An Examination of Tornadogenesis in a Marginally Unstable Air Mass

Mike Weiland WFO Cheyenne
307-772-2468 xtn 516
michael.weiland@noaa.gov

Abstract

During the mid afternoon of October 6, 2004 a brief tornado touched down just to the north of Sidney, NE. The low topped tornadic supercell was about 90 nmi from the Cheyenne, WY 88D radar and detection of any low level circulation was difficult. This case study will examine the environment for that day and use satellite imagery during and prior to the tornado touchdown to try to improve situational awareness for future similar events.

1. Introduction

During the mid-afternoon of October 6, 2004 a brief tornado occurred between 2100 UTC and 2110 UTC near Gurley, NE (north of Sidney) in north-central Cheyenne County. (Figure 1).

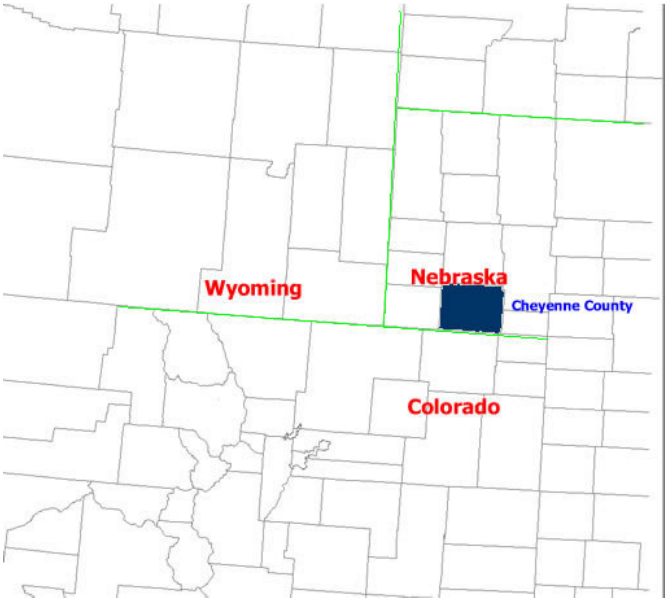


Figure 1 Area of Study

which is in the southern Nebraska panhandle. The tornado was very late in the season for that part of the country. The tornadic thunderstorm was at least 80 nmi from all of the area National Weather Service radars with the lowest radar beam at 11,000 feet AGL over the storm. Both factors limited the Doppler low level resolution of the nearest radars. This study is not an indictment of the limitations of the Doppler radar. Instead, it documents the importance of being proactive with multiple data sets to make informed decisions. No Tornado Warning was issued for this event, so this paper will examine the tornadic thunderstorm in the hope of providing some insight to better diagnose and produce more timely Warnings for low-topped supercells.

The synoptic pattern was slow to change. The previous afternoon, low topped tornadic supercells were observed in the vicinity of Denver, CO.

Recent studies of low topped tornadic supercells by NSSL have shown that most occur in environments which are strongly sheared with only weak instability (Davies). Other favored environmental factors per NSSL studies include a core of cold air aloft (which steepens lapse rates and CAPE near the ground and indicates at least the potential for increased vertical stretching in the low levels). Also, a surface boundary within 200 miles of a mid level low is important, providing enhanced vorticity east of the associated surface low. Keeping those ideas in mind, let's examine this case to see if a better awareness of the environment would have started the day with enhanced situational awareness.

2. Synoptic Overview

Low pressure at 500 mb was over central Colorado at 12 UTC (not shown) and moved slowly northeast to northeast Colorado by 21 UTC (Figure 2).

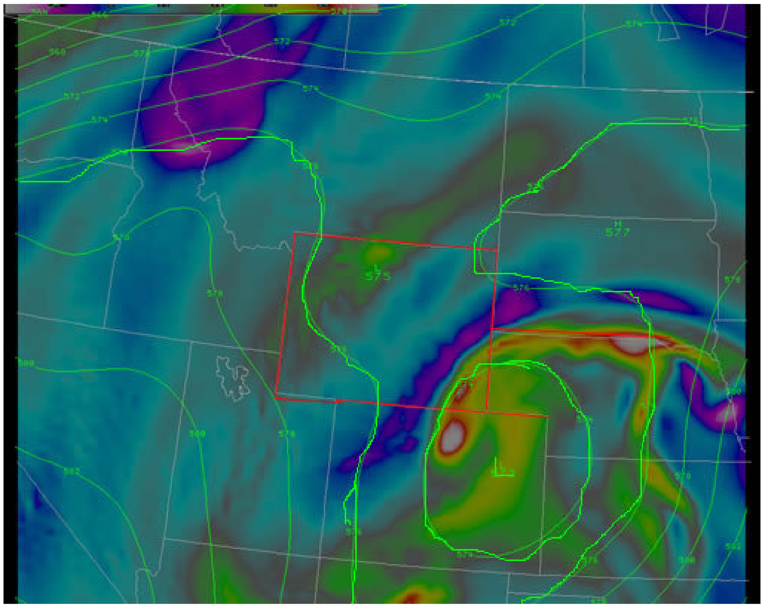


Figure 2 500 mb height and vorticity at 21 UTC from the Mesoeta

Satellite imagery and model data indicated a shortwave trough rotating around the upper level low into the western Nebraska panhandle in the early to mid afternoon hours (Figure 2). At the surface, a large area of high pressure was centered over the central Mississippi valley with a surface low near Limon, CO which was nearly under the upper low (Figure 3).

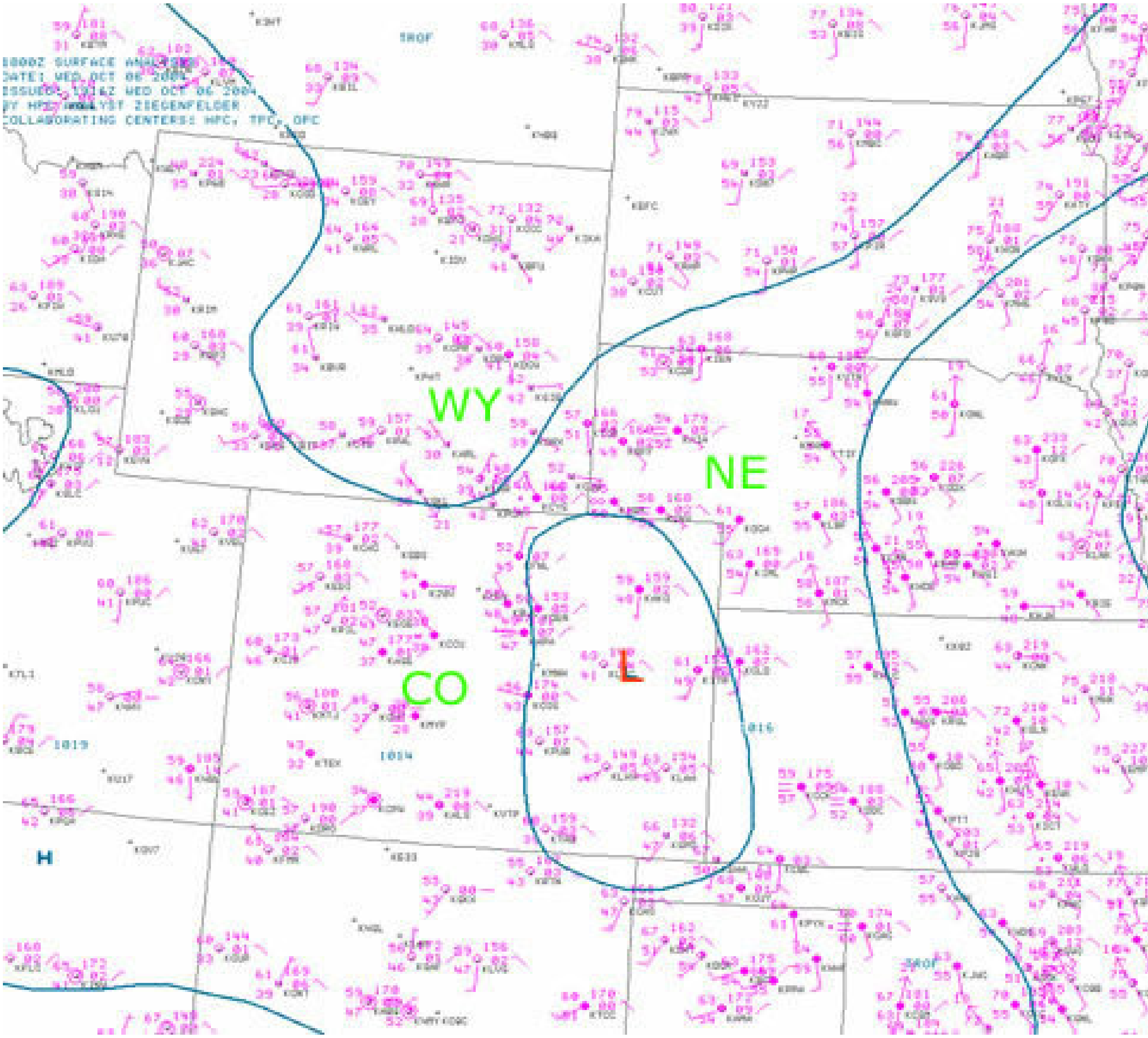


Figure 3 Surface plot and analysis at 2100 UTC Over Area of Study

Moist, southeast boundary layer winds were over the region during the afternoon. With the synoptic lift provided by the upper low, shortwave trough, increased boundary layer moisture, and instability thunderstorms were anticipated for the afternoon. The SPC day one outlook had the southern Nebraska panhandle in the area of general thunderstorms (not shown).

3. Mesoscale Overview

Surface dew points increased to around 10C in the southern Nebraska panhandle by midday. At the same time, the lapse rates between 850 mb and 500 mb had steepened over the area to 6.5C (both not shown). At 18 UTC, a boundary developed to the southeast of the area of study on both the visible satellite imagery and local mesoscale plots (MSAS) (Miller), (Figures 4 and 5). Unfortunately, the density of surface observations in the area of study (Figure 3) is not great enough to detect many small scale boundaries and so the use of other remote sensing equipment, such as satellite and radar is very important in their detection.

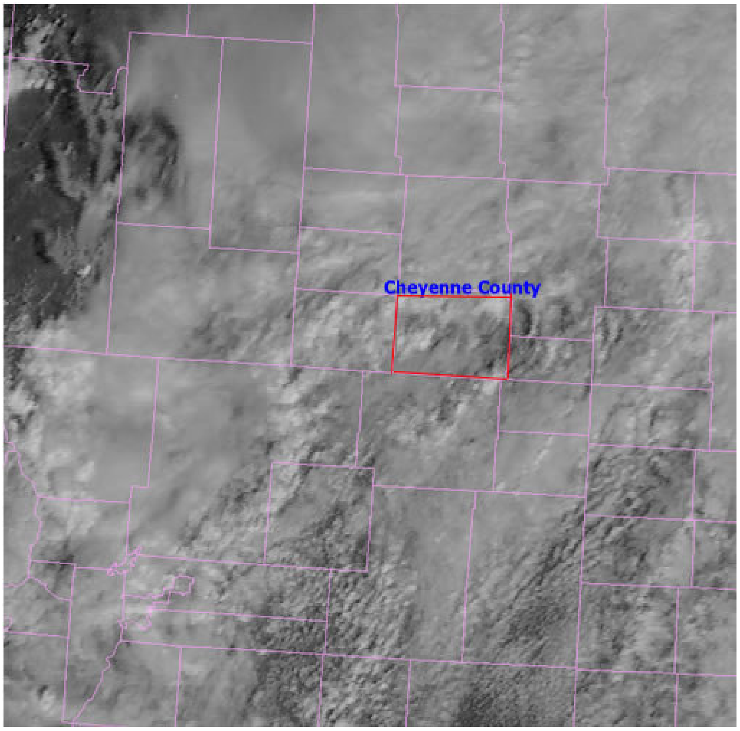


Figure 4 Visibile Satellite Image at 1800 UTC Over Area of Study

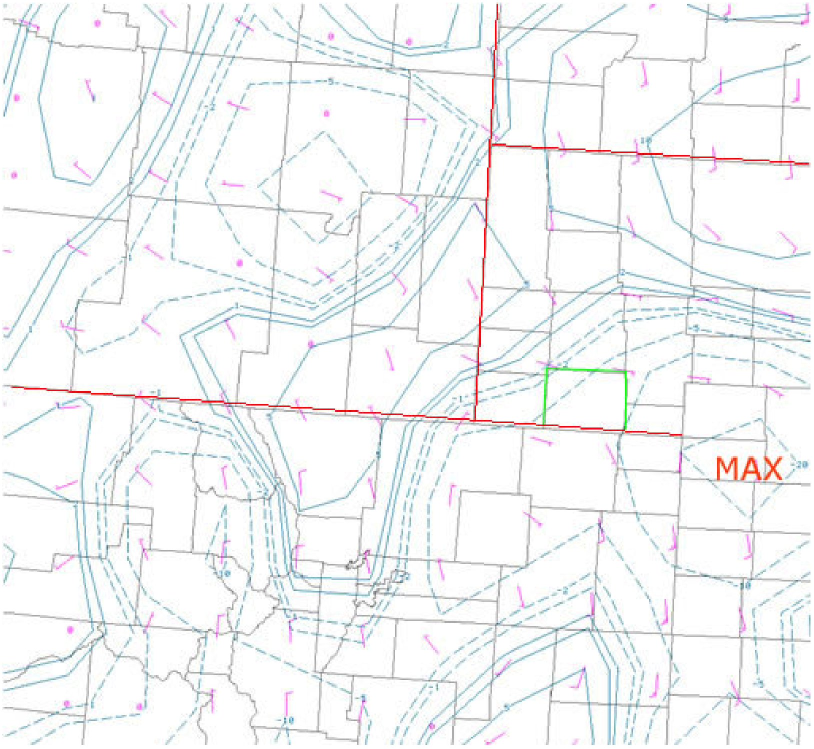


Figure 5 MSAS Surface Wind and Moisture Convergence at 1800 UTC Over Area of Study

Other parameters also became more favorable for thunderstorms over the southern Nebraska panhandle by the early afternoon. The surface boundary moved slowly northwest into central Cheyenne County by 21 UTC. To the west of the boundary temperatures were in the lower to mid 50s, while to the east they were in the upper 50s. MSAS indicated an axis of higher surface potential temperatures extending into Cheyenne County from the southeast by 21 UTC (not shown) as well as surface relative vorticity centered near Limon, CO, extending into Cheyenne County (Figure 6), indicating low level wind shear was present.

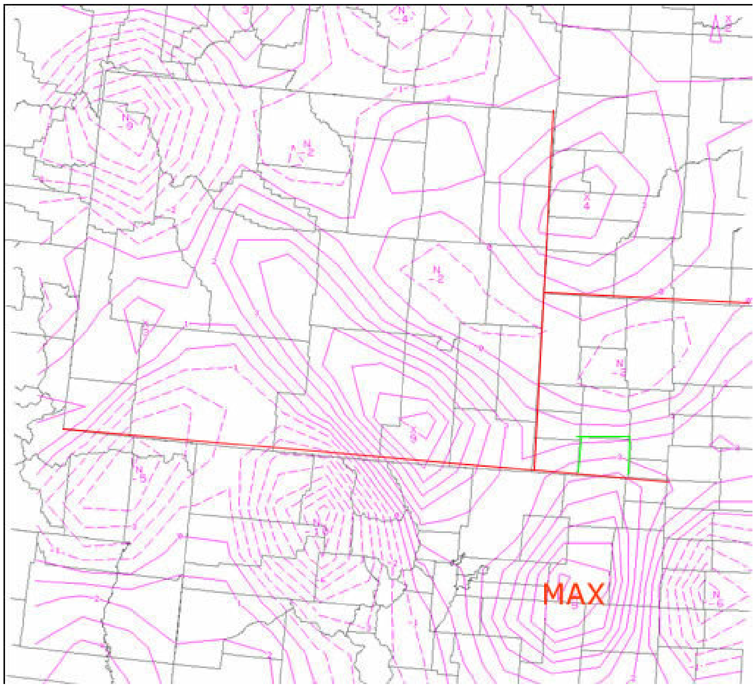
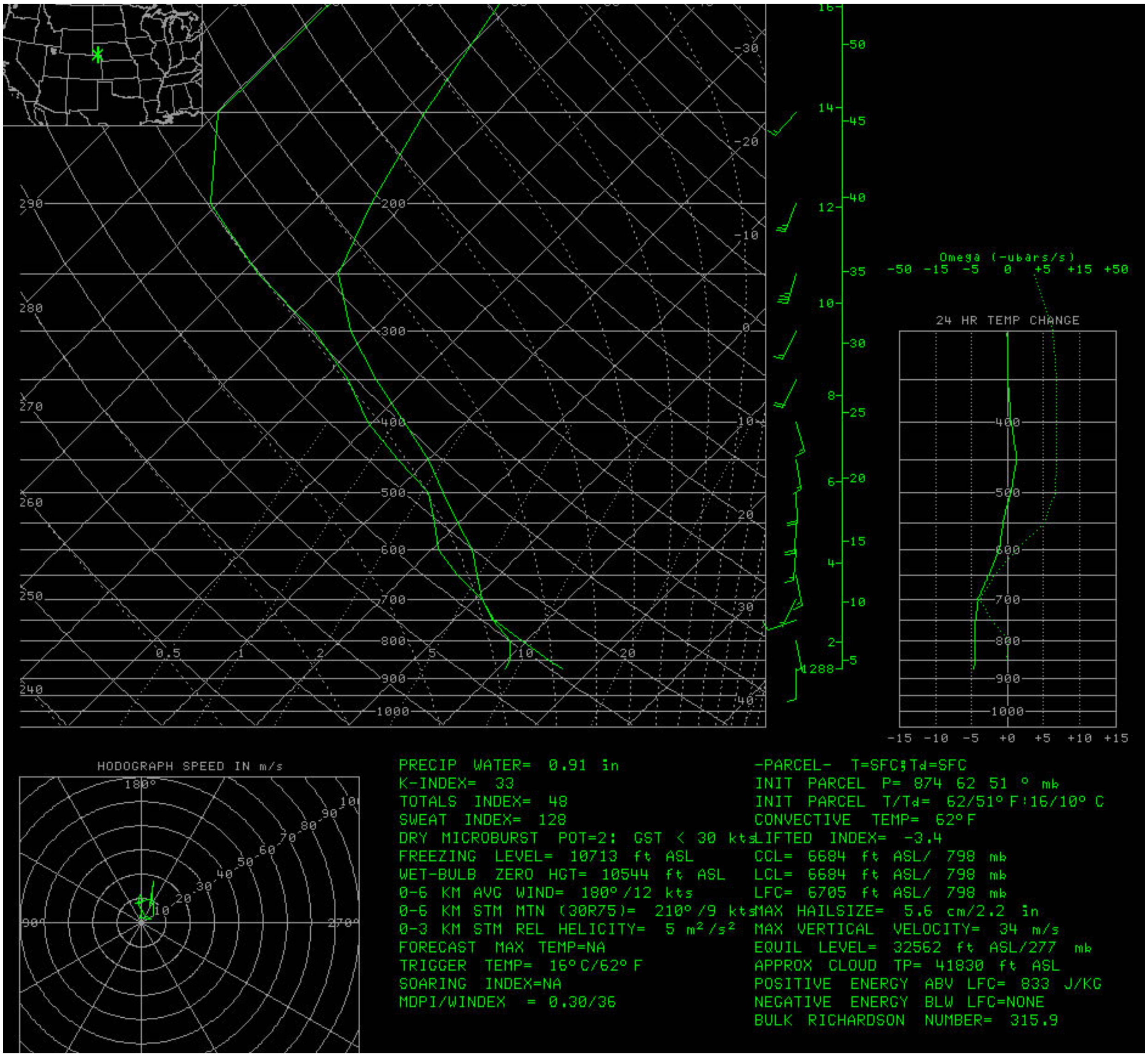


Figure 6 MSAS Surface Relative Vorticity at 2100 UTC Over Area of Study

The 21 UTC LAPS (Schultz) vertical profile for Sidney, NE (Figure 7) indicated positive buoyancy of about 833 j/kg, no CIN and lifted indices of -3.4C.



```
PRECIP  WATER=  0.91  in              -PARCEL-  T=SFC;Td=SFC
K-INDEX=  33                          INIT  PARCEL  P=  874  62  51  °  mb
TOTALS  INDEX=  48                    INIT  PARCEL  T/Td=  62/51° F:16/10° C
SWEAT  INDEX=  128                    CONVECTIVE  TEMP=  62° F
DRY  MICROBURST  POT=2:  GST  <  30  ktsLIFTED  INDEX=  -3.4
FREEZING  LEVEL=  10713  ft  ASL      CCL=  6684  ft  ASL/  798  mb
WET-BULB  ZERO  HGT=  10544  ft  ASL  LCL=  6684  ft  ASL/  798  mb
0-6  KM  AVG  WIND=  180° /12  kts    LFC=  6705  ft  ASL/  798  mb
0-6  KM  STM  MTN  (30R75)=  210° /9  ktsMAX  HAILSIZE=  5.6  cm/2.2  in
0-3  KM  STM  REL  HELICITY=  5  m²/s²  MAX  VERTICAL  VELOCITY=  34  m/s
FORECAST  MAX  TEMP=NA                EQUIL  LEVEL=  32562  ft  ASL/277  mb
TRIGGER  TEMP=  16° C/62° F           APPROX  CLOUD  TP=  41830  ft  ASL
SOARING  INDEX=NA                     POSITIVE  ENERGY  ABV  LFC=  833  J/KG
MDPI/WINDEX  =  0.30/36               NEGATIVE  ENERGY  BLW  LFC=NONE
                                      BULK  RICHARDSON  NUMBER=  315.9
```

Figure 7 21 UTC LAPS Raob for Sidney, NE

4. Radar

The area radars (including the CSU-CHILL facility north of Greeley, CO) had difficulty detecting any low level circulation on the afternoon of October 6, 2004 due to their distance from the area of study. There was an additional problem of range folding over that same area, limiting velocity and spectrum width base data. However, quickly reviewing the synoptic and mesoscale patterns described in earlier sections of the paper would at least cause one to think that low-topped strong thunderstorms are possible. There may also be enough environmental low level vorticity to cause the storms to rotate and possibly become tornadic. Let's now look at some radar data to see if there may be more clues to the tornadic nature of the storms possibly early enough to warn with adequate lead time.

By 1935 UTC the Cheyenne radar started to detect a small thunderstorm about 10 nmi to the northwest of Sidney, NE (Figure 8).

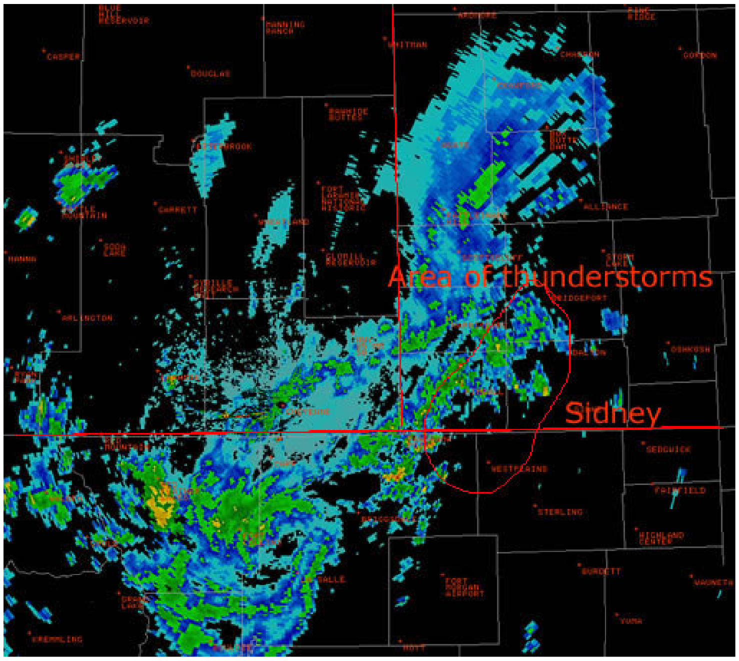


Figure 8 1935 UTC Cheyenne Radar base Reflectivity

At that time, there was a large area of showers and weak thunderstorms to the north and west of Sidney, NE, extending from Chadron, NE to Cheyenne, WY. Some weak reflectivity returns were also forming to the east of Sidney. The movement of the activity north and west of Sidney was to the southwest, with the few showers east of Sidney, moving to the north. On the Cheyenne radar, a convergent area was seen in the southern Nebraska panhandle pivoting around the upper and surface lows. By 2039 UTC, the convergent area was more pronounced on the Cheyenne radar and the developing strong cell was about 8 miles north-northwest of Sidney (Figure 9)

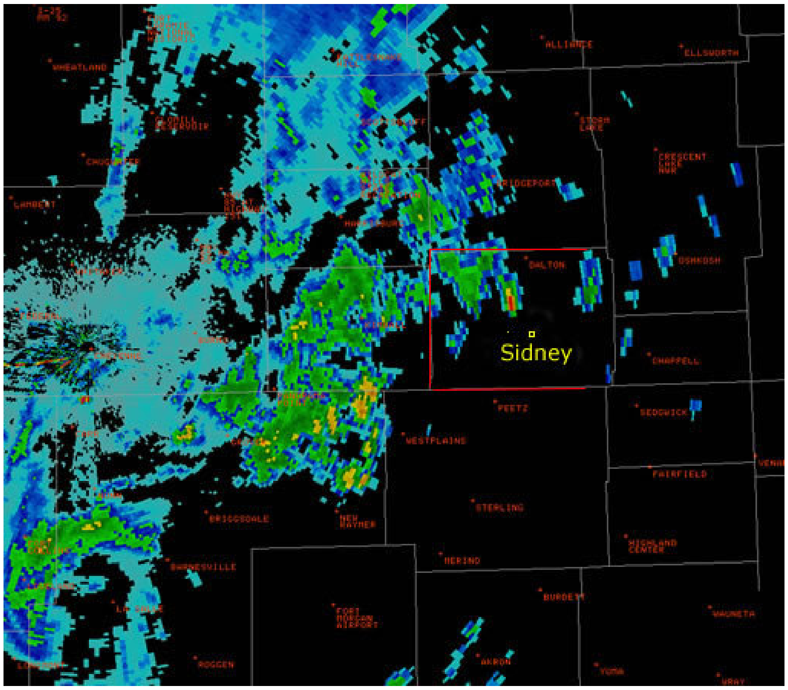


Figure 9 2039 UTC Cheyenne Radar Base Reflectivity

From the Cheyenne radar, the thunderstorm had base reflectivity at the 0.5 elevation slice to 57 dBz. The base velocity data for the storm had weak rotation of 10-15 kts over a 2 mile area (not shown).

Starting around 2044 UTC, the banded structure of the activity over and near Sidney became evident on the Cheyenne radar (not shown). The strong cell was 10 miles north-northwest of Sidney at that time, with the reflectivity at the 0.5 elevation now at 54 dBz on the Cheyenne radar. A slow northward movement of the cell was noted. At 2102 UTC, the time of the tornado, the cell was near Gurley, NE (north of Sidney), with a line of weaker convection extending back southwest into Colorado along a possible surface boundary (Figure 10).

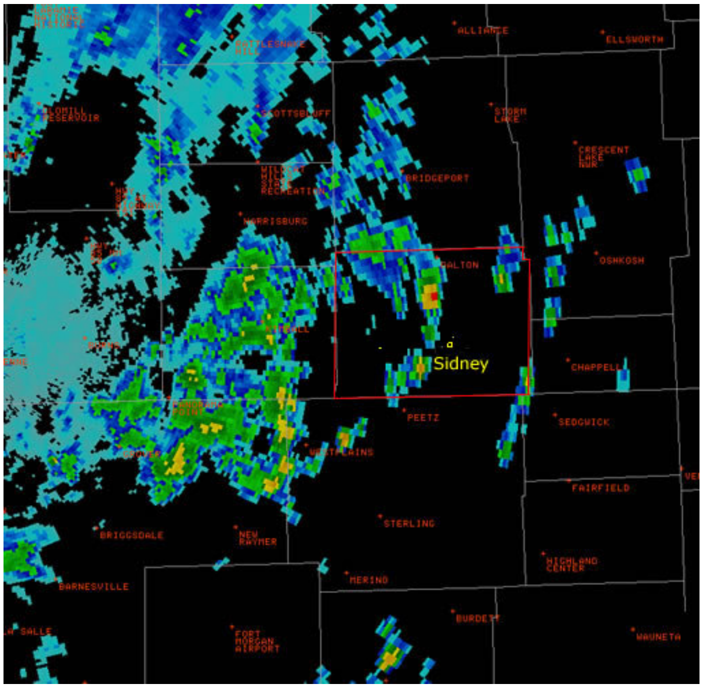


Figure 10 2102 UTC Cheyenne Radar Base Reflectivity

5. Satellite Imagery

Reviewing some of the radar data yielded some more clues for this situation, namely that there is weak rotation evident on the stronger storms as well as the identification of several possible boundaries within the area of study. The satellite data for the event will now be shown to, hopefully, provide more information.

The water vapor satellite imagery for the early afternoon showed the circulation that was over northeast Colorado and extending into the southern Nebraska panhandle (not shown). Perhaps most revealing was the visible satellite imagery which by 1930 UTC depicted a boundary over northwest Cheyenne County and another developing in the southeast part of the county (Figure 11).

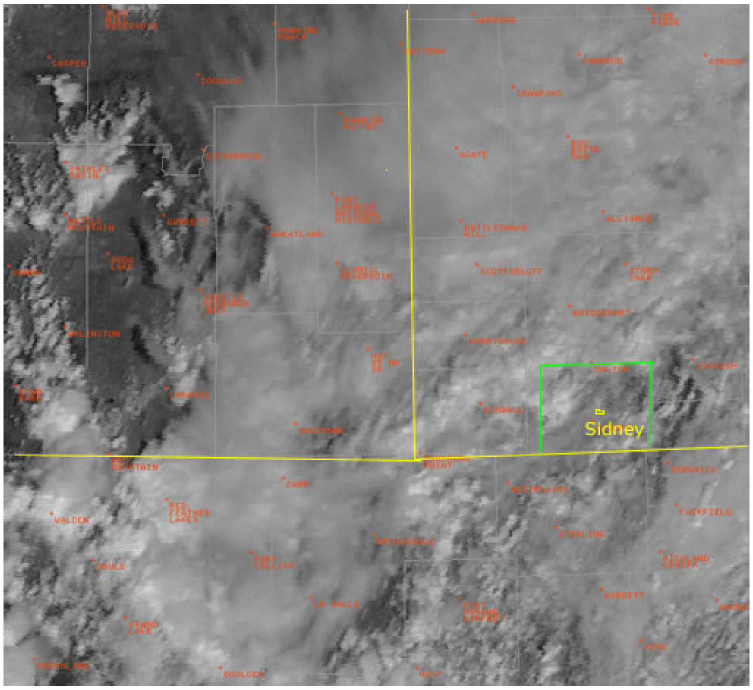


Figure 11 **1935 UTC Visible Satellite Imagery Over the Area of Study**

The boundary in the northwest part of the county drifted slowly east, while the boundary in the southeast part of the county was moving to the northwest. Convective showers and storms formed on each boundary. Using the visible satellite imagery and the Cheyenne radar's base reflectivity, the estimated width of each boundary was 1 to 3 miles. The movement of the northwest boundary was to the east at 1.75 m/s. While the movement of the southeast boundary was to the west at 5 m/s. At 21 UTC, the boundaries had collided, with the strong cell near the intersection point becoming tornadic (Figure 12).

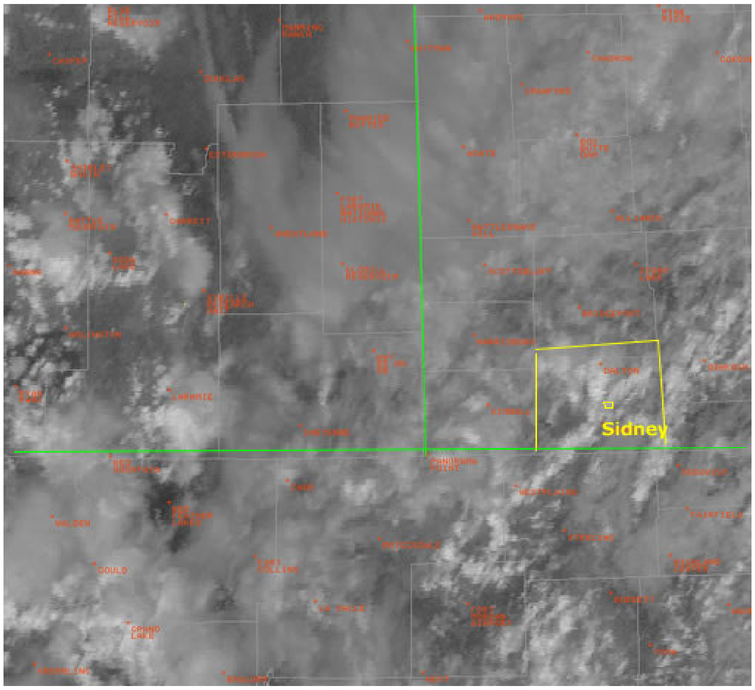


Figure 12 2100 UTC Visible Satellite Imagery Over Area of Study

6. Conclusion

No Warning was issued for this event, primarily due to the non-typical tornadic storm structure and the time of year. By keeping a high level of situational awareness well before the storms formed (knowing of the marginally favorable environment) and then using radar and satellite data, it may have been possible to anticipate weak tornadogenesis. Studies have shown that many tornadic supercells occur from boundary interactions (Mahoney). This case study is a good example where a boundary intersection was critical in the formation of a late season small and brief tornado by providing the needed shear.

The intersecting boundaries provided enhanced vertical and horizontal vorticity and increased storm relative helicity in the environment over Cheyenne County during the mid afternoon of October 6, 2004 (Brady). The vertical shear, instability and buoyancy from the 2100 UTC LAPS vertical profile at Sidney were probably insufficient to produce a tornado without the presence of a boundary.

Computing the updraft strength in this case using an estimated boundary width of 1.5 km and estimated depth of 2 km yielded 7 m/s (Mahoney). With the converging boundaries, the pre-storm vertical velocity was .009 s-1 which is near the threshold for favored non-mesocyclone tornadoes. It is thought that at the point of boundary intersection, updraft strength and vertical vorticity would be much greater.

This case study is an example of where maintaining situational awareness for a rare event is critical. Radars did not or could not indicate a tornado due to their limitations. But using visible satellite imagery in conjunction with the existing environment gave clues that a tornado could develop.

7. Acknowledgements

The author would like to thank David Copley (Science and Operations Office) and William Parker (Meteorologist in Charge) from the WFO Cheyenne office for their review of this paper.

8. References

Bluestein, H.B., 1985: The Formation of a "Landspout" in a "Broken Line" Squall Line in Oklahoma, Preprints, *14th Conf. on Severe Local Storms,* Indianapolis, IN, Amer. Meteor. Soc., 267-270.

Brady, R.H. and E.J. Szoke, 1989: A Case Study of Non Mesocyclone Tornado Development in Northeast Colorado Similar to Waterspout Formation. *Mon. Wea. Rev.,* **117**, 243-256.

Davies, Johnathin M. and Guyer, Jared L., 2004: A Preliminary Climatology of Tornado Events with Closed Cold Core 500 mb Lows in the Central and Eastern United States.

Mahoney, William 3, P., 1988: Gust Front Characteristics and the Kinematics Associated with Interacting Thunderstorm Outflows. *Mon. Wea. Rev.*, **116**, 1474-1492.

Miller P.A. and M.F. Barth, 2002: The AWIPS Build 5.2.2 MAPS Surface Assimilation System (MAPS). *Preprints, Interactive Symposium on the Advanced Weather Interactive Processing System (AWIPS),* Jan. 13-17, 2002.

Schultz P., 1996: Local Data Analysis and the Mesoscale Model on the WFO-Advanced Workstation. *Preprints, 12th International Conf. on Interactive and Processing Systems (IIPS) for Meteorology, Oceanography and Hydrology,* Atlanta, GA, Amer. Meteor. Soc., 216-219.