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# EXAMINATION OF AN APPARENT LANDSPOUT IN THE EASTERN BLACK HILLS OF WESTERN SOUTH DAKOTA

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## 1. Abstract

On June 29, 1994, an apparent landspout occurred in the Black Hills of South Dakota. This landspout exhibited most of the features characteristic of traditional landspouts documented in eastern Colorado. The landspout lasted 3 to 8 minutes, had a width of less than 20 m and a path of 1 to 3 km, produced estimated wind speeds of F1 intensity (33 to 50 m $s^{-1}$), and emanated from a towering cumulus (TCU) cloud located along a quasi-stationary convergence/cyclonic shear zone. No radar echo was observed with this event; however, a supercell thunderstorm was located 80-100 km to the east.

National Weather Service meteorologists surveyed the "very localized" damage area and ruled out the possibility of the landspout being related to microburst, gustnado, or dust devil activity, as winds away from the landspout were less than 3 m $s^{-1}$. The landspout apparently "detached" from the parent TCU and damaged a farm which resulted in $1,000 dollars in expenses.

## 2. Introduction

During the late 1980's and early 1990's researchers documented a phenomenon with subtle differences from traditional tornadoes and waterspouts, herein referred to as the landspout (Seargent 1994; Brady and Szoke 1988, 1989; Bluestein 1985). The term "landspout" was actually coined by Bluestein (1985)(in the formal literature) when he observed this type of vortex along an Oklahoma squall line. The landspout lies somewhere on the spectrum between a tornado and a waterspout, and most closely resembles a waterspout over land. Landspouts are not associated with a supercell thunderstorm. At times lightning and thunder are also absent from the parent cloud (Seargent 1994), which is usually a rapidly developing cumulonimbus (CB) or towering cumulus (TCU) (Brady and Szoke 1988).

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Szoke and Augustine (1990) hypothesized that when a convergence boundary containing large values of cyclonic relative vorticity was present on the eastern Colorado plains, tornadoes could occur under less than ideal synoptic conditions traditionally associated with supercell tornadoes. Most landspouts have been documented in eastern Colorado, initiating along intersecting convergence lines (Brady and Szoke 1988). These intersecting convergence lines are already established well before the TCU develops. The TCU develops over the convergence axis due to enhanced localized convergence. As the updraft strengthens, vortex tubes are stretched vertically beneath the TCU giving rise to the landspout.

Landspout development can be better understood using the schematic model in Figure 1. In stage A, a convergence zone with pronounced cyclonic horizontal wind shear is present. By stage B, TCU (or CB) begin rapidly developing along or nearby the boundary. Coincidental location of the TCU updraft over a misocyclone (i.e. < 4 km wide circulation, Fujita 1981) results in landspout formation at stage C. Doppler radar has been able to detect these misocyclones at distances < 45 km (Wakimoto and Wilson 1989), but WSR-88D data are not yet available to the National Weather Service in Rapid City. In the future (hopefully 1996), the WSR-88D will be operational and may be able to detect the signatures in the velocity display that identify landspouts or non-supercell tornadoes. In this paper, the authors present a case of an apparent landspout over the South Dakota Black Hills, and compare it to previous investigations of non-supercell tornadoes and landspouts.

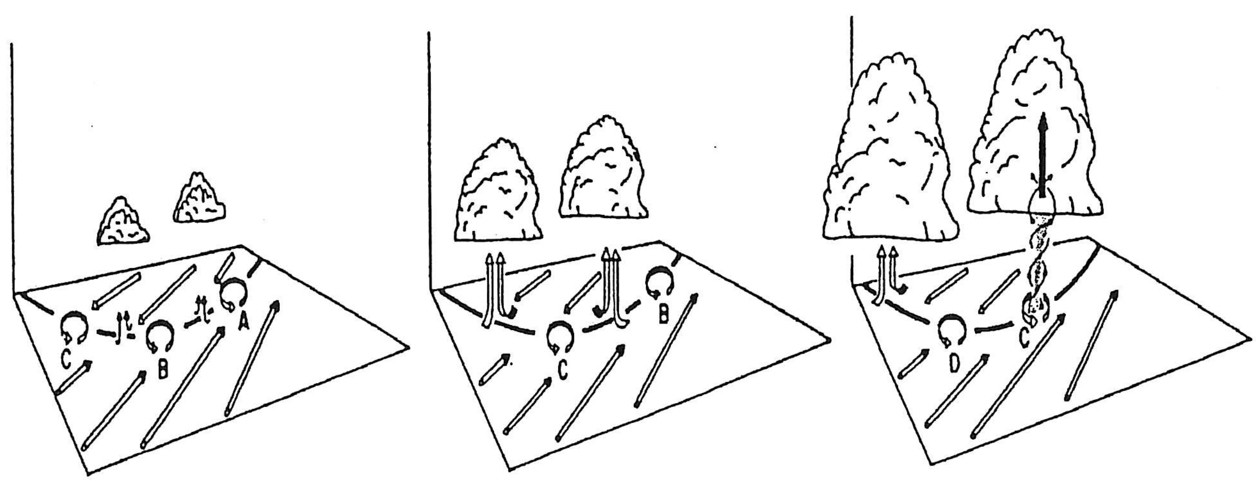


Figure 1. Schematic model of the development of a landspout. The relative solid dashed line is the convergence zone with pronounced cyclonic vorticity and horizontal wind shear. Low-level misocyclones (Fujita 1981) are labeled with letters A-D. Figure reproduced from Wakimoto and Wilson (1989).

## 3. The Event

On 29 June 1994, at approximately 2145 UTC, a rancher 14 km southwest of Custer, South Dakota (50 km southwest of Rapid City), observed a rapidly rotating column of air in contact with the ground. This vortex was very narrow and ropelike (< 20 m wide), lasted for 3 to 8 minutes, had estimated wind speeds of 33 to 50 m $s^{-1}$ (F1 tornado intensity), and traveled 1 to 3 km before it dissipated. Although the vortex developed beneath a TCU, the vortex eventually "detached" from the parent cloud and moved east. Skies were mostly clear when the vortex finally dissipated 1 to 2 km away from the parent TCU. Ambient winds were generally weak, less than 3 m $s^{-1}$. Many of these traits are characteristic of the reported landspouts in Colorado (Wakimoto and Wilson 1989).

The vortex produced considerable localized damage. A 725 kg (1600 pound) reinforced trailer was carried 20 meters and turned upside down, a chicken coup was destroyed, and a chain-link fence was flattened. The column also picked up an anchored shed from its foundation and held the debris suspended in the air for nearly 1 minute. The rancher estimated $1,000 dollars in damage. No other locations suffered any damage. The vortex was not recognized until it passed near the rancher's house, when it alerted individuals with a loud roar and bent 30 m pine trees 45 degrees from the vertical.

## 4. Synoptic Conditions

By late afternoon on 29 June 1994, a surface trough (associated with a convergence axis and moisture gradient) was located north-south across eastern Montana, the western South Dakota border, the Nebraska Panhandle, and eastern Colorado (Figure 2). East of the trough in the Dakotas and Nebraska, the airmass was generally conditionally unstable (not shown). Dew points in the mid to upper 50's were advected into western South Dakota by southeast winds. Behind the trough winds were westerly with dew points in the upper 20s and 30s. Further north, a weak area of low pressure was developing in north-central Montana and southern Saskatchewan in response to an advancing mid-tropospheric short-wave trough (not shown) from the Pacific Northwest. However, the mid-level dynamics were weak over western South Dakota due to the influence of a short-wave ridge over this area. Similar benign synoptic settings were also observed with many of the landspouts in Colorado (Brady and Szoke 1988, 1989).

The 0000 UTC 30 June 1994 Radiosonde Observation (RAOB) analysis for Rapid City indicated low to moderate instability with a CAPE of 443 J $kg^{-1}$, Lifted Index of -2°C, and a Total-total value of 53 °C, using the lowest 100 mb mixed layer (Figure 3). The Bulk Richardson Shear (BRS) was 95 $m^2$ $s^{-2}$, with a Bulk Richardson Number (BRN) of 5 (Hart and Korotky 1991).

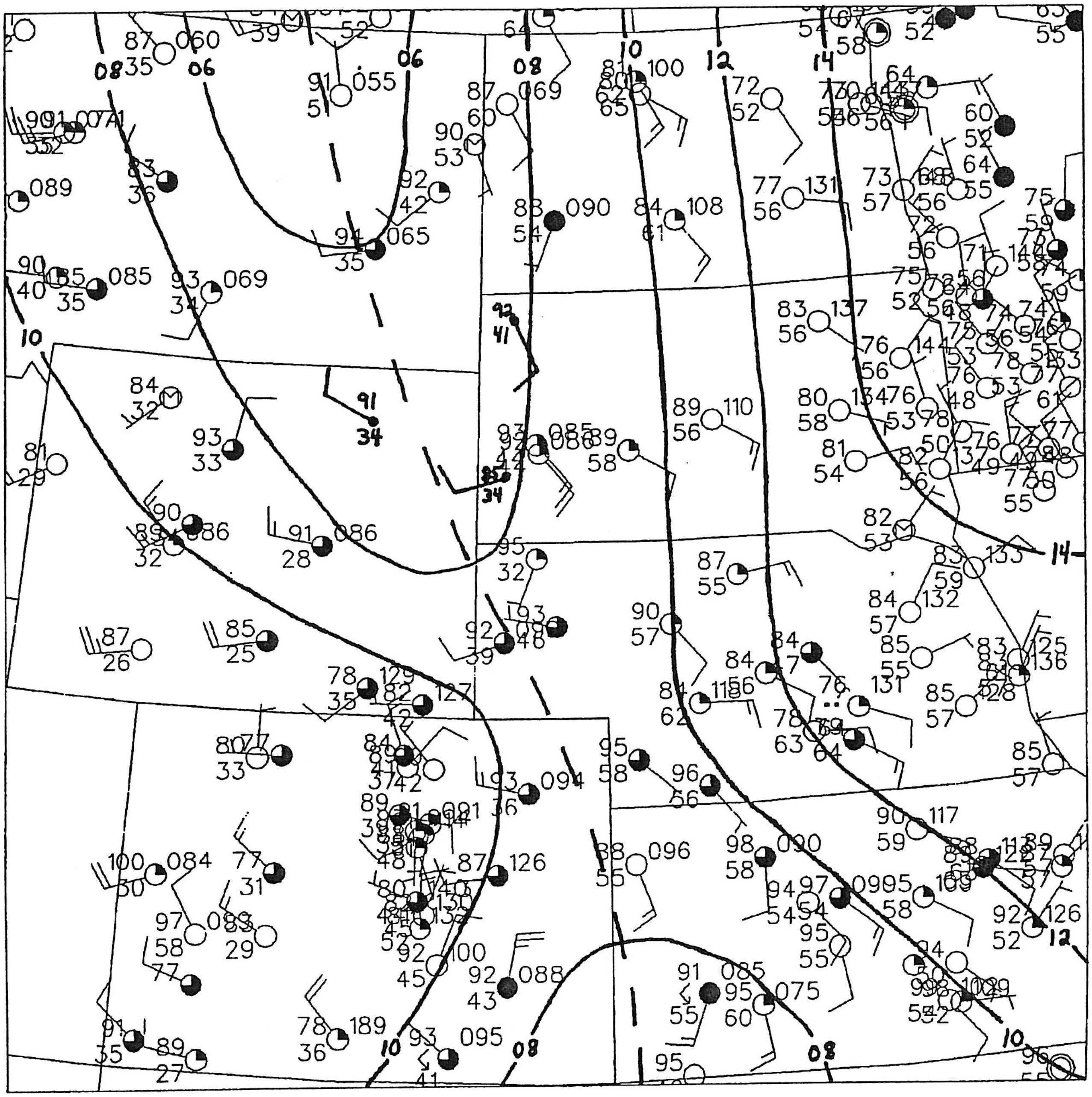


Figure 2. The surface map for 2200 UTC 29 June 1994, with conventional station plots and subjectively analyzed sea-level isobars at 2 hPa intervals. Observations of wind direction and speed (kts) and temperature/dew point (°F) were manually plotted for Gillette, Wyoming; and Buffalo and Custer, South Dakota. Custer is identified on the figure, and the surface trough is subjectively indicated with a dashed line.

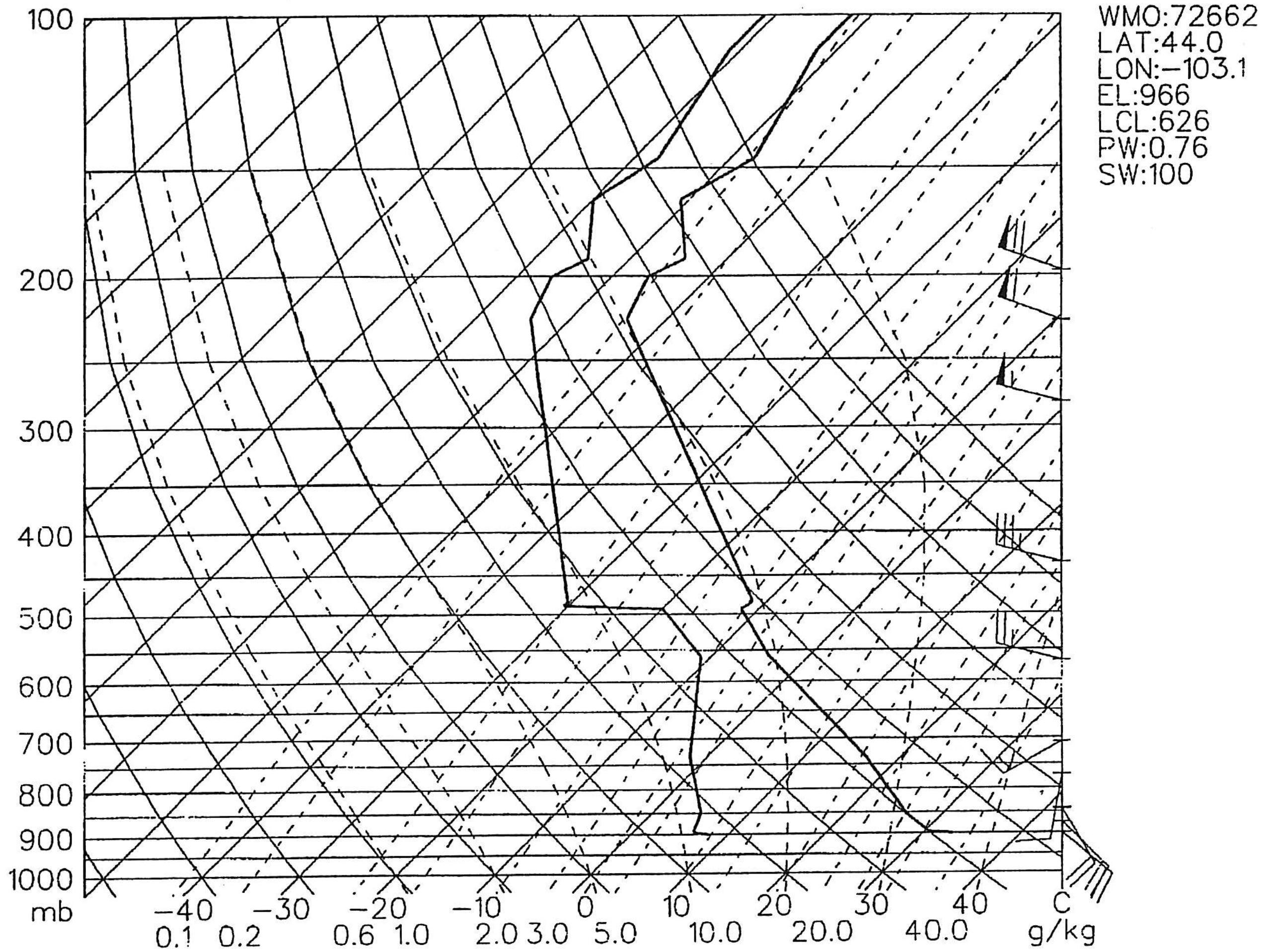


Figure 3. The Rapid City sounding for 0000 UTC 30 June 1994. Wind speed in knots and temperature/dew point in °C. Convective Available Potential Energy (CAPE) = 443 J kg$^{-1}$, Lifted Index (LI) = -2 °C, Total Totals (TT) = 53 °C, Bulk Richardson Number (BRN) = 5, and Energy-Helicity Index (EHI) = 0.39. The BRN and EHI are dimensionless.

The BRS describes the ambient shear without respect to effects of directional and speed shear components; and the BRN provides limited value as a predictor of storm type, defined crudely as the ratio of CAPE to shear (Weisman and Klemp 1982, 1984). Results from Weisman and Klemp (1986) suggest that the above values would not favor supercells or well organized convection. However, Johns et al. (1993) show that BRN values ranging from 0-7 were associated with 47% of their 242 strong and violent tornado cases.)

The radiosonde was released 1.25 hours after the reported landspout occurred, and is fairly representative of the vertical thermodynamic and wind profile for the area at that time. These sounding parameters agree very well with those found by Wakimoto and Wilson (1989) for 27 vortices studied on the Colorado plains ($\overline{CAPE}$ = 389 J kg$^{-1}$, $\overline{LI}$ = -1.7). The sounding exhibited an inverted

"V" resulting from the dry low-level environment, which suggested the possibility of microbursts on this day (in fact 20-30 m $s^{-1}$ microburst winds were recorded in eastern Wyoming). Finally, the steep low-level lapse rate (superadiabatic at the surface) and dry low-level environment were also supportive of dust devil development.

The veering of the wind in the lowest 3 km produces a favorable shear profile for tornadoes (Davies-Jones 1984; Klemp 1987). However, the Energy-Helicity Index (EHI) was 0.39 for this RAOB, which is not conducive to mesocyclone induced tornadoes (Davies 1993)[2]. In addition, mid-level winds were weak to moderate (12.9-18 m $s^{-1}$), which is not favorable for supercell development (Klemp 1987).

One of the most essential features for landspouts, a convergence zone with high values of cyclonic relative vorticity and horizontal wind shear, was located over the Black Hills (i.e. southwestern South Dakota), as evidenced by the interpolated wind vector field (Figure 4). Although not illustrated in Figure 4, winds were from the southwest at Custer and along the western Black Hills at 2200 UTC (Figure 2). An area of enhanced cyclonic relative vorticity was located just to the west of the Black Hills in eastern Wyoming (Figure 5), but the lack of surface observations for northeastern Wyoming may have erroneously placed this feature too far west. With the north-south convergence boundary, a cyclonic shear zone, and developing TCU, the ingredients were in place for landspout formation. Additionally, a thin cloud line was present in this area which indicated a second convergence zone. This boundary may have been produced by thunderstorm outflow which we next examine.

Shortly after the report of a "twister" was received, radar (WSR-74C) was used to thoroughly interrogate the suspect area, but no echo was observed. The lack of a radar echo near Custer is even more evidence of a landspout. Because landspouts sometimes form during the early stages of TCU development, there is not enough water present in the developing cloud to produce a detectable echo, also true for the WSR-88D. It is also possible that a radar echo was undetectable due to ground clutter near Custer. Nonetheless, no visual observations from Rapid City suggested CB development in that area, only TCU. Additionally, the Alliance, Nebraska, radar overlay for 2125 UTC (twenty minutes prior to the event) and at 2228 UTC confirmed the absence of radar echoes over Custer (not shown). (In the future, if there are strong updrafts at mid levels over a persistent low-level convergence boundary, the new WSR-88D may be able to detect landspout formation beneath any developing TCU by using numerous tilt sequences.) Although no radar echo was observed, visible satellite imagery indicated TCU over the immediate Custer area (Figures 6a, b). Notice

[2]Briefly, the EHI is a measure of the positive 0-2 km storm-relative helicity in combination with CAPE. The parameter was developed based on Johns et al. (1993) data set for 242 strong and violent tornadoes. Davies (1993) suggests that values greater than 2.5 are supportive of mesocyclone-induced tornadoes.

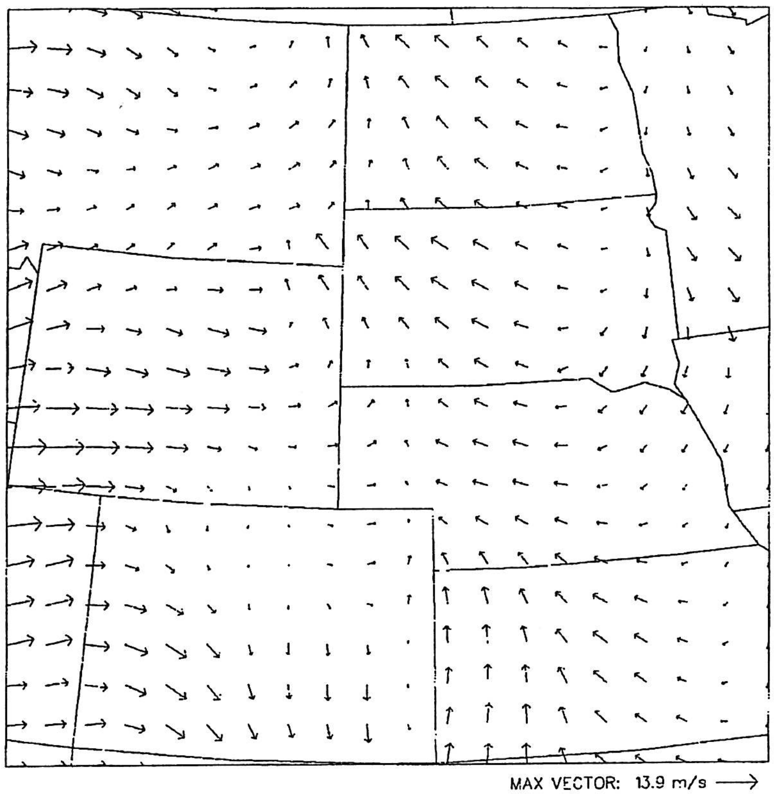


Figure 4. Interpolated surface wind vectors (m $s^{-1}$) for 2200 UTC 29 June 1994. Calculations performed using WXP (Purdue Weather Processor via Unidata) based on the surface data in Figure 2 (less the manually plotted stations).

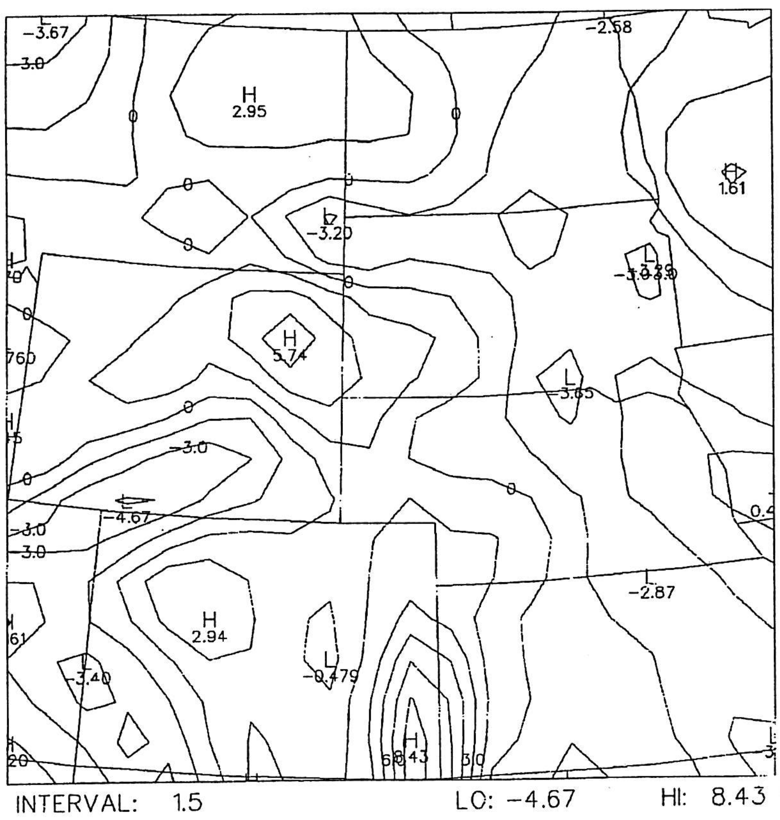


Figure 5. Surface relative vorticity for 2200 UTC 29 June 1994. (Interval spacing 1.5 $10^{-5}$ $s^{-1}$.) Calculations performed using WXP (Purdue Weather Processor via Unidata) based on the surface data in Figure 2 (less the manually plotted stations).

the growth in the photographs from 2000 UTC to 2200 UTC, indicative of strong updrafts. Also of interest is the thin cloud line (Figure 6a) which extended west from a thunderstorm located east of the Black Hills. The western "tip" of this cloud line is coincident with Custer. The importance of this cloud line is that it may have signaled yet another boundary, possibly produced by outflow from the thunderstorm to the east, which interacted with the established convergence boundary over the Black Hills to help produce the landspout. This is consistent with findings from Brady and Szoke (1988).

## 5. Similarities to a Landspout

Brady and Szoke (1988) define a landspout as a weak (F0 or F1) tornado which develops in a benign synoptic setting under a rapidly developing convective cloud. They require that the initial circulation is not associated with a thunderstorm mesocyclone or rear-flank downdraft (RFD) as described by Lemon and Doswell (1979). In addition, they specify that the landspout develops from the ground up to cloud base along colliding mesoscale boundaries which are present prior to the formation of the parent storm. In Seargent's (1994) examination of a landspout over Australia, he observed the following: (1) the cloud above the landspout was a TCU, and no one reported thunder or lightning; (2) the landspout formed along a trough axis; (3) the landspout cell showed no evidence of a rain shaft or glaciation; (4) updrafts were evident, but downdrafts were absent; and (5) a wall cloud or collar cloud was not evident. Wakimoto and Wilson (1989) also noted that these vortices tend to develop in the absence of a precipitation echo along convergence boundaries.

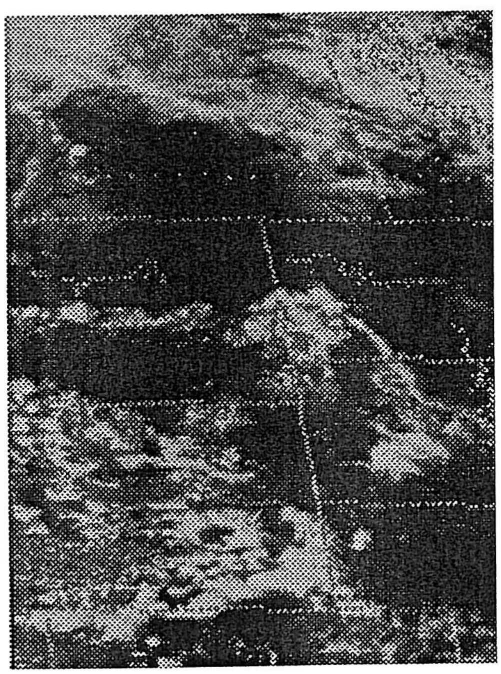

Figure 6a.

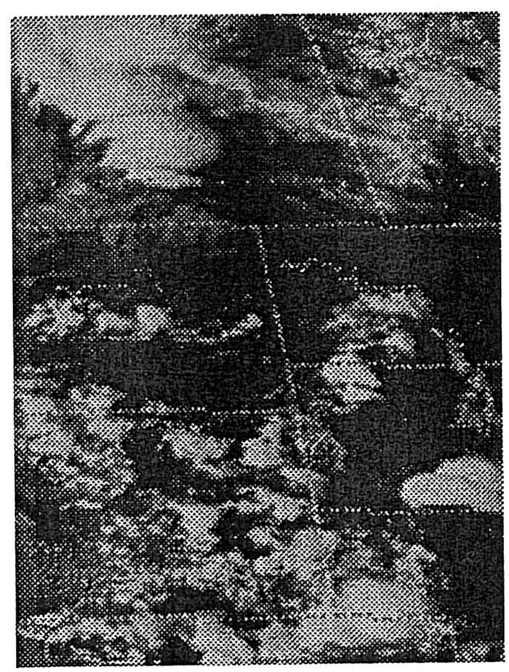

Figure 6b.

Figure 6. Visible satellite imagery on 29 June 1994 for (a) 2030 UTC and (b) 2130 UTC. (Resolution is 1 km.)

The apparent landspout near Custer, South Dakota, seemed to exhibit all these similarities. The topography of the Black Hills may have also interacted favorably with the convergence zone to aid in the production of cyclonic relative vorticity. The lack of a downdraft and rainshaft, and the duration of the landspout, refutes both microbursts and gustnadoes in this case. Furthermore, the considerable damage and eyewitness reports do not support the Custer vortex being a dust-devil, either. Also, wall cloud or any other cloud appendages were not seen with the landspout. Finally, Wilson (1986) indicated that nonprecipitation-induced cyclonic wind shear lines alone can result in tornadogenesis.

## 6. Summary and Conclusion

Although not previously documented in South Dakota, we have concluded the evidence most likely suggests the vortex near Custer, South Dakota, was a landspout. This type of phenomenon has been documented by Seargent (1994) in Australia, Bluestein (1985) in Oklahoma, and Brady and Szoke (1989), Wakimoto and Wilson (1989), and Szoke and Augustine (1990) in eastern Colorado, often times associated with the Denver Convergence Vorticity Zone (DCVZ). The Custer landspout was similar in almost all respects to the other documented landspout cases (i.e. Wakimoto and Wilson 1989). The only differences were that the landspout occurred over the Black Hills with the landspout apparently "detaching" from the parent cloud. Although tornadoes and landspouts are less common in elevated topography, landspouts have been observed over mountainous terrain (Bluestein 1993).

One possible explanation for the vortex detachment is that the atmosphere was too dry for condensation to be visible from ground to the parent cloud, which is not uncommon for tornadoes. Another reason may be that the TCU remained "anchored" to the ridge from which it originated because of orographic effects.

Finally, as discussed previously, the radar was not of value in detecting the landspout. However, it is possible that when the WSR-88D is deployed (~ September 1996), it can be used successfully to detect landspouts and the precursor convergence boundaries.

## 7. Acknowledgements

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