A CASE STUDY OF A DERECHO (WINDSTORM) IN THE CENTRAL PLAINS

by

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TABLE OF CONTENTS

ACKNOWLEDGMENTS.ii

ABSTRACT.v

LIST OF FIGURES.vii

CHAPTER

I. INTRODUCTION.1

Literature Review.3

Source Material.5

II. PRE-STORM ANALYSIS.8

Synoptic Scale Analysis (Standard Levels).8

Stability Analysis.14

Sub-Synoptic Scale Analysis.19

III. DERECHO STAGE.49

Synoptic Scale Analysis (Standard levels).49

Stability Analysis.S7

Sub-Synoptic Scale Analysis.63

IV. DISSIPATING STAGE.	.90
Sub-Synoptic Scale Analysis.	.90
Synoptic Scale Analysis.	.103
Stability Analysis.	.111
V. CONCLUSIONS.	.119
Recommendations.	.121
LIST OF REFERENCES.	.123
APPENDIXES	
A. STATION IDENTIFIERS WITH COMPLETE LOCATIONS.	.125
B. LID STRENGTH INDEX.	.128

ABSTRACT

During the afternoon of 29 July 1986 three separate supercell thunderstorms developed over central and eastern South Dakota. In their mature stages each storm produced numerous tornadoes; furthermore, one tornado reached F4 status and eventually devastated a power plant near Sioux City, Iowa. Other reports included large hail and an unusually high number of reports of strong winds exceeding 50 knots. During the period, the three supercells eventually merged into one convective complex, and shortly thereafter reached mesoscale convective complex (MCC) status over northwest Iowa. An extremely large area of the Central Plains was affected by this system including South Dakota, Minnesota, Nebraska, Iowa, Illinois, and Missouri. This system had similar characteristics to previous MCC events. However, it was different in some respects since many MCC systems have been known to become heavy-rain producers while this system continued to produce severe weather many hours after it had reached MCC status (especially involving straight-line winds which exceeded 90 knots in some places). To analyze this event (termed a derecho), the system has been considered from the perspectives of the synoptic and sub-synoptic

scales. The information used includes upper-air data, surface observations, satellite pictures, and radar data. Since this system basically occurred between rawinsonde sites the thermodynamic structure of the system itself would be difficult to ascertain without a true mesoscale network; however, since the magnitude of this system was not forecasted by the NWS or NSSFC, a detailed synoptic and sub-synoptic scale analysis of the pre-storm, storm, and post-storm conditions was performed to determine how similar this event was to other systems studied by other researchers. On the sub-synoptic scale, surface observations and radar data were used to determine how the system propagated throughout its history.

Although this convective system caused no deaths and only a few injuries, extensive crop and property damage followed in its wake. Climatology shows that during the summer months the most favorable regions for derecho storms are over the Central Plains.

LIST OF FIGURES

1. Plot of local storm reports as compiled in <u>Storm Data</u>	4
2. Time series of gust front positions that were producing damaging winds at 30-minute intervals from 2300Z 28 July 1986 to 0730Z 28 July 1986.	5
3. 850mb Isotherm analysis for 12Z 28 July 1986 using 2°C intervals.	9
4. 850mb Isodrosotherm analysis for 12Z 28 July 1986 using 2°C intervals.	9
5. 700mb Isotherm analysis for 12Z 28 July 1986 using 2°C intervals.	10
6. 700mb contour analysis for 12Z 28 July 1986 using 1 Cm intervals with associated synoptic features.	12
7. 500mb Isotherm analysis for 12Z 28 July 1986 using 1 °C intervals.	12
8. 500mb contour analysis for 12Z 28 July 1986 at 20m intervals with associated synoptic features.	13
9. 300mb Isotherm analysis for 12Z 28 July 1986 using 1°C intervals.	13
10. 200mb Isotach analysis for 12Z 28 July 1986 at 1 Okt. intervals.	15
11. Totals Total Index analysis for 12Z 28 July 1986 at 2 ° intervals.	17

12. Sweat Index analysis for 12Z 28 July 1986 at 50° intervals	17
13. Lifted Index (lowest SOmb) analysis for 12Z 28 July 1986 at 1 ** intervals.	.18
14. Lid Strength Index analysis for 12Z 28 July 1986 at 2' intervals.	.18
15. Surface Isotherm analysis at 3°F intervals along with surface features at 15Z 28 July 1986.	.20
16. Surface Isodrosotherm analysis at 3°F intervals with associated surface features at 15Z 28 July 1986.	.20
17. Surface Lifted Index for 15Z 28 July 1986 where dashed lines represent SLI values ≤ 0 and solid lines show SLI values > 0	.23
18. Surface Isotherm analysis at 3° F intervals along with surface features for 17Z 28 July 1986.	.24
19. Surface Isodrosotherm analysis at 3°F intervals along with surface features for 17Z 28 July 1986.	.24
20. Two-hour altimeter change analysis from 15Z-17Z 28 July 1986 where dashed lines represent regions of pressure falls at .02" of Hg. intervals and solid lines show pressure rises at .02" of Hg. intervals.	.25
21. Surface Lifted Index analysis for 17Z 28 July 1986 where dashed lines show SLI values ≤ 0 and solid lines indicate SLI values > 0	.25

22. Huron radar analysis at 1735Z 28 July 1986 where each contour represents an increase in intensity.	27
23. Visible satellite picture at 1730Z 28 July 1986.	27
24. Huron radar analysis for 1835Z 28 July 1986 where each contour represents an increase in intensity.	28
25. Visible satellite picture at 1830Z 28 July 1986.	28
26. Surface Isotherm analysis at 3" F intervals with associated surface features for 19Z 28 July 1986.	30
27. Surface Isodrosotherm analysis at 3* F intervals with surface features at 19Z 28 July 1986.	30
28. Two-hour altimeter change analysis from 17Z-19Z 28 July 1986 where solid lines show pressure falls at .02" of Hg. intervals and dashed lines indicate pressure rises at .02" of Hg. intervals.	31
29. Surface Lifted Index analysis at 19Z 28 July 1986 at 2° intervals where dashed lines indicate SLI values < 0.	31
30. Huron radar analysis at 1935Z 28 July 1986 where each contour represents an increase in intensity.	32
31. Visible satellite picture at 1930Z 28 July 1986.	32
32. Surface Isotherm analysis at B' F intervals with associated surface features at 20Z 28 July 1986.	34
33. Surface Isodrosotherm analysis at 3* F intervals with surface features at 20Z 28 July 1986.	34

34.	Two-hour altimeter change analysis from 18Z-20Z 28 July 1986 where dashed lines show pressure falls at .02" of Hg. intervals and solid lines indicate pressure rises at .02" of Hg. intervals.	35
35.	Surface Lifted Index analysis for 20Z 28 July 1986 where dashed lines show SLI values ≤ 0	35
36.	Huron radar analysis at 1935Z 28 July 1986 where each contour represents an increase in cell intensity.	37
37.	Visible satellite picture at 1930Z 28 July 1986.	37
38.	Surface Isotherm analysis at 3°F intervals with associated surface features at 21Z 28 July 1986.	38
39.	Surface Isodrosotherm analysis at 3°F intervals with surface features at 21Z 28 July 1986.	38
40.	Lid Strength Index analysis at 00Z 29 July 1986 using 2° intervals.	40
41.	Two-hour altimeter change analysis from 19Z-21Z 28 July 1986 where dashed lines show pressure falls at .02" of Hg. intervals and solid lines indicate pressure rises at .02" of Hg. intervals.	42
42.	Surface Lifted Index analysis for 21Z 28 July 1986 where dashed lines indicate SLI values 1 0	42
43.	Huron radar analysis at 2035Z 28 July 1986 where each contour represents an increase in cell intensity.	43

44. Visible satellite picture at 2030Z 28 July 1986.	43
45. Surface Isotherm analysis at 3* F intervals with associated surface features at 22Z 28 July 1986.	45
46. Surface Isodrosotherm analysis at 3**F intervals with surface features at 22Z 28 July 1986.	45
47. Two-hour altimeter change analysis from 20Z-22Z 28 July where dashed lines show pressure falls at .02" of Hg. and solid lines indicate pressure rises at .02" of Hg. intervals ..	46
48. Surface Lifted Index analysis for 22Z 28 July 1986 where dashed lines indicate SLI values_< 0.	46
49. Huron radar analysis at 2135Z 28 July 1986 where each contour represents an increase in cell intensity.	48
50. Visible satellite picture at 2130Z 28 July 1986.	48
51. 850mb contour analysis at 00Z 29 July 1986 using 1 Om intervals.	50
52. 850mb Isotherm analysis for 00Z 29 July 1986 using 2^oC intervals.	50
53. 850mb Isodrosotherm analysis for 00Z 29 July 1986 using 2'C intervals.	52
54. 700mb contour analysis at 00Z 29 July 1986 using 1 Om intervals.	52

55.	700mb Isotherm analysis for OOZ 29 July 1986 using 2 °C intervals.	53
56.	500mb contour analysis for OOZ 29 July 1986 using 20m intervals.	53
57.	500mb Isotherm analysis at OOZ 29 July 1986 using 1 °C intervals.	55
58.	500mb Isotach analysis for OOZ 29 July 1986 using 10 knot intervals.	55
59.	300mb Isotach analysis at OOZ 29 July 1986 using 10 knot intervals.	56
60.	200mb Isotach analysis at OOZ 29 July 1986 using 10 knot intervals.	56
61.	Totals Total Index analysis for OOZ 29 July 1986 using 2° intervals.	58
62.	12-hour Totals Total Index change analysis from 12Z-00Z 29 July 1986 at 3° intervals where dashed lines indicate values ≤ 0 and solid lines show values > 0.	58
63.	Lifted Index (lowest 500mb) analysis for OOZ 29 July 1986 at 2° intervals.	59
64.	12-hour Lifted Index change analysis for OOZ 29 July 1986 at 2° intervals where dashed lines indicate values 10 and solid lines show values > 0.	59

65.	Sweat Index analysis for OOZ 29 July 1986 at 5(f intervals	61
66.	12-hour Sweat change analysis for OOZ 29 July 1986 using 100*intervals where dashed lines indicate values ≤ 0 and solid lines show values >0	61
67.	Buoyancy analysis at OOZ 29 July 1986 using 2^* intervals.	62
68.	Surface Isotherm analysis at 3^*F intervals with associated surface features at 23Z 28 July 1986.	64
69.	Surface Isodrosotherm analysis at 3^*F intervals with surface features for 23Z 28 July 1986.	64
70.	Two-hour altimeter change analysis from 21Z-23Z 28 July 1986 where dashed lines show pressure falls at .02" of Hg. intervals and solid lines indicate pressure rises at .02" of Hg. intervals.	66
71.	Surface Lifted Index analysis for 23Z 28 July 1986 where dashed lines indicate SLI values < 0	66
72.	Huron radar analysis at 2335Z 28 July 1986 where each contour represents an increase in cell intensity.	67
73.	Visible satellite picture at 2330Z 28 July 1986.	67
74.	Surface Isotherm analysis at 3' F intervals with associated surface features at OOZ 29 July 1986.	69
75.	Surface Isodrosotherm analysis at 3'F intervals with surface features at OOZ 29 July 1986.	69

76.	Two-hour altimeter change analysis from 22Z-00Z 28 July 1986 where dashed lines show pressure falls at .02" of Hg. Intervals and solid lines indicate pressure rises at .02" of Hg. intervals.	.70
77.	Huron radar analysis at 0035Z 29 July 1986 where each contour represents an Increase in cell intensity.	.70
78.	Infrared satellite picture at 0030Z 29 July 1986.	.72
79.	Surface Isotherm analysis at 3°F intervals with associated surface features at 01Z 29 July 1986.	.72
80.	Surface Isodrosotherm analysis at 3°F intervals with surface features at 01Z 29 July 1986.	.73
81.	Two-hour altimeter change analysis from 23Z-01Z 29 July 1986 where dashed lines show pressure falls at .02" of Hg. intervals and solid lines indicate pressure rises at .02" of Hg. intervals.	.73
82.	Surface Lifted Index analysis for 01Z 29 July 1986 where dashed lines indicate SLI values IO and solid lines show SLI values > 0.	.74
83.	Infrared satellite picture for 0130Z 29 July 1986.	.76
84.	Surface Isotherm analysis at 3°F intervals with surface features at 03Z 29 July 1986.	.77
85.	Surface Isodrosotherm analysis at 3°F intervals with associated surface features at 03Z 29 July 1986.	.79

86.	Surface Lifted Index analysis for 03Z 29 July 1986 where dashed lines indicate SLI values ≤ 0 and solid lines show SLI values > 0 .	.79
87.	Two-hour altimeter change analysis from 01Z-03Z 29 July 1986 where dashed lines show pressure falls at .02" of Hg. intervals and solid lines indicate pressure rises at .02" of Hg. intervals.	.81
88.	Des Moines radar analysis at 0235Z 29 July 1986 where each contour represents an increase in cell intensity.	.81
89.	Infrared satellite picture at 0230Z 29 July 1986.	.82
90.	Infrared satellite picture at 0330Z 29 July 1986.	.82
91.	Surface Isotherm analysis at 3°F intervals with surface features for 05Z 29 July 1986.	.84
92.	Surface Isodrosotherm analysis at 3°F intervals with associated surface features for 05Z 29 July 1986.	.85
93.	Surface Lifted Index analysis at 05Z 29 July 1986 where dashed lines indicate SLI values ≤ 0 and solid lines show SLI values > 0 .	.85
94.	Two-hour altimeter change analysis from 03Z-05Z 29 July 1986 where dashed lines show pressure falls at .02" of Hg. intervals and solid lines indicate pressure rises at .02" of Hg. intervals.	.86

95.	Des Moines radar analysis at 0435Z 29 July 1986 where each contour represents an increase in cell intensity.	.86
96.	Infrared satellite picture at 0430Z 29 July 1986.	.87
97.	Des Moines radar analysis at 0535Z 29 July 1986 where each contour indicates an increase in cell intensity.	.89
98.	Infrared satellite picture at 0500Z 29 July 1986.	.89
99.	Surface Isotherm analysis at 3 ⁰ F intervals with surface features at 06Z 29 July 1986.	.91
100.	Surface Isodrosotherm analysis at 3°F intervals with associated surface features at 06Z 29 July 1986.	.91
101.	Surface Lifted Index analysis for 06Z 29 July 1986 where dashed lines indicate SLI values i 0 and solid lines show SLI values > 0.	.92
102.	One-hour altimeter change analysis from 05Z-06Z 29 July 1986 where dashed lines indicate pressure falls at .02" of Hg. intervals and solid lines show pressure rises at .02" of Hg. intervals.	.92
103.	St. Louis radar analysis for 0635Z 29 July 1986 where each contour indicates an increase in cell intensity.	.94
104.	Infrared satellite picture at 0630Z 29 July 1986.	.94
105.	Surface Isotherm analysis at 3* F intervals with surface features at 07Z 29 July 1986.	.95

106.	Surface Isodrosotherm analysis at 3° F intervals with associated surface features for 07Z 29 July 1986.	.95
107.	Surface Lifted Index analysis for 07Z 29 July 1986 with dashed lines indicate SLI values ≤ 0 and solid lines show SLI values > 0	.96
108.	Two-hour altimeter change analysis from 05Z-07Z 29 July 1986 where dashed lines show pressure falls at .02" of Hg. intervals and solid lines indicate pressure rises at .02" of Hg. intervals.	.96
109.	St. Louis radar analysis for 0735Z 29 July 1986 where each contour indicates an increase in cell intensity.	.97
110.	Infrared satellite picture at 0730Z 29 July 1986.	.99
111.	Surface Isotherm analysis at 3°F intervals with surface features at 08Z 29 July 1986.	.99
112.	Surface Isodrosotherm analysis at 3°F intervals with associated surface features at 08Z 29 July 1986.	.100
113.	Surface Lifted Index analysis for 08Z 29 July 1986 where dashed lines indicate SLI values ≤ 0 and solid lines show SLI values > 0	.100
114.	Two-hour altimeter change analysis from 06Z-08Z 29 July 1986 where dashed lines show pressure falls at .02" of Hg. intervals and solid lines indicate pressure rises at .02" of Hg. intervals.	.101

115.	St. Louis radar analysis at 0835Z 29 July 1986 where each contour represents an increase in Intensity cell.	.101
116.	Infrared satellite picture at 0830Z 29 July 1986.	.102
117.	Surface Isotherm analysis at 3° F intervals with surface features at 09Z 29 July 1986.	.102
118.	Surface Isodrosotherm analysis at 3° F intervals with associated surface features for 09Z 29 July 1986.	.104
119.	Surface Lifted Index analysis for 09Z 29 July 1986 where dashed lines indicate SLI values ≤ 0 and solid lines show SLI values > 0	.105
120.	Two-hour altimeter change analysis from 07Z-09Z 29 July 1986 where dashed lines show pressure falls at .02" of Hg. intervals and solid lines indicate pressure rises at .02" of Hg. Intervals.	.105
121.	Surface Isotherm analysis at 3°F intervals with surface features for 10Z 29 July 1986.	.106
122.	Two-hour altimeter change analysis from 08Z-10Z 29 July 1986 where dashed lines show pressure falls at .02" of Hg. intervals and solid lines indicate pressure rises at .02" of Hg. intervals.	.106
123.	850mb Isotherm analysis for 12Z 29 July 1986 using 2°C intervals.	.108
124.	850mb Isodrosotherm analysis for 12Z 29 July 1986 using 2°C intervals.	.109

125.	700mb contour analysis at 12Z 29 July 1986 using 10m intervals.	109
126.	700mb Isotherm analysis for 12Z 29 July 1986 using 2°C Intervals.	110
127.	500mb Isotherm analysis for 12Z 29 July 1986 using 1 ° C intervals.	110
128.	500mb contour analysis for 12Z 29 July 1986 using 20m Intervals.	112
129.	300mb Isotach analysis at 12Z 29 July 1986 using 10 knot Intervals.	112
130.	200mb Isotach analysis at 12Z 29 July 1986 using 10 knot intervals.	113
131.	Totals Total Index analysis for 12Z29July 1986 using 2" intervals.	113
132.	12-hour Totals-Total Index change analysis from 00Z-12Z 29 July 1986 at 3°intervals where dashed lines show values ≤ 0 and solid lines indicate values > 0	115
133.	12-hour Sweat change analysis from 00Z-12Z 29 July 1986 using 100°intervals where dashed lines indicate values ≤ 0 and solid lines show values > 0	115
134.	12-hour Lifted Index change analysis from 00Z-12Z 29 July 1986 at 2° intervals where dashed lines indicate values ≤ 0 and solid lines show values >0	116

135. Lid Strength analysis at 2* intervals for 12Z 29 July 1986. . . .118

CHAPTER I

INTRODUCTION

During the afternoon of 28 July 1986, three separate supercell thunderstorms developed over central and eastern South Dakota. Eventually these three storms merged into one convective system and reached mesoscale convective complex (MCC) status over northwest Iowa. Before reaching MCC status the system produced numerous tornadoes and large hail but few reports of damaging winds (>50 kt). However after attaining MCC status the system began producing numerous reports of strong winds exceeding (50 kt). This band of strong winds was oriented in a curved line and propagated from northwest Iowa and southwest Minnesota to northeast Missouri. This system was different since many MCC-type systems have been known to become heavy rain producers which result in flash flood events as noted by Maddox and others; however, this system continued to produce damaging winds (>50 kt) many hours after reaching MCC status.

Previous work by Johns and Hirt (1987) has led to the definition of a new type of convective system called a "derecho." The derecho is defined as a convectively-induced, low-level wind pattern that emanates from either a mesoscale convective system (MCS) or from a squall line system.

In order for a system to be classified as a derecho the following parameters must be met according to Johns and Hirt (1987):

- 1. There must be a concentrated area of reports consisting of convectively-induced wind damage and or convective gusts > 50 kt.**
- 2. This area must have a major axis length of at least 250 nm.**
The reports within this area must also exhibit a non-random pattern of occurrence. That is, the reports must show a pattern of chronological progression, either as a singular swath or as a series of swaths.
- 3. Within the area there must be at least three reports, separated by 40 nm or more, of either F1 damage (Fujita, 1971) and/or convective gusts of 65 kt or greater.**
- 4. No more than 3 hours can elapse between successive wind damage (gust) events.**
- 5. The associated convectively-induced system, as indicated by surface pressure and wind fields, must have temporal and spatial continuity. However, movement of radar echoes associated with the system need not be continuous.**
- 6. Multiple swaths of wind damage (including gusts) must be a part of the same mesoscale convective system as indicated by the National Weather Service radar summary charts.**

Note: These criteria are based on Fujita and Wakimoto's definition of a family of downburst clusters.

The genesis region for this system was centered in the central High Plains over central and eastern South Dakota. Eventually the system weakened over extreme eastern Missouri and western Illinois by 08Z 29 July. During the history of the system which affected South Dakota, Nebraska, Minnesota, Iowa, Illinois and Missouri, numerous reports of severe weather were reported which included 14 tornadoes, 22 reports of large hail > r in diameter, and 78 reports of damaging winds exceeding 50 kt. A complete plot of severe weather reports as reported by Storm Data is shown in Figure 1. As mentioned earlier, the majority of severe weather reports involved damaging winds; a time series of the gust front-producing these winds is shown in Figure 2. Note that the first reports came at 23Z on 28 July and the last reports occurred at 0730Z on 29 July. Also Figure 2 shows the peak wind speeds >85 kt occurred between 05Z and 06Z. For this system the major axis length was 400 nm and the other five parameters were met.

In this paper a thorough synoptic and sub-synoptic scale analysis using upper-air data, surface observations, satellite pictures, and radar data will be analyzed to get a better understanding of what conditions are present or develop when a system of this magnitude occurs.

Literature Discussion

Previous work by Johns and Hirt (1985, 1987) has led to a new classification of a convective weather system called a derecho. The word derecho is a Spanish word which means "straight ahead" or "direct."

Figure 1. Plot of local storm reports as compiled in Storm Data.

Figure 2. Time series of gust front positions that were producing damaging winds at 30-minute intervals from 2300Z 28 July to 0730Z 29 July 1986.

The word derecho was first introduced in meteorology during the late 19th century and was used to describe straight line windstorms in Iowa by Hinrichs (1888). The general region of derecho development extends from the Northern Plains through the Upper Midwest to the Ohio Valley. For the period from 1980 to 1983, Johns and Hirt (1987) identified a total of 70 derecho cases. Most derecho-type events take place during the months of May, June, July and August with the peak months being June and July. The derecho convective system usually emanates from one of two different types of thunderstorm systems with the first being associated with a squall line system occurring in the late winter and spring time period. However the most numerous derecho systems occur in the late spring and summer months associated with mesoscale convective systems (Maddox 1980). Along with having two alternate generating systems, previous work by Przybylinski and DeCaire (1985) has led to an identification of several types of radar signatures with derecho-type systems. The two main radar signatures include the progressive and serial patterns with the former pattern being the most dominant. The progressive pattern is characterized by a line of strong reflectivity values that form into a curved line (squall line) with a bulge in the line parallel to the mean wind. The second type of radar signature is a serial pattern which involves an extensive squall line that has numerous line echo wave pattern (LEWP) and bow echoes that move along the line. However the major difference between the two patterns

is that the serial pattern moves more slowly (30 kt or less) than the progressive pattern which moves at an average speed of 45 kt. The general time of occurrence for derecho systems is from 1600 CDT to 0400 CDT with the average duration being around 9 hours. However the life time of the system that produces the derecho is much longer. The basic effect of the derecho system is to produce damaging straight-line winds in the form of downburst clusters as described by Fujita and Wakimoto (1981). Although most derecho systems do produce tornadoes, the number of tornadoes per event decreases after June.

Source Material

Data for this case study included upper-air, surface, radar and satellite data. The upper-air and surface data were obtained from the weather research division at the Denver Federal Center in Denver, Colorado. The radar data was collected from the National Climatic Data Center in Asheville, North Carolina. This data was in coded form and had to be hand plotted to obtain a better resolution than that provided by the national radar summaries. Finally, the satellite pictures were obtained from both the NWS in Lubbock, Texas, and was also supplemented by the Department of Meteorology at Texas A&M University

CHAPTER 11

PRE-STORM ANALYSIS

Synoptic Scale Analysis (Standard Levels)

On the synoptic scale using 12Z upper-air observations for 850 mb, 700 mb, 500 mb, 300 mb and 200 mb on 28 July 1986, certain parameters were beginning to become apparent. The 12Z 850 mb isotherm analysis (Fig. 3) shows that there is an influx of very warm temperatures $>26^{\circ}\text{C}$ nosing up through Kansas into southern Nebraska. More importantly there is a thermal boundary from central South Dakota extending through Iowa into eastern Missouri. Across this thermal boundary there is a 4°C to 6°C temperature contrast. The dewpoint analysis at 850 mb (Fig. 4) shows dewpoint values around 10°C over the central High Plains; however, there is some indication of drier air working in from western Kansas. Previous work by Johns and Hirt (1987) found that the average 850 mb dewpoint for derecho-type systems was 15.6°C which is much higher than what this case shows. The winds at 850 mb reveal that the wind directions are basically out of the west (270°) with no organized convergence over South Dakota. Thus at 850 mb at 12Z there is no real strong indication of a major thunderstorm outbreak. At 700 mb, the isotherm analysis (Fig. 5) shows a pocket of very warm air $> 15^{\circ}\text{C}$ over southwest Kansas advecting northward toward Nebraska. Secondly there is evidence of the 850 mb thermal boundary existing at 700 mb also. It is notable

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 1923 ರಲ್ಲಿ 850 ಮೈ. ಮಂಜುಳು.

ಕರ್ನಾಟಕ. 850 ಮಿ. ಮೈ. ಮಂಜುಳು. 1922
 1922 ರಲ್ಲಿ 850 ಮೈ. ಮಂಜುಳು.

Figure 1: Map of Karnataka showing the distribution of 18 districts for the study.

that the 700 mb temperatures over Nebraska, South Dakota, Iowa and eastern Missouri are 8'C to 9'C while temperatures to the south and west of this region are > 11 'C. The Importance of this 700 mb thermal axis relates to the Identification of a capping Inversion In the elevated mixed layer from 850 mb to 700 mb. Research by Carlson (1968) and others had led to an identification of the Mexican plume which is a stable layer of air existing between 850 mb and 700 mb. Previous work by Carlson has shown this plume to provide a sufficient cap In prohibiting the development of thunderstorms. From the 700 mb temperature analysis notice the temperature difference between DDC and OMA with Omaha's temperature 7'C cooler than that at Dodge City (Station identifiers are in Appendix A). The 700 mb contour analysis (Fig. 6) shows that there is a strong high pressure system centered over Oklahoma with a ridge axis extending up through the Dakotas and a weak trough extending over the Ohio Valley. At 500 mb the isotherm analysis (Fig. 7) shows that at 12Z a thermal trough extends from western South Dakota to southwest Kansas with a temperature 4'C colder at North Platte (LBF) than at OMA. Also the 500 mb contour analysis (Fig. 8) shows that a weak shortwave trough Is entering the western Dakotas. Furthermore there Is a strong high pressure system centered over Oklahoma with a ridge axis extending up thru the central Dakotas. At 300 mb the isotherm analysis (Fig. 9) shows a strong thermal gradient across Nebraska and Iowa indicating the region of maximum winds with speeds approaching 80 kt. However there does not seem to be any noticeable diffluence over

Figure 7. 500mb isotherm analysis for July 1986 using 1° intervals.

Figure 8. 500mb isotherm analysis for July 1986 using 1° intervals with associated 1000mb pressure contours.

Figure 8. Isotherms and isohyets for July 1986. Isotherms are in degrees Fahrenheit and isohyets are in inches.

Figure 9. Isotherms and isohyets for July 1986. Isotherms are in degrees Fahrenheit and isohyets are in inches.

South Dakota at 12Z, although it does appear that South Dakota was in the left front quadrant of the maximum wind core, which is a favored region for increased vertical motion. At 200 mb the isotach analysis (Fig. 10) shows a jet maximum over Nebraska of 80 kt; also there appears to be an area of divergence developing over southern South Dakota and northern Nebraska.

Thus considering the overall picture on 12Z 28 July 1986, the atmosphere was not overly conducive to a major thunderstorm outbreak that day. The only positive factors at 12Z were the abundance of 850 mb moisture, the presence of a 500 mb thermal trough over the western High Plains, and a core of maximum winds over Nebraska. This type of synoptic-scale pattern with weak shortwave troughs at 700 mb and 500 mb often characterize summertime convective events; thus in order to have explosive convection there must be very unstable conditions in the lower layers from 850 mb to the surface. This primarily involves low-level thermal advection which was examined by Maddox (1982).

Stability Analysis

An analysis now will be done to determine the amount of instability in the atmosphere at 12Z that day. Indices include the totals-total index (TTI), lifted index (LI), Sweat index, lid strength index (LSI), and the surface lifted index (SLI). Examination of the

Figure 198. Map of India showing rainfall patterns for July 1980.

TTI (Fig. 11) shows that the greatest Instability with values > 56 stretched from western Kansas into western South Dakota. Correspondingly the Sweat Index (Fig. 12) also has the maximum Instability in the same general area. However, the LI (Fig. 13) shows that the instability extends further to the east and northeast than shown by the TTI and Sweat Indices. Another parameter that has been developed is the lid strength Index (LSI), which was proposed by Carlson (1983). As noted before, the LSI was developed to analyze how strong the capping Inversion is between 850 mb and 700 mb. From the above stability results, there was quite a large area of the central and northern High Plains that was convectively unstable; however, the LSI analysis (Fig. 14) shows that the area where thunderstorms may have developed in was considerably limited by the LSI. As denoted in Appendix B, the LSI index consists of two parameters, the lid strength term and the buoyancy term. Basically the lid strength term measures how strong the inversion is for an elevated mixed layer, while the buoyancy term gives an indication of how unstable the air is under the elevated mixed layer. For the LSI the more positive the value the stronger the capping inversion. Previous work by Graziano (1984) and Goldman (1981) indicate LSI values $> +4$ represent a sufficient cap on convection. Figure 14 gives the LSI values at 12Z, indicating that the back edge of the stronger cap was centered roughly from eastern Nebraska through central South Dakota with a weaker cap to the northeast of this line and a stronger cap to the west

Fig 11. 1980 average monthly precipitation (inches) for July

Fig 12. 1980 average monthly precipitation (inches) for August

Fig. 13. Life of low (50mb) analyzed for 1986 July 1986 set of 1986

Fig. 14. Life of low (50mb) analyzed for 1986 July 1986 set of 1986

and south of this line. Previous work by Carlson (1983) led him to believe that the first development of convection would be on the western edge of the cap where the low-level moisture may be underrunning the lid. Thus if the back edge of the lid was propagating to the east slowly then it appears that the first supercell thunderstorm that formed in central South Dakota during the mid-afternoon formed on the back edge of the cap.

Sub-Synoptic Scale Analysis

At 15Z 28 July 1986 the surface features (Fig. 15) included a low pressure system in south central South Dakota with a warm front extending from the low into northwest Iowa. Furthermore a dry line extended southwest from the surface low through western Nebraska. Also a surface cold front associated with thunderstorms over southern North Dakota and extreme northern South Dakota was moving southward across northern South Dakota. The surface temperature analysis (Fig. 15) shows that south of the warm front temperatures were in the low to mid-80s, while north of the front temperatures were in the mid- to upper 70s. Meanwhile temperatures behind the cold front were in the upper 60s to lower 70s. The dewpoint analysis (Fig. 16) reveals that there was a region of "pooling" dewpoints in the vicinity of the warm front especially in eastern Nebraska and western Iowa extending into southeast South Dakota. This area generally had dewpoints in the low to mid-70s; there is no real evidence that these higher dewpoints were

Figure 1E: Surface isotherms and surface features along the 180° meridian, July 1986.

Figure 1E: Surface isotherms and surface features along the 180° meridian, July 1986.

being transported in from the Gulf of Mexico since the winds at 850 mb were primarily from the west to the south of this area. Furthermore this pooling of dewpoints near outflow boundaries and fronts has been found to occur with other derecho systems researched by Johns (1985).

Incorporated into the sub-synoptic scale analysis is a 2-hour altimeter change analysis. This two-hour altimeter change analysis has been suggested by Doswell (1982) to pick out pressure fall-rise couplets that have been noted to occur with intense convection. At 15Z there had been no significant changes in the previous two hours over the pre-storm area.

Another surfaced-based parameter incorporated into this analysis is the surface lifted index which can be used to locate areas of maximum instability at the surface. The SLI was described by Sanders (1986) and takes into account surface temperatures and dewpoints along with the environmental temperature at 500 mb. Using this information a surface lifted temperature (SLT) at 500 mb can be ascertained using a nomogram developed by Sanders (1986). After finding the SLT at 500 mb then a correction term is added to adjust for sea level pressure. Now from this value the environmental temperature at 500 mb is subtracted to obtain the SLI value. Sanders claims that the SLI gives a representative indication of how unstable certain areas are since he believes that the temperature and moisture in the low levels can be advected down to the surface, thus giving the impetus for the SLI. Thus the SLI can be important for summertime

convective events since they usually depend on strong thermodynamics especially in the lower levels from the surface to 700 mb. The 15Z SLI analysis (Fig. 17) shows two areas of maximum instability: one over southern Nebraska and northern Kansas; and the other over central South Dakota with SLI values approaching -10.

At 17Z the surface analysis (Fig. 18) has a surface low centered in south central South Dakota near Chamberlain (CBN) with an accompanying warm front extending southeastward into Iowa. The Isotherm analysis (Fig. 18) is starting to show a strong temperature contrast near the warm front with temperatures north of this front in the low to mid-80s while to the south the temperatures are in the upper 80s to mid-90s. Secondly, there continues to be a strengthening dry line extending from the surface low through central Nebraska that has moved eastward since 15Z. The Isodrosotherm analysis (Fig. 19) shows dewpoints in the upper 40s to mid-50s west of the dry line with upper 60s to low 70s dewpoints to the east of the dry line. The third major feature is the cold front moving slowly southward through central South Dakota which is still associated with the thunderstorms in southern North Dakota and northern South Dakota. Due to the cloud cover a strengthening temperature gradient is developing across the front with temperatures behind the front in the mid-70s, while ahead of the front the temperatures are in the mid-80s.

The 2-hour altimeter change analysis (Fig. 20) from 15Z to 17Z still does not indicate any significant features. The SLI analysis (Fig. 21)

 

Figure 18. Surface isotherm analysis at 3°C
 showing surface features for 17Z 88
 July 1988.

Figure 9. Surface isotherm analysis at
 10°C showing surface features for 17Z
 August 88.

Figure 21. A map of the region of the V N M area for the 17Z 28 July 86. The values are in the range 10 to 100.

Figure 20. A map of the region of the V N M area for the 17Z 28 July 86. The values are in the range 10 to 100. The letters 'V N M' are written in the center of the map.

still indicates that two major instability locations. The first region lies across northern Kansas into south central Nebraska with a second region extending along the warm front from southeast South Dakota into northwest Iowa where SLI values approaching -11 over southeast South Dakota. At 1730Z Huron radar indicated thunderstorms over northern South Dakota with maximum tops to 43,000 ft with movement to the east at 20 kt (Fig. 22). The visible satellite picture at 1730Z (Fig. 23) indicates the convection in northern South Dakota with towering cumulus forming over southwest Minnesota. Secondly, a low-level boundary bisects Iowa from northwest to southeast with low clouds forming to the north of this boundary. By 1830Z Huron radar (Fig. 24) indicates that the storms over northern South Dakota are weakening while moving east at 25 kt. The visible satellite photograph at 1830Z (Fig. 25) shows evidence of a boundary which may be a gust front forming south of the previous convection over northern South Dakota.

At 19Z, one hour before the development of the first supercell thunderstorm, the surface analysis (Fig. 26, see pg. 30) still shows a low near Chamberlain (CBN) in south central South Dakota, as well as, extending from the low a nearly stationary warm front across Iowa. Furthermore a dry line extends from the low through central Nebraska. Finally the surface cold front was still moving slowly southward through central South Dakota and was beginning to interact with the low pressure

Figure 2. The satellite image of the area of the study.

Figure 2. The satellite image of the area of the study.

Figure 2. High resolution picture of
1830228 July 1986.

Figure 2. High resolution picture of
1830228 July 1986. Each contour represents
an intensity.

system and warm front over southern South Dakota. The isotherm analysis (Fig. 26) shows that south of the warm front temperatures were in the low to mid-90s while to the north of the front temperatures remained in the low to mid-80s. Secondly behind the surface cold front temperatures are near SOT while to the south they are hovering in the low 90s. Also the Isodrosotherm analysis (Fig. 27) continues to show that the dewpoints are in the low 70s along the warm frontal boundary. Secondly the dewpoints in north central Nebraska are in the upper 40s while just to the northeast the dewpoints are in the low 70s across the dry line.

The 17Z to 19Z altimeter change analysis (Fig. 28) reveals a slight decrease in pressure over northeast Nebraska into southeastern South Dakota; however there is still no noticeable pressure perturbation associated with the thunderstorms of the type noted by Doswell (1982). The SLI analysis (Fig. 29) indicates that there has been a rapid destabilization across northeast Kansas, eastern Nebraska into southern and eastern South Dakota. In this region the SLI values are approaching -12 and within the hour the first supercell thunderstorm develops near Pierre, South Dakota. At 1930Z Huron radar (Fig. 30) continues to indicate that the original thunderstorms over northern South Dakota are weakening while a new cell has formed to the northeast of Huron. The 19Z visible satellite picture (Fig. 31) definitely indicates the presence of a gust front (outflow boundary) with towering cumulus clouds forming along this

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Figure 29. Sum of Limited index 8881 at 19Z 28 July 1986. Contour lines indicate SLI ≥ 0 .

Figure 30. Sum of Limited index 8881 at 19Z 28 July 1986. Contour lines indicate SLI ≥ 0 .

Figure 30. Aeronautical map of the
 area around the 1986 → 1987 transition
 of the 1986 → 1987 transition.

Figure 30. Aeronautical map of the
 area around the 1986 → 1987 transition
 of the 1986 → 1987 transition.

line from Pierre (PIR), South Dakota, to Watertown (ATY), South Dakota. Also the nearly stationary warm frontal boundary shows up from southeast South Dakota into northwest Iowa with thickening low clouds to the north of this boundary indicating pooling of moisture in this region.

By 20Z the surface analysis (Fig. 32) still indicates a low pressure system near Chamberlain, South Dakota, with a nearly stationary warm front extending through central Iowa. The Isotherm analysis (Fig. 33) shows temperatures in the low to mid-90s south of the warm front with temperatures in the low to mid-80s north of this front. The dewpoint analysis (Fig. 33) shows that the dewpoints are pooling over northeast Nebraska near the surface boundary. Secondly the dewpoint analysis still indicates a dry line extending southward from the surface low into central Nebraska with dewpoints over north central Nebraska in the mid-40s while just to the east of the dry line dewpoints remain in the low 70s. Finally the outflow boundary (surface cold front) is beginning to interact with the surface low and the stationary warm front over southeastern South Dakota. Although the thermal contrast associated with this outflow boundary is weakening, the easterly winds behind the outflow boundary were providing additional convergence over southeastern South Dakota.

The altimeter change analysis from 18Z to 20Z (Fig. 34) shows a general area of pressure falls from central South Dakota through eastern Nebraska. However this area does not appear to be associated with any thunderstorms and might be related to the surface warming. The SLI analysis (Fig. 35) indicates that there is an instability axis aligned

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from southeastern South Dakota through eastern Nebraska into northeast Kansas. It appears the northern part of the instability axis was associated with the surface low and nearly stationary warm front over southeastern South Dakota. By 2030Z Huron radar (Fig. 36) shows a rapid explosion of convection has taken place with three isolated thunderstorms developing along the leading edge of the gust front with maximum tops from 45,000 ft to 53,000 ft. Rapid development occurred over Pierre, South Dakota, with no echo reported at 1930Z while at 2030Z a 53,000 ft thunderstorm had formed. The 2030Z visible satellite picture (Fig. 37) still indicates the gust front across central South Dakota with thickening low clouds over northwest Iowa, southwest Minnesota and eastern South Dakota to the north of the warm frontal boundary.

By 21Z there are now two supercell thunderstorms in the genesis region with one cell near PIR and the other cell close to BKX in South Dakota. The surface features (Fig. 38) still resemble the orientation at 20Z. However the isotherm analysis (Fig. 38) shows that the temperatures have cooled drastically into the mid-70s over northeast South Dakota while over southeastern South Dakota temperatures remain in the upper-80s to mid-90s. The isodrosotherm analysis (Fig. 39) still indicates a higher concentration of dewpoints near the stationary warm front over southern South Dakota, eastern Nebraska, and western Iowa. Secondly the dewpoint analysis continues to show an impressive dry line over central Nebraska with a 41 °F dewpoint at

Fig. 1. Visible satellite image at 1900Z
28 July 1986.

Figure 26. Map of Sri Lanka showing the location of the
28 July 1986 — the 1986 C-119 crash site
go through the 11th day

Fig. 2. ^{238}U and ^{235}U concentrations in the sediment of the Tiber River (Italy) and in the sediment of the Tiber River (Italy) and in the sediment of the Tiber River (Italy).

[illegible]

VTN and a 7 r F dewpoint at Chamberlain. It is very Interesting to note that with a strong surface low along with an Intense dry line that no storms developed over north central Nebraska; In fact, the only thunderstorm that developed was near OFK In northeast Nebraska, but this storm only lasted an hour and no new activity would develop in Nebraska. Since there were only a few thunderstorms in South Dakota at this time then there must have been a factor suppressing the convection In this region, since the amount of instability was very strong. Thus the presence of the capping Inversion between 850 mb and 700 mb must have been that factor. The 12Z LSI analysis (Fig. 14) shows that if the hot, dry pocket of air at 700 mb was advected to the northeast then there would be a stronger cap over Nebraska and western Iowa. The 00Z 29 July 86 LSI analysis (Fig. 40) definitely shows the capping inversion had propagated northeastward Into northern Nebraska and possibly southern South Dakota. Also the weakest part of the cap was located over eastern South Dakota and over northeast Kansas. Thus it is possible that the first two supercell thunderstorms formed on the back edge of the cap. At the time I was interning as a meteorologist at a television station; in fact, I definitely noted that there were no cumulus clouds anywhere that afternoon In eastern Nebraska or western Iowa, which would seem to indicate that there was a strong cap. As a matter of fact, the only clouds that whole day was a band of altocumulus castellanus to the north and northwest of Omaha. Thus It appears the capping inversion played an

Figure 40. - වසරේ උපරිම වර්ෂාව x 1000
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important role in the development of this system. Also at 21Z, the surface analysis indicates the surface cold front (outflow boundary) continued to move southward into southern South Dakota.

The 2-hour altimeter change analysis from 19Z to 21Z (Fig. 41) is beginning to develop a pressure perturbation with a definite area of strong pressure falls developing over central South Dakota with a maximum over PIR near the first supercell. Secondly the area of pressure falls extends into northwest Iowa along the stationary warm frontal boundary. The SLI analysis (Fig. 42) still indicates extreme instability over southeastern South Dakota through eastern Nebraska, western Iowa into northeast Kansas with values approaching -12. At 2130Z Huron radar (Fig. 43) shows that the two cells over central South Dakota are merging while the third storm near BKX is intensifying and moving east into Minnesota. Maximum storm tops ranged from 50,000 ft to 60,000 ft with movement to the southeast at 25 kt. At this time tornadoes and large hail were being reported with the cells near PIR while hail to 4-1 in diameter was being reported to the east of BKX. The visible satellite picture at 2130Z (Fig. 44) shows an interesting feature near PIR with a circular notch on the southwest side of the merging cells over central South Dakota. The surface analysis (Fig. 38) at this time indicated a surface low near Chamberlain, South Dakota, with an associated dry line in the vicinity of this notch.

By 22Z the third supercell thunderstorm developed over extreme southeastern South Dakota just north of SUX in Iowa. The 22Z surface

vignettes

Figure 8. ^{13}C NMR spectra of poly(2,5-furandimethoxy) (PFD) and poly(2,5-furandimethoxy-co-2,5-furandimethoxy) (PFD-co-PFD).

analysis (Fig. 45) now shows that the surface cold front (outflow boundary), surface low, dry line and stationary warm front have begun to interact over southeastern South Dakota. The isotherm analysis (Fig. 45) indicates temperatures north of the warm front in the mid-80s while temperatures to the south are in the mid-90s. The isodrosotherm analysis (Fig. 46) now indicates a narrow band of low-70 dewpoints north of the warm front extending from Fort Dodge (FOD), Iowa, to Mitchell (MHE), South Dakota. Secondly the dewpoint analysis still shows a dry line slicing through central Nebraska; however, the eastward movement of the dry line is no longer present.

The 2-hour altimeter change from 20Z to 22Z (Fig. 47) indicates a strong area of pressure rises over central South Dakota indicating the presence of a meso-high developing due to the passage of the strong gust front. Secondly this analysis shows moderate pressure falls occurring over southeastern South Dakota and northwestern Iowa in the vicinity of where the third supercell is beginning to develop. The 22Z SLI analysis (Fig. 48) indicates the region over central South Dakota has stabilized from 21Z, however, the analysis still shows considerable instability over eastern Nebraska, southeast South Dakota and western Iowa. Eventually this third supercell produced an F4 tornado over northeast Nebraska which subsequently devastated a coal-burning power plant near Sioux City, Iowa (Storm Data, 1986).

At 2230Z Huron radar (Fig. 49) Indicated maximum storm tops from 50,000 ft to 56,000 ft with cell movement to the southeast at 30 kt. Once again the cell near Sioux City, Iowa, was not present at 2130Z and grew to 50,000 ft in less than an hour. The general explosiveness of these thunderstorms Indicate that the region was very unstable and that some type of moderate cap was present. The visible satellite Imagery at 2230Z (Fig. 50) Indicates at least three overshooting tops, which is highly Indicative of severe weather especially over southwest Minnesota and eastern South Dakota. Furthermore the satellite Imagery still indicates that no thunderstorm development is taking place over north central Nebraska In the presence of the strong dry line. After 22Z the three separate supercell thunderstorms began to interact and form into a single convective system over northwest Iowa. Shortly thereafter the system reached MCC status as described by Maddox (1982). After attaining MCC status the system began to produce widespread wind damage in an organized pattern which began to meet derecho criteria as spelled out by Johns and Hirt (1987).

Figure 1. Hypothesis analysis at 21000
 28 July 1985. The figure represents
 the intensity.

Figure 2. Hypothesis analysis at 21000
 28 July 1985.

CHAPTER III

DERECHO STAGE

From 23Z to 05Z 29 July 1986 the derecho system produced a swath of wind damage from northwest Iowa through eastern Missouri. I will now analyze the synoptic conditions present at 00Z 29 July 1986 when the derecho system was in its formative stages.

Synoptic Scale Analysis

At 850 mb the contour analysis (Fig. 51) indicates on 850 mb low over north central Nebraska which is reflected at the surface near Chamberlain (CBN), South Dakota. Secondly a distinct thermal ridge extends up through Missouri, Iowa and Minnesota. The 850 mb isotherm analysis (Fig. 52) shows a thermal axis from eastern Kansas, eastern Nebraska into eastern South Dakota. Much warmer air is being advected in from the southwest with 850 mb temperature $>30^{\circ}\text{C}$. The isodrosotherm analysis at 850 mb (Fig. 53, see pg. 52) shows dewpoints pooling from eastern Missouri, western and central Iowa into eastern Nebraska. This observation matches up well with the pooling of dewpoints along the rather stationary warm frontal boundary at the surface. Analysis of the wind fields indicates there is no strong low-level jet over the genesis region. Thus the presence of a strong low-level jet (as required by Miller (1972)) does not seem to be an important parameter. Also the advection of moisture from the south

Figure 52. 850 mb Isotherm analysis for 00Z.
CM 1986 using 2° C intervals.

Figure 52. 850 mb Isotherm analysis for 00Z.
CM 1986 using 2° C intervals.

was not occurring either; in fact, the dewpoints actually decreased from the 12Z analysis. Thus the increase in the dewpoints at the surface probably was due to evapotranspiration since there is a considerable amount of agriculture in the area. One item to note is that the 850 mb thermal axis is west of the 850 mb moist axis; this alignment has been found to be a key parameter in the development of severe convective activity by Miller (1972).

The 700 mb contour analysis (Fig. 54) still shows a strong high centered over southeastern Oklahoma with a ridge axis aligned from Missouri and Iowa into Minnesota. Also there is a weak shortwave trough extending through the eastern Dakotas and Nebraska. The 700 mb isotherm analysis (Fig. 55) indicates that 700 mb temperatures over Nebraska have warmed up significantly from 12Z, however, the temperatures over central Iowa and eastern Missouri have not changed from 12Z. This intense thermal axis seems to parallel the stationary warm frontal boundary over Iowa. Secondly the convective system appeared to propagate along this stationary boundary, which Johns and Hirt (1987) have noticed in other derecho events.

At 500 mb the contour analysis (Fig. 56) shows a weak shortwave trough extending from the eastern Dakotas thru eastern Nebraska. However and more importantly the 500 mb isotherm analysis (Fig. 57, see pg. 55) reveals a thermal trough aligned with the shortwave trough with 3°C of cooling taking place over eastern Nebraska and northern Kansas. But once again even with 3°C of cooling at 500 mb no thunderstorms

Figure 50. Isotherm values for July 1986 in Karnataka.

Figure 51. Rainfall values for July 1986 in Karnataka.

Figure 55. 300mb isotherms for 00Z
June 5, 1986 using 2°C intervals.

Figure 56. 300mb isotherms for 00Z
June 6, 1986 using 2°C intervals.

formed over eastern Nebraska or northeast Kansas, which continues to support the idea that this region was yet under the influence of the capping inversion. Also as this thermal trough moved eastward into a weaker cap it probably helped produce additional thunderstorms over central Iowa and Missouri. The isotach analysis at 500 mb (Fig. 58) shows 40 to 50 kt winds across the Dakotas and Nebraska with diffluence aloft over southern Iowa and Missouri. Secondly note the wind flow over Iowa, Missouri and Illinois was basically from the northwest (320°) with speeds from 30 to 40 kt; these wind speeds match up with the general movement and speed of the derecho system at the surface. Both the 300 mb and 200 mb isotach analyses (Figs. 59 and 60) show a band of strong winds (>70 kt) across the Dakotas, Nebraska, Iowa and Illinois. There were no areas of strong diffluence at 200 mb or 300 mb either; also, the wind flow was basically west-northwest. Over the genesis area the stronger band of winds probably increased the vertical motion over southeast South Dakota and northwest Iowa. Also it is apparent from the OZ analysis that the derecho eventually crossed over the core of maximum winds over southern Iowa and northern Missouri; consequently, the highest reported wind gusts with the system occurred over southern Iowa and northeast Missouri.

Figure 1. Isotherm analysis for July 1988. Contour interval is 1.0 degree Celsius.

Figure 2. Isotherm analysis for July 1988. Contour interval is 1.0 degree Celsius.

Figure 29. 200mb isotach analysis for July 1966. Wind speed in knots.

Figure 29. 200mb isotach analysis for July 1966. Wind speed in knots.

Stability Analysis

The stability analysis at 00Z 29 July 1985 using the totals-totals Index shows a very unstable region with TTI values >52 from northeast Kansas across eastern Nebraska, western Iowa into southeastern South Dakota in (Fig. 61). The 12-hour change from 12Z to 00Z (Fig. 62) indicates rapid destabilization occurring over eastern Nebraska and western Iowa. Thus the pocket of instability which was over central Nebraska moved eastward and probably was associated with the thermal trough at 500 mb. Secondly the 12-hour change over Missouri and Illinois indicates that the air has stabilized substantially by 00Z. This stabilizing pocket of air may help explain why the derecho system weakened as it approached southeastern Missouri and southern Illinois.

The lifted index at 00Z (Fig. 63) also shows very unstable conditions with LI values <-8 extending from eastern Nebraska, northeast Kansas through western Iowa extending into northern Missouri and southern Illinois. The propagation of the derecho system paralleled this axis of instability. The 12-hour LI change analysis (Fig. 64) shows the greatest destabilization occurring from northeast Kansas through Missouri into southern Illinois; however, the 12-hour TTI change analysis shows that the area over Missouri was stabilizing which is an interesting result. The explanation for this could result from the destabilization taking place from the surface to 700 mb as a result of daytime heating and evapotranspiration of moisture in the lower levels which would be incorporated into the LI. However, since the

Figure 5. Index anomaly for 00Z 29 July 1986. Contour lines indicate values ≤ 0 and ≥ 0 show values > 0 .

Figure 6. Total Index anomaly for 00Z 29 July 1986. Contour lines indicate values ≤ 0 and ≥ 0 show values > 0 .

Figure 4. Isotherms for July 1983. Isotherms are shown for 10, 20, 30, and 40 degrees Fahrenheit. Dashed lines indicate areas of precipitation, and solid lines indicate areas of no precipitation.

Figure 5. Isotherms for July 1983. Isotherms are shown for 10, 20, 30, and 40 degrees Fahrenheit. Dashed lines indicate areas of precipitation, and solid lines indicate areas of no precipitation.

thermal trough had not reached Missouri or Illinois by 00Z this may explain why the TTI analysis showed the region stabilizing.

The Sweat index at 00Z (Fig. 65) shows a maximum of instability over eastern Nebraska and western Iowa which coincides well with the other stability indices. The 12-hour change from 12Z to 00Z (Fig. 66) still shows destabilization across eastern Nebraska and western Iowa while across Missouri the air is stabilizing which coincides with the TTI analysis. As mentioned above, the derecho system eventually weakened over central Missouri, thus the stabilizing tendencies demonstrated by the 12-hour change in the Sweat and TTI analyses might help explain why the system weakened over central Missouri.

Analysis of the LSI at 00Z (Fig. 40) along with the buoyancy term (Fig. 67) indicates the greatest instability over eastern Nebraska, western Iowa, northeast Kansas into Missouri. Thus at 00Z there still was very unstable air feeding into the system. The LSI analysis shows the back edge of the cap extending from the eastern Dakotas through eastern Nebraska into northeast Kansas eastward through Missouri into central Illinois. Earlier work by Johns and Hirt (1987) indicates that many derechos propagate along the back edge of this cap.

Fig 26. 12-hour Sweating Index for 9 July 1968. Sweating Index values are shown in the map. Values > 0.

Fig 27. Heat Index for 00Z. Heat Index values are shown in the map. Heat Index values are at 10° intervals.

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Sub-Synoptic Scale Analysis

At 23Z the first organized line of straight line winds began to develop. The surface analysis (Fig. 68) still showed a surface cold front (gust front) which was strengthening due to the downdrafts associated with the supercell thunderstorms. Connected to the gust front was a surface low south of Chamberlain (CBN), South Dakota, which had a dry line extending southwest through central Nebraska. Also connected to the surface low was a nearly stationary warm front which bisected Iowa. By this time the third supercell was fully developed over Sioux City (SUX), Iowa. The Isotherm analysis (Fig. 68) indicates a strong thermal contrast with temperatures behind the surface cold front in the upper 70s while to the south temperatures are in the mid-90s. North of the warm front temperatures are in the mid-80s while south of the warm front temperatures are in the mid-90s across Iowa. Meanwhile the dewpoint analysis (Fig. 69) still shows the strong dry line over central Nebraska with dewpoints in the low-40s west and in the low-70s east of the dry line. Secondly this analysis continues to show pooling over northeast Kansas, southeast Nebraska and southwest Iowa into northern Missouri. This second area of higher dewpoints may eventually be entrained into the system as it propagated southeastward.

The 2-hour altimeter change analysis from 21Z to 23Z still indicates strong pressure rises centered over central South Dakota with weaker rises extending over into eastern South Dakota behind the

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gust front as shown in figure 70. Secondly there is a smaller area of pressure falls over northwest Iowa and northeast Nebraska into southwest Minnesota which probably relates to the third supercell storm. The development of the first concentrated reports of strong winds coincides with the general area of the strongest pressure falls across northwest Iowa. The SLI analysis at 23Z (Fig. 71) still has values <-10 over western Iowa, eastern Nebraska, northeast Kansas and northwest Missouri. Thus it appears the system moved along the front edge of the Instability axis. At 2330Z Huron radar (Fig. 72) shows that the original two supercell thunderstorms are starting to interact and form into one thunderstorm complex with three separate pockets of peak intensity. The third supercell thunderstorm over northeast Nebraska is still separated from the main thunderstorm complex and continuing to produce tornadoes and large hail. Maximum storm tops now reach up to 60,000 ft with cell movement to the southeast at 25 kts. It appears that the original gust front over central South Dakota was intensified further by the development of the thunderstorm complex over South Dakota, and when this gust front interacted with the nearly stationary warm front over extreme southeastern South Dakota the third supercell formed. The 2330Z visible satellite picture (Fig. 73) also shows that the three supercell storms were starting to coalesce into a convective complex with at least two overshooting tops still indicated over southeast South Dakota. Also the lack of clouds

Figure 2. Two views of the area where the flow of the river is solid line. The area is at the top of the map. The area is at the bottom of the map.

Figure 3. Two views of the area where the flow of the river is solid line. The area is at the top of the map. The area is at the bottom of the map.

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over eastern Nebraska and western Iowa may indicate that the cap was still very strong in this area.

By 00Z 29 July 1986 the surface features (Fig. 74) shows the surface low to be centered near YKN with a warm front still bisecting Iowa. Also the surface cold front (gust front) extends into extreme northern Nebraska while a dry line extends southwest from the surface low into southwest Nebraska. The Isotherm analysis (Fig. 74) still shows a fairly strong temperature contrast with temperatures in the mid-70s north of the gust front while south of this front temperatures are in the low-90s. The isodrosotherm analysis (Fig. 75) continues to show pooling of dewpoints over northern Iowa north of the warm frontal boundary; furthermore, there seems to be a second region of moisture pooling over northern Missouri and western Illinois with dewpoints in the mid-70s across this region.

The 2-hour altimeter change analysis from 22Z to 00Z (Fig. 76) shows a distinct pressure fall-rise couplet over southeast South Dakota into northwest Iowa. This type of pressure perturbation has been noted by Doswell (1982) to be associated with severe weather events. At 0030Z Huron radar (Fig. 77) shows that all three supercells are merging into a mesoscale convective system (MCS) over southeast South Dakota and northwest Iowa. Maximum storm tops range from 50,000 ft to 60,000 ft with general movement to the southeast at

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Fig 76. * 10-hour altimeter change
from 22-00Z to 0200Z, 1966 where
lines show pressure fall of .02" of Hg.
in the 10 hr period. The lines are
at 100 ft intervals of Hg. > 100 ft.

Fig 77. * 10-hour altimeter change
from 22-00Z to 0200Z, 1966 where
lines show pressure fall of .02" of Hg.
in the 10 hr period. The lines are
at 100 ft intervals of Hg. > 100 ft.

30 kts. The 0030Z Infrared satellite picture (Fig. 78) is showing an area of colder cloud tops over northwest Iowa and southwest Minnesota which corresponds to the surface reports of strong winds > 50 kts.

Another interesting feature that appears is a band of mid-level clouds over western Missouri which may be an indication of the warm air advection in the low levels advecting to the east.

At 01Z the MCS continued to exhibit derecho characteristics, the surface analysis (Fig. 79) shows the surface low near OFK while the gust front has continued to move southward on a line from VTN to SUX to SPW in Iowa. Meanwhile the warm frontal boundary still was located over central Iowa but was becoming diffuse; also, the dry line was beginning to lose definition as it began to propagate back to the west. The isotherm analysis (Fig. 79) indicates the thermal contrast across the gust front was still quite strong; however, the thermal contrast across the warm front was beginning to weaken. The Isodrosotherm analysis (Fig. 80) shows that the dewpoints were increasing over southern Iowa, northern Missouri into central Illinois with values in the low to mid-70s. Especially notable were the pooling of upper-70s dewpoints over northern Missouri.

The 2-hour altimeter change analysis from 23Z to 01Z (Fig. 81) shows an area of pressure rises over northwest Iowa but the area of strong pressure falls is no longer present. The SLI analysis at 01Z (Fig. 82)

Figure 78. A photograph of the area shown in Figure 77, taken on 29 July 1963.

Figure 79. A map of the area shown in Figure 77, showing the location of the various points of interest. The map is drawn with black lines on a white background. The landmass has a complex, jagged coastline with many small inlets and peninsulas. The surrounding water is dark, and the land is lighter, with some internal features visible. The map is labeled with various numbers and letters, indicating specific locations and features.

shows the effects of the gust front especially over northwest Iowa where the SLI values indicate a rapid stabilization of the air over this region; however, just to the south the values are still high (<-10) with the maximum instability axis from OFK to MKC. Furthermore the system continued to propagate to the right of the main Instability axis; this behavior has also been noticed by Johns and Hirt (1987). Thus the movement of the system may have indicated the location of the back edge of the cap that night. Unfortunately there was no radar data available at 0130Z due to a power failure at D5M. The Infrared satellite picture at 0130Z (Fig. 83) indicates that the system had reached mesoscale convective complex (MCC) status as described by Maddox (1980). Furthermore the most enhanced region remains over northwest Iowa where the leading edge of the strong winds were located. Also the mid-level clouds over Missouri were still advecting eastward into central Missouri.

By 03Z the system continued to move southeast at 35-40 kt., and at this time the surface analysis (Fig. 84) shows the surface gust front from south of VTN to south of OFK through FOD to MCW. However, the western part of the gust front was moving only at 20 kt to the south while the gust front over Iowa was moving about 40 kt to the southeast. Also the dry line over Nebraska had disappeared along with the surface low, and the warm frontal boundary is no longer apparent either. The Isotherm analysis (Fig. 84) still indicates a strong thermal gradient near

Figure 83. Infrared satellite picture for
0130Z 25 July 1986.

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the gust front with temperatures in the mid to upper-60's behind and in the low to mid-80s ahead of the gust front. Furthermore the isodrosotherm analysis (Fig. 85) continues to show high dewpoints over southern Iowa, northern Missouri and western Illinois that are being entrained into the system. There also appears to be a moist axis of mid-70T dewpoints from STL extending up to OMA.

The SLI analysis at 03Z (Fig. 86) shows the effects of the Intense gust front with FOD having an SLI value of +3. South of the gust front the SLI values are <-7; however, the area over northeast Missouri and southeast Iowa is beginning to show signs of stabilizing, with the greatest instability to the southwest of the derecho's path. What is more intriguing is that the area over southeastern Iowa and northeastern Missouri has relatively high values of heat and moisture which would normally produce a more unstable SLI value. The only explanation for the more stable SLI values could be attributed to the environmental temperature at 500 mb which is a major factor in determining SLI values. However, referring back to the TTI at 00Z, the 12-hour change analysis in (Fig. 62) showed a substantial increase in stability in this same region which seems to indicate there was warm air advection at 500 mb over this area which is in contradiction to the classical severe weather situation where cold air advection is favored at 500 mb. This led to an interesting scenario because it is over this same area (northeast Missouri, southern Iowa and western Illinois) where the greatest wind speeds will occur. The 01Z to 03Z

Figure 86. Surface Lined by analysis for July 1985 where the predicted values are solid lines and values > 0 .

Figure 87. Surface Lined by analysis for July 1985 where the predicted values are solid lines and values > 0 .

altimeter change analysis (Fig. 87) shows a strong east-west oriented line of pressure rises aligning behind the strongest part of the gust front but once again there are no pressure fall centers ahead of the gust front. At 0230Z Des Moines radar (Fig. 88) was operating again and was indicating the leading edge of strong reflectivity values from half way between OMA and SUX to the north of DSM. Radar was also indicating numerous hook echoes with maximum storm tops to 65,000 ft with the area moving to the southeast at 35 kt. It was also evident that the line of strong convective winds was associated with the strong reflectivities at the leading edge of the system. The 0235Z Infrared satellite picture (Fig. 89) continues to show that the system had an MCC structure with the coldest cloud tops still over northwest Iowa. Also the area of mid-level clouds still are propagating to the east into eastern Missouri and may indicate the influx of warmer air at 700 mb. There is no radar data for 0335Z due to DSM radar being knocked out by the storm; however, the 0330Z Infrared satellite picture (Fig. 90) is showing signs that the MCC system is beginning to weaken with the best enhancement near DSM which matches well with the 03Z position of the gust front. Furthermore the middle clouds over Missouri are still present indicating the capping inversion is in place over western and central Missouri. By 05Z the derecho system had begun to reach its peak intensity as it propagated into southern Iowa.

Figure 87. Topographic map of the area around the town of H. The map shows the presence of a large area of high ground (elevation 1000 feet) and a large area of low ground (elevation 100 feet). The map also shows the location of the town of H.

Figure 88. Topographic map of the area around the town of H. The map shows the presence of a large area of high ground (elevation 1000 feet) and a large area of low ground (elevation 100 feet). The map also shows the location of the town of H.

Figure 89. Infrared satellite photograph of the Gulf of Mexico, July 1968.

Figure 89. Infrared satellite photograph of the Gulf of Mexico, July 1968.

The 05Z surface analysis (Fig. 91) indicates that the gust front extended from south of OFK to south of OMA to south of DSM to CID. The Isotherm analysis (Fig. 91) still indicates a thermal gradient near the gust front over southern Iowa but it is becoming more localized which seems to coincide well with the area of strongest winds especially between DSM and OTM in Iowa. The dewpoint analysis (Fig. 92) indicates strong pooling of dewpoints occurring over southeast Iowa and northeast Missouri with values in the m1d-70s.

The SLI analysis (Fig. 93) clearly shows the effects of the derecho system, especially over much of Iowa where values are now > 0 indicating that this area has become very stable. However, in southeastern Iowa and northern Missouri SLI values are < -7 ; thus there is still unstable air feeding into the system. There does appear however to be a decrease in the degree of instability over much of Missouri and Illinois, which is partly due to the loss of daytime heating. The 2-hour altimeter change from 03Z to 05Z (Fig. 94) shows quite a strong pressure rise couplet across much of southern Iowa extending into northeast Nebraska and southeast South Dakota. This general area of pressure rises nearly parallels the gust front, however, there still are no signs of a pressure fall couplet. At 0435Z DSM radar (Fig. 95) is operating again and shows that the system is breaking apart into separate clusters with the main core of the system moving to the southeast at 40 kt towards southeastern Iowa and northeast Missouri. Also there is some redevelopment to the west of the main system which produces large hail and a few funnel clouds. The 0430Z infrared satellite picture (Fig. 96)

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Figure 93. Index of Isotonicity
July 1980. Value > 0.

Figure 94. Other analysis
July 1980. Value > 0.

Figure 4. Two-hour contour map of the area around the town of ...
The map shows the distribution of ...
The highest values are found in the ...
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The map is oriented with a north arrow pointing towards the top right corner.

Figure 4. Two-hour contour map of the area around the town of ...
The map shows the distribution of ...
The highest values are found in the ...
The lowest values are found in the ...
The map is oriented with a north arrow pointing towards the top right corner.

Figure 5. Infrared image of the area
0430 > 9 July 1983.

continues to show the system weakening with some new redevelopment on the west side of the system. Also the band of mid-level clouds are moving into extreme eastern Missouri associated with warm air advection in the mid-levels. Furthermore the satellite picture does not show any leading gradient signature either which was found by McCarthy (1985) to be a strong indicator of damaging winds. By 0530Z DSM radar (Fig. 97) shows that the MCC had fallen apart and broken into separate thunderstorm clusters; however, the main group of cells is still intense with maximum storm tops to 56,000 ft over Iowa. Also the cell movement continues to the southeast at 40 kt and seems to be propagating along the low-level thermal boundary that had extended from southeast South Dakota into northeast Missouri. The 0500Z infrared satellite picture (Fig. 98) confirms the radar reports that the MCC system is falling apart; however, there are still no signs of the leading gradient signature as described by McCarthy (1985).

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CHAPTER IV

DISSIPATING STAGE

Sub-Synoptic Scale Analysis

Between 05Z and 06Z the strongest convective wind gusts were developing over southeastern Iowa and northeastern Missouri with peak gusts to 85 kt. The 06Z surface analysis (Fig. 99) indicated that the leading edge of the gust front extended from northwest of GRI to south of LMN to just north of BRL. The Isotherm analysis (Fig. 99) shows temperatures behind the gust front in the upper 60s while to the south temperatures are in the upper 70s. The isodrosotherm analysis (Fig. 100) still shows dewpoints in the mid-70s feeding into the system especially over northeast Missouri and western Illinois.

The SLI analysis (Fig. 101) indicates that there is a narrow band of SLI values < -7 over northern Missouri but south of this axis the air is not as unstable. This may indicate why the system weakens after 06Z, also the effects of the gust front show up with very stable air indicated by the SLI analysis. Analyzing the 1-hour altimeter changes from 05Z to 06Z (Fig. 102), a pressure fall-rise couplet is beginning to redevelop over central and eastern Iowa. This feature does not appear until the strongest wind gusts were being reported. Why this pressure perturbation developed may be an important key to understanding the peak wind speeds. The 0630Z St. Louis radar analysis indicated that the main core of the system

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as shown in Figure 103 had moved into west central Illinois with maximum storm tops to 50,000 ft. At this time the strongest winds were being reported over northeast Missouri and west central Illinois with gusts to 85 kt. The 0630Z infrared satellite picture (Fig. 104) confirms the radar observation that the main part of the system was moving into westcentral Illinois.

According to the surface analysis (Fig. 105) by 07Z the gust front was oriented from south of GRI to north of MKC through DIN and to the south of BRL. The isotherm analysis (Fig. 105) shows temperatures behind the gust front are in the mid-to upper 60s while south of the gust front temperatures are in the mid-70s to low 80s. The isodrosotherm analysis (Fig. 106) still shows mid-70°F dewpoints feeding into the system from the southeast.

Although the temperatures and dewpoints are fairly high south of the gust front, the SLI analysis (Fig. 107) continues to show the area over eastern Missouri and western Illinois to be stabilizing. However, a small pocket of decreasing stability has developed over extreme southeastern Missouri. The 2-hour altimeter change from 05Z to 07Z (Fig. 108) shows a very intense pressure fall-rise couplet developing over the eastern two-thirds of Iowa, northwestern Illinois and northeastern Missouri. During this period the most intense wind speeds were being reported. The 0730 STL radar analysis (Fig. 109) still indicates that the system was weakening; however, new development was taking place in northern Missouri

Figure 1. Map of the study area for the 1990 census. The map shows the location of the study area (indicated by a rectangle) within the larger context of the region. The map is oriented vertically on the page.

Figure 2. Map of the study area for the 1990 census. The map shows the location of the study area (indicated by a rectangle) within the larger context of the region. The map is oriented horizontally on the page.

Figure 106. Map of the region of the ...
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Figure 107. Map of the region of the ...
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to the north of CBI. Also the infrared satellite picture (Fig. 110) indicates it was moving into central Illinois and was continuing to weaken.

By 08Z the surface analysis (Fig. 111) shows the westward extent of the gust front becoming nearly stationary while the eastern part was propagating rapidly to the southeast. The temperature and dewpoint analyses (Figs. 111-112) indicate the main thrust of the gust front extends from MKC to CBI to near PI A.

The SLI analysis (Fig. 113) still shows moderate instability over eastern Missouri, while the 2-hour altimeter change analysis (Fig. 114) from 06Z to 08Z still shows an intense pressure fall-rise couplet over southeast Iowa, eastern Missouri and western Illinois. At this time the derecho system was producing winds of 50 kt to the north of STL but the overall number of high wind reports was rapidly diminishing. Also a new line of thunderstorms began to develop to the north of CBI, but no reports of severe weather came from these storms. By 0830Z STL radar (Fig. 115) shows the weakening derecho system entering into the St. Louis area with maximum storm tops to 40,000 ft while moving to the southeast at 30 kt. At this time the last reports of wind gusts exceeding 50 kt were reported. The Infrared satellite analysis at 0830Z (Fig. 116) indicates the brunt of the system was located in central Illinois and was finally dissipating over southeast Missouri and southern Illinois.

At 09Z the surface analysis (Fig. 117) shows the gust front aligned from GRI thru MKC to CBI to STL in Missouri. The Isotherm analysis (Fig. 117) still shows a 10°F temperature difference across the gust

Figure 1. Topographic map of the study area. The map shows the location of the study area (indicated by a rectangle) and the location of the study area (indicated by a rectangle). The map also shows the location of the study area (indicated by a rectangle) and the location of the study area (indicated by a rectangle).

Figure 2. Topographic map of the study area. The map shows the location of the study area (indicated by a rectangle) and the location of the study area (indicated by a rectangle). The map also shows the location of the study area (indicated by a rectangle) and the location of the study area (indicated by a rectangle).

Figure 11 is a map of the area around the city of New York, showing the distribution of the concentration of the gas, in parts per million, at the time of the attack on September 11, 2001. The map shows the concentration of the gas in the area around the World Trade Center, and the concentration of the gas in the area around the Pentagon. The map also shows the concentration of the gas in the area around the White House, and the concentration of the gas in the area around the Capitol Building. The map is a contour map, and the contours represent the concentration of the gas in parts per million. The highest concentration of the gas is in the area around the World Trade Center, and the lowest concentration is in the area around the Pentagon.

Figure 12 is a map of the area around the city of New York, showing the distribution of the concentration of the gas, in parts per million, at the time of the attack on September 11, 2001. The map shows the concentration of the gas in the area around the World Trade Center, and the concentration of the gas in the area around the Pentagon. The map also shows the concentration of the gas in the area around the White House, and the concentration of the gas in the area around the Capitol Building. The map is a contour map, and the contours represent the concentration of the gas in parts per million. The highest concentration of the gas is in the area around the World Trade Center, and the lowest concentration is in the area around the Pentagon.

Fig. 1. Map of the area of the study.

Fig. 2. Map of the area of the study.

front while the isodrosotherm analysis (Fig. 118) Indicates m1d-70 F dewpoints over southeastern Missouri. The SLI analysis (Fig. 119) shows a maximum of instability over southern Missouri. Furthermore **the** derecho system was no longer producing damaging winds. Also the second group of thunderstorms over central Missouri were still occurring but no severe weather was reported with these storms.

The 2-hour altimeter change analysis from 07Z to 09Z (Fig. 120) the pressure fall-rise couplet has Intensified from the 06Z to 08Z analysis. This Increase In intensity of this pressure perturbation might be an indication that the system was beginning to collapse.

At 10Z the surface analysis (Fig. 121) shows that the gust front had become nearly stationary from GRI to TOP to south of CBI to STL. The most Important feature Is the 08Z - 10Z altimeter change analysis (Fig. 122) which no longer has a strong pressure fall-rise couplet. Instead only a pressure fall couplet over central Illinois lies behind the gust front with no pressure perturbation south of the gust front; this coincides with the fact that there were no more damaging wind reports after 0830Z.

Synoptic Scale Analysis

The factors leading to the demise of the derecho system after 08Z will be examined by analyzing the synoptic scale and stability indices at 12Z 29 July 1986. It is logical that something had to change from 00Z to 12Z over Illinois and Missouri for the derecho system to weaken

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after 08Z. On the synoptic scale at 850 mb, the 12Z Isotherm analysis (Fig. 123) shows there is warm air advection into Missouri from the southwest with temperatures ($>25^{\circ}\text{C}$). The Isodrosotherm analysis at 850 mb (Fig. 124) Indicates there is a moist axis over western Missouri while over eastern Missouri and western Illinois the 850 mb dewpoints decrease substantially. However the surface dewpoint analyses from 00Z to 06Z Indicated that the surface dewpoints were in the low to mid-70s. At 00Z the 850 mb dewpoint analysis showed pooling of dewpoints, especially over eastern Missouri. Work by Maddox (1982) indicated that low-level thermal advection was a key parameter in the maintenance of intense convective systems during the summer months. In this case it appears that there was strong warm air advection coming from the southwest of the system; however, to the southeast of the derecho system there appears to be weaker warm air advection and moisture at 850 mb.

At 700 mb the contour analysis (Fig. 125) shows that there may be a weak shortwave trough at 700 mb over Iowa at 12Z. The isotherm analysis at 700 mb (Fig. 126) shows that there was advection of warmer 700 mb temperatures into Missouri from the southwest; this also may have Influenced the propagation of the system due to the capping inversion.

At 500 mb the isotherm analysis (Fig. 127) shows a thermal trough through western Missouri at 12Z; however, the system was in its

FIGURE 23. Distribution of grasshopper populations for 1938.

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Fig. 25. $\pi^0\pi^0$ correlation ρ as a function of $\sqrt{s}$.

Figure 127. 300 mb isotherms for 1986-1987 interval.

Figure 128. 12Z 300 mb isotherms for 1986-1987 interval.

dissipating **stage** even though there appears to be cold air advection west of the system. Also the contour analysis (Fig. 128) shows a weak shortwave trough approaching eastern Missouri at 12Z which matches up with the thermal trough. Between 06Z and 12Z convection was still developing over central and southern Missouri, however, it did not organize into any type of convective system.

At 300 mb and 200 mb the wind pattern (Figs. 129-130) shows a basic northwesterly component with the maximum core of winds from RAP to OMA to PI A. Thus as the system moved southeastward it may have travelled far enough from the maximum core of winds which may have caused the system to not respond to the right rear quadrant of the 200 mb and 300 mb jet overhead; this would have lessened the amount of vertical motion. Thus it appears that as the derecho system moved southeast it eventually began entraining air that was becoming more stabilized as the night progressed which probably caused the system to weaken.

Stability Analysis

To demonstrate that the air was becoming stabilized, the stability indices at 12Z 29 July 1986 were analyzed. The 12Z TTI (Fig. 131) indicated there was a maximum values of >55 centered over western Missouri, which is probably associated with the strong warm air advection at low levels along with the thermal trough in the area; however, the area over eastern Missouri and western Illinois have TTI

Figure 128 Contour map for 128 m intervals.

Figure 129 Contour map for 129 m intervals.

Figure 3: Global Indexing for

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values that are much lower (<45). The 12-hour TTI change analysis (Fig. 132) from 00Z to 12Z shows the increasing instability over southwest Missouri, while there is an increase in stability over eastern Missouri and western Illinois. The increase of instability over southwestern Missouri probably helped trigger the non-severe convection over central Missouri around 06Z.

Furthermore, the Sweat Index change analysis from 00Z to 12Z (Fig. 133) confirms the trends of the TTI analysis; however, the LI 12-hour change from 00Z to 12Z (Fig. 134) shows a dramatic difference, especially in the stability over Missouri, Iowa and Illinois which had become more stabilized. Some of this stabilization was due to the effects of the derecho system, especially at the low levels. However, the surface analysis from 06Z to 10Z clearly indicates that southeast Missouri and southern Illinois were not affected by the gust front from the derecho system. The two parameters that might have affected this region corresponding to the LI are the amount of heat and moisture in the low-levels relating to the LCL and the temperature of the environmental air at 500 mb. Thus from the upper-air analysis at 850 mb the dewpoints had decreased from the 00Z sounding over southeastern Missouri. Secondly the 12Z 500 mb isotherm analysis showed that there was warm air advection into southeastern Missouri and southern Illinois ahead of the path of the derecho system. These two factors would have led to a

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Figure 1 shows the range of the α parameter for the different models. The α parameter is defined as the ratio of the α parameter to the α parameter of the α parameter.

Figure 10. Map of the lake showing contours of depth from 0 to 40 feet. The contours are drawn at 5-foot intervals. The map is oriented with the top of the page towards the left.

Stabilizing influence over this area; since the system was relying on Inflow of air from this region the system would have weakened. Perhaps the most interesting Index at 12Z is the LSI analysis (Fig. 135) which has values >10 extending from Oklahoma through southern Illinois. However, at 00Z the LSI values were around $+4$ over southern Illinois but increased to $+10$ by 12Z the next morning. Thus it seems from 00Z to 12Z that the capping Inversion became stronger over southern Missouri and southern Illinois as the derecho system was moving southeast into this area. Thus the possibility of new thunderstorm development along the leading edge of the gust front may have been suppressed due to the increase in the cap strength. The position of the stronger cap may be further indicated by the development of the second line of thunderstorms north of CBI at 06Z; however as this line moved southeast it also dissipated. Also the thermal trough and associated cold air (-10°C pocket at 500 mb did not produce convection over southwest Missouri that night either. Thus I believe the derecho system dissipated due to two main factors. First, the advection of warmer air between 850 mb and 700 mb served to enhance the capping inversion over southern Missouri and southern Illinois which suppressed convection to the south and east of the derecho system. Secondly, the appearance of a warm pocket of air at 500 mb over southeast Missouri and southern Illinois also contributed to the stabilization of the atmosphere at mid-levels, which was indicated by the 12-hour change LI analysis.

Figure 2. Isotherms for January 1985.
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CHAPTER V

CONCLUSIONS

The convective event that occurred during 28-29 July 1986 was a different system in the sense that the magnitude of the area it affected was so large. Although severe weather during late July is usually at a minimum, systems of this type have been found to occur more frequently than one would imagine. This is confirmed by a climatological study done on derecho events from 1980-1983, especially over the central High Plains extending into the Ohio Valley region as described by Johns and Hirt (1987). The initial stages of this convective event involved the development of three separate intense supercell thunderstorms during the late afternoon of 28 July 1986. It appears that the first two supercell thunderstorms developed along a surface cold front (outflow boundary) that emanated from previous convection over southern North Dakota and northern South Dakota. Thus due to this surface cold front (outflow boundary) and its interaction with a surface low and associated strong dry line along with a weak shortwave trough at 500 mb, the first two supercell thunderstorms developed over central and eastern South Dakota. Eventually the strong downdrafts from these two storms intensified the surface cold front which then interacted with a nearly stationary warm frontal boundary over southeastern South Dakota to help produce the third supercell thunderstorm near Sioux City, Iowa, which eventually produced an F4

tornado. A major factor that limited the amount of convection over South Dakota to three separate thunderstorms was the presence of a capping inversion between 850 mb and 700 mb. The LSI analysis showed that the first supercell thunderstorm developed near the back edge of the lid in the moist axis. This capping inversion also suppressed convection near the surface low and associated dry line over northcentral and northeast Nebraska which seemed to be a favored region for convective development also. Eventually the three supercell thunderstorms began to merge into a MCS and later achieve MCC status over northwest Iowa. It was at this time that concentrated reports of strong winds (>50 kt) started to be reported over southwest Minnesota and northwest Iowa. As the system propagated to the southeast it developed derecho characteristics as described by Johns and Hirt (1987). This derecho system was similar to other derecho events in that it tracked southeastward along a pre-existing thermal boundary that was reflected in both the 850 mb and 700 mb isotherm analyses which bisected Iowa into northeast Missouri. This thermal boundary was reflected at the surface by a nearly stationary warm frontal boundary and was related to the capping inversion in the low-levels. Furthermore this capping inversion inhibited convection from developing over eastern Nebraska, southwest Iowa and much of western and central Missouri, which allowed the derecho system to entrain warm moist unstable air as it propagated southeastward across Iowa. However, after the system

moved into northeast Missouri and western Illinois it began to produce wind gusts up to 85 kt over northeast Missouri. The reason for the derecho system weakening after entering eastern Missouri and western Illinois related to the amount of Instability over this region. The LSI analysis at 12Z 29 July 1986 indicated that the cap was becoming stronger over southern Missouri and southwestern Illinois, which indicates that warmer air was being advected in between 850 mb and 500 mb. Thus due to this mid-level warming the environment was becoming more stable over eastern Missouri and western Illinois which cause the derecho system to weaken.

Recommendations

Some of the questions arising out of this study are;

1. How did the original three supercell thunderstorms interact with each other to eventually form into an MCC?
 2. After reaching MCC status, how did the internal structure change to become a convectively-induced wind system (derecho)?
 3. What created the Intense pressure fall-rise couplet which was associated with the most intense convective wind gusts over northeast Missouri?
 4. What effects were produced when the derecho system crossed the main jet axis in the upper-levels over southern Iowa and northern Missouri which was in the vicinity of the strongest wind reports?
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To deal with the above questions some type of mesoscale network could be used to collect information on derecho type systems. Since the majority of derecho events occur from the Northern Plains extending into the Ohio Valley, the mesoscale network should be located in the above mentioned areas. Hopefully, this mesoscale network could provide important data concerning the development and maintenance of the internal and external characteristics of derecho events.

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APPENDIX A

STATION IDENTIFIERS WITH COMPLETE LOCATIONS

<u>STATION IDENTIFIER^</u>	<u>LOCATION</u>
ABR	ABERDEEN, SOUTH DAKOTA
ALO	WATERLOO, IOWA
ANW	AINSWORTH, NEBRASKA
ATY	WATERTOWN, SOUTH DAKOTA
AXN	ALEXANDRIA, MINNESOTA
BBW	BROKEN BOW, NEBRASKA
BIE	BEATRICE, NEBRASKA
BIS	BISMARCK, NORTH DAKOTA
BJI	BEMIDJI, MINNESOTA
BKX	BROOKINGS, SOUTH DAKOTA
BMI	BLOOMINGTON, ILLINOIS
BRD	BRAINERD, MINNESOTA
BRL	BURLINGTON, IOWA
CBI	COLUMBIA, MISSOURI
CBN	CHAMBERLAIN, SOUTH DAKOTA
CDR	CHADRON, NEBRASKA
CGI	CAPE GIRARDEAU, MISSOURI
CID	CEDAR RAPIDS, IOWA
CNK	CONCORDIA, KANSAS
CNU	CHANUTE, KANSAS
DBQ	DUBUQUE, IOWA
DDC	DODGE CITY, KANSAS
DEC	DECAATUR, ILLINOIS
DIK	DICKINSON, NORTH DAKOTA
DSM	DES MOINES, IOWA
DVL	DEVILS LAKE, NORTH DAKOTA
EAR	KEARNEY, NEBRASKA

^^^	EAU CLAIRE, WISCONSIN
^"P	EMPORIA, KANSAS
"AR	FARGO, NORTH DAKOTA
^OD	FORT DODGE, IOWA
^SD	SIOUX FALLS, SOUTH DAKOTA
GCK	GARDEN CITY, KANSAS
^^^	6RAND FORKS, NORTH DAKOTA
GLD	GOODLAND, KANSAS
GRI	GRAND ISLAND, NEBRASKA
HLC	HILL CITY, KANSAS
HON	HURON, SOUTH DAKOTA
ICT	WICHITA, KANSAS
•ML	IMPERIAL, NEBRASKA
«RK	KIRKSVILLE, MISSOURI
JLN	JOPLIN, MISSOURI
JMS	JAMESTOWN, NORTH DAKOTA
LEM	LEMMON, SOUTH DAKOTA
LNK	LINCOLN, NEBRASKA
LNR	LONE ROCK, WISCONSIN
LSE	LACROSSE, WISCONSIN
MBG	MOBRIDGE, SOUTH DAKOTA
MC I	KANSAS CI TY, MISSOURI
MCK	MC COOK, NEBRASKA
MCW	MASON CITY, IOWA
MHE	MITCHELL, SOUTH DAKOTA
MHK	MANHATTAN, KANSAS
MKT	MANKATO, MINNESOTA
MLI	MOLINE, ILLINOIS
MOT	MOTLEY, NORTH DAKOTA
MSN	MADISON, WISCONSIN
MSP	MINNEAPOLIS, MINNESOTA
MVN	MT. VERNON, ILLINOIS
OFK	NORFOLK, NEBRASKA
OLU	COLUMBUS, NEBRASKA

OMA	OMAHA, NEBRASKA
OTG	WORTHINGTON, MINNESOTA
OTM	OTTUMWA, IOWA
PHP	PHILLIPS, SOUTH DAKOTA
PIA	PEORIA, ILLINOIS
PIR	PIERRE, SOUTH DAKOTA
RAP	RAPID CITY, SOUTH DAKOTA
RFD	ROCKFORD, ILLINOIS
RST	ROCHESTER, MINNESOTA
5GF	SPRINGFIELD, MISSOURI
SLN	SALINA, KANSAS
SPI	SPRINGFIELD, ILLINOIS
SPW	SPIRIT LAKE, IOWA
STL	ST. LOUIS, MISSOURI
SZL	KNOB NOSTER, MISSOURI
SUX	SIOUX CITY, IOWA
TOP	TOPEKA, KANSAS
UIN	QUINCY, ILLINOIS
VTN	VALENTINE, NEBRASKA
YKN	YANKTON, SOUTH DAKOTA

APPENDIX B

LID STRENGTH INDEX (LSI)

The LSI consists of two terms:

1. Buoyancy term

where θ_{ws} is the value of the moist adiabat that intersects the temperature sounding at 500 mb.

Also $\bar{\theta}^*$ is the maximum value of the potential temperature θ over the lowest 50 mb of the sounding.

2. Lid Strength term

where θ_{wmx} is the highest wet-bulb potential temperature in the lowest 50 mb of the sounding.

Also θ_5^* is the maximum value of the potential temperature θ over the lowest 50 mb of the sounding.

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