Tornado Warning Systems:

An Evaluation of Their Effectiveness

by

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Introduction

1.1 Historic Disasters: Could they have been averted?

Mother Nature is the most powerful force on the planet. Man, in his arrogance, has often felt that he can control or withstand the power that Mother Nature displays. Technology used to track, study, and understand what is happening with the weather has given man a false sense of safety. This false sense of safety contributes to death and destruction by the forces of the atmosphere. The embodiment of this power cannot be better illustrated than by a tornado.

Settlements are found in the heart of Tornado Alley, an area in the interior of North America that ranges from Canada to Texas. In these areas, the atmosphere continues to produce the powerful anomalies that it always has since time began, but now man is in the path of these terrifically powerful displays by Mother Nature. To deal with these situations, a method of warning the public has been developed. The product of this development is a disaster warning system.

A disaster warning system is a term that is loosely used to denote a course of action employed to inform the public of an oncoming disaster. There is not one specific way such warnings are disseminated. Disaster warning systems have many variables upon which they are regionally, economically, socially, and technically dependant. The goal of the warning system is always the same: to inform the public of danger. This information must be disseminated in a way that will allow people time to prepare for a tornado. The question that must be posed is, "How effective are present tornado warning systems?"

1.2 Devastating Tornadoes in History

Beginning in the morning of April 3 and extending into April 4, 1974, an outbreak of tornadoes hit the Plains of North America. This was the largest outbreak of tornadoes ever recorded. The thunderstorms of April 3 and 4, 1974, hit the Plains with what became known as the Super Outbreak, 127 tornadoes -- the largest, most damaging tornado outbreak in history (Williams 115). There were tornadoes in over ten states, causing devastating damages and casualties. Three hundred fifteen people in eleven states were killed; 6,142 were injured (Williams 115 - 116). Tremendous property damage and loss of life were the aftermath of these storms.

The Super Outbreak was preceded by warnings, but could these warnings have been better? If these warnings were better, would more lives have been saved? This is the question that must be addressed and examined, not only for this specific case, but for tornado warnings as a whole. To the credit of the National Weather Service, it was the key to the lives that were saved. Without warnings, many more would have died (Williams 116).

How did this Super Outbreak affect our respect for and attention to tornadoes? This event catapulted tornadoes into an arena of increased investigation and importance. Since then, new projects have been implemented to study tornadoes, such at TOTO (Totable Tornado Observatory), project VORTEX (Verification of the Origins of Rotation in Tornadoes Experiment), and new high resolution radars such as NEXRAD (Next Generation of Radar). Immediately after these storms, a special group was established at the National Severe Storms Forecast Center to improve severe weather forecasts. Thus, when nature decided to rise up and show her power during the Super Outbreak, people took notice and began taking action. The Committee on Natural Disasters, the Commission on Sociotechnical Systems and the National Research Council jointly concluded in their report <u>Engineering Aspects of the Tornadoes of April 3 - 4, 1974</u> that:

> The significance of these storms -- termed the worst series of storms and the most significant meteorological event in 50 years -- lies in the dramatic signalling the public of major, persistent problem in the United States -- protection of people and property from the effects of tornadoes and extreme winds. (Abernathy et al 1)

1.3 What is a Tornador Warning System?

A tornado warning system may be better explained by first stating what it is not. A tornado warning system is not a thing, an object or a machine. A tornado warning system is a combination of elements, information, and procedures that are examined together to determine the best possible course of action for the situation.

There are two primary stages of readiness and response to the disaster warning system for tornadoes. The first of the two parts is the "tornado watch." According to a preparedness guide published by U.S. Department of Commerce in conjunction with the National Oceanic and Atmospheric Administration and the National Weather Service, a "tornado watch" is defined as a time, "When conditions are favorable for a tornado to develop" (Tornadoes 7). The second stage of the warning system is a "tornado warning." A tornado warning is defined by a policy statement of the American Meteorological Society, from the <u>Bulletin of the American Meteorological Society</u>, in these terms: "A tornado warning is issued only after a storm of known or highly likely to include a tornado has been identified. It warns of a high probability of imminent danger." (1270)

The effectiveness of the tornado warning system depends on the ability of these messages to be disseminated accurately and completely. Some of the responsibility rests in the hands of the public, who must take the necessary steps to receive this information. Once the information is received people must then act on it in the proper manner. People must be educated on how to act during a tornado warning or watch.

1.4 The Tornado

The tornado is a sporadic event produced by the atmosphere which has extremely destructive capabilities. To complicate their dangerous effects, tornadoes often form without being seen, or they form and disappear so quickly that there is no time to take action. The New Merriam-Webster Dictionary defines a tornado as "A violent destructive whirling wind accompanied by a funnel-shaped cloud that moves over a narrow path" (755). This is a simple definition of a tornado, but it leaves out some information. A tornado's path may be narrow compared to the coverage of the thunderstorm that produced the tornado, but a tornado's path may be up to a mile wide in some cases. There are also cases of multiple tornadoes in a concentrated area. The intensity of tornadoes varies , which is another factor that must be taken into account.

All of this information is a prelude to an examination of tornadoes and tornado warning systems. This information will hopefully enable us to come a step closer to understanding what this forceful display of nature is and to evaluating the effectiveness of our present ability to warn people of impending danger from a tornado.

CHAPTER II

The Tornado

2.1 How the Tornado Forms

The mechanism of tornado formation is not entirely known presently. Scientists have spent uncountable hours gathering data and researching this data in order to understand tornadic wind formations. Different theories have surfaced and have been discounted over time. To further complicate our understanding of tornado formation, there is the problem that not all tornadoes form in the same way.

The general idea of how a tornado forms is as follows, according to the tornado pamphlet distributed by the U.S. Dept. of Commerce in conjunction with the National Oceanic and Atmospheric Administration and the National Weather Service:

> Before thunderstorms develop, a change in wind direction and an increase in wind speed with increasing height creates an invisible, horizontal spinning effect in the lower atmosphere. Rising air within the thunderstorm updraft tilts the rotating air from horizontal to vertical. An area of rotation, 2 - 6 miles wide, now extends through much of the storm. Most violent strong tornadoes form within this area of strong rotation. (United States 3)

This can be visualized by the layman as follows. Picture the horizontal spinning effect as a tube of air, shaped like a paper towel roll, spinning on the ground, but lying horizontally or parallel to the ground. Then the air that is rising up and feeding the thunderstorm grabs this horizontally spinning air and bends it upward toward the storm cell. Now this spinning air mass is tilted upward into a vertical orientation and is drawing power from the thunderstorm clouds, and this allows the layer of spinning air to increase in intensity. The higher in the atmosphere the storm cell is, the more powerful it is, and thus the more powerful the tornado will be. This spinning body of air is known as a vortex.

The previous explanation of how a tornado forms is the general consensus of weather scientists. There are circumstances that do not perfectly follow this paradigm. These circumstances must be examined in their own light and on their own account. One must also remember that science has not unlocked all of the information on tornadoes, so that there is much more to learn.

2.2 Measurement of Tornado Intensity

The scale used to classify the intensity of a tornado is the Fujita scale. This scale was developed by T. Theodore Fujita at the University of

Chicago. This scale rates the intensity of a tornadic event after it has occured by the amount of damage that it inflicts on anything in its path.

Though this scale is not a perfect measure of a tornado's intensity, it is the best and most applicable method of rating a tornado's intensity in terms of wind speed. The downfall of this scale is best summed up by The Tornado Project website: "The entire premise of estimating wind speeds from damage to non-engineered structures is very subjective and is difficult to defend from various meteorological perspectives" (1). Even with this problem of putting all of the subjectivity of evaluation in the hands of the observer, this scale is still the best and most applicable used today.

A point that needs to be addressed is that the size of a tornado is not necessarily an indication of its intensity. The official estimate of a tornado's intensity is made through the ratings of the Fujita scale after the tornado has passed. The Fujita scale is an index of intensities used for classifying a tornado's strength. This index is presented in the form of a table, seen in figure 2.2.1.

Though the Fujita scale is the standard method of rating the intensity of a tornado, tornadoes are often grouped into more general classifications. These classifications are: weak tornadoes, strong tornadoes, and violent tornadoes. The American Meteorological Society describes a weak tornado in these terms: "In general, weak tornadoes have lifetimes less than 10 minutes, with paths less than 1.6 km (one mile) in length and 100m (yards) in width. Typical wind speed is on the order of ~100mph." ("Tornado Forcasting" 1270) On the Fujita scale these tornadoes would be considered an F0 or F1. One cannot let the description of these tornadoes fool one into a false sense of security. These tornadoes can be destructive and lethal, and their short lifespans make them very difficult to monitor for the sake of issuing warnings to the public.

The strongest tornadoes are lumped into the category of "violent tornadoes." The American Meteorological Society explains this category thus:

> Such tornadoes may last for as little as 10 minutes, to over 2 hours in extreme cases, and may be produced in cyclic fashion from the same thunderstorm cell. For cyclic events, each tornado sequence may last for tens of minutes, with the damage extending essentially in a continuous path more than 160 km (~100 miles) long and 1 km (~1000 yards wide. Often, such storms also produce damaging hail and strong straight-line winds. While reliable direct measurements of wind speeds in tornadoes are lacking, maximum wind speeds estimated from tornado -- damage surveys range upward to ~280mph. ("Tornado Forcasting" 1270)

On the Fujita scale these tornadoes would be considered an F4 or F5. The F6 would be put into this category, but to date their have been no F6 tornadoes documented.

The Fujita Scale

F-Scale Number	Intensity Phrase	Wind Speed	Type of Damage Done
F0	Gale tornado	40 -72 mph	Some damage to chimneys; breaks branches off trees: pushes over shallow-rooted trees; damages sign boards.
F1	Moderate tornado	73 - 112 mph	The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.
F2	Significant tornado	113 - 157 mph	Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light object missiles generated.
F3	Severe tornado	158 - 206 mph	Roof and some walls torn off well constructed houses; trains overturned; most trees in fores uprooted.
F4	Devastating tornado	207 - 260 mph	Well constructed houses leveled; structures with weak foundations blown off some distance; cars thrown and large missiles generated.
F5	Incredible tornado	261 - 318 mph	Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air in excess of 100 meters; trees debarked; steel re-enforced concrete structures badly damaged.
F6	Inconceivable tornado	319 - 379 mph	These winds are very unlikely. The small area of damage they might produce would probably not be recognizable along with the mess produced by F4 and F5 wind that would surround the F6 winds. Missiles, such as cars and refrigerators would do serious secondary damage that could not be directly identified as F6 damage. If this level is ever achieved, evidence for it might only be found in some manner of ground swirl pattern, for it may never be identified through engineering studies.

Table 2.2.1 (The Tornado Project 2-3)

There is a positive aspect to the enormity of these types of tornadoes in terms of their duration. The longer duration of these tornadoes make them more possible to detect, but not all of these tornadoes have long paths. This ability to track these tornadoes gives meteorologists a greater chance of issuing warnings for the people in threatened areas.

All other tornadoes would fall into the category of "strong" tornadoes. This category is characterized by winds ranging from 113mph to 206mph. Strong tornadoes are classified as F2 or F3. These are very destructive tornadoes, and they should be respected as much as the violent tornadoes, but one cannot forget that all tornadoes can kill and should be respected.

2.3 Types of Tornadoes

There are generally two types of tornadoes. The first type of tornado forms in the outflow of air from a thunderstorm. This type of tornado is described best by The Weather Book:

> It has a shallow, localized vortex resembling a narrow, rope-like tube. Appearing barely attached to the parent storm cloud, these tornadoes usually are weak, with winds rarely exceeding 150 mph, F-2 on the Fujita scale, and normally last less than five minutes. They spin up like swirls of water running past obstacles in a fast-moving stream. (Williams 127).

This type of tornado can be observed in the form of a gustnado, a landspout or a waterspout. The Weather Book explains a gustnado thus: "A gustnado is a vortex whipped up by intense, small-scale wind shear along the outflow boundary, or 'gust-front' of a thunderstorm: thus the name 'gust-nado'" (Williams 127). A waterspout, as defined by the American Meteorological Society's Glossary of Weather and Climate,:

> Usually a tornado-like rotating column of air (whirlwind) under a parent cumuliform cloud occurring over water; waterspouts are most common over tropical and subtropical waters and tend to dissipate upon reaching shore. (Williams 128)

Then there are landspouts, which are just tornadoes that exhibit the same characteristics as waterspouts, except that, these tornadoes form over land. A picture of a waterspout may be seen in figure 2.3.1.

The second type of tornado is much more intense in strength and destructive capabilities:

> These storms are found where air is flowing into a thunderstorm, in the updraft area. Doppler radar measurements show that such tornadoes begin at the storm's middle levels and then grow both up into the storm and down toward the ground. Often appearing as a broad cylinder or cone sometimes a mile wide, their winds can reach 200 - 300 mph, F-4 to F-5 on the Fujita scale. (Williams 128)

These are the tornadoes that do the intense destruction of property and structures. These are the legendary tornadoes that make history, such as

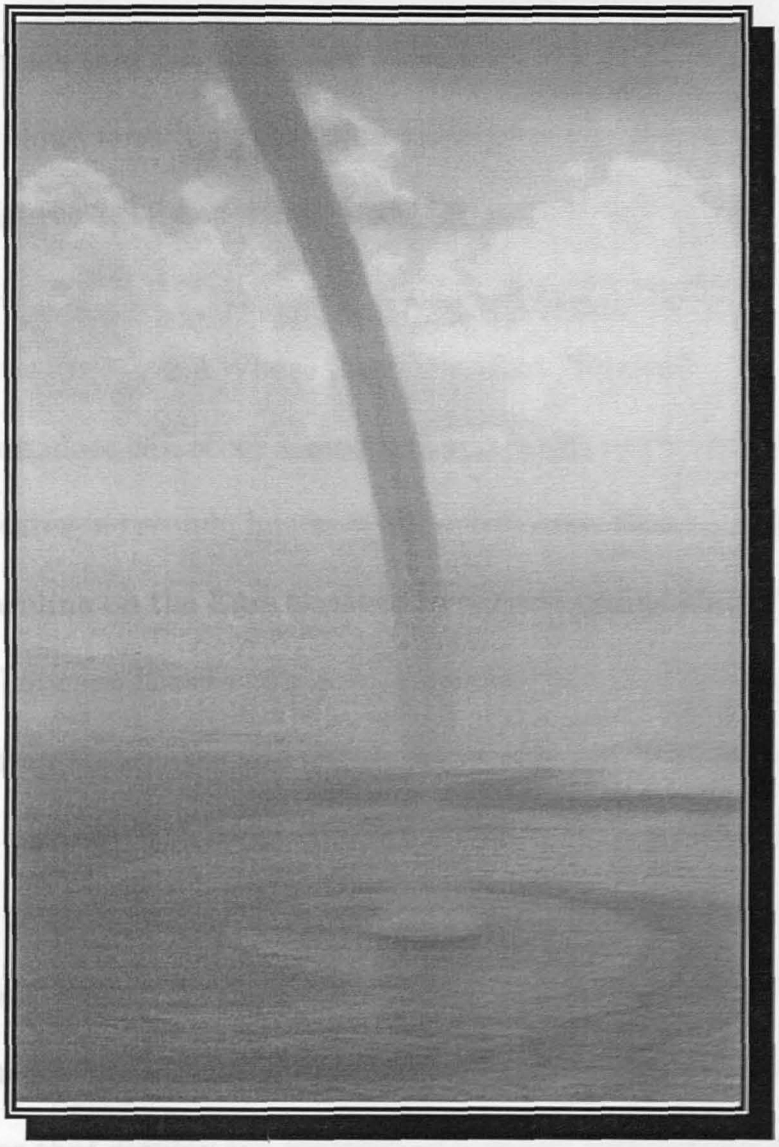

Figure 2.3.1 (United States 2)

the recent F-5 tornado that hit Jarrel, Texas on May 27, 1997. This tornado ripped houses from their foundations and left little or no debris. This incredible power is able to annihilate anything in its path. A picture of the tornado that destroyed Jarrel, as well as a satellite photo of the supercell cloud formation that fueled this powerful F-5 tornado may be seen in figures 2.3.2 and 2.3.3.

2.4 Where Can Tornadoes Happen?

Tornadoes can occur almost anywhere. In every major region of the United States, a tornado has been recorded, from North Carolina and South Carolina on the East Coast to California on the West Coast. It is the land between these two coasts, especially the land between th Appalachian Mountains and the Rocky Mountains, that is associated with the most tornado activity of all. The region, known as Tornado Alley, is the area of the most highly concentrated outbreaks of tornadic activity on a consistent basis. Tornado Alley runs right up the center of the North American continent from Texas into the south central provinces of Canada. The states that display the majority of tornado outbreaks within Tornado Alley are Texas, Oklahoma, and Kansas.

Figure 2.3.2 (The Tornado Project 4)

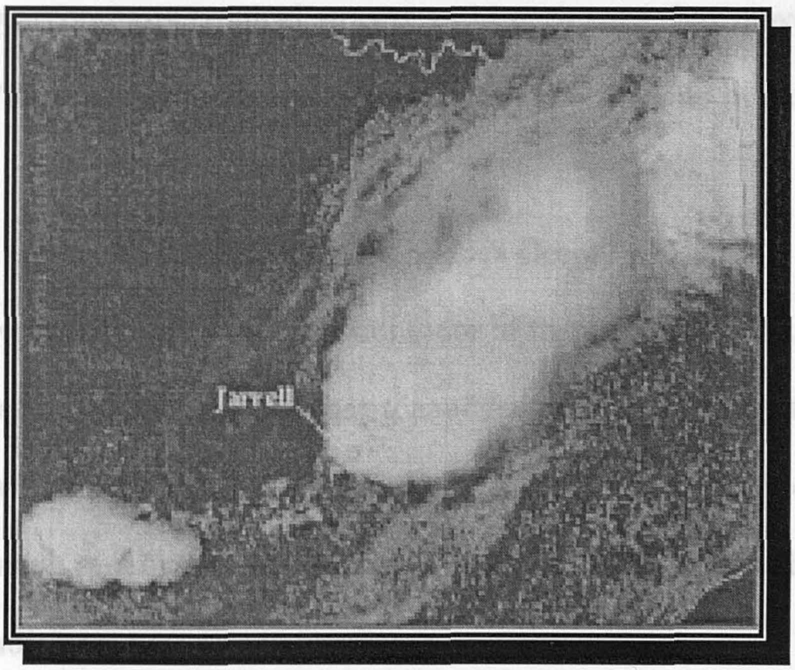

Figure 2.3.3 (The Tornado Project 4)

The reason for the great number of tornadoes in these regions can be attributed to atmospheric weather patterns. Throughout this part of North America, cold dense air masses push in from the north-west. When these air masses meet the warm water vapor rich air masses coming out of the Gulf of Mexico, thunderstorms form. Very often these thunderstorms are incredibly intense, and very often these thunderstorms produce tornadoes.

Tornadoes are not an anomaly of predictable behavior. Even though the interior plains of North America have the greatest concentration of tornadoes, tornadoes may form anywhere that conditions are favorable. As U.S. Department of Commerce state in its pamphlet, "Tornadoes occasionally accompany tropical storms and hurricanes that move over land" (2). There has even been a reported case of a tornado in Alaska.

2.5 When do Tornadoes Occur?

Following the unpredictable behavior of tornadoes that has thus far been discussed, it is no surprise that tornadoes can occur at any time of the year. Tornadoes may occur at any hour of the day, but are most common in the afternoon and evenings. They can occur any time, given the right weather conditions.

There are, however, some specific tornadic activity patterns that have been observed throughout the United States. One of the major observations is discussed by the tornadoes pamphlet: "In the southern states, peak tornado occurrence is in March through May, while peak months in the northern states are during the summer" (6). Normally tornadoes also tend to form between the hours of 3:00pm to 9:00pm. These observable, more frequent characteristics do not mean that this is the only time tornadoes can form. One must also remember that the frequency may be higher in areas of lesser populations. This idea can be attributed to the fact that because there may be no one to report the tornadoes that happen in the non-populated areas, there is a possibility of many unrecorded tornadoes. A chart displaying the months of peak tornado activity throughout the contiguous United States can be seen in figure 2.5.1.

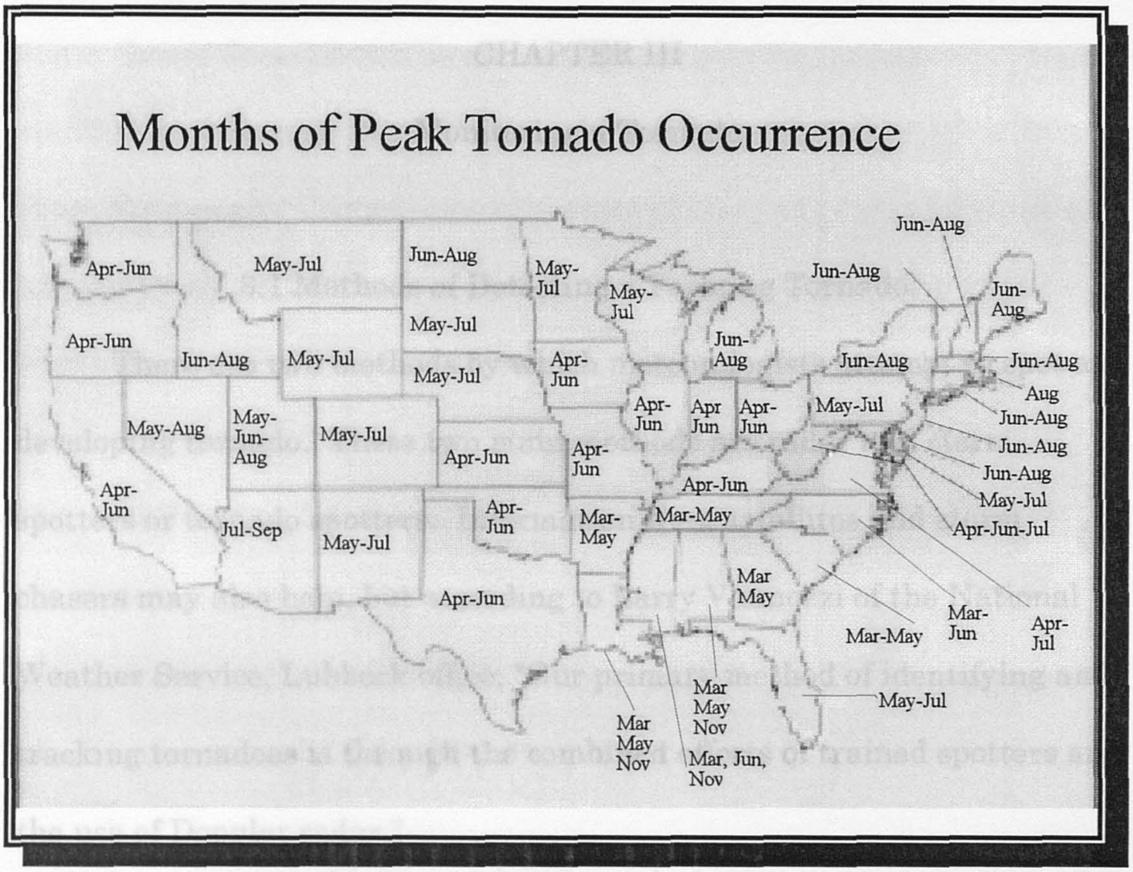

Figure 2.6.1 (United States 4)

CHAPTER III

Monitoring a Tornado

3.1 Methods of Detecting a Forming Tornado.

There are two methods by which meteorologists attempt to spot a developing tornado. These two main methods are radar and storm spotters or tornado spotters. Information from satellites and storm chasers may also help, but according to Larry Vannozzi of the National Weather Service, Lubbock office, "Our primary method of identifying and tracking tornadoes is through the combined efforts of trained spotters and the use of Doppler radar."

3.2 What Is a Spotter?

A tornado spotter is someone who watches a specific geographic area for signs of a tornado or a thunderstorm that exhibits characteristics that may precede the formation of a tornado. Storm spotters are trained individuals who are often civil servants of some capacity. County sheriffs, firemen, local police, and amateur radio operators are just some of the likely candidates for a storm spotter.

A storm spotter should not be confused with a storm chaser. The storm chaser does not stay in one specific area for the purpose of monitoring that area; storm chasers do just as their name implies: they chase the storms. Spotters are in place to visually identify and verify a tornado or severe storm; they then relay this information back to the weather service. Storm chasers may monitor and video or record a tornado or storm, but their function is not to relay this information to the local National Weather Service office in a real-time fashion for the purpose of the meteorologist.

Storm spotters are irreplaceable in terms of accurate identification of a forming tornado. The American Meteorological Society best sums up the role of the storm spotter:

> Since prompt visual sightings of rotating cloud forms and funnels are still one of the most reliable indications of the presence or likelihood of a tornado, law-enforcement officials and trained volunteer-spotter networks will continue to form and indispensable part of the warning system in the foreseeable future, regardless of the new technological improvements. ("Tornado Forcasting" 1271)

The human factor plays an important role in verifying the existence of a tornado. Radar images can be misinterpreted, but when someone observes a tornado, there is indisputable verification. The verification is an invaluable tool for meteorologists.

3.3 What Is the Function of Radar?

Radar is the technological tool used for identifying and tracking a tornado. Doppler radar is the cutting-edge technology used today for the tracking of severe thunderstorms and tornadoes. The introduction of Doppler radar, commonly referred to as NEXRAD (Next Generation Radar), has enabled meteorologists to look more closely into the storm.

Doppler radar has an advantage over that conventional radars that may still be in use today. Doppler radar measures the velocity of airborne particles in the atmosphere:

> While conventional weather radars in use today only measure the intensity and spatial configuration of precipitation particles and other reflectors, Doppler radar will also provide estimates of the air velocities in the vicinity of and within the storm. Thus, in addition to identifying certain radar reflectivity signatures that are related to tornado occurrence, Doppler radars will also be able to identify incipient rotational circulations of tornadoes that might exist within the storm. ("Tornado Forcasting" 1271)

Meteorologists have gained, in the form of Doppler radar, a looking glass into a thunderstorm. Through this looking glass, meteorologists are often able to detect a tornado before it forms. This looking glass also allows meteorologists to track the tornado.

Doppler radar, spotters, and the use of weather satellite imagery to spot storms combine to form the crucial links in a chain of information that is used to analyze a storm and tornado for the purpose of predicting its movement. It is this deciphering of storms or tornadoes that allows meteorologists to issue tornado watches and tornado warnings in time to save lives.

3.4 Warning Signs Observable by the Public

All of the trained spotters, expert meteorologists, and technology can not replace common sense and responsibility. The public must open their eyes and ears to what is happening with the weather around them during times of severe thunderstorms and tornadic activity. Once a tornado warning is issued, there are several signs, that the public can observe that may precede a tornado. The Tornado Project website lays out this simple list of warning signs that the public can observe during times of a tornado warning:

1. A sickly greenish or greenish black color to the sky.
2. If there is a watch or warning posted, then the fall of hail should be considered as a real danger sign.
3. A strange quiet that occurs within or shortly after the thunderstorm.
4. Clouds moving by very fast, especially in a rotating pattern or converging toward an area of the sky.
5. A sound a little like a waterfall or rushing air at first, but turning into a roar as it comes closer. The sound of a tornado has been likened to that of both a railroad train and a jet.
6. Debris dropping from the sky.
7. An obvious "funnel-shaped" cloud that is rotating, or

> debris such as branches or leaves being pulled upwards, even if no funnel cloud is visible (1).

This is a simple list of the major observable atmospheric signs that often precede the possibility of a tornado.

3.5 Projects to Study Tornadoes.

There have been scientific projects attempted in hopes of better understanding how a tornado works. Two of these are the project TOTO (Totable Tornado Observatory) and the project VORTEX (Verification of the Origins of Rotation in Tornadoes Experiment). Both of these projects were conducted by scientists and university students in the hopes of unlocking some of the secrets of tornado behavior.

In the years from 1981 through 1983, scientists and students, led by tornado researcher Dr. Howard Bluestein of the University of Oklahoma, attempted the TOTO project. Their goal was to place a portable laboratory of instruments in a tornado's path. This laboratory would then relay information out of the heart of the tornado. However, Project TOTO was never able to accomplish this goal, and eventually the project was discontinued. Williams reports on the project as follows:

> Chasers managed to place TOTO close to twisters and obtained some useful information, Bluestein says, but never

> saw how it would work in the heart of a twister. "We gave up on it: we decided it was much too difficult to get in the path." (Williams 120)

The next project that attempted to unlock the secrets of a tornado was VORTEX. This project was led by Dr. Eric Rasmussen, who earned his degrees from University of Oklahoma, Texas Tech University, and Colorado State University, some of the leading centers of research in the field of tornadoes. The project was a two-year intensive field study conducted during 1994 and 1995. The Weather Book best sums up Project VORTEX:

> The goal was to probe a tornado with sophisticated instruments and learn its secrets. More than 100 meteorologists and students were part of VORTEX, the largest and most successful tornado chase in history. (Williams 133)

Data from this experiment are still being and will continue to be examined by scientists for years to come in the hope that a key characteristic or warning sign in a storm will become a spottable tip-off to a forming tornado. This key factor can then be applied to future storms for the purpose of tornado prediction and the issuing of tornado warnings.

CHAPTER IV

The Tornado Warning System

4.1 Methods of Dissemination

All the work of meteorologists and spotters perform would be in vain if it were not for the dissemination of the tornado warning. This is the crucial point in the chain of events that make up the tornado warning system. If people are unable to get a warning at all, or unable to get a warning in enough time to react, then all of the effort and technology put into the warning system is in vain. There are many different outlets through which a tornado warning can be disseminated. Education projects that teach the public how to react to a tornado warning are another essential part of the tornado warning system. Together, a tornado warning and the knowledge and ability to properly react to a warning and a tornado can save lives. This life-saving warning is disseminated through multiple types of outlets, including NOAA Weather Radio, television, local radio, short-wave radio, and sirens. All people can have access to one, if not more, of these outlets of information.

NOAA Weather Radio, known as "The Voice of the National Weather Service," is the radio broadcast of forecasts, watches, warnings, and other weather-related information. This broadcast is continuous, twenty four hours a day, 7 days a week, and 52 weeks a year. According to a pamphlet NOAA Weather Radio distributed by the U.S. Department of Commerce in conjunction with the National Oceanic and Atmospheric Administration and the National Weather Service, "The NOAA Weather Radio network has more than 425 stations in 50 states and near adjacent coastal waters, Puerto Rico, the U.S. Virgin Islands, and U.S. Pacific Territories" (1). This radio broadcast is always found in the 162 MHz range on the dial. In Lubbock, Texas, the dial setting to get NOAA weather Radio is 162.400 MHz. The NOAA is reliable even in the event of a power outage because all NOAA radio towers are backed up with power generators.

There are special weather radios that are permanently tuned to NOAA frequencies. These radios are inexpensive and can be bought at many electronics retail outlets. It is a good idea to get a radio that has a battery back-up in case of a power outage during a tornado event. NOAA Weather Radio can also be received by some CB radios, scanners, short wave, and AM/FM radios (NOAA Weather Radio pamphlet 2). For the hearing impaired, radios may be connected to other attention-grabbing devices such as flashing lights, pagers that vibrate, or personal computers.

Another source of weather information, in the event of a tornado, is the television. Most homes today in the United States have at least one television set. Local news may continually inform the public of tornado watches and warnings, and if the threat is immediate, these news stations will break into regular programming and deliver the warning with preparedness instructions to follow. In some cases where people have cable or satellite television, they may be able to get additional information through these means. The Tornado Project website suggests, "Check The Weather Channel for additional information" (1). However, in general, the cable-only stations will not have local weather warnings. Often a power outage, a cable becoming disabled, or even a television station being hit by the tornado can end the use of television as a source of information. To stay on top of severe weather, people need not only to rely on television but also to use it as a supplement to a battery powered NOAA weather radio.

Local radio stations are also an excellent source of weather information during sever thunderstorms and tornadoes. Often these sources can inform of the impending arrival of a tornado. The local radio stations should not be grouped together with NOAA Weather Radio because NOAA broadcasts only weather whereas local stations may give weather information only between music or talk radio programming.

In our technological age, there is also the computer. People can now use the internet to monitor weather conditions in their area. This again is an information source that relies on a power source, but frequently power is out during a tornado. There is also the risk of damaging a computer should your home take a lightning strike during the tornadic event or any severe thunderstorm event.

Short-wave radio operators are also a valuable asset to the dissemination of weather information. Many times people may be located in isolated places, and the short-wave radio may be their only connection to the outside world. The American Meteorological Society acknowledges the contribution of short-wave radio operators: "Participating amateur radio operators also provide an important communications capability" ("Tornado Forcasting" 1271). Short-wave radio operators are often trained tornado spotters. Again, however, it should be stressed that the best source of information is a battery powered NOAA weather radio.

Sirens are another source of warning for a community, but these are becoming far and few between. Often warning sirens are broken, or there is a delay from the time the National Weather Service issues a warning to the time when the sirens are set off. Larry Vannozzi of the National Weather Service, Lubbock office, gives two reasons why sirens are becoming less common: "Sirens are expensive to install and maintain, and it has been concluded that society today can be reached by television or radio more thoroughly than by siren." Sirens are also another warning system that can be disabled by a power failure, or a siren can be destroyed by the very tornado, that it is warning against.

There are still yet other entities that can inform people of impending dangers from tornadoes. Some privately run beeper services can inform a person of any severe weather event that is about to take place. There are also National Weather Service wire machines that display a continuous teletype of current weather phenomena. This system is not really geared toward the public, since most people do not have a teletype machine in their home.

4.2 Present Tornado Warning Times

Often the phrase "warning time" is applied to tornadoes. This is the amount of time between a tornado warning and when a tornado hits an area. Warning times are not based on a universal time length applied to all tornadoes in all areas. Warning times vary with many factors. Some of these are the local technology of the meteorologist and of the outlets for dissemination of messages or the traits of the tornado and thunderstorm., (Indeed, nearly all of the topics thus far discussed affect the amount of time a warning is issued before a tornado hits.)

Today warning times have greatly improved over those of the past. As White notes, "Warnings of tornadoes, where minutes count, are now issued on average 15 - 17 minutes before a twister strikes, as contrasted with the typical 5 - 10 minute lead time that older technology typically provided" (2). Warning times have increased, according to this statement, and that increase is a double in the amount of warning time over older warning times. This increase in warning time is crucial to saving lives.

Warning times may vary regionally, and this is well illustrated by comparing Lubbock and Midland, Texas. The total number of tornadoes for a year is averaged for each city to provide a range of warning times. In Lubbock and Midland for the year of 1992, both cities' warning times were in the 15 - 19 minute range, based on National Weather Service statistics. Two years later both cities' prior warning times had dropped to the 10 14 minute category. Then in 1995 Lubbock remained in the 10 - 14 minute category while Midland increased warning times to 15 - 19 minutes. (Vannozzi) By looking at these numbers, one can see that there is no concrete change to improving warning times for an area; some year's warning times are greater than in other years.

These variations in prior warning times can be attributed to the fact that the very element that is being predicted is in reality a very unpredictable weather anomaly. A tornado is a weather anomaly that requires specific conditions to form, yet even in the presence of perfect conditions a tornado may not form. To further increase the unpredictability of tornadoes, scientists still do not fully understand the workings of the tornado.

There is another reason for the differences in prior warning times, and that involves the verification of a tornado. A tornado must be verified so that the time between when the tornado hits and when the warning was communicated to the public can be estimated. If a warning is issued for an area, and a tornado hits a part of that area that is not populated, then there is no one there to witness the tornado. The fact that no one is able to verify the tornado then means that there is no record of the tornado occurring; but even if there are signs of physical damage to an area, no one was there to record when the tornado touched down. This lack of verification means that there is no recorded time of touchdown of the tornado. Larry Vannozzi of the National Weather Service, Lubbock office, offers this idea for the differences in warning times from year to year and area to area: "Possible reasons for the jump would be increased verification efforts through spotters, radar monitoring, and increased effort toward contacting people in the area of the speculated storm."

The goal of achieving adequate warning times is to warn people of a tornado prior to its arrival with sufficient time for them to seek shelter. The future goal is to increase warning times. There is no exact number of minutes set as an improvement goal for warnings, just a push to increase these warning times as much as possible. The more time the public has to prepare for a tornado, the better their chances of survival.

CHAPTER V

Effectiveness of warning systems

5.1 Case Studies and Findings

One of the best ways to illustrate the effectiveness of a warning system to examine past tornadoes. If we know what measures were taken for a specific event, how much time the warning system allowed the public, and how well the public reacted to the warning system, then the effectiveness of a warning system can be estimated. The effectiveness of a warning system can be evaluated only subjectively, if the entire system is studied holisticly. This mode of thinking can be illustrated by a statement from the Assessment of Research on Natural Hazards:

> Warning systems must be assessed from an integrated perspective including every stage of the total warning process from the first detection and forecast of the hazard threat trough public response. (White and Haas 487)

A warning system can also be evaluated for its effectiveness in terms of specific aspects. Some of these aspects for evaluation are mortality rates, monetary property damages, or length of warning time given to the public.

On April 10, 1979, a series of tornadoes hit the Red River Valley area of Texas and Oklahoma. The main settlements that were seriously hit were Wichita Falls, Texas; Lawton, Oklahoma; and Vernon, Oklahoma. The assessment of the overall warnings for these three cities and surrounding areas was a consensus of "very effective." The Natural Disaster Survey report on the Red River Valley Tornadoes notes that The Wichita Falls Record News printed this headline: "Action by the Wichita Falls office of the National Weather Service saved hundreds, perhaps even thousands of lives" (38).

In that instance, there were many crucial methods of disseminating the tornado warnings. NOAA Weather Radio provided continuous broadcasts with up to the minute information on tornado location and path. "On April 10, the Oklahoma City, Fort Worth, and Wichita Falls offices all broadcast severe weather safety messages on NWR" (Natural Disaster Survey Report 80.1, 44). The NOAA wire service was also integral in getting information out to news agencies, radio stations, and emergency management officials. "Watches, warnings, and statements were transmitted on to Texas and Oklahoma NWWS (National Weather Wire Service) in a timely manner" (Natural Disaster Survey Report 80.1, 46). The telephone also played a key role in informing the public by distributing information to key local officials. The Wichita Falls Emergency Communications Hotline was another link to information.

Sirens were also an integral part of the warning process. This region uses sirens to a large extent. Sirens sounded three times in Wichita Falls before the tornado hit. The Disaster Survey Report states that in Lawton, Oklahoma, "Sirens were sounded 15 minutes before the tornado struck Lawton" (Natural Disaster Survey Report 80.1, 48). Thus sirens were another powerful tool for warning the public of the imminent arrival of a tornado during these Red River Valley tornadoes.

What saved lives during the Red River tornadoes was the coordinated efforts of trained officials, trained tornado spotters, media, and civil defense officials. The Disaster Survey Report emphasized the effectiveness of the combined efforts:

> The most important factor was the community teamwork generated by dedicated officials working in concert with motivated civic organizations, business interests, and public spirited citizens. Organized networks of trained tornado spotters performed according to plan. Radio and television stations recognized the emergency nature of the situation and responded with timely and accurate broadcasts. Civil defense officials used sirens in a timely manner to warn all three of the hard hit cities. (Disaster Survey 80.1 40)

All of these different actions combined to produce an effective tornado early warning system, a system that saved hundreds or even thousands of lives. To judge this system as effective would be correct, but a key point about the publics' response needs to be brought out to understand this judgement. This is an area that experiences many tornadoes and conducts many tornado exercises. Therefore the public in this area were knowledgeable about how to react to a tornado warning.

5.2 How the Public Should React to a Warning System

When all of the efforts of meteorologists, tornado spotters, media, and civil defense officials combine to issue a tornado warning then it is up to the public to know what to do after receiving this warning. A timely tornado warning is useless if the public is ignorant about what steps to take once a tornado warning is received. The public must be educated and continually updated on how to react to a possible tornado.

The success of saving lives in the case of the Red River Valley tornadoes was greatly dependent on this area's people having the knowledge of how to respond to a tornado warning. The importance of tornado drill practice is clearly cited as crucial by the Natural Disaster Survey Report:

> Just 2 weeks before the tornado struck, Wichita Falls had held a complete citywide drill involving all elements of the total warning system. But the 1979 Wichita Falls tornado drill was not a chance occurrence. Ever since the April 3, 1964, tornado struck the area leaving 7 dead and more than 100 injured, county and city officials have held annual tornado drills. Schools, hospitals, and others participate. The media (radio, television, and newspapers) are involved heavily in the drills, especially emphasizing tornado safety information. (Disaster Survey 80.1 40)

The importance of educating the public on how to react to a tornado warning cannot be measured. The benefit of this kind of education is observed in the survival of people during a tornado. The only wrong reaction consistently displayed by the people of Wichita Falls was a reluctance to leave their cars. "Nearly 60 percent of the deaths in Wichita Falls involved people in cars" (Natural Disaster Survey Results 80.1 48). These statements illustrate the importance of educating the public on how to react to a tornado warning.

There are some key guidelines that the public should follow when facing a tornado. Some of these guidelines are summarized as follows:

> 1. In school, students and faculty should proceed to interior hallways or rooms, and crouch down and cover their heads.
> 2. If in a car then leave the car and take shelter; if no shelter is available then lay in a ditch or other low area, but if it is raining then a ditch may flood and this would not be a good place to be.
> 3. In a high rise building move to interior halls or rooms, stair wells are very good, but do not go to the elevator.
> 4. In homes basements or tornado shelters are the best place, but if these are not readily available then go to windowless closets or bathrooms on the first floor in the interior of the house (All guidelines are summarized from the Tornado Project Website).

The goal when in a home or building is to put as many walls as possible between you and the tornado. Another important point is that people should try to cover themselves with mattresses, heavy blankets, or even metal trash cans so as to protect their bodies from flying debris. All of these suggestions should be consistently practiced and rehearsed.

In large buildings, such as office buildings, there should be a building-wide tornado contingency plan. This plan should be practiced and reviewed in hopes of improving the plan. According to the journal Security Management:

> After testing a plan, an organization should have key participants immediately report to a central location for a debriefing. The meeting should focus on what employees learned during the drill as well as which parts of the plan worked and which didn't. ("Plan Essentials" 5).

The great need for educating the public on how to react to a tornado warning should be very apparent by now. The government pamphlent "Tornado, Nature's Most Violent Storms," sums this idea up as follows, "Each year, many people are killed or seriously injured by tornadoes despite advance warning" (United States 9).

A central question in this thesis is , "How effective are tornado warning systems?" and the answer is "very effective under the right circumstances." This question is often difficult to answer for all tornado warning situations; each situation must be judged on its own merit. Evidence supports that a well-informed and educated public will respond to a timely warning in the correct way, thus making the tornado warning very effective. One must remember that for the best outcome, all the parts of the warning system (tornado detection, message dissemination, message reception, and public reaction) must work together correctly. Generally, today's advance tornado warning systems are effective, especially when compared to warning systems of the past. There is, however, still room for improvement, which will come as technology advances and the public takes more of the responsibility for their own safety. The increased effectiveness in tornado warnings compared to the number of tornadoes experienced can be observed in figure 5.2.1.

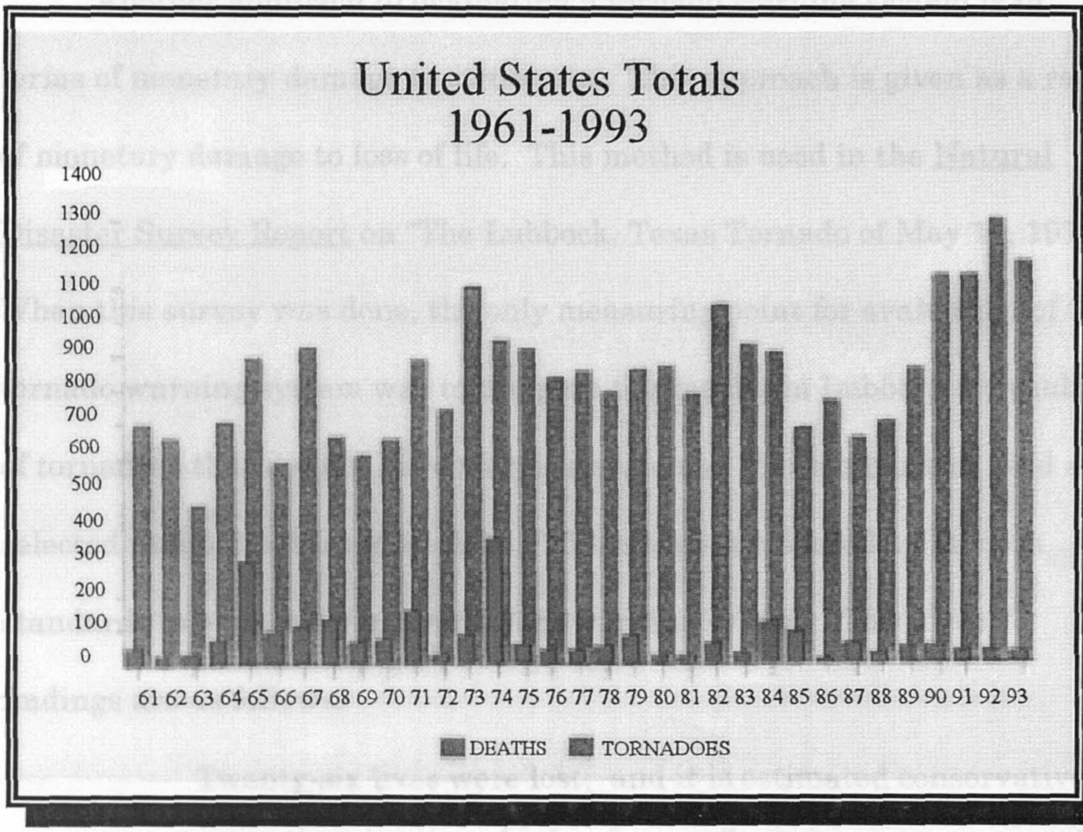

Figure 5.2.1 (United States 4)

Another approach to evaluating a tornado warning system is in terms of monetary damage to structures. This approach is given as a ratio of monetary damage to loss of life. This method is used in the Natural Disaster Survey Report on "The Lubbock, Texas Tornado of May 11, 1970." When this survey was done, the only measuring point for evaluation of the tornado warning system was to compare the results in Lubbock to results of tornadoes that did not have warning systems. The comparison used a selected number of tornadoes from 1953, a time considered by modern standards to be lacking in a sufficient warning system. The survey's findings are as follows:

> Twenty-six lives were lost; and it is estimated conservatively that $125,000,000 property damage was sustained on May 11, 1970, giving a ratio of loss of life to property damage of approximately one life per $5,000,000 of damage. The extrapolation of the 1953 experience to the present would indicate that as many as 125 lives were saved because of the effectiveness of the warning system .
> (Disaster Survey 70.1 17).

This is just another way in which a tornado warning system may be evaluated. In the case of the Lubbock tornado of 1970, the survey found the warning system to be relatively effective.

CHAPTER VI

New Technologies Being Applied to the Study of Tornadoes

There have been many new methods are being applied to studying tornadoes. Some of the big projects, such as TOTO and project VORTEX, have already been mentioned. Some of the new efforts employed to reveal the secrets of the tornado focus on improving the present-day Doppler radar; others concentrate on new techniques for studying the tornado; and yet others focus on developing new technology.

One method that has been attempted in the study of tornadoes is to use Super High-Resolution Doppler radar. The downside of this method is that as resolution increases, the area of coverage decreases; hence Super High-Resolution Doppler radar can only detect nearby tornadoes. This idea was put into practice in 1989 when a portable radar was constructed at the Los Alamos National Laboratory. The rationale for this close observation is best expressed by a statement from the Monthly Weather Review:

> With a portable radar, one can go to the tornado itself, and simultaneous boresighted video documentation can be obtained. Furthermore, the sensitivity of the radar to small volumes in which the wind speed may be very high is greater if the radar is very close to the tornado (Bluestein et al 2201).

Data from this project is still being evaluated and examined. Whether or not this project has unlocked a new secret to understanding the tornado is still unknown.

There are ideas to use the GPS [(Global Positioning Satellites) originally designed for military use] to monitor the atmosphere. Robert M. White explains this idea:

> One idea is to use the Global Positioning System satellites, designed as navigation aids for military purposes, as microwave probes to generate continuous readings of temperature and humidity throughout the atmosphere. (2)

The data from the GPS satellites is continuously fed into a software program designed to interpret it. This project shows great promise, it has not yet been implemented, but is presently being considered.

Computer technology that combines multiple inputs of information is taking atmosphere monitoring into a new dimension. Presently there are interactive computer systems in use by the National Weather Service; these are described in The Weather Book by Jack Williams:

> They use an interactive computer system to combine many kinds of data on one computer screen, for example, radar images with satellite photos, computer forecasts of the day's weather features and the latest map showing every lightning bolt that has hit the ground in the last 15 minutes. The computer calculates information such as the air's stability and analyzes wind speeds and directions at various altitudes. (136)

Dr. Joseph Shaefer, Director of the Storm Prediction Center, states that this computer system, "Gives the forecaster a detailed look at the weather situation quickly. It tells us if indeed we're getting conditions conducive to severe storms." (Williams 138)

New computer systems are also under development, such as AWIPS (Advanced Weather Interaction and Processing System), which is expected to be implemented by 1999. This system is explained by Robert M. White: "A new communications and data display system - will provide a graphics - rich presentation of information compiled from satellites, radar, and surface observation stations" (2).

Improving present technology is an ongoing process for the purpose of improving tornado warnings. In addition, to better train tornado spotters and to increase the number of trained spotters is another significant effort at improving tornado monitoring. Increasing the resolution of present widescale Doppler radars is also a field being researched. Moreover, public education programs focusing on how to react to a tornado warning are being expanded. These increased efforts of education and improvements in radar are all done to enhance the effectiveness of tornado warning systems. Better tornado warning systems will save lives, and that is the ultimate goal of all of these efforts.

CHAPTER VII

Conclusion

What are the answers to the mysteries of the tornado? Scientist do not yet entirely understand tornadoes, but they are continuing their quest. Is today's tornado warning system effective? Yes, today's tornado warning system is effective when all parts of it are executed correctly. Will tornado warning systems continue to improve? Yes, these systems will improve as technology improves and as public education improves.

Human beings will continue to live where they please, and the atmosphere will continue to show its force as it always has. This show of force will often be embodied in the form of a tornado. These very tornadoes will continue to inflict damage to property and will continue to take lives. No matter how good our tornado warning systems become, we must remember that we are attempting to predict the most powerful and unpredictable force on the planet, Mother Nature. She exercises her strength periodically and impartially upon the planet, and man will inevitably be caught in these sometimes unpredictable events. All we can hope for is to reduce the number of people who are injured and killed during these displays of natural force that we know as the tornado.

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