QC
995
.U61
no.115

HNICAL MEMORANDUM NWS CR-115

THE EVOLUTION OF TWO TORNADIC SUPERCELLS INTO AN INTENSE BOW ECHO OVER SOUTHWEST NEBRASKA AND NORTHWEST KANSAS

Eric Martello
National Weather Service Office
Goodland, Kansas

October 1999

U.S DEPARTMENT OF Commerce / National Oceanic and Atmospheric Administration / National Weather Service

NOAA TECHNICAL MEMORANDA
National Weather Service, Central Region Subseries

The National Weather Service Central Region (CR) subseries provides an informal medium for the documentation and quick dissemination of results not appropriate, or not yet ready, for formal publication. The series is used to report on work in progress, to describe technical procedures and practices, or to relate progress to a limited audience. These Technical Memoranda report on investigations devoted primarily to regional and local problems of interest mainly to regional personnel, and hence will not be widely distributed.

Papers 1 through 15 are in the former series, ESSA Technical Memoranda, Central Region Technical Memoranda (CRTM); Papers 16 through 36 are in th former series, ESSA Technical Memoranda, Weather Bureau Technical Memoranda (WBTM). Beginning with Paper 37, the papers are part of the series, Technical Memoranda NWS.

Papers that have a PB or COM number are available from the National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22151. Order by accession number shown in parenthesis at the end of each entry. Prices vary for all paper copies. Microfiche are $4.50. All other papers are available from the National Weather Service Central Region, Scientific Services, Room 1836, 601 East 12th Street, Kansas City, MO 64106.

ESSA Technical Memoranda

CRTM 1	Precipitation Probability Forecast Verification Summary Nov. 1965 - Mar. 1966, SSD Staff, WBCRH, May 1966.
CRTM 2	A Study of Summer Showers Over the Colorado Mountains. William G. Sullivan, Jr., and James O. Severson, June 1966.
CRTM 3	Areal Shower Distribution - Mountain Versus Valley Coverage. William G. Sullivan, Jr., and James O. Severson, June 1966.
CRTM 4	Heavy Rains in Colorado June 16 and 17, 1965. SSD Staff, WBCRH, July 1966.
CRTM 5	The Plum Fire. William G. Sullivan, Jr., August 1966.
CRTM 6	Precipitation Probability Forecast Verification Summary Nov. 1965 - July 1966. SSD Staff, WBCRH, September 1966.
CRTM 7	Effect of Diurnal Weather Variations on Soybean Harvest Efficiency. Leonard F. Hand, October 1966.
CRTM 8	Climatic Frequency of Precipitation at Central Region Stations. SSD Staff, WBCRH, November 1966.
CRTM 9	Heavy Snow or Glazing. Harry W. Waldheuser, December 1966.
CRTM 10	Detection of a Weak Front by WSR-57 Radar. G. W. Polensky, December 1966.
CRTM 11	Public Probability Forecasts. SSD Staff, WBCRH, January 1967.
CRTM 12	Heavy Snow Forecasting in the Central United States (an Interim Report). SSD Staff, January 1967.
CRTM 13	Diurnal Surface Geostrophic Wind Variations Over the Great Plains. Wayne E. Sangster, March 1967.
CRTM 14	Forecasting Probability of Summertime Precipitation at Denver. Wm. G. Sullivan, Jr., and James O. Severson, March 1967.
CRTM 15	Improving Precipitation Probability Forecasts Using the Central Region Verification Printout. Lawrence A. Hughes, May 1967.
WBTM CR 16	Small-Scale Circulations Associated with Radiational Cooling. Jack R. Cooley, June 1967.
WBTM CR 17	Probability Verification Results (6-month and 18-month). Lawrence A. Hughes, June 1967.
WBTM CR 18	On the Use and Misuse of the Brier Verification Score. Lawrence A. Hughes, August 1967 (PB 175 771).
WBTM CR 19	Probability Verification Results (24 months). Lawrence A. Hughes, February 1968.
WBTM CR 20	Radar Prediction of the Topeka Tornado. Norman E. Prosser, April 1968.
WBTM CR 21	Wind Waves on the Great Lakes. Lawrence A. Hughes, May 1968.
WBTM CR 22	Seasonal Aspects of Probability Forecasts: 1. Summer. Lawrence A. Hughes, June 1968 (PB 185 733).
WBTM CR 23	Seasonal Aspects of Probability Forecasts: 2. Fall. Lawrence A. Hughes, September 1968 (PB 185 734).
WBTM CR 24	The Importance of Areal Coverage in Precipitation Probability Forecasting. John T. Curran and Lawrence A. Hughes, September 1968.
WBTM CR 25	Meteorological Conditions as Related to Air Pollution, Chicago, Illinois, April 12-13, 1963. Charles H. Swan, October 1968.
WBTM CR 26	Seasonal Aspects of Probability Forecasts: 3. Winter. Lawrence A. Hughes, December 1968 (PB 185 735).
WBTM CR 27	Seasonal Aspects of Probability Forecasts: 4. Spring. Lawrence A. Hughes, February 1969 (PB 185 736).
WBTM CR 28	Minimum Temperature Forecasting During Possible Frost Periods at Agricultural Weather Stations in Western Michigan. Marshall E. Soderberg, March 1969.
WBTM CR 29	An Aid for Tornado Warnings. Harry W. Waldheuser and Lawrence A. Hughes, April 1969.
WBTM CR 30	An Aid in Forecasting Significant Lake Snows. H. J. Rothrock, November 1969.
WBTM CR 31	A Forecast Aid for Boulder Winds. Wayne E. Sangster, February 1970.
WBTM CR 32	An Objective Method for Estimating the Probability of Severe Thunderstorms. Clarence L. David, February 1970.
WBTM CR 33	Kentucky Air-Soil Temperature Climatology. Clyde B. Lee, February 1970.
WBTM CR 34	Effective Use of Non-Structural Methods in Water Management. Verne Alexander, March 1970.
WBTM CR 35	A Note on the Categorical Verification of Probability Forecasts. Lawrence A. Hughes and Wayne E. Sangster, August 1970.
WBTM CR 36	A Comparison of Observed and Calculated Urban Mixing Depths. Donald E. Wuerch, August 1970.

NOAA Technical Memoranda NWS

NWS CR 37	Forecasting Maximum and Minimum Surface Temperatures at Topeka, Kansas, Using Guidance from the PE Numerical Prediction Model (FOUS). Morris S. Webb, Jr., November 1970 (COM 71-00118).
NWS CR 38	Snow Forecasting for Southeastern Wisconsin. Rheinhart W. Harms, November 1970 (COM 71-00019).
NWS CR 39	A Synoptic Climatology of Blizzards on the North-Central Plains of the United States. Robert E. Black, February 1971 (COM 71-00369).
NWS CR 40	Forecasting the Spring 1969 Midwest Snowmelt Floods. Herman F. Mondschein, February 1971 (COM 71-00489).
NWS CR 41	The Temperature Cycle of Lake Michigan 1. (Spring and Summer). Lawrence A. Hughes, April 1971 (COM 71-00545).
NWS CR 42	Dust Devil Meteorology. Jack R. Cooley, May 1971 (COM 71-00628).
NWS CR 43	Summer Shower Probability in Colorado as Related to Altitude. Alois G. Topil, May 1971 (COM 71-00712).
NWS CR 44	An Investigation of the Resultant Transport Wind Within the Urban Complex. Donald E. Wuerch, June 1971 (COM 71-00766).
NWS CR 45	The Relationship of Some Cirrus Formations to Severe Local Storms. William E. Williams, July 1971 (COM 71-00844).
NWS CR 46	The Temperature Cycle of Lake Michigan 2. (Fall and Winter). Lawrence A. Hughes, September 1971 (COM 71-01039).
NWS CR 47	Practical Application of a Graphical Method of Geostrophic Wind Determination. C.B. Johnson, November 1971 (COM 71-01084).
NWS CR 48	Manual of Great Lakes Ice Forecasting. C. Robert Snider, December 1971 (COM 72-10143).
NWS CR 49	A Preliminary Transport Wind and Mixing Height Climatology, St. Louis, Missouri. Donald E. Wuerch, Albert J. Courtois, Carl Ewald, Gary Ernst, June 1972 (COM 72-10859).
NWS CR 50	An Objective Forecast Technique for Colorado Downslope Winds. Wayne E. Sangster, December 1972 (COM 73-10280).
NWS CR 51	Effect on Temperature and Precipitation of Observation Site Change at Columbia, Missouri. Warren M. Wisner, March 1973 (COM 73-10734).
NWS CR 52	Cold Air Funnel Clouds. Jack R. Cooley and Marshall E. Soderberg, September 1973, (COM 73-11753/AS).
NWS CR 53	The Frequency of Potentially Unfavorable Temperature Conditions in St. Louis, Missouri. Warren M. Wisner, October 1973.
NWS CR 54	Objective Probabilities of Severe Thunderstorms Using Predictors from FOUS and Observed Surface Data. Clarence A. David, May 1974 (COM 74-11258/AS).
NWS CR 55	Detecting and Predicting Severe Thunderstorms Using Radar and Sferics. John V. Graff and Duane C. O'Malley, June 1974 (COM 74-11335/AS).
NWS CR 56	The Prediction of Daily Drying Rates. Jerry D. Hill, November 1974 (COM 74-11806/AS).
NWS CR 57	Summer Radar Echo Distribution Around Limon, Colorado. Thomas D. Karr and Ronald L. Wooten, November 1974 (COM 75-10076/AS).
NWS CR 58	Guidelines for Flash Flood and Small Tributary Flood Prediction. Lawrence A. Hughes and Lawrence L. Longsdorf, October 1975 (PB-247569/AS).
NWS CR 58	(Revised) March 1978 (PB-281461/AS).
NWS CR 59	Hourly Cumulative Totals of Rainfall - Black Hills Flash Flood June 9-10, 1972. Don K. Halligan and Lawrence L. Longsdorf, April 1976 (PB-256087).
NWS CR 60	Meteorological Effects on the Drift of Chemical Sprays. Jerry D. Hill, July 1976 (PB-259593).
NWS CR 61	An Updated Objective Forecast Technique for Colorado Downslope Winds. Wayne E. Sangster, March 1977 (PB-266966/AS).
NWS CR 62	Design Weather Conditions for Prescribed Burning. Ronald E. Haug, April 1977 (PB-268034).
NWS CR 63	A Program of Chart Analysis (With Some Diagnostic and Forecast Implications). Lawrence A. Hughes, December 1977 (PB-279866/AS).
NWS CR 64	Warm Season Nocturnal Quantitative Precipitation Forecasting for Eastern Kansas Using the Surface Geostrophic Wind Chart. Wayne E. Sangster, April 1979 (PB-295982/AS).
NWS CR 65	The Utilization of Long Term Temperature Data in the Description of Forecast Temperatures. Arno Perlow, November 1981 (PB82-163064).
NWS CR 66	The Effect of Diurnal Heating on the Movement of Cold Fronts Through Eastern Colorado. James L. Wiesmueller, August 1982 (PB83-118463).
NWS CR 67	An Explanation of the Standard Hydrologic Exchange Format (SHEF) and Its Implementation in the Central Region. Geoffrey M. Bonn and Robert S. Cox, April 1983 (PB83-193623).
NWS CR 68	The Posting of SHEF Data to the RFC Gateway Database. Geoffrey M. Bonnin, April 1983 (PB83-222554).
NWS CR 69	Some Basic Elements of Thunderstorm Forecasting. Richard P. McNulty, May 1983 (PB83-222604).
NWS CR 70	Automatic Distribution of AFOS Products Created at the NOAA Central Computer Facility via Hamlet (RJE) Punch Stream.Billy G. Olsen and Dale G. Lillie, November 1983 (PB84-122605).
NWS CR 71	An Investigation of Summertime Convection Over the Upper Current River Valley of Southeast Missouri. Bartlett C. Hagemeyer, July 1984 (PB84-222389).
NWS CR 72	The Standard SHEF Decoder Version 1.1. Geoffrey M. Bonnin, August 1984 (PB85-106508).
NWS CR 73	The Blizzard of February 4-5, 1984 Over the Eastern Dakotas and Western Minnesota. Michael Weiland, October 1984 (PB85-120087).

(Continued on Back Cover)

NOAA TECHNICAL MEMORANDUM NWS CR-115

THE EVOLUTION OF TWO TORNADIC SUPERCELLS INTO AN INTENSE BOW ECHO OVER SOUTHWEST NEBRASKA AND NORTHWEST KANSAS

QC
995
.U61
no. 115

Eric Martello
National Weather Service Office
Goodland, Kansas

LIBRARY
MAR 2000
National Oceanic &
Atmospheric Administration
U.S. Dept. of Commerce

Scientific Services Division
Central Region
Kansas City, Missouri

October 1999

UNITED STATES
DEPARTMENT OF COMMERCE
William M. Daley
Secretary

National Oceanic and
Atmospheric Administration
D. James Baker
Under Secretary and Administrator

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

Table of Contents

THE EVOLUTION OF TWO TORNADIC SUPERCELLS INTO AN INTENSE BOW ECHO OVER SOUTHWEST NEBRASKA AND NORTHWEST KANSAS

Eric Martello[1]
National Weather Service Office
Goodland, Kansas

I. INTRODUCTION

On August 21, 1997, two tornadic supercells formed in southwest Nebraska, merged, then moved rapidly into northwest Kansas as a bow echo system (Figure 1). Prior to the merger, the two storms produced 4.5 cm (1.75 in) diameter hail just before crossing the Kansas/Nebraska state line. After the storms evolved into the bow echo, wind damage became more pronounced and widespread as the system moved rapidly southeast across portions of northwest Kansas. Although there were some differences during the mesocyclonic stage, the event was similar to one that occurred near Lahoma, Oklahoma in 1994 (Conway1994). This study will examine the environmental conditions, radar signatures, and structural damage associated with the event.

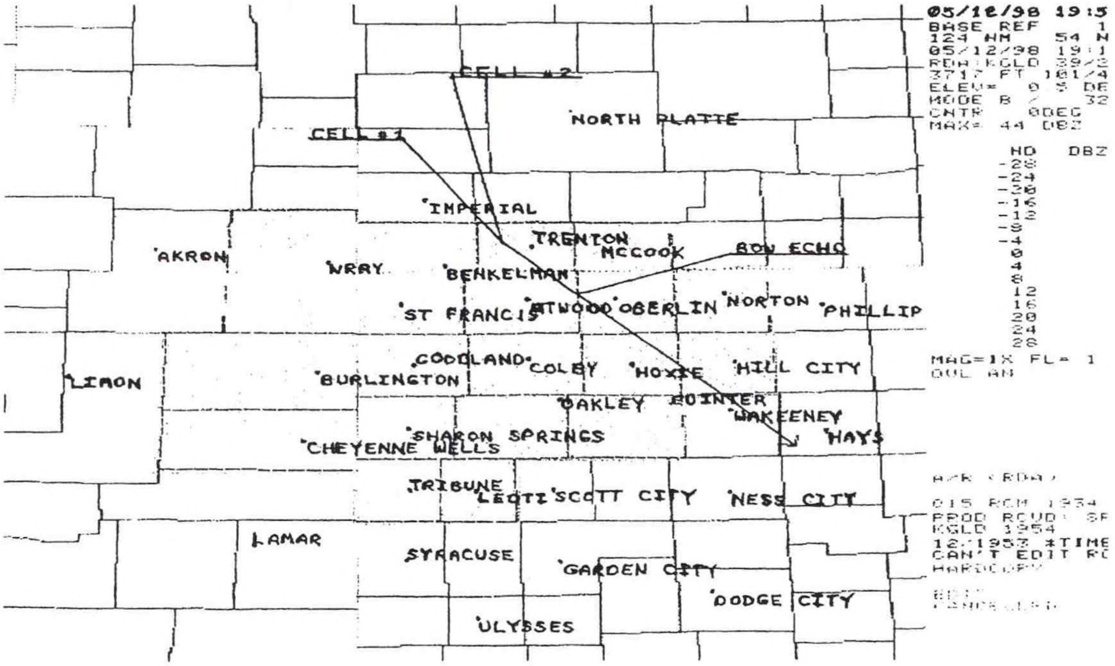


Figure 1. Track of two supercells and resultants bow echo of August 21, 1997.

II. THERMODYNAMIC PARAMETERS

Area soundings at 1200 UTC 21 August, showed that a surface-based inversion existed over western Kansas with surface temperatures ranging between 16-19°C and 850 mb temperatures in the 26-28°C range. At this time, Convective Available Potential Energy (CAPE) values of 1000-1500 J kg^{-1} existed over the region. A northwest-southeast oriented 500 mb baroclinic zone existed over central Nebraska and Kansas between a low over the upper Midwest and a ridge situated over the central Rocky Mountains, resulting in a northwest flow regime over western Kansas. 1200 UTC Lifted Indices (LI) at 1000-500mb ranged between -2°C and -4°C over the region (Figure 2). By 0000 UTC 22 August, ample surface heating had broken the surface-based inversion with LI values approaching -10°C (Figure 3). Mid-level (700-500mb) lapse rates over Goodland, Kansas, were 7.7°C km^{-1} based on a modified sounding taken from Dodge City, Kansas, at 0000 UTC 22 August.

---

[1] Current affiliation, NWS Jackson, Mississippi.

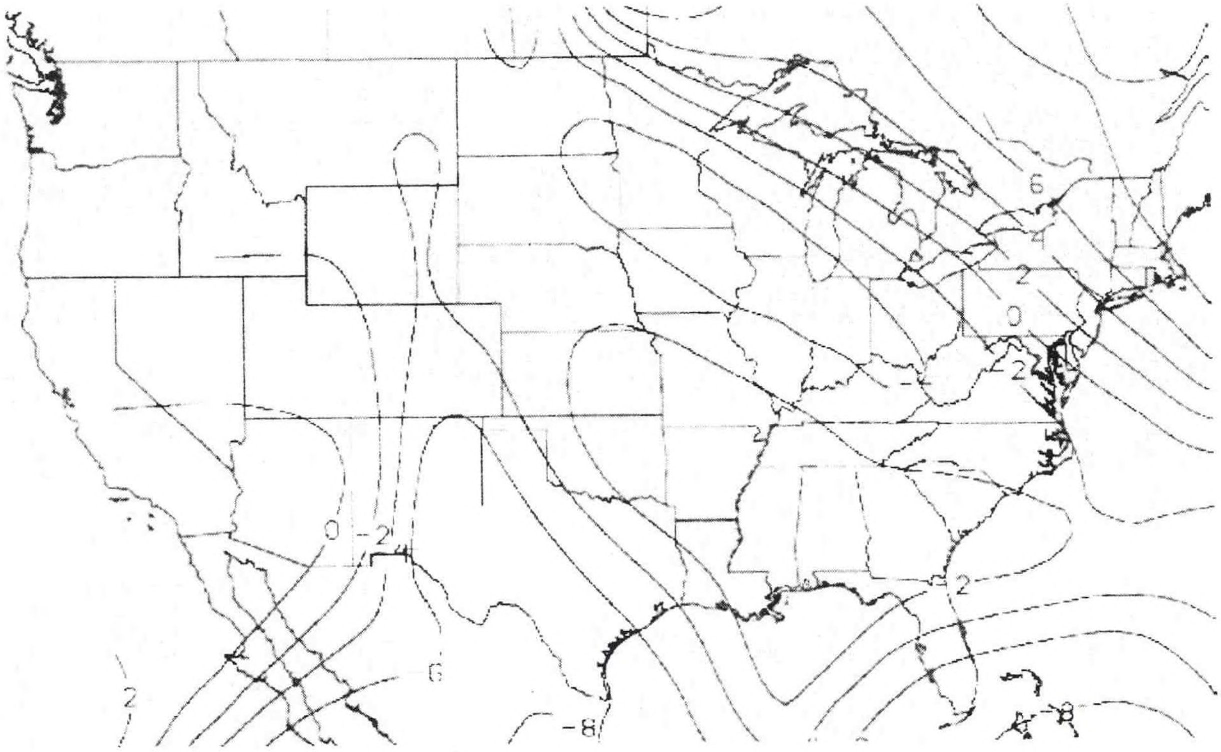


Figure 2. Surface-based lifted indices (°C) 1200 UTC 21 August 1997.

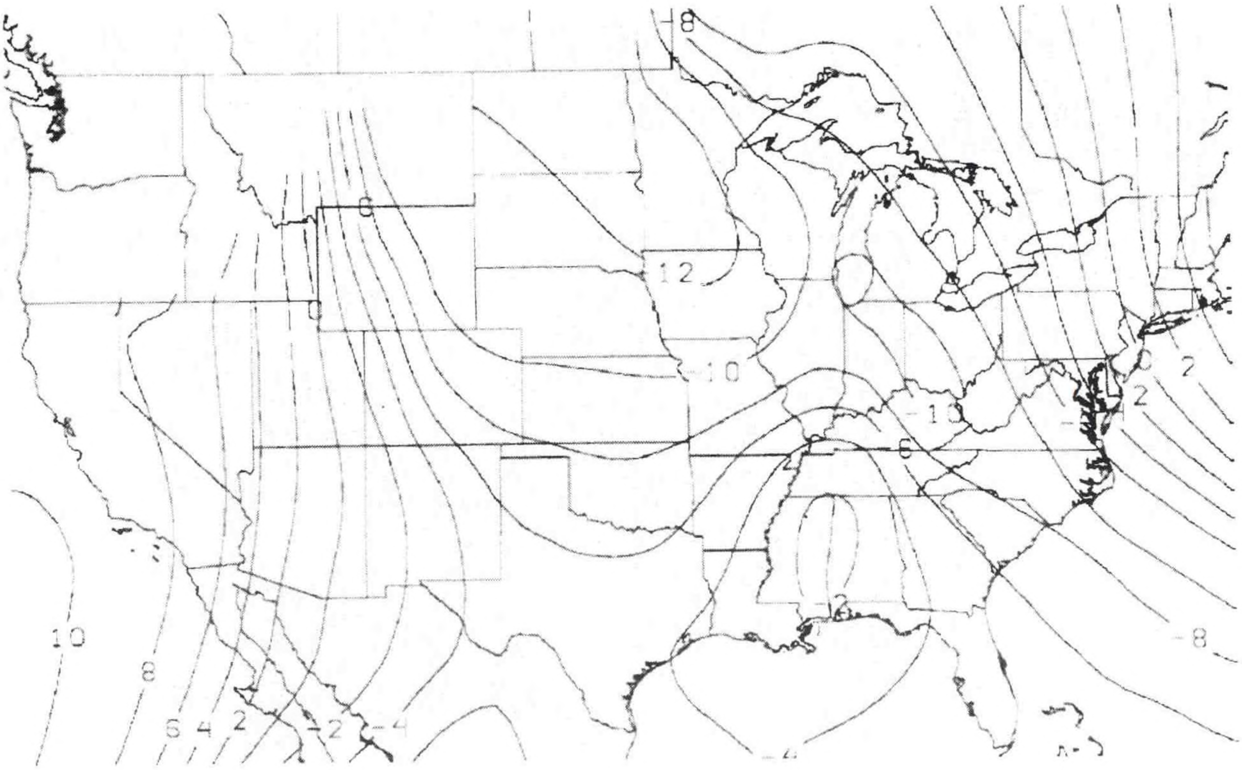
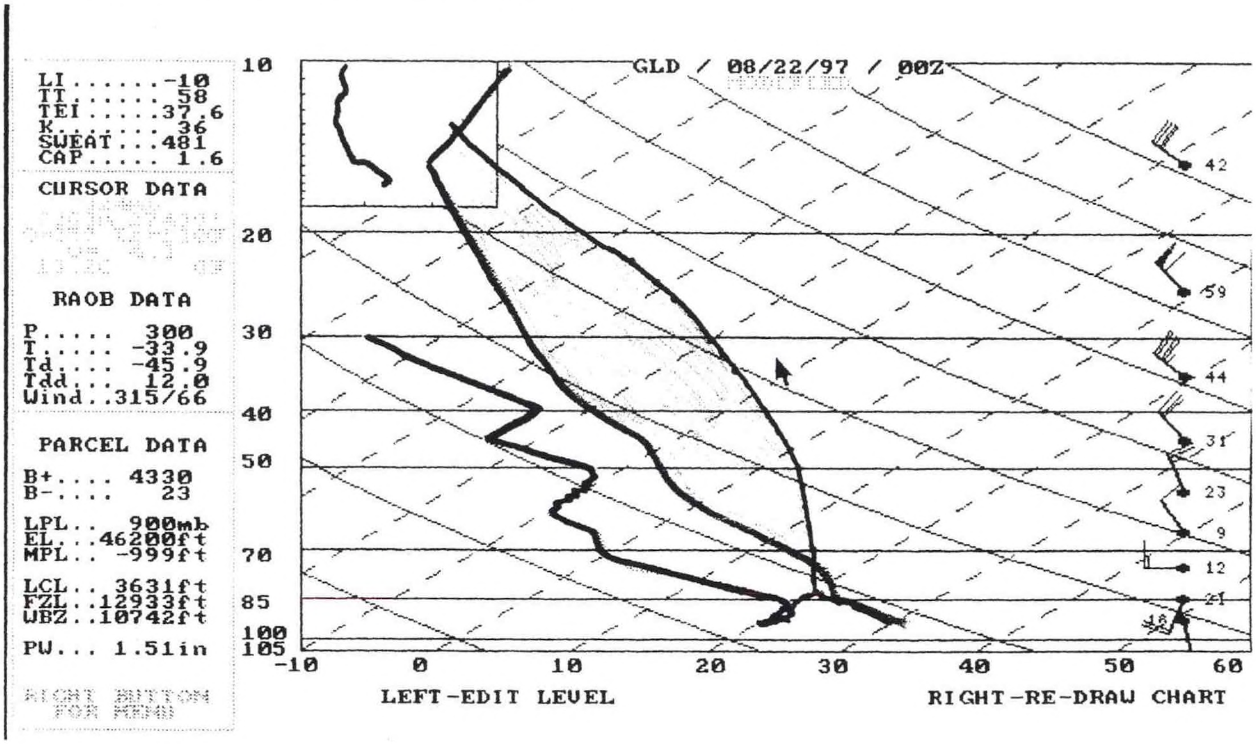


Figure 3. Surface-based lifted indices (°C) 0000 UTC 22 August 1997.

The modified sounding for Goodland, based on a sounding from Dodge City, Kansas, using Eta temperatures and dew points up to 500 mb (Figure 4) at the same time, indicated advection of dry air from the southwest at 750 mb. It also showed that a dry, westerly flow off the Rockies existed at 700-600mb with the potential for strong evaporative cooling in this layer increasing the potential for large hail and downbursts. A shallow, moist layer existed between 850-800 mb. A south wind at these levels backed to the southeast at the surface. CAPE values increased to between 4000 and 5000 J kg^{-1} by late afternoon with 32°C and 20°C surface temperatures and dew points, respectively, at 0000 UTC 22 August. In this case, the system developed in existing high CAPES, whereas, the 1994 Lahoma system advected into a steep CAPE gradient which increased storm-relative (SR) inflow into the system and resulted in a change in storm structure as the system moved south-southeast (Conway 1994).



```
LI......-10
TT......58
TEI.....37.6
K.......36
SWEAT...481
CAP..... 1.6

RAOB DATA
P.....  300
T..... -33.9
Td.... -45.9
Tdd...  12.0
Wind..315/66

PARCEL DATA
B+.... 4330
B-....   23

LPL..  900mb
EL...46200ft
MPL..  -999ft

LCL.. 3631ft
FZL..12933ft
WBZ..10742ft

PW... 1.51in
```

Figure 4. Modified sounding for Goodland 0000 UTC 22 August 1997, showing Convective Available Potential Energy (CAPE) area.

Johns (1993) states that high CAPES are an important ingredient for long-lived warm season bow echoes in the absence of strong dynamic forcing aloft. Once the 1.6°C cap shown in the modified sounding was broken, thunderstorms developed rapidly. A storm-type derivation chart (Brooks and Doswell 1994), shown as Figure 5, was used in conjunction with the modified sounding for Goodland to estimate the probable storm-type of the activity. The chart uses mixing ratios and helicity values to determine types of severe weather associated with thunderstorms. The location of Goodland's parameters for the afternoon on the chart indicated that straight-line-wind-type storms were a strong possibility. The potential for tornadoes was significant as well, and tornadoes did occur during the mesocyclone stages of the two supercells.

However, no horizontal vorticity-induced tornadoes were reported during the bow echo stage. Although mesocyclones may develop along the "bookends" of a bow-echo (Johns 1993), only damaging straight-line winds occurred with this event.

III. MESOSCALE AND SYNOPTIC CONTRIBUTORS

The mean sea level (MSL) pressure pattern at 0000 UTC indicated a lee trough from the Nebraska panhandle to the eastern plains of Colorado. Dew points across the lee trough ranged from 12-15°C in eastern Colorado to 19-22°C in eastern portions of northwest Kansas and southwest Nebraska (Figure 6). An east-west quasi-stationary front existed from west-central Nebraska southeast to near Concordia, Kansas. Johns (1993) found that weak wind-extreme instability events tend to occur along and to the south of stationary fronts, similar to the situation in place over northwest Kansas. A surface to 850 mb Theta-E (θ_e) ridge (Figure 7) existed from Texas into western Nebraska with a developing 25 to 35 kt southerly low-level jet (LLJ) situated east of the surface trough. At 2330 UTC, two isolated supercells formed in southwest Nebraska east of this trough, which is a typical location for convective initiation (Kriehn 1992). Winds of 25 to 35 kts were noted in the 600mb-700mb layer at this time (Figure 11). Winds of this magnitude are strong enough to produce tornadogenesis within a storm-relative (SR) helicity field of 150-175 m^2s^{-2} (Brooks and Doswell 1994). In the Lahoma, Oklahoma event, SR mid-level winds of 15 to 20 kts (Conway 1994) were not enough to generate and stretch the low-level horizontal vorticity in the mesocyclonic stage of the supercell, as happened in the northwest Kansas case. However, both events transformed into bow echoes after moving into higher low-level moisture regimes. Johns (1993) states that in extreme instability conditions, weak mid-level winds are common in warm season bow echo events. In addition, he suggests that optimum condition for bow echo maintenance consists of strong vertical wind shear in the lowest 2.5 km AGL with unidirectional winds in the mid-levels. Wind profiles the evening of August 21 correlated well with Johns' observations.

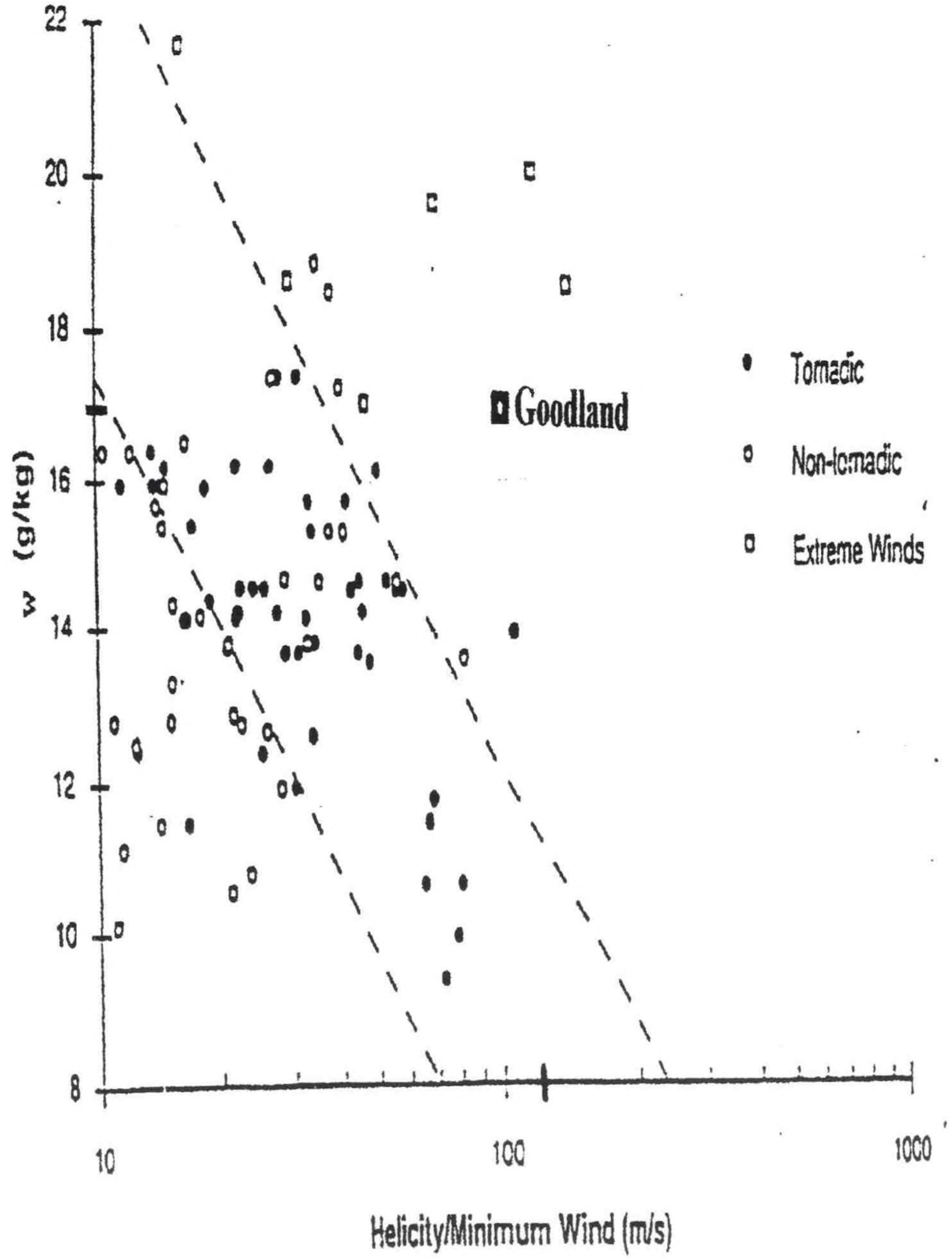


Figure 5. Mixing ratio and helicity values for Goodland 0000UTC 22 August 1997 plotted on Brooks and Doswell's (1994) storm-type chart.

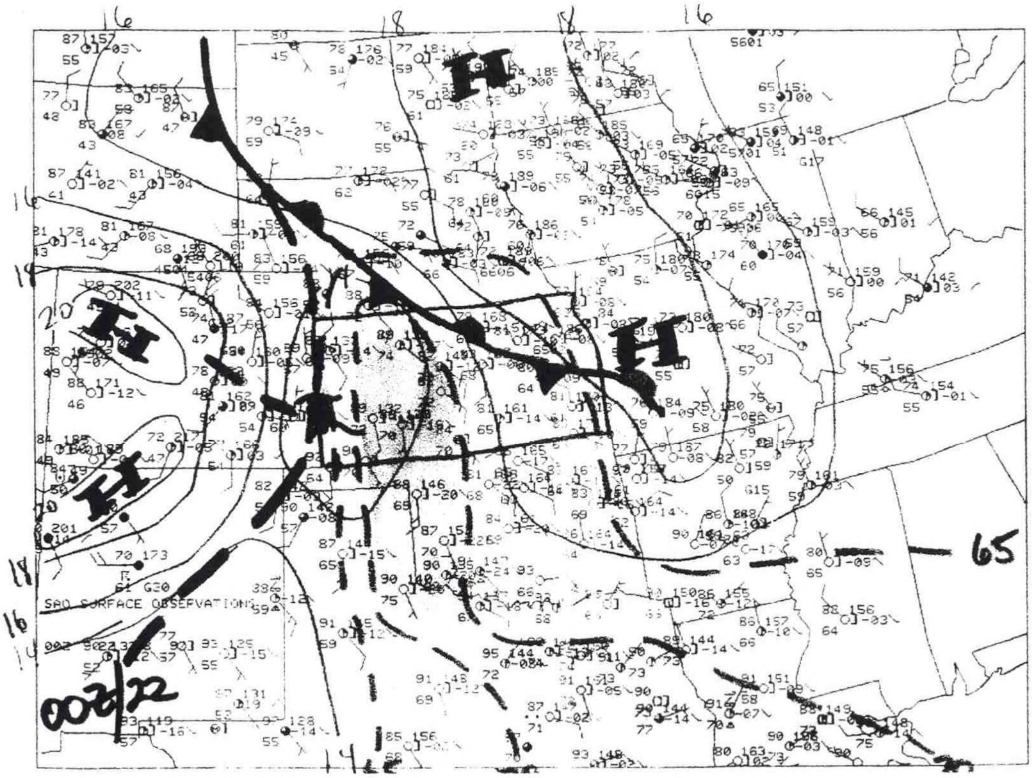


Figure 6. Surface observations, analyzed surface pressures, fronts, and dew point temperatures for 0000 UTC 22 August 1997.

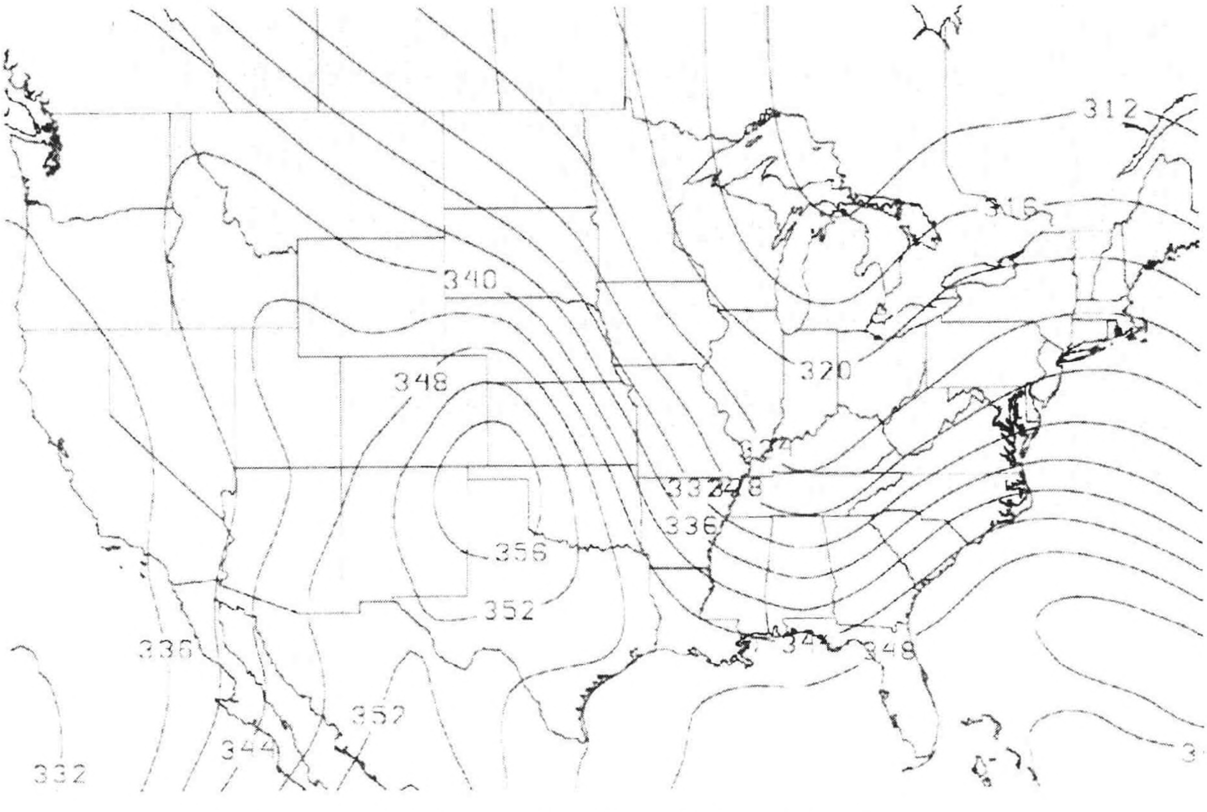


Figure 7. Surface-850 mb layer Theta-E (θ_e) analysis for 0000 UTC 22 August 1997.

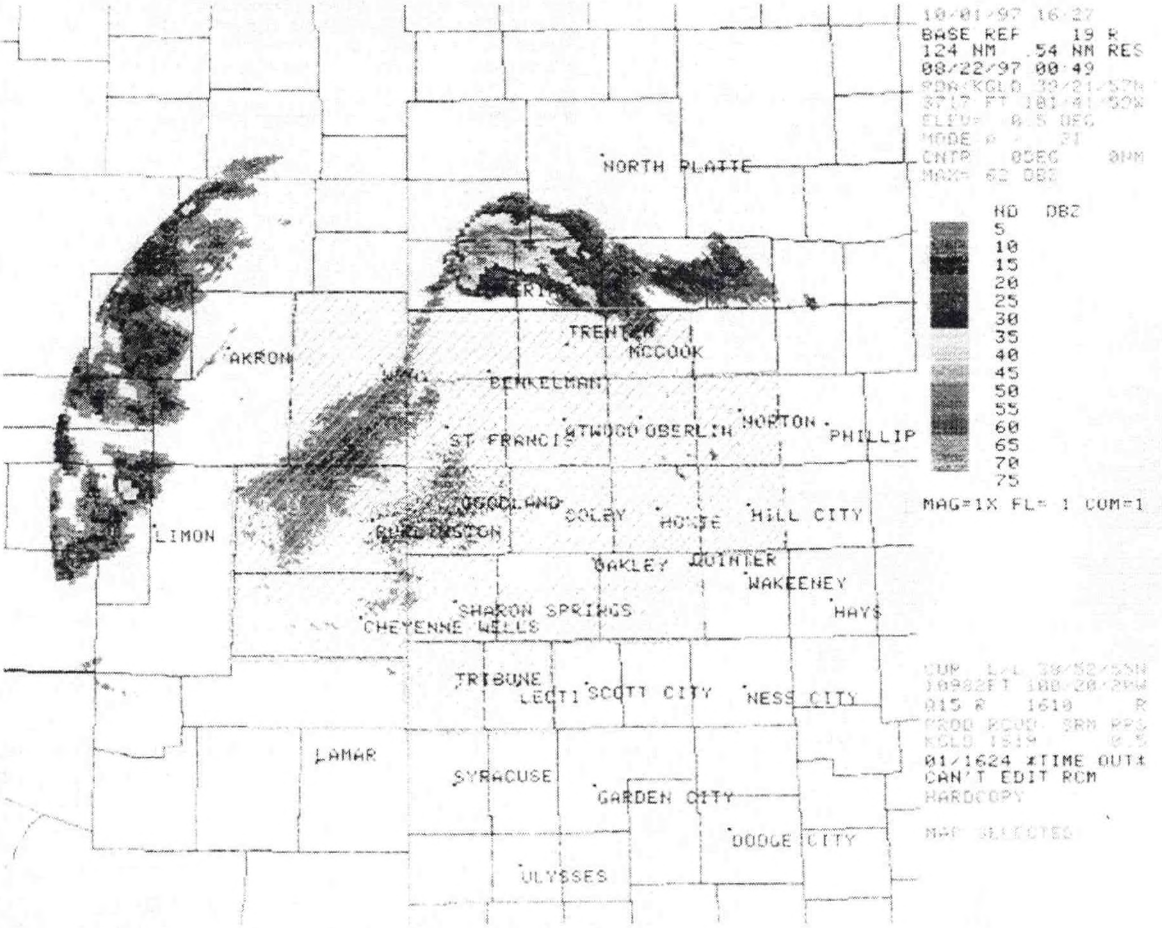


Figure 8. Goodland WSR-88D 0.5° base reflectivity product for 0049 UTC 22 August 1997.

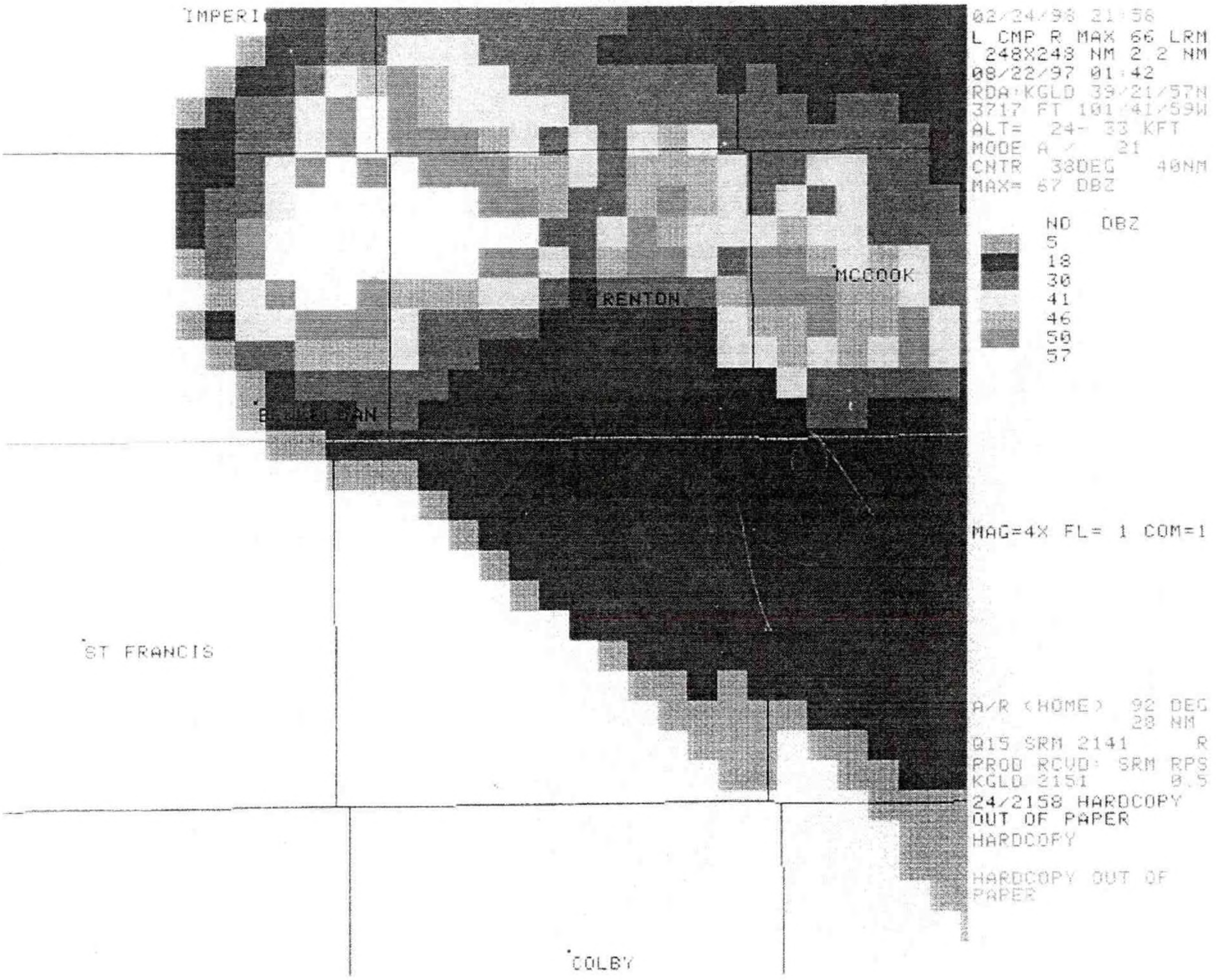


Figure 9. Goodland WSR-88D mid-level layer reflectivity maximum product (LRM, 24-33 kft) for 0142 UTC 22, August 1997.

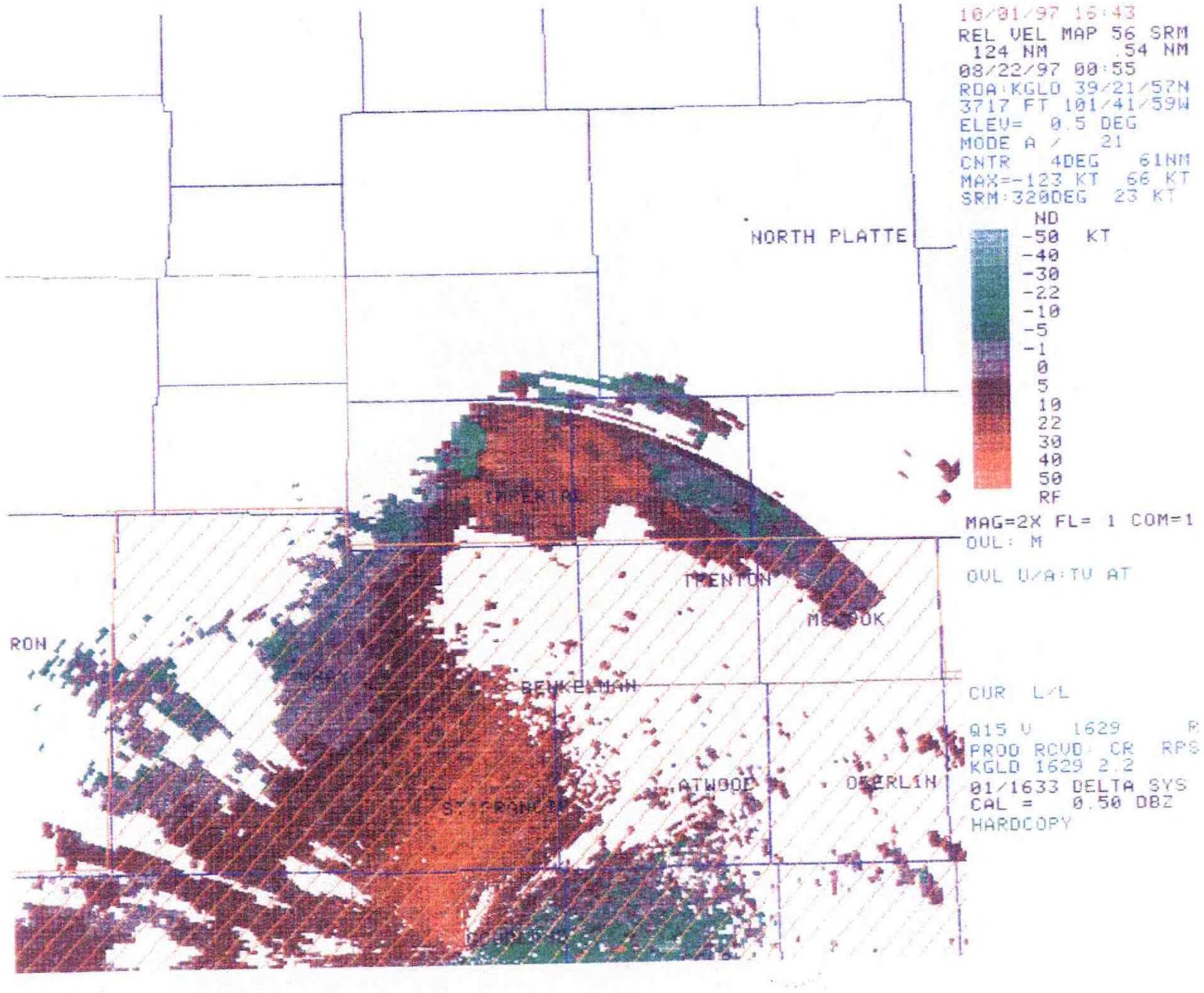


Figure 10. Goodland WSR-88D 0.5° storm-relative velocity product (SRM) for 0055 UTC 22 August 1997.

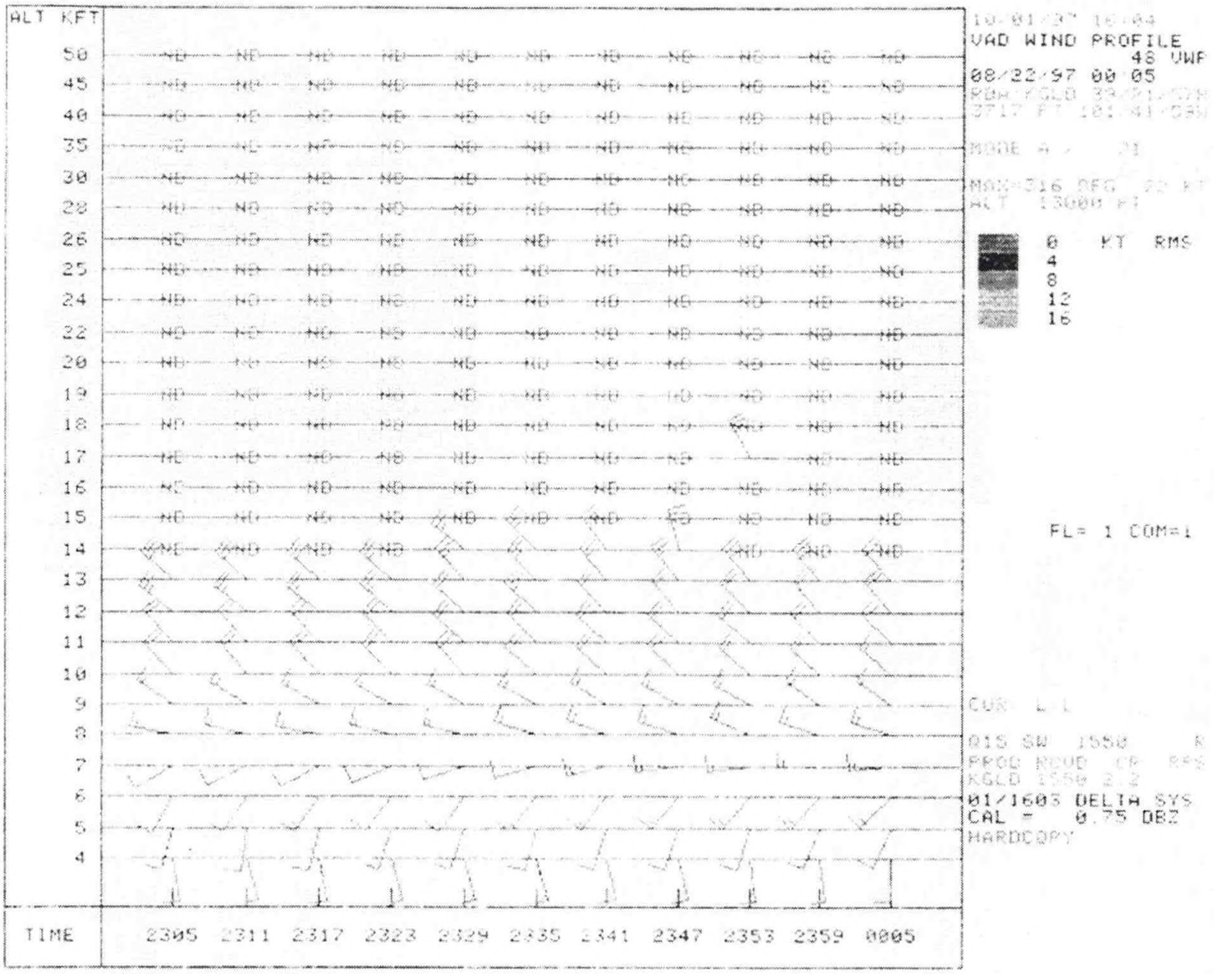


Figure 11. Goodland WSR-88D velocity azimuth display (VAD) wind profile product for 0005 UTC 22, August 1997, showing wind direction and velocities through the vertical in kft MSL.

Once boundary layer winds decoupled from the surface, the LLJ shifted slightly east by mid-evening. Such a shift is primarily due to thermal wind relationships related to differential cooling associated with the east-west sloping terrain (Bluestein 1984). Similar to a case documented by Kriehn (1992), these storms moved into a region of lower levels of free convection (LFC) where deeper low level moisture existed. This is similar to the Lahoma case where both events occurred in environmental surface mixing ratios around 17 g kg^{-1}. Less lift is needed to initiate convection where lower LFCs exist. By 0300 UTC 22 August, this system behaved similarly to Kriehn's observations as outflow produced by the full-fledged bow echo system initiated new convection along its front flank.

The bow echo propagated south-southeast into the nose of the Theta-E (θ_e) ridge over west-central Kansas (Figure 7), then into northwest Oklahoma by 0900 UTC 22 August. Strong SR inflow from a 30 to 40 kt LLJ over western Oklahoma sustained the bow echo through the night. By 1200 UTC 22 August, the storms dissipated as SR inflow decreased and the nocturnal LLJ weakened.

IV. RADAR SIGNATURES: MESOCYCLONE STAGE

After the two rotating supercells formed over southwest Nebraska, the larger northern cell turned right of the mean flow. By 0049 UTC 22 August, it began to merge with the slower and smaller supercell to the south over Chase County, Nebraska (Figure 8). Storm Top Divergence was estimated by the Goodland WSR-88D radar to be 184 knots as the two supercells merged between Imperial and McCook, Nebraska. Divergent flow aloft of this magnitude is strong enough to produce hail up to baseball size (WSR-88D Operational Support Facility 1993). Spotter reports from Dundy County in southwest Nebraska indicated hail 4.5 cm in diameter fell near locations of the maximum reflectivity on Goodland WSR-88D's mid-level (24-33Kft) LRM product (Figure 9). Both supercells produced tornadoes around this time (0045 UTC) and the Goodland WSR-88D radar showed the associated cyclonic rotation signatures on the 0.5° base velocity product (Figure 10).

As the storms merged, they moved into a more unstable thermodynamic environment. Evaporative cooling in response to dry mid levels helped to generate strong baroclinic vorticity within the storm complex. Once this occurred, the downdraft strength increased and formed the familiar spearhead shape indicative of an intensifying rear inflow jet (RIJ) (Przybylinski and Gery 1993). Between 0130 UTC and 0230 UTC, the RIJ and associated precipitation helped to undercut the low-level updraft which occluded the storm and eliminated the mid-level mesocyclone, similar to the Lahoma case (Conway 1994).

Two major differences arise between this event and the 1994 Lahoma, Oklahoma event during the initial mesocyclonic stage. Only one supercell existed prior to transition in the Lahoma case where two merging supercells existed in the northwest Kansas case. Furthermore, the Lahoma storm did not produce a tornado in its early mesocyclone stage whereas in this case both supercells produced tornadoes. Stronger mid-level winds in the northwest Kansas case most likely attributed to the tornadogenesis that occurred.

V. RADAR SIGNATURES: BOW ECHO STAGE

By 0330 UTC, the LLJ in the boundary to 850 mb layer had developed. The Red Willow, Nebraska profiler showed this feature strengthened to 40 knots. This LLJ helped to feed in high Theta-E (θ_e) air into the broadening thunderstorm complex. The convection then moved into an environment consisting of a lower LFC, higher CAPE, and a more linear wind profile in northeast portions of Goodland's CWA, similar to the later stages of Conway's (1994) observation of the Lahoma, Oklahoma event.

A well-defined weak-echo region can also be seen along with an outflow boundary from the southwest flank of the storm extending west to Goodland. Furthermore, a strong reflectivity gradient existed along the front edge of the thunderstorm complex (Przybylinski and Gery's 1993). In addition, the maximum echo top was over or ahead of the strong front flank low-level gradient (Figure 12). Fujita (1978) described this characteristic of a mature bow echo.

The storms continued to move southeast, reaching Hays, Kansas (HYS) around 0430 UTC. Base velocity estimates at that time (Figure 13) indicated the potential for 80 knot winds mixing to the surface. A strong rear inflow notch (RIN) can be seen in the corresponding reflectivity (Figure 14) as mid-level evaporative cooling intensified the downdraft and produced an outflow surge along the front edge of the thunderstorm. However, these storms were moving nearly perpendicular (70-80°) to the radial of Goodland's WSR-88D electromagnetic beam. Since the WSR-88D estimates velocity best when scatterers move parallel to the radial of the beam, this likely led to an underestimation of mid-level winds. In addition, velocity estimates were probably degraded due a decrease of the beam's power density through volume averaging spatially as one moves away from the RDA. Przybylinski and Gery (1993) suggest that such limitations on the WSR-88D can be supplemented by a good spotter network to verify severity of ongoing weather.

VI. DISCUSSION OF SURFACE REPORTS AND DAMAGE

During the period of transition (0130-0230 UTC), the convective storm structure observed on the Goodland WSR-88D reflectivity loop began to resemble a pattern that implies damaging winds and downbursts, as described by Fujita (1978). At 0153 UTC, the Automated Surface Observation System (ASOS) in McCook, Nebraska took a special observation which recorded west winds sustained at 26 kts gusting to 33 kts. Convective activity at this time was approximately 80 km to the west of the McCook ASOS. Southeast Dundy County experienced wind gusts in excess of 58 kts and hail 4.5 cm in diameter ten minutes prior to the McCook observation (Figure 15). At that time, the merging supercells still had their mesocyclonic characteristics with tornadoes and large hail being the main concern of the operational staff.

The storms began to surge into northwest Kansas by 0200 UTC. A bow echo took shape at that time as the RFD was intensifying. The extent of damaging winds was approximately 85 km wide, extending from Rawlins County, Kansas to Norton County, Kansas. Wind gusts greater than 58 kts were reported by several spotters in this area (Figure 15). Downed power poles, uprooted trees, blown out windows, and siding ripped off the sides of homes were reported near Dresden, Kansas. Johns (1993) states that bow echo induced downbursts account for the majority of casualties and damage from convectively-induced non-tornadic winds.

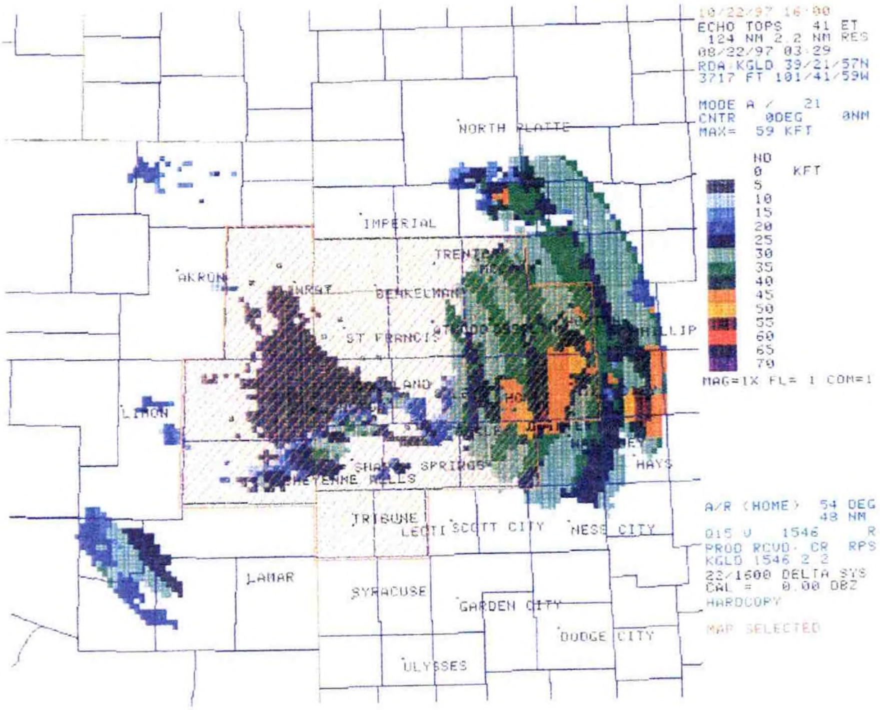


Figure 12. Goodland WSR-88D Echo Tops (ET) and base reflectivity product for 0329 UTC 22 August 1997 showing radar indicated storm tops during bow echo stage.

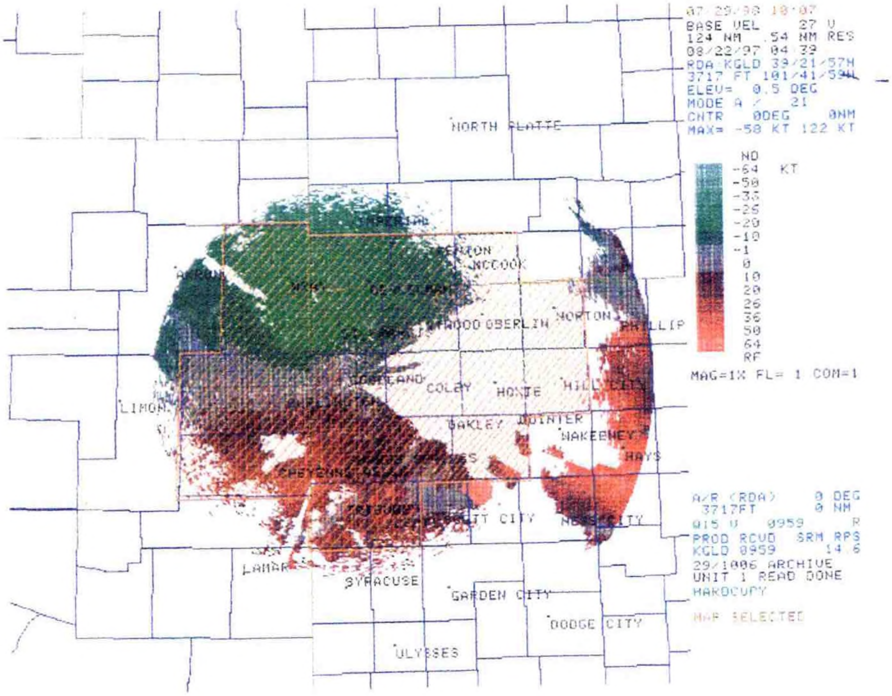


Figure 13. Goodland WSR-88D 0.5° base velocity product for 0439 UTC 22 August 1997, during bow echo stage.

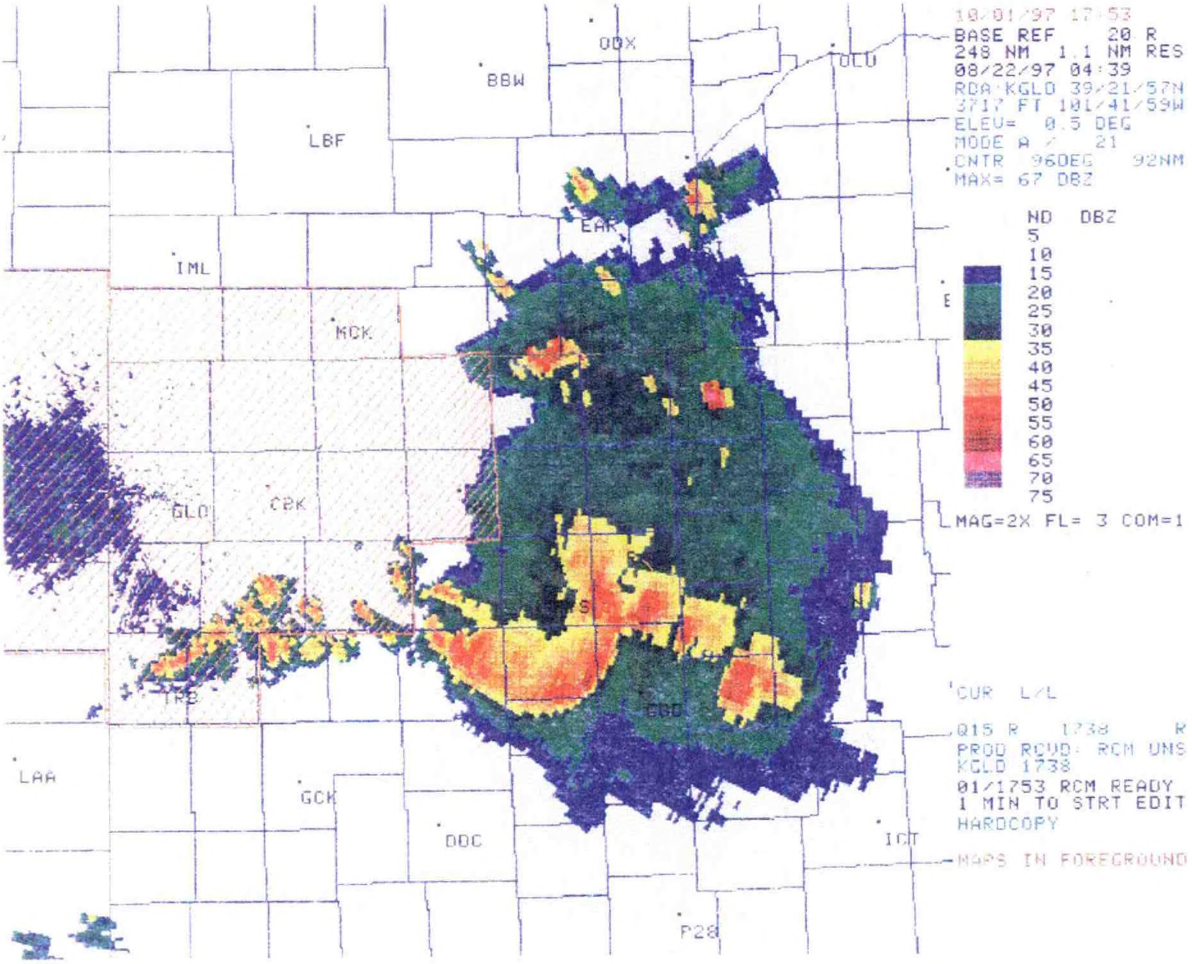


Figure 14. Goodland WSR-88D 0.5° base reflectivity product for 0439 UTC 22 August 1997, during bow echo stage.

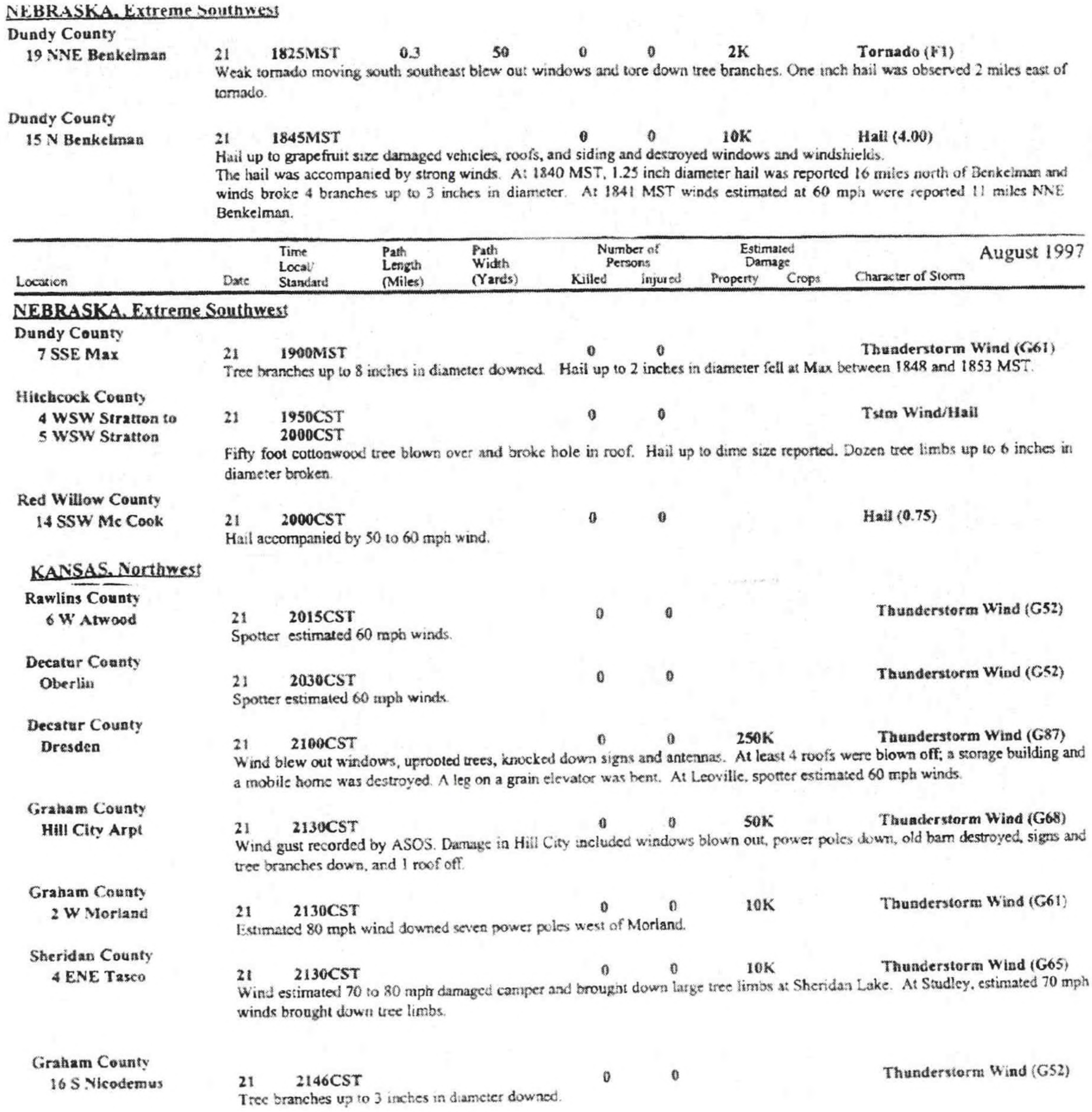
The RIN and associated weak-echo region (WER) continued to show further intensification as the system moved into Graham and Sheridan Counties of northwest Kansas after 0300 UTC. The system reached the Hill City ASOS site (HLC) at 0331 UTC with sustained winds up to 59 kts and gusts to 68 kts.

The intense rain kept visibilities below one statute mile (1.6 km) from 0325 UTC until around 0355 UTC. Sheridan County to the west reported similar conditions resulting in large tree limbs being snapped off, campers being flipped, and electricity being knocked out at Sheridan Lake near Hoxie, Kansas (Figure 15). The storms produced a 50-knot gust in Hays, Kansas at 0436 UTC.

The bow echo continued south-southeast into southwest Oklahoma. At 1400 UTC, the GOES 8 Infrared (12μ) satellite imagery showed remnants of this system between Lawton, Oklahoma, and Wichita Falls, Texas. Storm damage from this system emphasized that warm season, mesoscale induced bow echoes can be as intense as dynamic-type bow echos, that occur more often in fall and spring.

VII. SUMMARY

Changing atmospheric environments and subsequent effects on thunderstorm structure were instrumental in the evolution of the August 21, 1997, supercell merger into a bow echo system. Potential moisture availability, strength of LLJ feeding the convection, and SR mid-level winds, thermodynamic instability (CAPE, LI, etc.), and vertical/horizontal wind shear all played vital roles in how the convection formed and behaved. A thunderstorm's internal dynamics can change the ambient environment in which it resides in (Fujita 1978), which is what occurred with the two supercells as they merged together north of the Kansas/Nebraska state line. Strong SR low level inflow combined with high CAPES induced precipitation loading at the top of the updraft once the LLJ developed after sunset and fed into the system. The consequential precipitation cascade evaporating in the dry mid levels created a strong RFD descending from the mid levels. The resulting RIJ surged out of the storm's leading edge cutting off inflow into the mesocyclone and developing the wedge-shaped signature.



NEBRASKA, Extreme Southwest									
Dundy County **19 NNE Benkelman**	21	1825MST	0.3	50	0	0	2K		**Tornado (F1)**
	Weak tornado moving south southeast blew out windows and tore down tree branches. One inch hail was observed 2 miles east of tornado.								
Dundy County **15 N Benkelman**	21	1845MST			0	0	10K		**Hail (4.00)**
	Hail up to grapefruit size damaged vehicles, roofs, and siding and destroyed windows and windshields. The hail was accompanied by strong winds. At 1840 MST, 1.25 inch diameter hail was reported 16 miles north of Benkelman and winds broke 4 branches up to 3 inches in diameter. At 1841 MST winds estimated at 60 mph were reported 11 miles NNE Benkelman.								

August 1997

Location	Date	Time Local/ Standard	Path Length (Miles)	Path Width (Yards)	Number of Persons Killed	Number of Persons Injured	Estimated Damage Property	Estimated Damage Crops	Character of Storm
NEBRASKA, Extreme Southwest									
Dundy County **7 SSE Max**	21	1900MST			0	0			**Thunderstorm Wind (G61)**
	Tree branches up to 8 inches in diameter downed. Hail up to 2 inches in diameter fell at Max between 1848 and 1853 MST.								
Hitchcock County **4 WSW Stratton to** **5 WSW Stratton**	21	1950CST 2000CST			0	0			**Tstm Wind/Hail**
	Fifty foot cottonwood tree blown over and broke hole in roof. Hail up to dime size reported. Dozen tree limbs up to 6 inches in diameter broken.								
Red Willow County **14 SSW Mc Cook**	21	2000CST			0	0			**Hail (0.75)**
	Hail accompanied by 50 to 60 mph wind.								
KANSAS, Northwest									
Rawlins County **6 W Atwood**	21	2015CST			0	0			**Thunderstorm Wind (G52)**
	Spotter estimated 60 mph winds.								
Decatur County **Oberlin**	21	2030CST			0	0			**Thunderstorm Wind (G52)**
	Spotter estimated 60 mph winds.								
Decatur County **Dresden**	21	2100CST			0	0	250K		**Thunderstorm Wind (G87)**
	Wind blew out windows, uprooted trees, knocked down signs and antennas. At least 4 roofs were blown off; a storage building and a mobile home was destroyed. A leg on a grain elevator was bent. At Leoville, spotter estimated 60 mph winds.								
Graham County **Hill City Arpt**	21	2130CST			0	0	50K		**Thunderstorm Wind (G68)**
	Wind gust recorded by ASOS. Damage in Hill City included windows blown out, power poles down, old barn destroyed, signs and tree branches down, and 1 roof off.								
Graham County **2 W Morland**	21	2130CST			0	0	10K		**Thunderstorm Wind (G61)**
	Estimated 80 mph wind downed seven power poles west of Morland.								
Sheridan County **4 ENE Tasco**	21	2130CST			0	0	10K		**Thunderstorm Wind (G65)**
	Wind estimated 70 to 80 mph damaged camper and brought down large tree limbs at Sheridan Lake. At Studley, estimated 70 mph winds brought down tree limbs.								
Graham County **16 S Nicodemus**	21	2146CST			0	0			**Thunderstorm Wind (G52)**
	Tree branches up to 3 inches in diameter downed.								

Figure 15. Storm Data complied in local standard time (LST) for areas in Goodland's County Warning Area (CWA).

The Goodland WSR-88D provided vital clues to the convective metamorphosis. The Echo Top radar product showed a migration to the front edge of the convection. Reflectivity products in the lowest two elevation scans gave early signs of a "wedge" developing as the storms moved into the nose of a 30 to 40 knot LLJ. The "classic hook" of the merging storms soon disappeared as the low level flow into the mesocyclones was cut off. Once into a higher CAPE and moisture environment, the "wedge" in reflectivity sharpened and showed a weak-echo region (WER) where the strong RFD transferred momentum down to the surface.

The Goodland WSR-88D's ability to estimate velocities along the radial of the beam indicated the stronger winds associated with the RIJ. Due to larger volume averaging of the radar's electromagnetic beam, velocity measurements of storm-outflow were likely underestimated. Furthermore, the eventual perpendicular orientation to the Doppler radar's beam added to estimations misrepresenting actual wind. Even so, WSR-88D velocity products were instrumental in estimating downdraft potential.

The RIJ cutoff of SR low level inflow into the merging storms dissipated the mesocyclone, leading to a more multicellular structure. Consequently, after the RIN developed on the base reflectivity scan, straight-line wind damage began to occur. A mesoscale observation network (mesonet) combined with a well-trained spotter network were invaluable when confirming signatures on radar. This convective event demonstrated that warm season bow echoes can be just as intense as dynamic-type fall and spring systems. Storm damage from this warm season event documents how bow echoes, in general, can produce destructive winds and can pose a serious threat.

VIII. ACKNOWLEDGMENTS

Thanks to Timothy O. Mathewson , National Weather Service Office (NWSO) Goodland, Kansas for his efforts in obtaining environmental data through GEMPAK, to Joy Hayden, Administrative Assistant, NWSO Goodland, Kansas for performing a literature search on bow echoes, and to J. William Conway, National Severe Storms Lab (NSSL) for supplying me with a copy of his 1994 research on the Lahoma, Oklahoma bow echo event.

IX. REFERENCES

Bluestein, H.B., 1984: Fronts and Jet Streaks: A Theoretical Perspective. Mesoscale Meteorology and Forecasting, Peter S. Ray, Ed., American Meteorological Society, Boston, 173-215.

Brooks, H.E., and C.A. Doswell III, 1994: On the Environments of Tornadic and Non tornadic Mesocyclones. *Wea. Forecasting,* **9,** 613-618.

Conway, J.W., H.E. Brooks, and K.D Hondl, 1996: The 17 August 1994 Lahoma, OK Supercell: Issues of Tornadogenesis and Bow Echo Formation. *Preprints, 18th Conf. Severe Local Storms,* San Francisco, AMS (Boston), 52-55.

Fujita, T.T., 1978 Manual of Downbursts Identification for Project Nimrod. SMRP Research Paper-156, Univ. Of Chicago, 42-44.

Johns, R.H., 1993: Meteorological Conditions Associated with Bow Echo Development in Convective Storms. *Wea. Forecasting,* **8,** 294-299.

Kriehn, T.E., 1993: The June 16, 1992 Severe Weather Outbreak...A Case Exhibiting Supercell and Bow Echo/Type II Derecho Development. Central Region Applied Research Papers 10. DOC, NOAA, NWS Central Region, Scientific Services Division, Kansas City, MO, 127-138.

Operational Support Facility (OSF), 1993: Student Guide for WSR-88D Training Course. Topic 5 Lesson 2 Convective Storms: Structure, Evolution, and Radar Depiction. Operations Training Branch, Operational Support Facility, DOC, NOAA, National Weather Service, Norman, OK, 118pp.

Przybylinski, R.W., and Gery, William J., 1993: The Reliability of The Bow Echo as an Important Severe Weather Signature. Central Region Applied Research Papers, 9. DOC, NOAA, NWS Central Region, Scientific Services Division, Kansas City, MO, 270-273.

NWS CR 74 On the Observation and Modeling of the Slope Winds of the Upper Current River Valley of Southeast Missouri and Their Relationship to Air-Mass Thunderstorm Formation. Bartlett C. Hagemeyer, June 1985 (PB85-226926/AS).
NWS CR 75 Complete Guide to Canadian Products in AFOS. Craig Sanders, July 1985 (PB85-228153/AS).
NWS CR 76 The Reliability of the Bow Echo as an Important Severe Weather Signature. Ron W. Przybylinski and William J. Gery, September 1985 (PB86-102340).
NWS CR 77 Observation of Bow Echoes with the Marseilles Radar System. John E. Wright, Jr., September 1985 (PB86-102340).
NWS CR 78 Statistical Analysis of SHEF Coding Errors. Robert S. Cox, Jr., January 1986 (PB86-145141).
NWS CR 79 On the Midwestern Diurnal Convergence Zone on the West Side of the Warm Season Bermuda High. Bartlett C. Hagemeyer, March 1986 (PB86-171378).
NW 0 Some Characteristics of Northeast Kansas Severe Weather 1963-1984. Larry W. Schultz, March 1986 (PB86-173952/AS).
NW 1 The Severe Thunderstorm Outbreak of July 6, 1983 in Southeast Idaho, Western Wyoming and Southwest Montana. Gary L. Cox, April 1986 (PB86-184322/AS).
NWS CR 82 Some Proposals for Modifying the Probability of Precipitation Program of the National Weather Service. Wayne E. Sangster and Michael D. Manker, July 1986 (PB86-226636/AS).
NWS CR 83 Deformation Zones and Heavy Precipitation. Henry Steigerwaldt, August 1986 (PB86-229085/AS).
NWS CR 84 An Overview of the June 7, 1984 Iowa Tornado Outbreak. Charles H. Myers, August 1987.
NWS CR 85 Operational Detection of Hail by Radar Using Heights of VIP-5 Reflectivity Echoes. Richard B. Wagenmaker, September 1987.
NWS CR 86 Fire Weather Verification: The Forecaster Does Make a Difference. Therese Z. Pierce and Scott A. Mentzer, December 1987 (PB88-140744).
NWS CR 87 Operational Use of Water Vapor Imagery. Samuel K. Beckman, December 1987 (PB88-140751).
NWS CR 88 Central Region Applied Research Papers 88-1 Through 88-7. NWS Central Region, Scientific Services Division, May 1988 (PB88-210836).
NWS CR 89 Compendiums of Information for the Missouri Basin River Forecast Center and the North Central River Forecast Center. NWS Central Region, Scientific Services Division, June 1988 (PB88-226204).
NWS CR 90 Synoptic-Scale Regimes Most Conducive to Tornadoes in Eastern Wyoming - A Link Between the Northern Hemispheric Scale Circulation and Convective-Scale Dynamics. William T. Parker and Edward K. Berry, July 1988 (PB88-231337).
NWS CR 91 Heavy Snowfall in Northwest Wyoming. Michael S. Weiland, September 1988 (PB89-109524).
NWS CR 91 Heavy Snowfall in Northwest Wyoming. Michael S. Weiland, September 1988 (PB89-109524).
NWS CR 92 On the Utility of a Geographic Information System in Modelling Climatic Suitability. Bartlett C. Hagemeyer, September 1988 (PB89-109516).
NWS CR 93 The Synoptic and Meso-Alpha Scale Meteorology of Wyoming Flash Floods. Joseph A. Rogash, October 1988 (PB89-117709).
NWS CR 94 The Removal of Stagnant Winter Air Masses From Wyoming's Wind River Basin. Gary L. Cox and Jeffrey M. Graham, November 1988 (PB89-128664).
NWS CR 95 Floods Along Des Plaines and Fox Rivers: September-October 1986. Thomas L. Dietrich, February 1989 (PB89-152797/AS).
NWS CR 96 A Case Study Evaluation of Satellite-Derived Rainfall Estimates and Their Application to Numerical Model Precipitation Forecast Verification. Glenn A. Field, May 1989 (PB89-194591).
NWS CR 97 Central Region Applied Research Papers 97-1 through 97-6. NWS Central Region, Scientific Services Division, July 1989 (PB89-213375/AS).
NWS CR 98 The Record Rainfall of August 13-14, 1987 at Chicago, Illinois. Paul Merzlock, November 1989.
NWS CR 99 Central Region Applied Research Papers 99-1 through 99-7. NWS Central Region, Scientific Services Division, November 1989 (PB90-151325).
NWS CR 100 A Guide to Forecasters in Judging Weather Impact on Growth Environments and Farm Operations in the Midwest. John W. Kottke, December 1989 (PB90-141011).
NWS CR 101 Numerical Solutions to the Shallow Water Equations as Applied to a Local Meteorological Forecast Problem. Eric R. Thaler, March 1990 (PB90-191230).
NWS CR 102 Postprint Volume National Weather Service Aviation Workshop Kansas City, Missouri, December 10-13, 1991. NWS Central Region, Scientific Services Division, March 1992 (PB92-176148).
NWS CR 103 An Investigation of Two Microburst Producing Storms Using A Microburst Recognition Algorithm. David Eversole, January 1994 (PB94-156577).
NWS CR 104 Lincoln ASOS Temperature Test January 13-15, 1993, Gregory Grosshans and Phil Clark, March 1994 (PB94-159993).
NWS CR 105 Forecasting Snowfall Using Mixing Ratios on an Isentropic Surface "An Empirical Study", Crispin Garcia, Jr, May 1994(PB94-188760).
NWS CR 106 The Use of Profiler Data for Analysis and Nowcasting of a Winter Season Extratropical Cyclone, Bradley S. Small, June 1994 (PB94-187804).
NWS CR 107 Flood Forecasting for the Lower Missouri River Basin: June - September, 1993, John F. Pescatore, September 1994 (PB95-123568).
NWS CR 108 Heterogeneous Nucleation and its Relationship to Precipitation Type, Gregory Smith, April 1995 (PB95-217170).
NWS CR 109 Synoptic, Mesoscale and Radar Aspects of the Northeast Kansas Supercell of September 21, 1993, Kenneth Labas and Brian Walawender, October 1995 (PB96-125075).
10 The Effect of Quantitative Precipitation Forecasts on River Forecasts, Noreen O. Schwein, January 1996 (PB96-154893)
11 Global Model Errors Associated with Rapid Low to High Zonal Wave Number Transitions, Edward K. Berry, March 1996 (PB96-166509).
NW -112 Postprint: Fourth NWS Winter Weather Workshop, September 19-22, 1995, NWS CR, Scientific Services Division, Kansas City, MO, July 1996 (PB96-210190).
NWS CR-113 Frequency Mapping of Maximum Water Equivalent of March Snow Cover over Minnesota and the Eastern Dakotas, Steven D. Buan, July 1997 (PB97-194005).
NWS CR-114 Hailstorms at Cheyenne, Wyoming 1892-1996. Jack Daseler, October 1998 (PB99-104598).

NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

The National Oceanic and Atmospheric Administration was established as part of the Department of Commerce on October 3, 1970. The mission responsibilities of NOAA are to assess the socioeconomic impact of natural and technological changes in the environment and to monitor and predict the state of tha solid Earth, the oceans and their living resources, the atmosphere, and the space environment of the Earth.

The major components of NOAA regularly produce various types of scientific and technical information in the following kinds of publications.

PROFESSIONAL PAPERS--Important definitive research results, major techniques, and special investigations.

CONTRACT AND GRANT REPORTS--Reports prepared by contractors or grantees under NOAA sponsorship.

ATLAS--Presentation of analyzed data generally in the form of maps showing distribution of rainfall, chemical and physical conditions of oceans and atmosphere, distribution of fishes and marine mammals, ionospheric conditions, etc.

TECHNICAL SERVICE PUBLICATION--Reports containing data, observations, instructions, etc. A partial listing includes data serials; prediction and outlook periodicals; technical manuals, training papers, planning reports, and information serials; and miscellaneous technical publications.

TECHINCAL REPORTS--Journal quality with extensive details, mathematical developments, or data listings.

TECHNICAL MEMORANDUMS--Reports of preliminary, partial, or negative research or technology results, interim instructions, and the like.

N.O.A.A. CENTRAL LIBRARY
3 8398 1006 8184 4

Information on availability of NOAA publication can be obtained from:

**NATIONAL TECHNICAL INFORMATIN SERVICE
U.S. DEPARTMENT OF COMMERCE
5285 PORT ROYAL ROAD
SPRINGFIELD, VA 22161**