Service Assessment

The Central Texas Tornadoes of May 27, 1997

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Silver Spring, Maryland

Cover:

Left: Ground view of the Jarrell tornado on May 27, 1997, between 3:40-3:45 p.m. Central Daylight Time (CDT), just before it entered the Double Creek Estates subdivision. Photograph courtesy of Scott Beckwith, Jarrell, Texas.

Right: Aerial view taken May 31, 1997, of a portion of the Double Creek Estates subdivision in Jarrell, Texas. Note that only the home foundations remain. Photograph by L. Phan, National Institute of Standards and Technology (NIST).

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U.S. DEPARTMENT OF COMMERCE
William M. Daley, Secretary

National Oceanic and Atmospheric Administration
D. James Baker, Administrator

National Weather Service

John J. Kelly, Jr., Assistant Administrator

Preface

Participation on a Service Assessment survey team is both a rewarding and potentially trying experience. Witnessing the personal tragedy caused by a disaster and assessing services provided by the National Weather Service (NWS) are responsibilities not taken lightly. Reports on natural disasters are very important. The recommendations, which represent the team's views, are given careful consideration by the Agency in its attempts to continuously improve warning services.

The magnitude of this event made it emotionally troubling for every team member. I wish to express sincere appreciation to the Service Assessment Team members for their thorough, professional, and unbiased review of the disaster and for their recommendations toward service improvements.

Robert S. Winokur
Acting Assistant Administrator for Weather Services

April 1998

Foreword

This report on the series of tornadoes which struck central Texas on May 27, 1997, was prepared by a National Oceanic and Atmospheric Administration (NOAA) Service Assessment Team following a 4-day visit to the storm sites. The meteorological analyses presented in the report were developed by the Team during a 4-month period following the on-site assessment. The team has drawn upon a number of external resources, including the Storm Prediction Center (SPC), National Environmental Satellite, Data, and Information Service (NESDIS), Operational Support Facility (OSF), and university resources to make the interpretations of the severe weather setting. It should be noted that the meteorological analyses and interpretations, since they were done after the fact, make use of all available information. Some of the charts and photographs shown in this report were not available to the staffs of the Next Generation Weather Radar (NEXRAD) Weather Service Forecast Offices (NWSFOs) Dallas/Fort Worth and Austin/San Antonio, Texas, prior to the occurrence of the tornadic thunderstorms.

The report is based upon information gathered by the team through a visit to the Austin/San Antonio NWSFO in New Braunfels, Texas; aerial and ground surveys of three of the tornado track sites; and interviews with members of other agencies and organizations and state, county and municipal governments. The team expresses its appreciation to the county and municipal officials who took time from urgent disaster response duties to share their impressions of the event and interpretations of the effectiveness of NWS products and services. Similarly, the team would like to extend its appreciation to the staffs of the Dallas/Fort Worth and Austin/San Antonio NWSFOs for making themselves readily available and for outlining their actions before and during the event.

This report assesses the effectiveness of NWS products and services before and during the period of the severe thunderstorms as they moved through central Texas. Furthermore, the report presents the team's facts, findings and recommendations as defined by their survey.

The Service Assessment Team

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Service Assessment Team

Following a major severe weather event in which there has been extensive damage or loss of life, a Service Assessment Team may be assigned by NOAA to evaluate the role played by the NWS, to provide an objective appraisal of products and services, and to make findings and recommendations for improving the service. Such a team was assembled to survey tornadic thunderstorms which struck parts of central Texas on May 27, 1997. This document is the final report from this team.

Team Members

Leader, **James H. Henderson**, Deputy Director, Aviation Weather Center, National Centers for Environmental Prediction (NCEP), NWS, Kansas City, Missouri

Team Coordinator/Editor, **Ida M. Hakkarinen**, NWS Liaison and Meteorologist, NOAA Program Coordination Office, Washington, D.C.

Assessment Facilitator, **William H. Lerner**, Meteorologist, Office Of Meteorology, NWS Headquarters, Silver Spring, Maryland

Melvin R. McLaughlin, Chief, Meteorological Services Division, NWS Southern Region Headquarters, Fort Worth, Texas

James M. Looney, Chief, Meteorological Services Division, NWS Central Region Headquarters, Kansas City, Missouri

E. L. (Buddy) McIntyre, Chief, Transition Management Unit, NWS Southern Region Headquarters, Fort Worth, Texas

Brian E. Peters, Warning Coordination Meteorologist (WCM), NWS NWSFO Birmingham, Alabama

Marilu Trainor, NOAA Public Affairs Specialist, NWS Western Region Headquarters, Salt Lake City, Utah

Dr. Enrique Paz, U.S. Centers for Disease Control and Prevention (CDC), Atlanta, Georgia

Dr. Shellie Ann Kolavic, Epidemic Intelligence Service, CDC, Texas Department of Health (TDH), Austin, Texas

David Zane, Director, Injury Prevention and Control Program, TDH, Austin, Texas

Adjunct Member

Dr. Long T. Phan, Professional Engineer, Structures Division, NIST, Gaithersburg, Maryland (accompanied Brian Peters on the aerial surveys)

Acronyms

ARC	American Red Cross
AVHRR	Advanced Very High Resolution Radiometer
AWIPS	Advanced Weather Interactive Processing System
C	Celsius
CAPE	Convective Available Potential Energy
CDC	U.S. Centers for Disease Control and Prevention
CDT	Central Daylight Time
CIMSS	Cooperative Institute for Meteorological Satellite Studies
CIRA	Cooperative Institute for Research in the Atmosphere
CR	County Road
CST	Central Standard Time
CSTAR	Collaborative Science, Technology, and Applied Research Program
CWA	County Warning Area
DLF	Del Rio, Texas (DOD radar site at Laughlin Air Force Base)
DMIC	Deputy Meteorologist in Charge
DOD	Department of Defense
EAS	Emergency Alert System
EWX	Austin/San Antonio NWSFO, New Braunfels, Texas
FCC	Federal Communications Commission
FWD	Dallas/Fort Worth NWSFO, Fort Worth, Texas
FEMA	Federal Emergency Management Agency
FFA	Flash Flood Advisory
FFW	Flash Flood Warning
FLW	Flood Warning
ft	feet
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GRK	Granger, Texas, WSR-88D (DOD radar site at Fort Hood)
J/kg	Joules per kilogram
km	kilometer
LI	Lifted Index
LSR	Local Storm Report
m^2/s^2	meters squared per second squared
mb	millibar
MCS	Mesoscale Convective System
MESO	Mesocyclone Algorithm-Signature
MIC	Meteorologist in Charge
NAWAS	National Warning System
NCEP	National Centers for Environmental Prediction
NESDIS	National Environmental Satellite, Data, and Information Service
NEXRAD	Next Generation Weather Radar

NIST	National Institute of Standards and Technology
nm	nautical miles
NOAA	National Oceanic and Atmospheric Administration
NOW	Short Term Forecast (nowcast)
NWR	NOAA Weather Radio
NWS	National Weather Service
NWSFO	NEXRAD Weather Service Forecast Office
OSF	Operational Support Facility
RAMM	Regional Atmospheric Modeling System
RAMSDIS	RAMM Advanced Meteorological Satellite Demonstration and Interpretation System
RVS	River Statement
SEL	Tornado Watch
SPC	Storm Prediction Center
SPS	Special Weather Statement (e.g., Hazardous Weather Outlook)
SR	State Road
SVR	Severe Thunderstorm Warning
SVS	Severe Weather Statement
TDH	Texas Department of Health
TLETS	Texas Law Enforcement Telecommunication System
TOR	Tornado Warning
TVS	Tornado Vortex Signature
μm	micrometer
USWRP	U.S. Weather Research Program
UTC	Coordinated Universal Time
VAD	Velocity Azimuth Display
WCM	Warning Coordination Meteorologist
WFO	Weather Forecast Office
WSR-88D	Weather Surveillance Radar-1988 Doppler
ZFP	Zone Forecast Product

Event Summary

Overview

During the mid-afternoon and early evening of May 27, 1997, a severe weather outbreak produced numerous severe thunderstorms and multiple tornadoes across central Texas. The synoptic weather situation that occurred was an atypical pattern for springtime central Texas tornadoes. Outbreaks of Texas tornadoes are usually associated with a “classic” meteorological pattern that has a strong mid-level (500 millibar [mb]) trough of low pressure combined with favorable jet stream winds and integral strong low-level boundaries to form and enhance the thunderstorms.

On this day, the 500 mb low center was located well to the north over Nebraska, and the upper-level jet stream axis was over northern Oklahoma. There was not a well defined low-level jet. A weak cold front extended from northeastern Texas southwestward to near Del Rio. The numerous severe thunderstorms that occurred throughout central Texas developed in a situation of weak wind shear and high thermodynamic instability, along the surface boundary, where the greatest threat is typically strong winds and large hail. On this day in central Texas, there were 34 reports of severe weather—12 for large hail and 22 for tornadoes.

The F5 tornado (see Appendix F, Fujita Tornado Intensity Scale) that occurred near the unincorporated community of Jarrell in Williamson County caused 27 of the 30 fatalities. Another tornado death occurred in Cedar Park, which is also in Williamson County. In Travis County, The Pedernales Valley tornado killed one person. One additional death from drowning occurred at Shoal Creek in Austin.

Since 1950, there have been 40 tornadoes in Williamson County. On April 7, 1980, an F3 tornado killed one and injured two. A May 17, 1989, tornado (also rated an F3) killed one and injured 28. Since 1950, 46 tornadoes have occurred in Travis County. On July 4, 1970, an F2 tornado killed one and injured four. Until May 27, 1997, there had never been an F5 or F4 tornado reported in either Williamson or Travis County.

Meteorological Situation

(Italicized sections contain detailed information which may be of more interest to technically oriented individuals.)

In the early morning hours of May 27, a large Mesoscale Convective System (MCS) developed over Arkansas and eastern Oklahoma. The MCS moved slowly eastward and produced gravity waves that radiated away from the system. An analysis of the satellite data, using sophisticated tools not available to the Austin/San Antonio NWSFO (EWX) forecasters, showed that one of *these gravity waves appears to have played a role in the initiation of the thunderstorm complex that eventually produced the tornado activity when it intersected the cold front in the vicinity of Waco. However, this gravity wave moved south of the storm complex before the beginning of the tornado activity.*

Meteorological conditions were conducive to widespread severe convection during the afternoon of May 27. Area upper air soundings indicated extreme instability. Modified Convective Available Potential Energy (CAPE) exceeded 7500 Joules per kilogram (J/kg) in central Texas. (CAPE is a measure of the amount of energy available for convection and is directly related to the maximum potential vertical speed within a thunderstorm updraft. Higher values for CAPE indicate a greater potential for severe weather. Observed values in thunderstorm environments often exceed 1000 J/kg; in extreme cases, values may exceed 5000 J/kg.)

Although the atmospheric instability was extreme, the environmental wind fields were not indicative of those typically expected for supercell thunderstorm development. Vertical wind shear in the atmosphere is an important ingredient for tornadic development. Storm-relative helicity is used by NWS meteorologists to quantify this vertical wind shear. In particular, the measure of helicity in the lowest 3 kilometers (km) of the atmosphere (3 km helicity) is used extensively. In general, 3 km helicity values below 300 meters squared per second squared (m^2/s^2) *correlate to weak tornadoes.*

On May 27, winds were relatively light through much of the lower atmosphere, and storm-relative helicity values from the 7 a.m. CDT NEXRAD Weather Service Office Corpus Christi sounding were 70 m^2/s^2. *(Note: All times listed are in Central Daylight Time.) A forecast sounding from the Rapid Update Cycle numerical model, valid for 7 a.m. near the Austin, Texas, area, had values of 117* m^2/s^2. *Consequently, the convection was strongly influenced by storm-scale processes and confined to the vicinity of the existing surface boundaries.*

The thunderstorm complex that would eventually become tornadic and produce the Jarrell tornado developed in McLennan County over the southern sections of Waco around 12:40 p.m. in the Dallas/Fort Worth NWSFO (FWD) county warning area. The storm developed rapidly and produced its first tornado at 1:20 p.m. near Lorena, approximately 15 miles south of Waco in southern McLennan County. This tornado, classified as very briefly reaching category F1, damaged several mobile homes and severely damaged one frame house 2 miles west of Lorena. The storm continued to intensify and propagate southward and produced a second, much stronger tornado near Moody in extreme southern McLennan County, about 22 miles south of Waco, at 1:45 p.m. The Moody tornado, classified as an F3, had a path length of 3.7 miles and a width of 150 yards. It did extensive damage to trees, destroyed a house and a barn, damaged another small house, and tossed a car and a pickup truck several hundred feet.

A third tornado was produced by this same storm complex in Bell County near Belton at 2:35 p.m. This F3 tornado began near Morgan's Point on the north side of Lake Belton, crossed the lake, and came ashore near the community of Woodland, creating a path 1.4 miles long and 275 yards wide. The Belton tornado reached its maximum intensity after crossing the lake, causing total destruction to trees and substantial damage to structures.

Early radar data of these storms from the EWX Weather Surveillance Radar-1988 Doppler (WSR-88D) were significantly range-folded due to second trip ground clutter. An analysis of the radar data showed that when the storm emerged from the range-folded area at 2:56 p.m., about 20 minutes prior to the development of the Jarrell tornado, there was a deep mesocyclone of minimal strength in southern Bell County. Mesocyclonic rotation strengthened to moderate to strong values (>40 knots at 70 nautical mile [nm] range) and a strong and deep gate-to-gate signature was detected in southern Bell County at 3:19 p.m. Gate-to-gate velocity differences continued to be strong until after the 3:43 p.m. radar volume scan.

The aerial survey (see Appendix C) showed that the final and most devastating tornado produced by this particular storm complex developed near the community of Prairie Dell in the extreme southern part of Bell County, approximately 3 miles north of the Williamson County line.

An analysis of the radar data from the Department of Defense (DOD) WSR-88D radar at Granger, Texas (GRK), showed a detailed view of the developing circulation at 1,500 feet (ft) elevation and above. Prior to the development of the tornadic circulation, two fine lines were detected in the reflectivity field. The gust front on the western side of the Jarrell storm intersected the larger scale wind shift boundary where the tornadic signature developed in an area of strong and deep convergence. The tornadic circulation in the lowest 5,000 ft appeared to link up with the mesocyclone rotation in the middle and upper levels. This radar ceased operation at 3:38 p.m. and was no longer available to the EWX forecasters.

Actual time of the Jarrell tornado's development was hard to pinpoint but is believed to be between 3:15 p.m. and 3:20 p.m. Initially, the tornado was quite weak and small, probably being no more than F0 or F1. The tornado moved slowly south-southwest, crossing into Williamson County at approximately 3:25 p.m. Shortly thereafter, the tornado explosively strengthened, becoming a multi-vortex F5 tornado before moving into the Double Creek Estates subdivision on the west side of Jarrell at 3:40 p.m. Here, devastation was complete. The entire subdivision, consisting of approximately 38 single-family structures and several mobile homes, was destroyed. Three businesses, located adjacent to the subdivision, were also destroyed.

Even though the Jarrell storm produced a mesocyclone and a violent tornado, the radar reflectivity field did not show a distinct hook echo directly preceding the tornado. A small hook was apparent on the Granger radar data after the tornadic circulation developed. Although most supercells contain mesocyclones on the right rear flank with respect to storm motion, the mesocyclones on this day were located on the front flank (southwest quadrant) as they moved slowly south-southwestward. The difference in mesocyclone location was probably due to enhanced southwestward propagation along the boundary. Despite the fact that the reflectivity features were not typical and could have somewhat confused a radar interpreter, the rotational signals were clear and easy to follow.

Twenty-seven people perished in Jarrell. There were relatively few injuries reported—one serious and less than ten minor, an inference to the small probability of survival. The Jarrell tornado had a total path length of 7.6 miles and a maximum width of 3/4 mile. Shortly after exiting the Double Creek Estates subdivision, the tornado dissipated and the parent tornadic storm itself weakened.

While the Jarrell tornado was evolving, a separate storm developed on the larger scale wind shift boundary to the southwest.

On the flank of this new storm, the EWX radar detected an area of deep convergence with weak shear around 3:25 p.m. that eventually evolved into the Cedar Park mesocyclone. The Cedar Park circulation developed similarly to the Jarrell circulation in that it formed in an area of strong convergence along the wind shift boundary in a large weak echo region (6 nm in horizontal extent) well displaced from the low-level reflectivity field. The weak shear rapidly intensified during the 3:48 p.m. radar volume scan, when a mesocyclone of moderate strength was detected with maximum rotational velocities of 36 knots and a maximum radial velocity difference of 70 knots at 50 nm from the radar. The moderate to strong mesocyclone rotational velocities and strong gate-to-gate shear continued until about 4:12 p.m. and weakened thereafter. The Cedar Park mesocyclone and gate-to-gate shears were different from their Jarrell counterparts in that the strong signatures for Cedar Park remained aloft for much of the time while the strong signatures for Jarrell were seen at all vertical levels.

The Cedar Park mesocyclone produced its first tornado at approximately 3:45 p.m. The tornado began about 3.5 miles north of Cedar Park, which is also in Williamson County. This tornado initially caused mainly F0 and F1 damage until it moved into the business district of Cedar Park at 4 p.m., where F3 damage was evident in a small area. An Albertsons Food and Drug Store was severely damaged, and one person in the store was seriously injured as the tornado moved through the shopping center. There were a number of other customers in the Albertsons store, but the store manager had directed them into one of the store's walk-in refrigeration units which provided them safe refuge during the storm.

The Cedar Park tornado continued moving south-southwest, then gradually turned more southwest as it moved through the Buttercup Creek subdivision on the southwest side of Cedar Park. In the subdivision made up of well-constructed, upscale homes, damage ranged from F1 to F3, with some homes suffering only minor roof damage while others suffered major damage. As the tornado moved through the subdivision, 136 homes sustained damage. One person, a 69-year-old male, died from a cardiac arrest apparently as he was waiting out the storm inside his truck in the garage.

The tornado then exited Cedar Park and dissipated about 1.1 miles from the northern shore of Lake Travis in Travis County. As were all of the tornadoes on this day, the Cedar Park tornado was slow-moving. In fact, some residents videotaped the approaching funnel for 10 to 15 minutes and still had ample time to seek shelter in interior rooms of their homes before the wind began to increase with the approach of the vortex itself. The Cedar Park tornado path dimensions were 9.2 miles in length and 250 yards in maximum width.

A second tornado developed from this storm complex near the south shore of Lake Travis around 4:30 p.m. As it rapidly achieved at least F3 intensity, it caused extensive damage to a marina on the lake shore. Then increasing to F4 intensity, it severely damaged a reinforced building containing a telephone switching center and completely destroying a stone house nearby, leaving the foundation slab swept clean.

The tornado initially moved just south of west before turning southwest for a short distance, then back to the west-southwest before moving into the Hazy Hills subdivision of the Pedernales Valley in western Travis County. The tornado was a strong F3, with some evidence of F4 intensity, as it moved through the subdivision destroying numerous houses and mobile homes. A 25-year-old male died when he was either blown from his mobile home or from his pickup truck as he attempted to flee the storm. The Pedernales Valley tornado damaged or destroyed 45 homes and a Southwestern Bell telecommunications switching center. It had a path length of 5.6 miles with a maximum width of 440 yards.

One additional death from drowning occurred at Shoal Creek in Austin. This fatality, a 38-year-old female, was likely a result of the localized flash flooding that accompanied the storm system.

NWS Products and Services

The possibility of severe thunderstorms on this day had been anticipated. The NWS's SPC, part of the NCEP and located in Norman, Oklahoma, had placed the area in a moderate risk of severe thunderstorms in the Severe Weather Outlook that was issued at 1:03 a.m. on Tuesday morning, May 27.

As the severe weather event progressed during the day, the SPC continued to monitor the development and subsequently issued two tornado watches for the area as well as several status updates. The SPC issued Tornado Watch #338 at 12:54 p.m. for portions of east Texas, valid from 1:15 p.m. until 7 p.m. This included Bell, McLennan and Williamson Counties. At 3:31 p.m., the SPC issued Tornado Watch #340 for south Texas, including Williamson and Travis Counties, valid from 3:45 p.m. until 10 p.m. (Refer to Appendix A for details of SPC actions.)

- **NWSFO Dallas/Fort Worth Products**

The NWSFO Dallas/Fort Worth office issued a Severe Weather Outlook at 5:32 a.m. The Outlook noted there was a moderate risk of severe thunderstorms during the afternoon and night over much of north Texas, including Bell and McLennan Counties. Subsequent forecasts and discussions issued in the late morning continued to mention the threat of severe weather. (Refer to Appendix A for a chronology of NWSFO FWD actions.)

Forecasters were obviously concerned about the extreme atmospheric instability in evidence on this day. In an updated Severe Weather Outlook for North Texas issued at 12:20 p.m., NWSFO FWD stated:

> *High instabilities aloft mean that thunderstorms that do form in the slight risk area should rapidly become severe.*

Nevertheless, forecasters were still focusing on the threat of large hail and damaging straight-line winds rather than tornadoes. This was because of a lack of strong vertical wind shear as evidenced by early morning atmospheric soundings. In the same Severe Weather Outlook mentioned above, the forecaster went on to state:

> *Strong vertical motions in these storms...due to strong CAPES [convective available potential energy]...suggest a main threat of large hail or damaging straight-line winds. Weak wind shear profiles suggests that the tornado potential is low.*

As convection began to develop in McLennan County shortly before 12:45 p.m., the NWSFO FWD wasted no time in immediately issuing a severe thunderstorm warning for the county at 12:50 p.m., anticipating that the storm would quickly become severe in the extremely unstable atmosphere. Shortly thereafter, at 12:54 p.m., the SPC issued Tornado Watch #338. This watch was valid from 1:15 p.m. until 7 p.m. and included McLennan and Bell Counties, as well as Williamson County further to the south.

As the NWS WSR-88D in Fort Worth began showing significant updraft rotation in the McLennan County storm, the office quickly switched to tornado mode and issued a tornado warning for McLennan County at 1:21 p.m., noting that the radar was detecting a tornado near Hewitt, a suburb of Waco located approximately 14 miles north-northeast of Moody. A severe weather statement at 1:26 p.m. noted the tornado was west of Lorena, approximately 10 miles north-northeast of Moody. The tornado was now confirmed by spotters as well as being detected by the WSR-88D. At 1:48 p.m., the NWSFO FWD issued a tornado warning for Bell County stating:

> *National Weather Service Doppler radar detected a tornado between Eddy and Moody. This tornado has been confirmed by storm spotters.*

A follow-up severe weather statement at 2:16 p.m. noted:

> *Spotters and radar continue to track a tornado located in northern Bell County near Highway 317 and Southerland Road at 2:15 p.m. If you live in Moffat or Morgans Point Resort...take cover immediately.*

Subsequent storm surveys indicated a weak tornado (probably F0 or F1) lasting about 3 minutes, occurred at Lorena at 1:20 p.m. A brief but intense tornado (classified as F3) occurred at Moody at 1:45 p.m., and another brief F3 tornado occurred at Lake Belton, Bell County (Morgans Point), at 2:35 p.m.

The NWSFO FWD issued the first tornado warning at 1:21 p.m. for McLennan County, 24 minutes prior to the tornado at Moody but minus 1-minute lead time for the county (the Lorena tornado). This was followed at 1:48 p.m. by a tornado warning for Bell County (that was extended at 2:30 p.m.), providing a 47-minute lead time for the county (the Lake Belton tornado).

The NWSFO FWD issued a total of ten tornado warnings, five severe thunderstorm warnings, nine severe weather statements, and eight short-term forecasts during the 4-hour period from

1 p.m. until 5 p.m. on the afternoon of May 27.

- **NWSFO Dallas/Fort Worth Staffing**

During the period from 12 noon until 5 p.m. on May 27, the NWSFO FWD was operationally staffed in the following manner. The Forecaster in Charge and a journeyman forecaster handled the routine forecast operations. A meteorologist intern was in training with the Forecaster in Charge on the synoptic (long-term) desk. As convective activity began to develop, the WCM assumed operation and monitoring of the WSR-88D, initially the NWSFO FWD WSR-88D and then the DOD GRK WSR-88D as the activity moved south. (The Fort Worth NWSFO is an associated user of the DOD GRK radar.) The Meteorologist in Charge (MIC) also assumed operational duties, assisting with the radars and issuing warnings. A second meteorologist intern assisted with coordination activities and in warning issuance, dissemination, and confirmation of receipt. Two hydrometeorological technicians provided public service and NOAA Weather Radio (NWR) programming, and a summer aide assisted with the phone load and NWR programming. A second journeyman forecaster was called in on overtime at 3 p.m. to assist with warning operations. In addition to the "normal" operational staffing, the NWSFO FWD used seven additional personnel to handle this severe weather event.

- **NWSFO Austin/San Antonio Products**

Forecasters at the Austin/San Antonio office were also concerned about the very high CAPE values present in the atmosphere on May 27. (Refer to Appendix A for a chronology of NWSFO EWX actions.) The forecast discussion issued at 3:40 a.m. noted the unstable air mass present over the area, and stated, *"...will mention possibly severe (thunderstorms) for this afternoon."* Subsequent public forecasts which included the counties of Williamson and Travis called for a 30 percent chance of showers and thunderstorms, some possibly severe. In addition, the NWSFO EWX issued a Hazardous Weather Outlook at 6 a.m., calling for the possibility of severe thunderstorms area wide during the afternoon and extending into the nighttime hours. Another forecast discussion issued at 10:15 a.m. dropped mention of severe weather, but an updated Hazardous Weather Outlook issued at 11:15 a.m. continued the call for possible severe thunderstorms and isolated tornadoes and was headlined *"...Severe Thunderstorm and Heavy Rain Event Developing Across South Texas and the Hill Country this Afternoon and Tonight...."* The Outlook went on to state:

> *"The atmosphere is very moist and unstable across south Texas. Conditions are becoming increasingly favorable for the development of scattered severe thunderstorms with large hail...damaging winds and very heavy rainfall. The most severe storms may produce isolated tornadoes."*

Following the SPC's issuance of Tornado Watch #338 at 12:54 p.m., which included Williamson County, the NWSFO issued updated zone forecasts at 1:09 p.m., headlining the watch in the appropriate zones. A Short Term Forecast issued at 1:10 p.m. for Williamson and Travis Counties was headlined with the watch information but noted no significant precipitation was indicated on radar.

At 2:15 p.m., the staff contacted both the Georgetown Police Department and the Williamson County Sheriff's Department to alert them that severe thunderstorms were moving southward through Bell County and that severe weather was very likely in the next 1 to 1 ½ hours.

At 2:48 p.m., another Short Term Forecast was issued for Williamson and Travis Counties and mentioned *"...radar indicated a severe thunderstorm centered just west of Temple moving slowly southwestward. Through 5 PM...partly cloudy skies will prevail with scattered showers and thunderstorms developing by late afternoon...some could possibly be severe...."* This forecast also headlined the existence of the tornado watch for Williamson County.

The forecast discussion issued at 2:50 p.m. emphasized a heavy rain threat. The discussion stated in part:

> *"Complicated weather pattern setting up with weak cold front dropping through hill country tonight then upper level disturbance near 300 mb moves across south central Texas at or about 18Z Wednesday. Tricky to decide where and when heaviest rain will fall because amounts will be high requiring FFA [Flash Flood Advisory] if activity is anything more than scattered.*
>
> *...Service hydro feels activity and boundary will remain mostly stationary and drift slowly southward and get intercepted by upper level 300 mb disturbance early Wednesday AM 12-18Z producing very heavy rain across escarpment area....After discussion with staff...rather than issue blanket FFA will wait until location of heavy rain becomes clearer...."*

The next issuance from the NWSFO EWX was the tornado warning for Williamson County at 3:30 p.m. The text of the warning stated in part:

> *"At 3:25 p.m. a tornadic thunderstorm was located about 5 miles west of Jarral [sic] moving southeast at 10 mph. This storm has had a history of producing tornadoes and large hail. The City of Jarrel [sic] is in the path of this storm."*

This warning gave a lead time of 10 minutes for the town of Jarrell, but no lead time for the extreme northern portion of Williamson County.

A few minutes later, at 3:35 p.m., the office issued a Short Term Forecast for Williamson and Travis Counties (among others) stating:

> *"At 3:30 PM radar indicated a tornadic thunderstorm centered just north of Jarrel [sic] with another developing rapidly north of Georgetown. Movement was southwest at around 10 mph. Residents are warned these storms have a history of producing baseball [size] hail and tornadoes across central Texas this afternoon. Through 5 PM...severe thunderstorms are developing across northern portions of south central Texas and should continue marching southwest."*

At 3:31 p.m., the SPC issued a subsequent tornado watch, #340, for south Texas which included Williamson and Travis Counties. Tornado Watch #340 was posted at 3:45 p.m. and remained in effect until 10 p.m.

At 4 p.m., the NWSFO EWX issued the routine afternoon package of zone forecasts for south Texas. The forecast for Williamson and Travis Counties, in addition to the obligatory tornado watch headline, called for *"Mostly cloudy with a 50% chance of showers or thunderstorms... some possibly severe with locally heavy rainfall."* This was followed at 4:09 p.m. with a tornado warning for Travis County. The warning stated in part:

> *"At 4:05 PM a tornadic thunderstorm was located over Cedar Park. This storm is moving south at 10 mph. This storm will move into northern portions of the City of Austin by 4:30 PM. A tornado was spotted over Cedar Park in Williamson county at 4 PM."*

This warning gave a lead time of 21 minutes for Travis County (the Pedernales Valley tornado). As heavy rains accompanied the tornadic storms, a flash flood warning was issued at 4:34 p.m. for both Williamson and Travis Counties, valid until 6:30 p.m.

The NWSFO EWX issued a total of eight tornado warnings, twenty-four severe thunderstorm warnings, ten flash flood warnings, four severe weather statements and fourteen short-term forecasts during the afternoon and evening of May 27. Approximately 80 percent of these issuances took place after 5 p.m. It also should be noted that, in addition to tracking the tornadic storm in Williamson and Travis Counties, the NWSFO EWX was working a second severe thunderstorm complex which had developed to the west in Edwards County. After 6 p.m., more widespread severe weather developed throughout much of the NWSFO EWX's county warning area (CWA).

- **NWSFO Austin/San Antonio Staffing**

During the daytime hours on May 27 (8 a.m. to 4 p.m.), operational staffing at the NWSFO EWX consisted of: (1) the Forecaster in Charge working the short-term forecast desk (Meso desk) and responsible for monitoring the EWX radar; (2) a journeyman forecaster working the synoptic (long-term) desk and responsible for monitoring the DOD WSR-88D radar at Del Rio, Texas (DLF); (3) two hydrometeorological technicians—one operating and interpreting data from the EWX WSR-88D and the other programming NWR; and (4) two meteorologist interns—one handling public service duties and the other assisting the EWX and DOD DLF radar operations by composing and issuing warnings. During this period of time, in addition to the "normal" operational staffing, the NWSFO EWX used the MIC, the Deputy MIC (DMIC), and the WCM to assist in working the early stages of the severe weather event.

During the late afternoon and evening hours (4 p.m. to midnight), staffing consisted of: (1) Forecaster in Charge working the short-term forecast desk; (2) a journeyman forecaster working the synoptic desk as well as operating and monitoring the EWX WSR-88D; (3) a second journeyman forecaster monitoring the DOD DLF WSR-88D; (4) three meteorologist interns—two handling public service and the phone load while the third intern assisted the DOD DLF WSR-88D forecaster in issuing warnings. Also, two hydrometeorological technicians were on duty—one assisting the EWX WSR-88D operator while the other handled programming the NWR. The DMIC stayed on duty until 6:45 p.m. During the late afternoon and evening hours in addition to the "normal" operational staffing, the NWSFO EWX used five additional personnel to assist in working the latter stages of the event.

An analysis of the staffing and delivery of products issued by the meteorologists during the mid-afternoon of May 27 indicated that the routine forecast packages were prepared and disseminated on schedule. A hydrometeorological technician and a meteorologist intern operated and interpreted the EWX WSR-88D for severe weather; neither of whom had completed formal WSR-88D training at the OSF. Interviews also indicated the staff was somewhat perplexed with the inconsistent behavior of the WSR-88D mesocyclone algorithm and a transitory weakening of the storm. These facts, combined with the atypical meteorological situation, may have influenced the warning decision process.

Dissemination

Communication of warning information, especially in Williamson and Travis Counties, was somewhat problematic during this episode. The Emergency Alert System (EAS) was not activated in a timely fashion in at least one case. The delay of 25-30 minutes was verified by a representative of the Texas Broadcasters Association. According to local media representatives, the delay in broadcasting warning information from NWFSO EWX to the general public via EAS may have been caused by the media outlet choosing to manually activate EAS instead of allowing automatic activation. This choice is prevalent throughout the central Texas area because broadcasters maintain that, due to the number of warnings that can be issued, automatic activation would cause too many interruptions of their programming. Such decisions are part of state and local EAS plans.

The Texas Department of Public Safety Law Enforcement Telecommunication System (TLETS) is used throughout the state to convey important information about criminal activity to agencies. In addition to police-related messages, TLETS is used to distribute weather warning information to law enforcement and emergency management agencies. TLETS functioned as designed throughout the episode and was effective in communicating warning information to Williamson and Travis Counties.

Public Response

The Service Assessment Team conducted interviews with residents of Jarrell, Cedar Park and the Pedernales Valley to determine if the tornado warnings were received by the residents and if so, their response to the warnings. Appendix D lists the persons contacted by the Service Assessment Team. Concurrent with the NWS interviews, a team from the U.S. Centers for Disease Control and Prevention and the Texas Department of Health conducted an assessment to describe mortality and morbidity related to the tornadoes and to provide casual hypotheses for fatalities and injuries. This report is provided in Appendix E.

Almost everyone interviewed said they were aware of the tornado warnings. Most said they first learned of the warnings through commercial television. Others said they received telephone calls from relatives or friends about the approaching storms. Although most were aware of the availability of the NWR, no one mentioned NWR as a source of receiving the tornado warnings.

Due to the slow movement and high visibility of the tornadoes, most of the residents interviewed said they watched the approach of the tornadoes prior to taking shelter. Most said they knew to go to the center of their houses, to avoid staying in mobile homes, and to seek shelter rather than trying to flee the tornadoes. These actions definitely saved lives. However, in the case of the F5 tornado at Jarrell, people were killed even though they took the appropriate safety measures.

Actions taken by the residents of Buttercup Creek (Cedar Park tornado) and Hazy Hills (Pedernales Valley tornado) attest to the value of tornado preparedness efforts and adherence to tornado safety rules. Although approximately 175 homes were damaged or destroyed in these two subdivisions, there was only one fatality and no serious injuries. The single fatality, in the Hazy Hills subdivision, occurred either when the occupant was blown from his mobile home or from his pickup truck as he attempted to flee the storm.

Media stories written and aired during the aftermath highlighted people in the path of the Jarrell tornado who fled the area and survived while many others who obviously followed prescribed safety measures perished. Media reports such as this provide conflicting guidance to the public about appropriate safety measures. This “mixed message” may lead to some people in the future trying to flee the storm area rather than seeking appropriate shelter.

It appeared through interviews with store and restaurant managers that formal tornado or other severe weather safety plans for protection of employees and customers did not exist. The Albertsons grocery and Taco Bell managers in Cedar Park, however, instructed their employees to move to reinforced areas of their buildings. In the case of the Albertsons store, which sustained significant damage, these actions undoubtedly saved many from serious injury and possibly death.

Two stories told to the Service Assessment Team illustrate how knowledge of tornado safety rules can save lives. The manager of the Albertsons grocery store in Cedar Park went outside into the parking lot to watch the approaching thunderstorm. While approximately 60 customers were shopping inside, he watched for a few minutes as the tornado developed. Going back inside the store, he instructed that an announcement be made asking everyone to gather in the center of the store so he could lead them into the store’s cooler in the rear of the building. He also asked customers trying to leave the store to stay inside. Although the store’s wide-span roof collapsed into the center of the store, the customers survived in the cooler with only a few minor injuries. One store employee who did not make it into the cooler suffered serious injury. The actions of the store manager saved many from certain serious injury and possibly death. When asked how he knew to keep customers from fleeing the store and to move customers and employees into the store's cooler, the manager replied that he "was raised in Wichita Falls and was there during the 1979 tornado." The 1979 Wichita Falls tornado killed more than 40 people. Over half the fatalities in Wichita Falls occurred in automobiles, many of whom were trying to flee the tornado.

In the Jarrell tornado, structures in its immediate path were totally destroyed. A few residences on the fringe of the tornado path, while sustaining nearly total destruction, still had some walls left standing. In one such residence, a grandmother, her daughter, daughter-in-law and two young grandchildren survived in a centrally located bathroom. The walls of the bathroom were all that were left standing of the home. The grandmother and daughter told the Assessment Team that they did not know where in the house to seek shelter from the tornado, which they could see approaching them. The daughter told the Assessment Team, "My sister-in-law saved our lives." The daughter-in-law, who lived just down the road, had run to the house with her child to seek shelter from the storm. She instructed everyone to get into the central bathroom. Her relatives commented that she had picked the correct bathroom of the two in the house. She stated "But you always go to the center of the house." The Assessment Team asked how she knew about what to do and she replied that she had "learned the [tornado] safety rules as a child." Without this knowledge and quick action on her part, there most certainly would have been five additional fatalities in the Jarrell tornado.

Events related to the Jarrell tornado were indescribably tragic. It is the consensus of the Service Assessment Team that most residents in the Double Creek Estates subdivision were aware of the impending danger and knew the proper precautionary measures to take. Nevertheless, due to the force (F5), width, and slow rate of movement of the tornado, the protective measures taken were to no avail for those directly in its path of destruction.

Remains of a home adjacent to the Double Creek Estates subdivision of Jarrell. This home is located on the edge of the tornado path. Five people survived the storm in a bathroom (center of picture). Photograph by E. L. McIntyre, NOAA/NWS.

Home destroyed in Buttercup Creek subdivision during Cedar Park tornado. Several people took shelter in a utility closet, shown just to the left of the woman in the picture. Photograph by NWSFO Austin/San Antonio.

Aerial view of Albertsons grocery store showing damage from the Cedar Park tornado. Photograph by L. Phan, NIST.

Ground view of damage to Albertsons grocery store. Photograph by M. Trainor, NOAA.

Facts, Findings and Recommendations

A. Observations

Finding 1:

The amateur radio base station at NWSFO EWX was not activated for Tornado Watch #338. The NWSFO EWX did try to contact the amateur radio coordinator for Tornado Watch #340 but could not raise him. They also could not contact a backup coordinator. No one on duty at NWSFO EWX knew how to turn on the amateur radio equipment for passive monitoring. Therefore, vital spotter information was not received via this amateur radio link. A meteorologist intern at NWSFO EWX indicated he did receive one report via a phone call from an amateur radio operator.

Recommendation 1:

Personnel at NWSFO EWX should be trained in how to turn on the amateur radio equipment so that they can at least hear reports, even if the network is not activated. NWSFO EWX should also work with the amateur radio coordinator on backup procedures for contacting key people in impending emergencies.

Finding 2:

The Fort Hood WSR-88D (GRK) (Granger, Texas, WSR-88D) ceased to function after the 3:38 p.m. volume scan and remained out of service for a number of hours. This radar is operated and maintained by the U.S. Air Force. The radar was located only 20 miles from the Jarrell tornado. An associated Principal User Processor display system from this radar is installed in the NWSFO FWD. The radar was invaluable to NWSFO FWD for warnings issued in McLennan and Bell Counties. If the radar had ceased to function earlier in the afternoon, warning operations would have been severely impacted.

It was subsequently learned that the radar had shut down because of a commercial power failure and that its emergency power failed to come on-line because a control switch had been left in the improper position during a previous maintenance visit.

Recommendation 2:

The NOAA and the NWS should increase efforts in working with the DOD to ensure that DOD commanders and personnel understand that properly maintained and operated DOD WSR-88Ds are vital to the severe weather warning programs for both the bases and the civilian populations under the radars' umbrellas.

Finding 3:

Satellite data provided a number of valuable pieces of information for use in severe thunderstorm nowcasting over Texas on May 27, 1997. (Appendix B provides a research analysis of the May 27 events using NOAA meteorological satellite data.) The storm complex that produced the tornado activity between Moody and the Pedernales Valley on this day had cloud top features that are often associated with thunderstorms that have very intense updrafts. The precise location, orientation and movement of the front along which the tornadic storm complex evolved was easily monitored using Geostationary Operational Environmental Satellite (GOES) imagery. Unfortunately, real-time data flow into a satellite analysis and display system that would have allowed for a number of useful applications was not available to the NWSFO EWX forecasters.

Recommendation 3:

The NOAA/NWS should move rapidly to ensure that all Weather Forecast Offices (WFOs) in the NWS are equipped with the best possible satellite analysis capabilities that are part of the Advanced Weather Interactive Processing System (AWIPS). The NWS should also provide proper training to ensure that satellite data are used in the warning and forecast program.

B. Forecast Guidance

Finding 4:

A coordination call was not made from the SPC to NWSFO EWX prior to Tornado Watch #338 being issued even though the watch included a part of NWSFO EWX's CWA. Such a coordination call may have further heightened the severe weather awareness of the staff at the NWSFO EWX.

Recommendation 4:

The SPC should make every effort to coordinate with any NWS office that has warning responsibility before a watch is issued that covers a part of the CWA of that NWS office.

Finding 5:

The tornado outbreak was a unique event in that significant tornadoes were produced in a situation of weak shear and high instability. Although storms exhibited supercell characteristics (mesocyclones with tornadoes, weak echo regions, deviate storm motion), an unusual storm evolution occurred. High thermodynamic instability and storm interactions with a pre-existing wind shift boundary resulted in highly deviate storm motion and the rapid development of mesocyclones and tornadoes. The mesocyclone and tornado development formed farther ahead (to the southwest) of the low-level radar reflectivity field than is typically observed. The mesocyclones grew from areas of deep convergence within large weak echo regions characteristic of very strong updrafts. While the evolution may have been unexpected, easily detectable mesocyclones developed prior to the tornadoes. However, the mesocyclone algorithm-signature (MESO) on the EWX WSR-88D was inconsistent and missed several significant circulations. The tornado vortex signature (TVS) algorithm did not trigger. The team is concerned with these failures.

Recommendation 5:

The OSF should evaluate the Level-2 Archive data from the EWX radar and further investigate these anomalies. The NEXRAD Program should continue its plans to implement the National Severe Storm Laboratory's experimental mesocyclone algorithm because of its higher skill and informative outputs, including probabilistic guidance values.

Finding 6:

This outbreak of tornadoes was perceived as an unusual event in that the tornadoes tracked to the southwest with several tracks having a right loop at the end. The storm environment was characterized by weak vertical wind shear and high thermodynamic instability. Interpretation of GOES satellite loop imagery suggests the possibility of a gravity wave moving southwest across northern Texas and the lower Mississippi Valley into this area of extreme low-level instability. This feature may have initiated the first supercell thunderstorm that formed.

Recommendation 6:

A thorough scientific study of these events should be undertaken by researchers and academicians with the results made available to forecasters of the NWS. Any study should include the U.S. Weather Research Program (USWRP), the NWS Collaborative Science, Technology, and Applied Research Program (CSTAR) and NOAA/NWS Cooperative Institutes.

C. Watches, Warnings and Statements

FACT C1:

The actual time of the Jarrell tornado development was hard to pinpoint, but it is believed to be between 3:15 p.m. and 3:20 p.m. Initially, the tornado was weak and small, probably no more than F0 or F1. It moved slowly south-southwestward crossing into Williamson County around 3:25 p.m. Shortly thereafter, the tornado explosively strengthened to F5 before moving into the Double Creek Estates subdivision on the west side of Jarrell around 3:40 p.m.

FACT C2:

The SPC issued Tornado Watch #338 at 12:54 p.m. for portions of east Texas valid from 1:15 p.m. until 7 p.m. At 3:31 p.m., the SPC issued Tornado Watch #340 for south Texas, including Williamson County, valid from 3:45 p.m. until 10 p.m.

FACT C3:

At 2:15 p.m., the NWSFO EWX staff phoned the Georgetown Police Department and the Williamson County Sheriff's Department to alert them that severe thunderstorms were moving southward through Bell County and that severe weather was likely in the next 1 to 1 ½ hours.

FACT C4:

NWSFO EWX issued a tornado warning for Williamson County at 3:30 p.m. This gave a lead time of at least 10 minutes for the town of Jarrell but no lead time for the northern portion of Williamson County.

Finding 7.1:

Individuals at NWSFO EWX who were directly associated with WSR-88D manipulation and interpretation of the data it was providing on May 27, 1997, had not attended the intense 4-week OSF operational training course. The OSF course has been canceled, and the NWS is planning a new method of training for those personnel who will manipulate and interpret the WSR-88D radar.

Finding 7.2:

Prior to the development of the Jarrell tornado, a series of mesocyclones had a history of producing tornadoes in McLennan and Bell Counties in the NWSFO FWD's CWA. Early data on the storms from the NWSFO EWX WSR-88D were significantly range-folded due to second trip ground clutter. This range-folding could have been mitigated if the NWSFO EWX radar operators had changed the pulse repetition frequency.

Finding 7.3:

Although most supercell thunderstorms contain mesocyclones on the right rear flank with respect to storm motion, the mesocyclones on this day were located on the front flank (southwest quadrant) as they moved slowly south-southwestward. The difference in mesocyclone location is probably due to enhanced southwestward propagation along the boundary. The storms emerged from the range-folded area on the NWSFO EWX WSR-88D about 20 minutes prior to the development of the Jarrell tornado. Despite the fact that the reflectivity features were not typical and could have perplexed a radar interpreter accustomed to viewing radar reflectivity signatures alone, the rotational velocity signatures were clear and easy to follow and should not have confused an operator trained in WSR-88D data interpretation.

Finding 7.4:

Meteorologists trained in mesoscale events recognize that fluctuations in storm strength should not be surprising when storms form in an environment of weak shear but high instability. At the same time, with an explosively unstable thermodynamic environment, transient weakening in existing convection should be viewed with extreme caution. Furthermore, this “atypical” (see Finding 5) meteorological situation may have influenced the performance of the WSR-88D MESO.

Recommendation 7:

Use and interpretation of the WSR-88D data, especially in convective situations, should be left to meteorologists trained in both mesoscale meteorology and the interpretation of WSR-88D data. In addition, NWS WFOs should be appropriately staffed with a sufficient number of such meteorologists to meet these requirements. Further, the NWS needs to ensure that any future training programs being developed to replace the OSF WSR-88D course should be of equal or better effectiveness than was that course. Meteorologists must have the ability to quickly interpret reflectivity and velocity signatures within the context of the overall mesoscale weather pattern, and relate the radar information to the other analyses and observing tools such as a detailed mesoscale surface analysis combined with satellite, surface observations, profiler and radar Velocity Azimuth Display (VAD) vertical wind profiles, etc. Accordingly, the NWS should ensure that the expertise, materials, and other resources, including field staff time, are made available to meet such a training requirement.

Finding 8.1:

At NWS NWSFOs, the Forecaster in Charge on duty is the “supervising operational meteorologist” and is responsible for warning and forecast operations, including severe weather staffing and products, if a storm event develops. This procedure was not implemented effectively at NWSFO EWX on May 27, 1997. Responsibility for severe weather operations was assumed by a meteorologist intern and a radar operator. During the early stages of the severe weather episode, no single forecaster supervised, monitored and coordinated closely the activities and decision-making processes.

Finding 8.2:

As the severe weather approached the northern part of NWSFO EWX's CWA, short-term forecasts were limited in number and not sufficient. This occurred as the office transitioned from a stance of routine operations into immediate full-scale warning operations as the severe weather moved into the area. The office issued many more short-term forecasts, as well as a number of severe weather statements, later in the evening to supplement warnings on a number of tornadic events that occurred further south in the southern portions of the NWSFO EWX's CWA.

Finding 8.3:

The product mix flowing from the office early in the severe weather event did not seem to be coherent in terms of the warnings, short-term forecasts and severe weather statements.

Finding 8.4:

A review of the state forecast discussion and other products issued by NWSFO EWX indicated that the office was focusing upon the potential for a heavy rain episode, which did occur later in the evening, instead of tornadic activity. In addition, interviews with the staff mentioned that, early in the severe weather episode, they were concerned with getting the routine afternoon forecast package "out on time" and devoted considerable resources to that effort.

Recommendation 8:

Management at NWSFO EWX should establish and enforce clear lines of authority and responsibility to be followed during severe weather operations. Further, emphasis should be given to keeping all staff current regarding such operational procedures.

Protection of life and property is the fundamental mission of the NWS. NWS offices need to develop a strategy for a coherent product suite encompassing warnings, statements and short-term forecasts throughout severe weather episodes. They need to work with customers to apprise them of priority which will be placed upon products during such events. All NWS WFOs should have a standing policy that routine products have a much lower priority during periods of ongoing severe weather. They should ensure that all staffing resources be brought into a cohesive severe weather mind set and that the focus of the office is always on the fundamental mission.

D. Internal and External Service Coordination

Finding 9:

After the issuance of warnings, considerable staff resources were invested by NWSFO EWX to confirm receipt of warning information by emergency management officials. In some cases, multiple phone calls were made into the same county.

Recommendation 9:

The staff at NWSFO EWX is commended for their dedication and extra effort to seek confirmation that warning information was being received by officials who had a critical need for it. Nevertheless, it is recommended that NWSFO EWX work with emergency management officials to seek alternative and more efficient methods to confirm receipt of warnings.

Finding 10:

During the severe weather events of May 27, 1997, there were occasional delays in coordination between the NWSFO FWD and the NWSFO EWX as the tornadic situation shifted from NWSFO FWD's CWA to NWSFO EWX's CWA. The coordination mechanism of choice, commercial telephone, was hampered by busy signals. The Texas State National Warning System (NAWAS) circuit was available to both FWD and EWX, but NWS offices in Texas use commercial telephones for coordination because of various logistical problems associated with NAWAS.

The Texas NAWAS links intra-state warning points and NWS offices throughout Texas. The circuit is divided into two sub-circuits, but Texas has made the decision to operate the circuit as a single state-level circuit. Considering the size of the state, the circuit can be busy with law enforcement traffic, and the state discourages its use for routine business. It was noted that NAWAS traffic was heavy on May 27, and if NWS personnel had chosen to use the circuit for coordination purposes, they may have had to ask others to get off the circuit (an unlikely scenario in non-emergency, coordination-only situations).

Nationally, NAWAS was in the process of being upgraded to better accommodate the internal/external communication and coordination requirements of the NWS and the emergency management community. Because of Federal budget constraints, the upgrade has been halted, and Texas NAWAS terminals have not been fully upgraded.

Recommendation 10:

The NWS should reach consensus with the Federal Emergency Management Agency (FEMA) and the state emergency management agencies on a single communication/ coordination system that is consistent nationally and meets the internal and external communication/coordination requirements of both the NWS and the emergency management community. All NWS offices should be provided with needed technology to facilitate efficient internal and external coordination.

E. Dissemination

Finding 11.1:

There was a significant delay in the activation of the EAS. For example, the official notification to EAS from the NWR was at 3:30 p.m. The EAS was not activated until 3:56 p.m. in at least one instance.

Finding 11.2:

Broadcasters maintain that the EAS "ticker" does not identify why EAS activation is being requested. Consequently, they have to wait for hard copy which says "EAS activation requested." This introduces delays in the activation procedure.

Finding 11.3:

Media outlets apparently choose manual activation of EAS instead of automatic activation. This choice is prevalent throughout the central Texas area because broadcasters maintain that automatic activation would cause too many interruptions of their programming.

FACT E1:

NWS policy only requires EAS activation requests on tornado warnings and flash flood warnings.

Recommendation 11:

The NWS has sent to the Federal Communications Commission (FCC) proposed revisions to the EAS rules. The NWS should continue to work with the FCC to clarify situations that need automated activation. The NWS and the FCC, in cooperation with the National Association of Broadcasters, should agree on a limited set of critical weather warning products which would be programmed for automatic activation of the EAS.

Finding 12:

The TLETS is designed to carry information primarily related to law enforcement activities. It is not designed to be a weather warning dissemination system; nevertheless, it is used by emergency managers and law enforcement agencies to obtain weather information. In this particular event, TLETS was effective in disseminating warning information in a timely manner. However, since TLETS is not a totally automated system (i.e., it requires the manual routing of products), delays in the dissemination of time-sensitive weather information can occur.

Recommendation 12:

The NWS should continue to work with the state of Texas Division of Emergency Management to seek ways to improve the timely transmission of weather warnings via TLETS and should intensify efforts on both a local and state level to explore alternative methods of communicating critical weather products to emergency management officials.

Finding 13:

The general public interviewed by the survey team did not use NWR as a first-choice source of weather information. They relied on commercial radio and television. The broadcast media, in general, used NWR as a backup source of severe weather information, but not all radio stations have NWR receivers. Some emergency managers used NWR as a primary source of severe weather information.

Recommendation 13:

The NWS should develop additional partnership initiatives with the public and private sector to encourage the use of NWR for the receipt of critical weather information.

Finding 14:

The NWR transmitter serving Austin and surrounding communities lost power as the storms moved through the general Austin area, and there is no backup power for the site.

Recommendation 14:

All the NWR transmitters should be equipped with backup power.

F. Response

Finding 15.1

After the Jarrell tornado, which moved unusually slowly, there was a widespread belief by the general population that persons who took appropriate safety actions were killed, while persons who took inappropriate safety actions lived. This has prompted questions from the public as well as the media regarding the viability of tornado safety rules the NWS promotes.

Finding 15.2:

Through a limited number of interviews with people in the Cedar Park area, the Pedernales Valley area, and even some people in the Jarrell area, the Service Assessment Team found that lives were definitely saved because people took appropriate safety actions in accordance with long-standing recommendations of the NWS, FEMA, the American Red Cross (ARC) and the emergency management community.

Recommendation 15:

The NWS, in concert with FEMA and the ARC, should continue to emphasize the importance of not attempting to flee an approaching tornado and reemphasize the importance of adhering to long established tornado safety rules. (In the vast majority of situations, people who take shelter in sturdy, well-built structures will survive most tornadoes whereas people who try to flee in automobiles will place themselves at much greater risk.) The Service Assessment Team also recommends that there be significant public and industry education on the meaning of well-built tornado shelters.

G. Preparedness

Finding 16:

The majority of managers of supermarkets, restaurants and other stores that the Service Assessment Team interviewed did not have predetermined tornado or other severe weather safety plans to activate for protection of their employees and customers during severe weather threats. Worthy of note, however, is that the Albertsons and Taco Bell managers in Cedar Park instructed their employees and customers to move to a reinforced area of their buildings as the tornado approached. The action of the Albertsons manager undoubtedly saved many lives.

Recommendation 16:

The NWS should partner with other public agencies and the private sector to develop plans for protection of employees and the public located in large buildings during severe weather threats.

H. System/Infrastructure

FACT H1:

NWS offices are typically staffed for fair weather situations. During difficult mesoscale weather events, offices frequently have to either recruit all personnel on duty, hold people on overtime, or call in whomever they can reach from home to help with the increased workload associated with programming the NWR, operating and interpreting data from WSR-88Ds, performing analyses, and assisting in warning operations.

As the NWS continues to move forward with its restructuring, the staffing at offices, such as the NWSFOs at Fort Worth and Austin/San Antonio, although currently augmented with transitional staffing, is projected to decrease. The NWS also plans, in a multi-phased approach, to decentralize severe weather watches from the SPC to the field WFOs. To mitigate the workload associated with these and other responsibilities, the NWS is depending upon AWIPS, an automated Console Replacement System for NWR, and the integration of other functions to allow forecasters to more easily handle duties covering the continuum of information.

Finding 17:

The workload associated with the events of May 27, 1997, challenged the staffs of the NWSFOs involved. At NWSFO FWD, seven additional personnel beyond the normal shift complement were pressed into service, including the MIC and WCM who were intimately involved in the warning process. NWSFO Austin/San Antonio augmented their normal shift structure with five personnel, including the MIC and Deputy MIC who were on the forecast floor and available as necessary.

Recommendation 17:

First, the NWS should ensure that all field offices develop strategies that make full use of all office personnel qualified to assist in warning and forecast operations during critical weather situations.

Second, the NWS should evaluate its plans regarding future staffing and service changes to ensure that workload constraints do not compromise the agency's safety of life and property mission. Specifically, transitional staffing which has been placed at selected offices should be retained until such time as new technology can demonstrate it is capable of mitigating the workload associated with warning and forecast operations to an extent that a reduction in staff is feasible.

Finding 18:

Over 10,000 tornadoes have occurred in the United States during the last 10 years. During that period of time, only six of these tornadoes have been rated as an F5. Of those six, only two tornadoes occurred under the synoptically evident southwesterly flow. The other four occurred in atypical westerly or northwesterly flow. Such situations are often accompanied by extreme instability. The extreme instability is not sufficient to determine storm type and/or tornado development since these same patterns often produce bow echoes and associated derechos instead of tornadoes. Extreme instability could play a role in tornado intensity through stretching or some other storm-scale effect.

Recommendation 18:

Studies should be undertaken by the research and academic community to help identify these types of patterns which may aid in the development of these rare but catastrophic tornadoes. Such studies should have the participation of the USWRP, CSTAR, and NOAA/NWS Cooperative Institutes. The results of these studies should be made available to NWS forecasters to aid in the warning and forecast process.

Finding 19:

Since NOAA and the NWS do not have a Quick Response Hazards Survey Team in place, it usually takes 48-72 hours to assemble a team and put that team into the centroid of the outbreak. This is especially true for the aerial part of the survey which allows highly detailed documentation which is necessary to support findings that are generated by the NWS modernized suite of equipment. In the case of the central Texas tornadoes, there were not a lot of trees and local authorities were quick to repair damage and remove debris. This hampered the exact location of the damage paths and the times of occurrence. The uncertainty of the times or the paths of tornadoes makes it very difficult to analyze the data for current performance or develop strategies for better future performance.

Recommendation 19:

NOAA/NWS should compile a list of potential, quick-response team members, drawn from appropriate expertise in the NOAA line and staff offices, other Department of Commerce Bureaus such as NIST, and from the universities and private sector. The team should be interdisciplinary in nature. Following a significant tornado outbreak, a team of three to five scientists should be assembled and dispatched to the centroid of the outbreak within 24 hours. Teams should include meteorologists, a wind engineer, and a social scientist, an epidemiologist and a public affairs specialist. Funding to carry out the travel costs of the team and an aerial damage-mapping survey should be set aside yearly in a revolving budget.

Aerial view of damage from the Moody tornado. Photograph by L. Phan, NIST.

Aerial view of damage to boats at Belton Lake from the Belton tornado. Photograph by L. Phan, NIST.

Close-up aerial view of the remains of a home in the Double Creek Estates subdivision of Jarrell. Photograph by L. Phan, NIST.

Close-up view of a home foundation in the Double Creek Estates subdivision of Jarrell. Note the plumbing pulled out of the concrete in the center of the picture. Photograph by NWSFO Austin/San Antonio.

Asphalt stripped from the road by the Jarrell tornado in the Double Creek Estates subdivision. Photograph by I. Hakkarinen, NOAA/NWS.

Remnants of a mobile home trailer in the Double Creek Estates subdivision of Jarrell. Photograph by NWSFO Austin/San Antonio.

Damage to a telephone switching station caused by the Pedernales Valley tornado. Photograph by M. Trainor, NOAA.

Truck in the Hazy Hills subdivision that was blown up a hill by the Pedernales Valley tornado. Photograph by I. Hakkarinen, NOAA/NWS.

Appendix A

Chronology of Releases
Related to the Central Texas Tornadoes

Chronology of Events at the Storm Prediction Center

From 1:00 am CDT through 11:00 pm CDT - Tuesday, May 27, 1997

103 AM	DY1	CONVECTIVE OUTLOOK...MODERATE RISK OF SEVERE THUNDERSTORMS FOR HAIL AND DAMAGING WINDS INCLUDING TRAVIS AND WILLIAMSON COUNTIES...
1016 AM	DY1	CONVECTIVE OUTLOOK...MODERATE RISK OF SEVERE THUNDERSTORMS. NCLUDING TRAVIS AND WILLIAMSON COUNTIES...CONDS WILL BE FVRBL FOR THE DVLPMT OF SCTD INTENSE STMS WITH VRY LRG HAIL..LCLY DMGG WINDS AND PSBLY ISOLD BRIEF TORNADOES.
1254 PM	AWW	QUICKIE NOTIFICATION OF TORNADO WATCH 338
1254 PM	SEL8	TORNADO WATCH #338 ISSUED FOR EAST TEXAS INCLUDING BELL, MCCLENNAN AND WILLIAMSON COUNTIES. DISCUSSION MENTIONED VERY LARGE HAIL/LOCALLY DAMAGING WINDS AND ISOLATED TORNADOES POSSIBLE THIS AFTERNOON IN VERY UNSTABLE AIR ASS/CAPE TO 5000 J/KG/ OVER REGION. ANY TORNADOES WILL LIKELY BE CONFINED TO BOUNDARY INTERSECTIONS GIVEN COMPARATIVELY WEAK VERTICAL SHEAR.
306 PM	MCD	STATUS OF TORNADIC STORM NEAR TPL...VERTICAL WIND PROFILES ARE QUITE WEAK...WITH LATEST KEWX DATA SHOWING VARIABLE WINDS AT 5-10 KNOTS THROUGH 700 MB. DEGREE OF INSTABILITY CERTAINLY SUPPORTS LARGE HAIL AND WIND DAMAGE...BUT IT IS UNCLEAR HOW TORNADIC SUPERCELL NEAR TPL WILL EVOLVE AS IT ENCOUNTERS APPARENTLY WEAKER MID LEVEL FLOW OVER THE NEXT FEW HOURS. DUE TO PROPAGATION OF THIS STORM AND EXPECTED RAPID DEVELOPMENT OF NEW CONVECTION TOWARD DRT...A NEW TORNADO WATCH WILL BE REQUIRED SOUTH AND WEST OF #338 SHORTLY.
331 PM	AWW	QUICKIE NOTIFICATION OF TORNADO WATCH 340
331 PM	SEL0	TORNADO WATCH 340 ISSUED FOR SOUTH TEXAS INCLUDING WILLIAMSON AND TRAVIS COUNTIES. DISCUSSION MENTIONED INTENSE THUNDERSTORMS WITH VERY LARGE HAIL...HIGH WINDS AND ISOLATED TORNADOES POSSIBLE THIS EVENING WHERE MODERATE LOW LEVEL INFLOW OF VERY MOIST AIR CONTINUES BENEATH AXIS OF STEEP LOW TO MID LEVEL LAPSE RATES AHEAD OF SOUTHEAST MOVING COLD FRONT. DEEP LAYER VERTICAL SHEAR LIMITED...BUT TORNADOES STILL POSSIBLE IN VICINITY OF BOUNDARY INTERSECTIONS.

339 PM	WWA	STATUS OF WW#338...ISOLD SVR TSTMS ARE OCCURRING OVR PARTS OF ERN TX ALG/AHD OF WEAK SFC CDFNT. SUPERCELL NOW OVR BELL CNTY TX NR TPL CONTS TO DVLP SLOWLY SWD ALG FRONT. THIS STORM HAS ALREADY PRODUCED SVRL TORNADOES WITH RPTS OF SGFNT DMG. ANOTHER SUPERCELL APPRS TO HAVE DVLPD OVR NAVARRO CNTY. TORNADO THREAT SHUD REMAIN FOCUSED ALG BNDRY OVR NAVARRO/HILL/MCLENNAN/BELL/WILLIAMSON/TRAVIS CNTYS NEXT 1-2 HOURS WHERE STG CONVERGENCE IS OCCURRING. WW 340 HAS JUST BEEN ISSUED S OF CURRENT WATCH.
457 PM	WWA	STATUS OF WW#338...AN EXTRMLY UNSTBL AMS RMNS IN PLACE OVR MUCH OF ERN TX/WRN LA. SFC OBS SHOW TEMPS IN THE UPR 80S AND LWR 90S AND DWPNTS IN THE LOW TO MID 70S...YIELDING SFC BASED CAPE VALUES AOA 4500 J/KG. THE STGST CELLS WERE CURRENTLY LOCATED IN PONOLA...LIMESTONE...AND WILLIAMSON CNTYS. A TORNADO WAS RPRTD WITHIN THE PAST HR IN CEDAR PARK IN NRN WILLIAMSON CNTY. THIS PARTICULAR CELL CONTS TO MOV/PROPAGATE TO THE S AND WILL LIKELY MOVE INTO WW 340 WITHIN THE NEXT HR OR SO. ALTHOUGH WNDS ARE WK ALF...THERE IS STG VEERING IN THE LOW TO MID LVLS. GIVEN THE DEGREE OF INSTABILITY...THE WND FIELDS SUG THE PTNL FOR FURTHER TORNADIC DVLPMNT WL CONT FOR THE NXT SVRL HRS.

SPC Tornado and Severe Thunderstorm Reports

Partial Preliminary List For Texas
For 0600 Central Standard Time Tue May 27 1997
Thru 0600 CST Wed May 28 1997

	EVENT	LOCATION			REMARKS DATE/TIME LAT/LON
.....TORNADO REPORTS.................TORNADO REPORTS.............TORNADO REPORTS......					
1	TORN	3 W LORENA TX	(16 S ACT)		27/1224
				FTW/LSR	3138 9727
2	TORN	2 W LORENA TX	(16 S ACT)		27/1254
		SEVERAL MOBILE HOMES DAMAGED AND ONE HOUSE			
		DESTROYED		FTW/LSR	3138 9725
3	TORN	1 E MOODY TX	(11 NNE TPL)		27/1259
		BUILDINGS DAMAGED		FTW/LSR	3131 9733
4	TORN	BELTON TX	(5 SSW TPL)		27/1331
				FTW/LSR	3106 9746
5	TORN	3 N BELTON TX	(3 SW TPL)		27/1340
				FTW/LSR	3111 9746
6	TORN	3 W BELTON TX	(8 SW TPL)		27/1354
		TORNADO BETWEEN NOLANVILLE AND BELTON			
				FTW/LSR	3106 9752
7	TORN	BLOOMING GROVE TX	(44 NE ACT)		27/1405
				FTW/LSR	3210 9671
8	TORN	2 W HUBBARD TX	(27 ENE ACT)		27/1450
				FTW/LSR	3184 9683
9	TORN	6 N GEORGETOWN TX			27/1455
		ALONG I-35		SAT/LSR	3073 9766
10	TORN	LEANDER TX	(20 NNW AUS)		27/1500
				SAT/LSR	3058 9784
11	TORN	JARRELL TX	(25 SSW TPL)		27/1515
		*** 30 DEAD ***		SAT/LSR	3081 9759
12	TORN	AUSTIN TX	(2 WSW AUS)		27/1515
		AUSTIN PD REPORTED TORNADO ON GROUND			
		NEAR 2222 AND ANDERSON MILL			
				SAT/LSR	3028 9774
13	TORN	CEDAR PARK TX	(13 NNW AUS)		27/1515
		*** 2 DEAD ***	REPORT OF GROCERY STORE		
		COLLAPSE IN CEDAR PARK. REPORTS			
				SAT/LSR	3049 9781
14	TORN	AUSTIN TX	(2 WSW AUS)		27/1550
		TORNADO ON GROUND NEAR LAKEWAY AND 620			
				SAT/LSR	3028 9774
15	TORN	LEANDER TX	(20 NNW AUS)		27/1600
				SAT/LSR	3058 9784

16	TORN	KENDALIA TX (28 N SAT)			27/1745
		SHERIFF REPORTS TORNADO IN SW BLANCO			
		COUNTY MOVING TOWARDS KENDALI			
				SAT/LSR	2996 9851
17	TORN	BLANCO COUNTY	(40 W AUS)		27/1745
		TX		SAT/LSR	3026 9838
		SHERIFF REPORTS TORNADO IN SW BLANCO COUNTY			
		MOVING TOWARDS KENDALI			
18	TORN	BLANCO TX	(38 N SAT)		27/1808
		TORNADO ON GROUND SW OF BLANCO			
				SAT/LSR	3009 9841
19	TORN	UTOPIA TX	(27 NW HDO)		27/1900
		SHERIFF REPORTED TORNADO ON GROUND			
				SAT/LSR	2961 9953
20	TORN	MOUNTAIN HOME TX			
			(34 SE JCT)		27/1903
		TORNADO REPORTED ALONG I-10 IN KERR			
		COUNTY		SAT/LSR	3016 9936
21	TORN	SISTERDALE TX	(33 NNW SAT)		27/1930
		HAM REPORTED POSSIBLE TORNADO ON GROUND			
				SAT/LSR	2996 9873

.............LRG HAIL/STRONG WIND RPTS..................LRG HAIL/STRONG WIND RPTS......

22	A275	BRUCEVILLE TX	(14 NE TPL)		27/1305
				FTW/LSR	3131 9723
23	A275	EDDY TX	(13 NE TPL)		27/1306
				FTW/LSR	3130 9725
24	A175	TROY TX	(6 ENE TPL)		27/1325
				FTW/LSR	3120 9730
25	A125	TATUM TX	(25 ESE GGG)		27/1330
		NWS COOP OBSERVER ON RUSK-PANOLA			
		COUNTY LINE REPORTED HAIL ON BOTH			
				SHV/LSR	3219 9433
26	A125	TATUM TX	(17 S GGG)		27/1330
		NWS COOP OBSERVOR ON RUSK-PANOLA			
		COUNTY LINE REPORTED HAIL ON BOTH			
				SHV/LSR	3213 9476
27	G52	ROUND ROCK TX	(12 N AUS)		27/1545
				SAT/LSR	3049 9768
28	A175	MEXIA TX	(42 E ACT)		27/1553
				FTW/LSR	3168 9650
29	G62	AUSTIN MUELLER MUNI ARPT TX			
			(0 E AUS)		27/1620
		KAUS METAR PK WIND 02062/2220			
				SPC/LSR	3030 9769
30	G52	ROUND ROCK TX	(12 N AUS)		27/1645
				SAT/LSR	3049 9768
31	A175	DRIFTWOOD TX	(23 WSW AUS)		27/1650
		REPORTED BY SHERIFFS DEPT		SAT/LSR	3011 9803

Chronology of Events at NWSFO Fort Worth, TX

From 5:00 am CDT through 6:00 pm CDT - Tuesday, May 27, 1997

Time	Product	Description
532 AM	SPS	SEVERE OUTLOOK FOR NORTH TEXAS...MODERATE RISK OF SEVERE THUNDERSTORMS THIS AFTERNOON AND TONIGHT GENERALLY SOUTHEAST AND EAST OF A KILLEEN, TO MERIDIAN TO TEXARKANA LINE.
1100 AM	SFD	NORTH TEXAS FORECAST DISCUSSION. MORNING SOUNDINGS SHOWING A STRONG CAPPING INVERSION OVER NORTH TEXAS..HOWEVER, ABOVE THE CAP..A STEEP LAPSE LEADS TO VERY STRONG INSTABILITY IF THE CAP IS BROKEN.
1130 AM	ZFP	BELL AND MCLENNAN COUNTIES. PARTLY CLOUDY WITH A 30 PERCENT CHANCE OF THUNDERSTORMS..SOME SEVERE AND WITH LOCALLY HEAVY RAIN.
1250 PM	SVR	SEVERE THUNDERSTORM WARNING FOR MCLENNAN COUNTY. A RAPIDLY DEVELOPING THUNDERSTORM LOCATED NEAR WOODWAY CURRENTLY PRODUCING PEA TO MARBLE (SIZE) HAIL...CONDITIONS ARE FAVORABLE FOR MUCH LARGER HAIL BY 1 PM. 0.75 INCH HAIL REPORTED NEAR WOODWAY AT 110 PM.
1255 PM	NOW	FOR BELL AND MCLENNAN COUNTIES..SCATTERED THUNDERSTORMS NOW IN PROGRESS WILL CONTINUE TO DEVELOP AND WILL BE CAPABLE OF PRODUCING DAMAGING WINDS AND LARGE HAIL.
121 PM	TOR	FOR MCLENNAN COUNTY. NWS DOPPLER RADAR INDICATES TORNADO NEAR HEWITT.
126 PM	SVS	NWS RADAR INDICATES A TORNADO 3 MILES WEST OF LORENA (MCLENNAN COUNTY). STORM SPOTTERS CONFIRM THIS TORNADO..PEOPLE IN LORENA TAKE COVER! SUBSEQUENT INFORMATION INDICATED A TORNADO, PROBABLY F1 AND LASTING ABOUT 3 MINUTES, OCCURRED NEAR LORENA AT 120 PM. SEVERAL MOBILE HOMES DAMAGED, ONE HOUSE DESTROYED.
132 PM	SVR	SEVERE THUNDERSTORM WARNING FOR FALLS COUNTY (JUST SE OF MCLENNAN COUNTY).
142 PM	TOR	TORNADO WARNING FOR FALLS COUNTY. NWS DOPPLER RADAR DETECTED A DEVELOPING TORNADO NEAR EDDY.

		AT 145 PM, A TORNADO, CLASSIFIED AS F3, DID EXTENSIVE DAMAGE NEAR MOODY, TX, IN MCLENNAN COUNTY. A TORNADO WARNING HAD BEEN ISSUED AT 121 PM AND REMAINED IN EFFECT UNTIL 200 PM.
148 PM	TOR	TORNADO WARNING FOR BELL COUNTY. NWS DOPPLER RADAR DETECTED A TORNADO BETWEEN EDDY AND MOODY (IN MCLENNAN COUNTY). CONFIRMED BY SPOTTERS.
157 PM	SVS	TORNADIC THUNDERSTORM LOCATED FROM JUST SOUTH OF MOODY TO THE TOWN OF NORTH PARIRIE. TORNADO REPORTED BY SPOTTERS AND NOW ENTERING BELL COUNTY.
200 PM	NOW	SEVERE STORMS WILL MOVE SOUTH TO SOUTH SOUTHWEST. TORNADO WATCH IN EFFECT.
		REPORTS RECEIVED AT 205 PM AND 206 PM RESPECTIVELY OF 2.75 INCH HAIL IN MCLENNAN AND FALLS COUNTIES.
200 PM	SVR	SEVERE THUNDERSTORM WARNING FOR HILL AND NAVARRO COUNTIES. (THUNDERSTORMS PROMPTING THIS WARNING WERE SEPARATE AND TO THE NORTHEAST OF THE TORNADIC STORM IN MCLENNAN COUNTY)
216 PM	SVS	SPOTTERS AND RADAR CONTINUE TO TRACK TORNADO IN NORTHERN BELL COUNTY NEAR HIGHWAY 317 AND SOUTHERLAND ROAD AT 215 PM. IF YOU LIVE IN MORGANS POINT RESORT..TAKE COVER IMMEDIATELY. STORM ALSO PRODUCING VERY LARGE HAIL.
230 PM	TOR	EXTENSION OF TORNADO WARNING FOR BELL COUNTY. NWS DOPPLER RADAR DETECTED A TORNADIC THUNDERSTORM BETWEEN TROY AND BELTON. STORM MOVING SOUTH. RADAR CONTINUE TO INDICATE CIRCULATION AND TORNADOES ARE PROBABLE.
		SUBSEQUENT REPORTS INDICATE A TORNADO CLASSIFIED AS F3 STRUCK THE MOGANS POINT AREA OF LAKE BELTON AT 235 PM DOING EXTENSIVE PROPERTY DAMAGE. TORNADO WARNING HAD BEEN IN EFFECT SINCE 148 PM WITH EXTENSION AT 230 PM.
237 PM	SVS	DOPPLER RADAR DETECTED TWO TORNADIC THUNDERSTORMS. ONE CIRCULATION CENTER WAS NEAR BELTON AND THE OTHER ONE WAS 5 MILES NORTH OF BELTON. STORMS MOVING SOUTH. PEOPLE IN AND NEAR BELTON SHOULD TAKE COVER NOW!!!
300 PM	TOR	TORNADO WARNING FOR NAVARRO COUNTY. NWS DOPPLER RADAR DETECTED A DEVELOPING TORNADO NEAR CORSICANA. (AGAIN, THIS IS A SEPARATE STORM TO THE NORTHEAST OF THE BELL COUNTY STORM)
		A TORNADO WAS REPORTED NEAR BLOOMING GROVE IN NAVARRO COUNTY AROUND 305 PM. NO SIGNIFICANT DAMAGE REPORTED.

305 PM	SVS	TORNADO WARNING IN EFFECT. NWS DOPPLER RADAR DETECTED A VERY DANGEROUS STORM NEAR BELTON. THIS STORM HAS A HISTORY OF PRODUCING TORNADOES WITH NUMEROUS REPORTS OF SUBSTANTIAL DAMAGE BETWEEN KILLEEN AND TEMPLE...TAKE COVER AS THIS STORM APPROACHES. IT WILL CONTAIN BASEBALL OR LARGER SIZE HAIL AND PRODUCE OCCASIONAL TORNADOES.
309 PM	SVS	UPDATE ON TORNADO WARNING FOR NAVARRO COUNTY.
315 PM	TOR	TORNADO WARNING FOR BELL COUNTY EXTENDED UNTIL 4 PM. NWS DOPPLER RADAR DETECTED AND STORM SPOTTERS CONFIRMED A TORNADO JUST NORTH OF SALADO. STORM MOVING SOUTH AT 15 MPH.
322 PM	NOW	SEVERE THUNDERSTORMS OVER NAVARRO AND BELL COUNTIES WERE MOVING SLOWLY SOUTH. TORNADOES HAVE BEEN REPORTED WITH THE STORM IN BELL COUNTY..AND THE STORM IN NAVARRO COUNTY HAS THE POTENTIAL TO PRODUCE A TORNADO. TAKE COVER AS THEY APPROACH.
328 PM	SVR	SEVERE THUNDERSTORM WARNING FOR HILL COUNTY. THIS WAS REDEVELOPMENT TO THE NORTH OF THE TORNADIC STORM IN BELL COUNTY.
336 PM	TOR	TORNADO WARNING FOR HILL AND LIMESTONE COUNTIES.
		TORNADO REPORTED NEAR HUBBARD IN HILL COUNTY AT 350 PM. NO SIGNIFICANT DAMAGE REPORTED.
343 PM	TOR	TORNADO WARNING FOR FREESTONE COUNTY...EXTENDED FOR NAVARRO COUNTY. DOPPLER RADAR INDICATED A TORNADIC STORM NEAR CORSICANA IN NAVARRO COUNTY. LARGE HAIL ALSO LIKELY.
345 PM	ZFP	ROUTINE ZONE [FORECAST] ISSUANCE.
352 PM	SVS	UPDATE ON TORNADO WARNINGS FOR HILL, NAVARRO, FREESTONE AND LIMESTONE COUNTIES.
421 PM	SVS	FURTHER UPDATE ON WARNINGS FOR HILL, NAVARRO, FREESTONE AND LIMESTONE COUNTIES.
428 PM	TOR	EXTENSION OF TORNADO WARNING FOR LIMESTONE COUNTY.
430 PM	NOW	SHORT RANGE FORECAST ISSUED FOR ENTIRE COUNTY WARNING AREA (SEGMENTED). SPECIFIC DETAILS PROVIDED ON SEVERE STORMS IN COUNTIES AFFECTED.
458 PM	SVS	UPDATE ON TORNADO WARNING FOR LIMESTONE COUNTY.

505 PM	SVR	SEVERE THUNDERSTORM WARNING FOR FREESTONE COUNTY. STORM WILL AFFECT TEAGUE...FREESTONE...KIRVIN..AND DONIE. EXPECT LARGE HAIL.
		0.75 INCH HAIL REPORTED NEAR MEXIA IN FREESTONE COUNTY AT 520 PM.
514 PM	TOR	TORNADO WARNING FOR LIMESTONE AND MCLENNAN COUNTIES. NWS DOPPLER RADAR INDICATED A TORNADIC THUNDERSTORM IN LIMESTONE COUNTY NEAR GROESBECK...MOVING SOUTH. NO REPORTS OF TORNADOES BUT RADAR SHOWS ROTATION...TORNADOES POSSIBLE.
525 PM	NOW	UPDATE ON POSSIBLE TORNADIC STORM NOW IN EASTERN MCLENNAN COUNTY.

Chronology of Events at NWSFO Austin/San Antonio, TX

From 11:00 am through 11:00 pm CDT - Tuesday, May 27, 1997

Time	Product	Description
1115 AM	SPS	HAZARDOUS WEATHER OUTLOOK...SEVERE THUNDERSTORM AND HEAVY RAIN EVENT DEVELOPING ACROSS SOUTH TEXAS AND THE HILL COUNTRY THIS AFTERNOON AND TONIGHT...
1254 PM	SEL	TORNADO WATCH FOR PORTIONS OF EAST TEXAS (INCLUDES WILLIAMSON COUNTY OF SOUTH CENTRAL TEXAS). VALID FROM 115 PM CDT UNTIL 700 PM CDT.
109 PM	ZFP	UPDATED ZONE FORECAST FOR WILLIAMSON COUNTY AND CITY OF GEORGETOWN WITH TORNADO WATCH UNTIL 7 PM.
110 PM	NOW	UPDATED SHORT TERM FORECAST FOR WILLIAMSON COUNTY AND CITY OF GEORGETOWN WITH TORNADO WATCH UNTIL 7 PM. CURRENTLY NO THUNDERSTORMS...BUT STORMS EXPECTED TO DEVELOP BY LATE AFTERNOON.
215 PM	PHONE CALL	TO GEORGETOWN POLICE DEPARTMENT AND WILLIAMSON COUNTY SHERIFFS DEPARTMENT ALERTING THAT SEVERE THUNDERSTORMS WERE LOCATED IN BELL COUNTY...MOVING SOUTHWARD AND THAT SEVERE WEATHER WAS VERY LIKELY IN THE NEXT HOUR TO HOUR AND A HALF.
248 PM	NOW	UPDATED SHORT TERM FORECAST FOR WILLIAMSON COUNTY AND CITY OF GEORGETOWN WITH TORNADO WATCH UNTIL 7 PM. SEVERE THUNDERSTORM AT 245 WEST OF TEMPLE MOVING SLOWLY SOUTHWESTWARD.
300 PM	PHONE CALL	TO AUSTIN EOC [EMERGENCY OPERATIONS CENTER] ALERTING THAT TORNADIC THUNDERSTORMS IN BELTON WERE MOVING SOUTHWARD. SEVERE WEATHER WAS HIGHLY POSSIBLE AROUND 400 PM.
330 PM	TOR	TORNADO WARNING VALID UNTIL 430 PM CDT FOR WILLIAMSON COUNTY. STORM 5 MILES WEST OF 'JARRAL' MOVING SOUTHEAST AT 10 MPH. CITY OF 'JARREL' IS IN THE PATH OF THIS STORM.
		AT APPROXIMATELY 340 PM CDT..AN F5 TORNADO STRUCK JARRELL...KILLING 27. IT WAS ½ MILE IN WIDTH AND HAD A PATH LENGTH ESTIMATED AT 5 TO 6 MILE TRACK.
334 PM	NOW	UPDATED SHORT TERM FORECAST FOR SEVERAL COUNTIES... INCLUDING WILLIAMSON COUNTY AND CITY OF GEORGETOWN WITH TORNADO WATCH UNTIL 7 PM. TORNADIC THUNDERSTORM JUST NORTH OF 'JARREL' WITH ANOTHER DEVELOPING RAPIDLY NORTH OF GEORGETOWN.

334 PM	SVR	SEVERE THUNDERSTORM WARNING VALID TIL 430 PM CDT FOR EDWARDS COUNTY. 3/4 INCH HAIL REPORTED AT 415 PM BY POLICE DEPARTMENT AT CARTA VALLEY. GOLFBALL-SIZED HAIL 26 MILES SSW OF ROCKSPRINGS AT 425 PM.
331 PM	SEL	TORNADO WATCH FOR MUCH OF CENTRAL AND SOUTH CENTRAL TEXAS UNTIL 10 PM CDT.
358 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 500 PM FOR REAL COUNTY. STORM LOCATED ABOUT 15 MILES WEST OF LEAKY. HAIL REPORTED NEAR BARKSDALE ON THE RIVER AT 410 PM.
400 PM	ZFP	ZONE FORECASTS FOR SOUTH TEXAS...INCLUDING WILLIAMSON COUNTY AND CITY OF GEORGETOWN WITH TORNADO WATCH UNTIL 7 PM.
409 PM	TOR	TORNADO WARNING VALID UNTIL 515 PM CDT FOR TRAVIS COUNTY. TORNADIC THUNDERSTORM OVER CEDAR PART AT 405 PM IS MOVING SOUTH AT 10 MPH AND INTO THE NORTHERN PORTIONS OF THE CITY OF AUSTIN. AT 415 PM...A TORNADO IS REPORTED AT 2222 AND ANDERSON MILL IN NORTHWEST TRAVIS COUNTY. AT 450 PM..AN F4 TORNADO STRIKES NEAR LAKEWAY AND 620 IN THE PEDERNALES VALLEY AREA...1 DEAD IN THIS TORNADO.
426 PM	FFW	FLASH FLOOD WARNING VALID UNTIL 630 PM FOR EDWARDS AND REAL COUNTIES. AT 500 PM...FLASH FLOODING IS REPORTED ALONG HIGHWAY 377 NEAR CARTA VALLEY.
431 PM	NOW	UPDATED SHORT TERM FORECAST FOR SEVERAL COUNTIES... INCLUDING WILLIAMSON AND TRAVIS COUNTIES. TORNADO WATCHES AND WARNINGS HIGHLIGHTED. TORNADO INDICATED OVER NORTHWEST TRAVIS COUNTY NEAR FM2222 AND ANDERSON MILL...MOVING SOUTH AT 20 MPH.
432 PM	FFW	FLASH FLOOD WARNING VALID UNTIL 630 PM CDT FOR TRAVIS AND WILLIAMSON COUNTIES. 1 DROWNING IN SHOAL CREEK IN AUSTIN... TIME NOT AVAILABLE.
437 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 545 PM CDT FOR WILLIAMSON COUNTY. HIGH WINDS AND HAIL TO BE EXPECTED IN THE ROUND ROCK...GEORGETOWN...GRANDER AND TAYLOR AREAS. AT 445 PM CDT...60 MPH WINDS REPORTED IN ROUND ROCK
449 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 545 PM CDT FOR EDWARDS COUNTY. LARGE HAIL POSSIBLE BETWEEN BARKSDALE AND CARTA VALLEY.

458 PM	TOR	TORNADO WARNING VALID UNTIL 600 PM CDT FOR HAYS COUNTY. INCLUDED A REPORT OF A TORNADO AT LAKEWAY AND HIGHWAY 620 IN SOUTH TRAVIS COUNTY...MOVING TOWARD DRIPPING SPRINGS...HAYS...BUDA...KYLE...WIMBERLY AND SAN MARCOS.
		AT 538 PM CDT...TREES AND POWER LINES REPORTED BLOWN DOWN IN THE KYLE AREA.
500 PM	NOW	UPDATED SHORT TERM FORECAST FOR ALL COUNTIES... HIGHLIGHTING TORNADO WATCH. RADAR UPDATES ON STORMS IN BOTH WESTERN AND CENTRAL COUNTIES AND THEIR MOVEMENTS.
506 PM	SPS	HAZARDOUS WEATHER OUTLOOK...TORNADO WATCH IN EFFECT THROUGH 10 PM CDT. SYSTEM WILL EVOLVE INTO A HEAVY RAIN EVENT LATER THIS EVENING.
519 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 615 PM CDT FOR TRAVIS COUNTY- MOST DANGEROUS STORMS JUST EAST OF PFLUGERVILLE AND BEECAVE. FUNNEL CLOUDS WERE BEING REPORTED IN SOUTH AUSTIN.
		AT 524 PM...WIND GUSTS TO 64 MPH RECORDED AT ROBERT MUELLER AIRPORT IN DOWNTOWN AUSTIN.
524 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 630 PM CDT FOR BLANCO - SEVERE THUNDERSTORM JUST SOUTHEAST OF JOHNSON CITY NEAR HIGHWAY 290.
		UNCONFIRMED REPORT BY PUBLIC OF A TORNADO NEAR BLANCO AT 530 PM CDT.
531 PM	NOW	UPDATED SHORT TERM FORECAST FOR ALL COUNTIES... HIGHLIGHTING TORNADO WATCH. RADAR UPDATES ON STORMS IN BOTH WESTERN AND CENTRAL COUNTIES AND THEIR MOVEMENTS.
537 PM	SVR/FFW	SEVERE THUNDERSTORM AND FLASH FLOOD WARNING VALID UNTIL 715 PM CDT FOR UVALDE COUNTY. SEVERE THUNDERSTORM MOVING SOUTH ALONG THE NUECES RIVER TOWARD MONTEL.
552 PM	TOR	TORNADO WARNING VALID UNTIL 700 PM CDT FOR KENDALL COUNTY. SHERIFFS DEPARTMENT IN BLANCO OBSERVED A TORNADO APPROACHING KENDALIA.
558 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 8 PM CDT FOR BASTROP AND CALDWELL COUNTIES. LEADING EDGE OF SEVERE THUNDERSTORMS FROM ELROY IN BASTROP COUNTY TO NEAR SAN MARCOS
		AT 635 PM... NICKEL-SIZED HAIL IS REPORTED IN ELGIN IN BASTROP COUNTY.

601 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 700 PM CDT FOR HAYS COUNTY. GOLFBALL SIZED HAIL HAD BEEN REPORTED IN DRIFTWOOD WITH WIDESPREAD NICKEL SIZED HAIL.
		AT 645 PM CDT...3/4 INCH HAIL IS REPORTED AT SAN MARCOS.
606 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 715 PM CDT FOR VAL VERDE COUNTY. RADAR INDICATED A SEVERE THUNDERSTORM WITH LARGE HAIL NEAR LOMA ALTA AND JUST NORTHEAST OF COMSTOCK.
		AT 615 PM CDT...GOLFBALL-SIZED HAIL IS OBSERVED AT COMSTOCK.
614 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 715 PM CDT FOR COMAL COUNTY. A SEVERE THUNDERSTORM WAS ENTERING COMAL COUNTY NEAR FISHER AND WILL MOVE OVER CANYON LAKE IN THE NEXT 15 MINUTES.
		AT 645 PM CDT...DIME-SIZED HAIL IS REPORTED FROM CANYON LAKE.
621 PM	NOW	UPDATED SHORT TERM FORECAST FOR ALL COUNTIES... HIGHLIGHTING TORNADO WATCH. RADAR UPDATES ON STORMS IN BOTH WESTERN AND CENTRAL COUNTIES AND THEIR MOVEMENTS.
624 PM	TOR	TORNADO WARNING VALID UNTIL 700 PM CDT FOR NORTHERN UVALDE COUNTY. THE TORNADIC THUNDERSTORM WAS WEST OF UTOPIA.
		AT 635 PM CDT...GOLFBALL SIZED HAIL IS OBSERVED AT SABINAL. AT 645 PM CDT...THE PUBLIC REPORTS A FUNNEL ALONG FM1050. AT 655 PM...A REPORT OF A POSSIBLE TORNADO BETWEEN UTOPIA AND SABINAL IS PASSED BY THE SHERIFF TO A HAM OPERATOR.
628 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 730 PM CDT FOR EDWARDS COUNTY. THE THUNDERSTORM WAS NEAR HIGHWAY 377...15 MILES NORTHEAST OF ROCKSPRINGS. RADAR HAS INDICATED HAIL OF UP TO 2 INCHES WITH THIS STORM.
629 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 930 PM CDT FOR GUADALUPE COUNTY. THE STORM WAS MOVING SOUTHWARD INTO THE NORTHERN PART OF THE COUNTY.
		AT 640 PM CDT...REPORT IF SEVERE WINDS BLOWING A PLANE OVER ON ITS TOP AT THE SEGUIN AIRPORT
629 PM	SEL	TORNADO WATCH FOR MUCH OF NORTH CENTRAL AND EAST TEXAS UNTIL 1 AM CDT WEDNESDAY MORNING.
656 PM	TOR	TORNADO WARNING VALID UNTIL 8 PM CDT FOR KENDALL COUNTY. TORNADIC THUNDERSTORM INDICATED JUST SOUTH OF SISTERDALE MOVING TOWARD THE SOUTH AT 15 MPH. THE STORM IS MOVING ALONG FM1367 TOWARDS BOERNE.
		AT 730 PM CDT...HAMS REPORT A TORNADO AT SISTERDALE. NO DAMAGE INDICATED AT THAT TIME.

659 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 830 PM CDT FOR BEXAR COUNTY. SEVERE THUNDERSTORMS WITH HIGH WINDS MOVING INTO NORTHERN BEXAR COUNTY EXTENDING FROM RANDOLPH AFB TO BULVERDE AND BOERNE.
		AT 803 PM CDT...A WIND GUST TO 122 MPH REPORTED AT KELLY AFB IN SOUTHWEST SAN ANTONIO. DAMAGE WAS WIDESPREAD IN THE SAN ANTONIO AREA...WITH POWER OUT TO NEARLY 100,000 PERSONS.
700 PM	SVS	SEVERE WEATHER STATEMENT SUMMARIZING THE TORNADO WATCH VALID UNTIL 1 AM CDT...AND THE WARNINGS FOR KENDALL...UVALDE...HAYS...COMAL...VAL VERDE...EDWARDS... GUADALUPE...CALDWELL AND BASTROP COUNTIES.
705 PM	RVS	RIVER STATEMENT FOR BRUSHY CREEK IN WILLIAMSON COUNTY. HEAVY RAIN BETWEEN 2 AND 4 INCHES HAS BEEN RECEIVED AND BRUSHY CREEK WILL BE OUT OF BANKS FROM THE HEADWATERS ABOVE ROUND ROCK TO DOWNSTREAM ABOVE THORNDALE THIS EVENING.
706 PM	ZFP	ZONE FORECASTS FOR MANY SOUTH CENTRAL TEXAS COUNTIES... INCLUDING WILLIAMSON COUNTY AND CITY OF GEORGETOWN WITH TORNADO WATCH UNTIL 1 AM.
710 PM	NOW	UPDATED SHORT TERM FORECAST FOR ALL COUNTIES... HIGHLIGHTING BOTH TORNADO WATCHES. RADAR UPDATES ON STORMS IN BOTH WESTERN AND CENTRAL COUNTIES AND THEIR MOVEMENTS.
714 PM	SVS	SEVERE WEATHER STATEMENT INCLUDING TORNADO WATCH AND WARNINGS FOR KENDALL...UVALDE...HAYS...COMAL...VAL VERDE... EDWARDS... GUADALUPE...CALDWELL AND BASTROP COUNTIES.
710 PM	RVS	RIVER STATEMENT FOR RED BLUFF AND SYCAMORE CREEKS IN EDWARDS AND VAL VERDE COUNTIES. RADAR INDICATES AN AREA OF 4 TO 5 INCHES OF RAIN IN THE PAST 3 HOURS IN EDWARDS COUNTY.
722 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 9 PM CDT FOR EDWARDS...KERR AND VAL VERDE COUNTIES. AT 720 PM A SEVERE THUNDERSTORM WAS BETWEEN DEL RIO AND LOMA ALTA IN VAL VERDE COUNTY...MOVING EAST AT 10 MPH. M OER SEVERE THUNDERSTORMS WERE NEAR HWY 277 IN NORTHWEST EDWARDS COUNTY AND NEAR HWY 83 WEST OF MOUNTAIN HOME IN KERR COUNTY.
		AT 830 PM CDT...3/4 INCH HAIL REPORTED IN THE CITY OF DEL RIO WITH .88 INCH HAIL AT THE DEL RIO AIRPORT. AT 836 PM CDT...THE DEL RIO AIRPORT RECORDS A WIND GUST TO 61 MPH.
727 PM	FFW	FLASH FLOOD WARNING VALID UNTIL 1030 PM CDT FOR BLANCO AND KENDALL COUNTIES. HEAVY RAINS OVER NORTHERN KENDALL AND SOUTHERN BLANCO COUNTY ESTIMATED AT 2 TO 3 INCHES WITH ISOLATED 3 TO 5 INCHES. EXTRA CAUTION URGED AT NIGHT.

		REPORTS WERE LATER RECEIVED OF MOST ROADS IN SOUTHERN BLANCO AND NORTHERN KENDALL COUNTIES CLOSED DUE TO FLASH FLOODING BETWEEN 830 PM CDT AND 10 PM CDT.
734 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 830 PM CDT FOR GONZALES COUNTY. SEVERE THUNDERSTORMS EXTENDING FROM SMILEY NORTH TO BELMONT...WITH ANOTHER STRONG STORM NEAR FLATONIA.
		AT 735 PM CDT A FUNNEL WAS OBSERVED NEAR WRIGHTSBORO. ALSO...AT 735 PM CDT...TREES WERE REPORTED BLOWN DOWN BETWEEN LEESVILLE AND CHEAPSIDE. AT 815 PM CDT...1.5 INCH HAIL FELL JUST NORTH OF THE TOWN OF NIXON.
738 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 915 PM CDT FOR FRIO COUNTY. SEVERE THUNDERSTORM WITH LARGE HAIL NORTHWEST OF PEARSALL NEAR HIGHWAY 140...MOVING SOUTHEAST AT 20 MPH.
		AT 830 PM CDT...GOLFBALL-SIZED HAIL FELL IN PEARSALL WITH QUARTER-SIZED HAIL AT 855 PM CDT REPORTED FROM DILLEY BY HAM SPOTTERS.
739 PM	SVS	SEVERE WEATHER STATEMENT INCLUDING TORNADO WATCH. WARNINGS CANCELED FOR CALDWELL AND BASTROP.
751 PM	NOW	UPDATED SHORT TERM FORECAST FOR ALL COUNTIES... HIGHLIGHTING LINES OF THUNDERSTORMS IN TWO DIFFERENT ALIGNMENTS. RADAR UPDATES ON STORMS IN ALL COUNTIES.
752 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 9 PM CDT FOR MEDINA COUNTY. SEVERE THUNDERSTORM WITH LARGE HAIL BETWEEN YANCEY AND DEVINE MOVING EAST AT 20 MPH. THIS STORM WILL AFFECT DEVINE.
		AT 830 PM CDT...3/4 INCH HAIL REPORTED IN DEVINE.
800 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 9 PM CDT FOR BEXAR COUNTY. LINE OF THUNDERSTORMS MOVING THROUGH BEXAR COUNTY WITH POSSIBLE LARGE HAIL...DAMAGING WINDS AND LIGHTNING. RAINFALL RATES OF 1 TO 2 INCHES PER HOUR.
		AGAIN...AS NOTED BEFORE..AT 803 PM CDT..A WIND GUST TO 122 MPH WAS RECORDED AT KELLY AFB IN SAN ANTONIO...ALONG WITH WIDESPREAD DAMAGE AND POWER OUTAGES TO 100,000 PERSONS.
801 PM	TOR	TORNADO WARNING VALID UNTIL 9 PM CDT FOR GONZALES COUNTY. RADAR INDICATED A TORNADO NEAR THE GONZALES AIRPORT...MOVING SOUTHEAST AT 15 MPH.
		AT 810 PM CDT...FUNNEL CLOUDS WERE SIGHTED NORTH OF THE CITY OF GONZALES.

809 PM	SPS	SPECIAL WEATHER STATEMENT INDICATING THAT KIMBLE... MASON...LLANO...BURNET AND WILLIAMSON COUNTIES HAVE BEEN CLEARED FROM THE TORNADO WATCH.
803 PM	NOW	UPDATED SHORT TERM FORECAST FOR THE COUNTIES THAT HAD BEEN CLEARED FROM THE WATCH.
813 PM	NOW	UPDATED SHORT TERM FORECAST FOR BURNET...LLANO AND WILLIAMSON COUNTIES. STORMS HAVE MOVED SOUTHWARD AND NO LONGER THREATEN THESE COUNTIES.
813 PM	FFW	FLASH FLOOD WARNING VALID UNTIL 1015 PM CDT FOR BANDERA AND VAL VERDE COUNTIES. HEAVY RAIN FROM DEL RIO TO LOMA ALTA HAVE PRODUCED BETWEEN 3 AND 5 INCHES BY RADAR ESTIMATION SINCE 5 PM. ADDITIONAL RAINFALL IS EXPECTED THROUGH 9 PM. BETWEEN 830 PM CDT AND 9 PM CDT... FLASH FLOODING WAS REPORTED IN VAL VERDE COUNTY... ACROSS CITY STREETS IN DEL RIO..AND ALONG HIGHWAY 90 FROM DEL RIO TO COMSTOCK.
818 PM	TOR	TORNADO WARNING VALID UNTIL 915 PM CDT FOR FRIO COUNTY BASED ON A FUNNEL REPORTED BY THE SHERIFF IN PEARSALL. DEVELOPING TORNADO BETWEEN PEARSALL AND DILLEY. SHERIFF HAS SPOTTED A FUNNEL NEAR PEARSALL. THE STORMS ARE MOVING SOUTHEAST AT 20 MPH. AT 820 PM CDT...THE SHERIFF REPORTED NICKLE-SIZED HAIL AS WELL AS A TORNADO JUST NORTHEAST OF MOORE.
819 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 915 PM CDT FOR ATASCOSA COUNTY. THUNDERSTORMS ENTERING NORTHERN ATASCOSA COUNTY...MOVING EAST AT 20 MPH. WILL MOVE THROUGH POTEET...JOURDANTON...AND PLEASANTON DURING THE NEXT HOUR. AT 830 PM CDT...TREES WERE BLOWN OVER IN PLEASANTON...WITH SOME BLOWN ONTO CARS CAUSING DAMAGE.
821 PM	ZFP	ZONE FORECAST UPDATE FOR SOUTH TEXAS COUNTIES GENERALLY ALONG AND SOUTH OF A LINE FROM LAREDO TO VICTORIA.
823 PM	SEL	TORNADO WATCH FOR MUCH OF SOUTH CENTRAL AND SOUTHEAST TEXAS UNTIL 3 AM CDT WEDNESDAY MORNING.

829 PM	FFW	FLASH FLOOD WARNING VALID UNTIL 1130 PM CDT FOR GONZALES COUNTY. THUNDERSTORMS WITH HEAVY RAIN INDICATED OVER MUCH OF GONZALES COUNTY. 2 TO 3 INCHES OF RAIN HAVE FALLEN OVER THE PAST HOUR WITH AN ADDITIONAL 1 OR 2 INCHES POSSIBLE.
		FLASH FLOODING WAS REPORTED WITH FM532 AND 1116 CLOSED DUE TO HIGH WATER.
840 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 945 PM CDT FOR DEWITT...KARNES...WILSON AND LAVACA COUNTIES. RADAR INDICATED SEVERE THUNDERSTORMS FROM JOURDANTON TO KARNES CITY TO CUERO AND HALLETTSVILLE...MOVING TOWARD THE SOUTHEAST AT 20 MPH.
		AT 925 PM CDT...TREES AND POWER LINES WERE REPORTED BLOWN DOWN IN DEWITT COUNTY BY THE SHERIFF'S DEPARTMENT. LARGE TREES WERE UPROOTED AND SPLIT BY HIGH WINDS IN THE LA VERNIA AREA IN WILSON COUNTY NEAR 9 PM CDT.
851 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 10 PM CDT FOR SOUTHERN VAL VERDE COUNTY. SHOWERS AND THUNDERSTORMS CONTINUED TO DEVELOP OVER THE SOUTHERN PART OF THE COUNTY. THE STORMS WERE MOVING SOUTHEAST AT 15 MPH.
		AT 9 PM CDT...GOLFBALL-SIZED HAIL WAS REPORTED 6 MILES EAST OF COMSTOCK.
855 PM	ZFP	ZONE FORECAST UPDATE FOR ALL SOUTH TEXAS COUNTIES TO INCLUDE THE NEW WATCH VALID UNTIL 3 AM CDT WEDNESDAY MORNING.
855 PM	FLW	FLOOD WARNING FOR RED BLUFF AND SYCAMORE CREEKS IN EDWARDS AND VAL VERDE COUNTIES. CONTINUED RAINFALL OVER THE HEADWATERS HAS BROUGHT RAINFALL AMOUNTS UP TO NEARLY SIX INCHES IN MANY AREAS. RED BLUFF CREEK WILL BE WELL OUT OF BANKS AND FLOODING SECONDARY AND PRIMARY ROADS. SYCAMORE CREEK WILL ALSO BE WELL OUT OF BANKS AND FLOODING THE FLOOD PLAIN AND ROADS.
858 PM	FFW	FLASH FLOOD WARNING VALID UNTIL 11 PM CDT FOR FRIO COUNTY. RAINFALL OF NEARLY 2 INCHES PER HOUR ACROSS THE COUNTY...WITH ADDITIONAL 1 TO 2 INCHES EXPECTED. THE STORMS WERE LOCATED FROM MOORE TO PEARSALL TO DIVOT AND SOUTHWEST THROUGH THE COUNTY.
		NUMEROUS ROADS WERE CLOSED FROM 9 PM UNTIL 11 PM CDT ACROSS FRIO COUNTY.

905 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 1030 PM CDT FOR DIMMIT COUNTY. SEVERE THUNDERSTORM WITH VERY LARGE HAIL BETWEEN BIG WELLS AND CARRIZO SPRING...MOVING EAST AT 10 MPH.
		AT 915 PM CDT...3/4 INCH HAIL WAS REPORTED NEAR BRUNDAGE.
914 PM	NOW	UPDATED SHORT TERM FORECAST FOR COUNTY WARNING AREA WITH LATEST RADAR LOCATIONS AND MOVEMENTS.
933 PM	LSR	LOCAL STORM REPORT SUMMARIZING EVENING SEVERE WEATHER.
939 PM	FFW	FLASH FLOOD WARNING VALID UNTIL 1245 AM CDT WEDNESDAY MORNING FOR KARNES COUNTY. DOPPLER ESTIMATES OF 2 TO 3 INCHES OF RAIN IN THE NORTHERN PART OF THE COUNTY FROM GILLETT TO HOBSON SINCE 8 PM. 1 OR 2 MORE INCHES POSSIBLE.
956 PM	FFW	FLASH FLOOD WARNING VALID UNTIL 1 AM WEDNESDAY MORNING CDT FOR FAYETTE COUNTY.
958 PM	FFW	ZONE FORECAST UPDATE FOR SOUTHEAST TEXAS COUNTIES.
1000 PM	NOW	UPDATED SHORT TERM FORECAST FOR COUNTY WARNING AREA WITH LATEST RADAR LOCATIONS AND MOVEMENTS.
1003 PM	SVR	SEVERE THUNDERSTORM WARNING VALID UNTIL 1145 PM CDT FOR VAL VERDE COUNTY. SEVERE THUNDERSTORM NEAR LANGTRY. THIS STORM INDICATED WITH LARGE HAIL...MOVING SOUTHEAST AT 10 MPH.
1015 PM	SEL	TORNADO WATCH FOR MUCH OF SOUTH CENTRAL TEXAS UNTIL 4 AM CDT WEDNESDAY MORNING.
1035 PM	ZFP	ZONE FORECAST UPDATE FOR COUNTIES OF DEEP SOUTH TEXAS.
1051 PM	ZFP	ZONE FORECAST UPDATE FOR THE HILL COUNTRY AND SOUTH CENTRAL TEXAS COUNTIES.
1052 PM	SVS	SEVERE WEATHER STATEMENT SUMMARIZING TORNADO WATCH AND FLASH FLOOD AND SEVERE THUNDERSTORM WARNINGS VALID.
1054 PM	NOW	UPDATED SHORT TERM FORECAST FOR COUNTY WARNING AREA WITH LATEST RADAR LOCATIONS AND MOVEMENTS.
1100 PM	RVS	RIVER STATEMENT FOR THE BLANCO...SAN MARCOS AND GUADALUPE RIVERS. FORECASTS OF RIVER STAGES AND COMMENTS ON OVERBANK AND BANKFULL RISES.
1145 PM	LSR	LOCAL STORM REPORT SUMMARIZING EVENING SEVERE WEATHER.

Appendix B

The Jarrell, Texas, Tornado Outbreak: A Meteorological Satellite Perspective

James F. W. Purdom[1,2] and Brian C. Motta[2]
NOAA/National Environmental Satellite, Data and Information Service[1]
Office of Research and Applications
Regional and Mesoscale Meteorology Team
and
Cooperative Institute for Research in the Atmosphere (CIRA) [2]
Colorado State University
Fort Collins, Colorado

Authors' note: This paper has been abridged in order to fit within the Service Assessment report. For the complete text, contact either of the two authors at: <James.Fw.Purdom@noaa.gov> or <motta@terra.cira.colostate.edu>.

Service Assessment Team Note: Much of the data and many of the techniques described within this research report were not available in real-time to the NWSFO FWD and EWX forecasters on May 27, 1997.

Introduction

This note describes thunderstorm development and evolution that may be observed using NOAA meteorological satellite data over the Texas area on May 27, 1997, the day of the Jarrell tornadic storm event. A number of interesting features were clearly discernable using satellite imagery. Those features are discussed in this report along with image examples when appropriate.

Large-scale features, such as cumulus cloudiness along the frontal zone on which the major tornado complex formed and evolved, are easily detected using GOES imagery from early in the day until late afternoon when the low cloudiness becomes obscured by anvil cirrus. Products derived from GOES sounder data reveal the very unstable air on which the tornadic storm complex fed. On the cloud scale, satellite-based anvil-top characteristics that are often associated with severe thunderstorms are apparent in satellite imagery. When the imagery is viewed in a storm-relative mode and tornadic tracks are added to the sequence, it is evident that the major tornadic activity was associated with a thunderstorm complex that evolved to the south along the frontal zone.

Data Sources

GOES-8 and GOES-9 data were acquired by CIRA's direct receive station where they were processed for analysis on a Regional Atmospheric Modeling System (RAMM) Advanced Meteorological Satellite Demonstration and Interpretation System (RAMSDIS) workstation. Both GOES satellites were in a routine mode of operation during the entire episode. Imagery was available at 15-minute intervals with the exception of once every 3 hours when a 30-minute full disk image was taken. Unfortunately, the satellite was not placed in a 7 ½-minute severe storm observing mode during the event, nor had a special 1-minute interval imaging day been requested for research purposes. GOES-8 sounder products were obtained from the NESDIS Forecast Product Development Team's Home page, accessible via Internet. The Advanced Very High Resolution Radiometer (AVHRR) imagery from the polar-orbiting NOAA-14 satellite 1957 Coordinated Universal Time (UTC) ascending node pass was obtained from the National Climatic Data Center. *[Note: Subtract 5 hours from UTC to get CDT.]* A complete set of surface and upper air observations were obtained from the Cooperative Institute for Meteorological Satellite Studies (CIMSS), CIRA's sister Institute at the University of Wisconsin. Tornado track information was extracted from a preliminary NOAA report that was based on aerial damage surveys. Times for the tornadoes were based on estimates from members of the NOAA Service Assessment Team. Track information is very accurate, to within a few hundred feet, while time information may be off by several minutes, depending on the portion of the track with which time is associated.

Pre-Storm: Synoptic and Regional Scale Analysis

The 6.7 micrometer (μm) channel on GOES senses emission from upper-level water vapor and high cloud; because of this, 6.7 μm imagery is very useful for revealing upper-level flow patterns and for analysis of mesoscale features within the larger scale flow. As might be expected, animated 6.7 μm channel imagery very nicely revealed upper-level flow at the 300-200 mb level (Figure 1).

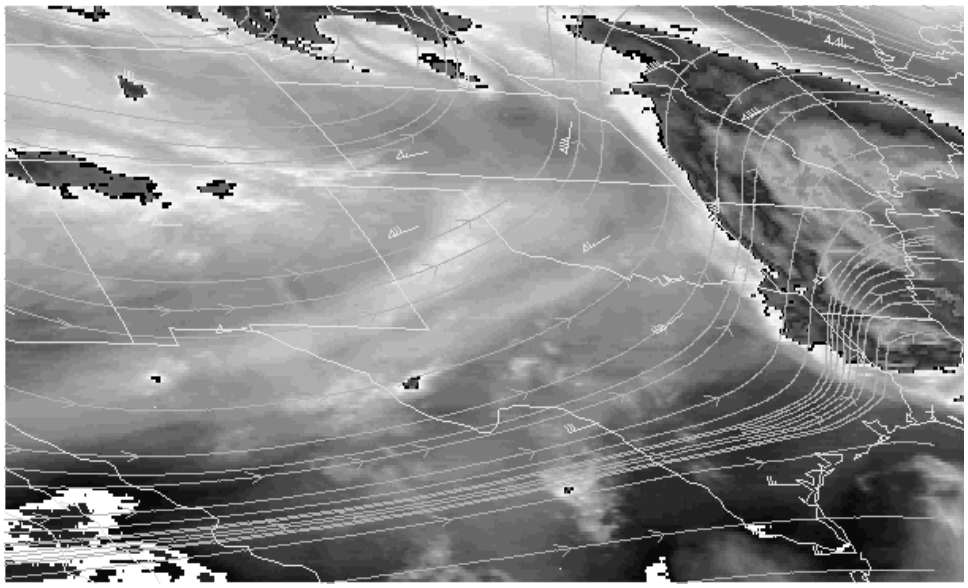


Figure 1. Eight kilometer resolution 6.7 μm image from GOES-9 displayed at the 4 km scale. The image was taken at 1200 UTC on May 27, 1997. The 200 mb winds and streamlines are plotted on the image.

When Figure 1 is viewed as part of an animated image sequence, the circulation around the upper-level low in Nebraska and the location and movement of the upper-level trough and jet stream are all well defined. Both 6.7 and 10.7 μm imagery show the development of a large MCS over Arkansas and eastern Oklahoma during the night (Figure 2).

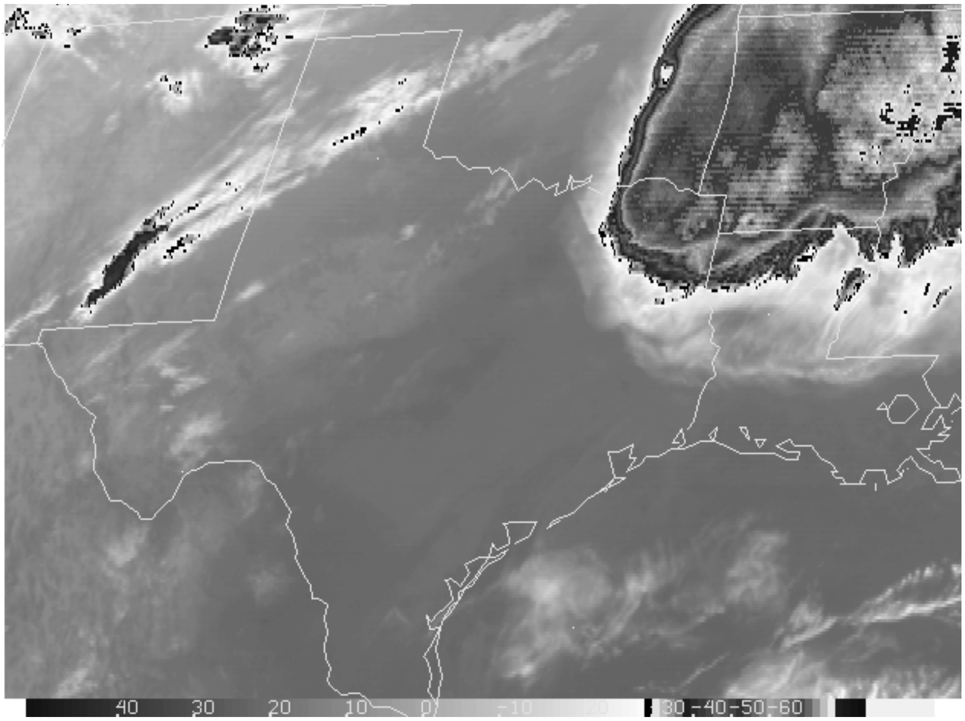


Figure 2. Four kilometer resolution 10.7 μm image from GOES-8, taken at 0915 UTC on May 27, 1997. Temperature (in $^\circ$Celsius [C]) as it relates to the gray scale is shown at the bottom of the image. The cloud shield of the large mesoscale convective cloud system, referred to in the text, covers most of Arkansas.

This MCS moved slowly eastward and produced gravity waves that radiated away from the system. One of those gravity waves appears to have played a role in the initiation of the thunderstorm complex that eventually produced the tornado activity; however, that gravity wave moved south of the storm complex before the beginning of tornado activity. In advance of the upper trough, both 6.7 and 10.7 μm imagery showed numerous patches of cirrus move across Mexico and into Texas during the nighttime and into the early afternoon.

(Figure 3 and its discussion are not part of this abbreviated report.)

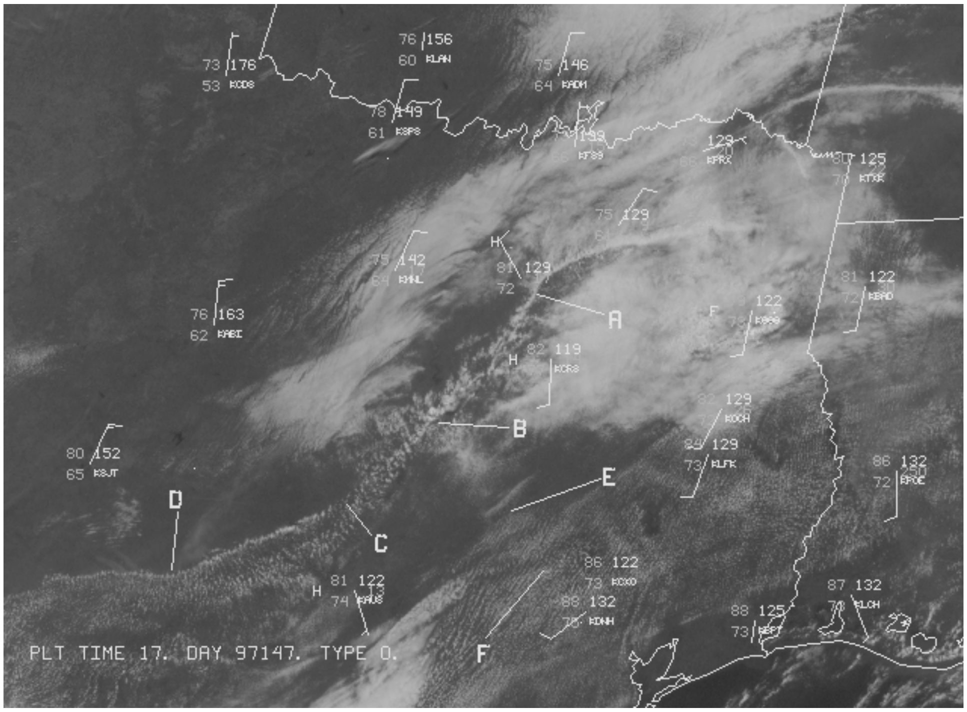


Figure 4a. One kilometer resolution visible image from GOES-8, taken at 1645 UTC on May 27, 1997. Surface observations are plotted on the image.

From early in the day, combining surface observations with GOES visible imagery allowed precise positioning of the surface front—evident as a northeast- to southwest-oriented line of cumulus coincident with the surface low pressure trough and cyclonic wind shift in Figure 4a. Details in the front's orientation and movement were easily monitored by animating GOES visible imagery on RAMSDIS until anvil cirrus, associated with thunderstorms along the front, obscured the satellite's view. In Figure 4a, notice the well-defined line of organized convection that extends from northeast to southwest along the frontal convergence zone, from A-B-C-D. Initiation of deeper cumulus that eventually develop into the main tornado-producing thunderstorm complex is underway at location B. At B, a broad area of cumulus intersects the frontal cloud band, from B-E-F. The cloudiness from B-E-F is associated with a gravity wave that emanated from the MCS shown in Figure 2.

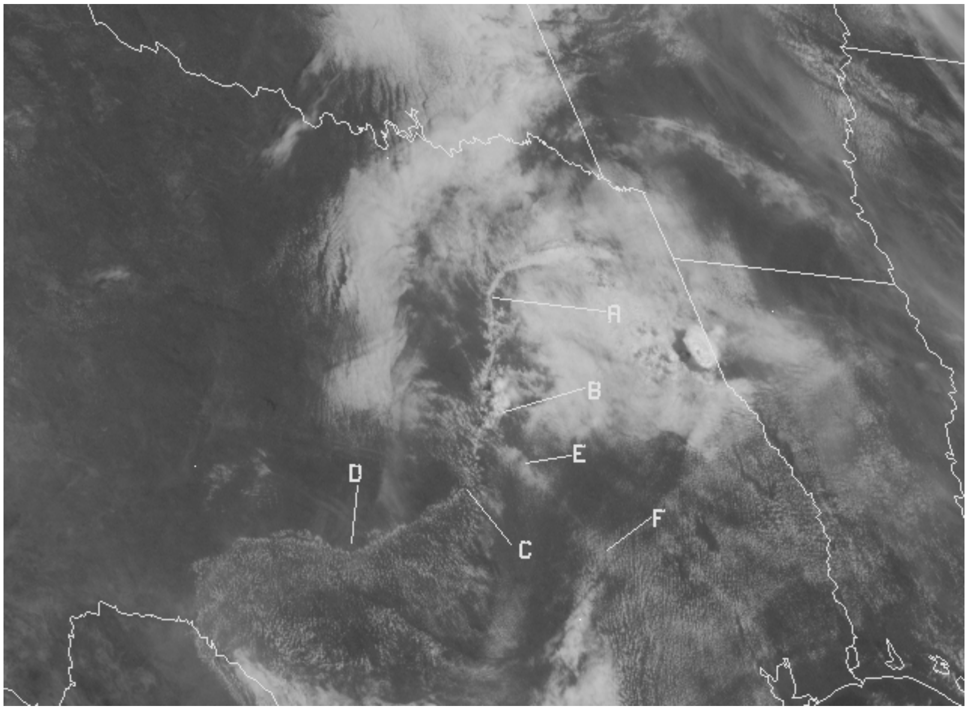


Figure 4b. One kilometer resolution visible image from GOES-9, taken at 1715 UTC on May 27, 1997.

Figure 4b, from GOES-9 and taken 30 minutes after the image in Figure 4a, shows that deeper convection has initiated at B and that the gravity wave has moved to the south of the convective genesis area. Notice the difference in viewing perspective between GOES-9 and GOES-8. Because there is very little deep convection or thick cirrus, low-level cloud details are seen equally well in both images.

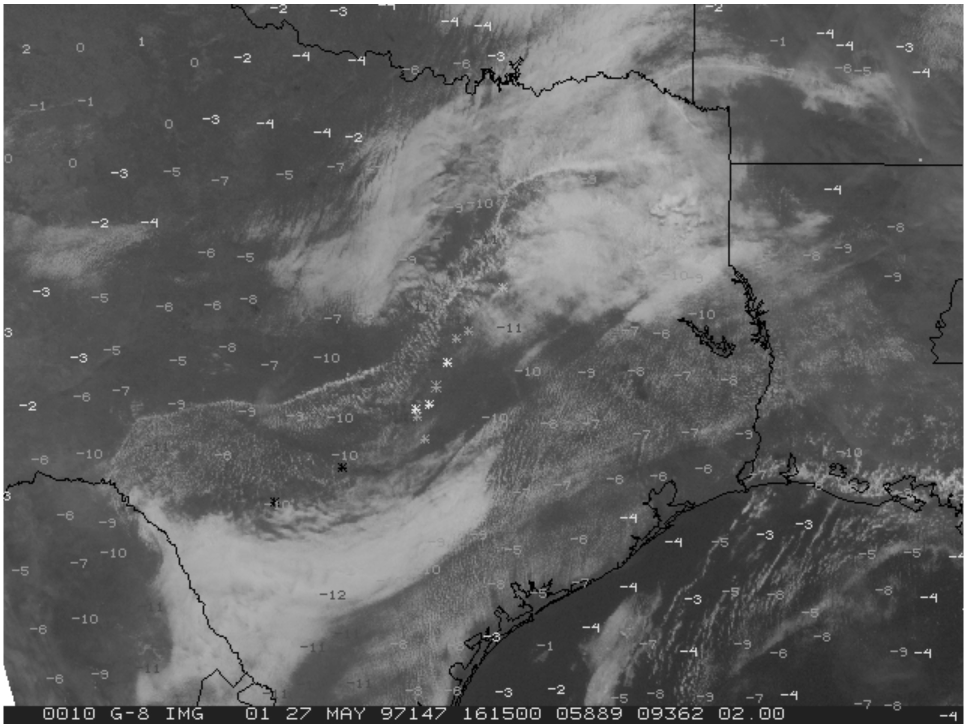


Figure 5. GOES sounder derived LI values (°C) for 1500 UTC on May 27, 1997, plotted over the 1615 UTC NOAA GOES-8 visible satellite image. The gray scale represents ranges of LI values. LI's greater than 0 indicate stable atmospheric conditions; less than 0, unstable. LI values less than -10° C indicate extremely unstable conditions.

Experimental GOES-8 satellite soundings are generated by the NESDIS Forecast Products Development Team on an hourly basis, using GOES-8 sounder data, surface observations and information from the Eta numerical forecast model. These experimental products are available via Internet, from which Figure 5 was extracted. The Lifted Index (LI) values shown in Figure 5 highlight strong instability along the frontal boundary, with values of -11° C to -13° C in the Jarrell, Texas, region. Sounder products from later in the day were consistent with what is shown in Figure 5; very unstable air was available to fuel intense storms in the vicinity of the frontal zone. It should be noted that sounder calibration problems during this time may have resulted in boundary layer moisture values that were too high, and thus the extreme LI values. However, the relative values and gradients of instability shown in Figure 5 indicate the potential of GOES sounder products for severe storm nowcasting. It is important to realize that soundings derived from GOES sounder data are only made for clear or partly cloudy conditions.

Storm Scale Analysis

For the storm scale analysis, all GOES figures are centered at the beginning location of the tornado track that corresponds to a particular image and image times are for that center scan line. When viewing GOES imagery, the observer must keep in mind that three dimensional features are being observed over a curved Earth, while being displayed on a two dimensional flat surface. This means that when locating features with respect to a *surface-based grid*, features at the surface will be accurately located while features above the surface will be mislocated. The mislocation will be radially away from the satellite subpoint and will increase as cloud height increases. This parallax shift is illustrated in Figure 6a, where the ground tornado track is located between asterisks, and the track with respect to cloud top is located between plus marks. *(Note: For the sake of brevity, only GOES-8 imagery is used. Refer to the author's original paper for the comparison of GOES-8 and GOES-9 imagery.)* For all infrared imagery, the gray scale bar versus temperature (Celsius) relationship at the bottom of Figure 6b is valid.

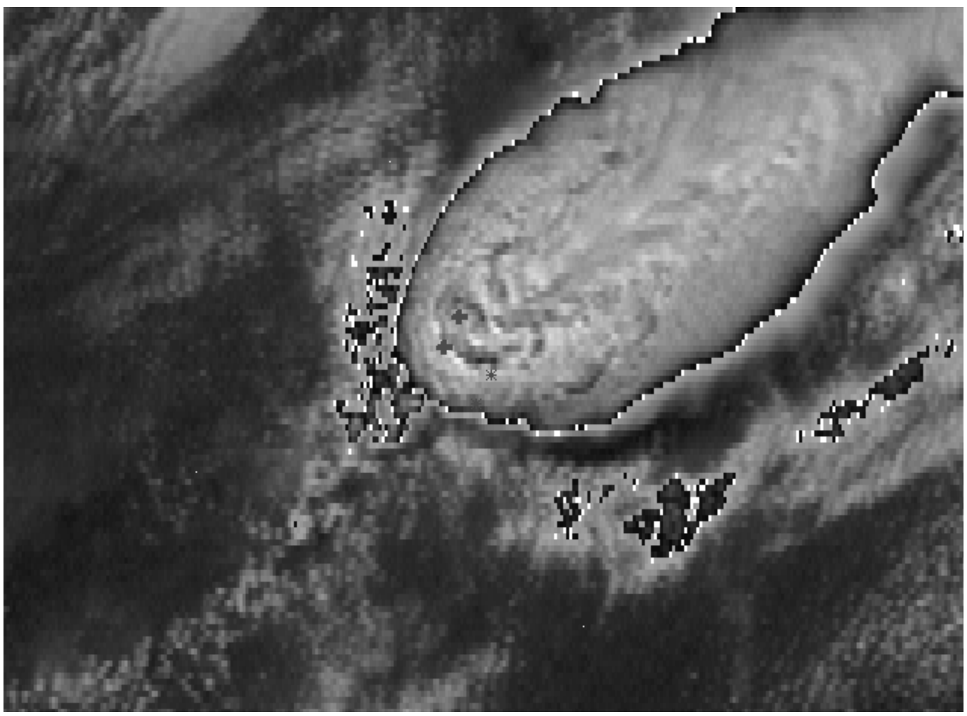


Figure 6a. One kilometer resolution visible image from GOES-8 displayed at a 0.25 km scale. The image is centered at 31°17'54" North and 97°20'07" West, the beginning point of the Moody, Texas, tornado track. The time for the scan line at picture center is 18:49:10 UTC. Both beginning and ending points of ground (*) and cloud top (+) locations of tornado track are shown. Note the adjustment that must be made due to parallax to associate features at the ground to those at cloud top.

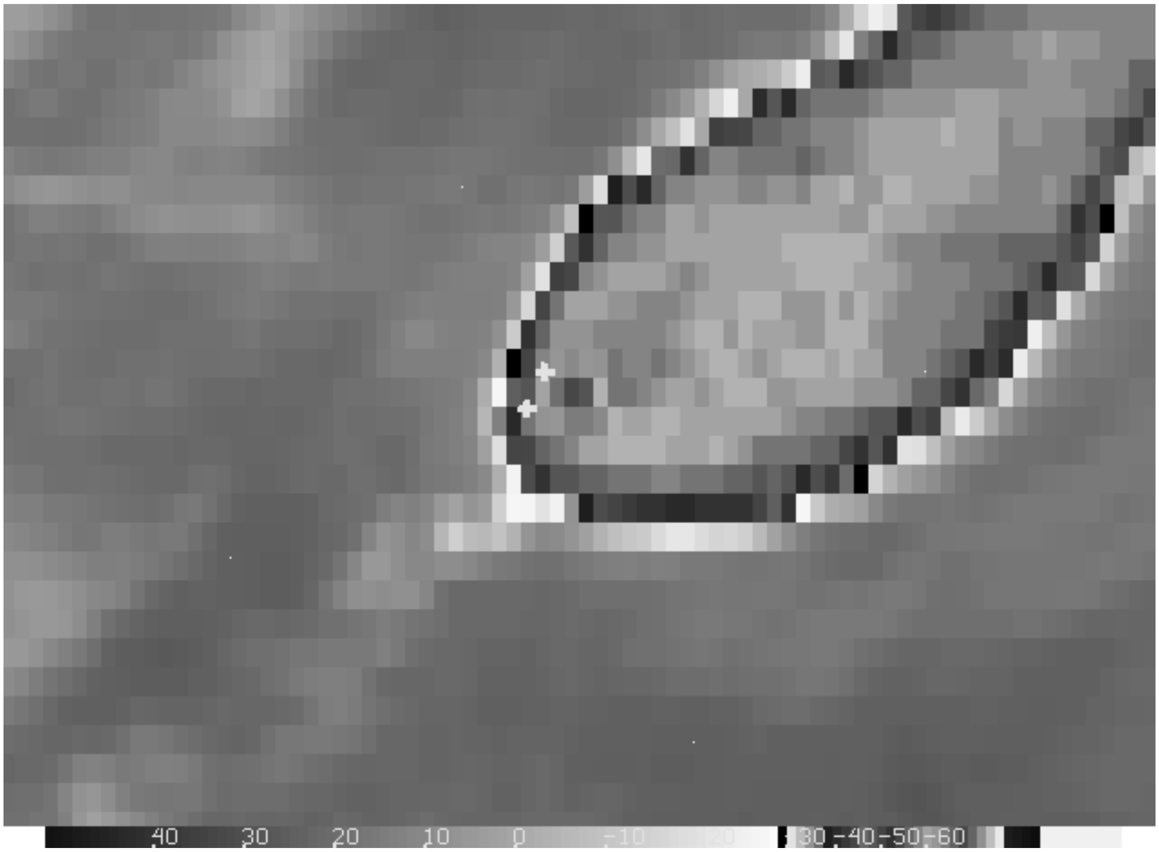


Figure 6b. Four kilometer resolution GOES-8 infrared image matching the visible image in Figure 6a. Minimum cloud top temperature in the overshooting top area is -66.7° C. Beginning and end points of the tornado track (+) are mapped to a cloud top height of 15 km.

The visible images reveal plumes of veil-like cirrus cloud extending downwind from the thunderstorm's overshooting top. Above-anvil cirrus plumes are often observed with very intense and long-lived thunderstorms. In most of the corresponding infrared images, an enhanced V signature (a V-shaped region of colder cloud extending downwind from the overshooting top) was evident; such signatures are common with very intense thunderstorms. Strong overshooting top activity was evident with the main tornado-producing thunderstorm area throughout its life.

The Moody, Belton and Jarrell, Texas, tornadoes (Figures 6, 7 and 8) were from the same thunderstorm complex. When GOES imagery is animated in a storm-relative mode with tornado locations superimposed, it is evident that the tornadoes occurred in almost exactly the same location—on the west side of the storm and associated with the coldest overshooting top. During the Moody to Jarrell portion of the storm's life, the overshooting top region of the storm developed southwestward (from 31° at 10 meters per second). This motion is a result of the storm developing south along the northeast to southwest oriented front which is moving gradually eastward. At the time of the Jarrell tornado, a new cell was rapidly developing along the front to the south of Jarrell. The overshooting top associated with the new storm is evident at the southwest end of the anvil in Figure 8. *(Figure 9 and its discussion are not part of this abbreviated report.)* During the next 1 ½ hours, that new storm produced the Pedernales Valley tornado. Storm-relative animation revealed that at 2100 UTC the storm changed velocity, moving faster and in a more westerly direction. That change in storm motion coincides with a change in orientation of the frontal boundary, to a more east-to-west orientation, as is evident at point C in Figure 4. This change in direction helps explain the near east-to-west tornado track at Pedernales Valley. As with the earlier activity, those tornadoes were located in close proximity to the overshooting/cold cloud top area.

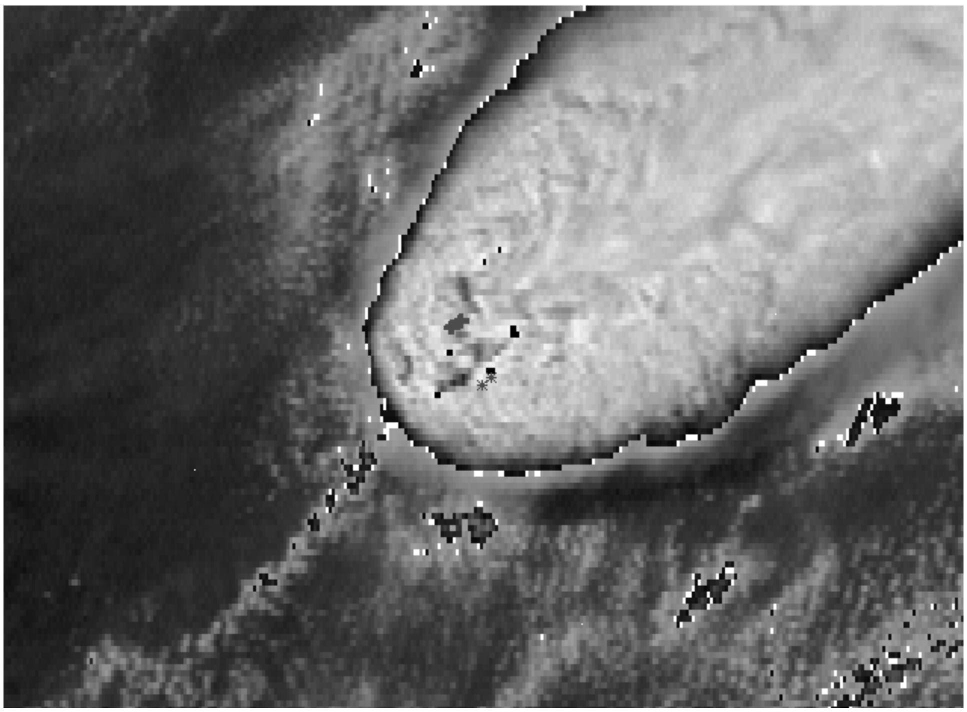


Figure 7a. One kilometer resolution visible image from GOES-8 displayed at a 0.25 km scale. The image is centered at 31°08'55" North and 97°28'17" West, the beginning point of the Belton, Texas, tornado track. The time for the scan line across picture center is 19:34:16 UTC. Both beginning and ending points of ground (*) and cloud top (+) locations of the tornado track are shown.

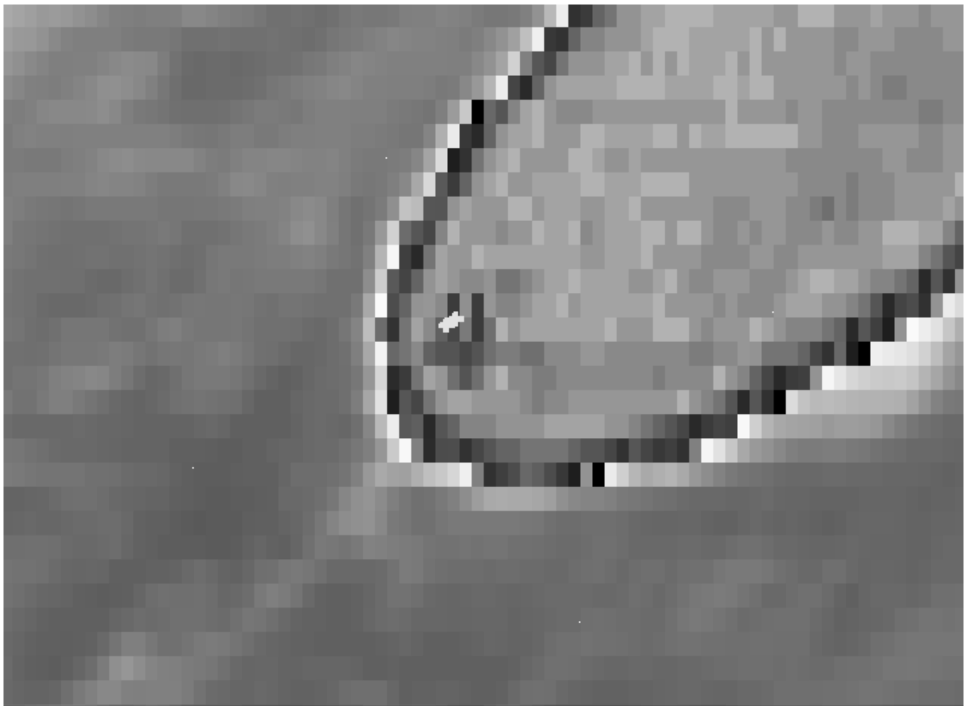


Figure 7b. Four kilometer resolution GOES-8 infrared image matching the visible image in Figure 7a. Minimum cloud top temperature in the overshooting top area is -70.2°C. Beginning and end points of the tornado track (+) are mapped to a cloud top height of 15 km.

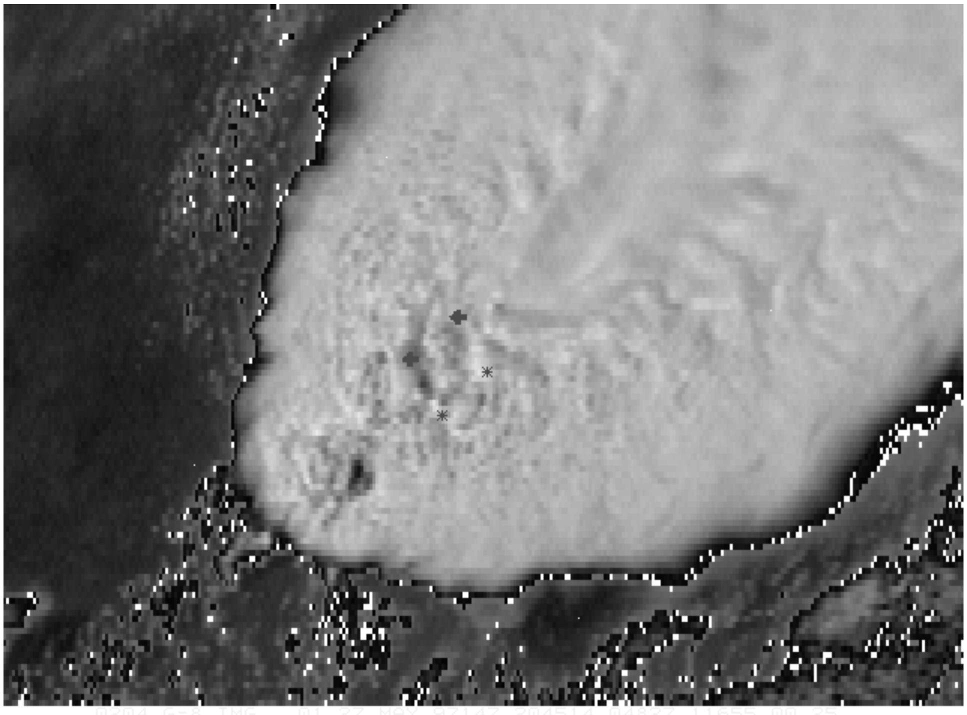


Figure 8a. One kilometer resolution visible image from GOES-8 displayed at a 0.25 km scale. The image is centered at 30°53'54" North and 97°35'12" West, the beginning point of the Jarrell, Texas, tornado track. The time for the scan line at picture center is 20:50:45 UTC. Both beginning and ending points of ground (*) and cloud top (+) locations of the tornado track are shown. Note the shadow immediately downwind of the overshooting top (almost traced out by a line between the southwestern most * and + marks); this overshooting top is associated with the Jarrell storm's updraft at cloud top.

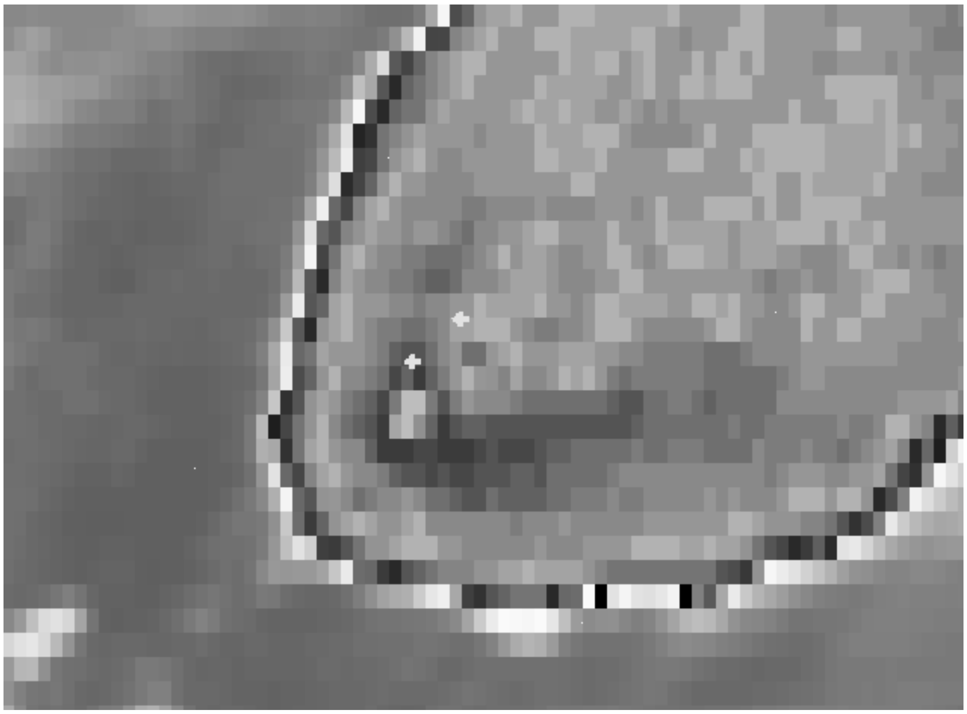


Figure 8b. Four kilometer resolution GOES-8 infrared image matching the visible image in Figure 8a. The minimum cloud top temperature is -72^{o} C and corresponds to the bright overshooting top area in the visible image in Figure 8a. This cloud top area was 6 degrees warmer 20 minutes prior to this image. Beginning and end points of the tornado track (+) are mapped to a cloud top height of 15 km.

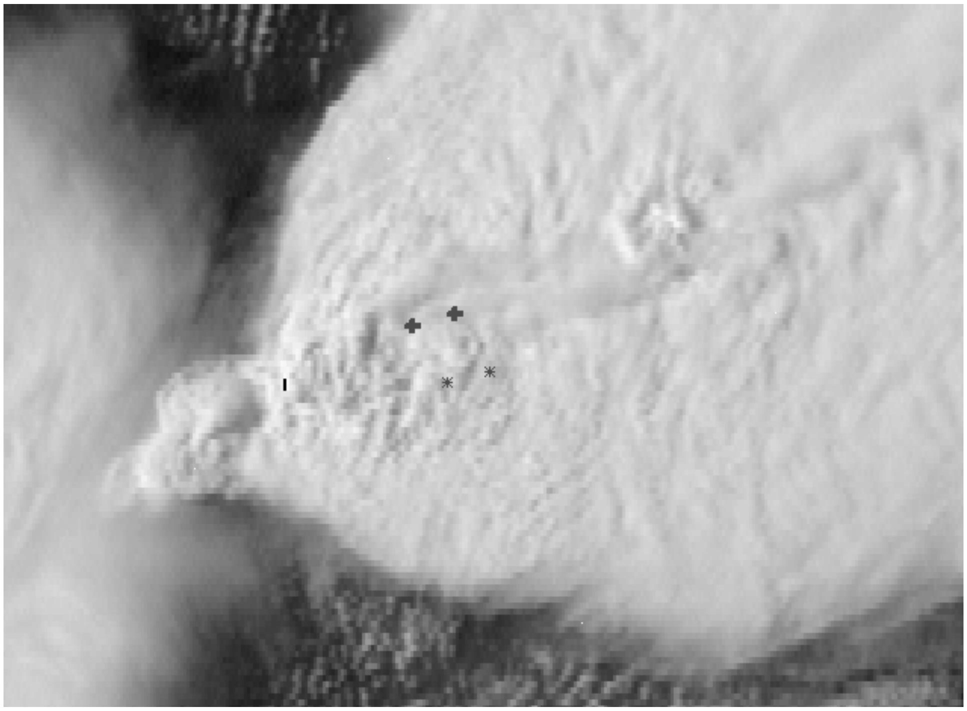


Figure 10a. One kilometer resolution visible image from GOES-8 displayed at a 0.25 km scale. The image is centered at 30°23'21" North and 98°00'45" West, the beginning point of the Pedernales Valley tornado track. The time for the scan line at picture center is 22:04:20 UTC. Both beginning and ending points of ground (*) and cloud top (+) locations of the tornado track are shown.

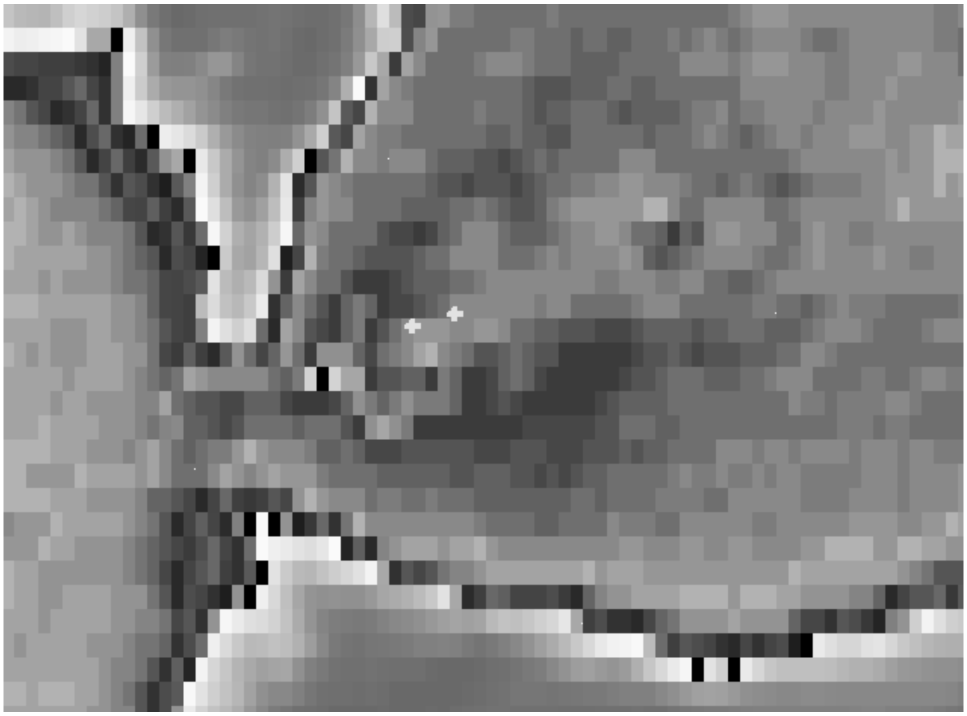


Figure 10b. Four kilometer resolution GOES-8 infrared image matching the visible image in Figure 10a. Minimum cloud top temperature in the overshooting top area is -75° C. Beginning and end points of the tornado track (+) are mapped to a cloud top height of 15 km.

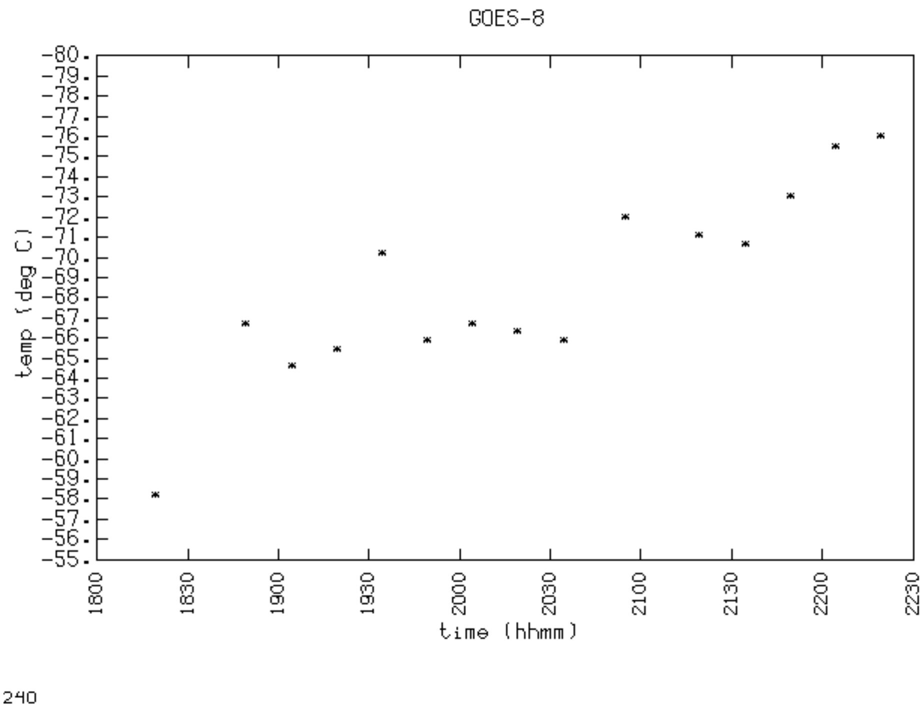


Figure 12. Minimum overshooting cloud top temperature for the tornadic storm complex versus UTC for GOES-8.

The relationship between overshooting tops, cloud top temperature and storm updraft intensity is fairly well understood. It is instructive to inspect plots of minimum cloud top temperature for the tornadic storm complex as a function of time for GOES-8 during the outbreak period. This is done in Figure 12. It is interesting that the cloud top temperatures closest to the Moody, Belton and Jarrell tornado times are all 4° to 5°C colder than a smooth curve fitting minimum cloud top temperatures at non-tornado times. This apparent relationship is not as clear for the Cedar Park or the Pedernales Valley storms.

Between the times of the Belton and Jarrell tornadoes, NOAA-14 provided AVHRR imagery over the tornado outbreak area. While GOES and AVHRR visible channel imagery is of comparable resolution, AVHRR's 10.7 μm infrared channel provides 1-km resolution imagery versus the 4 km resolution available from GOES. The four panel image in Figure 11 may be used to compare visible and 10.7 μm imagery from GOES with that from AVHRR. The GOES and AVHRR visible images have been enhanced to show detail at cloud top, while the same color enhancement is used for the infrared images. Notice how well the enhanced GOES and AVHRR visible imagery define cloud top features—the veil-like cirrus plume above the anvil can be seen extending downwind from well-defined overshooting tops. In the corresponding infrared images, those same features are less well defined in GOES imagery than in AVHRR imagery. Cloud top temperature structure is better defined in the AVHRR imagery, with AVHRR minimum temperatures in the overshooting top region approximately 10°C colder than in the GOES imagery. In the AVHRR imagery, relatively warmer anvil downwind from the overshooting top area is clearly surrounded on both downwind sides of the anvil by colder cirrus—the "enhanced-V" signature. This comparison of AVHRR and GOES points to the potential for use of AVHRR imagery as a companion to GOES imagery for convective nowcasting purposes.

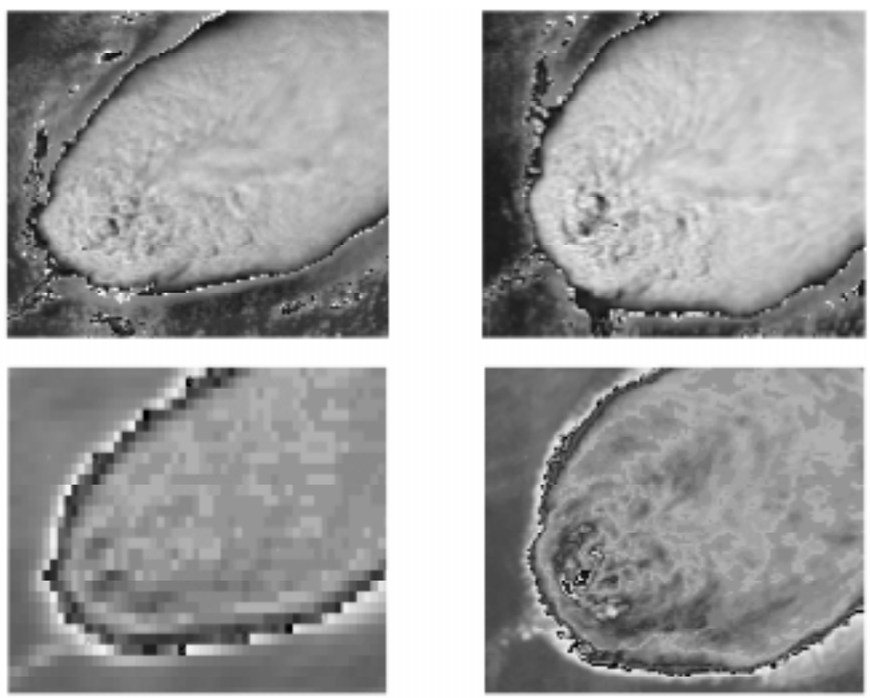


Figure 11. GOES visible upper left; AVHRR visible upper right; GOES infrared lower left; AVHRR lower right. The GOES imagery was taken near 2004 UTC while the AVHRR imagery was taken approximately 1 minute earlier.

Conclusions

Satellite data provided a number of valuable pieces of information for use in severe thunderstorm nowcasting over Texas on May 27, 1997. The storm complex that produced the tornado activity between Moody and Pedernales Valley on this day had features at cloud top that are often associated with thunderstorms that have very intense updrafts: (a) overshooting tops in the visible imagery; (b) veil-like cirrus plumes above the anvil extending downstream from the overshooting top area; (c) cold top areas associated with the overshooting region that were colder than the ambient anvil temperature; and (d) enhanced “V” shaped cold regions with warm wakes extending downwind from the cold top area. It should be noted that cold cloud top features similar to these were noted in other intense thunderstorm complexes that produced intense weather over Texas on this day. The precise location, orientation and movement of the front along which the tornadic storm complex evolved was easily monitored using GOES imagery.

Real-time data flow into a satellite analysis system with capability similar to RAMSDIS would have allowed for a number of useful applications. Storm-relative animation would have revealed that tornadic activity was confined to one major thunderstorm complex, highlighting the threat to any who lay in the path of the storm and its intersection with the front. Imagery could have been enhanced, revealing cloud top characteristics commonly associated with severe thunderstorm activity.

As shown in Figure 12, there appears to be a relationship between storm intensity, as revealed by cloud top temperature, and tornado activity. However, it is not possible to verify this with the 15-minute imagery, because storm dynamics with intense tornadic storms such as these are very strong, and explosive overshooting at cloud top may last for only a few minutes. It is indeed unfortunate that the satellite was not placed in a 7 ½-minute severe storm observing mode during the event, nor had a special 1-minute interval imaging day been requested for research purposes. The AVHRR imagery should be included as a part of routine real-time satellite imagery provided to field users; it also gives an enticing glimpse to what might be observed with higher resolution infrared imagery from geostationary satellites.

Appendix C

Aerial Damage Survey of the Central Texas Tornadoes of May 27, 1997

Brian E. Peters
Warning Coordination Meteorologist
National Weather Service, Birmingham, Alabama

Introduction

During the afternoon of May 27, 1997, severe thunderstorms spawned a series of tornadoes over portions of Central Texas from just south of Waco to west of Austin. As part of the NOAA Service Assessment Team investigating the storm event, an aerial damage survey was conducted. The intent of the aerial survey was to provide information to pinpoint the beginning and ending points of the tornado tracks, as well as provide information on the Fujita Tornado Intensity Scale (F-scale) along the track.

The aerial survey was conducted on Friday and Saturday, May 30-31, using a fixed-wing aircraft flying at approximately 3,000 feet and a helicopter flying between 500 and 1,000 feet. Additional aerial surveying was done on Monday, June 2, using a helicopter arranged by the Travis County Emergency Management Agency and the Fire Marshal's office. A total of about 9 hours of air time was logged in the flights. Some of that air time was spent in getting to and between the various tornado tracks. Additional assistance was obtained by using a Global Positioning System (GPS) and mapping software to accurately plot damage locations. The GPS/software combination claims an accuracy of ±300 feet.

THE MOODY TORNADO

Maximum F-scale: F3
Path Length = 3.7 miles   Path Width = 150 yds
Path Length by County: McLennan [3.2 miles]; Bell [0.5 miles]
Beg: 31° 17.91'/97° 20.16'   End: 31° 14.91'/97° 21.48'

The Moody tornado began on the southside Farm to Market Road (FM) 107, 1.6 miles east-southeast of Moody in open country. The tornado traveled south-southwest moving across Dowell Road where two structures, a house and a barn, were destroyed. Another structure, a small house, was damaged just north of this location. A pickup truck and a car were each tossed several hundred feet; the pickup truck to the left of the tornado path and the vehicle along the path. The tornado continued south-southwest from Dowell Road, crossing the McLennan/Bell County line covering open country with trees down in numerous locations.

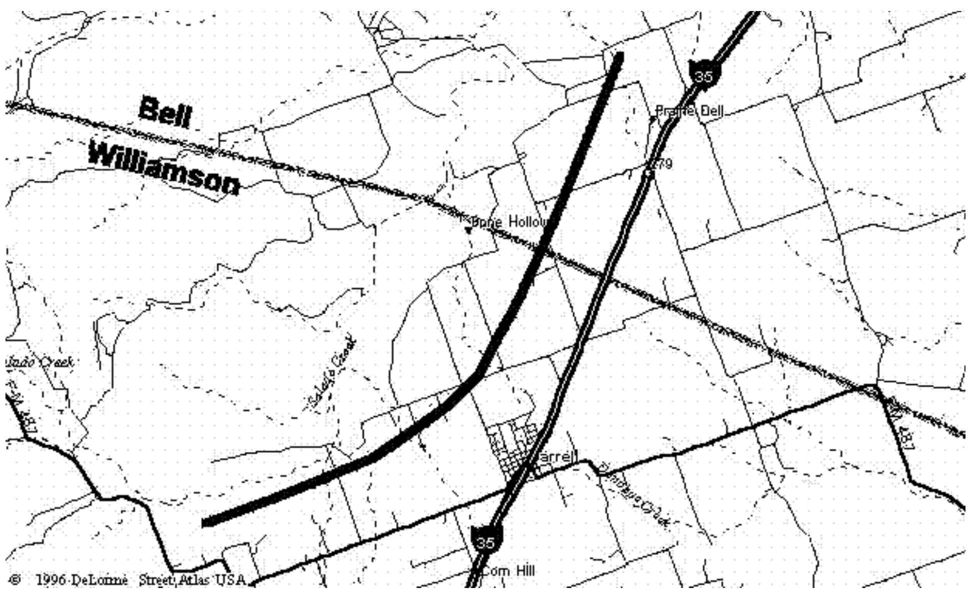
Maximum F-scale assignment was based upon the damage that occurred at only one location, where the house and barn were destroyed. There was an absence of other structures to make an effective assessment.

THE BELTON TORNADO

Maximum F-scale: F3
Path Length = 1.4 miles Path Width = 275 yds
County: Bell
Beg: 31° 08.92'/97° 28.29' End: 31° 08.01'/97° 29.19'

The tornado began 6.5 miles north of Belton in an area called Morgan's Point on the northside of Belton Lake. The tornado moved from land along a slough with tree damage on the west side of the slough. A number of structures also on the west side of the slough sustained damage which appeared to be minor. Continuing south-southwest, the tornado crossed a bend in Belton Lake, moving ashore just northeast of a community called Woodland. As the tornado moved ashore, destruction to trees was nearly total, with substantial damage to at least six structures.

The tornado ended abruptly only 1/3 of a mile after coming ashore at a point 5.6 miles north-northwest of Belton.



Ground Track of the Jarrell Tornado

THE JARRELL TORNADO

Maximum F-scale: F5
Path Length = 7.6 miles Path Width = 3/4 miles
County: Bell [2.4 miles]; Williamson [5.2 miles]
Beg: 30° 53.90'/97° 35.20' End: 30° 49.18'/97° 40.12'

The damage path associated with the Jarrell tornado actually begins in Bell County at a point about 0.8 miles northwest of the Prairie Dell exit from Interstate 35, near mile marker 280. The tornado tracked south-southwestward across open country. Damage was primarily to trees, with only a couple of structures damaged.

The tornado remained primarily in open country as it crossed the Bell/Williamson County line before taking a more southwestward turn that took it to the northwestern edge of Jarrell. The tornado crossed the county line very close to where Williamson Road ends and County Road (CR) 304 (Bell County) begins. The tornado crossed CR 308, CR 305, and then CR 307. Where the tornado crossed each of these county roads, approximately 525 feet of asphalt was ripped off each of the roadways. This particular destruction was believed to be very close to the centerline of the tornado circulation.

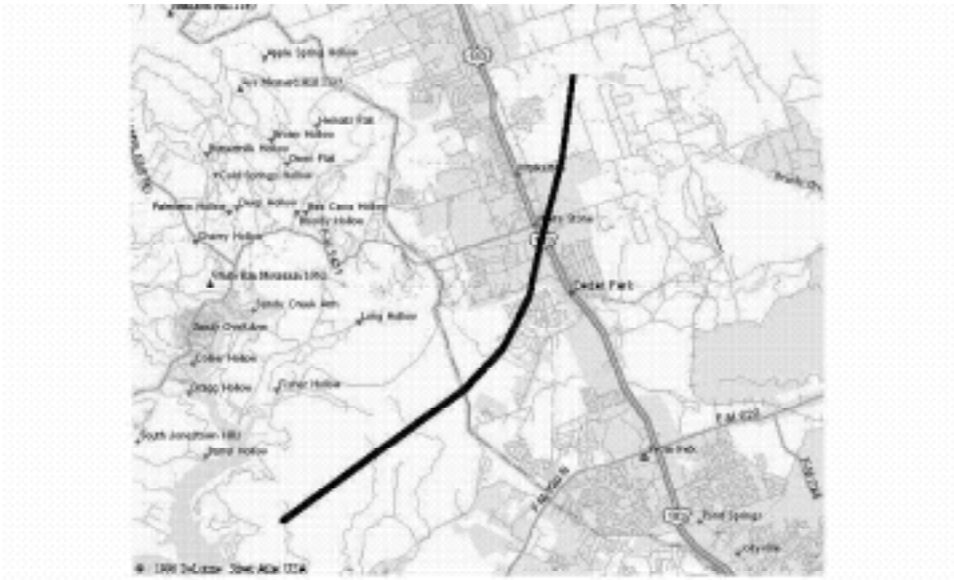
Observations recounted by eyewitnesses and revealed in interviews made by other members of the Service Assessment Team indicated that the damage path may not have been made strictly by one tornado. A number of eyewitnesses reported seeing several small, rope-like funnels before the character of the tornado changed drastically into the killer tornado.

As the tornado crossed the intersection of CR 305 and 307, a business on the corner was destroyed. The tornado moved into the Double Creek Estates subdivision at this point with total destruction. F5 destruction begins shortly after the tornado moved into Williamson County and continued until very close to the end of the damage path.

Moving through the Double Creek Estates subdivision and the surrounding area, the tornado widened to the maximum width of three-quarters of a mile. From the air, the ground appearance changed abruptly in the vicinity of CR 308 and continued until very near the end of the path. No definitive circulation patterns or suction spots were evident, but there was the noted obvious change in the appearance of the ground.

In the Double Creek area, approximately 40 structures were totally destroyed. One of the most striking signs in approaching this area was the distinct lack of debris of any size. Closer inspection showed lots of little debris, but no sign of large items. At least half a dozen cars were identified from the air lying in the open areas, most of them flattened and encrusted with mud and grass. Later, a ground survey revealed that most of the debris that was left in the area was extremely small, indicating the power of the tornadic winds. All 27 deaths associated with the Jarrell tornado occurred in the Double Creek area.

After passing through the Double Creek area, the tornado moved across CR 309 and into a heavily wooded area of cedar trees. The total destruction of the tornado ends abruptly shortly after entering the wooded area. However, a small swath of tree damage on the north side of the main damage path suggested the possibility of a multiple vortex pattern. No other evidence of multiple vorticies was observed.



Ground Track of the Cedar Park Tornado

THE CEDAR PARK TORNADO

Maximum F-scale: F3
Path Length = 9.2 miles Path Width = 250 yds
County: Williamson [5.6 miles]/Travis [3.6 miles]
Beg: 30° 33.39'/97° 49.24' End: 30° 27.30'/97° 54.11'

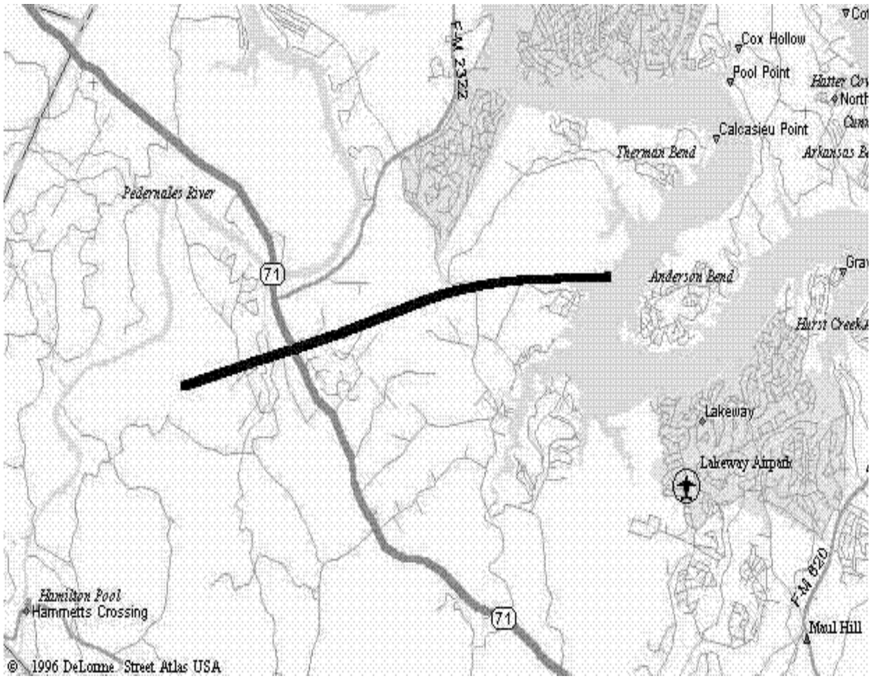
The Cedar Park tornado began about 3.5 miles north of Cedar Park, at a location 0.6 miles south of CR 178 and 1.4 miles east of the intersection of US 183 and CR 178. The initial damage was to trees, however, the ground survey revealed damage nearby to a church and a trucking company. The aerial survey did not reflect this damage as being in line with the damage path. It is quite possible this damage was caused by strong wind near the tornado. The beginning point was in a relatively open area, with damage primarily to a few trees and minor shingle damage to one house.

The tornado moved south-southwestward, skirting a residential area before it crossed CR 180 immediately east of US 183. It was at this intersection that an Albertsons grocery store was severely damaged. The tornado crossed US 183, causing additional damage to a number of businesses. One business on the west side of US 183 lost nearly the entire roof. Most damage to other businesses was believed to be minor.

A historic train located on the north side of CR 180, just to the east of US 183, was in the direct path of the tornado. While the engine remained on the track, a coal tender converted to hold diesel fuel and weighing approximately 65,000 pounds, including the 1,000 gallons of diesel fuel, was flipped over and thrown a short distance.

After crossing US 183, the tornado moved across Marquis Lane and North Park Circle through an area with widely scattered housing and a relative abundance of trees. Most damage to structures in this area was minor.

From North Park Circle, the tornado moved into the northwestern portion of Buttercup Creek, a subdivision of well constructed homes. Damage to homes was irregular, with one house losing a roof but the house next door losing only shingles. Damage ranged from F0 to F2. At this point, the tornado track was taking a gentle right turn and became more southwesterly. The tornado moved into a wooded area crossing into Travis County before ending 1.1 miles from Lake Travis. Damage in the wooded area was irregular, ranging from near total destruction of all trees to sections with about 10 percent of the trees down.



Ground Track of the Pedernales Valley Tornado

THE PEDERNALES VALLEY TORNADO

Maximum F-scale: F4
Path Length = 5.6 miles   Path Width = 440 yds
County: Travis
Beg: 30° 23.35'/98° 00.75'   End: 30° 22.39'/98° 06.25'

The Pedernales Valley tornado began on the shore of Lake Travis, destroying trees and a floating marina where nearly all of the watercraft were destroyed. While numerous trees were twisted and uprooted in this area, several structures sustained only what appeared to be minor damage that would be no more than F0.

The tornado was initially on a heading of 265 degrees as it moved into rough terrain. A number of structures sustained varying damage until the tornado reached Bee Creek Road. At that location, a Southwest Bell building housing telephone switching equipment was destroyed. The building was well-constructed and was one of several buildings which indicated at F4 rating for this tornado. Bee Creek Road takes a bend close to the telephone building, and across the street a house was destroyed with walls knocked down.

Approximately 2.2 miles from the lake, the tornado path takes a distinct dog-leg turn toward the southwest. The point at which this turn occurred also corresponds with a knoll. Trees and buildings at the top of the knoll were destroyed.

After the turn, the tornado assumed a heading of 250 degrees and crossed a major power distribution line. One steel tower was destroyed, bringing all lines to the ground. The tornado remained on the 250 degree heading, moving through the area described as the Hazy Hills subdivision. Numerous houses and several mobile homes were totally destroyed. Several houses survived but sustained major damage that made them totally uninhabitable.

The only death associated with this tornado occurred here, when one man was killed. He lived in a mobile home that was demolished and his vehicle was tossed several hundred feet. Service Assessment Team members were unable to learn whether he was in the mobile home during the storm or had left it to drive away.

The tornado continued west-southwest, moving across State Road (SR) 71. A number of well-built homes in the Hazy Hills subdivision were heavily damaged or destroyed. Crossing SR 71, the tornado moved into another subdivision with widely-separated houses in the Lick Creek valley, a steep walled creek that feeds into the Pedernales River. One stone-walled house located just north of Pedernales Drive and west of SR 71 was completely deroofed. Other structures in this subdivision sustained roof damage in the F2 range. After following the terrain into the cree, the tornado climbed another rise in the land before ending shortly after passing the crest of the small hill. As the tornado ended, damage was minimal to trees.

Appendix D

Persons Interviewed and/or Contacted by the Service Assessment Team

Name	Date	Affiliation
John Sneed	05/29/97	Williamson County Sheriff's Department
Shawn Newsom	05/29/97	Williamson County Sheriff's Department
Mike Faught	05/29/97	Georgetown Fire Department
Mark Moss	05/29/97	Chief, Georgetown Fire Department
Kevin McEleney	05/29/97	Jarrell Volunteer Fire Department
Larry Fore	05/30/97	Albertsons grocery store manager
Tim Travis	05/30/97	Cedar Park Police Department
Paul Christ	05/30/97	Austin Police Department
Pat Pingston	05/30/97	Post Net store owner
Nick Olarti	05/30/97	Taco Bell store manager
Bob Russell	05/30/97	Cedar Park fire department
Mrs. & Mrs. Jim McCarty	05/30/97	Buttercup Creek residents
Ken Van Rens	05/30/97	Chief, Pedernales Valley Volunteer Fire Department
Steve Poulson	05/30/97	Pedernales Valley Volunteer Fire Department
David & Ann Butler	05/30/97	Hazy Hills residents
Scott Beckwith	06/01/97	Jarrell resident
Cliff Tschoerner, Jr.	06/01/97	Jarrell Volunteer Fire Department
Joyce Wilson	06/01/97	Double Creek Estates subdivision resident
LaDonna Peterson	06/01/97	Double Creek Estates subdivision resident
Jaunitta Peterson	06/01/97	Double Creek Estates subdivision resident
Bonnie Hammett	06/01/97	Double Creek Estates subdivision resident
Ken Adams	06/01/97	Double Creek Estates subdivision resident
Steve Collier	06/02/97	Austin Office of Emergency Management
Eric Carter	06/02/97	Austin Office of Emergency Management
Joe Hidrogo	06/02/97	Austin Office of Emergency Management
Scott Swearengen	06/02/97	Austin Office of Emergency Management
Clay Shell	06/02/97	Georgetown Fire Department
Bob Rose	06/02/97	Lower Colorado River Authority
Geniva Simpson	06/02/97	Williamson County Sheriff's Office
Richard Gasten	06/02/97	Travis County
Brad Beauchamd	06/02/97	Travis County
Pete Baldwin	06/02/97	Travis County Emergency Management
Chris Causen	06/02/97	Travis County Emergency Services
Bobby Dewsman	06/02/97	State Office of Emergency Management

Jo Moss	06/02/97	State Office of Emergency Management
Linda Moorer	06/02/97	State Office of Emergency Management
Steve Vaughan	06/02/97	State Office of Emergency Management
Ken Lott	06/02/97	Austin American Statesman newspaper
Clara Herrera	06/02/97	Austin American Statesman newspaper
Larry Kolvoor	06/02/97	Austin American Statesman newspaper
Dave Martis	06/02/97	KVET/KASE radio
Michael Schmid	06/02/97	Texas Association of Broadcasters
David Gaiewski	06/02/97	Time Warner Communications
George Warmingham	06/02/97	Austin Cablevision
Kenneth Pulliam	06/02/97	KDFW-TV
Cliff Morrison	06/02/97	KEYE-TV
Andrew Sowder	06/02/97	KTBC-TV
Kimberly Flemming	06/02/97	KTBC-TV
Mike Wenglar	06/02/97	KVUE-TV
Keith Harris	06/02/97	KVUE-TV
Mark Murray	06/02/97	KVUE-TV
Curtis Nichols	06/02/97	KVUE-TV
Brent Annear	06/02/97	KVUE-TV
Troy Kimmel	06/02/97	KTBC-TV
R. J. DeSilva	06/02/97	KXAN-TV
Dale Fuller	06/03/97	Cedar Park Emergency Management
Rodney Baden	06/13/97	McClennan County Emergency Management

Appendix E

CDC Field Epidemiological-Health Report

Dr. Enrique Paz, Epidemic Intelligence Service
U.S. Centers for Disease Control and Prevention (CDC)

Dr. Shellie Kolavic, Epidemic Intelligence Service, CDC
and
Texas Department of Health (TDH)

David Zane, MS, Director, Injury Prevention and Control Program, TDH

Background

On May 28, 1997, the CDC received an invitation from the NWS to participate in a NOAA Service Assessment Team in central Texas, where several tornadoes occurred on May 27. A Texas-based CDC epidemiologist and a TDH injury epidemiologist joined a scientist from the CDC to take part in the assessment. The CDC assessment was conducted from Friday, May 29, to Monday, June 2, 1997.

Objective

The purpose of the CDC assessment was to describe mortality and morbidity related to the tornadoes in the impacted population and to provide causal hypotheses for fatalities and injuries.

Assessment Methodology

Data-gathering techniques consisted of the following methods:

1. On-site observation

Time:	1-3 days
Resources:	Automobiles, Texas Department of Transportation area maps
Indicators:	Direct observations
	Discussions with local leaders and health workers
	Number of deaths
	Number of injuries

2. Quick field surveys

Time:	2-3 days
Resources:	National Weather Service
	Texas Department of Health
	Local hospitals
	Newspapers and other media
	Local law enforcement officials
	Emergency Response Services
	Williamson County Health Department
	American Red Cross
Indicators:	Rapid surveys, number of deaths, number of injuries

Results

Preliminary mortality and morbidity data was obtained from various sources, including the American Red Cross, local hospitals, newspapers, television, and anecdotal information in the field. This information was used to establish a base line for further surveillance and epidemiological studies regarding the health impact and possible causal factors of tornado-related deaths and injuries in the affected counties. Extensive damage, most notably in the Double Creek Estates subdivision, hampered the assessment. No random sample or cluster sampling techniques were conducted and no questionnaires were administered due to the gravity of the events, the short period of our survey, and the lack of persons in the immediate area during our visits.

Fatalities and Injuries

A total of 30 deaths occurred: 27 (90 percent) in Jarrell, 1 in Pedernales Valley, 1 in Cedar Park, and 1 in Austin. The 27 people died from multiple trauma; the other deaths were caused by heart attack, suffocation, and drowning. The mean age of the decedents was 27 years and the range was 5-69 years. The mean age for male decedents was 24 years; for females, the mean age was 33 years. These deaths directly affected 13 family units.

In Jarrell, 27 deaths occurred in the Double Creek Estates subdivision that had an estimated population of 132. The mean age of the decedents was 26 years and the range was 5-51 years. Of those who died, 14 were male (52 percent) and 13 were female (48 percent). Fourteen (52 percent) school-aged persons died. Ten families experienced two or more deaths; one family of five perished. The deaths in Jarrell represented 7 percent of that town's 1993 population.

In Cedar Park, one death (a male, age 69) occurred from cardiac arrest, probably due to storm-related stress. In Austin, one person (a female, age 38) drowned in a storm-swollen creek. In Pedernales Valley, one mobile home resident (a male, age 25) died. It is unclear where the decedents were located during the storms. None of the decedents lived in residences with basements, and most of the dead were recovered various distances from their homes. Several Double Creek Estate residents survived in bathtubs, while others successfully sheltered in a neighbor's storm cellar. This was apparently the only underground shelter in this subdivision.

Local hospitals reported that a total of 33 persons (13 from Jarrell, 15 from Cedar Park and 5 from Pedernales Valley) were treated for tornado-related injuries. One of the 13 injured from Jarrell died in the emergency room. Overall injuries, many multiple, included lacerations (55 percent), contusions (46 percent), abrasions (30 percent), strain/sprain/muscle spasm (18 percent), penetrating wound (0.03 percent), fracture (0.06 percent), and closed head injury (0.03 percent). The median age of the injured persons was 38 years with the range 1-75 years. Twenty-six injured persons were treated and released, one injured person died in the emergency room (as noted above), and five persons were admitted. The median length of hospital stay was 11.5 days and the range was 1-31 days. Four persons were discharged home and one to an inpatient rehabilitation facility.

Table 1. Mortality Data by County and Affected Area

County	Town or Place	Age	Sex
Williamson	**Jarrell**	51	F
		46	M
		46	F
		45	F
		41	M
		40	F
		40	M
		40	F
		38	F
		36	F
		36	F
		35	F
		21	M
		17	F
		17	M
		17	M
		16	M
		16	M
		15	M
		15	M
		15	M
		14	F
		14	M
		13	F
		11	M
		10	F
		5	M
	Cedar Park	69	M
Travis	**Shoal Creek Austin**	38	F
	Pedernales Valley	25	M

Sources of information: American Red Cross/CDC surveillance system and Texas Department of Health.

Table 2. Preliminary Descriptive Analysis

	Williamson Co.				Travis Co.	
	Total	**Jarrell**		**Cedar Park**	**Austin**	**Pedernales Valley**
Fatalities	30	27	(90%)	1	1	1
Males	16	14	(52%)	1	0	1
Females	14	13	(48%)	0	1	0
Mean age	27	26		69	38	25
Min age	5	5				
Max age	69	51				
Mean age males	24	21				
Mean age females	33	32				
Deaths under 18 years old	14	14				
Affected families	13	10				
Families with more than 1 death	9	9				

Conclusions

The majority of reported deaths occurred in Jarrell, in the Double Creek Estates subdivision. In Cedar Park, there was one reported death, and 15 injured persons were treated at local hospitals. In Austin, one drowning occurred. In the Pedernales Valley area, there was one reported death, and 5 persons were treated at local hospitals.

Limitations of the Survey

This survey has some limitations because quantitative data were unobtainable and access was limited by the devastating impact of the event. The data collection provided partial information and may be limited by selection bias. A comprehensive survey that included a questionnaire was not administered due to the short field visit.

Recommendations

- Encourage the recovery efforts of the affected population.
- Continue collecting data from the American Red Cross-CDC surveillance system, Texas Department of Health, hospitals, and other data sources related to fatalities and injuries for the final report.
- Follow up with data sources regarding risk factors and causal factors of the mortality and injuries due to the tornadoes in different areas, particularly in Jarrell.
- Continue improving warning systems and develop future technology to prevent fatalities and injuries.
- Continue effort in prevention, disaster mitigation and education in local communities.

Appendix F

Fujita Tornado Intensity Scale

The Fujita Tornado Intensity Scale is a scale of wind damage intensity which wind *speeds* are inferred from an analysis of wind *damage*.

Category	**Definition and Effect**
F0	Gale tornado (40-72 mph): Light damage. Some damage to chimneys; break branches off trees; push over shallow-rooted trees; damage sign boards.
F1	Moderate tornado (73-112 mph): Moderate damage. The lower limit is the beginning of hurricane wind speed; peel surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads.
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): Severe damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off ground and thrown.
F4	Devastating tornado (207-260 mph): Devastating damage. Well-constructed houses leveled; structure with weak foundation blown off some distance; cars thrown and large missiles generated.
F5	Incredible tornado (261-318 mph): Incredible damage. Strong frame houses lifted off foundations and carried considerable distance to disintegrate; automobile-sized missiles fly through the air in excess of 100 yards; trees debarked; steel-reinforced structures badly damaged; incredible phenomena will occur.

Status of Actions
April 1998

Recommendation 1:
Personnel at NWSFO EWX should be trained in how to turn on the amateur radio equipment so that they can at least hear reports, even if the network is not activated. NWSFO EWX should also work with the amateur radio coordinator on backup procedures for contacting key people in impending emergencies.
Status:
Personnel at NWSFO EWX were given instructions during the late summer of 1997 on how to turn on and monitor amateur radio equipment in the event no amateur radio operator is on duty to operate the equipment.

Recommendation 2:
The NOAA and the NWS should increase efforts in working with the DOD to ensure that DOD commanders and personnel understand that properly maintained and operated DOD WSR-88Ds are vital to the severe weather warning programs for both the bases and the civilian populations under the radars' umbrellas.
Status:
Since the early days of the deployment of the tri-agency WSR-88D network, there has been an ongoing concern at the NEXRAD Program Management Committee of the radar maintenance program capability. The GAO brought this factor to closer scrutiny in a 1995 report titled "Weather Forecasting--Radar Availability Not Being Met" (AIMD-95-132). Following the publication of this report, senior NWS and USAF senior management met to discuss these issues and agreed that the USAF would cooperate in any way possible to support the NWS mission. Lines of communication were established between DOD and NWS technical personnel for quick problem resolution.

In recent months, DOD availability has matched the tri-agency standard of 96 percent, and there is no systematic problem with the WSR-88D maintenance program.

Recommendation 3:
The NOAA/NWS should move rapidly to ensure that all Weather Forecast Offices (WFOs) in the NWS are equipped with the best possible satellite analysis capabilities that are part of the Advanced Weather Interactive Processing System (AWIPS). The NWS should also provide proper training to ensure that satellite data are used in the warning and forecast program.
Status:
As of the end of March 1998, AWIPS is being used in operations at 20 WFOs and 8 River Forecast Centers. The next group of AWIPS sites will be deployed this summer at 15 WFOs and 3 RFCs. Authorization for nationwide deployment of the remaining systems is pending from the

Secretary of Commerce. The offices that currently have AWIPS are accessing the high-resolution data from geostationary satellites. With AWIPS, these satellite data can be integrated with radar data, observational data, and numerical model data in a way never before available to operations.

The NWS will complete the initial phase of training on using the new GOES satellite by June 1998 via the following methods: (1) Provision of an in-depth, 2-week course on mesoscale satellite meteorology at COMET; (2) Completion of a series of three computer-based learning modules; (3) Establishment and maintenance of a Satellite Meteorology Web page.

Recommendation 4:
The SPC should make every effort to coordinate with any NWS office that has warning responsibility before a watch is issued that covers a part of the CWA of that NWS office.

Status:
The SPC concurs that it did not coordinate with the Austin-San Antonio NWSFO prior to issuing the Tornado Watch in advance of the Jarrell tornado.

The SPC is working with the Office of Meteorology, NWS Headquarters, to instigate the teleconferencing call lists needed to ensure such oversights cannot happen in the future. The NWS plans to have these lists in place nationwide by June 1, 1998.

Recommendation 5:
The OSF should evaluate the Level-2 Archive data from the EWX radar and further investigate these anomalies. The NEXRAD Program should continue its plans to implement the National Severe Storm Laboratory's experimental mesocyclone algorithm because of its higher skill and informative outputs, including probabilistic guidance values.

Status:
On June 18, 1997, Don Burgess, Chief, Operations Branch, Operational Support Facility, delivered a report to the Service Assessment Team. Conclusions from that report were included in the Event Summary.

The NEXRAD Technical Advisory Committee is charged with evaluating experimental algorithms to review proposed scientific changes and additions. The tri-agency System Recommendation and Evaluation Committee approves and prioritizes proposed changes to the WSR-88D baseline.

Recommendation 6:
A thorough scientific study of these events should be undertaken by researchers and academicians with the results made available to forecasters of the NWS. Any study should include the U.S. Weather Research Program (USWRP), the NWS Collaborative Science, Technology, and Applied Research Program (CSTAR) and NOAA/NWS Cooperative Institutes.

Status:

Scientific research on the Jarrell, Texas, tornado is being undertaken by the university community, NOAA Cooperative Institutes, and NWS personnel, often in close collaboration. During the CSTAR Workshop held October 7-10, 1997, a special session on the Jarrell tornado was presented to illustrate science and service issues that must be addressed in order for forecasts and warnings of extreme weather events to be improved in the future. Presentations were given by researchers from the NWS and NOAA Cooperative Institutes. The workshop was attended by more than 60 representatives from the universities, the NWS, other NOAA research laboratories, and the USWRP. The full workshop report can be found on the Internet at: <http://www.nws.noaa.gov/om/cstar97.htm>.

Recommendation 7:
Use and interpretation of the WSR-88D data, especially in convective situations, should be left to meteorologists trained in both mesoscale meteorology and the interpretation of WSR-88D data. In addition, NWS WFOs should be appropriately staffed with a sufficient number of such meteorologists to meet these requirements. Further, the NWS needs to ensure that any future training programs being developed to replace the OSF WSR-88D course should be of equal or better effectiveness than was that course. Meteorologists must have the ability to quickly interpret reflectivity and velocity signatures within the context of the overall mesoscale weather pattern, and relate the radar information to the other analyses and observing tools such as a detailed mesoscale surface analysis combined with satellite, surface observations, profiler and radar Velocity Azimuth Display (VAD) vertical wind profiles, etc. Accordingly, the NWS should ensure that the expertise, materials, and other resources, including field staff time, are made available to meet such a training requirement.

Status:
The NWS Southern Region policy regarding the operation of the WSR-88D and the interpretation of radar data was restated to all NWSFOs in a memo dated July 9, 1997.

The Operations Training Branch of the OSF is developing a set of on-site training modules to replace the in-residence WSR-88D course. The Distance Learning (DL) Operations Course consists of printed materials, CD-ROMs, Web-based materials and Teletraining. The same final exam will be used in the new DL version to ensure the course is equally effective. All Southern Region meteorologist interns are currently in training using the modules which have been released.

Recommendation 8:
Management at NWSFO EWX should establish and enforce clear lines of authority and responsibility to be followed during severe weather operations. Further, emphasis should be given to keeping all staff current regarding such operational procedures.

Protection of life and property is the fundamental mission of the NWS. NWS offices need to develop a strategy for a coherent product suite encompassing warnings, statements and short-term forecasts throughout severe weather episodes. They need to work with customers to apprise them of priority which will be placed upon products during such events. All NWS WFOs should have a standing policy that routine products have a much lower priority during periods of ongoing severe weather. They should ensure that all staffing resources be brought into a cohesive severe weather mind set and that the focus of the office is always on the fundamental mission.

Status:

Management at NWSFO EWX has instructed the staff regarding lines of authority, i.e, that the Forecaster in Charge on shift has the responsibility to assign tasks during significant weather events. Also, existing policy regarding priority of duties has been reemphasized to the staff and such instructions are included in the Station Duty Manual.

Recommendation 9:

The staff at NWSFO EWX is commended for their dedication and extra effort to seek confirmation that warning information was being received by officials who had a critical need for it. Nevertheless, it is recommended that NWSFO EWX work with emergency management officials to seek alternative and more efficient methods to confirm receipt of warnings.

Status:

NWSFO EWX efforts are ongoing to promote the Emergency Managers Weather Information Network (EMWIN) technology for the dissemination of NWS warnings as well as the NOAA Weather Radio SAME (Specific Area Message Encoding) technology. EMWIN is a personal computer-based system using inexpensive, user-friendly software that provides warning and forecast products, graphics, and limited satellite imagery in near real-time. A SAME-capable receiver allows the user to program the weather radio to receive warnings for the areas of the user's choosing.

Recommendation 10:

The NWS should reach consensus with the Federal Emergency Management Agency (FEMA) and the state emergency management agencies on a single communication/coordination system that is consistent nationally and meets the internal and external communication/coordination requirements of both the NWS and the emergency management community. All NWS offices should be provided with needed technology to facilitate efficient internal and external coordination.

Status:

The Office of Meteorology and FEMA's Information Technologies Directorate have examined a number of communication technologies over the past year. Currently, neither FEMA nor the NWS have the funding necessary to complete the NAWAS Upgrade started in 1996.

In response to the continuing requirement for a National coordination/communication system, the NWS Office of Meteorology (OM) and the Office of Systems Operations (OSO) have identified FTS2000 as an interim system that can meet the basic internal and external coordination requirements of NWS field offices and National Centers. The goal is to have the interim FTS2000 system operational by the end of June 1998.

Recommendation 11:

The NWS has sent to the Federal Communications Commission (FCC) proposed revisions to the EAS rules. The NWS should continue to work with the FCC to clarify situations that need automated activation. The NWS and the FCC, in cooperation with the National Association of Broadcasters, should agree on a limited set of critical weather warning products which would be programmed for automatic activation of the EAS.

Status:

The NWS works very closely with the FCC on all matters relating to the EAS. The FCC is expected to adopt NWS-generated proposals in the fall of 1998 that include the optional use of many more non-weather related and a few more weather-related EAS event codes.

The EAS media facilities, however, are not required by Federal law (FCC Rules, Part 11) to disseminate any messages other than Presidentially-declared disaster information. If EAS facilities choose to broadcast local emergency information, whether from the NWS or other authorities, they have the option to either automatically activate or delay for later manual activation. Furthermore, many EAS facilities want to use their own broadcasters rather than use NWR broadcasts directly. These actions are decided and documented in local EAS Plans across the country on a case-by-case basis. The NWS participates in these local plans via the efforts of the WCM and designated staff.

Recommendation 12:

The NWS should continue to work with the state of Texas Division of Emergency Management to seek ways to improve the timely transmission of weather warnings via TLETS and should intensify efforts on both a local and state level to explore alternative methods of communicating critical weather products to emergency management officials.

Status:

Working relationships with the Texas Division of Emergency Management have been greatly expanded during the past 10 months. Changing the TLETS to a fully automated system is a state funding issued beyond the control of the NWS. The NWS continues to promote the Emergency Managers Weather Information Network and NOAA Weather Radio with SAME capabilities.

Recommendation 13:

The NWS should develop additional partnership initiatives with the public and private sector to encourage the use of NWR for the receipt of critical weather information.

Status:

With the FCC's adoption of NWR's digital protocols for the new EAS, the NWR now becomes the NWS's primary input into this nationwide warning delivery service. Much interest and visibility has already been generated by NWR input to the 14,000 some participating radio and TV stations across the country. Starting in 1999, cable TV will join the EAS and can optionally broadcast, for the first time, NWS warnings via NWR.

Recommendation 14:
All the NWR transmitters should be equipped with backup power.
Status:
A large minority of NWR transmitters do have backup power. Many of these typically are systems co-located or associated with commercial broadcast facilities. Others with backup power are found within large government or commercial buildings.

There is no backup power for the majority of transmitter sites because it is cost-prohibitive to install generators at more than 400 locations, provide personnel with special knowledge on generator maintenance and logistical support, and comply with EPA regulations on fuel storage and containment.

Recommendation 15:
The NWS, in concert with FEMA and the ARC, should continue to emphasize the importance of not attempting to flee an approaching tornado and reemphasize the importance of adhering to long established tornado safety rules. (In the vast majority of situations, people who take shelter in sturdy, well-built structures will survive most tornadoes whereas people who try to flee in automobiles will place themselves at much greater risk.) The Service Assessment Team also recommends that there be significant public and industry education on the meaning of well-built tornado shelters.
Status:
The NWS remains a strong player in the National Disaster Education Coalition and will continue to work within the coalition to effect this recommendation. The coalition consists of representatives from FEMA, the U.S. Geological Survey, NWS, and The American Red Cross. In meetings after the Jarrell tornado, the coalition agreed that tornado safety measures should not be modified. It agreed to continue to emphasize the standard tornado safety measures well before the recommendations from Jarrell were published realizing those safety measures still applied.

The current 12-page, tri-agency brochure “Tornadoes...Nature’s Most Violent Storms” explicitly explains the long established tornado safety rules. Other Red Cross pamphlets also fully detail these same consistent safety messages. The NWS will ensure that any future tornado brochures will strengthen this message. The coalition will continue to support this recommendation, not only in printed material but in all other venues.

The NWS has worked with local media in the central Texas area (primarily through efforts of the EWX WCM) to reemphasize the importance of existing tornado safety rules. We have also communicated the importance of reemphasizing this message to all our WCMs in the Southern Region through routine coordination calls.

Recommendation 16:

The NWS should partner with other public agencies and the private sector to develop plans for protection of employees and the public located in large buildings during severe weather threats.

Status:

The process for developing a network of public shelters has been in place for many years. As part of the emergency management's all hazard response, each state is required to develop a shelter network to meet the evacuation and sheltering needs of its citizens. Many states have legislated that counties and cities identify shelter space within public meeting places, such as court houses and shopping malls. In addition, local Warning Coordination Meteorologists are constantly working with emergency managers to educate the public on how to protect themselves. For the past 5 years, the NWS has partnered with FEMA and the American Red Cross to produce and distribute natural hazard awareness materials necessary to heighten the public's awareness.

Recommendation 17:

First, the NWS should ensure that all field offices develop strategies that make full use of all office personnel qualified to assist in warning and forecast operations during critical weather situations.

Second, the NWS should evaluate its plans regarding future staffing and service changes to ensure that workload constraints do not compromise the agency's safety of life and property mission. Specifically, transitional staffing which has been placed at selected offices should be retained until such time as new technology can demonstrate it is capable of mitigating the workload associated with warning and forecast operations to an extent that a reduction in staff is feasible.

Status:

See Recommendation 8.

On February 26, 1998, NWS senior managers met to discuss AWIPS capabilities and field office staffing requirements. They agreed to maintain transition staffing at NWS offices with multiple associated WSR-88Ds and at offices with heavy NWR programming loads until the software builds of AWIPS provide the necessary functionality to assist effectively and efficiently in the delivery of these services. The Southern Region has ensured that staffing levels at offices meet these guidelines.

Recommendation 18:

Studies should be undertaken by the research and academic community to help identify these types of patterns which may aid in the development of these rare but catastrophic tornadoes. Such studies should have the participation of the USWRP, CSTAR, and NOAA/NWS Cooperative Institutes. The results of these studies should be made available to NWS forecasters to aid in the warning and forecast process.

Status:

See Recommendation 6.

Recommendation 19:

NOAA/NWS should compile a list of potential, quick-response team members, drawn from appropriate expertise in the NOAA line and staff offices, other Department of Commerce Bureaus such as NIST, and from the universities and private sector. The team should be interdisciplinary in nature. Following a significant tornado outbreak, a team of three to five scientists should be assembled and dispatched to the centroid of the outbreak within 24 hours. Teams should include meteorologists, a wind engineer, and a social scientist, an epidemiologist and a public affairs specialist. Funding to carry out the travel costs of the team and an aerial damage-mapping survey should be set aside yearly in a revolving budget.

Status:

NOAA line offices led by the NWS have partnered with FEMA, the U.S. Geological Survey, and the Department of Agriculture in the development of a Post-Storm Data Acquisition (PSDA) capability. Funding for the PSDA is shared by the participating agency partners. The NWS has allocated an annual funding of $300K to meet post storm event assessment needs. The oversight responsibility and activation of the PSDA resides with the Office of the Federal Coordinator for Meteorological Services (OFCM). The OFCM, with assistance of the participating agencies has drafted an plan for timely and coordinated post storm data collection.

To meet the aerial support requirement for damage-mapping, the OFCM, with the assistance of the Office of Meteorology, has secured a Memorandum of Understanding between the OFCM and the Civil Air Patrol. The data collected and the post storm reports will be made available to agencies who are represented at the OFCM and to the remainder of the research and operations communities through the OFCM Web page.

Currently, the NWS and OFCM attempt to field and deploy rapid service assessment teams within 24 hours of the event. The greatest limitation to date has been the small pool of human resources available for these teams. The Office of Meteorology has proposed that the NWS and OFCM support the development of a quick response training program to meet the demands being placed on this small cadre of individuals. The goal is to identify, train and support individuals in the deployment of quick response teams on a regional basis.

The NWS already have several names from volunteers and from people suggested by other elements of the agency. OM will continue to add to it as the opportunity arises.