THE UNPARALLELED THRALL, TEXAS RAINSTORM

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INTRODUCTION

The largest observed rainstorm in the United States in terms of the depth-duration-area relation (see fig. 1) occurred at the fringe of the Edwards Plateau area of Texas on September 9–10, 1921. The purpose of this paper is to review this great storm as a matter of general interest and to present all the available data for use by those concerned with quantitative rainfall problems. This paper on the Thrall storm is one of a group on intense rainstorms which are important in American hydrologic work. The factors that produce heavy rainfall are probably more in evidence here in the great storms than in lesser more common ones.

Large flood-producing storms are more frequent over the Edwards Plateau and its escarpment than over any other area in the United States east of the 105th meridian [1]. The floods created by the torrential rains of the 1921 storm took 215 lives and caused $19,000,000 worth of property damage. Homes and crops were destroyed; bridges and railroad tracks were washed out; power and communication lines were crippled [2]. This was not only the largest storm of the Edwards Plateau group but also produced the highest official point-rainfall total recorded in the United States, 19.65 inches in 12 hours. An unofficial point-rainfall total, a record 32 inches in 12 hours, fell about 2 miles north of Thrall, Tex. This intense concentration of rain in both time and place caused unprecedented rises in the level of many streams. On the San Gabriel River the first rise, at midnight of the 9th, came as a 4-foot wall of water. Thereafter, the river

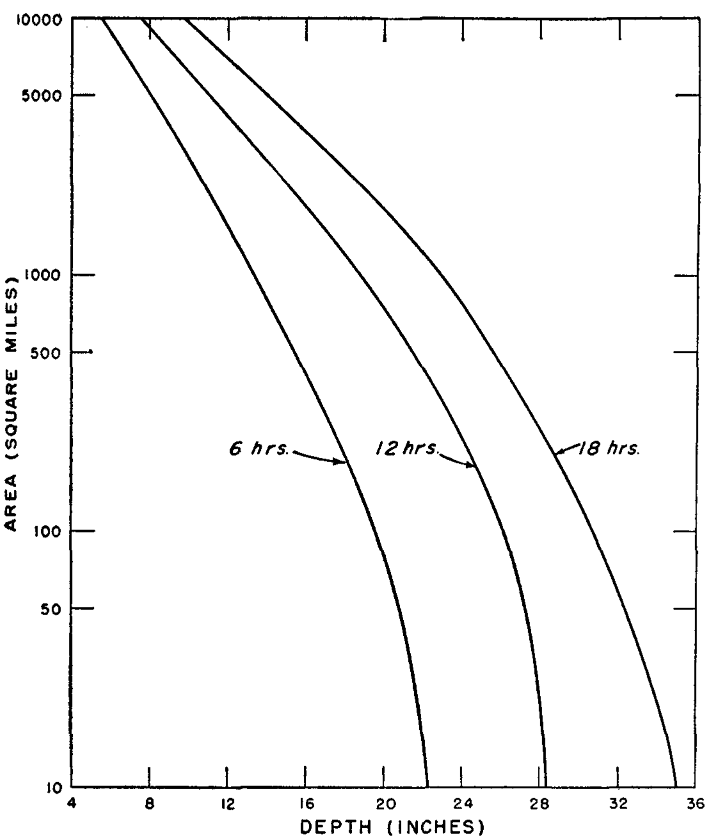

Figure 1.—Depth-duration-area curves for the Thrall, Tex., rainstorm during the period noon Sept. 8 to 1 p. m. Sept. 10 (local time), 1921.

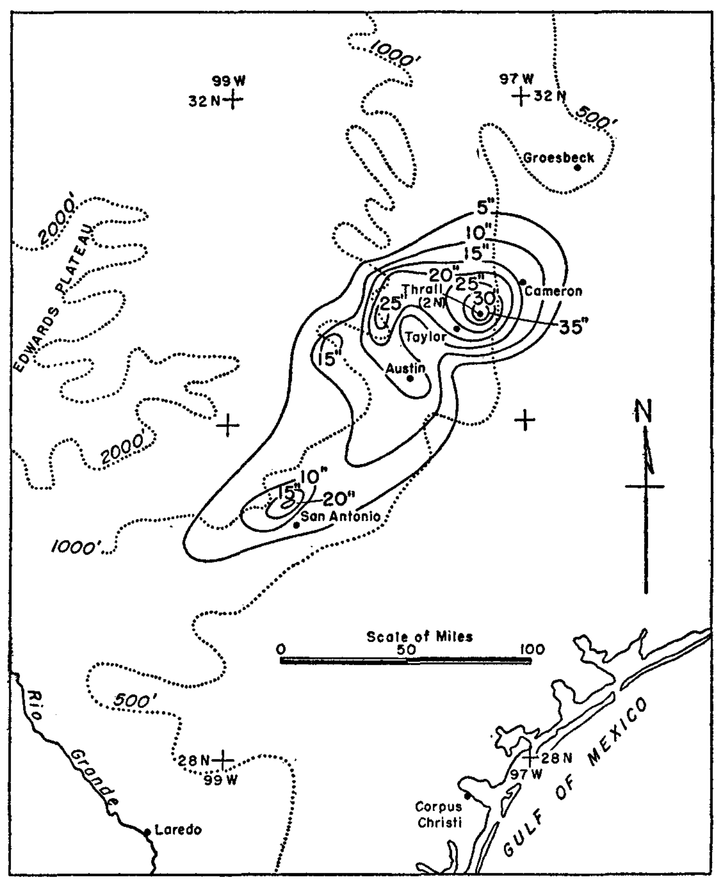

Figure 2.—Generalized isohyetal pattern (solid lines, in inches) for the Thrall, Tex., rainstorm, covering the period noon Sept. 8 to noon Sept. 10 (local time), 1921, superimposed on the ground contours (dotted lines, in feet). The intense rain fell in two bursts which traveled from the southwest to the northeast.

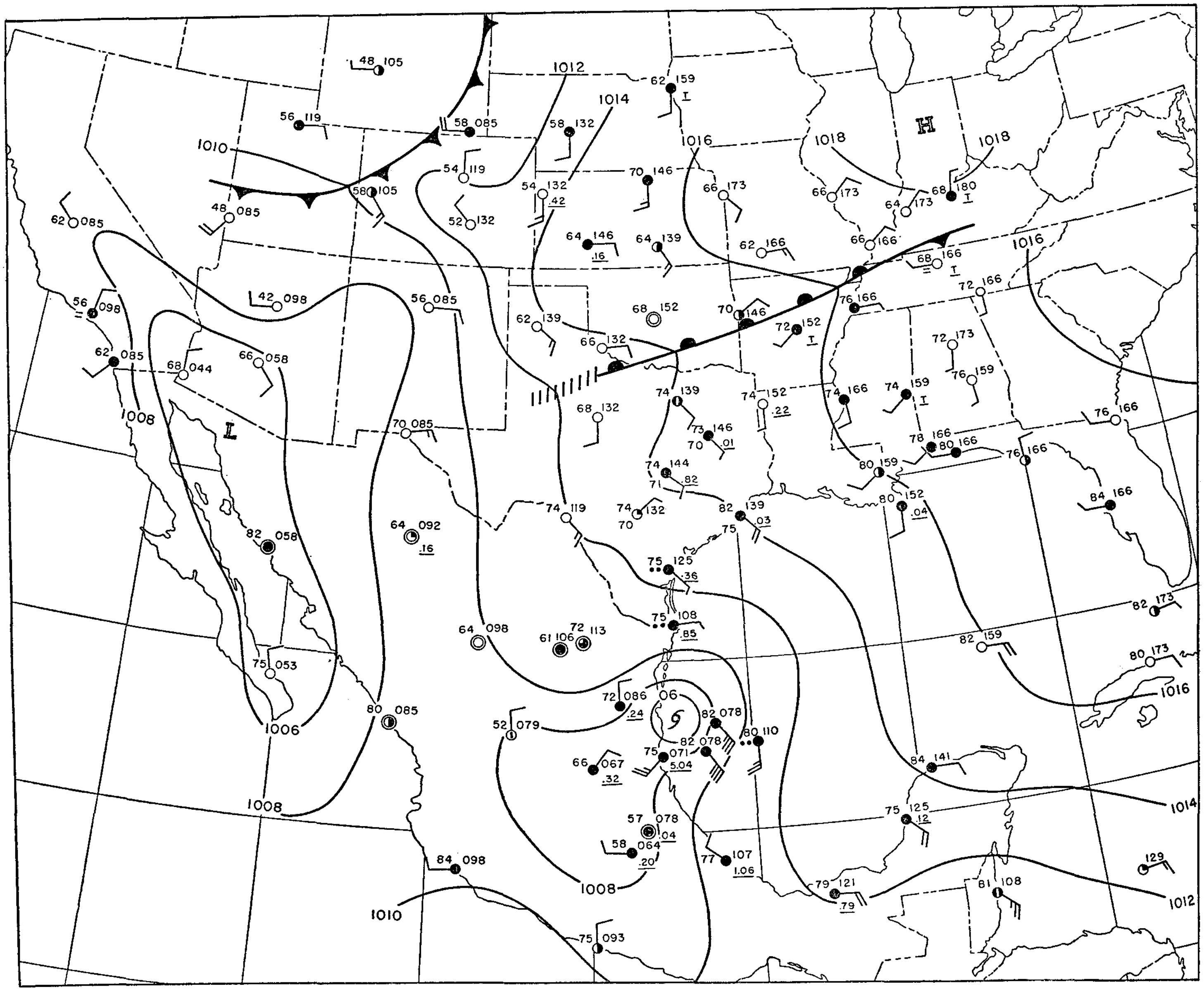

FIGURE 3.—Surface weather map for 0630 CST, September 7, 1921. 12-hour precipitation amounts are shown at United States stations and 24-hour amounts at Mexican stations.

rose at the rate of 2 feet a minute until it overflowed its banks. The second and third rises completely submerged the lowlands, raising the river at least 7 feet higher than ever before known.

The storm isohyetal pattern had an orientation roughly paralleling the ground contours. (See fig. 2.) The topography in the vicinity of Taylor and Thrall consists of a gentle upslope toward the west of about 500 feet in 50 miles. The region is dissected by small rivers and creeks, with hills of about 200–300 feet above the river levels. The Gulf of Mexico lies about 150 miles to the southeast of Thrall making the average ground-slope about 3 feet/mile from Thrall to the Gulf. In a southeast-northwest line (the approximate direction of gradient inflow wind at the time of beginning of heavy rain) the average land slope is about 300 feet in 50 miles in the Thrall area.

The intense rain fell in two well-defined bursts which traveled from southwest toward the northeast. The first burst, the more intense of the two, passed Taylor during the evening of the 9th from approximately 1900 to 2300 CST. The second burst started at about 0300 CST of the 10th and lasted until about 0700. Lighter rain fell during the daylight hours of the 9th and between the two heavy bursts on the night of the 9th and early morning of the 10th.

Rainfall centers of lesser intensity occurred in the Laredo, Tex., area and near the Gulf coast in the Houston-Beaumont region, but this study will concern itself almost exclusively with the Thrall center.

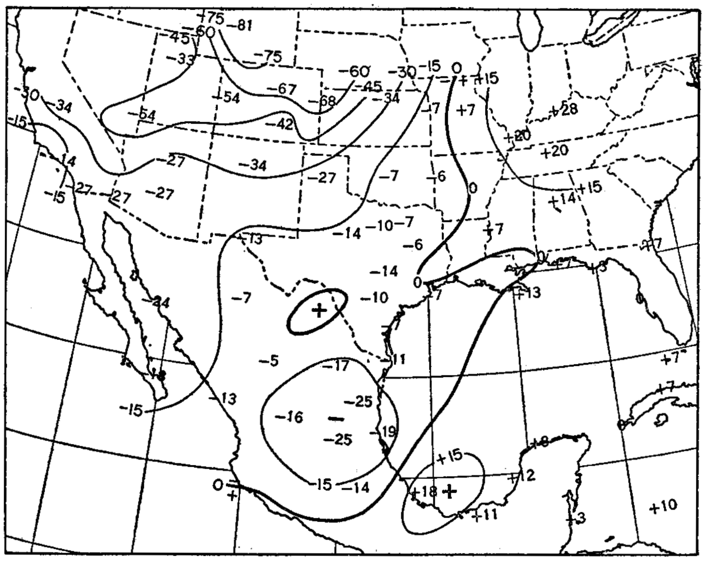

FIGURE 4.—24-hour sea level pressure change from 0700 CST, September 6 to 0700 CST, September 7, 1921. Isallobars are in tenths of millibars.

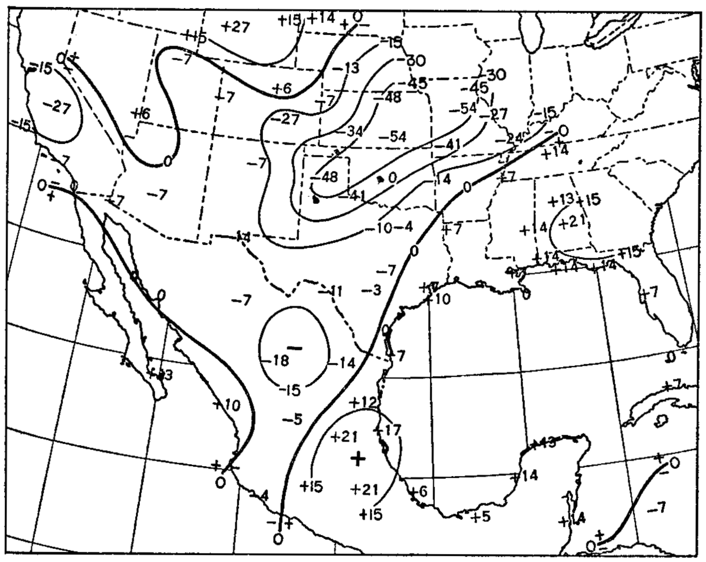

FIGURE 5.—24-hour sea level pressure change from 0700 CST, September 7 to 0700 CST, September 8, 1921. Isallobars are in tenths of millibars.

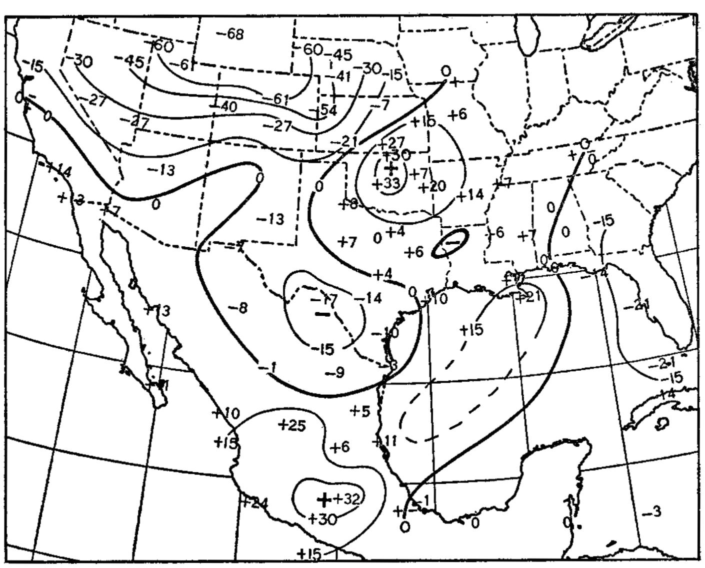

FIGURE 6.—24-hour sea level pressure change from 0700 CST, September 8 to 0700 CST, September 9, 1921. Isallobars are in tenths of millibars.

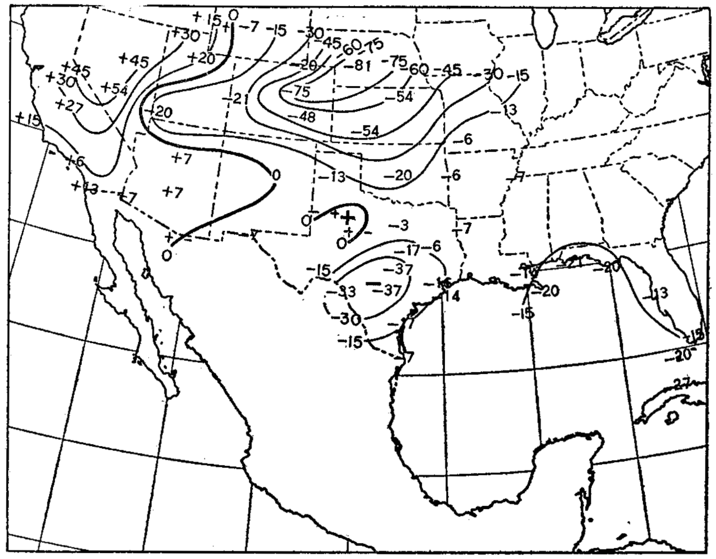

FIGURE 7.—24-hour sea level pressure change from 1900 CST, September 8 to 1900 CST, September 9, 1921. Isallobars are in tenths of millibars.

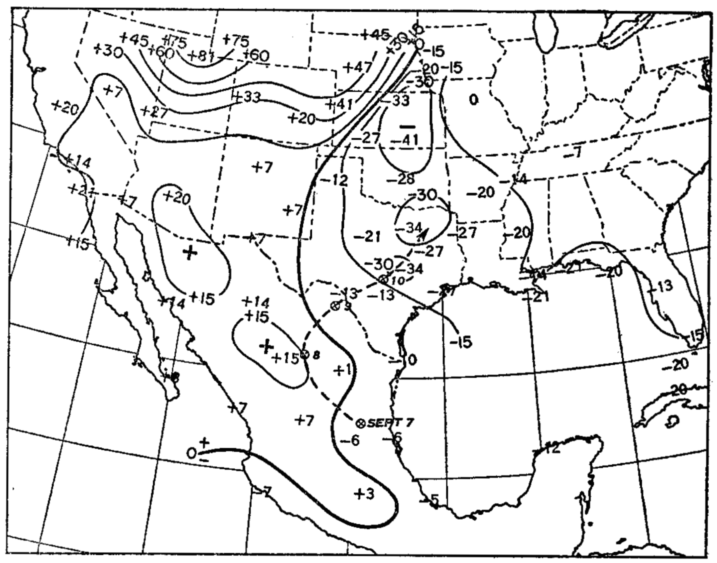

FIGURE 8.—24-hour sea level pressure change from 0700 CST, September 9 to 0700 CST, September 10, 1921. Isallobars are in tenths of millibars. The track of the 24-hour katallobaric center for the period covered by figures 4–8 is shown by the dashed arrow.

GENERAL SYNOPTIC SITUATION

Figure 3 gives a general picture of the synoptic situation on the morning of September 7, 1921, about 2½ days before the start of the intense rain at Thrall. The weak front in southern Oklahoma had been as far south as the Fort Worth-Abilene line but then retreated northward. No fronts had been in southern Texas for many weeks prior to the storm. The hurricane entering the Mexican coast in figure 3 had formed in the Gulf of Campeche and was not of unusual size or intensity. Heavy rains accompanied the storm near Tampico, however, and in the coastal range nearby. Although all traces of a surface circulation disappeared when the storm reached the Mexican Plateau, pressure falls could be followed through this region and on into southern and central Texas. Figures 4–8 are 24-hour pressure change charts covering

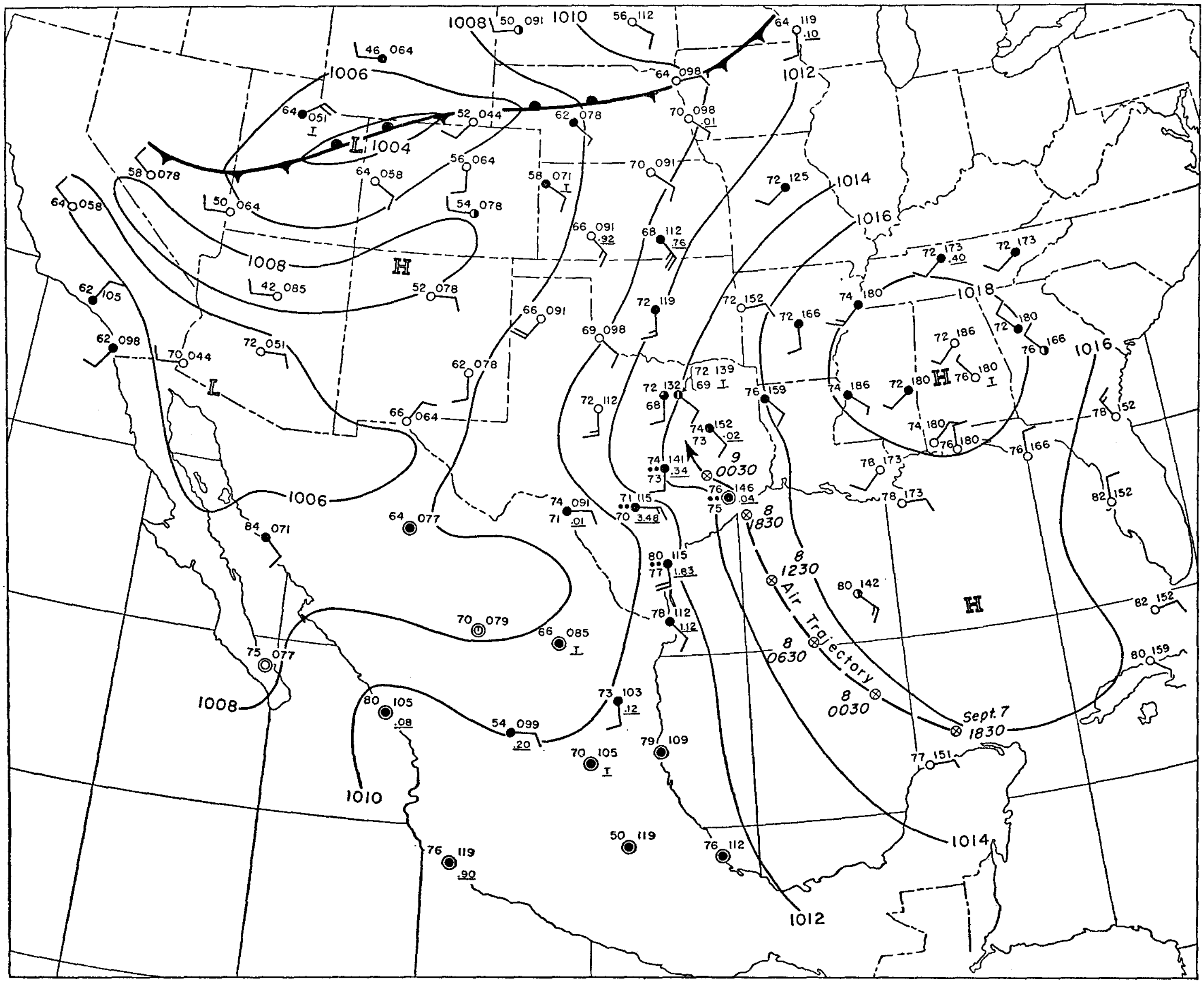

FIGURE 9.—Surface weather map for 0630 CST, September 9, 1921. The air trajectory from 1830 CST, September 7 to 0630 CST, September 9, shown by the dashed arrow, indicates the tropical maritime source of the air in the ridge in the Taylor-Groesbeck area of Texas. 12-hour precipitation amounts are shown at United States stations, and 24-hour amounts at Mexican stations.

the period September 6–10, with the path of the katallobaric center plotted on figure 8. It can be seen on this figure (in the United States where the station density is greater) that the center was double. The cause of the double nature of the center has not been ascertained, but its effect on the rainfall distribution with time was very marked. The two bursts of the Thrall storm occurred with the passage of these two fall centers.

Rain showers progressed northward over eastern Texas on the morning of September 7 reaching the San Antonio-Taylor-Groesbeck area early on the afternoon of the 7th. Scattered showers and thunderstorms were observed throughout the moist southerly current over southern and central Texas from this time until the climactic bursts of the Thrall storm itself, indicating the general unstable nature of the air mass.

Figure 9 illustrates conditions 12 hours before the first burst at Taylor, Tex. A comparison between figures 3 and 9 shows that the pressure gradient had increased considerably in the northwestern part of the Gulf. Pressure had risen over Alabama and Mississippi, while the pressure fall associated with the hurricane remnants over northern Mexico caused a further strengthening of the gradient. The east-west pressure ridge north of 30° N. latitude in central Texas was created by a large mass of rain-cooled air where showers had clustered over the somewhat higher ground. The sharpness of the trough upwind from this ridge increased in intensity

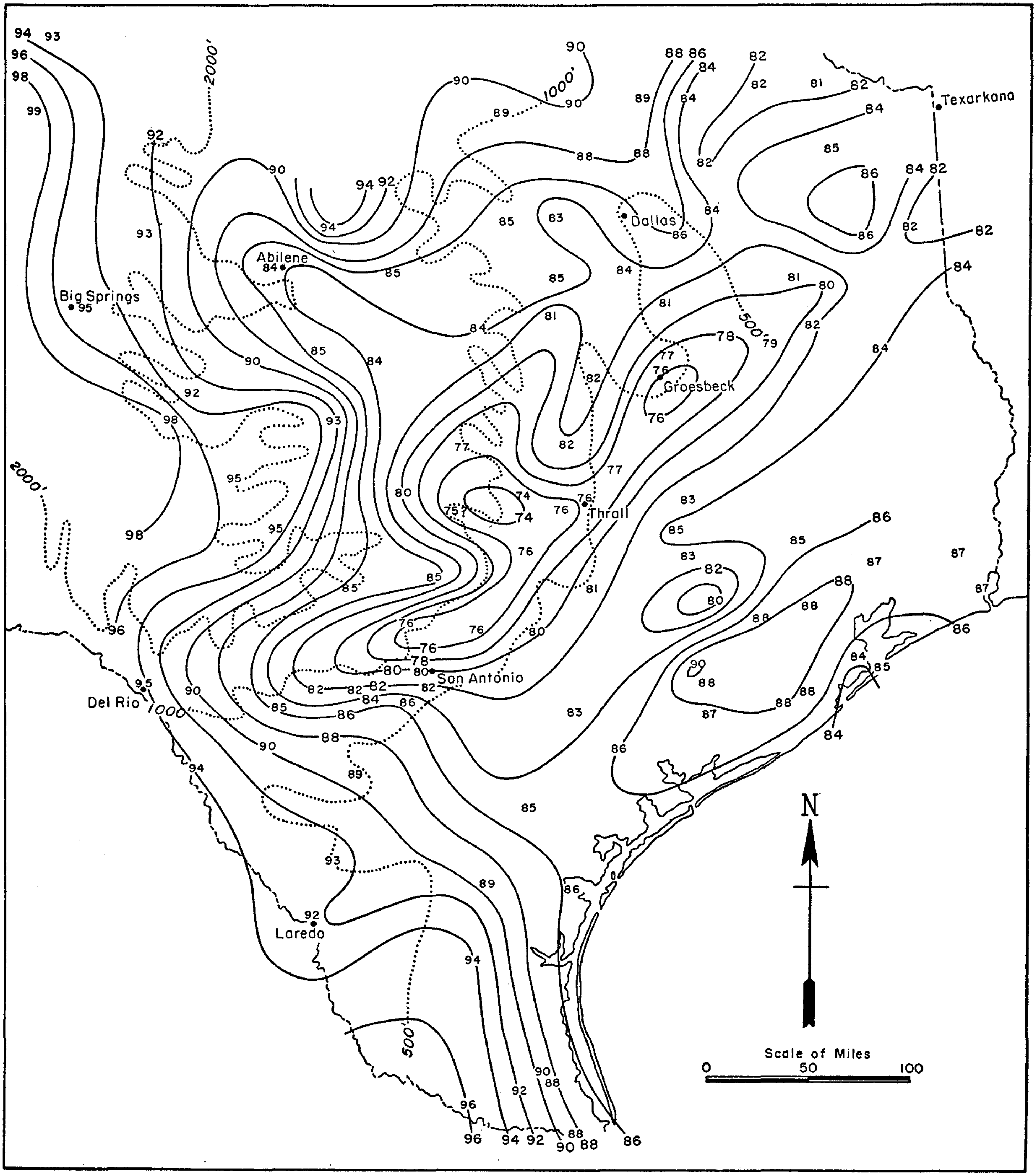

FIGURE 10.—Maximum temperature isotherms (solid lines, ° F.) for September 9, 1921, in relation to the ground contours (dotted lines, feet).

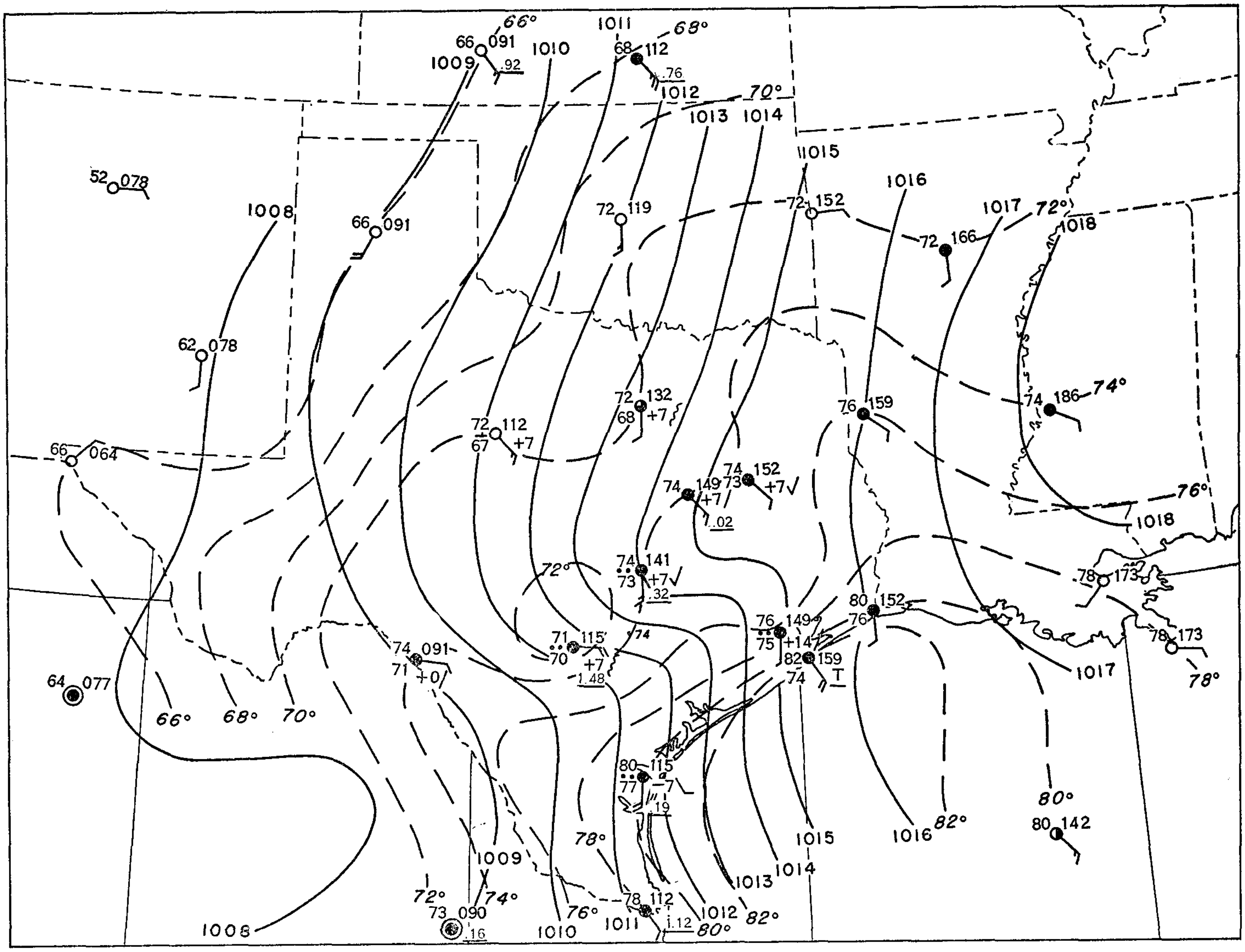

FIGURE 11.—Surface weather map for 0630 CST, September 9, 1921, showing isobars at 1-mb. intervals and isotherms at 2° F. intervals.

during the warmer part of the day when the thermal contrast was greater between the hot coastal plain and the cooler "uplands". The air trajectory on figure 9 upwind from Groesbeck, Tex. shows the tropical maritime source of the "cool" air in this ridge.

Figure 10 illustrates the position of the cool air in relation to the ground contours during daytime on the 9th. The lines of equal maximum temperature were derived from cooperative observer records and other official sources. It will be noted that the isotherms roughly parallel the ground contours from about San Antonio northeastward to Palestine, Tex. A temperature gradient, then, was maintained during the day prior to the Thrall storm along the lines of equal elevation. The air passed through this temperature gradient from the south, as illustrated in the air trajectory (fig. 9). This temperature gradient was only indirectly due to the effect of elevation, since maximum temperatures average several degrees higher at Austin and San Antonio than along the coast in September. The effect of elevation was to touch off showers which then produced a temperature gradient.

Figure 11, a detailed surface weather map for 0630 CST, September 9, 1921, shows isotherms for each 2° F. and isobars for each millibar. A few current temperatures derived from cooperative observer readings were used in this figure and in figure 12 to aid in placing the isotherms. The 24-hour pressure-fall center was in Mexico, a short distance south of Del Rio, Tex. at this time. Moderate warm air advection accompanied by heavy showers can be noted in the region just southeast of San Antonio.

Figure 12 shows details of the surface pressure-temperature distribution when the heaviest rainburst was in progress. This burst had reached the Taylor-Thrall region. The small Low near Taylor was the result of the pressure fall that originated from the Tampico hurricane. This Low was traveling northeastward and resulted in

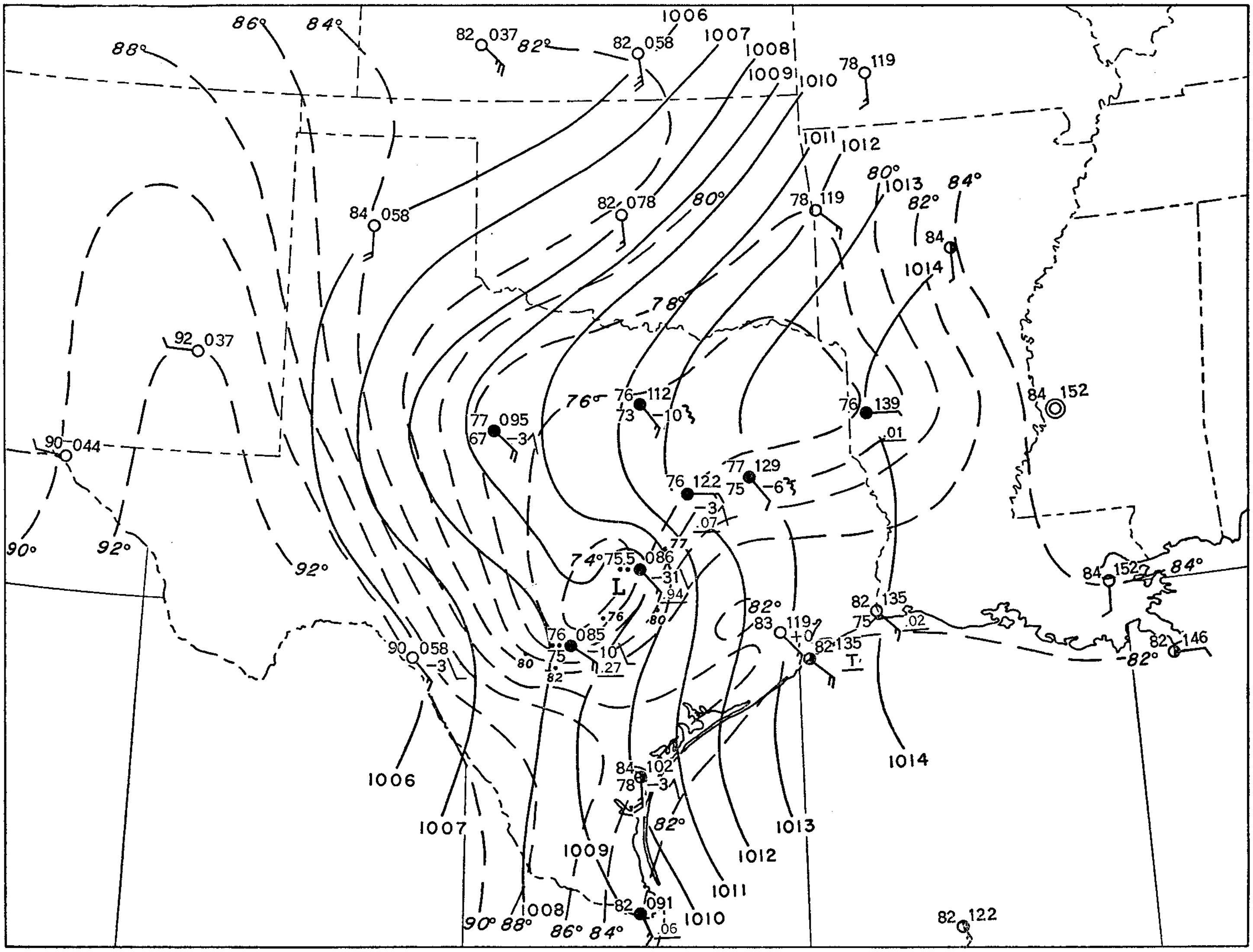

FIGURE 12.—Surface weather map for 1830 CST, September 9, 1921, showing the pressure-temperature distribution at the time the heaviest rainburst had reached the Taylor-Thrall area. The area of strong warm air advection is centered near Taylor.

temporary wind shifts to a westerly component at Del Rio, San Antonio, and Taylor. The area of strong warm air advection centered near Taylor on this map was closely associated in time and place with the beginning of the monumental burst. (For a development of the theory of warm advection as a cause of vertical motion see Gilman [3].) Heavy rain continued to fall for 3 or 4 hours after the warm advection started to decrease in magnitude. A much smaller drop in pressure resulting in an increase in gradient winds from the south-southeast was observed to accompany the second burst at about 4 a. m. at Taylor.

UPPER AIR SITUATION

Upper air data were very sparse in the early 1920's. The kite sounding and winds aloft station at Groesbeck, Tex., 75 miles northeast of the rainfall center, was the only one in operation during the storm period within many hundreds of miles of Thrall, Tex. During the 24 hours prior to the storm, Groesbeck was immersed in the low level "cool" air (see fig. 11) similar to the Taylor area. Unlike the storm area, however, the cool air surrounding Groesbeck was swept away during the night of the 9th-10th, probably as a consequence of a generally less steep rise in the ground level downwind from Groesbeck.

Figure 13 is a time cross-section of the upper wind, temperature, and relative humidity observations taken at Groesbeck from September 7 through September 11. Times of beginning of ascent, maximum height, and ending of descent (if observations were taken on descent) are given.

The Groesbeck morning soundings on the 8th and 9th were characterized by coldness, considering the time of year. The observed temperatures at the 3-km. level on both days are exceeded on 85 to 90 percent of the days in September

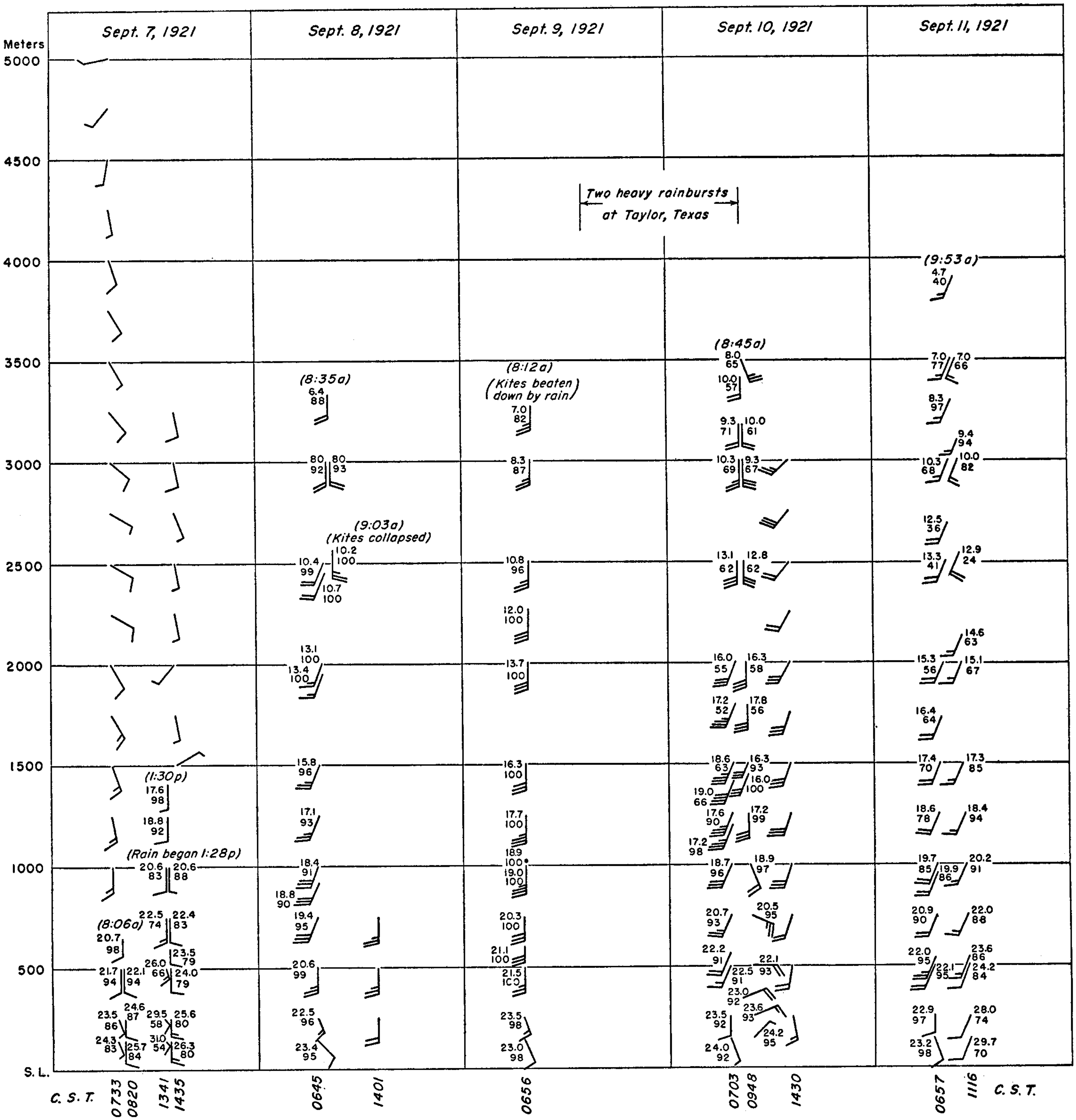

FIGURE 13.—Time cross-section of the upper wind, temperature, and relative humidity observations at Groesbeck, Tex., September 7–11, 1921. A full wind barb indicates a value of 10 m. p. h.

[4]. The moisture content in the layer between the surface and 3 km. was high on the 9th (1.65 in. of precipitable water) but it was by no means a record. The mean September precipitable water in the Groesbeck, Tex., area is about 1.05 in. and the maximum of record about 1.99 in.

[5]. Below the 1.25-km. level little change in the air mass properties is evident in the 48-hour period starting at 0700 CST on September 8. Above this level, however, the sounding on the morning of the 10th shows warming and drying accompanied by a wind shift from southerly to

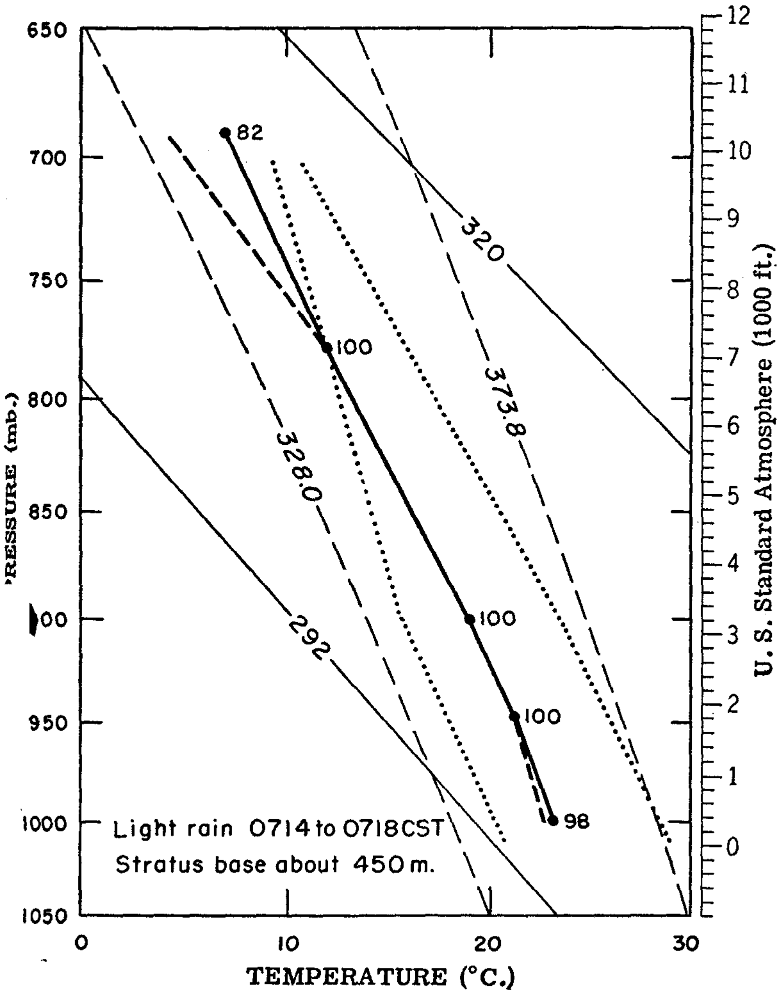

FIGURE 14.—Upper air sounding at Groesbeck, Tex., 0656–0812 CST, September 9, 1921, showing temperature (solid line) and dew point (dashed line). Numbers indicate relative humidity. The dotted temperature and humidity curves show a mean sounding for summer mT air of Gulf origin.

south-southwesterly. The bringing in aloft of drier air from the Mexican highlands was responsible for the abrupt cessation of rainfall over central Texas on the 10th.

An interesting feature of the wind record is the maximum at the 3,000–4,000-foot level as shown in the 24 hours from the morning of the 9th to the morning of the 10th. (The heavy rain occurred at Taylor and Thrall between these observation times.) A wind maximum at this level has been found in many of the greatest rainstorms of record [6].

The Groesbeck sounding for the morning of the 9th appears in figure 14. The air was completely saturated in the layer from 500 to 2,250 meters above sea level, with a lapse rate between moist and dry adiabatic, making the layer unstable. Convective instability characterized the air mass between 2,250 and 3,250 meters. The trajectory on figure 2 shows the origin of the air that was sampled by this sounding. For comparison purposes a mean sounding for summer mT air (at Pensacola, Fla.) of Gulf origin is included on figure 14 [7].

SUMMARY

This greatest of all United States rainstorms owed its existence to a combination of several important factors: (1) invasion of southern Texas by an unusually unstable moist air mass, (2) lifting of the unstable air mass up the escarpment of the Edwards Plateau, producing a local rain-cooled air mass (a continuous process), (3) a rapid increase in the wind velocity (rate of air processing) due to a katallobaric system of tropical hurricane origin, (4) near coincidence of the path of the katallobaric center with the strong temperature gradient, an area of concentrated warm advection being formed by the combination.

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