ical Memorandum NWS CR-57

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

SUMMER RADAR ECHO DISTRIBUTION AROUND LIMON, COLORADO

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and
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Scientific Services Division
Central Region Headquarters
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Frederick B. Dent, Secretary

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Robert M. White, Administrator

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WSMO Limon, Colorado

ABSTRACT

Radar echoes for the area within 125 n.m. of Limon, Colorado for the summer (June-August) months of 1971 and 1972 are examined for diurnal characteristics and relationships to the terrain. As the convective day starts, there is little daylight echo frequency until a sudden generation occurs over the east slopes of the Rockies about 1100 MDT. From then until 1730 MDT the frequency of echoes increases everywhere but at the greatest rate over the Rockies, then over the E-W ridges that extend well into the Plains. By 2130 the decreased frequency over the mountains is low enough that the max frequency is well over 100 n.m. east of the Continental Divide. There is then decay everywhere to near zero frequencies almost everywhere by 0530 MDT. The pattern of echoes and of precipitation amount supports quite well the 2-cell convection pattern in a line perpendicular to the mountains as proposed by Dirks. The data also suggest smaller scale cells along a N-S line because of the E-W ridges.

INTRODUCTION

Radar provides the best tool we have so far for studying the areal and temporal variations in precipitation on the meso-scale, especially in a sparsely settled region such as Eastern Colorado. WSR-57 radar data have been available for Limon, Colorado since June of 1971, and the 1971 and 1972 data within 125 nautical miles of Limon for the months of June, July, and August have been examined primarily to show the diurnal characteristics of echoes and orographic effects. Similar studies have been done elsewhere, such as that of Hales (1) (portions of Arizona using ARTC radars) and that of Sheffield (2) (an area around Buffalo, N.Y. using a WSR-57).

Sheffield was mostly concerned with the space variation of radar echoes throughout the year while Hales was primarily concerned with the diurnal variation in the summer. This study is similar to that of Hales because

*now at Birmingham, Alabama

diurnal characteristics were believed pronounced and regular in the summer season over Eastern Colorado. If this regularity is confirmed and the variations established along with orographic considerations, the predictability of short-term precipitation events should be enhanced. This is the prime purpose of this study. A secondary effort was made to correlate this study with the idealized Rocky Mountains-Great Plains Daytime Circulation expressed by Dirks (3).

Hourly overlay maps of echoes as created operationally in real time for radar reports, served as the data base. These maps were drawn about 30 minutes after the hour for the area within 125 n. m. of the radar site. About 158 maps were available for each hour of the day (June - 60, July - 60, and August - 38). The lesser figure for August is due to unavailable data for much of August, 1971. Hours the radar was out for maintenance or other reasons were noted and also not used. Periods when no echoes were present were included in the number of observations used. No effort was made to separate echoes by intensity.

In a study using radar data, it is important to recognize and allow for various limiting factors in regard to radar performance. The limiting factors include ground clutter, blocking, anomalous propagation, beam filling, range attenuation, and overshooting. Ground clutter is a minimal problem as the radar operators tilt the antenna to detect nearby echoes. No blocking problem exists with this radar. Anomalous propagation is observed and can be quite extensive, especially behind a line of strong thunderstorms. However, it is easily recognized and no problem is noted with this phenomena, and such echoes were eliminated. Since virtually all summer seasons echoes are cumuliform with high vertical development, beam filling, range attenuation, and overshooting were not significant factors for the 125 nautical mile radius used in the study especially since the radar presentation was range normalized a good portion of the study period.

FREQUENCY DISTRIBUTIONS

Diurnal-Overall

Figure 1 shows the overall diurnal frequency of echoes anywhere in the area, i. e., within 125 n. m. of the radar site. It shows a minimum at 0930 MDT, when echoes were present only about 25% of the time, and a maximum 1730-1830 MDT when echoes were present about 92% of the time. The rise in frequency in late morning and early afternoon is much more rapid than the fall during the night and early morning.

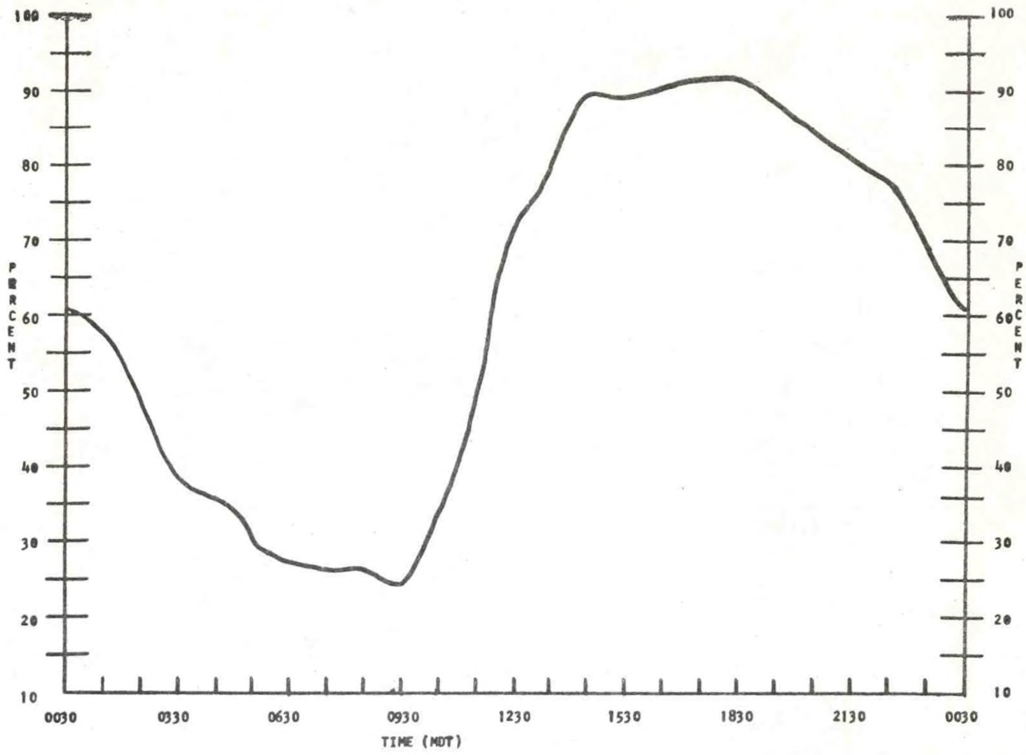


Figure 1. Frequency of Radar Echo for the area within 125 Nautical Miles of Limon, Colorado.

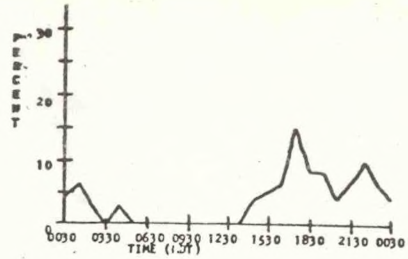
Diurnal - Selected Stations

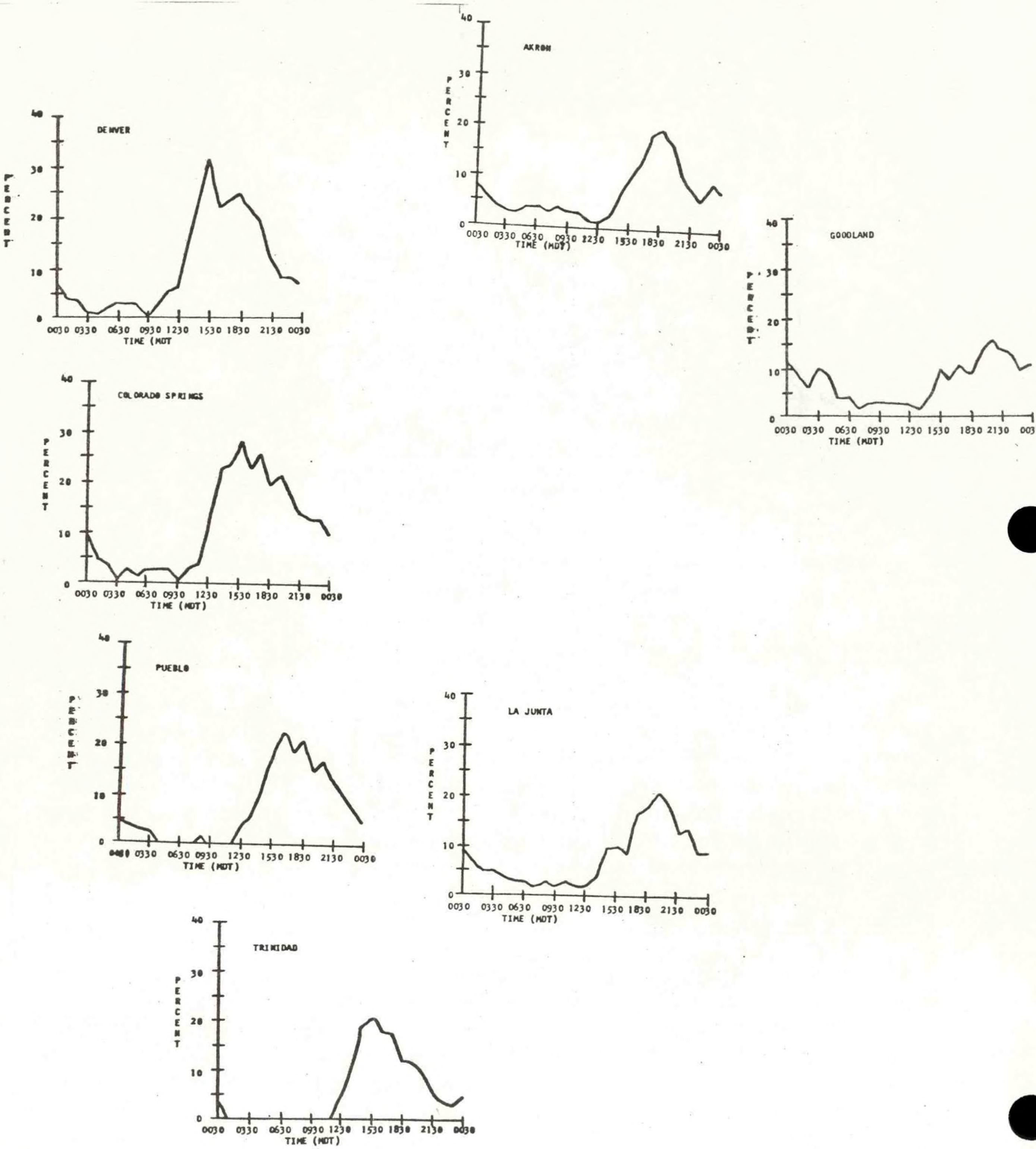
The diurnal distribution for selected stations is shown in Figure 2, where the graph for each station is shown in its approximate relative geographic location. There are marked differences in these graphs, ordered by the geography, such that the peak frequency both lowers and shifts to a later time as one goes eastward. Less obvious is a N-S variation which is little in the time of the maximum but some in the magnitude, with the peak frequency at the latitude of Denver.

Diurnal - Selected Times

To get the complete picture of the diurnal variation over the area, hourly maps of frequency were prepared for each hour of the day. Using a 14.7 nautical mile grid size (small enough for detail; large enough to allow a manual effort), the hourly radar overlays were placed over the grid on the light table, and if any part of an echo was in the grid square it was noted on a work sheet. Echo frequency was computed for each square, each hour and plotted on maps. Hourly maps (H + 30) were then plotted, 24 in all.

Figure 2. Radar echo frequency for selected stations arranged in an approximate geographic relationship.





These hourly grid maps were then analyzed using an interval of 5% frequency except where no probability reached that high.

Surface elevations were taken from aviation sectional charts, smoothed somewhat, analyzed, and transferred to the maps as dashed-line contours (Figure 3). The terrain contours shown were chosen to best delineate the east-west ridges in the eastern Colorado plains. They do not have a uniform interval and the detail west of the Divide is now shown.

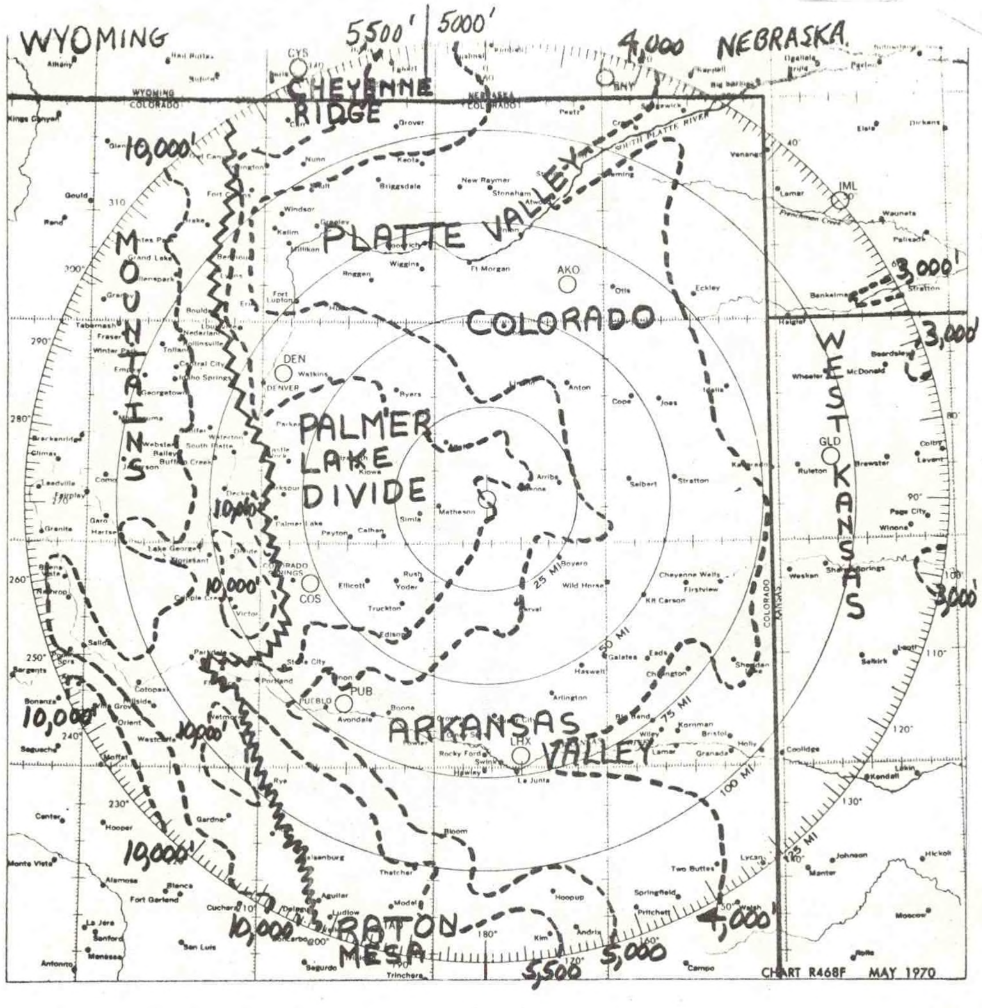


Figure 3. Area Topography Map with Selected Areas Denoted

A map of the total hours of some radar echo in each grid square (Figure 4) was compiled by totaling the hourly grid maps for the entire 24-hour day and analyzing the field. This shows the overall space variation of echo frequency. A total of 3785 hours were used, thus the peak frequency of 628 is only about 17%. This peak frequency occurs just east of the Continental Divide and just west of the Palmer Lake Divide. The axis of high frequency from this maximum, a bit south of Denver, shows a clear decrease eastward and is nearly coincident with the ridge line of the Palmer Lake Divide extending into the Plains, indicating a clear orographic relationship for this ridge.

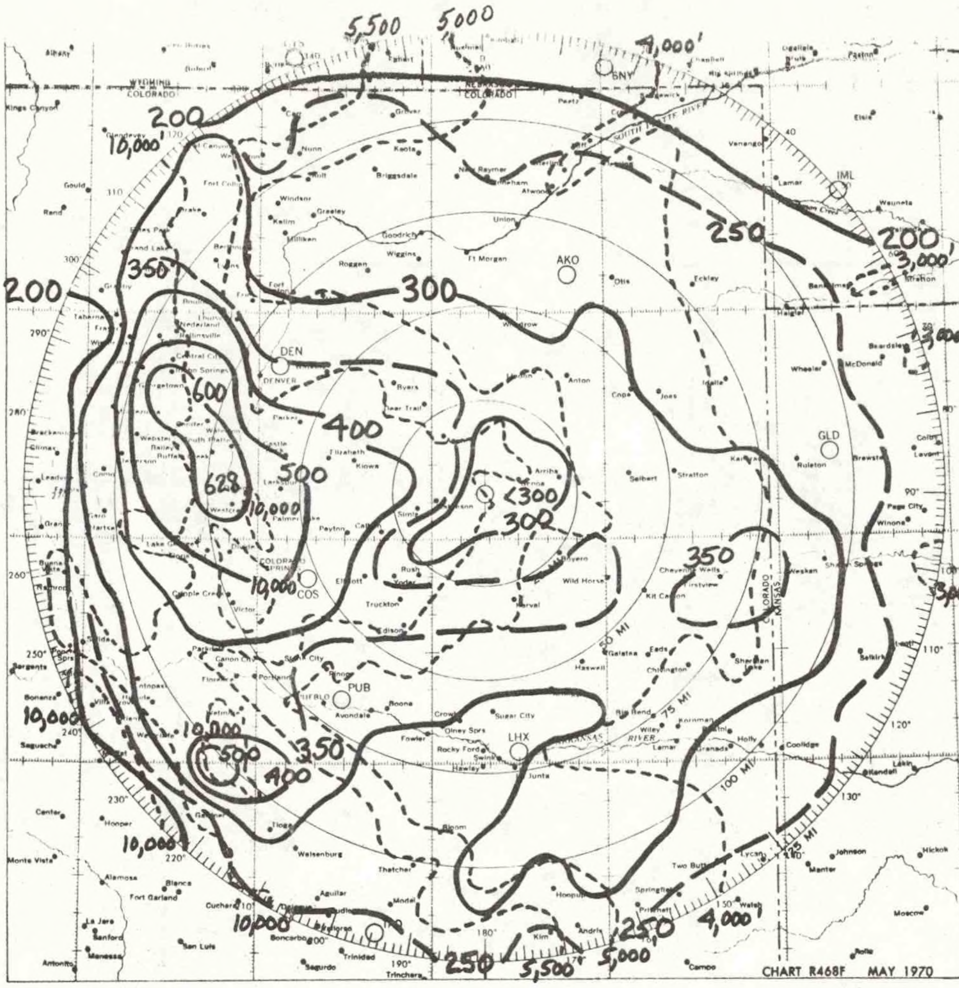


Figure 4. The Total Echo Frequency (Hours). Maximum Possible Hours is 3785.

To get the full diurnal picture in mind, all the hourly maps were then examined. Because the pattern on some adjacent maps was very similar, the total number of maps was reduced by combining those with very similar distributions in adjacent hours.

0530 - 1030 MDT. Figure 5 shows the average conditions through this period. It is a period of minimum activity with a tendency toward a weak maximum from near Cheyenne Wells southward to near Lamar. The 1030 MDT map did not deviate significantly from the mean pattern except for a slight increase in frequency for favored mountain areas. (see next).

1130 MDT. Figure 6 shows a sudden generation of activity over the mountains. The areas of favored development also begin to appear with a maximum centered near Bailey and minor maxima near Estes Park and west of Rye. The weak maximum near Cheyenne Wells continues.

1230 MDT. Figure 7 shows the continued increase in frequency over the mountain area, most notable in favored areas, and also the start of the spread of activity eastward. This spreading is related orographically to the east-west ridges, especially the Palmer Lake Divide and the Raton Mesa ridges.

1330 MDT. In Figure 8, the mountain activity is very near a maximum and the eastward extension of frequencies continues. It is easiest to see the effects of the ridges over the plains in this figure.

1430 MDT. Figure 9 shows little change in the maximum near Denver. The Fort Collins max to the north has increased to its peak value, while the max to the south is still increasing.

1530 - 1730 MDT. Figure 10, the mountain activity is in a general steady state. There is a slight but significant change, however, over the source regions. Note the slow decay of the northern area (Fort Collins)and the slight increase for the southern area (near Rye) as the central area remains the same. During this period the eastward extension of the maximum continues.

1830 MDT. Figure 11 marks the start of the primary decay period. The breakdown of the whole mountain source region can be seen. However, over the Plains to the east, the frequency continues to show some increase.

1930 MDT. In Figure 12, the mountain decay is quite visible and starting to extend into the adjacent Plains. In the eastern Colorado Plains, there is a general steady state frequency with some increase for extreme eastern Colorado and west Kansas.

2030 MDT. Figure 13, the continued decay of the mountain maximum gives a rather uniform frequency over much of the east-west ridges.

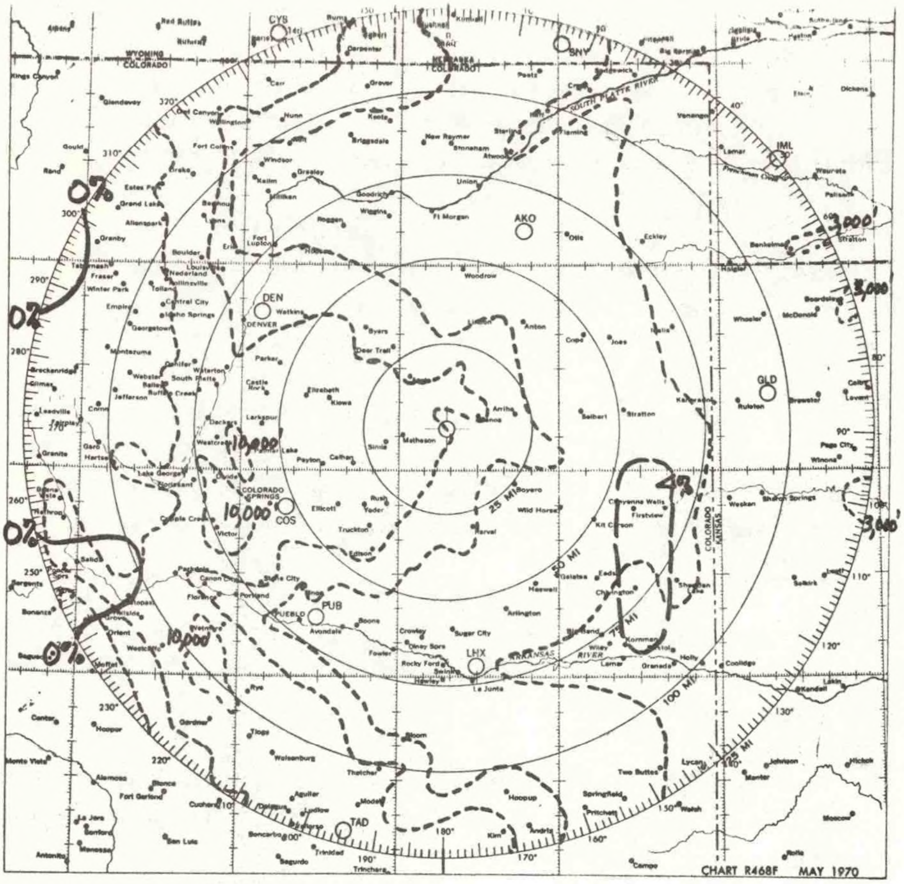


Figure 5. Radar Echo Frequency, 0530 thru 1030 MDT.

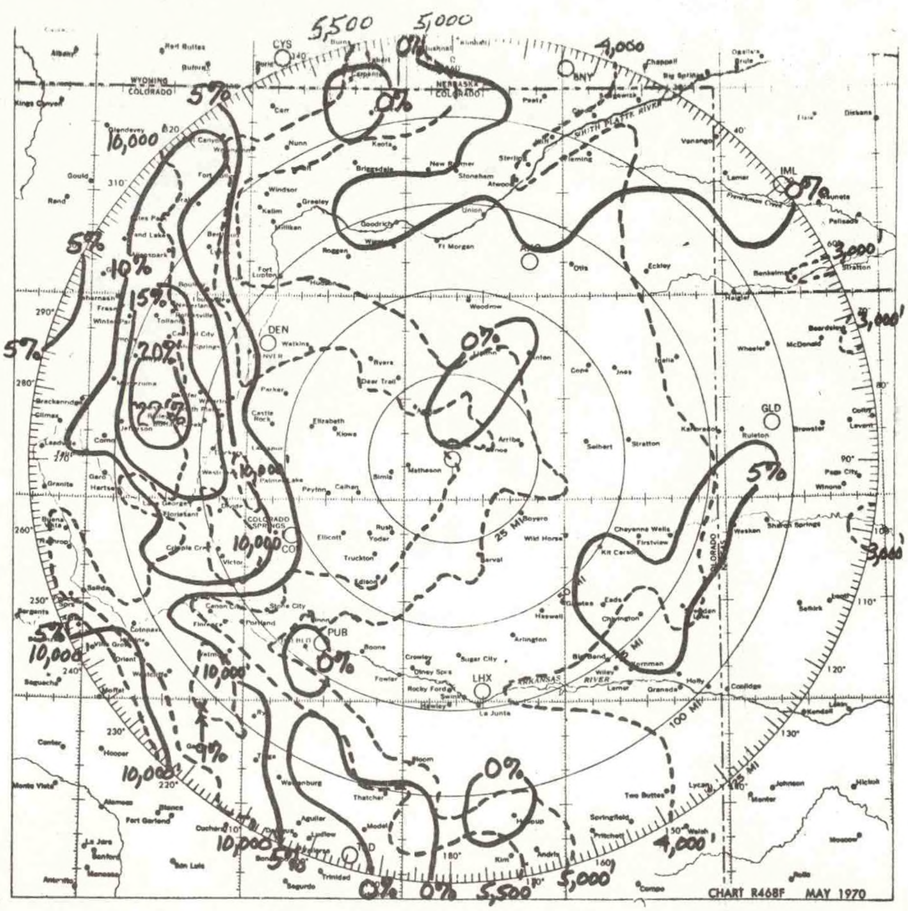


Figure 6. Radar Echo Frequency, 1130 MDT.

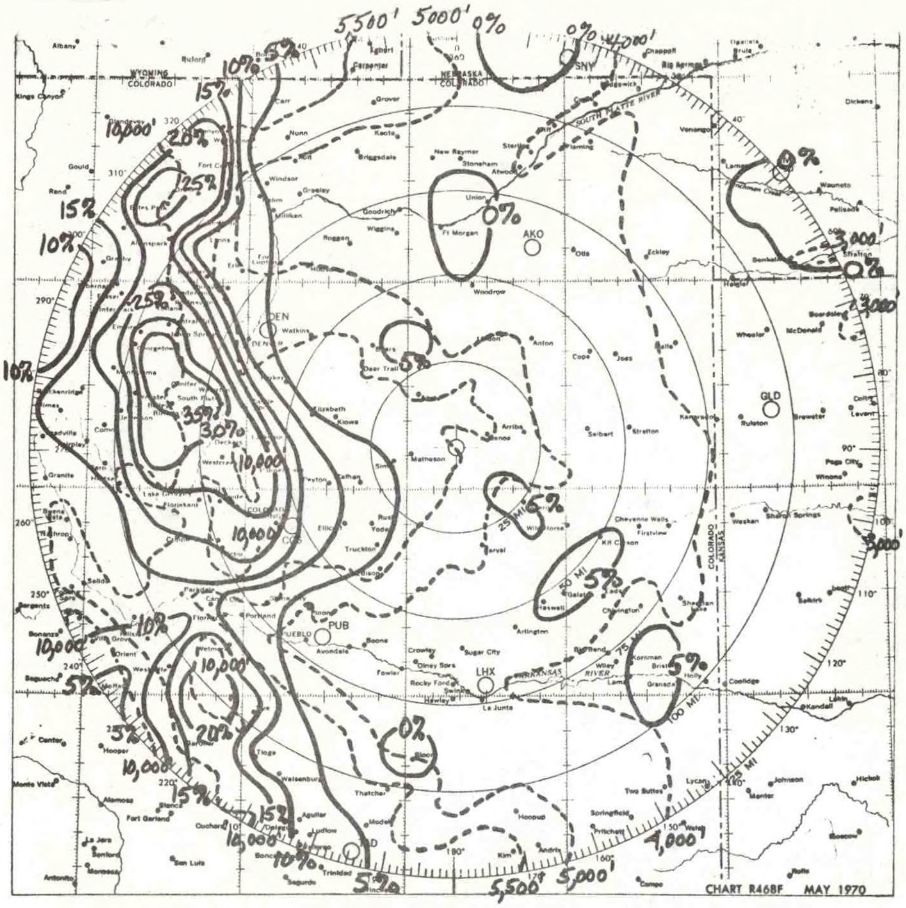


Figure 7. Radar Echo Frequency, 1230 MDT.

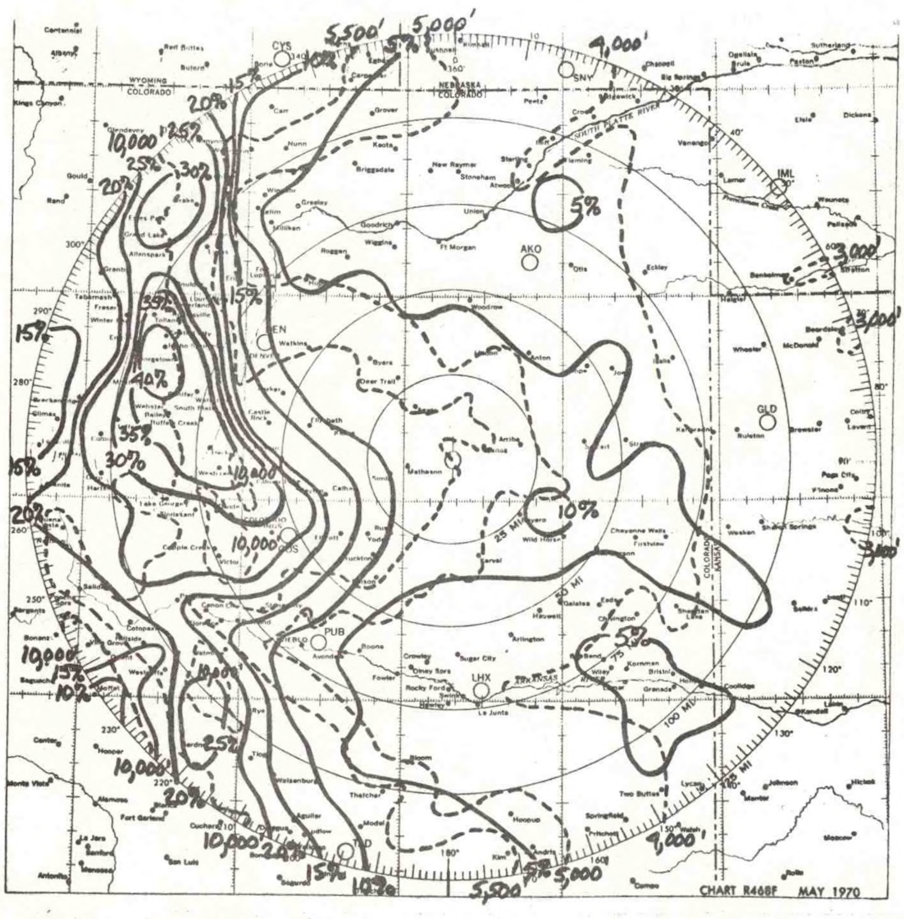


Figure 8. Radar Echo Frequency, 1330 MDT.

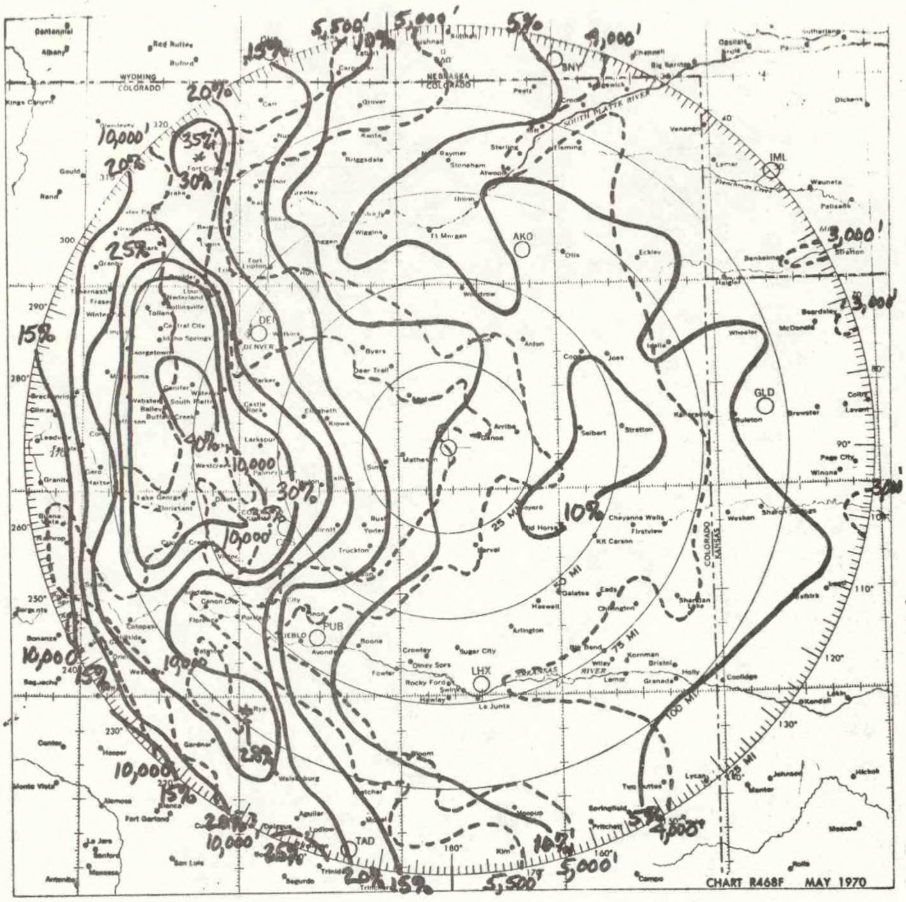


Figure 9. Radar Echo Frequency, 1430 MDT.

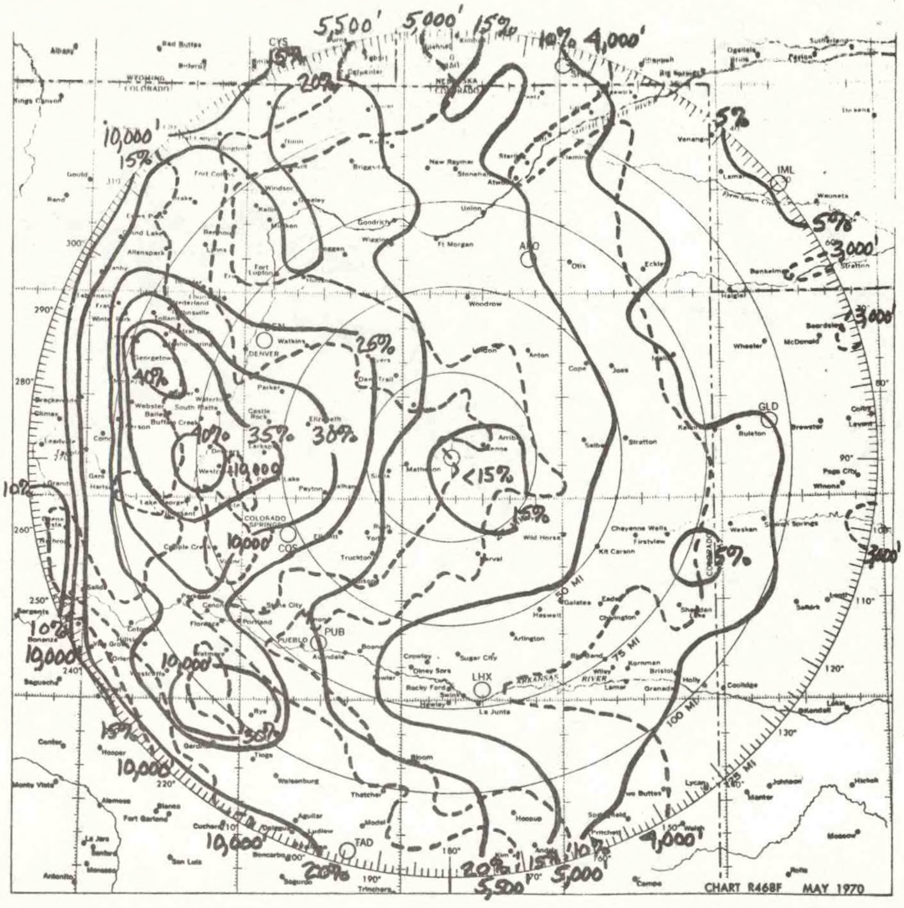


Figure 10. Radar Echo Frequency, 1530 thru 1730 MDT.

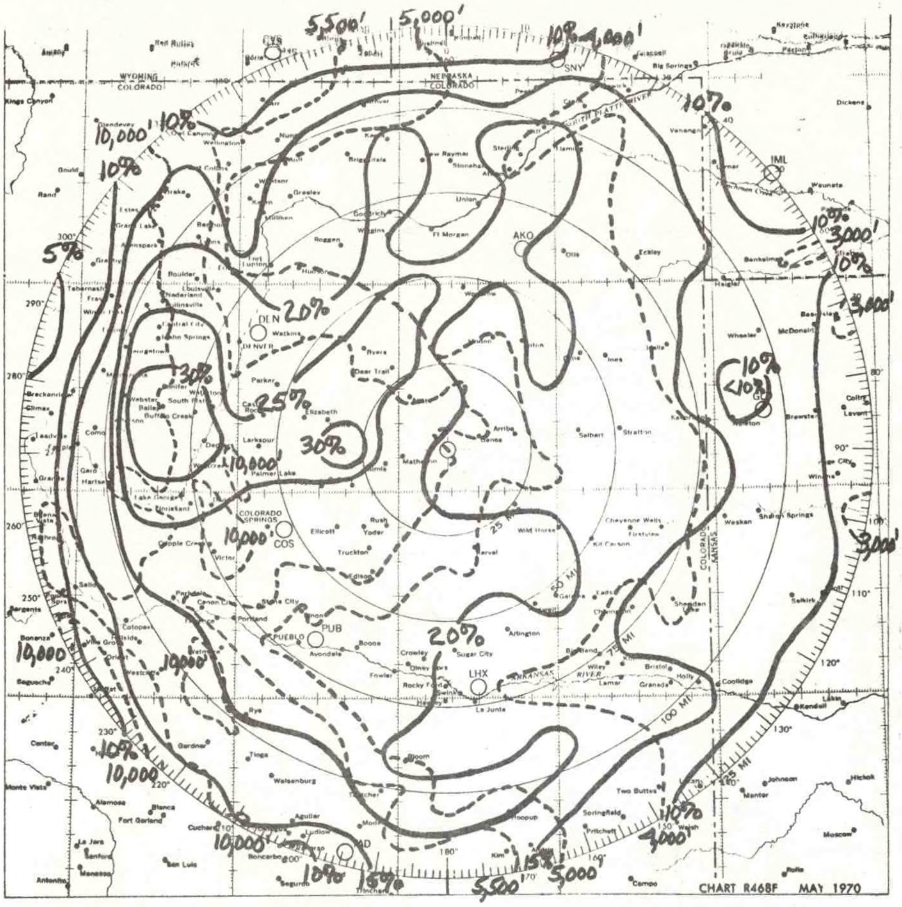


Figure 11. Radar Echo Frequency, 1830 MDT.

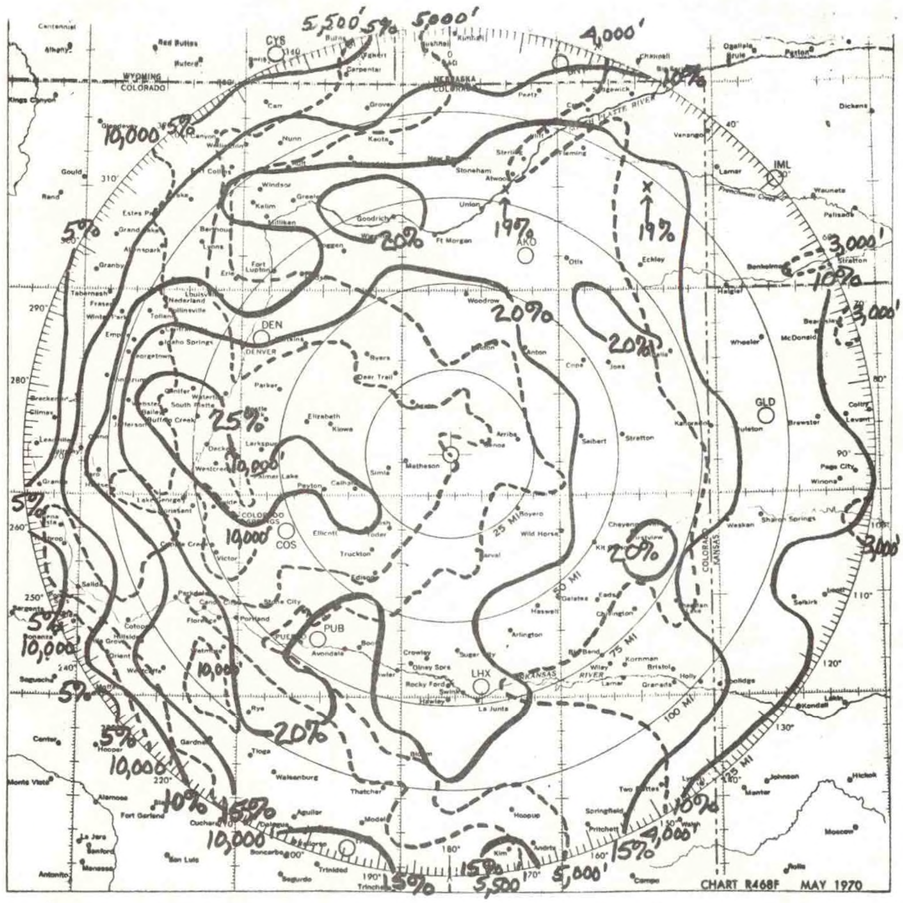


Figure 12. Radar Echo Frequency, 1930 MDT.

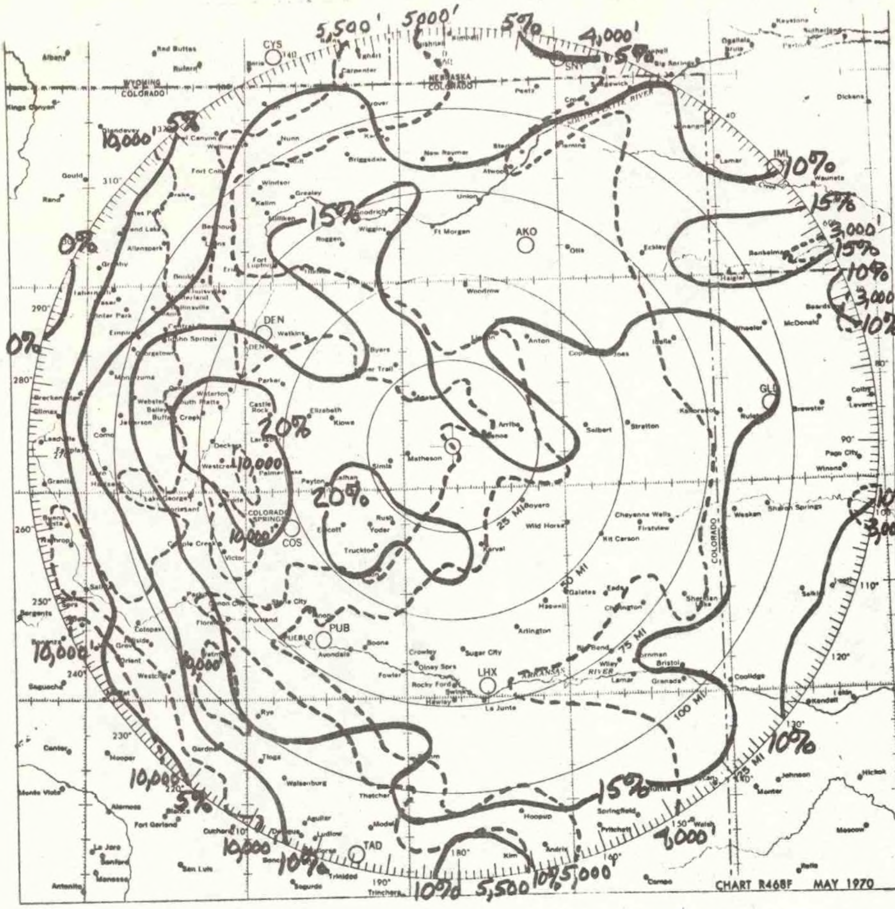


Figure 13. Radar Echo Frequency, 2030 MDT.

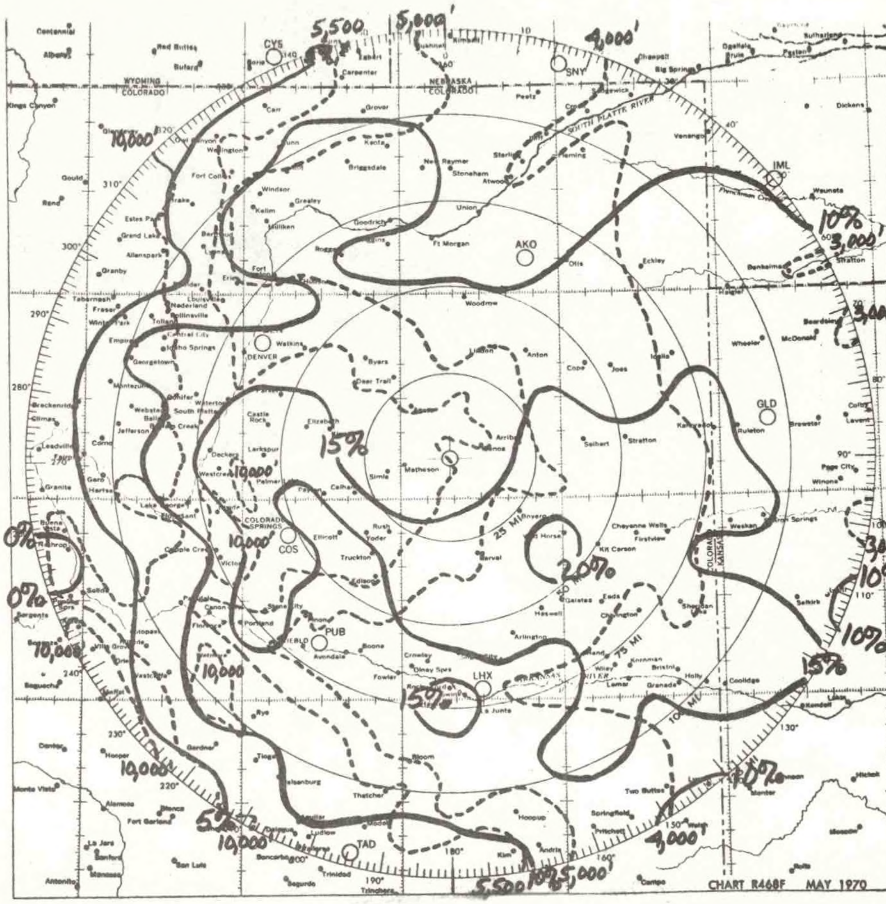


Figure 14. Radar Echo Frequency, 2130 MDT.

2130 MDT. Figure 14. The mountain decay has gone so far that for the first time the maximum frequency is well east of the earlier maximum in the mountains.

2230 - 0130 MDT. Figure 15. This is a period of almost uniform echo frequency. It is important to point out that it represents near minimum frequency for the mountains and continued decay for much of the plains. This is true except for the portions of West Kansas and the extreme east central and extreme southeast Colorado, where a steady state frequency continues. Several small areas in southwest Kansas reach their maximum frequency about 2300 MDT.

0230 - 0430 MDT. Figure 16 shows a very low level of activity through much of the area but with a maximum near Goodland, Kansas.

To see the space variation of the time of maximum frequency, this time was determined and plotted for each grid square (periods where a high frequency persisted for several hours were averaged), and the field analyzed with hourly isochrones (Figure 17). The eastward shift to a later time is very evident but a N-S variation is not significant. Crow (4) showed a similar west-east shift with time. (see Figure 18).

The generality of the echo pattern is supported by the average July-August precipitation probability for 24-hour periods (Figure 19) as taken from Topil (5) who used 10 years of data. Compare Figure 19 with Figure 10 where the echo frequency is nearly a maximum everywhere.

Figure 20 shows the total precipitation amount for the period. While it is realized that precipitation amount for such a short period is not as stable as precipitation frequency or radar echo frequency, the pattern shown in Figure 17 seems reasonable for a general situation. A peak amount is in the mountains in the vicinity of Pike's Peak and somewhat southeast of the area of maximum echo frequency. That maximum is equalled in the eastern portion of the area studied, even though the echo frequency is much less (see Figure 4). In between is a definite area of minimum amount. Figure 21, with 30 years data (from 6), provides strong support for this minimum. But even in this N-S minimum, the E-W ridges have more precipitation than the E-W valleys. Overall this suggests more vigorous upward motion over the mountains and well east of the mountains although more moisture may also be a factor in the east with lesser vertical motion between.

This pattern fits the model proposed by Dirks (3) reproduced as Figure 22. With this figure, Dirks states, "A strong circulation cell forms over the mountain slope with large ascending motions over the upper slope and strong downward motions over the lower slope and extending 50 km or more out over the Plain. A weaker larger scale cell forms over the plain as a result

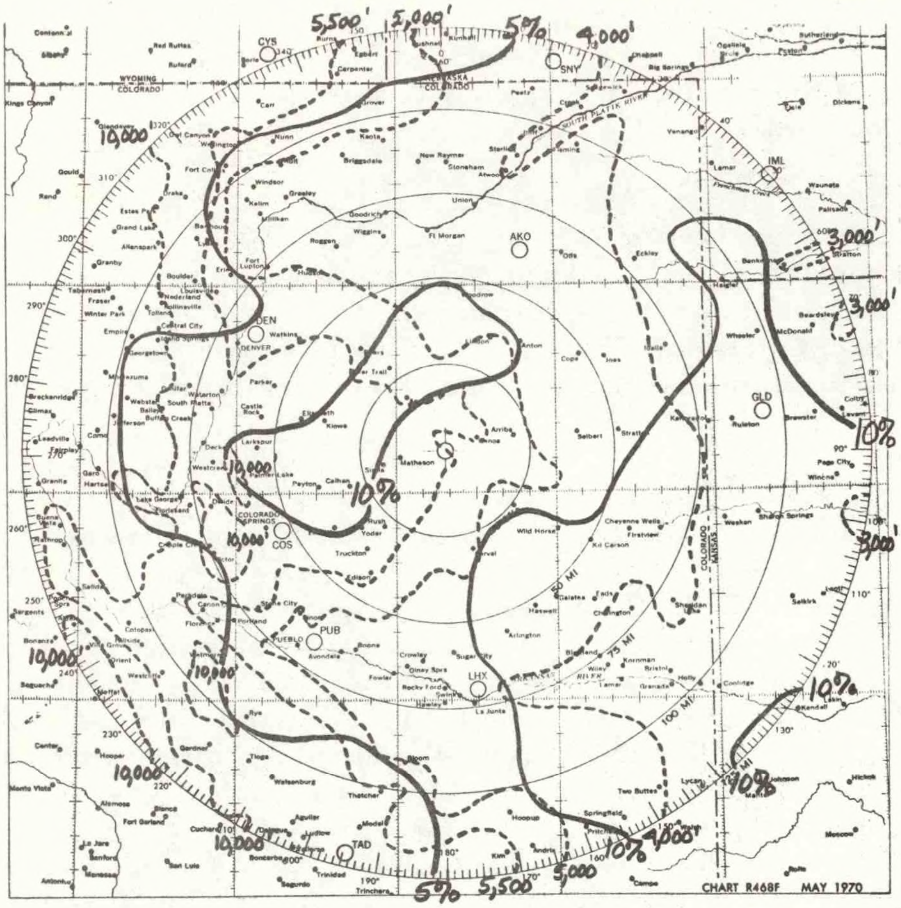


Figure 15. Radar Echo Frequency, 2230 MDT thru 0130 MDT.

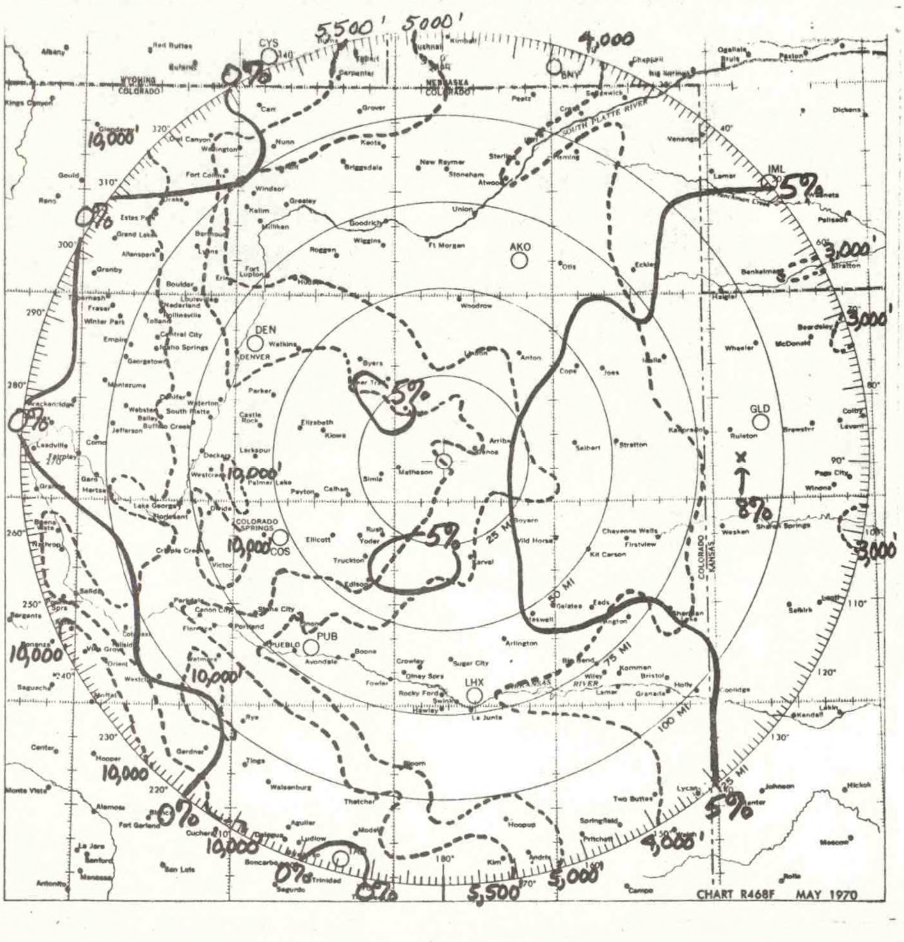


Figure 16. Radar Echo Frequency, 0230 MDT thru 0430 MDT.

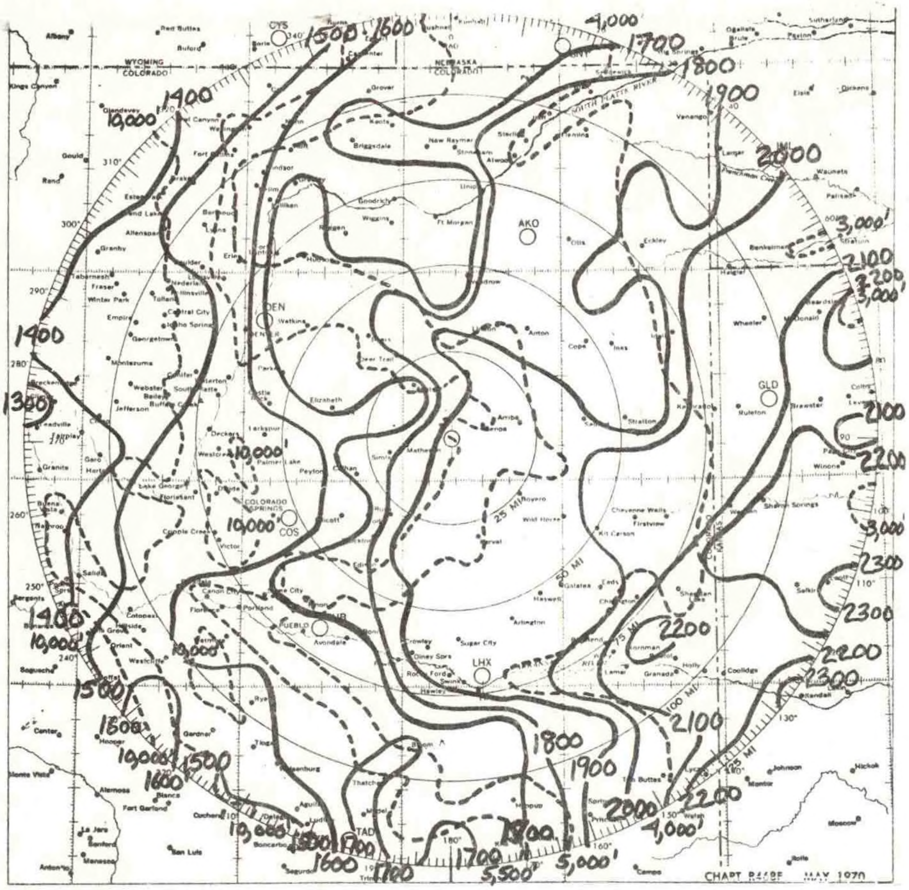
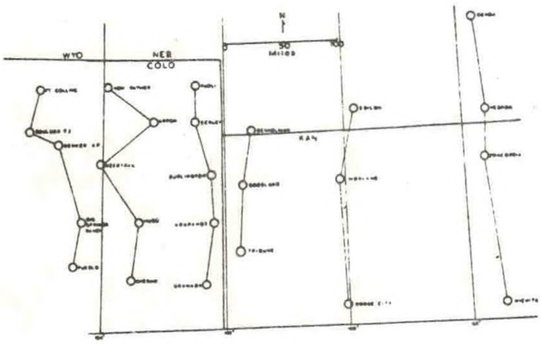


Figure 17. Time (MDT) of Maximum Echo Frequency.



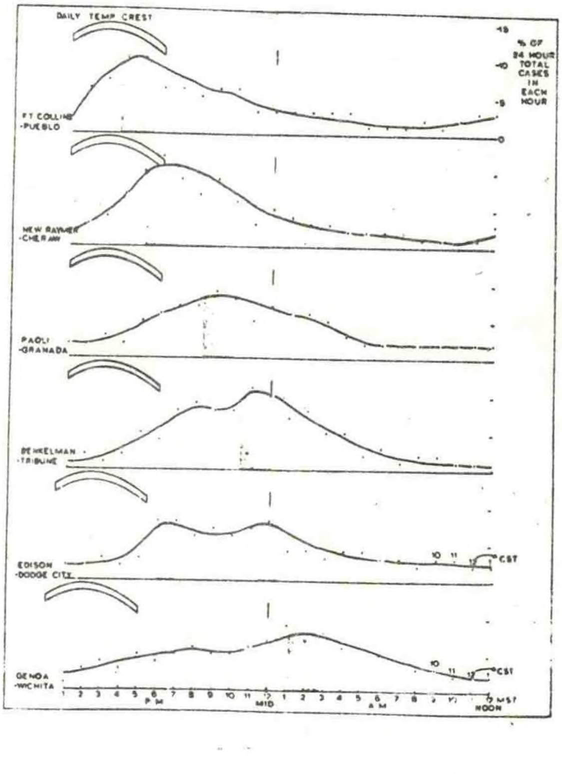


Figure 18. (Above) Six groups of stations with north-south orientations used in the timing analysis of convective shower activity. (Right) Timing of major convective activity for ten-year summary of hourly precipitation ≥ .10 inch for the six groups of stations (from Crow, 1969).

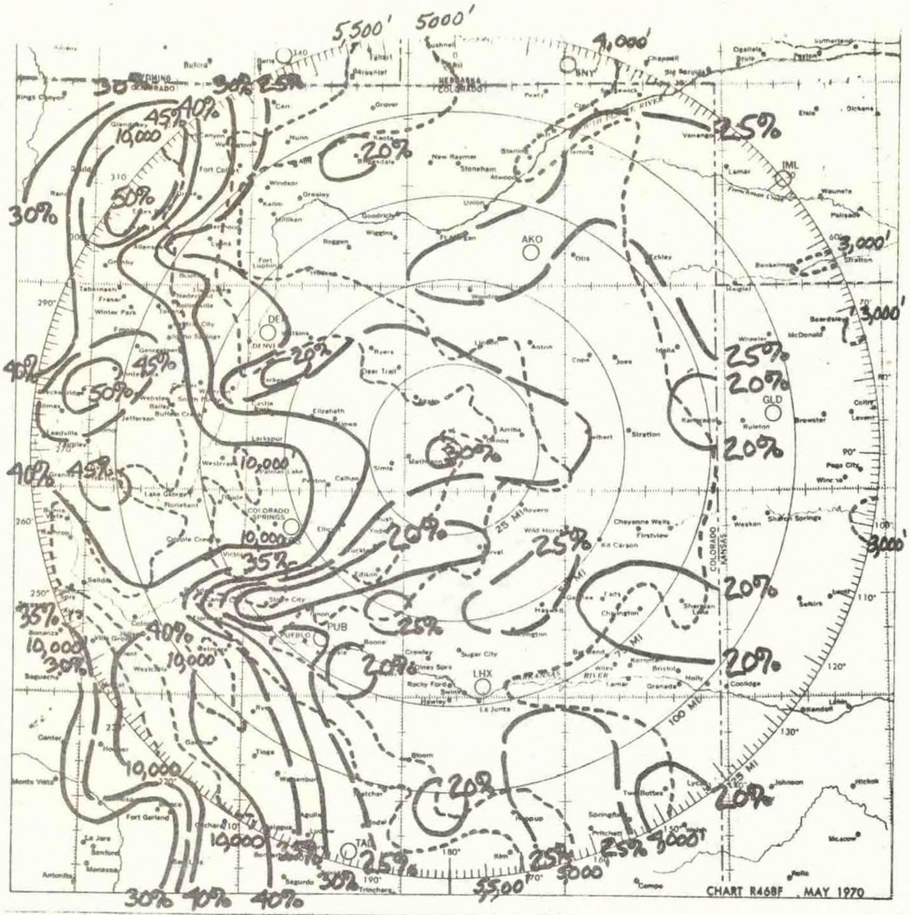


Figure 19. 24 Hour Precipitation Probability for July and August, 1959-68.

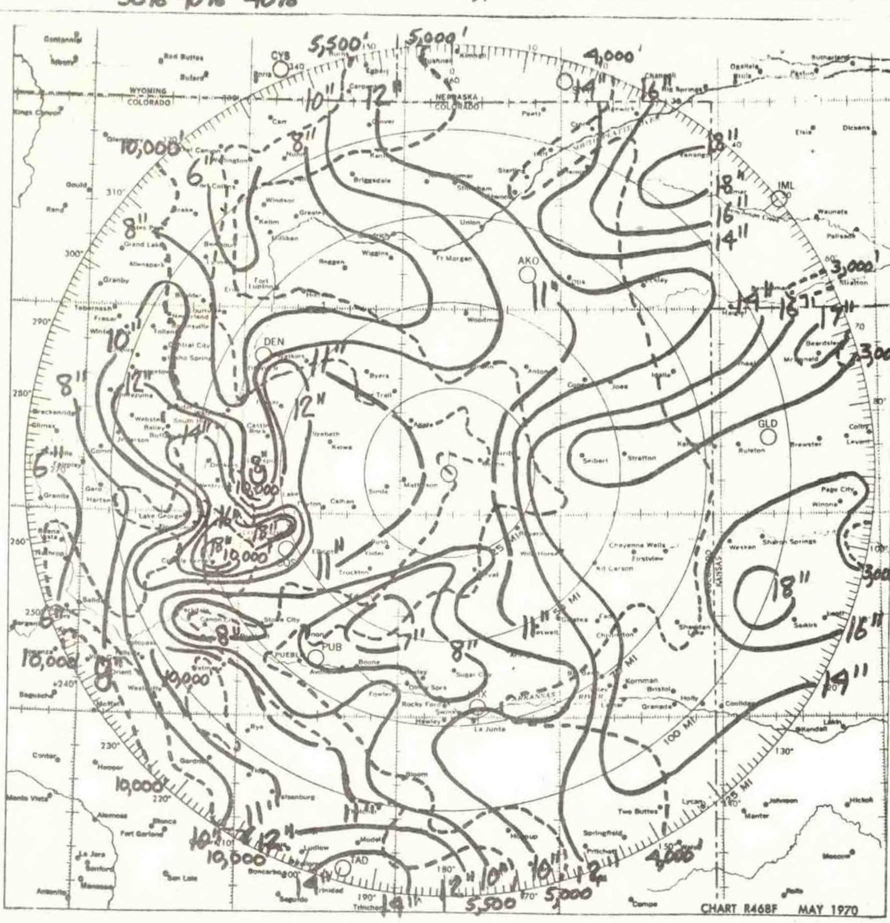


Figure 20. Total Precipitation, Summer Season, 1971-72.

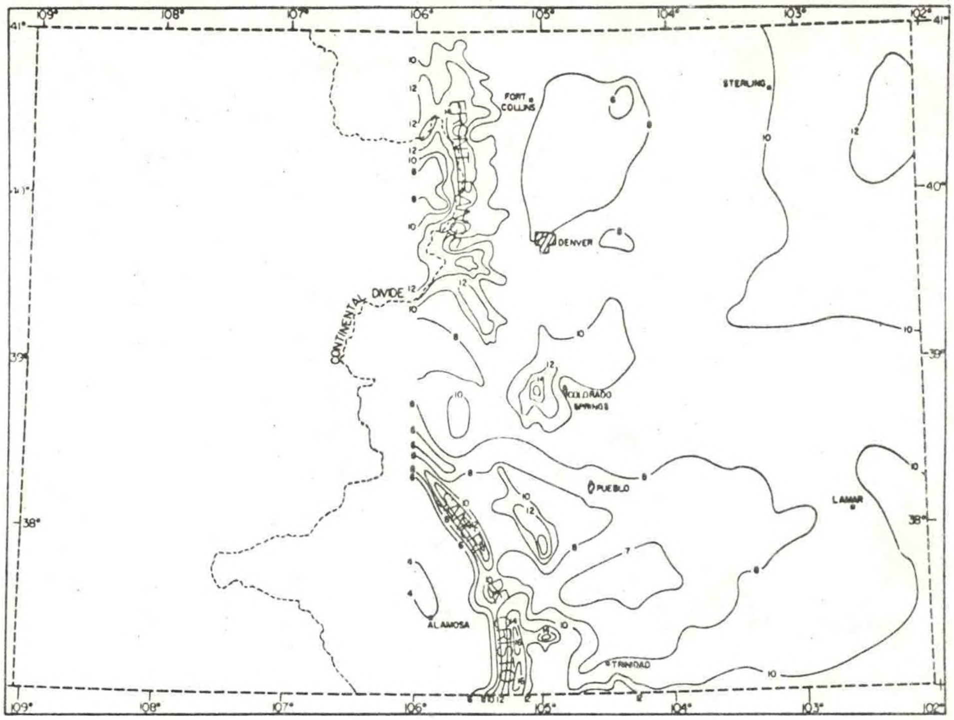


Figure 21. Colorado map showing normal May-September precipitation (1931-1960) east of longitude 106°W. Isolines are in inches. Note regions of reduced rainfall leeward of both the Front Range and Sangre de Cristo Range. (Analysis from U. S. Department of Commerce Map) (See Dirks).

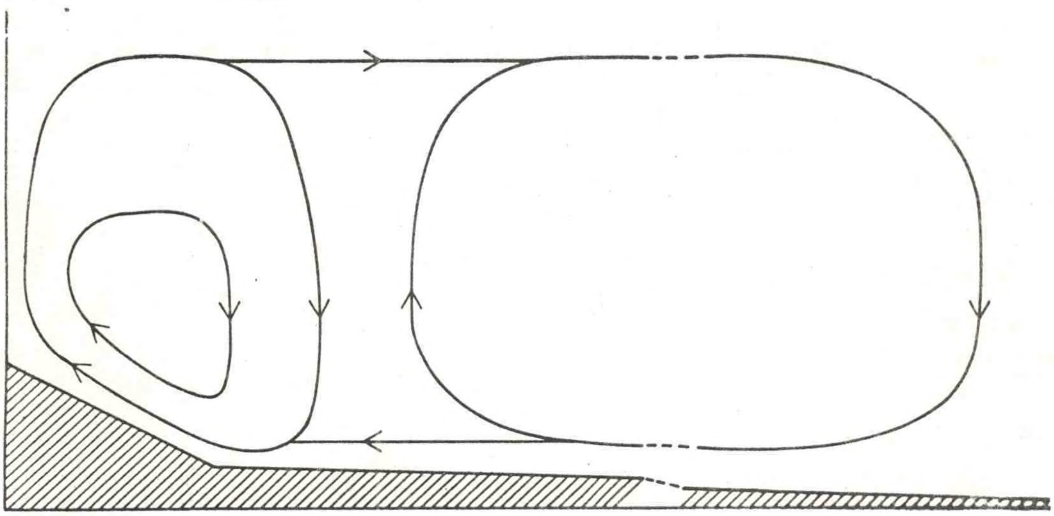


Fig. 22. Schematic Illustration of the Idealized Rocky Mountains-Great Plains Daytime Circulation (Dirks).

of the plain slope and a coupling with the cell over the mountain slope. The resulting circulation advects air from the plain into the mountain slope circulation and also creates a zone of ascending flow from 50 to several hundred kilometers east of the mountains". He further states, "The entire circulation pattern is essentially reversed during the night", and "Various modifications of the model are plausible such as the mountain range to include a broad plateau or a modification to represent more detailed terrain and plain slope features."

It seems logical that echo frequency and other selected precipitation parameters would be a function of this circulation. This means that a higher frequency would be expected with ascending flow and lower frequency with descending flow. Our data support this circulation qualitatively as it shows a high frequency over the mountains with limited activity over the adjacent plains and a slightly higher frequency further out on the plains. It is indicative of a strong-cell-weak-cell circulation in the vertical. The reversing of this circulation seems likely for if the echo activity decrease late in the day were entirely diurnal without any circulation features, there would be little likelihood of the relatively high frequency of nocturnal activity over the eastern portion of the study area.

The favored position of the strong-cell descending flow corresponds to the 5000 to 5500 foot terrain elevation in the study area. The start of the ascending flow of the weak cell appears to favor a position 10 to 20 miles east of this elevation. The strong cell develops first and expands eastward. The weak cell flow seems to develop more slowly than that of the strong cell and possibly is set up by mid-afternoon. In the reversing process, it is likely that the strong cell reverses first and slightly faster than the weak cell. A possible explanation of this is that when the strong cell breaks down, it helps to slightly enhance the weak cell. With the down-slope surface winds, a "chinook effect" is created and warms the low levels thus retarding the diurnal cooling process. The breaking down and reversal process appears to occur in a west to east movement, just as the development did.

The intrusion of the east-west river basins into the north-south terrain and precipitation pattern suggests the possibility that the east-west vertical circulation would have also cellular properties in the north-south direction, with the upward portion over each of the ridges and the downward over the valleys.

SUMMARY

On the basis of comparative data, this study is shown to be representative of general summer precipitation patterns for the area. The diurnal characteristics and orographic effects are well documented. Their effects on precipitation patterns are indeed pronounced and regular.

For the mountains, precipitation can be expected to begin over a wide area suddenly between 1100 and 1200 MDT with three areas of favored development (source regions). These regions are a large area centered from Idaho Springs to south of Deckers (relatively strong), a smaller area centered west of Rye (moderate strength), and another small area centered near Estes Park (weaker). The frequency of mountain precipitation continues to increase reaching a maximum about 1400 MDT and remaining in a nearly steady state until about 1730 MDT. After this time, a decay begins and, usually, mountain activity ceases by 2130 MDT.

Plains precipitation begins to appear at about 1230 MDT starting in the extreme western edges of the east-west ridges. The precipitation pattern spreads eastward more prominently over these ridges, reaching its maximum frequency usually between 1600 and 1800 MDT. The precipitation then begins decaying and usually has nearly ended for the ridge areas of the plains by 2130 MDT. At this time the peak activity, while not strong, is well east of the Rockies where it remains, slowly decreasing, until late the next morning when the mountain activity once again suddenly develops.

The operational forecaster, keeping in mind these time and frequency relationships, can, with a consideration of other parameters, issue his forecast concerning precipitation events with an enhanced degree of confidence, especially in the short term. In regard to short term forecasts, the importance of relatively continuous consideration of radar information becomes apparent.

An idealized Rocky-Mountain-Great Plains Circulation proposed by Dirks (3)--see Figure 19, is supported at least qualitatively by this study and believed to be correct. The main downward motion appears to occur at the 5000' to 5500' elevation at the peak of diurnal heating. A mesoscale modification of this circulation for Eastern Colorado and Western Kansas seems likely in that the E-W mountain cell be expanded to include a series of N-S cells with the ascending flow on the ridges. The circulation cycle theory we propose, based on radar data, suggests the following time relation. The strong mountain cell develops first usually by late morning and close to the mountains and expands over the ridges of the plains. The E-W cell over the Plains is created as a result of the strong mountain cell and its strong descending flow. It is usually formed by early afternoon. It then remains in a semi-steady state until diurnal cooling begins. The strong mountain cell begins to reverse in early evening. This cell reversal has an enhancing effect on the Plains cell and retards the diurnal cooling effect. When the mountain cell breaks down and reverses, it exhibits a chinook effect with downslope adiabatic warming. The reversing process of the weak cell, as noted by Dirks, appears to begin moving in a west to east manner in Eastern Colorado by mid-evening, then continues eastward breaking down slowly. This effect could possibly explain in part the occurrence of the late nocturnal thunderstorm activity for extreme Eastern Colorado and Western Kansas. The entire circulation cycle is usually completed by early morning and then begins again in late morning.

The above shows that careful analysis of radar data will bring out mesoscale details of precipitation induced by terrain, and the prominent effect of the E-W ridges shows that the terrain variation need not be large. The next step would be to interrelate the radar events with satellite information.

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