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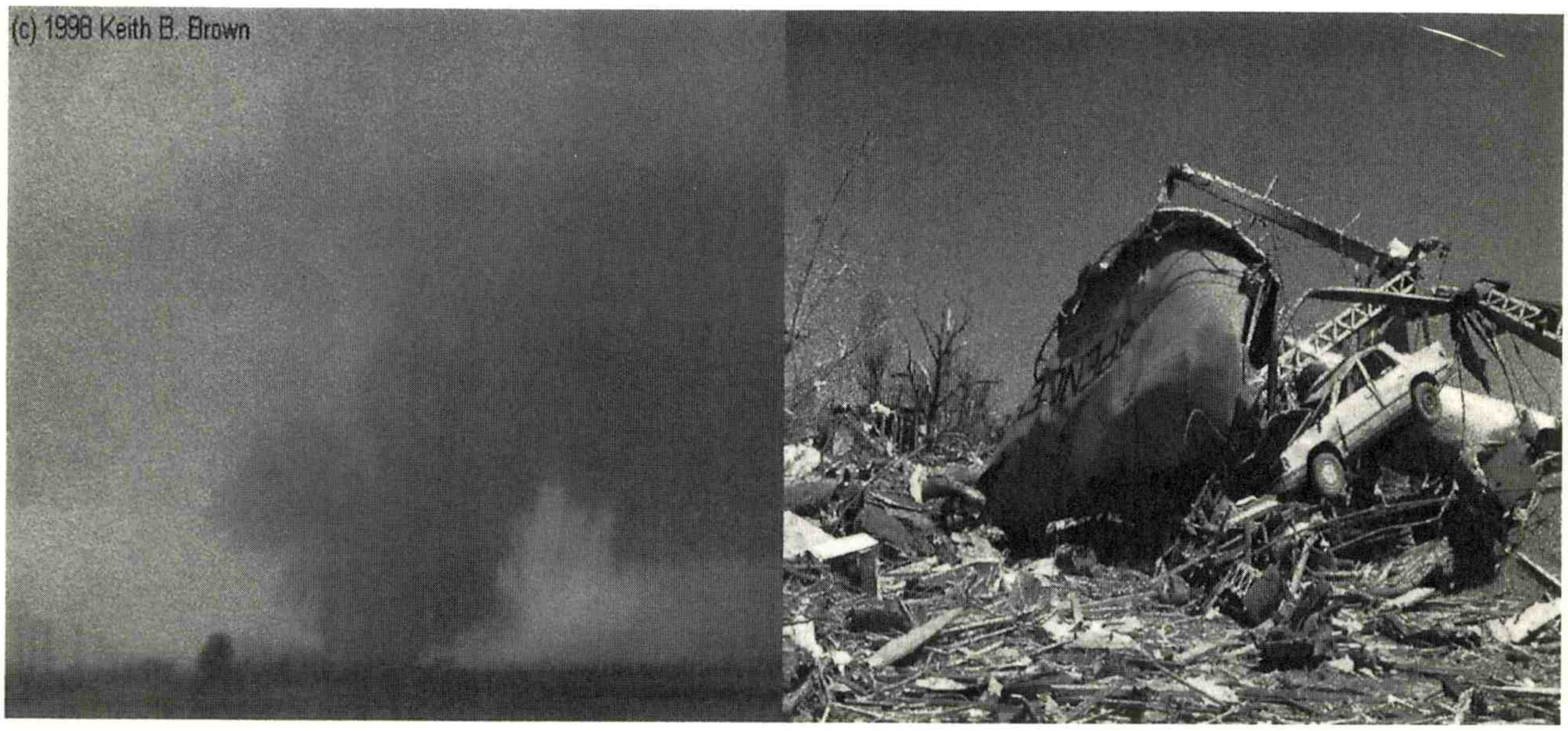
Service Assessment

Spencer, South Dakota, Tornado
May 30, 1998



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

Cover: The Spencer tornado viewed from about 4 miles east of town on Highway 38 (courtesy of Keith Brown), and the Spencer water tower, an example of the catastrophic damage inflicted on the town (courtesy of Dr. Josh Wurman).

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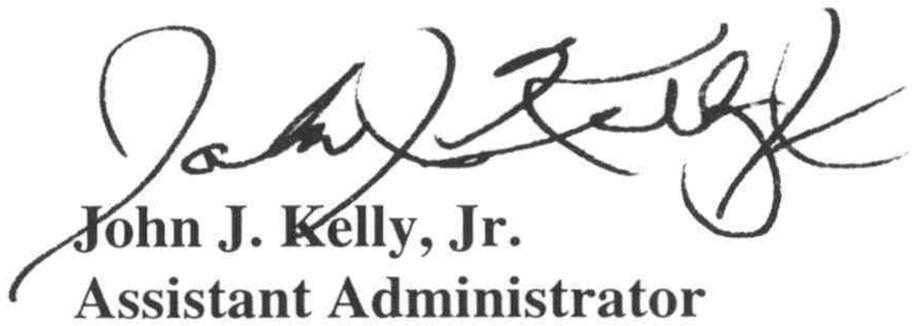
John J. Kelly, Jr., Assistant Administrator

Preface

The violent tornado which struck Spencer, South Dakota, on the evening of May 30, 1998, killed six residents and destroyed almost the entire town. The National Weather Service (NWS) conducted a Service Assessment to examine the effectiveness of the warning process that evening, focusing on the performance of the Next Generation Weather Radar (NEXRAD) Weather Service Forecast Office (NWSFO) at Sioux Falls, the usefulness of NWS warnings and forecasts from the perspective of our partners in the media and emergency agencies, and the public response.

Service Assessments are critical to the ongoing efforts of the NWS to improve the quality and timeliness of our warning and forecast services, especially as offices like NWSFO Sioux Falls complete the transition to a fully modernized Weather Forecast Office (WFO). By reviewing the performance of one operational team at one forecast office during one such devastating event, we look for ways to ensure that the application of new technology and new concepts will yield the most timely and accurate warnings and forecasts.



John J. Kelly, Jr.
Assistant Administrator
for Weather Services

August 1998

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Service Assessment Team

The NWS assembled a Service Assessment Team to review the effectiveness of the warning process during the evening of May 30, 1998, when a violent tornado struck the town of Spencer, South Dakota. The team met in Sioux Falls on June 2 and spent the following 3 days in South Dakota collecting information and conducting interviews with the NWS staff at the Sioux Falls NWSFO, emergency managers, law enforcement officials, media representatives, and a number of residents of Spencer. Additional information was obtained from the NWS Storm Prediction Center (SPC) in Norman, Oklahoma, from other NWS meteorologists who participated in post-storm damage surveys, and from engineers at the National Institute of Science and Technology.

The team was comprised of the following individuals:

Dennis H. McCarthy	*Team Leader*, Meteorologist in Charge (MIC), NWSFO Norman, Oklahoma
Ricky L. Shanklin	Warning Coordination Meteorologist (WCM), NEXRAD Weather Service Office (NWSO) Paducah, Kentucky
Patrick J. Slattery	Public Affairs Specialist, NWS Central Region Headquarters, Kansas City, Missouri
James G. LaDue	Meteorologist (Instructor), WSR-88D Operational Support Facility, Operations Training Branch, Norman, Oklahoma
Randall C. Duncan	Emergency Management Coordinator, Cowley County, Kansas, President, International Association of Emergency Managers

Other valuable contributors include:

D. Gregory Harmon	MIC, NWSFO Sioux Falls, South Dakota
Todd A. Heitkamp	WCM, NWSFO Sioux Falls, South Dakota
David L. Andra	Science and Operations Officer (SOO), NWSFO Norman, Oklahoma
Brian E. Smith	WCM, NWSFO Omaha, Nebraska
William F. Bunting	WCM, NWSO Pleasant Hill (Kansas City), Missouri
Michael Foster	SOO, NWSFO Fort Worth, Texas

David A. Imy	Chief, Operations Branch, NWS SPC, Norman, Oklahoma
David Dowell	Graduate Research Assistant, University of Oklahoma
Long Phan **Dat Duthinh**	National Institute of Science and Technology
William H. Lerner	Weather Service Headquarters (WSH), Office of Meteorology, Silver Spring, Maryland
Linda S. Kremkau	Technical Editor, WSH, Office of Meteorology, Silver Spring, Maryland
Argus Leader	Daily Sioux Falls Newspaper

Acronyms

AFOS	Automation of Field Operations and Services
AWIPS	Advanced Weather Interactive Processing System
CAPE	Convective Available Potential Energy
CDT	Central Daylight Time
CRS	Console Replacement System
CWA	County Warning Area
DOW	Doppler on Wheels
EAS	Emergency Alert System
EMWIN	Emergency Management Weather Information Network
GOES	Geostationary Operational Environmental Satellite
HMT	Hydrometeorological Technician
MCD	Mesoscale Convective Discussion
MIC	Meteorologist in Charge
m/s	meters per second
NAWAS	National Warning System
NEXRAD	Next Generation Weather Radar
NOAA	National Oceanic and Atmospheric Administration
NOW	Short Term Forecast (product identifier)
NWR	NOAA Weather Radio
NWS	National Weather Service
NWSO	NEXRAD Weather Service Office
NWSFO	NEXRAD Weather Service Forecast Office
NWWS	NOAA Weather Wire Service
PC	Personal Computer
PDS	Particularly Dangerous Situation
PSD	Peripheral Sharing Device
PUP	Principal User Processor
RFD	Rear Flank Downdraft
ROTATE	Radar Observation of Tornadoes and Thunderstorms Experiment
SEL	Severe Thunderstorm or Tornado Watch (product identifier)
SFP	State Forecast Product (product identifier)
SOO	Science and Operations Officer
SPC	Storm Prediction Center
SPS	Special Weather Statement (product identifier)
SVR	Severe Thunderstorm Warning (product identifier)
SVS	Severe Weather Statement (product identifier)
SWO	Severe Weather Outlook (product identifier)
TOR	Tornado Warning (product identifier)
TVS	Tornado Vortex Signature
VCP	Volume Coverage Pattern

WCM	Warning Coordination Meteorologist
WFO	Weather Forecast Office
WISE	Warning and Interactive Statement Editor
WSH	Weather Service Headquarters
WSR-88D	Weather Surveillance Radar-1988 Doppler
ZFP	Zone Forecast Product (product identifier)

Event Summary

Overview

At approximately 8:40 p.m. (all times Central Daylight Time [CDT]) on Saturday, May 30, 1998, a violent tornado struck the small town of Spencer, South Dakota. Spencer is in extreme western McCook County, about 45 miles west-northwest of Sioux Falls. The tornado killed six people, injured more than one-third of the town's 320 residents, and destroyed most of the town's 190 buildings. Damage is estimated at $18 million. The Spencer tornado (rated F4 on the Fujita Tornado Intensity Scale, as described in Appendix A) was one of five tornadoes, along a nearly continuous damage track approximately 30 miles long. All five tornadoes were produced by one supercell thunderstorm during a 1 hour and 5-minute period. The most devastating damage was limited to less than 1 mile along the tornado track, but significant damage (F1 to F3 intensity) was inflicted on several farmsteads in McCook County and neighboring Hanson County, including damaged or destroyed buildings, loss of crops, and loss of approximately 75 head of livestock.

The six tornado fatalities in Spencer were the first in the NWSFO Sioux Falls County Warning Area (CWA) since the Chandler, Minnesota, tornado in June 1992 and the first deaths in South Dakota in nearly 28 years. On July 14, 1970, one person was killed by a tornado in Lincoln County, just south of Sioux Falls. The last violent (F4) tornado in the Sioux Falls CWA occurred on June 7, 1993, just north of Sioux Falls.

The NWSFO in Sioux Falls issued a Tornado Warning for northern McCook County, including the town of Spencer, at 8:32 p.m. based on data from its Weather Surveillance Radar-1988 Doppler (WSR-88D) and reports from law enforcement officials. The warning was promptly disseminated over the National Oceanic and Atmospheric Administration (NOAA) Weather Wire Service (NWWS), commercial radio and television, NOAA Weather Radio (NWR), the Emergency Alert System (EAS), and the National Warning System (NAWAS). The outdoor warning siren at the Spencer Volunteer Fire Department could not be activated apparently due to loss of electricity from the storm.

Storm Summary

By late afternoon on May 30, the atmospheric environment over the north-central United States had become conducive to a significant severe weather outbreak. The air mass over southeastern South Dakota was extremely unstable (note the shaded area in Figure 1). A dry line/cold front combination was pushing slowly to the east and southeast into this unstable air, while at jet stream level in the atmosphere, a well-defined wind maximum (a jet streak) was approaching the dry line/cold front intersection. One favorable ingredient that was lacking ahead of the dry line/cold front was a low-level wind maximum (low-level jet). It was displaced farther east, over eastern Iowa and Minnesota (arrow in Figure 1). However, even with the lack of

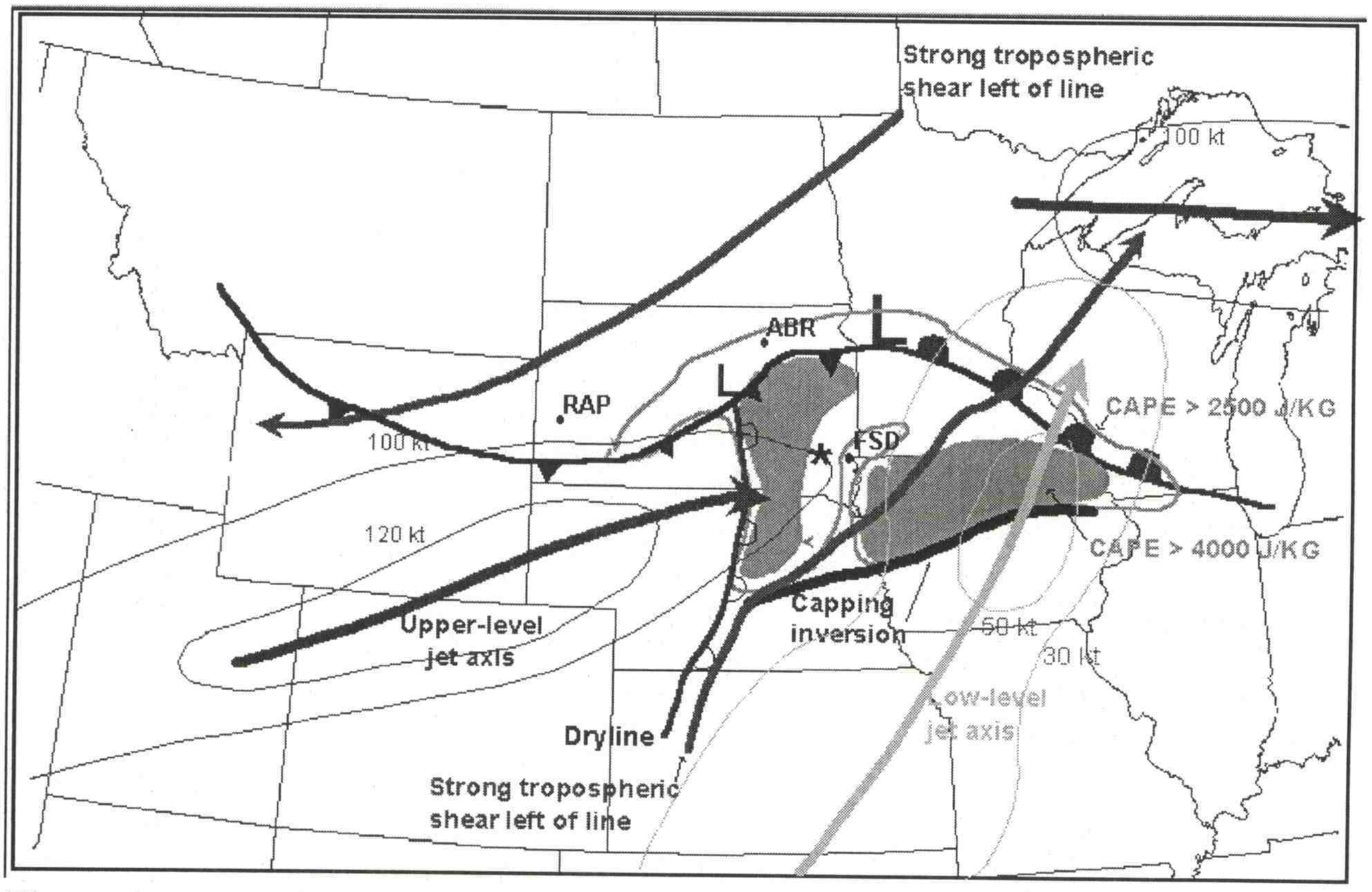

Figure 1. A composite analysis, indicating the synoptic conditions relevant to the Spencer tornado as the parent thunderstorm, developed at 6 p.m. CDT. The (*) indicates Spencer, and FSD indicates Sioux Falls. Thick lines with arrows indicate the upper and lower level jet streams, with relevant isotachs shown in thin, labeled contours. The shaded regions indicate areas of high Convective Available Potential Energy (CAPE), implying strongest instability. The label of strong tropospheric shear indicates regions with more that 50 knots shear in the 700 to 300 mb layer. Surface low pressure centers are depicted by an "L."

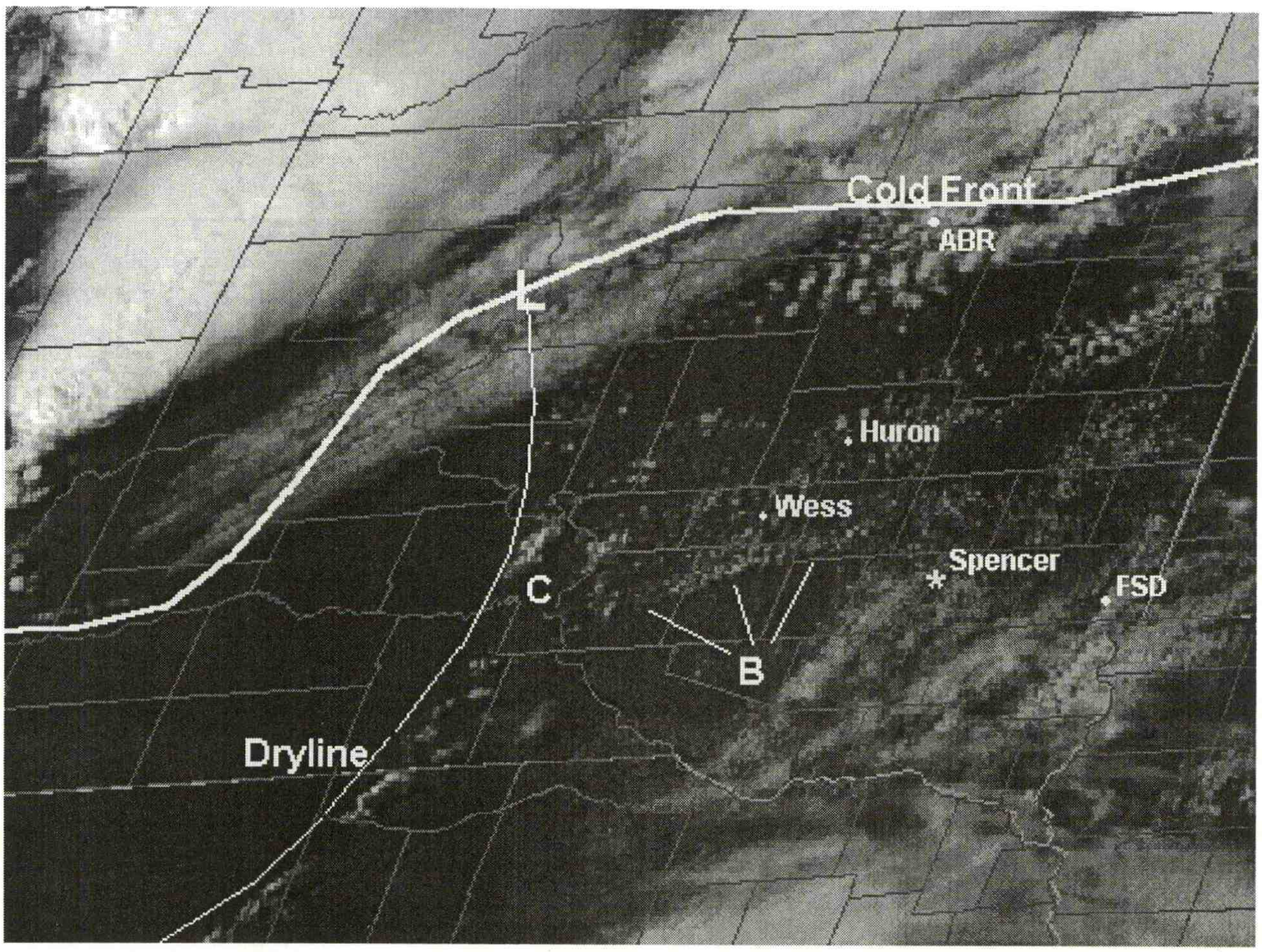

Figure 2. A Geostationary Operational Environmental Satellite (GOES)-8 1 km visible image at 4:32 p.m. CDT (2132 Coordinated Universal Time [UTC]). The letter "C" corresponds to towering cumulus; "B" indicates a surface boundary; "*" indicates the location of Spencer; and "L" indicates a surface low pressure center.

strong low-level winds, instability along the advancing dry line/cold front boundaries was sufficient for thunderstorm development, and the approaching jet streak provided more than adequate vertical wind shear for supercell evolution once storms developed.

Towering cumulus formed on the dry line by 4:30 p.m. near the Missouri River, about 90 miles west-northwest of Spencer (indicated by a "C" in Figure 2). Convective development in that area over the next hour could have been related to the intersection of a weak east-west boundary with the dry line. The enhanced band of cumulus in the area marked "B" in Figure 2 provided a hint of this boundary. Initial convection produced a brief thunderstorm by 5 p.m., however, stronger storms developed by 6:35 p.m. southwest of Wessington Springs, about 60 miles west-northwest of Spencer. The thunderstorm that would eventually produce the Spencer tornado evolved from this new development.

The Spencer storm almost immediately split into left and right moving cells with the right-mover becoming a supercell as a mid-level mesocyclone developed by 7:26 p.m. The mesocyclone grew downward toward cloud base as observed by the Sioux Falls WSR-88D between 7:45 and 7:50 p.m. During the same time, a rear flank downdraft (RFD) was developing south of the mesocyclone. RFD features are common prior to tornadogenesis in many supercells.

The Spencer supercell began to show stronger tornadic potential at 7:55 p.m., as a spotter observed a funnel cloud in northeast Davison County and the Sioux Falls WSR-88D indicated a significant mesocyclone in the storm. The first spotter report of a tornado associated with this storm came at 8:08 p.m., about 8 miles northeast of Mitchell. Tornado #1 (shown in Figure 3) actually began a few minutes earlier in that area, based on observations by members of a tornado field research project who were located on Highway 38, south of the storm. The ROTATE-98 project (Radar Observation of Tornadoes and Thunderstorms Experiment), coordinated at the University of Oklahoma, employs two truck-mounted Doppler radars, referred to as Doppler on Wheels (DOW), which are designed to gather high-resolution reflectivity and velocity data from locations within a few miles of tornadic thunderstorms.

Even though the first tornado ended northwest of Fulton at 8:15 p.m., the mesocyclone was still situated at ground-level. By 8:17 p.m., the low-level circulation produced Tornado #2 (Figure 3). This tornado passed about 2 miles north of Fulton, producing F1 to F2 damage before weakening about 4 miles west-northwest of Farmer, or 7 miles west-northwest of Spencer, at approximately 8:22 p.m. The parent mesocyclone, still appearing very strong on the NWSFO Sioux Falls WSR-88D, continued moving east-southeast.

A new damage track (Tornado #3 in Figure 3) began almost immediately, approximately 1 mile northeast of the end of Tornado #2. Reports of Tornado #3 were passed from law enforcement officers through NAWAS warning points to NWSFO Sioux Falls between 8:23 and 8:29 p.m. At 8:28 p.m., the Sioux Falls WSR-88D showed a well-defined hook echo in reflectivity data and a well-defined circulation (strong mesocyclone) in velocity data (Figure 4).

From 8:23 to 8:37 p.m., the Spencer tornado tracked through farmland, within 1 mile of the town of Farmer, prior to crossing the Hanson/McCook County line and striking the town of

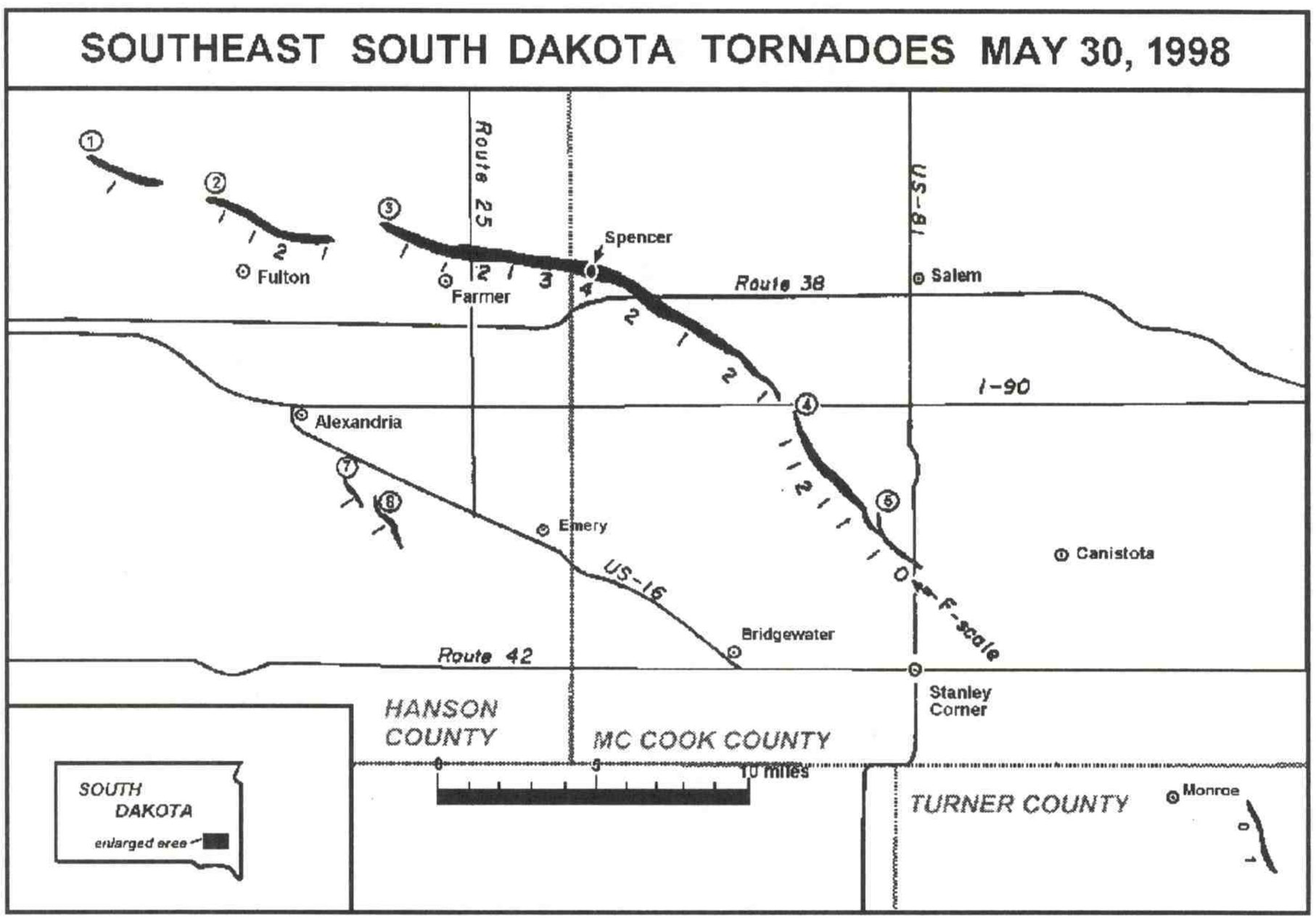

Figure 3. A composite of tornado damage tracks based on aerial surveys. Eight tracks are indicated, however, only the first five are addressed in the text. Relative path length, width, and F-scale damage are shown. (Brian E. Smith)

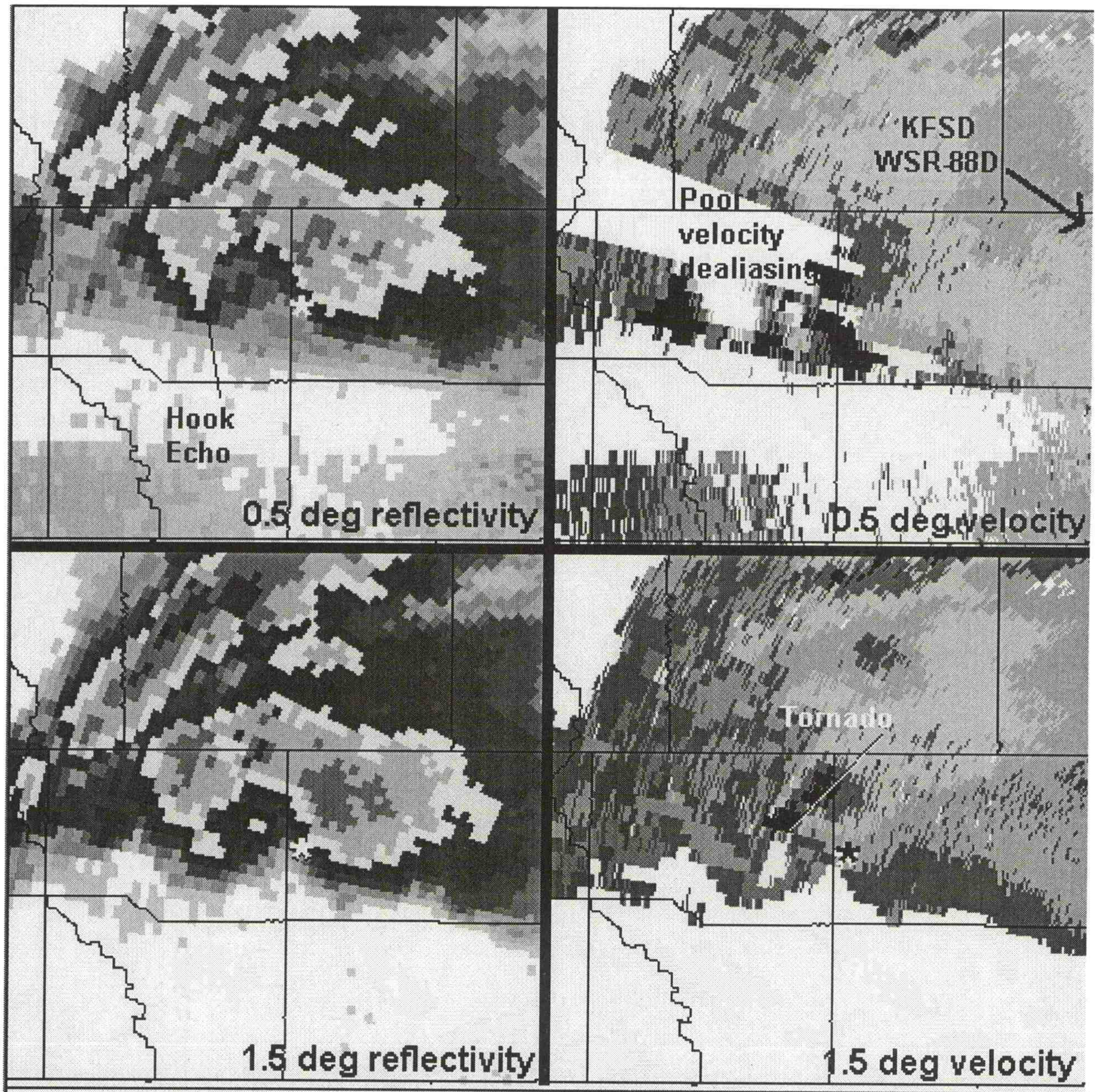

Figure 4. A four-panel radar image from the Sioux Falls WSR-88D showing the Spencer supercell at 8:28 p.m. CDT (0128 UTC). The gray shading for the reflectivity panels progress from light to dark from 0 to 40 dBZ and again from 45 to 70 dBZ. For the velocity panels, the very light shaded region just south (north) of the tornado indicates inbound (outbound) winds more than 64 kt (more than 15 kt) respectively.

Spencer. Photographs from storm chasers show that it had grown to a large tornado west of Spencer. Apparently, it became so large that some chasers and storm spotters within 2 miles of the tornado became confused because of the large dust cloud surrounding the tornado, especially along the west and south sides where dust was raised by strong RFD winds. The DOW used by the ROTATE-98 project measured velocities of at least 90 meters per second (m/s) (200 mph) during this period.

The impact time of the tornado on Spencer varies somewhat according to the source of information. Data from the ROTATE-98 project place the tornado near the western edge of town as early as 8:37 p.m., while the local electric company logged power failure in town at 8:42 p.m. and survivor accounts run as late as 8:45 p.m. Based on DOW and WSR-88D data, however, the town of Spencer experienced violent tornadic conditions from 8:38 to 8:39 p.m. Wind speeds observed by the DOW, as the tornado passed through Spencer, reached 98 m/s (nearly 220 mph) just south of the tornado center. While tracking through town, dirt and rain wrapping around the tornado might have obscured it somewhat as the parent thunderstorm took on high-precipitation supercell characteristics.

After leaving a path of destruction nearly 1-mile wide in Spencer, the tornado curved southeast through more farmland, most likely hidden in wrapping rain curtains. This damage track finally ended just north of I-90. Tornado #4 (see Figure 3) developed just south of I-90 and tracked southeast, followed by the weaker Tornado #5, which dissipated just northeast of Stanley Corner, about 30 miles west of Sioux Falls, at approximately 9:10 p.m.

Summary of Warning and Forecast Services

NWSFO Sioux Falls is a full-service forecast office in the midst of a transition to a modernized WFO. The staff provides warning and forecast services for 45 counties in parts of four states (South Dakota, Minnesota, Nebraska, Iowa), while maintaining many of the traditional forecast office responsibilities for the entire state of South Dakota (e.g., public/zone forecasts). The office uses a combination of modern technology, such as the WSR-88D radar, and older systems, such as the Automation of Field Operations and Services (AFOS) workstations and NWR consoles employing play/record decks for magnetic tapes. (The office operates three NWR stations.)

The potential for severe weather on May 30 in parts of South Dakota, Minnesota, Nebraska, and Iowa was recognized by forecasters the day before. The NWS SPC included the Sioux Falls CWA in its Day 2 Severe Weather Outlook (SWO) first issued at 2:55 a.m. Friday, May 29. In an update issued at 12:02 p.m. Friday, the SPC forecaster specifically mentioned "EXTREME INSTABILITY," "SUPERCELL THUNDERSTORMS," and the "THREAT OF ISOLATED TORNADOES." The NWSFO Sioux Falls forecasters were also monitoring the severe weather threat for Saturday very carefully. A forecast discussion issued at 9:10 p.m. Friday mentioned increasingly favorable conditions for severe weather "...IN THE FORECAST AREA ANYTIME FROM LATE TONIGHT THROUGH SATURDAY EVENING." The scenario anticipated by forecasters on the midnight shift early Saturday morning called for two rounds of severe weather—one early in the morning and the other late in the day.

The Day 1 SWO issued by SPC at 12:54 a.m. Saturday placed a moderate risk of severe storms from eastern portions of the Sioux Falls CWA into Iowa, Minnesota, and Wisconsin. However, a slight risk area covered most of the rest of the Sioux Falls CWA, including the area around Spencer. The 5:20 a.m. update from SPC included no significant changes in the north-central United States. However, based on their local analysis, the NWSFO Sioux Falls forecasters opted to upgrade the outlook for their CWA, and in a Special Weather Statement (SPS) issued at 4:35 a.m. headlined a "...MODERATE RISK OF SEVERE WEATHER TODAY...SOME THIS MORNING AND SOME THIS EVENING...."

Strong thunderstorms developed in south-central and southeastern portions of South Dakota early Saturday morning, prompting a severe thunderstorm watch from SPC at 3:22 a.m. and a number of severe thunderstorm warnings and statements from NWSFO Sioux Falls. These storms subsided around midday. One forecaster who remained on duty from the midnight shift (midnight to 8 a.m.) in an augmented staffing configuration for the morning severe weather told the day-shift staff as he departed that he would be available to come in early if necessary that night to help again with severe weather operations.

Midday and early afternoon provided a short break. However, a Significant Weather Outlook issued by NWSFO Sioux Falls at 11:47 a.m. was already focused on the likely redevelopment of thunderstorms "...LATE THIS AFTERNOON OR EARLY THIS EVENING...." While formulating the public forecasts to be issued by 4:30 p.m., the NWSFO Sioux Falls forecasters planned staffing for the anticipated redevelopment. An updated Day 1 Outlook from SPC issued at 2:41 p.m. maintained roughly the same configuration of slight and moderate risk areas as the earlier issuance, except for an expansion of the moderate risk area to the west to include extreme northeastern South Dakota. A Mesoscale Convective Discussion (MCD) issued by SPC at 12:54 p.m. highlighted the increasing threat of severe weather in western South Dakota for mid and late afternoon. Another MCD issued at 2:19 p.m. focused on the increasing threat from east-central South Dakota into parts of Minnesota and Wisconsin. Both mentioned portions of South Dakota as candidates for severe weather watches later in the afternoon.

The SPC issued a Severe Thunderstorm Watch at 3:33 p.m. for much of South Dakota, north of I-90, and a Tornado Watch at 3:50 p.m. for an adjacent area from eastern South Dakota through southern Minnesota. McCook County was included in the tornado watch. Both watches were in effect until 10 p.m. The watches were disseminated before 4 p.m. and the public forecasts were issued by 4:30 p.m. As often occurs at NWS forecast offices during late afternoon severe weather events, the two forecasters who had worked the day shift remained on duty to augment staffing for the evening shift. One forecaster stationed himself at the WSR-88D Principal User Processor (PUP) workstation while the other went to the personal computer (PC) workstation used to generate warnings and statements.

The staffing configuration at the start of the evening severe weather event consisted of four forecasters (two in the standard public and aviation forecaster roles and two handling warnings and statements) and one Hydrometeorological Technician (HMT). One of the staff interns was called at home and asked to report for duty by 7 p.m. to take over NWR broadcasts. This brought

total staffing to six just as severe storms entered the Sioux Falls CWA. The staffing level remained at six until 9 p.m. At that time, the forecaster who had already worked an extra 4 hours from 8 a.m. until noon reported 3 hours early for his upcoming midnight shift. This brought the total staff to seven for about 1 hour as the severe storms moved through the Sioux Falls area.

During the severe weather episode on the evening of May 30, WSR-88D data analyzed at the PUP workstation and spotter reports became the primary input for warning decisions. Most of the key spotter reports were relayed from law enforcement officials through NAWAS warning points to the NWSFO. A few came from storm chasers who were in the area.

The first warning issued by the Sioux Falls NWSFO for this event was a severe thunderstorm warning at 6:45 p.m. for Beadle County, the farthest northwest county in the CWA. Over the next 4 hours, the Sioux Falls staff issued a total of 11 Severe Thunderstorm Warnings, covering 15 counties, and eight Tornado Warnings, covering nine counties. In addition, forecasters issued five Short Term Forecasts and 26 Severe Weather Statements during the evening.

The first severe weather report of the evening (three-quarter-inch diameter hail) came from 3 miles west of Huron in Beadle County at 7:19 p.m., more than 30 minutes after the first warning was issued. The first significant report on the storm that would eventually produce the Spencer tornado was the 7:55 p.m. funnel cloud report in northeast Davison County from the County Sheriff. A Severe Thunderstorm Warning had been in effect since 7:44 p.m. for northeast Davison and northern Hanson Counties, but the funnel cloud report combined with radar data led to the first tornado warning, issued at 8:01 p.m. for northeast Davison and northern Hanson Counties. The first tornado report on the Spencer storm was the 8:08 p.m. report from approximately 8 miles northeast of Mitchell.

The 8:01 p.m. tornado warning received limited dissemination, mainly through NAWAS and secondary law enforcement channels. It did not go from the PC used to prepare warning products to AFOS and, consequently, did not reach NWWS and other systems feeding the media and EAS. The apparent reason for this dissemination problem was a communications traffic "bottleneck" at a peripheral sharing device (PSD) serving as the interface between a cluster of four PCs and AFOS. One of the NAWAS warning points, having been notified of the tornado warning at 8:02 p.m. by NAWAS phone, but not seeing a hard copy of the message on the state law enforcement telecommunications system, notified the forecast office at approximately 8:10 p.m. that the message had not been received. By this time, the tornadic thunderstorm had crossed the Hanson County line.

Just as a new Tornado Warning was being issued for northern Hanson County (at 8:12 p.m.), a telephone call came from the Kansas City NWSO relaying a report of a tornado in northern Hanson County, west of the town of Farmer. The report came from the WCM from the Kansas City NWSO, one of the many storm chasers in southeast South Dakota that evening. Hearing no active amateur radio networks or other accessible spotter networks at the time, and not having the telephone number of the Sioux Falls office handy, this NWS employee used his

personal cell phone to call back to his own office. Just 1 minute later at 8:13 p.m., a report of a large tornado northeast of Mitchell was relayed by the Mitchell NAWAS warning point.

At 8:16 p.m., the SPC issued a new Tornado Watch for extreme southeast South Dakota, northeast Nebraska, and northwest Iowa. This watch emphasized the "PARTICULARLY DANGEROUS SITUATION" (a PDS watch) evolving in southeast South Dakota. The NWSFO included McCook County in this new Tornado Watch.

The next tornado reports came from several law enforcement officials between 8:23 and 8:29 p.m. The first, relayed through the Mitchell NAWAS point at 8:23 p.m., indicated a tornado 5 miles northwest of Fulton. Between 8:25 and 8:29 p.m., NAWAS points at Mitchell and Sioux Falls (Metro Communications Center) relayed reports from a South Dakota Highway Patrol officer, the McCook County Sheriff, and a deputy sheriff all indicating a tornado west of Spencer. A Tornado Warning was issued for northern McCook County at 8:32 p.m., and it was promptly disseminated through usual means to the media and law enforcement officials (i.e., NWWS, NAWAS, EAS, etc.). The NWR log indicates that the warning was broadcast live within 1 minute of issuance.

At 8:50 p.m., the tornado was reported as it reorganized on the south side of I-90, approximately 5 miles southeast of Spencer. Reports of damage in Spencer started reaching the forecast office just after 9 p.m. However, details regarding fatalities and the scope of the destruction did not reach the forecast office until after 10 p.m.

With the exception of the PSD problem, resulting in the missed transmission of the 8:01 p.m tornado warning to AFOS, all of the equipment and computer systems used by the staff at the Sioux Falls NWSFO functioned well throughout the severe weather episode on the evening of May 30. Forecasters changed power at the WSR-88D radar from commercial to generator just after issuing the 8:12 p.m. Tornado Warning for northern Hanson County rather than risk loss of radar data as severe storms continued to approach Sioux Falls. The power change resulted in some loss of archive data but no loss of real-time data critical to the warning process.

Assessment team interviews with key representatives of Sioux Falls television stations and area radio stations and service feedback questionnaires distributed to the media by the Sioux Falls WCM indicate a universal satisfaction with the service provided by the NWSFO during the May 30 severe weather events. Broadcasters who were on the air that evening all indicated they had timely and accurate information. One TV meteorologist described the service provided as "excellent" and "perfect."

Interviews with Spencer residents and second-hand information gathered through media accounts indicate a wide range in the level of awareness prior to the tornado and a wide variety of safety precautions taken during the event. Many survivors had some indication, either through media reports or by first-hand observation, of the potential severity of the event, although many residents were quite unaware. Many had time to take shelter in a basement or some other part of their homes, while others were caught with just enough time to get behind a piece of furniture or to lie on the floor. All six fatalities were adults, ranging in age from 62 to 93, and occurred in the southern half of Spencer where destruction was worst.

Apparently, most of those who were watching television were tuned to one of the local network affiliates. The three local stations did an excellent job of broadcasting warnings as they were issued and providing "cut-ins" with displays of radar images. There were also many comments that the commercial radio stations did an excellent job of relaying critical warning information and reports. Two stations located in Mitchell played an especially vital role because of their proximity to Spencer and their first-hand accounts of upstream severe weather. The cable TV provider for Spencer has approximately 95 subscribers, but there was no cable-override system for the town. NWR reception from the Sioux Falls and DeSmet transmitters is marginal at best in Spencer. No one from the Service Assessment Team or the NWSFO is aware of any regular NWR listeners in Spencer. A few residents knew the radio frequency used by local spotters and received very timely and valuable information while monitoring on a scanner.

Facts, Findings and Recommendations

Data and Guidance Available to Forecasters

FACT: Computer model data and surface and upper air observations, which are key elements of the forecasts and severe weather outlooks issued by an NWS forecast office, were available to the Sioux Falls staff in a timely manner prior to the severe weather events of May 30, 1998.

FACT: Severe Weather Outlooks, Mesoscale Convective Discussions, and Severe Thunderstorm and Tornado Watches issued by the NWS SPC in Norman, Oklahoma, provided valuable and timely guidance to NWSFO Sioux Falls, the media, and emergency officials. The SPC called the forecast office just before issuing each of the three watches affecting its CWA during the afternoon and evening of May 30. The SPC made an additional coordination call at 7:15 p.m.

FACT: During the severe weather events surrounding the Spencer tornado, the Sioux Falls WSR-88D was the primary source of data on which warnings and other products, such as Severe Weather Statements, were based. The radar was operated in Volume Coverage Pattern (VCP) 11 to provide the highest vertical resolution. The system operated without interruption, except briefly for a change to generator power at approximately 8:15 p.m. Radar imagery was available at the PUP workstation and on one "slave" monitor at the public forecaster's AFOS workstation.

FACT: WSR-88D reflectivity and velocity data exhibited supercell characteristics in the thunderstorm that would eventually produce the Spencer tornado at about the same time (7:55 p.m.) the first report of a funnel cloud was received at the Sioux Falls NWSFO. The funnel cloud was reported in northeast Davison County, about 22 miles west-northwest of Spencer. WSR-88D computer algorithms indicated a mesocyclone at 8 p.m. over extreme northwest Hanson County, about 19 miles from Spencer, and a Tornado Vortex Signature (TVS) at 8:38 p.m. near Spencer.

FACT: Valuable severe weather observations from law enforcement officials were relayed in a timely manner through NAWAS warning points at Huron, Mitchell, and Sioux Falls (Metro Communications Center). These and a few reports from meteorologists who were storm chasing were the most reliable spotter reports available. They contributed significantly to many of the Severe Thunderstorm and Tornado Warnings issued during the event.

Finding 1: There were at least 10 meteorologists from other parts of the country, including NWS forecasters, "chasing" the supercell thunderstorm which eventually produced the Spencer tornado. Two of these storm chasers provided reports to NWSFO Sioux Falls, but most were unaware of how to contact the office. One who did, the WCM from NWSO Kansas City, called his own office and asked the staff to relay his report to Sioux Falls.

Recommendation 1: The NWS Office of Meteorology should form a team of NWS forecasters and experienced storm chasers to recommend methods of improving coordination between NWS forecast offices and "visiting" meteorologists engaged in storm chasing.

Finding 2: Most of the key severe weather reports prior to the Spencer tornado originated from law enforcement officials. A small contingent of trained spotters from McCook County was activated prior to the Spencer tornado, but there is no record of their reports reaching the NWSFO at Sioux Falls. The NWSFO Sioux Falls WCM has tried on numerous occasions to enlist the aid of area amateur radio (HAM) operators to improve severe weather communications in the CWA, but progress has been slow.

Recommendation 2: Central Region should provide the Sioux Falls NWSFO with examples of proven methods of enhancing communications with amateur radio networks for severe storm reporting.

NWSFO Sioux Falls Operational Procedures

FACT: NWSFO Sioux Falls has a well organized severe weather operation which receives strong emphasis in terms of guidance and training from station managers.

FACT: Warning and forecast operations at NWSFO Sioux Falls are conducted using a combination of new and old technology, ranging from the state-of-the-art WSR-88D radar to systems, such as AFOS and tape-based NWR consoles which have been in use for two decades. The Automated Weather Information Processing System (AWIPS) is scheduled for delivery at Sioux Falls in March 1999, and the NOAA Weather Radio 2000 Console Replacement System (CRS), delivered in June 1998, will be implemented during the fall of 1998.

FACT: At NWSFO Sioux Falls, warnings and related products are generated primarily by a two-person team, consisting of a PUP operator who analyzes WSR-88D data and a warning forecaster who prepares warnings and statements at a PC. The PC is equipped with NWS

developed formatting software for warnings (WISE) and locally developed formatting software for statements and Short Term Forecasts.

FACT: The NWSFO Sioux Falls forecasters conducted a thorough analysis of all meteorological data available to them prior to the development of severe storms on the afternoon of May 30 and made an accurate and timely assessment of the severe weather threat in their CWA.

FACT: Through detailed local analysis, forecasters at the NWSFO Sioux Falls decided to upgrade the early morning SPC Severe Weather Outlook on May 30 to a moderate risk for their CWA. The local outlook accurately specified two episodes of severe weather—one in the morning and the other in the evening.

FACT: Staffing at the peak of severe weather events on May 30 consisted of four forecasters, one hydrometeorological technician, and one meteorologist intern. Two forecasters focused on warning operations (one at the PUP and one at the PC for warning and statement generation), and the intern worked exclusively on NWR programming.

FACT: Senior forecasters at NWSFO Sioux Falls, well aware of the severe weather potential on May 30, made careful plans and adjustments to ensure adequate staffing for the severe weather events of the day. Five members of the staff worked a total of 18 hours in addition to their assigned shifts. This does not include the undocumented extra hours spent by the MIC the night of May 30 after the storm. One forecaster working the midnight shift remained on duty until noon Saturday morning, volunteered to return early that night, and was called back to duty at 9 p.m.

FACT: Between 5:30 p.m. and midnight on May 30, the NWSFO Sioux Falls staff issued 11 Severe Thunderstorm Warnings covering 15 counties, eight Tornado Warnings covering nine counties, 26 Severe Weather Statements, and five Short Term Forecasts.

FACT: The lead time on the Tornado Warning issued at 8:32 p.m. for northern McCook County was 6 minutes.

Finding 3: The NWSFO Sioux Falls staff "rose to the occasion," working the extra hours necessary to ensure adequate staffing on May 30. The only staffing shortage noted was on the day following the Spencer tornado when the NWSFO was besieged by media inquiries from around the country, and most of the office managers were engaged in initial damage surveys and on-site coordination with the media and local officials.

Recommendation 3: WSH should alert Regional Directors to advise managers of forecast offices to include in significant event staffing plans additional staff for the day or two following an event.

Finding 4: The number and types of warning and forecast products issued by NWSFO Sioux Falls during the Spencer event are consistent with that office's stage of evolution to a fully modernized NWS WFO. However, the PUP-based severe weather operation limited the availability of radar data to forecasters at other workstations. This hampered the issuance of more frequent, detailed Short Term Forecasts which could have provided an hour or two "heads up" for areas downstream of existing severe weather.

Recommendation 4: With the implementation of AWIPS, and the increased availability of radar data at workstations in forecast offices, NWS should emphasize the utility of frequent, detailed Short Term Forecasts to provide a "heads-up" for areas where severe weather is expected in a 1- to 2-hour time frame and to provide a "bridge" between watches and warnings.

Finding 5: Of the 45 warnings and statements issued by NWSFO Sioux Falls during the evening of May 30, only 13 contained spotter reports. Finding 2 addressed limited spotter reports initiated from the field; however, the PUP-based severe weather operation also limited the ability of the NWSFO staff to make probing calls into severe weather areas to obtain reports.

Recommendation 5: With the implementation of AWIPS, and the availability of radar data at all workstations, the NWS regional offices should provide direction to forecast offices on adopting a more proactive approach to obtaining spotter reports and incorporating them in their warning products.

Dissemination of Warning and Forecast Products

FACT: The Sioux Falls NWSFO operates three NWR stations which broadcast warnings and forecasts for 25 of the 45 counties in the CWA. The warning alarm on the Sioux Falls NWR (WXM-28) transmitter is activated when warnings are issued for McCook County; however, the broadcast signal is only strong enough for reliable reception in the eastern part of the county.

FACT: The NWR equipment used at the Sioux Falls NWSFO on May 30 is older technology and uses record/play decks and magnetic tapes. Hardware for the NOAA Weather Radio 2000 Console Replacement System arrived at the NWSFO in early June. The system will be implemented through the fall of 1998.

FACT: Between 7 p.m. and midnight on May 30, one of the NWSFO Sioux Falls meteorologist interns was assigned the specific task of NWR broadcasts. During the peak of the severe weather, all of his warning broadcasts were made within 2 minutes of the time the warnings were issued.

FACT: From logs which were available and from interviews with media representatives, the EAS functioned properly and was useful in the relay of critical warning information to the media.

FACT: From all accounts obtained by the Service Assessment Team, the dissemination of critical severe weather information through the commercial media was excellent. Most of those in Spencer who were aware of warnings and ongoing severe weather received information through the commercial media. Sioux Falls television stations and two commercial radio stations in Mitchell were mentioned most often by those interviewed, however, other radio stations in the area, including those in Sioux Falls and Yankton, also played valuable roles in disseminating warnings.

FACT: The cable television provider for Spencer has 95 subscribers in town, however, there was no cable override system for local emergency management access.

FACT: Several residents of Spencer who knew the radio frequency used by local storm spotters kept themselves informed on the approaching tornado by listening to the spotter traffic on a scanner.

Finding 6: The Tornado Warning issued at 8:01 p.m. for northeast Davison and northern Hanson Counties did not reach AFOS from the PC used to compose warning products. Consequently, the warning was not disseminated over NWWS and other distribution systems which feed the media and other users. While it is impossible to be certain, the most likely point of failure is the peripheral sharing device used to link four PCs with one AFOS communications port.

Recommendation 6: The Sioux Falls NWSFO should move the PC used to generate warnings to a dedicated AFOS port. If a dedicated port cannot be made available, alternatives should be explored to reduce the number of PCs sharing the PSD with the warning PC.

Finding 7: The NWR coverage on May 30 was not adequate to ensure reliable reception of severe weather information on standard, home-use receivers in Spencer.

Recommendation 7: The Sioux Falls NWSFO should review its NWR expansion plan, update it if necessary, and redistribute. By spring 1999, the office should identify potential partners for obtaining NWR transmitters for each site in their plan.

Finding 8: In spite of attempts by NWSFO Sioux Falls to promote use of the Emergency Management Weather Information Network (EMWIN), there are no known users of the system in the Sioux Falls CWA. This system could have been useful on May 30 for the dissemination of warning and forecast products to emergency managers, law enforcement officials, etc.

Recommendation 8: Central Region should contact the appropriate state officials responsible for the emergency management programs to encourage emergency managers in the Sioux Falls CWA to install EMWIN before the next severe weather season.

Response

FACT: In spite of the devastation inflicted on Spencer, many residents obtained sufficient warning information through media sources or by first-hand observation and avoided death or serious injury by taking appropriate precautions. There was, however, a significant segment of the small population who remained uninformed until the destruction began. With the volunteer fire department siren not functioning and the nearest NWR station essentially out of range, the only practical, readily available sources of warning information for most Spencer residents were television and commercial radio.

FACT: The Spencer tornado occurred when many people were watching television. Viewers in Spencer who were tuned to a Sioux Falls station were provided information on the 8:12 p.m. Tornado Warning for northern Hanson County and the 8:32 p.m. Tornado Warning for northern McCook County.

FACT: Residents who heard some type of warning in time to take precautions indicated Sioux Falls television stations or commercial radio stations as their source of warning information. Several residents of the area cited two radio stations in Mitchell, which included listener reports with warnings from NWSFO Sioux Falls.

FACT: Residents who took precautions indicated they took steps to protect themselves from flying debris, taking refuge in basements, under stairways, in hallways, and in closets.

FACT: Basements in many of the homes which were completely destroyed were filled with debris. Some residents survived by taking the extra precaution of finding a secondary sturdy shelter within the basement.

FACT: The six persons killed by the Spencer tornado ranged in age from 62 to 93.

Service Coordination and Preparedness

FACT: The NWSFO Sioux Falls staff, especially the MIC and WCM, maintain very active and effective preparedness and outreach programs. Documentation for 1997 and 1998 shows a very long list of spotter training classes, presentations for service organizations, school visits, media visits and workshops, and other public activities. Spotter training was conducted in April for several of the counties affected by the May 30 severe weather outbreak. Severe weather preparedness week was conducted in South Dakota during the week of April 20. All of these efforts have no doubt raised the level of severe weather awareness and education throughout the NWSFO Sioux Falls CWA.

FACT: A long-term relationship between the staff at NWSFO Sioux Falls and local media has produced an excellent working relationship which played a major role in effective severe weather warning operations on May 30. Representatives of the media who were interviewed by members of the Service Assessment Team were very familiar with the NWS products and services and with the NWSFO Sioux Falls warning operation.

FACT: The NWSFO Sioux Falls MIC and WCM also have an excellent working relationship with the Federal, state, and local officials who have jurisdiction in their CWA.

FACT: The NWSFO Sioux Falls staff was well prepared for the events of May 30. It is obvious to members of the Service Assessment Team that severe weather operations have received a great deal of emphasis and that guidance and training for warning operations have been a high priority among the NWSFO managers.

Appendix A

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.

Appendix B

Spencer, South Dakota, Tornado
May 30, 1998
Chronological Log

Valid Time CDT	Product Type/Report	Counties Affected	NWR Log Time	EAS Log Time	Remarks
0405	SFP	Southeast SD	NA	NA	"some thunder/ storms could be severe south/ east" - tonight
0405	ZFP	Hanson, McCook and Turner	NA	NA	"some thunder/ storms could be severe" -tonight
0435	SPS	Southeast SD	NA	NA	"Moderate Risk of severe weather today"
1100	ZFP	Hanson, McCook, Turner	NA	NA	"some thunder/ storms could be severe" - tonight
1147	SPS	Southeast SD	NA	NA	"severe winds, large hail and **tornadoes** possible" / "spotter activation likely after 4 PM"
1550-2200	SEL8	McCook	1548	NA	Tornado Watch #468
1625	ZFP	McCook, Hanson, Turner	NA	NA	Tornado Watch for McCook, "severe thunderstorms" Hanson and Turner

1730	NOW	McCook, Hanson, Turner	NA	NA	Thunderstorms this evening "could become severe"
1845-1955	SVR	Beadle	NA	NA	
1850	NOW	Huron (city)	NA	NA	storms impact on Huron
1903	SVS	Beadle	NA	NA	Pathcast update
1919	.75 inch hail	Beadle			3 W of Huron
1923	SVR	Beadle	NA	NA	
1940-2010	SVR	Sanborn	1937	NA	10 to 40 miles northwest of Spencer
1944-2015	SVR	NE Davison N Hanson	NA	NA	
1945	**TORNADO**	Kingsbury			Between Desmet & Lake Preston
1946	SVS	Sanborn	NA	NA	Updated location and movement
1955	FUNNEL CLOUD	NE Davison			Spotter
1955	SVS	Beadle	1956	NA	Warning Expiration
2001-2035	TOR	NE Davison N Hanson	NA	NA	Replaced SVR (NAWAS only)
2002	**TORNADO**	Kingsbury			5 W Lake Preston
2008	**TORNADO**	Hanson			8 NE Mitchell
2012	**TORNADO**	Hanson			W of Farmer. Report from EAX WCM
2012-2045	TOR	N Hanson	NA	NA	
2013	**LARGE TORNADO**	Hanson			NE of Mitchell

2013	SVS	NE Davison	NA	NA	Cancelled TOR for NE Davison
2015	1.75 inch hail	Hanson			7 E Loomis
2016-0300	SEL9	Hanson, McCook, Turner	2039	NA	Tornado Watch #469 PDS Watch
2023	**TORNADO**	Hanson			5 NW Fulton. Report from Mitchell PD
2024-2055	SVR	Miner	2026	NA	
2025	**TORNADO**	Hanson			1 W Spencer. Report from McCook Co. Sheriff
2029	**LARGE TORNADO**	Hanson			W of Spencer. Report from Mitchell PD
2032-2105	TOR	McCook	2032	2034	Live and recorded simultaneously on NWR
2034	SVS	Miner	NA	NA	
2044	**TORNADO**	McCook			1 Dead, 47 Injured. Extensive damage in Spencer
2045	**TORNADO**	Hanson			5 W Emery
2045-2120	TOR	Hanson	NA	NA	
2050	TORNADO	McCook			9 N Bridgewater
2052	SVS	Miner	2052	NA	Cancelled Warning
2054	SVS	N McCook	2058	NA	Tornado report near I-90 & Bridgewater exit
2055	**TORNADO**	Hanson			At Alexandria

2055	ZFP	Hanson, McCook, Turner	NA	NA	Updated for Tornado Watch #469
2059	SVS	Hanson	NA	NA	Tornado report & radar indication near Alexandria
2100	Wind G60	W Lyon			From Lyon EM
2104-2140	TOR	McCook	2106	2107	Live and recorded simultaneously on NWR
2109-2140	SVR	E Lake, Moody	2110	2112	Live and recorded simultaneously on NWR
2110	**TORNADO**	McCook			At Bridgewater
2111	SVS	McCook	2117	NA	Tornado reported near Bridgewater. Radar indicated near Bridgewater & SW of Montrose
2115	Wind Damage	Lyon MN			N Russell
2116-2150	SVR	Lincoln MN, Lyon MN	NA	NA	
2117	Funnel Cloud	Minnehaha			2 W Wall Lake. Source Spotter
2120	**TORNADO**	Turner			2 E Monroe
2120-2210	TOR	Minnehaha	2122	2124	Live and recorded simultaneously on NWR
2121	SVS	Hanson	NA	NA	Warning Expiration
2125	NOW	Most of CWA	NA	NA	Severe Weather Potential

2128-2200	TOR	N Turner	2129	2131	Live and recorded simultaneously on NWR
2131	SVS	E Lake, Moody	2134	NA	Updated location
2134	SVS	McCook	2136	NA	Updated tornado location (radar)
2136	Wind Damage	Lyon MN			5 N Russell
2138	SVS	Lincoln Lyon MN	NA	NA	Updated storm location
2141	SVS	Moody	2143	NA	Warning expiration
2144	SVS	E McCook	2146	NA	Warning expiration
2146	SVS	Lyon MN	NA	NA	Warning expiration
2148-2220	SVR	Lincoln (N&C)	2149	2150	
2148	SVS	N Turner	NA	NA	Updated storm location
2150	SVS	Minnehaha	2154	NA	Public report of tornado west of Sioux Falls
2156-2220	TOR	Lincoln (N&C)	2157	2159	
2201-2255	SVR	Rock MN Lyon IA	2205	2205	Live and recorded simultaneously on NWR
2203	SVS	N Turner	2206	NA	Warning Expiration
2208-2240	SVR	S Lincoln Sioux IA	2210	2211	Live an recorded simultaneously on NWR

2210	SVS	Minnehaha	2213	NA	Warning Expiration
2218	SVS	Lincoln (N&C)	2219	NA	Warning Expiration
2228-2300	SVR	Nobles	2229	2230	Live and recorded simultaneously on NWR
2229	SVS	Rock MN Lincoln	2231	NA	Warning Expiration
2232	SVS	Sioux IA Lincoln	2241	NA	Warning Cancellation
2240	ZFP	All covered by Watch #469	NA	NA	Remove Tornado Watch
2240	SVS	Sioux IA	NA	NA	Warning Expiration
2242	SVS	Nobles MN	2245	NA	Updated location & pathcast
2300	SVS	Nobles MN	2302	NA	Warning Expiration

Notes: For Column 3, Counties Affected, only Hanson, McCook and Turner Counties are listed, as applicable, for ZFPs, SPSs, and Watches.

NA = Not Available or Not Applicable.