCSWODY1 000
ACUS1 KMKC 032049
MKC AC 032049

CONVECTIVE OUTLOOK...REF AFOS NMCGPH94O.

VALID 032000Z - 041200Z

THERE IS A HIGH RISK OF SVR TSTMS TONIGHT ACROSS PARTS OF SRN KS...WRN AND CENTRAL OK...AND PARTS OF N CENTRAL AND NWRN TX. THE HIGHT RISK IS TO THE RIGHT OF A LINE FROM 20 W CDS 40 W GAG 25 S DDC 40 SSW RSL 15 ENE SLN 10 NW EMP 30 NE BVO 25 ENE MLC 40 SSW PRX 35 SE DAL SEP 25 SSW ABI 65 WNW ABI 20 W CDS.

THERE IS A SLGT RISK OF SVR TSTMS TO THE RIGHT OF A LINE FROM 45 W Y26 25 ENE Y26 20 ENE HON 10 S SUX 10 SE FLV 15 W UMN 30 ESE PGO 10 E GGG CLL 40 SE JCT 70 SSW SJT 65 SSW CDS 35 SSE LBL 25 W MCK 60 ENE CDR 45 W Y26.

GEN TSTMS ARE FCST TO THE RIGHT OF A LINE FROM 35 E PSX 20 NNW NIR 30 NW LRD 40 E P07 20 E DHT 25 ESE 4LJ 25 ESE TAD 15 W LVS 20 NW GUP 20 SW CDC 30 NE BAM 55 ESE BKE 10 E PUW 85 WNW FCA.

GEN TSTMS ARE FCST TO THE RIGHT OF A LINE FROM 40 E INL 55 SE DLH 30 E DBQ 20 ESE BLV 45 ENE GWO 30 S LUL 45 SW HUM.

...SEVERE THUNDERSTORM FORECAST DISCUSSION...
LATEST SURFACE DATA SHOWS SURFACE DRYLINE EXTENDS FROM WRN KS SWD INTO WRN SECTIONS OF CENTRAL TX. LATEST ETA MODEL SHOWS EXIT REGION OF MID LEVEL WIND MAX WILL MOVE INTO THE SRN HI PLAINS WHICH WILL ENHANCE UVVS ALONG THE DRY LINE. STRONG LOW LEVEL WIND MAX OF 60 KT WILL EXTEND NWD ACROSS ERN TX INTO ERN OK WHICH WILL INCREASE DEEP LAYER SHEAR ACROSS THE CENTRAL AND SRN PLAINS.

STORM RELATIVE INFLOW ID FORECAST TO INCREASE THIS EVENING ACROSS OK WITH 50 KT FORECAST INTO THE DRY LINE AFTER 00Z. THIS IS EXPECTED TO ENHANCE HELICITY IN THE VICINITY OF THE SQUALL LINE. THUS...ISOLATED TORNADOES ARE EXPECTED WITH THE ACTIVITY THIS EVENING WITH THE MAIN THREAT BEING LARGE HAIL. RUC2 SOUNDINGS FROM 18Z RUN SHOWS MUCAPE BETWEEN 3000 AND 4000 J/KG ACROSS THE AREA WITH HELICITIES BETWEEN 300 AND 400 M2/S2.

..MCCARTHY.. 05/03/99

NNNN
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ZCZC MKCWWAMKC ALL 040300;335,0993 360,0993 360,0961 335,0962;
WWUS8 KMKC 032333
MKC WW-A 032333
OKZ000-040200-

STATUS REPORT ON WW NUMBER 195

CLUSTER OF INTENSE THUNDERSTORMS...INCLUDING STRONG TORNADIC SUPERCELLS WEST/SOUTHWEST OF OKLAHOMA CITY AREA IS ONGOING. STRONG AND INTENSIFYING DIVERGENT UPPER FLOW FIELD...ENHANCED BY MID/UPPER JET DIGGING ACROSS THE SOUTHERN ROCKIES...WILL CONTINUE TO SUPPORT EVOLUTION INTO LARGER SEVERE CONVECTIVE SYSTEM...AHEAD OF DRY LINE ...THROUGH THE EVENING HOURS. GIVEN ONGOING AND EXPECTED TRENDS... WW MAY BE REPLACED WITH NEW WW INCLUDING NORTHERN OKLAHOMA AND PARTS OF NORTH CENTRAL TEXAS WITHIN THE NEXT HOUR OR SO.

..KERR.. 05/03/99
NNNN

ZCZC MKCSELS ALL 040300;335,0993 360,0993 360,0961 335,0962;
WWUS9 KMKC 032130
MKC WW 032130
OKZ000-040300-

URGENT - IMMEDIATE BROADCAST REQUESTED
TORNADO WATCH NUMBER 195
STORM PREDICTION CENTER NORMAN OK
430 PM CDT MON MAY 3 1999

THE STORM PREDICTION CENTER HAS ISSUED A TORNADO WATCH FOR PORTIONS OF

WESTERN AND CENTRAL OKLAHOMA

EFFECTIVE THIS MONDAY AFTERNOON AND EVENING FROM 445 PM UNTIL 1000 PM CDT.

TORNADOES...HAIL TO 3 INCHES IN DIAMETER...THUNDERSTORM WIND GUSTS TO 80 MPH...AND DANGEROUS LIGHTNING ARE POSSIBLE IN THESE AREAS.

THE TORNADO WATCH AREA IS ALONG AND 90 STATUTE MILES EAST AND WEST OF A LINE FROM 25 MILES EAST OF WICHITA FALLS TEXAS TO 50 MILES NORTH NORTHWEST OF OKLAHOMA CITY OKLAHOMA.

REMEMBER...A TORNADO WATCH MEANS CONDITIONS ARE FAVORABLE FOR TORNADOES AND SEVERE THUNDERSTORMS IN AND CLOSE TO THE WATCH AREA. PERSONS IN THESE AREAS SHOULD BE ON THE LOOKOUT FOR THREATENING WEATHER CONDITIONS AND LISTEN FOR LATER STATEMENTS AND POSSIBLE WARNINGS.

DISCUSSION...THUNDERSTORMS ARE BEGINNING TO DEVELOP OVER SWRN OK AHEAD OF DRYLINE WHERE CAP HAS LOCALLY BROKEN. EXTREME INSTABILITY AND FAVORABLE SHEAR SUGGEST THAT SUPERCELLS AND ISOLATED TORNADOES ARE POSSIBLE.

AVIATION...TORNADOES AND A FEW SEVERE THUNDERSTORMS WITH HAIL SURFACE AND ALOFT TO 3 INCHES. EXTREME TURBULENCE AND SURFACE WIND GUSTS TO 70 KNOTS. A FEW CUMULONIMBI WITH MAXIMUM TOPS TO 550. MEAN STORM MOTION VECTOR 25030.

...VESCIO

;335,0993 360,0993 360,0961 335,0962;

NNNN

ZCZC MKCSEL8 ALL 040500;335,0984 370,0982 370,0954 335,0960;
WWUS9 KMKC 032359
MKC WW 032359
OKZ000-040500-

URGENT - IMMEDIATE BROADCAST REQUESTED
TORNADO WATCH NUMBER 198

PREDICTION CENTER NORMAN OK
PM CDT MON MAY 3 1999

THE STORM PREDICTION CENTER HAS ISSUED A
TORNADO WATCH FOR PORTIONS OF

CENTRAL OKLAHOMA

EFFECTIVE THIS MONDAY NIGHT AND TUESDAY MORNING FROM 715 PM UNTIL MIDNIGHT CDT.

...THIS IS A PARTICULARLY DANGEROUS SITUATION...

DESTRUCTIVE TORNADOES...LARGE HAIL TO 3 INCHES IN DIAMETER...THUNDERSTORM WIND GUSTS TO 80 MPH...AND DANGEROUS LIGHTNING ARE POSSIBLE IN THESE AREAS.

THE TORNADO WATCH AREA IS ALONG AND 75 STATUTE MILES EAST AND WEST OF A LINE FROM 35 MILES SOUTHWEST OF ARDMORE OKLAHOMA TO 20 MILES NORTH OF PONCA CITY OKLAHOMA.

REMEMBER...A TORNADO WATCH MEANS CONDITIONS ARE FAVORABLE FOR TORNADOES AND SEVERE THUNDERSTORMS IN AND CLOSE TO THE WATCH AREA. PERSONS IN THESE AREAS SHOULD BE ON THE LOOKOUT FOR THREATENING WEATHER CONDITIONS AND LISTEN FOR LATER STATEMENTS AND POSSIBLE WARNINGS.

OTHER WATCH INFORMATION...THIS TORNADO WATCH REPLACES TORNADO WATCH NUMBER 195. WATCH NUMBER 195 WILL NOT BE IN EFFECT AFTER 715 PM CDT. CONTINUE...WW 196...WW 197...

DISCUSSION...LONG TRACKED VIOLENT TORNADO IS APPROACHING THE OKC METRO AREA. EXTREME INSTABILITY IS COMPENSATING FOR SOMEWHAT MARGINAL SHEAR...RESULTING IN AN VERY DANGEROUS SITUATION.

AVIATION...TORNADOES AND A FEW SEVERE THUNDERSTORMS WITH HAIL SURFACE AND ALOFT TO 3 INCHES. EXTREME TURBULENCE AND SURFACE WIND GUSTS TO 70 KNOTS. A FEW CUMULONIMBI WITH MAXIMUM TOPS TO 500. MEAN STORM MOTION VECTOR 23025.

...VESCIO

;335,0984 370,0982 370,0954 335,0960;

NNNN
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WFUS1 KOKC 032227
TOROKC
OKC015-051-032315-

BULLETIN - EAS ACTIVATION REQUESTED
TORNADO WARNING
NATIONAL WEATHER SERVICE NORMAN OK
522 PM CDT MON MAY 3 1999

THE NATIONAL WEATHER SERVICE IN NORMAN HAS ISSUED A

* TORNADO WARNING FOR...
  GRADY COUNTY IN CENTRAL OKLAHOMA
  CADDO COUNTY IN SOUTHWEST OKLAHOMA

* UNTIL 615 PM CDT

* AT 521 PM CDT...A TORNADO WAS REPORTED JUST WEST OF CYRIL. THIS STORM WAS MOVING NORTHEAST AT 35 MPH.

* LOCATIONS IN THE WARNING INCLUDE AMBER...ANADARKO...APACHE...
  BINGER...CEMENT...CHICKASHA...COGAR...CYRIL...GRACEMONT...MINCO...
  NINNEKAH...NORGE...POCASSET...STECKER...TABLER...TUTTLE AND VERDEN

TAKE COVER NOW. ABANDON MOBILE HOMES AND VEHICLES. MOVE TO AN INTERIOR ROOM OR HALLWAY ON THE LOWEST FLOOR. STAY AWAY FROM WINDOWS.

LAT...LON 3488 9841 3488 9786 3531 9769 3537 9835

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WWUS34 KOKC 032233
SVSOKC
OKZ023-027-032300-

SEVERE WEATHER STATEMENT
NATIONAL WEATHER SERVICE NORMAN OK
527 PM CDT MON MAY 3 1999

AT 528 PM CDT...A TORNADO WAS ON THE GROUND 3 MILES NORTHWEST OF CYRIL. THE STORM WAS MOVING NORTHEAST AT 35 MPH. A TORNADO WARNING REMAINS IN EFFECT UNTIL 615 PM FOR CADDO AND GRADY COUNTY

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WWUS34 KOKC 032243
SVSOKC
OKZ023-032245-

SEVERE WEATHER STATEMENT
NATIONAL WEATHER SERVICE NORMAN OK
540 PM CDT MON MAY 3 1999

AT 540 PM... A TORNADO WAS 2 MILES SOUTH OF ANADARKO... MOVING NORTHEAST AT 30 MPH. ANADARKO IS IN THE IMMEDIATE PATH OF THIS STORM. TAKE SHELTER NOW!

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WWUS34 KOKC 032300
SVSOKC
OKZ023-027-032330-

SEVERE WEATHER STATEMENT
NATIONAL WEATHER SERVICE NORMAN OK
555 PM CDT MON MAY 3 1999

AT 555 PM CDT...A LARGE TORNADO WAS ON THE GROUND 2 MILES NORTH OF LAVERTY MOVING NORTHEAST AT 35 MPH. A TORNADO WARNING REMAINS IN EFFECT UNTIL 615 PM FOR GRADY AND CADDO COUNTY. PEOPLE IN THE TOWN OF CHICKASHA SHOULD TAKE COVER NOW THIS IS A VERY DANGEROUS SITUATION

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WFUS1 KOKC 032314
TOROKC
OKC051-040000-

BULLETIN - EAS ACTIVATION REQUESTED
TORNADO WARNING
NATIONAL WEATHER SERVICE NORMAN OK
607 PM CDT MON MAY 3 1999

THE NATIONAL WEATHER SERVICE IN NORMAN HAS ISSUED A

* TORNADO WARNING FOR...
  GRADY COUNTY IN CENTRAL OKLAHOMA

* UNTIL 700 PM CDT

* AT 607 PM CDT...MULTIPLE TORNADOS WERE REPORTED IN GRADY COUNTY NEAR AND IN THE TOWN OF CHICKASHA. THE TORNADOES WERE MOVING NORTHEAST AT 25 MPH.

* LOCATIONS IN THE WARNING INCLUDE ALEX...AMBER...BRADLEY... CHICKASHA...MIDDLEBERG...MINCO...NINNEKAH...NORGE...POCASSET... TABLER AND TUTTLE

TAKE COVER NOW. ABANDON MOBILE HOMES AND VEHICLES. MOVE TO AN INTERIOR ROOM OR HALLWAY ON THE LOWEST FLOOR. STAY AWAY FROM WINDOWS.

LAT...LON 3521 9809 3487 9809 3487 9769 3531 9767
3536 9795

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WWUS34 KOKC 032323
SVSOKC
OKZ027-032345-

SEVERE WEATHER STATEMENT
NATIONAL WEATHER SERVICE NORMAN OK
619 PM CDT MON MAY 3 1999

AT 619 PM CDT...A TORNADO WAS LOCATED ON THE NORTH SIDE OF CHICKASHA...NEAR THE AIRPORT DAMAGE TO STRUCTURES ON THE NORTH SIDE OF CHICKASHA WAS REPORTED

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WWUS34 KOKC 032330
SVSOKC
OKZ027-040000-

SEVERE WEATHER STATEMENT
NATIONAL WEATHER SERVICE NORMAN OK
626 PM CDT MON MAY 3 1999

AT 624 PM CDT...A STORM SPOTTER REPORTED 4 1/2 INCH HAIL 5 MILES SOUTH OF MINCO. ALSO A TORNADO WAS REPORTED AT 626 PM JUST SOUTH OF AMBER MOVING NORTHEAST AT 25 MPH.

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WFUS1 KOKC 032344
TOROKC
OKC027-051-087-040030-

BULLETIN - EAS ACTIVATION REQUESTED
TORNADO WARNING
NATIONAL WEATHER SERVICE NORMAN OK
640 PM CDT MON MAY 3 1999

THE NATIONAL WEATHER SERVICE IN NORMAN HAS ISSUED A

* TORNADO WARNING FOR...
  CLEVELAND COUNTY IN CENTRAL OKLAHOMA
  GRADY COUNTY IN CENTRAL OKLAHOMA
  MCCLAIN COUNTY IN CENTRAL OKLAHOMA

* UNTIL 730 PM CDT

* AT 640 PM CDT...A TORNADO WAS REPORTED 6 MILES NORTH OF MIDDLEBERG...MOVING NORTHEAST AT 30 MPH.

* LOCATIONS IN THE WARNING INCLUDE BLANCHARD. MIDDLEBERG.. MOORE NEWCASTLE NORMAN AND TUTTLE

TAKE COVER NOW ABANDON MOBILE HOMES AND VEHICLES. MOVE TO AN INTERIOR ROOM OR HALLWAY ON THE LOWEST FLOOR STAY AWAY FROM WINDOWS

LAT...LON 3520 9791 3508 9776 3515 9748 3535 9737
          3538 9763

30

WWUS34 KOKC 032355
SVSOKC
OKZ025-027>029-040015-

SEVERE WEATHER STATEMENT
NATIONAL WEATHER SERVICE NORMAN OK
651 PM CDT MON MAY 3 1999

AT 651 PM CDT...A TORNADO WAS REPORTED AT THE ACCESS TO THE H.E. BAILEY TURNPIKE ON THE NORTH SIDE OF NEWCASTLE.

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&

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WWUS34 KOKC 040004
SVSOKC
OKZ025-027>029-040030-

SEVERE WEATHER STATEMENT
NATIONAL WEATHER SERVICE NORMAN OK
657 PM CDT MON MAY 3 1999

...TORNADO EMERGENCY IN SOUTH OKLAHOMA CITY METRO AREA...

AT 657 PM CDT...A LARGE TORNADO WAS MOVING ALONG INTERSTATE 44 WEST OF NEWCASTLE. ON ITS PRESENT PATH...THIS LARGE DAMAGING TORNADO WILL ENTER SOUTHWEST SECTIONS OF THE OKLAHOMA CITY METRO AREA BETWEEN 715 PM AND 730 PM. PERSONS IN MOORE AND SOUTH OKLAHOMA CITY SHOULD TAKE IMMEDIATE TORNADO PRECAUTIONS!

THIS IS AN EXTREMELY DANGEROUS AND LIFE THREATENING SITUATION. IF YOU ARE IN THE PATH OF THIS LARGE AND DESTRUCTIVE TORNADO...TAKE COVER IMMEDIATELY.

DOPPLER RADAR INDICATED THIS STORM MAY CONTAIN DESTRUCTIVE HAIL TO THE SIZE OF BASEBALLS...OR LARGER

LAT...LON 3524 9784 3511 9769 3536 9735 3552 9754

ANDRA

APPENDIX G - NOAA STORM DATA -

A record outbreak of tornadoes struck Oklahoma from late afternoon of May 3, 1999, through early morning of May 4, 1999. To date, 58 tornadoes have been recorded across portions of western and central Oklahoma. Additional tornadoes were reported across eastern Oklahoma from late evening of May 3rd through the early morning of May 4th, and are listed under the eastern Oklahoma portion of Storm Data, provided by the National Weather Service Office in Tulsa, Oklahoma. All direct fatalities (40) and all direct injuries (675) occurred in the Norman National Weather Service Warning Area. The most notable tornado was rated F5 and formed over Grady County near Amber and tracked northeast for 37 miles eventually into the Oklahoma City metropolitan area. Bridge Creek, Oklahoma City, Moore, Del City, and Midwest City suffered tremendous damage. Thirty-six direct fatalities and 583 direct injuries were recorded. There were many other significant tornadoes as well, including F4 tornadoes in Kingfisher and Logan Counties, and F3 tornadoes in Caddo, Grady, Kingfisher, Logan, and Lincoln Counties. Due to the magnitude of the tornado outbreak, and for easier reference, each tornado has received its own identification. There were 8 tornadic producing thunderstorms, called supercells, and most of them spawned numerous tornadoes, one after another. Occasionally, these thunderstorms spawned tornadoes at the same time. The first tornado producing thunderstorm of the day was labeled storm A, while the last tornado producing thunderstorm of the day was labeled storm I. Tornadoes produced by the same supercell thunderstorm have the same letter and were then numbered chronologically. For example, the 3rd tornado produced by storm B was labeled B3.

Storm A produced 14 tornadoes over a period of about 7 hours and was eventually responsible for the F5 tornado that struck Bridge Creek, Oklahoma City and Moore. The 1st tornado of the outbreak, A1, touched down on US 62, 2 miles north of Interstate 44 in Comanche County at 1641 CST. No damage is believed to have occurred (F0). The 2nd tornado, A2, formed approximately 3 miles west of Elgin in Comanche County. Several witnesses, confirmed this tornado, however no damage was observed (F0). The 3rd tornado, A3, touched down in a rural area 3 miles east of Apache in Caddo County. As the tornado moved northward to near Anadarko, one house was destroyed near the town of Stecker, with its roof ripped off and several walls knocked down (F3). Three persons inside the house were injured. Several witnesses reported the 4th tornado, A4, 3 miles northwest of Cyril in Caddo County just west of SH 8. No damage was reported (F0). The 5th tornado, A5, formed 2 miles south of Anadarko in Caddo County. Two witnesses reported the tornado to be brief, and no damage was observed (F0).

The 6th tornado, A6, developed about 3 miles north-northeast of Cement near the Caddo Grady County border, and quickly intensified to a strong tornado with associated damage rated at the high end of the F3 scale. The tornado tracked northeast for 9 miles before dissipating 2 5 miles west-northwest of downtown Chickasha. Two homes had just a few interior walls standing (F3), one located near US 62 on the northwest side of Chickasha, and several wooden high tension power lines were downed. Several persons were injured south of Verden near the Caddo Grady County border. The 7th tornado, A7, has been referred to as a satellite tornado, and rotated around A6 for a short period of time, 5 miles west of Chickasha in Grady County. Damage from this satellite tornado was not discovered and therefore rated F0. The 8th tornado, A8, developed 2 5 miles northwest of downtown Chickasha just north of US 62, and tracked northeast, striking the Chickasha Municipal Airport, resulting in high-end F2 damage to two hangar buildings and destroying several aircraft. An aircraft wing, believed to have originated from this airport was eventually carried airborne approximately 45 miles and dropped in southwest Oklahoma City. Approximately 20 mobile homes near the airport were either damaged or destroyed with several persons injured. The tornado then crossed US 81 about 2 miles north of its intersection with US 62 destroying a large building, then dissipated 4 miles north-northeast of downtown Chickasha

The 9th tornado, A9, was a violent and long-tracked tornado, and eventually produced F5 damage in Bridge Creek, Oklahoma City, and Moore. This tornado developed in Grady County about 2 miles south-southwest of Amber, and quickly intensified as it crossed SH 92. F4 damage was first discovered about 4 miles east-northeast of Amber and extended for 6 1/2 miles, as the tornado continued to move northeast. Two areas of F5 damage were observed. The first was in the Willow Lake Addition, a rural subdivision of mobile homes and some concrete slab homes, in Bridge Creek in far eastern Grady County. Two homes were completely swept from their concrete slabs, and about one dozen automobiles were carried about 1/4 of a mile. All mobile homes in this area in the direct path of the tornado were obliterated, resulting in a high concentration of fatalities. Asphalt pavement about 1-inch thick was also peeled from a section of rural road EW125. The second area of F5 damage was observed about 1 mile west of the Grady/McClain County line and consisted of a cleanly swept slab home with foundation anchor bolts and another vehicle lofted 1/4 of a mile. The maximum width of damage in Bridge Creek was estimated to be 1 mile. Approximately 200 mobile homes/houses were destroyed, and hundreds of other structures were damaged. The Ridgecrest Baptist Church in Bridge Creek was also destroyed. Twelve persons died in Bridge Creek, nine in mobile homes, and all fatalities and the majority of injuries were concentrated in the Willow Lake Addition, Southern Hills Addition, and Bridge Creek Estates, consisting mostly of mobile homes. Compared to sections of Oklahoma and Cleveland Counties, other counties in the path of this tornado which are more densely populated, eastern Grady County including the Bridge Creek area, is rural and sparsely populated.

The tornado maintained a nearly straight path to the northeast paralleling Interstate 44, as it entered McClain County, except when it made a slight jog to the right and moved directly over the 16th Street overpass in Newcastle where a woman was killed when she was blown out from under the overpass. The tornado continued into northern sections of rural Newcastle and crossed the Interstate again just north of the US 62 Newcastle interchange. While this tornado was moving through the northern portion of Newcastle, a satellite tornado (A10) touched down in a field in rural areas north of Newcastle, and caused no damage (F0). Two areas of F4 damage were observed in McClain County, all associated with tornado A9. The first area overlapped the Grady/McClain County line and extended to about 3 miles northwest of Newcastle, ending just west of the 16th St. overpass on Interstate 44, while the other area was observed 2 miles northwest of Newcastle. Thirty-eight homes and 2 businesses were destroyed in McClain County, and 40 homes were damaged. Damage then diminished to F2 intensity as the tornado crossed the Canadian River into northern Cleveland County.

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3 May 1999

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The tornado entered Cleveland County between Portland and May and between SW 164th and SW 179th in south Oklahoma City. Damage was rated F2 in this area with a path width averaging 1/2 of a mile. The first major housing development to be struck in Cleveland County was Country Place Estates located just west of Pennsylvania Ave. where about 50 homes were damaged, with 1 dozen of these homes receiving F4 damage. One slab home was cleanly swept from its foundation, and several vehicles were picked up from the subdivision and tossed across Pennsylvania Ave., a distance of approximately 1/4 of a mile. One vehicle was found under a bridge just east of the intersection of Pennsylvania and SW 134th. This particular area of damage has been rated high F4/low F5. Oklahoma City Police indicated that part of an airplane wing, believed to have originated from Chickasha Municipal Airport in Grady County, landed in this area. The tornado then tracked through Eastlake Estates, a densely populated housing development, located north of SW 134th and between Pennsylvania and Western Ave, where 3 fatalities occurred. Entire rows of homes were virtually flattened to piles of rubble. Four adjacent homes on one street were virtually cleaned off their foundations leaving only concrete slabs, which earned an F5 rating. Three other homes in this housing division also received F5 damage, with the remaining destruction rated high F4. Three persons also died in the 600-unit Emerald Springs Apartments on Western Ave. located across the street from Eastlake Estates. One 2-story apartment building on the north end of the apartment complex was virtually flattened, and received an F5 rating. Westmoore High School, located just north of Eastlake Estates, was also heavily damaged. Although a well-attended awards ceremony was being held at the school during the tornado, no one was injured, however dozens of vehicles in the school parking lot were either damaged or destroyed. F4 damage continued northeast into another residential area east of Western Ave. and south of 119th St. The tornado then entered the western city limits of Moore (Cleveland County) along Santa Fe and near NW 12th, and produced damage between 1/2 and 3/4 of a mile wide. Maximum damage, rated high F4/low F5, extended northeast to near Janeway with several large groups of homes flattened. Four persons died in this residential area. F4 damage continued to S. Shields just north of the junction with Interstate 35. A woman was also killed when she was blown out from under the Shields overpass of Interstate 35. The tornado appeared to weaken just slightly after crossing Interstate 35, however it remained a formidable storm with widespread high F3/low F4 damage observed in Highland Park, a residential area south of the First Baptist Church on 27th St. in Moore. Escaping with relatively minor damage, and being located near the halfway point of the tornado path, the First Baptist Church in Moore eventually served as the primary coordination center for most tornado relief efforts. The tornado then continued northeast and entered the southern portion of a sparsely populated industrial district. F4 damage continued through this area, to near SE 89th St., the Cleveland/Oklahoma County border.

Moving into Oklahoma County, the tornado curved northward, through the remaining industrial district north of Interstate 240 where 2 businesses were destroyed, with the damage rated F4. Two persons were also killed at a trucking company near the intersection of S. Bryant Ave. and Interstate 240. A freight car, with an approximate weight of 18 tons, was picked up intermittently and blown 3/4 of a mile across an open field, with the body of the freight car being deposited southeast of the intersection of S. Sunnylane Rd. and SE 59th. Gouge marks were observed in the field every 50 to 100 yards, suggesting the freight car had been airborne for at least a short distance. While tornado A9 was moving through southeast Oklahoma City, another tornado (A11) touched down briefly about 1/2 mile south of Interstate 240 (Oklahoma County), near the intersection of SE 80th and Sooner Rd. Damage from tornado A11, rated F0, included fences being blown down and minor roof damage inflicted to a couple of houses. Tornado A9 then entered residential neighborhoods between SE 59th and SE 44th where 1 woman was killed in her house. Crossing SE 44th into Del City (Oklahoma County) the tornado moved through the highly-populated Del Aire housing addition killing 6 persons and damaging or destroying hundreds of homes, many with F3/F4 damage. The tornado then crossed Sooner Rd., damaged an entry gate and several costly structures at Tinker Air Force Base, then crossed 29th St. into Midwest City (Oklahoma County), destroying 1 building in the Boeing Complex and damaging 2 others. Widespread F3/F4 damage continued as the tornado moved across Interstate 40 affecting a large business district. Approximately 800 vehicles were damaged at Hudiburg Auto Group, located just south of Interstate 40. Hundreds of the vehicles were moved from their original location, and dozens of vehicles were picked up and tossed northward across Interstate 40 into several motels, a distance of approximately 2/10 of a mile. Numerous motels and other businesses including Hampton Inn, Comfort Inn, Inn Suites, Clarion Inn, Cracker Barrel, and portions of Rose State College, were destroyed. Some of the damage through this area was rated high F4, however low F5 was considered. The tornado then continued into another residential area located between SE 15th and Reno Ave. where 3 fatalities occurred. High F4 damage was inflicted to 4 homes in this area. Two of these homes were located between SE 12th and SE 11th, near Buena Vista, and the other 2 homes were located on Will Rogers Rd. just south of SE 15th. Damage then diminished rapidly to F0/F1 as the tornado crossed Reno Ave. before dissipating 3 blocks north of Reno Ave. between Sooner Rd. and Air Depot Blvd.

The Oklahoma State Department of Health in Oklahoma City recorded 36 direct fatalities. In addition, 5 persons died of illness or accident during or shortly after the tornado and were not considered in the direct fatality total. Five hundred eighty-three injuries were estimated based on numbers provided from the Department of Health, which were then adjusted to account for persons assumed to be unaccounted for. Injuries which resulted from removing debris, conducting search and rescue efforts, and taking shelter from the tornado, were not considered in the injury total. An estimated 1800 homes were destroyed, and 2500 homes were damaged, resulting in approximately 1 billion dollars in damage.