NOAA Technical Memorandum NWS SR-172

EVALUATION OF RAINFALL ESTIMATES FROM THE WSR-88D DOPPLER RADAR USING DATA FROM A RECORDING RAIN GAGE NETWORK

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December 1995

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1. Introduction

During the month of August 1994, a field experiment was conducted in the area surrounding Big Spring, Texas. The project was entitled TEXARC to denote the **T**exas **EX**periment in **A**ugmenting **R**ainfall through **C**loud-Seeding (TEXARC) and was conducted under the supervision of the Texas Natural Resource Conservation Commission (TNRCC). The overall goal of the TEXARC is to develop and demonstrate an effective technology for the enhancement of rainwater from summertime convective clouds in the southern U.S. Great Plains region. The experiment utilized aircraft, weather radars, and a recording rain gage network and is described in detail in the project Operations Plan (TNRCC, 1994). The project area is shown in Fig. 1a.

As in previous field projects, the primary on-site weather radar was a 5 cm SWR-75 Skywater radar operated in a volume scan mode. This study addresses a second radar utilized in support of field operations. The WSR-88D Doppler radar operated by the National Weather Service (NWS) Forecast Office in Lubbock, Texas, was employed in two ways: (1) for data archival for subsequent analysis; and (2) in real-time support of aircraft operations. Descriptions of the components of the WSR-88D radar system and the data products available from it are described in Klazura and Imy (1993) and Crum and Alberty (1993). Coverage of the Lubbock radar applied to this project is shown in Fig. 1b.

The WSR-88D was included as part of the project to test whether a facility primarily engaged in operational weather forecasting could contribute to the objectives of the research project. The anticipated deployment of WSR-88D radars at Midland and San Angelo in the near future offered the possibility of excellent coverage of field operations.

2. Comparison of Rain Gage and Radar Rainfall

Sources of Data

The two primary sources of data for this study are the NWS WSR-88D radar located in Lubbock and the network of recording rain gages located near Big Spring and operated by the Colorado River Municipal Water District (CRMWD). The CRMWD has operated a rain gage network for many years in support of their rainfall enhancement program. A total of 106 Belfort weighing bucket rain gages were placed in the field for the TEXARC 1994 project. Of these, 87 were in operation during the time period of this study. A detailed map of the rain gage network is given in Fig. 2.

Following the completion of the field project, all charts were removed from the rain gages, and rainfall data were extracted by Mr. Ray Jones of the CRMWD. The results were tabulated for 15-min intervals and delivered to Texas Tech for analysis.

The WSR-88D became operational at Lubbock during the spring of 1994. The system was equipped with a Level II data recorder which permitted the archival on 8 mm exabyte data cartridges of the volume scan data which comprises the radar data set for this study. The Level II data were recorded continuously for the duration of the field project in order to capture as many events as possible. Each data tape was copied to provide an on-site data set.

A number of occasions occurred during the field project which warranted aircraft operations somewhere in or around the project target area. However, the only period of significant precipitation over the recording rain gage network occurred at the end of field operations on August 31. All comparisons of rainfall recorded by the rain gages and the WSR-88D presented here apply to that date.

It is possible to record the rainfall products generated during operations at the forecast office by appending recent products to a data file named HYPROD.DAT. It was our intention to utilize this capability to preserve rainfall products generated during episodes of interest. However, the procedure that was employed failed to operate correctly, and no products were archived in this manner.

It became necessary to utilize the volume scan data that had been archived on the Level II data tapes that had been recorded. NWS personnel at the WSR-88D Operational Support Facility (OSF) in Norman, Oklahoma, agreed to process a limited amount of the Level II archive data and were provided an 8 mm exabyte tape containing the volume scan data for August 31.

Analysis of Data

The period from 1700 to 2300 UTC on August 31, 1994, has been selected for analysis. Rainfall amounts for the complete 6-hr period, as well as for two shorter intervals within the 6-hr period, were computed for both the rain gages and the radar. In order to compare rainfall amounts over individual rain gages, radar-estimated rainfall amounts were extracted from the Level II data tapes. The latitude and longitude of each rain gage were provided to Mr. D. Scott Kelly at the WSR-88D Operational Support Facility. He used the algorithm designed to compute rainfall for the WSR-88D to compute rainfall amounts for each 30-min interval from 1700 through 2300 UTC on August 31, 1994.

Early Period of Light Rain. A 2-hr period of rather light rainfall from 1700 to 1900 UTC was selected for a rain gage-radar comparison. The reflectivity pattern at the base elevation angle of 0.5 deg at 1842 UTC is shown in Plate 1. At this time, the echoes were moving northward and had entered the southern portion of the rain gage network. The maximum reflectivity of 61 dBZ was located just south of the network. The rainfall accumulation measured by the rain gage network over the 2-hr period 1700-1900 UTC is shown in Fig. 3. A single rain gage in the northeast portion of the network recorded 0.85 in. The principal area of rainfall was in the southern portion, with maximum values approaching 0.50 in. Rainfall accumulations derived from the WSR-88D data are shown in Fig. 4. The spatial distribution of rainfall is very similar to that in Fig. 3, especially in southern Howard County. However, the radar did not detect the 0.85-in rain gage-recorded rainfall amount in Scurry County.

Detailed comparisons of rainfall accumulation with time were performed for two rain gages along the southern border of the network and are shown in Figs. 5 and 6 for rain gages TI9 and TD9, respectively (refer to Fig. 2). Rain gage accumulations are presented in 15-min intervals, while radar-derived amounts are given every 30 min. Both rain gage and radar rainfall values are zero at 1700 UTC. Rain gage TI9 measured 0.44 in over the 2-hr period; the radar-derived total was 0.79 in, an 80 percent overestimate. Rain gage TD9 recorded 0.48 in of rainfall; the radar-derived total was 0.22 in, a 54 percent underestimate.

Later period of heavier rain. Rainfall amounts were heaviest near the end of the 6-hr period. The 3-hr period 1930-2230 UTC was selected for a rain gage-radar comparison. The reflectivity pattern at an elevation angle of 0.5 deg at 2034 UTC is shown in Plate 2. Individual echoes had continued to move northward over the past 2 hr and had formed a line extending from west-southwest toward east-northeast across the northern half of the rain gage network. Reflectivity values exceeded 55 dBZ in several of the cells within the line.

The rainfall accumulation measured by the rain gage network over the 3-hr period 1930-2230 UTC is shown in Fig. 7. Rainfall amounts in excess of 0.5 in occurred over a rather large area along the boundary between Borden and Scurry Counties with a maximum value of 1.61 in. Rainfall accumulations derived from the WSR-88D data are shown in Fig. 8. As was found for the 1700-1900 UTC period, the spatial distribution of radar-derived rainfall is similar to that measured by the rain gages. However, over the northern portion of the area, radar-derived rainfall amounts were quite a bit greater in Borden County.

Detailed comparisons of rainfall accumulation with time were performed for two rain gages in the vicinity of the rainfall maximum and are shown in Figs. 9 and 10 for rain gages TJ6 and TJ9, respectively (refer to Fig. 2). During the 3-hr period, rain gage TJ6 measured 0.32 in, increasing from a total of 1.10 in at 1930 UTC to a total of 1.42 in at 2230 UTC. Over the same interval a radar-derived rainfall of 1.74 in occurred, increasing from 0.00 in at 1930 UTC to a value of 1.74 in at 2230 UTC. This difference represents a 443 percent overestimate by the radar. Rain gage TJ9 measured 0.35 in, changing from 0.85 to 1.20 in from 1930 to 2230 UTC. The radar-derived rainfall over the 3 hr was 1.22 in, increasing from 0.01 inch at 1930 UTC to 1.23 in at 2230 UTC. These values represent an overestimate of 249 percent by the radar.

At least a partial explanation exists for these large discrepancies. It can be seen from Figs. 9 and 10 that the onset of rain appeared to occur earlier at the rain gages—30 min earlier at rain gage TJ6 and nearly 1½ hr earlier at rain gage TJ9. The only explanation which appears likely is that the clocks on the rain gages were incorrectly set.

If it is assumed that the rain recorded by rain gage TJ6 should be delayed by 30 min and by 1½ hr for rain gage TJ9, both rain gages capture the event. The rainfall for the 1930-2230 UTC period recorded at rain gage TJ6 becomes 1.40 in, and the 1.74 in derived from the radar data is now an overestimate of only 24 percent. After delaying the rainfall measured by rain gage TJ9 by 1½ hr, the amount falling in the interval from 1730 to 2230 UTC becomes 1.20 in, and the radar-derived estimate of 1.22 in is reduced to an overestimate of only 2 percent.

Total period of analysis. The rainfall accumulations measured by the rain gage network over the complete 6-hr period 1700-2300 UTC are shown in Fig. 11, and those derived from the WSR-88D data are shown in Fig. 12. The spatial distribution of rainfall is seen to be nearly a composite of the two sub-intervals discussed above. A region of light rainfall associated with the earlier 1700-1900 UTC period is found in the southern portion of the rain gage network, and a band of heavier rain associated with the later 1930-2230 UTC period extends from west to east across the northern half of the network. The rainfall amounts derived from the radar data were in good agreement with the rain gage-recorded amounts over the southern region of the network. Within the band of heavier rain over the northern portion of the rain gage network, larger areas of rainfall amounts exceeding 1.00 and 1.50 in are found in the radar-derived results.

Another comparison of the observed rainfall amounts with radar-derived values was performed by stratifying the data into categories representing a transition from light to heavier values. The total rainfall recorded by the recording rain gages and by the WSR-88D radar are compared in the Table. Of the 87 rain gages, 22 recorded no rain, 42 measured less than 0.50 in, 16 recorded from 0.50-0.99 in, and seven recorded an inch or more of rainfall. The composite average rainfall recorded by the 87 rain gages was 0.29 in. The average radar-derived rainfall at the same 87 locations of 0.44 in is greater than the rain gage average by a ratio of 1.52, corresponding to a 52 percent overestimate.

Rain Gage and Radar Estimates of Rainfall
for the period 1700-2300 UTC, August 31, 1994

Class*	Number of Rain Gages	Average Rainfall (in) Rain Gage	Average Rainfall (in) Radar	Radar Excess#	Radar Rain Gage Ratio	Radar Excess %
1	22	0.00	0.14	0.14	----	----
2	42	0.14	0.30	0.16	2.14	114%
3	16	0.63	0.76	0.13	1.21	21%
4	7	1.31	1.47	0.16	1.12	12%
All	87	0.29	0.44	0.15	1.52	52%

Radar Excess ≡ Radar - Rain gage

* Classes are defined by the rain gage-recorded rainfall as follows:

Class	Rainfall (in)
1	0.00
2	0.01 - 0.49
3	0.50 - 0.99
4	≥ 1.00

The amount by which the radar-derived rainfall amounts exceed rain gage measurements increases with increasing rainfall intensity. However, the ratios of radar-derived to rain gage-measured rainfall decrease as rainfall amounts increase. For rain gage rainfall amounts less than 0.50 in, the radar-derived average of 0.30 in at the same 42 locations exceeds the rain gage average of 0.14 in by 0.16 in, a 114 percent overestimate. The measured rainfall in the 0.50-0.99 in class averaged 0.63 in. The average radar-derived estimate at these 16 locations is 0.76 in, a 21 percent overestimate. The average rainfall for the seven rain gages recording at least 1 in averaged 1.31 in. The corresponding radar-derived estimate is 1.47 in. The excess of 0.16 in is a 12 percent overestimate.

One factor which contributes to a radar overestimate of rainfall is the process of sub-cloud evaporation. The range from the radar to various rain gages within the recording network varied from 80 to 180 km. For these distances the height of the center of the radar beam above ground level ranged from 1.34 to 3.83 km.

In a study of sub-cloud evaporation over West Texas, Weaver (1992) concluded that convective cloud systems developing in warm, dry environments with high cloud bases will suffer large depletions of liquid water as a result of evaporation between cloud base and the ground. He simulated a 20-min rainshower, with a rainfall rate of 25 mm/hr falling from a thunderstorm a cloud base 3.48 km above ground level. Of the 8.3 mm of rain which left the cloud base, only 1.3 mm reached the ground, corresponding to a loss to evaporation of 7.0 mm, or 0.28 in. It appears that sub-cloud evaporative losses can account for large overestimates of radar-derived rainfall for the radar-to-rain gage distances of this study.

3. Conclusions and Recommendations

The TEXARC field experiment conducted during August 1994 in the vicinity of Big Spring, Texas, provided an opportunity to evaluate the accuracy of rainfall estimates derived from the reflectivity data of the WSR-88D radar located in Lubbock, Texas. Storm Total Precipitation values produced by the radar software were compared with rainfall measured with a network of Belfort recording rain gages. Data from a 6-hr period on August 31, 1994, have been presented.

Over the 6-hr period, an average rainfall of 0.29 in was recorded by the rain gages, while the radar-derived rainfall amounts averaged 0.45 in. The average rainfall estimate by the radar was greater than that of the rain gages by a ratio of 1.55. The radar-to-rain gage rainfall ratio decreased from a value of 2.14 for the smaller amounts to 1.18 for rainfall totals of 1 in or greater. Austin (1987) performed 374 comparisons in 20 storms between radar reflectivity and recording rain gages. She found that the ratio of radar-derived to rain gage-measured rainfall amounts varied from 0.39 to 1.54. The results of this very limited study are judged not to disagree with those of Austin.

Two recommendations can be made. First, the value for this project of the WSR-88D at Lubbock would be improved if additional rain gages were located to the north of the present network. More detailed evaluations of the rainfall estimates could be pursued if sub-cloud evaporation were reduced.

Second, extensive investigations of the WSR-88D rainfall estimation process will require implementation of the source code for the Storm Total Precipitation products. At this time, the source code has been obtained from the Operational Support Facility in Norman and has been installed on an HP workstation at the NWS Forecast Office and on a Sun workstation at Texas Tech. Additional studies are planned for the upcoming months.

References

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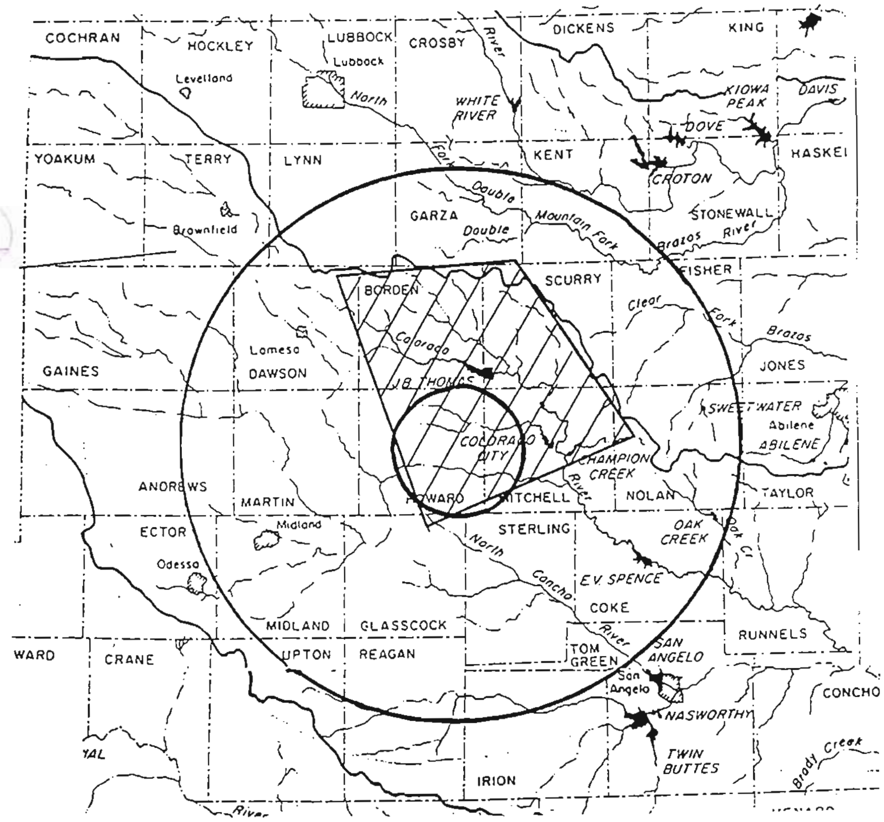
TNRCC, 1994: Operations Plan for TEXARC 1994, the **T**exas **EX**periment in **A**ugmenting **R**ainfall through **C**loud-Seeding. Texas Natural Resource Conservation Commission, Austin, Texas, 37 pp.

Weaver, J. E., 1992: Evaporation of Rainfall Below Convective Clouds. M.S. Thesis, Texas Tech University, 115 pp.



(a)

(b)

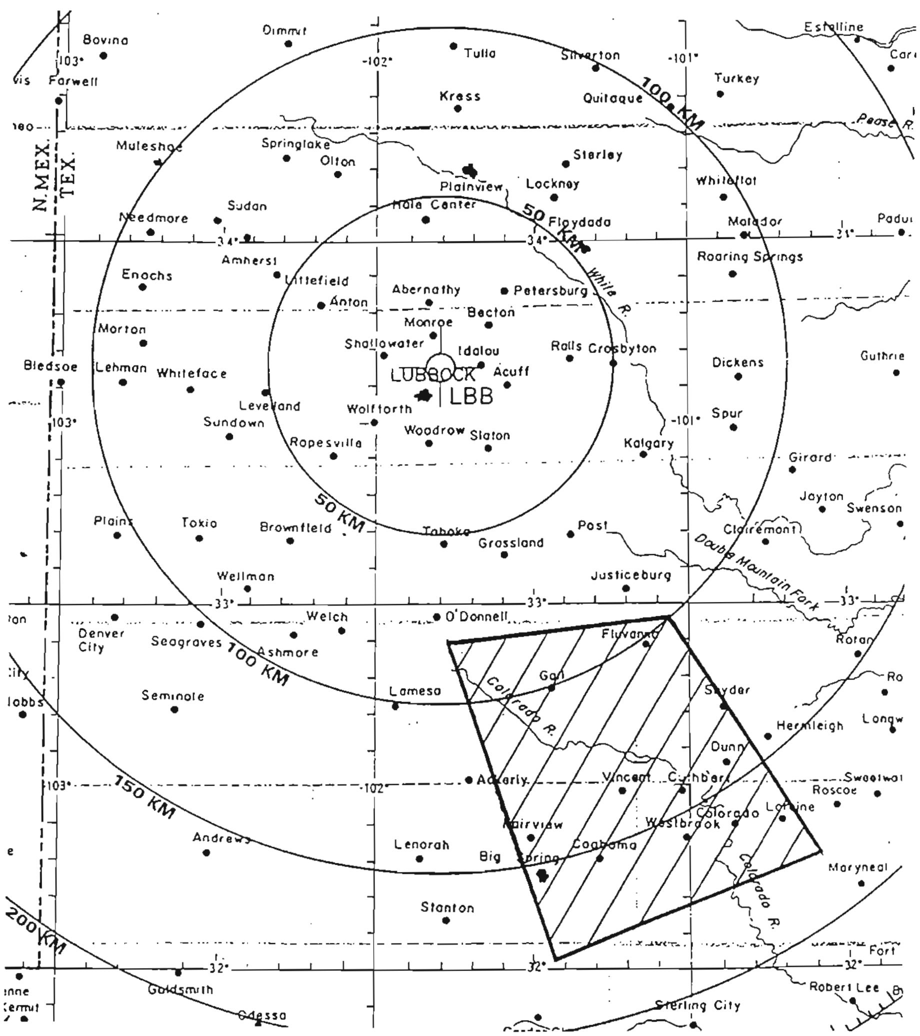


Fig. 1. (a) The TEXARC 1994 field experiment project area. The 100-km radius circle is centered at the location of the Skywater radar near Big Spring, with a 30-km radius circle removed. The hatched area denotes the location of the recording rain gage network. (b) The operational area of the WSR-88D Doppler radar. The hatched area denotes the location of the recording rain gage network.

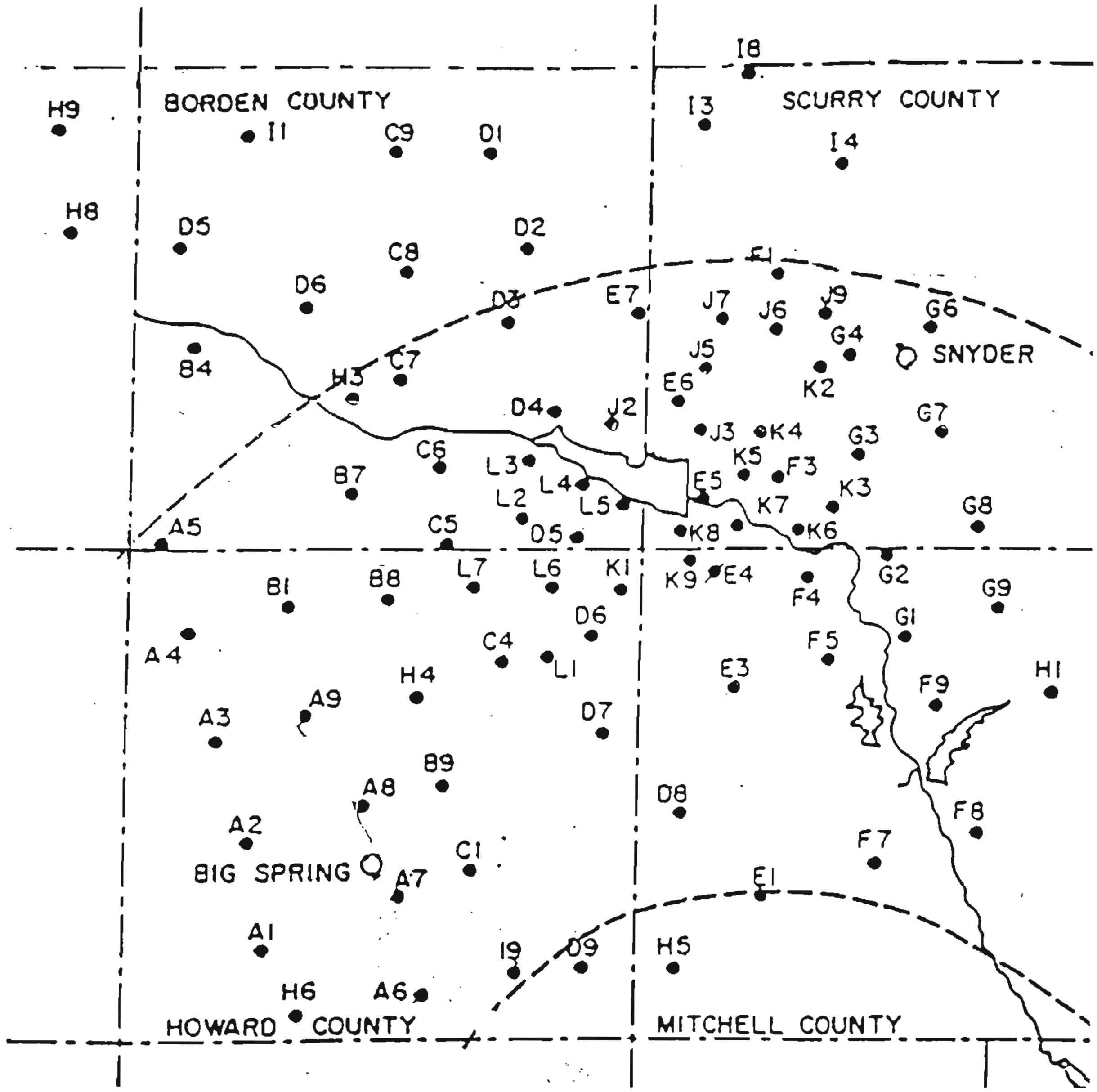


Fig. 2. The recording rain gage network. The prefix letter "T" included in rain gage identifiers in the text has been deleted to avoid crowding.

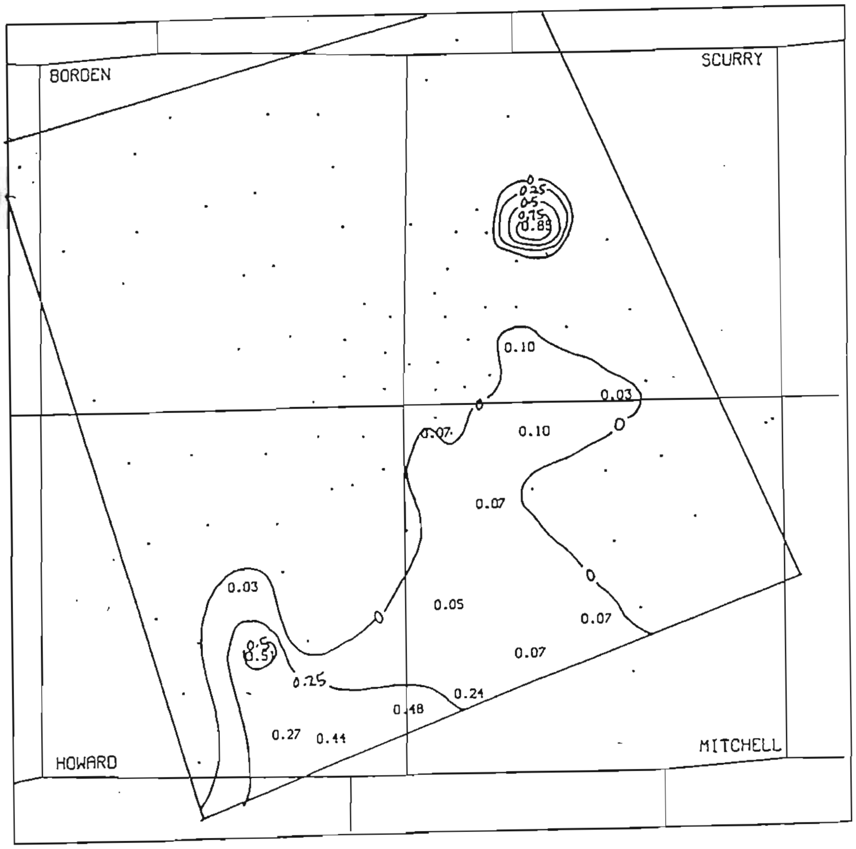


Fig. 3. Rain gage-recorded rainfall for the period 1700-1900 UTC, August 31, 1994. Isohyets in 0.25 in intervals.

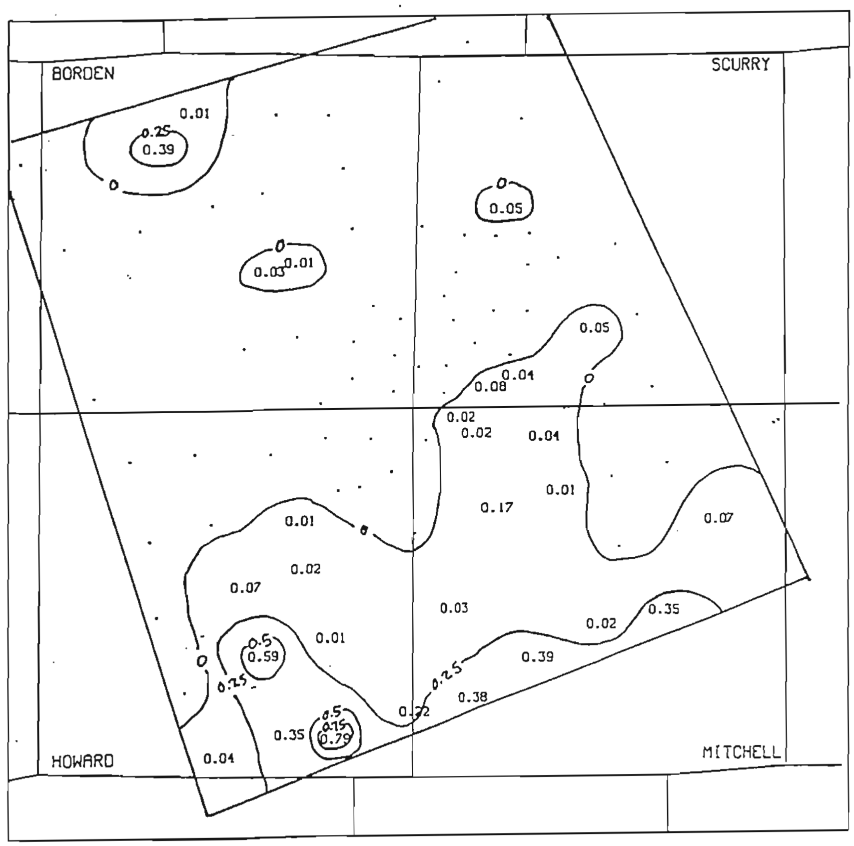


Fig. 4. Radar-derived rainfall for the period 1700-1900 UTC, August 31, 1994. Isohyets in 0.25 in intervals.

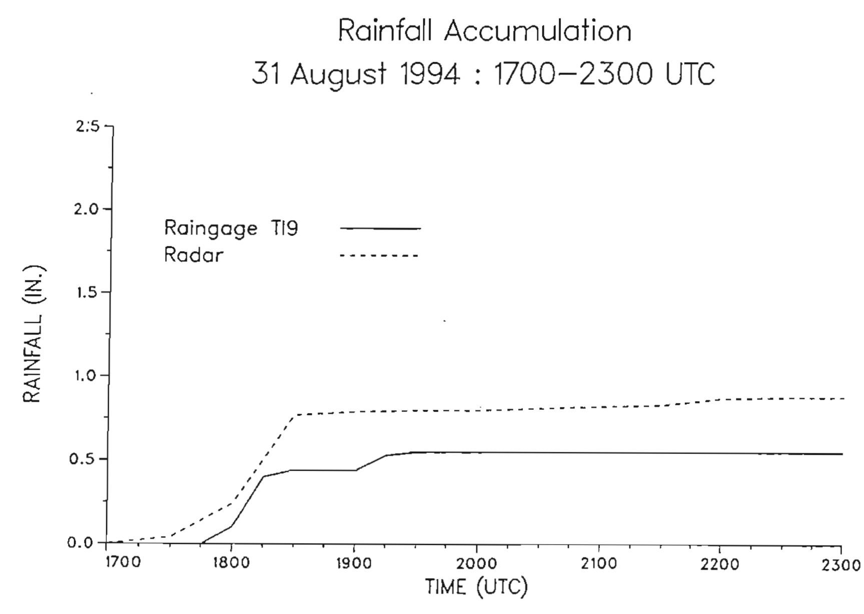


Fig. 5. Rainfall accumulation with time for rain gage TI9.

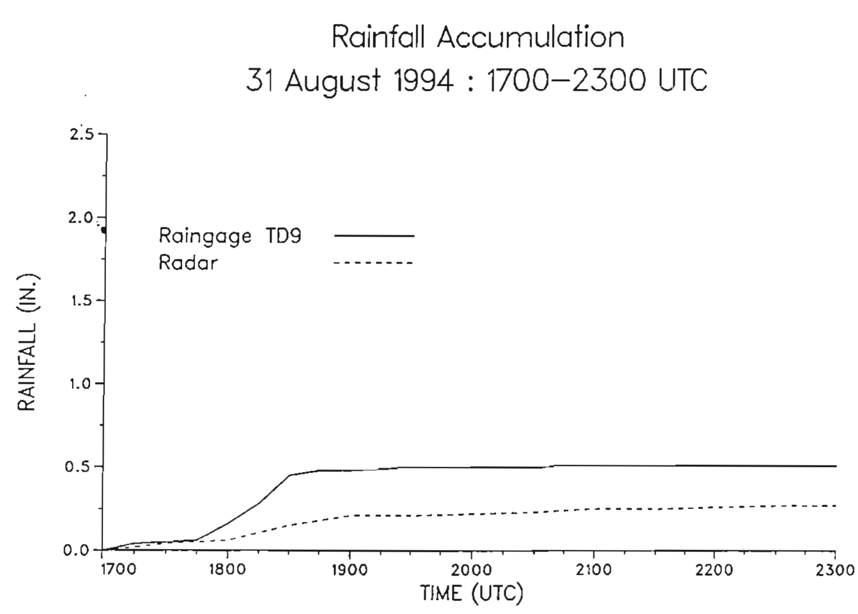
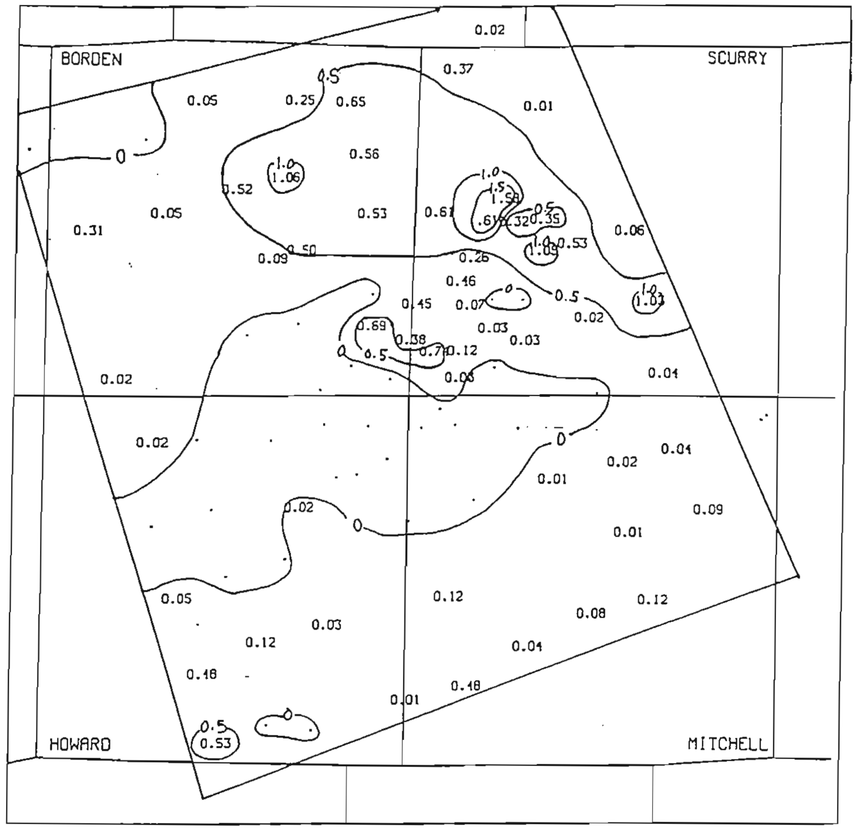


Fig. 6 Rainfall accumulation with time for rain gage TD9.

Fig. 7. Rain gage-recorded rainfall for the period 1930-2230 UTC, August 31, 1994. Isohyets in 0.50-in intervals.



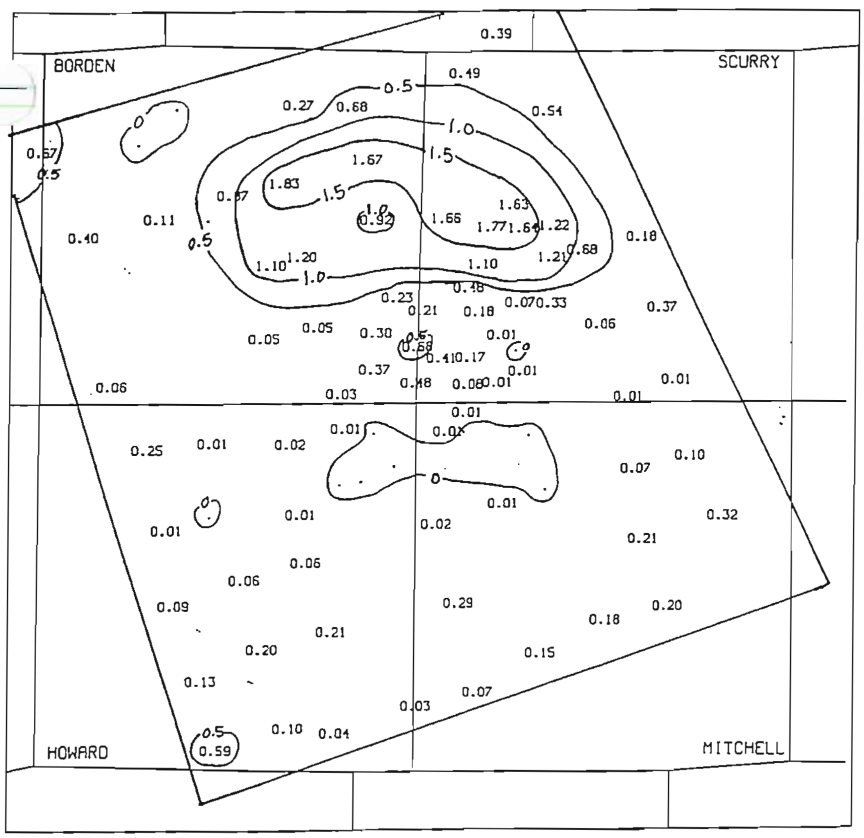


Fig. 8. Radar-derived rainfall for the period 1930-2230 UTC, August 31, 1994. Isohyets in 0.50-in intervals.

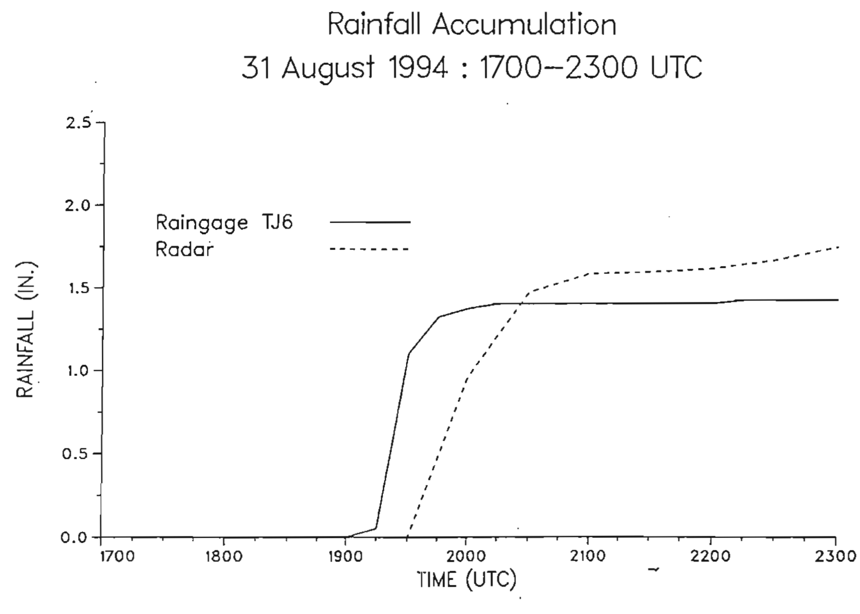


Fig. 9. Rainfall accumulation with time for rain gage TJ6.

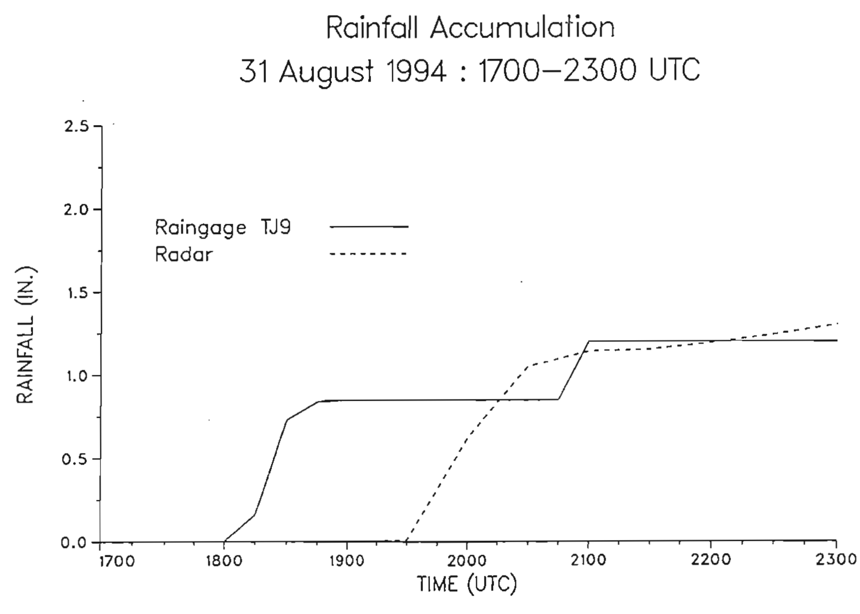


Fig. 10. Rainfall accumulation with time for rain gage TJ9.

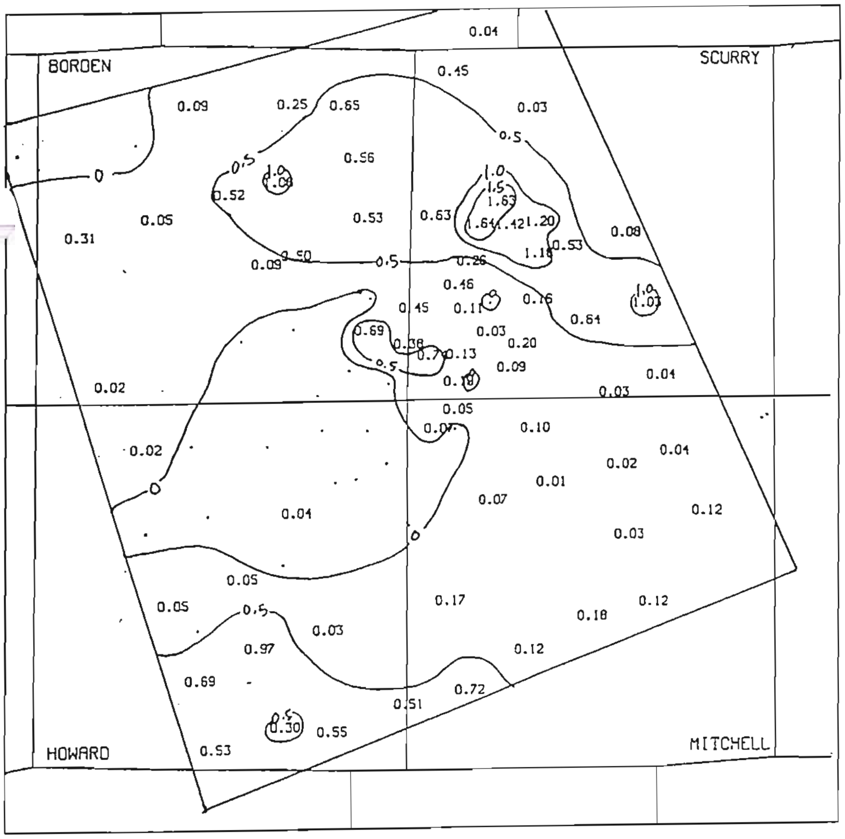


Fig. 11. Rain gage-recorded rainfall for the period 1700-2300 UTC, August 31, 1994. Isohyets in 0.50-in intervals.

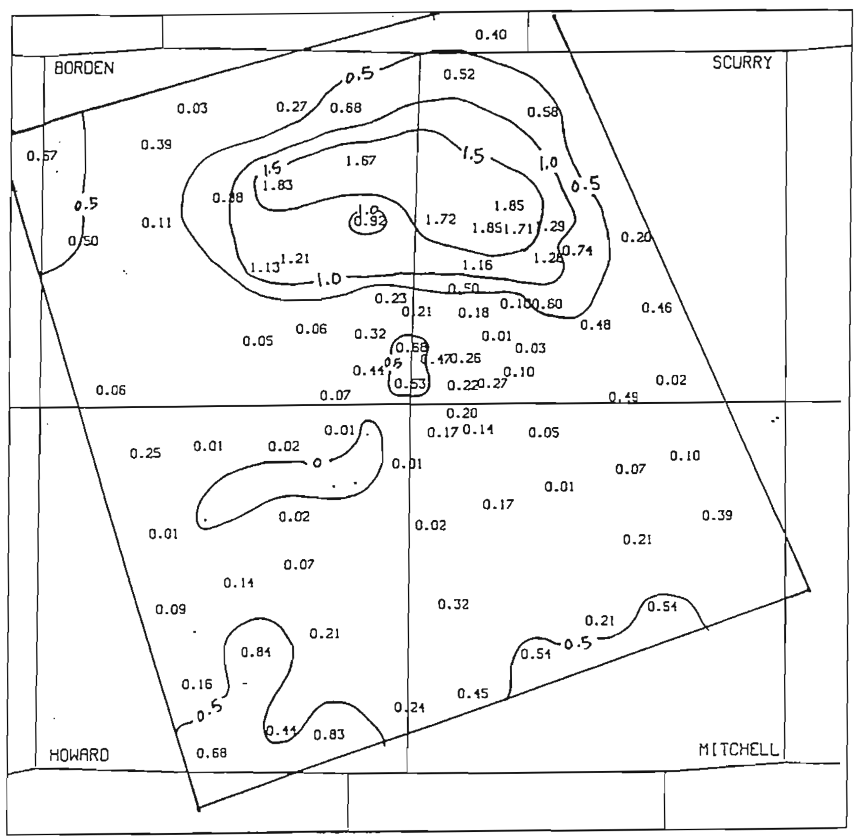


Fig. 12. Radar-derived rainfall for the period 1700-2300 UTC, August 31, 1994. Isohyets in 0.50-in intervals.

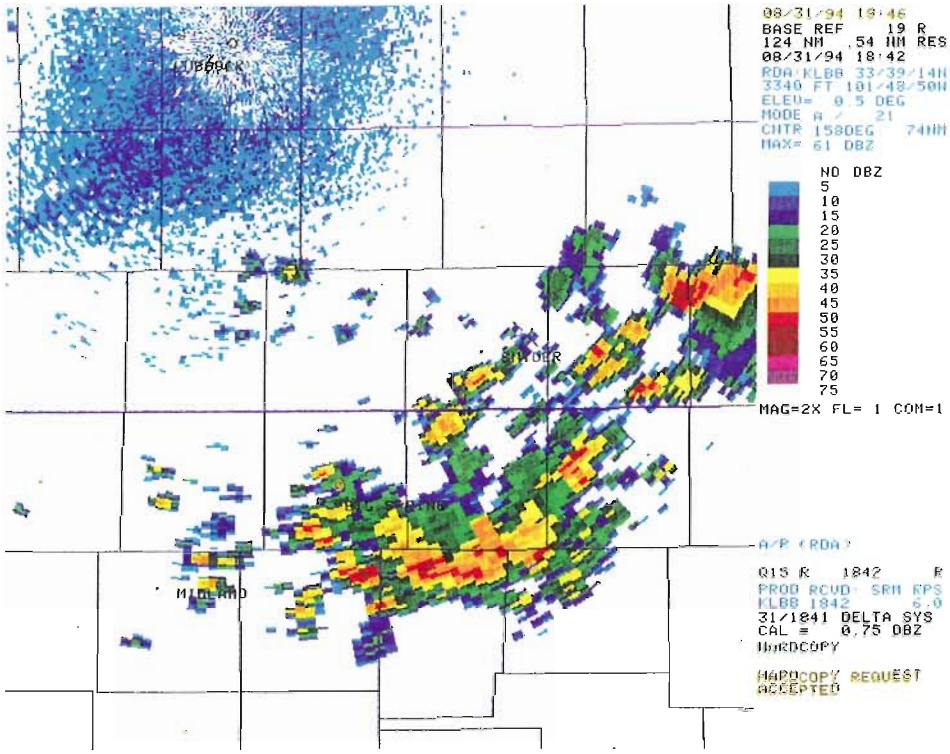


Plate 1. WSR-88D radar reflectivity at an elevation angle of 0.5 deg at 1842 UTC on August 31, 1994.

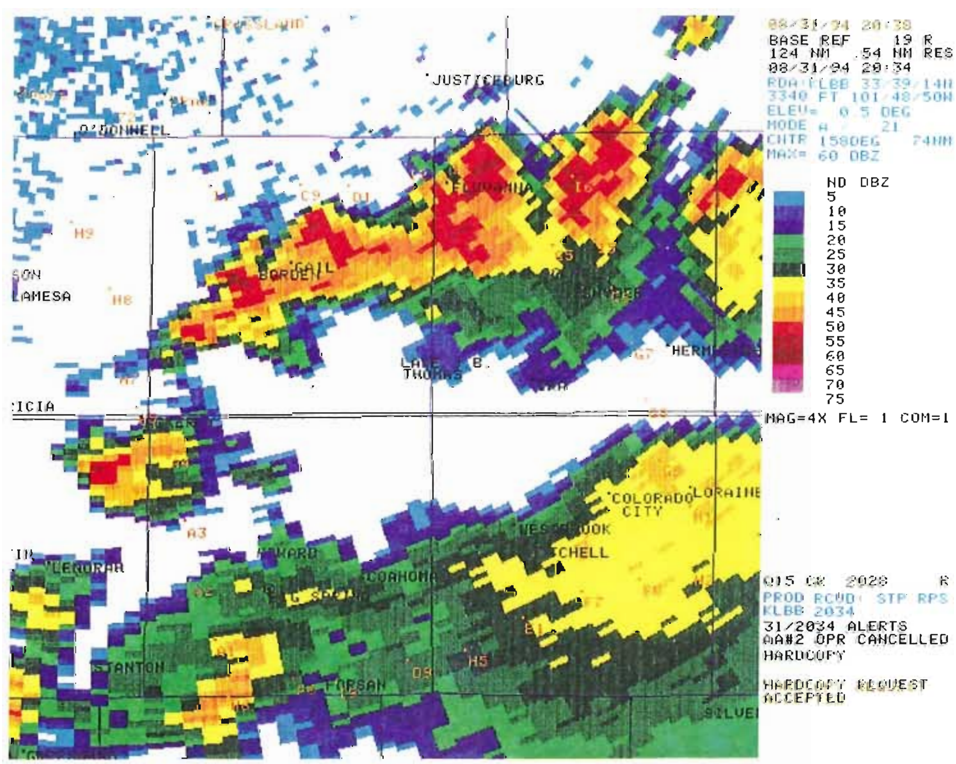


Plate 2. WSR-88D radar reflectivity at an elevation angle of 0.5 deg at 2034 UTC on August 31, 1994.