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THE CHEYENNE TORNADO OF 16 JULY 1979

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ABSTRACT

The most destructive tornado in Wyoming history moved across the north part of Cheyenne during the afternoon of 16 July 1979. The synoptic and mesoscale conditions leading up to that unprecedented event were highlighted by an outflow band from a Nebraska thunderstorm complex reinforcing a cold front near Cheyenne. The tornado's life cycle and transit across the city are described and depicted by a map and photographs, some of which reveal distinctive patterns of airflow in the immediate tornado environment.

1. INTRODUCTION

During the 3-month period 15 June - 15 September 1979, six tornadoes and numerous funnel clouds were observed from the National Weather Service office in Cheyenne. One of the largest of the tornadoes struck the city on the afternoon of 16 July, leaving in its wake one person dead, 57 injured, and an estimated $40 million in property damage. It was the first tornado to occur within the 112-year-old city of Cheyenne, and the most devastating tornado in the history of Wyoming. It thoroughly demonstrated the destructive capability of a tornado occurring along the front range of the Rocky Mountains.

Prior to the Cheyenne tornado, the most destructive tornado in the state, according to Beebe (1), occurred on 25 June 1928. It struck the town of Midwest, in central Wyoming, causing approximately $350,000 in damages. Despite this occurrence, however, extensive tornado damage in the state has been relatively rare. This fact is interesting to note, since Beebe indicated that the number of tornado reports in the state has risen sharply during the past few years (1). While only six tornadoes were recorded from 1870 to 1920, an average of 17 tornadoes were reported each year from 1976 to 1978. In addition, 33 tornadoes were reported during the 1979 tornado season, continuing the upward trend. It is believed that an increase in population, growing public awareness, and the establishment of better reporting channels were responsible for this increase rather than a change in climatic conditions.

Figure 1 depicts the distribution of tornado reports by county in the

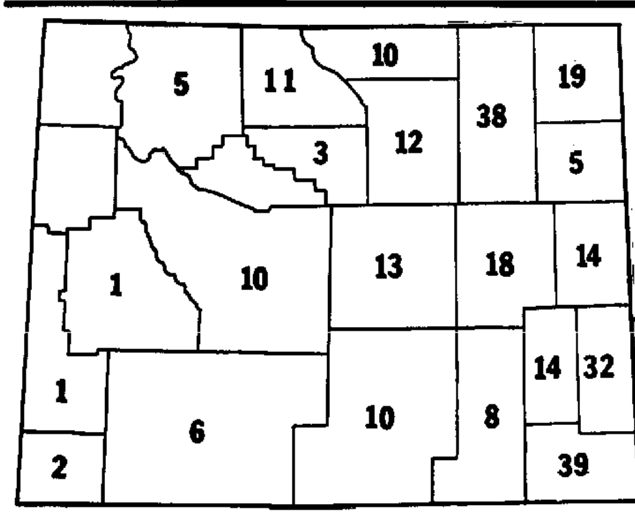

Fig. 1. The number of tornadoes reported by county for the state of Wyoming based on the historical record from 1870-1979. Revised after Beebe (1).

state of Wyoming. Eastern Wyoming is the area of greatest tornado frequency, and Laramie County in the southeast corner leads the list.

Coinciding with the apparent maximum of tornado reports in southeastern Wyoming, northeastern Colorado, according to Tecson et al (2), is the area of greatest tornado activity in that state. In addition, evidence suggests that the frequency of tornadoes in this area can be comparable to other ares of the country. Pearson et al (3) noted that Weld County adjacent to Laramie County, Wyoming, led the nation with the greatest number of reported tornadoes in 1976.

Despite this apparent frequency of tornado activity in northeastern Colorado, extensive damage from tornadoes there have been rare. Cook (4) noted that the town of Julesburg was hit by a tornado on 6 June 1947, causing an estimated $500,000 in damages, and Auer (5) cited a tornado that struck Loveland on 4 June 1965, injuring 19 people and causing approximately $750,000 in damages. While other reports of lesser damage have been noted, most tornadoes occurred over open rangeland, away from populated areas.

Even though damage reports are few for southeastern Wyoming and northeastern Colorado, it should not be assumed that all tornadoes that occur in these areas are relatively weak. Ominous looking tornadoes have been documented by Connel (6), Prosser (7), Golden (8), and Zipser and Golden (9). While these tornadoes produced relatively little damage, in each case their appearance was quite threatening. Given the apparent tornado frequency in southeastern Wyoming and northwestern Colorado, it would seem only a matter of time until a populated area would become victim to a significant tornado.

With the occurrence of the Cheyenne tornado, the destructive capability of a front range tornado was clearly revealed. The tornado inflicted severe damage to an airport, residential districts, a school, and a trailer park before dissipating.

The intent of this paper is to document the synoptic and mesoscale environment of the tornado, depict its physical characteristics by means of selected photographs, and describe the resulting damage. It is hoped that the information provided in this paper will contribute to a better understanding of the front range tornado.

2. SYNOPTIC AND MESOSCALE ANALYSIS

On 16 July, development of the tornado was determined to be caused by localized events along the front range, and no significant synoptic scale disturbances were found. In fact, most of the western and southern United States were dominated by weak flow aloft. Only in the extreme northcentral portion of the country could stronger winds be identified. A speed max at 300mb from the Dakotas to Michigan was on the underside of a trough, the axis of which extended northward into eastern Canada at 1200 GMT. Northwesterly flow was present over Montana and northeastern Wyoming. A summertime regime had been established over the western and southern portions of the country and a warm temperature anomaly blanketed much of the western states. A 30C isotherm at 850mb was centered over southern Utah at 1200 GMT.

As a result of the northwesterly flow over the northcentral United States, a strong high pressure system at the surface had moved into the northcentral states. By mid morning, a 1031mb center was over eastern North Dakota. On the southern extremity of the high, a cold front was positioned from central Ohio westward into northeastern Kansas, then northwest through Nebraska and northeastern Wyoming. The western boundary of the cold front showed indications of becoming diffuse by mid morning, however.

Buried in the northwesterly flow over Montana was a short wave trough, as evidenced on satellite imagery at 1200 GMT. The disturbance was positioned from northeastern Montana to northwestern Wyoming moving eastward at about 15 m/s. In advance of this disturbance, thunderstorms had developed in southeastern Montana after midnight, and by 1230 GMT they had moved to western South Dakota and intensified. The thunderstorms proceeded southeastward at about 17 m/s, moving into northcentral Nebraska by midday.

At 1802 GMT (Fig. 2), an arc cloud could clearly be seen in the southern portion of the Nebraska panhandle, a direct result of the thunderstorm outflow to the north. The arc cloud was estimated to be expanding southwestward at 17 m/s, and penetrated northeastern Colorado and southeastern Wyoming during the remainder of the day. Passage of the outflow boundary was estimated to be through Cheyenne around the time of the tornado.

Figs. 3a through 3d show the surface synoptic data at 1600, 1800, 2100, and 2300 GMT. Backing of the winds and an increase in speeds were noted in the Nebraska panhandle. Furthermore, low level confluent flow became pronounced around the outflow boundary as it moved through

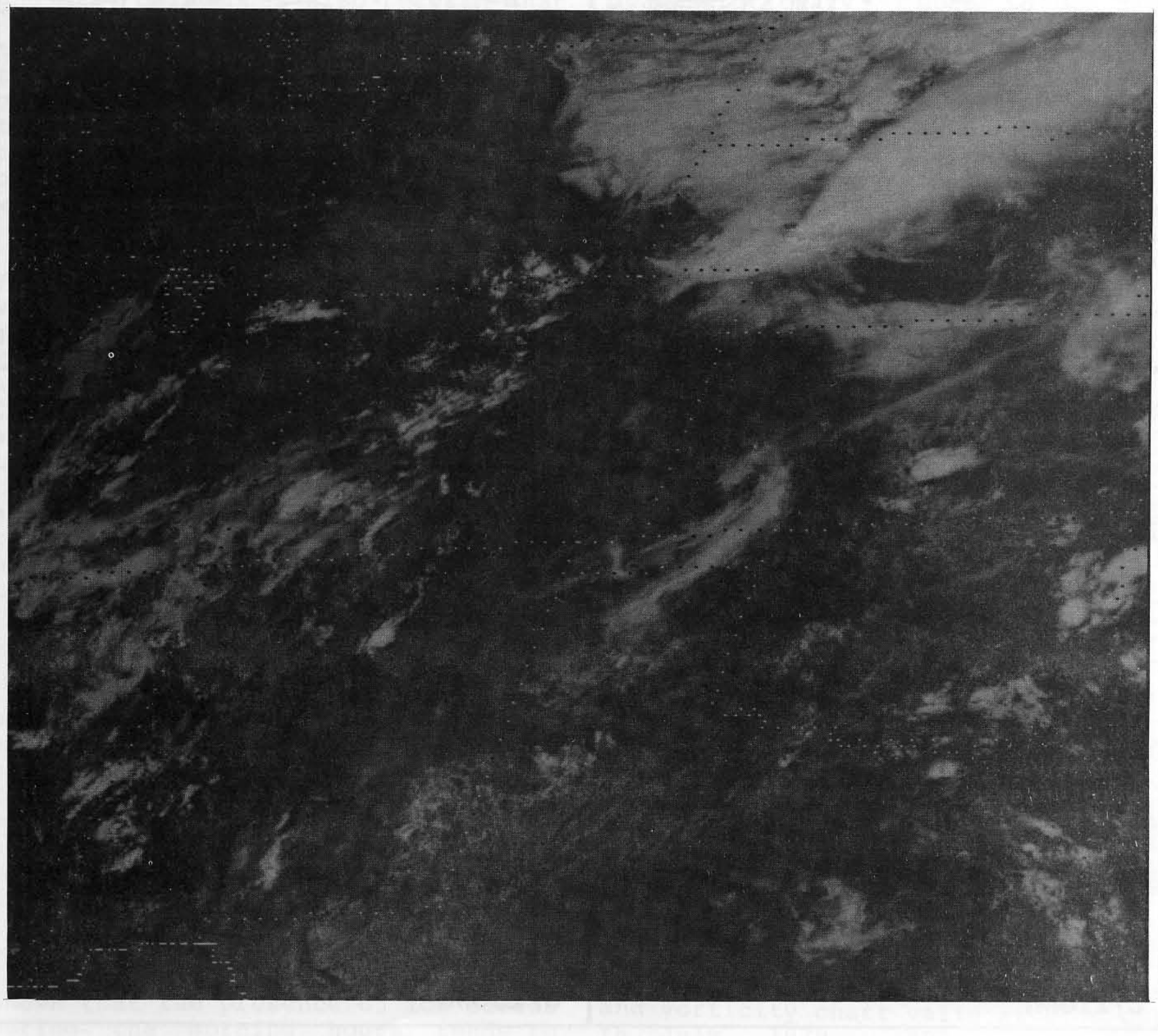

Fig. 2. GOES satellite imagery at 1802 GMT 16 July 1979. One half mile visual resolution. Depicts a thunderstorm outflow boundary in the form of an arc cloud in the southern Nebraska panhandle.

Nebraska, Wyoming, and Colorado. In advance of the outflow boundary in eastern Colorado, a thermal ridge intensified around 2100 GMT, further enhancing the dynamics.

Zipser and Golden (9) noted similar synoptic and mesoscale conditions associated with the tornadoes at Bennett, CO. The outflow from a mesohigh reinforced the orographic

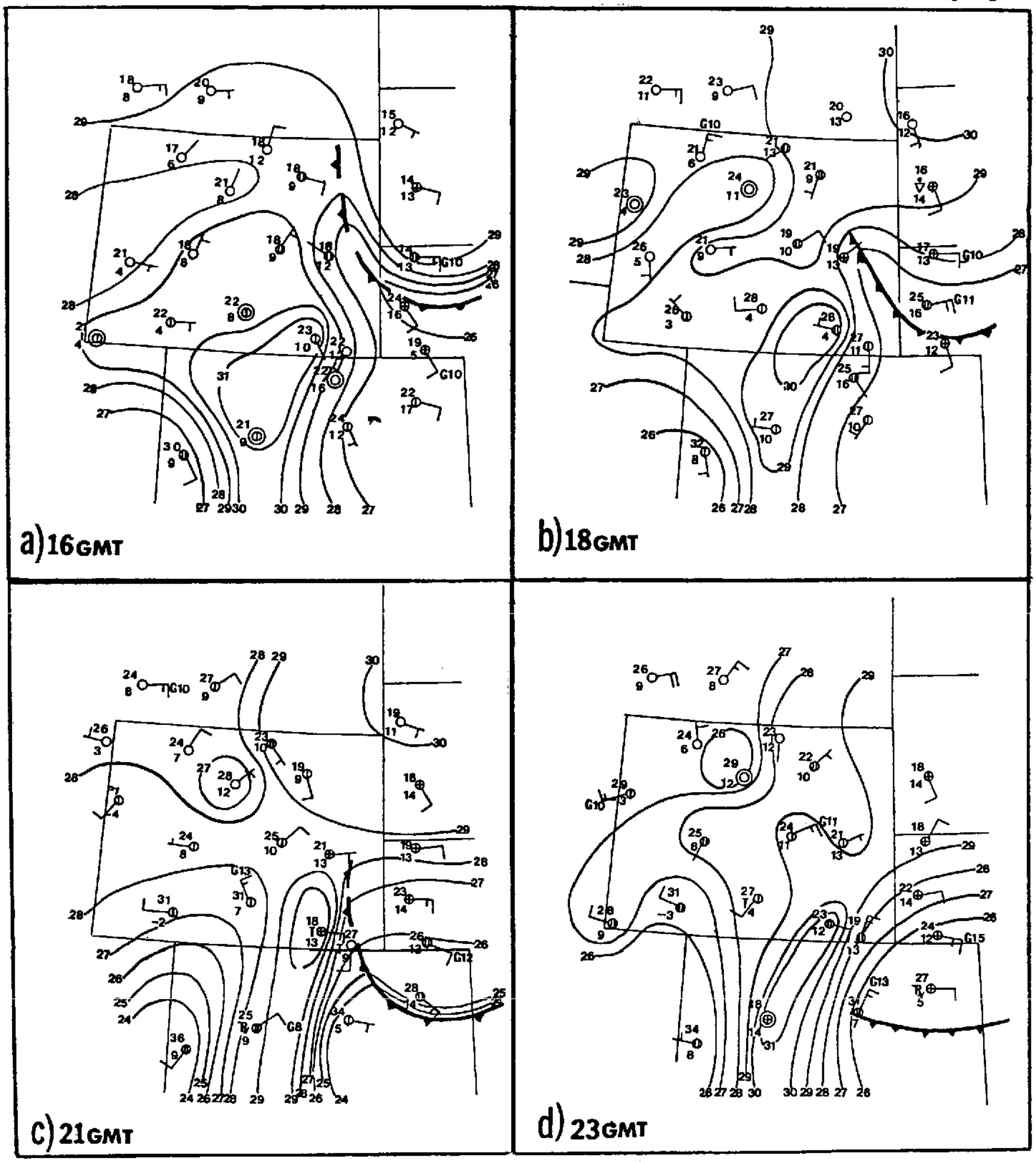

Fig. 3. Surface analyses for 16 July 1979. Pressure is altimeter setting converted to millibars less 1000. Full wind barb is 5 m/s. Temperature is dewpoint in degrees C.

upslope flow tendency in eastern Colorado, as well as enhancing an old frontal boundary. As with the Cheyenne tornado, an outflow boundary from previous thunderstorm activity was a key ingredient.

In a paper by Maddox et al (10), the importance of these outflow boundaries and their interaction with convective storms was emphasized. It was noted that the air mass provided by the thunderstorm outflow boundary was generally meso - β in scale (25 - 250 km), and therefore balanced flow does not exist. Furthermore, Maddox and his colleagues also stated that storms often reach maximum intensity and possibly become tornadic when they approach the thermal boundaries produced by thunderstorm outflow. In the case of the Cheyenne tornado, thunderstorms developed to the west of Cheyenne and eventually interacted with the intruding outflow boundary.

Fig. 4 shows the surface geostrophic winds with the associated absolute geostrophic vorticity values valid at 2100 GMT. It should be noted that an area of 'E' values is evident west of Cheyenne. 'E' represents values of absolute vorticity from 16 to 18 x 10 to -5 /sec. Given the latitude of this enhanced area, the values of absolute vorticity would mean that cyclonic relative vorticity was present. It is interesting to note that the area of 'E's developed and remained west of Cheyenne, showing no tendency for movement during the day.

In conjunction with the outflow boundary, it should be noted that low clouds were present in the Nebraska panhandle as well as northeastern Colorado by midday. Earlier that morning, low clouds and higher surface dewpoints spread into southeastern Wyoming. However, some drying took place along the front range shortly after sunrise. Studies by Purdom (11), Purdom and Gurka (12), and Weiss and Purdom (13) have shown that the presence of low clouds during the morning hours tends to retard surface heating, whereas adjacent clear areas will receive more insolation earlier and warm more rapidly. Such areas of persistent low clouds, as those in the Nebraska panhandle, tended to retard the convective development in that area, while the cloud-free area east of the front range favored thunderstorm development.

Along with the outflow boundary, as well as some moderate amounts of low-level moisture, mid-level tropospheric moisture was also available. Earlier that morning satellite imagery showed moisture, as indicated by enhanced cloud top temperatures, rotating anticyclonically in the circulation north of a quasi-stationary upper level high situated in the "Four Corners" area of the southwestern United States. Advection of this moisture became increasingly apparent as convection began to develop along the central mountains of Colorado and southern Wyoming by mid morning. Westerly to westnorthwesterly winds above 500mb tended to advect the developing thunderstorms eastward once deep convection had been established.

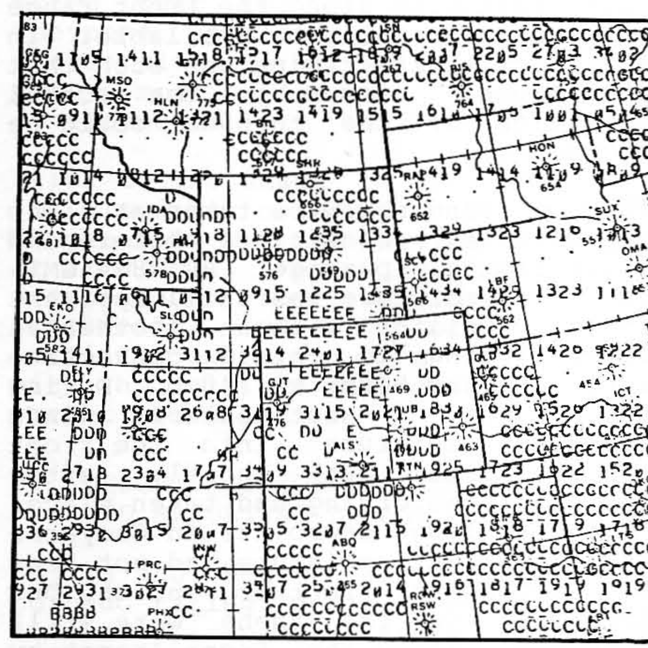

Fig. 4. The Surface geostrophic wind and vorticity chart valid at 2100 GMT 16 July 1979. "E" represents absolute vorticity values from 16 - 18 X 10 to -5 /sec. Winds are in tens of degrees and knots, ddff. After Hughes and Sangster (23).

With the presence of convection along the front range, and the outflow boundary moving in from the northeast, conditions appeared to be ripe for severe weather. Both low-level and upper-level moisture combined with the intrusion of the outflow boundary were felt to be key ingredients for the eventual tornado formation.

3. AIR MASS CHARACTERISTICS

Generally the closest soundings to Cheyenne would be either Denver, Colorado, or North Platte, Nebraska. However, on the day of the tornado, two special soundings were taken by personnel at the Department of Atmospheric Science on the Colorado State University campus in Fort Collins. The campus is located approximately 70km south southwest of Cheyenne at an elevation of 1579m MSL at the foot of the Colorado front range. The elevation of the Cheyenne airport is 1880m MLS. The soundings were taken at 1854 GMT and 2220 GMT and are depicted in Fig. 5. It is felt that these soundings provided a better estimation of the air mass characteristics along the front range than would normally be available. In addition, their timing was such that conditions closer to the actual formation of the tornado could be documented.

The two soundings were taken at times representing conditions before and after frontal passage. By 1854 GMT, low-level moisture was still apparent in Fort Collins with an isothermal layer acting to retard convective activity from 800mb to 740mb. During the night, southeasterly winds advected moisture into the front range area, but shortly after sunrise, some drying had taken place. Slightly lower dewpoints in Cheyenne suggested that moisture had not been as extensive further north, but dewpoints in the teens were still observed along the front range by midday.

While rapid drying was indicated above the low-level moisture on the midday sounding, another moist layer was again evident around 500mb. The advection of moisture northeast from the "Four Corners" area during the previous night was reflected in this region of moderate dewpoint depressions.

One of the most significant features of the 1854 GMT sounding was the deep adiabatic layer extending from 740mb to just above 500mb. The sounding was conditionally unstable, and a measure of the degree of instability was made by computing various severe weather indices. The vertical totals index, the total-totals index, and the sweat index discussed by Miller (14), were found to be 37.4, 56.3, and 290, respectively. Moreover, the SELS lifted index, described by Galway (15), was -5.5, based on the lowest 100mb. On the day of the tornado, it was felt that the deep

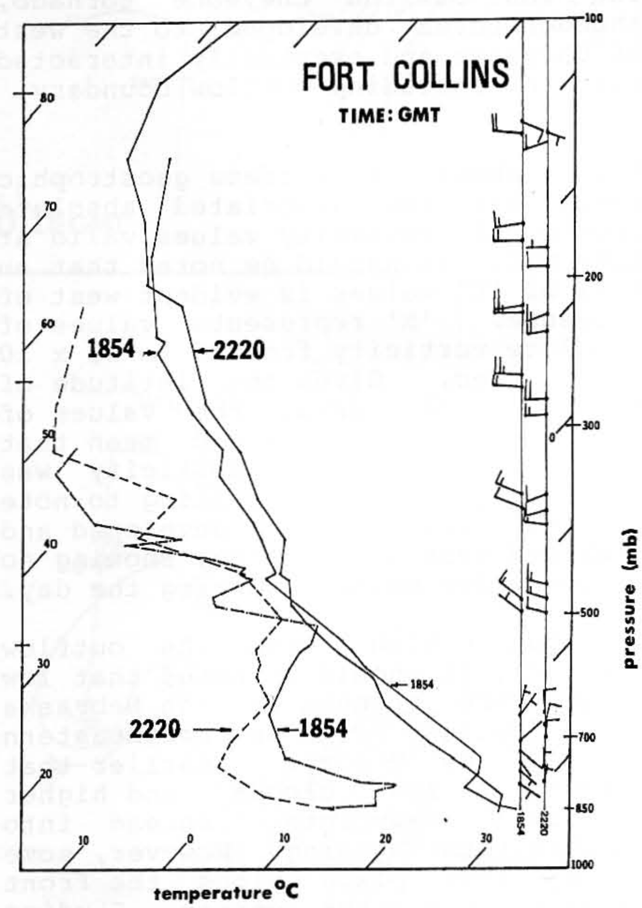

Fig. 5. Skew T, Log P diagram for two soundings taken in Fort Collins, Colorado, 16 July 1979, by the Department of Atmospheric Science at Colorado State University. The soundings were taken at 1854 GMT (1254 MDT) and 2220 GMT (1620 MDT). Full wind barb is 10 m/s.

adiabatic layer was a homogeneous property of the air mass along the front range, and that conditional instability was also present in the air over Cheyenne.

By 2220 GMT a backing of the winds and cooler temperatures were noted in the lower levels, indicating that the outflow boundary had pushed through Fort Collins. Drying was also evident in the low levels, but moisture around 500mb was still available. As with the earlier sounding, the deep adiabatic layer was still present. However, it had been slightly modified by late afternoon. The SELS lifted index was now -0.5, whereas, the vertical totals index had increased to 37.7, the total-totals index climbed to 59, and the sweat index was 374. Even though drying had taken place in the lower levels, the sounding was still conditionally unstable.

Another important property on both soundings was the presence of wind shear. As would be expected, the wind shear became more pronounced, as indicated on the latter sounding, by passage of the outflow boundary. The backing of the winds and an increase in speeds enhanced the wind shear, as westerly winds prevailed aloft. Maddox (16) presented evidence that low level wind shear was a critical factor in the tornado environment. By constructing mean hodographs, he was able to show this result. Even though the hodograph for the 2220 GMT sounding differed from those drawn by Maddox, the wind shear was clearly evident.

With the presence of a deep adiabatic layer along the front range on the day of the tornado, conditions for intense convection were possible. It was felt that the formation of the tornado, however, was strongly linked to the passage of the outflow boundary and associated wind shear.

4. EVENTS PRECEDING TOUCHDOWN

By 1800 GMT thunderstorms had developed in the southeastern portion of Wyoming as well as along and west of the mountains in central Colorado and south central Wyoming. As shown on the Alliance, Nebraska, radar scope photography (Fig. 6) the thunderstorms which developed in southeast Wyoming were in proximity to the Cheyenne Ridge, an east-west rise aligned from Cheyenne to the Laramie Range. In a paper by Henz (17), an attempt was made to identify favored areas for convective development along the front range of southeastern Wyoming and eastern Colorado. The Cheyenne Ridge was determined to be a region that showed a tendency for frequent thunderstorm activity.

While thunderstorms continued to develop in southeastern Wyoming, by 2038 GMT (Fig. 6a), two storms were of particular interest: one to the west of Cheyenne, over the Laramie Range, and another in northeastern Colorado, cells A and B, respectively. By 2138 GMT (Fig. 6b), cell A to the west of Cheyenne had approached in intensity. Cell B over northeastern Colorado had reached severe limits, and was clearly the more threatening of the two. At the time of the tornado, it should be noted that Cell A to the west of Cheyenne appeared to be the parent cloud, with the vortex to the east of the most intense convective development.

Prior to the onset of the tornado, a low cloud was observed to the west of Cheyenne by Weather Service personnel at 2110 GMT. Eventually, the tornado dropped down from the cloud over the northwest portion of the city, initially appearing as a "dust devil" with no visible attachment to the parent cloud.

5. DESCRIPTION OF THE TORNADO AND RESULTING DAMAGE

Fujita and Pearson (18) described a tornado rating scale based on damage intensity, path length, and path width - the FPP Scale. The values for the Cheyenne tornado based on this rating scale were determined to be 422. F4 damage was found in a portion of the Buffalo Ridge housing area (Fig. 7) where large two-story, single family houses were reduced to foundations surrounded and covered by debris. Fujita and Pearson also indicated that F4 damage would result from tangential wind speeds of 92-117 m/s (200-250 mph).

The length of the tornado's track from first sighting to last systematic deposition of debris was 11.2km (6.7mi). However, it was found that the tornado apparently was

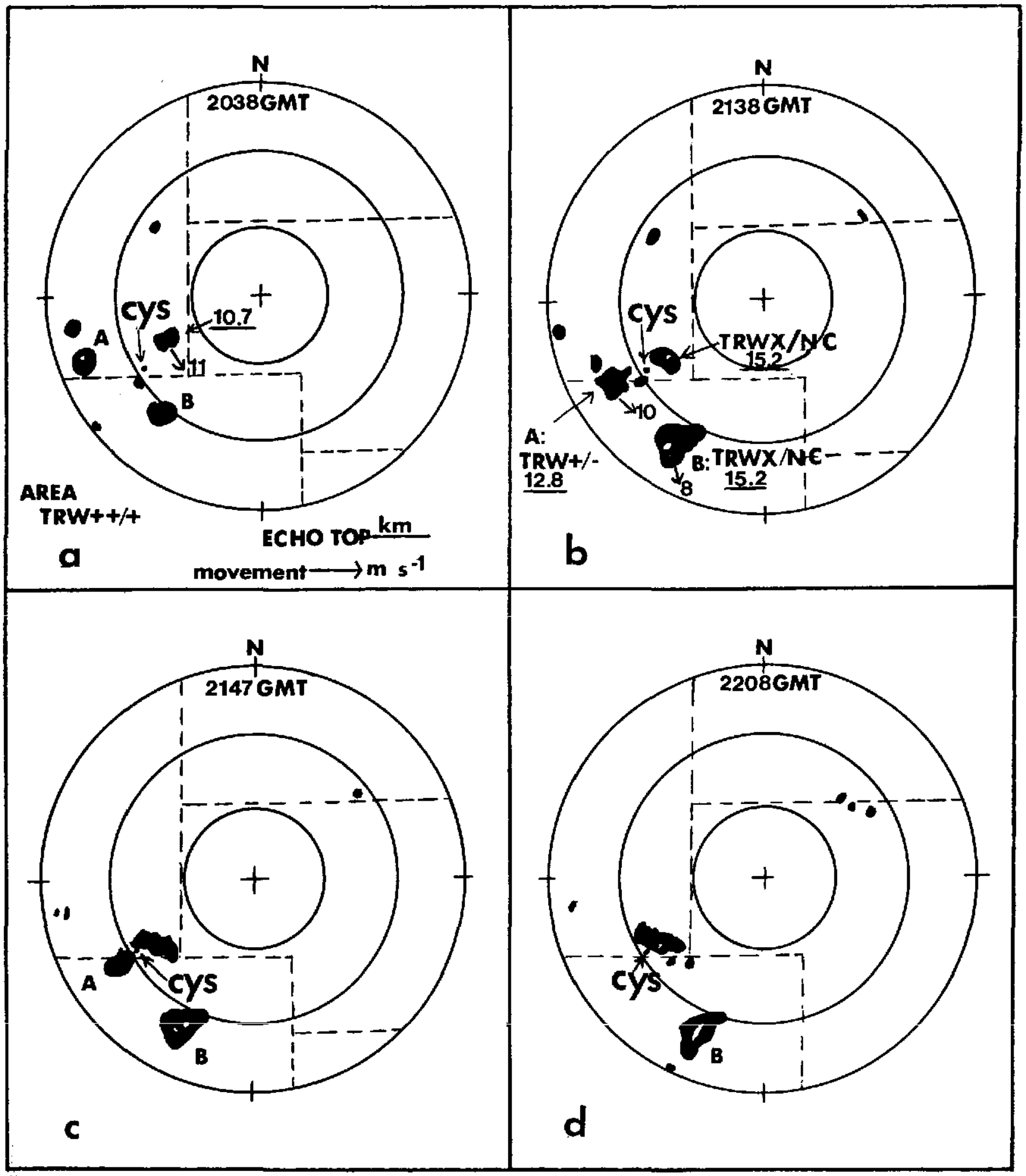

Fig. 6. Alliance, Nebraska, radar scope echoes for 16 July 1979. Each contour ring is 100km, and Cheyenne is located at 240 degrees/195km. Alliance radar is a WSR-74S. Echo tops are in kilometers with cell motion depicted in meters per second.

not in ground contact during its entire course. For a brief period in its early life it crossed a golf course and a wooded area at treetop level, ripping off upper limbs but leaving lower branches unscathed.

The mean path width of at least F1 damage was 100m. The width of the F1 damage path varied from 50m to 220m. The mean translational speed was 4.7 m/s (10.6 mph). It moved slowly at the beginning and accelerated its translation at the end.

Figure 7 depicts the path of the tornado through the city and will be referred to in the following discussion. The description of the tornado, its life cycle, and the resulting damage has been broken down into three phases: early stage, maturity, and dissipation.

a. Early stage

The earliest known position of the tornado was near the intersection of Vandehei Ave. and Valley View Rd. At 2120 GMT, Daren Clary encountered there what he thought was a "dust devil." Another early eyewitness account, by David Palmer, positioned a 30m diameter "dust devil" moving over the Francis E. Warren Air Force Base stables, some 130m WSW of his position in front of 940 Western Hills Blvd., adjacent to the Air Force Base. This second sighting was approximately 1.1km SSW of Clary's location and occurred five minutes later. The "dust devil" was then seen to move slowly off southeastward toward the State Game and Fish Buildings. It was later ascertained that these initial sightings were under the leading edge of a

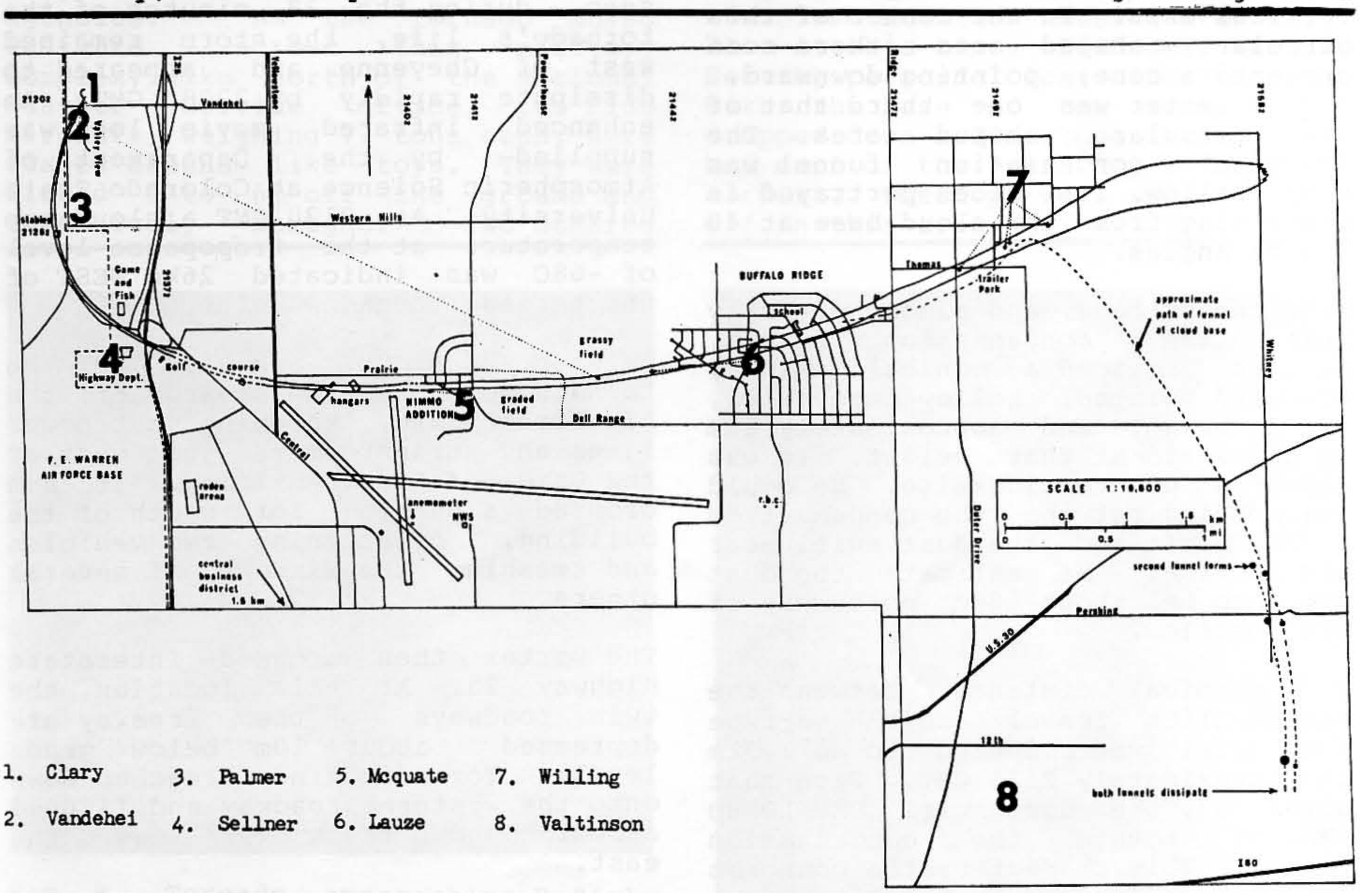

Fig. 7. Path of tornado across north portion of Cheyenne, WY. Dashed borders along paths indicate areas lacking tornadic surface winds. F1 damage track slightly wider. Numbers represent locations of persons cited in text and photographers. Locations of NWS employees affected were: 5- Mcquate, 6- Lauze, and the three X's in Buffalo Ridge representing Vetere, Cox, and Hooker, respectively. The spectacular photographs were taken at 7. Times on margins are in GMT.

thunderstorm that was still west of the city.

Wilson Sellner, a professional photogrammetrist with the Wyoming Highway Department, gave a detailed account of the events in the vicinity of and northwest of the Highway Department (Fig. 7). At 2120 GMT he reported a linear cloud formation from 5 to 8km in length, oriented 250 degrees - 070 degrees azimuth from the true north. It was moving slowly to the southeast. Within 5 to 10 minutes, the northeast end appeared to become turbulent and "circular shaped." It had a smooth appearance, and was 100 - 150m in diameter. In addition, the "circular shape" was surrounded by a narrow band of greenish-gray clouds 8 - 16m in width. These surrounding clouds appeared to be rotating about a vertical axis. In the center of this circular shaped area there soon appeared a cone, pointing downward. Its diameter was one third that of the circular shaped area. The incipient condensation funnel was very shallow, its sides portrayed as descending from the cloud base at 40 degree angles.

Near the surface, and almost directly below the condensation funnel, Sellner noticed a conical shaped, downward pointed, hollow dust swirl, 12m in height and approximately 25m in diameter at that height. It was rotating counterclockwise. He could see nothing between the condensation funnel aloft and the dust swirl near the surface. He estimated the dust swirl to be about 600m northwest of his position.

The vertical distance between the condensation funnel and the surface dust swirl was computed to be 1.3km at approximately 2125 GMT. From that point on, the dust swirl DEVELOPED UPWARDS toward the condensation funnel. This characteristic conforms to a case described by Golden (8).

Sellner watched the dust swirl move down off a ridge and grow rapidly in height as it approached the state buildings where he was located (Fig. 7). It became darker with time. The conical shape became columnar, reaching upward approximately 50m.

At 2130 GMT (1530 MDT) the Cheyenne WSR-74C weather radar indicated a thunderstorm west of the city with a maximum top to near 16km, and a reflective intensity of 4 on the Video Integrator Processor (VIP) mode. A more intense thunderstorm was located about 45km ENE of Cheyenne at that time. This thunderstorm (Fig. 6b) was positioned between the Alliance radar and the tornado-producing thunderstorm west of Cheyenne. The report from Alliance at 2138 GMT showed tops of the tornado-producing storm to only 12.8km and a VIP 3 in intensity. The cell was showing signs of decay . Figures 6c and 6d show the Alliance radar depiction of the storms during the period of the tornado. As can be seen, during the 38 minutes of the tornado's life, the storm remained west of Cheyenne and appeared to dissipate rapidly by 2208 GMT. An enhanced infrared movie loop was supplied by the Department of Atmospheric Science at Colorado State University. At 2130 GMT a cloud top temperature at the tropopause level of -68C was indicated 26km WEST of the tornado touchdown site.

Between 2130 GMT and 2135 GMT the tornado moved southeastward, off the Air Force Base, knocking out power lines and transformers just west of the Game and Fish Building. It then crossed a parking lot south of the building, overturning two vehicles and smashing the windows of several others.

The vortex then crossed Interstate Highway 25. At this location, the twin roadways of the freeway are depressed about 10m below grade level. Tornadic winds reached down onto the western roadway and flipped a southbound truck over toward the east.

As viewed from the Weather Service office, the tornado still resembled a giant dust whirl. No condensation funnel was visible. It was possibly obscured by the low hanging wall cloud evident in Fig. 10, which was taken approximately 5km further east.

The tornado began to turn slowly eastward. It then crossed the yard of the Governor's Mansion. Nearby, it severed a main power line at 2137 GMT. During this early stage the tornado moved 2.6km in 17 minutes, a translational speed of 2.5 m/s (5.6 mph).

As previously mentioned, the tornado crossed a golf course, somewhat above ground level, ripping only the upper limbs off trees. An off-duty Weather Sevice employee, who was nearby, described the dust swirl over the golf course as "wispy and multi-stranded," an indication of possible suction vortices.

At 2138 GMT the tornado entered the northwest corner of the Cheyenne Airport. The north portion of the airport is occupied by two military agencies. As the tornado moved eastward across this military complex, 1km north of the National Weather Service office, two C130 aircraft, weighing 77 tons each, were tossed around like toys. They were lifted 3 to 6m off the ground and extensively damaged. Two othered hangared C130s were also heavily damaged. In addition, a small aircraft was seen flying over the hangars with no pilot aboard. A brief (5 sec) super-8 millimeter movie was obtained. It shows the base of the tornado while over the airport. Four apparent suction vortices can be seen rotating counterclockwise around a semi-transparent core. The photographer was 1.5km north of the tornado.

A light rainshower began 35 minutes past the hour at the National Weather Service office. At 2138 GMT the ceiling height was estimated to be 1.2km (4,000 ft.).

b. Maturity

Tracking in an easterly direction, the tornado, now entering its mature stage, moved off the airport and into the Nimmo Addition housing area (Fig. 7). At this time, 2140 GMT, Weather Service personnel lost visual contact with the base of the funnel as it dropped down a 20m slope into a creek bed east of the military area of the airport. Treetops were again sheared off in this area.

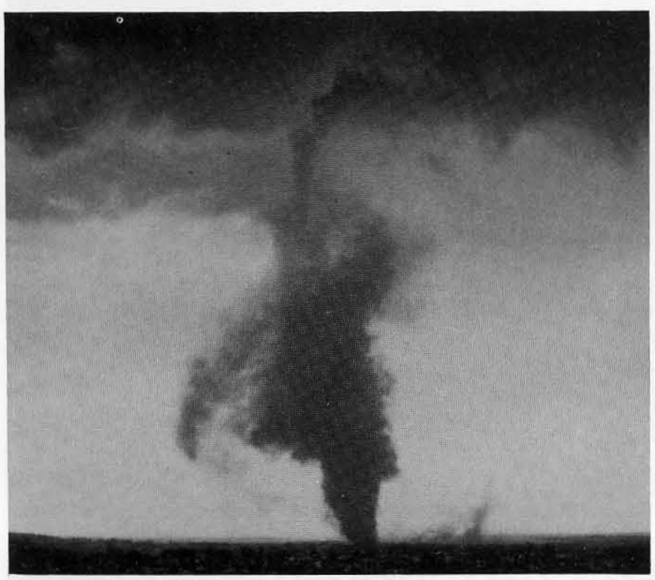

Fig. 8. Tornado approaching Buffalo Ridge. Ceiling 1220m (4000 ft.). Tornado, 4.8Km (3 mi.) SE of photographer, has just crossed a graded field, and dust has risen almost to cloud base. Note low-level dust streamer on right side (S) of vortex. Photo by G.F. Vandehei.

Fig. 9. View upward at condensation funnel. Looking W. Elevation angle approximately 80 degrees. Below this small funnel, surface vortex has just crossed airport, causing heavy damage. Photo by M.G. Mcquate.

As the tornado moved through the Nimmo Addition, about 35 twenty-year- old single story houses were destroyed or heavily damaged. Here the path width of at least F1 damage was 100 to 150m. Basements played a key role in providing shelter for those trapped in the storm, as no fatalities were reported in this area. A videotape taken during the tornado's transit through this area showed large objects that appeared to be entire roofs carried approximately 30m upward and then thrown down as far as 150m north and south of the vortex. Figure 9 shows the condensation funnel as it appeared just before the tornado entered the Nimmo Addition. The photo was taken at an elevation angle of 75 to 80 degrees. The photographer's position is No. 5 on Fig. 7.

The tornado crossed Powder House Road at 2141 GMT and then passed over freshly graded ground. An examination of aerial photos taken four days after the tornado revealed no evidence of suction marks as described by Fujita et al (19). Either no markings were left on the ground, or, during the intervening four days, the earth was once again graded. The tornado suddenly turned dark as loose dust was carried upwards. Figure 8 shows the tornado shortly after it crossed the graded field. The tornado's dark aspect at this time led many observers to conclude that they were watching smoke from a fire, even though the condensation funnel briefly extended below its wall cloud at this time, becoming visible throughout the city. The funnel continued to darken as it crossed the plowed field and proceeded to move into the extensive Buffalo Ridge housing area.

Trailing south and westward from a point just west of the tornado was an apparent gust front. This situation appeared to be similar to a model described by Maddox and Gray (20) in which a tornado's location under the thunderstorm was slightly ahead (east) of a gust front that was aligned underneath a band of cumulus congestus clouds.

As the surface vortex crossed Powder House Road, 1.2km north northeast of the National Weather Service's anemometer, the gust front crossed the center of the airport one minute later. A peak gust of 21 m/s (41kt) was recorded. The direction was from the southwest, 240 degrees azimuth. Coincident with the passage of the gust front, hail showers pelted areas SOUTH of the tornado's track. Pea-size hail fell at the Weather Service between 2145 GMT and 2147 GMT, and again between 2152 GMT and 2205 GMT.

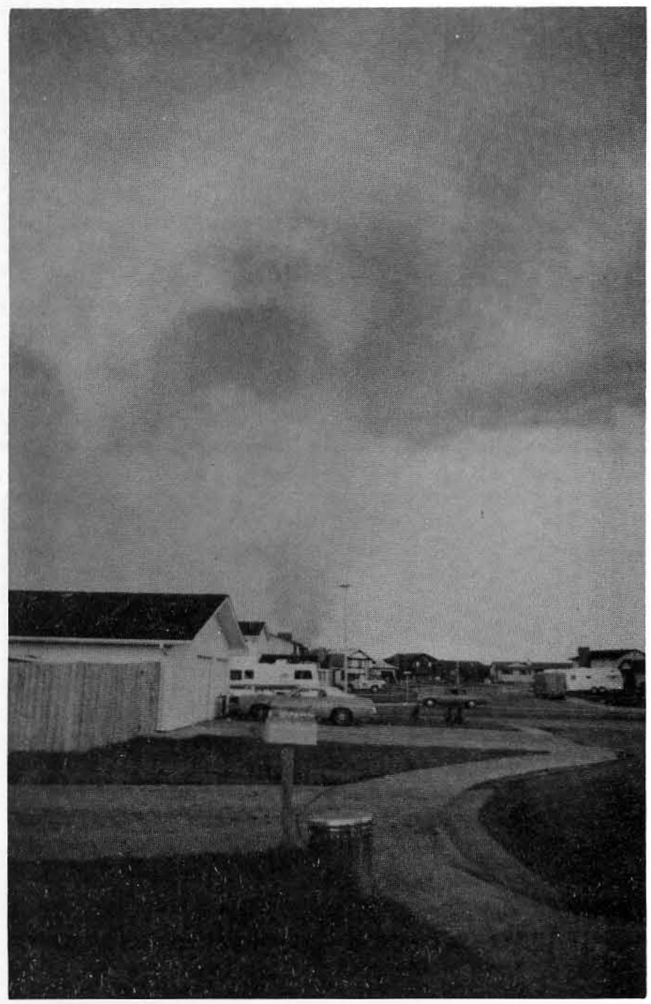

Fig. 10. Tornado approaching Buffalo Ridge, taken about 1 minute after Fig. 8. View to W. Dust thinning and condensation funnel has receded. Note low-hanging wall cloud. Two minutes after photo was taken, tornado moved down street on right side of picture. Photo by J. Lauze.

The Weather Service barograph registered at 1.7mb rise in a six-minute period beginning at 2147 GMT. It is believed that this pressure surge was caused by the gust front and not the tornado, since at no time was the vortex closer than 1km to the Weather Service barograph.

During the passage of the gust front, the main business district of the city was briefly obscured by dust. After three to five minutes the wind at the airport diminished to an average speed of 10.3 m/s (20kt).

Just prior to entering Buffalo Ridge, the tornado was at its closest to the National Weather Service's rotating beam ceilometer. It passed about 1km north of the instrument (r.b.c. on Fig.7), a sufficient distance to avoid measurement of the low hanging wall cloud (Fig. 10). An examination of the recorder trace revealed a cloud height of 1.4km (4,560ft), between 2130 GMT and 2140 GMT.

It is noted that during the day of the tornado, the largest 24-hour reported amount of precipitation in the surrounding area was 11.0mm at Kimball, in the southwest corner of the Nebraska panhandle. While heavier amounts probably fell in northeast Colorado, the storms that were immediately around the Cheyenne area, and those to the east, appeared to be relatively dry.

When the tornado entered Buffalo Ridge at 2144 GMT, it encountered a 2-km stretch of houses, most very new, and all very close together. Within three to four minutes it had virtually destroyed 100 homes and damaged 200 others. Again, injuries were few, and no fatalities were reported. The path width of F1 damage had varied from 100m to 150m. The most intense and extensive destruction was in the southwest corner of this area where the tornado hit two-story houses immediately after traversing the obstruction-free

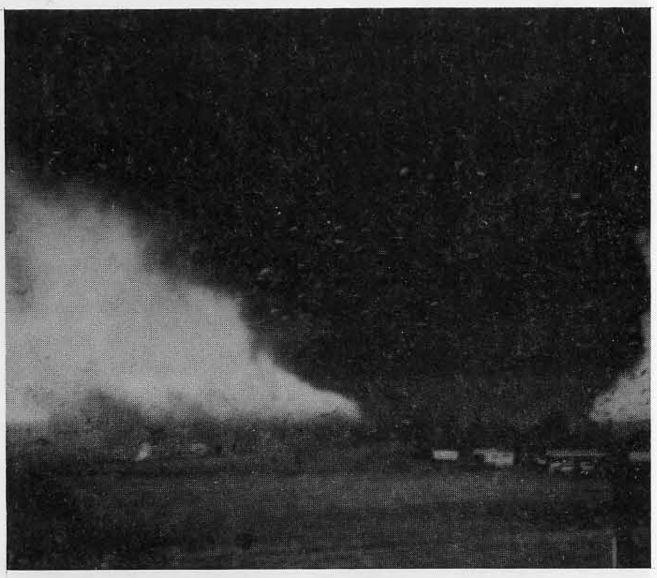

Fig. 11. Bottom third of tornado over intersection of Thomas Road and Outer Drive, E of Cheyenne. Tornado 1,005m (3,300 ft.) SW of photographer. Surface diameter 70m (230 ft). Note flying debris. Tornado moving from far right to near left, approaching trailer park on left side of photo. Camera: Pentax, 50mm lens, field of view 46 degrees, shutter speed unknown. Photo by P. Willing.

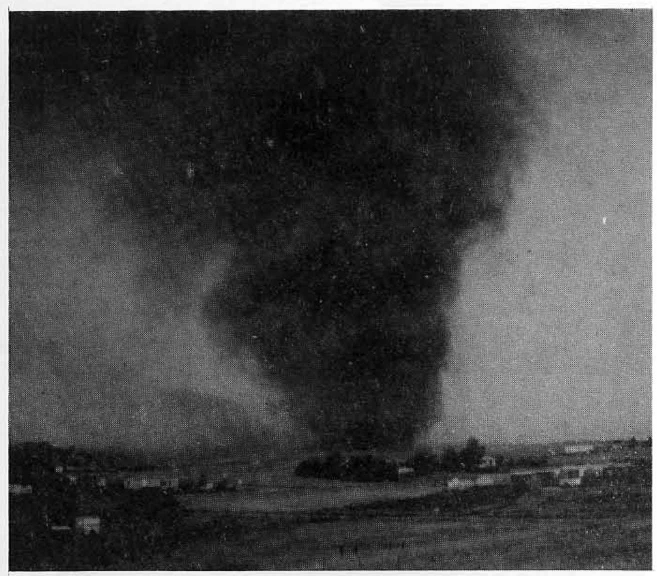

Fig. 12. Tornado exiting trailer park. View to SSW. Distance to front edge of vortex 411m (1,350 ft). Surface diameter 73m (240 ft). Debris on outer edge of vortex appears to have an upward trajectory. Inflow band seen on left side of photo, connected to SE side of vortex. Notice sheds and small travel trailer on left side of picture. Photo by P. Willing.

open field to the west. On the north side of the path, north and east surfaces of the houses were literally bombarded and impaled by flying debris. Houses in the center and on the south side supplied the missiles.

Most of Buffalo Ridge is devoid of mature trees. It is suggested by Minor et al (21) that a lack of substantial vegetation contributes to the magnitude of structural damage.

As the tornado crossed Buffalo Ridge it gradually assumed an ENE heading. Photographs revealed that the condensation funnel, as it slowly extended downward and became narrower, continued on a more easterly heading than the surface vortex. Thus, a southward tilt with height was induced. Eyewitnesses reported that the tornado almost stopped its translation at times while crossing the vast housing area.

Midway through Buffalo Ridge the tornado heavily damaged the south half of a school building. At this point the surface vortex began to climb up a 30m hillside. As it did so, the severity of damage appeared to increase. At 2147 GMT, the tornado crossed Ridge Road, severing a major power line, and exiting the eastern city limits. The mean translational speed across Buffalo Ridge was about 11 m/s (25 mph).

Zipser and Golden (9) mentioned a "feeder band" of dust adjacent to a Colorado tornado. A similar feature was noted on several photos of the Cheyenne tornado.

c. Dissipation

Beyond Buffalo Ridge, the tornado

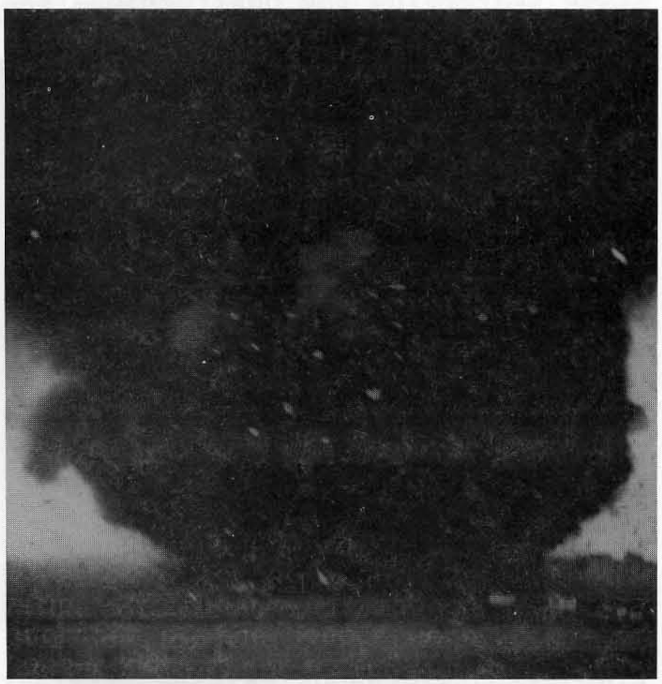

Fig. 13. Taken a few seconds after Fig. 12. Shed and trailer, well outside vortex, are disintegrating and flying towards W. Note low-level dust streamers angling and rising into funnel. A tangential wind speed gradient outside of vortex is evident. Trajectory of debris on outside edge of tornado is now downward. Photo by P. Willing.

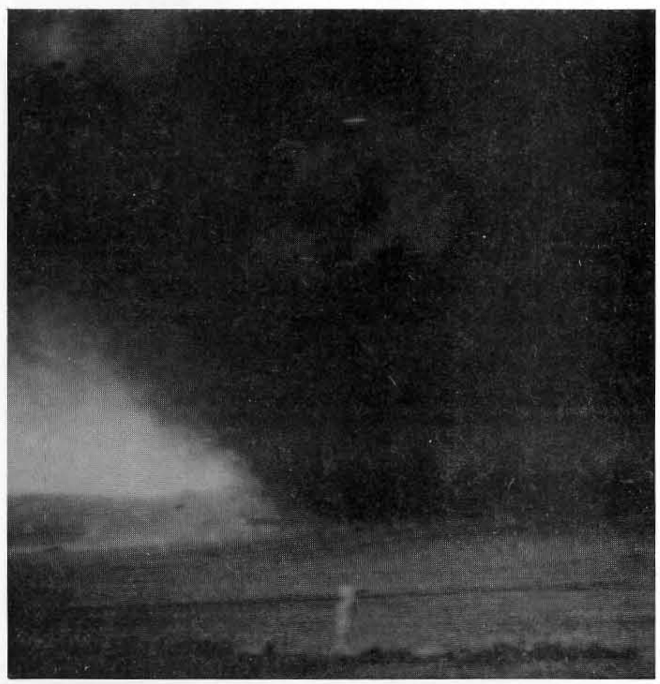

Fig. 14. Expanding tornado moving away from photographer. Looking SE. Distance to near side of tornado 396m (1,300 ft). On lower left side of funnel, note house breaking apart; a woman and two children are in the basement. On left edge of photo, a car can be seen racing up dirt road. Photo by P. Willing.

once again crossed largely open country for about 1km. Three isolated houses were heavily damaged.

At 2149 GMT the tornado violently struck the Shannon Heights Trailer Park. The single fatality and four injuries, two of them serious, occurred there. Seventeen trailer homes, seven of which were equipped with cable or chain tiedowns, were destroyed. Two were demolished in place and the rest were reduced to twisted frames and strewn about a large area (Fig. 15). Two frames were found 400m east of their original positions. Other frames were scattered up to 50m both east and west of their former locations. The path width of F4 damage across the trailer park was 220m.

One eyewitness described the tornado as "one big brown whirl, about two blocks wide." Another watched from a basement window of a house just south of the trailer park, and saw a five to seven meter wide "small tornado" pass to the east and take off the roof of a nearby shed. This "small tornado" was south of the larger vortex which, simultaneously, moved across the trailer park.

The presence of at least one subsidiary vortex was supported by eyewitnesses on both sides of the storm's path. Figure 12 shows the tornado moving out of the trailer park. No subsidiary vortices could be seen on the photo. However, Fujita and Forbes (22) stated that these vortices were often obscured by dust.

Fig. 15. Oblique aerial photo of trailer park taken approximately two hours after tornado. View toward SW. Tornado moved from topright to bottom left. Note twisted frames. Subtle swirl pattern of grass on left center of photo suggests the presence of one or more suction vortices. Photo by W.T. Parker.

Fig. 16. Typical damage in Buffalo Ridge section of Cheyenne. The narrow but powerful funnel ripped apart houses that were in center of its path. View to E. The N - S street is Hickory Place. Tornado moved from bottom right to left center. Photo taken from bottom right to left center. Photo taken about one hour after tornado. Photo by R.G. Beebe.

An examination of aerial photographs of the damage track through the trailer park revealed a linear concentration of debris stretching east northeastward from the trailers. Fujita and Forbes attributed such a feature to the presence of a single central suction vortex. In the case of the Cheyenne tornado, the debris line was 3-5m north of the axis of translation. An examination of the left center portion of Fig. 15 reveals at least three 10m diameter swirls in the grass, suggesting the presence of one or more suction vortices.

On Figure 13 can be seen two dust bands moving into the periphery of the vortex within 10m of the surface. It is believed that these features constituted what Fujita and Forbes (22) called a "vorticity feeder."

The single fatality occurred when a child in a trailer on the north edge of the tornado was carried by the wind about 30m to the west and landed on a road. In an adjacent trailer, two other people were hurled 15m northward and deposited on the remains of another trailer.

The tornado continued on for another 1.7km, destroying two isolated houses, one of which can be seen breaking apart in Fig. 14. In this area, aerial photos showed debris scattered over a 1.5km wide area perpendicular to the storm's path. As a result, determination of a precise track was impossible. An eyewitness stated that high winds ceased as the tornado crossed Whitney Road (Fig. 7).

Approximately one kilometer beyond the trailer park the dust swirl near the surface could be seen on photographs to be widening while the condensation funnel was extending further down from the cloud base and narrowing, as it entered the rope stage. Several photographs and two movies showed a section of the condensation funnel assuming an attitude horizontal to the ground at 2155 GMT. As the tornado roped out, the strength of rotation at the surface remained undiminished for a few minutes. At the surface, the vortex continued its movement east northeastward. The lowering dust and debris column became wider, attaining a diameter of 274m (900ft).

Meanwhile, the funnel at the base of the thunderstorm turned abruptly to a southerly direction. As a result, the condensation funnel rapidly lengthened. The dashed lines on Fig. 7 indicate the approximate path of the funnel at the cloud base.

As the original funnel continued its roping phase, a second funnel, larger than the first, developed immediately to the north and west of the original funnel. The approximate location of formation and the path of this second funnel are depicted on Fig. 7. Off-duty National Weather Service meteorologist L. Valtinson watched the events in the latter stages, and indicated that the new funnel rotated cyclonically around the original funnel, within the wall cloud of the original funnel. In a matter of seconds both funnels dissipated. The time was 2158 GMT.

In all, the tornado destroyed 140 houses. One hundred homes received major damage, and another 225 houses had various amounts of damage. Seventeen trailers were destroyed. Fifty-three apartment units in Buffalo Ridge were damaged to some degree. City-owned property at the airport sustained a $10 million loss, and damage to the military property was approximately $12 million. The total storm damage was estimated at $40 million.

6. CONCLUSION

The intent of this paper was to document the Cheyenne tornado of 16 July 1979. It was shown that interaction of an existing thunderstorm with an intruding frontal boundary, enhanced by thunderstorm outflow in Nebraska, was a likely cause of the tornado. In addition, the characteristics of the tornado and the resulting destruction were analyzed. It was found that the tornado in its initial stage appeared as a "dust devil" which served to confuse the public.

The Fujita-Pearson scale values were determined to be 422, with F4 damage in a portion of the Buffalo Ridge subdivisions. Spectacular photographs taken of the tornado in the vicinity of a trailer park, besides portraying the power of the storm, showed dust moving in unique patterns. We hope these will aid in the understanding of airflow in the near tornado environment.

Evidence indicates tornadoes in southeastern Wyoming and northeastern Colorado are not a rare event. Also, with the occurrence of the Cheyenne tornado, the potential for destruction from one of these tornadoes was thoroughly demonstrated. With a growing population along the front range, it is hoped that increased public awareness through education and better warning systems will minimize the losses to life and property in the future.

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