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The Role of Persistence, Instability, and Moisture in the Intense Rainstorms in Eastern Colorado, June 14-17, 1965

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U.S. DEPARTMENT OF COMMERCE / ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

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ABSTRACT

Heavy rains in eastern Colorado June 14-17, 1965 caused widespread flooding including the greatest flood of record in Denver. A persistent rain-favoring flow pattern over a restricted area provided the framework for these rains. Moisture and instability in this flow are evaluated and implications to forecasting discussed.

1. INTRODUCTION

Outstanding flood-producing rains centered in eastern Colorado on June 16-17, 1965. The meteorology of these rains is appraised with particular attention directed toward a diagnosis of the moisture field. An accurate diagnosis is important not only in a post mortem analysis of a storm but also in storm forecasting. Present meteorological networks are inadequate for accurate moisture appraisal. The sparse networks of upper-air observations precludes accurate moisture appraisal in the June 1965 storm as well as in storms generally. Differences in station elevation further impede accurate moisture appraisal. This indicates a need for adjustment to a common elevation.

The dense network of stations making dew point observations provides an invaluable source of data for adequately accurate estimates of storm moisture. This paper suggests how these data may be used to help in the problem of moisture appraisal for aid in the forecasting of heavy precipitation. Basic to the procedure is the willingness to accept the hypothesis that, in the vicinity and upwind of a heavy rain area, low-level moisture is transported upward to provide a greater degree of saturation than normally indicated by sparsely located upper-air stations [1]. There is little probability of such widely spaced stations being located in the relatively restricted area where moisture is being advected upward in a storm situation. Even in rather large rainstorms the area of active overturning is rather restricted compared to the spacing between upper-air stations. The lack of large mesoscale networks of upper-air stations makes it mandatory that the maximum amount of information be obtained from the most dense coverage we have of moisture measurements - the surface network of dew point observations.

2. RAINFALL

From June 14 through June 17, 1965, periods of heavy rainfall accompanying severe thunderstorms caused some of the most disastrous floods of history in portions of eastern Colorado. The South Platte and Arkansas River drainages of eastern Colorado (fig. 1) suffered the most destructive floods [2]. Substantial rains occurred also in portions of the surrounding areas as shown in figure 2. This chart, taken from the Weekly Weather and Crop Bulletin [3] does not show extreme unofficial rainfall amounts. For example, amounts up to 12 inches were reported in northeastern Colorado the night of June 14 [4] and up to 14 inches between Colorado Springs and Denver during the afternoon and evening of June 16 [5]. Figure 3 shows Bureau of Reclamation analyses of intense rainfall centers for June 16 and 17, 1965.

Maximum 6-hr. isohyetal maps were constructed for both the rain on June 16 and June 17. Resulting 6-hr. depth-area curves, in percent of 10-sq. mi. rainfall, are shown in figure 4, along with those for two outstanding historical rainstorms, the Cherry Creek, Colo. storm of May 30-31, 1935 and the Smethport, Pa. storm of July 17-18, 1942.

3. PERSISTENCE OF RAIN-FAVORING FLOW PATTERNS

The large westward decrease in normal June rainfall [6] from eastern Kansas into eastern Colorado (fig. 5) highlights the difficulty for Gulf of Mexico moisture to reach westward into Colorado. Normally a moist tongue extends from the western Gulf of Mexico anticyclonically toward the Great Lakes or Ohio River Valley. It takes a strong and persistent cyclonic flow pattern to bring a continuing supply of sufficient moisture into eastern Colorado for flood-producing rains. The June 1965 rain period is ideal to demonstrate such a pattern.

Figures 6 and 7 show the persistence of lower- and upper-level flow during June 14-17, 1965. Successive daily positions of the sea-level isobar (fig. 6) and the 18,900-ft. 500-mb. contour (fig. 7) are traced upwind from Denver. The significance of the persistent low-level flow is that strong influx of moisture is involved. This is supported by the large pressure difference between Duluth and El Paso as tabulated in figure 6. The nearly stationary 500-mb. jet axis is also shown in figure 7.

The quasi-stationary pressure trough at 500 mb. over the western United States (fig. 7) provided the framework for the persistent character of meteorological features in the lower levels, and temperatures in this trough over Grand Junction, Colo., for example, averaged 1 to 2 degrees C. below normal for the June 1965 storm period [7].

When persistence is pronounced, composite maps highlight important features. Figures 8 and 9 are composite maps for the 850- and 700-mb. levels for the period June 14-17, 1965. Persistent strong winds within the elongated moist tongue at 850 mb., stretching from southern Texas across eastern Colorado, indicate a prolonged influx of moisture in the lower levels.

4. BROAD-SCALE INSTABILITY CONSIDERATIONS

Various indices were evaluated for depicting the instability characteristics of the air flowing northward toward eastern Colorado. Different thicknesses of the moist layer were tried. The 0500 MST Amarillo, Tex. sounding for June 16 is typical, with rapid influx of moisture (e.g., a 35-kt. wind at 850 mb.) at low levels. Instability indices were computed on the basis of a surface moist layer 1500 feet thick. Accordingly the "lifted index" [8] results from the difference between the temperature acquired by a parcel of air (with mean moisture and temperature of the 1500-ft. moist layer) after being lifted to 500 mb. and the observed 500-mb. temperature. Instability is indicated by negative values (i.e., lifted-parcel temperature higher than environmental temperature). Figures 11 and 12 are analyses of the lifted indices based on eight upper-air stations. There is a persistent band of unstable air extending from southern Texas into eastern Colorado and its alignment corresponds to the 850-mb. moisture pattern of figure 8. Its orientation during the June 14-17 period as shown in figure 13 is about 45° counterclockwise from the axis of average Showalter instability indices [9] for the first half of June 1965.

Reports of severe weather [4] including cloudbursts (R), tornadoes (T) or funnel clouds (F) and hail (H) are plotted on the analyzed stability charts (figs. 11 and 12). They appear in unstable areas for the most part. One exception is the severe weather shown in New Mexico on the 1700 MST June 17 chart. The upper-air network apparently did not sample this unstable area, pointing up the difficulty in sampling mesoscale instability with the existing upper-air network.

Lacking dense mesoscale networks one can only speculate on the exact mechanism(s) which provided the trigger or lift to promote active overturning of the air. In [5] the role of topography and of the strong low-level winds are emphasized. Also, the persistent upper-level flow contributed to the critical alignment and movement of the showers.

5. MOISTURE EVALUATION

The description of the June 1965 storm has certain implications for forecasting heavy rains particularly with regard to diagnosis of the moisture field. Readily available charts depicting moisture may be deficient in providing information to enable one to adequately define the moisture field. For example, a particular 850-mb. chart may mislead if it so happens that the moisture influx is taking place below 5000 feet, as it quite often does, particularly in the Southern Plains and Gulf Coast region.

The moisture remained below 5000 feet for a portion of the June 1965 storm. However, it showed up at 850 mb. enough during June 14-17, 1965 to make a mean chart for this period useful even though some individual 850-mb. charts would have been misleading. Figure 8 is such a mean chart and shows the 850-mb. moist tongue stretching from the Gulf north-northwestward into eastern Colorado. Figure 9 is a similar mean chart for the 700-mb. level showing a downwind displacement of the main moist tongue. Let's take a look at the other readily available moisture charts to see how well they contributed to a diagnosis of the moisture in this important rain situation.

A measure of the moisture field in depth is the liquid equivalent of water vapor (precipitable water) from radiosonde data. An analysis of such data, for the same period as figures 8 and 9, is shown in figures 14 and 15. Figure 14 shows the liquid equivalent for the total column (to 500 mb.) while figure 15 shows the liquid equivalent for the first 150 mb. above the surface. Neither of these mean charts shows any semblance of the pronounced tongue of moisture into eastern Colorado as shown in figure 8. Why? Because the 850-mb. chart had the dual desirable characteristics of being high enough to be above the terrain yet low enough to adequately sample the inflowing moisture. On the other hand, the intervening terrain distorts the moisture field when liquid equivalent of moisture above the ground is used. Thus an unusual moist tongue over higher terrain goes unnoticed because an "apparent" moist tongue occurs where elevations are lower (giving a deeper column and therefore greater total amount of moisture).

One way to overcome the difficulties introduced by varying terrain elevation is to use a departure-from-normal approach. To do this requires that "normal" liquid equivalent charts be available. A meaningful departure-from-normal approach must await the availability of such charts. Even when adequate normal charts are available the fact of wide spacing of upper-air stations confronts one who is interested in accurate moisture diagnosis. Surface dew points provide a much denser coverage of stations. But how can we use these?

The diagnosis of the moisture in the June 1965 storm involves use of the dense network of surface dew points in a twofold manner: 1. Adjustment to a common elevation and 2. use of a departure-from-normal approach.

Surface dew points in an area of significant elevation variations show only a chaotic pattern. Obviously something needs to be done to make the surface dew point pattern meaningful just as pressures are reduced to sea level to provide a meaningful pressure field. A meaningful dew point pattern results when one adjusts the surface dew points to sea level (i.e., 1000 mb.) by assuming moist adiabatic conditions. This is accomplished by starting with the station dew point and adjusting it moist adiabatically to 1000 mb. Figure 16 shows the results of doing this for the June 1965 storm period. The outline of the area of 70°F. or higher "adjusted" dew points shows a tongue of moisture pointing from the western Gulf toward the eastern Colorado area. (Note similarity to fig. 8). An analysis of the relatively unrepresentative surface unadjusted dew points is also shown in figure 16. The adjustment applied made this rather unintelligible pattern of surface dew points meaningful. Since a dense network of surface dew points is always available, the importance of such a procedure for moisture diagnosis in areas of varying elevations is obvious. Likewise a departure-from-normal (mean) approach is equally rewarding.

In using a departure-from-mean approach in the June 1965 storm, recent mean charts were used. These are from Dodd [10] and are in the form of mean <u>monthly</u> dew point charts. An analysis of the mean June 14-18, 1965 dew points was made in terms of departures, in standard deviations of monthly dew points, from the mean monthly dew points the sole purpose being to point up where the dew points were <u>relatively</u> the most unusual. The standard deviations measured in mean monthly terms thus serve only as a yardstick of comparison. Figure 17 shows the results. The dew point departures (in standard deviations) in a band from the Texas Panhandle and especially into eastern Colorado were appreciably higher compared to those farther east in Kansas and Nebraska.

Why wasn't the liquid equivalent a better diagnostic tool of the moisture in eastern Colorado? The average liquid equivalent to 500 mb. at Denver during the June 1965 storm was 0.67 compared to a 1949-1964 June average of 0.59 inch, or a departure of less than half the standard deviation. This degree of saturation compares well with normals [11, 12]. The liquid equivalent analyses of figures 14 and 15 suggest the high moisture was over the lower elevations in the plains yet the surface dew points were not as unusual in this area as in eastern Colorado. The unusual rains occurred in eastern Colorado.

To adequately portray the moisture near heavy rains one must ordinarily make some adjustments to soundings. For example, as in many important rains the moisture in the June 1965 storm came in fast in low levels then likely reached to high levels in the convergence area responsible for the rainfall. What has been learned in recent years suggests acceptance of such a hypothesis. For example, Long [13] in a study of aerial soundings near squall lines, found strong evidence of the disappearance of the low-level moisture inversion as far as 50 to 100 miles ahead of the squall line. In the

June 1965 storm situation the low-level inversion in soundings to the southeast (fig. 10 for Amarillo) lifted downstream but even Denver was apparently not close enough to heavy rain areas for its sounding to sample this effect adequately.

A possible difference in the observed liquid equivalent at Denver and at the rain area is presented below with support from other heavy rain situations in the mid continent area.

It is suggested that, due to the increase in depth of moisture ("pull-up") immediately upstream of the June 1965 heaviest rain areas, liquid equivalent there was approximately 50 percent greater than the observed Denver value. This estimate, based on the 0500 MST June 15 sounding (fig. 18) when Denver was nearest the heavy rain area, assumes that a greater depth of liquid equivalent existed east of Denver. That this assumption is reasonable is suggested by an analysis (fig. 19) at 0500 MST June 15 of the previous 12-hr. changes in depth of the moist layer (from the surface to the level where a distinct decrease in moisture existed) and in the liquid equivalent within this layer. The chart indicates "pull-up" of moisture. Thus, in northeastern Colorado, slightly closer to the area of extreme rain, saturation to a great depth might be expected. From the magnitude of the reported rains, one reasonably assumes high thunderstorm efficiency with little evaporational loss near the area of heaviest rain suggesting approximation to a moist adiabatic sounding for the region of heaviest rain. Assuming such a "proximity" lapse rate above either the surface or 700-mb. levels to the 500-mb. level at Denver would show about 1.25 inches of liquid equivalent above the surface. The observed liquid equivalent at Denver was 0.81 inch at 0500 MST, June 15. How does this compare with increases of liquid equivalent in other selected storms? To answer this ten recent rains of 3 inches or more in 24 hours were investigated.

A moving grid was used to compare precipitation amounts for 24 hours ending at 0700 EST with the 24-hr. changes in liquid equivalent. The mean of the maximum changes in liquid equivalent for these cases is assumed to be representative of the unmeasured moisture in the vicinity of significant rain areas, and offsets the effects of sparsity of upper-air stations. Toward this end the locations and maximum liquid equivalent changes within about 300 miles of the rain center were tabulated and summarized. The mean of the maximum liquid equivalent increases for these ten cases amounted to 0.55 inch. Soundings close to the rain centers sometimes showed greater increases. Concentric areas of percentage of storms showing increases of 0.50 inch or more in liquid equivalent are shown in figure 20. Also shown on this figure are the mean location of maximum liquid equivalent prior to rain and also the mean and extreme geographical centers of rainfall. Interestingly these ten warm-season rain cases showed about the same magnitude of increase of liquid equivalent as was suggested in the adjusted sounding in the June 1965 storm situation.

CONCLUSIONS

The persistence of a flow of very unstable moist air set the stage for the record flood-producing Colorado rains in June 1965. Despite extreme rains nearby, Denver's upper-air soundings did not indicate unusual moisture during this period. Low-level indices did indicate rather unusual moisture conditions. It is concluded that the moisture came in at low levels and was distributed aloft on the storm's fringes, producing saturation to high levels upstream of the heaviest rainfall.

Accurate diagnosis of storm moisture requires use of all available moisture indices. This includes use of the relatively dense network of surface dew points since the use of the liquid equivalent from widely spaced soundings is subject to serious shortcomings.

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13. Michael J. Long, "Serial Soundings Near Squall Lines," Conference Review for Third Conference on Severe Local Storms," University of Illinois, 1963.

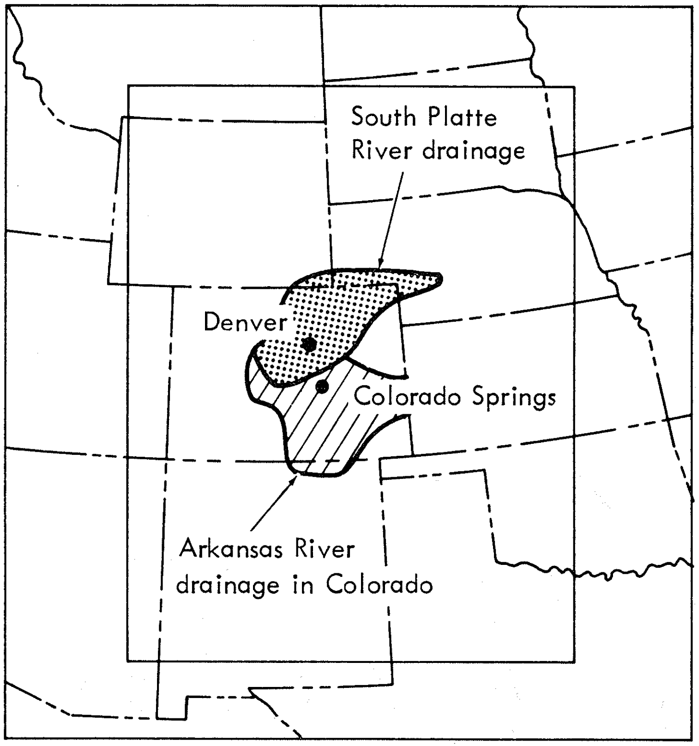

Figure 1. - South Platte and Arkansas River drainage basins.

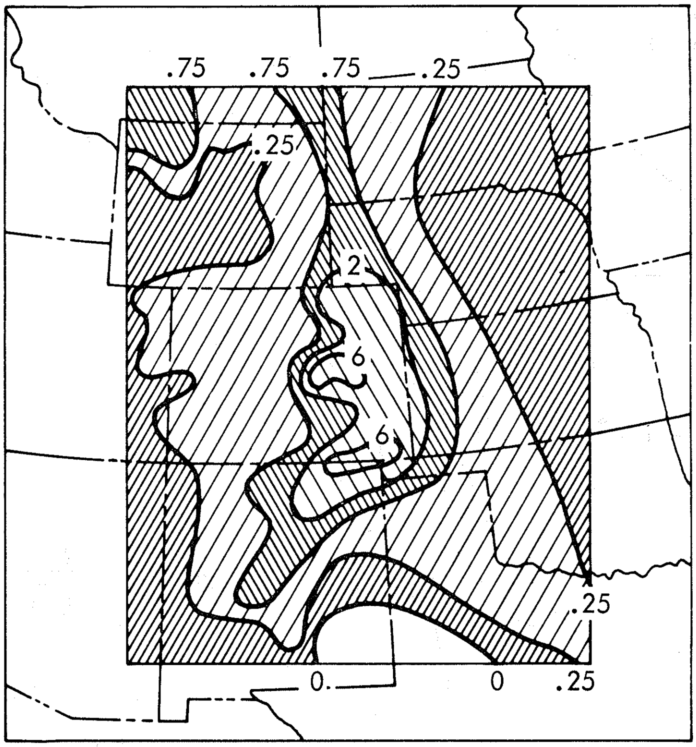

Figure 2. - Total storm precipitation (in.), June 14-17, 1965.

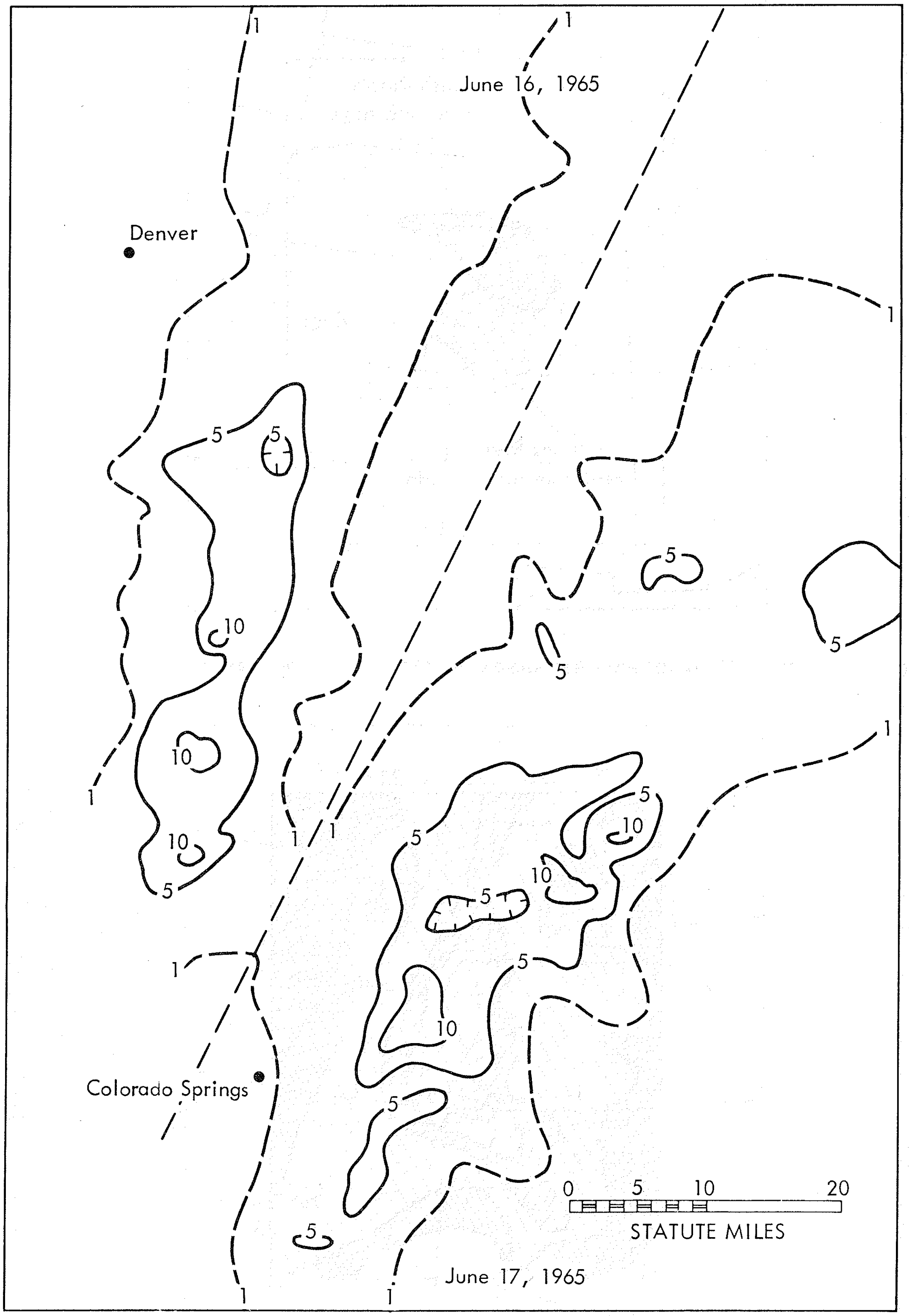

Figure 3. - Isohyets (in.) Denver area, June 16, 1965 (upper left); Colorado Springs area, June 17, 1965 (lower right).

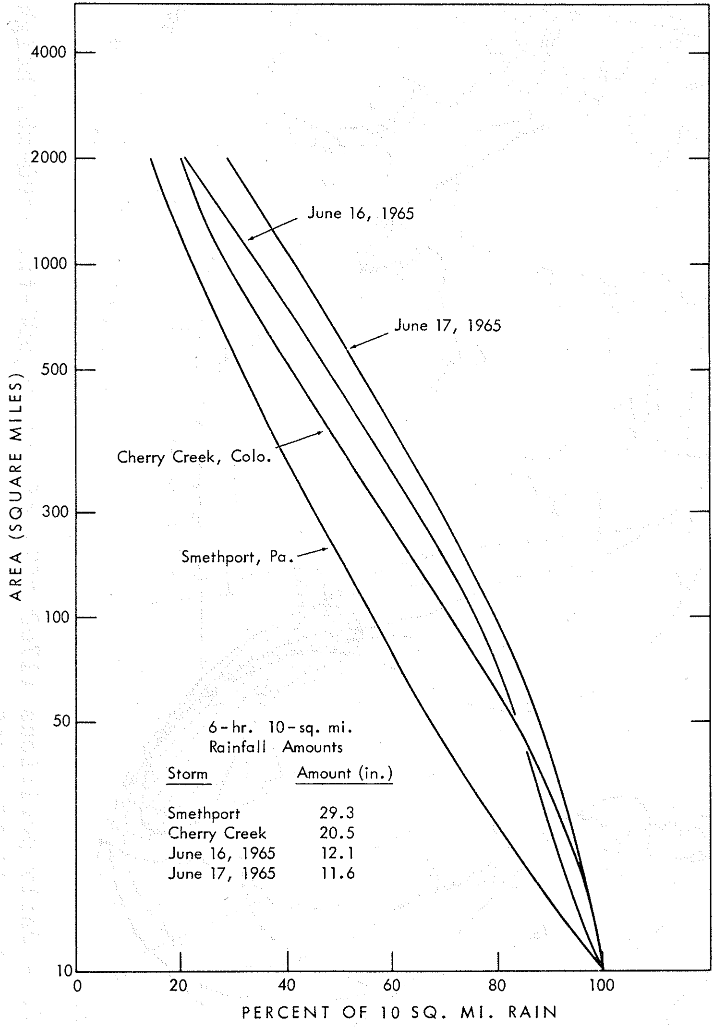

Figure 4. - 6-hr. rain depth-area relations for June 1965 storms compared with two outstanding storms.

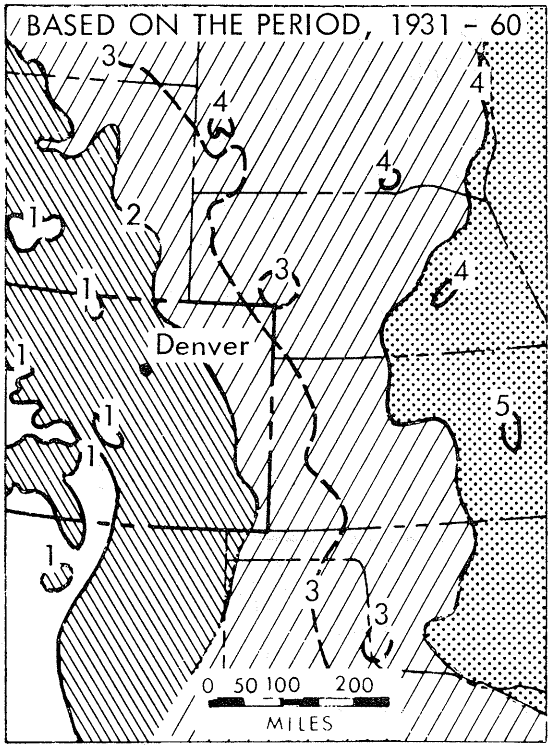

Figure 5. - Normal June precipitation (in.)

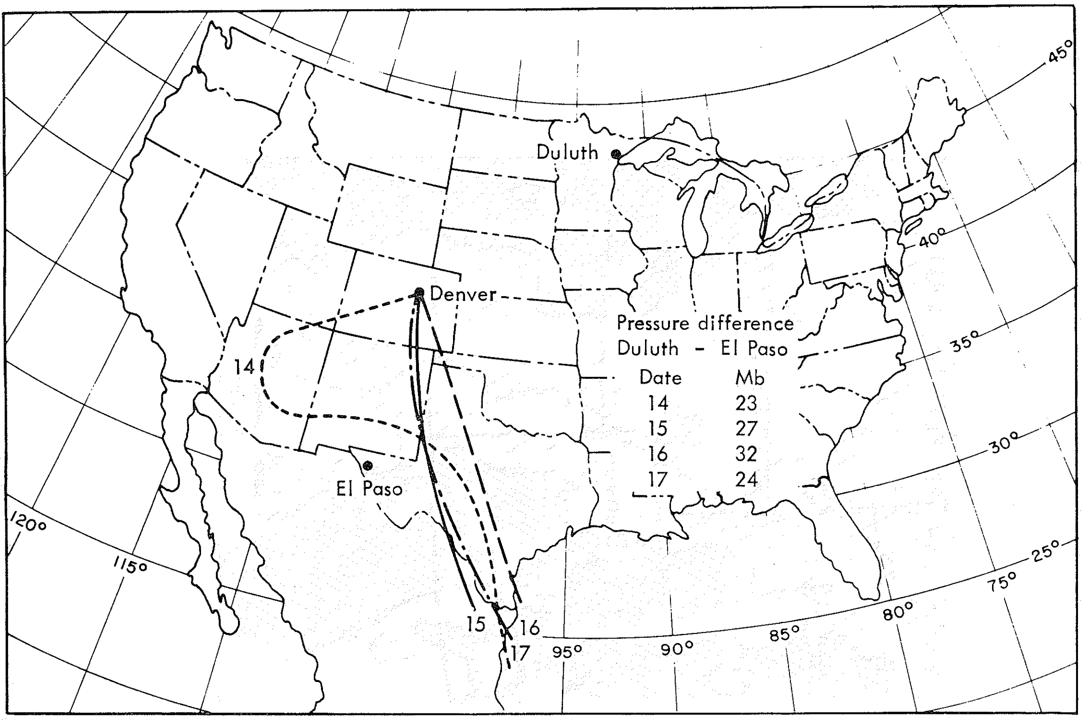

Figure 6. - Daily positions (1700 MST) of the sea-level isobar through Denver, June 14-17, 1965 and daily pressure difference between Duluth and El Paso.

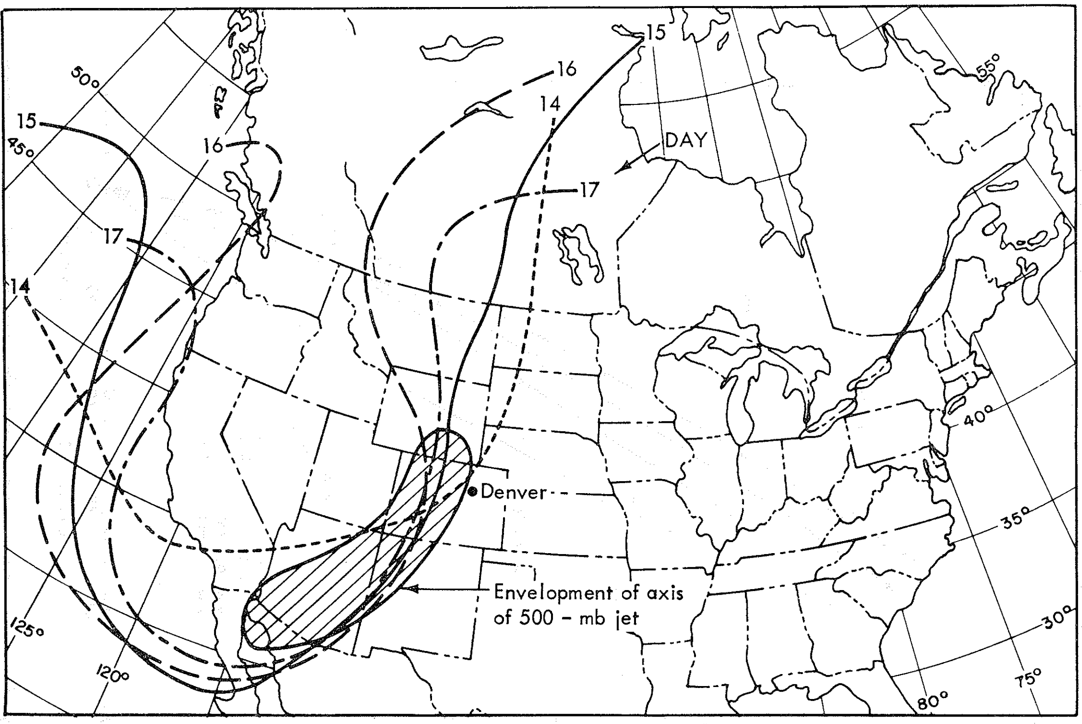

Figure 7. - Daily positions (1700 MST) of the 18,900-ft. (500-mb. height) contour, June 14-17, 1965.

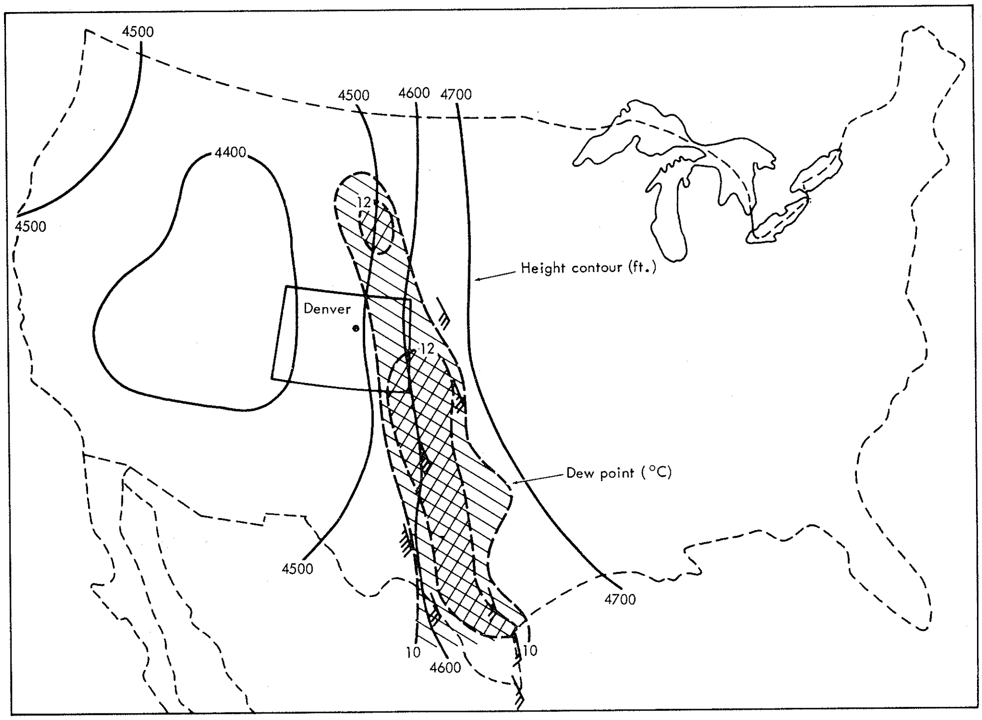

Figure 8. - Composite 850-mb. chart, June 14-18, 1965.

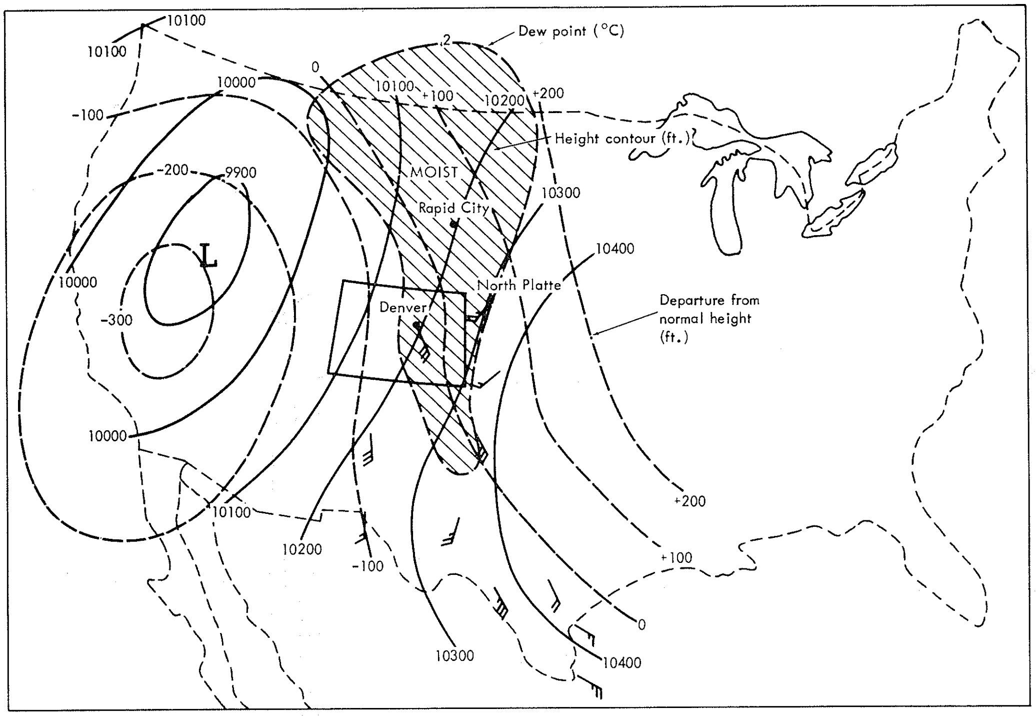

Figure 9. - Composite 700-mb. chart, June 14-18, 1965.

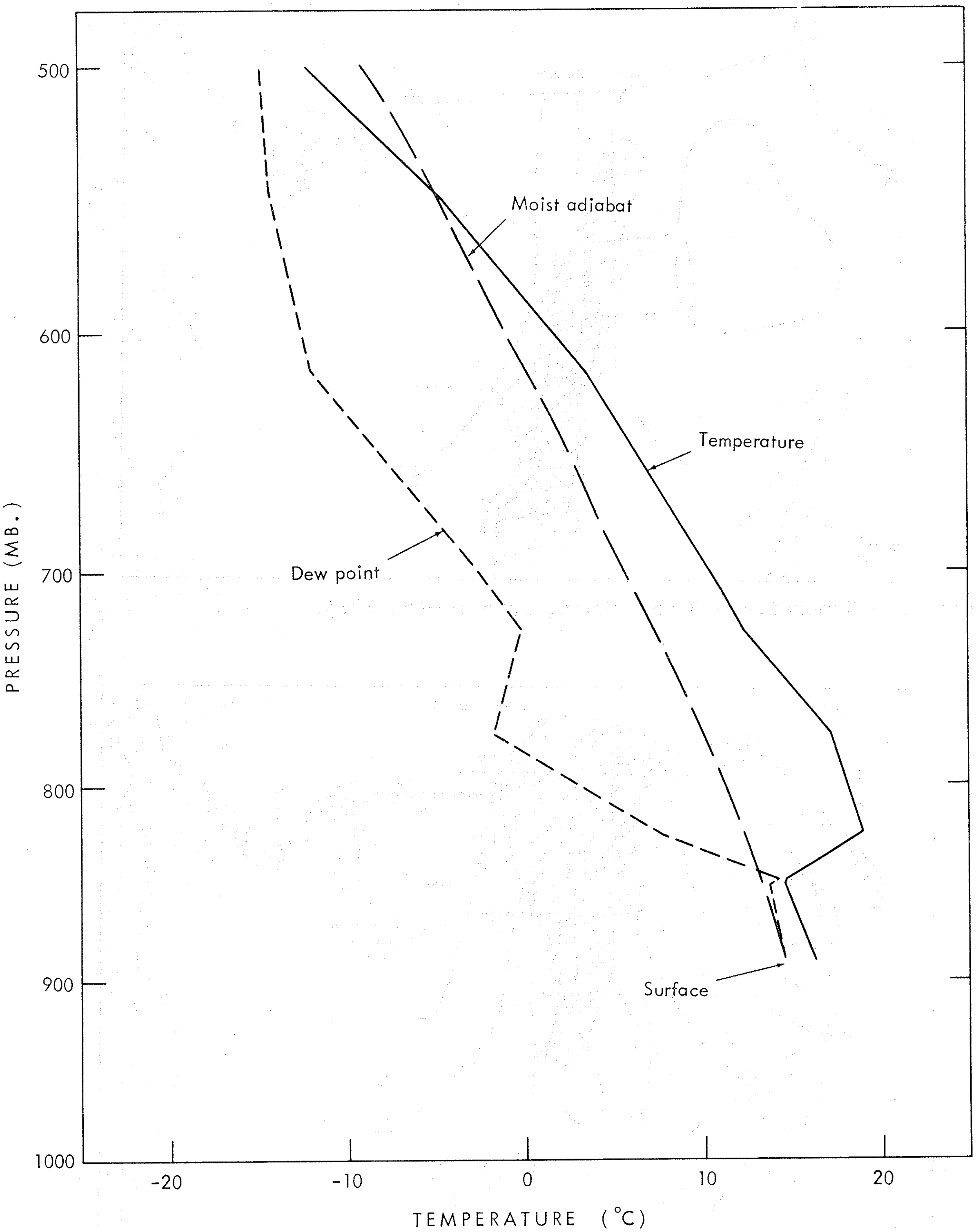

Figure 10. - Atmospheric sounding at Amarillo, Texas, 0500 MST June 16, 1965.

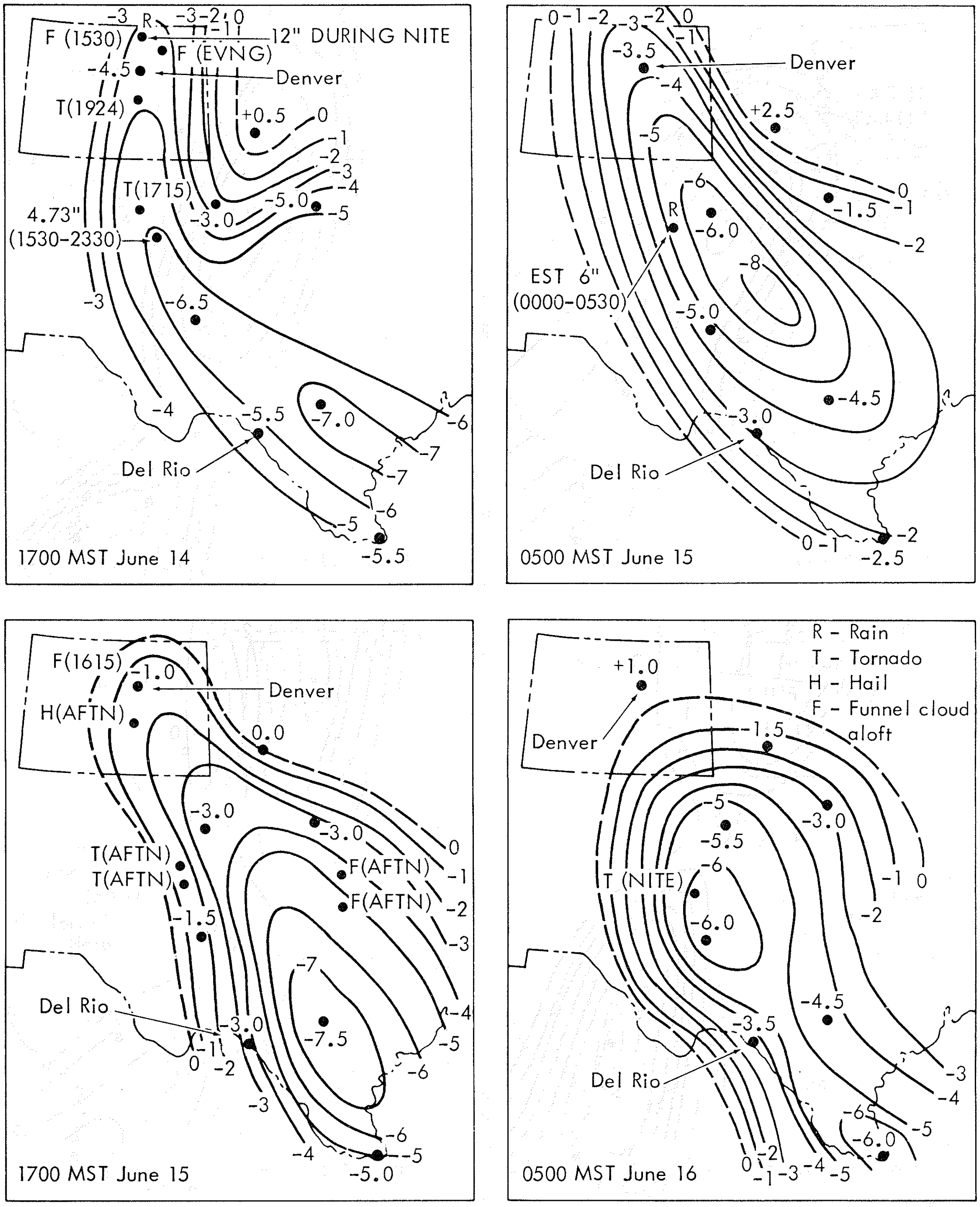

Figure 11. - "Lifted index" patterns at 12-hr. intervals June 14-16, 1965.

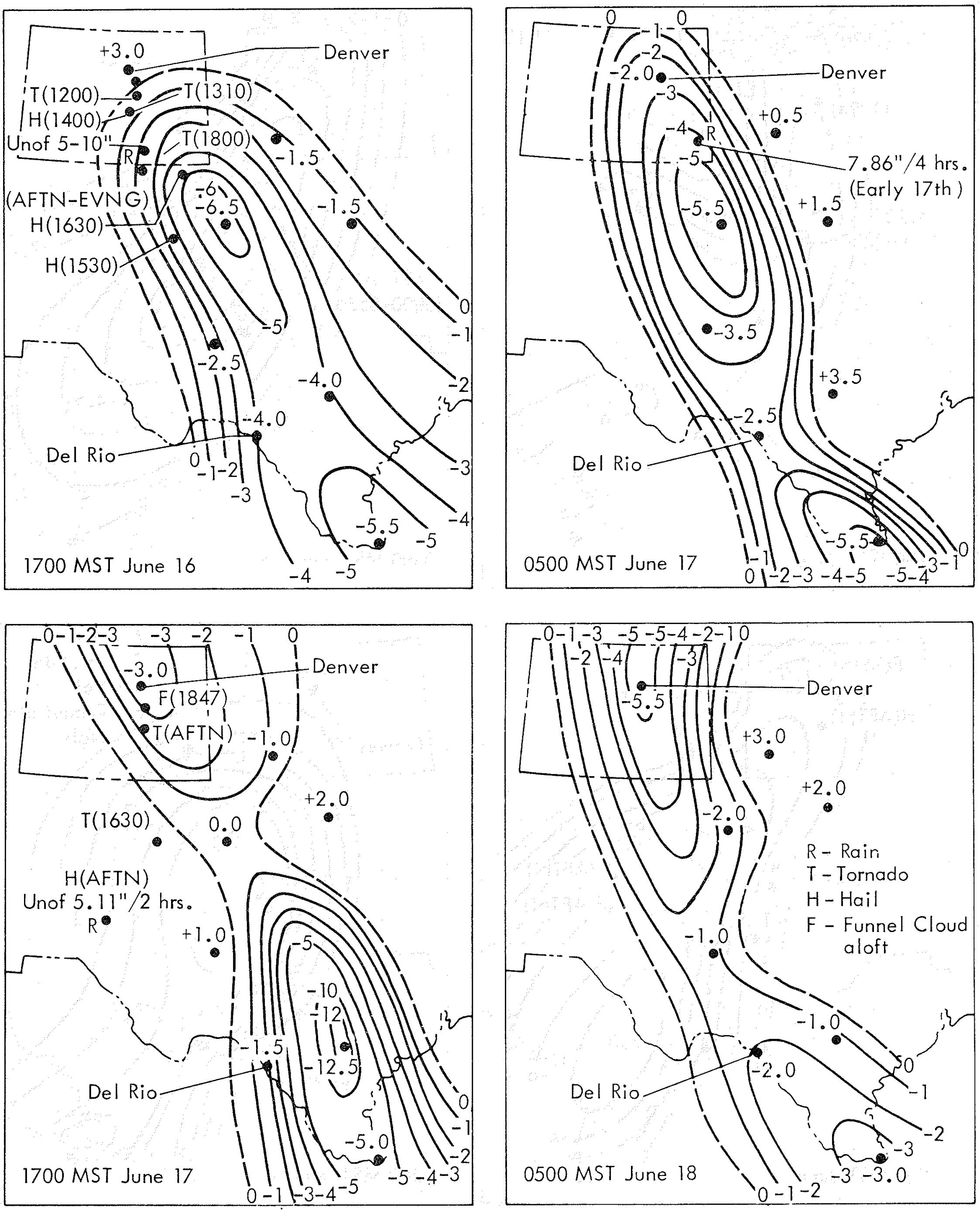

Figure 12. - "Lifted index" patterns at 12-hr. intervals June 16-18, 1965.

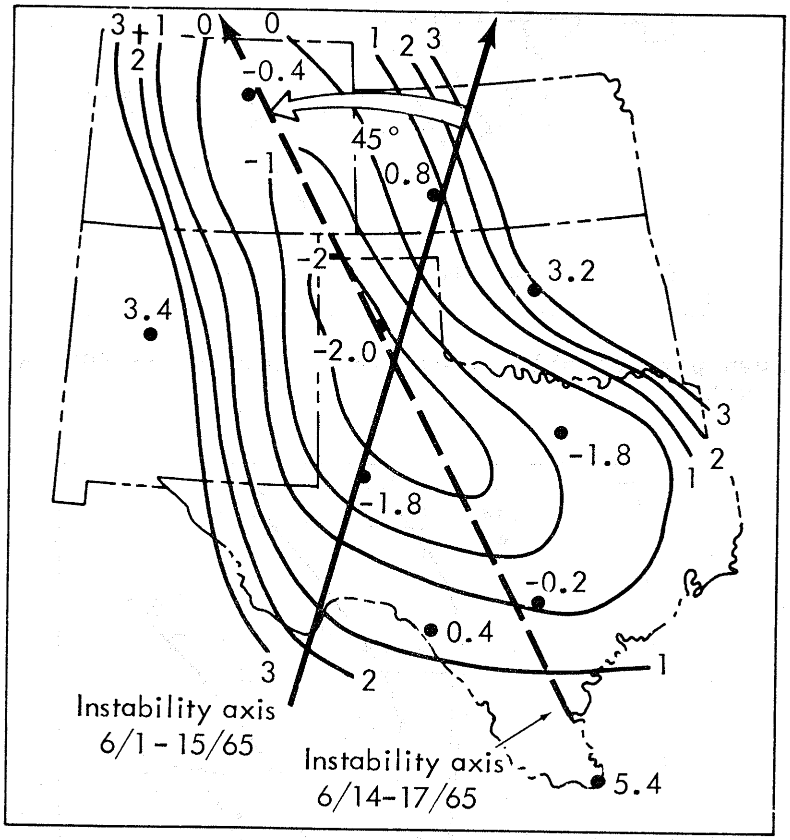

Figure 13. - Mean June 14-17, 1965 Showalter Stability Index showing rotation from mean index for June 1-15, 1965.

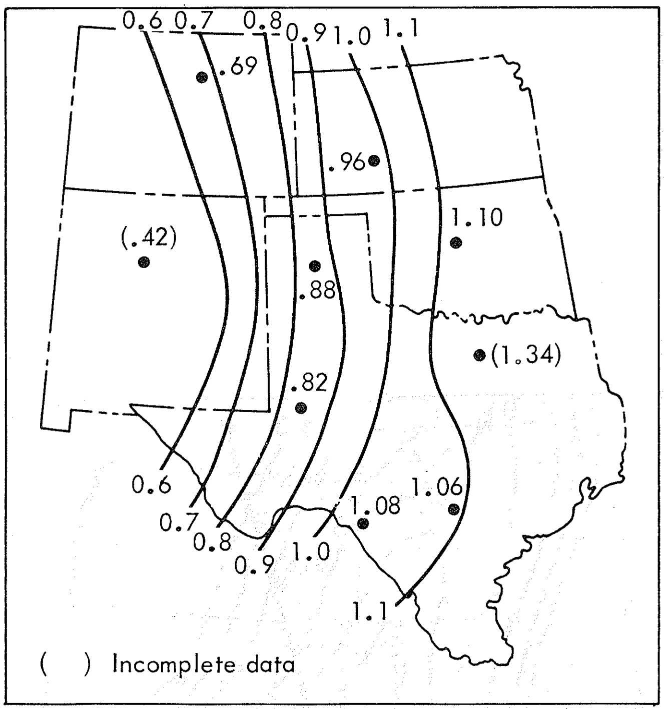

Figure 14. - Mean precipitable water (in.), surface to 500-mb. level - June 14-18, 1965.

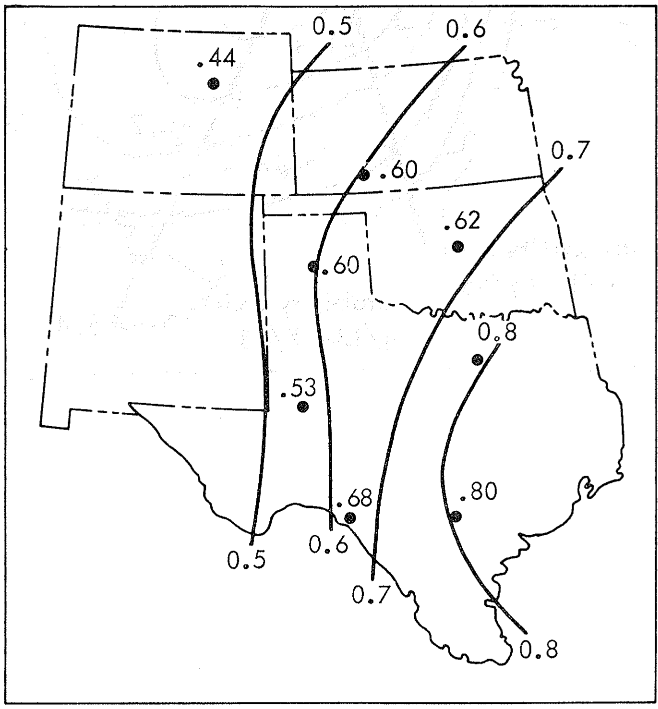

Figure 15. - Mean precipitable water (in.) first 150 mb. above the surface - June 14-18, 1965.

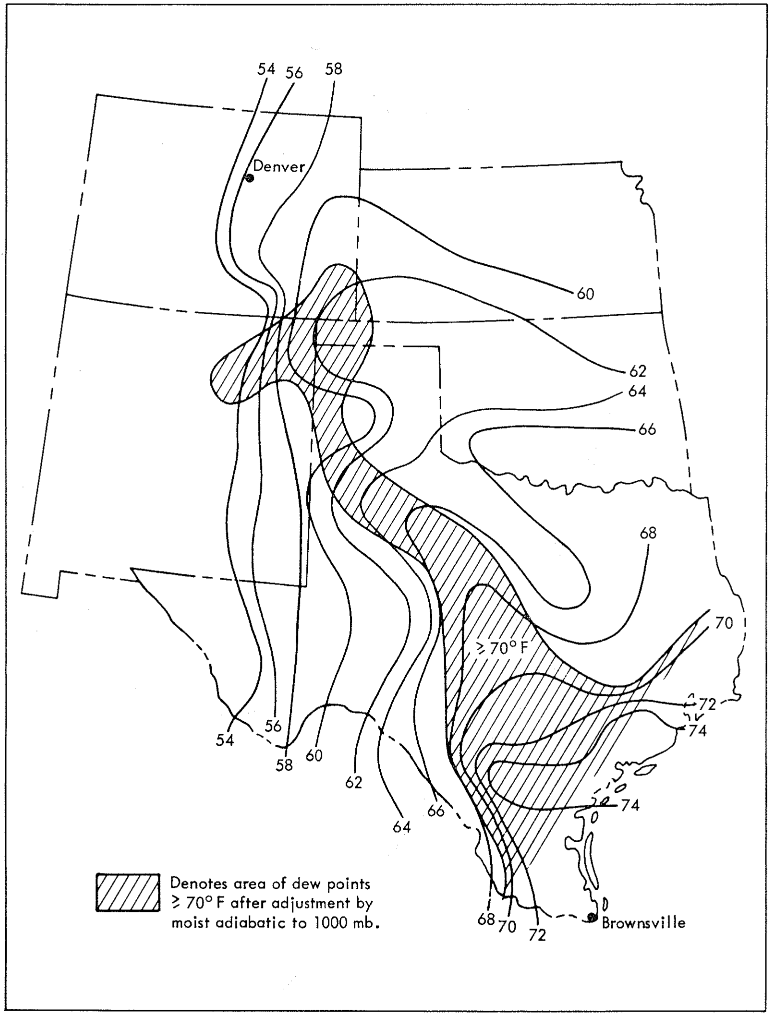

Figure 16. - Mean surface and adjusted 1000-mb. dew points (°F), June 14-18, 1965.

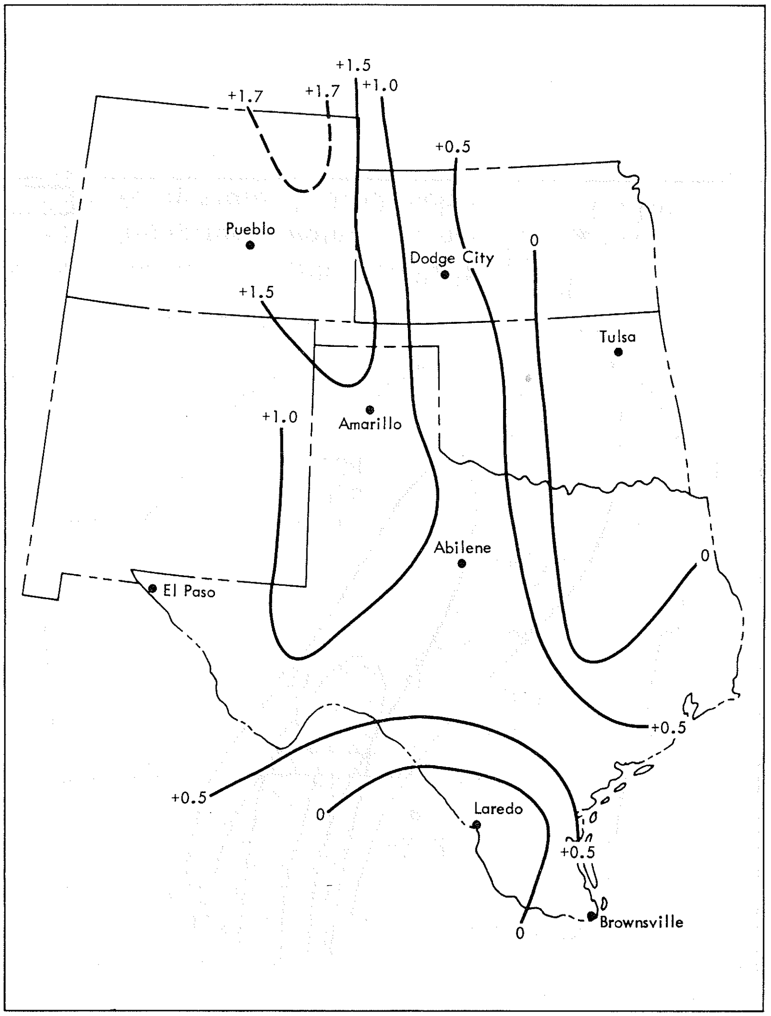

Figure 17. - Departure (in standard deviations) of June 14-18, 1965 dew points (fig. 16) from mean June dew points.

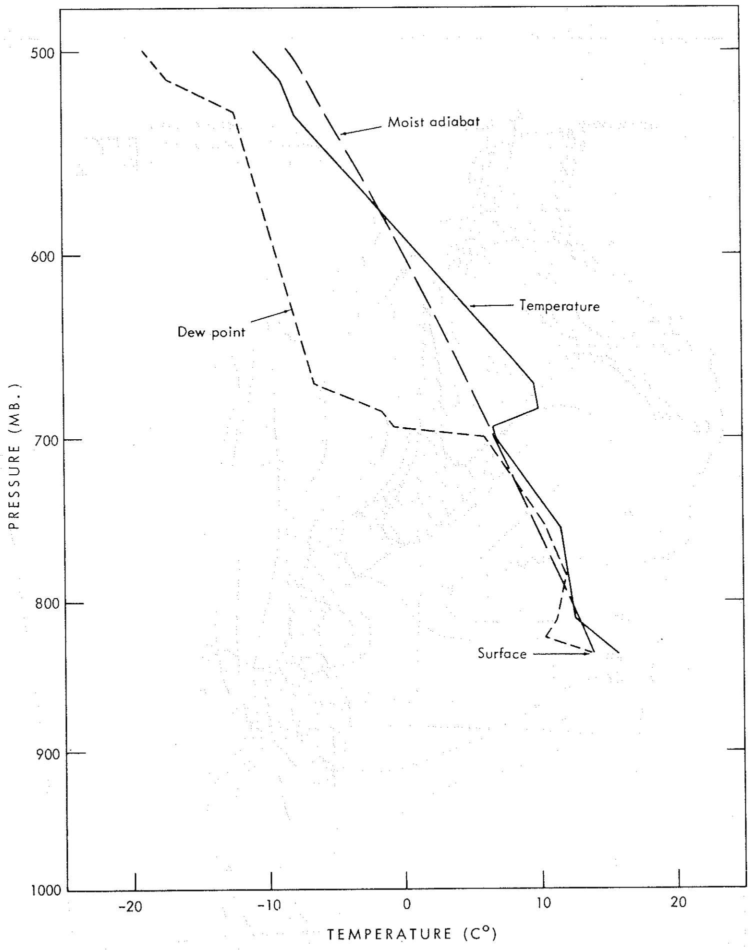

Figure 18. - Atmospheric sounding at Denver, Colo. 0500 MST June 15, 1965.

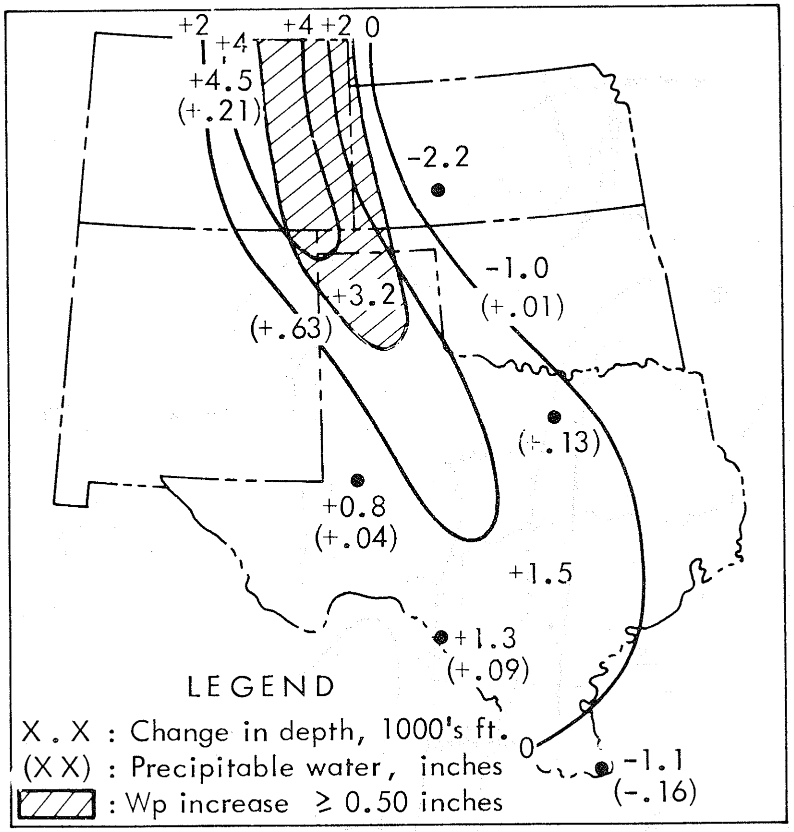

Figure 19. - 12-hr. change in depth of moist layer and precipitable water within this layer, June 14-15, 1965 (1700 to 0500 MST).

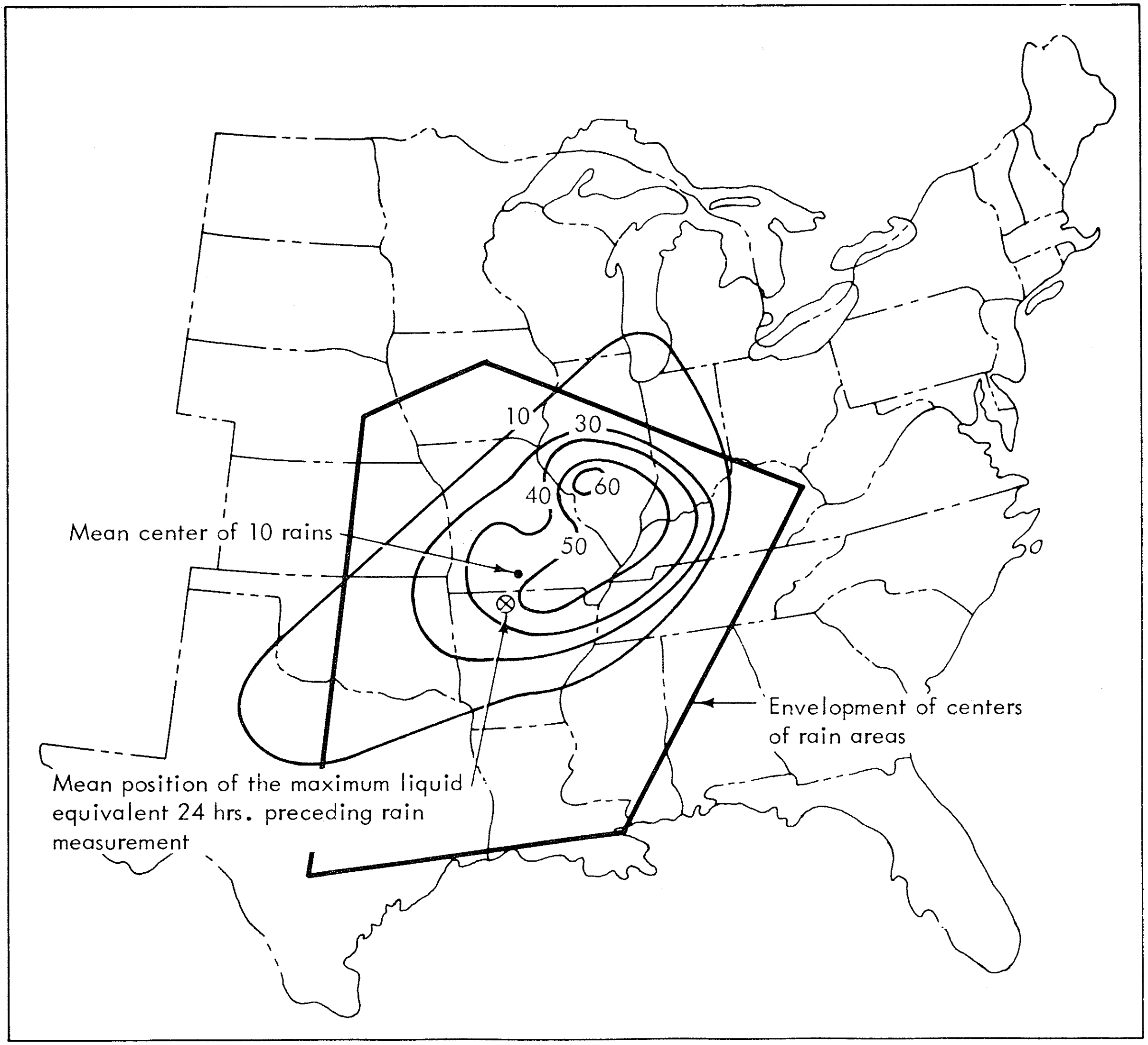

Figure 20. - Percentages of storms showing increase of liquid equivalent greater than 0.50 in./24-hr. for 10 warm-season heavy rains.