NOAA Technical Memorandum NWS WR-197

THE EFFECTS OF EASTERN NORTH PACIFIC TROPICAL CYCLONES ON THE SOUTHWESTERN UNITED STATES

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Salt Lake City, Utah
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U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

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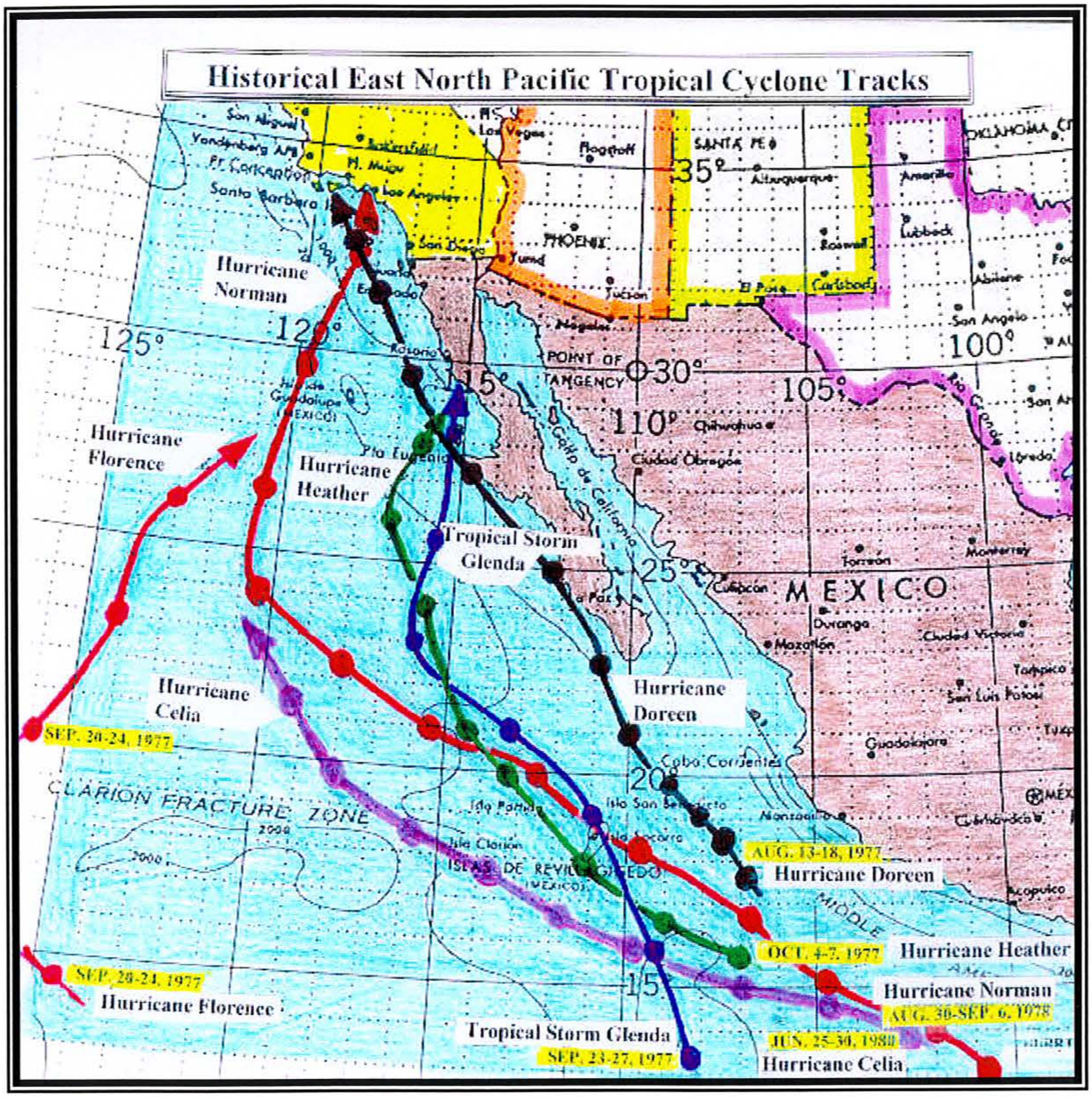

APPENDIX I
Historical tropical cyclone tracks for the East North Pacific for the period 1977-1980.

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ABSTRACT

This report describes the effects that 84 documented eastern north Pacific tropical cyclones had on the southwestern United States from 1900-84. These effects range from the trivial; isolated light showers, to the severe; high winds, heavy rains, and disastrous flash floods. Maps of tropical cyclone-related rainfall are presented for all 84 tropical cyclones along with a description of each storm. The tracks of these cyclones are also plotted on the aforementioned maps as are sea surface temperatures for all storms from 1947-84. In addition, a series of 500 mb height maps are presented for each cyclone from 1946-83.

Eastern north Pacific tropical cyclones occasionally have a major effect on the southwestern United States. Nearly every year an eastern north Pacific tropical cyclone will move into a position for upper level winds to bring clouds and moisture from the cyclone inland over the Southwest to produce showers and thunderstorms. This has happened as early in the year as late June and as late as the last week of October. However, September has been the most likely month for a tropical cyclone to have an effect on the weather of the southwestern United States. Tropical cyclones have not been associated with widespread damaging storm surges or high waves along the coast of California. No hurricanes and only three tropical storms have entered the southwestern United States this century. As a result, high winds have not been the major problem with these tropical cyclones.

Heavy rains have been and will continue to be the most important effect associated with eastern north Pacific tropical cyclones. Many persons have drowned in floods caused by these heavy rains which typically have fallen when a tropical cyclone has interacted with a midlatitude disturbance, like a trough or cutoff low, over the Southwest. Significant rainfall (8.00 or more inches of precipitation) has been reported from 11 different tropical cyclones this century, 5 times before satellite imagery became routinely available in 1966 and 6 times since then. Part of the increase in frequency of significant rains, from 5 in the first 66 years of the century to 6 in the following 19 years, probably is the result of satellite imagery which now detects about twice as many eastern north Pacific tropical cyclones each year when compared to the years prior to 1966.

I. INTRODUCTION

In the last several decades many eastern north Pacific tropical cyclones have moved close enough to, and in a few cases into, the southwestern United States (California, Nevada, Utah, western Colorado, Arizona, New Mexico, and extreme western Texas) to cause heavy rains and occasionally floods, usually in late summer or early fall. This paper will discuss the effects that eastern north Pacific tropical cyclones had on the Southwest in the period 1900 through 1984. The effects attributable to these storms range from a few light showers with very little rain from the Hurricane of September 14-18, 1918 to the high winds, heavy rains, and flash floods caused by Hurricane Kathleen in September 1976.

Until about 1920 the U.S. Weather Bureau ignored all evidence of tropical cyclones in the eastern north Pacific Ocean (Court, 1980) despite the fact that several cities in Mexico, including Mazatlan and Loreto, were devastated by hurricanes in the preceding century. Fortunately, few people familiar with the weather and climate of the Southwest still ignore these storms. This is due primarily to a number of recent floods associated with several tropical cyclones; i.e. Tropical Storm Norma in September 1970, Hurricane Kathleen in September 1976, Hurricane Doreen in August 1977, Hurricane Heather in October 1977, Hurricane Olivia in September 1982, and Tropical Storm Octave and Hurricane Tico in October 1983. Papers by Eidemiller (1978) and Court (1980) also have contributed to the increase in awareness of these tropical cyclones.

Eastern north Pacific tropical cyclones usually do not cause high winds in the Southwest. No hurricanes and only three documented tropical storms have entered the southwestern U.S. since 1900. A tropical cyclone with maximum sustained winds less than 35 kn is classified as a tropical depression while one with maximum sustained winds between 35 and 64 kn is called a tropical storm. A tropical cyclone is classified as a hurricane when maximum sustained winds reach 65 kn. One tropical storm entered southern California just south of Los Angeles on September 25, 1939 with gale force winds of about 45 kn (Hurd, 1939). On October 6, 1972 Hurricane Joanne moved inland from the Gulf of California through Mexico into Arizona as a tropical storm with winds as high as 40 kn (Kangieser, 1972). Finally, Hurricane Kathleen blew into the Imperial Valley of California with gale force winds that included a gust of 66 kn at Yuma WSO, Arizona on September 10, 1976 (major El Niños occurred in each of these years: 1939, 1972, and 1976).

Heavy rains and floods are by far the most important effects eastern north Pacific tropical cyclones have on the Southwest. Most recent tropical cyclone related floods have been the result of heavy rains caused by the lifting of moisture-laden air from a dissipating storm by either a midlatitude trough or a cut-off low and the mountains, in conjunction with diurnal heating, over a portion of the Southwest. The earliest documented case this century of serious tropical cyclone-related flooding took place in early October 1911 in southwestern Colorado (Brandenburg, 1911). Different parts of the Southwest have experienced similar disastrous floods in each of the following decades.

II. DATA

A. Tropical Cyclone

A major problem encountered during this research was the poor quality and lack of data concerning pre-1966 tropical cyclones, many of which went undetected by either a single ship or plane. Only with the advent of satellite imagery in 1966 did the detection of eastern north Pacific tropical storms and hurricanes approach 100%. Consequently, an unknown number of pre-1966 tropical cyclones are excluded from this report.

Most of the tropical cyclone information from 1900 through 1953 came from the historical weather map series of surface observations and sea level pressure. The sparseness and poor quality of data in the eastern north Pacific during this period has led to errors in the tracks of several cyclones known to have affected the Southwest. For example, the Hurricane of August 24-28, 1951 (see Figure 49) moved northwestward parallel to the Baja California coast before moving inland south of Ensenada, Mexico on August 28th (Oliver, 1951). However, the historical weather maps of August 1951 incorrectly show the storm moving almost due west along 23°N from the 27th through the 29th with another low appearing at 28°N, 116°W (the correct location of the storm) on the 28th.

The paucity of data also has resulted in the complete omission of an unknown number of tropical storms and hurricanes from the historical weather map series. For example, the Hurricane of September 14-18, 1918 is absent from the aforementioned maps but is described in detail by Tingley (1918) in Monthly Weather Review. The percentage of tropical cyclones omitted in the relatively recent 5-year period 1947-1951 can be estimated by comparing Table 1, which shows the average number of reported disturbances by month and for the year based on that 5-year period, with the bottom line of Table 2, which shows the average number of tropical cyclones by month and for the year from 1966-1984 (the period for which reliable records exist due to satellite coverage). The annual average for 1947-1951 is 6.0 while the average for 1966-84 is 15.2. This suggests that approximately 60% of all eastern north Pacific tropical cyclones may not have been detected in the earlier years.

Other sources of data for the 1900-1953 period were Court (1980), various articles published in Monthly Weather Review

Table 1. Average number of Eastern North Pacific tropical cyclones by month and for the year based on the 5-year period 1947-1951 (from Kalstrom, 1952).

Year	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Total	1	6	3	5	11	3	1	0	30
Average	.2	1.2	.6	1.0	2.2	.6	.2	0	6.0

Table 2. Frequency of Eastern North Pacific tropical storms and hurricanes by months and years for 1966-1984 (from Gunther and Cross, 1985).

Year	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1966	0	1	0	4	6	2	0	0	13
1967	0	3	4	4	3	3	0	0	17
1968	0	1	4	8	3	3	0	0	19
1969	0	0	3	2	4	1	0	0	10
1970	1	3	6	4	1	2	1	0	18
1971	1	1	7	4	2	2	1	0	18
1972	1	0	1	6	2	1	1	0	12
1973	0	3	4	1	3	1	0	0	12
1974	1	3	3	6	2	2	0	0	17
1975	0	2	4	5	3	1	1	0	16
1976	0	2	4	4	3	1	0	0	14
1977	1	1	1	1	3	1	0	0	8
1978	1	3	4	6	2	2	0	0	18
1979	0	2	2	2	1	2	1	0	10
1980	0	3	5	2	2	2	0	0	14
1981	1	1	3	4	2	4	0	0	15
1982	1	1	6	5	4	2	0	0	19
1983	1	1	6	3	5	3	1	1	21
1984	2	3	3	4	4	2	0	0	18
Total	11	34	70	75	55	37	6	1	289
Average	.6	1.8	3.7	3.9	2.9	1.9	.3	.1	15.2

which include Hurd (1925,1926,1929,1939,1941) and Visher (1922), and Eidemiller (1978).

Tropical cyclone information from 1954 and 1955 came from the annual summaries of eastern north Pacific tropical cyclones described in the annual issues of Climatological Data National Summary (Rasey 1955,1956). The data from subsequent years was taken from the annual summaries published in Mariners Weather Log.

Table 3 lists the eastern north Pacific tropical cyclones which affected the Southwest in chronological order from 1900 through 1984. The dates in the table refer to the time the tropical cyclone existed and are not necessarily the times when the cyclone affected the Southwest. The rains associated with a tropical cyclone usually began a day before the storm either moved onshore in Mexico or in a few cases California or a day before the storm completely dissipated at sea. The rain ended anywhere from one to seven days after it began. Evidence linking a tropical cyclone with precipitation in the Southwest is

Table 3. Eastern North Pacific tropical cyclones which affected the Southwestern United States from 1900 through 1984.

Name		Date	
1.	Tropical Cyclone of	9/8-11	1901
2.	Tropical Cyclone of	7/20-23	1902
3.	Tropical Cyclone of	9/18-20	1902
4.	Tropical Cyclone of	8/13-17	1906
5.	Tropical Cyclone of	9/8-15	1910
6.	Tropical Cyclone of	10/1-5	1911
7.	Tropical Cyclone of	8/23-27	1915
8.	Tropical Cyclone of	9/15-19	1917
9.	Tropical Cyclone of	9/11-12	1918
10.	Hurricane of	9/14-18	1918
11.	Tropical Cyclone of	9/10-13	1920
12.	Tropical Cyclone of	8/15-20	1921
13.	Tropical Cyclone of	9/25-30	1921
14.	Tropical Cyclone of	9/2-8	1924
15.	Tropical Cyclone of	10/22-25	1925
16.	Tropical Cyclone of	9/20-25	1926
17.	Tropical Cyclone of	9/27-30	1926
18.	Tropical Cyclone of	10/3-8	1926
19.	Tropical Cyclone of	10/8-13	1926
20.	Hurricane of	9/7-12	1927
21.	Tropical Cyclone of	8/6-11	1928
22.	Tropical Cyclone of	9/11-17	1929
23.	Tropical Cyclone of	9/10-13	1931
24.	Hurricane of	9/22-25	1931
25.	Tropical Cyclone of	8/25-29	1932
26.	Tropical Cyclone of	9/26-30	1932
27.	Tropical Cyclone of	8/19-22	1935
28.	Tropical Cyclone of	8/23-26	1935
29.	Tropical Cyclone of	8/4-9	1936
30.	Tropical Cyclone of	9/8-11	1936
31.	Hurricane of	9/4-6	1939
32.	Tropical Cyclone of	9/6-12	1939
33.	Tropical Cyclone of	9/15-17	1939
34.	Tropical Cyclone of	9/15-25	1939
35.	Hurricane of	9/8-12	1941
36.	Hurricane of	9/15-22	1941
37.	Tropical Cyclone of	9/5-8	1945
38.	Tropical Storm of	9/26-29	1946
39.	Tropical Storm of	9/3-9	1949
40.	Tropical Storm of	8/24-28	1951
41.	Tropical Storm of	9/23-29	1951
42.	Tropical Storm of	9/15-21	1952
43.	Hurricane of	8/24-26	1953
44.	Hurricane of	7/11-17	1954
45.	Tropical Storm of	10/1-4	1955
46.	Hurricane of	10/1-5	1957
47.	Tropical Storm of	7/26-29	1958
48.	Tropical Storm of	9/10-11	1958
49.	Hurricane of	9/29-10/4	1958

numbers before the slash refer to month with: 6=June, 7=July, 8=August, 9=September, 10=October.

Table 3. (continued) Eastern North Pacific tropical cyclones which affected the Southwestern United States from 1900 through 1984.

	Name	Date	
50.	Hurricane of	9/3-11	1959
51.	Hurricane Diana	8/16-19	1960
52.	Hurricane Estelle	8/28-9/9	1960
53.	Tropical Storm Bernice	9/1-6	1962
54.	Tropical Storm Claudia	9/20-24	1962
55.	Hurricane Doreen	10/1-5	1962
56.	Tropical Storm Katherine	9/17-18	1963
57.	Tropical Storm Tillie	9/7-9	1964
58.	Hurricane Emily	8/29-9/4	1965
59.	Tropical Storm Kirsten	9/25-29	1966
60.	Hurricane Katrina	8/29-9/2	1967
61.	Tropical Storm Hyacinth	8/16-20	1968
62.	Hurricane Pauline	9/26-10/3	1968
63.	Tropical Storm Norma	8/30-9/5	1970
64.	Hurricane Olivia	9/20-30	1971
65.	Hurricane Hyacinth	8/28-9/6	1972
66.	Hurricane Joanne	9/29-10/6	1972
67.	Hurricane Kathleen	9/6-10	1976
68.	Hurricane Liza	9/25-10/1	1976
69.	Hurricane Doreen	8/13-18	1977
70.	Hurricane Florence	9/20-24	1977
71.	Tropical Storm Glenda	9/23-27	1977
72.	Hurricane Heather	10/4-7	1977
73.	Hurricane Norman	8/30-9/6	1978
74.	Hurricane Celia	6/25-30	1980
75.	Hurricane Norman	9/9-18	1982
76.	Hurricane Olivia	9/18-25	1982
77.	Hurricane Paul	9/19-30	1982
78.	Hurricane Manuel	9/12-20	1983
79.	Tropical Storm Octave	9/27-10/2	1983
80.	Hurricane Priscella	9/30-10/7	1983
81.	Hurricane Tico	10/11-19	1983
82.	Hurricane Marie	9/5-11	1984
83.	Hurricane Norbert	9/14-26	1984
84.	Hurricane Polo	9/26-10/3	1984

numbers before the slash refer to month with:
6=June, 7=July, 8=August, 9=September, 10=October.

questionable for a few of the storms listed in Table 3. These as well as all other cases will be discussed in detail later in the paper.

The tropical cyclone track and associated rainfall maps (e.g. Figure 7) show the estimated track of the storms that did affect or are reasonably certain to have affected the Southwest. The intensity of the 1955 through 1984 tropical cyclones is also indicated.

B. Precipitation

Precipitation data was one of the main sources of information utilized to determine whether or not a tropical cyclone was associated either directly or indirectly with rain anywhere in the study area. If the cyclone was related to any precipitation in the Southwest, a map was drawn presenting the best estimate of the track of the storm and the related rainfall.

Most of the precipitation data employed in this paper came from the National Oceanic and Atmospheric Administration (NOAA) publication Climatological Data for the states of California, Nevada, Utah, Colorado, Arizona, New Mexico, and Texas. From July 1909 through December 1913 the U.S. Weather Bureau changed the format of this publication so that climatic stations in the U.S. were grouped by river drainage basin instead of by state. The drainage basins used were the Lower Mississippi Valley, Texas and Rio Grande Valley, Colorado Valley, California, and Great Basin. Additional information was taken from the NOAA publication Local Climatological Data.

The climatic stations selected for use are presented in Table 4 and their locations are shown in Figure 1. The selection of most stations was based on length of record, amount of missing data, and number and distance of any station moves. In addition, an attempt was made to obtain a group of climate stations that were as evenly distributed as possible over the southwestern U.S. Some stations; such as San Diego, California and Austin, Nevada; fulfilled all these requirements and were in continuous operation throughout the 1900-1984 period. On the other hand; some stations; e.g. Grant Grove, California and Springerville, Arizona; were chosen primarily to provide representative rainfall totals in the mountains.

Missing data was substituted for in many cases to provide needed information for the construction of reliable isohyets. The stations listed under the "Alternate Station/s" column of Table 4 were employed as substitutions when the site shown under the "Station" column either had missing data, was permanently closed, or when a National Weather Service (NWS) office opened. For example, Blue Canyon, California was closed in 1944 and was replaced by Blue Canyon WSMO.

Figure 7 presents the tropical cyclone track and associated rainfall map for the cyclone of September 8-11, 1901, the first eastern north Pacific tropical cyclone believed to have affected the southwestern United States this century. The actual rainfall totals (in inches) associated with this storm are plotted at the appropriate places. If a particular station has no value plotted, the data is either missing or the station was not yet in operation. The isohyets drawn on all the tropical cyclone track and associated rainfall maps (with a few exceptions, e.g. the Tropical Cyclone of September 8-15, 1910) were contoured using only the data plotted on the maps. The isohyets were drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches.

Table 4. Climate stations used on the tropical cyclone track and associated rainfall maps.

No.	Station	Alternate Station/s
California		
1.	Fort Bidwell	
2.	Eureka WSO City	
3.	Red Bluff WSO Airport	
4.	Chester	
5.	Ukiah	
6.	Blue Canyon (1901-1944)	Blue Canyon WSMO (1945-1984)
7.	Tahoe City	
8.	Sacramento WSO City	
9.	San Francisco WSO City	
10.	Hetch Hetchy	
11.	Fresno WSO Airport	
12.	Grant Grove	Giant Forest (1929-1931,1939)
13.	Independence	Bishop (September 1972)
14.	Paso Robles	
15.	Bakersfield WSO	
16.	Trona	
17.	Los Angeles Civic Center	
18.	Lake Arrowhead	Lytle Creek (1929-31,1939)
19.	Blythe	
20.	Cuyamaca	
21.	San Diego WSO Airport	
Nevada		
22.	Winnemucca WSO Airport	
23.	Elko FAA Airport	
24.	Fallon Experimental Station	Reno (1902)
25.	Austin	
26.	McGill	Ely (1902-1911)
27.	Mina	
28.	Adaven (1915-1979)	Pioche (1906); Blue Jay Highway Station (1980-1984); Sunnyside (September 1984)
29.	Las Vegas (1901-1937)	Las Vegas WSO Airport (1938-84)
30.	Searchlight	Needles (September 1921)
Utah		
31.	Logan Utah State University	
32.	Ogden (1901-1936)	Ogden Sugar Factory (1939); Ogden Pioneer Powerhouse (1940-1984)
33.	Wendover	
34.	Silver Lake Brighton	
35.	Vernal Airport	Fort Duchense (1927)
36.	Levan	
37.	Green River Aviation	
38.	Modena	
39.	Escalante	
40.	Blanding	
41.	St. George	
42.	Kanab	

Table 4. (continued) Climate stations used on the tropical cyclone track and associated rainfall maps.

No.	Station	Alternate Station/s
Colorado		
43.	Steamboat Springs	
44.	Dillon 1E	
45.	Grand Junction WSO Airport	
46.	Glenwood Springs	
47.	Gunnison	Pitkin (1929)
48.	Canon City	
49.	Durango	
50.	Trinidad	
Arizona		
51.	Window Rock	
52.	Flagstaff WSO Airport	
53.	Prescott	
54.	Springerville	
55.	Mesa Experimental Farm	
56.	Clifton	Eagle Creek (October 1983)
57.	Yuma WSO Airport	
58.	Ajo	
59.	Tucson-University of Arizona (1901-1916,1931-1940)	Tucson (1917-1930); Tucson WSO Airport (1941-1984)
60.	Nogales (1901-1982)	Nogales 6N (1983-1984)
New Mexico		
61.	Bloomfield 3SE	Aztec (1901-1902)
62.	Red River	
63.	Clayton WSO Airport	
64.	Albuquerque WSFO Airport	
65.	Tucumcari 3NE	Tucumcari 4NE (October 1983, September 1984)
66.	Socorro	
67.	Elephant Butte Dam	
68.	Alamogordo	White Sands (October 1972)
69.	Lordsburg 4SE	Hachita (1917); Animas (September 1976,September 1977)
70.	Carlsbad	
Texas		
71.	El Paso WSO Airport	
72.	Balmorhea	Fort Stockton (1920-1922,1962)
73.	Presidio	

C. 500 mb Heights

500 mb heights were available for the Northern Hemisphere north of 20°N for the period January 1946 through December 1983 and were used for three important reasons. One reason was to determine if the tropical cyclone in question could have affected the southwestern U.S. The others were to reveal the upper air circulation that caused the cyclone to affect the Southwest and to reveal the disturbance; i.e. midlatitude trough, cut-off low,

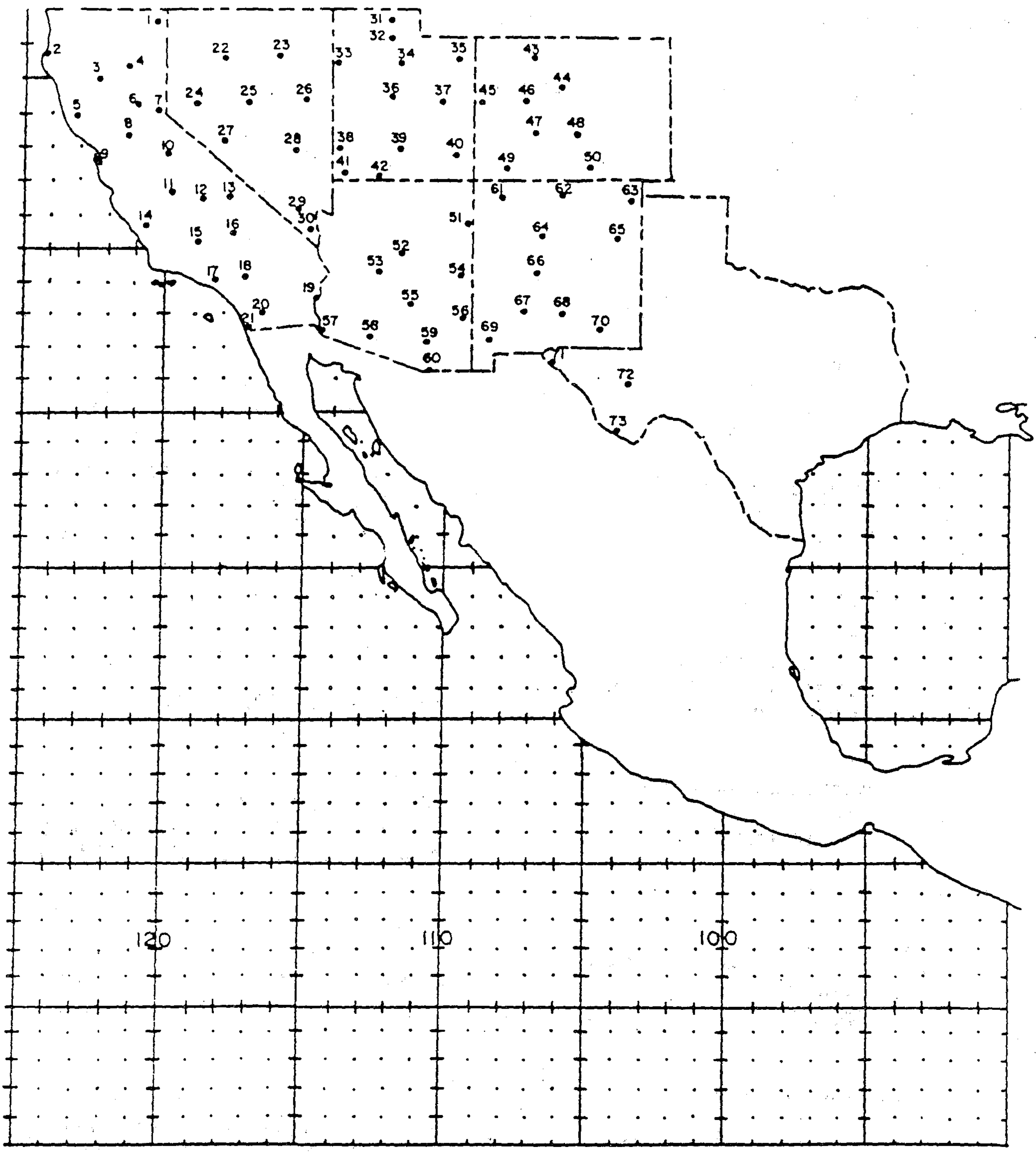

Figure 1. Location of the climatic stations used on the tropical cyclone track and associated rainfall maps. The names which correspond to the numbers are listed in Table 4.

or cyclone itself; that was directly responsible for the precipitation.

This data was provided by the National Center for Atmospheric Research (NCAR) and all 500 mb height data in this report is from 1200 GMT except the data of October 1955 which is from 1500 GMT. This data set contains some missing days and as a result several sequences of 500 mb height maps are not continuous (see Figure 70). A 5° X 5° grid of points was used to produce these plots which were contoured by the graphics subroutines of DISSPLA version 9.0 (a product of Integrated Software Systems Corporation) and later modified by hand to correct obvious errors, such as straight or crossed height lines and to add contour labels. The contour interval is 6 dekameters.

D. Sea Surface Temperatures

Sea surface temperature (SST) data was plotted on the tropical cyclone track and associated rainfall maps to demonstrate the well known relationship between SSTs and tropical cyclone intensity. Scripps Institution of Oceanography kindly provided the 1947-1980 SST data[1]. This information is in °F and is presented as monthly averages of 2° x 2° grid areas for the Pacific north of 20°N. The values were converted to °C before being plotted. The data from 1981 through 1984 was obtained from the appropriate issues of Oceanographic Monthly Summary and covers the entire area of the eastern north Pacific displayed on the aforementioned maps. All SSTs are in °C and the contour interval is 2°.

Figures 2-6 show the monthly mean SSTs for June through October, respectively. One of the most important features of these plots is the very sharp decline in SST as one moves northward from the tropics along the Baja California coast to the area of very cool upwelled water along the central California coast. For instance, the mean SST at 23°N, 112°W in September is about 27°C but at 28°N, 117°W it is just over 20°C, far too cool to maintain a tropical cyclone of hurricane intensity. This probably is the most important reason for the usual rapid weakening of northward moving tropical cyclones in the Pacific west of Baja California. Low SSTs also account for the rare occurrence of tropical storms in the Pacific west of southern California.

Another interesting feature of these figures is the very warm SSTs found in the Gulf of California from July through October. In fact, the mean SSTs in August and September are greater than 29°C. Although the water in the Gulf is extremely warm in the late summer and early fall and able to sustain a very powerful hurricane, only a relatively small number of tropical cyclones have moved more than a hundred kilometers through the Gulf, one exception being Hurricane Katrina in 1967. Possible reasons for this include the orientation and narrowness of the Gulf, the

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[1] The National Climatic Data Center in Asheville, N.C. should be contacted by those interested in obtaining this data.

MEAN SEA SURFACE TEMPERATURE
JUNE

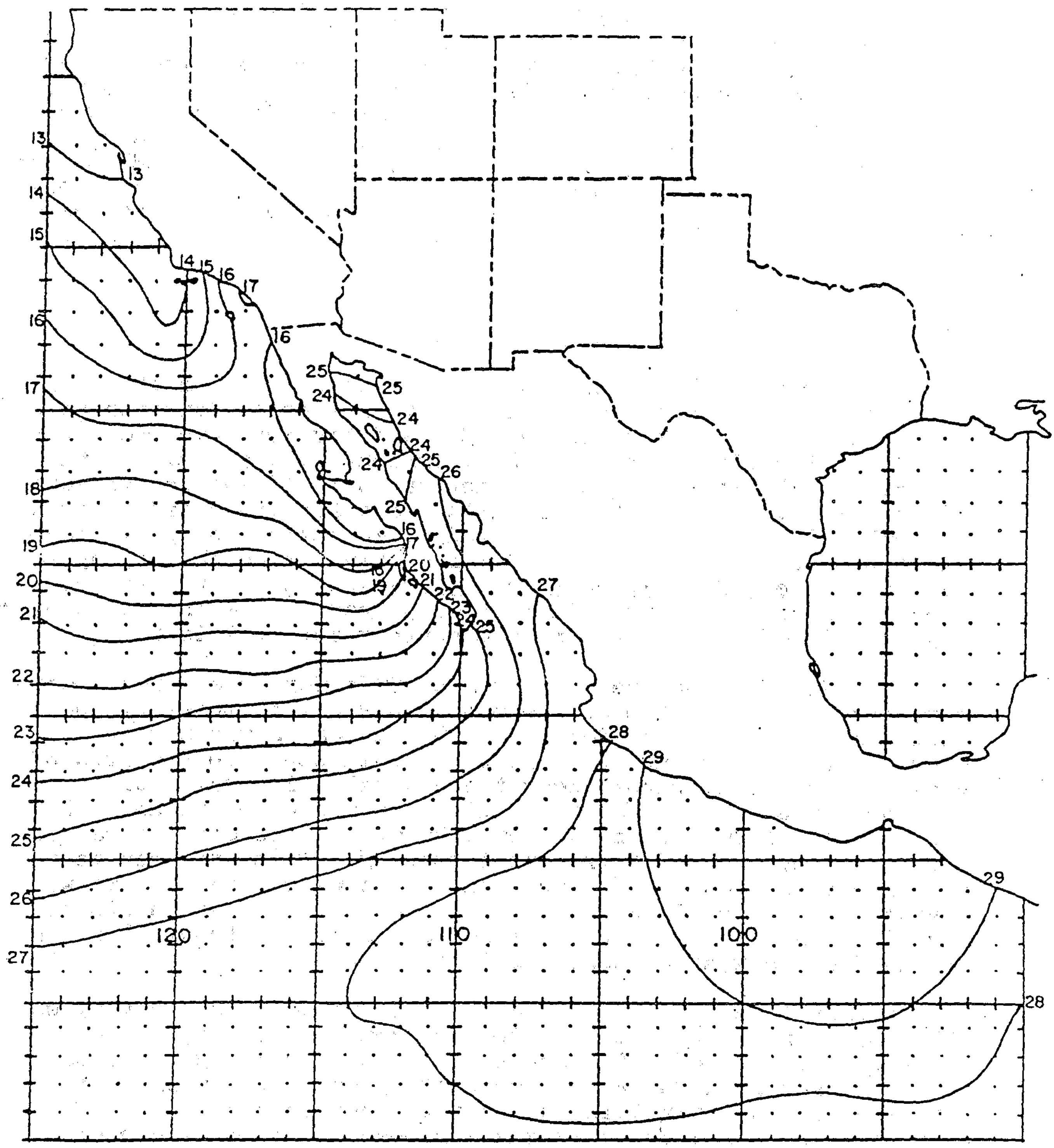

Figure 2. Mean sea surface temperature for June. Temperatures are in °C and the contour interval is 1° (from Oceanographic Monthly Summary Sea Surface Temperature Climatology, April 1982).

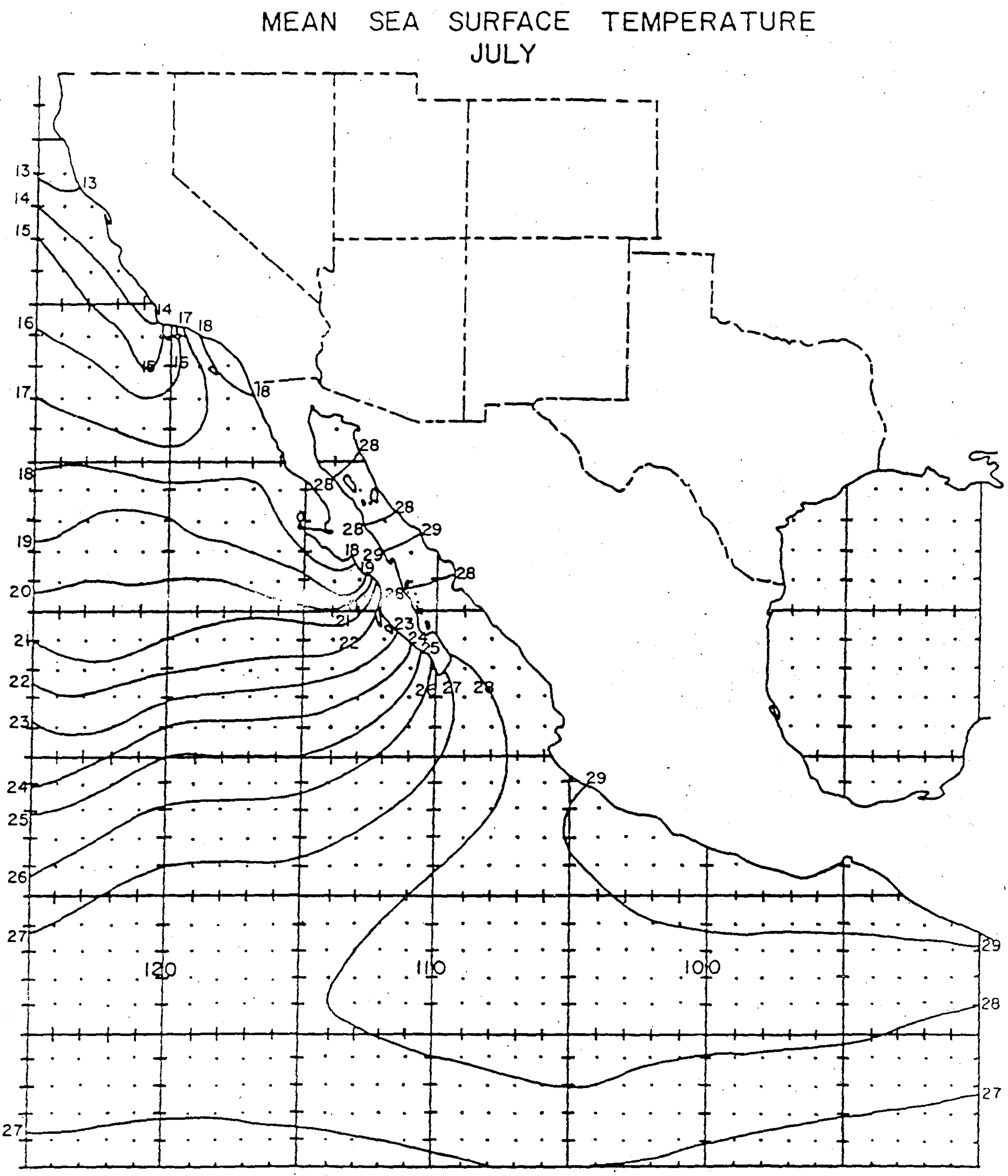

Figure 3. Mean sea surface temperature for July. Temperatures are in °C and the contour interval is 1° (from Oceanographic Monthly Summary Sea Surface Temperature Climatology, April 1982).

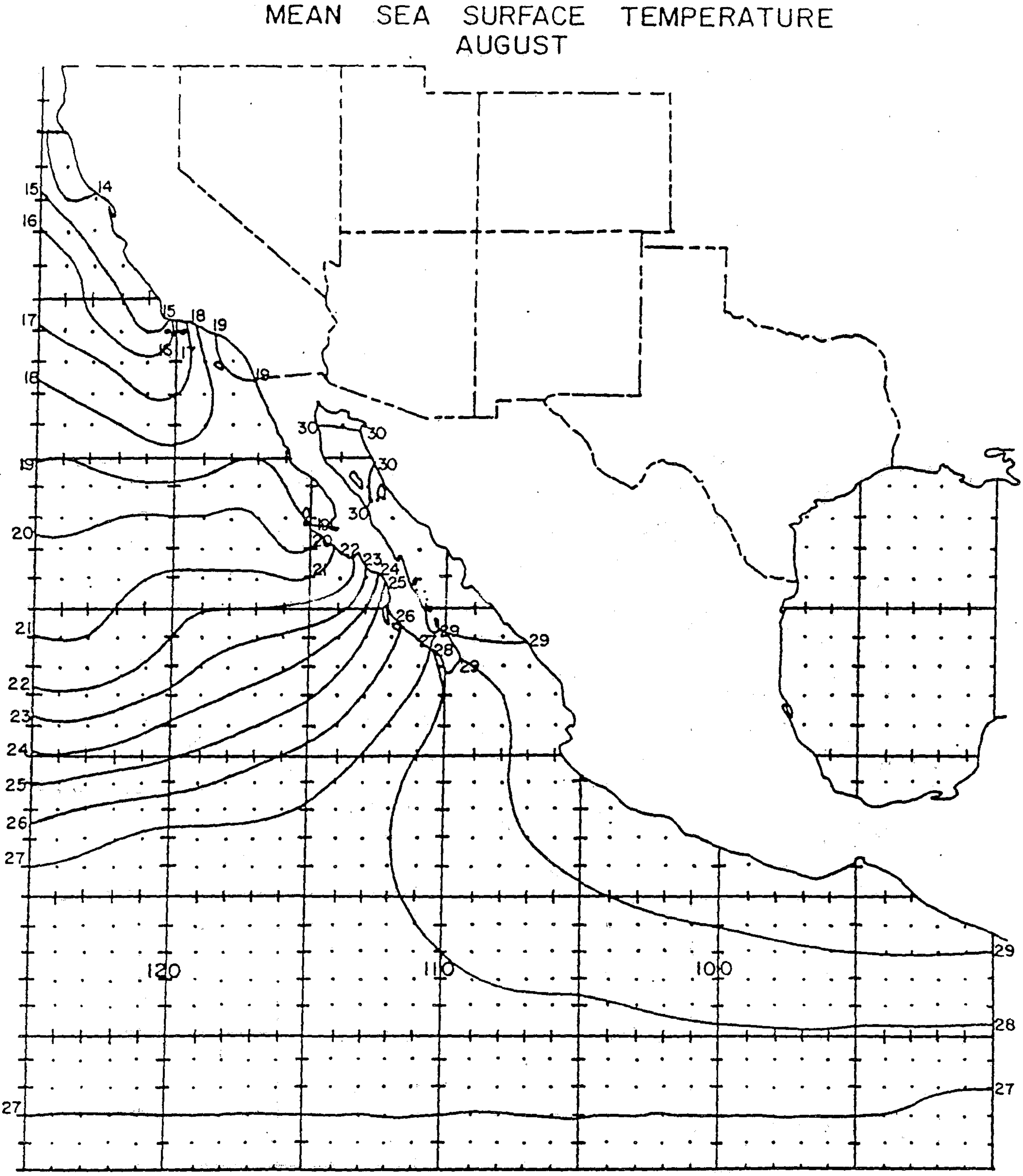

Figure 4. Mean sea surface temperature for August. Temperatures are in °C and the contour interval is 1° (from Oceanographic Monthly Summary Sea Surface Temperature Climatology, April 1982).

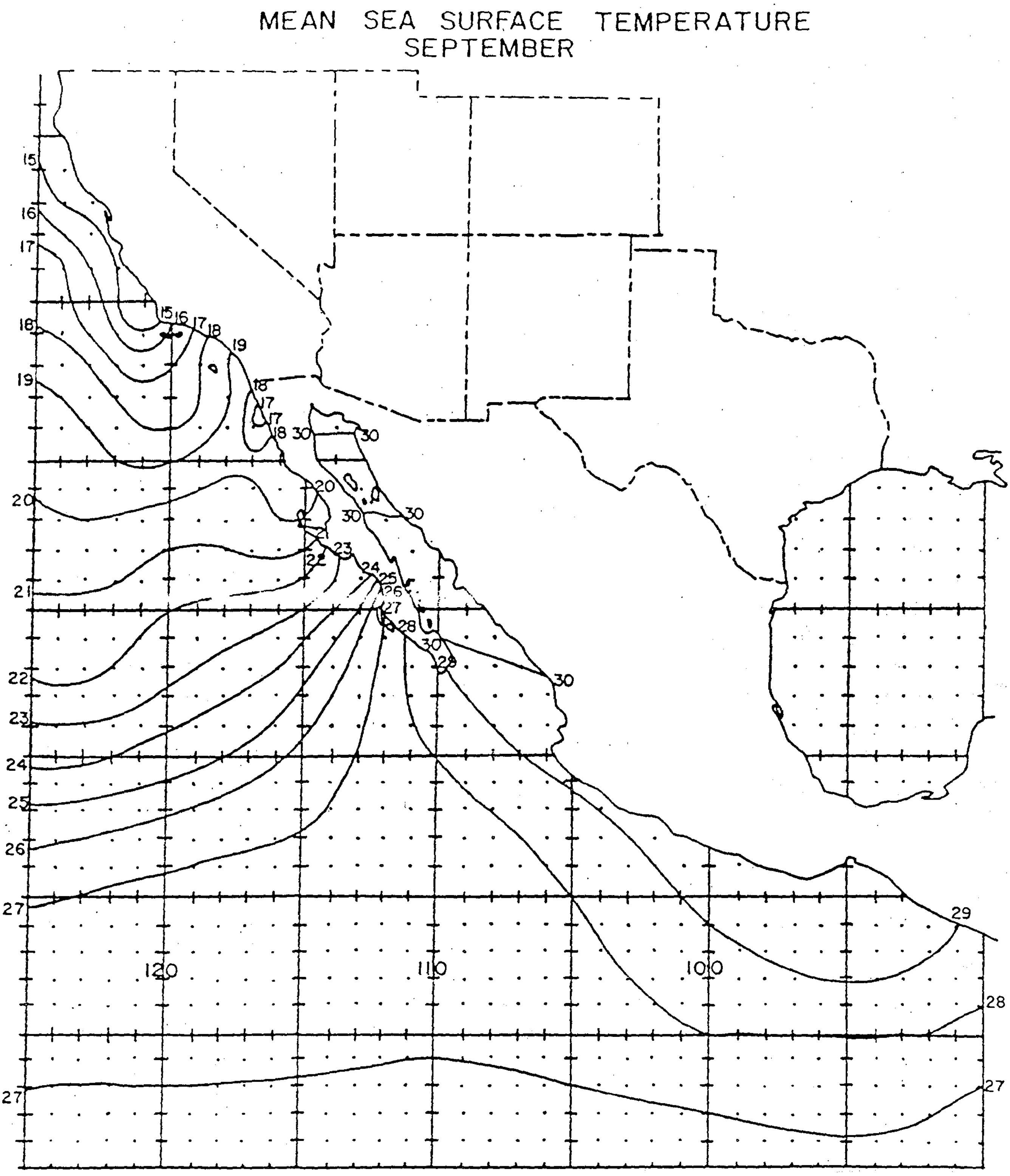

Figure 5. Mean sea surface temperatures for September. Temperature are in °C and the contour interval is 1° (from Oceanographic Monthly Summary Sea Surface Temperature Climatology, April 1982).

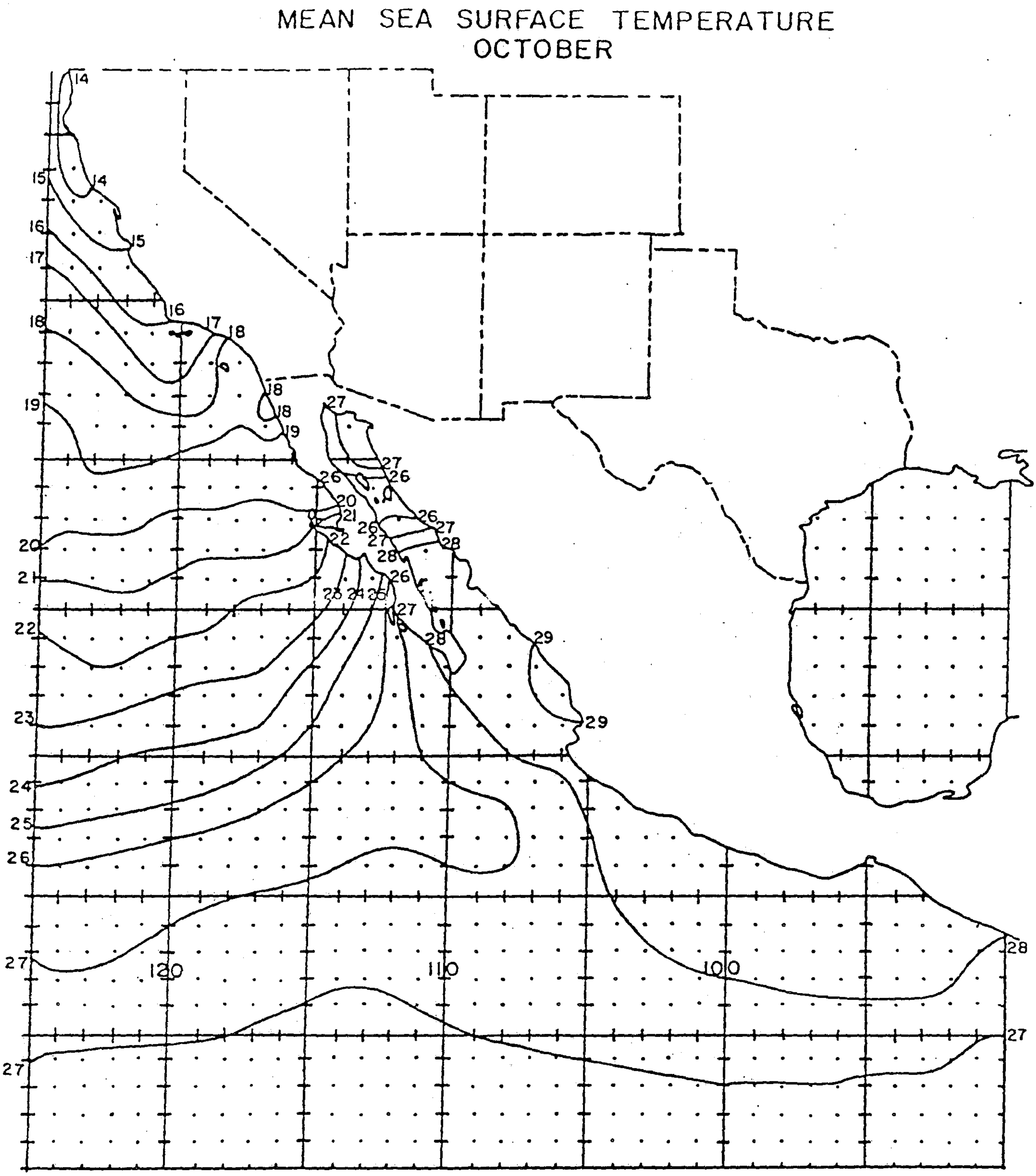

Figure 6. Mean sea surface temperatures for October. Temperature are in °C and the contour interval is 1° (from Oceanographic Monthly Summary Sea Surface Temperature Climatology, April 1982).

rugged topography of the Baja peninsula, and the close proximity of the Pacific subtropical anticyclone with its attendant strong subsidence.

III. THE PRE-SATELLITE ERA: 1900 - 1965

A. Early Years, 1900 - 1945

This period is characterized by its poor record of tropical cyclones. The U.S. Weather Bureau only began acknowledging the existence of tropical cyclones in the eastern north Pacific west of Mexico just prior to 1920 (Court, 1980). In addition, the precipitation record prior to about 1940 is deficient because there were far fewer climate stations, especially in the mountains, and some stations reported only monthly precipitation amounts.

Tropical Cyclone of September 8-11, 1901

The path of this storm and the rainfall associated with it can be seen in Figure 7. The track of this storm is similar to that of Tropical Storm Octave (Figure 129) which implies the steering flow was similiar in both cases, i.e. from the south-southwest for several days, in this case from the 9th through at least the 12th (all times are GMT). This suggests a cut-off low caused the tropical cyclone to move to the north-northeast with the cyclone supplying the moisture and the cut-off low the lifting for the scattered showers that developed in Arizona, New Mexico, and extreme western Texas. The precipitation linked to the tropical cyclone began on September 9 and ended on the 12th, with most falling on the 10th and 11th. The heaviest reported rainfall was 2.17 in. at Mt. Huachuca, Arizona.

Tropical Cyclone of July 20-23, 1902

There was some difficulty in determining how much rain was related to this storm and several others in July and August because normally the summer monsoon is well developed (widespread shower activity almost every day) at this time of year and moist unstable air prevails over a large part of the Southwest. In a few cases it was nearly impossible to ascertain if the tropical cyclone in question did affect any part of the study area without the aid of satellite imagery which was not available until the 1960's.

The precipitation probably linked to this storm and it's track are shown in Figure 8. Data presented on the historical weather maps suggests the cyclone dissipated over the southern end of Baja California on the 23rd and that moist air from the ex-tropical cyclone spread into southern California over the next two days. A short wave and accompanying cool front lifted the moist tropical air and caused the rain in California and Utah on

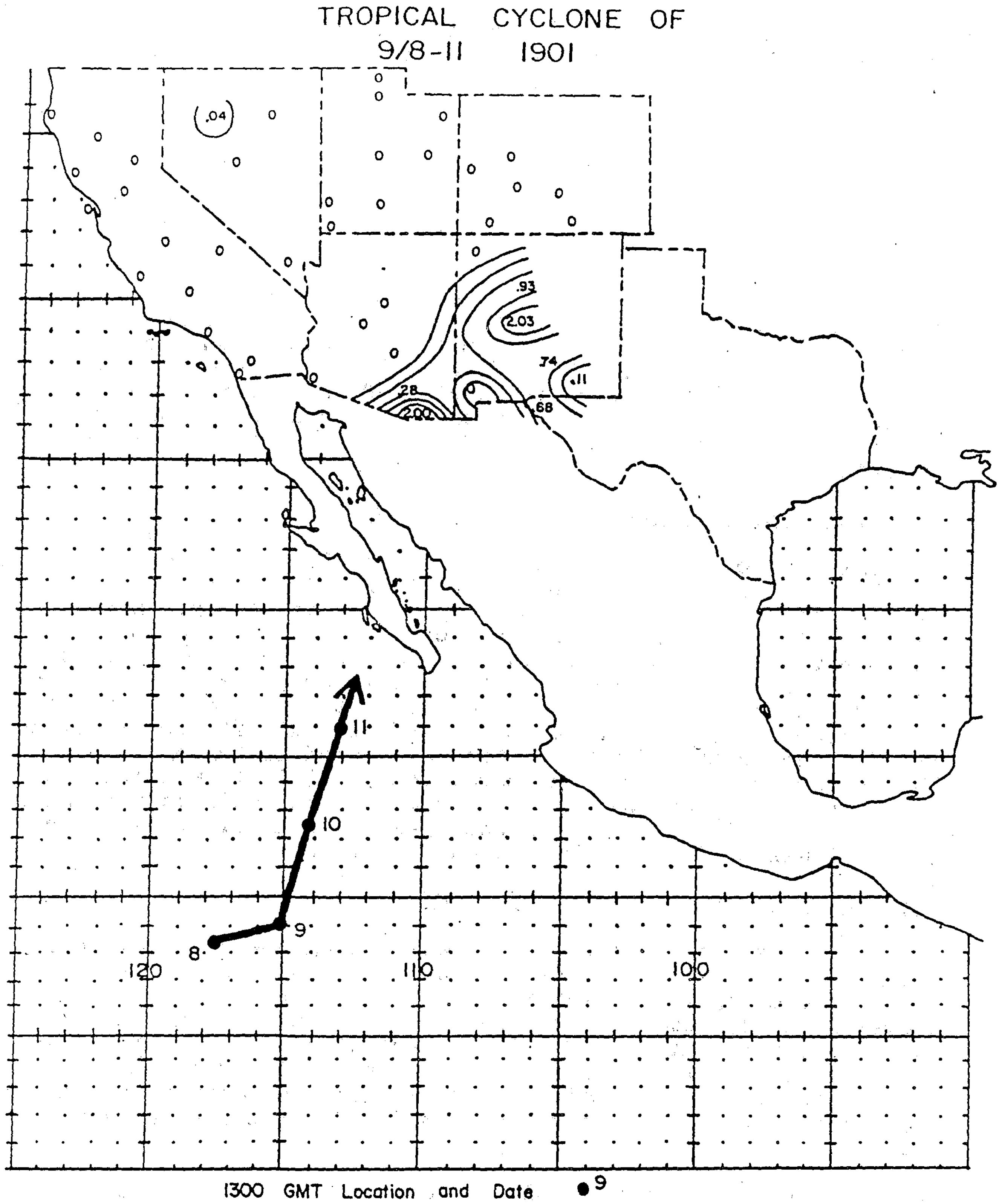

Figure 7. Track of the Tropical Cyclone of September 8-11, 1901 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

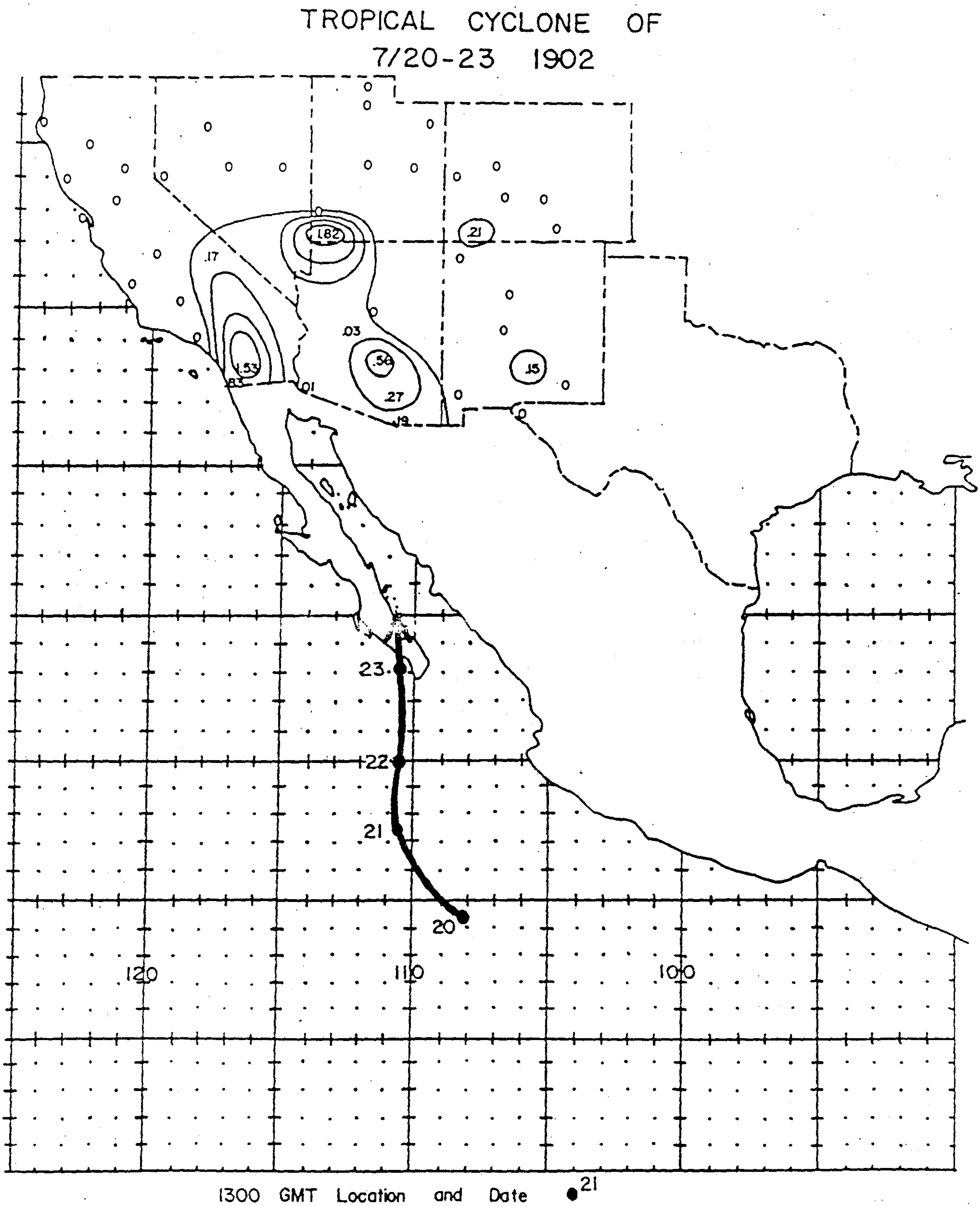

Figure 8. Track of the Tropical Cyclone of July 20-23, 1902 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches.

the 25th-26th. The .83 in. of rain reported in San Diego with this storm is one of the highest July amounts ever measured there. Since the summer monsoon was in progress over Arizona prior to the formation of the cyclone, the rainfall amounts in Arizona may be due to either the monsoon and/or the tropical cyclone.

Tropical Cyclone of September 18-20, 1902

Figure 9 shows the track and rains related to this tropical cyclone. The rains began on the 19th and ended on the 22nd with the heaviest precipitation taking place on the 20th and 21st as the tropical cyclone recurved to the northeast and weakened ahead of an advancing short wave. By 1300 GMT September 20, the surface low was centered in Utah and the cold front was moving into Arizona causing showers in southern Utah, southwestern Colorado, western New Mexico, and most of Arizona. The highest reported rainfall was 2.03 in. at Lasal, Utah.

Tropical Cyclone of August 13-17, 1906

The most unusual aspect of the storm was it's track through the Gulf of California (Figure 10). The influx of moisture from the tropical cyclone led to heavy rains in southern California, Arizona, eastern Nevada and western Utah with many stations in these areas receiving more than one inch of rain. In addition to the precipitation amounts shown in Figure 10, Table 5 presents daily rainfall at several stations that reported some of the highest storm totals. Needles, California recorded 3.49 in. of rain on the 19th which was the largest calendar day rainfall reported for the storm and is approximately 85% of the average annual precipitation there.

Tropical Cyclone of September 8-15, 1910

Precipitation linked with this tropical cyclone started on the 13th when Yuma and Kingman, Arizona recorded 1.22 and 1.00 in., respectively. However, the heaviest rains occurred from September 14-16 along the central California coast and in the Sierra Nevada Mountains where some places reported more than 4 in. (see Table 6). The track of the storm (Figure 11) is similar to those of Hurricane Norman in September 1978 (Figure 117) and Hurricane Olivia in September 1982 (Figure 123). All three tropical cyclones completely dissipated before reaching the California coast but moist air associated with them still brought unusually heavy September rains to much of California. For example, Blue Canyon reported 2.20, 3.68, and 2.95 in. of rain from each of the aforementioned storms while Fresno received 1.00, 1.00, and 1.10 in. respectively. The average September precipitation at Blue Canyon is about .50 in. while at Fresno it is less than .10.

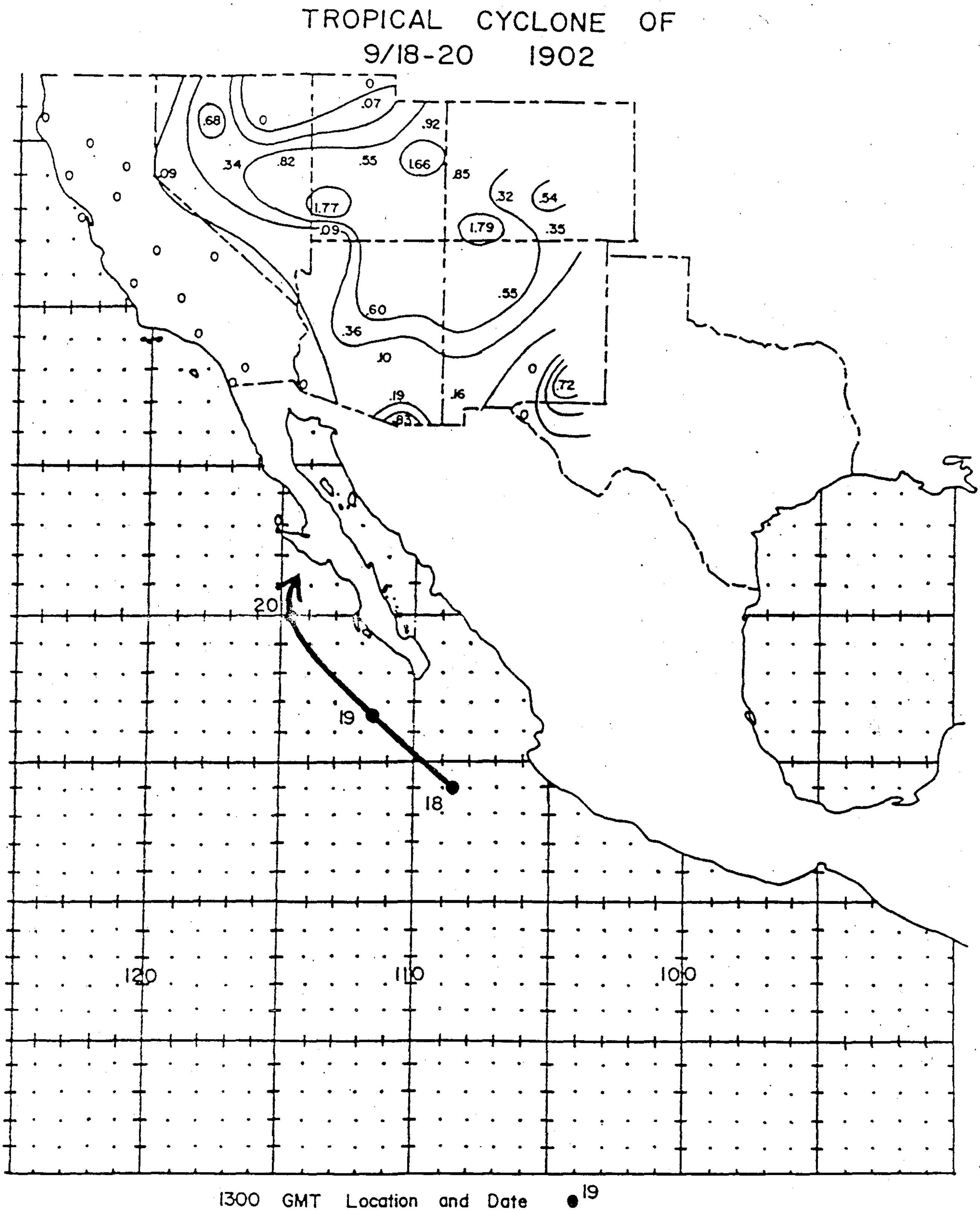

Figure 9. Track of the Tropical Cyclone of September 18-20, 1902 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches.

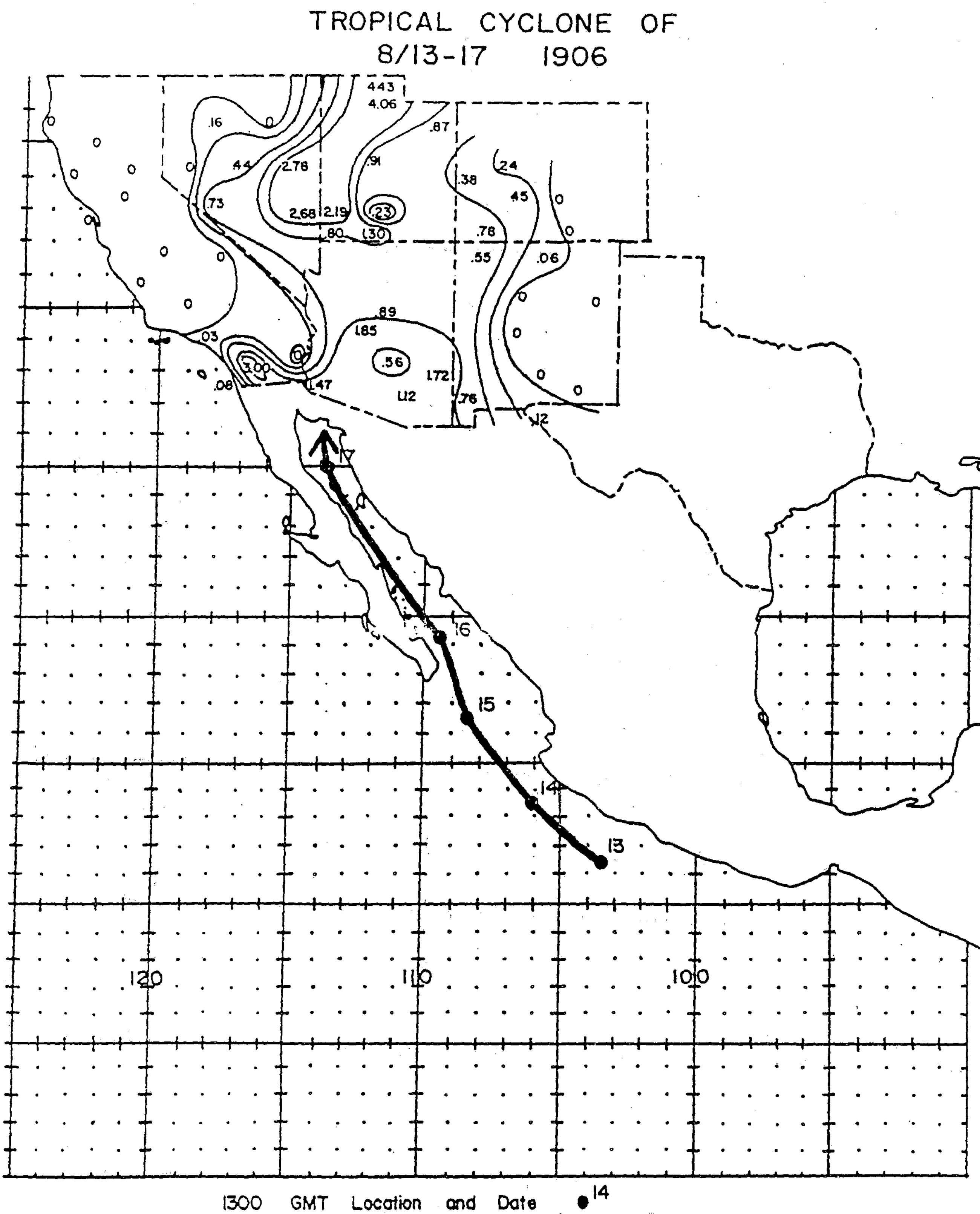

Figure 10. Track of the Tropical Cyclone of August 13-17, 1906 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

Table 5. Tropical Cyclone of August 13-17, 1906 daily precipitation

	August							
Station	17	18	19	20	21	22	23	Total
Cuyamaca, Ca.	1.00	1.75	00	.25	0	0	0	3.00
Needles, Ca.	0	0	3.49	0	.25	0	0	3.74
Geyser, Nev.	0	00	.17	.62	2.07	1.35	.15	4.36
Canal Dam, Az.	0	2.00	.15	1.05	0	0	0	3.20
Fort Mohave, Az.	0	.20	2.00	.10	.20	0	0	2.50
Corinne, Utah	0	0	00	1.97	1.40	.33	.15	3.85

00 = trace; amounts in inches.

Table 6. Tropical Cyclone of September 8-15, 1910 daily precipitation

	September				
Station	13	14	15	16	Total
Fordyce Dam, Ca.	0	.12	1.40	2.60	4.12
Mono Ranch, Ca.	00	.20	4.15	0	4.35
Ozena, Ca.	0	2.20	2.30	0	4.50
Las Vegas, Nev.	.75	.20	0	0	.95

00 = trace; amounts in inches.

Tropical Cyclone of October 1-5, 1911

The track of the tropical cyclone and the associated rainfall in the southwestern U.S. is shown in Figure 12. The storm apparently weakened rapidly on October 4 after moving inland over Baja California just west of La Paz. Nevertheless, moist tropical air was drawn northward ahead of a digging short wave which by 1300 GMT on the 4th was located in northern Nevada. A day later the surface low was situated on the Utah-Arizona border producing heavy rains over the eastern half of Arizona, northwestern New Mexico, southeastern Utah, and southwestern Colorado where torrential rains fell causing a major flood in the San Juan River basin and five fatalities (Brandenburg, 1911). Gladstone, Colorado (elevation 3,200 m) reported a total of 8.16 in. of rain, 8.05 of it falling on October 5 (Table 7).

Tropical Cyclone of August 23-27, 1915

This tropical cyclone probably originated on the 23rd in the Pacific Ocean near Acapulco from where it moved to the northwest for several days finally dissipating in the relatively cool water off the central Baja California coast on the 27th (see Figure 13). Table 8 lists some daily rainfall totals from the cyclone and shows that most rain fell on August 26. All reported precipitation amounts were less than two inches except at Pinal Ranch, Arizona where 3.63 in. was recorded. The 1.01 in. measured at Riverside, California fell in 90 minutes (Court, 1980) and is approximately 10 times the average August precipitation.

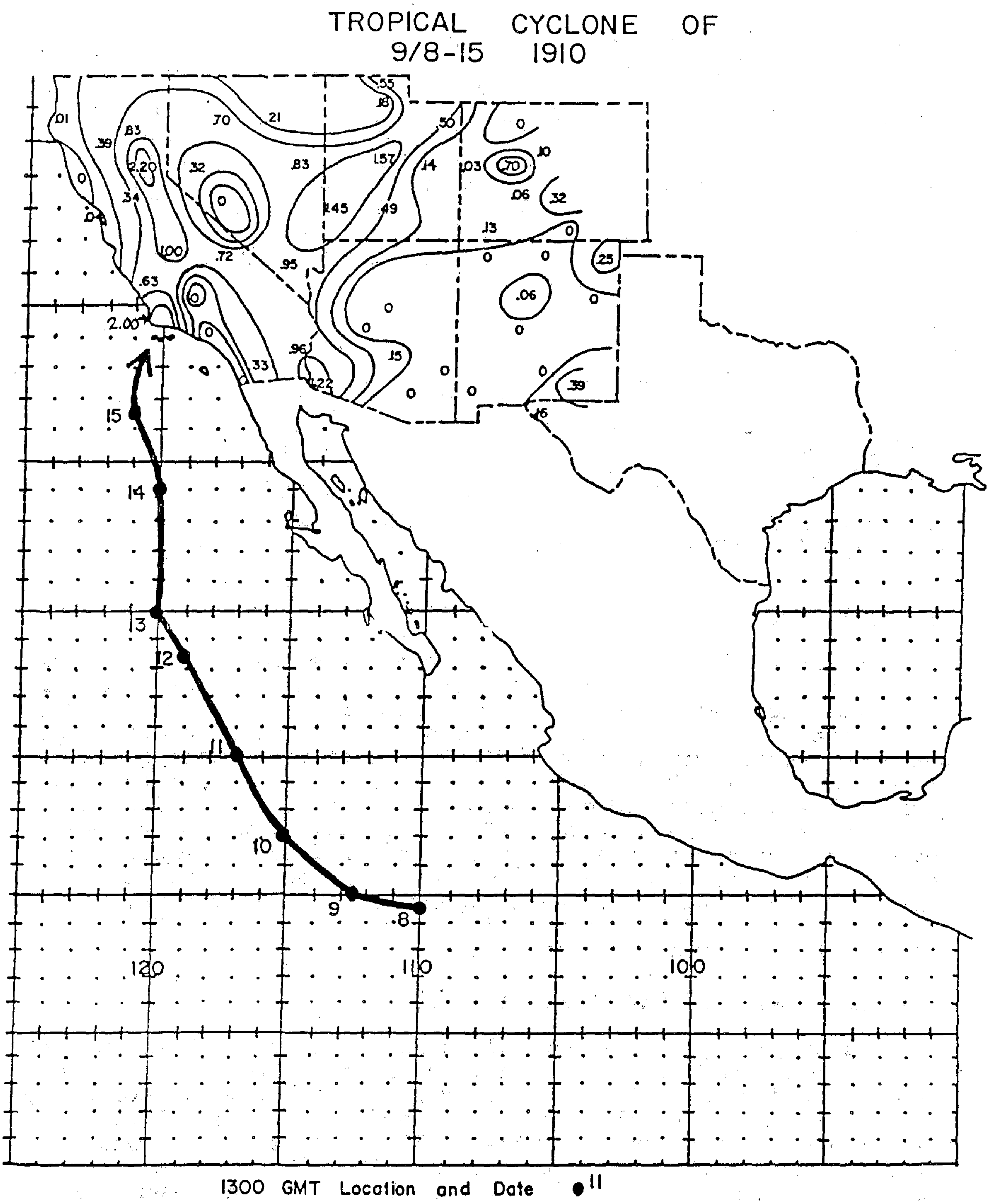

Figure 11. Track of the Tropical Cyclone of September 8-15, 1910 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

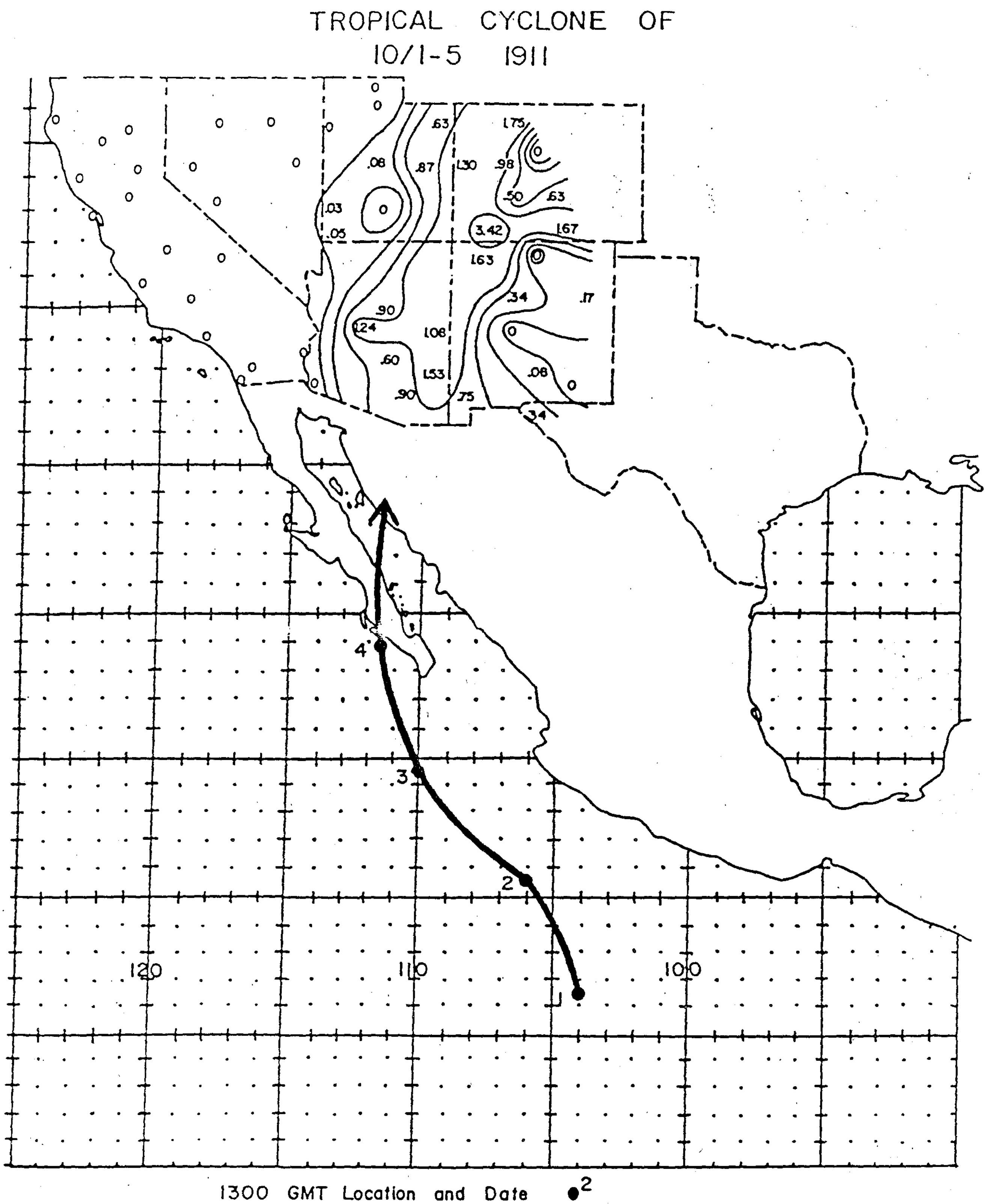

Figure 12. Track of the Tropical Cyclone of October 1-5, 1911 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

Table 7. Tropical Cyclone of October 1-5, 1911 daily precipitation

Station	October 4	5	6	Total
Durango, Co.	1.16	2.26	0	3.42
Gladstone, Co.	.11	8.05	00	8.16
Silverton, Co.	.20	4.05	0	4.25
Monticello, Utah	.32	4.10	0	4.42

00 = trace; amounts in inches.

Table 8. Tropical Cyclone of August 23-27, 1915 daily precipitation

Station	August 25	26	27	28	Total
Globe, Az.	00	.77	1.25	.07	2.09
Pinal Ranch, Az.	0	3.48	.15	0	3.63
Julian, Ca.	0	1.73	0	0	1.73
Riverside, Ca.	0	1.01	0	0	1.01

00 = trace; amounts in inches.

Tropical Cyclone of September 15-19, 1917

The main influx of moisture from the cyclone into the Southwest, as seen in Figure 14, was over the Arizona-New Mexico border where several stations; including Lordsburg and Hachita, New Mexico and Springerville, Arizona; received more than 2.00 in. of precipitation. The heaviest rain occurred on the 19th and 20th just after the storm moved inland over Sinaloa state, Mexico and dissipated.

Tropical Cyclone of September 11-12, 1918

This cyclone moved northwestward parallel to the West Coast on the 11th and 12th as indicated in Figure 15 while a short wave moved southeastward from the Gulf of Alaska. The moisture from the dying tropical cyclone and the midlatitude trough combined over northern California to produce phenomenally heavy September rains. Many stations in northern California, Table 9 lists some of them, received more than 5 in. of precipitation. The 7.14 in. recorded at Red Bluff is more than 20 times the normal September precipitation of .31 in. while the 6.25 in. reported at San Jose is more than 40 times the normal of .15 inches.

Hurricane of September 14-18, 1918

The remnants of this hurricane had very little effect on the Southwest. Only a few stations received more than a trace of rain, the heaviest being 1.50 in. on the 18th at Arivaca, Arizona which is on the border with Mexico. In contrast, several villages south of La Paz, Baja California were almost totally destroyed by this severe hurricane on the night of September 16, 1918 (Tingley, 1918). High winds and floods caused many deaths in San Jose del Cabo and approximately 20 in. of rain fell at El

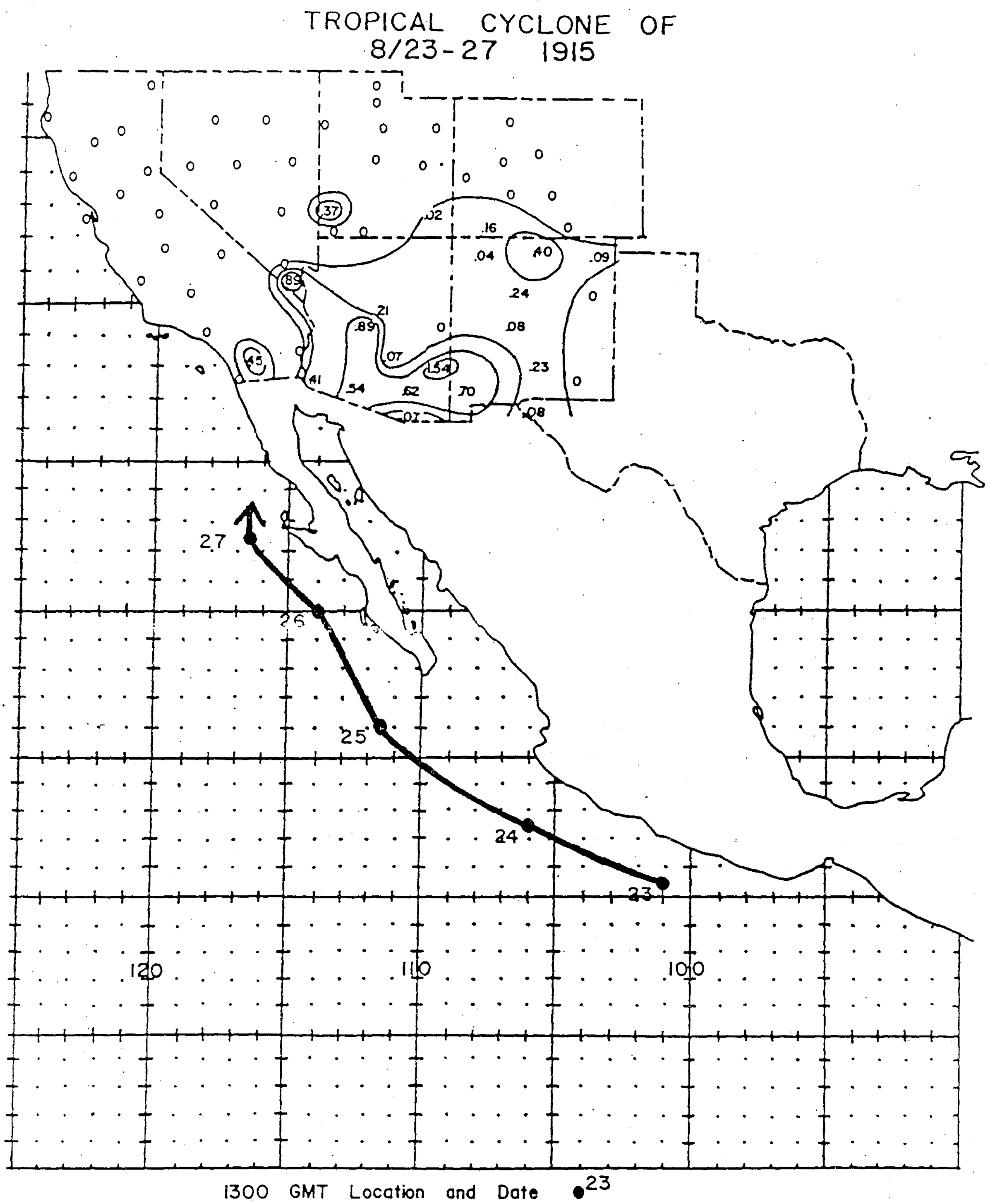

Figure 13. Track of the Tropical Cyclone of August 23-27, 1915 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches.

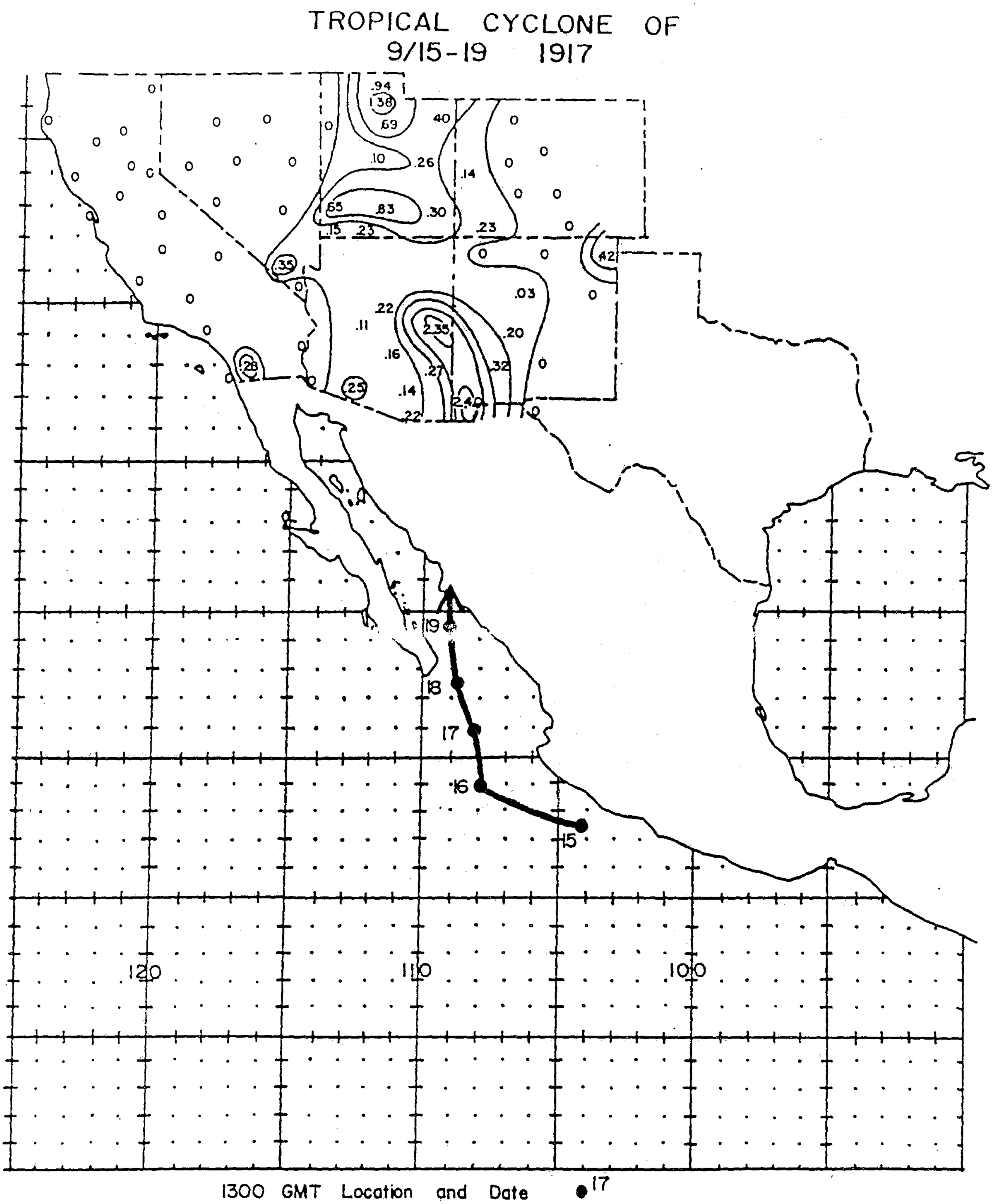

Figure 14. Track of the Tropical Cyclone of September 15-19, 1917 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

Table 9. Tropical Cyclone of September 11-12, 1918 daily precipitation

	September				
Station	11	12	13	14	Total
Antioch, Ca.	0	3.88	1.50	1.21	6.59
La Porte, Ca.	00	2.50	2.08	1.61	6.19
Red Bluff, Ca.	.02	.92	2.68	3.52	7.14
San Jose, Ca.	.47	4.32	1.43	.03	6.25
Santa Cruz, Ca.	2.60	3.20	.70	0	6.50

00 = trace; amounts in inches.

Triunfo (elevation about 800 m). The eye of the hurricane either passed over the tip of Baja California or very close to it because the circulation of the storm was disrupted enough that only light winds were felt on the Mexican mainland on the following days as the ex-hurricane tracked northwestward through the Gulf (Figure 16).

Tropical Cyclone of September 10-13, 1920

Figure 17 shows the track of the storm and associated rainfall in the Southwest. The remains of the tropical cyclone moved into southeastern California on September 14 while a weakening cold front moved into Arizona and New Mexico. Shower activity was more widespread the following day as the cold front became stationary and peaked on the 16th when Rodeo, New Mexico, which is located in the extreme southwestern part of the state, received 2.00 in. of rain.

Tropical Cyclone of August 15-20, 1921

Precipitation from the tropical cyclone was moderate to heavy over a relatively large area as seen in Figure 18. The path (from Court, 1980) of the storm was ideal for the transport of tropical air into the Southwest. Most stations in northern Arizona and western Colorado reported at least 1.00 in. of rain between the 20th and the 23rd. Parts of southern Utah, northwestern New Mexico, southern Nevada, and southeastern California also received more than an inch of rain. Ashdale Ranger Station, Arizona recorded significantly more precipitation, 6.25 in., than anyplace else as seen in Table 10, which shows the daily rainfall at the stations that received the heaviest rains. The 2.84 in. of rain reported at Calexico, California is more than the average annual precipitation of 2.33 inches.

Tropical Cyclone of September 25-30, 1921

This tropical cyclone brought heavy rains to the lower Colorado River Valley, Imperial Valley, and coastal mountains and valleys of southern California as it moved ashore near Ensenada, Baja California on September 30. The track of the storm is shown in Figure 19 and is one that has been closely followed by at least three tropical cyclones since 1921. All three; the Hurricane of September 4-6, 1939 (Figure 37); Tropical Cyclone of

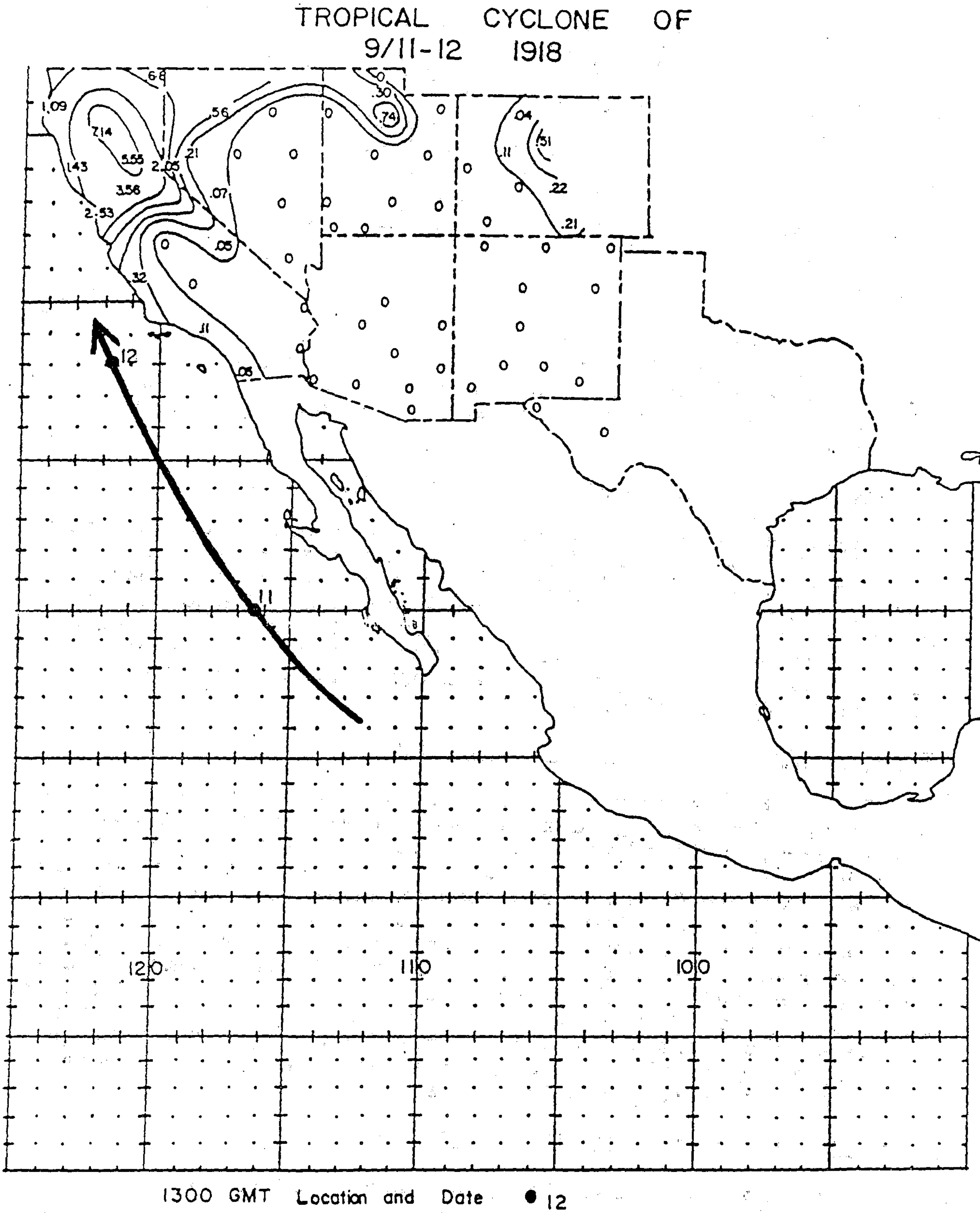

Figure 15. Track of the Tropical Cyclone of September 11-12, 1918 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches.

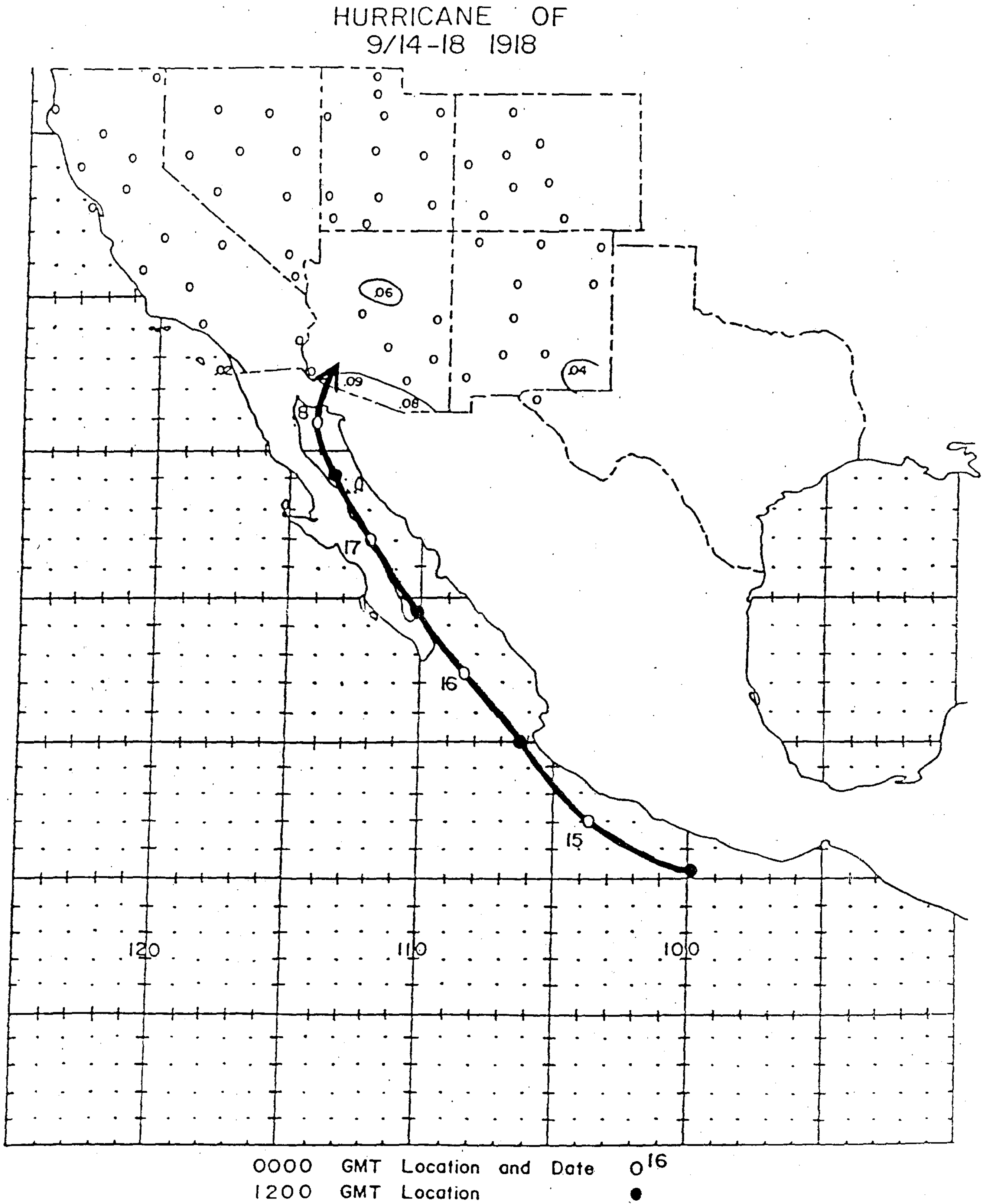

Figure 16. Track (from Court, 1980) of the Hurricane of September 14-18, 1918 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyet is drawn at .01 inches.

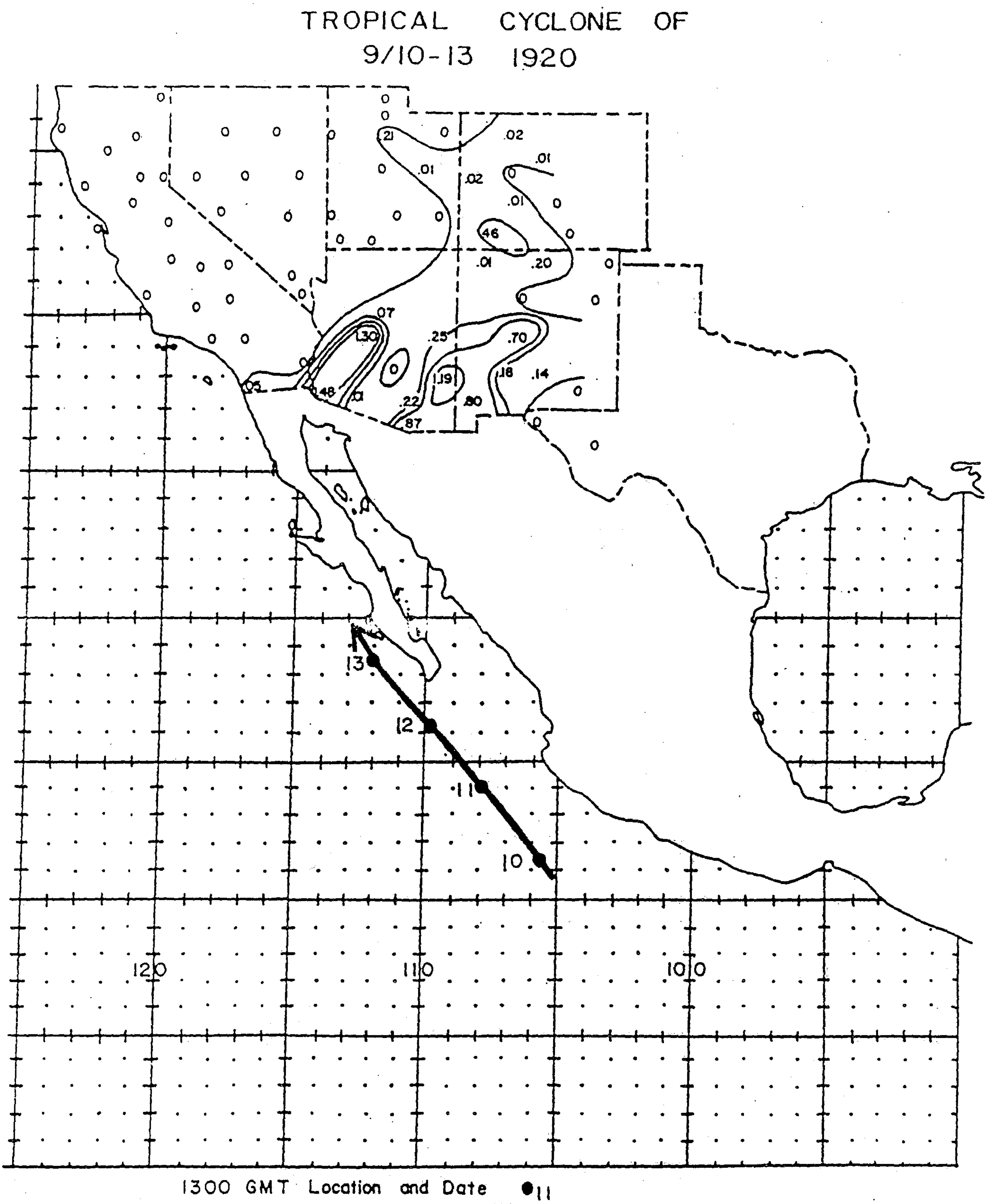

Figure 17. Track of the Tropical Cyclone of September 10-13, 1920 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches.

TROPICAL CYCLONE OF
8/15-20 1921

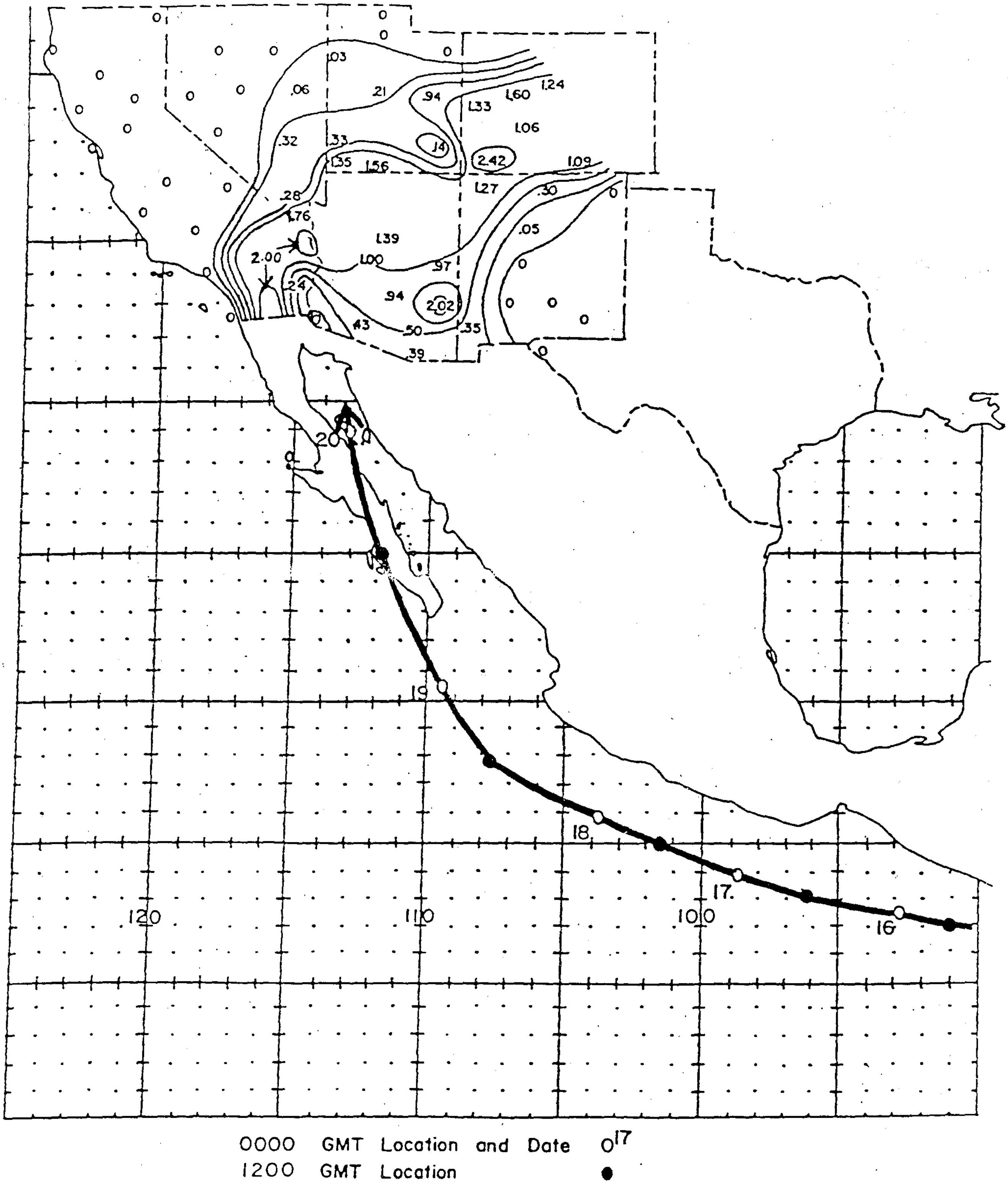

Figure 18. Track (from Court, 1980) of the Tropical Cyclone of August 15-20, 1921 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

Table 10. Tropical Cyclone of August 15-20, 1921 daily precipitation

Station	August 18	19	20	21	22	23	24	Total
Ashdale Ranger Station, Az.	0	0	2.10	4.15	0	0	0	6.25
Seligman, Az.	00	00	1.20	2.20	0	0	0	3.40
Calexico, Ca.	0	0	0	2.04	00	.80	00	2.84
Needles, Ca.	0	0	00	1.92	.18	.28	0	2.38

00 = trace; amounts in inches.

Table 11. Tropical Cyclone of September 25-30, 1921 daily precipitation

Station	September 29	30	October 1	2	Total
Blythe, Ca.	0	2.95	.46	0	3.41
Mecca, Ca.	0	2.16	.03	0	2.19
Canon, Az.	0	1.92	1.40	0	3.32
Seligman, Az.	.40	.10	3.40	0	3.90
Yuma, Az.	.02	3.63	0	00	3.65
Searchlight, Nev.	0	2.02	1.69	0	3.71

00 = trace; amounts in inches.

September 6-12, 1939 (Figure 38); and Hurricane of August 24-28, 1951 (Figure 49); produced extreme rainfalls in the Southwest.

It appears that storms which have followed this path cause significant rains for several potentially important reasons. One is that in August and September the warmest water in the eastern north Pacific east of 150°W and south of 28°N is adjacent to the Baja California coast as shown in Figures 4 and 5. For instance, at 23°N, 114°W the average SST in September is about 25.5°C while at 23°N, 122°W the average is only 22°. Thus, any cyclone moving to the northwest in this part of the ocean will be more intense if it travels just a few degrees west of the peninsula over the relatively warm water than if it travels 5 to 10 degrees west of the peninsula over the cooler water.

Another important reason is that both the large-scale flow steering the storm and the circulation around the tropical cyclone itself tends to bring the tropical air associated with the summer monsoon in northwestern Mexico and the moist air overlying the Gulf of California into southeastern California and southwestern Arizona. Finally, if the cyclone maintains a low level circulation after crossing the mountains the convergence associated with the surface low will also tend to enhance the rainfall.

Many stations in southern California and western Arizona received more than 2.00 in. of rain from the storm. Table 11 shows that most of the precipitation fell on September 30 and October 1. Blythe, California and Yuma, Arizona both recorded

TROPICAL CYCLONE OF
9/25-30 1921

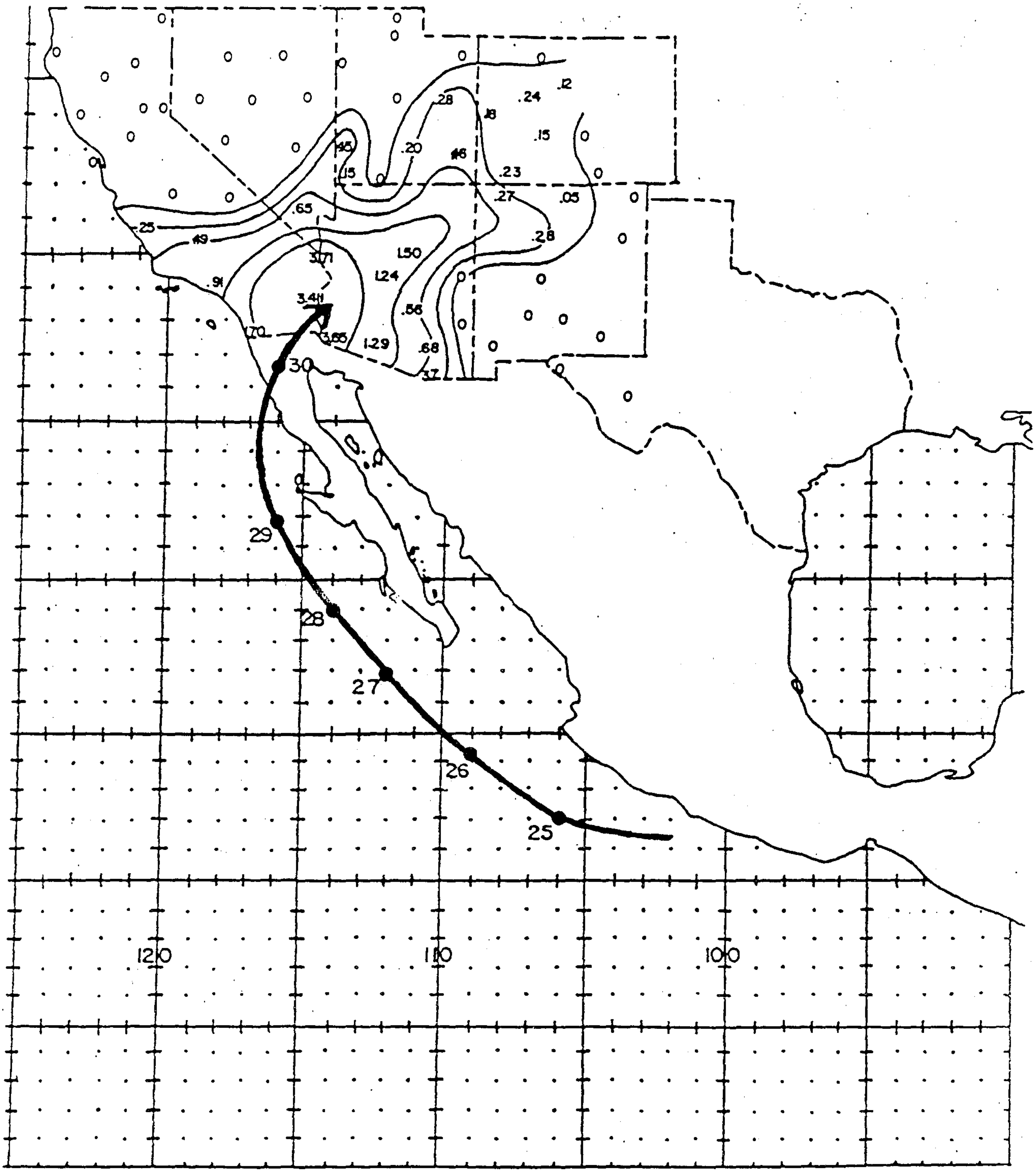

Figure 19. Track of the Tropical Cyclone of September 25-30, 1921 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

more rain than normally falls in an entire year at their respective locations.

Tropical Cyclone of September 2-8, 1924

Precipitation from the storm began on the 8th when a short wave moved into northern Nevada and the accompanying cold front moved into central California causing showers in Utah and northern Arizona. By 1300 GMT September 9 the surface low was centered over northern Utah and the cold front extended from it to the northeastern corner of Arizona and from there to Yuma. During the ensuing 24 hours the heaviest rains fell as the cold front exited Arizona. Precipitation was concentrated over eastern Utah and northern Arizona (see Figure 20) where the highest totals, 2.54 in. at Williams and 2.30 in. at Flagstaff, were recorded.

Tropical Cyclone of October 22-25, 1925

The most noteworthy feature of the tropical cyclone is that it can be linked to rainfall in the Southwest at a later calendar date, October 24, than any other eastern north Pacific tropical cyclone this century. The track of the storm and the associated rains are shown in Figure 21. Scattered, light showers were the rule with the storm and Tucson, which received .54 in., was the only station to record more than a half inch of precipitation.

Tropical Cyclone of September 20-25, 1926

The rain from this ex-tropical cyclone was extremely heavy over the southern portion of the Arizona-New Mexico border. The best estimate of the track of the storm is shown in Figure 22 as is the pattern of precipitation. The historical weather maps show the storm heading almost due west along 17°N from the 23rd through the 25th. However, this is incorrect because the Associated Press reported on September 29 that the storm had caused "terrific" damage at Mazatlan (23°N) and "minor" damage at Guaymas (28°N). Consequently, the tropical cyclone must have tracked into the Gulf of California and moved onshore over the Mexican mainland sending a vast amount of moist air into the Southwest.

Most places in southeastern Arizona, southern New Mexico, and extreme western Texas received at least 2.00 in. of rain. Table 12 lists the daily precipitation at five stations, all within 100 km of the Arizona-New Mexico-Mexico border, where the heaviest rains fell. The main body of moisture began moving over the Southwest on September 26 when the precipitation became nearly torrential. A steady, heavy rain fell at Bisbee, Arizona for more than 24 hours and produced almost all of the record monthly precipitation of 10.19 in. Runoff from the storm caused major flooding in the San Pedro River basin of southeastern Arizona where on the 28th a peak discharge of 2,775 $m^3 s^{-1}$ was measured at Charleston (drainage area 3157 km^2) and a peak discharge of 2,549

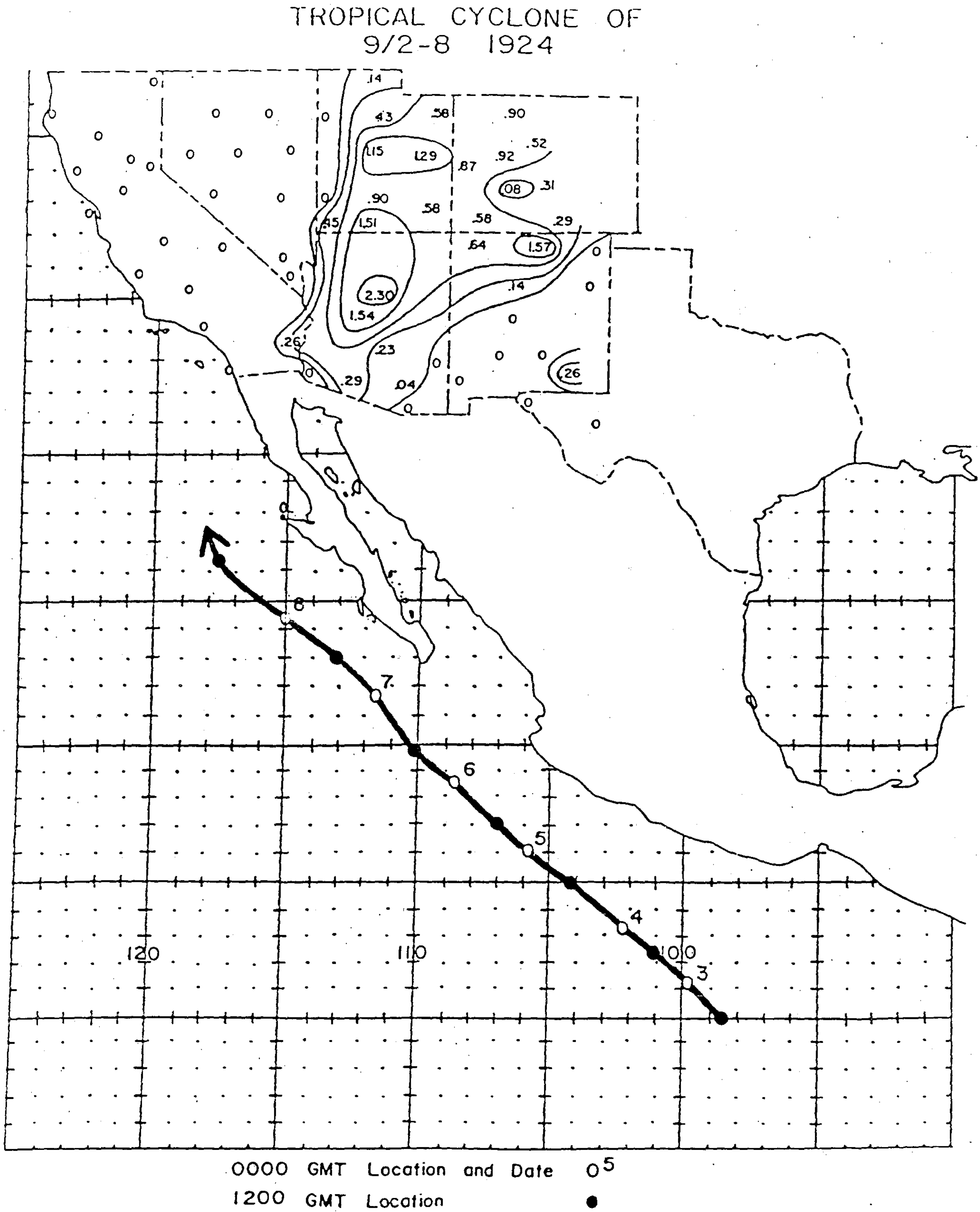

Figure 20. **Track (from Court, 1980) of the Tropical Cyclone of September 2-8, 1924 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.**

TROPICAL CYCLONE OF 10/22-25 1925

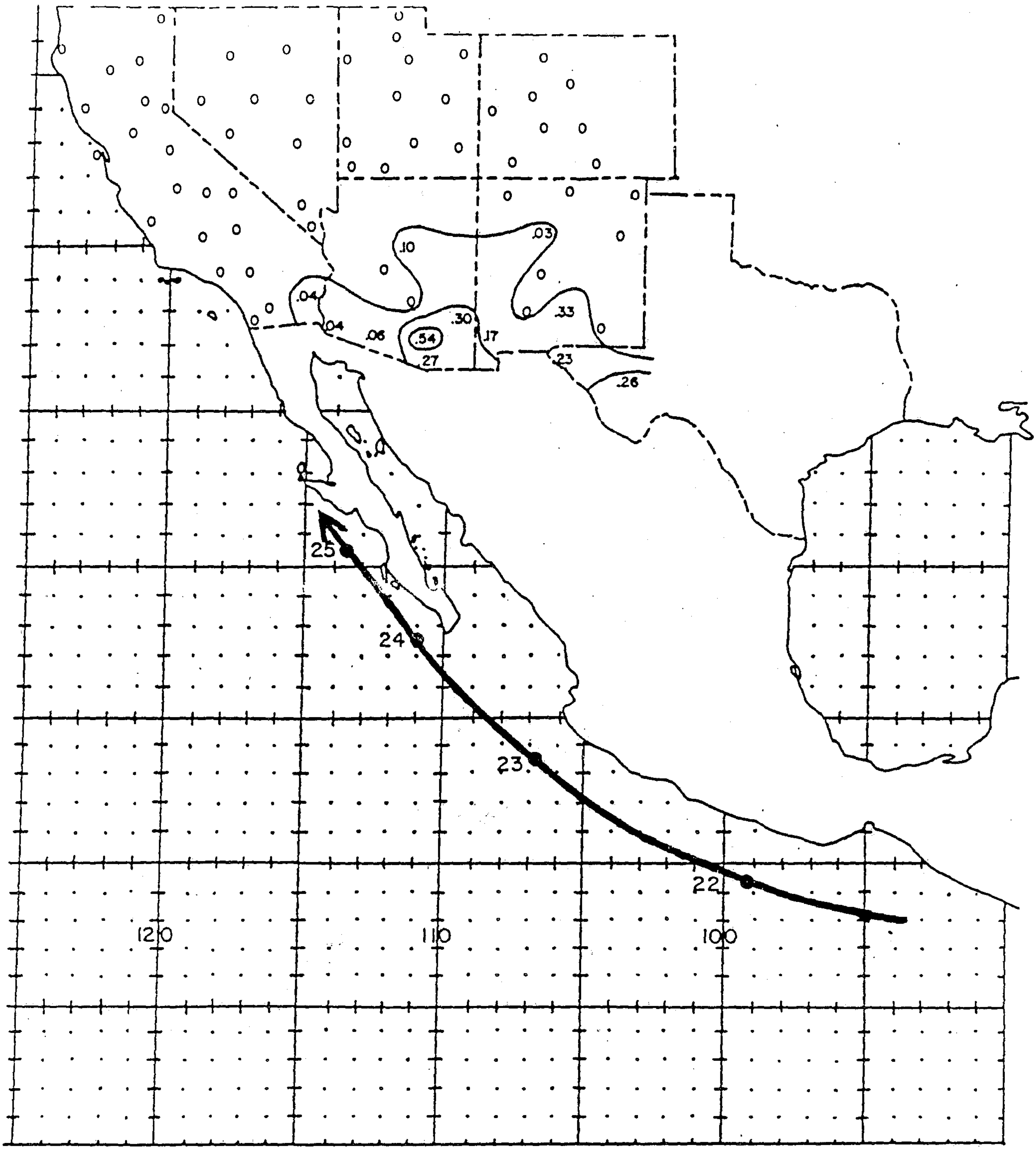

Figure 21. Track of the Tropical Cyclone of October 22-25, 1925 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, and .50 inches.

TROPICAL CYCLONE OF
9/20-25 1926

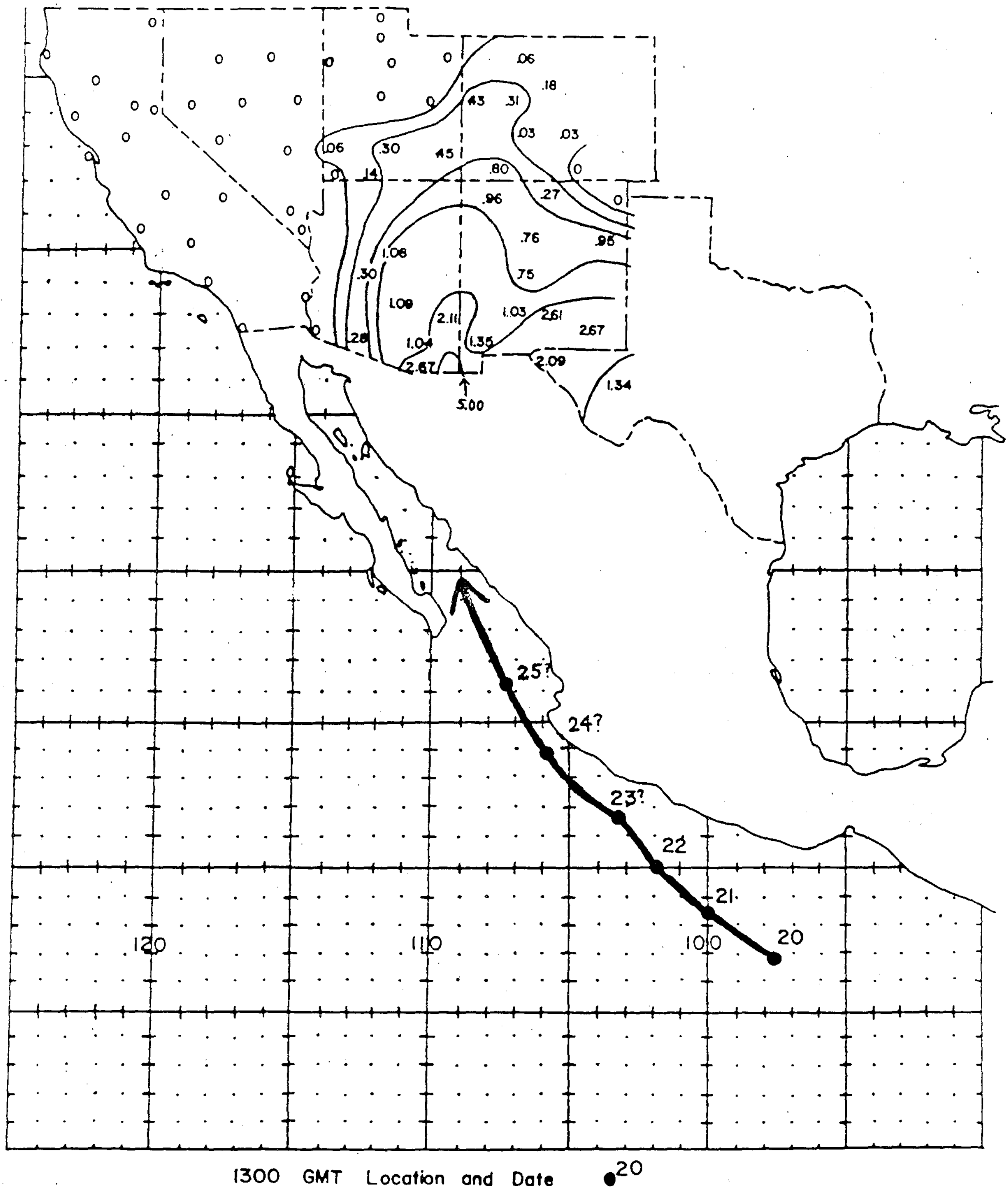

Figure 22. Track of the Tropical Cyclone of September 20-25, 1926 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches.

Table 12. Tropical Cyclone of September 20-25, 1926 daily precipitation

	September						
Station	23	24	25	26	27	28	Total
Douglas, Az.	.68	0	.05	1.68	3.58	.91	6.90
Hereford, Az.	0	.05	.07	3.10	5.05	0	8.27
Naco, Az.	0	.30	0	4.70	1.50	0	6.50
Animas, NM.	0	0	.35	.30	2.70	.78	4.13
Rodeo, NM.	0	0	0	1.44	2.58	.79	4.81

amounts in inches.

$m^3 s^{-1}$ was estimated downstream at Redington (drainage area 7612 km^2)[2].

Tropical Cyclone of September 27-30, 1926

In contrast with the previous tropical cyclone, this storm could not be linked with any known floods and was associated with relatively minor amounts of precipitation. On September 30, the cyclone tracked into the Gulf of California and, subsequently, moved ashore and dissipated (Figure 23). Scattered showers began in New Mexico and Arizona on October 1 and became more numerous the following day as a cold front pushed into Arizona. By the 3rd, the showers were located in eastern New Mexico and west Texas and headed east. Balmorhea, Texas and Hobbs, New Mexico received the most rain, 1.76 and 1.71 in. respectively.

Tropical Cyclone of October 3-8, 1926

The third tropical cyclone in two weeks to affect the Southwest brought only light precipitation with the highest reported total being just 1.33 in. at Naco, Arizona. A weakening cold front triggered the showers, nearly all of which occurred on the 8th and 9th. Most of the rain in Utah and Colorado probably was not associated with moisture from the tropical cyclone but due entirely to the short wave trough and cold front (see Figure 24).

Tropical Cyclone of October 8-13, 1926

The best estimate of the path of the storm is shown in Figure 25 as is the rainfall. The cyclone apparently recurved on October 12 in response to a trough that moved in from the northwest. Late on the following day, moist air from the weakening tropical cyclone flowed over southern New Mexico and extreme west Texas and combined with the midlatitude trough to produce rain, which became heavy on the 13th. The heaviest rains though were recorded east of the study area in north central Texas. In the Southwest, Plainview, New Mexico reported the highest total, 3.20 inches.

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[2] personal communication from Rod Roeske U.S. Geological Survey, Tucson, Az.

TROPICAL CYCLONE OF
9/27-30 1926

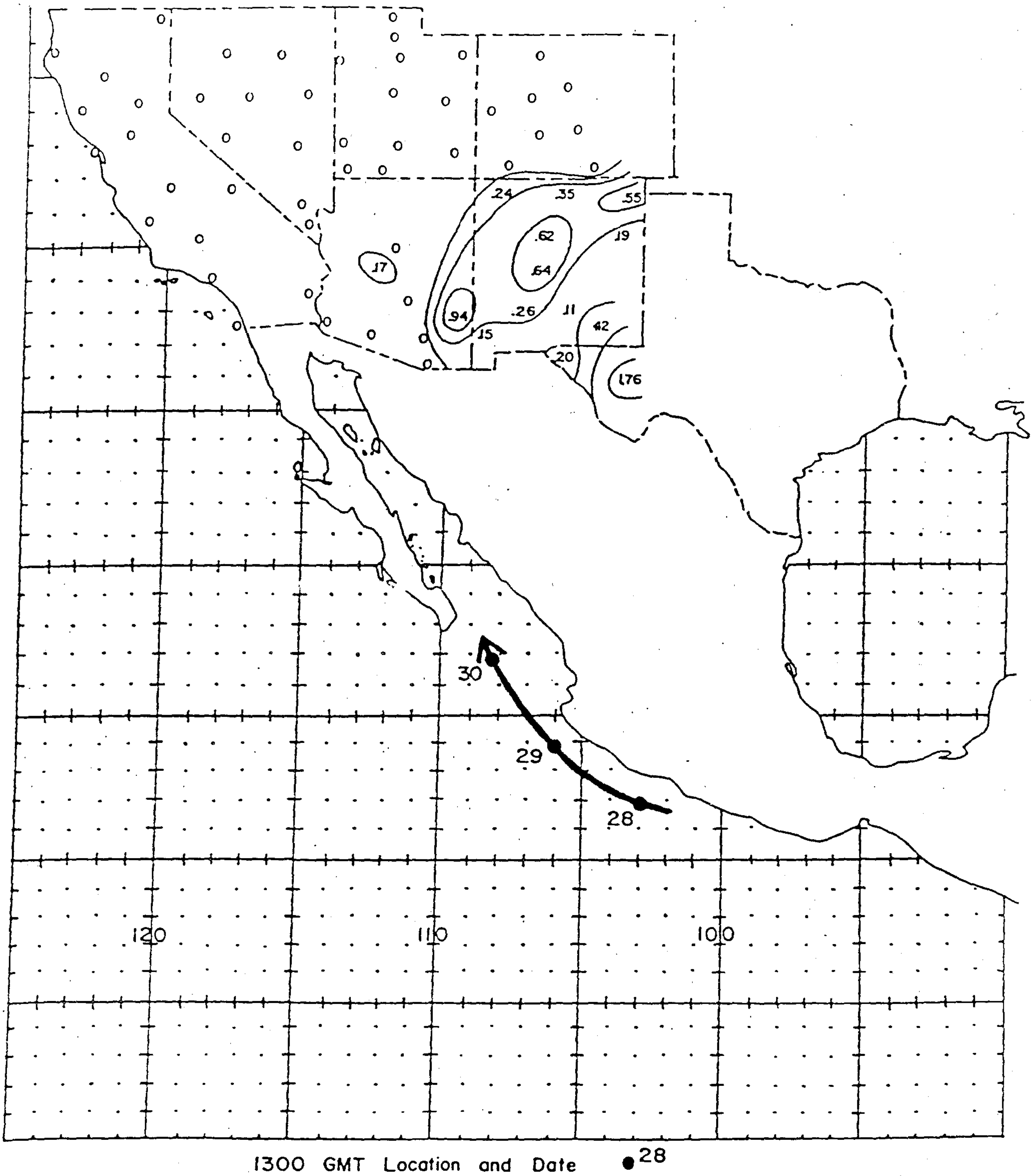


Figure 23. Track of the Tropical Cyclone of September 27-30, 1926 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches.

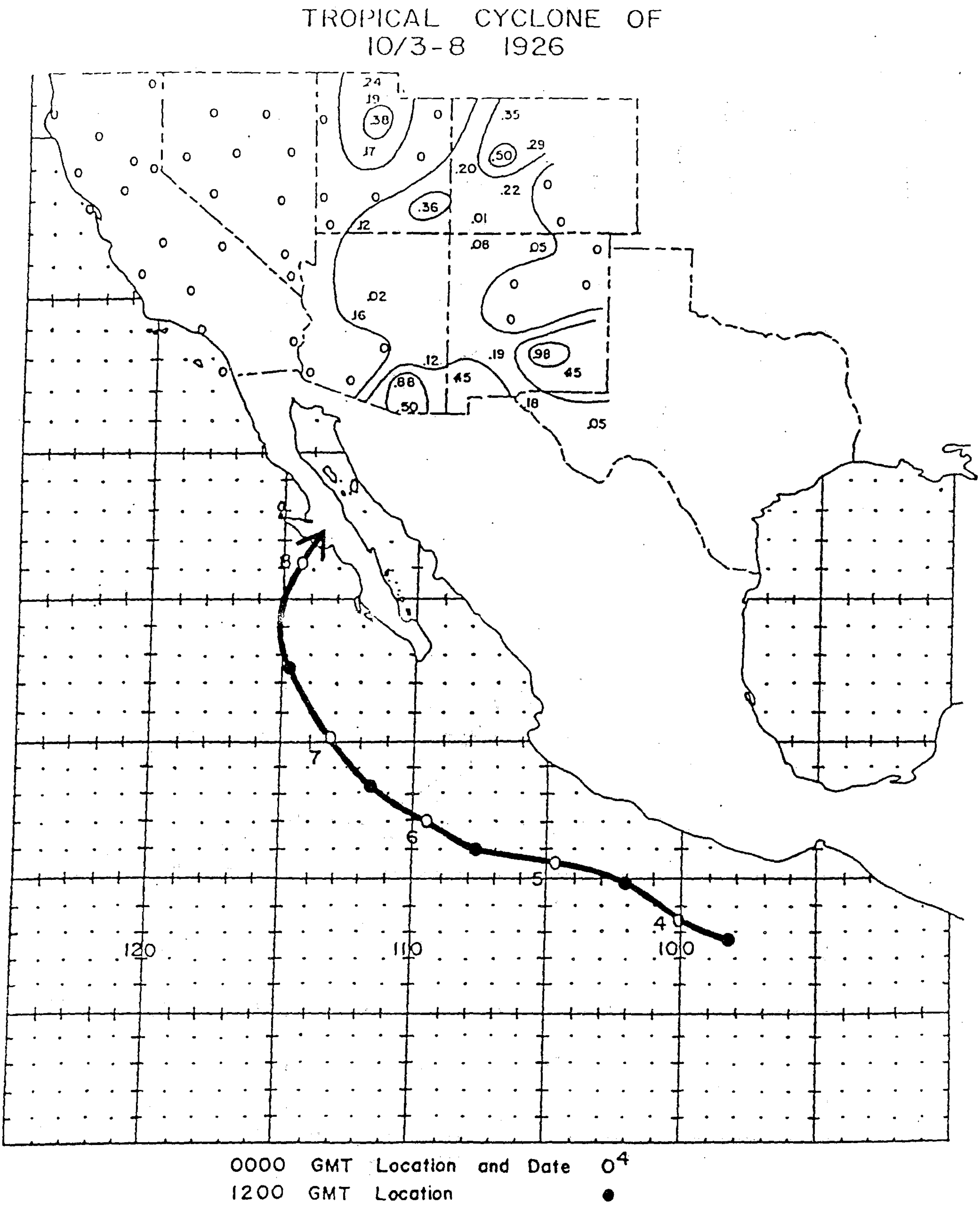


Figure 24. Track (from Court, 1980) of the Tropical Cyclone of October 3-8, 1926 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, and .50 inches.

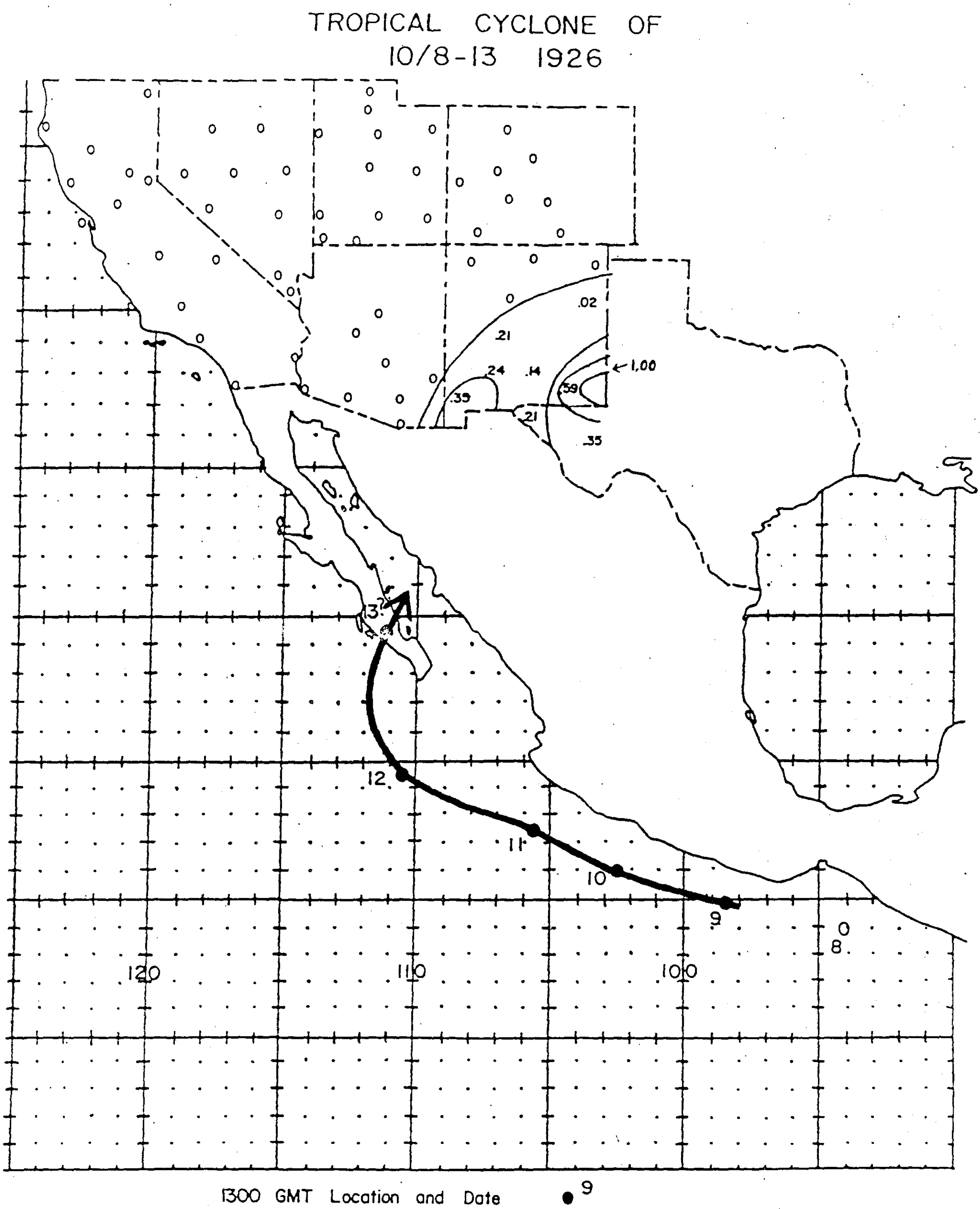


Figure 25. Track of the Tropical Cyclone of October 8-13, 1926 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches.

Hurricane of September 7-12, 1927

The combination of very warm, moist tropical air from a dissipating hurricane, upper level trough, and surface cold front resulted in heavy rains over a relatively large part of the Southwest. Figure 26 shows that most of Arizona and Utah and the western third of both Colorado and New Mexico received at least an inch of precipitation. Nearly all of the area from the Mogollon Rim in Arizona northward to the Wyoming-Utah border recorded more than 2.00 in. of rain and several stations measured more than 3.00. Table 13 lists some of the highest precipitation amounts by day and indicates that the heaviest showers fell on the 12th and 13th, when the remnants of the hurricane were entrained into the circulation of the midlatitude short wave.

Although there were a number of flash floods, numerous washouts of highways and railroads, and many earth slides; no widespread flooding or serious damage was reported. However, there was a significant rise of the Colorado River but flood stages were not reached anywhere except at Parker, Arizona where the river peaked at 3.8 ft. above flood stage on September 18. The river was above flood stage at Parker from the 14th through the 25th (Frankenfield, 1927).

Tropical Cyclone of August 6-11, 1928

This tropical cyclone was first reported southeast of Acapulco on the 6th and tracked northwestward for four days when it recurved to the northeast across Baja California, the Gulf of California, and then over the Mexican mainland as indicated in Figure 27. The summer monsoon was in progress over the Southwest at the time and the available evidence suggests that rain associated with the ex-tropical cyclone fell on the 11th and 12th. southeastern Arizona and southern New Mexico received most of the precipitation with Paradise, Arizona the highest amount, 2.20 inches.

Tropical Cyclone of September 11-17, 1929

The storm formed in the Gulf of Tehuantepec on September 11 and churned through the eastern north Pacific until the 17th, possibly the 18th (see Court, 1980 Figure 8 page 17), when it dissipated off the northern Baja California coast. Figure 28 shows the estimated track of the cyclone and the associated rainfall which was heaviest over the mountains of southern California where Cuyamaca recorded the highest amount, 3.21 in., all of which fell on September 18 (Table 14). An isolated storm total of 2.30 in. was reported at Benson, Arizona and is not representative of the rainfall received in southeastern Arizona which generally was less than .25 in. In addition, the precipitation totals shown in Figure 28 over southwestern Colorado may not be related to the tropical cyclone.

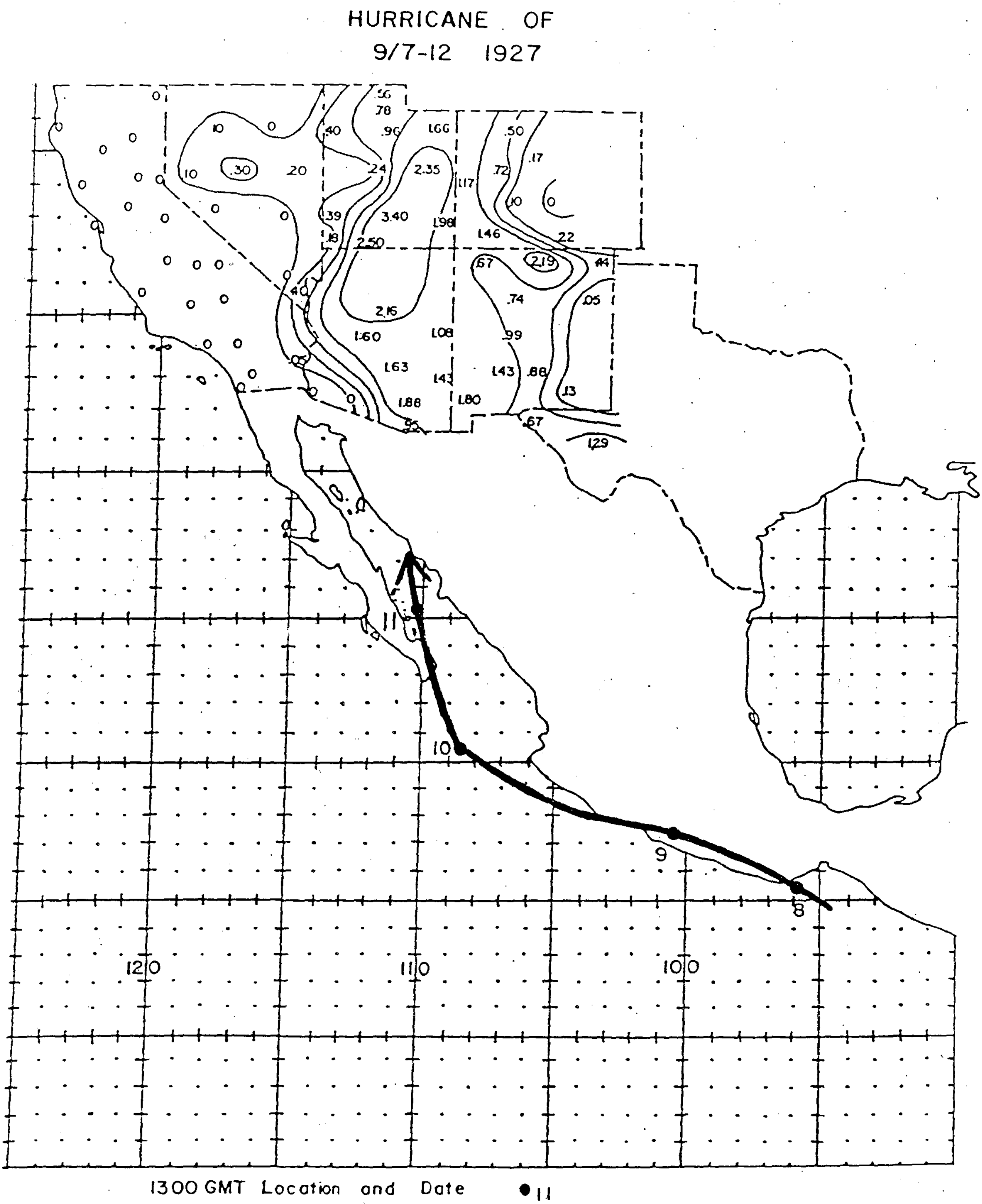


Figure 26. Track of the Hurricane of September 7-12, 1927 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

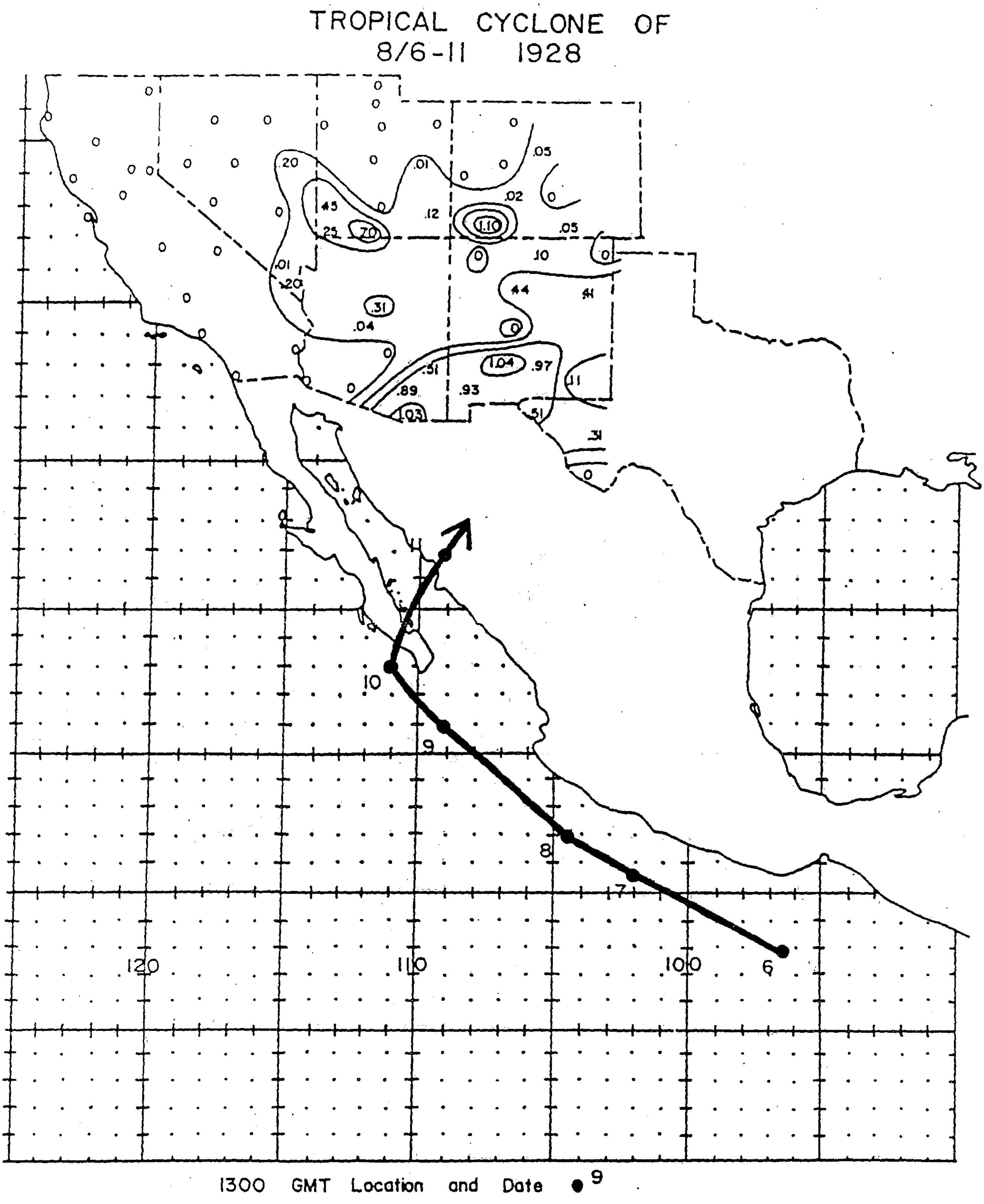
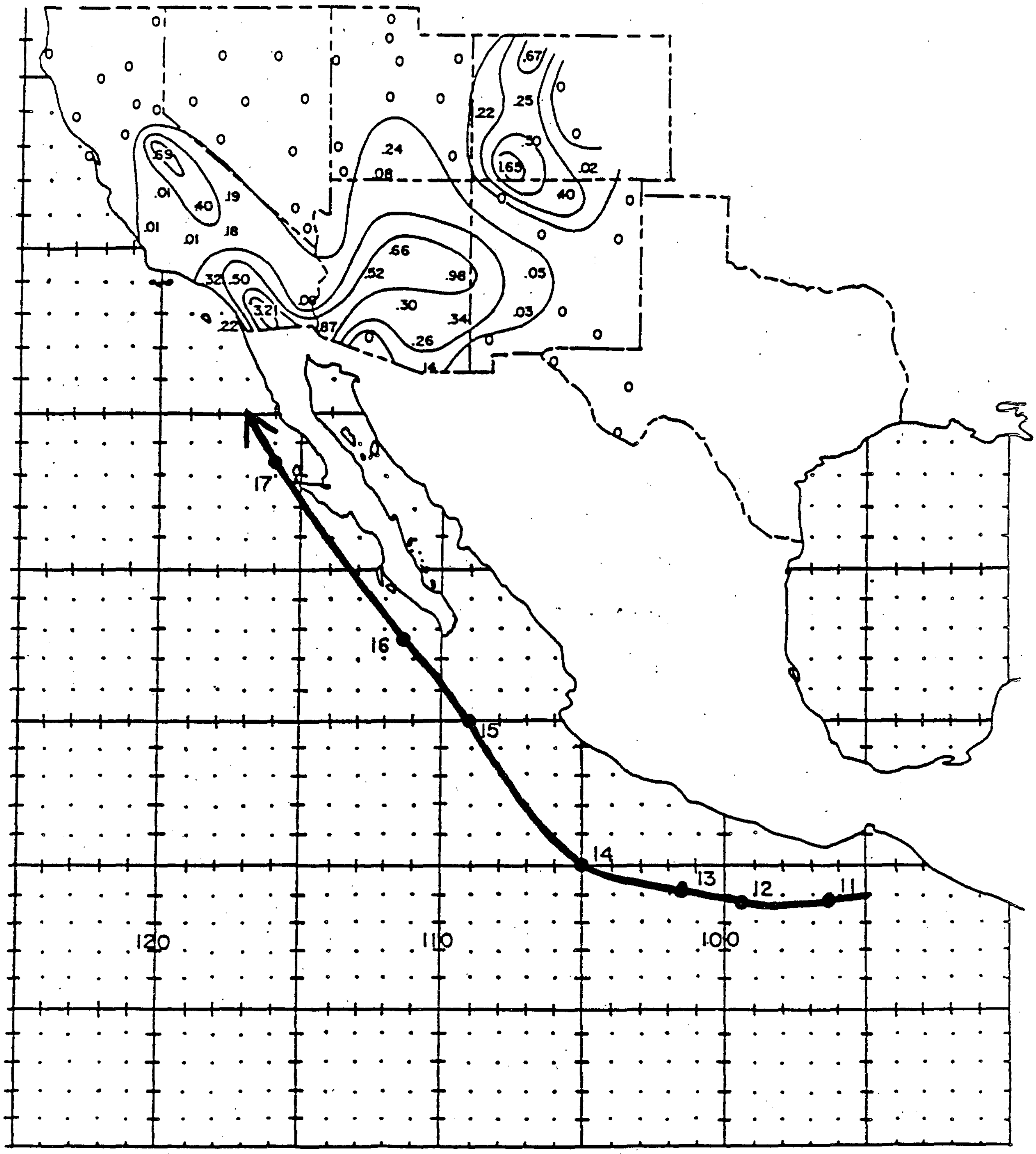


Figure 27. Track of the Tropical Cyclone of August 6-11, 1928 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches.

TROPICAL CYCLONE OF
9/11-17 1929



1300 GMT Location and Date ● 12

Figure 28. Track of the Tropical Cyclone of September 11-17, 1929 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

Table 13. Hurricane of September 7-12, 1927 daily precipitation

Station	September 11	12	13	14	Total
Natural Bridge, Az.	.25	4.10	.75	.02	5.12
Walnut Creek, Az.	0	3.15	1.53	0	4.68
Young, Az.	0	2.22	.68	0	2.90
Alton, Utah	0	1.37	1.53	0	2.90
Escalante, Utah	0	0	3.20	.20	3.40
Price, Utah	0	2.00	1.07	.01	3.08
Animas, NM.	0	2.15	0	0	2.15

amounts in inches.

Table 14. Tropical Cyclone of September 11-17, 1929 daily precipitation

Station	September 17	18	19	20	Total
Cuyamaca, Ca.	0	3.21	0	0	3.21
Palm Springs, Ca.	0	1.80	0	0	1.80
Benson, Az.	.95	.22	.23	.90	2.30

amounts in inches.

Tropical Cyclone of September 10-13, 1931

Figure 29 presents the track of the tropical cyclone and the rain in the southwestern United States. The storm made an abrupt turn to the north on September 11 ahead of a slow moving trough that was moving east. The surface front associated with the upper air trough was situated in Arizona on the 12th and finally crossed into New Mexico by 1300 GMT on the 15th triggering showers as it went. The rain peaked on the 14th as shown in Table 15. Isolated areas in Arizona, around Flagstaff and Bisbee, measured in excess of an inch of rain but most places had less than a half inch. In contrast, much of New Mexico recorded at least .50 in. of precipitation and many locations in the middle of the state, centered on the Rio Grande Valley, received more than one inch.

Hurricane of September 22-25, 1931

A midlatitude trough probably forced this storm to recurve to the northeast across Baja California causing moisture-laden air to stream over southeastern Arizona and New Mexico. Observations from these areas indicate the first showers began on the 25th and continued sporadically for several more days. Most stations measured less than an inch of precipitation. Two exceptions were Rucker Canyon, located in the Chiricahua Mountains of Arizona, and Mescalero, situated in the Sacramento Mountains of New Mexico, which received 2.97 and 2.28 in. of rain, respectively. The meager rains shown on Figure 30 in Nevada, northern Utah, and all of California except for the Colorado River Valley probably had nothing to do with the tropical cyclone.

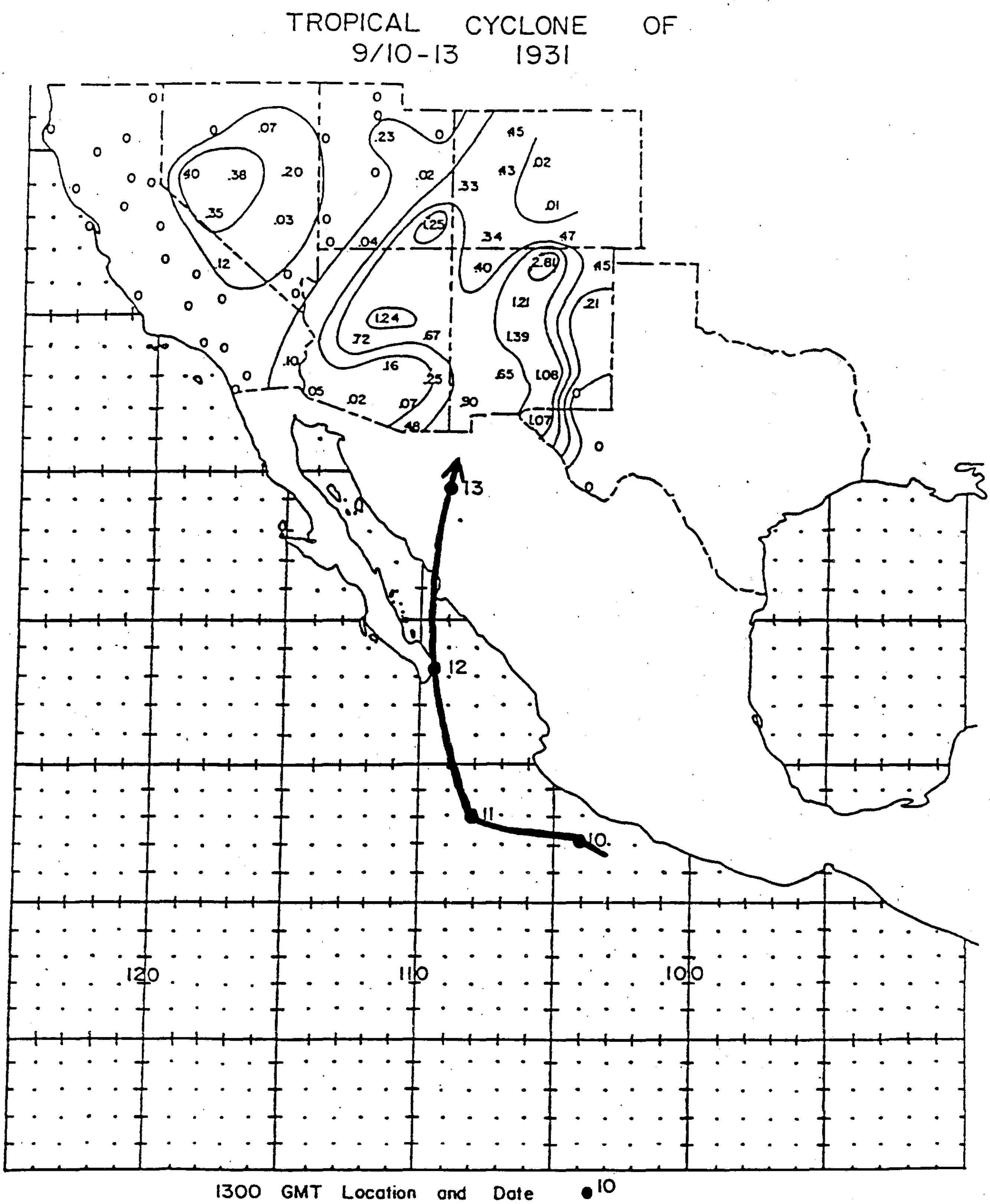


Figure 29. Track of the Tropical Cyclone of September 10-13, 1931 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

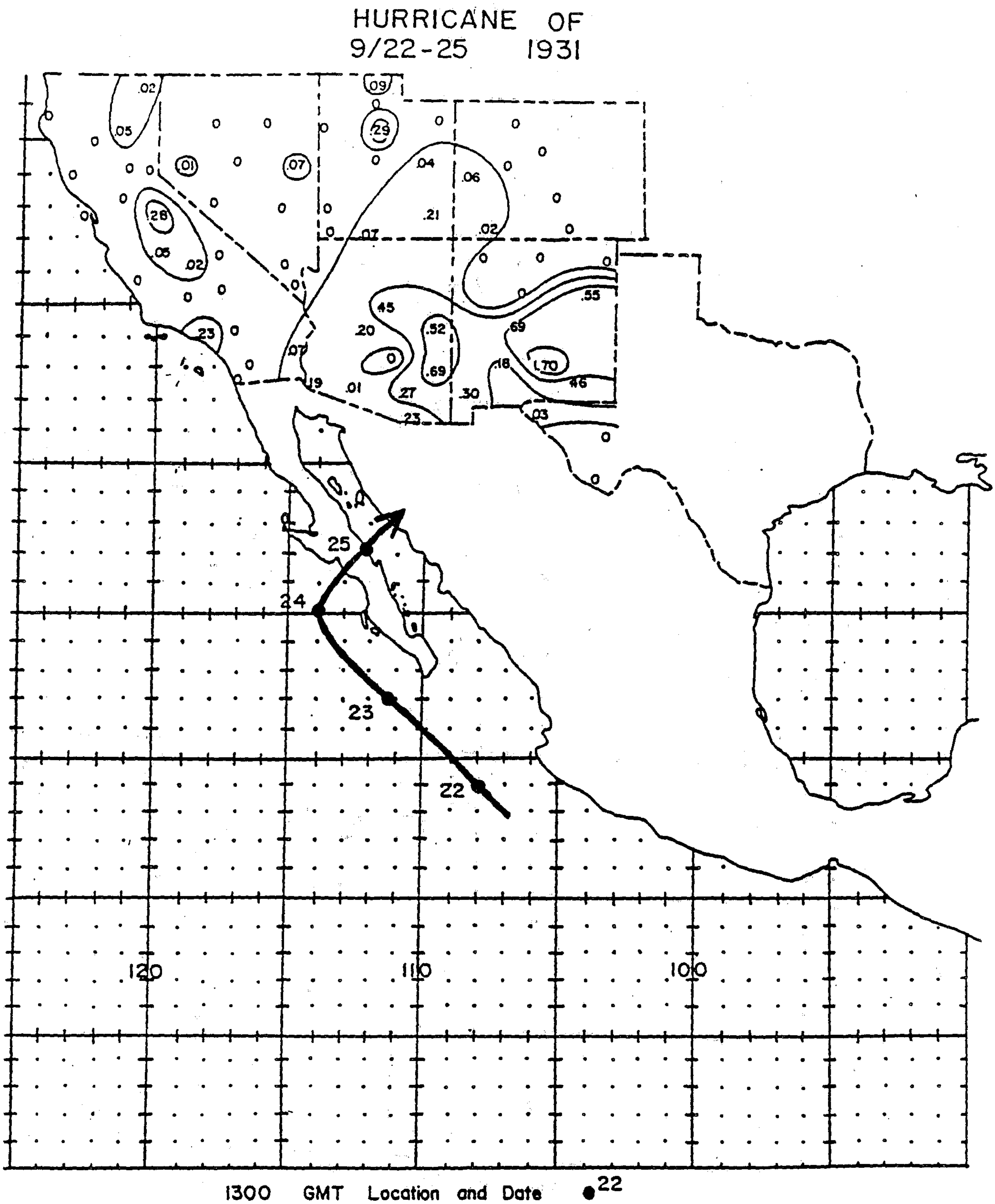


Figure 30. Track of the Hurricane of September 22-25, 1931 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches.

Table 15. Tropical Cyclone of September 10-13, 1931 daily precipitation

Station	September 12	13	14	15	Total
Bisbee, Az.	.05	0	2.05	0	2.10
Williams, Az.	0	.10	1.90	.20	2.20
Pinos Altos, NM.	.30	.66	1.78	.47	3.21

amounts in inches.

Tropical Cyclone of August 25-29, 1932

The precipitation associated with the tropical cyclone was confined to easternmost Arizona, New Mexico, and Texas. The track of the storm (Figure 31) indicates the reason: the cyclone recurved over Mexico and dissipated before ever reaching 110°W thus sending the majority of it's remaining moisture into New Mexico which correspondingly received the heaviest rainfall. The stations that received the highest amounts are listed in Table 16. The 4.36 in. of rain recorded at Clovis, New Mexico on the 28th is one of the largest daily totals associated with an eastern north Pacific tropical cyclone before 1939 and strongly suggests that moist air moved into New Mexico before the cyclone moved ashore over the state of Sinaloa.

Tropical Cyclone of September 26-30, 1932

Observations reveal that the heaviest rains occurred from September 29 through October 1 as the remains of the tropical cyclone entered the Southwest. However, as indicated in Table 17, which lists the precipitation by day at selected stations, scattered heavy showers also were recorded on September 27 and 28 while this storm was still far away as seen in Figure 32. The source of moisture for the showers on the 27th and 28th may have been either the moist air associated with the summer monsoon and/or the tropical cyclone.

Many stations in northwestern Arizona, southern Nevada, and southern California received more than an inch of precipitation. Extraordinary heavy rains occurred in the Tehachapi Mountains of southern California where rainfall peaked on September 30 when 4.38 in. fell at Tehachapi between 1:30 pm and 8:00 pm local time[3]. The deluge caused flash floods on Agua Caliente and Tehachapi creeks and the deaths of 15 people (Sprague, 1932).

Tropical Cyclone of August 19-22, 1935

The best estimate of both the track of the cyclone and the associated rainfall are given in Figure 33. Normally the summer

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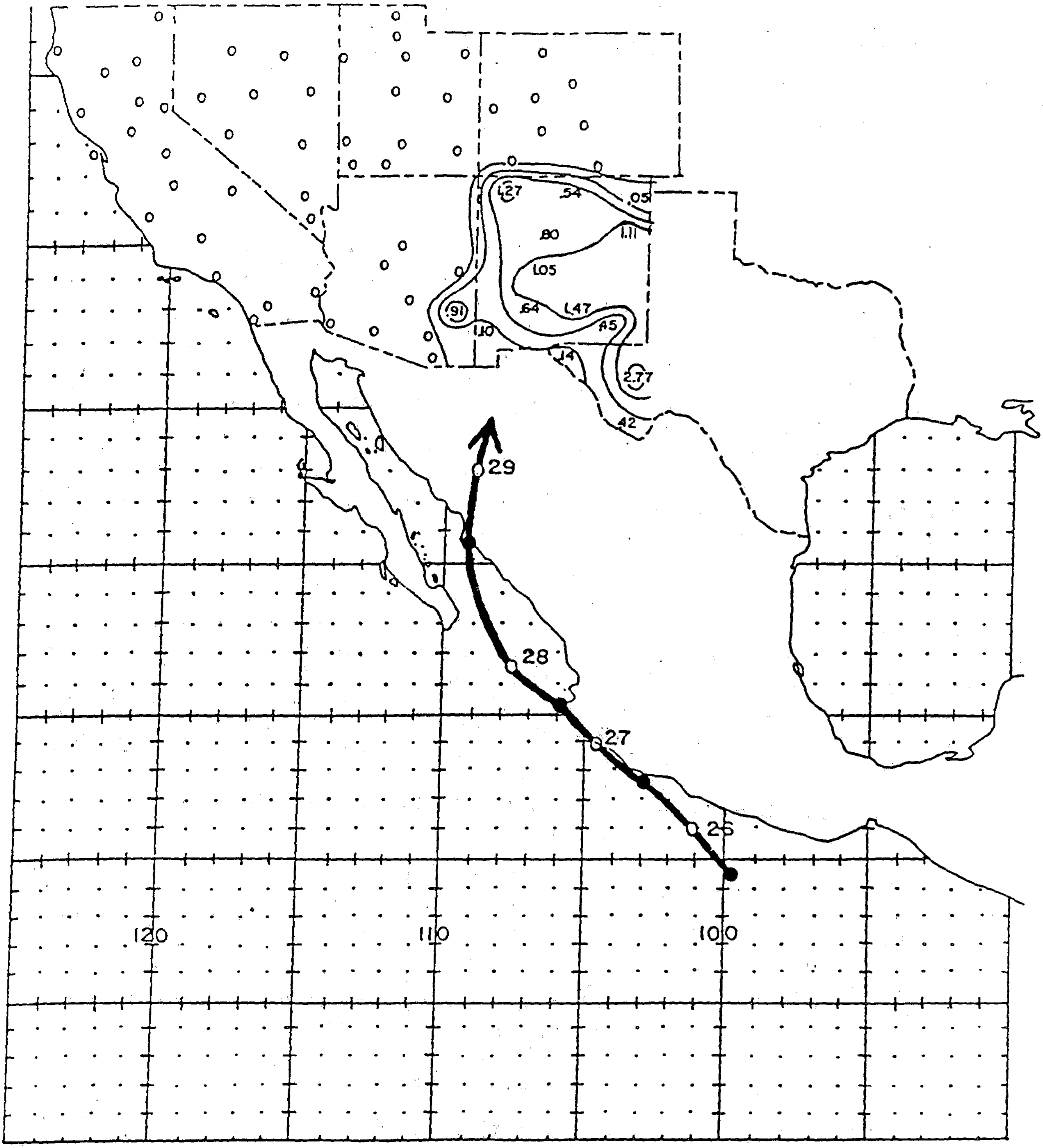
[3] Climatological Data California lists 2.20 in. of rain (see Table 17) at Tehachapi on the 30th when at least 4.38 in. fell that day. Observations were taken in the afternoon while the rain was still in progress so that much of the precipitation on September 30 was recorded on October 1.

TROPICAL CYCLONE OF
8/25-29 1932



0000 GMT Location and Date $\circ^{26}$
1200 GMT Location ●

Figure 31. Track (from Court, 1980) of the Tropical Cyclone of August 25-29, 1932 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

TROPICAL CYCLONE OF
9/26-30 1932

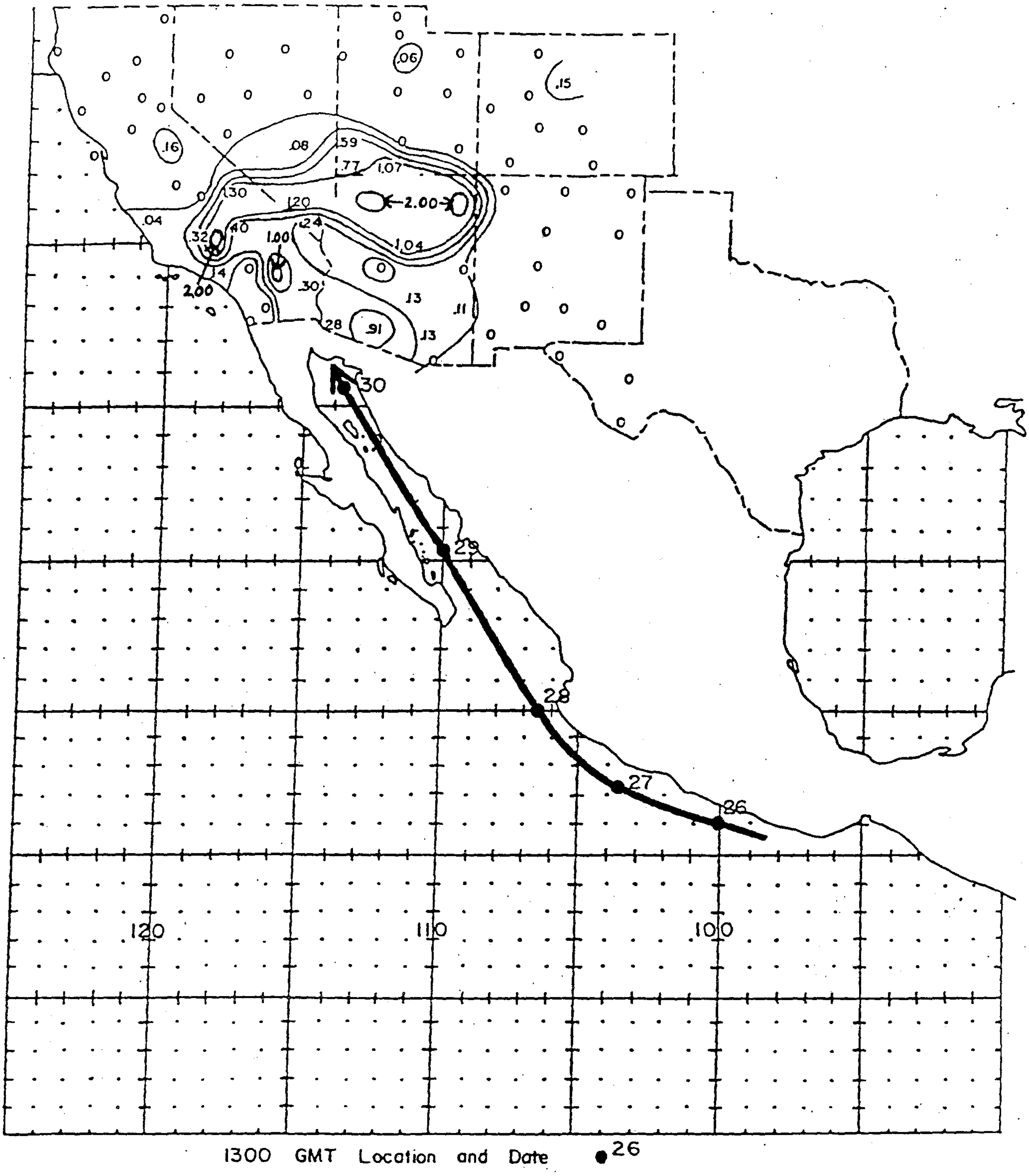


Figure 32. Track (from Court, 1980) of the Tropical Cyclone of September 26-30, 1932 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

Table 16. Tropical Cyclone of August 25-29, 1932
daily precipitation

Station	September 27	28	29	30	Total
Clovis, NM.	0	4.36	.14	.01	4.51
Hobbs, NM.	0	0	2.80	.05	2.85
Roswell, NM.	1.53	.31	2.03	0	3.87
San Marcial, NM.	0	.27	.48	2.45	3.20

amounts in inches.

Table 17. Tropical Cyclone of September 26-30, 1932
daily precipitation

Station	September 27	28	29	30	October 1	Total
Ganado, Az.	0	0	1.25	1.00	0	2.25
Truxton, Az.	.18	1.03	.06	1.00	0	2.27
Beaumont (near), Ca.	0	0	0	0	2.18	2.18
Tehachapi, Ca.	0	2.14	.17	2.20	2.60	7.11
Beatty, Nev.	0	0	0	0	1.95	1.95
Las Vegas, Nev.	0	00	.10	1.10	0	1.20

00 = trace; amounts in inches.

monsoon is very active during the last half of August and this can make it difficult to separate monsoon related rainfall from tropical cyclone related rainfall. Precipitation from the 22nd through the 24th was deemed to be linked with this particular storm and is plotted on Figure 33. One inch rains were scattered over southern Arizona, southwestern Colorado, and northern New Mexico. Patagonia, Arizona and Richland, New Mexico received the most rain in the period of August 22 through 24, 2.89 and 2.87 in. respectively.

Tropical Cyclone of August 23-26, 1935

This tropical cyclone was detected shortly after the previous cyclone broke up over Baja California. The storm tracked to the northwest parallel to the coast for about three days after it was first located and then recurved and dissipated over northern Baja California (Figure 34). By August 25, enough moist air had moved over southern California to cause widespread showers east and southeast of Los Angeles. For instance, Riverside received 2.01 in. and Imperial .99 in. on the 25th. The moisture associated with the ex-tropical cyclone spread over Arizona the following day and caused scattered moderate to heavy showers. Wickenburg reported the heaviest rain, 3.01 inches. Widely scattered, mostly light showers continued over Arizona, New Mexico, and extreme west Texas from the 26th through the 29th. However, on August 30 there was a marked increase in areal coverage and intensity of the precipitation which suggests the monsoon returned. Hence, rain from August 25-29 is plotted in Figure 34.

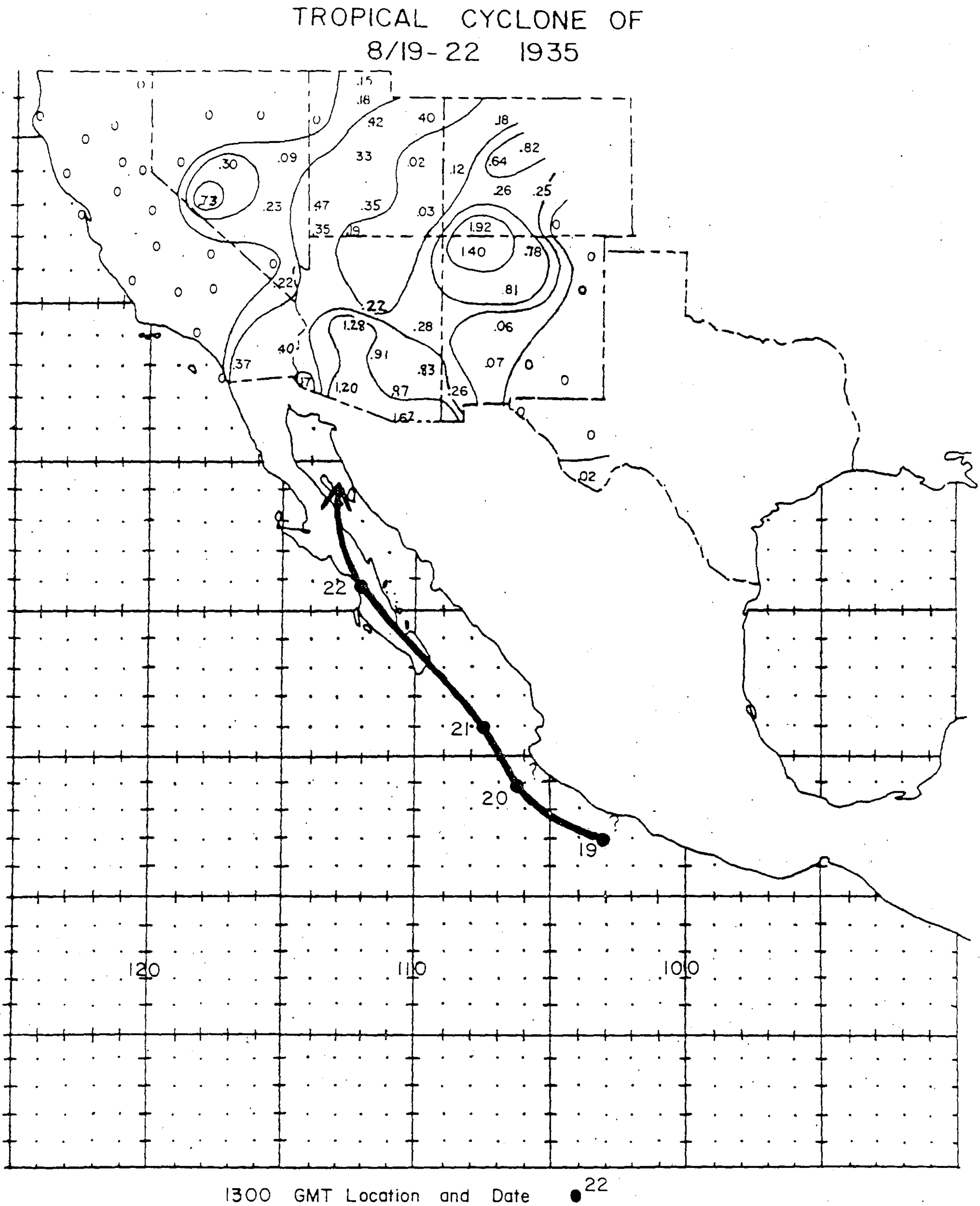


Figure 33. Track of the Tropical Cyclone of August 19-22, 1935 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches.

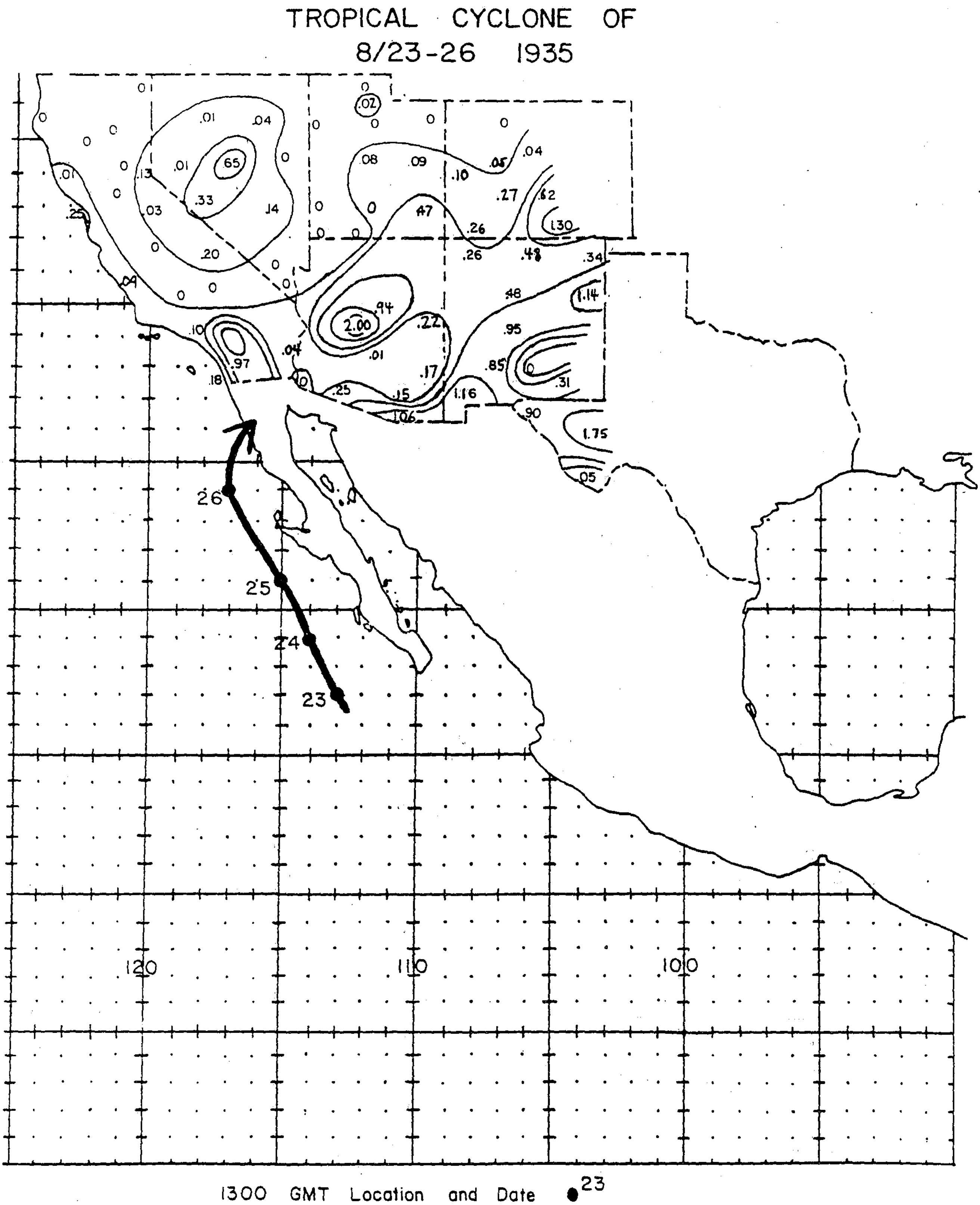


Figure 34. **Track of the Tropical Cyclone of August 23-26,** 1935 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

Tropical Cyclone of August 4-9, 1936

The track and rainfall linked with the tropical cyclone are plotted in Figure 35. This cyclone is one of the few that have moved the full length of the Gulf of California but it apparently weakened rapidly while proceeding northwards into the United States because precipitation over most of Southwest was very light. Table 18, which lists the daily rainfall at several sta tions in Arizona, shows the precipitation peaked on August 9 when much of southeastern Arizona recorded over a half inch of rain and a few places recorded over one inch. Although most of New Mexico, western Colorado, Utah, Nevada, and southern California received only light showers, a few isolated areas; e.g. the California-Nevada border near Bridgeport, California; parts of eastern Nevada around Adaven; and the mountains surrounding Los Angeles; did report heavy rains (Court, 1980).

Tropical Cyclone of September 8-11, 1936

Approximately one month after the storm discussed above affected the Southwest, another tropical cyclone moved into the Gulf of California and subsequently into Sonora, Mexico; where it broke up (see Figure 36). The Arizona-New Mexico border and the Mogollon Rim country of Arizona received more than 1.00 in. of rain from the remains of the cyclone while stations in Utah and western Colorado generally received less than a half inch. Ruby and Helvetia, Arizona reported two of the highest amounts of precipitation, 2.42 and 2.18 in. respectively, all of which fell from the 10th through the 13th.

Hurricane of September 4-6, 1939

This hurricane followed a path (Figure 37) very similar to that of the Tropical Cyclone of September 25-30, 1921 (Figure 19) and produced a similar precipitation pattern, unusually heavy rains in southern California and western Arizona centered on the Colorado River Valley. However, rainfall was more widespread and heavier with the 1939 storm. Showers began on September 4 as indicated in Table 19, which lists daily precipitation amounts at some selected stations, when moist air began moving into the Southwest ahead of an approaching short wave and culminated with exceptionally heavy rains in the Mojave Desert on the 5th and 6th.

The 6.85 in. rain reported from near Truxton, Arizona was the highest total associated with the ex-hurricane. Yuma, Blythe, and Iron Mountain received more rain than usually occurs in an entire year while Brawley and Imperial both received more rain than normally falls in two years. As shown in Figure 37, heavy rains, as delineated by the two inch isohyet, extended from just east of San Diego to south central Utah where Escalante measured 2.70 inches. Even Vernal, Utah (1.44 in.) and Steamboat Springs, Colorado (1.77 in.) recorded well in excess of an inch of rain.

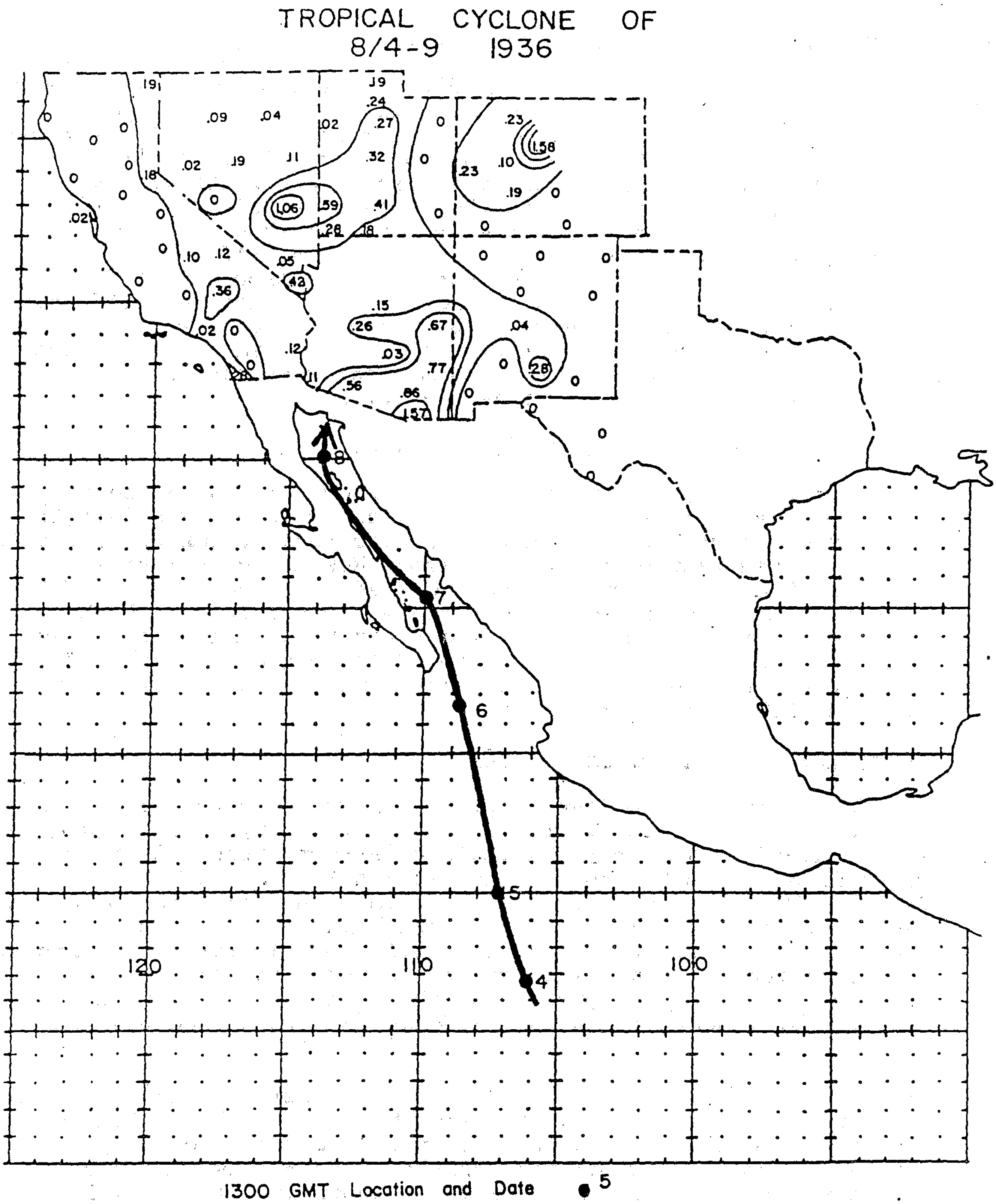


Figure 35. Track of the Tropical Cyclone of August 4-9, 1936 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches.

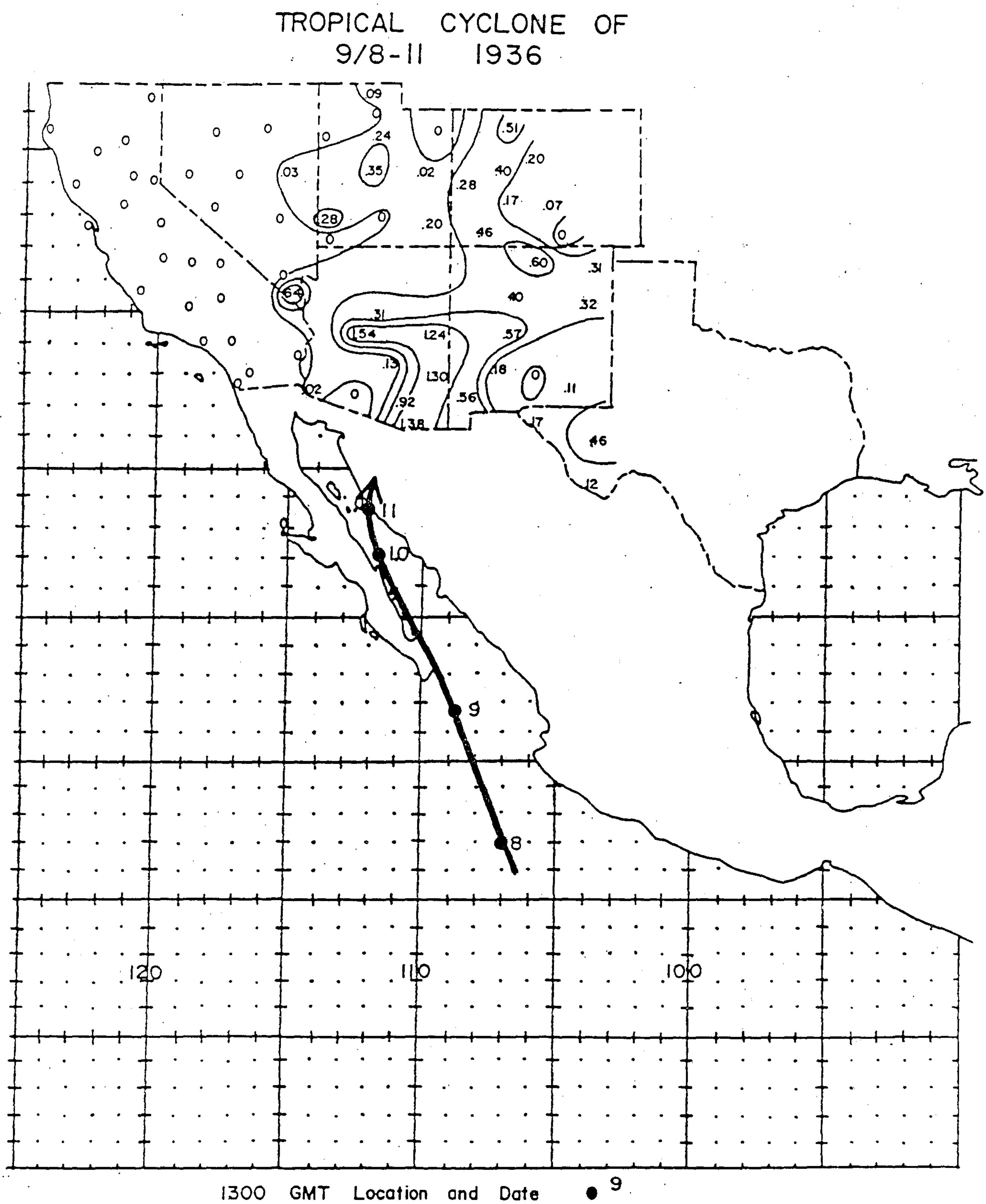


Figure 36. Track of the Tropical Cyclone of September 8-11, 1936 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches.

HURRICANE OF
9/4-6 1939

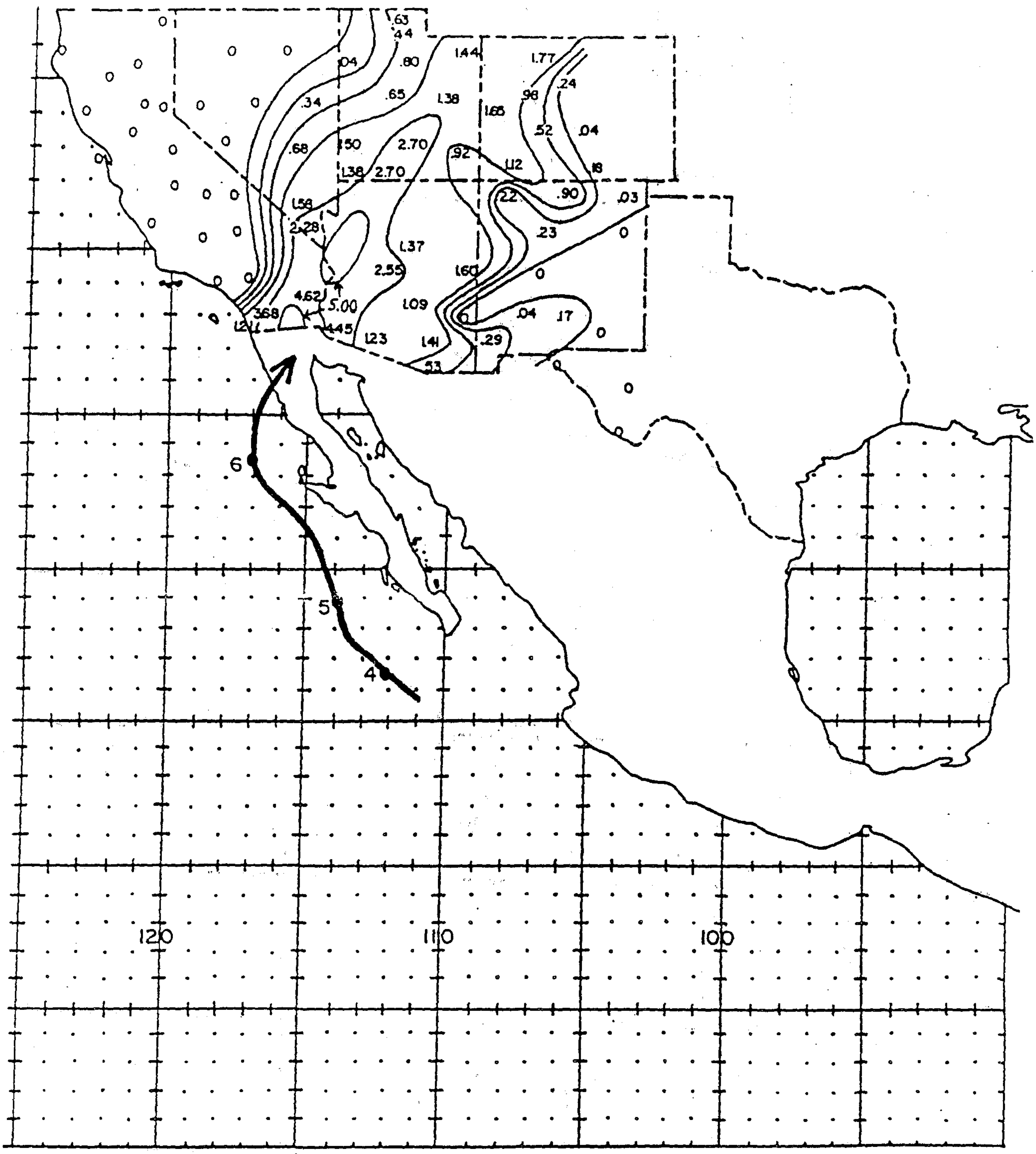


Figure 37. Track of the Tropical Cyclone of September 4-6, 1939 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches.

Table 18. Tropical Cyclone of August 4-9, 1936 daily precipitation

Station	August 7	8	9	10	Total
Nogales, Az.	.60	.08	.86	.03	1.57
Patagonia, Az.	1.05	.30	1.51	.21	3.07
Wickenburg, Az.	0	0	1.60	.06	1.66

amounts in inches.

Table 19. Hurricane of September 4-6, 1939 daily precipitation

Station	September 3	4	5	6	7	Total
Bright Angel Ranger Station, Az.	0	1.62	2.72	1.54	.67	6.55
Kingman, Az.	0	.46	2.10	2.70	.19	5.45
Parker, Az.	.10	.13	3.43	1.66	.13	5.45
Truxton (near), Az.	0	3.62	1.16	2.02	.05	6.85
Yarnell, Az.	0	1.69	1.87	2.92	.02	6.50
Brawley, Ca.	0	0	2.53	3.80	0	6.33
Hayfield Reservoir, Ca.	0	0	2.50	3.05	.40	5.95
Imperial, Ca.	0	0	.39	4.08	.55	5.02
Iron Mountain, Ca.	.03	.04	2.41	2.98	.13	5.59
Alton, Utah	0	1.51	.10	1.70	.24	3.55
Springdale, Utah	0	1.18	.37	1.85	.05	3.45

amounts in inches.

Tropical Cyclone of September 6-12, 1939

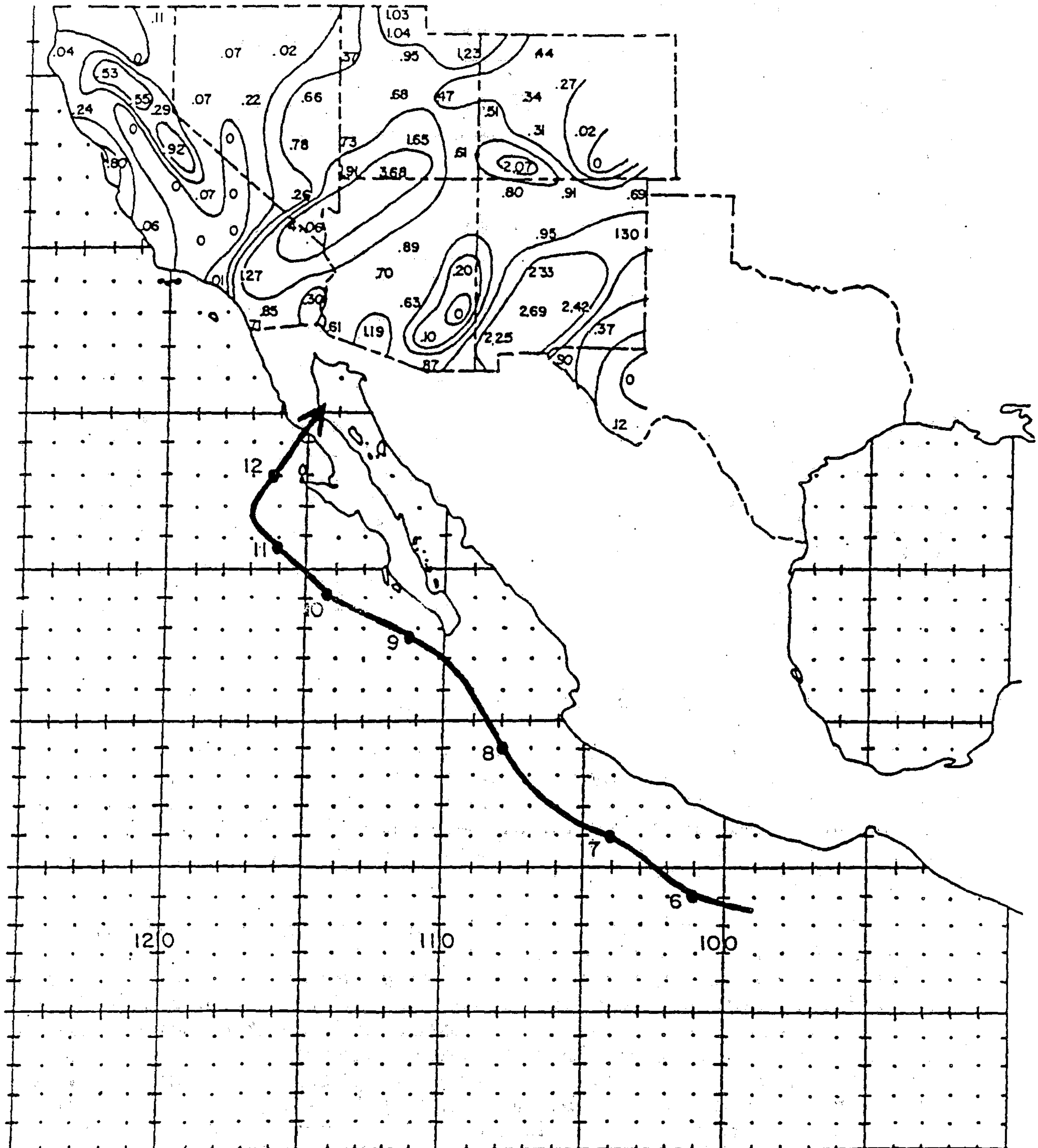
For the second time in a week the remnants of an eastern north Pacific tropical cyclone brought copious amounts of moisture into the Southwest. As previously stated, the track of the cyclone was similar to those of September 25-30, 1921 and September 4-6, 1939. Figure 38 illustrates this path and presents the rainfall linked to the storm.

A midlatitude disturbance and accompanying cold front, which was located at the surface in northern California, caused the weakening tropical cyclone to recurve at about 27°N on September 11. A day later, as seen in Table 20, the heaviest rains fell in southern Nevada, northwestern Arizona, and southwestern Utah as the surface low traveled into northern Nevada and the cold front moved into central California. Precipitation decreased to west of the Arizona-New Mexico border on the 13th but increased to the east as the surface low tracked eastward over northern Utah and the cold front sliced across Arizona. The cold front then continued eastward across New Mexico producing widespread rain, which was most intense on the 15th.

Tropical Cyclone of September 15-17, 1939

All available information suggests the storm was first detected on 15th just off the Mexican coast near Acapulco and

TROPICAL CYCLONE OF
9/6-12 1939



1200 GMT Location and Date ●11

Figure 38. Track of the Tropical Cyclone of September 6-12, 1939 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

Table 20. Tropical Cyclone of September 6-12, 1939 daily precipitation

Station	September 10	11	12	13	Total
Fredonia, Az.	.10	.82	2.15	.66	3.73
Mohawk, Az.	0	.53	1.50	1.00	3.03
Mt. Trumbell, Az.	.36	1.65	1.86	0	3.87
Yarnell, Az.	0	.52	1.55	1.19	3.26
Alton, Utah	.39	.27	1.57	1.12	3.35
Bryce Canyon, Utah	.51	.94	3.15	0	4.60
Tropic, Utah	.50	.85	1.10	1.73	4.18
Searchlight, Nev.	00	.11	3.84	.11	4.06

00 = trace; amounts in inches.

from there travelled to the northwest at least until the 17th. The storm most likely dissipated after hitting Baja California sometime on September 18 or 19. Moisture associated with the ex-tropical cyclone appears to have entered southern California and western Arizona on September 19 and led to isolated showers which continued sporadically for two more days. Figure 39 shows that most stations received less than a half inch of rain. In contrast, San Jacinto, California recorded 2.90 in. of precipitation, nearly twice as much as any other site in the Southwest.

Tropical Cyclone of September 15-25, 1939

Early on the morning of September 25, 1939 (local time) this cyclone moved onshore over southern California just south of Los Angeles as a tropical storm with gale force winds of around 45 kn. High winds and rough seas caused the loss of 45 lives at sea (Hurd, 1939). Approximately 4-6 in. of rain fell in the Los Angeles Basin while 5-12 in. was measured in the surrounding mountains.

The tropical cyclone originated near 10°N, 91°W on September 14 (at the very edge of Figure 40) and was tracked through it's entire lifetime, all the way into southern California. The cyclone moved several hundred kilometers farther northwest than the other two significant storms of September 1939, the Hurricane of the 4th-6th and the Tropical Cyclone of the 6th-12th. As a result, the precipitation was centered farther to the northwest. Very little rain was recorded in southeastern Arizona and New Mexico but more than an inch fell in the northern Sierra Nevada Mountains and at Red Bluff.

Precipitation in and around Los Angeles was most intense on the 25th (see Table 21) but at both Indio, California and Searchlight, Nevada rainfall was heaviest the preceding day. Evidently, moist air was advected into the Mojave Desert by way of the Gulf of California by the large-scale flow steering the tropical cyclone and/or by the circulation around the storm itself. The result was 6.45 in of rain at Indio in the 6 hours ending at 11 am local time (Court, 1980) and 2.18 in. at Searchlight. Mt. Wilson 2 recorded one of the highest calendar day rainfalls, 9.02

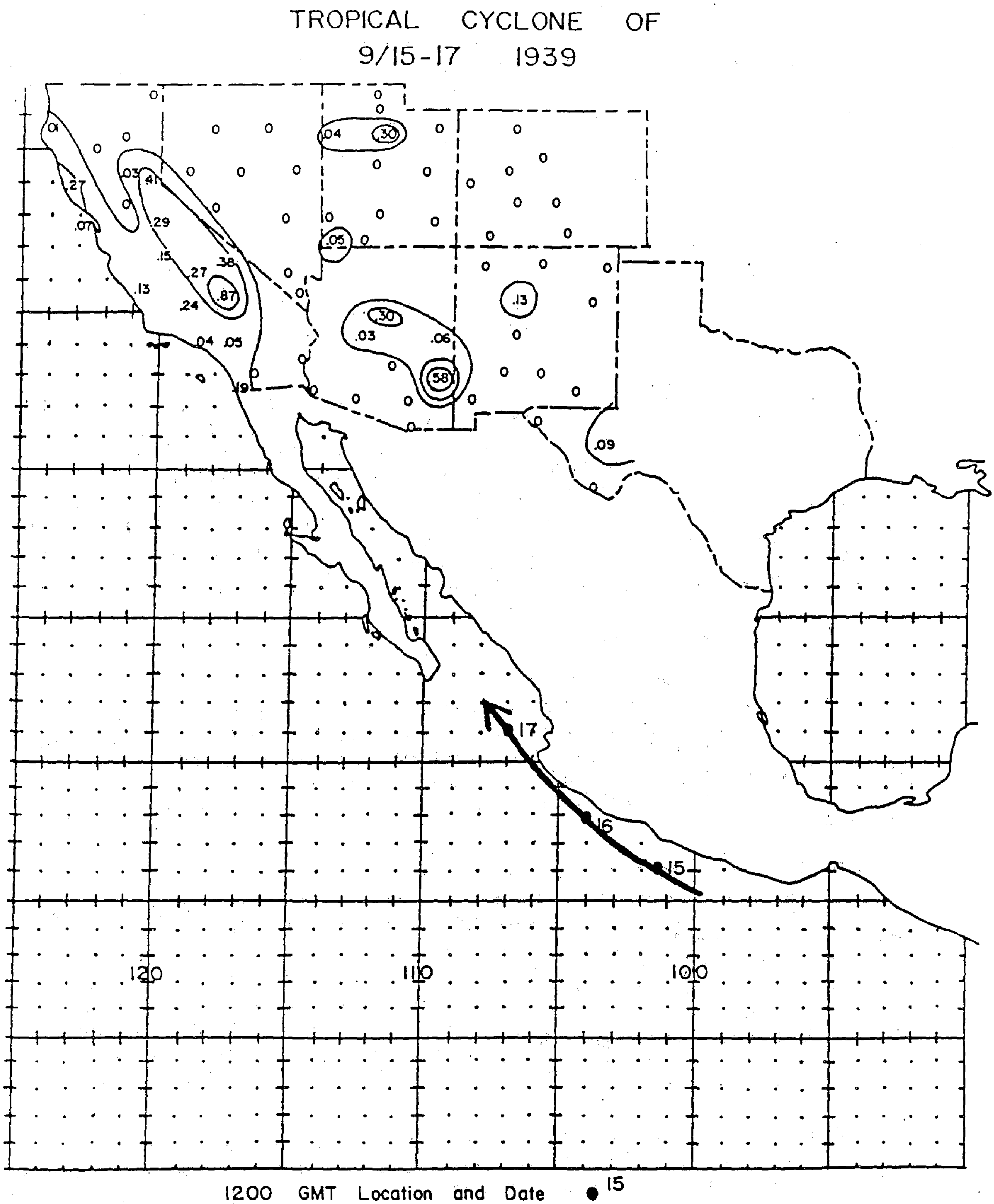


Figure 39. Track of the Tropical Cyclone of September 15-17, 1939 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, and .50 inches.

TROPICAL CYCLONE OF
9/15-25 1939

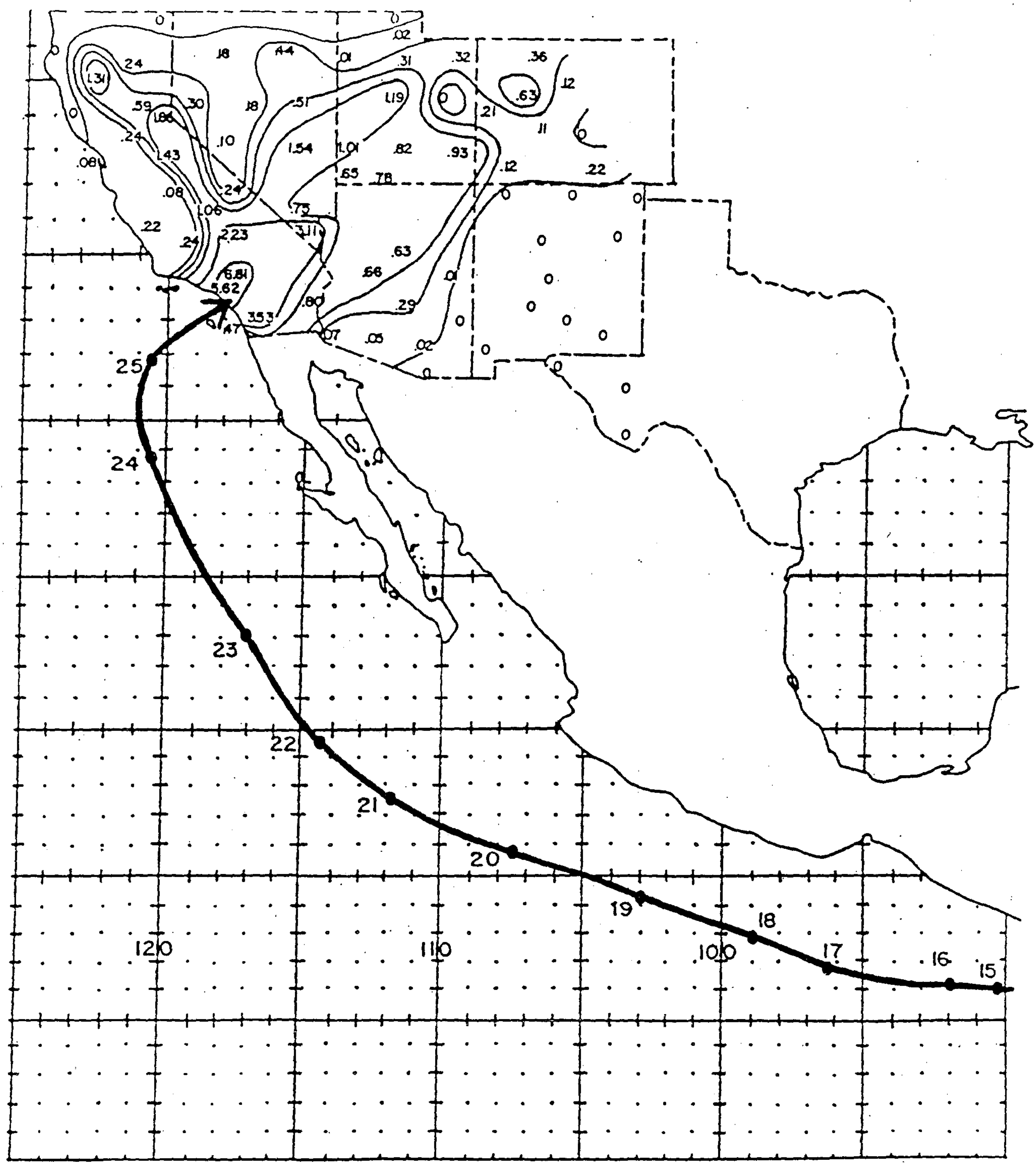


Figure 40. Track of the Tropical Cyclone of September 15-25, 1939 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches.

Table 21. Tropical Cyclone of September 15-25, 1939 daily precipitation

Station	September 23	24	25	26	Total
Parker, Az.	0	1.51	1.28	0	2.79
Charleston Ranger Station, Nev.	0	.28	2.48	.54	3.30
Searchlight, Nev.	.83	2.18	.10	0	3.11
Claremont, Ca.	00	1.29	3.20	.40	4.89
Fullerton, Ca.	0	.16	5.49	.32	5.97
Indio, Ca.	0	6.45	.33	0	6.78
Lytle Creek, Ca.	0	.25	5.50	1.06	6.81
Mt. Wilson 2, Ca.	0	.98	9.02	1.60	11.60

00 = trace; amounts in inches.

in., to ever be linked with an eastern north Pacific tropical cyclone and the storm total of 11.60 in. has only been exceeded in association with three other cyclones: the Hurricane of September 15-22, 1941; the Hurricane of August 24-28, 1951; and Hurricane Tico in October 1983 (but east of the study area).

September 1939 was the wettest month on record at many localities in southeastern California, southern Nevada, and western Arizona where at least 8 stations; e.g. Parker (8.85 in., 81 years of records), Kingman (9.85 in., 61 years of records); and Mohawk (5.31 in., 48 years of records); set all-time monthly precipitation records (Sellers et al., 1985). Searchlight measured 9.45 in. of rain from the three big storms of September 1939. The annual average precipitation there is 7.27 in. and the September average (for the period 1951-1980) is just .69 inches.

<u>Hurricane of September 8-12, 1941</u>

First located on September 8 near 21°N, 107°W; the hurricane moved very slowly to the north-northwest as shown in Figure 41 for two days when it made an abrupt turn and headed straight for La Paz, Baja California. Press accounts from Mexico City reported that the "fiercest" cyclone of the century had "thrashed" the southern end of Baja California for 48 hours ending at about noon on the 12th (Hurd, 1941). The villages of Santiago and El Triunfo were demolished with several dozen fatalities. The hurricane undoubtedly began to weaken after it's circulation encountered the Baja peninsula and by the 13th the former hurricane was no more than a mass of moist, unstable air moving north toward the southwestern U.S.

Precipitation linked with the remains of the once powerful storm is plotted in Figure 41 and Table 22 lists daily rainfall measured at several sites. Shower activity started on September 12 as a low pressure area moved into northern Nevada while the surface cold front pushed into central California. Rain was heaviest on the 13th, except in New Mexico when the rain peaked on the following day, as the low moved into southern Nevada and the surface cold front tracked into Arizona. The largest amounts

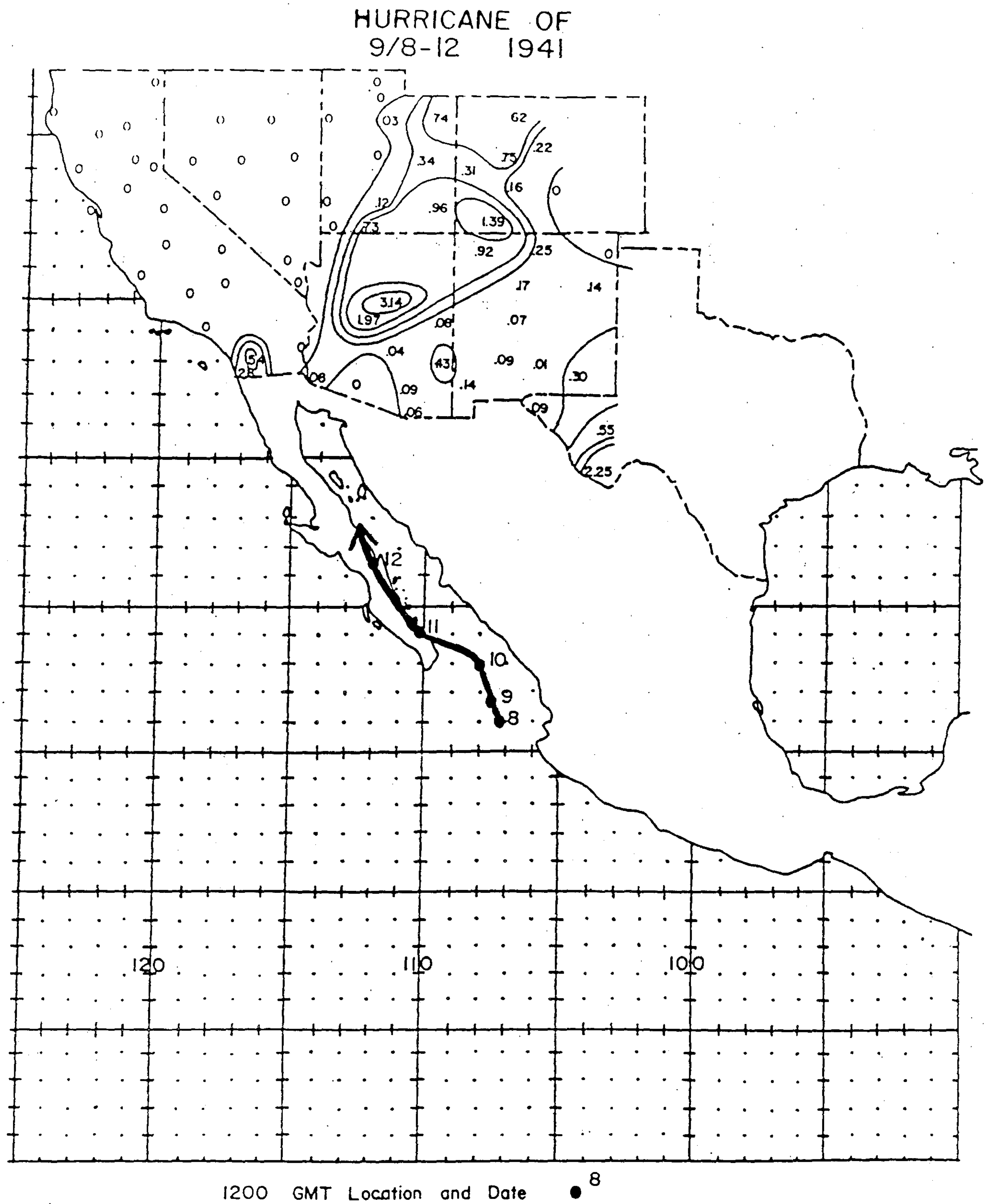


Figure 41. Track of the Hurricane of September 8-12, 1941 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

Table 22. Hurricane of September 8-12, 1941 daily precipitation

Station	September 12	13	14	15	Total
Junipine, Az.	.35	2.18	.27	0	2.80
Mormon Lake, Az.	.25	2.37	.92	00	3.54
Gavilan, NM.	00	.15	2.10	.55	2.80
Rico, Co.	0	1.80	.60	.46	2.86

00 = trace; amounts in inches.

of rain were recorded in northern Arizona where Mormon Lake received the highest total, 3.54 inches. Half inch rains were common throughout the four corners area (i.e. where the Utah, Arizona, Colorado, and New Mexico borders meet).

Hurricane of September 15-22, 1941

The disturbance which subsequently developed into this strong hurricane was located in the Gulf of Tehuantepec on September 15 indicated in Figure 42. Late on the 19th, a ship passed through the eye of the hurricane and reported a sea level pressure of 938 mb. Approximately 24 hours later the hurricane was located about 100 km southeast of Baja California. Nothing definite is known about the movement of the storm after that time but the cyclone probably continued moving to the northwest just west of the Baja peninsula before recurving northeastward on the 21st ahead of an upper level trough.

Precipitation began in New Mexico and west Texas on the 19th (see Table 23) when tropical air streamed over the region ahead of the advancing short wave. Scattered heavy to intense thunderstorms formed on the 20th when the moist air from the hurricane was lifted by the mountains and the midlatitude trough and cold front that was moving through Arizona at the time. A devastating flash flood, which claimed 11 lives, occurred at Carlsbad, New Mexico between 8 and 9 o'clock on Sunday evening September 20 as a result of intense rainfall in the Guadalupe Mountains west and southwest of town (General Summary, Climatological Data New Mexico September 1941). Cameron (1941) reported that reliable but unofficial measurements at the head of Dark Canyon in the Guadalupe Mountains indicated 10 in. of rain fell between noon and 6:00 pm on the 20th and that 21.25 in. fell during the 3-days ending on the 22nd. If accurate, this is the greatest amount of rain ever linked to an eastern north Pacific tropical cyclone anywhere in the continental United States.

On September 21, rainfall increased significantly at most stations in eastern New Mexico as the cold front continued eastward while the hurricane recurved across Baja California. The heaviest precipitation fell on the following day when the remnants of the cyclone moved inland over the Mexican mainland ahead of the slowly moving trough. Many places in eastern New Mexico, southeastern Colorado, and western Texas received more than 2.50 in. of rain. These phenomenal rains caused widespread flooding

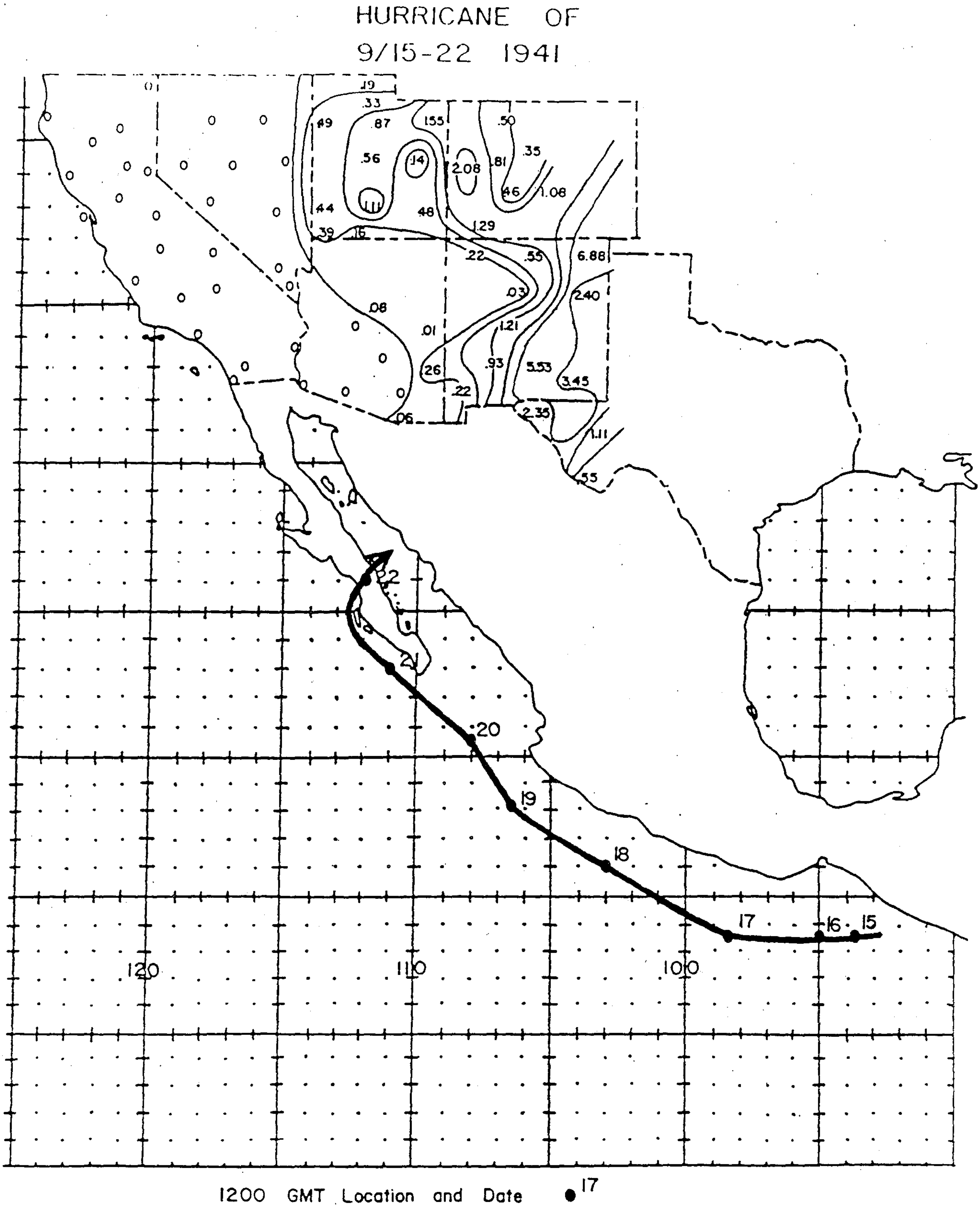


Figure 42. Track of the Hurricane of September 15-22, 1941 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches.

Table 23. Hurricane of September 15-22, 1941 daily precipitation

Station	19	20	21	22	23	24	Total
			September				
Alamogordo Dam, NM.	00	.02	.94	7.11	.39	0	8.46
Bueyeros, NM.	0	1.18	.65	6.45	.43	0	8.71
Carlsbad Caverns, NM.	1.15	1.60	.03	2.72	3.85	.57	9.92
Carlsbad (near), NM. (unofficial)	----	10.00	7.00	4.25	----		21.25
Grenville, NM.	0	0	3.61	5.18	1.63	.13	10.55
Mesa Service Station, NM.	.03	.12	3.19	2.66	3.04	0	9.04
Newkirk, NM.	0	.16	1.00	7.15	.10	0	8.41
Pennington (near), NM.	0	00	3.05	4.85	1.80	0	9.70
Yates (near), NM.	0	1.30	4.00	4.00	.25	0	9.55
Pine Springs, Texas	0	0	1.60	3.31	2.01	0	6.92
Stratton, Co.	0	.01	.03	4.64	.54	0	5.22

00 = trace; amounts in inches.

on all the western tributaries of the Pecos River including the Rio Hondo which inundated much of Roswell, New Mexico from the 22nd through the 24th.

Tropical Cyclone of September 5-8, 1945

This cyclone dissipated over cool water west of Baja California on the 8th (see Figure 43). The available 500 mb height information suggests the moisture from the ex-tropical cyclone was caught up in the circulation around a cut-off low that was located off the West Coast and that the low caused the showers of September 9 and 10. In general, the rain associated with the storm was confined almost entirely to the southern parts of California, Arizona, and New Mexico and was very light, although Natural Bridge, Arizona and Beaumont 4N, California did report 2.39 in. and 1.33 in., respectively.

B. Post World War II Period, 1946 - 1965

The quality and quantity of observations in the eastern north Pacific increased noticeably at the end of World War II. 500 mb height data and SSTs began to be taken and recorded on a regular basis. They now provide valuable information about the state of the atmosphere and the ocean. 500 mb height data from 1946 through 1983 for the Northern Hemisphere north of 20°N was employed to aid in the identification of the tropical cyclones that affected the Southwest and to show the circulation at the time of the storms. SST data from 1947 through 1984 was utilized to illustrate how water temperatures affect tropical cyclones.

Tropical Storm of September 26-29, 1946

A nearly stationary cut-off low caused this weakening tropical storm to linger at about 28.5°N on the 28th and 29th as seen

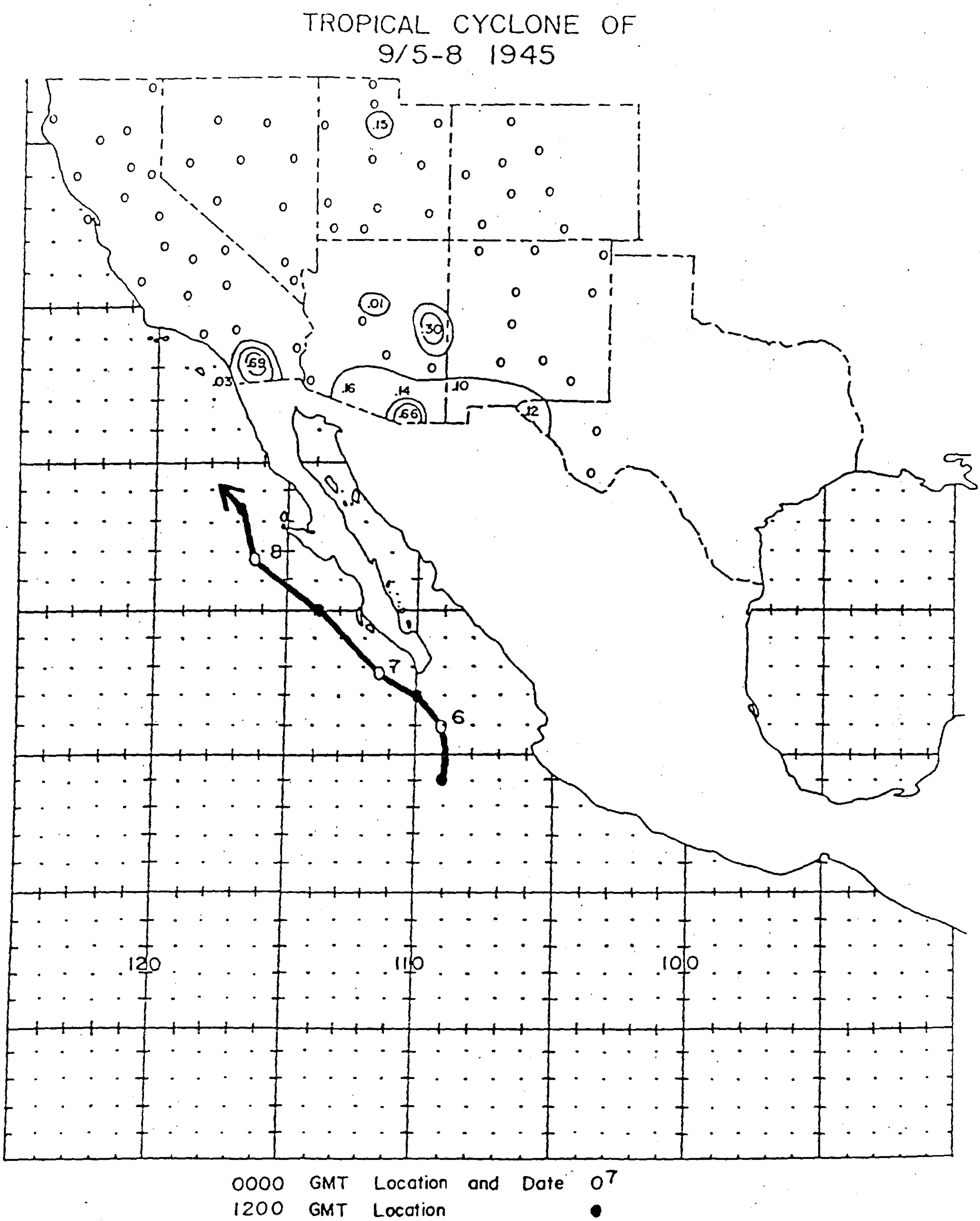


Figure 43. Track of the Tropical Cyclone of September 5-8, 1945 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, and .50 inches.

TROPICAL STORM OF 9/26–29, 1946

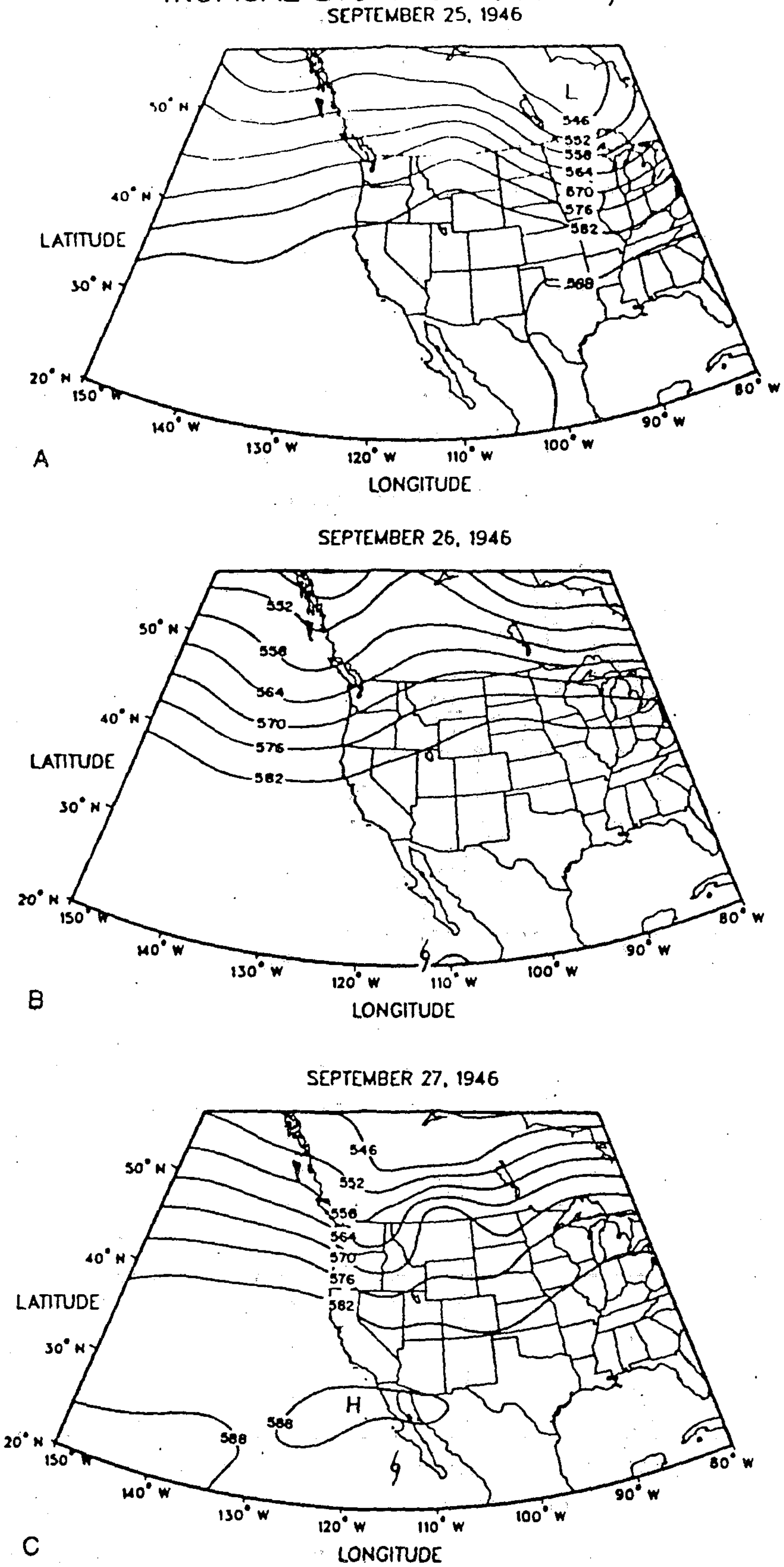


Figure 44. 1200 GMT 500 mb height contours for the indicated dates. H - approximate center of a ridge; L - approximate center of a trough; - hurricane; - tropical storm; ʟ - tropical depression.

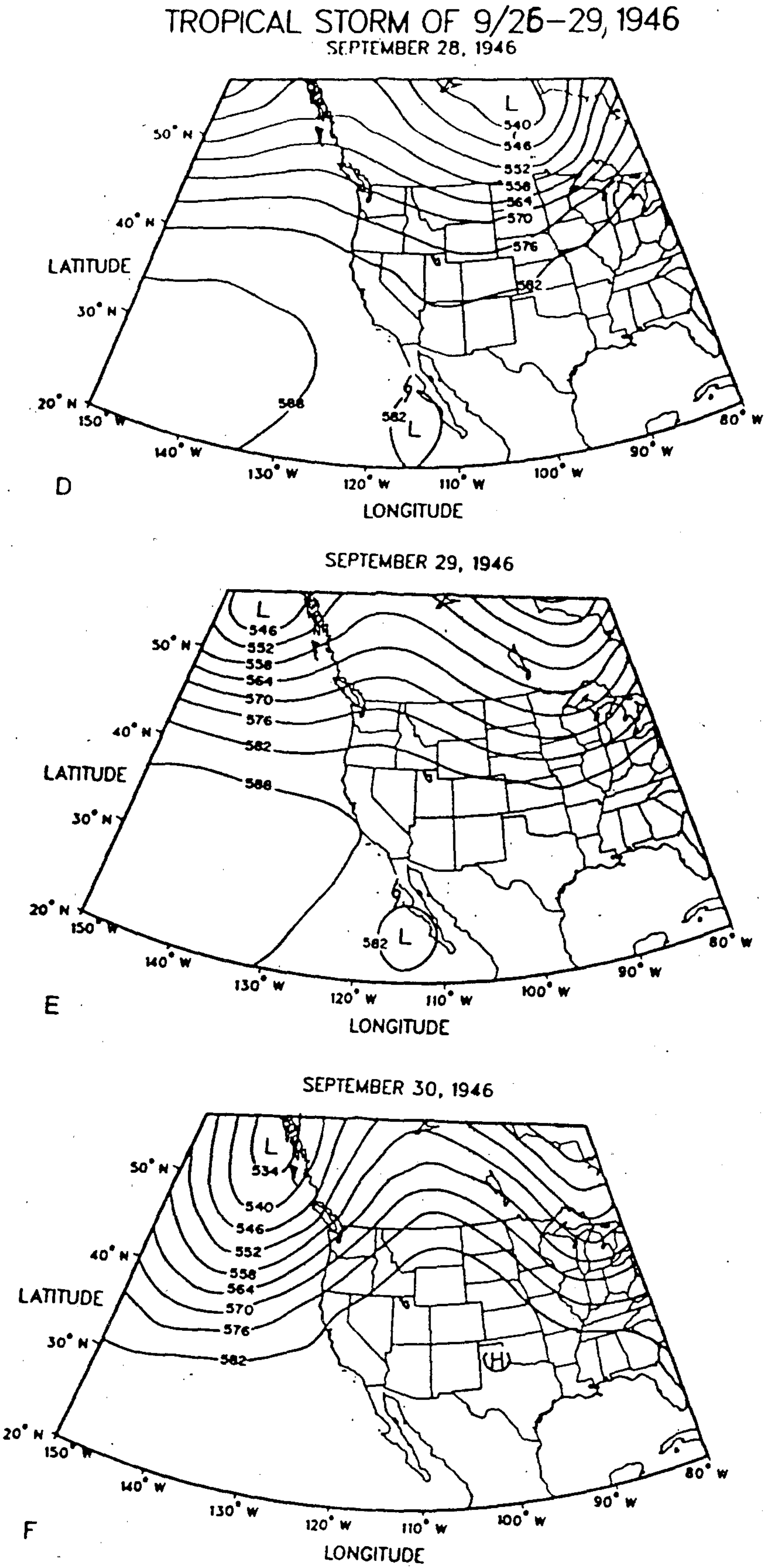
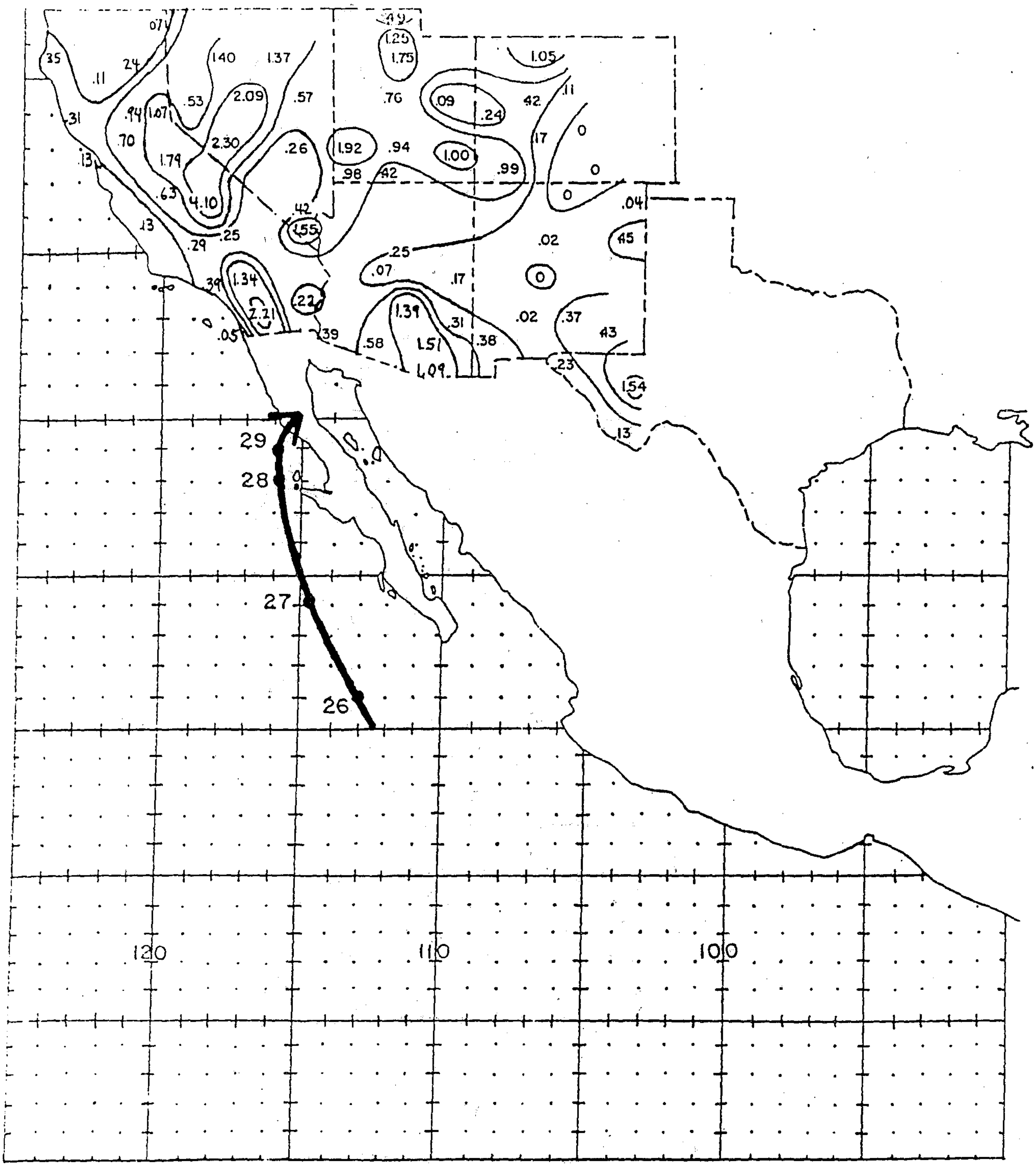


Figure 44. (continued) 1200 GMT 500 mb height contours for the indicated dates. H - approximate center of a ridge; L - approximate center of a trough; ϟ - hurricane; ϛ - tropical storm; ʟ - tropical depression.

TROPICAL STORM OF
9/26-29 1946



1200 GMT Location and Date ●26

Figure 45. Track of the Tropical Storm of September 26-29, 1946 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

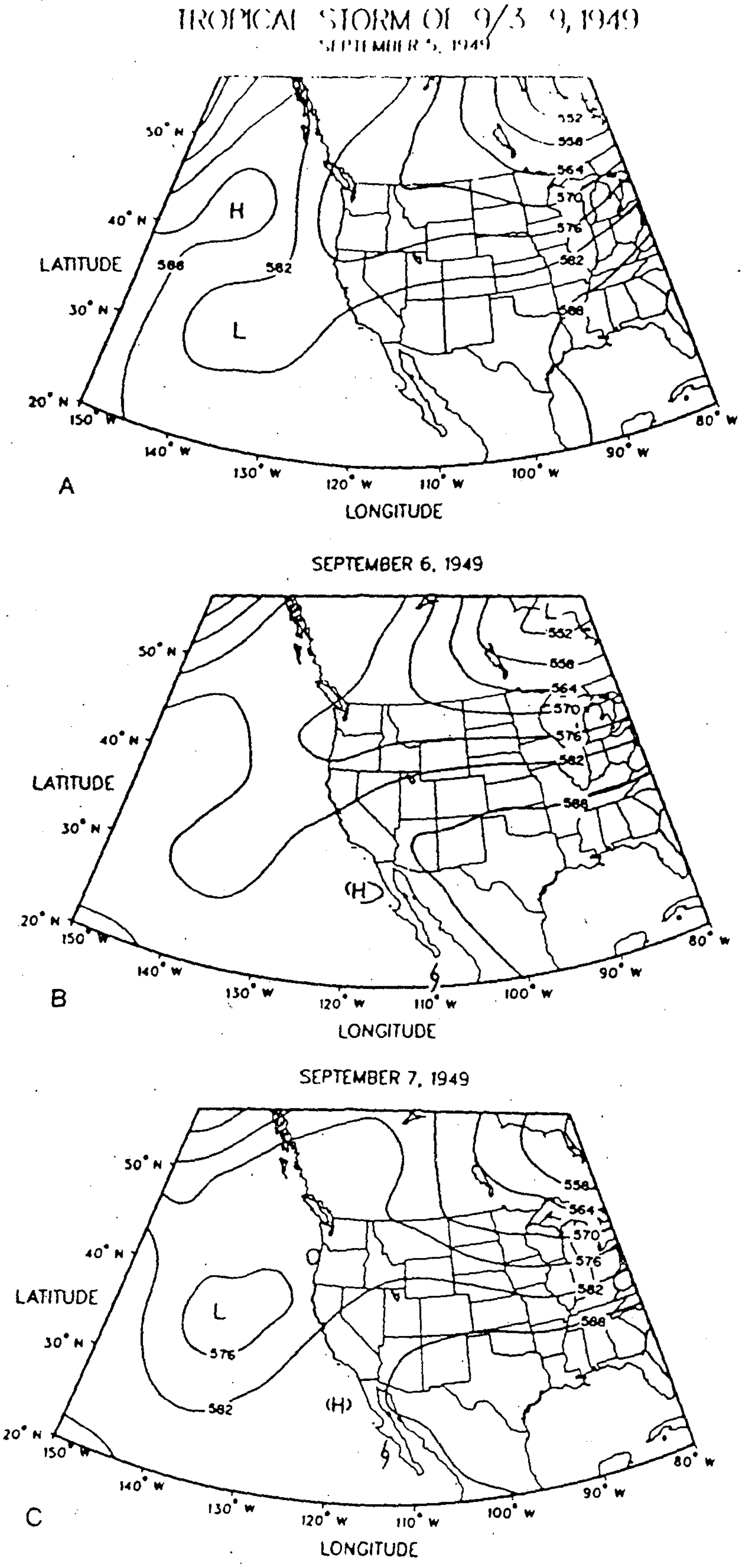


Figure 46. As in Figure 44.

TROPICAL STORM OF 9/3–9, 1949

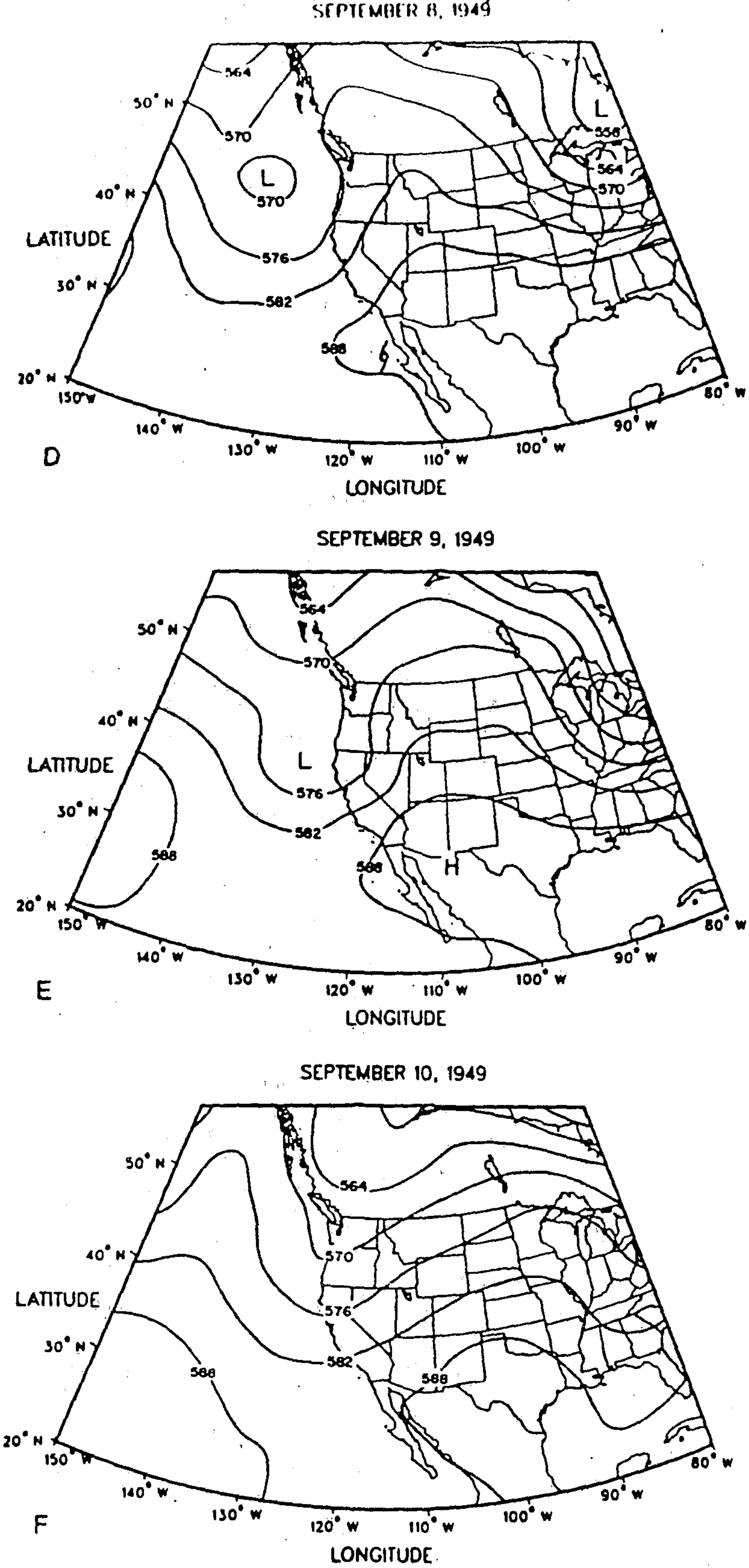


Figure 46. (continued) As in Figure 44.

TROPICAL STORM OF
9/3-9 1949

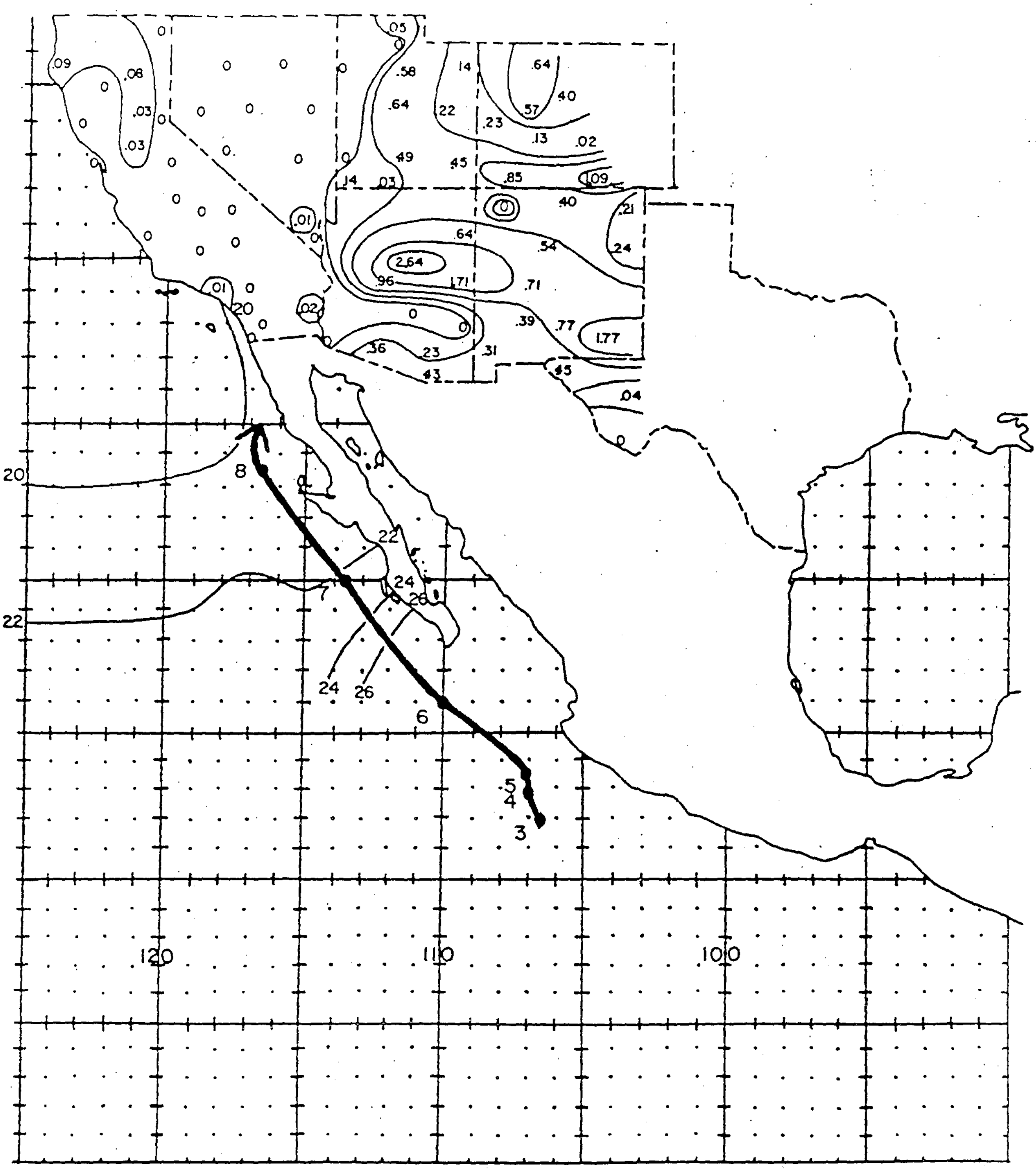


Figure 47. **Track of the Tropical Storm of September 3-9, 1949 and associated rainfall in the Southwest.** Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

Table 24. Tropical Storm of September 26-29, 1946 daily precipitation

Station	September 29	September 30	October 1	October 2	Total
Tucson Mountain Park, Az.	1.15	1.45	0	0	2.60
Julian, Ca.	0	3.78	.45	.07	4.30
Mina, Nev.	0	1.10	1.20	0	2.30
Modena, Utah	0	.55	1.37	0	1.92

amounts in inches.

Table 25. Tropical Storm of September 3-9, 1949 daily precipitation

Station	September 8	September 9	September 10	Total
Ash Fork, Az.	.10	2.05	.05	2.20
Tonto Creek Fish Hatchery, Az.	.24	2.55	.46	3.25
Valmora, NM.	00	1.90	.55	2.45

00 = trace; amounts in inches.

in Figures 44 and 45. Precipitation began in southern Arizona and southern California on September 29 and peaked on the 30th when Julian received 3.78 in. of rain. In contrast, rain was heaviest in the remainder of California, Nevada, and Utah on October 1 (see Table 24) as the upper level trough shown in Figure 44F moved inland over the West Coast. More than two inches of precipitation fell over much of central Nevada and in the mountains of southern California, where several stations reported more than 4 inches.

Tropical Storm of September 3-9, 1949

The tropical storm was first detected on September 3 several hundred kilometers to the west of Acapulco (Figure 47). The storm moved very slowly to the north until the 6th when the southwestern limb of the subtropical high reestablished itself over Mexico and caused the cyclone to change direction and move to the northwest parallel to the coast of Baja California (Figure 46). Mostly light showers fell over Arizona and southwestern New Mexico from the 8th-10th (see Table 25) as the moisture from the ex-tropical storm was advected over the Southwest ahead of a weak short wave. However, isolated heavy thunderstorms were reported on the 10th near Gila Bend, Arizona where four persons drowned in a flash flood (Sellers et al., 1985). Stations in the mountains of northern Arizona received the highest amounts of rain with Tonto Creek Fish Hatchery measuring the largest, 3.25 inches.

Hurricane of August 24-28, 1951

The historical weather map of August 23, 1951 suggests a tropical disturbance was intensifying in the eastern north Pacific Ocean several hundred kilometers southeast of Acapulco

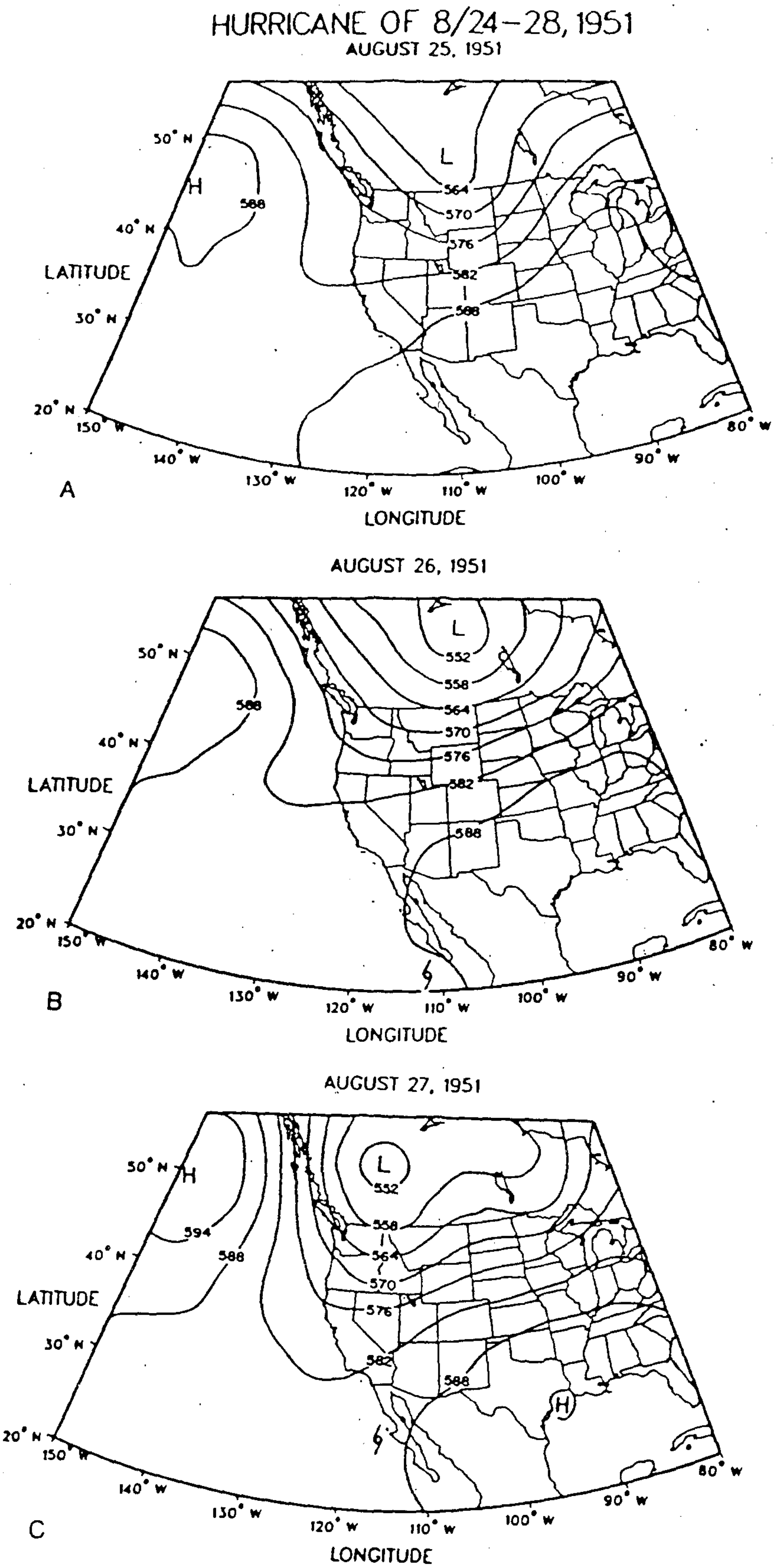


Figure 48. As in Figure 44.

HURRICANE OF 8/24-28, 1951

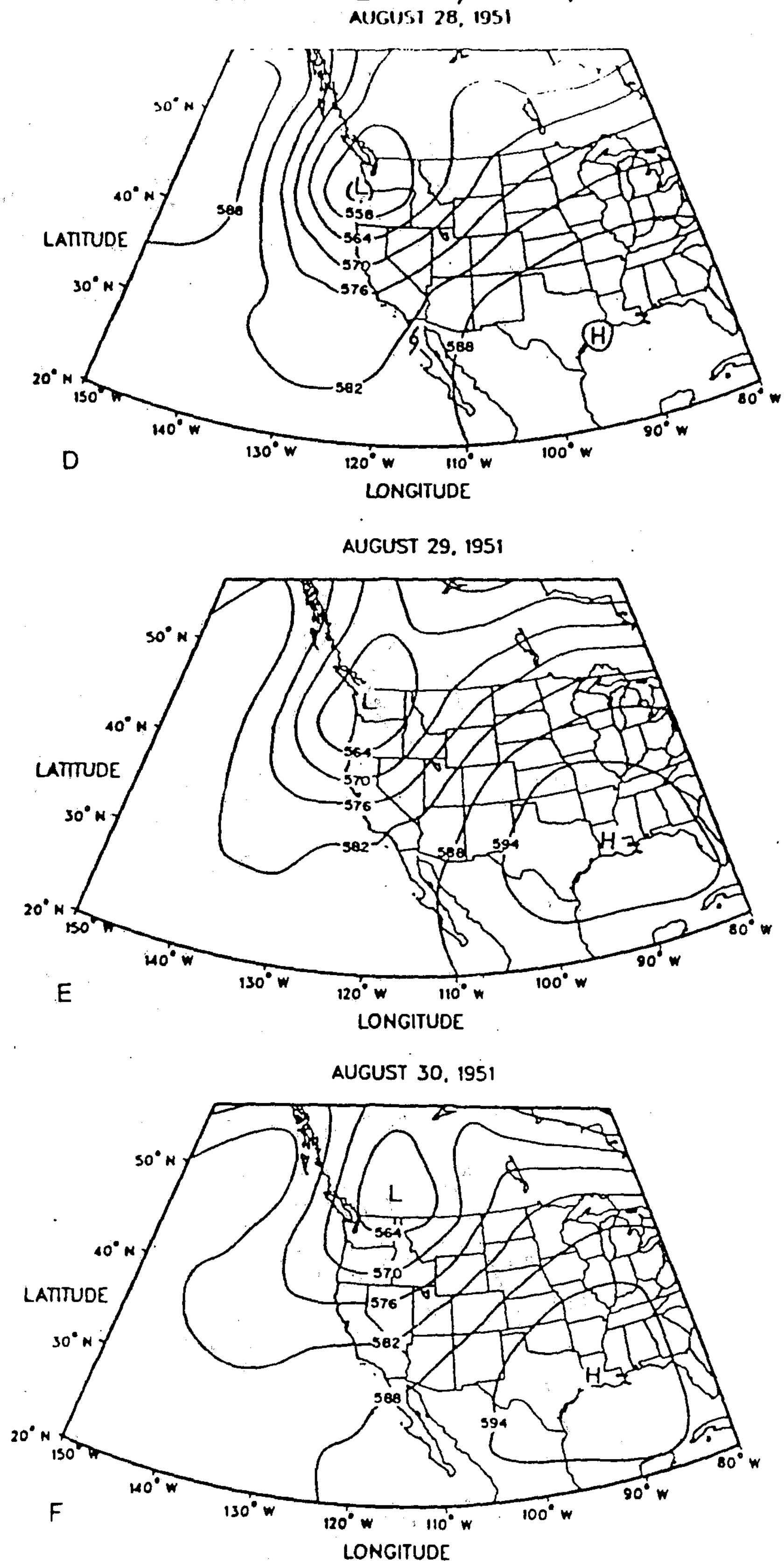


Figure 48. (continued) As in Figure 44.

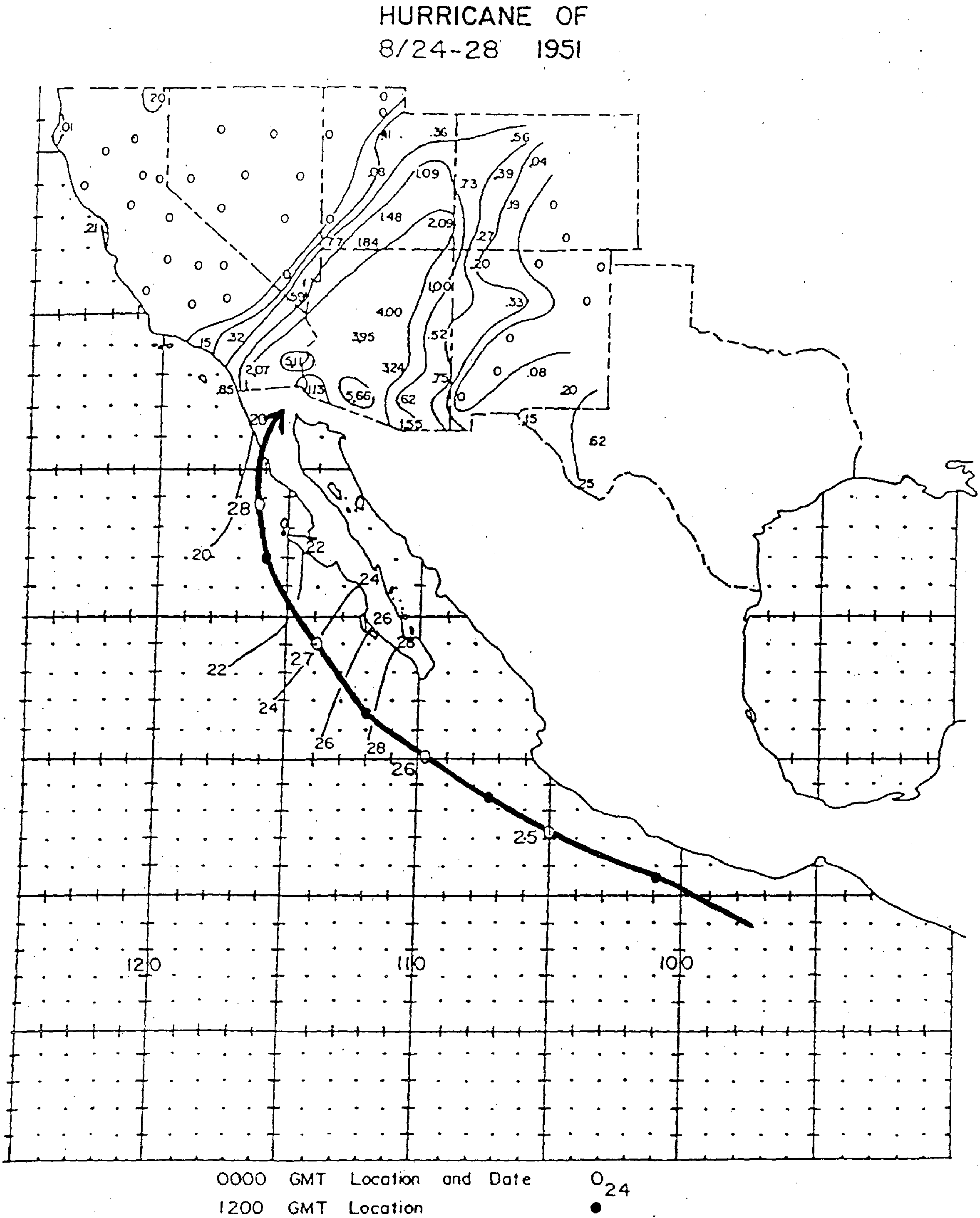


Figure 49. Track of the Hurricane of August 24-28, 1951 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches. Sea surface temperatures are in °C.

while, approximately 1000 km to the north, former Gulf of Mexico Hurricane Charlie was dissipating over the Sierra Madre Oriental west of Tampico, Mexico. By 1230 GMT on the 24th, observations indicate a tropical cyclone was moving northwestward about 200 km southwest of Acapulco. As already stated (see page 29), the path of the storm was very similar to that of several other tropical cyclones which brought heavy rains to southeastern California and southwestern Arizona. Unlike the previous storms, the Hurricane of August 24-28, 1951 concentrated it's rainfall over the mountains to the north and northeast of Phoenix instead of the Lower Colorado River Valley, although heavy rains did occur there.

The 500 mb height maps of the period, Figure 48, show the hurricane moved around the western end of the subtropical high and ahead of a deepening trough over the Pacific Northwest. The tropical cyclone tracked inland near Ensenada, Baja California on August 28 and not out to sea as plotted on the historical weather maps of the 27th-29th.

Total precipitation from the storm exceeded 10 inches at several localities near Phoenix. Showers began in southern California and Arizona on the 26th as the upper air circulation changed from the southwest to a more southerly direction thus bringing moist air associated with the summer monsoon and/or the hurricane over the Southwest. Rainfall increased dramatically over the next two days as the weakening tropical cyclone headed toward the Baja coast. As seen in Table 26, the greatest amounts of rain were recorded in southern California on the 27th and 28th while in most of Arizona they were reported on August 28 and 29. Crown King received 13.56 in. of rain during the period and the month's total of 16.95 in. is the greatest amount of precipitation ever measured in one month in Arizona. At least 12 other stations in Arizona; including Buckeye (6.89 in.), Granite Reef Dam (6.08 in.), Phoenix WSFO (5.56 in.), and Wickenburg (8.86 in.); set all-time monthly precipitation records in August 1951.

No widespread major damage was reported in either southern California or Arizona from these heavy rains. However, many roads were washed out in the Imperial Valley of California and numerous county roads and highways were severely damaged in western Arizona. Flooding appears to have been most severe around Litchfield Park, Arizona where water rose as high as three feet. No deaths were reported from the storm.

Tropical Storm of September 23-29, 1951

Figure 51 shows the tropical storm never came within 500 km of California. Nevertheless, upper level winds carried moisture from the dissipating cyclone over the Southwest on September 28 and 29 ahead of a midlatitude disturbance which was moving eastwards between 30° and 35°N (see Figure 50). Only light to moderate amounts of precipitation fell in the study area. Cave Creek, Arizona received the greatest amount of precipitation, 1.82 in., but most places reported less than one inch.

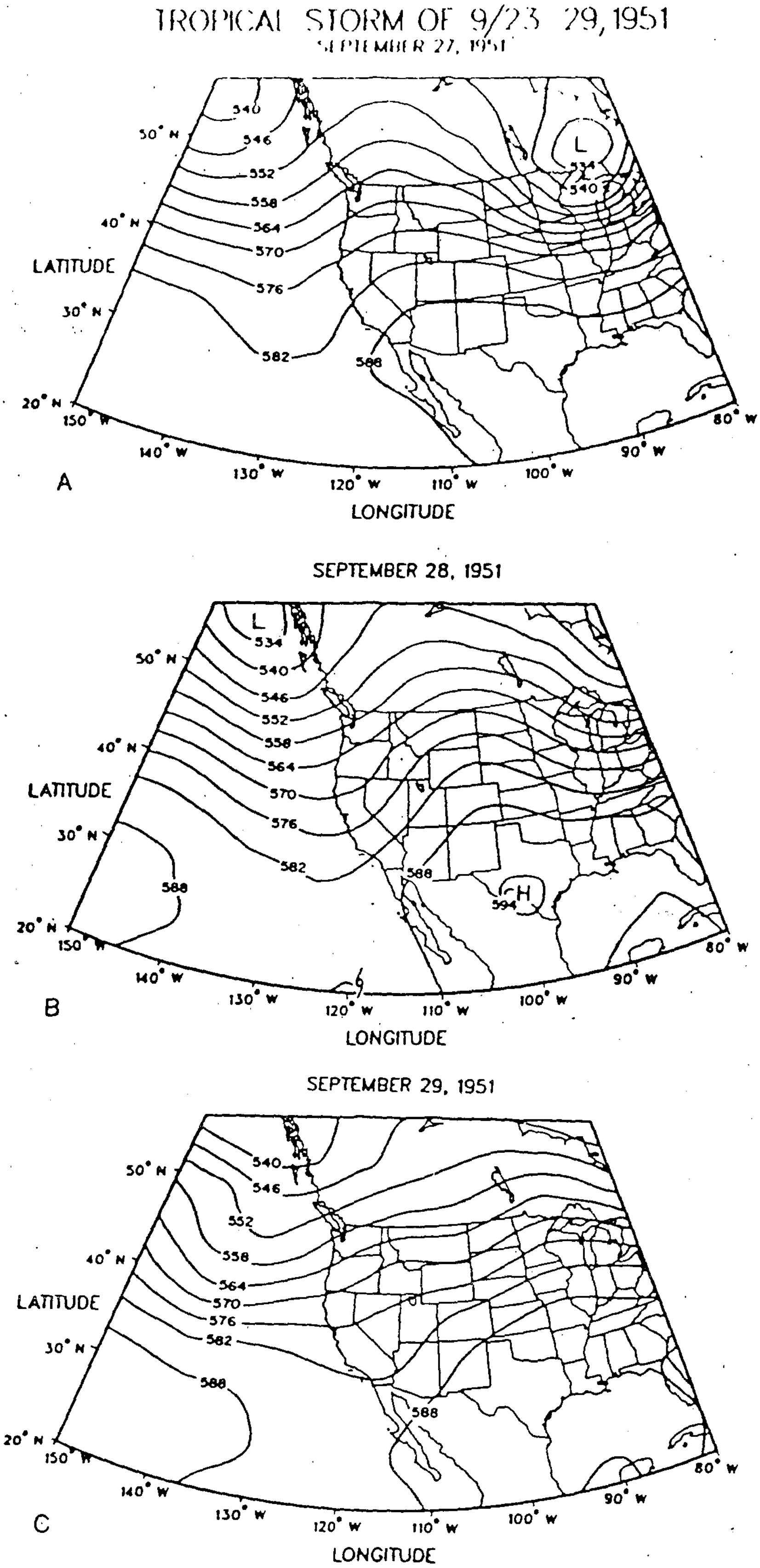


Figure 50. As in Figure 44.

TROPICAL STORM OF
9/23-29 1951

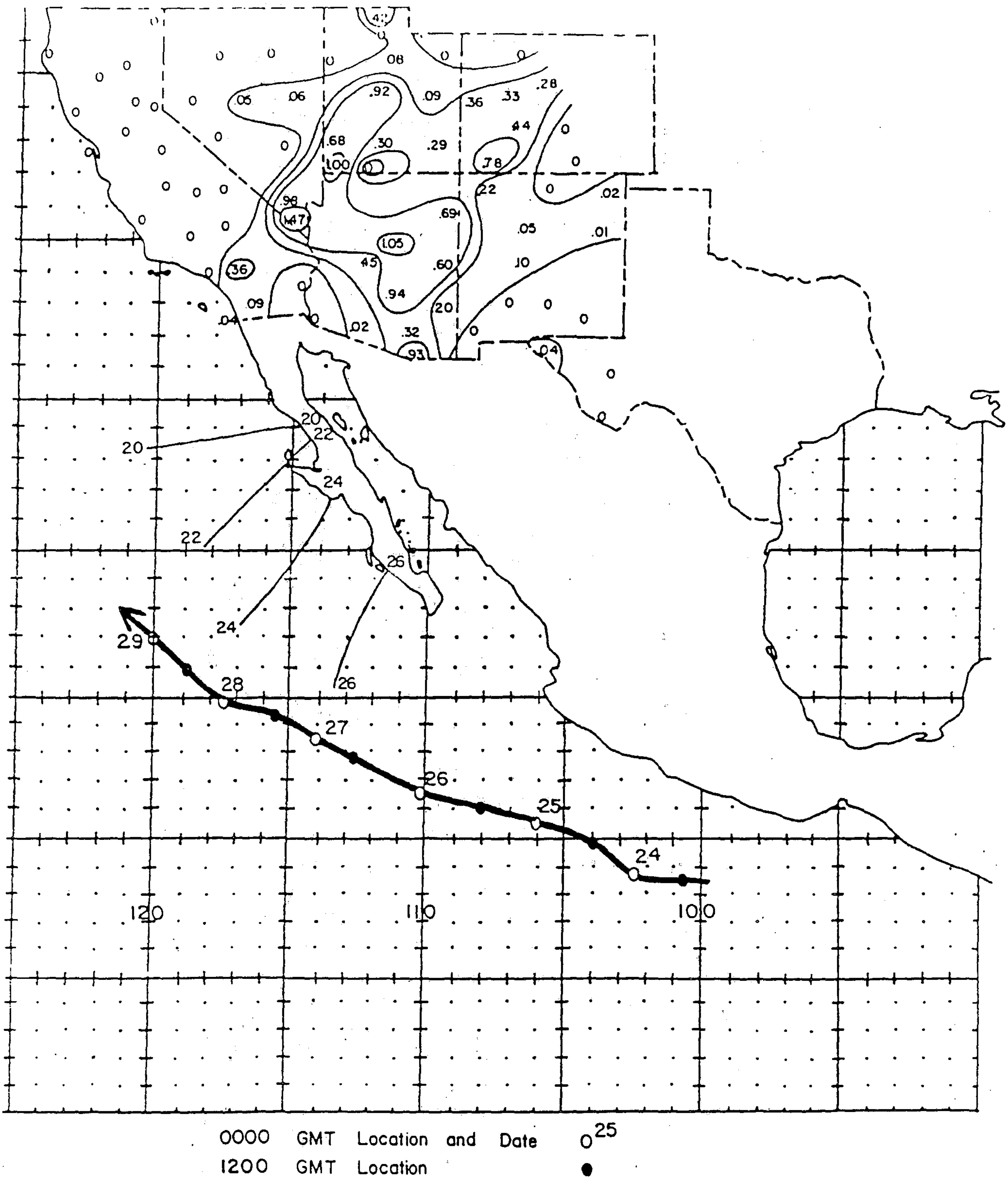


Figure 51. **Track of the Tropical Storm of September 23-29, 1951** and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches. Sea surface temperatures are in $^{\circ}C$.

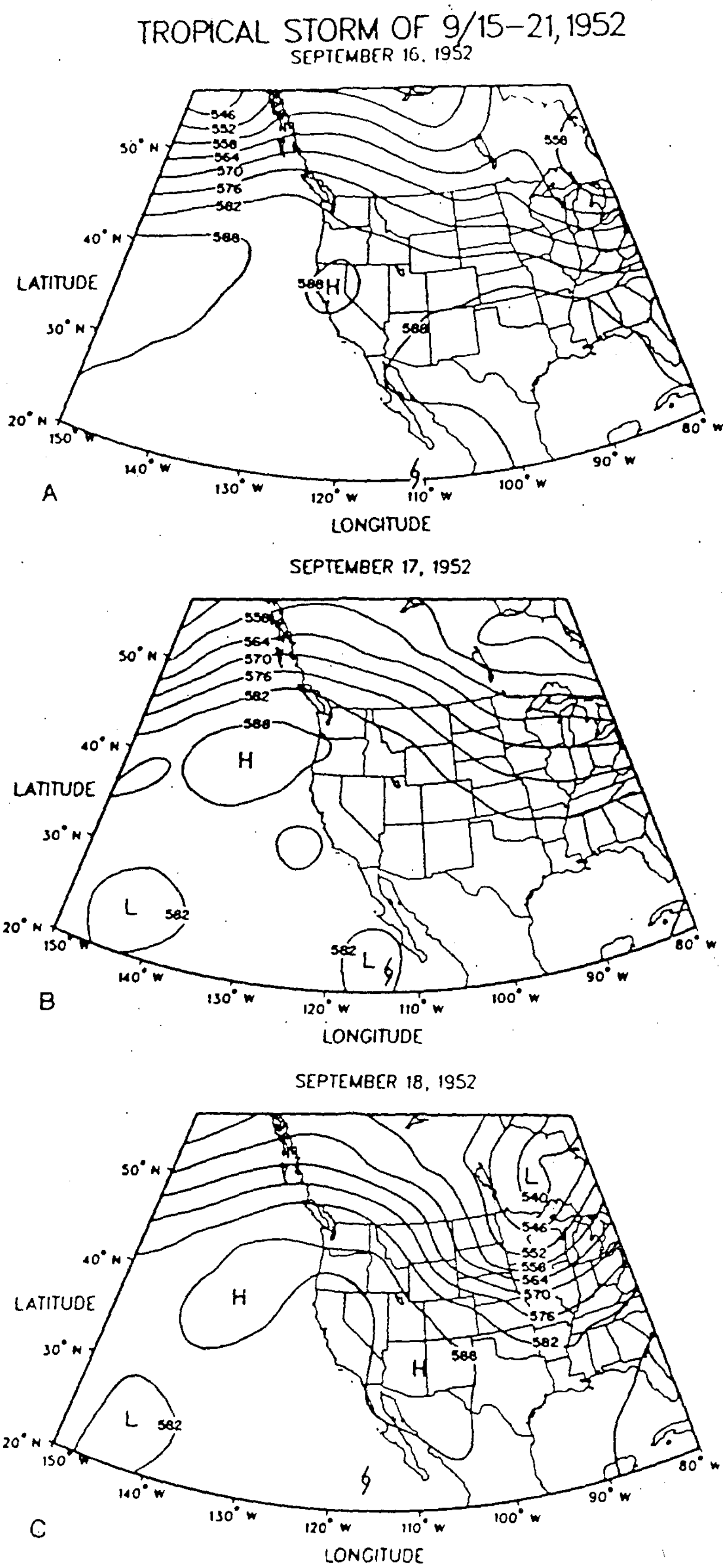


Figure 52. As in Figure 44.

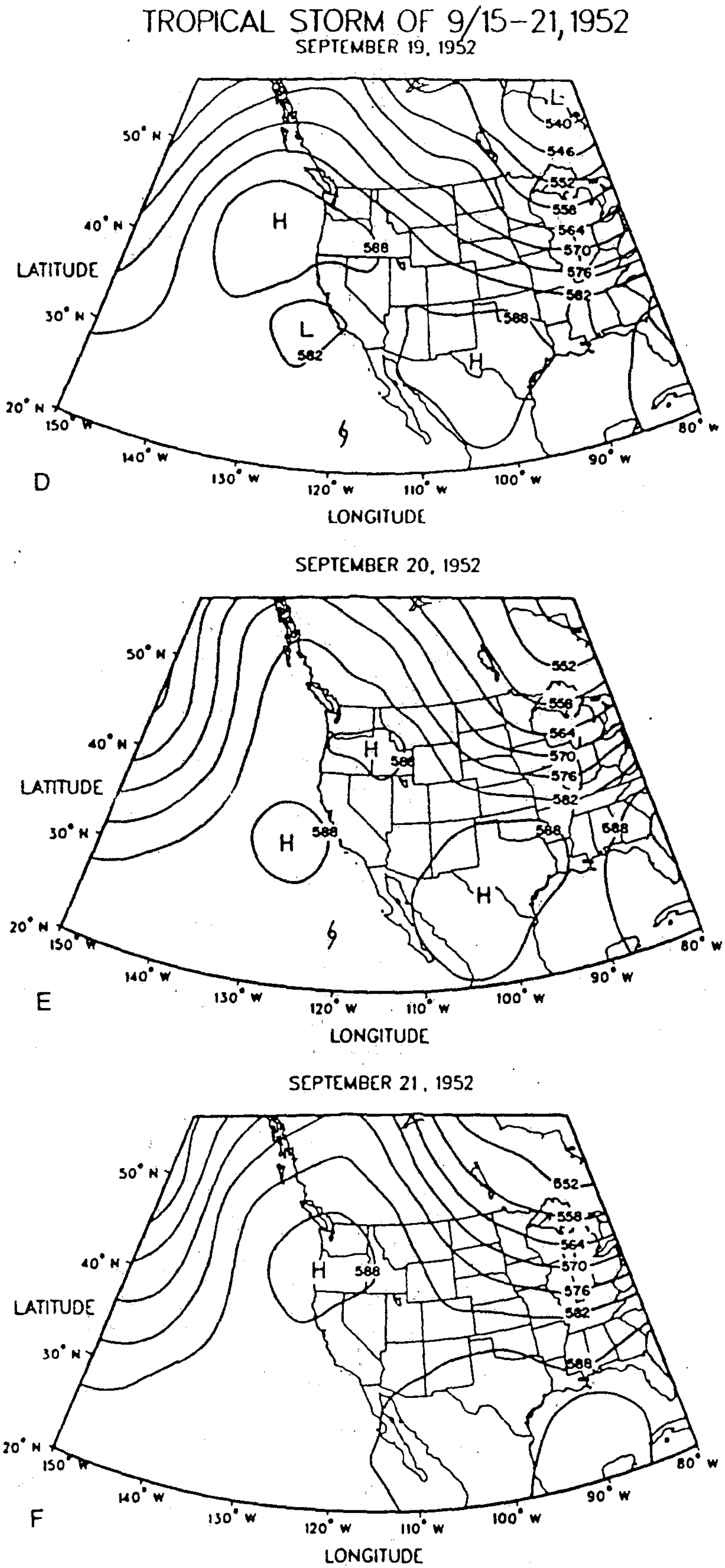


Figure 52. (continued) As in Figure 44.

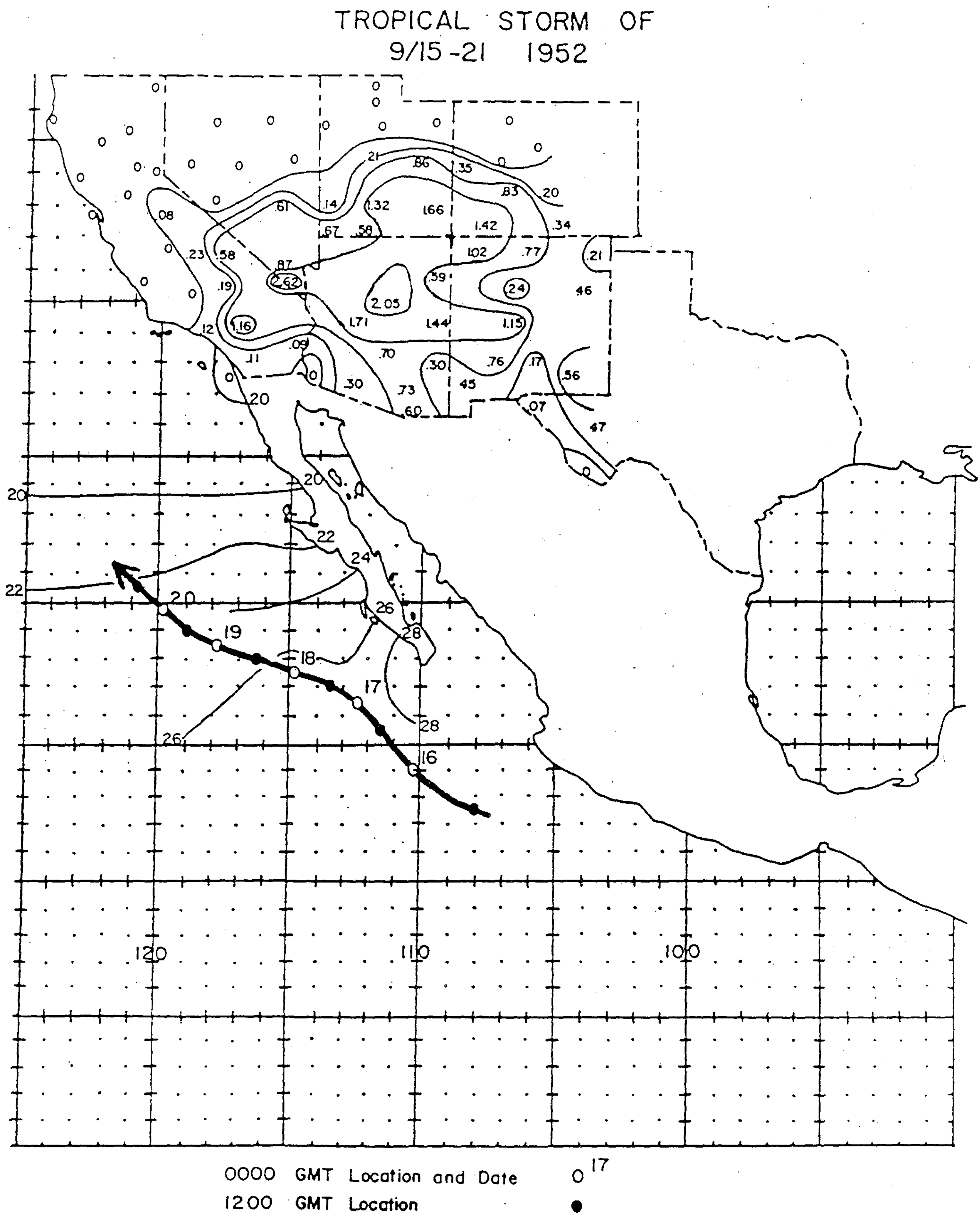


Figure 53. Track of the Tropical Storm of September 15-21, 1952 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

Table 26. Hurricane of August 24-28, 1951 daily precipitation

Station	August 26	27	28	29	30	Total
Ajo, Az.	0	4.75	.68	.23	0	5.66
Bagdad 8NE, Az.	0	00	2.02	5.38	0	7.40
Castle Hot Springs, Az.	0	1.41	5.32	5.14	0	11.87
Crown King, Az.	2.16	1.03	5.03	5.31	.03	13.56
Payson, Az.	0	2.10	2.92	1.12	1.15	7.29
Sierra Ancha, Az.	0	1.96	4.58	1.48	0	8.02
Sunflower, Az.	0	1.40	5.15	2.52	3.04	12.11
Blythe, Ca.	0	3.06	1.62	.43	0	5.11
Parker Reservoir, Ca.	.47	0	2.26	1.25	0	3.98
Alton, Utah	0	0	00	2.05	0	2.05

00 = trace; amounts in inches.

Table 27. Tropical Storm of September 15-21, 1952 daily precipitation

Station	September 19	20	21	22	23	Total
Ash Fork, Az.	0	.90	1.80	0	.25	2.95
Mormon Lake Ranger Station, Az.	0	1.40	2.30	.18	0	3.88
Tuba City, Az.	0	.40	2.65	.85	0	3.90
Idyllwild Ranger Station, Ca.	1.31	.34	.27	0	.19	2.11
Boulder City, Nev.	.08	1.65	.02	0	0	1.75
Searchlight, Nev.	.36	2.26	0	0	0	2.62
Durango, Co.	0	.28	.32	.70	.12	1.42

amounts in inches.

Tropical Storm of September 15-21, 1952

Although the tropical storm completely dissipated at sea far from the southern California coast, just as with the storm discussed above, the available evidence suggests that, beginning on the 19th, moisture-laden air from the vicinity of the cyclone was advected over the Southwest. The cut-off low shown in Figure 52D lifted the moist air and caused the rain which began in the southern parts of California and Nevada on September 19 (Table 27). Precipitation spread from there to the east over the next three days as the weak cut-off low became caught up in the westerlies again and tracked eastward. Figure 53 indicates the heaviest rains were centered over northeastern Arizona where many stations received more than 2 inches of rain and a few more than 3 inches.

Hurricane of August 24-26, 1953

The circulation at 500 mb during the time of this hurricane (Figure 54) is similar to that during the Hurricane of August 24-28, 1951 (Figure 48). In both periods the western end of the subtropical anticyclone was located over the west coast of Mexico

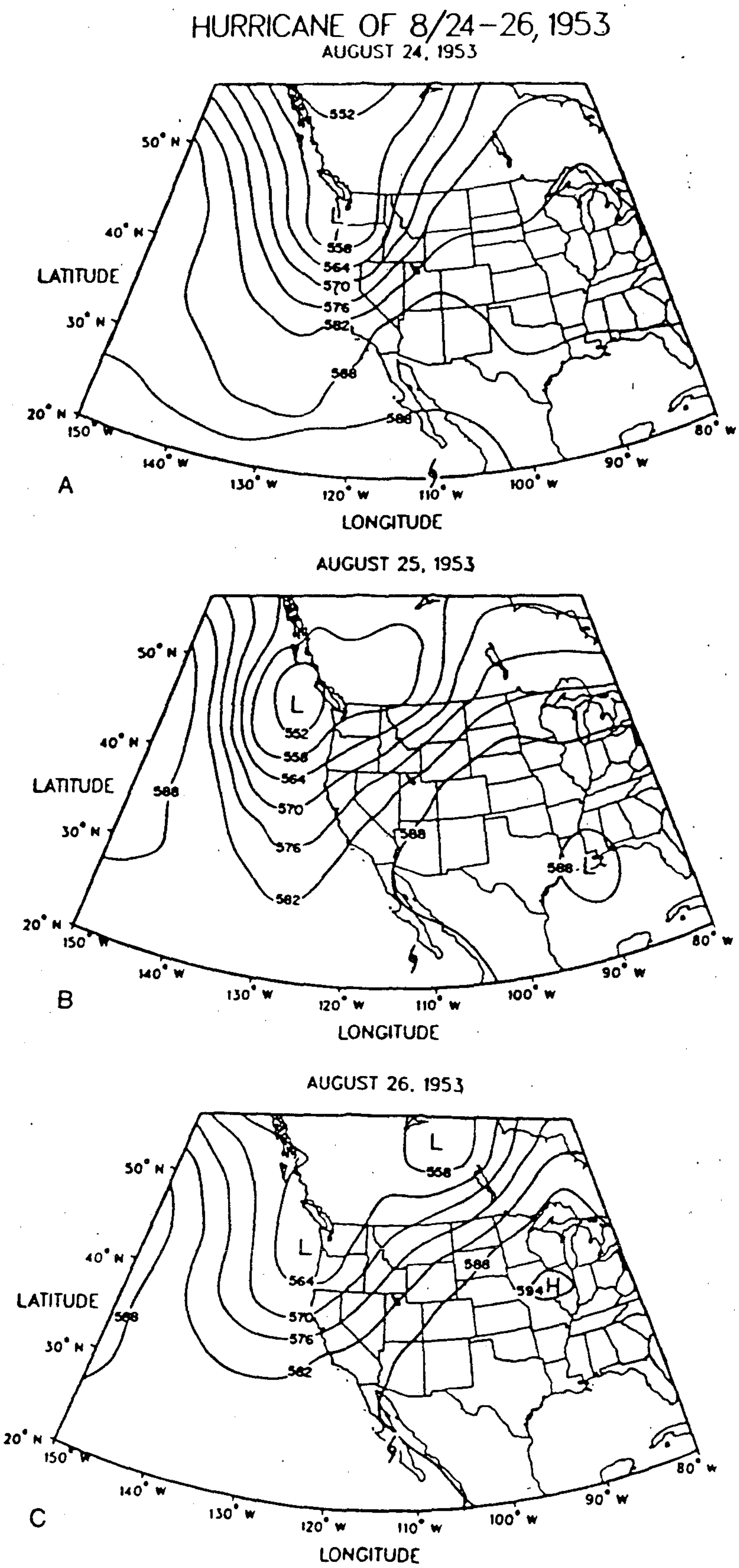


Figure 54. As in Figure 44.

HURRICANE OF 8/24-26, 1953

AUGUST 27, 1953

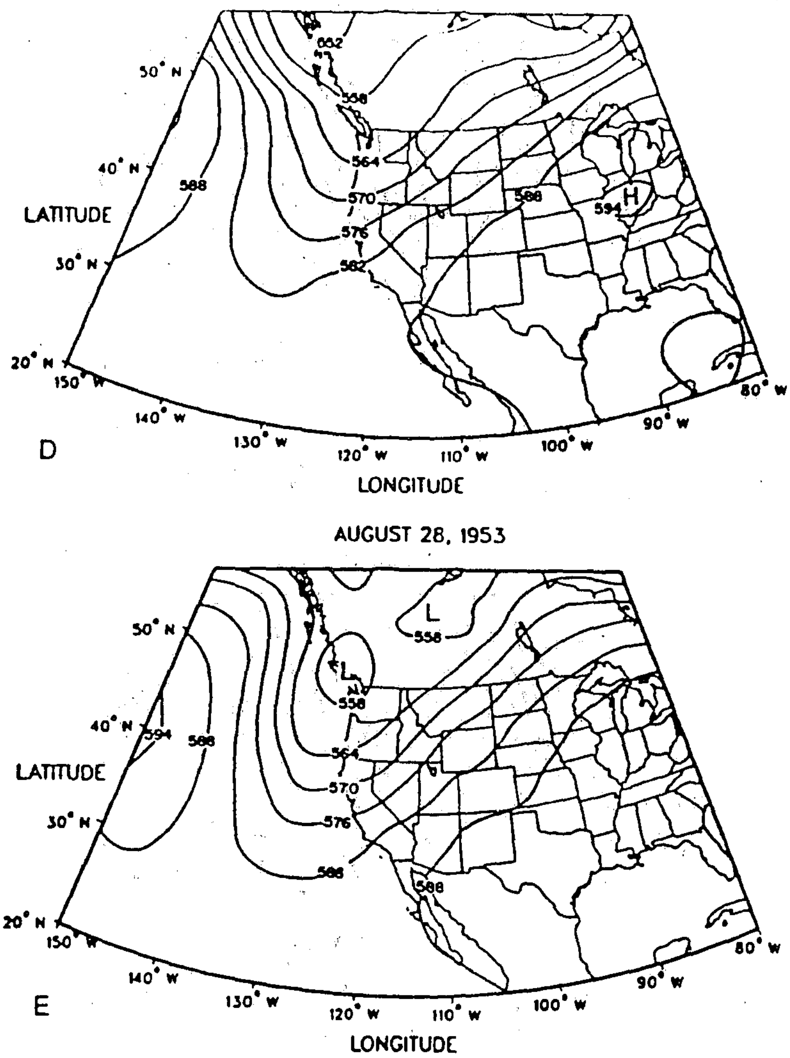


Figure 54. (continued) As in Figure 44.

Table 28. Hurricane of August 24-26, 1953 daily precipitation

	August					
Station	25	26	27	28	29	Total
Bright Angel Ranger Station, Az.	0	1.11	2.01	00	0	3.12
Camp Wood, Az.	.27	.46	.90	1.39	.15	3.17
Williams, Az.	.09	.20	1.62	1.05	.26	3.22

00 = trace; amounts in inches.

while an unusually deep (for August) upper level trough was situated to the northwest. Consequently, both tropical cyclones moved in the same general direction but there were some important differences in the paths of the storms and thus, the amount of rain associated with each.

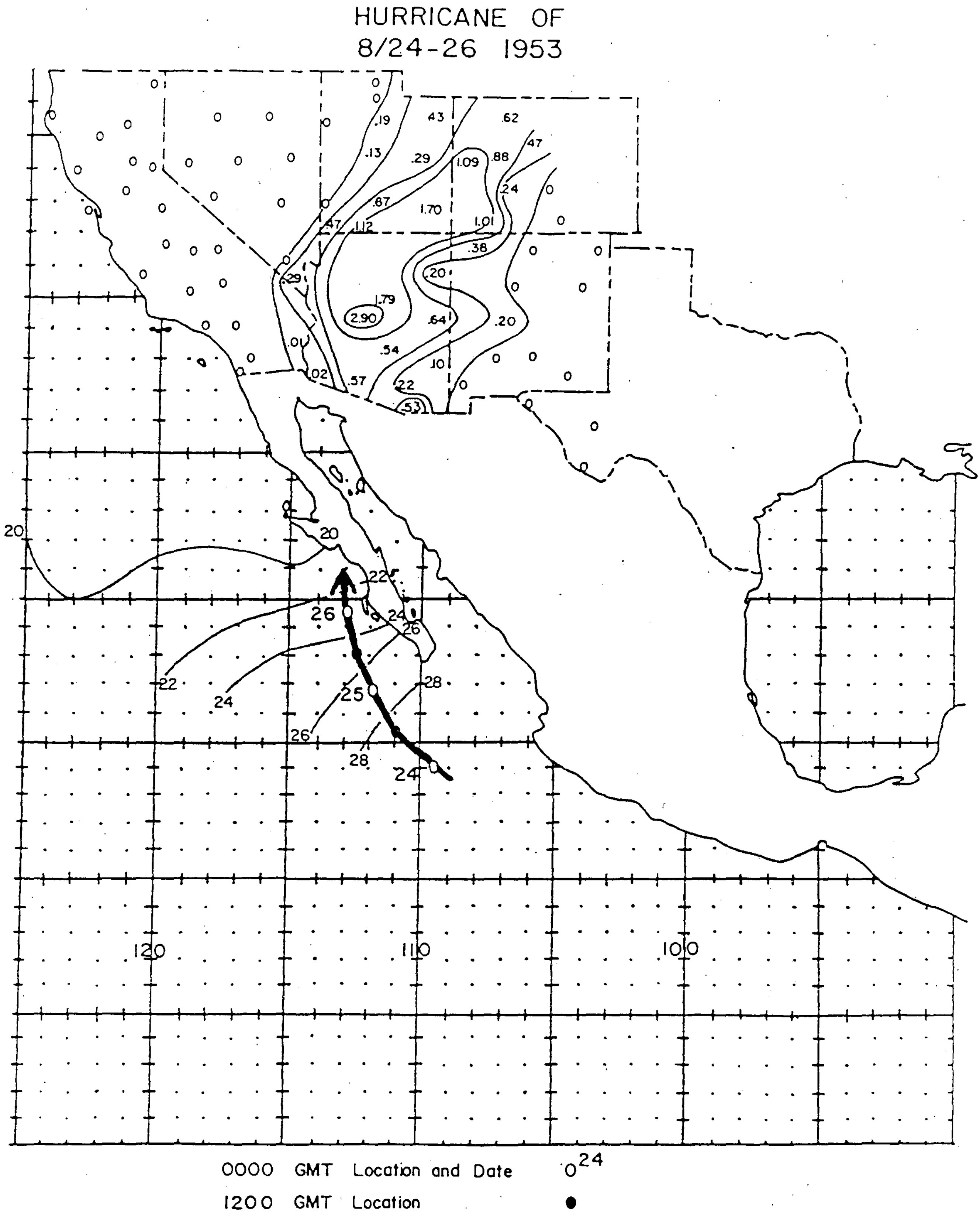


Figure 55. Track of the Hurricane of August 24-26, 1953 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

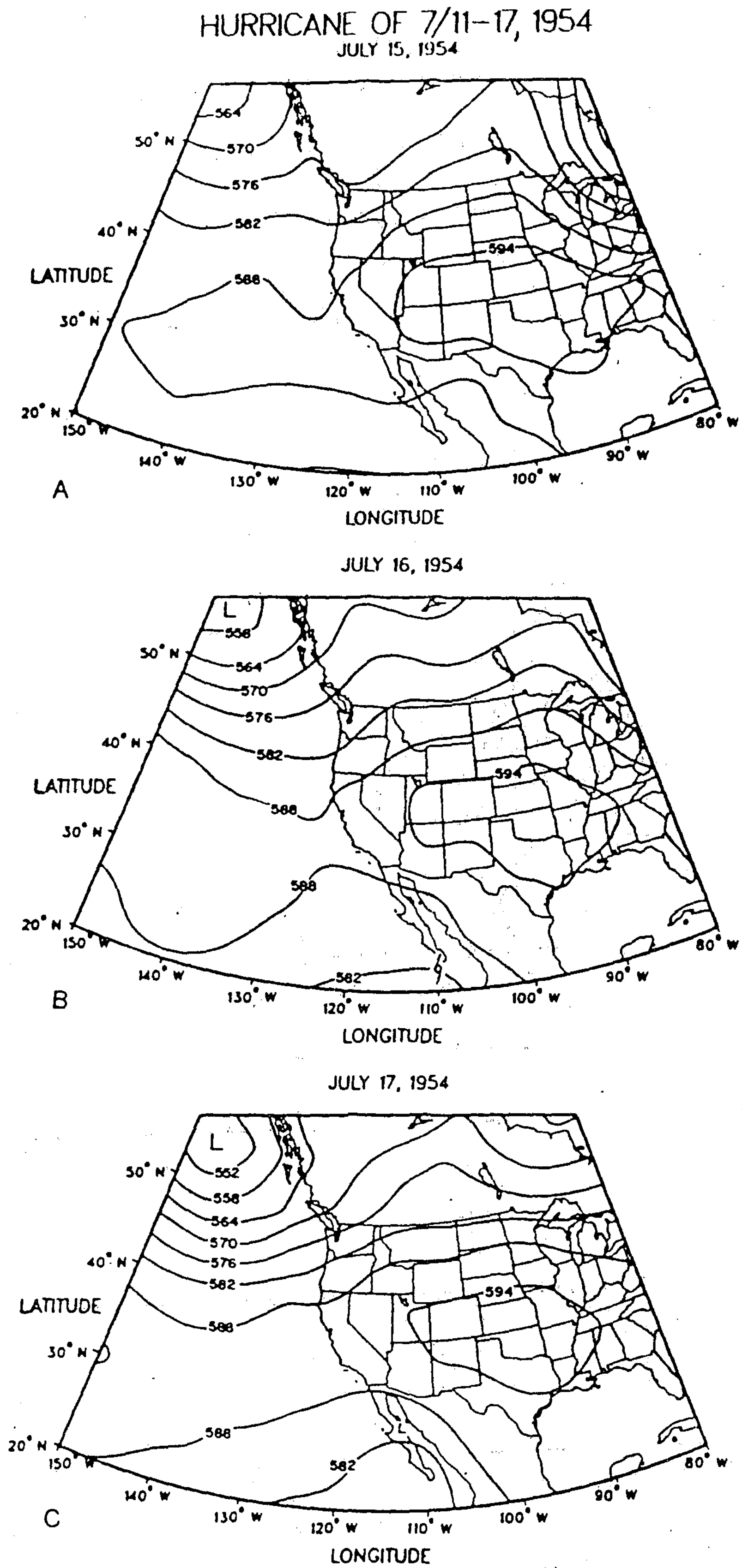


Figure 56. As in Figure 44.

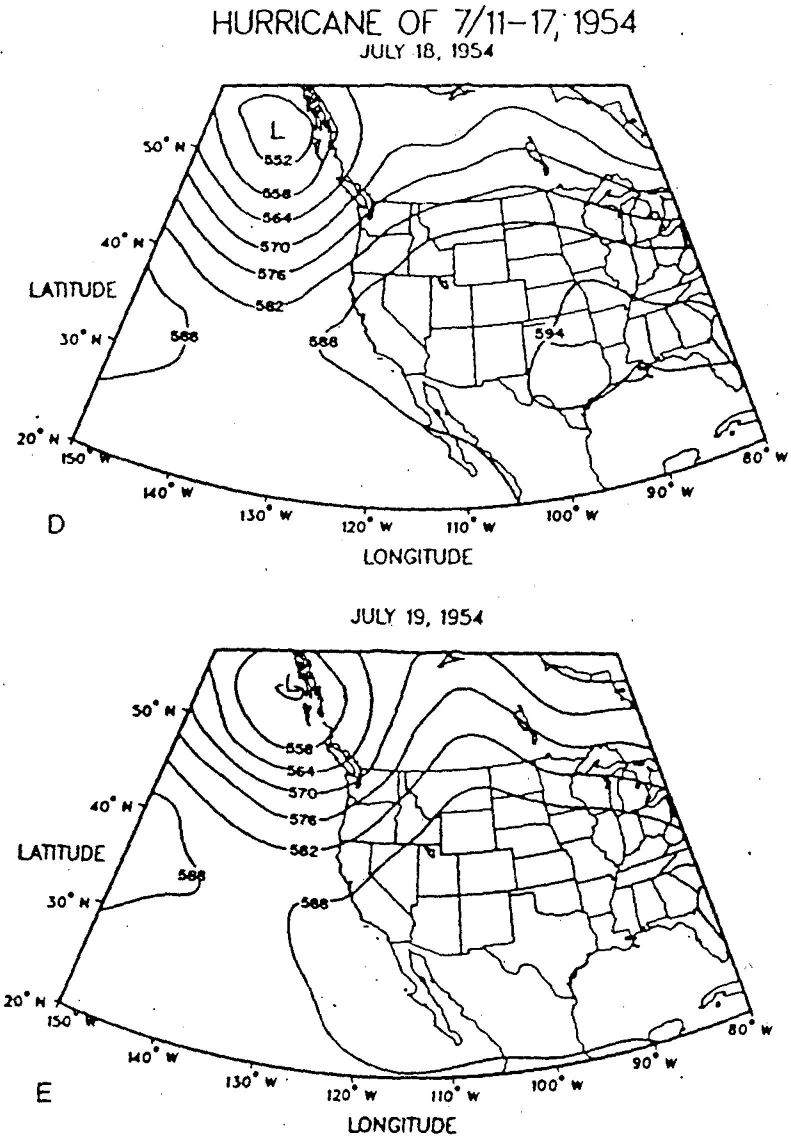


Figure 56. (continued) As in Figure 44.

First, this hurricane (Figure 55) moved over cooler water than the Hurricane of August 1951 (Figure 49) causing it to weaken faster. Second, the Hurricane of August 1953 moved closer to and apparently over the Baja coast while still well south of the United States. As a result, the circulation of the cyclone was disrupted much further south than that of the Hurricane of August 1951 which also caused this hurricane to dissipate much farther south. The result was that much less rain fell. Nonetheless, several stations in northern Arizona did receive in excess of 3 inches of rain, most of which occurred from the 26th through the 28th as shown in Table 28.

Hurricane of July 11-17, 1954

The hurricane originated in the Gulf of Tehuantepec on July 11 (Figure 57) and moved from there around the southwestern end of a large area of high pressure that was centered over the

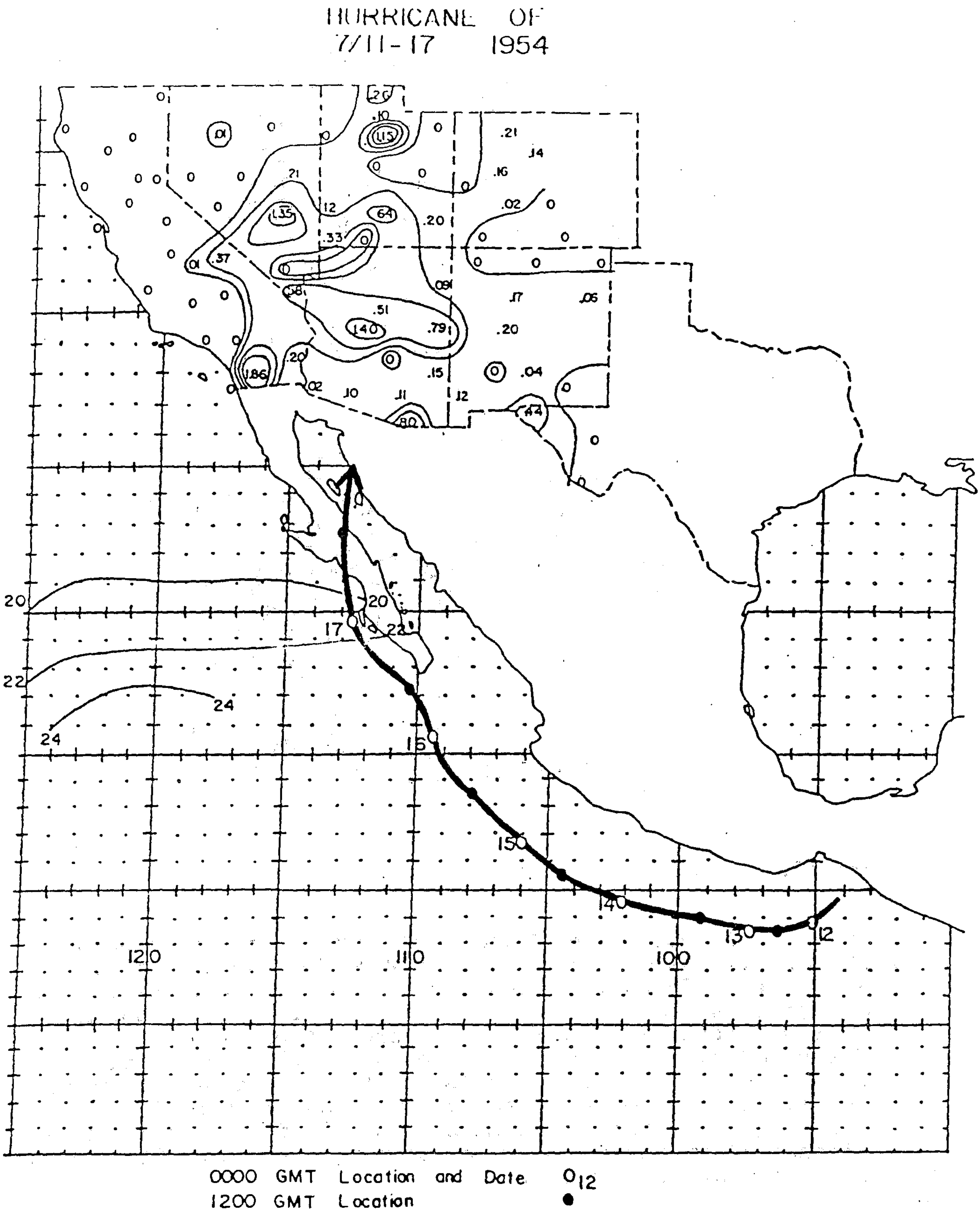


Figure 57. Track of the Hurricane of July 11-17, 1954 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches. Sea surface temperatures are in °C.

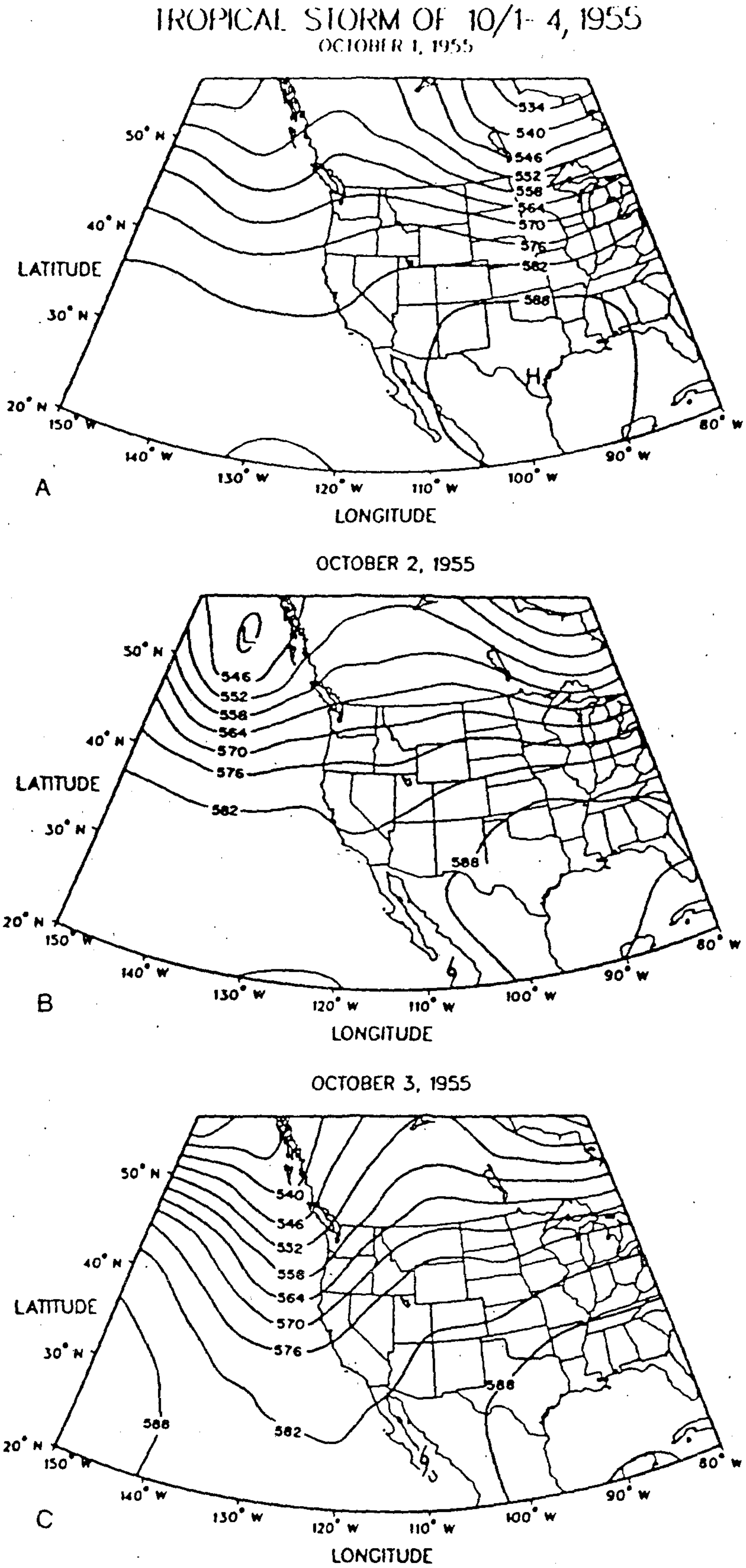


Figure 58. As in Figure 44 but for 1500 GMT.

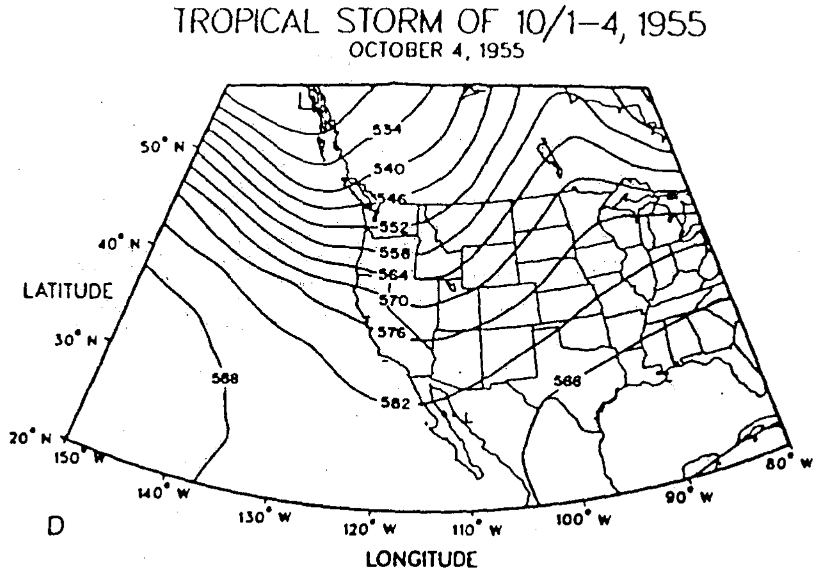


Figure 58. (continued) As in Figure 44 but for 1500 GMT.

Table 29. Hurricane of July 11-17, 1954 daily precipitation

	July				
Station	17	18	19	20	Total
Mt. Lemmon, Az.	.20	1.25	1.70	00	3.15
Cuyamaca, Ca.	.34	.97	.55	0	1.86

00 = trace; amounts in inches.

Table 30. Tropical Storm of October 1-4, 1955 daily precipitation

	October			
Station	2	3	4	Total
Childs, Az.	0	0	2.64	2.64
Duncan, Az.	0	.79	1.10	1.89
Nogales, Az.	1.60	.22	0	1.82
Balmorhea, Texas	.23	.11	1.16	1.50
Lovington 1WNW, NM.	1.97	3.34	.12	5.43
Tatum, NM.	2.16	3.54	.21	5.91

amounts in inches.

central United States (see Figure 56) to the Baja California coast where it dissipated late on the 17th. The summer monsoon was active in the Southwest prior to the arrival of moist air from the dying hurricane. Consequently, monsoon-derived rainfall can not be separated from tropical cyclone-derived rainfall. Moisture from the ex-hurricane appears to have entered the southern parts of California and Arizona on the 17th because there was a noticeable increase in precipitation that day. Rain was the heaviest on the following two days and tapered off on the 20th as indicated in Table 29. Mt. Lemmon measured the greatest amount of precipitation, 3.15 inches.

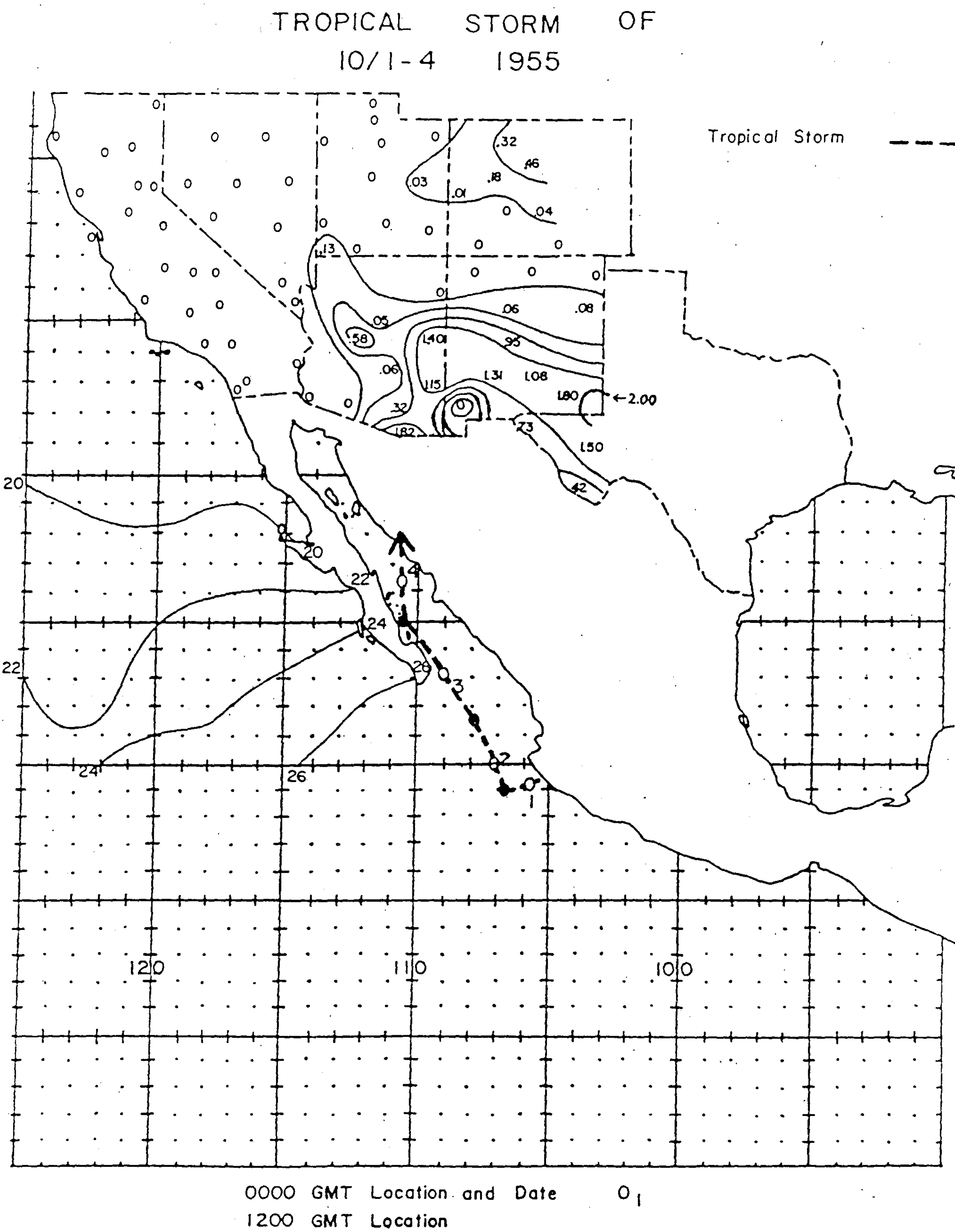


Figure 59. **Track of the Tropical Storm of** October 1-4, 1955 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

Tropical Storm of October 1-4, 1955

The remains of the Caribbean Hurricane Janet, which went ashore between Vera Cruz and Tampico on the east coast of Mexico, tracked across Mexico and promptly redeveloped into a tropical cyclone in the Pacific due west of Manzanillo early on October 1 (Rasey, 1956). Late on the 1st, the tropical storm, with sustained winds of at least 50 kn, turned to the northwest as it moved around a ridge that was centered over Texas (Figure 58). Moist air associated with the storm entered New Mexico, southeastern Arizona, and western Texas on the 2nd and produced some one inch rains as shown in Table 30. On the ensuing two days the short wave in Figure 58B proceeded inland over the west coast of the U.S. and forced the cyclone to turn to the north and then to the northeast (see Figure 59). The storm eventually went ashore for the last time early on October 4 in the state of Sonora, Mexico where flooding led to the deaths of a number of persons (Rasey, 1956).

Most of southeastern Arizona and the southern half of New Mexico received at least an inch of precipitation from the storm. Tatum and Lovington 1NNW, which are located in southeastern New Mexico, measured the two largest totals with both receiving more than 3 inches of rain on October 3.

Hurricane of October 1-5, 1957

The upper air circulation that brought the remains of the hurricane over the Southwest is illustrated in Figure 60 which shows 500 mb height contours for October 2 through 5. The tropical cyclone formed on the 1st and started toward the northwest but was forced to change direction the next day and proceed to the northeast as a longwave trough developed along the West Coast of North America. The trough remained nearly stationary as the hurricane trekked across the open ocean, over Magdalena Bay (with 90 knot winds), across Baja California, the Gulf of California, and finally inland near Guaymas.

Precipitation associated with the storm began on the 5th and ended on the 7th and is shown in Figure 61. Stations in southern New Mexico recorded the highest amounts of rain with most measuring between .50 and 1.25 inches. The heaviest rainfall reported in the Southwest was 2.12 in. at Rodeo, New Mexico.

Tropical Storm of July 26-29, 1958

Precipitation linked to the tropical storm began on July 28 when a weak area of low pressure off the southern California coast (Figure 62B) advected moist air over the Southwest and, in conjunction with the mountains and diurnal heating, lifted it causing scattered showers. The largest daily rainfall amounts (Table 31) fell on the 29th when exceptionally heavy rains were seen in and around Tucson. In fact, the 3.93 in. measured at Tucson WSO is the greatest 24-hour rainfall ever recorded there. On the 30th, relatively dry southwesterly winds developed over

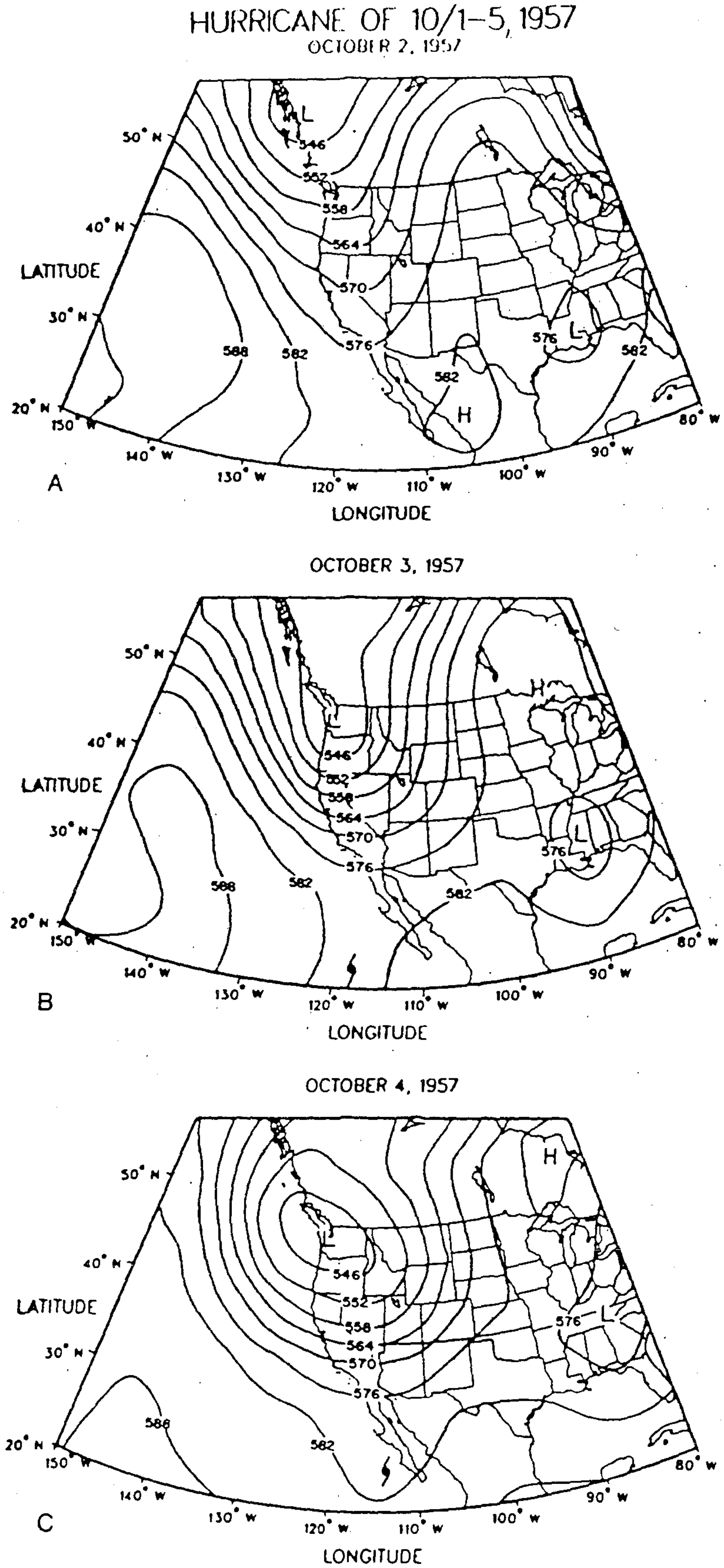


Figure 60. As in Figure 44.

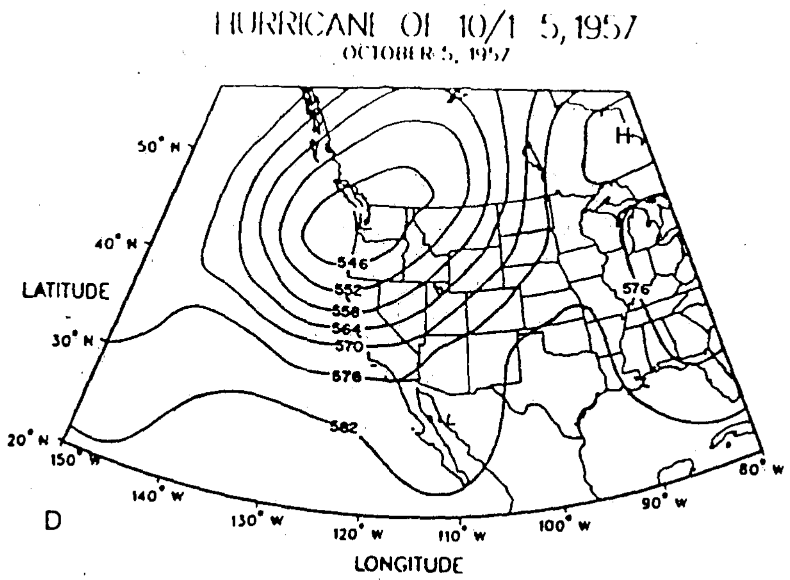


Figure 60. (continued) As in Figure 44.

Table 31. Tropical Storm of July 26-29, 1958
daily precipitation

Station	July 28	29	30	31	Total
Amado, Az.	0	2.44	0	0	2.44
Kofa Mountains, Az.	4.00	0	.36	.14	4.50
Organ Pipe National Monument, Az.	1.68	.29	.41	0	2.38
Silver Bell, Az.	0	5.30	0	0	5.30
Tucson WSO, Az.	0	3.93	0	0	3.93
Barstow, Ca.	.14	1.76	0	0	1.90

amounts in inches.

southern California and Arizona (Figure 62D) effectively ending the precipitation. As shown in Figure 63, only light amounts of rain fell outside of southern California and Arizona.

Tropical Storm of September 10-11, 1958

The tropical cyclone originated on the 10th about 200 km south-southwest of Mazatlan (Figure 65). The tropical storm gradually recurved to the north on September 11 and passed directly over the southern end of Baja California and as a result, weakened. Nevertheless, beginning on the 11th, a vast quantity of moist air from the vicinity of the storm was advected northward by southerly winds that separated a deep trough off the Pacific Northwest from a large ridge centered over Texas (Figure 64).

Nearly all stations in eastern Arizona, western New Mexico, extreme west Texas, western Colorado, and Utah received at least a half inch of rain. More than one inch of precipitation was measured over large parts of Arizona and New Mexico and more than

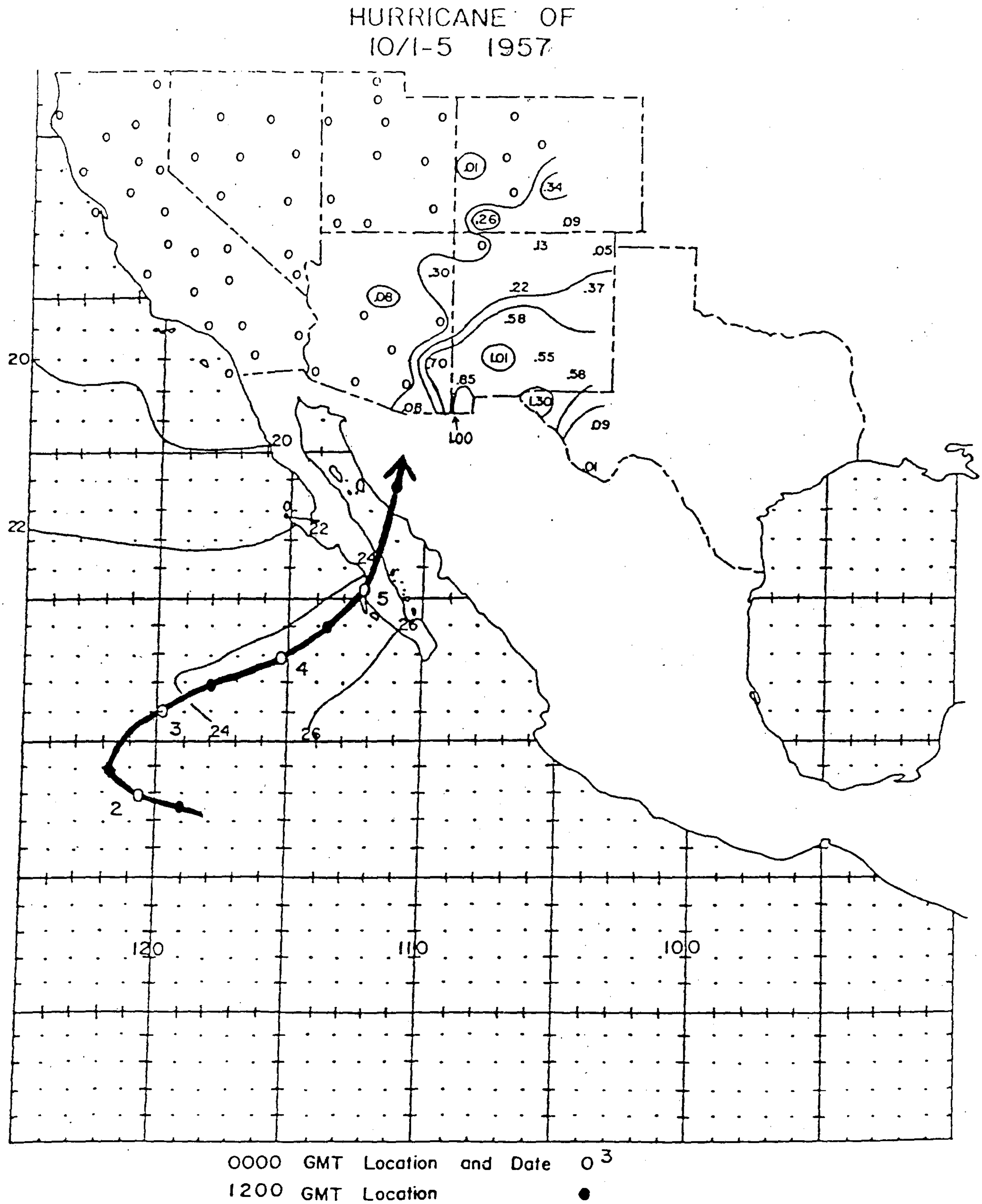


Figure 61. Track of the Hurricane of October 1-5, 1957 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches. Sea surface temperatures are in °C.

TROPICAL STORM OF 7/26–29, 1958

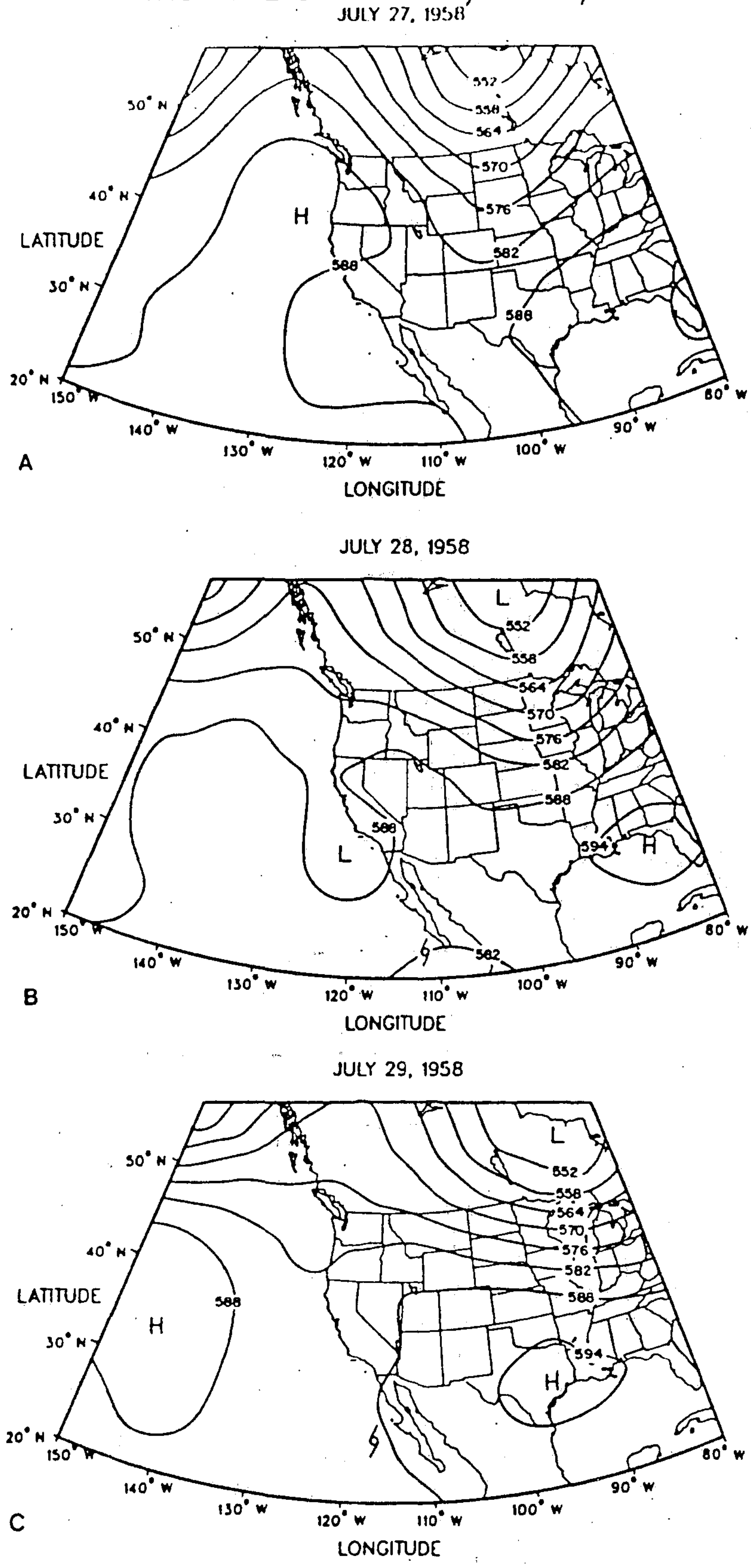


Figure 62. As in Figure 44.

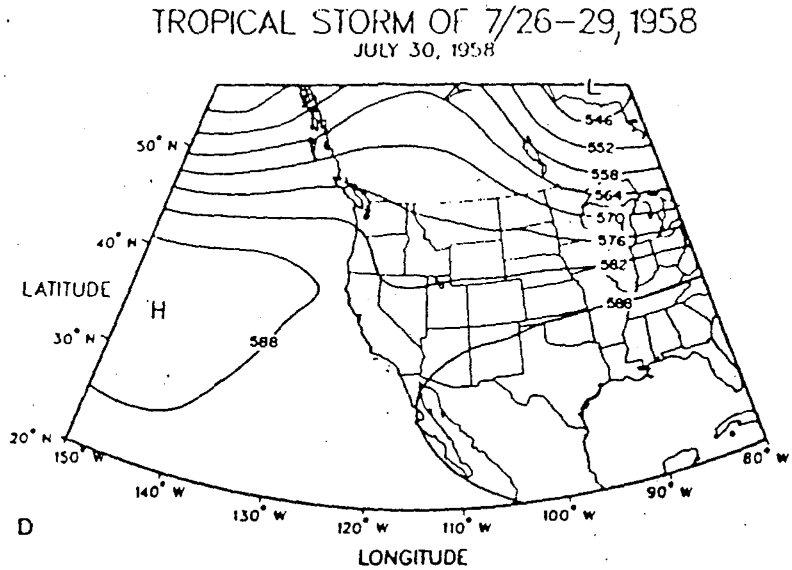


Figure 62. (continued) As in Figure 44.

Table 32. Tropical Storm of September 10-11, 1958 daily precipitation

	October					
Station	10	11	12	13	14	Total
Beaver Creek Ranger Station, Az.	0	0	2.57	.12	0	2.69
Stanton, Az.	0	0	2.85	0	0	2.85
Montezuma Castle National Monument, Az.	0	0	3.29	.15	0	3.44
Bandelier National Monument, NM.	0	0	.02	2.92	.51	3.45
Deming, NM.	.03	1.05	1.65	1.95	.03	4.71
Lordsburg, NM.	1.50	00	2.00	0	0	3.50

00 = trace; amounts in inches.

2.00 in. fell along the U.S.-Mexico border from just east of Nogales, Arizona to east of El Paso. Table 32 lists daily rainfall totals measured at the stations which reported the largest amounts and shows the heaviest showers fell on the 12th. Deming received the most rain, 4.71 inches. Precipitation reported on the 10th may not be related to the tropical storm.

Hurricane of September 29 - October 4, 1958

This tropical cyclone developed a few hundred kilometers southeast of Acapulco on September 29 and moved slowly to the northwest for about three more days when it became a hurricane and accelerated northward toward Baja California (see Figure 67). San Jose del Cabo at the southern end of the Baja peninsula suffered severe damage on October 3 as the hurricane made a direct hit (Quinn, 1959). A weak cut-off low that was located over the California-Arizona-Mexico border caused the hurricane to continue

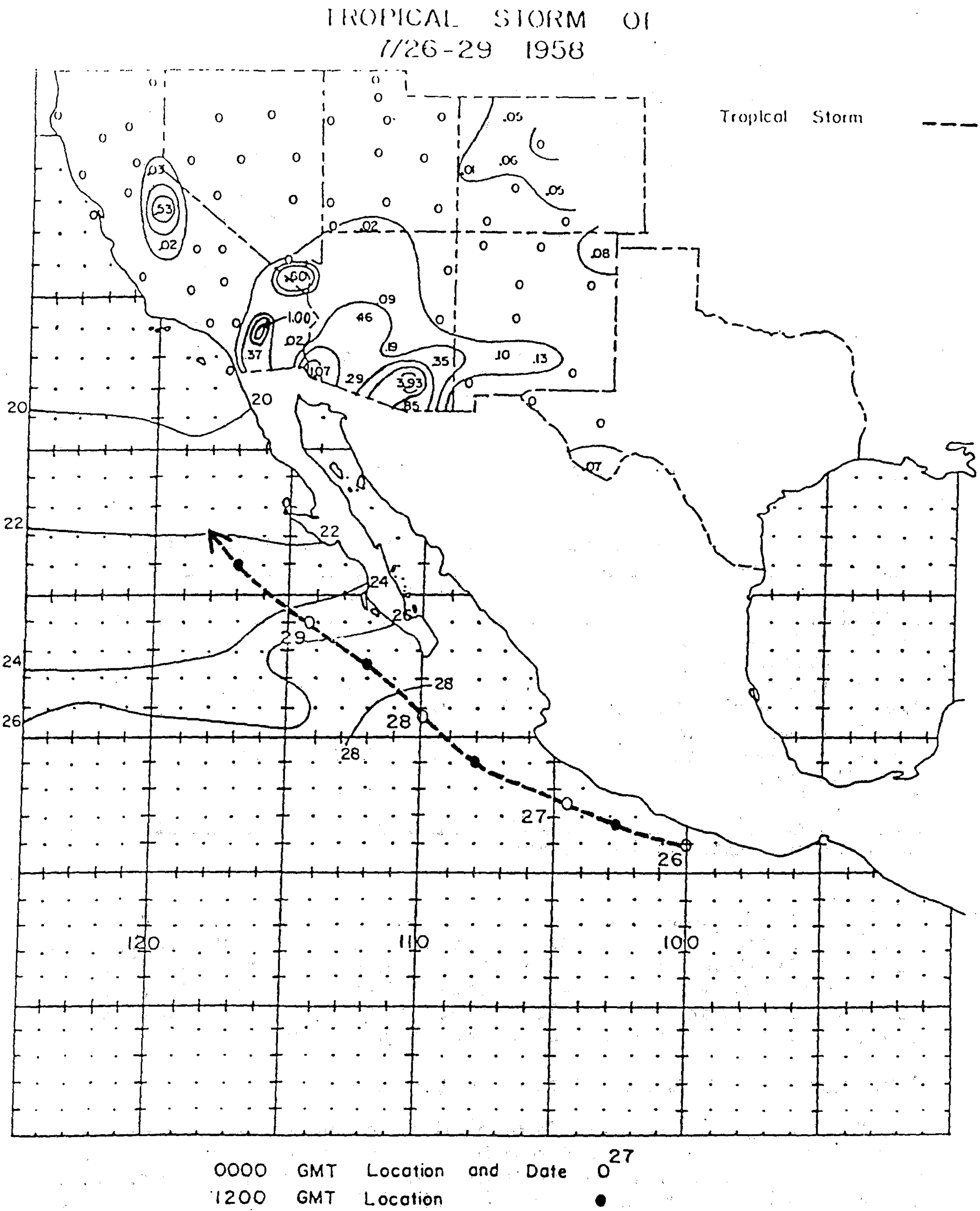


Figure 63. Track of the Tropical Storm of July 26-29, 1958 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

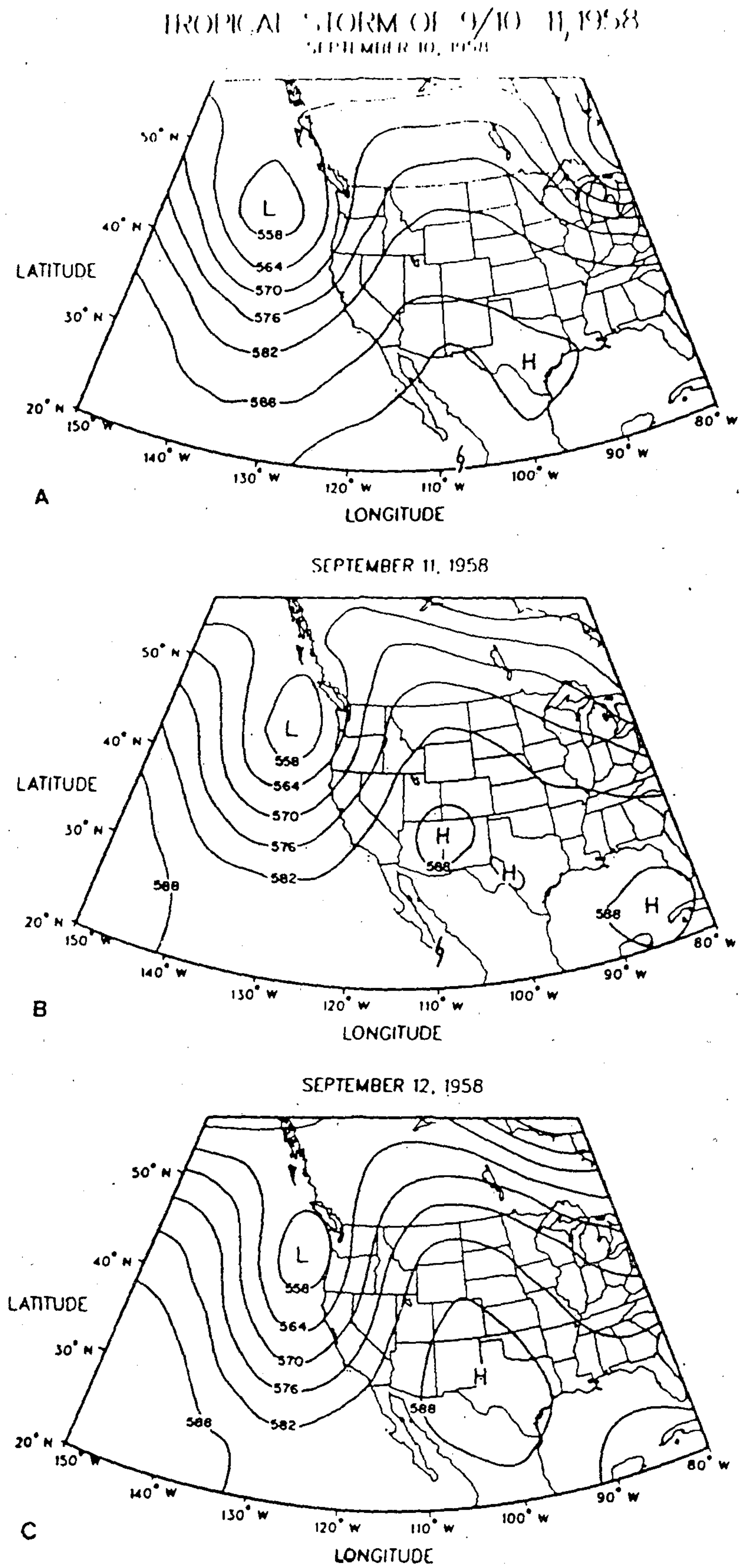


Figure 64. As in Figure 44.

TROPICAL STORM OF
9/10-11 1958

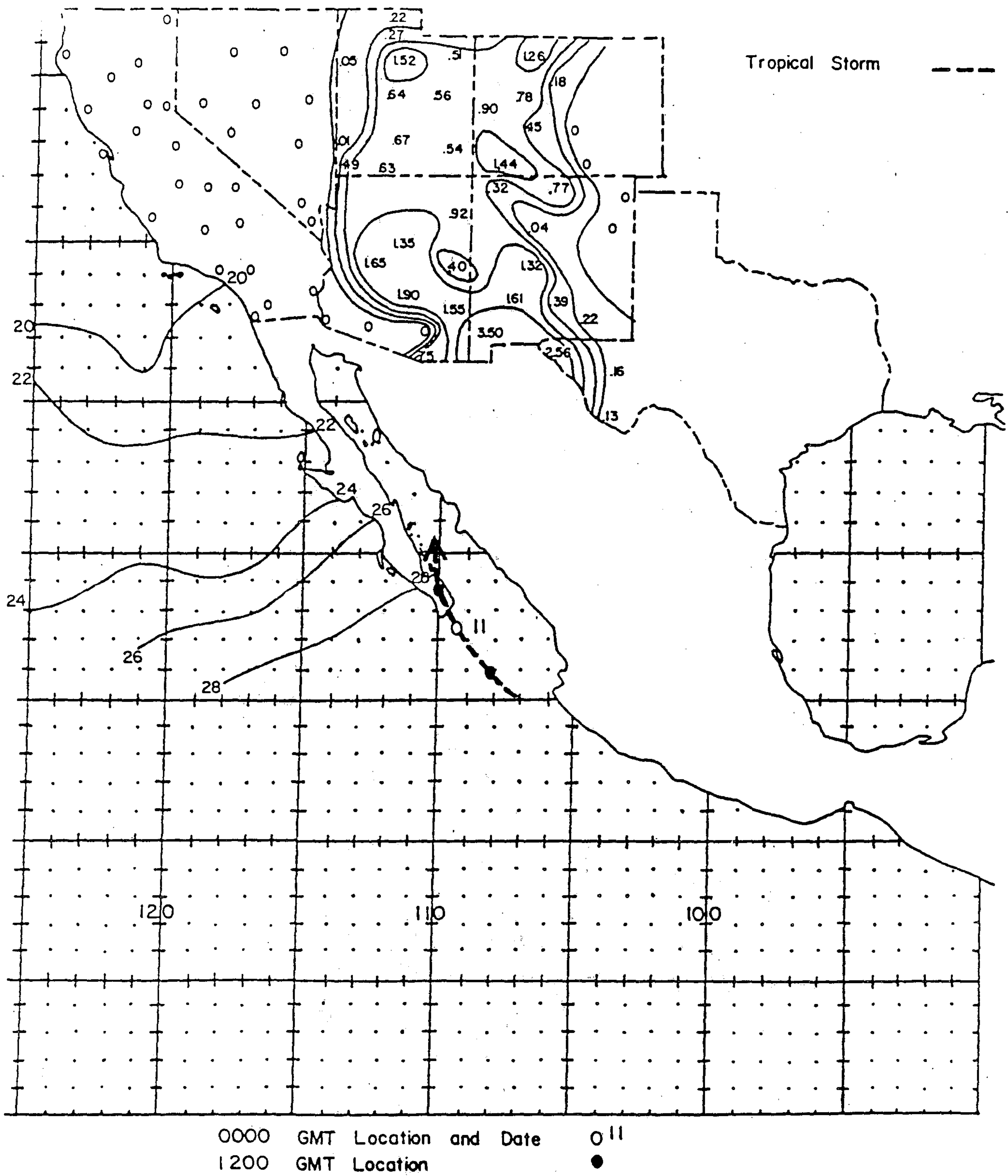


Figure 65. Track of the Tropical Storm of September 10-11, 1958 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

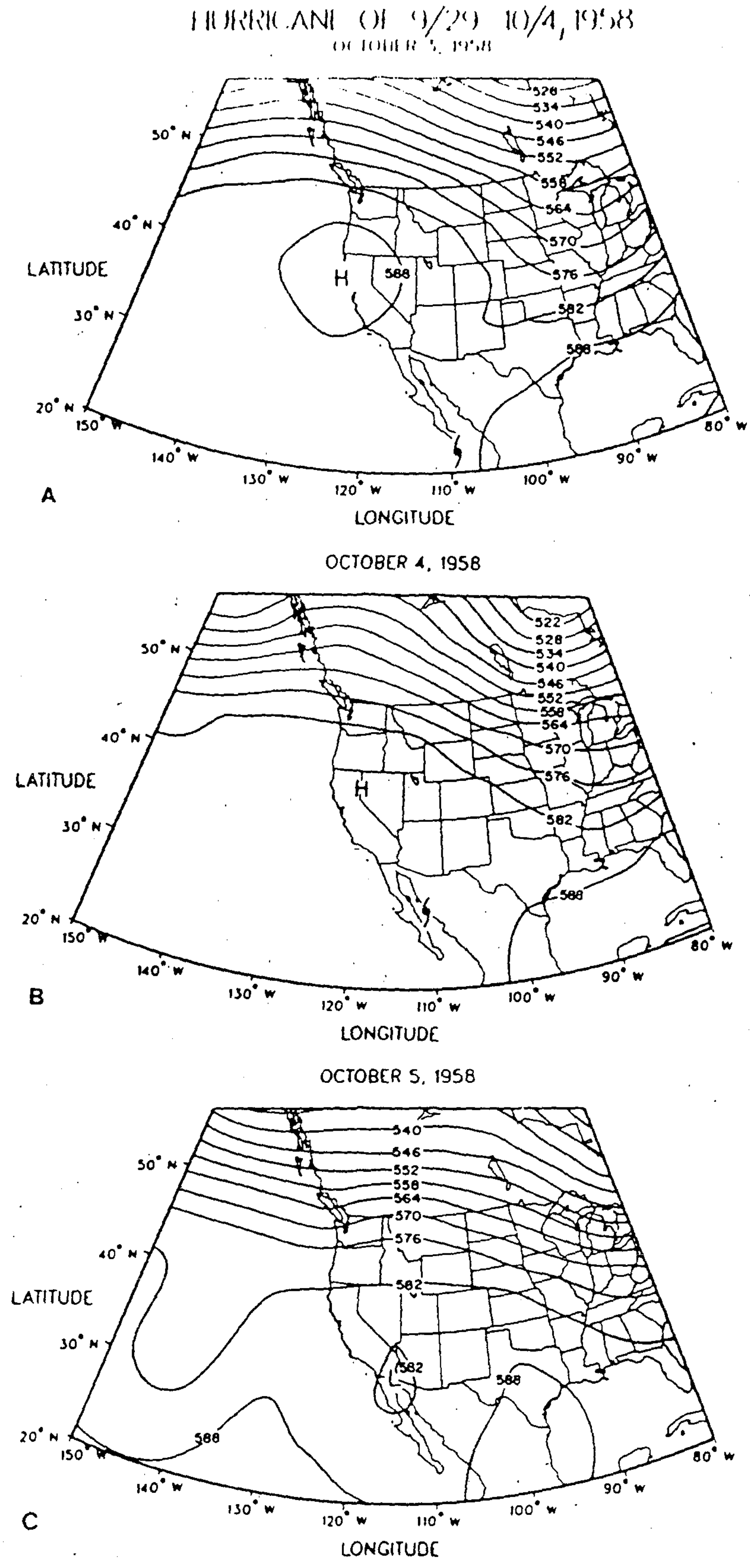


Figure 66. As in Figure 44.

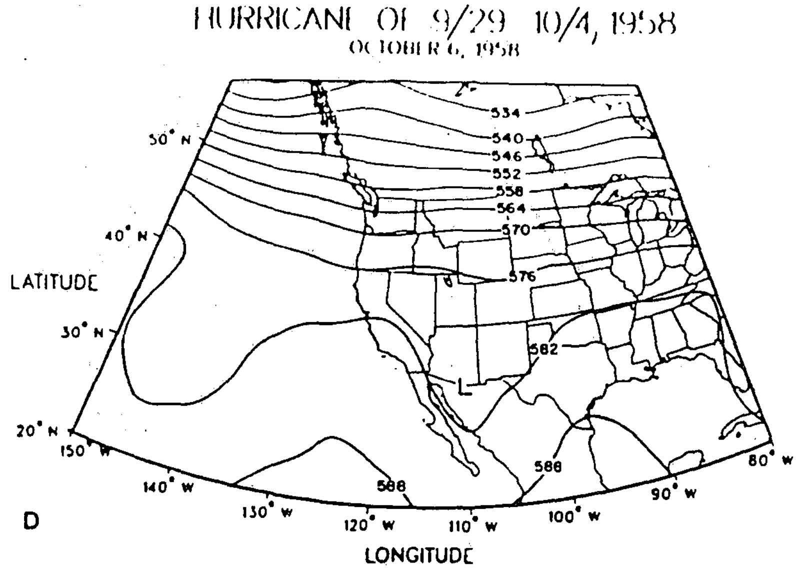


Figure 66. (continued) As in Figure 44.

Table 33. Hurricane of September 29 - October 4, 1958 daily precipitation

	October			
Station	4	5	6	Total
Kelvin, Az.	0	1.20	2.05	3.25
Mt. Lemmon Inn, Az.	00	2.42	.61	3.03

00 = trace; amounts in inches.

tracking northward (see Figure 66) and late on the 4th the hurricane went ashore near Guaymas, Sonora and rapidly weakened. Arizona and New Mexico received the bulk of the precipitation, nearly all of which fell on the 5th and 6th as the cut-off low became caught up in the westerlies and started moving east. Most places reported less than an inch of rain although the two stations listed in Table 33, Mt. Lemmon Inn and Kelvin, received more than 3.00 inches.

Hurricane of September 3-11, 1959

The sequence of events which caused the tropical cyclone to affect the southwestern United States are as follows. First, after forming along the Intertropical Convergence Zone near 12.5°N, 92.5°W on September 3, the cyclone tracked northwestward around the edge of a large ridge which forced the storm to cross the Baja peninsula north of La Paz, where 80 to 90 knot winds were reported, on the 10th. Due to the path over land the hurricane quickly weakened to tropical depression intensity on September 11 when the deep upper level trough shown in Figure 68 began bringing moisture from the cyclone over southern California thus producing widely scattered light showers. The trough eventually moved close enough to the West Coast to provide the lifting for moderate rains over much of Nevada where the highest total, 2.49 in., was recorded at Adaven. As indicated in Figure

HURRICANE OF
9/29-10/4 1958

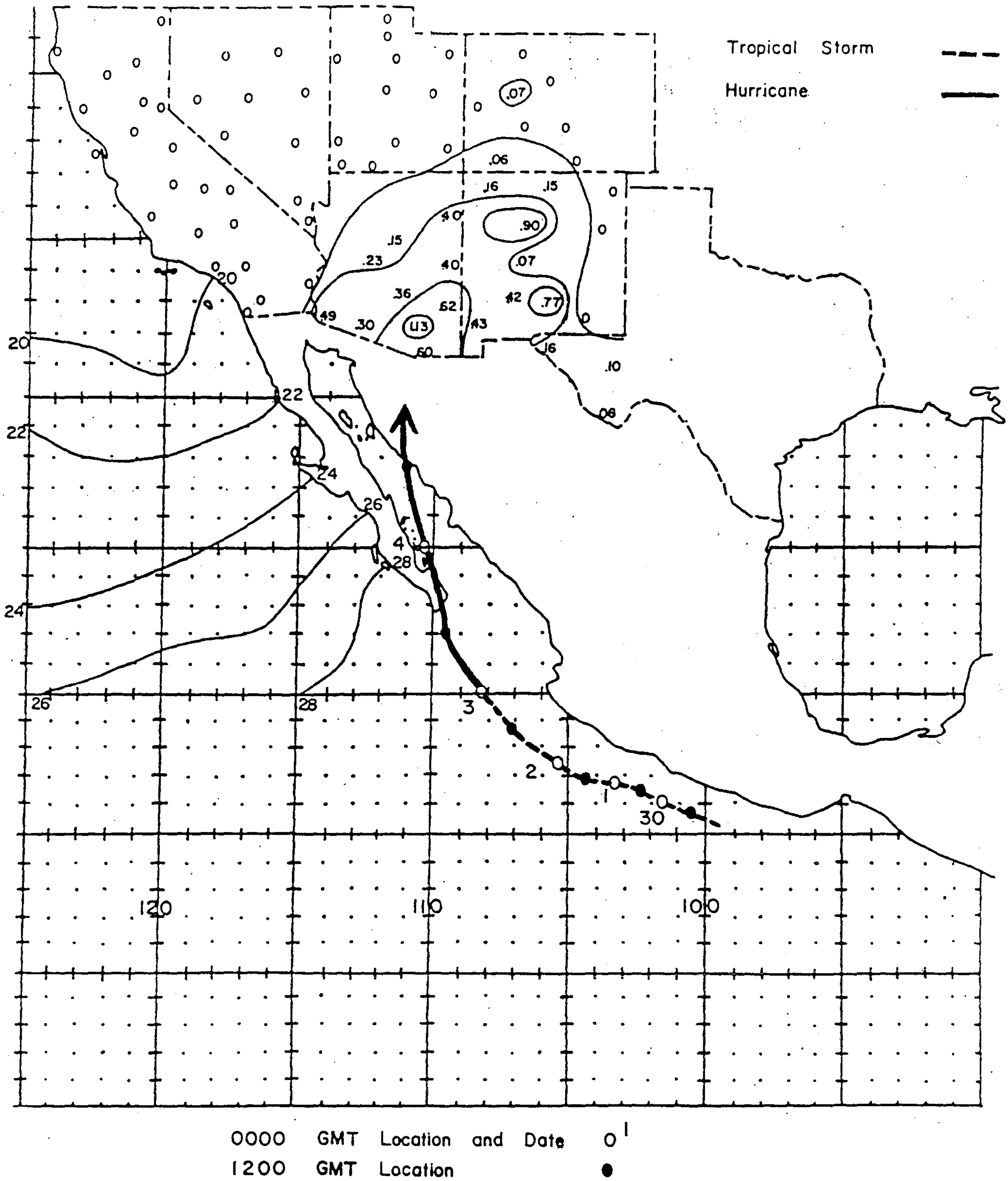


Figure 67. **Track of the Hurricane of September 29 - October 4, 1958 and associated rainfall in the Southwest.** Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches. Sea surface temperatures are in °C.

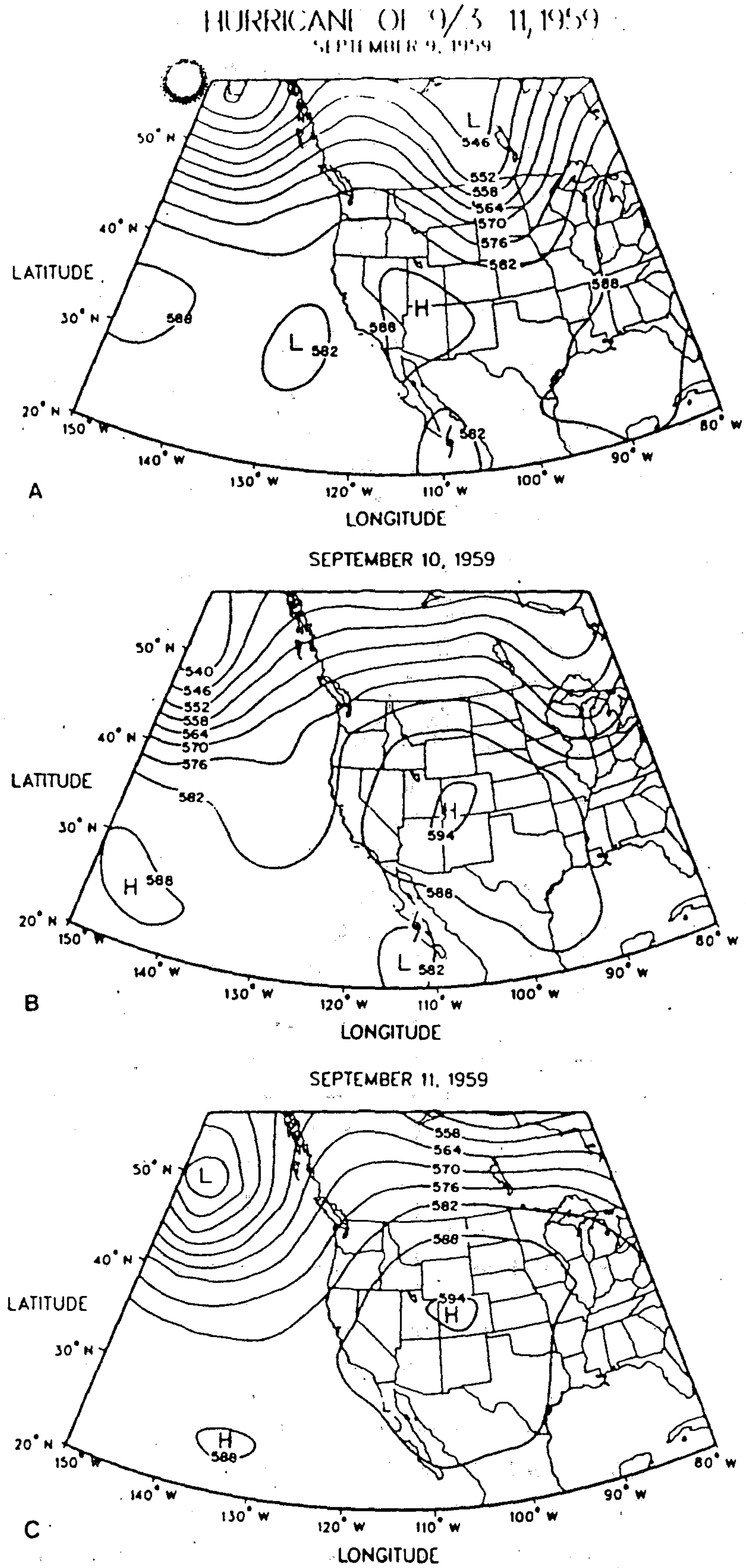


Figure 68. As in Figure 44.

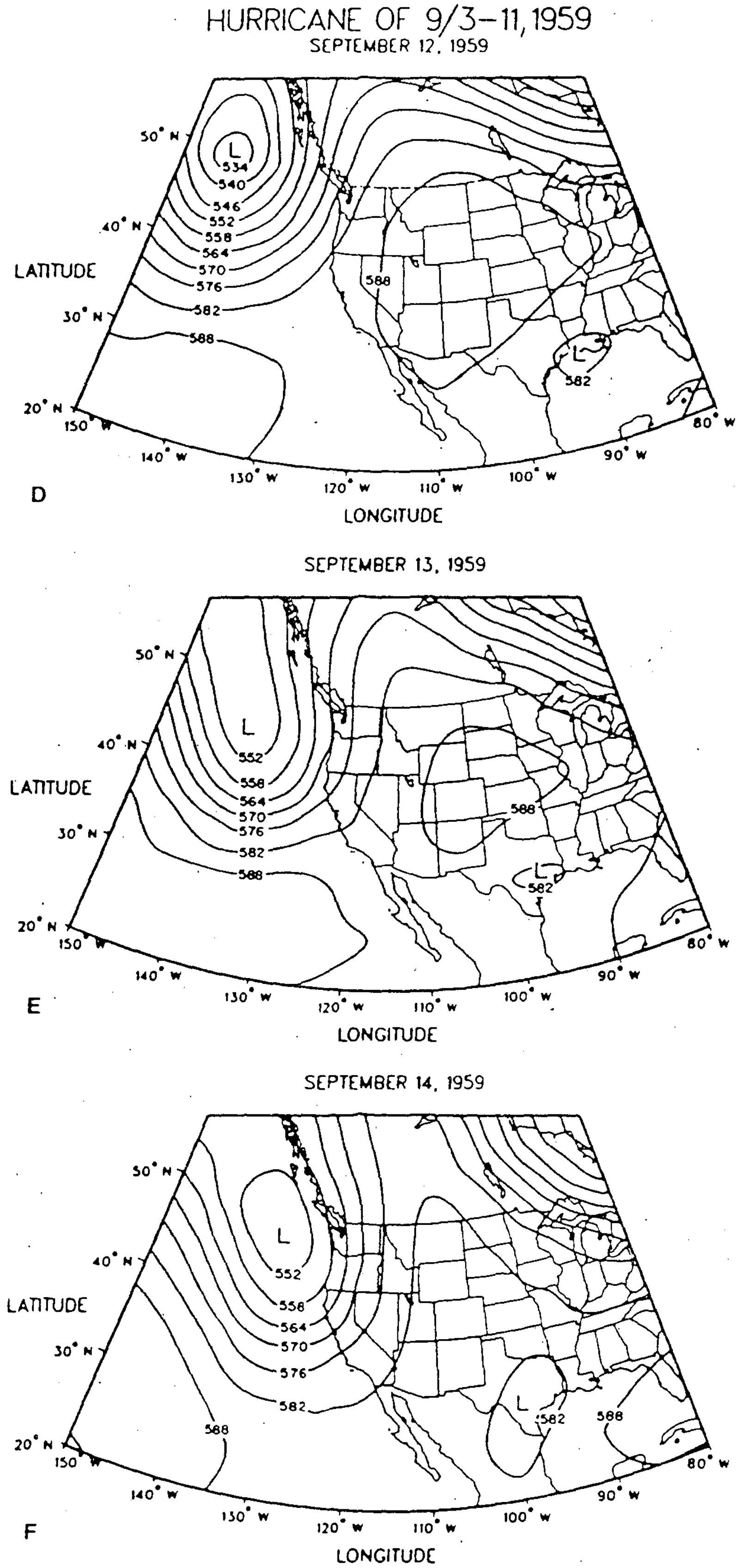


Figure 68. (continued) As in Figure 44.

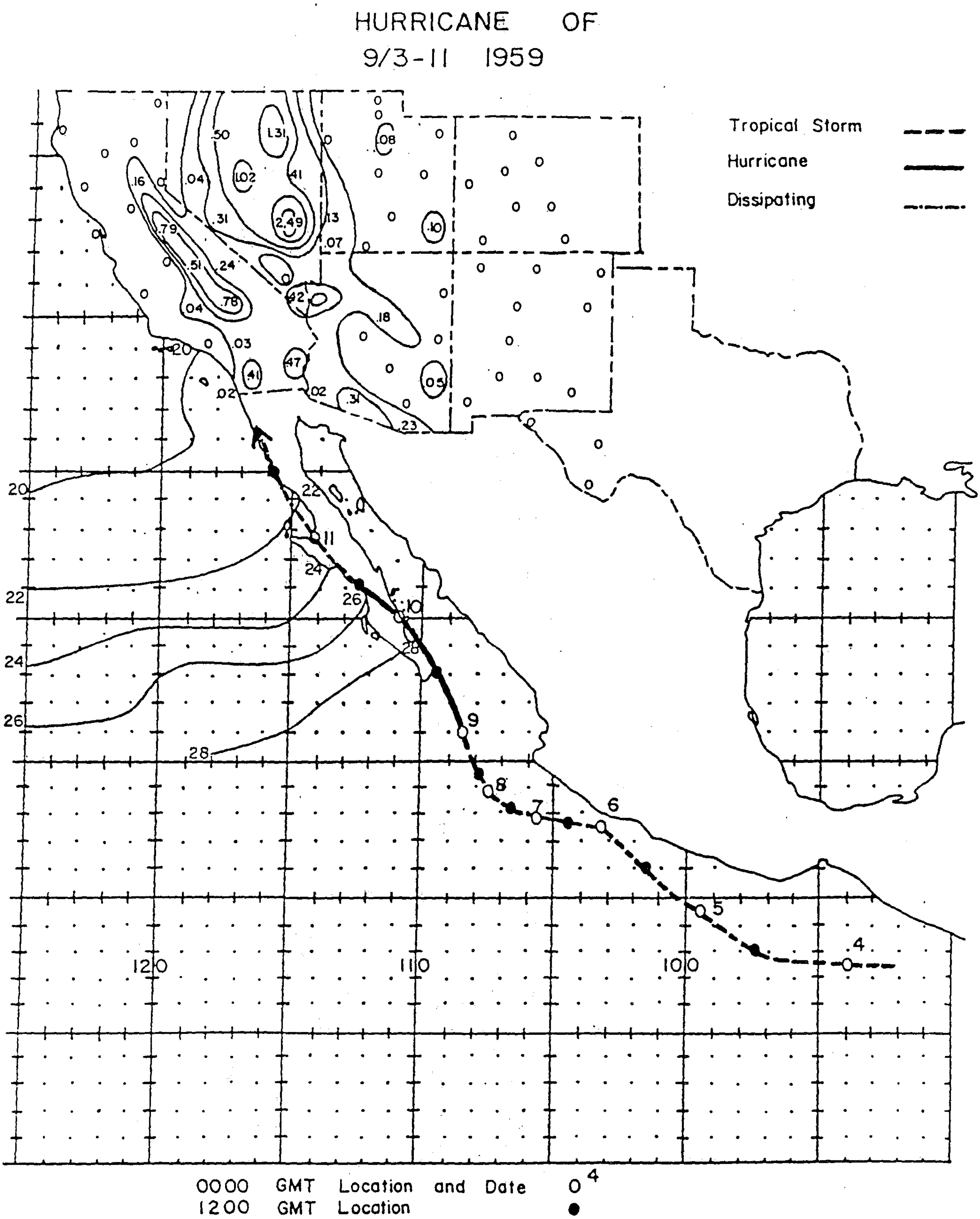


Figure 69. Track of the Hurricane of September 3-11, 1959 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

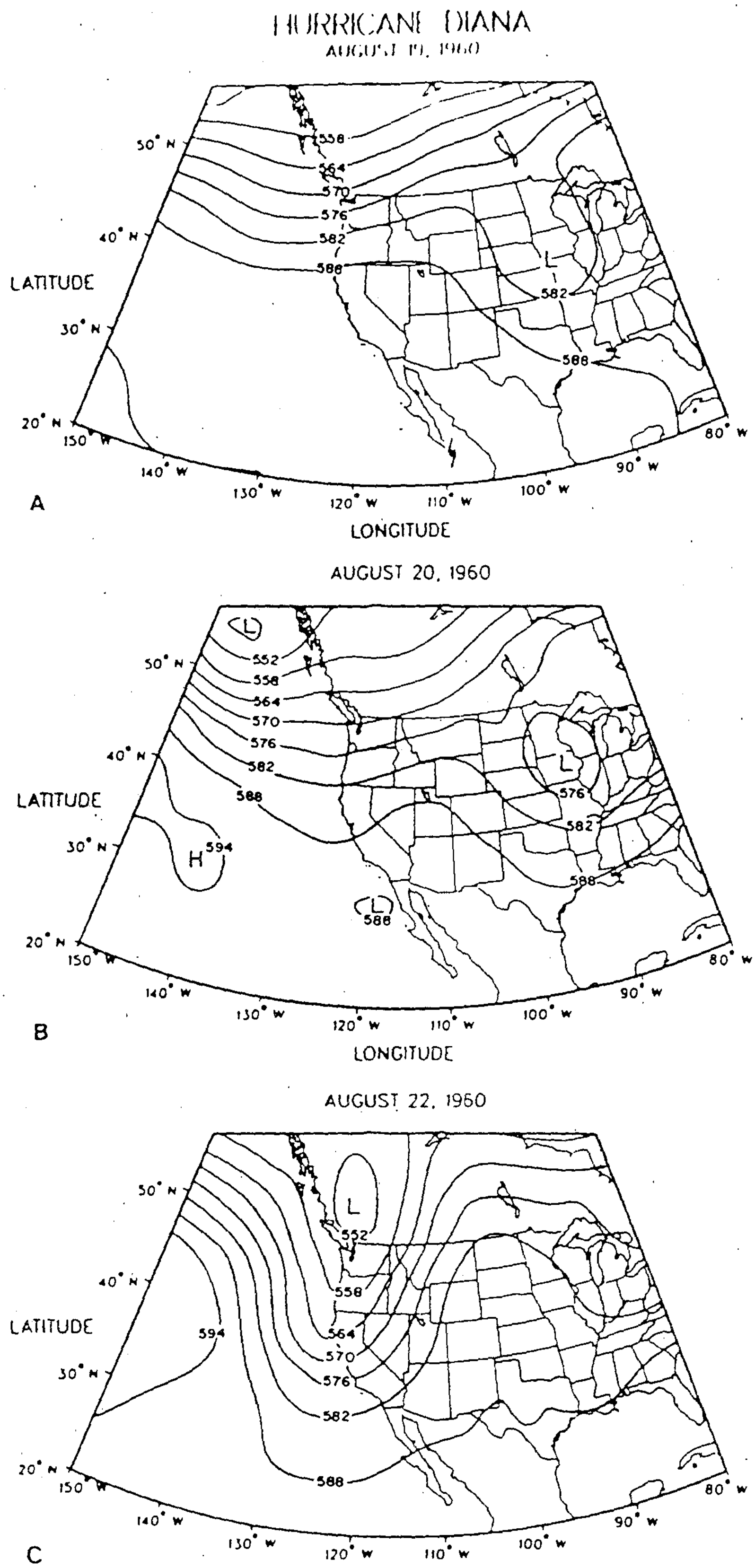


Figure 70. As in Figure 44.

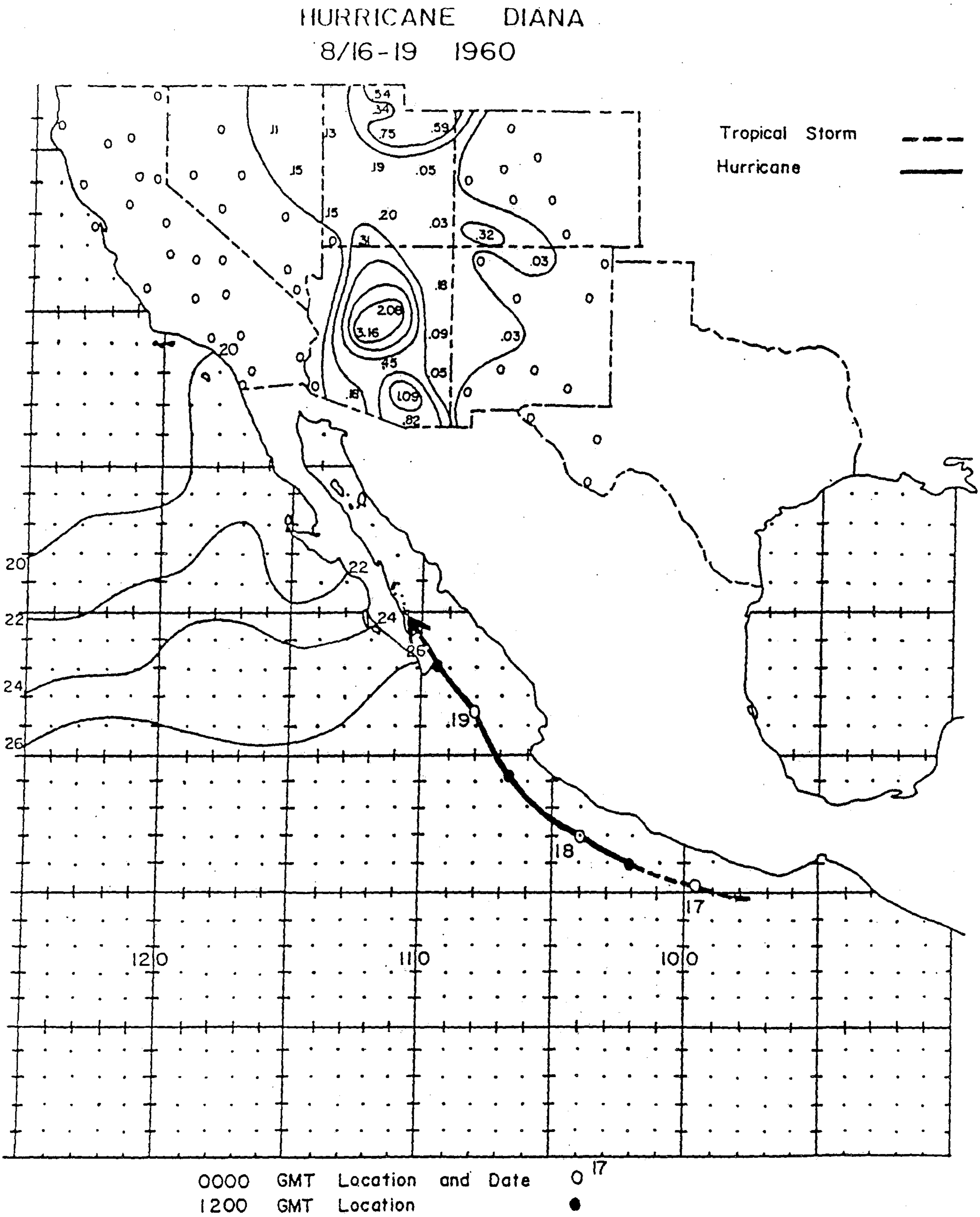


Figure 71. Track of Hurricane Diana; August 16-19, 1960; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

Table 34. Hurricane Diana; August 16-19, 1960; daily precipitation

Station	August 21	22	23	Total
Crown King, Az.	0	2.51	.80	3.31
Tonto Creek Fish Hatchery, Az.	1.19	2.14	.06	3.39
Prescott, Az.	0	3.15	.01	3.16

amounts in inches.

69, only the Sierra Nevada Mountains of California, Nevada, and the northwestern corner of Arizona received more than trivial amounts of rain.

Hurricane Diana; August 16-19, 1960

The Gulf of Tehuantepec was the origin of the disturbance that later intensified and became Hurricane Diana which then tracked northwestward, ultimately reaching the southern end of Baja California late on August 19 (Figure 71) where it dissipated. Moisture from the ex-hurricane probably combined with summer monsoon moisture on the following days, finally reaching southern Arizona on the 20th. Scattered showers began in Arizona on the 21st and were most intense and widespread on the 22nd when an unusually strong trough moved over the West Coast (Figure 70). Precipitation was confined almost entirely to Arizona and Utah as seen in Figure 71. The heaviest rains fell across northern Arizona where the three stations listed in Table 34 all received more than 3 inches.

Hurricane Estelle; August 28 - September 9, 1960

Dissipating ex-Hurricane Estelle's main effect on the Southwest was to increase the moisture content of the air over California and Arizona from September 8-10. The storm never actually reached land, dying over the cool waters of the eastern north Pacific on the 9th after a 13 day journey from near central America. As seen in Figure 72, high pressure dominated the Southwest on September 8 and 9. This suggests that moist air from the tropical cyclone and the summer monsoon flowed over California and Arizona beginning on the 8th for the rains of the 9th and 10th. Figure 73, which presents the total rainfall linked to the storm and it's track, indicates the heaviest rains were measured in southeastern Arizona and in the mountains of southern California where Julian Wynola received the largest amount, 3.40 inches.

Tropical Storm Bernice; September 1-6, 1962

The sequence of 500 mb height maps plotted in Figure 74 are misleading in that they suggest the upper level winds in the vicinity of Tropical Storm Bernice blew from the northwest from the 2nd through the 6th, nearly opposite the direction the storm moved. However, southeasterly winds prevailed from the 2nd to

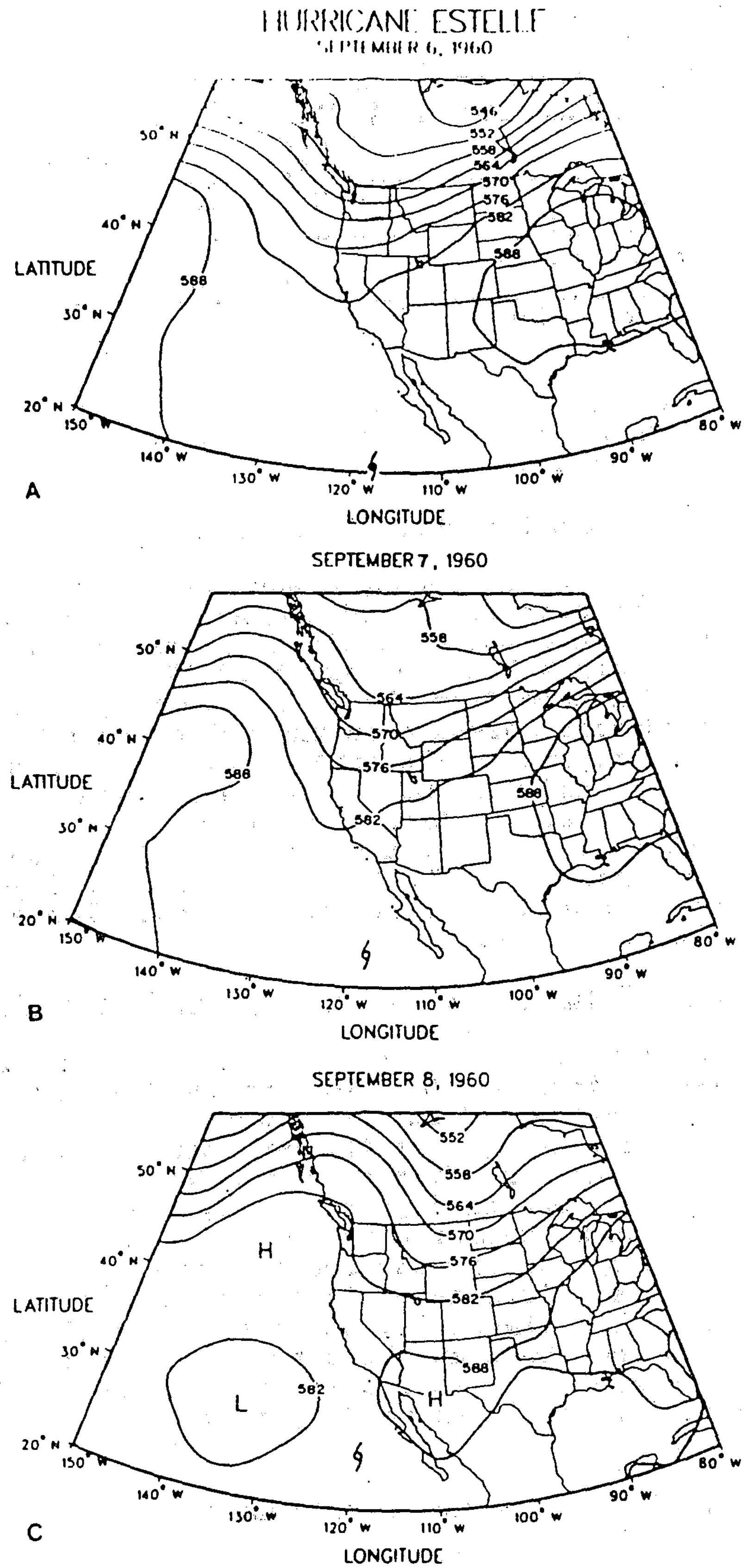


Figure 72. As in Figure 44.

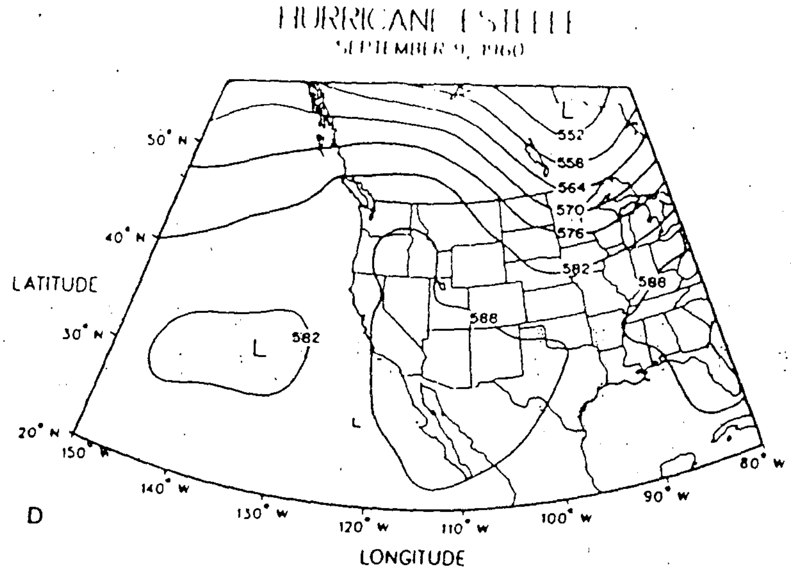


Figure 72. (continued) As in Figure 44.

the 4th because the storm tracked in that direction as indicated in Figure 75. Beginning on September 4, the steering winds became extremely light for the weakening tropical cyclone moved only about 400 km in a little more than 2 days (approximately 2 ms^{-1}). Moisture from the dissipating storm spread over Arizona, New Mexico, and westernmost Texas on the 4th resulting in isolated light rains. Precipitation peaked on the following two days as the weak trough located over southern California in Figure 74D headed eastward lifting the remaining moist air causing light to moderate showers. The two highest rainfall totals were 1.98 in. at Heber Ranger Station, Arizona and 1.95 in. at El Paso.

Tropical Storm Claudia: September 20-24, 1962

The tropical cyclone was first detected on the 20th several hundred kilometers due west of Acapulco by a ship which reported 35 kn winds and a pressure of a 1000 mb. Tropical Storm Claudia moved northwestward for the next 3 days, gradually weakening, before recurving to the north-northeast across Baja California on September 23 and 24 (see Figure 77). The cyclone dissipated shortly afterwards.

Precipitation linked to the storm began on the 22nd as indicated in Table 35, which presents daily rainfall totals at some selected stations, when winds from the south-southwest (Figure 76B) advected moisture over southern Arizona. The rain became more widespread on the 24th when the main body of moist air associated with the ex-tropical storm began streaming over the Southwest. The most intense showers occurred on the 26th when a short wave broke through the ridge that was moving eastwards across the West Coast (Figures 76E and F). Torrential rains of 5 to 7 in. fell that day to the west and northwest of Tucson and caused widespread flooding. Most stations in Arizona,

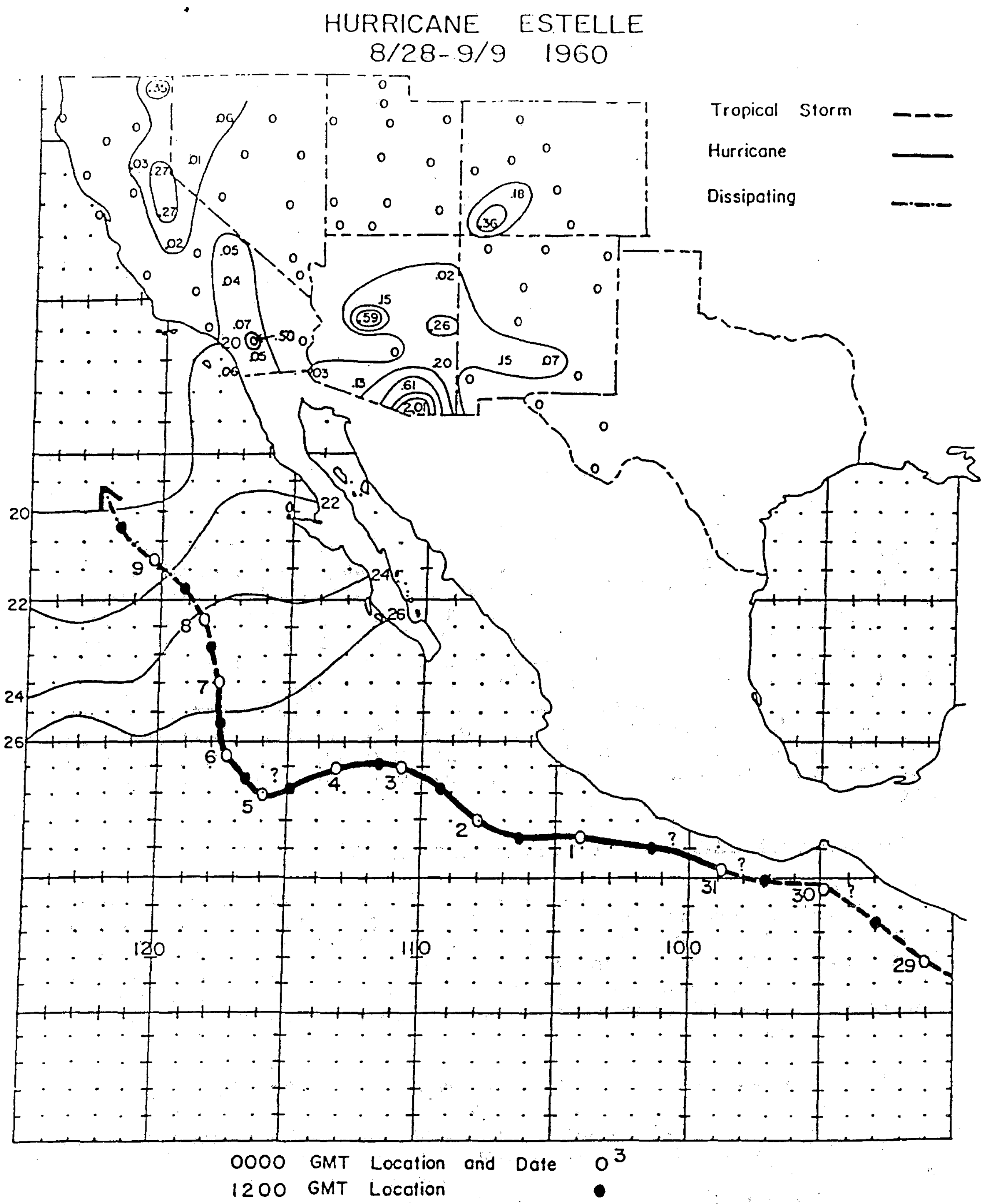


Figure 73. Track of Hurricane Estelle; August 28 - September 9, 1960; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00 and 2.00 inches. Sea surface temperatures are in °C.

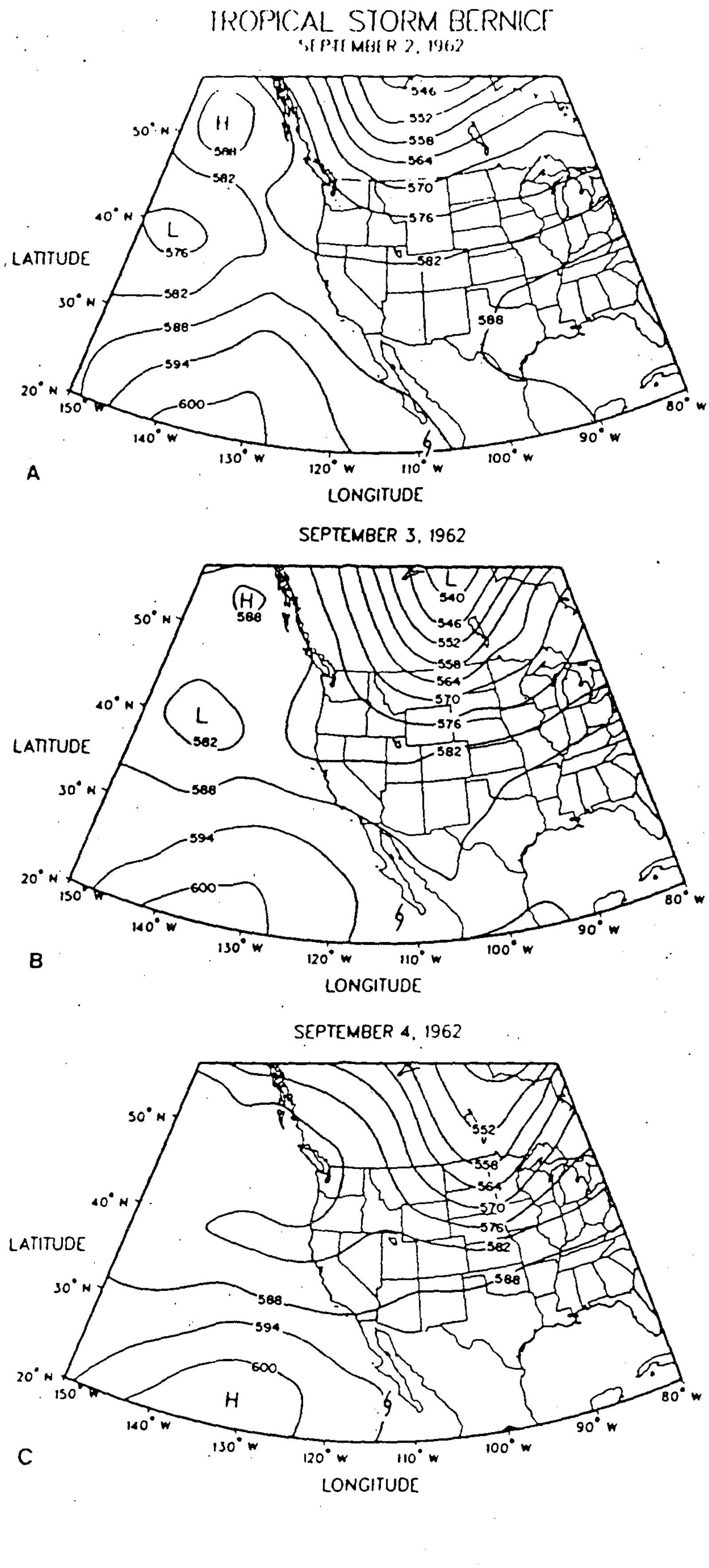


Figure 74. As in Figure 44.

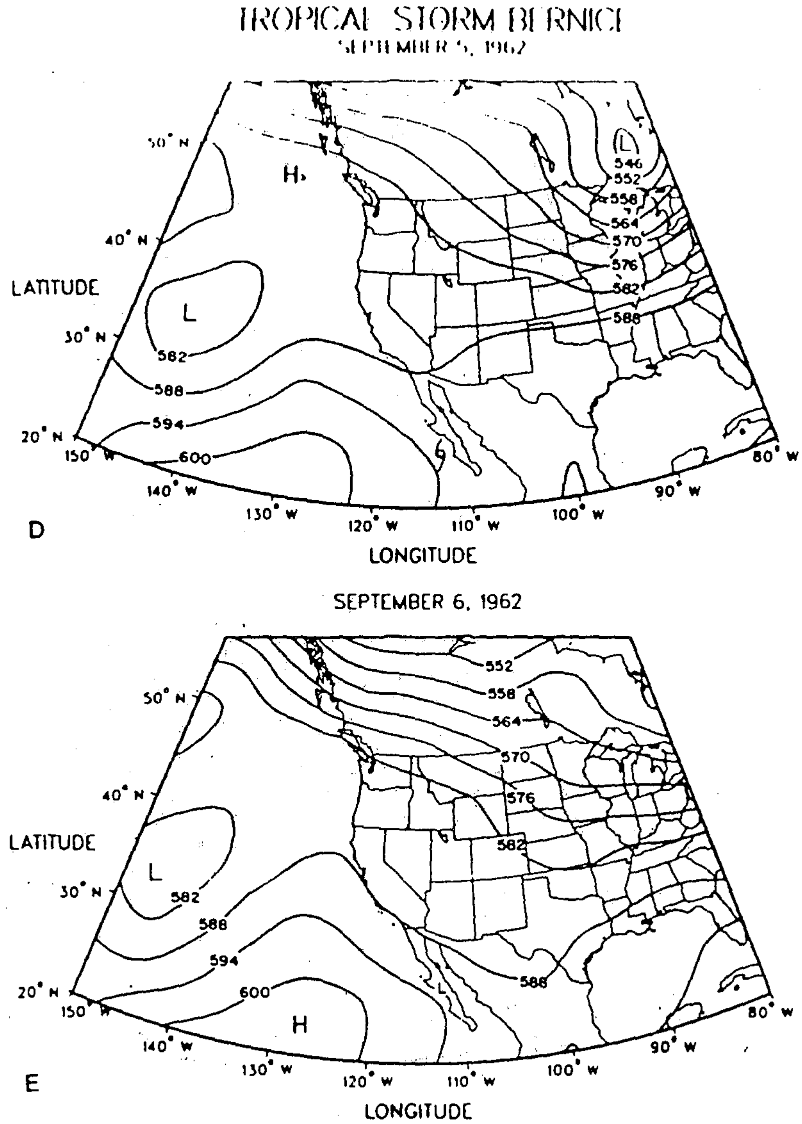


Figure 74. (continued) As in Figure 44.

Table 35. Tropical Storm Claudia; September 20-24, 1962; daily precipitation

	September								
Station	22	23	24	25	26	27	28	29	Total
Blue, Az.	0	.10	1.00	.30	1.40	.30	.30	0	3.40
Clifton, Az.	0	0	.15	.20	2.95	0	0	0	3.30
Organ Pipe National Monument, Az.	.41	.23	.44	1.18	1.19	0	0	0	3.45
Sells, Az.	0	0	0	0	3.55	.45	0	0	4.00
Tucson WSO, Az.	.01	00	.20	00	2.40	0	0	0	2.61
Buckhorn, NM.	0	.20	.26	.06	3.08	0	.07	0	3.67
Hillsboro, NM.	0	.18	0	1.28	1.08	.37	.10	0	3.01
Pinos Altos, NM.	0	.21	.24	1.85	.47	.48	.07	.11	3.43
Ruidoso, NM.	0	.45	1.59	.50	.88	.08	0	0	3.50

00 = trace; amounts in inches.

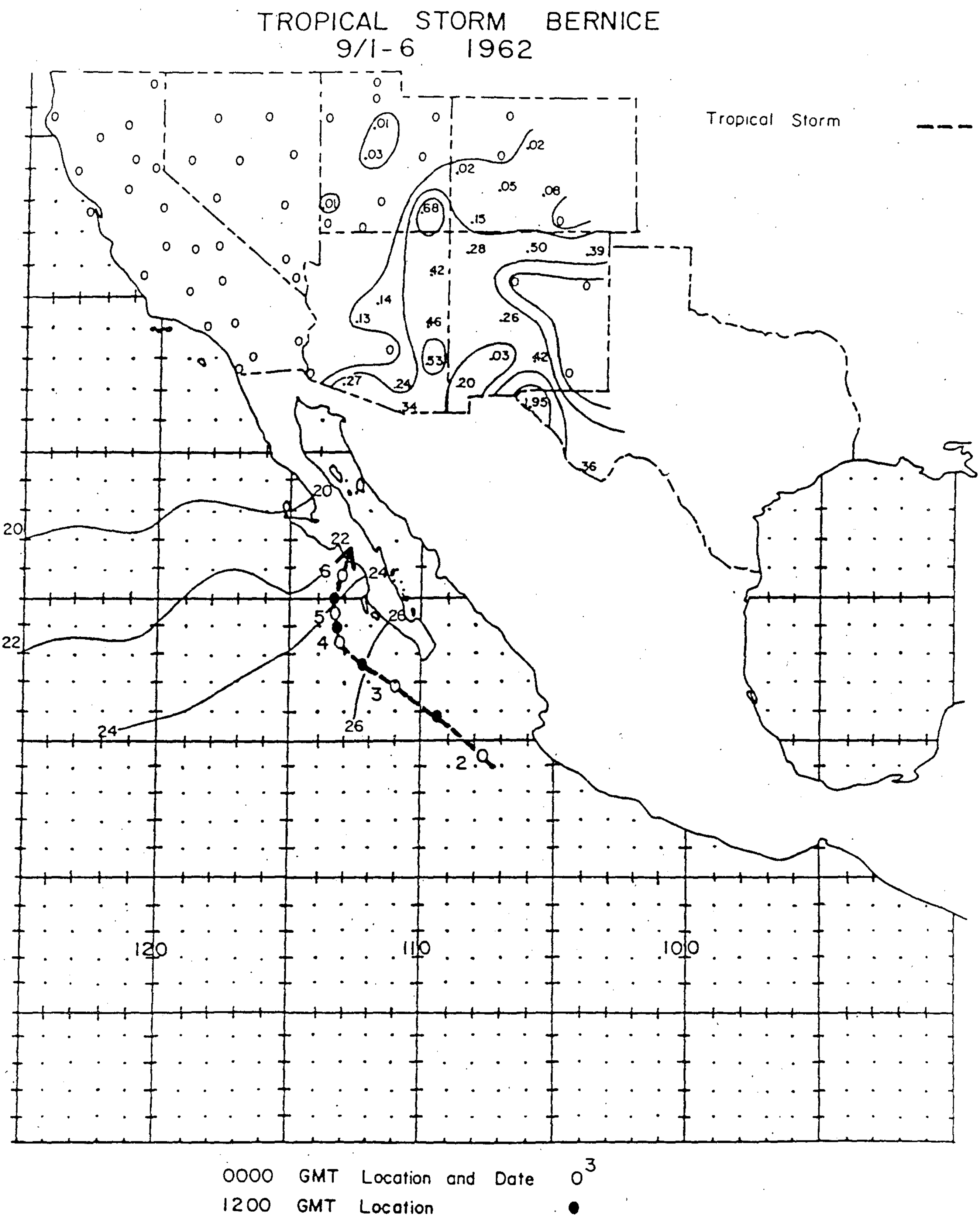


Figure 75. Track of Tropical Storm Bernice; September 1-6, 1962; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches. Sea surface temperatures are in °C.

TROPICAL STORM CLAUDIA
SEPTEMBER 21, 1962

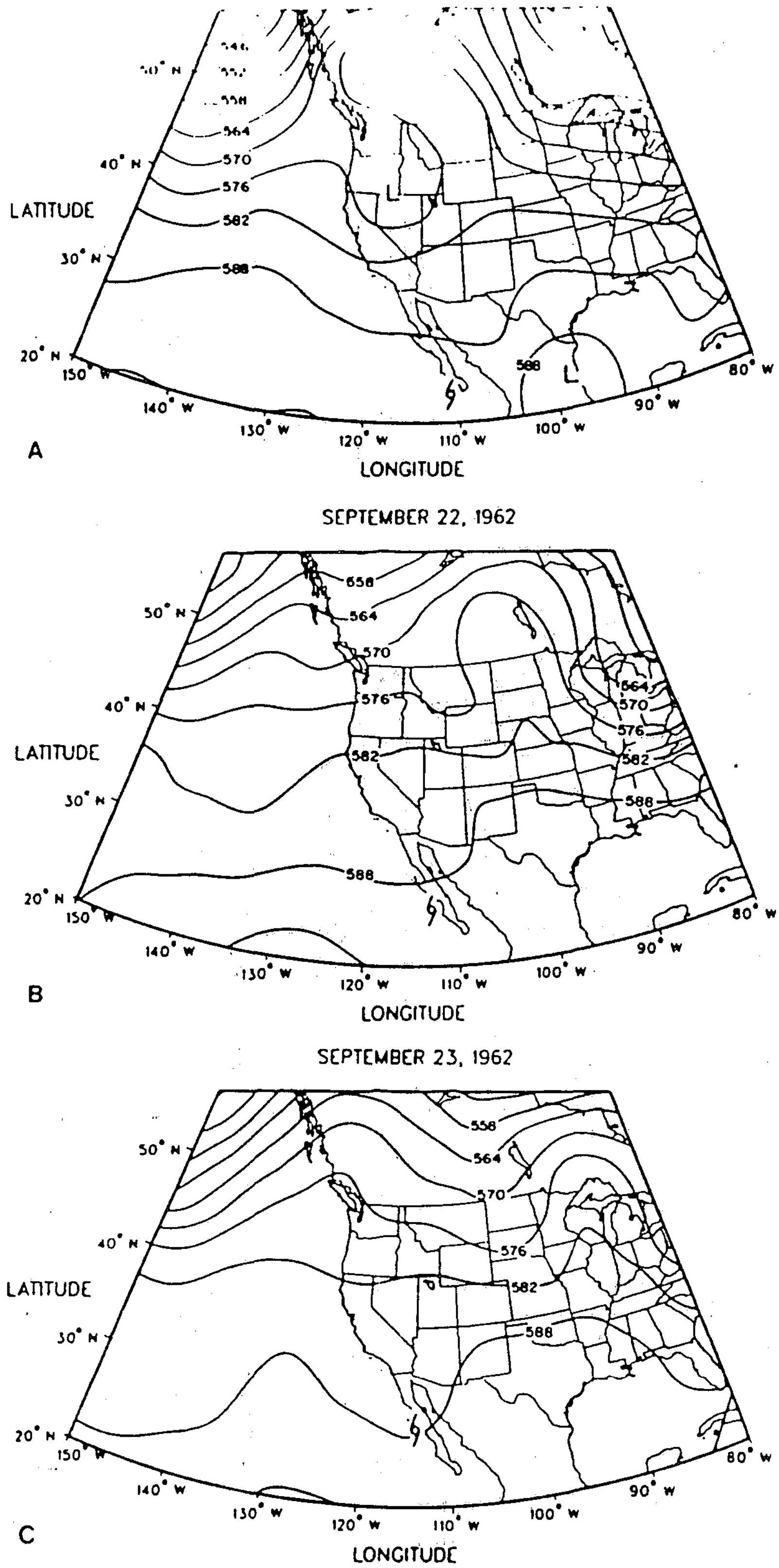


Figure 76. As in Figure 44.

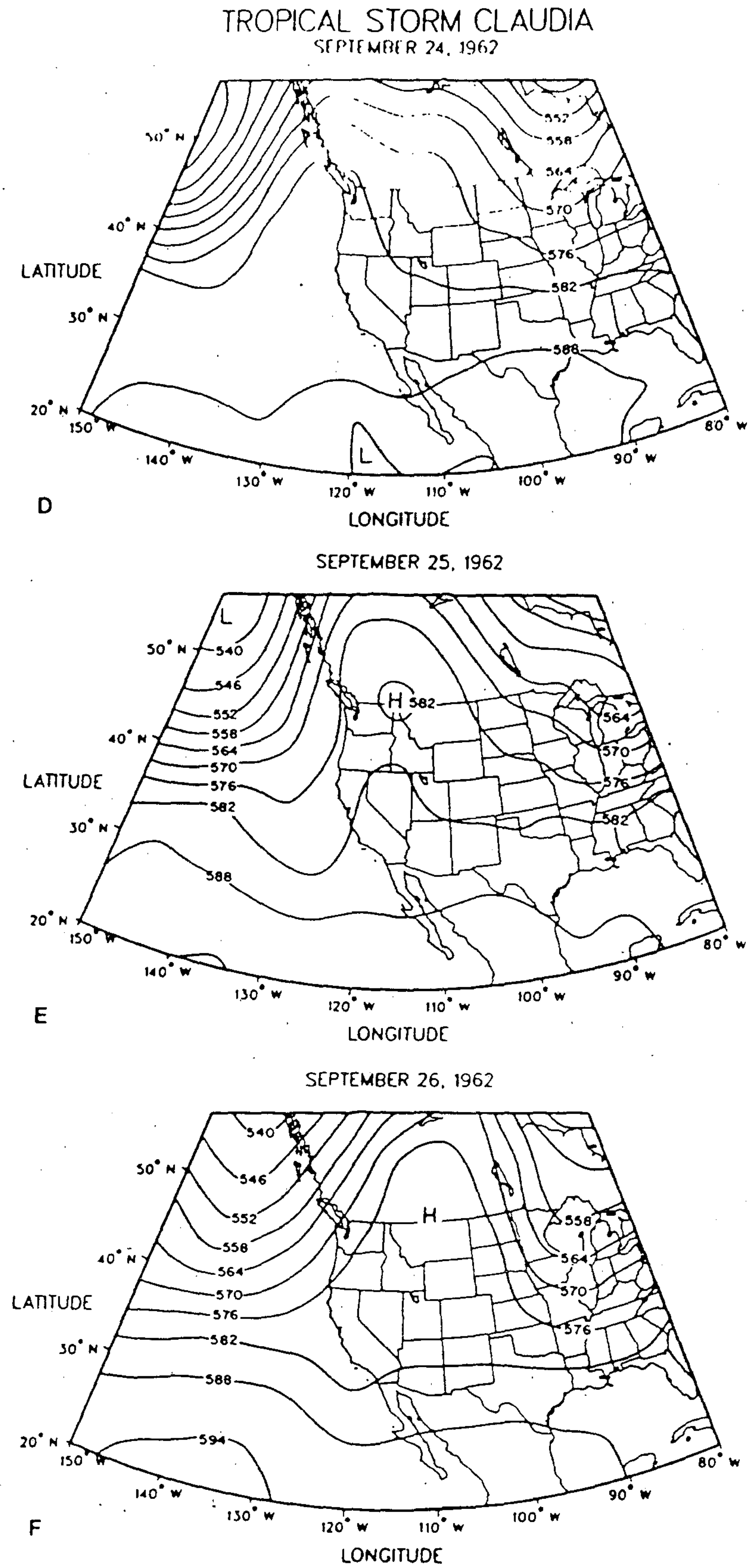


Figure 76. (continued) As in Figure 44.

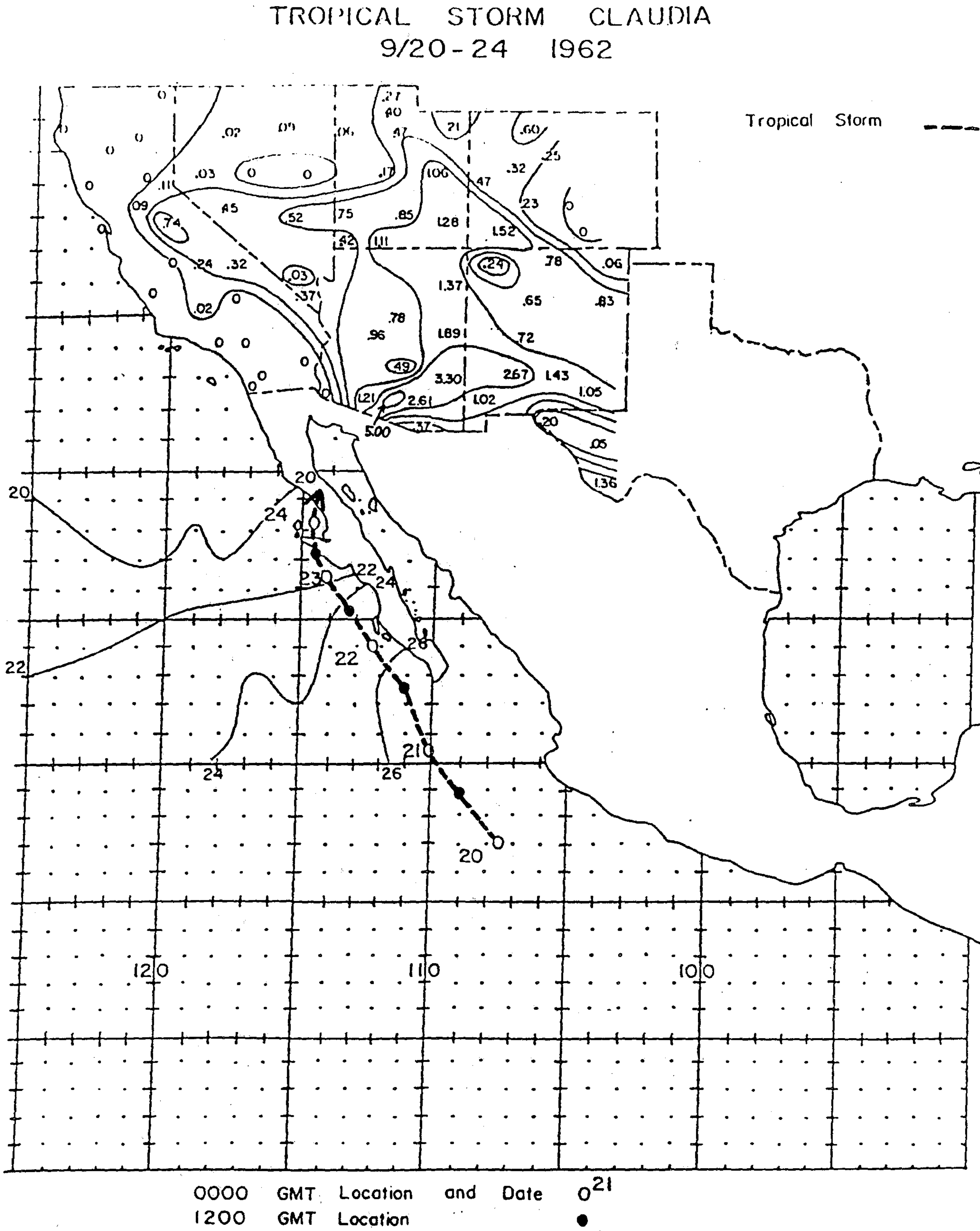


Figure 77. Track of Tropical Storm Claudia; September 20-24, 1962; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches. Sea surface temperatures are in °C.

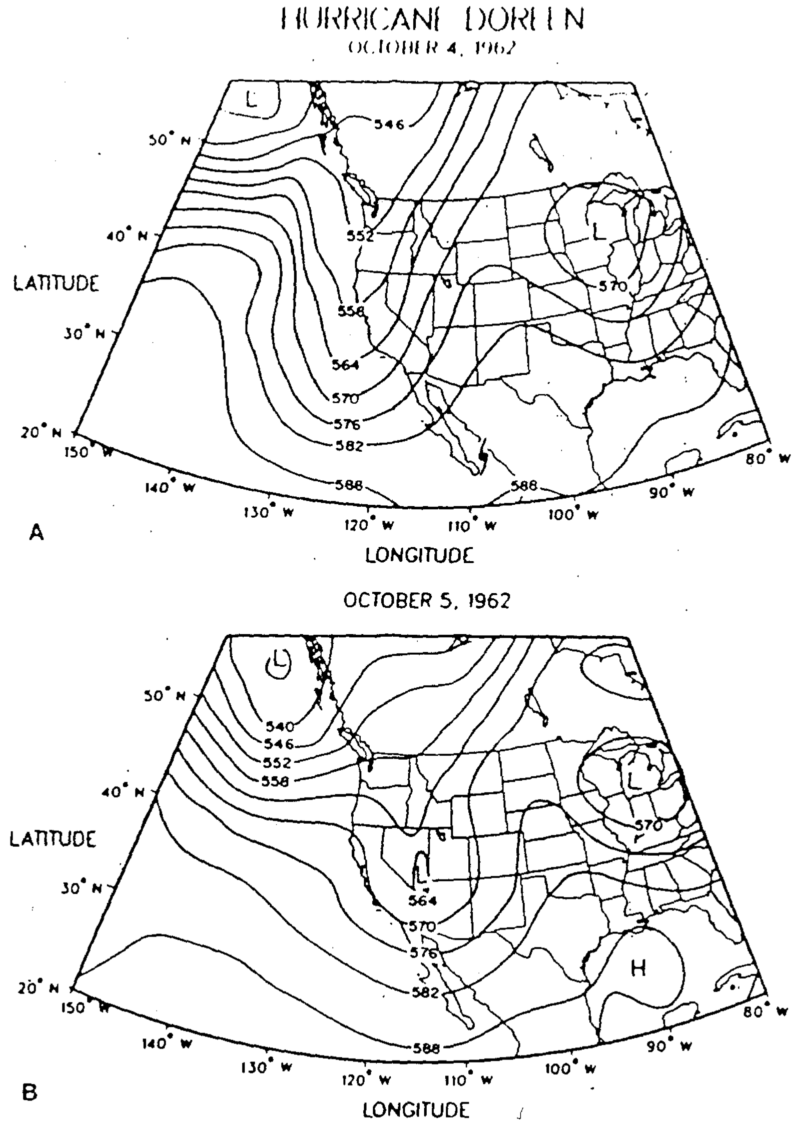


Figure 78. As in Figure 44.

New Mexico, southern Utah, and southwestern Colorado received at least a half inch of rain before the showers ended on the 29th and many reported more than an inch. The heaviest rains, as delineated by the two inch isohyet in Figure 77, fell in a 200 km wide band which extended from just west of Tucson eastward to the Sacramento Mountains of New Mexico where Ruidoso measured 3.50 inches.

<u>Hurricane Doreen: October 1-5, 1962</u>

A digging trough caused Hurricane Doreen to recurve inland over Sinaloa state, Mexico on October 4 (Figure 78) and brought moist air from the storm over the Southwest. In contrast with Tropical Storm Claudia, rainfall was light as shown in Figure 79. The tropical cyclone was the source of the moisture for most of the showers that fell in Arizona, New Mexico, and west Texas

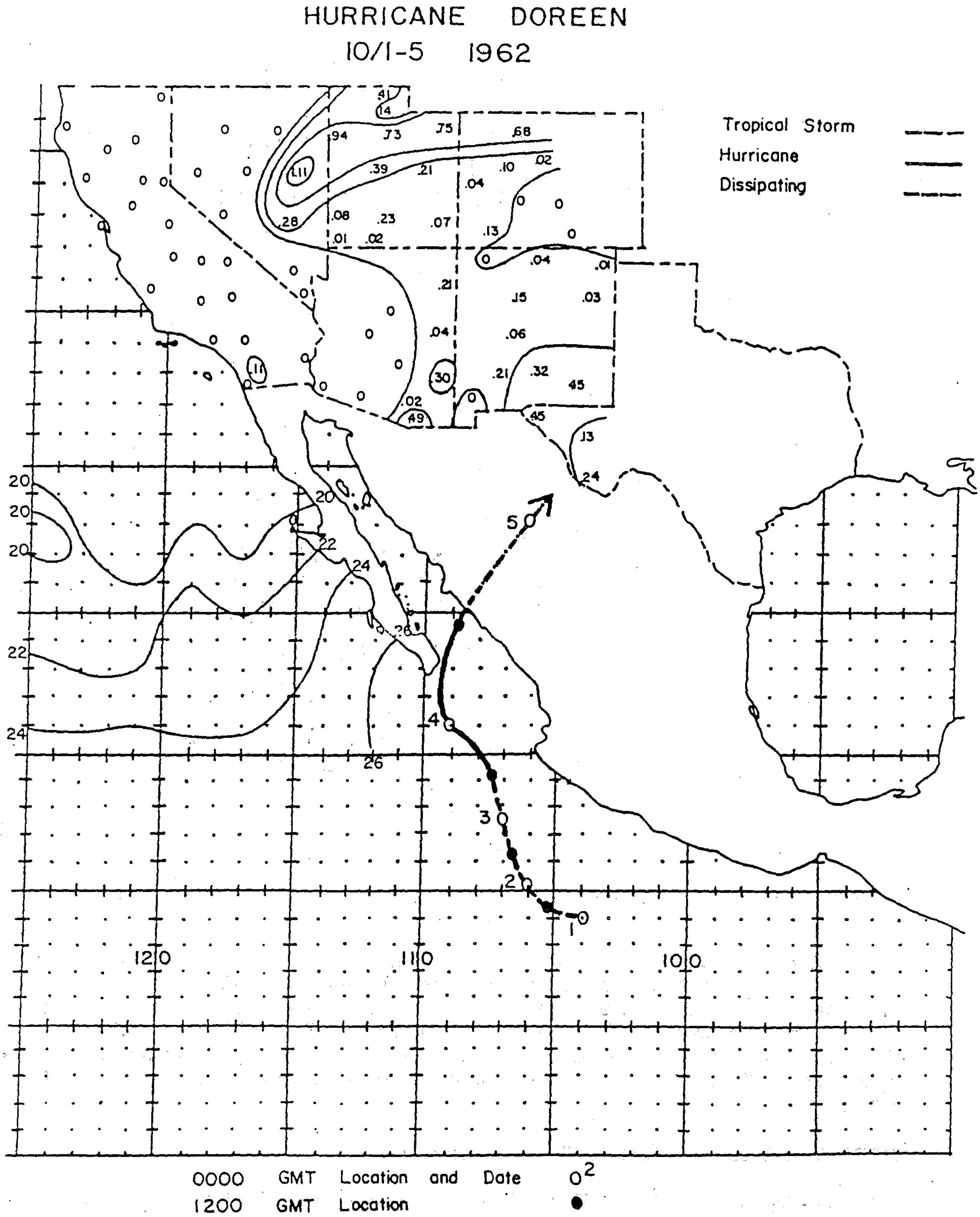


Figure 79. Track of Hurricane Doreen; October 1-5, 1962; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches. Sea surface temperatures are in °C.

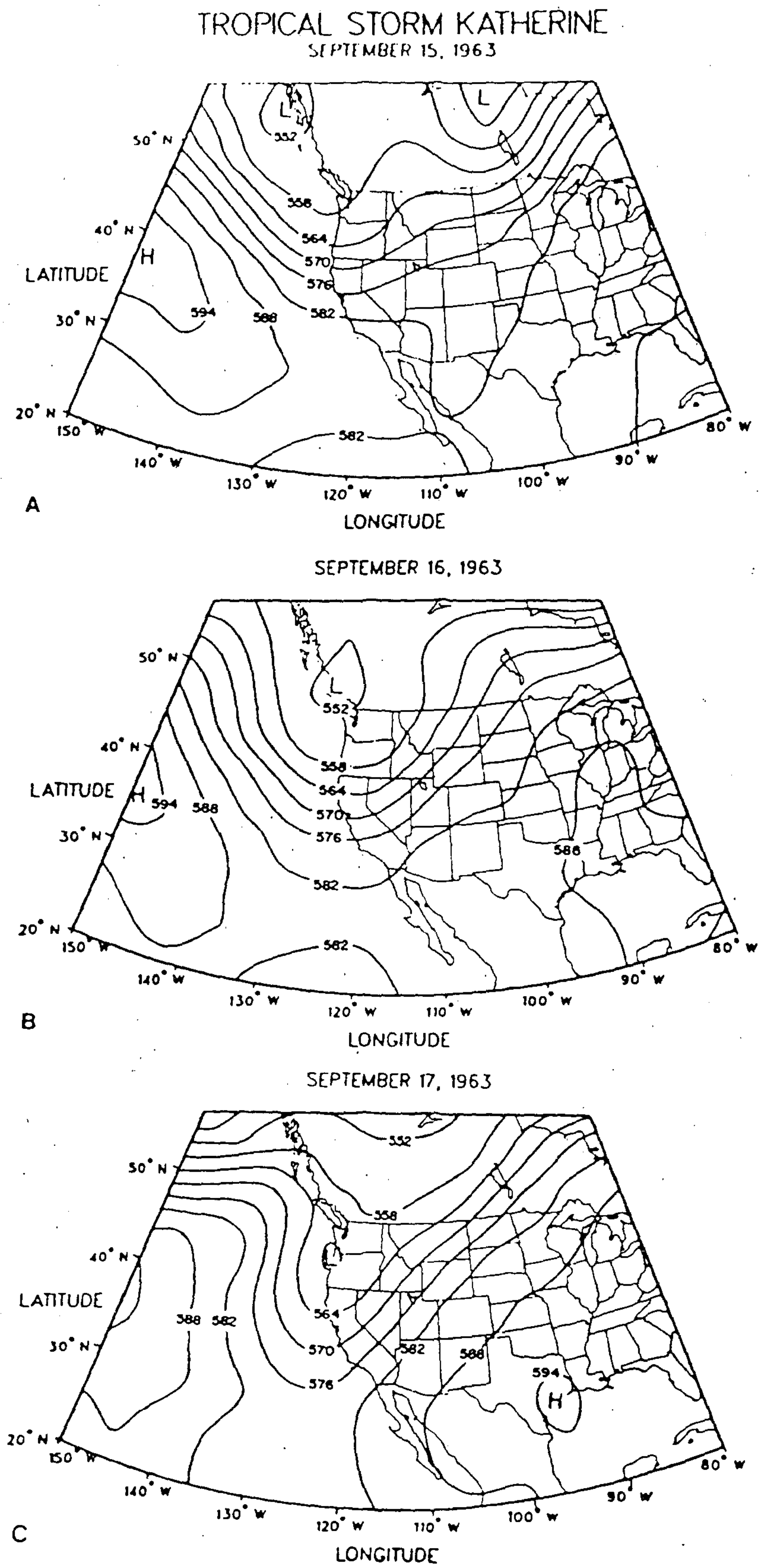


Figure 80. As in Figure 44.

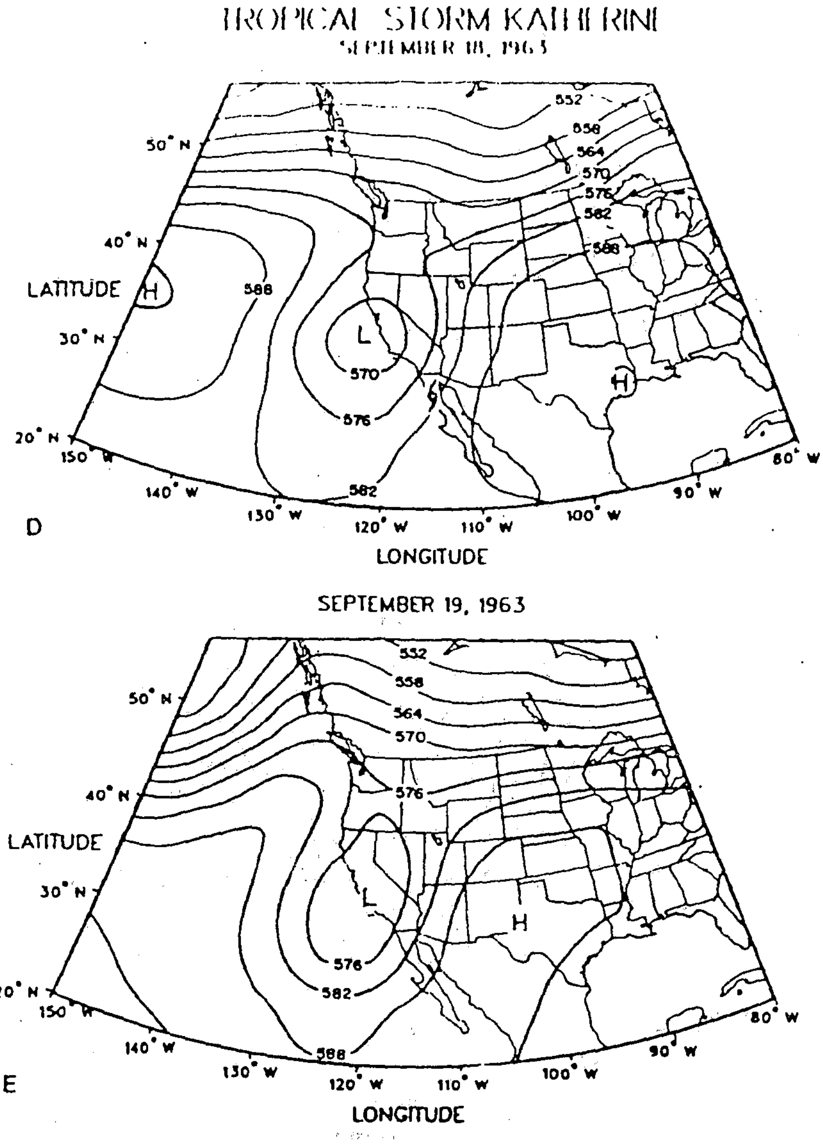


Figure 80. (continued) As in Figure 44.

while the midlatitude trough most likely was the source for the precipitation in the states of Nevada, Utah, and Colorado.

<u>Tropical Storm Katherine: September 17-18, 1963</u>

Satellite imagery, if available in September 1963, would have detected this tropical cyclone days before the 17th when several ships finally reported the storm only a few hundred kilometers southwest of Ensenada, Baja California. Figure 81 shows SSTs along the known path of the cyclone were less than 22°C, far below the threshold temperature of 26.5°C required for the genesis of tropical cyclones (Anthes, 1982). Thus, Tropical Storm Katherine, which may have been a hurricane before being located, must have formed much farther to the southeast of its first documented position; 28.5°N, 117°W.

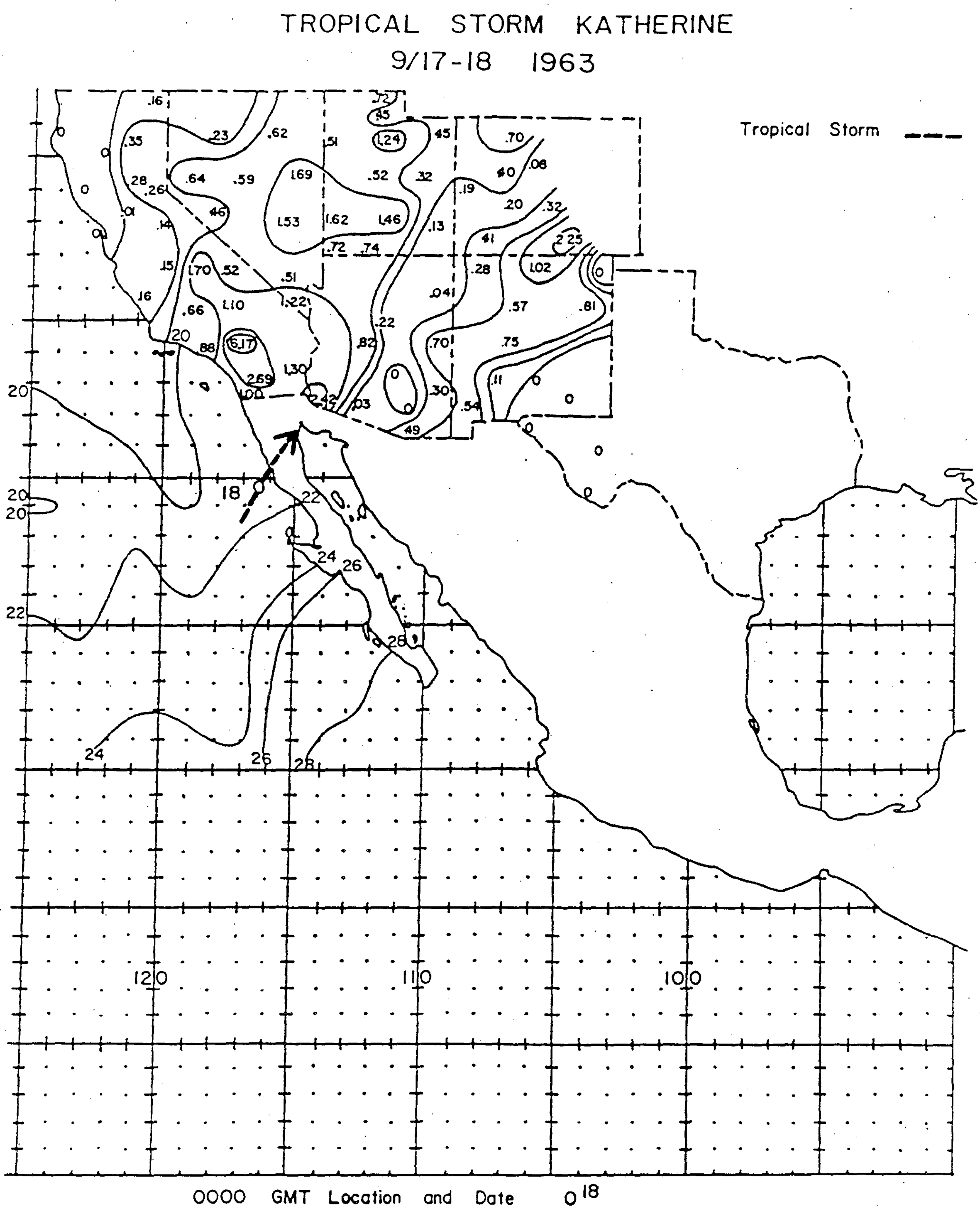


Figure 81. Track of Tropical Storm Katherine; September 17-18, 1963; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches. Sea surface temperatures are in °C.

Table 36. Tropical Storm Katherine; September 17-18, 1963; daily precipitation

Station	September 17	18	19	20	Total
Crown King, Az.	0	2.29	0	0	2.29
Yuma WSO, Az.	2.42	0	0	0	2.42
Bryce Canyon National Park, Utah	0	3.15	.01	.02	3.18
Lake Arrowhead, Ca.	1.27	2.99	1.91	0	6.17
Squirrel Inn 1, Ca.	1.23	4.26	1.05	0	6.54

amounts in inches.

A developing upper level trough, which later became cut-off from the westerlies (see Figure 80), caused the tropical cyclone to recurve inland with winds of at least 50 kn about 150 km south of Ensenada. Precipitation began on the 17th in southern California and around Yuma where a heavy thunderstorm dropped 2.42 in. of rain in less than 3 hours and caused flooding that resulted in widespread property damage, especially to newly planted lettuce. Crops also were damaged in California by heavy rains. Table 36 shows the most intense rainfall occurred on the 18th when many stations from the mountains of southern California to the mountains of northern Arizona and southwestern Utah received in excess of 2.00 inches. The 6.54 in. of rain measured at Squirrel Inn 1 was the largest storm total.

Tropical Storm Tillie; September 7-9, 1964

Precipitation from the 8th through the 11th was deemed to be related to the tropical cyclone for several reasons. First, a considerable increase in dewpoint temperature and shower activity occurred over southeastern Arizona on September 4, at least one day before the disturbance that later became Tropical Storm Tillie formed, which strongly suggests a return of monsoon weather. Also, the circulation was not favorable for the importation of moisture from the vicinity of the cyclone to the southwestern U.S. until about the 8th, when upper level winds over the eastern north Pacific west of Baja California turned from a westerly to a south-southwesterly direction (Figure 82). In addition, rainfall associated with the ex-tropical storm probably ended on the 11th because the cyclone had completely dissipated two days earlier (see Figure 83) and the bulk of the moist air from the dead storm had moved over the Southwest on the 10th producing heavy rains. Finally, upper level winds became south-southeasterly over the southern parts of Arizona and New Mexico on September 11 (map not shown) bringing back monsoon moisture.

As indicated in Figure 83, the most significant rains fell in southeastern Arizona, southern New Mexico, and around El Paso, Texas. Many stations in those areas received more than 2.00 in. of rain. The heaviest rains fell in southeastern Arizona where Tucson WSO received 3.11 in. of precipitation, 3.05 in. in 24 hours, from the 8th-11th and Amado 1SE (approximately 50 km due

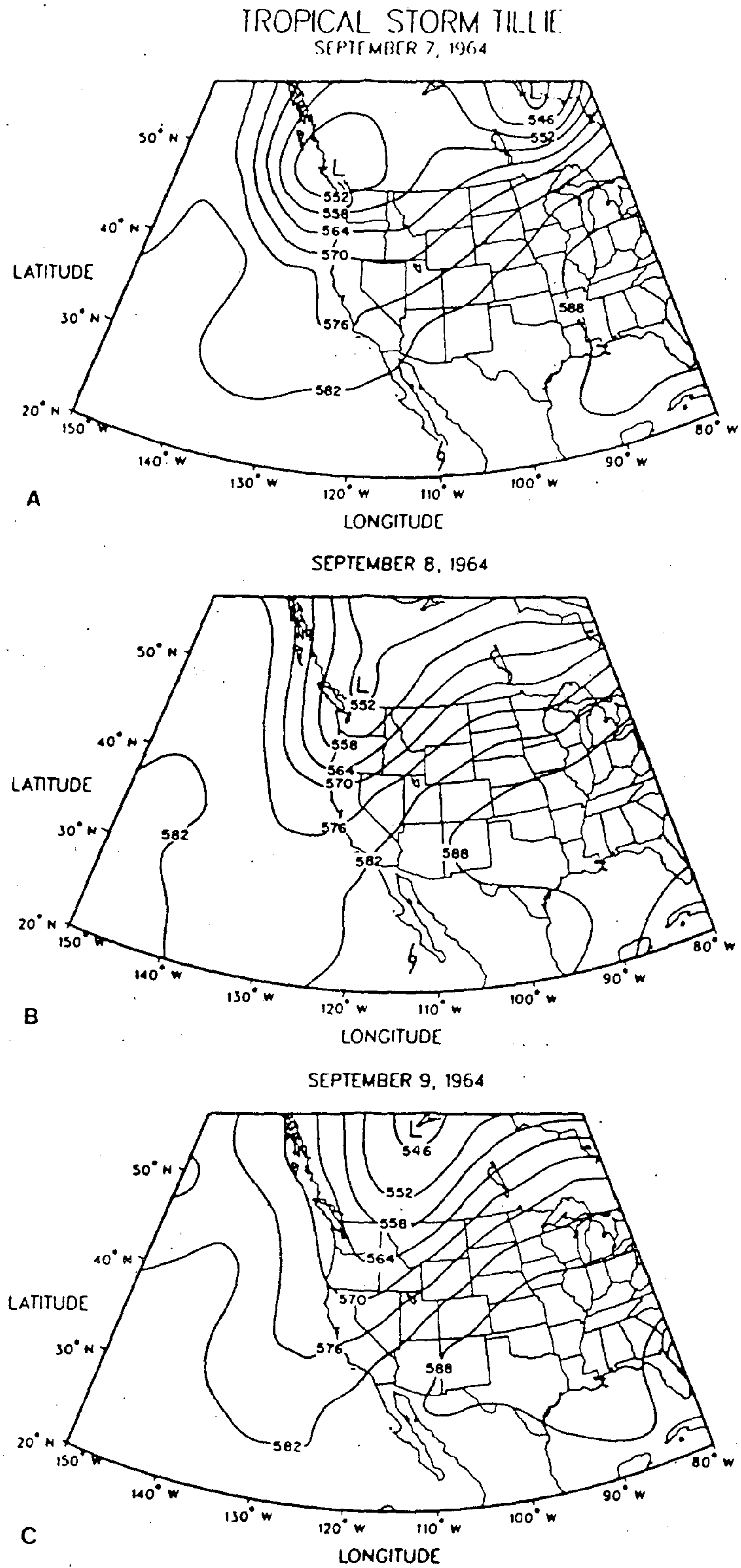


Figure 82. As in Figure 44.

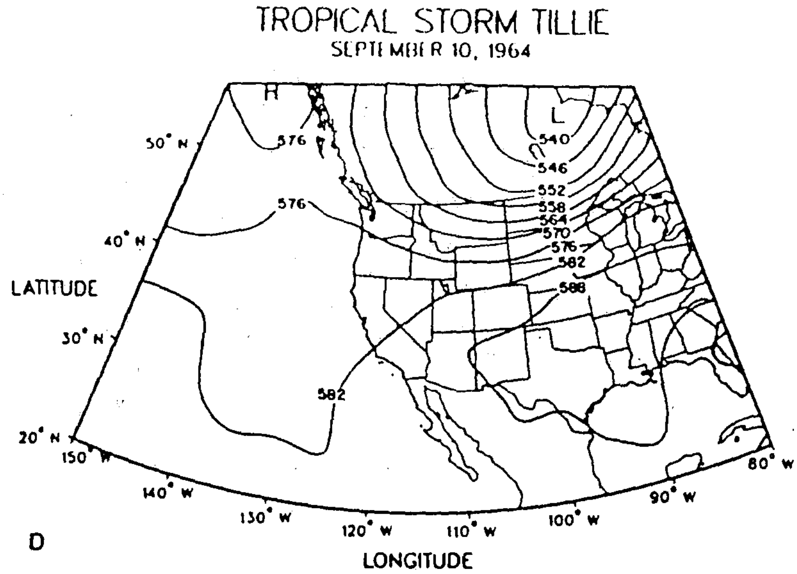


Figure 82. (continued) As in Figure 44.

Table 37. Tropical Storm Tillie; September 7-9, 1964; daily precipitation

	September				
Station	8	9	10	11	Total
Amado 1SE, Az.	.12	1.02	4.52	0	5.66
Tucson WSO, Az.	.05	.21	2.85	00	3.11

00 = trace; amounts in inches.

south of Tucson WSO) measured 5.66 in., the greatest amount related to Tropical Storm Tillie (Table 37).

Hurricane Emily; August 29 - September 4, 1965

This tropical cyclone formed in a large area of low pressure on August 29 as indicated in Figure 85, which shows the track of the storm and related rainfall over the Southwest. For the next 2 days the storm slowly intensified while proceeding toward the north and northwest, becoming a hurricane on September 1. Hurricane intensity was short lived because the cyclone moved over relatively cool water later on the 1st and continued moving over progressively cooler water until it finally dissipated on the September 4.

Winds steering the weakening storm were light form the 2nd through the 4th and the cyclone moved only a short distance in that time. However, late on the 4th, a trough developed over the West Coast (Figure 84) and caused upper level winds to increase in strength and turn to the southwest over the ex-hurricane. Subsequently, moist air was advected over the Southwest. Showers became more numerous on September 6 when the trough deepened but they were never widespread or heavy except over northern Utah where 2.00 in. of precipitation was measured at several places, including Silver Lake, which recorded the highest total of 2.79 inches.

TROPICAL STORM TILLIE
9/7-9 1964

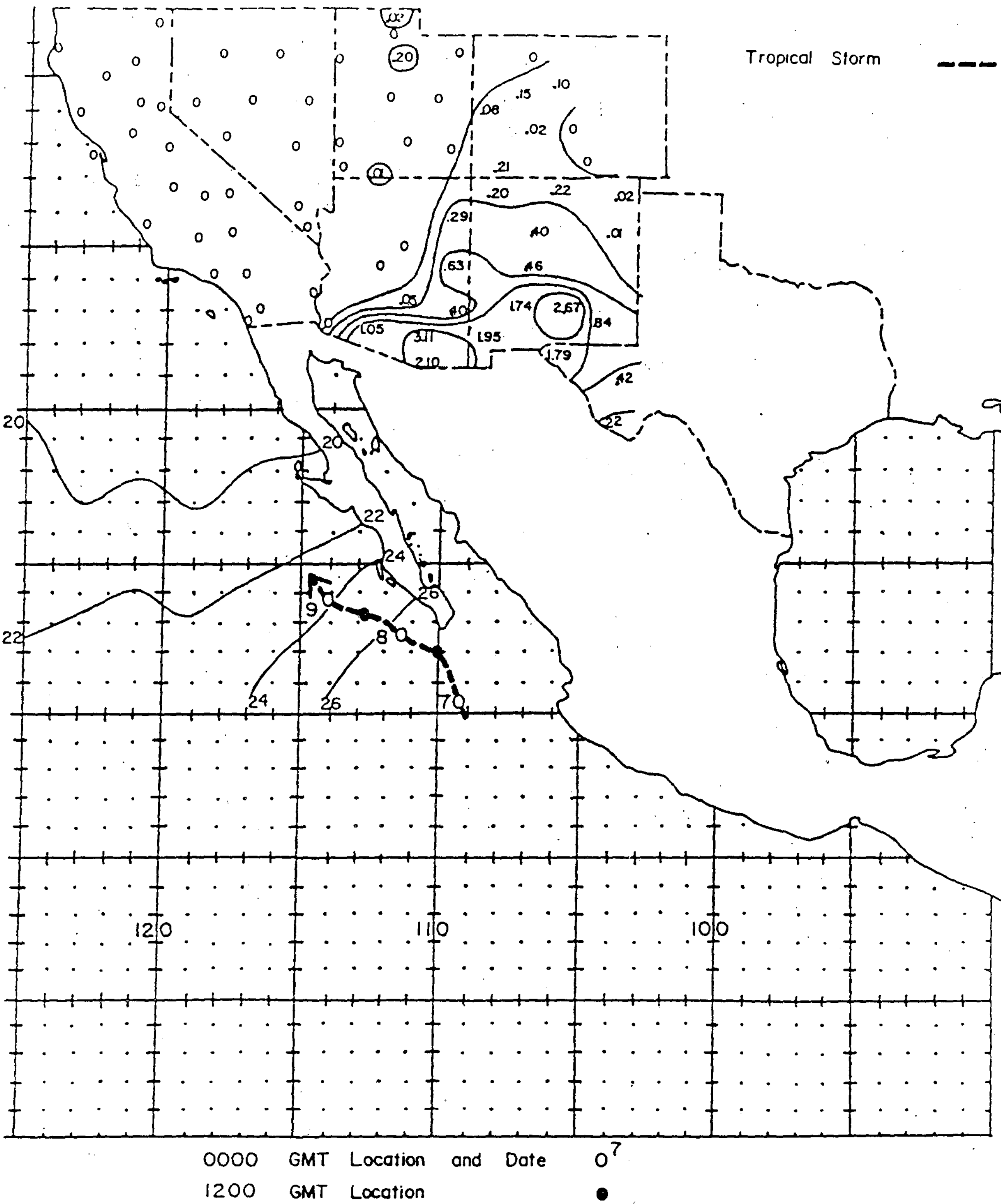


Figure 83. Track of Tropical Storm Tillie; September 7-9, 1964; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

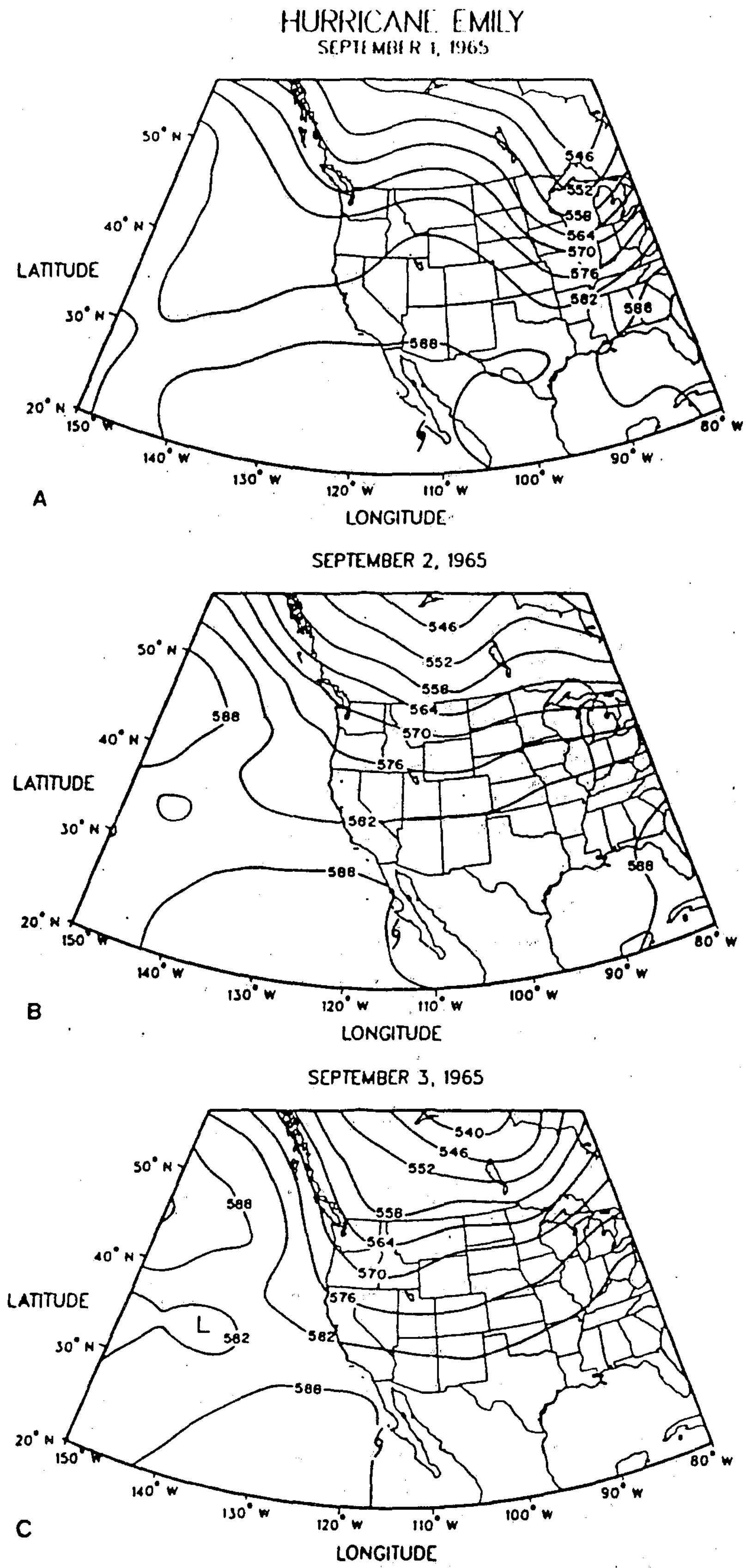


Figure 84. As in Figure 44.

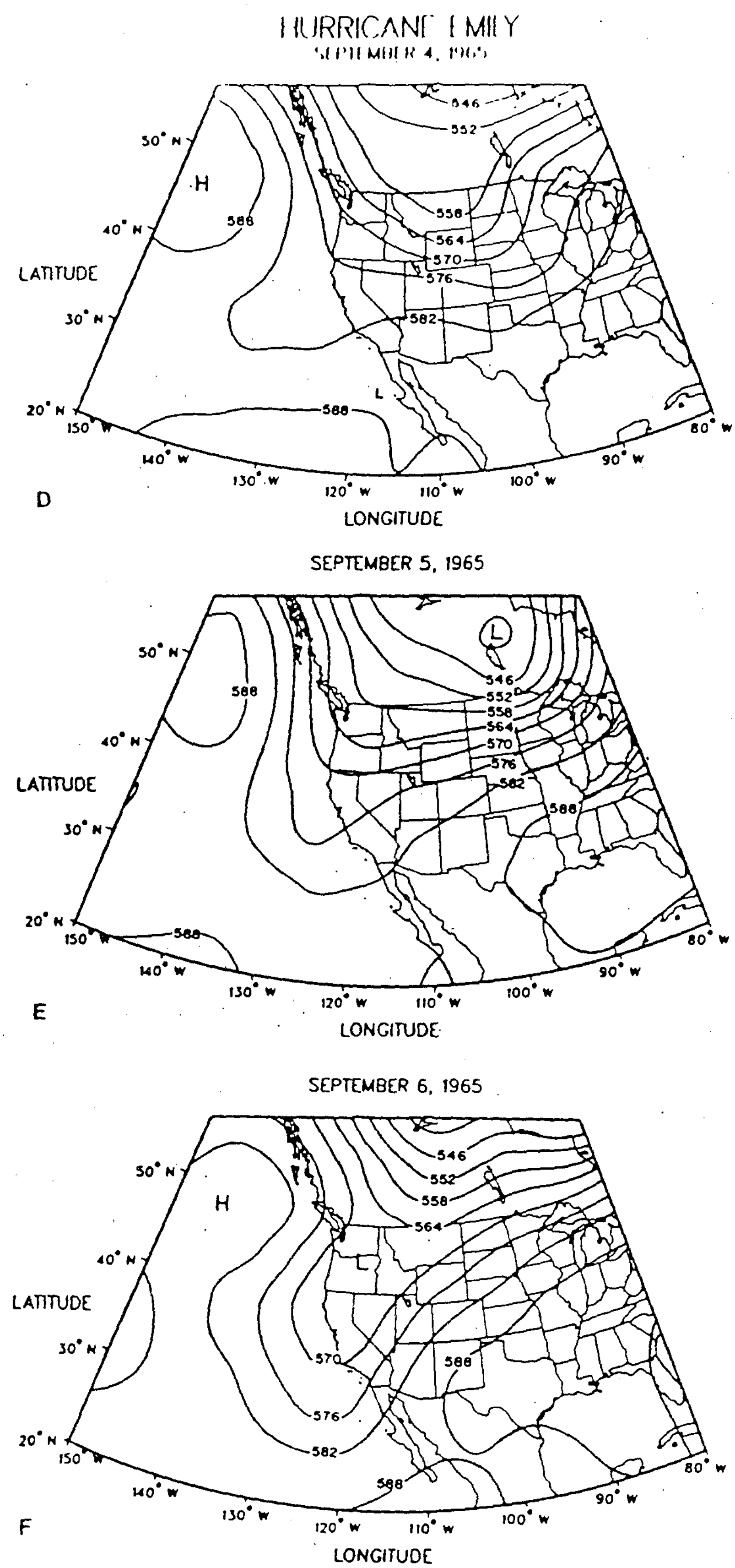


Figure 84. (continued) As in Figure 44.

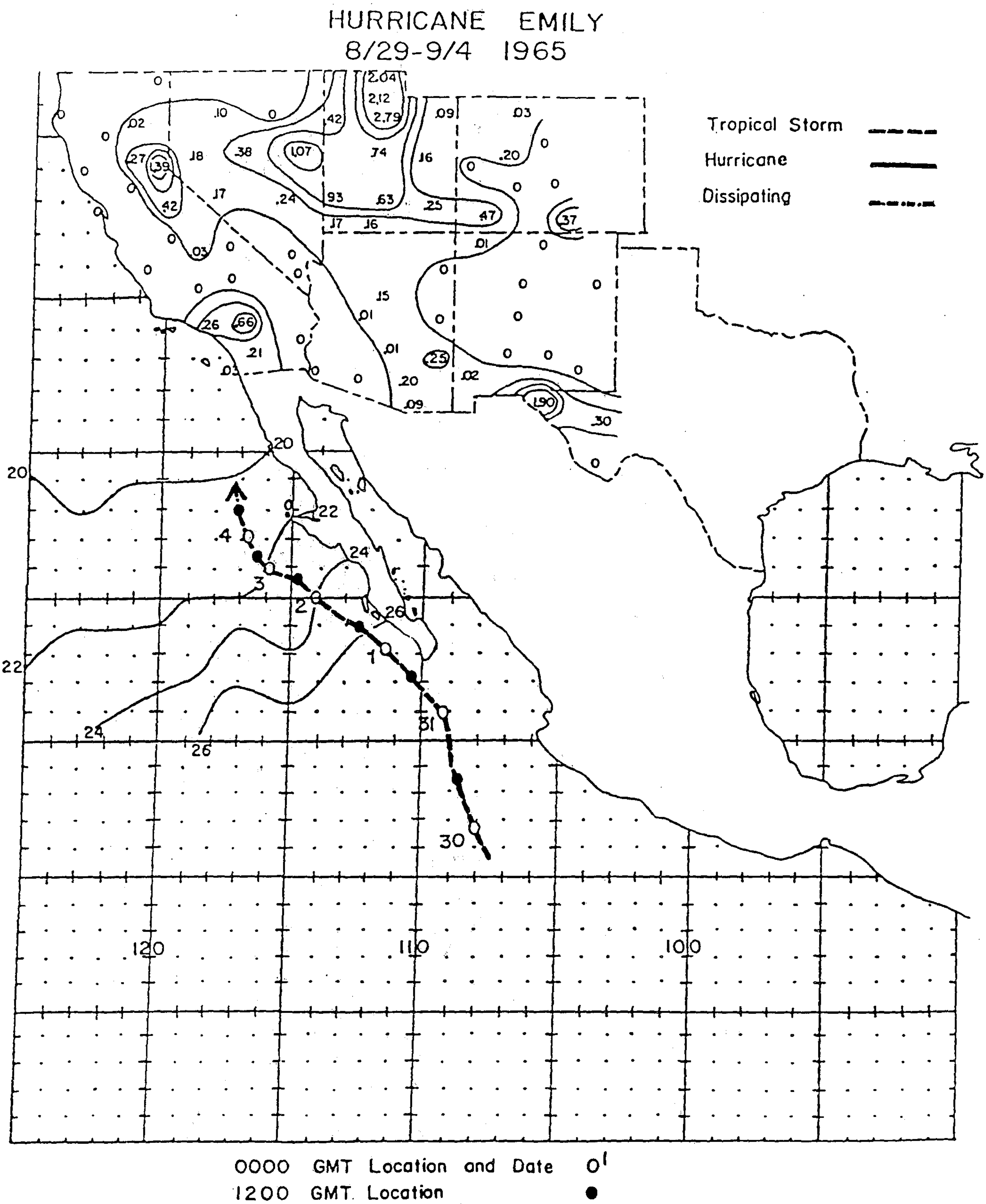


Figure 85. Track of Hurricane Emily; August 29 - September 4, 1965; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

In 1966, satellite imagery became (and still is) the most important instrument utilized in the detection, tracking, and evaluation of eastern north Pacific tropical cyclones (Gustafson, 1968). Satellites have shown that far more tropical cyclones than previously thought form in the eastern north Pacific west of Mexico and that more tropical cyclones form per 1000 km^2 in this area than anyplace else on Earth. In addition, satellite images show moist air is advected over the Southwest from eastern north Pacific tropical cyclones much more frequently than most people ever envisioned, usually more than once per year and from 1982-1984, at least 3 times a year.

Tropical Storm Kirsten; September 25-29, 1966

The cut-off low which formed off the northern coast of Baja California early on September 28 forced Tropical Storm Kirsten to track northeastward across the Baja peninsula, Gulf of California, and over the Mexican mainland late on the 28th (Figure 86). Scattered light showers fell the next 2 days over southeastern Arizona and southwestern New Mexico when moist air moved over and was lifted by the cut-off low, the mountains, and diurnal heating. The rain linked to the tropical storm most likely was confined to the aforementioned states (Figure 87). Most of the precipitation shown in Colorado occurred 2 days after the showers ended in Arizona and New Mexico and may have been due to a disturbance moving southward from Canada. Nogales, Arizona received a total of 1.28 in. of rain, the largest amount definitely related to the tropical cyclone.

Hurricane Katrina; August 29 - September 2, 1967

As indicated in Figure 89, Hurricane Katrina is one of the few tropical cyclones known to have moved nearly the full length of the Gulf of California this century. First detected on August 29 due west of Acapulco with tropical storm intensity, the storm subsequently strengthened to hurricane intensity late the following day as it began recurving to the northeast around the western end of a ridge that was centered to the east of Mexico (see Figure 88). The hurricane crossed Baja California and weakened slightly on the 31st but quickly regenerated over the very warm water in the Gulf and then tracked northwestward through the Gulf making landfall east of the mouth of the Colorado River on September 2. The primary victim of Hurricane Katrina was San Felipe, Baja California; which is located approximately 200 km south of Yuma; where torrential rains, a storm surge, and huge waves driven by 85 kn winds destroyed about half the town of 5,000 inhabitants and most of the town's fishing fleet.

Despite the ferocity of the storm at San Felipe, Yuma WSO reported sustained winds of less than 30 kn on September 1 and 2 as the hurricane quickly dissipated over the desert to the southeast. The extremely rapid degeneration of the hurricane after

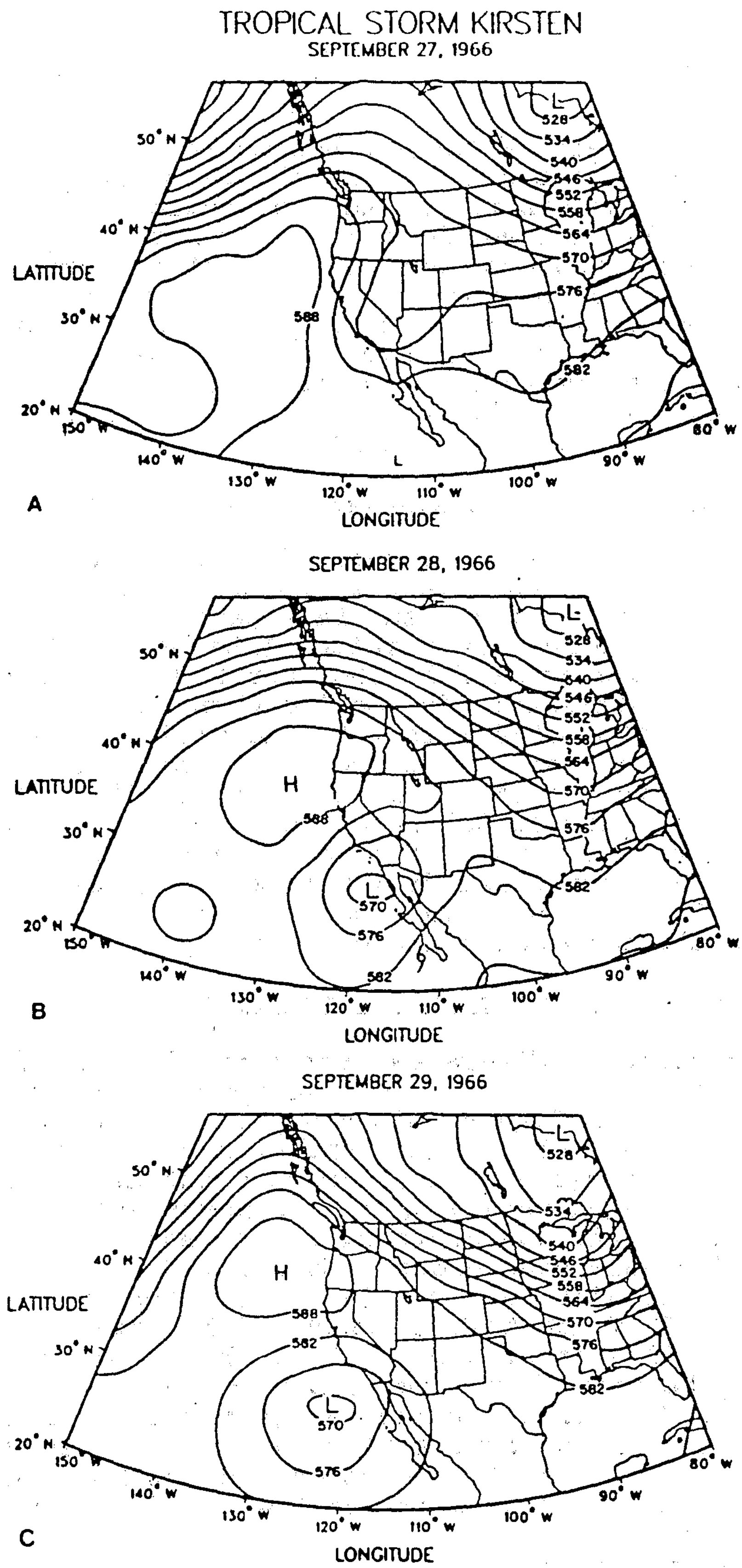


Figure 86. As in Figure 44.

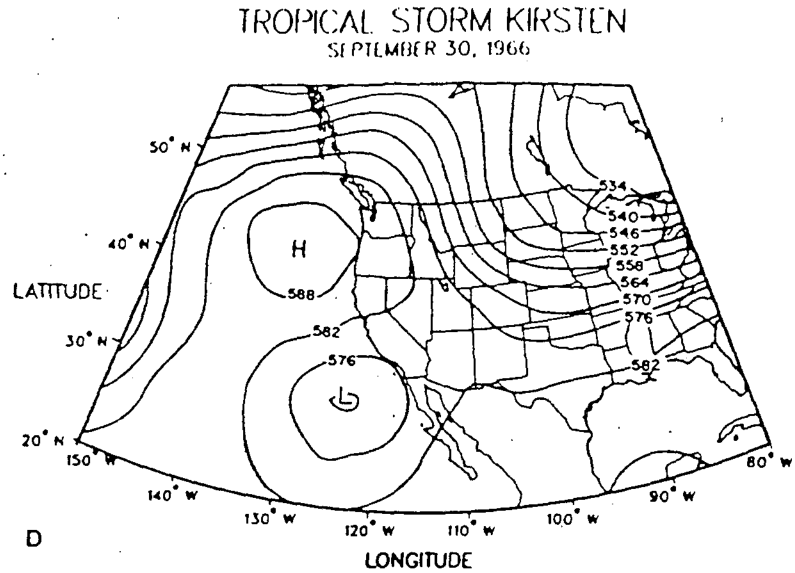


Figure 86. (continued) As in Figure 44.

Table 38. Hurricane Katrina; August 29 - September 2, 1967; daily precipitation

Station	August 31	September 1	2	3	4	Total
Ajo, Az.	0	.05	.35	1.36	.45	2.16
Wellton, Az.	.39	.87	3.25	.27	0	4.78
Yuma WSO, Az.	.23	.43	1.49	.04	0	2.19
Cuyamaca, Ca.	0	.65	.90	.60	0	2.15

amounts in inches.

reaching the northern end of the Gulf of California is the reason heavy rains, as indicated by the 2.00 in. isohyet on Figure 89, were confined to the immediate U.S.-Mexico border.

Precipitation related to Hurricane Katrina began on August 31 and ended on September 3. Table 38 lists daily rainfall totals at the stations that received the greatest amounts and shows the heaviest rains occurred on the 2nd while the hurricane was breaking up. These relatively small rainfall totals probably will be exceeded by a significant amount the next time a hurricane comes ashore at the northern end of the Gulf of California.

Tropical Storm Hyacinth; August 16-20, 1968

Southeastern Arizona received the only significant rains to be associated with Tropical Storm Hyacinth which formed on the 17th almost due south of the Arizona-New Mexico border. The cyclone moved almost straight northward in response to the circulation shown in Figure 90 until dissipating on August 20 a few hundred kilometers south of Arizona (Figure 91). Showers occurred on the 19th and 20th in eastern Arizona, New Mexico,

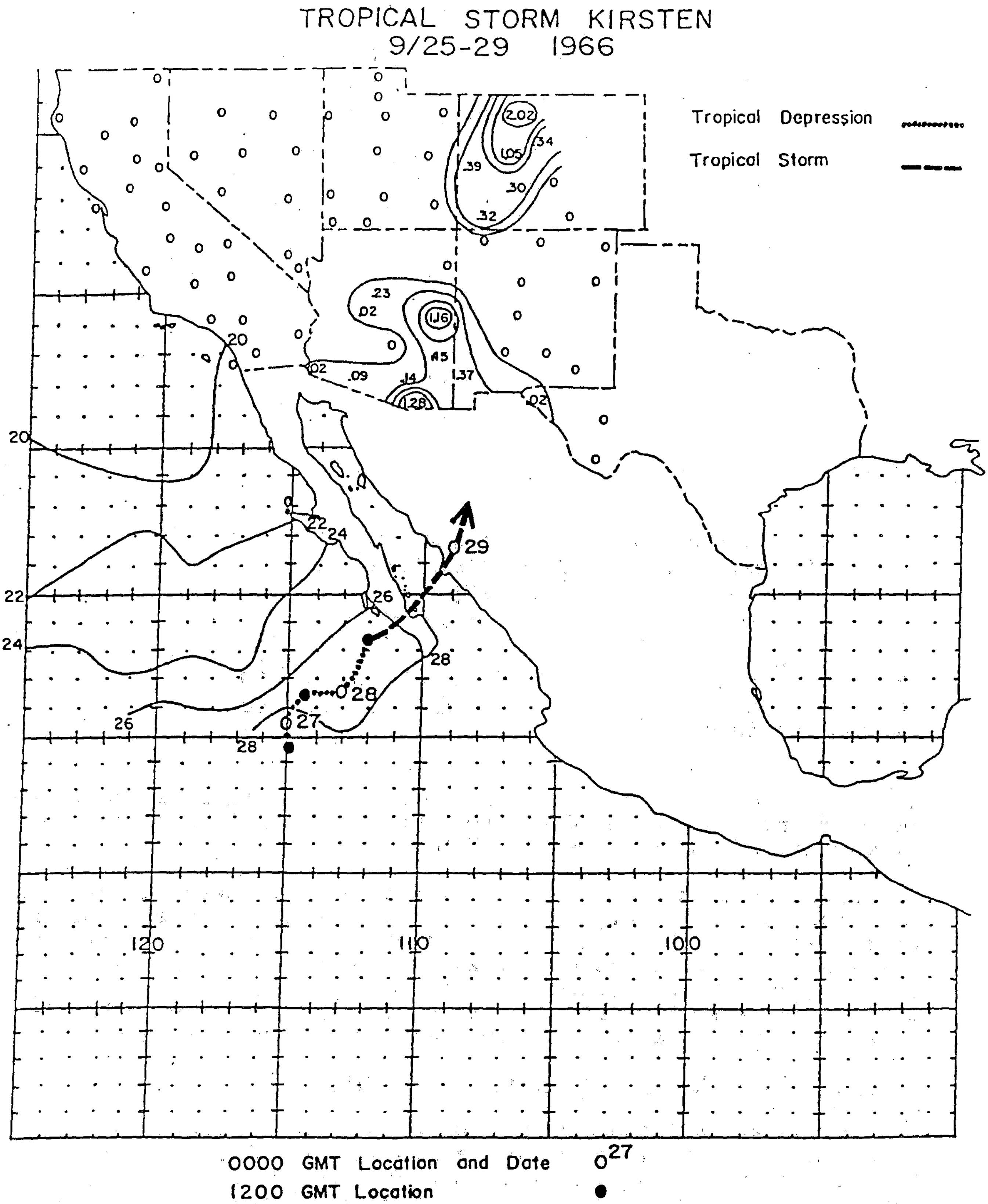


Figure 87. Track of Tropical Storm Kirsten; September 25-29, 1966; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

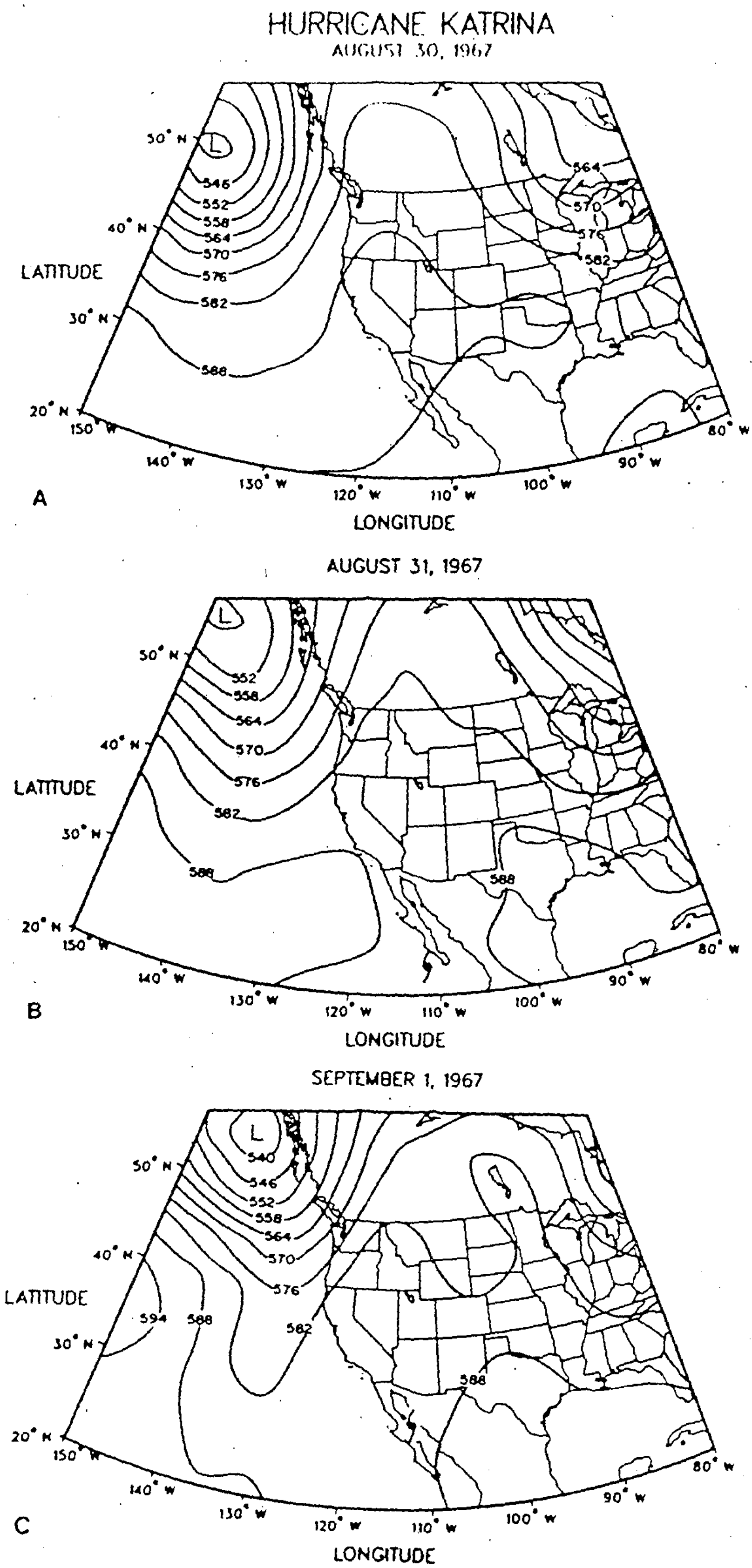


Figure 88. As in Figure 44.

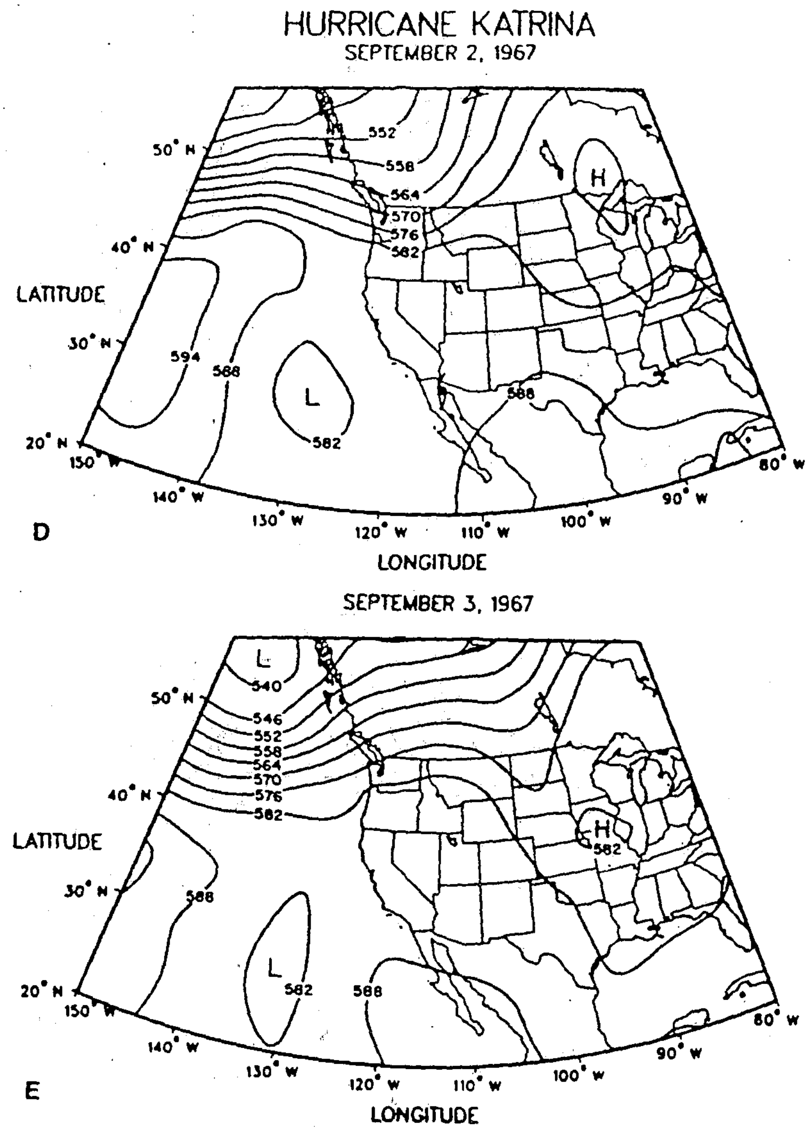


Figure 88. (continued) As in Figure 44.

west Texas, and southwestern Colorado as the tropical storm tracked inland over Mexico and weakened. Most stations in the Southwest received less than .25 inches of precipitation although a few places in the extreme southeastern corner of Arizona did report more than one inch. Y Lightning Ranch which is located along the Arizona-Mexico border accumulated 2.30 in. of rain, the largest amount, and was one of two sites to measure as much as 2.00 inches.

Hurricane Pauline: September 26 - October 3, 1968

Moist air from this tropical cyclone was advected over the Southwest on October 3 and lifted by a cut-off low which had developed several hundred kilometers southwest of San Diego late on the 1st (Figure 92). Scattered showers fell that day over southern California, Arizona, New Mexico, southeastern Utah, and

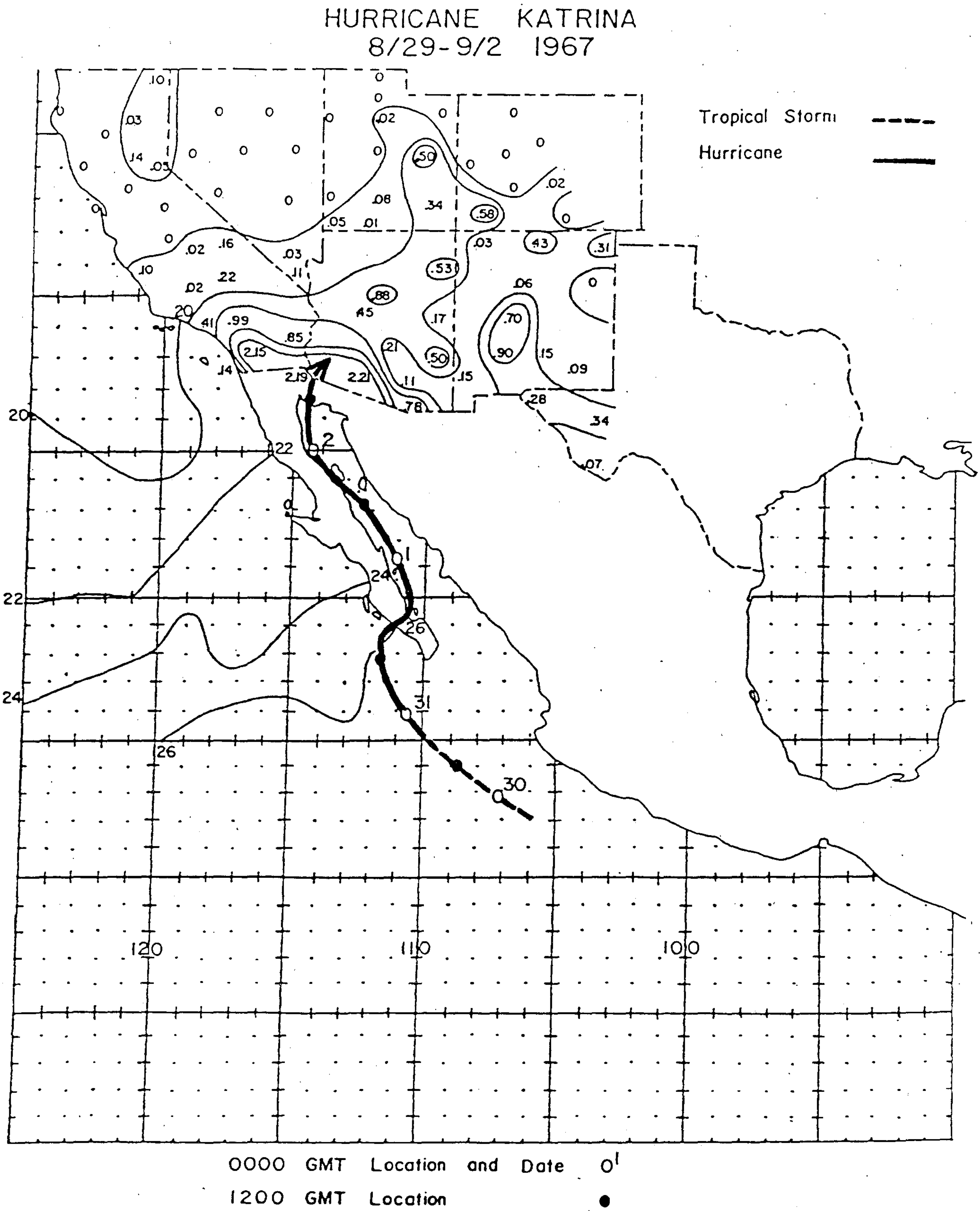


Figure 89. Track of Hurricane Katrina; August 29 - September 2, 1967; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

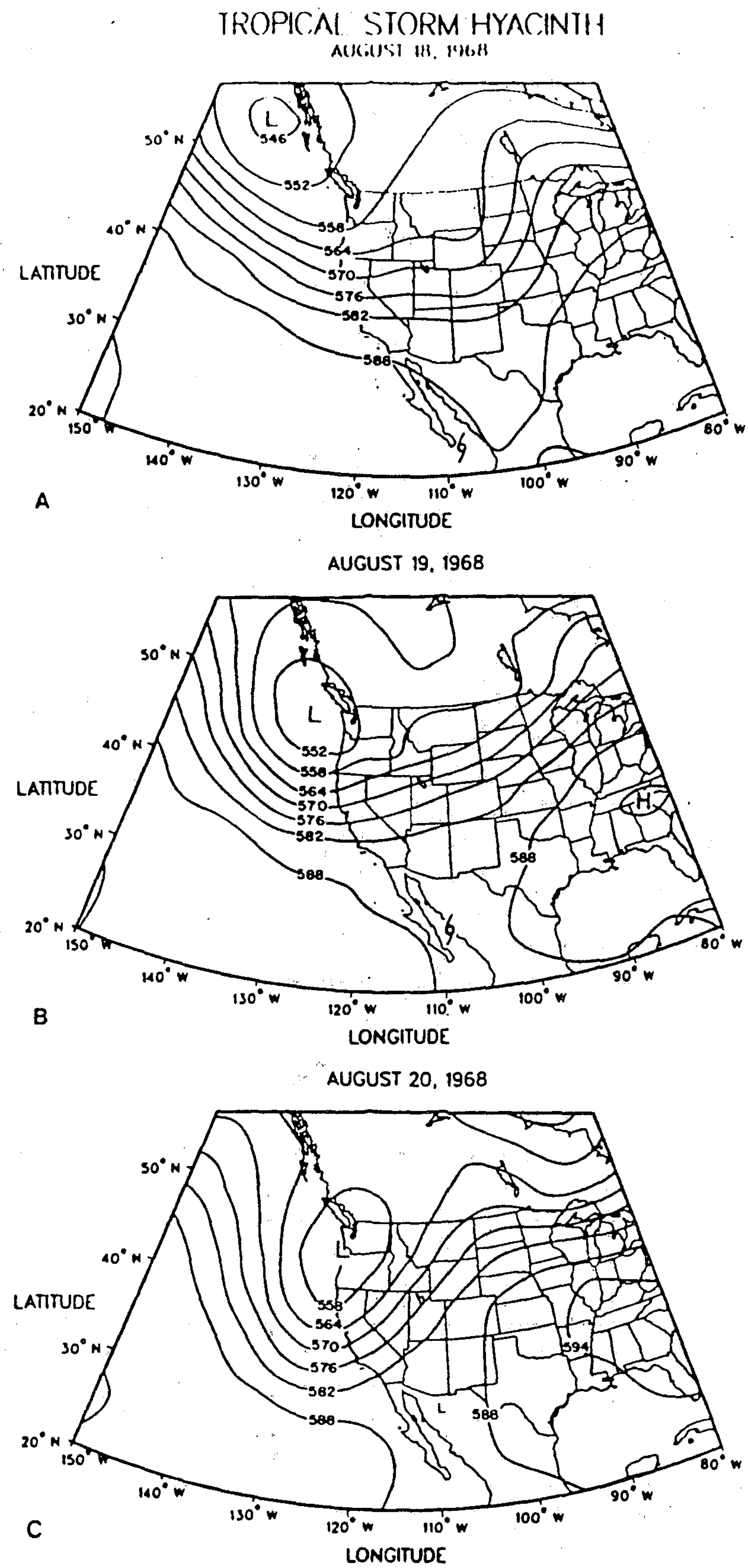


Figure 90. As in Figure 44.

TROPICAL STORM HYACINTH
8/16-20 1968

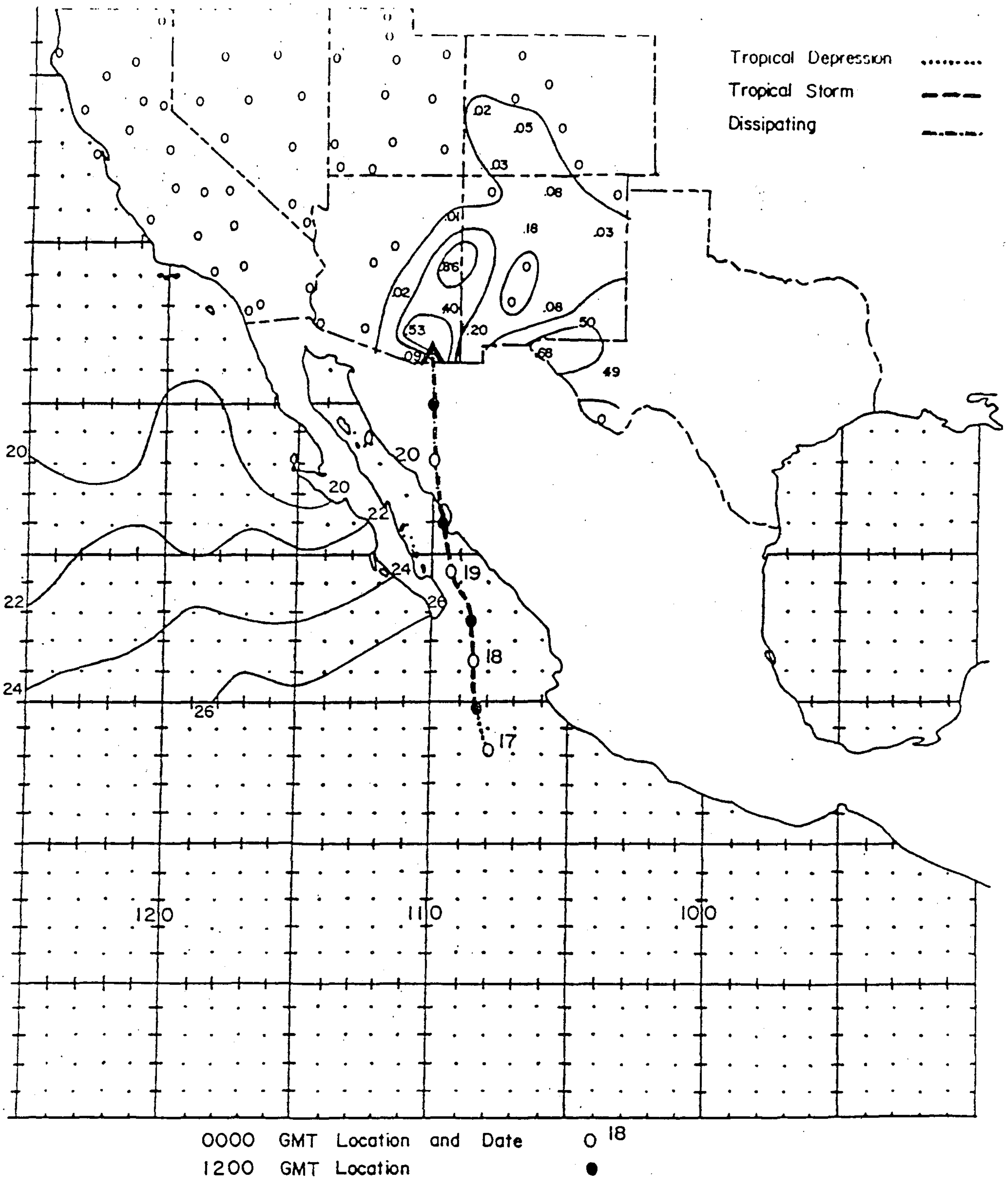


Figure 91. Track of Tropical Storm Hyacinth; August 16-20, 1968; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, and .50 inches. Sea surface temperatures are in °C.

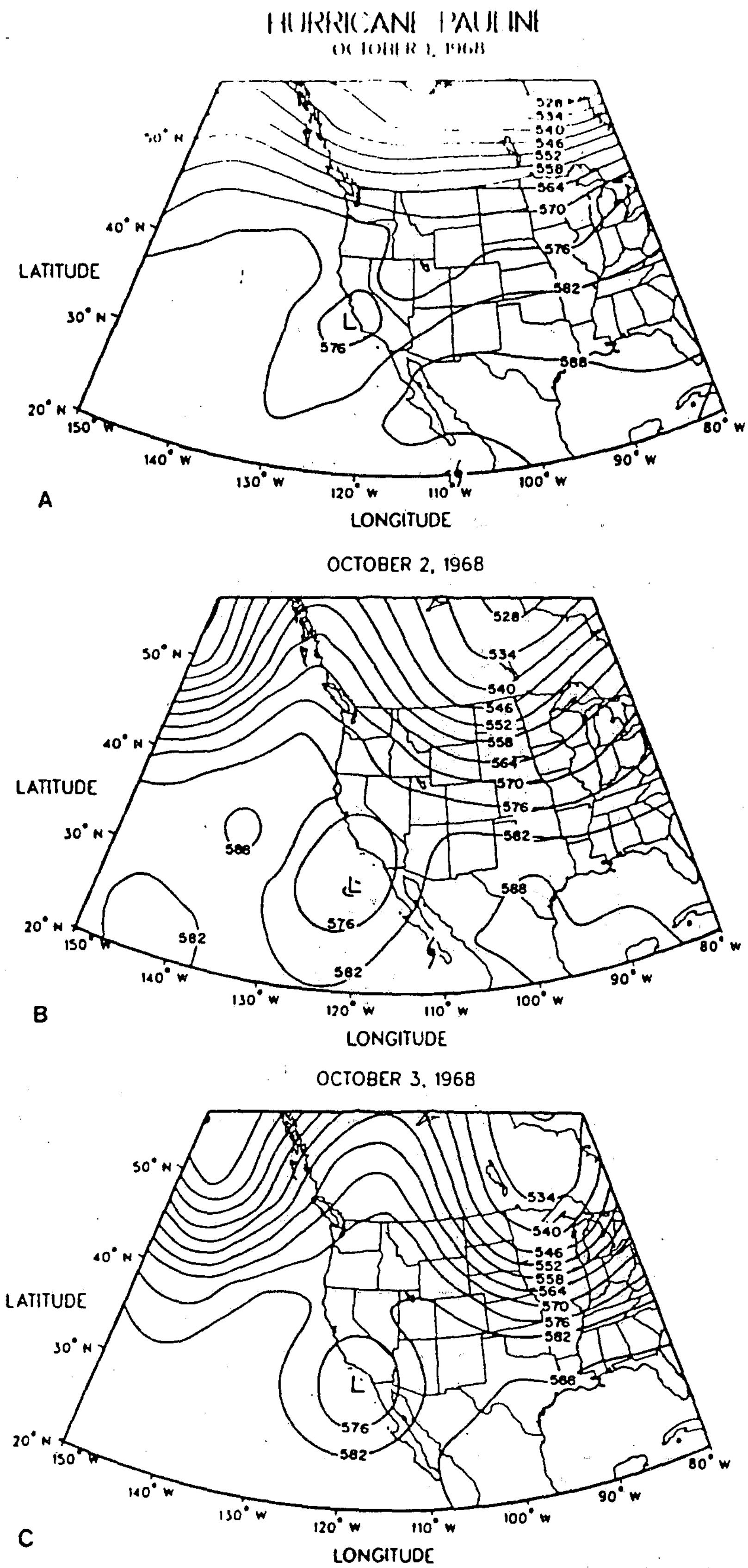


Figure 92. As in Figure 44.

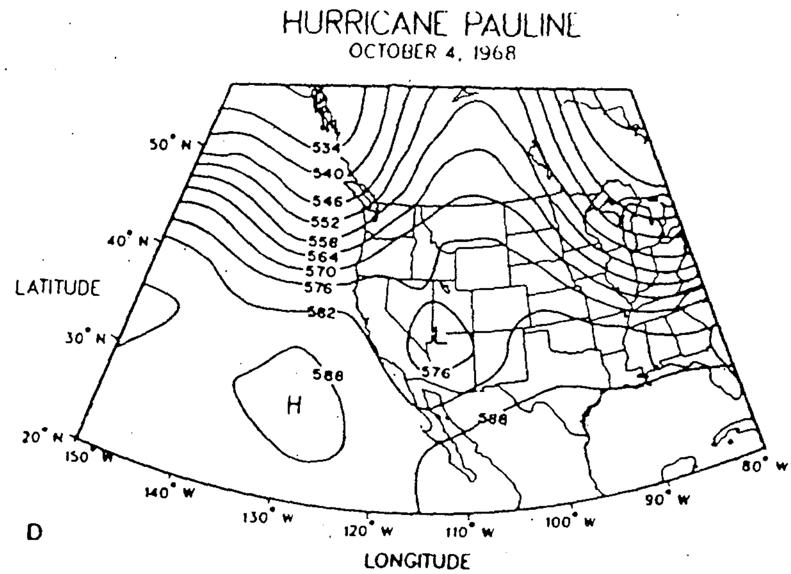


Figure 92. (continued) As in Figure 44.

southwestern Colorado and continued for approximately 48 hours as the cut-off low became caught in the westerlies and was forced eastward by a major trough. Much of the northern two-thirds of Arizona, southwestern Colorado, and southeastern Utah received from .50 to 1.00 in. of precipitation as indicated in Figure 93. Isolated areas of southern California and New Mexico also measured more than a half inch of rain but most received much less. The heaviest rains, which varied from about 1.00 to 2.30 in. at Lakeside Ranger Station, fell over the mountains of northern Arizona.

Tropical Storm Norma: August 30 - September 5, 1970

A total of 25 people lost their lives, 23 in Arizona and 2 in southwestern Utah, due to flooding caused by extremely heavy rains that fell from September 3 through 7, 1970 when moist air from dissipating Tropical Storm Norma was advected over Arizona, Utah, and southwestern Colorado and lifted by a strong trough (Zimmerman et al., 1971). The only documented eastern north Pacific tropical cyclone to produce more fatalities in the Southwest this century was the Tropical Cyclone of September 15-25, 1939 which was responsible for 45 deaths at sea southwest of southern California. A detailed discussion of the September 1970 disaster, which is the worst in recorded history of the state of Arizona, can be read in the Natural Disaster Survey Report 70-2, Arizona Floods Of September 5 And 6, 1970 by Zimmerman et al. Kangieser (1970, 1972a) also discusses various aspects of the disaster.

Unprecedented rains occurred on the 5th in the mountains of central Arizona when the tropical moisture combined with a very strong, early fall trough that was located over northern Nevada (Figure 94). The 11.40 in. of rain that fell in the 24 hours ending at 2200 local time on the 5th at Upper Workman Creek 1

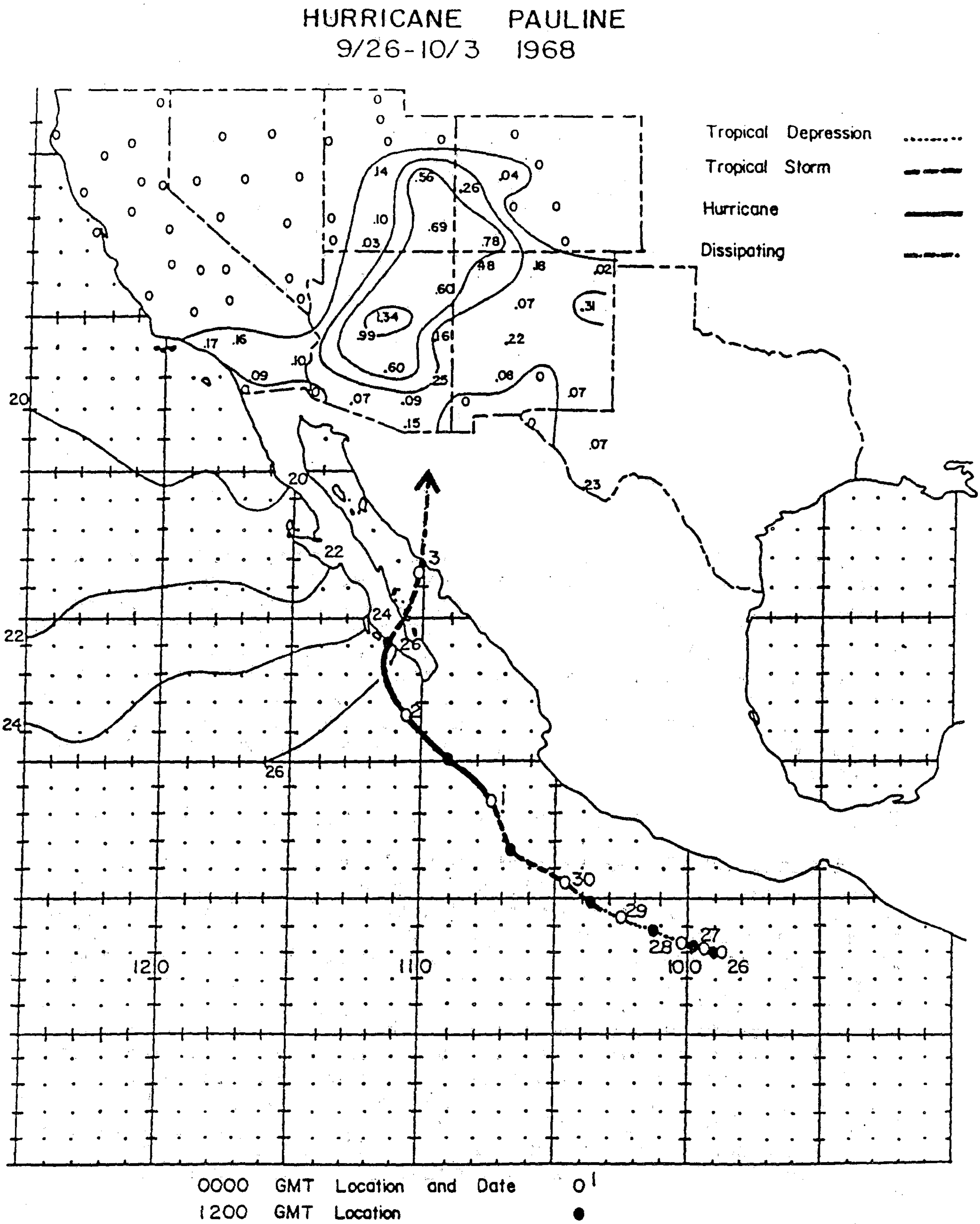


Figure 93. Track of Hurricane Pauline; September 26 - October 3, 1968; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches. Sea surface temperatures are in °C.

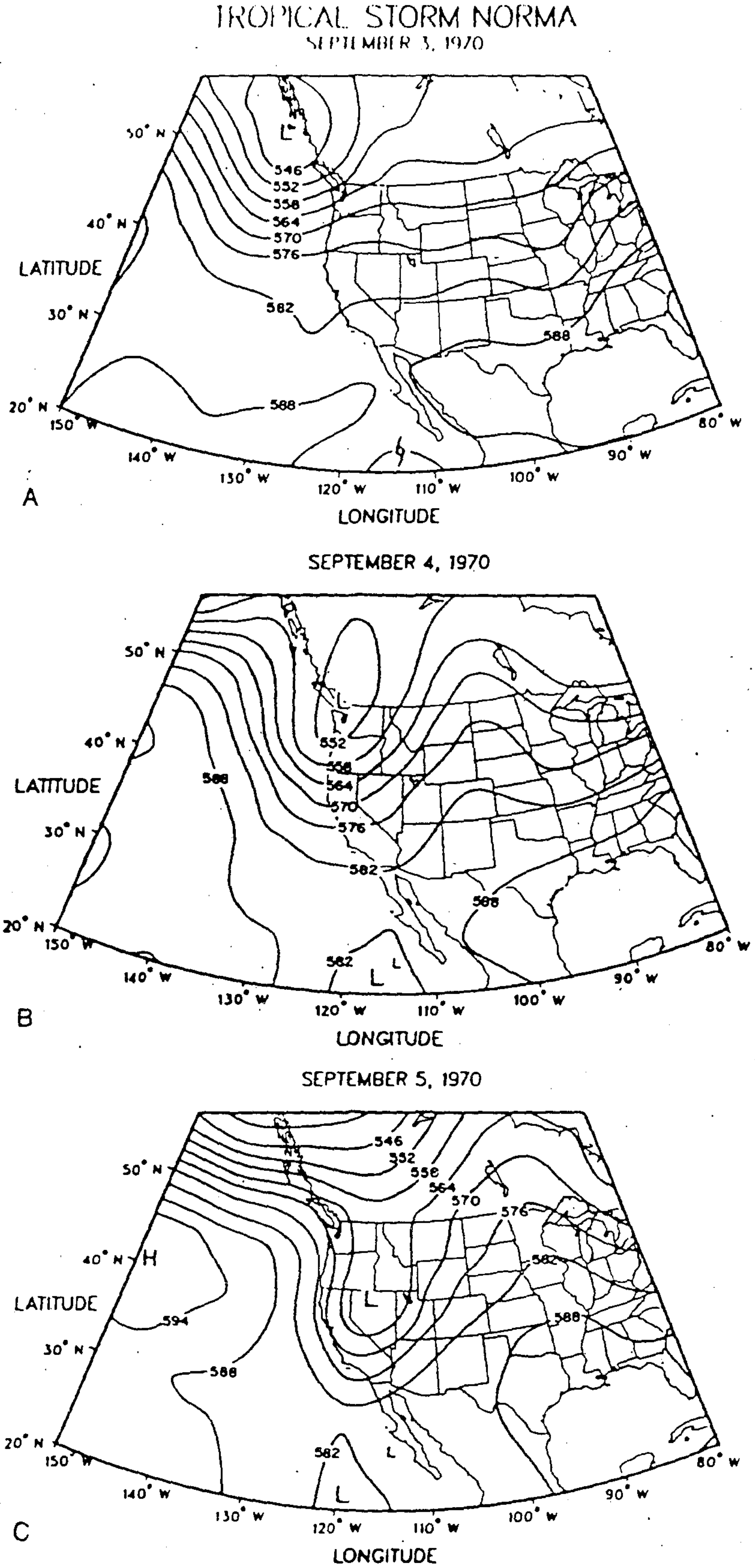


Figure 94. As in Figure 44.

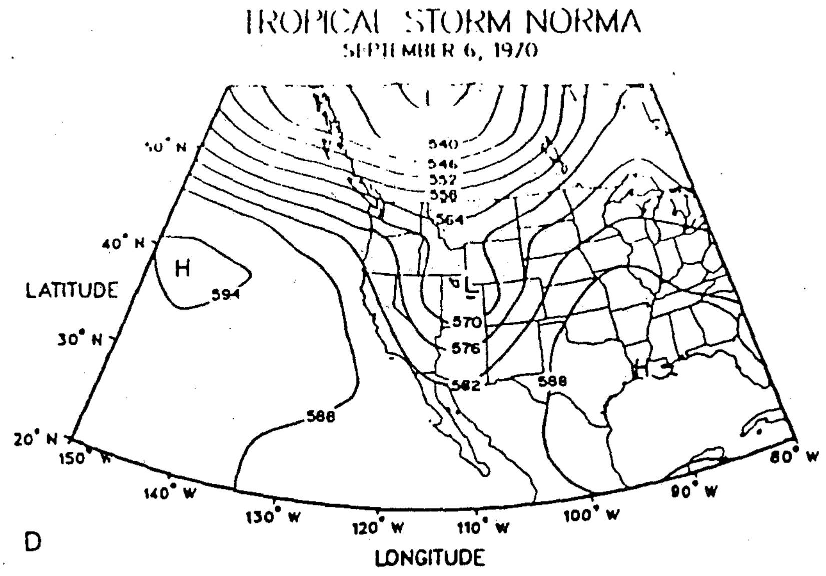


Figure 94. (continued) As in Figure 44.

Table 39. Tropical Storm Norma; August 30 - September 5, 1970; daily precipitation

	September					
Station	3	4	5	6	7	Total
Crown King, Az.	0	.85	4.50	1.66	0	7.01
Junipine, Az.	0	.76	5.28	0	0	6.04
Kitt Peak, Az.	.06	2.85	1.01	3.71	.45	8.08
Palisade Ranger Station, Az.	.62	1.51	2.50	3.76	.35	8.74
Payson Ranger Station, Az.	0	.23	6.20	0	0	6.43
Sedona Ranger Station, Az.	.05	.80	5.50	0	0	6.35
Sunflower 3NNW, Az.	0	.30	8.00	.14	0	8.44
Tonto Creek Fish Hatchery, Az.	0	.25	1.25	5.63	0	7.13
Workman Creek 1, Az.	-----	11.40		-----		11.40
Bug Point, Utah (unofficial)	0	0	6.50	0	0	6.50
Cedar Point, Utah	0	.30	3.75	.23	0	4.28
Durango, Co.	0	.81	2.62	0	0	3.43
Silverton, Co.	0	.71	1.43	2.05	0	4.19
Wolf Creek Pass 4W, Co.	0	0	.90	3.20	0	4.10

amounts in inches.

(elevation 2144 m) in the Sierra Ancha Mountains northeast of Phoenix is the greatest 24-hour rainfall ever recorded in Arizona. This is also the largest known 24-hour precipitation total ever linked to an eastern north Pacific tropical cyclone in the continental United States. However, 24-hour rainfall within the unofficial 30-hour total of 17 in. reported in the Guadalupe Mountains near Carlsbad, New Mexico from the Hurricane of September 15-22, 1941 may be larger.

Tropical Storm Norma, whose reported minimum sea level pressure was 988 mb and estimated maximum sustained winds were just 50 kn (Denney, 1971), never reached land before dissipating over 22°C water near the Baja Coast. This is indicated in Figure 95

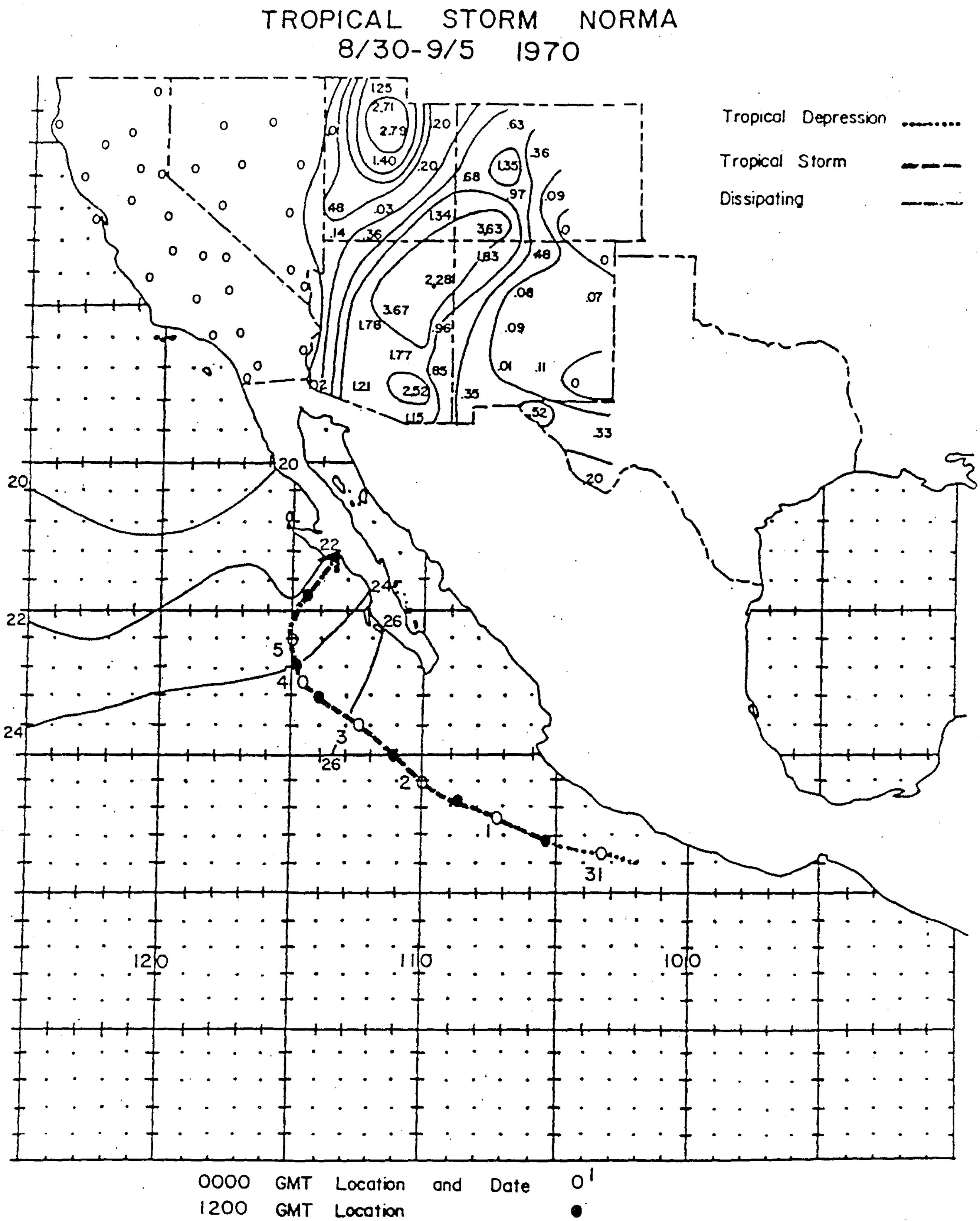


Figure 95. Track of Tropical Storm Norma; August 30 - September 5, 1970; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

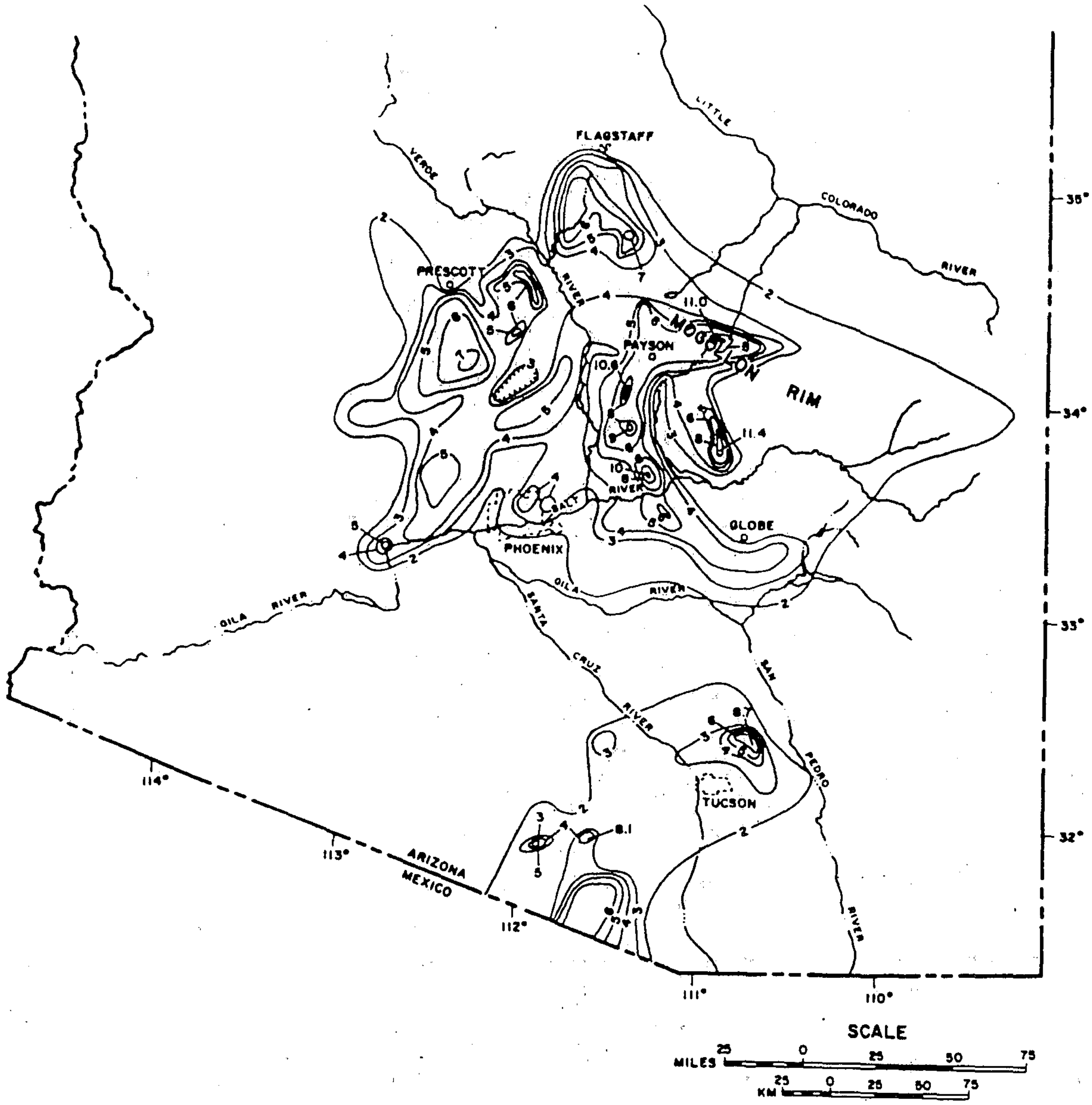


Figure 96. Southern and central Arizona precipitation from September 4-6, 1970 linked to Tropical Storm Norma, in inches (from Saarinen et al., 1984).

which also shows the precipitation that fell over the Southwest. A much more detailed map of the rainfall in southern and central Arizona can be seen in Figure 96. If Norma had recurved to the northeast with the same intensity as the Hurricane of September 15-22, 1941; which followed a similar path (see Figure 42); substantially more rain might have fallen. Rain associated with the tropical storm lasted from the 3rd through the 7th (Table 39). In addition to the all-time Arizona 24-hour precipitation record set at Upper Workman Creek 1, at least 12 other stations in Arizona, e.g. Junipine and Payson Ranger Station, with non-recording rain gauges set new observational day records during the period (Kangieser, 1970).

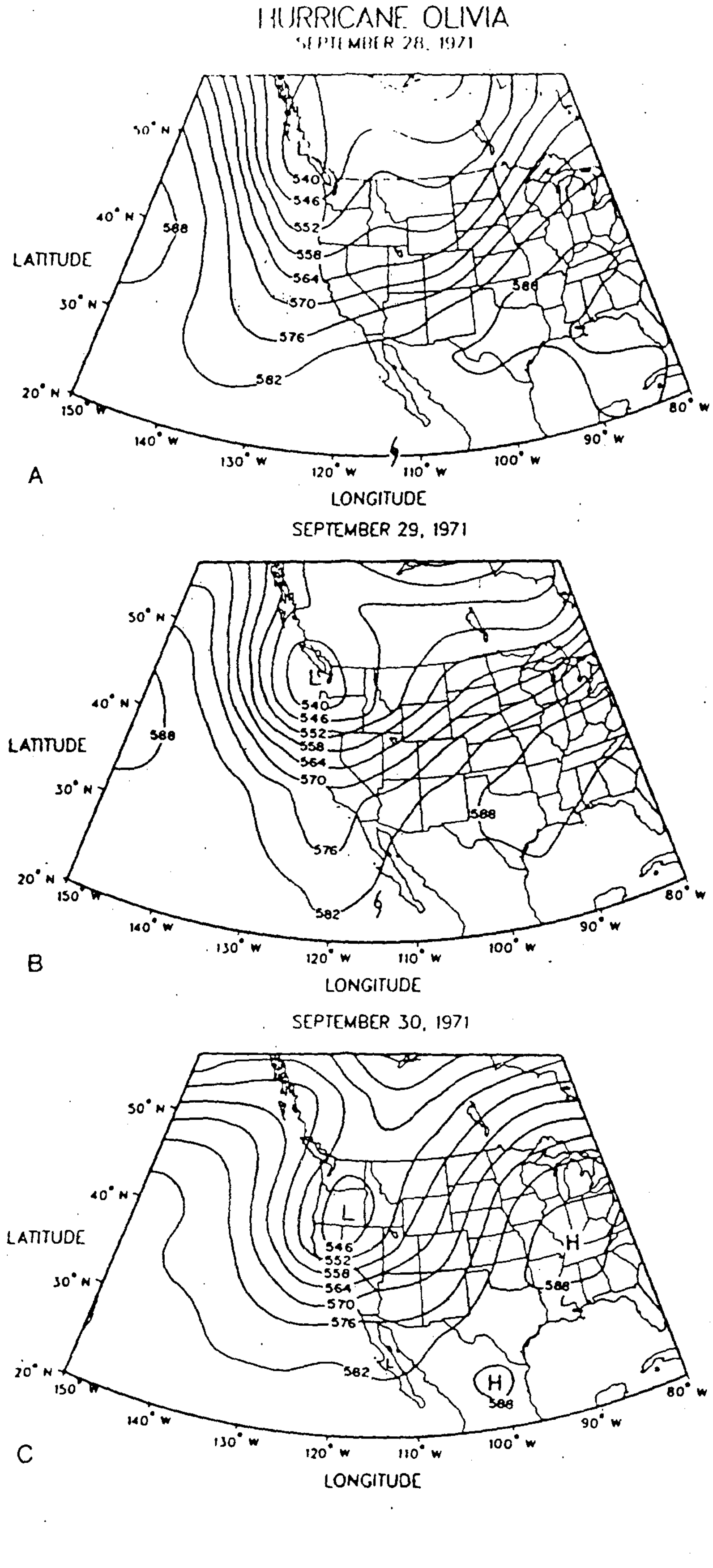


Figure 97. As in Figure 44.

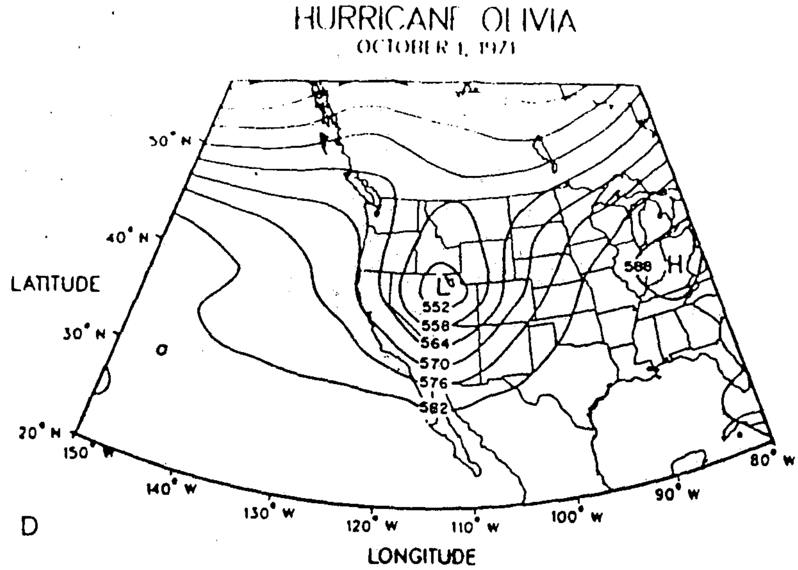


Figure 97. (continued) As in Figure 44.

Hurricane Olivia: September 20-30, 1971

Caribbean Sea Hurricane Irene moved ashore over Nicaragua on September 19 and weakened to a tropical depression but after crossing Nicaragua and moving over the eastern Pacific on the 20th, quickly redeveloped into Tropical Storm Olivia (Denney, 1972). After a long journey towards the northwest, Hurricane Olivia was forced to recurve early on the 28th by a midlatitude short wave that eventually moved over the western United States from the Gulf of Alaska (Figure 97). Cool SSTs and strong upper level winds caused the hurricane to weaken to tropical storm intensity late on 28th and, on September 30, Tropical Storm Olivia weakened to a tropical depression and finally dissipated over Baja California as seen in Figure 98.

Precipitation connected with the tropical cyclone lasted from September 29 through October 1 (see Table 40) and was initiated by the upper level trough which brought moisture from the dissipating hurricane over the Southwest and lifted it producing showers. Moderate rain fell over a significant portion of the study area and heavy rainfall was reported over parts of southwestern Colorado and eastern Arizona where number of communities reported localized flooding; e.g. Holbrook, which was flooded when a levee broke. Pinal Ranch measured the largest daily rainfall, 3.22 in. on the 1st, and the largest storm total, 5.33 inches.

Hurricane Hyacinth: August 28 - September 6, 1972

Hurricane Hyacinth went farther west, 125°W, before recurving and moving inland over southern California than any other tropical cyclone of the century (see Figures 99 and 100). The cyclone also apparently maintained tropical storm strength for nearly a day after tracking over water with a SST less than 20°C which is very unusual. Examination of the maps which present both the

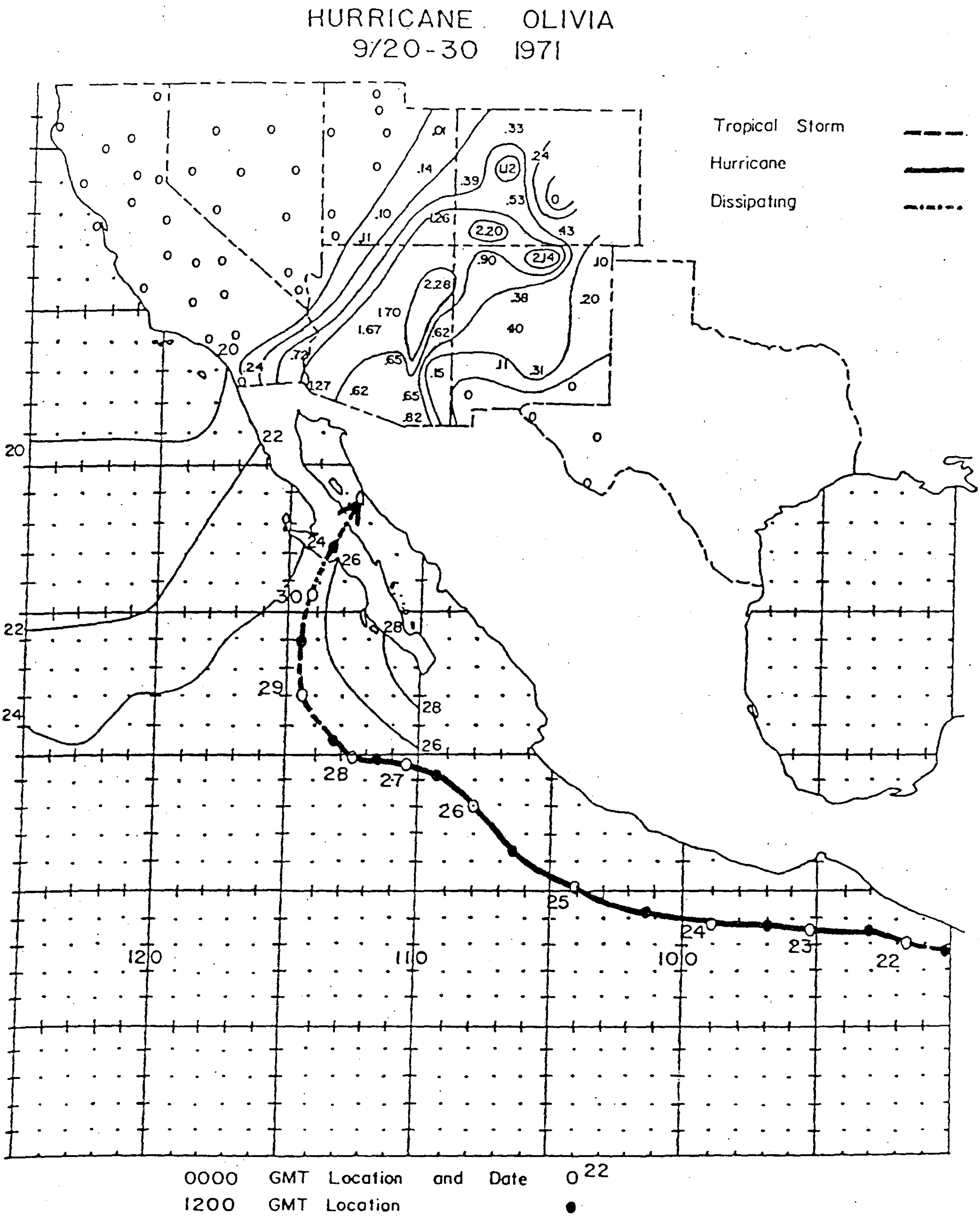


Figure 98. Track of Hurricane Olivia; September 20-30, 1971; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

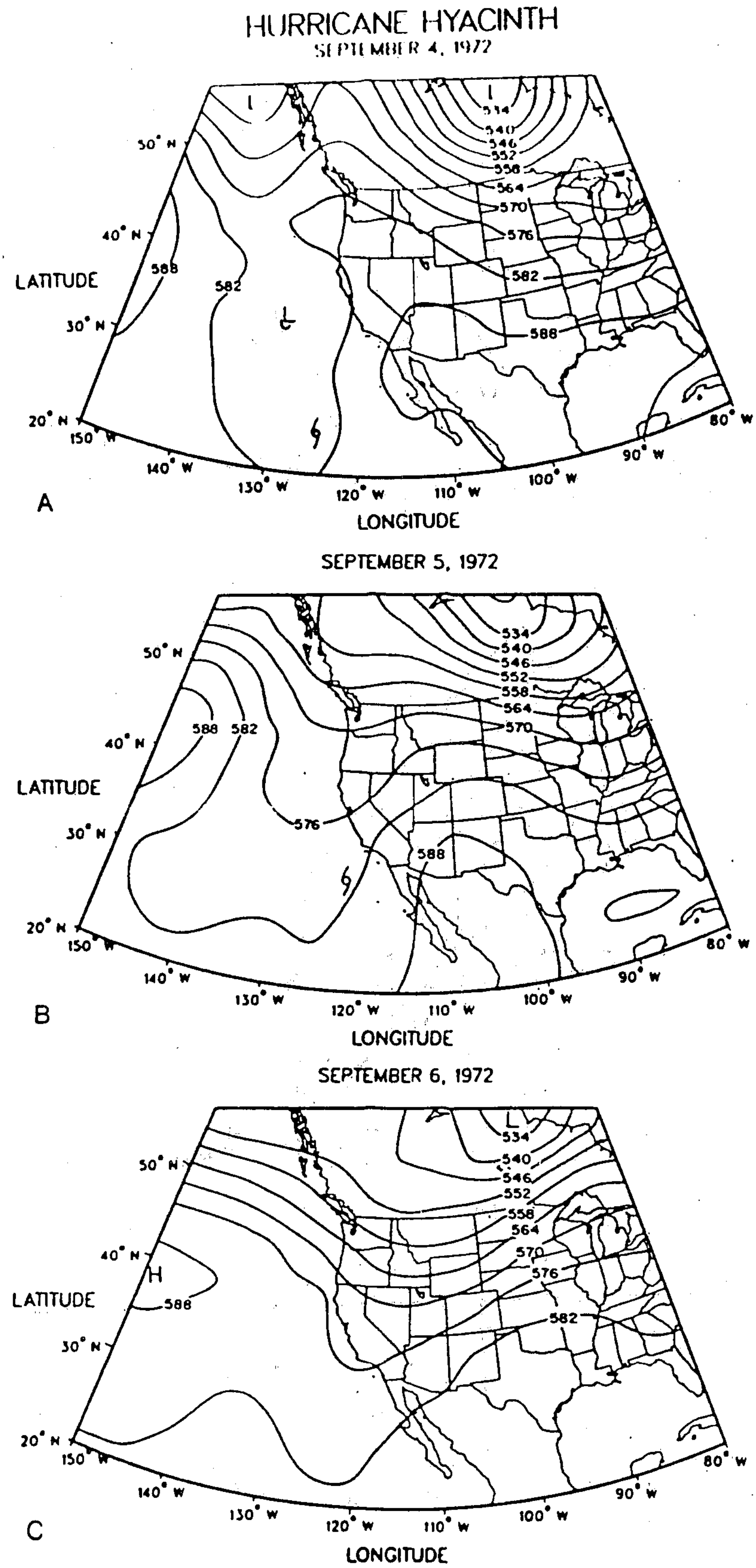


Figure 99. As in Figure 44.

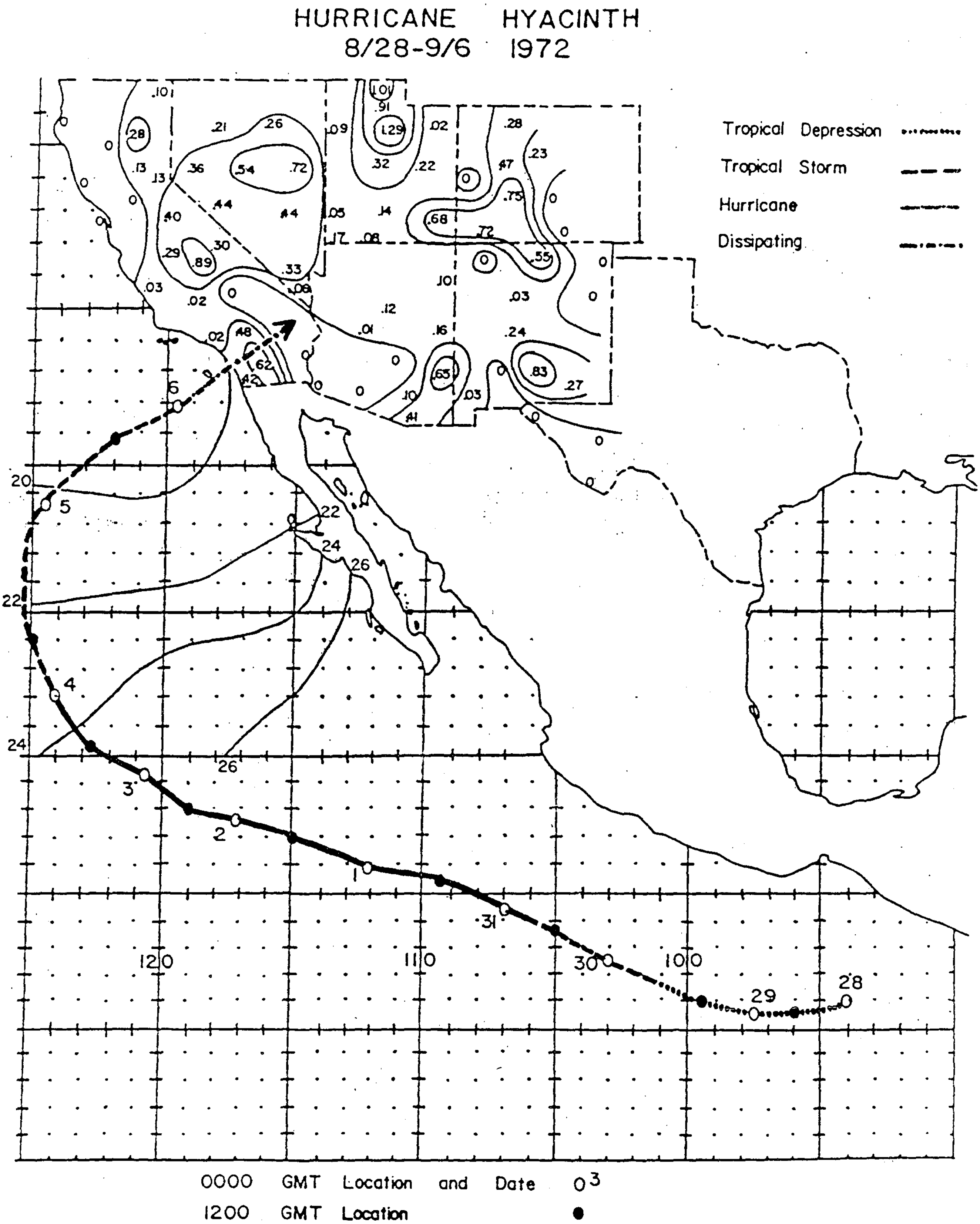


Figure 100. Track of Hurricane Hyacinth; August 28 - September 6, 1972; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches. Sea surface temperatures are in °C.

Table 40. Hurricane Olivia; September 20-30, 1971; daily precipitation

Station	September 29	September 30	October 1	Total
Heber Ranger Station, Az.	2.62	.63	.09	3.34
Palisade Ranger Station, Az.	.60	1.20	2.01	3.81
Pinal Ranch, Az.	.16	1.95	3.22	5.33
Sierra Ancha, Az.	2.63	1.19	.24	4.06
Pagosa Springs, Co.	.63	1.35	1.14	3.12

amounts in inches.

track of the tropical cyclone and accompanying SSTs will show that only Hurricane Doreen of August 1977 (Figure 108) and Hurricane Norman of September 1978 (Figure 117) remained at tropical storm intensity for more than a few hours where SSTs were less than 20°C. Hurricane Hyacinth became the first tropical cyclone to move over southern California since September 25, 1939 when it came ashore between Los Angeles and San Diego with 20 kn winds on September 6.

Satellite images clearly indicate high clouds emanating from the hurricane were over southern California on the 3rd. Nevertheless, precipitation was not reported until the following day when stations located high in the mountains received a few light showers. Rain showers increased in coverage and intensity on the 5th and 6th as the dying tropical storm and a weak trough approached and finally moved over the West Coast. Widely scattered, mostly light rains continued for a few more days before coming to an end on September 9. The two highest rainfalls, 1.72 and 1.62 in., were measured in the Sierra Nevada Mountains at Ellery Lake and Lodgepole, respectively.

Hurricane Joanne; September 29 - October 6, 1972

When Hurricane Joanne entered southwestern Arizona on October 6, 1972 with winds of 30-40 kn it was the second documented tropical storm to move into the Southwest since 1900 and the first to move into Arizona (Kangieser, 1972b). The track of the cyclone is illustrated in Figure 102, which also shows the associated rainfall in the Southwest and approximate SSTs during the period. The tropical cyclone developed from a disturbance that originally formed on September 26 several hundred kilometers west of Guatemala. Late on the 29th, the disturbance acquired a closed center of circulation and was named Tropical Storm Joanne. The cyclone became a hurricane on October 2 and, subsequently, began turning to the north as it encountered southerly winds ahead of a cut-off low that was centered about 300 km southwest of Los Angeles at 1200 GMT on the 3rd (Figure 101).

Moist air flowed over the Southwest on the 3rd resulting in some light showers, but moisture from Hurricane Joanne did not begin moving over southern Arizona until the 4th (Kangieser, 1972b) when heavy rain occurred over a large part of Arizona. More than 4 in. of rain fell that day at Payson 12NNE as seen in

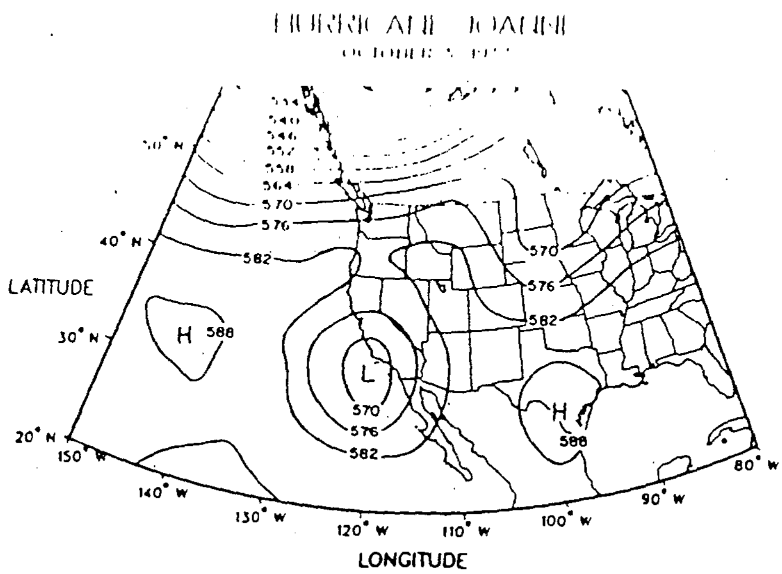


Figure 101. As in Figure 44 (data for October 4-7 is missing).

Table 41. Hurricane Joanne; September 29 - October 6, 1972; daily precipitation

Station	October 3	4	5	6	7	Total
Blythe, Ca.	.27	0	0	2.03	0	2.30
Calexico 2NE, Ca.	0	0	0	2.52	0	2.52
Flagstaff WSO, Az.	0	1.60	.01	1.70	1.13	4.44
Hawley Lake, Az.	0	.54	3.05	.70	.60	4.89
Payson 12NNE, Az.	.01	4.38	.13	.86	1.81	7.19
Sierra Ancha, Az.	.22	1.95	1.65	.45	3.89	8.16
Sunflower 3NNW, Az.	.20	3.77	.11	3.29	.29	7.66
Yuma Citrus Station, Az.	00	0	0	1.57	1.82	3.39

00 = trace; amounts in inches.

Table 41. Shower activity appears to have decreased at most stations on the 5th before increasing again as the storm neared Arizona. When Joanne passed Cedros Island (approximately 28°N, 115°W) early on October 6, maximum sustained winds were at least 60 kn. Soon thereafter, Hurricane Joanne crossed Baja California, proceeded rapidly across the warm waters of the Gulf of California, moved across Sonora where Puerto Penasco measured 45 kn winds, and entered southwestern Arizona.

The heaviest rains fell in a band about 400 km wide reaching from Yuma northeastward to Durango, Colorado (Figure 102). Just as they have with previous eastern north Pacific tropical cyclones, Sunflower and Sierra Ancha received two of the largest rainfalls, 7.66 and 8.16 in. respectively. No large-scale flooding was associated with Hurricane Joanne but the heavy rains did saturate the ground over a large portion of Arizona so that the heavy precipitation which fell from October 17-21 produced a major flood disaster in Arizona, the second in two years.

HURRICANE JOANNE
9/29 - 10/6 1972

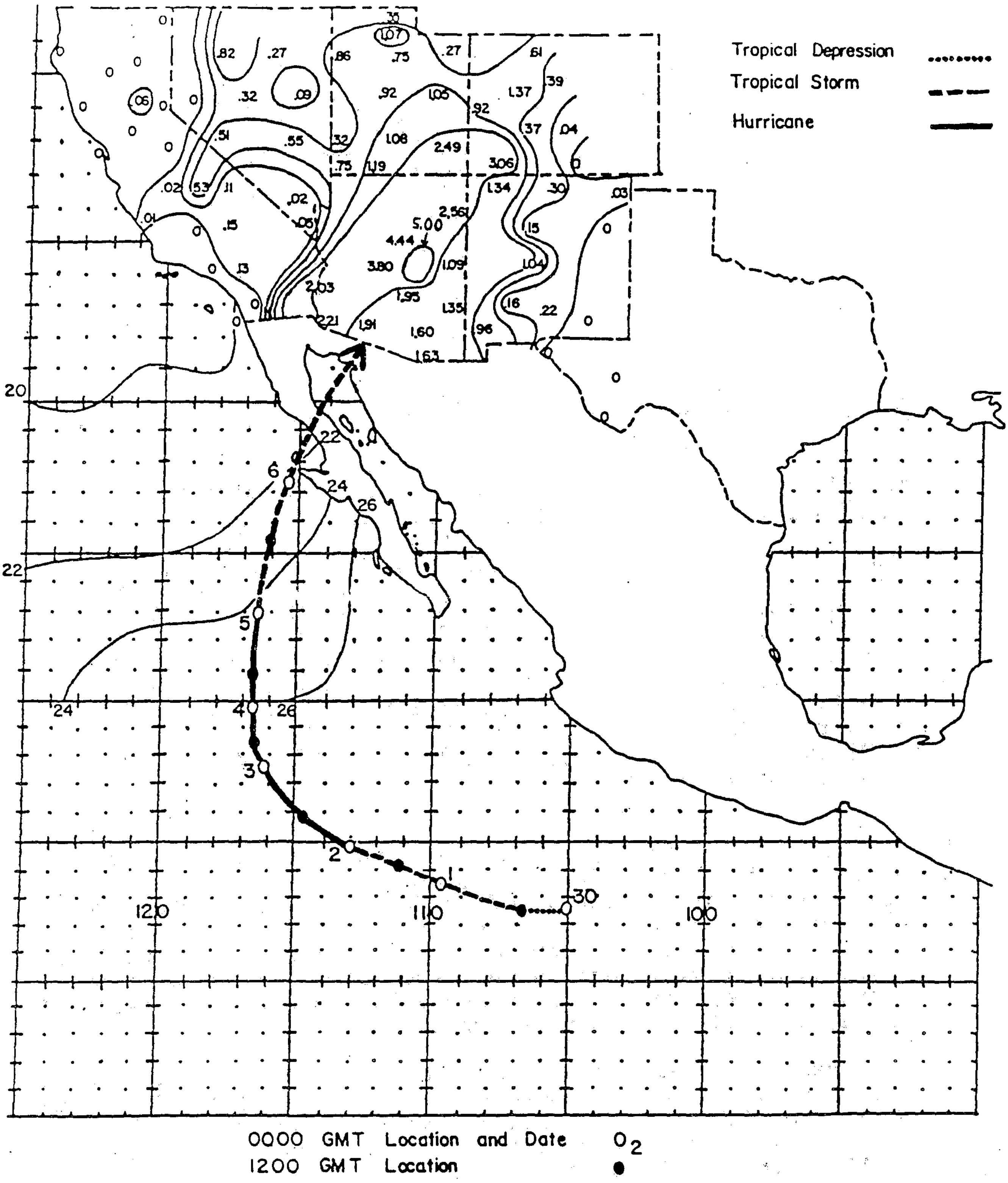


Figure 102. Track of Hurricane Joanne; September 29 - October 6, 1972; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches. Sea surface temperatures are in °C.

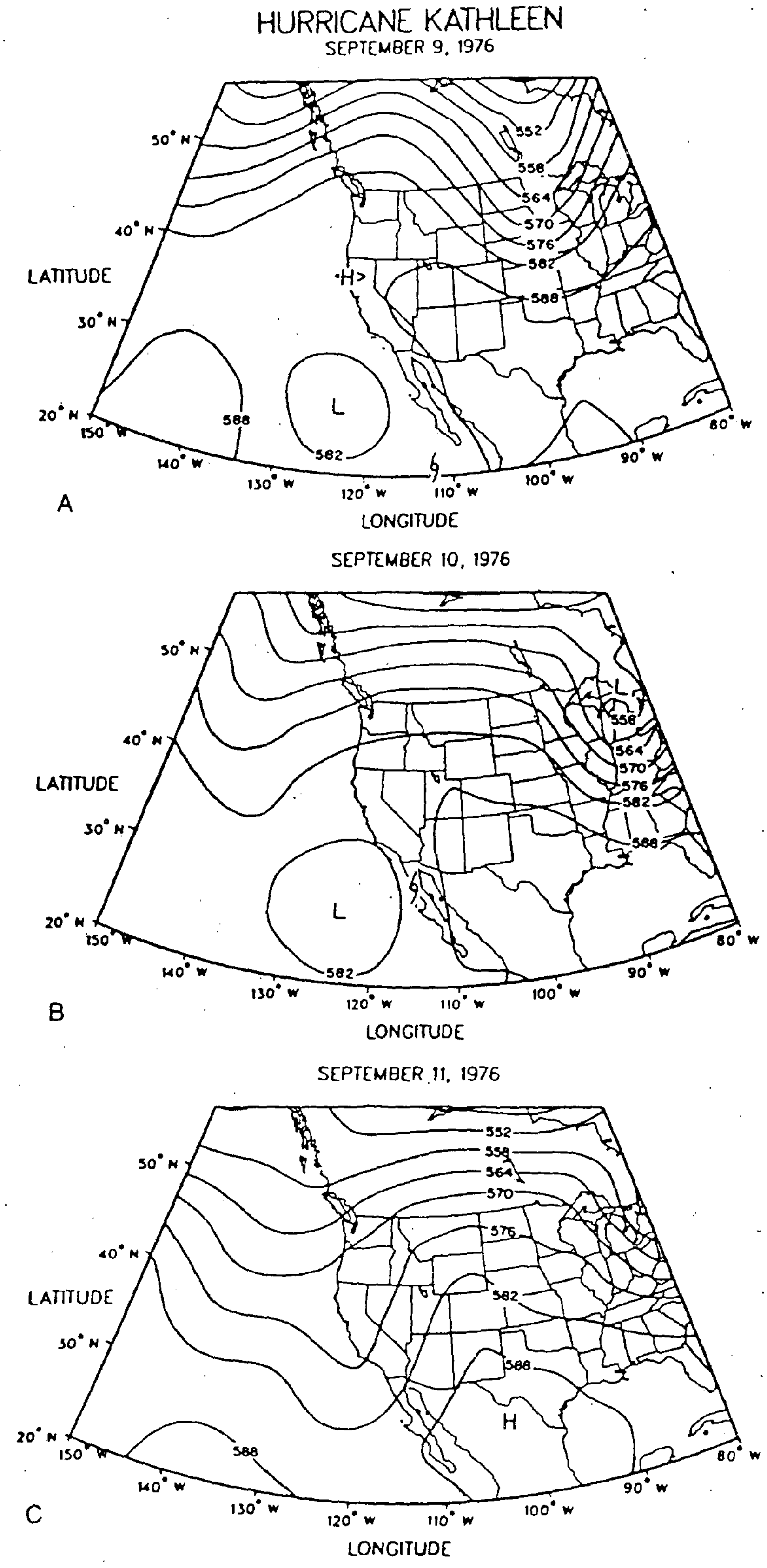


Figure 103. As in Figure 44.

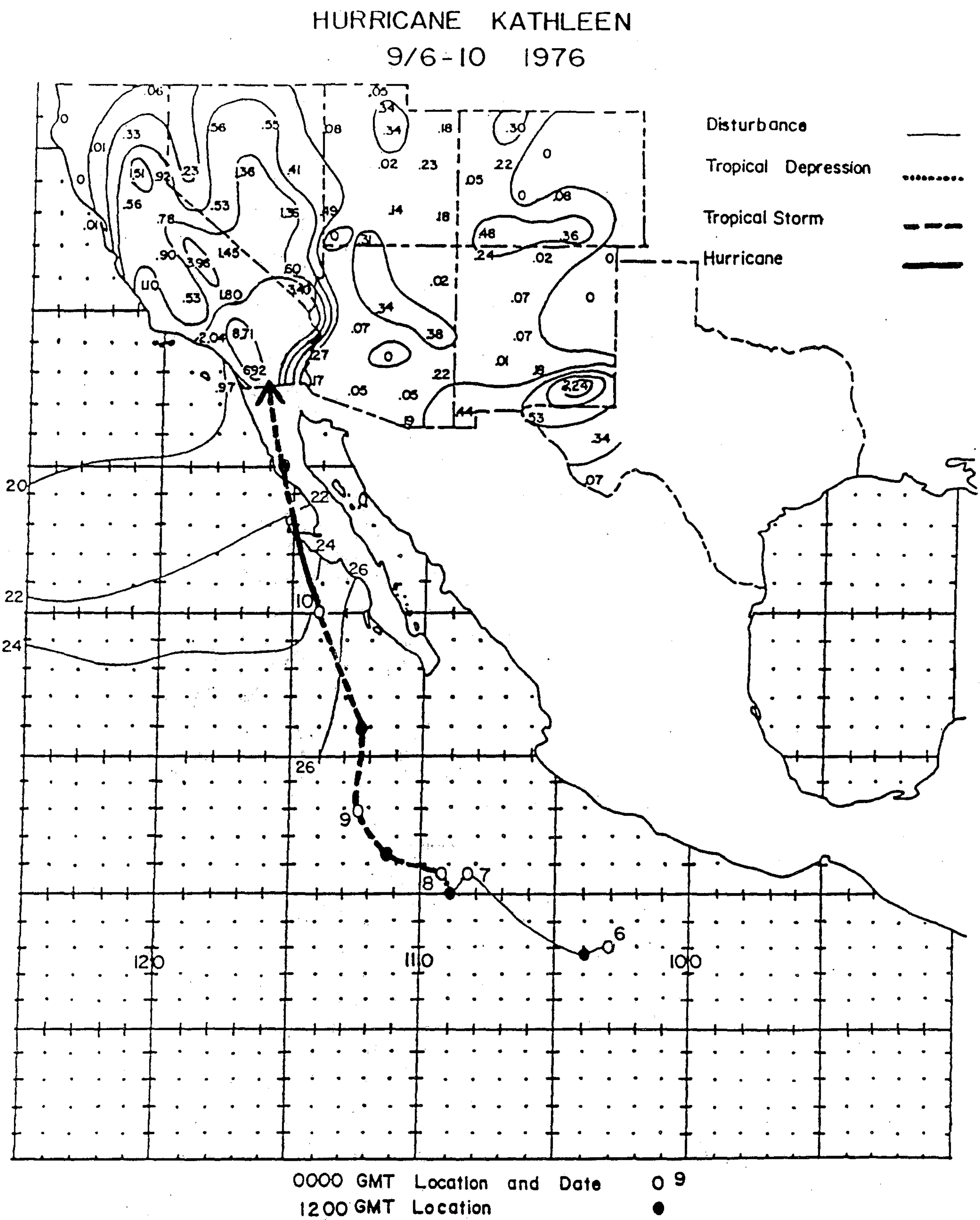


Figure 104. Track of Hurricane Kathleen; September 6-10, 1976; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches. Sea surface temperatures are in °C.

Hurricane Kathleen; September 6-10, 1976

Nearly four years elapsed from the time Hurricane Joanne affected the Southwest until Hurricane Kathleen became the third tropical cyclone this century to move over the southwestern U.S. with tropical storm intensity on September 10, 1976. The disturbance that developed into Kathleen formed on the 6th, intensified to a tropical depression on the 7th, and a short while later was upgraded to a tropical storm (Figure 104). The tropical storm moved to the northwest for about a day before encountering southerly winds between a weak cut-off low situated west of Baja California and the subtropical high to the east (see Figure 103). On September 9, the cyclone accelerated to the north and at 0000 GMT on the 10th was upgraded to a minimal hurricane with 80 kn winds and a central pressure of 986 mb. Due to cool SSTs and the close proximity of the Baja peninsula, Hurricane Kathleen maintained hurricane strength for just a few hours as it continued northward at about 30 kn. Kathleen moved onshore 200 km south of Ensenada, Baja California at 1130, crossed the mountains of the peninsula, and entered the Imperial Valley of California near Calexico at 1800.

Hurricane Kathleen brought to the Southwest the highest sustained winds ever associated with an eastern north Pacific tropical cyclone. Yuma, which was east of the center of the storm, recorded a peak wind gust of 66 kn and a fastest mile of 57 mph before a power outage. The high winds at Yuma blew down many trees (killing one person) and power lines, blew out the windows of many buildings, destroyed several small planes, and raised vast quantities of dust severely restricting visibility. Wind also damaged produce and citrus crops around the city and in the Imperial Valley.

Showers from Kathleen arrived in southern California late on the 9th and became heavy the next day when torrential rains fell in the mountains causing severe flash flooding, especially on the streams that drain into the Imperial Valley, and ended on the 12th (see Table 42). Much of the small community of Ocotillo, California was destroyed and three persons drowned when a wall of water estimated to be one-half mile wide and 4-6 feet high swept into town from Meyer Creek (Court, 1980). Most places in the mountains of southern California received from 5-10 in. of rain with Mt. Wilson 2 recording 10.78 in., less than the 11.60 in. recorded there with the Tropical Cyclone of September 15-25, 1939. Rainfall was also heavy in extreme southern Nevada and adjacent Mohave County, Arizona where Bullhead City suffered extensive flood damage from 2-5 in. of rain. Rain from Kathleen spread as far north as eastern Oregon and Idaho and as far east as eastern New Mexico and west Texas.

Hurricane Liza; September 25 - October 1, 1976

After forming on September 25 and slowly moving northward until the 30th, Hurricane Liza came under the influence of strong southerly winds on the eastern side of the cut-off low shown in

Table 42. Hurricane Kathleen; September 6 10, 1976; daily precipitation

Station	September 9	10	11	12	Total
Big Pines Park FC, Ca.	0	3.88	3.40	0	7.28
Camp Hi Hill Opids, Ca.	0	1.78	6.44	.03	8.25
Grant Grove, Ca.	0	.04	3.11	.81	3.96
Lake Arrowhead, Ca.	00	3.13	5.58	0	8.71
Lodgepole, Ca.	.09	.05	5.06	1.10	6.30
Mt. San Jacinto State Park, Ca.	----	6.00	2.00	0	8.00
Mt. Wilson 2, Ca.	.04	5.34	5.40	0	10.78
Palomar Mountain Observatory, Ca.	0	1.21	5.00	.03	6.24
Boulder City, Nev.	0	.02	2.62	.24	2.88
Searchlight, Nev.	0	.20	3.20	0	3.40

00 = trace; amounts in inches.

Figure 105 and moved rapidly northward past La Paz which was devastated by the combined effects of high winds, a 2 m storm surge, and 5-6 in. of rain. Hundreds of people, perhaps a thousand, were killed in and around La Paz. Hurricane Liza tracked onshore about 60 km south of Los Mochis, Sinaloa (see Figure 106) with 100 kn winds at 1300 GMT October 1 and dissipated exceptionally fast.

Very few places in Arizona, New Mexico, or west Texas recorded more than half inch of rain from the remains of Hurricane Liza as indicated in Figure 106. Although much of California reported rain during the first few days of October, satellite imagery suggests the moisture for the precipitation there originated with the cut-off low which moved inland after becoming caught in the westerlies and not from the weakening hurricane. Rainfall in Nevada and Utah was heavier than that measured in Arizona and New Mexico most likely because the trough produced stronger upward motion in the north than in the south.

Hurricane Doreen; August 13-18, 1977

For the second time in less than a year an eastern north Pacific tropical cyclone, dissipating Hurricane Doreen, brought heavy rains to southern California. Since the winds steering the cyclone blew consistently from the southeast, Doreen moved to the northwest from the time it became a tropical depression on the 13th until it dissipated on the 18th near San Clemente Island off the southern California coast (see Figures 107 and 108). As Doreen passed over relatively cool water (22°C) and very close to Baja California on August 16 it surprisingly maintained hurricane intensity all the way to 29°N, as far north as any documented eastern north Pacific hurricane. Only Hurricane Kathleen in September 1976 and Hurricane Marie in September 1984 possibly remained hurricanes until reaching 29°N in the eastern north Pacific.

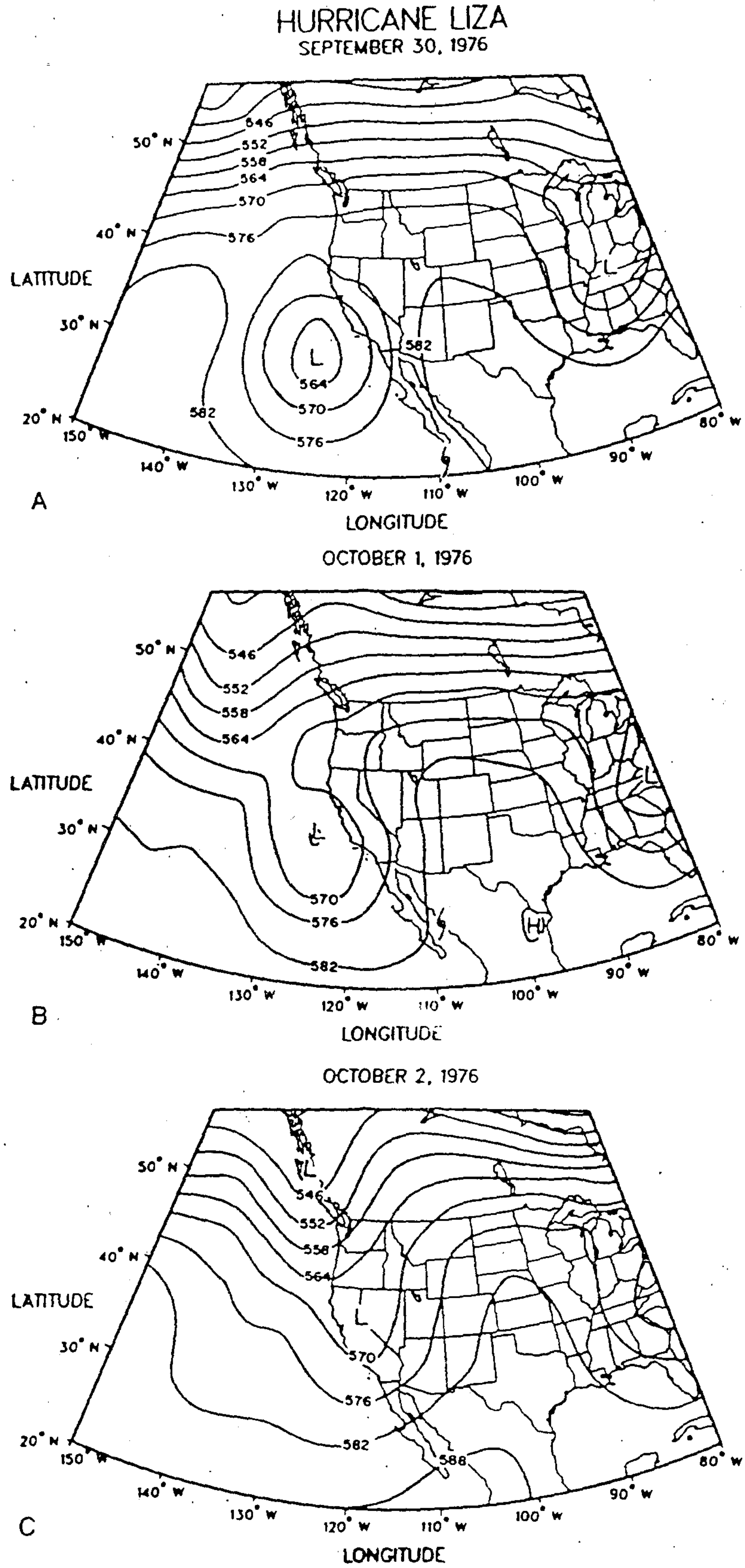


Figure 105. As in Figure 44.

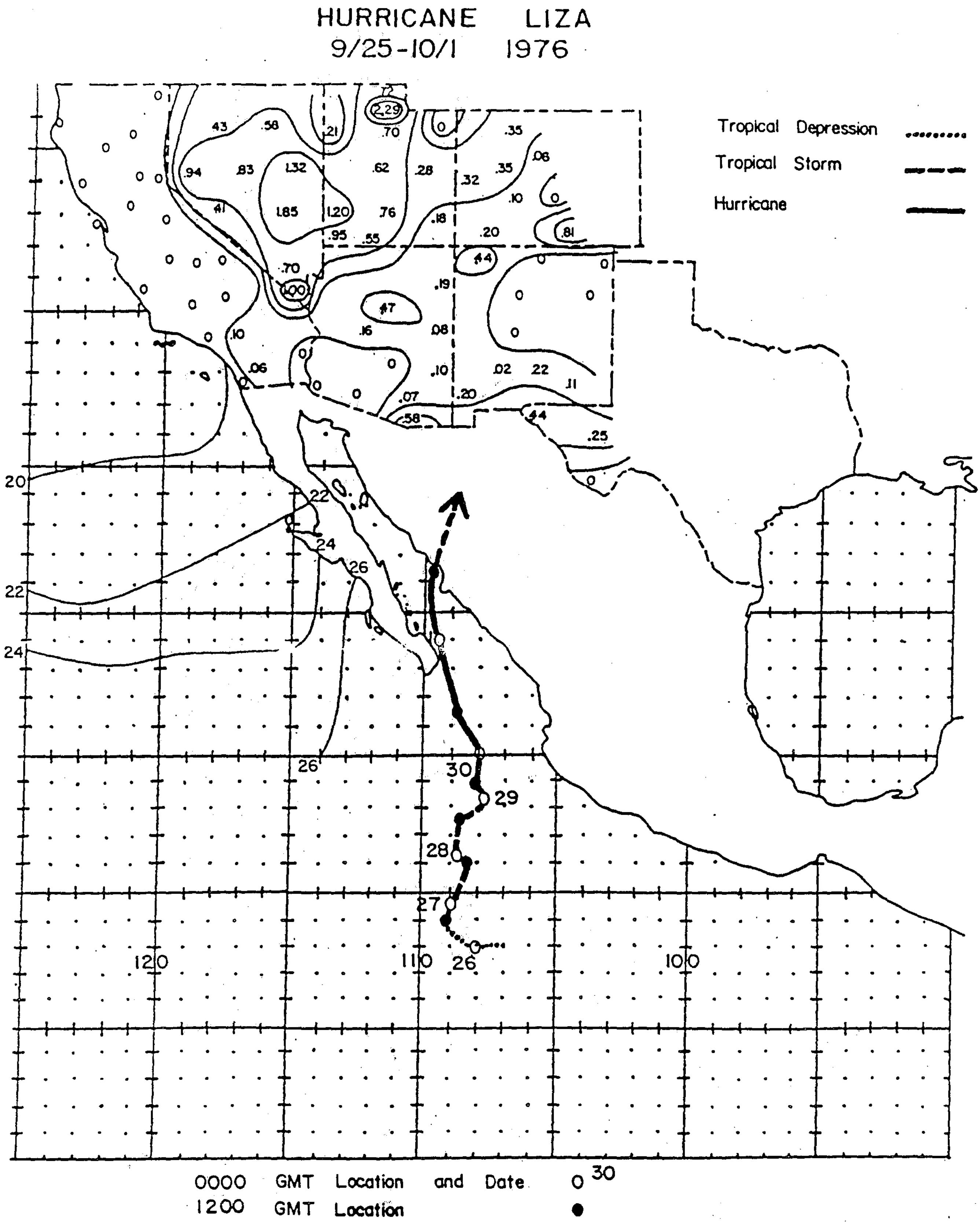


Figure 106. Track of Hurricane Liza; September 25 - October 1, 1976; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

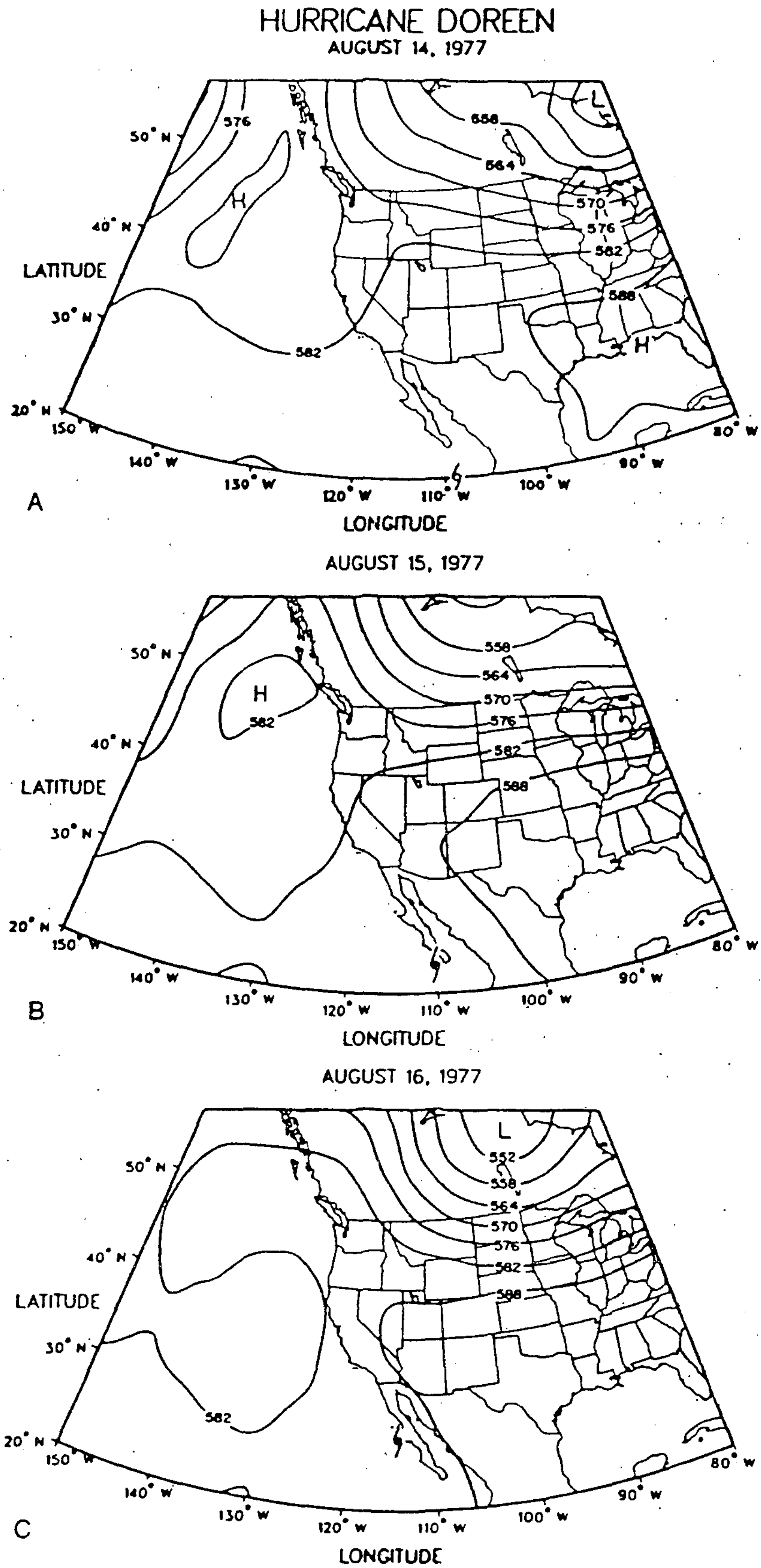


Figure 107. As in Figure 44.

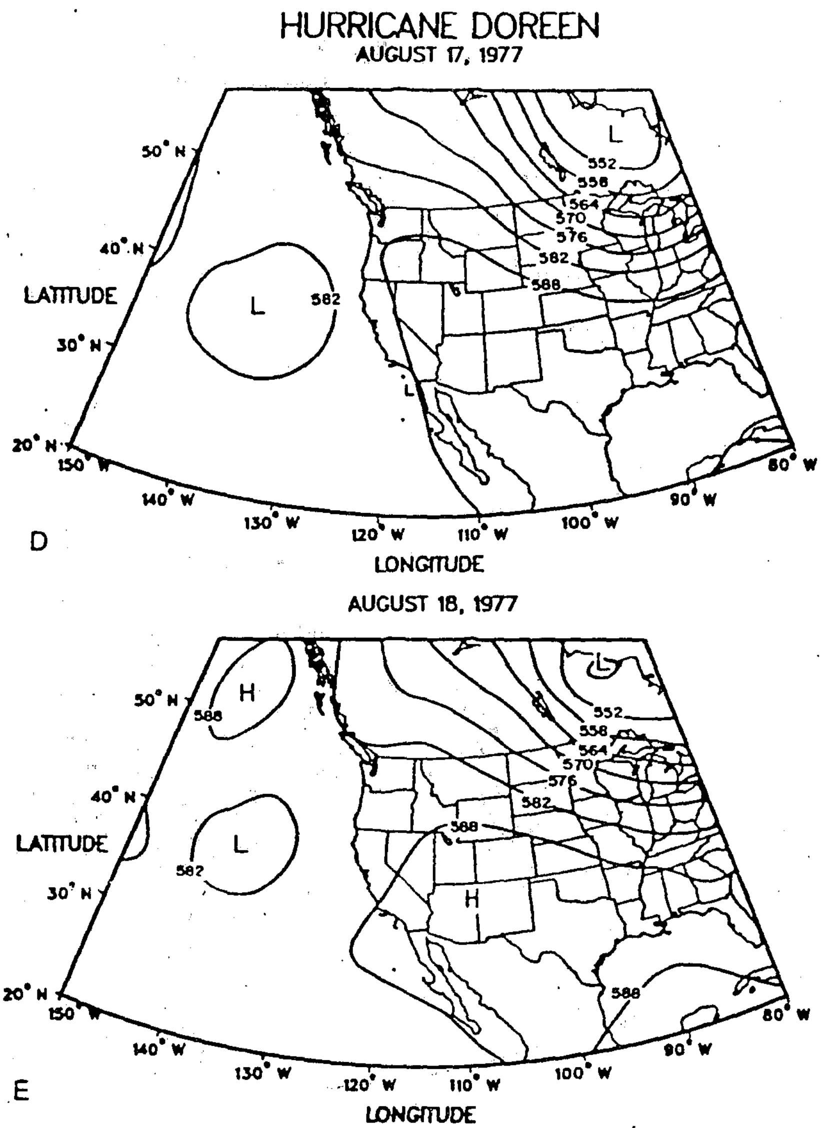


Figure 107. (continued) As in Figure 44.

Rain associated with Doreen began late on August 14 when the circulation around the tropical cyclone and the winds steering the storm combined to bring moist tropical air over southern Arizona where widely scattered showers and thunderstorms developed. As shown in Table 43, precipitation lasted till the 19th. The extraordinarily heavy rains that fell in the lower Colorado River Valley on the afternoon of August 15 were caused by a disturbance which formed after Hurricane Doreen and, subsequently, got caught in the cyclonic flow around Doreen and moved up through the Gulf of California and over the Yuma area (Gunther, 1978). Yuma WSO recorded 2.05 in. on the 15th but just 15 km away Yuma Valley recorded 6.45 in. (which was reported on the 16th). The average annual rainfall at these two stations is 2.59 (33 years of record) and 2.81 in. (48 years of record), respectively (Sellers et al., 1985).

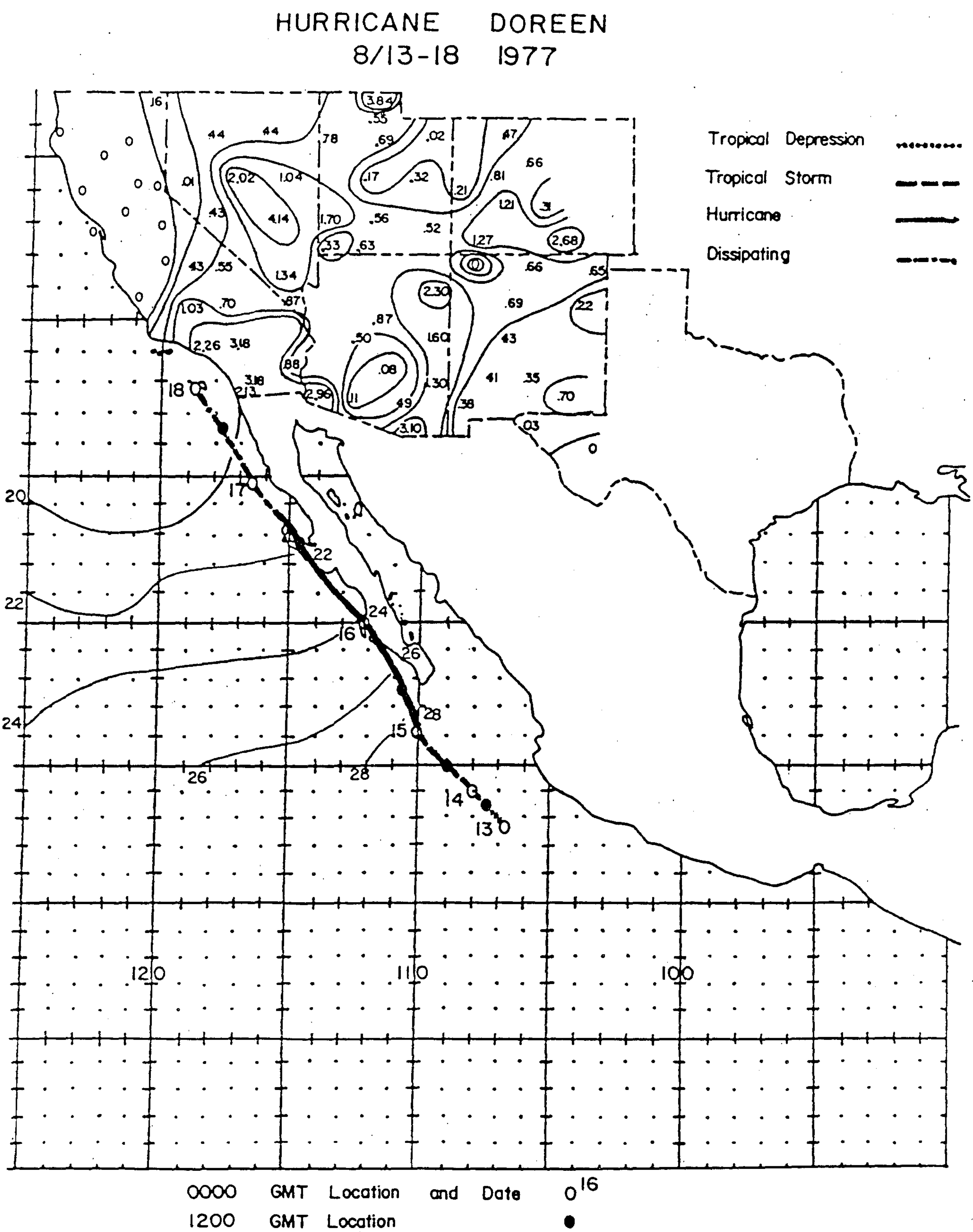


Figure 108. **Track of Hurricane Doreen; August 13-18, 1977;** and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

Table 43. Hurricane Doreen; August 13-18, 1977; daily precipitation

Station	August 14	15	16	17	18	19	Total
Nogales, Az.	.88	1.30	.92	0	0	0	3.10
Yuma Valley, Az.	0	00	6.45	.56	0	0	7.01
Yuma WSO Airport, Az.	.67	2.05	.24	0	0	0	2.96
Cuyamaca, Ca.	0	0	.22	2.61	.34	.01	3.18
Imperial FAA, Ca.	0	2.18	1.57	0	0	0	3.75
Mt. San Jacinto State Park, Ca.	0	1.83	----	5.60	.20	0	7.63
UCLA, Ca.	0	0	00	3.07	.16	0	3.23
Adaven, Nev.	0	0	.01	2.61	1.52	0	4.14

00 = trace; amounts in inches.

Rainfall in southern California, northwestern Arizona, and Nevada was the most intense from the 16th-17th. Nearly all of southern California received at least 2.00 and a few places more than 5.00 in. of rain. Flooding was widespread with many roads and crops extensively damaged. When compared with the precipitation from Hurricane Kathleen, Doreen brought far less rain to the mountains of southern California but more to the coast. However, both storms did bring heavy rains to many stations in Nevada and cause serious flooding in both Ocotillo and Bullhead City. Another feature common to both tropical cyclones is that no thunderstorms were reported from either Los Angeles or San Diego. Along the southern California coast, thunderstorms are not commonly associated with dissipating tropical cyclones. Usually continuous rain falls with varying intensity, ranging from just a trace to a half inch per hour.

Hurricane Florence; September 20-24, 1977

This tropical cyclone had very little effect on the Southwest. Southwesterly winds carried moisture from the hurricane over Arizona, New Mexico, and southern Colorado from September 23-25 while the storm was moving toward the northeast and weakening over cooler water (see Figures 109 and 110). Most stations reported less than one-tenth of an inch of rain and only a few measured more than one-quarter.

Tropical Storm Glenda; September 23-27, 1977

Although noticeably weaker than Hurricane Florence whose maximum sustained winds reached 90 kn, Tropical Storm Glenda was responsible for significantly more rain in the Southwest. Figure 111, which presents 500 mb heights from the 26th-28th, shows Glenda moved around the western end of a ridge until dissipating on the 27th when southwesterly winds advected moisture from the ex-tropical storm over Arizona and New Mexico. Precipitation linked to the tropical cyclone fell on September 27 and 28 and was heaviest in a band stretching from Yuma to the northeastern corner of Arizona (Figure 112). A relatively large number of stations in north central Arizona received more than .50 in. of

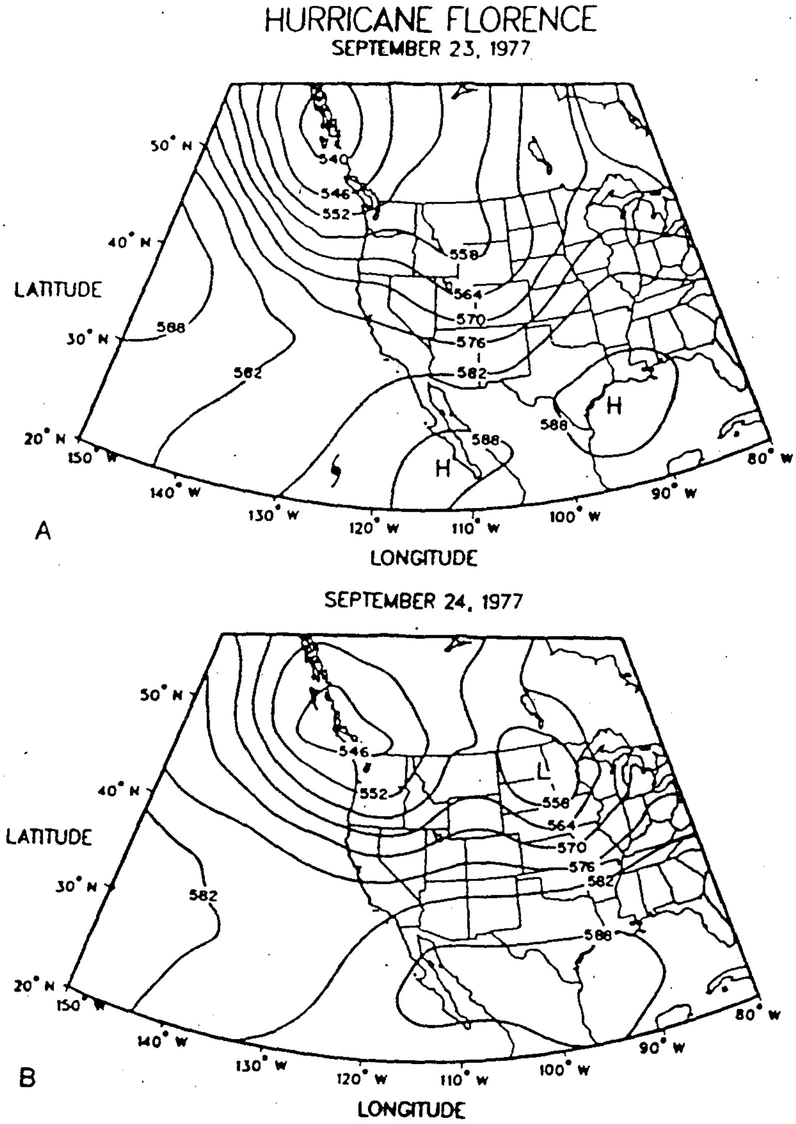


Figure 109. As in Figure 44.

rain and several received more than 1.50 in.; e.g. Happy Jack Ranger Station (1.91) and Miami (1.54). Camp Geronimo measured the greatest amount, 2.31 in., all of which fell on the 28th.

Hurricane Heather: October 4-7, 1977

Infrared imagery from 0615 GMT October 5 shows clouds from Heather streaming northeastward over southeastern Arizona, New Mexico, and west Texas (Gunther, 1978). The result was isolated showers which became heavier and more widespread the following day as the tropical cyclone moved around the western periphery of a large ridge (Figure 113) and the advection of moist air from the storm increased. By 1200 GMT on the 7th, Hurricane Heather had reached 28°N and was rapidly dissipating due west of Point Eugenia (Figure 114). Nonetheless, a vast quantity of moist air from the vicinity of the former hurricane continued flowing over

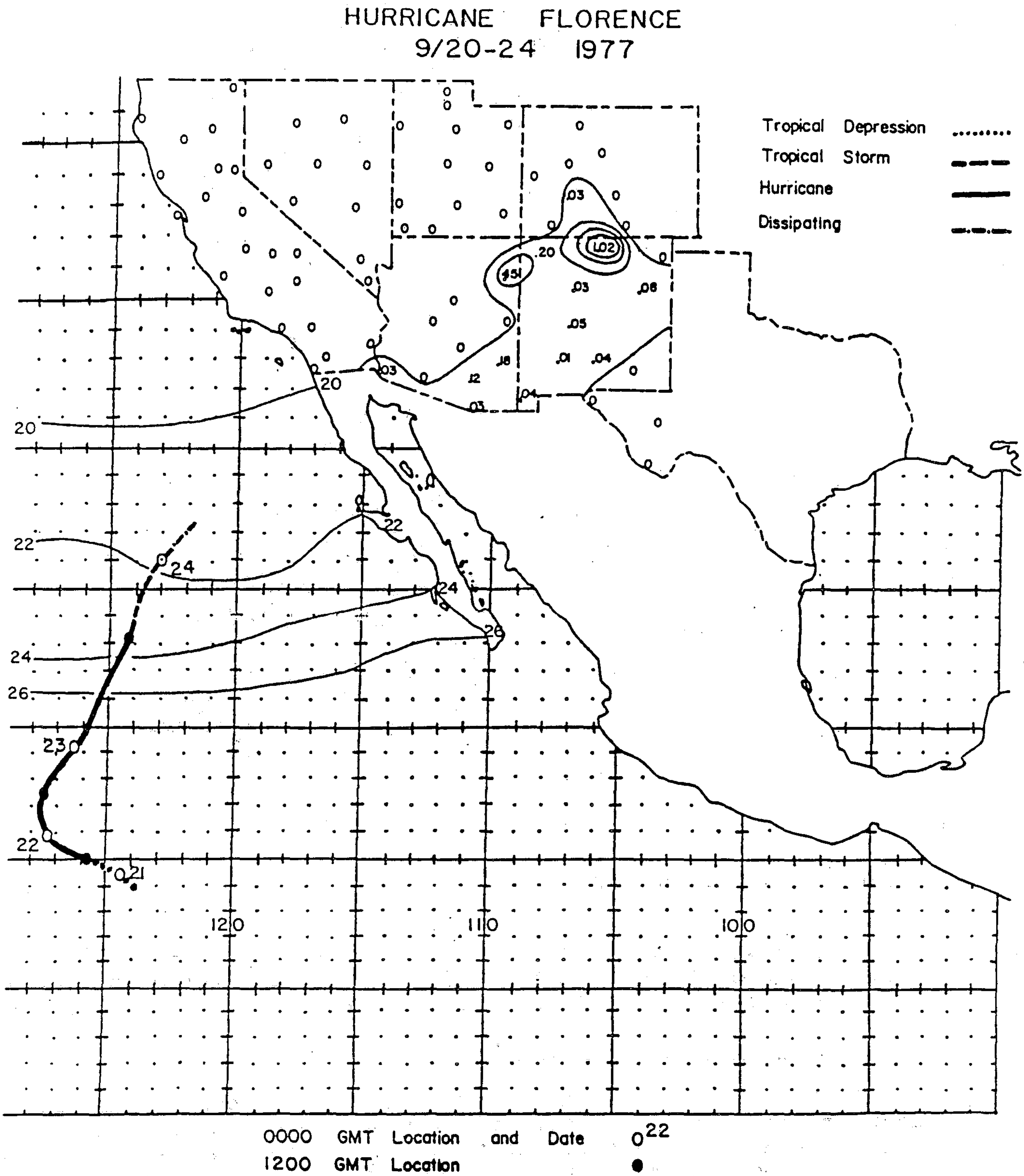


Figure 110. Track of Hurricane Florence; September 20-24, 1977; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches. Sea surface temperatures are in °C.

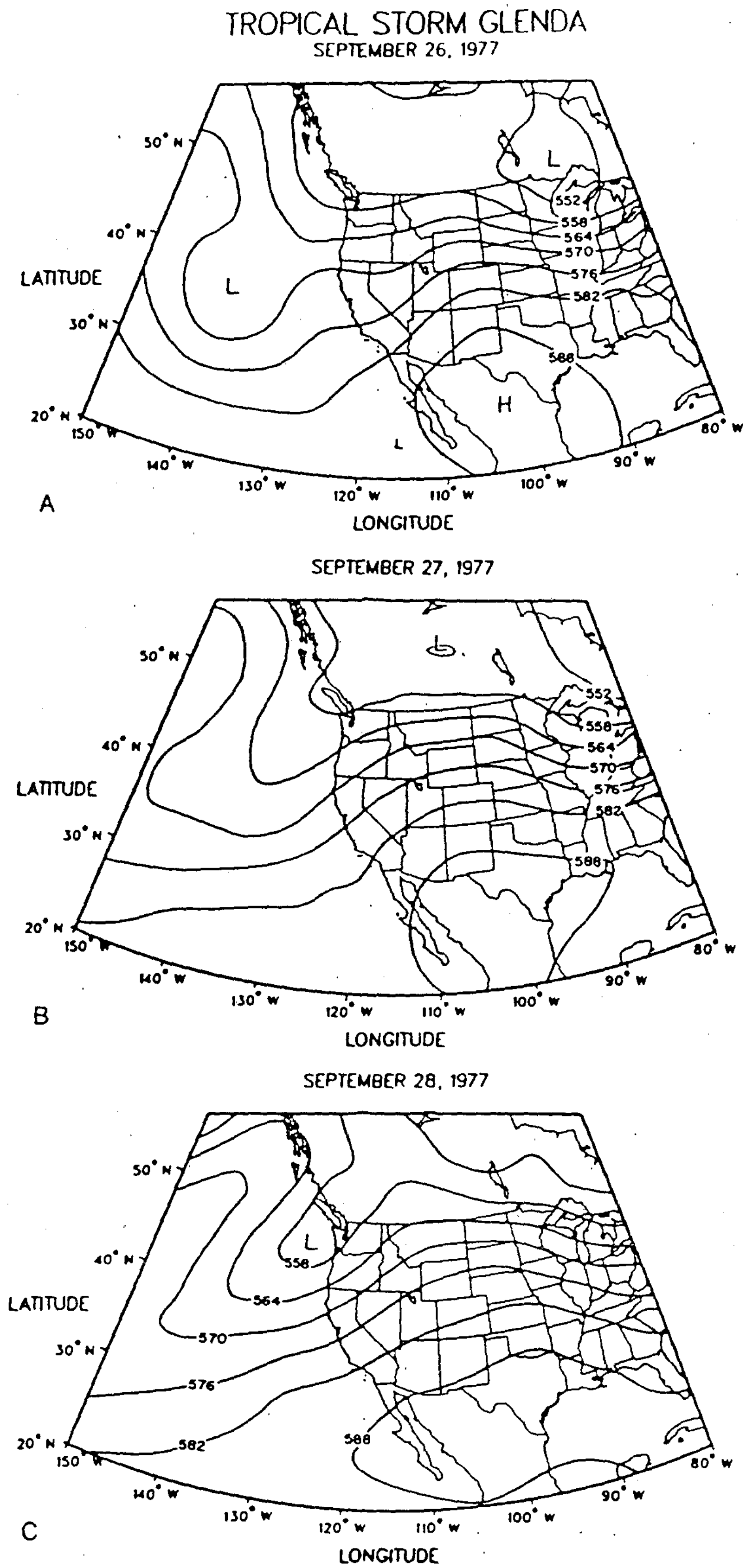


Figure 111. As in Figure 44.

TROPICAL STORM GLENDA
9/23-27 1977

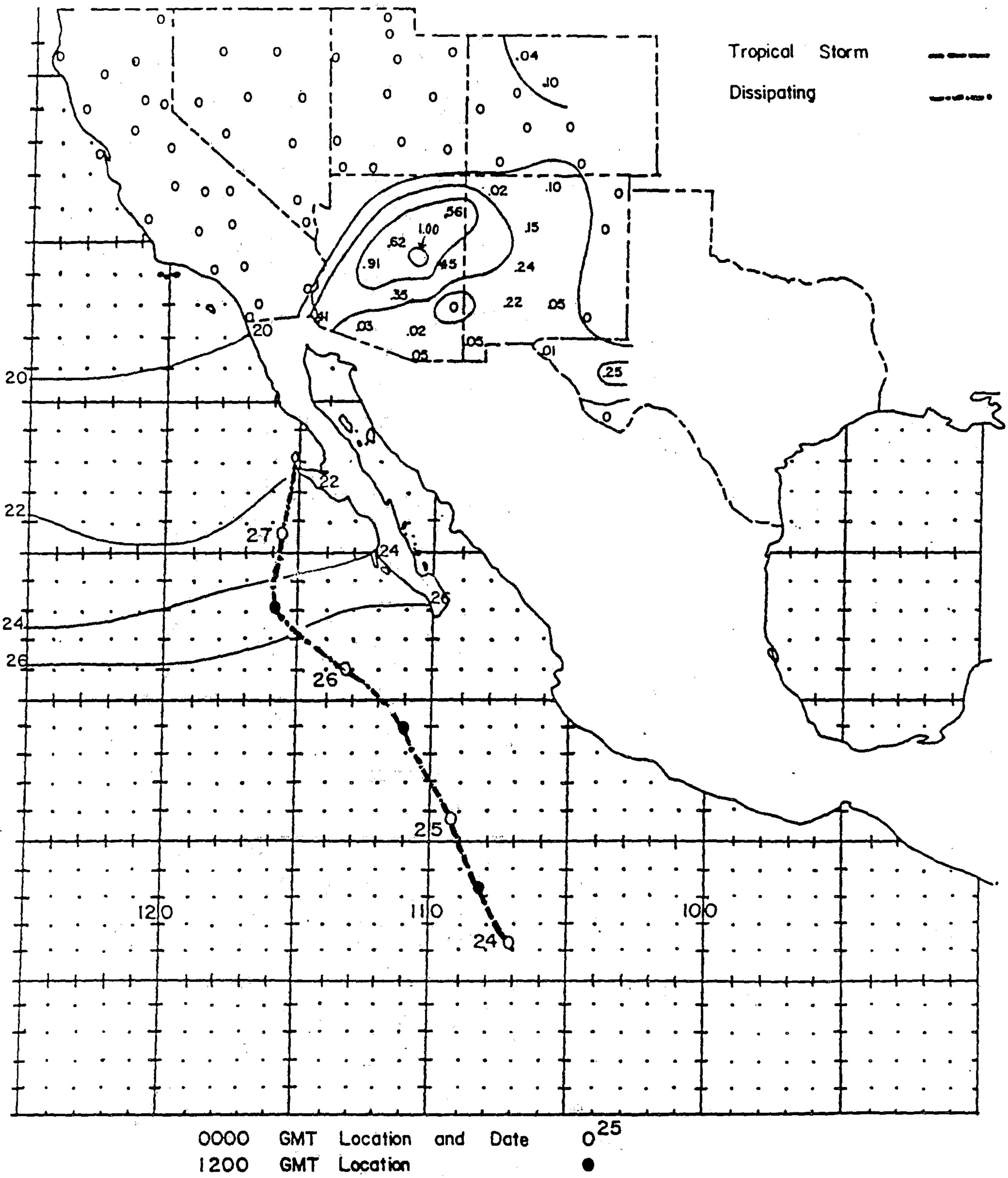


Figure 112. Track of Tropical Storm Glenda; September 23-27, 1977; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, and .50 inches. Sea surface temperatures are in °C

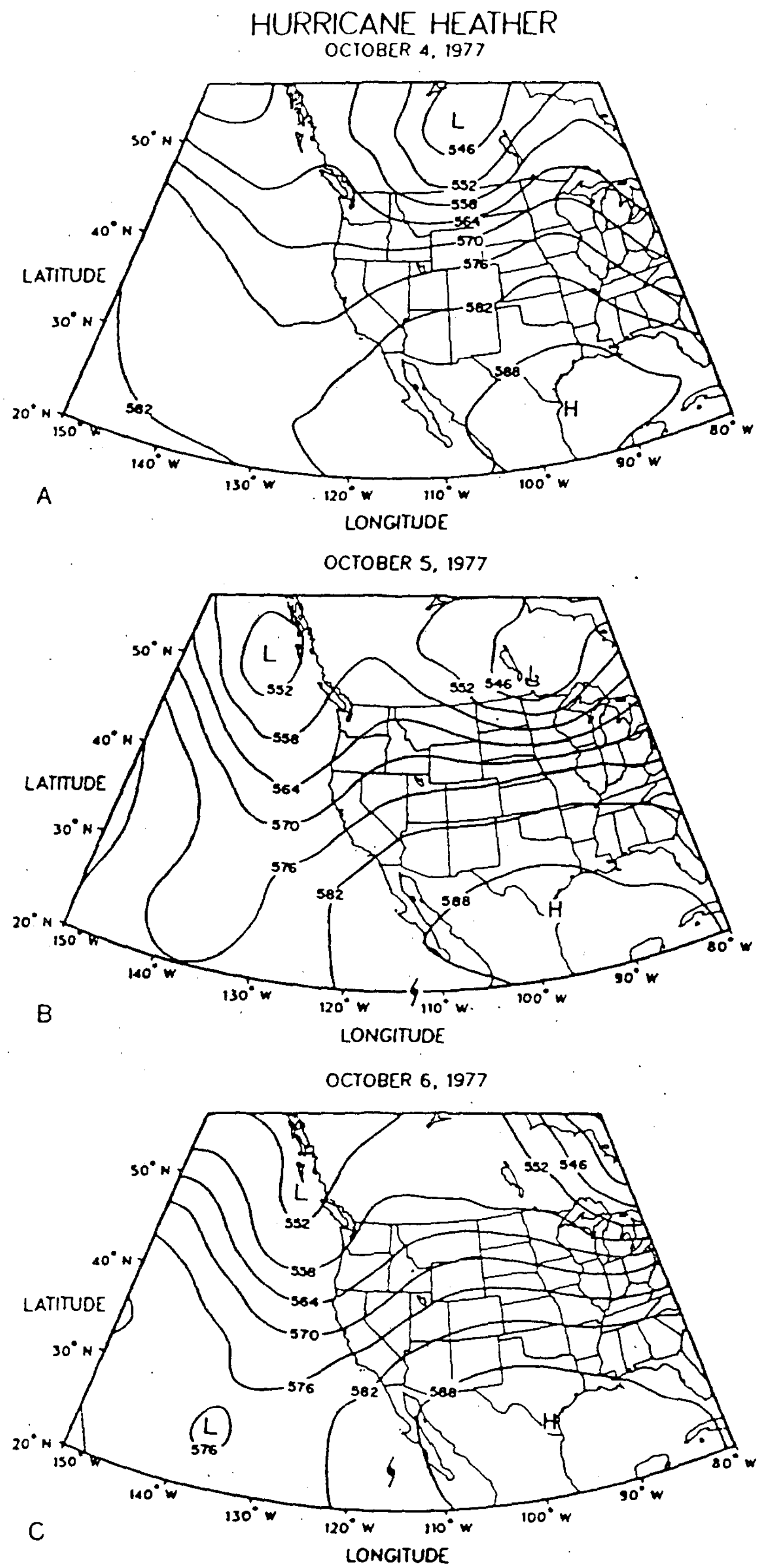
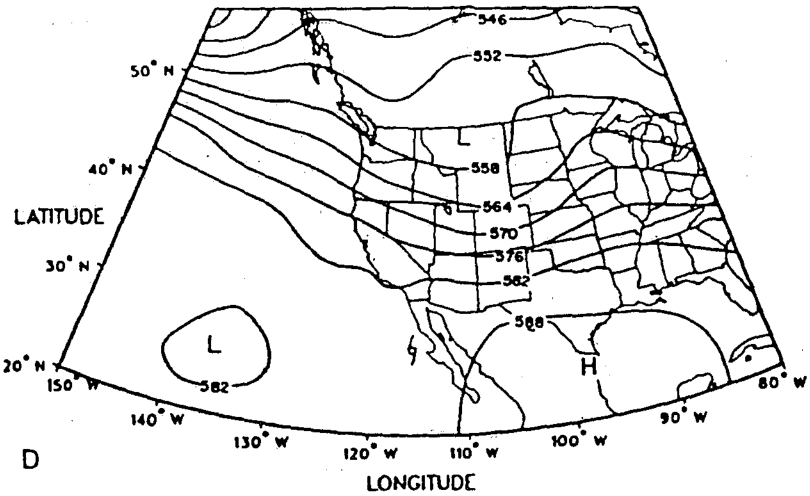


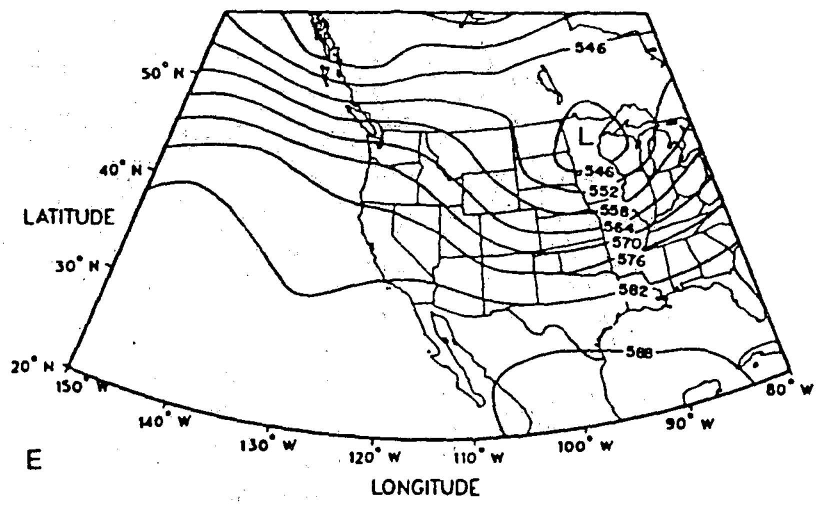
Figure 113. As in Figure 44.

HURRICANE HEATHER

OCTOBER 7, 1977



OCTOBER 8, 1977



OCTOBER 9, 1977

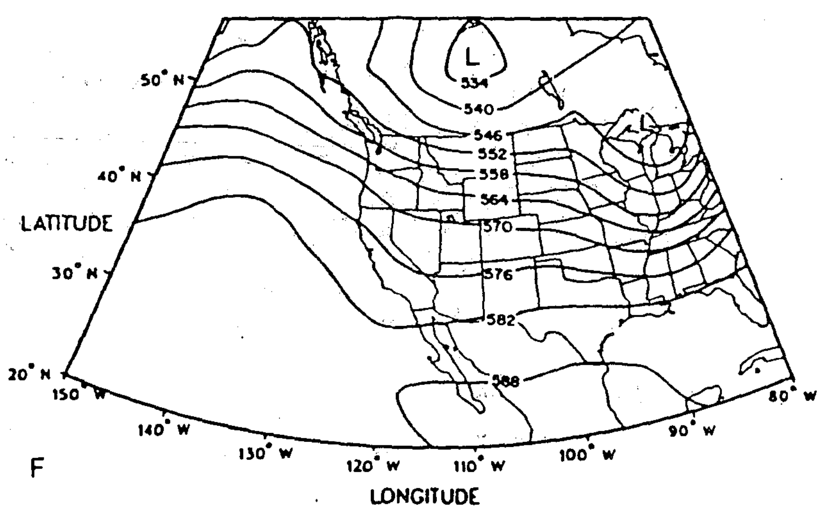


Figure 113. (continued) As in Figure 44.

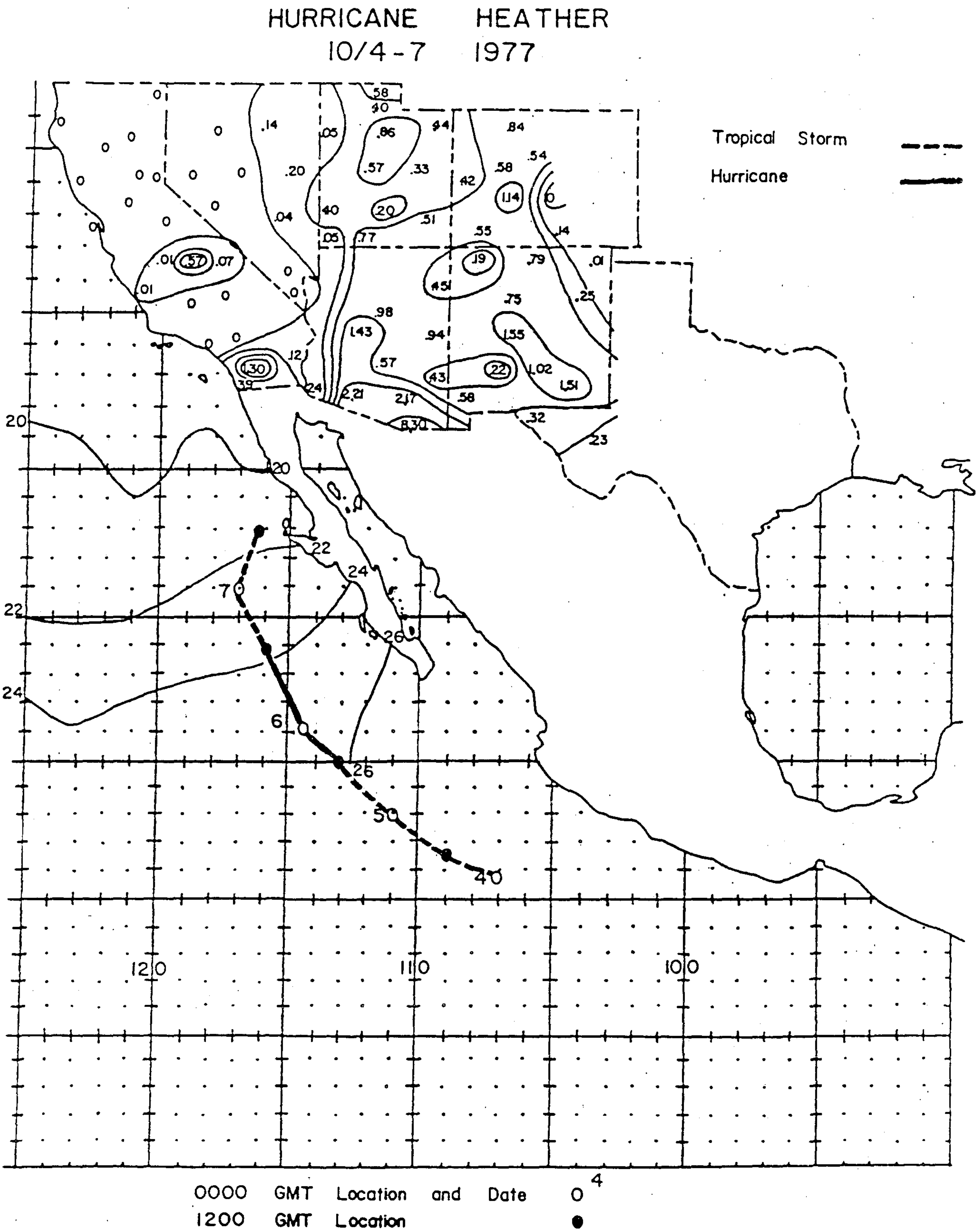


Figure 114. **Track of Hurricane Heather; October 4-7, 1977; and associated rainfall in the Southwest.** Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches. Sea surface temperatures are in °C.

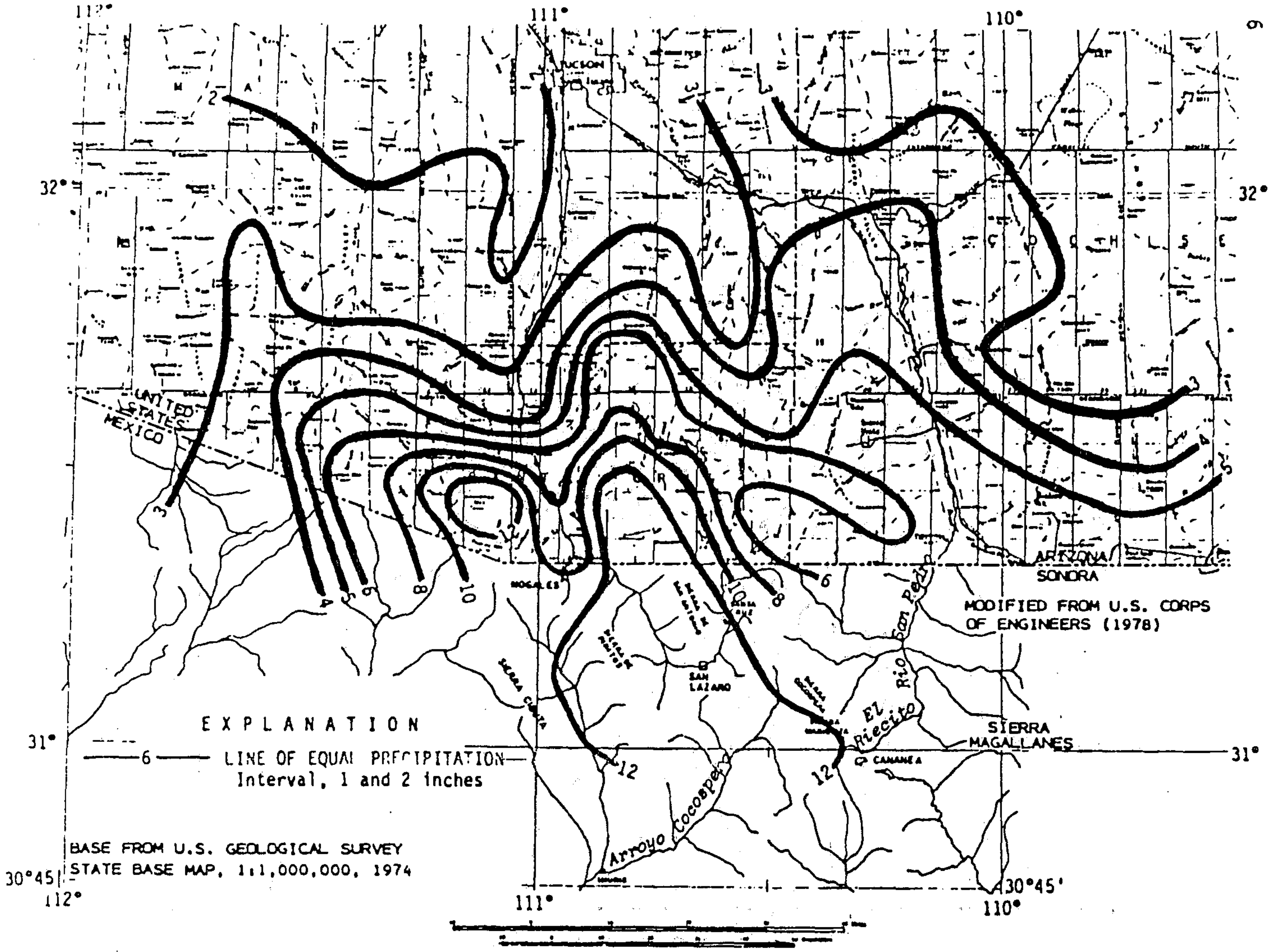


Figure 115. Total precipitation in southern Arizona and northern Mexico from October 6-10, 1977 (from Alderidge and Eychaner, 1982).

southeastern Arizona and southern New Mexico until late on the 9th.

Showers were widespread over the Southwest through the 7th as the trough in Figure 113C tracked inland. Subsequently, upper level winds turned to the west cutting off the supply of tropical air from all of the study area except extreme southeastern Arizona which remained under the moist air and experienced heavy precipitation from late on the 7th to early on the 9th when a weak trough and stationary front combined to produce heavy rains over the Arizona-Mexico border. During the period, Nogales received approximately 6 inches of rain bringing the storm total to 8.30 inches (Table 44). Figure 115, which presents the total precipitation from October 6-10 in southern Arizona and northern Mexico, indicates rain was heavier in the mountains surrounding Nogales where as much as 14 inches fell. This extremely heavy rain produced the largest known (prior to October 1983) discharge

Table 44. Hurricane Heather; October 4-7, 1977; daily precipitation

Station	October 5	6	7	8	9	10	Total
Bisbee 2, Az.	.04	00	.58	2.07	3.10	00	5.79
Douglas, Az.	0	0	.41	2.65	1.07	1.17	5.30
Hawley Lake, Az.	.37	.11	2.28	.12	0	0	2.88
Nogales, Az.	0	1.63	.69	3.06	2.92	0	8.30
Patagonia, Az.	0	2.66	2.30	2.12	.56	0	7.64
Wolf Creek Pass, Co.	0	.01	2.81	0	0	0	2.82

00 = trace; amounts in inches.

on the Santa Cruz River upstream from Tucson and caused major flooding (Alderidge and Eychaner, 1982).

Hurricane Norman: August 30 - September 6, 1978

Norman became a tropical depression on August 31 several hundred kilometers southeast of Acapulco and rapidly intensified into a hurricane by September 1 as seen in Figure 117. For the next three days the storm moved to the northwest around a large area of high pressure while a deep trough moved southeastward from the Gulf of Alaska (Figure 116). On the 4th, southerly winds ahead of the upper level trough brought clouds and moisture from Hurricane Norman inland over California causing light showers. The tropical cyclone changed direction and began to weaken rapidly late on the 4th over 23°C water but continued northward until September 6 when it completely dissipated a few kilometers from San Clemente Island near the California coast.

Rainfall associated with Hurricane Norman was most intense on the 5th-6th. Several stations in the Sierra Nevada Mountains, including the first four listed in Table 45, measured more than 3 in. of precipitation and by the time showers ended in California on September 7, most of the southern two-thirds of the state and nearly all of Nevada had received at least a half inch of rain. Crop losses in agricultural areas of California were estimated to be greater than $300 million (Gunther, 1979). The northwestern corner of California also reported rain from the 4th-7th but the rain there probably was due entirely to the midlatitude trough because satellite imagery suggests clouds and moisture from Norman never reached that far north.

Hurricane Celia: June 25-30, 1980

High clouds and moisture from this early season tropical cyclone were advected over California beginning late on June 29 by relatively strong southerly winds which existed between a weak trough off the West Coast and a massive, drought-producing ridge that was centered over the southern plains states (Figure 118). Celia entirely dissipated nearly 1000 km south-southwest of San Diego after encountering 21°C SSTs near 23°N on June 30 (Figure 119) but by this time moisture from the storm had already spread inland to Utah and combined with strong daytime heating to cause

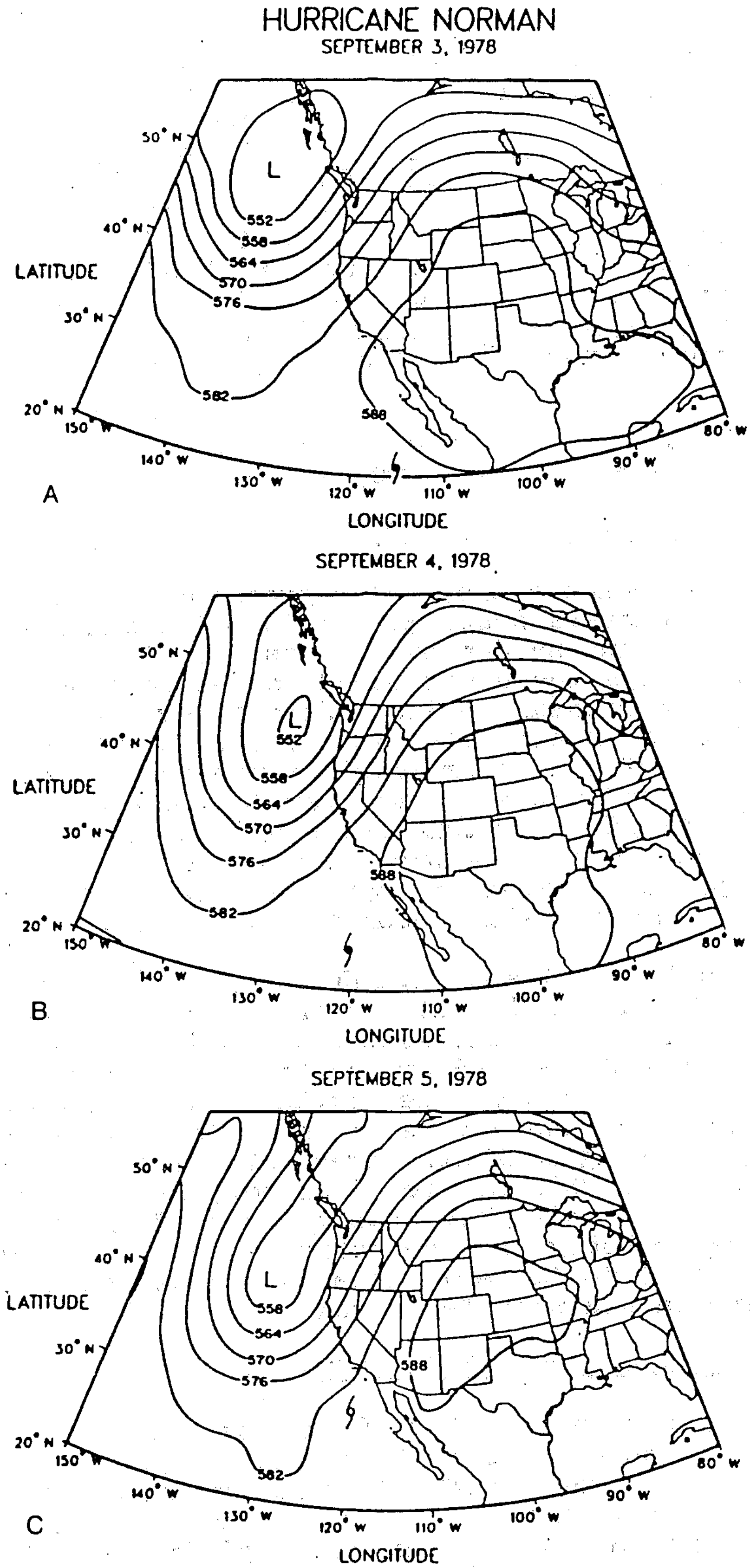


Figure 116. As in Figure 44.

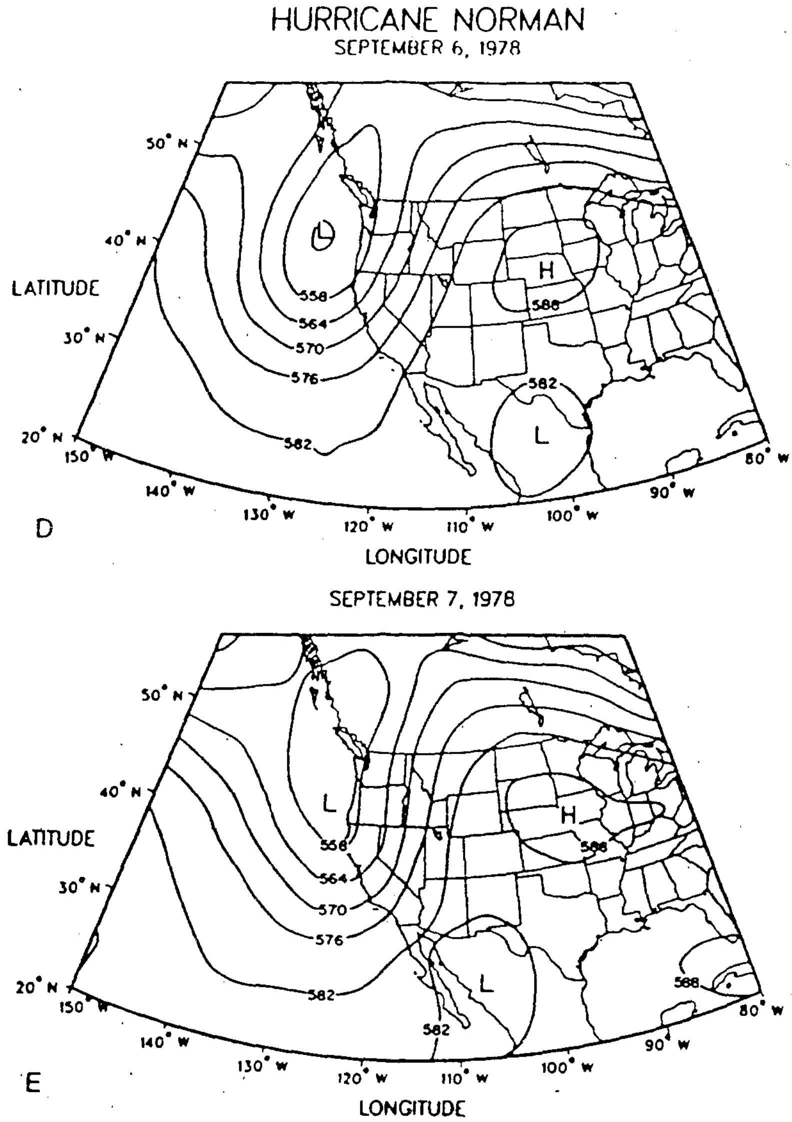


Figure 116. (continued) As in Figure 44.

Table 45. Hurricane Norman; August 30 - September 6, 1978: daily precipitation

	September				
Station	4	5	6	7	Total
Blue Canyon WSMO, Ca.	.46	2.68	.54	0	3.68
Calaveras Big Trees, Ca.	0	.67	2.53	.33	3.53
Grant Grove, Ca.	0	2.09	2.06	.49	4.64
Lodgepole, Ca.	.02	4.13	2.02	.84	7.01
Adaven, Nev.	0	1.15	1.75	0	2.90

amounts in inches.

scattered showers. Precipitation over California, Nevada, Utah, and western Colorado continued sporadically to about July 3 and was never widespread or heavy. More than a half inch of rain fell from the Sierra Nevada Mountains across the Great Basin to

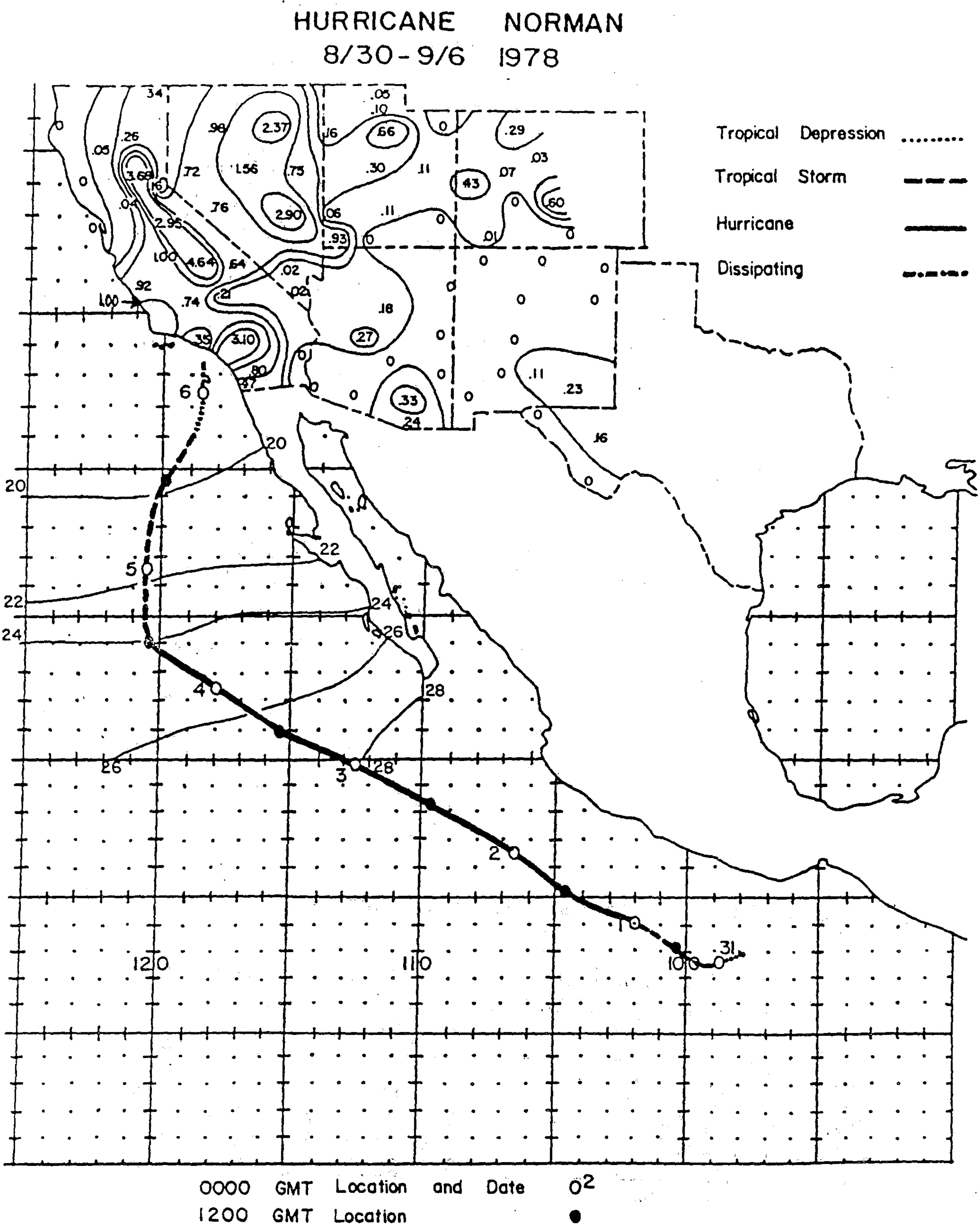


Figure 117. Track of Hurricane Norman; August 30 - September 6, 1978; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

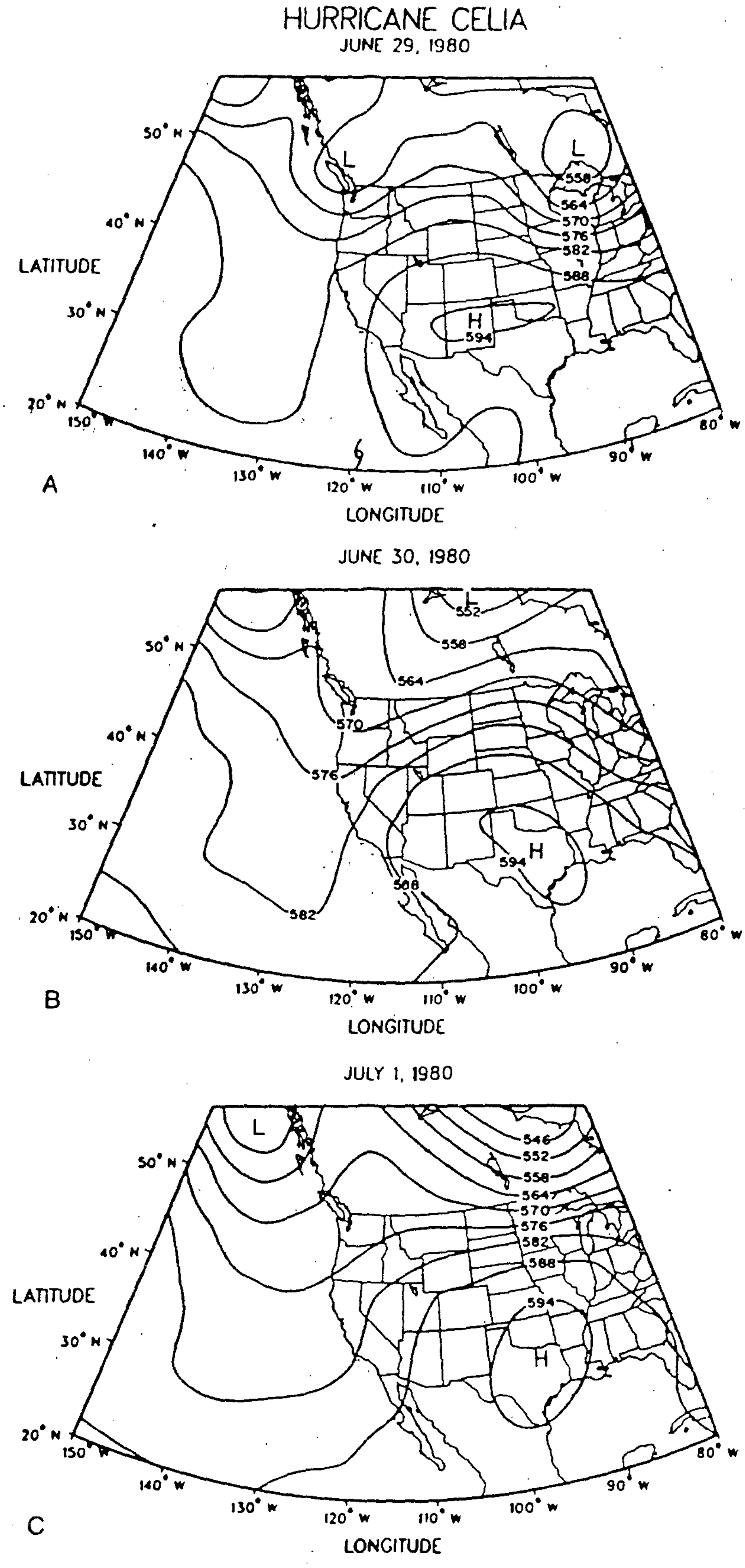


Figure 118. As in Figure 44.

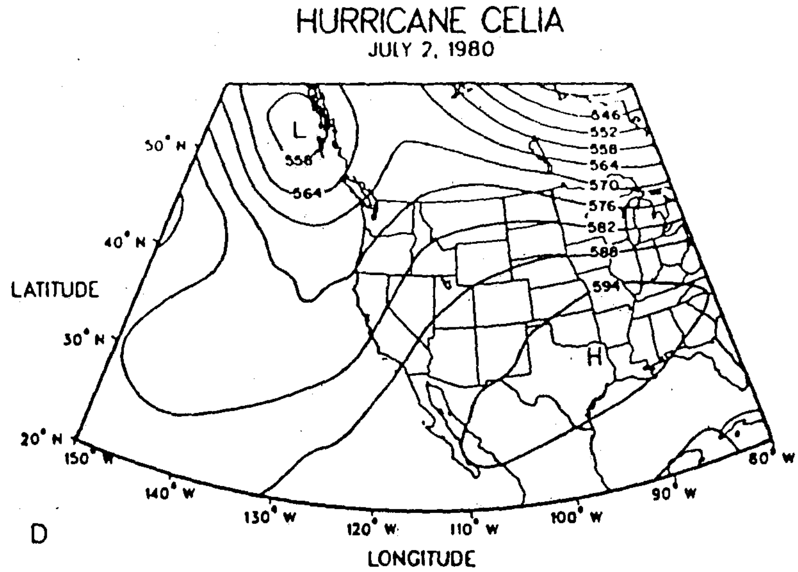


Figure 118. (continued) As in Figure 44.

western Colorado. Some stations in the aforementioned area received more than 1.00 in. of rain and Saltair Salt Plant, Utah received 2.13 in., the largest amount associated with Hurricane Celia.

Hurricane Norman: September 9-18, 1982

This tropical cyclone began as a very weak, disorganized tropical depression on the 9th at about 15°N, 110°W and gradually intensified while tracking to the northwest during the next three days to become a hurricane on the 13th (Figure 121). Norman slowly recurved to the northeast ahead of the developing cut-off low shown in Figure 120 on September 15 and 16 and started weakening due to the effects of strong vertical wind shear and cooler water. By 1200 GMT on the 17th, Hurricane Norman was a rapidly dissipating tropical depression. Moisture from Norman combined with the cut-off low and daytime heating to produce scattered, mostly light showers over much of the Southwest. Most stations measured less than .25 in. of rain and only a few places; e.g. Cuyamaca, Ca. (1.00) and El Paso WSO (2.46, which is not a representative amount); measured 1.00 in. or more.

Hurricane Olivia: September 18-25, 1982

Hurricane Olivia followed a path (Figure 123) very similar to that of Hurricane Norman of 1978 (Figure 117) in response to analogous atmospheric circulation (compare Figures 122 and 116) and produced comparable results in California, over $300 million in crop damage (Gunther et al., 1983). Precipitation totals over California and Nevada were also nearly the same from both storms although slightly higher with Olivia. However, rainfall amounts over northern Arizona and especially Utah were far greater with Hurricane Olivia.

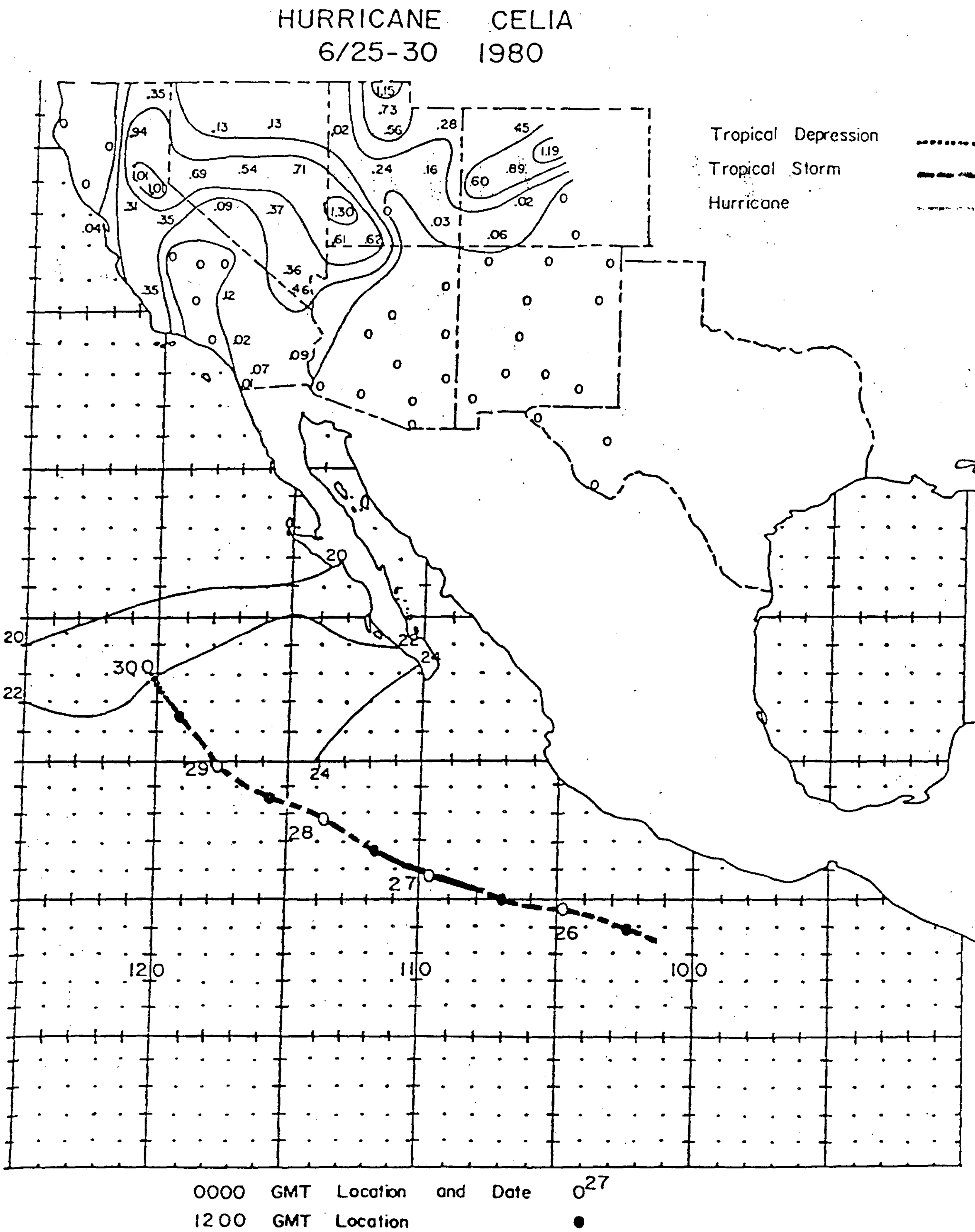


Figure 119. Track of Hurricane Celia; June 25-30, 1980; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches. Sea surface temperatures are in °C.

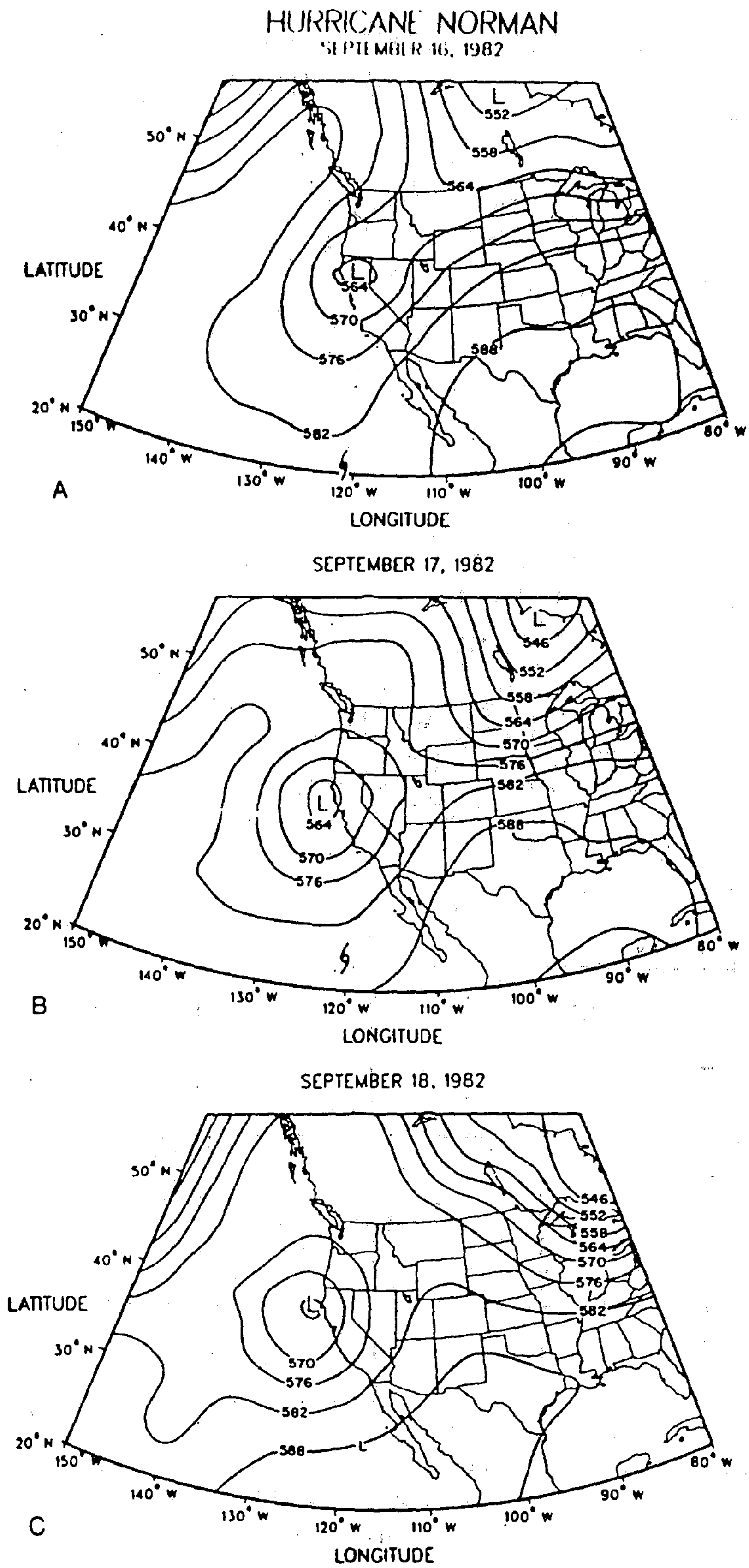


Figure 120. As in Figure 44.

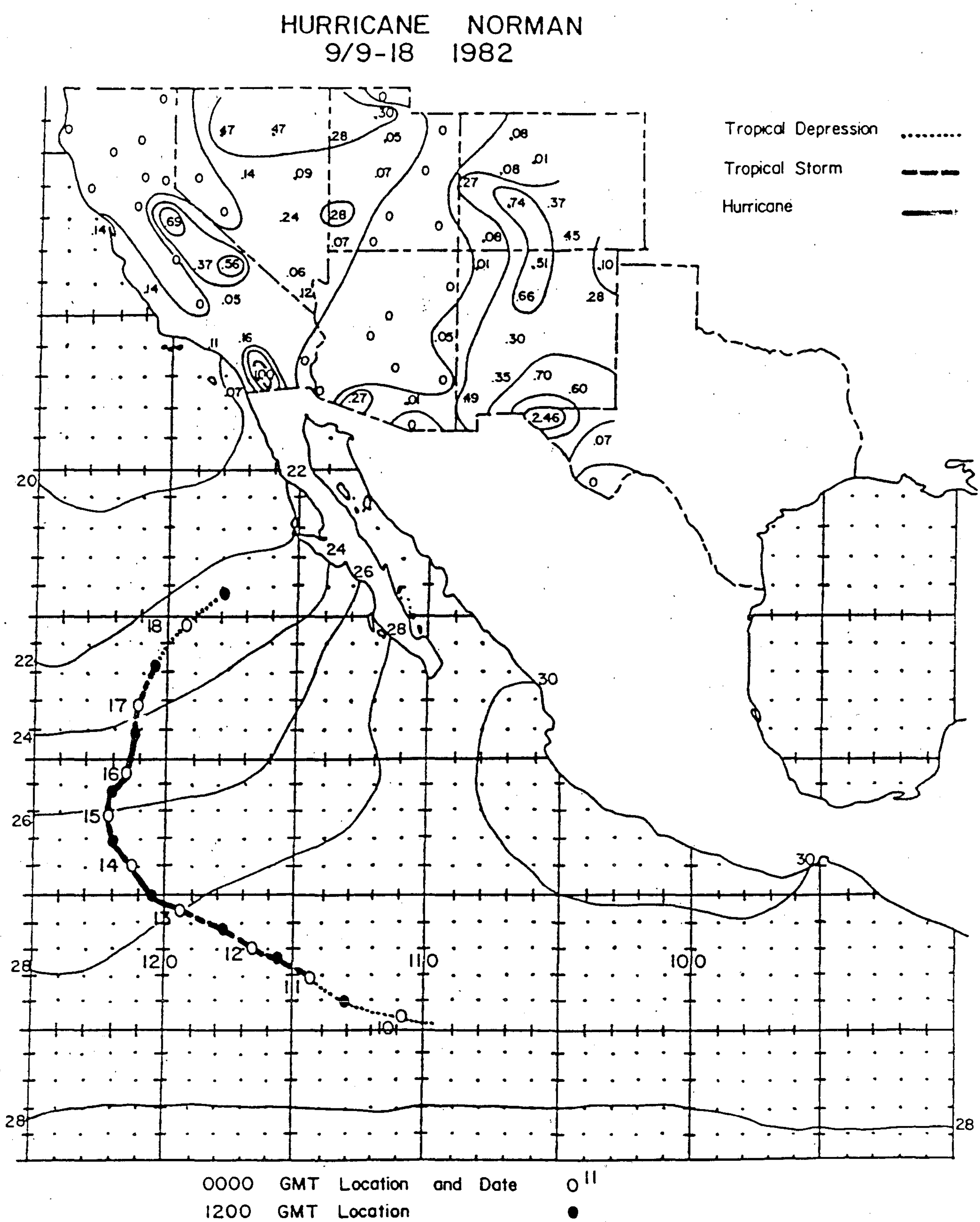


Figure 121. Track of Hurricane Norman; September 9-18, 1982; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

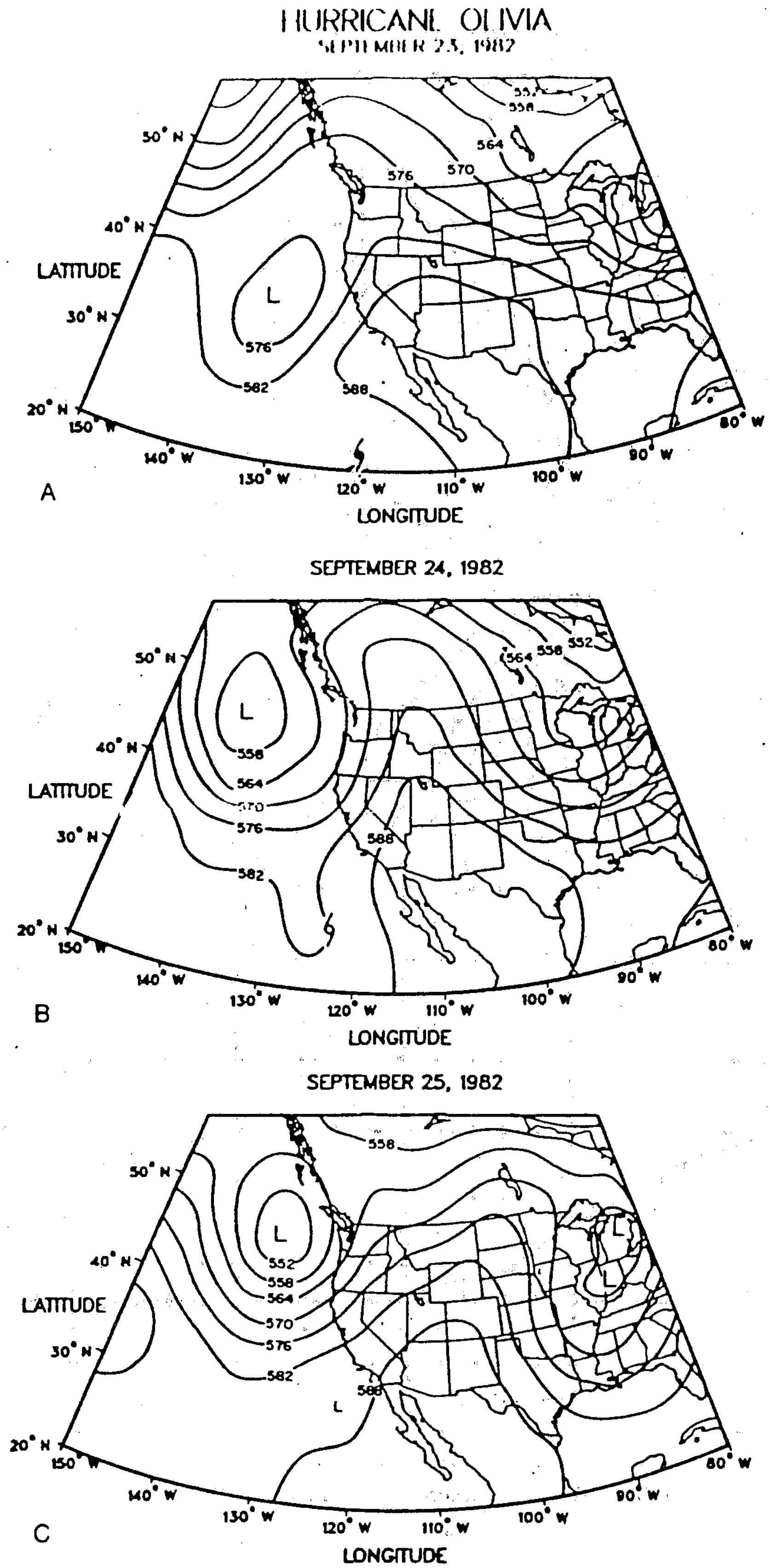


Figure 122. As in Figure 44.

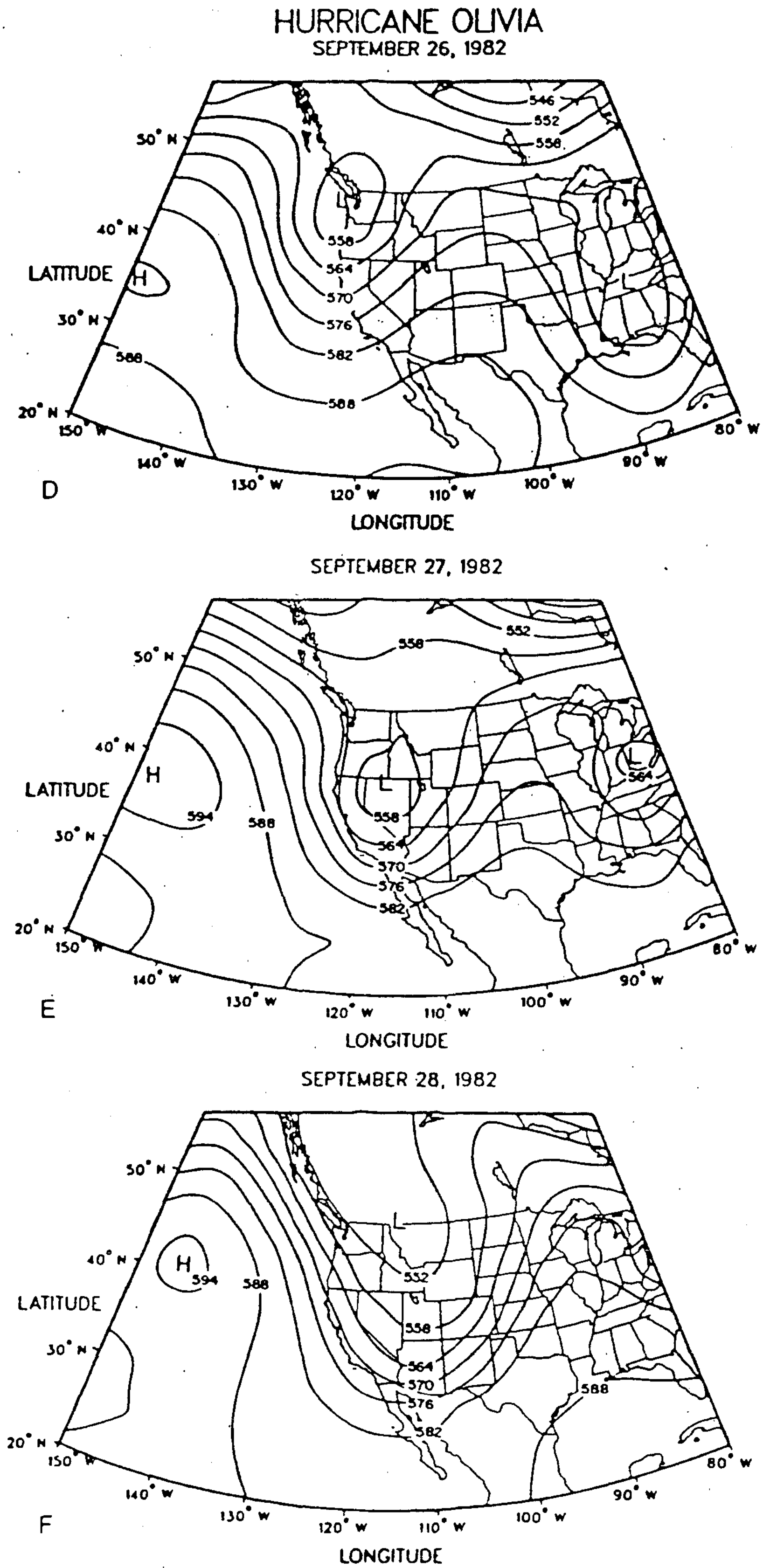


Figure 122. (continued) As in Figure 44.

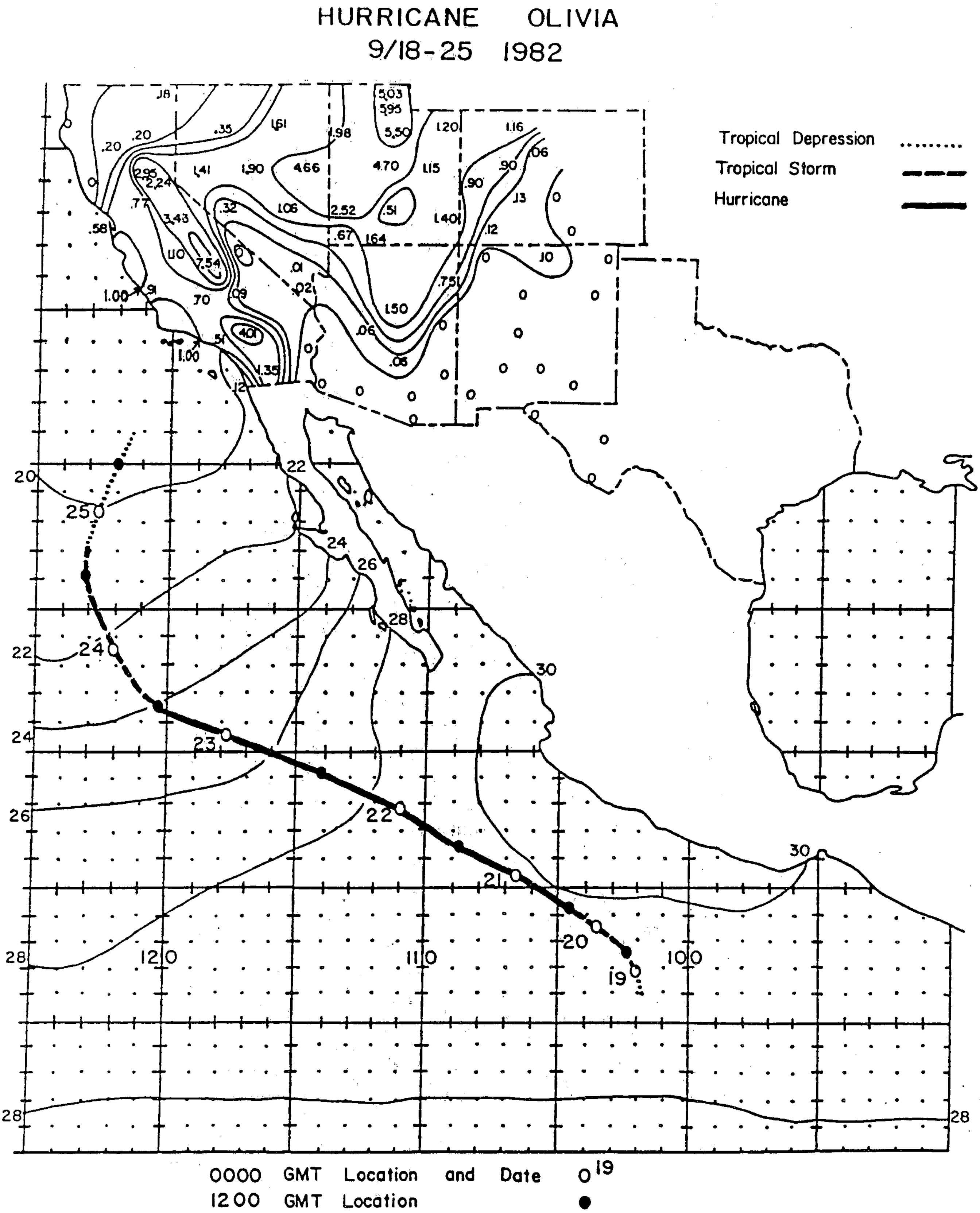


Figure 123. Track of Hurricane Olivia; September 18-25, 1982; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches. Sea surface temperatures are in °C.

Table 46. Hurricane Olivia; September 18-25, 1982; daily precipitation

Station	September 23	24	25	26	27	28	29	30	October 1	2	Total
Grant Grove, Ca.	0	1.19	1.91	4.09	.16	.19	00	0	0	0	7.54
Huntington Lake, Ca.	.10	1.50	1.20	2.60	0	0	0	0	0	0	5.40
Lake Arrowhead, Ca.	0	0	0	3.66	.35	0	0	0	0	0	4.01
Alta, Utah	0	0	.54	1.28	3.43	1.20	1.46	1.51	.58	.21	10.21
Cottonwood Weir, Utah	0	0	.36	4.65	.60	1.80	.93	.43	0	0	8.77
Ibapah, Utah	0	0	.22	.08	3.11	.09	.39	.75	0	0	4.64
Salt Lake City WSFO, Utah	0	.15	.18	2.27	.84	.96	.14	.25	00	0	4.79
Atlanta Mine, Nev.	0	0	.17	----	1.11	1.02	1.20	1.95	0	0	5.45
Ely WSO, Nev.	0	.01	.39	2.52	.60	.03	.31	.17	0	0	4.03

amounts in inches.

Southwesterly winds ahead of the weak trough in Figure 122A carried the first clouds and moisture from Olivia over California on September 23 and produced .36 in. of rain at Blue Canyon WSMO. The flow of moist air from weakening Hurricane Olivia significantly increased on the 24th as a strong short wave moved southeast toward the West Coast (Figure 122B). Rainfall was heaviest from California eastward through Utah on September 25 and 26 as seen on Table 46 when the trough tracked inland lifting the moisture-laden tropical air. Rain ended in California once the trough moved far enough inland on the 27th but moderate to heavy precipitation continued over eastern Nevada, Utah, and western Colorado until October 1 before tapering off. The reason for this is shown in Figures 122D and E and Figure 124: the upper level trough persisted over the Great Basin prolonging shower activity.

An inch or more of rain fell from the central California coast eastward across the Sierra Nevada Mountains, where most stations received at least 3.00 in., central Nevada, northern Arizona, to the Utah-Colorado border. Unusually heavy rains of 2.00 to 5.00 in. fell over east central Nevada and the northwestern half of Utah. The greatest amounts of precipitation were recorded in northern Utah, around Salt Lake City, and caused damaging flash floods and mudslides. Normally, September is one of the driest months in northern Utah but the exceptionally heavy rains that occurred there in the last week of September 1982 helped establish several all-time monthly precipitation records, including 7.04 in. at Salt Lake City WSFO. This storm period also marked the beginning of an extremely wet spell in Utah that caused the Great Salt Lake to rise to its highest level in modern times by May 1986.

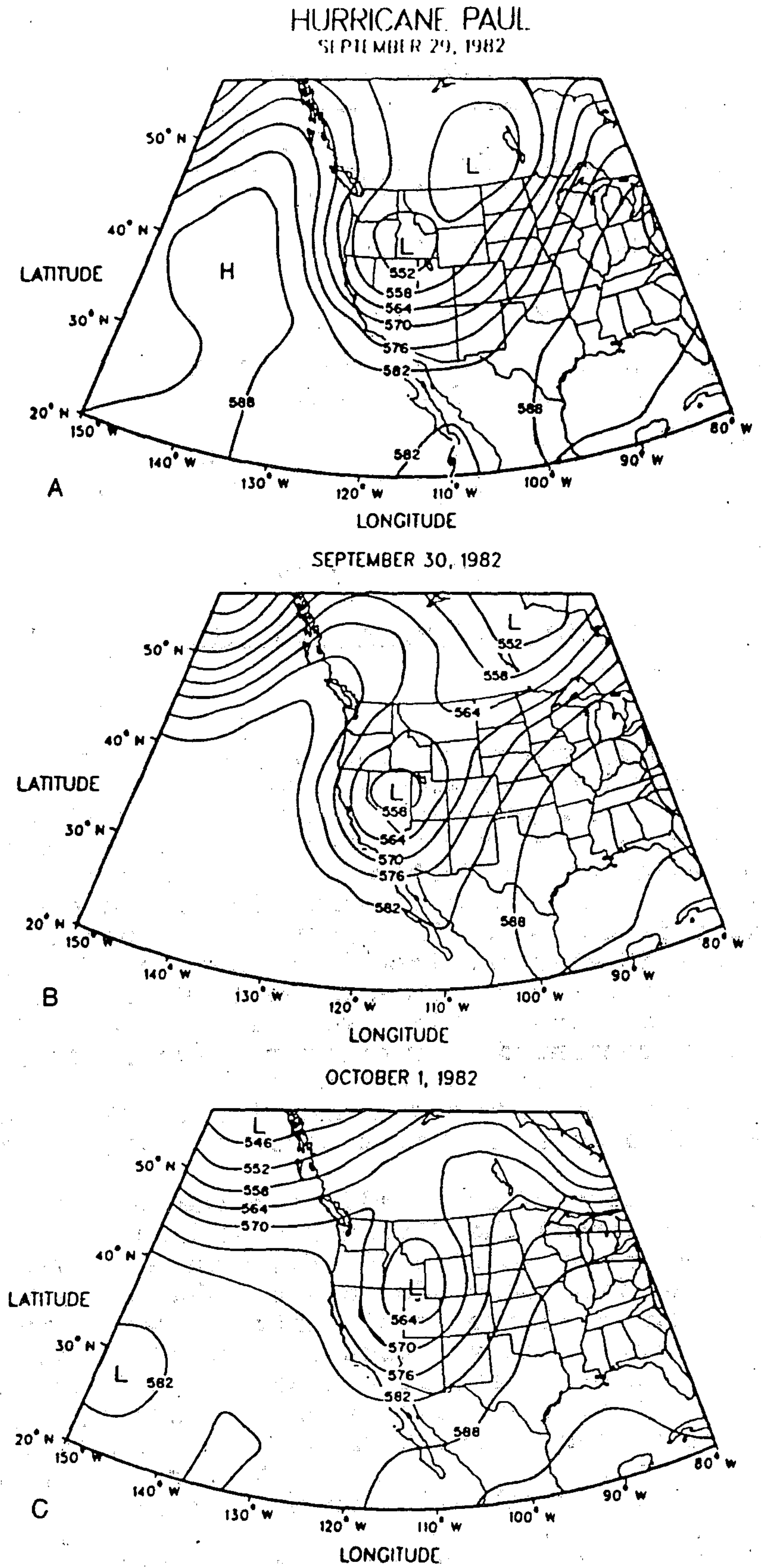


Figure 124. As in Figure 44.

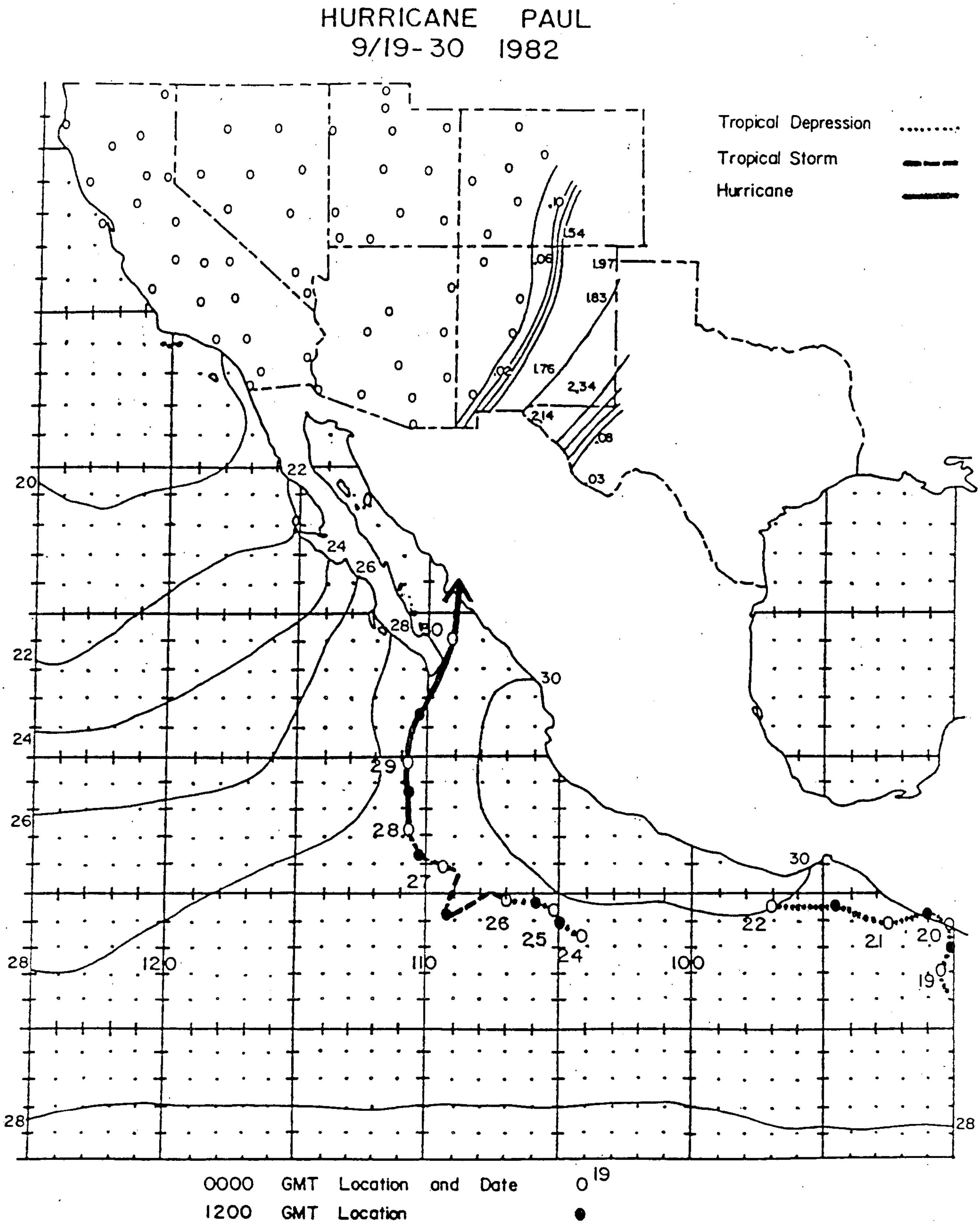


Figure 125. Track of Hurricane Paul; September 19-30, 1982; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

Table 47. Hurricane Paul; September 19-30, 1982; daily precipitation

Station	September 29	September 30	October 1	Total
Circle F Ranch, NM.	0	3.50	0	3.50
Ramon 4WSW, NM.	0	3.30	0	3.30

amounts in inches.

Hurricane Paul; September 19-30, 1982

While a tropical depression, the disturbance which later was named Paul moved over Central America late on September 19 causing heavy rains that produced disastrous floods and mudslides in Guatemala and El Salvador resulting in the deaths of more than 1000 people (Gunther et al., 1983). After spending a short time over land, the tropical depression tracked offshore and appeared ready to dissipate completely but reintensified on the 24th (see Figure 125). Paul became a tropical storm on the 26th, a hurricane on the 28th, and then gradually recurved and accelerated to the north-northeast under the influence of the trough shown in Figure 124 on the 29th. The eye passed over the southern end of Baja California late that day with winds estimated to be from 95-105 kn and headed inland south of Los Mochis, Sinaloa early on September 30 with 85 kn winds which killed several people. Moisture from Hurricane Paul reached southern New Mexico and west Texas on the morning of September 30 causing about 12 hours of moderate to heavy rain which totaled more than 3.00 in. at the two places listed in Table 47. Nearly all the stations located in the southeast half of New Mexico and extreme west Texas reported an inch of rain and many reported more than two.

Hurricane Manuel; September 12-20, 1983

This tropical cyclone was the first of four to affect the Southwest in the fall of 1983. Figure 126 shows the hurricane tracked around the western end of the subtropical high and that southwest winds between the high and a cut-off low advected clouds and moisture from the cyclone over California and Arizona. Since the summer monsoon was still active over much of the Southwest throughout the life of Hurricane Manuel, it was difficult, even with the aid of satellite imagery, to separate tropical cyclone rainfall from monsoon rainfall. In addition, short waves moving in the westerlies began tracking over the northern part of the study area about September 22 further complicating the determination of how much rain fell in association with Manuel's moisture.

The majority of the precipitation from September 18-21 was estimated to be linked to the influx of moist air from Hurricane Manuel while the bulk of the rainfall after the 21st was deemed to be due to midlatitude disturbances and the monsoon. Consequently, rain from 18th-21st is plotted on Figure 127, which also displays the track of the cyclone and the average SSTs for September 1983. The heaviest showers occurred over southern

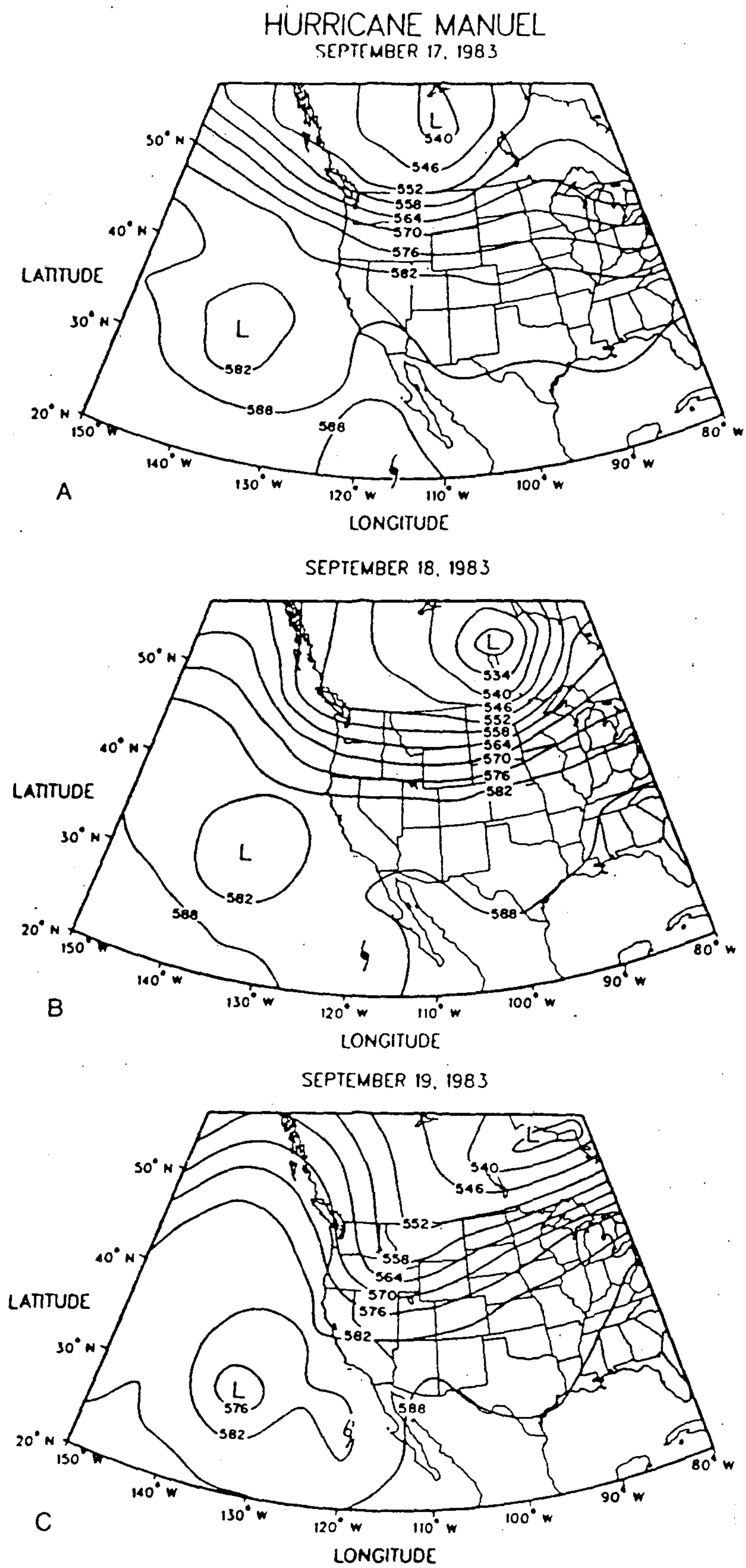


Figure 126. As in Figure 44.

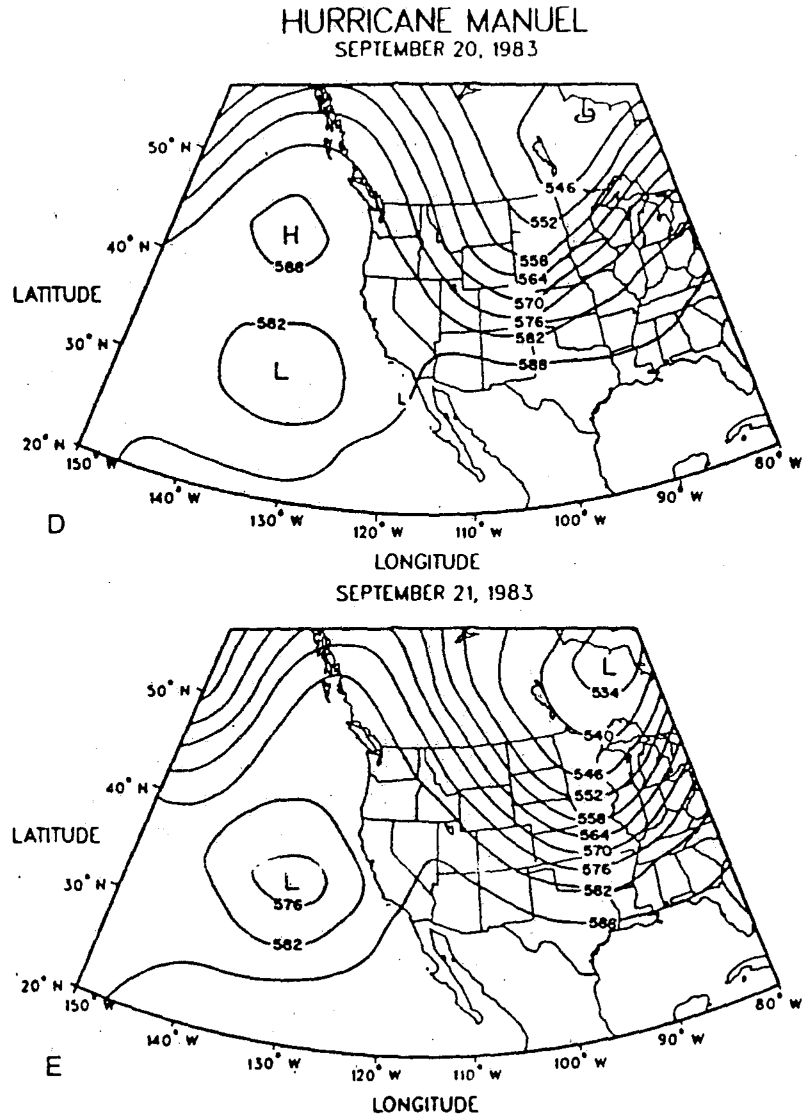


Figure 126. (continued) As in Figure 44.

California and western Arizona on September 20-21 as Manuel dissipated approximately 300 km southwest of San Diego. The largest amounts of rain were measured in the Palm Springs area by Deep Canyon Laboratory which reported 2.85 in., the highest total, and Borrego Desert Park which reported 2.35 inches. Isolated heavy showers also fell in Arizona where Alamo Dam received 2.56 in. but most stations received less than a half inch of precipitation.

Tropical Storm Octave: September 27 - October 2, 1983

When the longwave trough shown in Figure 128 developed over the West Coast of North America during the last week of September 1983, weather forecasters in Arizona could not have known that within a week southern Arizona would experience a major flood disaster. The flood was caused by widespread heavy rains which

HURRICANE MANUEL
9/12-20 1983

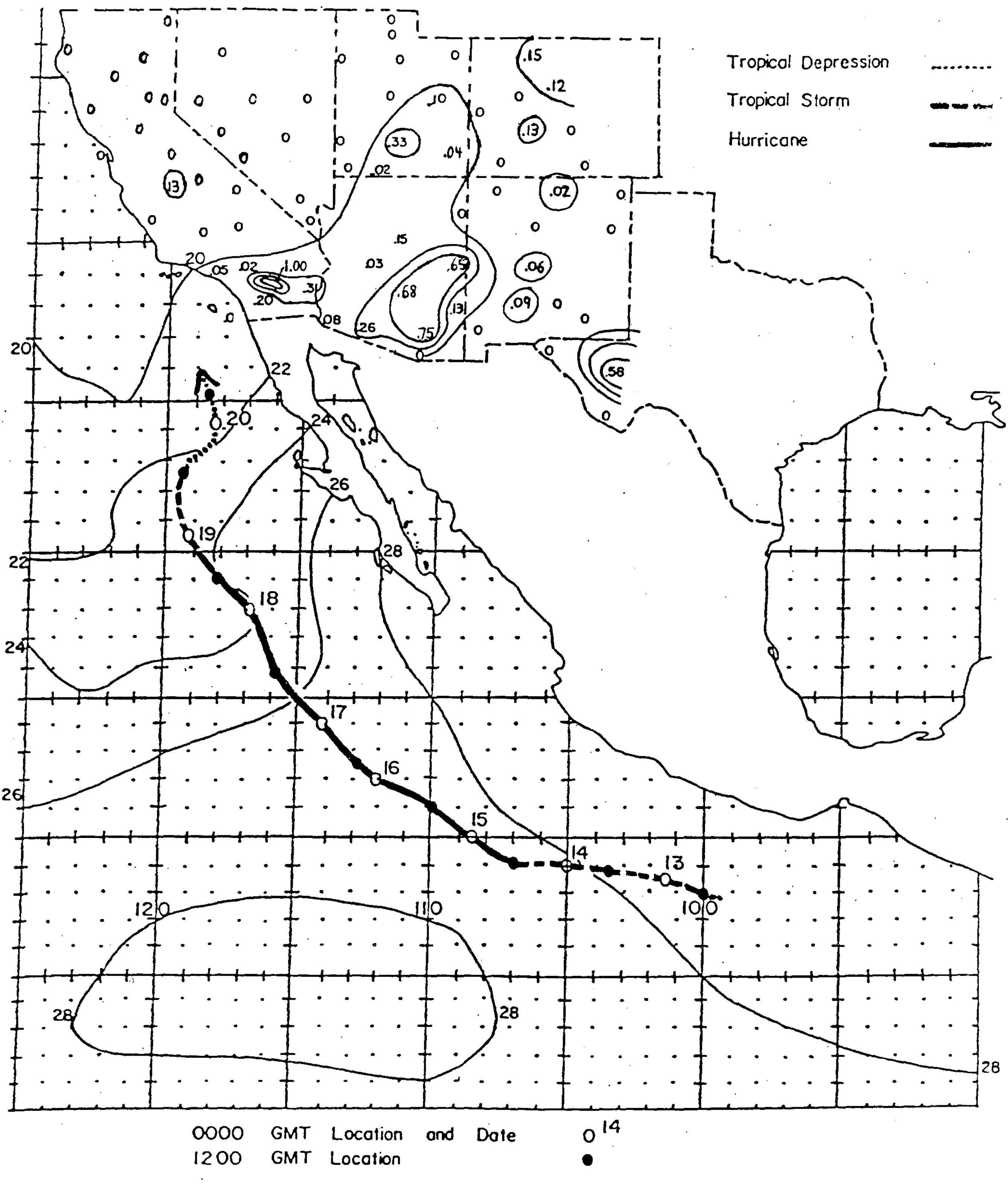


Figure 127. Track of Hurricane Manuel; September 12-20, 1983; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, and .50 inches. Sea surface temperatures are in °C.

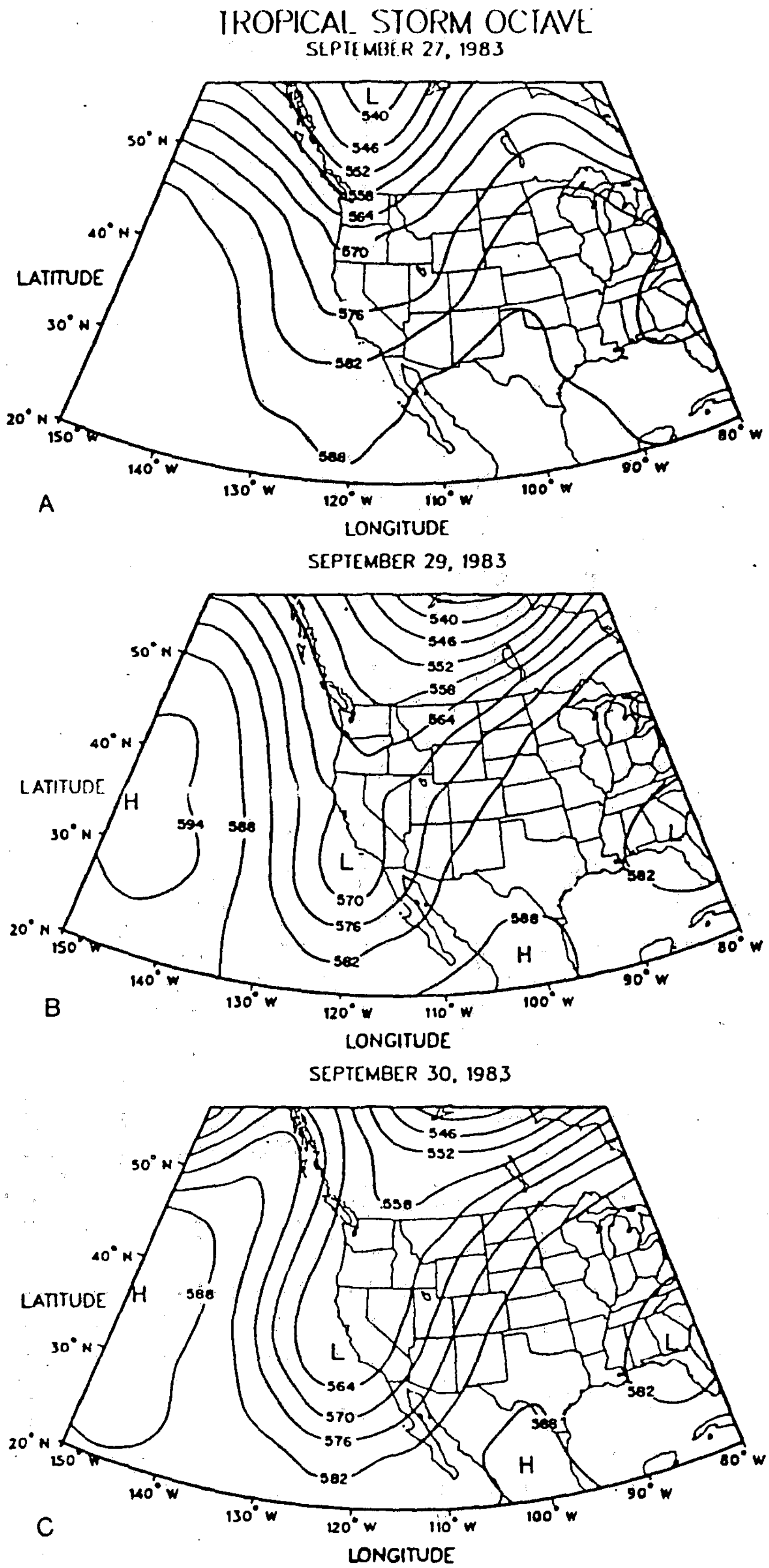


Figure 128. As in Figure 44.

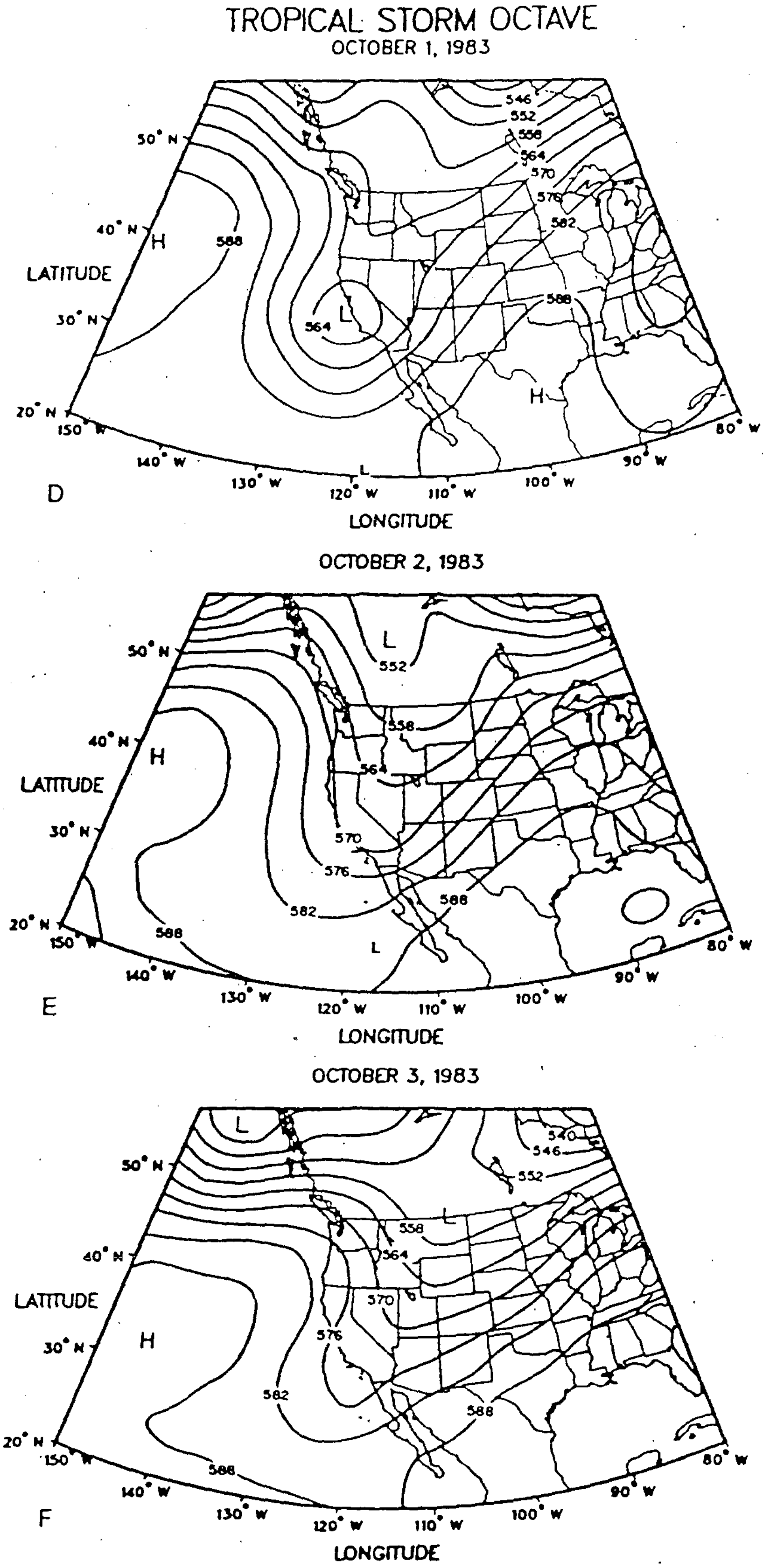


Figure 128. (continued) As in Figure 44.

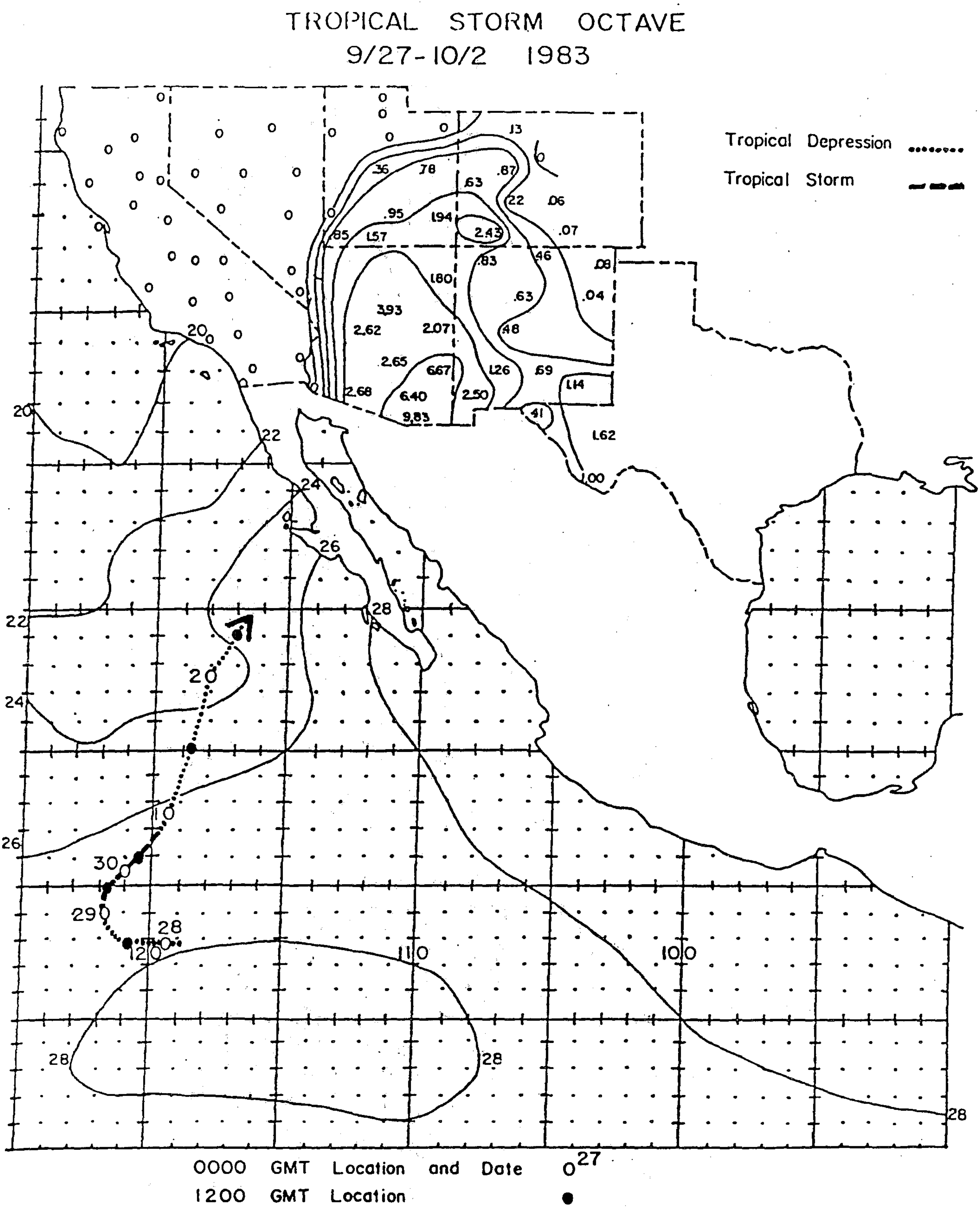


Figure 129. Track of Tropical Storm Octave; September 27 - October 2, 1983; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, 2.00, and 5.00 inches. Sea surface temperatures are in °C.

lasted for several days when the longwave trough persisted over the West Coast of North America for nearly a week and advected a vast quantity of moist air from Tropical Storm Octave over Arizona, primarily the southeastern part of the state (Brazel, 1983b). Saarinen et al. (1984) provide a much more detailed account of the meteorological events which brought about the flooding than will be presented here. In addition, they describe how the residents of the Tucson metropolitan area reacted to and were affected by the flood.

One reason for the severe flooding in southeastern Arizona was the moisture content of the ground was unusually high because of heavy monsoon rainfall in August and September. In fact, the monsoon persisted over most of Arizona until September 26, when isolated showers associated with the longwave trough began. As the upper level trough deepened over the West Coast on the 27th and 28th, a tropical depression gathered strength in the eastern Pacific near 18°N, 120°W (Figure 129) and scattered showers fell over Arizona, southern Utah, and western New Mexico. By 1200 GMT September 28, the upper level trough had extended its influence into the tropics, to about 15°N, and forced the tropical cyclone to change direction. Vertical wind shear associated with the trough slowed and limited the development of Tropical Storm Octave and eventually led to Octave's demise on October 2 about 800 km south of San Diego over water with a SST greater than 24°C (eastern north Pacific tropical cyclones have maintained tropical storm intensity over SSTs as low as 20°C, see Figures 100 and 108).

Satellite imagery indicates clouds and moisture from Tropical Storm Octave were advected over Arizona, New Mexico, southern Utah, and southwestern Colorado on the 28th leading to scattered showers and thunderstorms. Precipitation increased over nearly all the aforementioned area the next day when many places in Arizona reported more than one inch of rain. The heaviest rains linked to the tropical storm fell from September 30 to October 2 when the advection of clouds and moisture from Octave peaked and is shown in Table 48. The most intense rains during this period were caused by the passage of short waves that moved through the longwave trough position (Saarinen et al., 1984). One of these short waves moved over southeastern Arizona on the morning of October 1 and produced a heavy continuous rain which fell at the rate of a half inch per hour for about 6 hours. Isolated showers and a few thunderstorms continued over southeast Arizona until finally ending on the 6th.

As seen in Figure 129, most places in Arizona received at least 2 in. of precipitation between September 26 and October 6 and many in the southeastern part of the state received more than 5 inches. This is illustrated better by Figure 130 which presents the precipitation in Arizona from September 28 - October 3, when the overwhelming majority of the rain fell. Many stations in southern California also received heavy rain in the last week of September 1983 but the rain there was not related to Tropical

Table 48. Tropical Storm Octave; September 27 - October 2, 1983; daily precipitation

Station	26	27	28	29	30	1	2	3	4	5-6	Total
	September					October					
Childs, Az.	0	0	0	.50	3.80	1.23	.07	0	0	0	5.60
Hawley Lake, Az.	.40	.78	1.70	1.88	2.00	2.10	.03	0	0	0	8.89
Kitt Peak, Az.	0	0	0	.15	1.80	1.02	4.70	.26	.55	0	8.48
Mt. Lemmon, Az.	0	0	.90	.71	----	5.10	2.84	.35	0	0	9.90
Nogales 6N, Az.	0	0	0	2.06	1.95	1.17	3.15	1.39	.02	.09	9.83
Ruby Star Ranch, Az.	0	0	.62	1.65	2.30	2.00	2.10	.10	0	0	8.77
Tucson WSO Airport, Az.	0	0	.31	1.02	.48	2.96	1.21	.73	0	0	6.71
Tucson*, Az.	0	0	.64	.83	.79	3.73	1.33	.43	0	0	7.75
Luna Ranger Station, NM.	0	.35	.14	.57	2.14	1.35	1.23	.02	0	0	5.80
Glenwood, NM.	0	.23	.07	.19	2.09	1.62	1.27	.01	0	0	5.48

* author's residence, 15 km NW of Tucson WSO; amounts in inches.

Storm Octave and, therefore, is not plotted on Figure 129 or listed in Table 48.

Serious flooding occurred on most streams and rivers in the southeast quarter of Arizona with record peak flows established on several large rivers; e.g. 2,460 $m^3 s^{-1}$ on the San Francisco River at Clifton (Brazel, 1983b), 3,530 $m^3 s^{-1}$ on the Gila River at Safford (Brazel, 1983b), and 1,490 $m^3 s^{-1}$ on the Santa Cruz River at Tucson (Saarinen et al., 1984). The peak flow of 1,490 $m^3 s^{-1}$ on the Santa Cruz River at Tucson (drainage area of 5,754 km^2) is significantly less than the record peak flow of 2,775 $m^3 s^{-1}$ on the adjacent San Pedro River at Charleston (drainage area of 3157 km^2) which occurred on September 28, 1926 as the result of heavy rains from the Tropical Cyclone of September 20-25, 1926. The most important reason for this probably was that rainfall intensities were greater with the 1926 storm than with Tropical Storm Octave because total precipitation over each basin was comparable.

Many towns and communities in southeast Arizona suffered extensive damage but Clifton and Marana (about 20 km north of Tucson on the Santa Cruz River) were devastated. Property damage in Arizona was estimated at up to $500 million (Brazel, 1983b) and 9 persons drowned, most attempting to cross flooded streams. This was the second tropical cyclone related flood to occur in southeastern Arizona since October 1977 (the other was linked to Hurricane Heather) and was the most damaging flood ever recorded in Arizona (Sellers et al., 1985).

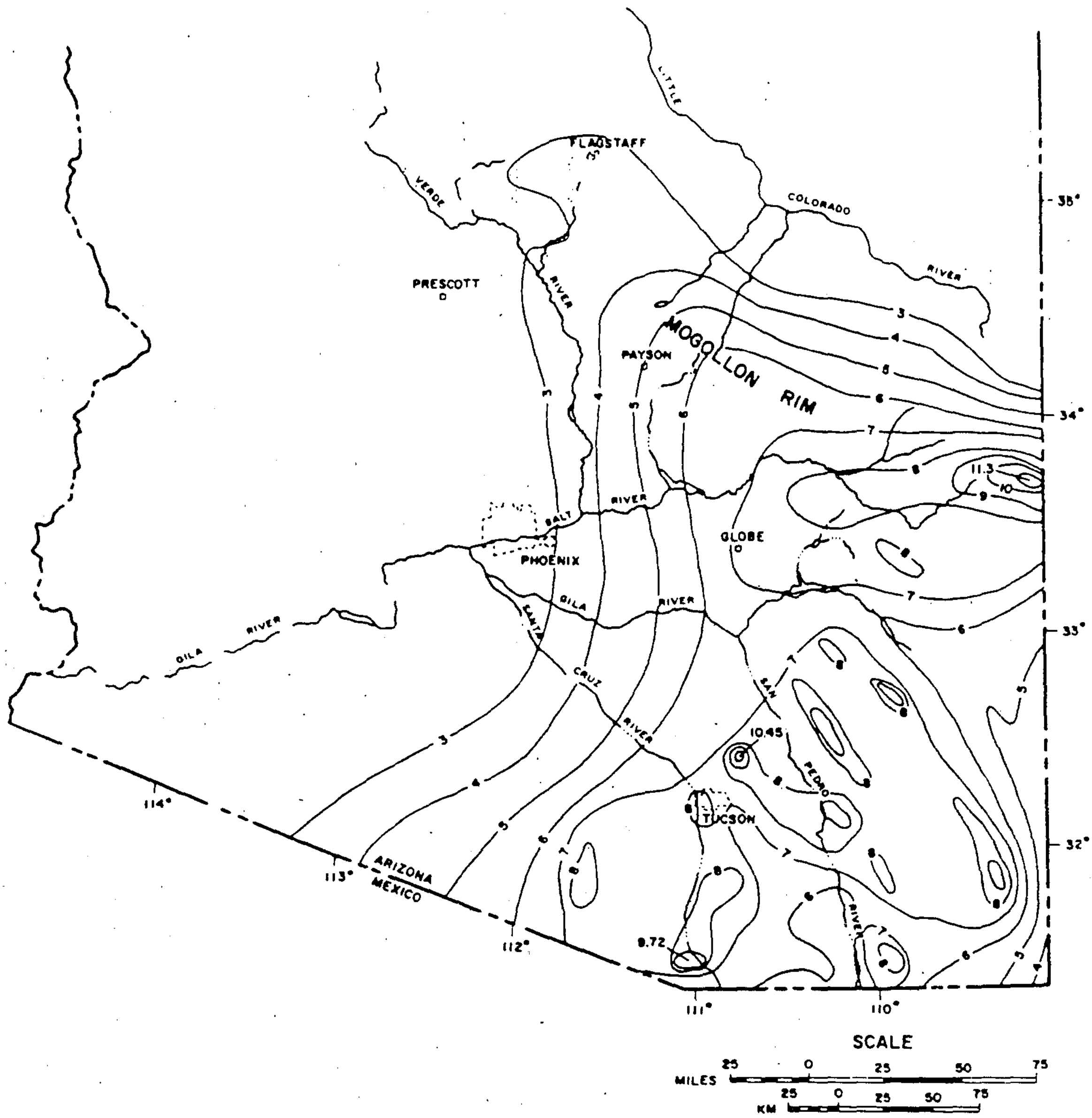


Figure 130. Arizona precipitation from September 28 - October 3, 1983 linked to Tropical Storm Octave; in inches (from Saarinen et al., 1984).

Hurricane Priscella: September 30 - October 7, 1983

After originating at 12°N, 108.5°W late on September 30, Priscella moved to the west around a ridge that was centered over Mexico and became a hurricane on the 3rd while over 28°C water (Figure 132). Hurricane Priscella reached its maximum intensity a day later when sustained winds topped out at 100 kn and then began to dissipate as it moved northward over cool water (Gunther and Cross, 1984) between the weak trough and the ridge shown in Figure 131. Priscella weakened rapidly on the 6th because of the cool water and vertical wind shear and completely dissipated on the 7th about 700 km southwest of San Diego.

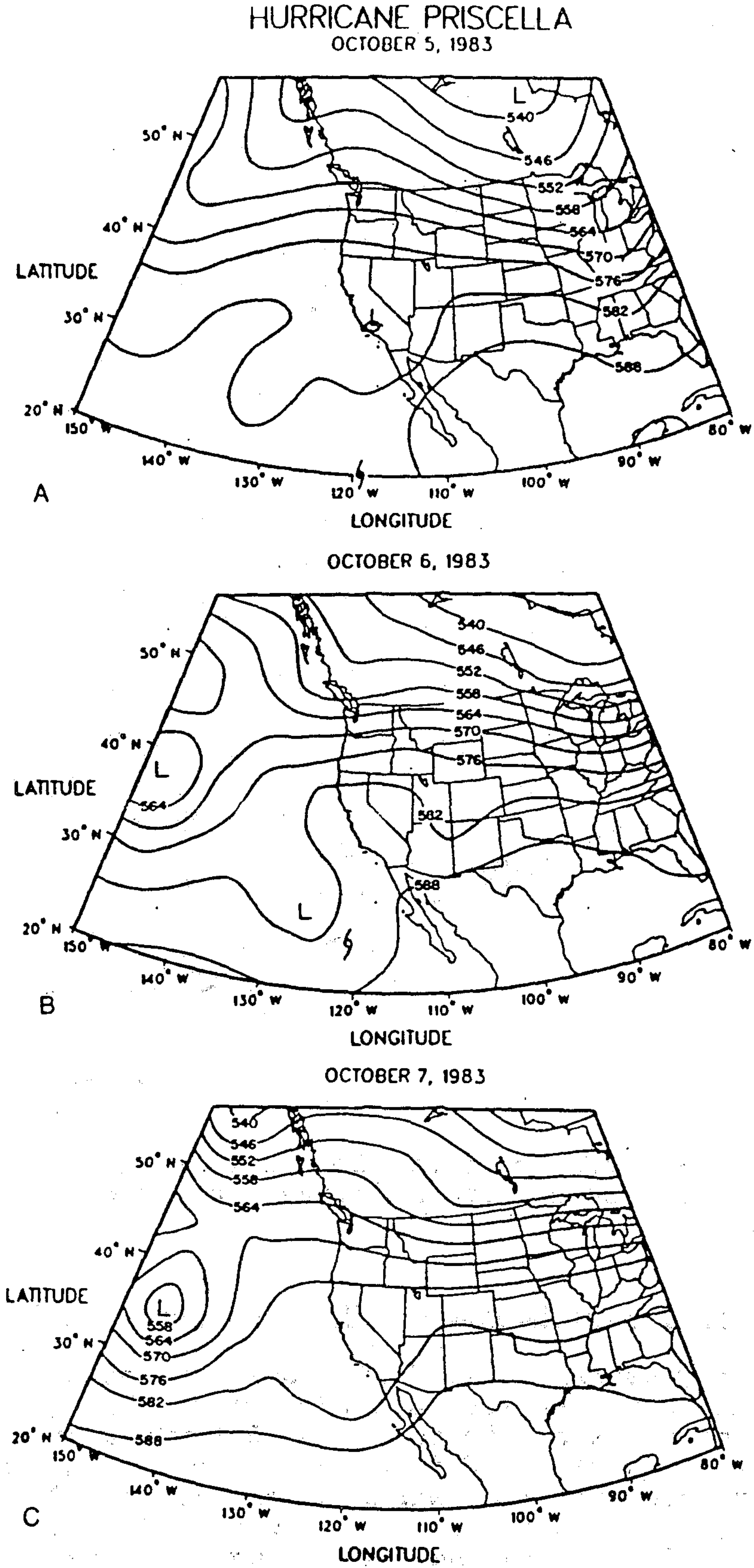


Figure 131. As in Figure 44.

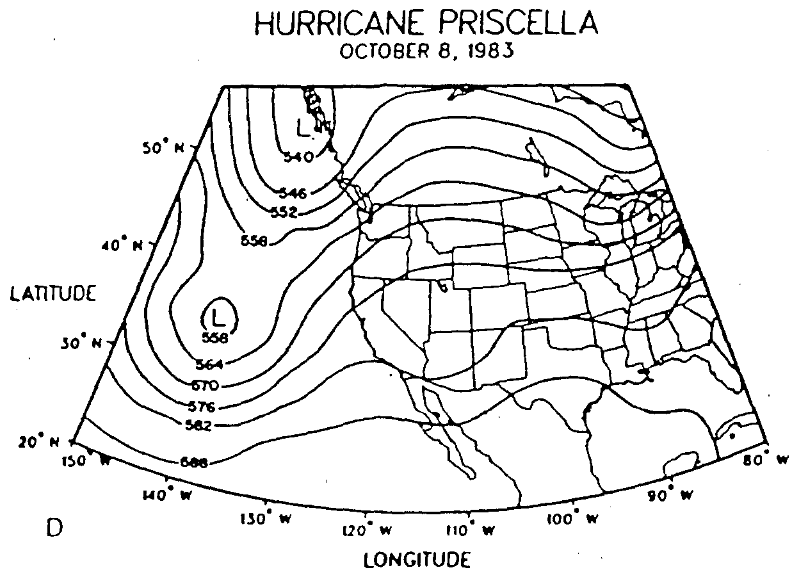


Figure 131. (continued) As in Figure 44.

For a time it appeared that Hurricane Priscella might track close enough to Arizona to produce heavy rains and cause renewed flooding. However, this tropical cyclone, although far more intense than Tropical Storm Octave whose maximum sustained winds were 45 kn, was associated with only trivial amounts of precipitation (Figure 132). Most stations did not receive any precipitation and the small number that did generally received less than a tenth of an inch.

Hurricane Tico: October 11-19, 1983

The digging trough shown in Figure 133 caused Hurricane Tico to recurve northeastward on October 18 and to track inland on the 19th over Mazatlan with 110 kn winds (Gunther and Cross, 1984). Damage was extensive in and around Mazatlan and at least 9 persons were killed and 105 reported missing several days after the storm. Tico's remains then moved extremely fast across northern Mexico and over the Southern Plains where the remnants combined with the upper level trough to produce torrential rains east of the study area on October 19 and 20.

Rainfall in the study area from the 17th-22nd is shown in Figure 134 while rainfall in the Southern Plains from the 17th-23rd is shown in Figure 135. Table 49 lists daily precipitation at selected stations in the study area and in the Southern Plains that received relatively large storm totals. The amounts listed from stations in the Southwest are far less than the storm totals measured at most places in northern Texas, Oklahoma, southeastern Kansas, and southwestern Missouri. Shawnee, Oklahoma reported the heaviest 24-hour precipitation, 10.62 in. on October 20 and Prague, Oklahoma reported one of the highest storm totals, 16.64 inches. Flooding was widespread in northern Texas and central Oklahoma. One fatality and $50 million worth of property damage was reported from Oklahoma (Fujita and Stiegler, 1983).

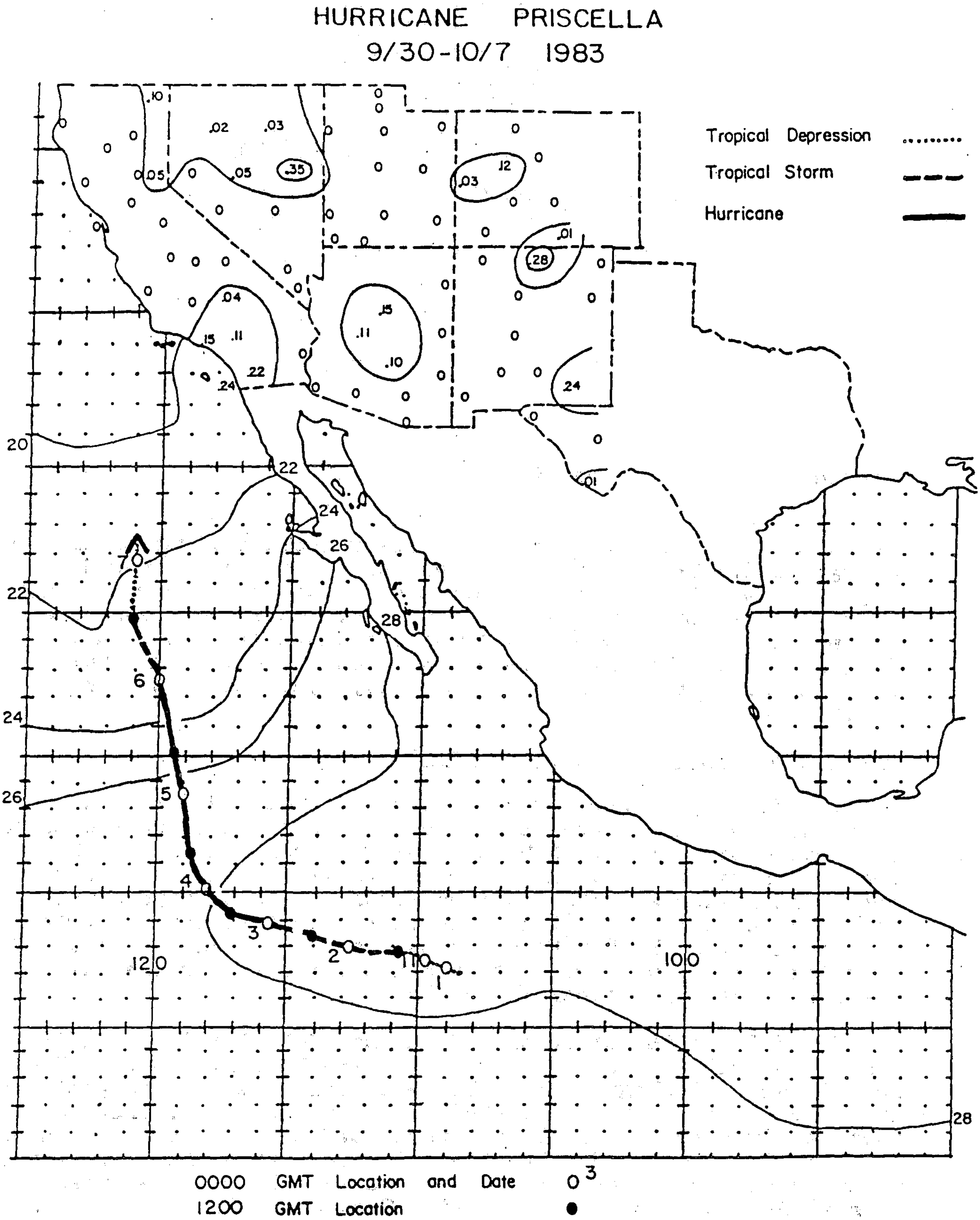


Figure 132. Track of Hurricane Priscella; September 30 - October 7, 1983; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01 and .25 inches. Sea surface temperatures are in °C.

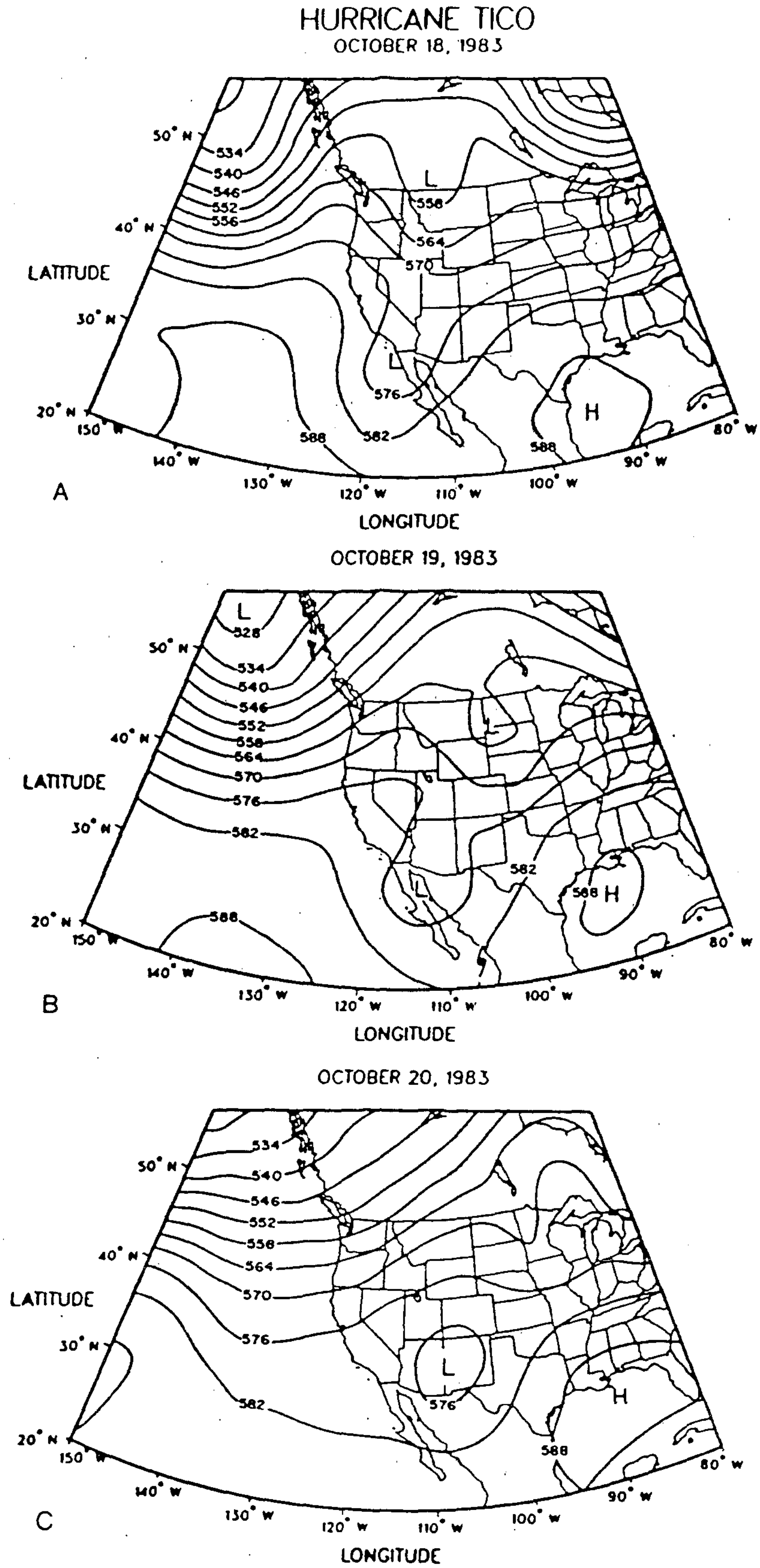


Figure 133. As in Figure 44.

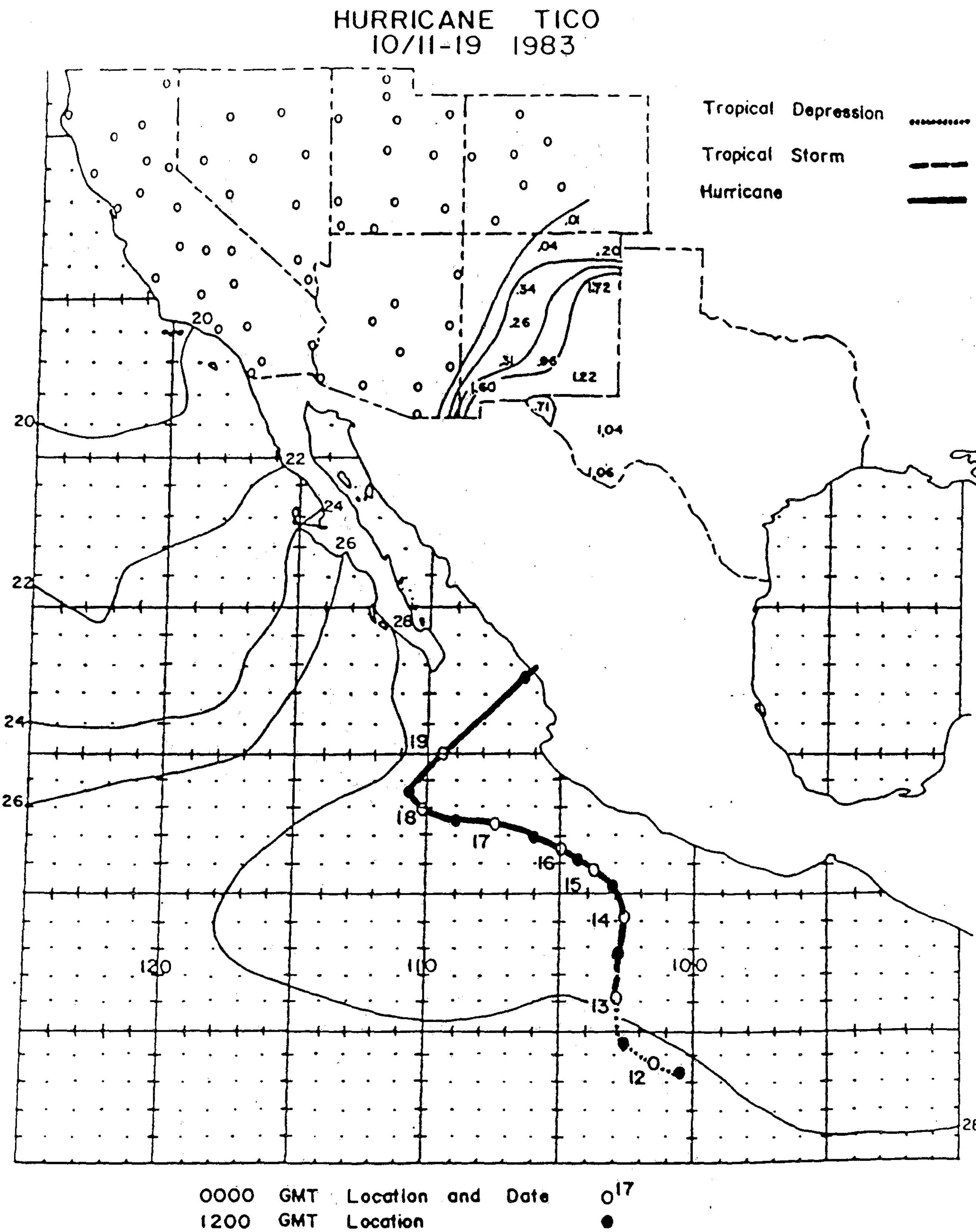


Figure 134. Track of Hurricane Tico; October 11-19, 1983; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, and 1.00 inches. Sea surface temperatures are in °C.

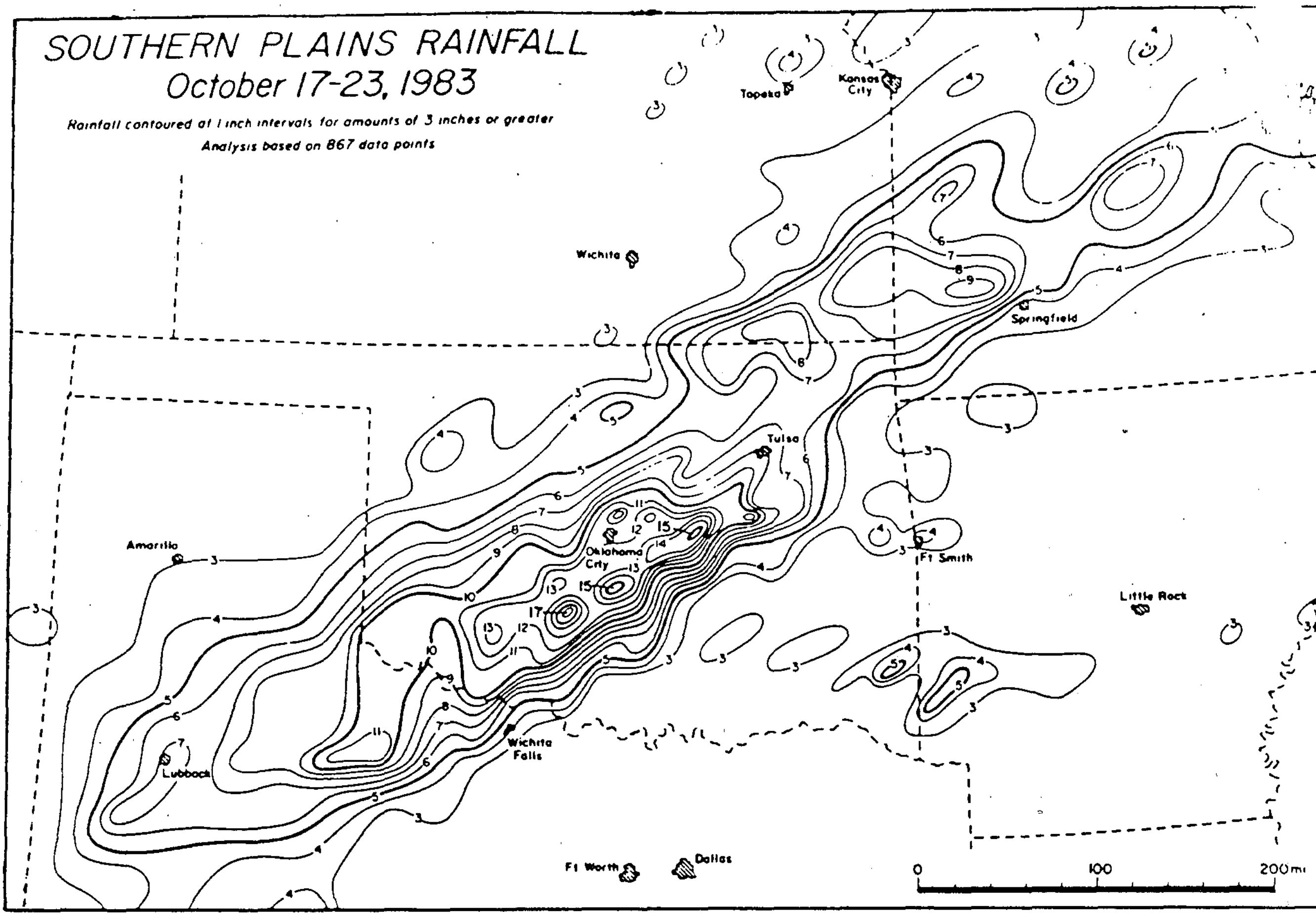


Figure 135. Southern Plains precipitation from October 17-23, 1983 linked to Hurricane Tico; in inches (from Fujita and Stiegler, 1983).

Table 49. Hurricane Tico; October 11-19, 1983; daily precipitation

Station	October 17	18	19	20	21	22	Total
Clovis 13N, NM.	.08	.74	1.39	1.59	.01	0	3.81
Orogrande, NM.	0	0	2.10	.87	0	0	2.97
Crane, Texas	0	0	2.00	1.40	0	0	3.40
Sheffield, Texas	0	0	3.00	0	0	0	3.00
*Truscott, Texas	1.76	.11	4.11	4.75	.74	0	11.47
*Oklahoma City WSFO Airport, Ok.	.30	1.10	4.98	5.45	.04	00	11.87
*Prague, Ok.	.51	2.97	2.41	8.81	1.94	0	16.64
*Shawnee, Ok.	00	.62	.87	10.62	1.63	00	13.74

00 = trace; amounts in inches; * = east of study area.

Hurricane Marie: September 5-11, 1984

On September 5, tropical depression Marie developed about 200 km southwest of Manzanillo, Mexico and within 24 hours became Hurricane Marie (Figure 136). Marie's maximum sustained winds peaked 80 kn at 0000 GMT on the 8th before slowly diminishing as the storm continued moving northwestward over cooler water west

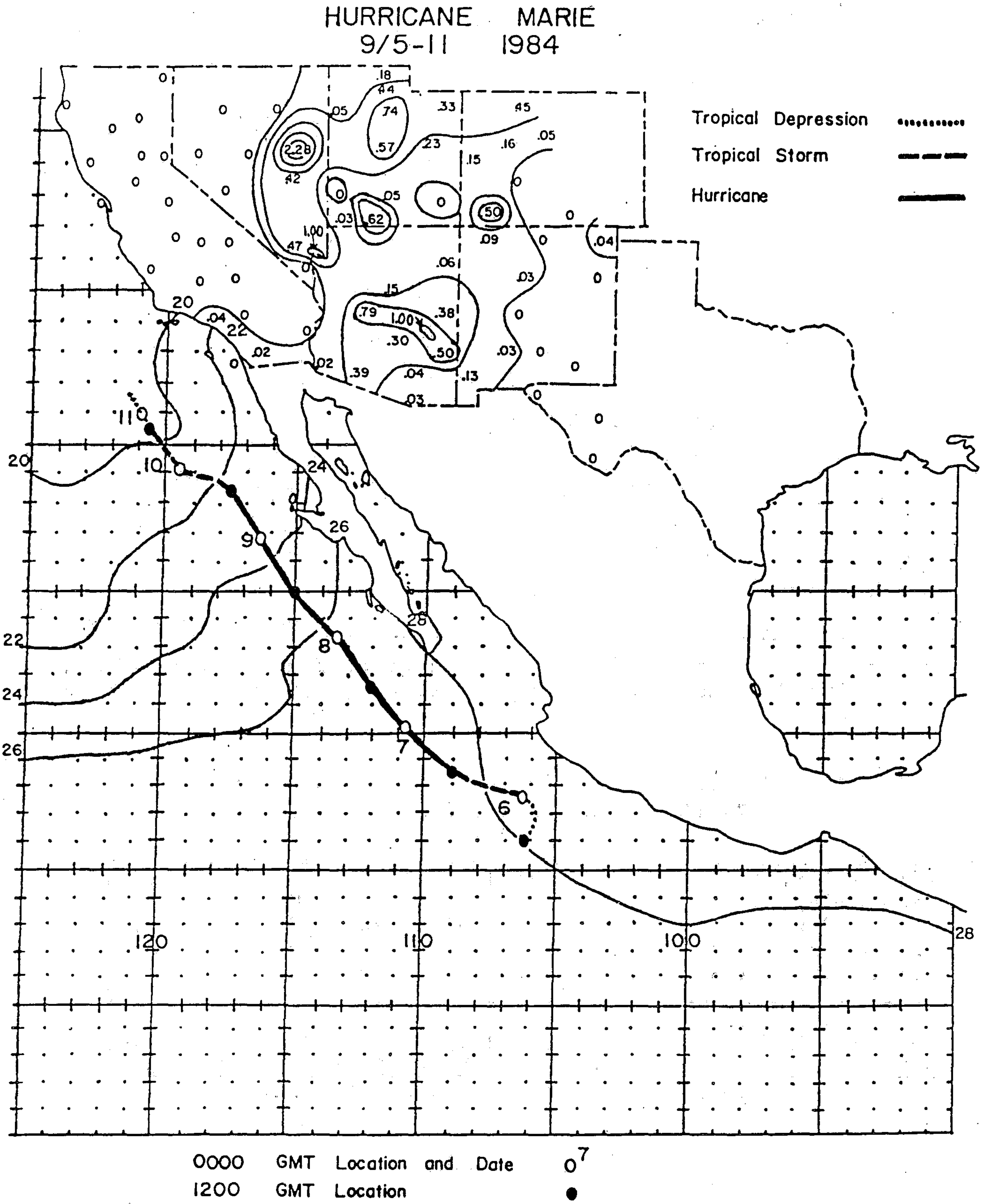


Figure 136. Track of Hurricane Marie; September 5-11, 1984; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

Table 50. Hurricane Marie; September 5-11, 1984; daily precipitation

Station	September 10	11	12	Total
Payson, Az.	1.60	1.20	0	2.80
Boulder City, Nev.	2.63	.49	0	3.12
Ely WSO, Nev.	1.62	.71	.03	2.36
Zion National Park, Utah	2.02	.04	0	2.06

amounts in inches.

of Baja California (Gunther and Cross, 1985). Soon after reaching 23°C water on the 9th, Hurricane Marie weakened to tropical storm intensity and shortly after moving over 20°C water on the 11th at 30°N, Marie was downgraded to a tropical depression. All that remained of the ex-hurricane on September 12 was a weak low level circulation centered about 500 km southwest of San Diego. This circulation was visible on satellite imagery for several more days.

Satellite imagery indicates Marie's counterclockwise circulation advected moisture over the California-Mexico and Arizona-Mexico border by 1200 GMT September 9. Showers and thunderstorms developed over Arizona, southern California, eastern Nevada, and southern Utah the next day and continued for several days with most areas receiving modest amounts of rain. However, as indicated in Table 50, some isolated heavy showers and thunderstorms did occur in the mountains of central Arizona, in southwestern Utah, and in eastern Nevada where up to 3.25 in. of rain fell in one half hour on the 10th at Boulder City (James, 1984). Tragically, five persons needlessly drowned attempting to cross a flooded wash west of Boulder City. Ely WSO, Nevada reported 2.36 in. of rain from the 10th-12th which helped establish the all-time monthly precipitation record of 3.73 in. there in September 1984.

Hurricane Norbert; September 14-26, 1984

Hurricane Norbert was an exceptional tropical cyclone for several reasons. One reason was the two complete loops Norbert made between the 14th, when he became a tropical depression, and the 22nd, by which time he was a powerful hurricane with sustained winds of over 100 kn (Figure 137). This cyclone also was unusual in that it maintained hurricane intensity for almost 10 days, longer than the entire lifetime of most tropical cyclones. Finally, Hurricane Norbert was one of the few tropical cyclones known to have entered the Southwest with an identifiable low level circulation.

After moving inland near Punta Abreojos, which reported 55 kn winds (Gunther and Cross, 1985), on the west coast of Baja California early on September 26; Norbert raced across the peninsula, the Gulf of California, and northern Sonora, and passed over the Tucson area at about 1530 GMT that same day. Norbert's passage was recorded on barographs at Tucson WSO and the Atmospheric

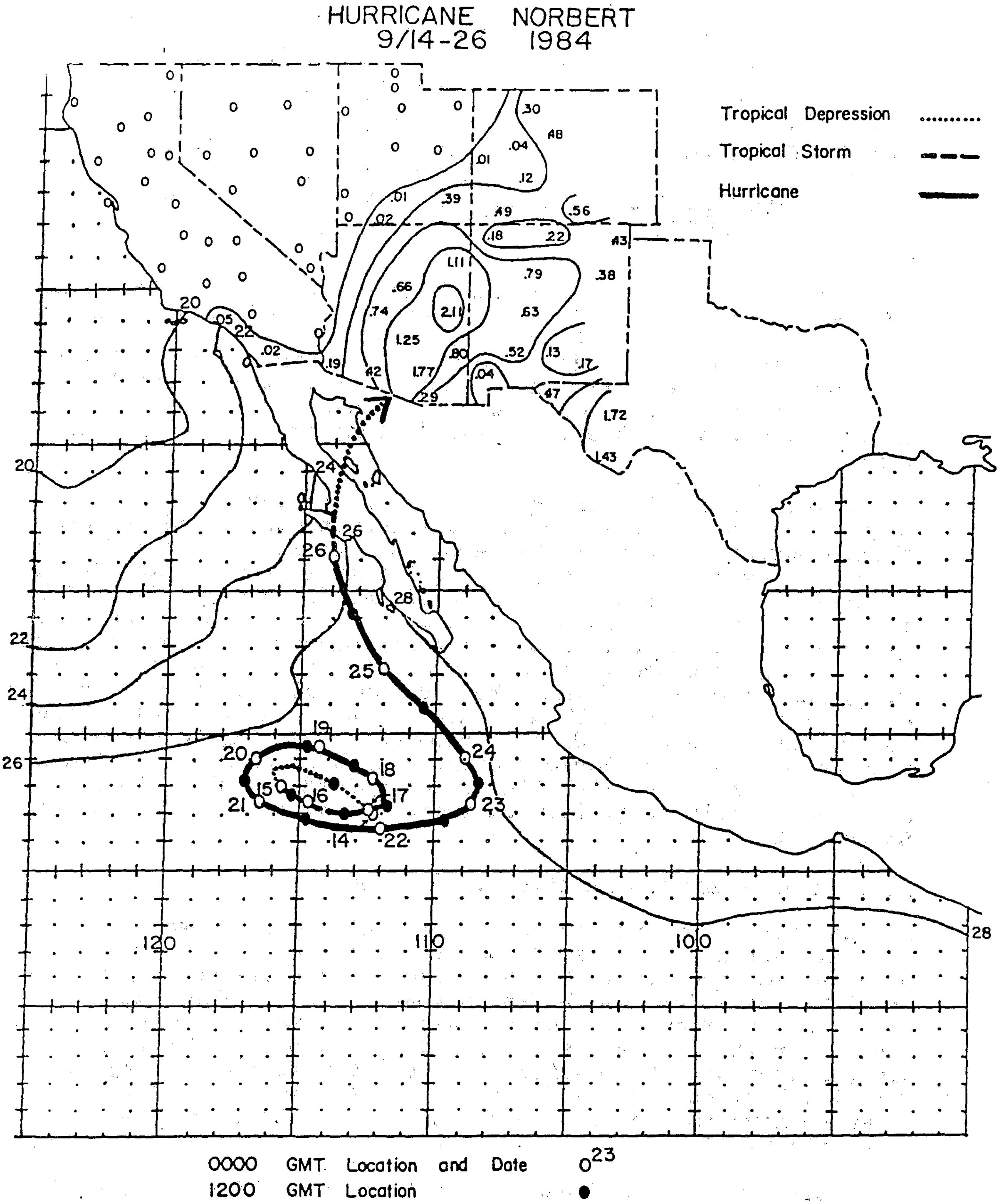


Figure 137. Track of Hurricane Norbert; September 14-26, 1984; and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

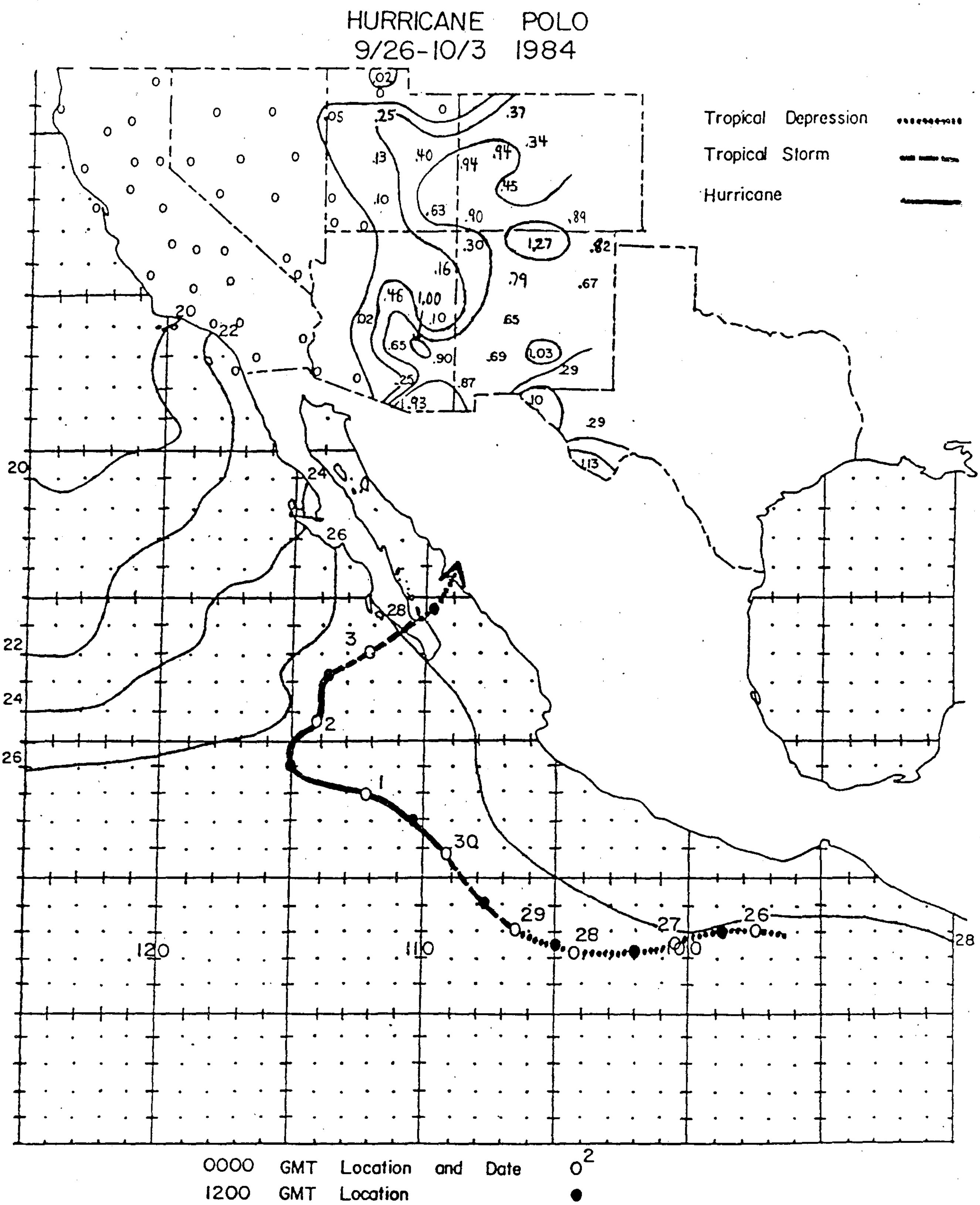


Figure 138. **Track of Hurricane Polo; September 26 - October 3, 1984; and associated rainfall in the Southwest.** Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches. Sea surface temperatures are in °C.

Table 51. Hurricane Norbert; September 14-26, 1984; daily precipitation

Station	September 25	26	27	Total
Clay Springs, Az.	1.08	2.30	00	3.38
Kitt Peak, Az.	.35	1.40	2.40	4.15

00 = trace; amounts in inches.

Science Department of the University of Arizona as a 2.5 mb drop in pressure between 1510 and 1530 GMT followed by a 2.5 mb rise in pressure in the subsequent 20 minutes. Maximum sustained winds at both Tucson WSO (22 kn) and on the roof of the Physics-Atmospheric Science building (21 kn) occurred at this time as did the peak wind gusts of 29 and 33 kn, respectively.

Light rain began falling at Tucson WSO at 1600 GMT and became heavy a few hours later before ending around 0400 GMT on the 27th. No thunderstorms were reported during the aforementioned period. Table 51 lists daily rainfall at the two stations, Kitt Peak and Clay Springs, that measured the heaviest amounts of rain. As seen in Figure 137, most of Arizona and western New Mexico received at least .50 in. of precipitation.

Hurricane Polo: September 26 - October 3, 1984

This tropical cyclone intensified slowly after originating in the Gulf of Tehauntepec on September 26 (Figure 138). Polo tracked to the west and then to the northwest until recurving northeastward ahead of a digging trough on October 1. Vertical wind shear caused Hurricane Polo to weaken rapidly on the 2nd and when the storm crossed the Baja peninsula on the 3rd, sustained winds were only about 30 kn (Gunther and Cross, 1985).

The upper level trough moved slowly east over the Southwest from October 1-4 and brought rain to much of Arizona, Utah, and Colorado as early as the 1st. Satellite imagery suggests moist air from Polo was entrained into the circulation around the trough late on the 2nd. Thus precipitation from October 1 and 2 probably was caused entirely by the midlatitude trough and, therefore, is not plotted in Figure 138. Some, but not all, of the precipitation from the 3rd-6th was made possible by the influx of moisture from Hurricane Polo. Even with the aid of satellite imagery it was impossible to separate the rain which was due entirely to the trough from that due to the upward vertical motion of the trough and the moisture from the ex-hurricane.

Colorado, New Mexico, west Texas, and most of Arizona and Utah received some rain from October 3-6. Rainfall totals between .50 and 1.00 in. were common in southeastern Utah, southern Colorado, New Mexico, and the mountains of eastern Arizona. The two heaviest precipitation amounts reported in this period were 2.50 and 1.93 in. at Mount Locke, Texas and Nogales 6N, respectively.

V. CONCLUSIONS

Many eastern north Pacific tropical cyclones have had significant effects on the southwestern United States during the late summer and early fall. This report described the effects attributable to 84 documented eastern north Pacific tropical cyclones in the period 1900-1984. Due to the incomplete detection of these cyclones prior to the advent of satellite imagery in 1966, many eastern north Pacific tropical cyclones in the 1900-1965 period were not observed by either a single ship or plane and it is likely that some of these undetected storms had important effects on the Southwest.

For instance, as discussed by Court (1980, pp. 32-33), an undetected tropical cyclone may have been associated with the unusually heavy precipitation of September 22-26, 1904 in central California but there is no record of any tropical cyclones in the eastern north Pacific Ocean at that time. In addition, Hansen et al. (1981) described the heavy rainfall of October 4-5, 1925 in southern California, southern Nevada, western Arizona, southern Utah, and western Colorado (see pp. 25-27) and wrote that it was caused by a tropical cyclone. However, the historical weather maps of October 1-6, 1925 do not indicate a tropical cyclone in the ocean west of Baja California during this period. Hurd (1925) also did not report a tropical cyclone in the Eastern North Pacific near Baja California in the aforementioned period but did write of a ship which encountered gale force winds at 27°N, 115°30'W on the 5th. This evidence plus the fact that the precipitation pattern shown in Figure 2.18 of Hansen et al. (1981, pp. 27) closely resembles the rainfall patterns associated with several documented eastern north Pacific tropical cyclones (see Figures 19, 37, and 81) strongly suggests a tropical cyclone was the cause of the precipitation.

There are four major effects a tropical cyclone can be associated with on land. Two of these effects, storm surges and high waves, can only occur at coastal locations. California is the one state in the Southwest which borders the Pacific Ocean and thus is the only state where an eastern north Pacific tropical cyclone could produce a storm surge or high damaging waves. There were no reported tropical cyclone caused storm surges along the California coast from 1900-1984. High waves resulting from tropical cyclones arrive on the southern California coast every year but usually do not cause any significant damage. Only a few tropical cyclones have moved close enough to southern California with sufficient intensity to cause damaging waves along and just off the coast. The most important of these storms was the Tropical Cyclone of September 15-25, 1939 which moved ashore with tropical storm intensity between Los Angeles and San Diego on the 25th and caused the deaths of 45 people at sea.

Another significant effect a tropical cyclone can be associated with is high winds which on several occasions have caused property damage and some loss of life in the Southwest. No known hurricane has moved inland over the Southwest this century. Just three documented tropical cyclones; the Tropical Cyclone of September 15-25, 1939; Hurricane Joanne in October 1972; and Hurricane Kathleen in September 1976; have entered the southwestern United States with tropical storm intensity winds from 1900-1984. Several tropical cyclones have tracked into the Southwest with tropical depression intensity, the last such storm being Hurricane Norbert on September 26, 1984.

The highest reported wind gust in the Southwest linked to an eastern north Pacific tropical cyclone was 66 kn at Yuma WSO on the morning of September 10, 1976. The maximum sustained winds associated with an eastern north Pacific tropical cyclone were 40-45 kn south of Los Angeles on September 25, 1939 and in the Imperial Valley of California and Lower Colorado River Valley on September 10, 1976. These wind speeds pale in comparison to the 135 kn sustained winds reported at Manzanillo, Mexico during a severe hurricane on October 27, 1959 (Fuller, 1960). The occurrence of sustained winds of even hurricane intensity, 65 kn, is extremely unlikely anywhere in the Southwest. The southern California coast south of Point Conception could conceivably experience a minimal hurricane if SSTs rose to about 24°C in the Pacific from Baja California west to 120°W and north to about 33°N and the hurricane moved onshore fast enough to avoid weakening to a tropical storm. In addition, a small hurricane could track over the Lower Colorado River Valley near Yuma if the hurricane moved through the middle of the Gulf of California and then quickly crossed the Colorado River delta. This nearly happened in September 1967 when Hurricane Katrina tracked inland over Sonora, Mexico. However, Katrina weakened exceptionally fast after moving ashore and apparently did not enter Arizona as an organized storm.

The most important effect associated with eastern north Pacific tropical cyclones in the southwestern United States is heavy rain. Heavy precipitation events in the southwestern United States have been linked to eastern north Pacific tropical cyclones in one of two basic ways. On several occasions the tropical cyclone has tracked inland with a low level circulation to produce heavy precipitation. Examples of this were Hurricane Joanne in October 1972 and Hurricane Kathleen in September 1976. However, it has been much more common for the moisture associated with a tropical cyclone to be advected over the Southwest ahead of a midlatitude disturbance, such as a cut-off low or upper level trough, which along with the mountains and diurnal heating then lifted the moisture-laden air to cause significant rain. This was the case with Tropical Storm Norma in September 1970 and Tropical Storm Octave in September-October 1983. Norma dissipated before reaching the west coast of Baja California but moisture from the storm was advected northward over the Southwest ahead of a strong trough. The combination of Norma's moisture and the upper level trough produced torrential rains over central Arizona and southeastern Utah while the combination of moisture from weakening Tropical Storm Octave, which also never reached

Table 52. Two-day Precipitation Totals associated with Eastern North Pacific Tropical Cyclones from 1900-1984 at selected stations in the Southwestern United States

Station	Month	Days	Year	Amount
(near) Carlsbad, NM. (unofficial)	September	20-21	1941	17.00
Workman Creek 1, Az.	September	4-5	1970	11.40
Mt. Wilson 2, Ca.	September	10-11	1976	10.74
Mt. Wilson 2, Ca.	September	25-26	1939	10.62
Castle Hot Springs, Az.	August	28-29	1951	10.46
Crown King, Az.	August	28-29	1951	10.44
Grenville, NM.	September	21-22	1941	8.79
Lake Arrowhead, Ca.	September	10-11	1976	8.71
Sunflower 3NNW, Az.	September	4-5	1970	8.30
Camp Hi Hill Opids, Ca.	September	10-11	1976	8.22
Gladstone, Co.	October	4-5	1911	8.16
Hereford, Az.	September	26-27	1926	8.15
Newkirk, NM.	September	21-22	1941	8.15
Alamogordo Dam, NM.	September	21-22	1941	8.05
Yates (near), NM.	September	21-22	1941	8.00

amounts in inches. Hurricane Tico's heaviest rains were in the Central United States.

the west coast of Baja California, and a cut-off low produced the rains which led to the Arizona flood disaster of October 1983.

Some 2-day precipitation totals from selected stations in the Southwest are listed in Table 52. The heaviest unofficial 2-day rainfall related to a tropical cyclone during the 1900-1984 period was 17.00 in. reported from the Guadalupe Mountains near Carlsbad, New Mexico on September 20-21, 1941 while the heaviest official amount was 11.40 in.; all of which fell in less than 24 hours, at Workman Creek 1, Arizona on September 4-5, 1970. When considering storm totals, the highest reported amount was the unofficial 21.25 in. from the Guadalupe Mountains near Carlsbad, New Mexico in connection with the Hurricane of September 15-22, 1941. Crown King, Arizona measured the largest official total, 13.56 in., from the Hurricane of August 24-28, 1951.

As indicated in Table 53, 10 documented eastern north Pacific tropical cyclones have been linked to at least 8.00 in. of precipitation at one or more stations in the Southwest this century. All three tropical storms which entered the Southwest are on this list. Minor flooding was described in connection with all 10 of these storms (and with many tropical cyclones not on this list) and major flooding was seen with several in the following areas: southwestern Colorado in early October 1911; southeastern Arizona in late September 1926, in October 1977, and early October 1983; eastern New Mexico in September 1941; central Arizona in late August 1951; central Arizona and southeast Utah in early September 1970; southern California and western Arizona in September 1976; and northern Utah in late September 1982. In addition to

Table 53. Documented Eastern North Pacific Tropical Cyclones from 1900-1984 that have been linked to at least 8.00 in. of precipitation at one or more climatic stations in the Southwestern United States

	Name	Date		
1.	Tropical Cyclone of	October	1-5	1911
2.	Tropical Cyclone of	September	20-25	1926
3.	Tropical Cyclone of	September	15-25	1939
4.	Hurricane of	September	15-22	1941
5.	Hurricane of	August	24-28	1951
6.	Tropical Storm Norma	August 30 - September 5		1970
7.	Hurricane Joanne	September 29 - October 6		1972
8.	Hurricane Kathleen	September	6-10	1976
9.	Hurricane Heather	October	4-7	1977
10.	Hurricane Olivia	September	18-25	1982
11.	Tropical Storm Octave	September 27 - October 2		1983

Hurricane Tico's (October 11-19, 1983) heaviest rains were in the Central United States.

being partly to mostly responsible for the major flood events described above, tropical cyclones have been responsible for many disastrous flash floods, e.g. the floods around Tehachapi, California on September 30, 1932 which took 15 lives and the floods in southern Nevada on September 10, 1984 in which 5 persons drowned.

Tropical cyclone-related rainfall also has helped establish many all-time monthly precipitation records at a number of stations scattered throughout the Southwest (Table 54). With the exception of parts of northern California and northwestern Nevada, all of the Southwest, including most of Nevada eastward to the Wasatch Mountains of Utah[4], has received at least one two inch tropical cyclone-related rainfall. In general, the heaviest rains have occurred as a result of the interaction of either a strong midlatitude disturbance (an upper level trough or a cut-off low) and relatively weak tropical cyclone; e.g. Tropical Storm Norma and Tropical Storm Octave; or a weak or nonexistent midlatitude disturbance and a relatively intense tropical cyclone; such as Hurricane Kathleen and Hurricane Doreen of August 1977. The merger of a strong trough or cut-off low with the remnants of an intense tropical cyclone probably occurred over New Mexico in late September 1941 to cause the extraordinary rains which fell in the eastern part of the state from the 20th-23rd.

Several of the heaviest rains ever recorded in the southwestern United States have been associated with eastern north Pacific tropical cyclones and have been used for the calculation of probable maximum precipitation (PMP) amounts (see Hansen et

[4] Hansen et al. (1977, pp. 80) state that "a large void existed in tropical cyclone rainfall in most of Nevada eastward to the Wasatch Mountains of Utah" but this is not true as indicated by the precipitation amounts shown in Figures 10 and 44.

Table 54. All-Time Monthly Precipitation Records at Selected Stations in the Southwest that are partly the result of Tropical Cyclone-related Rainfall

Station	Month	Year	Amount
Crown King, Az.	August	1951	16.95
Flagstaff WSO Airport, Az.	October	1972	9.86
Phoenix WSFO Airport, Az.	August	1951	5.56
Winslow WSO Airport, Az.	October	1972	5.61
Yuma Valley, Az.	August	1977	7.03
Yuma WSO Airport, Az.	August	1977	2.96
Ely WSO Airport, Nev.	September	1984	3.73
Las Vegas WSO Airport, Nev.	September	1939	3.39
Salt Lake City WSFO Airport, Utah	September	1982	7.04

amounts in inches.

al., 1977). The amount most often used now is the 11.40 in. of rain recorded in 24 hours at Workman Creek 1, Arizona which fell in connection with Tropical Storm Norma in September 1970. Hansen et al. (1981) suggest that for a tropical cyclone to produce PMP magnitude rainfall the storm must not move over water with a SST less than about 24°C, unless it is moving very fast, because any storm that does will arrive over the Southwest too weak to cause rains which approach PMP amounts. However, SSTs along the path of a landfalling tropical cyclone are only one factor among many which determine the intensity of precipitation. The strength of any accompanying midlatitude trough or cut-off low is probably of much greater importance as illustrated by the rainfall linked to Tropical Storm Norma.

Extremely heavy tropical cyclone-related rains, amounts greater than those associated with the Hurricane of September 15-22, 1941; could happen in the Southwest with the scenario suggested by Hansen et al. (1981). Their hypothesized conditions are: record or near record high SSTs in the Pacific west of Baja California; a slow-moving intense hurricane; an upper level circulation pattern which advects moisture from the hurricane inland over the Southwest for several days before the tropical cyclone arrives; the movement inland over the Southwest of a tropical cyclone of hurricane or near hurricane intensity; and the arrival of a strong upper level trough and cold front very soon after the tropical cyclone enters the Southwest. So far this century, record high SSTs in the Pacific west of the Baja peninsula have been reported during major El Nino events. Unusually high SSTs during three previous El Niño events; i.e. in 1939, 1972, and 1976; helped three tropical cyclones; the Tropical Cyclone of September 15-25, 1939; Hurricane Joanne; and Hurricane Kathleen; maintain tropical storm intensity all the way into the Southwest.

In addition, extreme tropical cyclone rains could occur when a relatively small but intense hurricane moves slowly through the Gulf of California and interacts with an upper level trough while still well south of the U.S.-Mexico border to produce heavy rains which last several days and culminate with the arrival of the hurricane. Since the mean SSTs in the Gulf of California are above 29°C in August and September, SSTs will not cause a tropical cyclone to weaken after entering the Gulf. This is best shown by Hurricane Katrina, which contrary to what Hansen et al. (1981) state, probably did not suffer a net loss of intensity upon entering the Gulf. In fact, San Felipe, Baja California at the northern end of the Gulf reported the highest sustained winds, 85 kn, with Hurricane Katrina (Gustafson, 1968).

Eastern north Pacific tropical cyclones have been and will continue to be associated with heavy precipitation and floods in late summer and early fall over much of the southwestern United States. Given the rapid growth and urbanization of many cities in the Southwest; e.g. Las Vegas, Phoenix, and Tucson; these storms most likely will cause many serious floods in the future.

ACKNOWLEDGEMENTS

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