SOME ASPECTS OF THE HEAVY RAINS OVER EASTERN KANSAS, JULY 10-13, 1951

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INTRODUCTION

Heavy rains on July 10–13, 1951, in eastern Kansas, followed a period of already substantial rainfall feeding into swollen streams and were climaxed by a major flood in the Kansas and Missouri Rivers. These rains and their persistence over a relatively small geographical area may be explained in terms of the slow movement of a synoptic situation that favored continued inflow and lifting of moist air over the region. The inflow was maintained by a particular large scale flow pattern, enhanced, perhaps, by some channeling effect of the east slope of the Rockies, and the lifting resulting from persistence of the thermal pattern.

THE HEAVY RAINS

Actually, the 4 days of rain (July 9–13) represented the climax to a number of periods of heavy rainfall which had their beginnings in April. Most of Kansas had had substantial amounts in April, with the departures from normal exceeding 2 inches in the Wichita-Goodland-Topeka triangle. In May, the entire southern half of the State had 100 to 200 percent of normal rainfall. Amounts during June and July are shown in table 1.

TABLE 1.—*Rainfall (inches) for selected stations, June–July, 1951* [1]

Station	June	July	Total	Total days 0.01 inch or more
St. Joseph, Mo.	13.73	5.72	19.45	29
Kansas City, Mo.	8.42	7.54	15.96	29
Lecompton, Kans.	11.17	10.87	22.04	25
Manhattan, Kans.	11.12	15.32	26.44	30
Topeka, Kans.	10.81	11.01	21.82	28
Wamego, Kans.	12.47	10.45	22.92	28

Heavy rains on the night of July 9–10 averaged 4 to 5 inches in the vicinity of Manhattan, Kans., and ranged as high as 5 to 7 inches on the 11th. Many places in central and eastern Kansas had 2 to 5 inches on the 12th. Sample 24-hour totals are shown in table 2.

Distribution of rainfall through a somewhat longer period is shown in figure 1. Most of this rainfall was recorded before the 13th. With such heavy rainfall, day after day, the water retaining capacity of the soil was exceeded, resulting in heavy runoff into the streams and rivers and subsequent overflowing of their banks.

According to a report by Hundeby [1], the runoff values approached 100 percent of the rainfall on the 12th. This same source states that the observed stage in the Fairfax

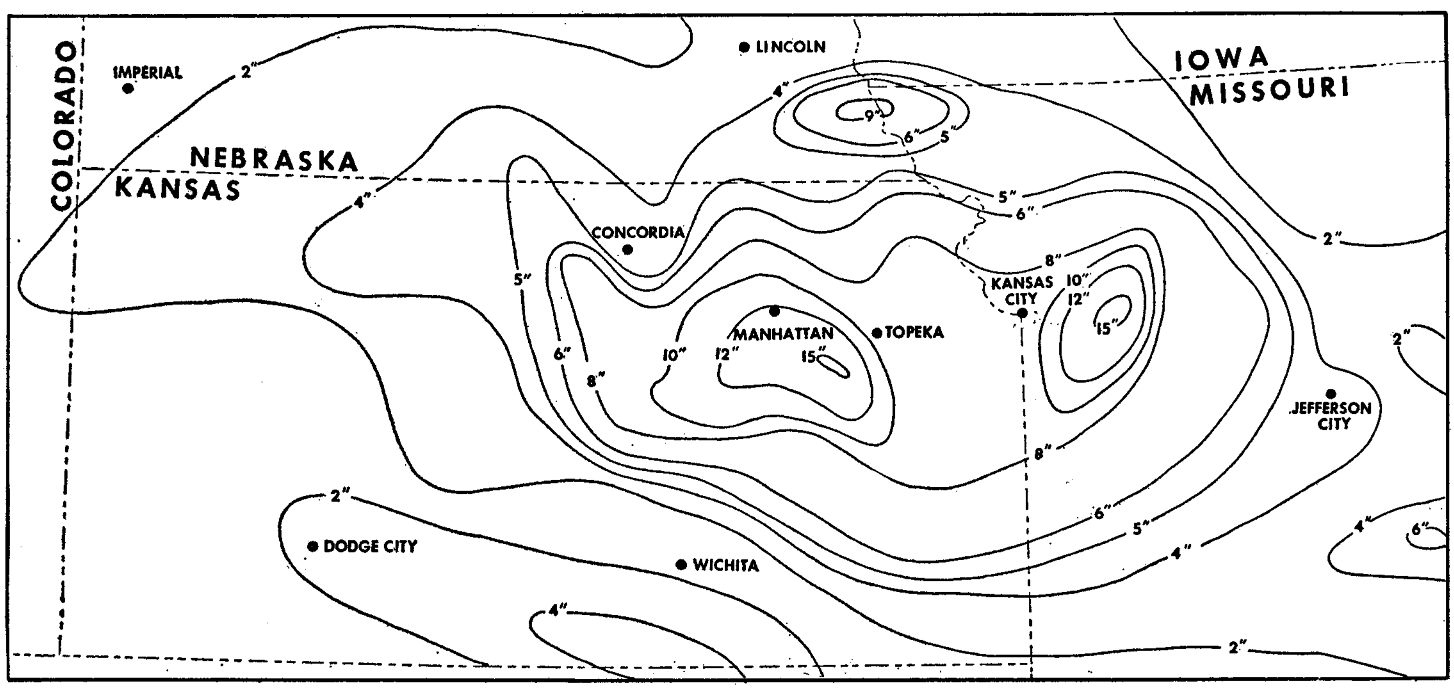

FIGURE 1.—Precipitation (inches) for period July 4–17, 1951. (Based on incomplete preliminary data. Map as drawn by the River Services Section, U. S. Weather Bureau.)

TABLE 2.—*24-hour totals of rainfall (inches) for selected Kansas stations* [2]

Station	July 10	July 11	July 12	July 13	Four-day total
Concordia	0.95	1.28	2.04		4.27
Dodge City	1.98	1.50	.03	.47	3.98
Emporia	1.63	4.60	3.11	1.69	11.03
Goodland	.45	.35	1.69	T	2.49
Harveyville	2.81	4.36	2.67	1.12	10.96
Herrington	2.70	5.50	2.30	.75	11.25
Hill City	.38	2.89	1.95		5.22
Kansas City	.34	1.78	1.38	.68	4.18
Manhattan	4.86	2.48	3.25	.48	11.07
Topeka	.49	2.34	4.00		6.83
Wichita	T	.42	.22	.27	.91

District of Kansas City was 35.86 feet at 0600 local time on the 14th. This is 13.86 feet above bankfull level. The all time high water mark for Kansas City is 38 feet, as gleaned from Indian markers and stories by witnesses to the flood of June 15, 1844 [1]. Bonner Springs, Kans. (southwest of Kansas City, on the Kansas River) had an observed highest stage of 38.9 feet at 2300 local time on the 13th, against a bankfull level of 21 feet [1].

SURFACE CIRCULATION

The series of surface weather maps (figs. 2–5) represents the surface pattern during the period July 10–13. Under the influence of an upper ridge over the Alaskan Gulf the cold fronts moved down the western Plains to Kansas, and then more slowly to Oklahoma where they finally frontolized. The map of July 10 (fig. 2) shows a cold front over southern Kansas which had come into that area on the previous day. By July 11 (fig. 3) it was in the process of "washing out" as a new surge had entered the northwest triangle of the State. This new surge slowed down over Kansas on July 12 (fig. 4) and then moved very

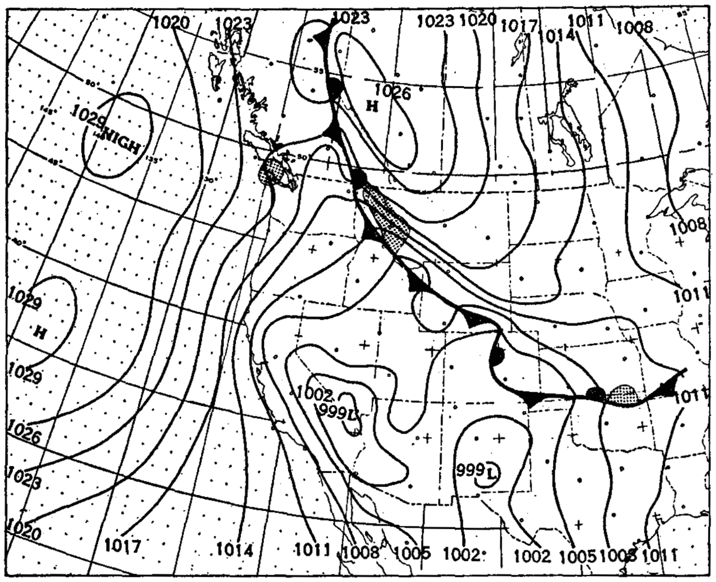

FIGURE 2.—Surface weather chart, 0030 GMT, July 10, 1951. Shading indicates areas of active precipitation.

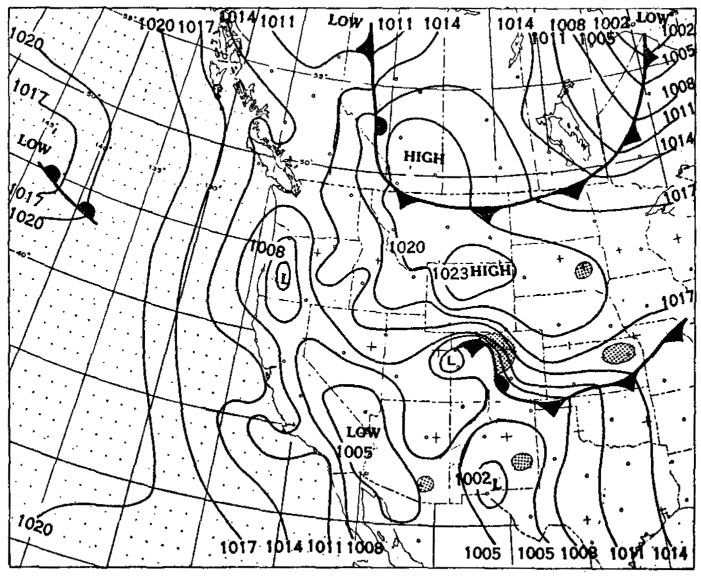

FIGURE 4.—Surface weather chart, 0030 GMT, July 12, 1951.

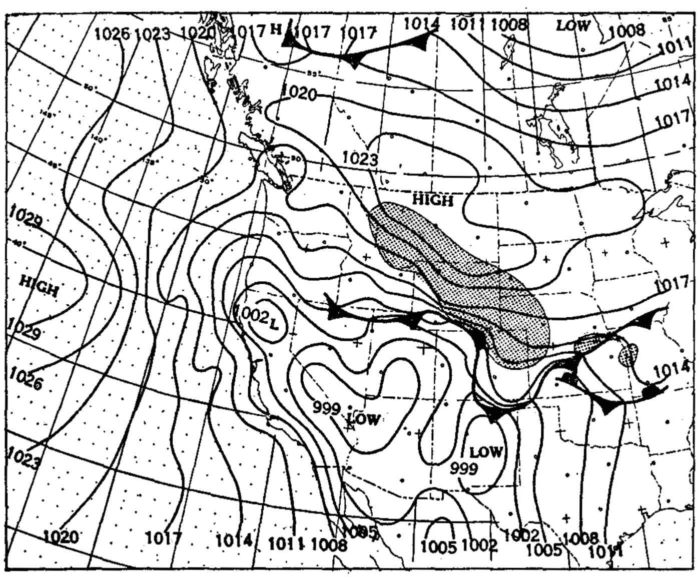

FIGURE 3.—Surface weather chart, 0030 GMT, July 11, 1951.

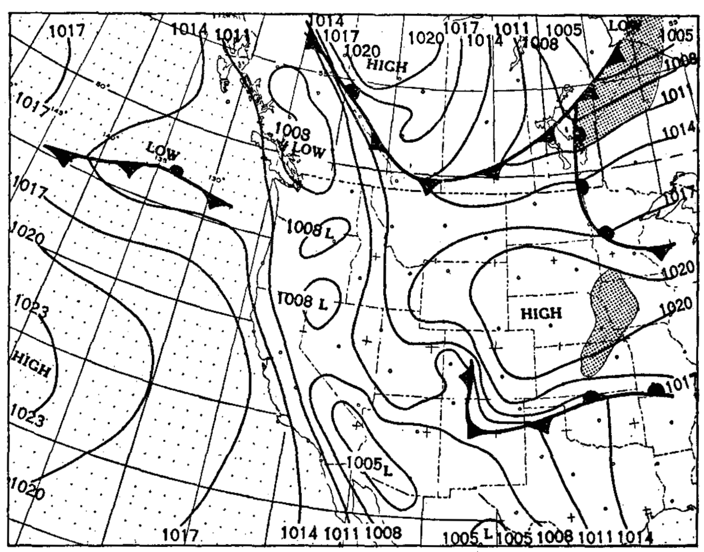

FIGURE 5.—Surface weather chart, 0030 GMT, July 13, 1951.

slowly into northern Oklahoma during the next 24 hours. By July 13 (fig. 5) it had changed its direction of movement and acted as a warm front.

This sequence produced not widespread rains over the Kansas-Oklahoma area, as often occur when cold air masses move in under warm air in that region, but rather, intense local showers and thunderstorms as the convectively unstable air rode up the frontal surface of the Polar air. These downpours occurred mainly during the night and early morning hours, as is typical of summer precipitation in the Middle Plains area. Before investigating the frontal lifting mechanism more closely, it will be helpful to examine the role of the circulation aloft in the surges of cold air.

CIRCULATION ALOFT

A characteristic pattern of the middle troposphere air flow during June and the early part of July consisted of a north-south ridge of high pressure over the Gulf of Alaska and a trough of low pressure extending from the northern Plains southwestward to the southern Plateau. Once this trough was established it persisted for 7 to 10 days at a time. While this pattern prevailed heavy rain fell over Kansas.

This ridge-trough pattern was accompanied by intermittent surges of Polar air into the northern Plains States. These masses of cold air moved southward along the eastern shoulders of the Rocky Mountains, displacing or blocking the northward flow of moist tropical maritime air from the Gulf of Mexico. The southward movement of cold air was associated with the circulation around the upper level ridge, while the northward flow of warm air was supported by the flow on the eastern side of the upper level trough.

The ridge might be looked upon as father to the trough in that, once it formed, a trough took shape downstream. This fact might be explained, in part, by considering Rossby's idea of constant vorticity trajectories, which requires that the trajectory of the air parcels tends to curve southward after passing through the ridge. However, a dynamic factor that seems important is an effect which has been pointed out by Wobus [3]; that is, particularly in the region referred to, the ridge tends to develop and remain nearly stationary with anticyclonic curvature (along and near the ridge line) which exceeds any possible curvature of the individual trajectories passing through the ridge.

Assuming that air parcels approaching the ridge from the southwest have a fairly high speed (as is often observed) they will not only fail to curve with the contours but will move across them toward lower contour heights, resulting in acceleration. Then, if the geostrophic wind as indicated by the contour gradient to the east of the ridge is less than the actual wind speed (as is frequently observed), the air parcels must curve to the right. In doing so they move toward higher contours, decelerate, and later recurve to the left, the trajectory taking the form of a trough.

It was also shown by Wobus [3] that the magnitude of this effect is such as to form a trough of the dimensions observed, as for example, over the plateau when there is a stationary ridge over western Canada. His theory assumes that the contour field tends eventually to become adjusted to the wind flow, requiring for the formation of the trough that the atmosphere undergo net horizontal mass divergence in the area of trough formation. This in turn requires that the total horizontal divergence which presumably occurs mostly in the middle troposphere, exceed the total convergence at other levels. These requirements seem to be met when winds in the middle and upper troposphere are relatively strong, particularly as a new surge of stronger winds moves into and through the stationary ridge.

These effects seem to have been important during the period of recurring flood rains, when northeast-southwest troughs formed from time to time and moved only slowly across the northern Plains and Plateau areas. While conditions to the northward and northwestward are not shown completely on the accompanying charts, some evidence of the effect may be seen by comparing figures 6 and 7. In figure 6, the 700-mb. chart for July 9, there is a rather weak east-west trough across Washington and northern Montana. Figure 7, the 700-mb. chart 24 hours later, shows easterly winds over Washington. These winds could only have originated in the ridge to the north, and were accompanied by an east-west trough within which a developing low pressure center was forming over southeastern Idaho.

From time to time during June and the first half of July, the ridge would split in the Alaskan Gulf. Whenever this happened, new adjustments were called for downstream and so the trough would either disappear,

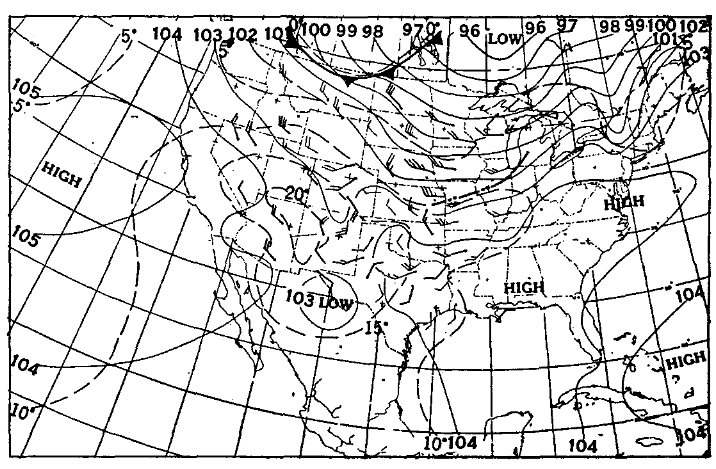

FIGURE 6.—700-mb. chart, 0300 GMT, July 9, 1951. Contours (solid lines) at 100-foot intervals are labeled in hundreds of geopotential feet. Isotherms (dashed lines) are at intervals of 5° C. Barbs on wind shafts are for speed in knots (pennant=50 knots, full bab=r10 knots, and half barb=5 knots).

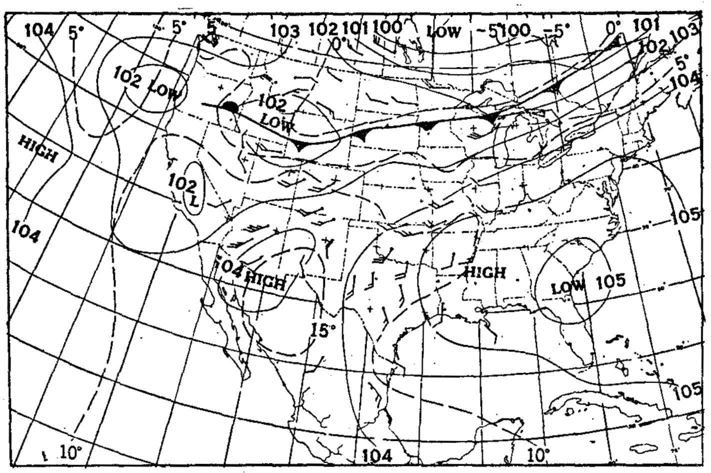

FIGURE 7.—700-mb. chart, 1500 GMT, July 11, 1951.

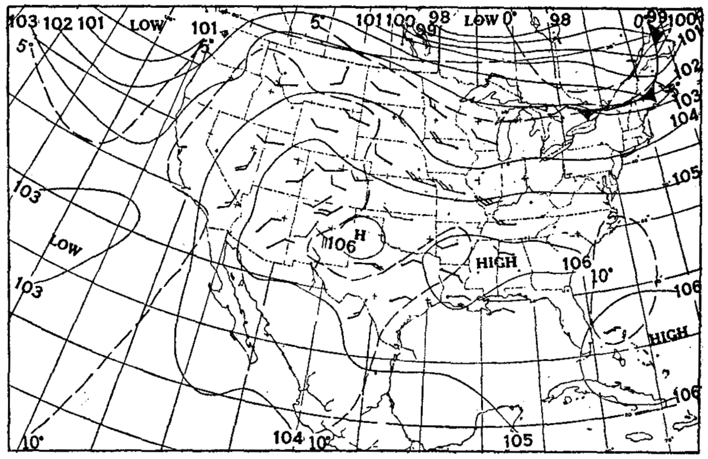

FIGURE 8.—700-mb. chart, 1500 GMT, July 13, 1951.

move bodily, or re-form elsewhere. Such disruption took place July 13, when the rains ceased and the more normal summer weather returned to Kansas. The changes in the circulation aloft during the heavy rain period are examined in more detail in the next section by reference to 700-mb. charts. A fuller discussion of the changing pattern of the general circulation and the associated surface effects is covered elsewhere in this issue by Oliver [4] and in a previous issue of the Review by Clem [5].

700-MB CIRCULATION

Three maps serve to illustrate the circulation at the 700-mb. level during the period of heavy rain. The 0300 GMT map of July 9 (fig. 6) shows the Kansas area under a stream of downslope northwest winds with only a small area of cold air advection in extreme northeast Kansas. Along both coast lines of the United States, and generally south of 40° N. latitude, ridge conditions predominated. A connecting ridge of high pressure stretched across the southern tier of States. Temperatures aloft over the southwest were quite warm with a belt of warm southwest winds extending up the Mississippi Valley to Illinois and Indiana.

A decided change in the air flow from Texas to Kansas took place by the time of the 1500 GMT map of July 11 (fig. 7). A lobe of the Bermuda High had pushed westward along the central Gulf States. This development led to a band of southerly winds streaming northward over Texas to Oklahoma, where they turned anticyclonically. These 15- to 20-knot winds could be traced to Illinois where the speed dropped off suddenly.

Twenty-four hours later the circulation had again changed rapidly. On the map for 1500 GMT of July 13 (fig. 8), a portion of a Low in the Gulf of Alaska can be seen, just off the coast of Washington. As this trough developed in strength and area the ridge downstream from it underwent readjustment. On this map a ridge extended in a southeast to northwest direction from Texas

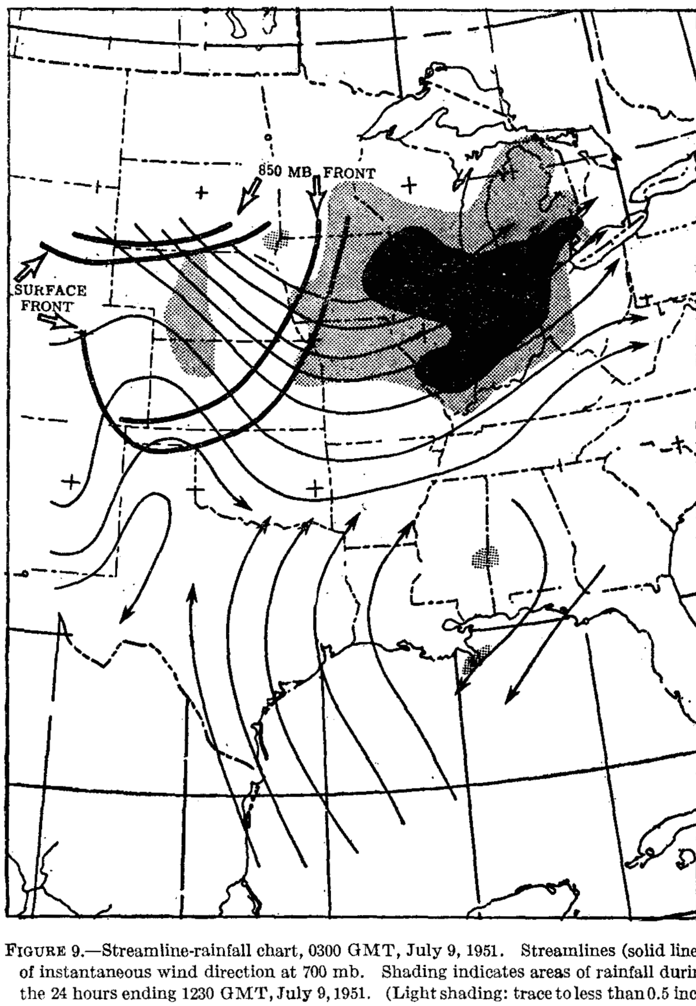

FIGURE 9.—Streamline-rainfall chart, 0300 GMT, July 9, 1951. Streamlines (solid lines) of instantaneous wind direction at 700 mb. Shading indicates areas of rainfall during the 24 hours ending 1230 GMT, July 9, 1951. (Light shading: trace to less than 0.5 inch; dark shading: 0.5 inch or greater.) Surface and 850-mb. fronts (heavy solid lines) are appropriately labeled.

to Idaho. As the heights rose over Texas, the southerly winds from the Gulf of Mexico were cut off. All that can be seen of the mass of warm air is a narrow band of high temperatures extending from Del Rio, Tex., to near Memphis, Tenn.

FRONTAL LIFTING

In order to see how the frontal lifting mechanism worked in the lower troposphere, the weather may be examined in terms of the flow pattern aloft as indicated by the streamlines of instantaneous wind direction at 700 mb., the positions of the surface and 850-mb. fronts, and the reported rainfall areas and amounts. The resulting series of maps (figs. 9–11) shows the relationship between all these elements.

On the map for 0300 GMT July 9 (fig. 9), rainfall is shown in a small area east of Goodland, Kans., and in the Kansas City area. In both areas the rain occurred with thunderstorms prior to midnight of July 8. The broad area of heavy rainfall over the Illinois region occurred with a squall line in the deep layer of moist, unstable air. The rains in Kansas occurred only in relation to the frontal passage and amounts were light (less than 0.25 inch).

The air flow, as depicted by the arrows, was in two broad streams. The first moved downslope over the top of the cold dome in northwest Kansas. The second moved up from Texas, its northern boundary being just north of the Red River Valley of Oklahoma. This air was maritime-tropical in type and convectively unstable aloft. Its surface temperatures ranged from low to middle eighties, and dew points from 70° to 75° F. In the confluence zone, where the two major air streams met over eastern Oklahoma and Arkansas, no rain fell during the 24 hours because lifting, if any, was insufficient. Over Kansas, no rains of consequence developed because of the prevalence of downslope flow.

In the 24 hours ending at 1500 GMT, July 11 (fig. 10), the picture changed rapidly as heavy rains developed over Kansas and Missouri. Just west of Topeka, amounts were as high as 4.5 inches. The zone of Gulf air extended all the way from Texas to Illinois. The southern limit of the heavy rains coincided rather closely with the surface cold front. Where the air stream was intercepted by the leading edge of the cold air dome, heavy falls of rain took place, as can be seen by the shaded areas on the map. By tracing the path of the moist winds it is rather clearly indicated that frontal lifting was the action which produced the heavy rainfall. Only light showers had fallen along the Gulf coast of Texas, and from there to the front no rain was reported.

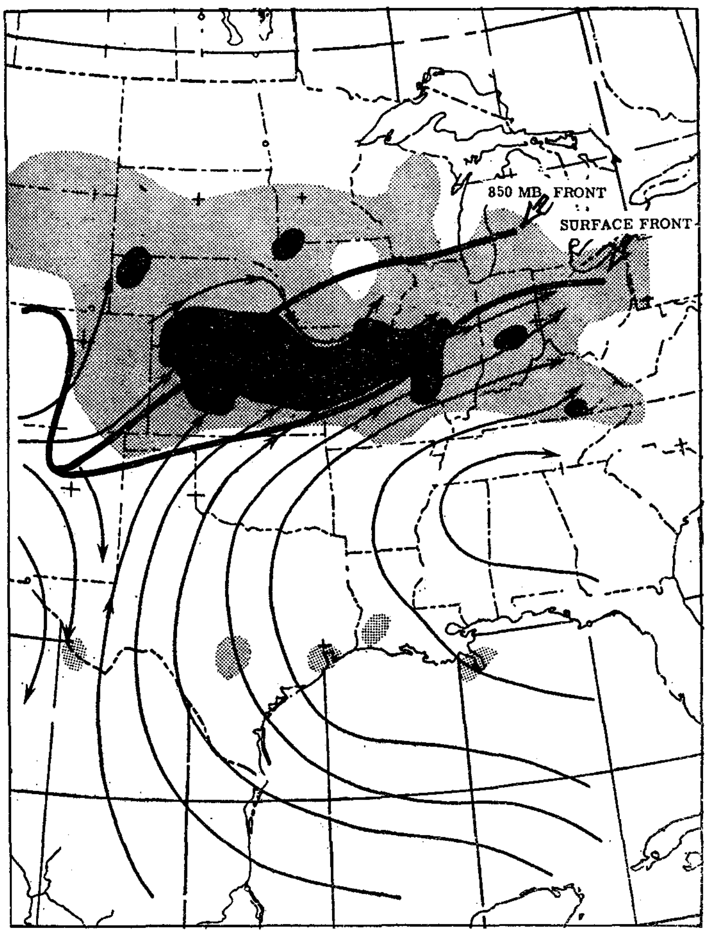

FIGURE 10.—Streamline-rainfall chart, 1500 GMT, July 11, 1951. Shading indicates areas of rainfall during the 24 hours ending 1230 GMT, July 12, 1951.

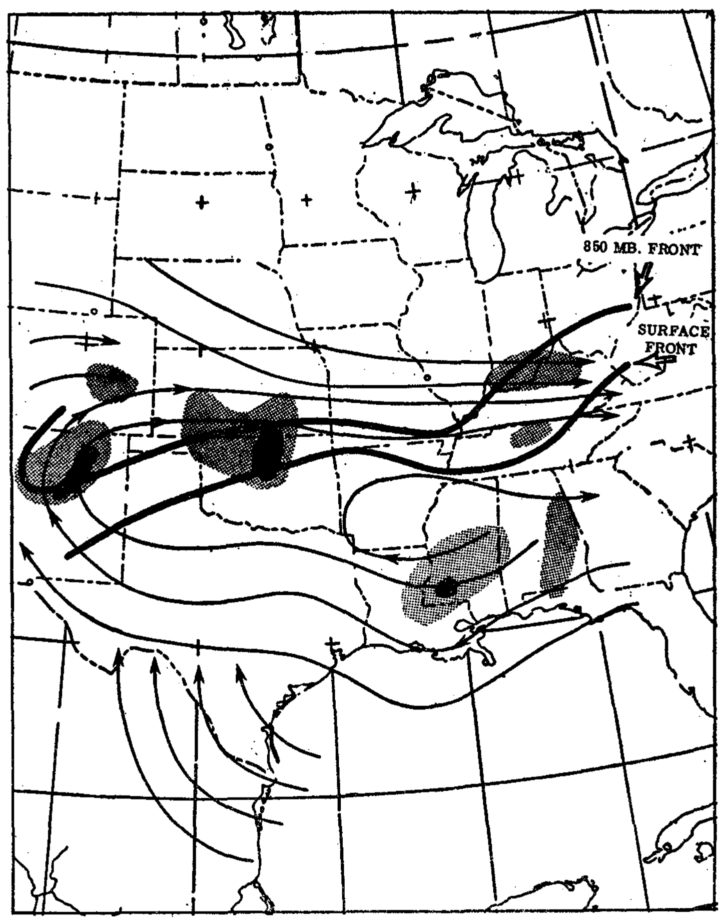

FIGURE 11.—Streamline-rainfall chart, 1500 GMT, July 13, 1951. Shading indicates areas of rainfall during the 24 hours ending 1230 GMT, July 14, 1951.

The sounding for San Antonio, Tex., showed moist air to just above 700 mb. with a rapid drop-off in moisture content above that level. At the same time, the air above Oklahoma City was just as moist to about the same level, but at higher levels was even dryer than over San Antonio. In other words, unstable air moved long distances with a high potential for rain which was realized only when subjected to frontal lifting.

The sounding at Albuquerque indicated very dry air from the surface to about 600 mb. which, together with the fact that the flow in that region was anticyclonic, suggests that this air was subsiding.

On the map for 1500 GMT, July 13 (fig. 11), the belt of southerly winds is found mostly below 36° N. latitude. The San *Antonio sounding, in the tropical air,* is more moist than the day before. All that remained of the moisture band at Oklahoma City was a sharply defined layer some 30 millibars thick at 700 mb. Over the Kansas region the winds were once again from a westerly direction and essentially downslope. Although the front moved on to Oklahoma, only a small rain area had developed and the amounts were less than .25 inch. Rains in the Enid to Oklahoma City zone were the result of thunderstorms in the evening of July 12.

It is interesting to see that although the rains stopped over Kansas (fig. 11) as the southerly flow was cut off by the downslope motion and rearrangement of the flow pattern, the eastern portion of New Mexico showed thunderstorm rains exceeding one inch where the southeast winds, moving upslope, were further lifted by the advancing cold front.

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1. Gordon Hundeby, Report on the Great Flood of July 1951 on the Kansas and Missouri Rivers at Kansas City, U. S. Weather Bureau Airport Station, Kansas City, Mo., August 1951. (In cooperation with Weather Bureau Area Hydrologic Engineer and River Forecast Center.) (Unpublished.)
2. U. S. Weather Bureau, *Climatological Data, Kansas.* vol. LXV, No. 7, July 1951.
3. H. B. Wobus, "A Systematic Method of Wind Forecasting at 500 mb.," paper presented at 98th National Meeting of American Meteorological Society, Washington, D. C., April 20–22, 1948. (Unpublished.)
4. V. J. Oliver, "The Weather and Circulation of July 1951," *Monthly Weather Review*, vol. 79, No. 7, July 1951, pp. 143–146.
5. L. H. Clem, "The Weather and Circulation of June 1951," *Monthly Weather Review*, vol. 79, No. 6, June 1951, pp. 125–128.

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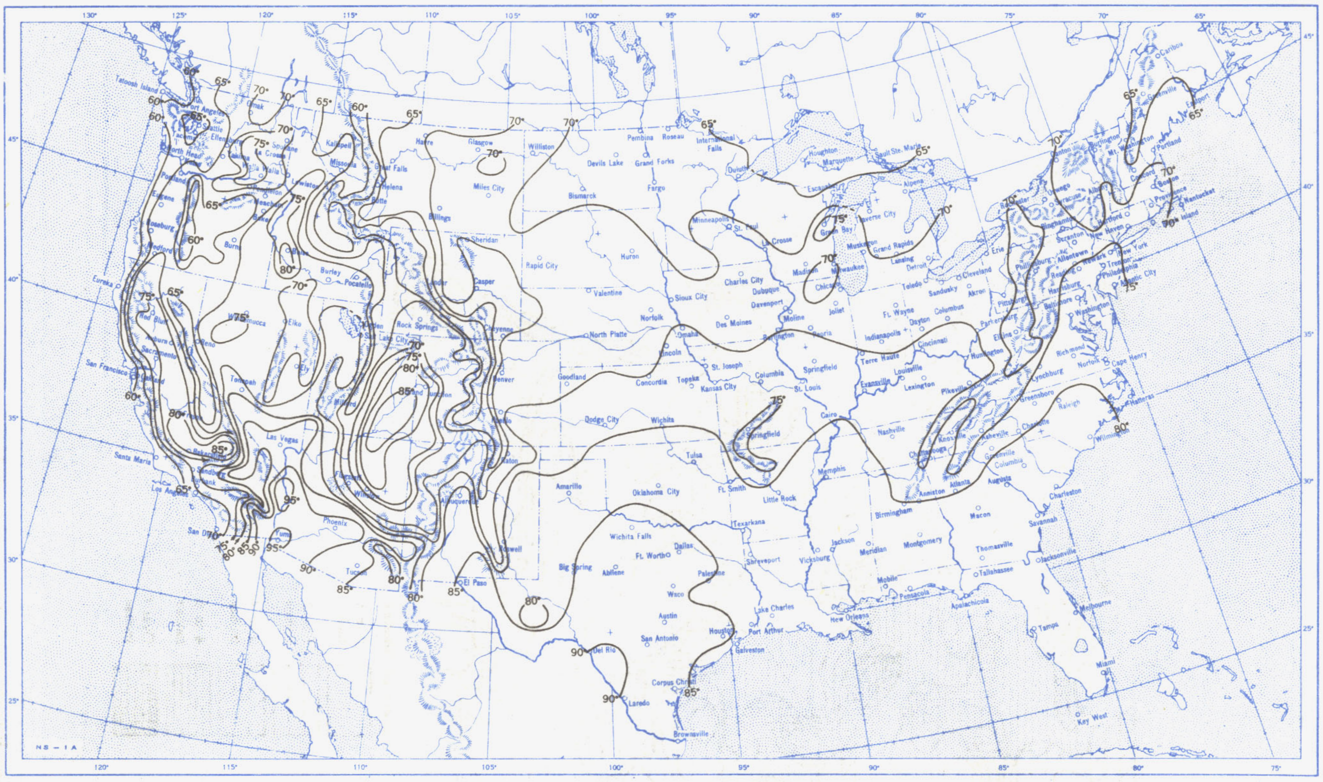
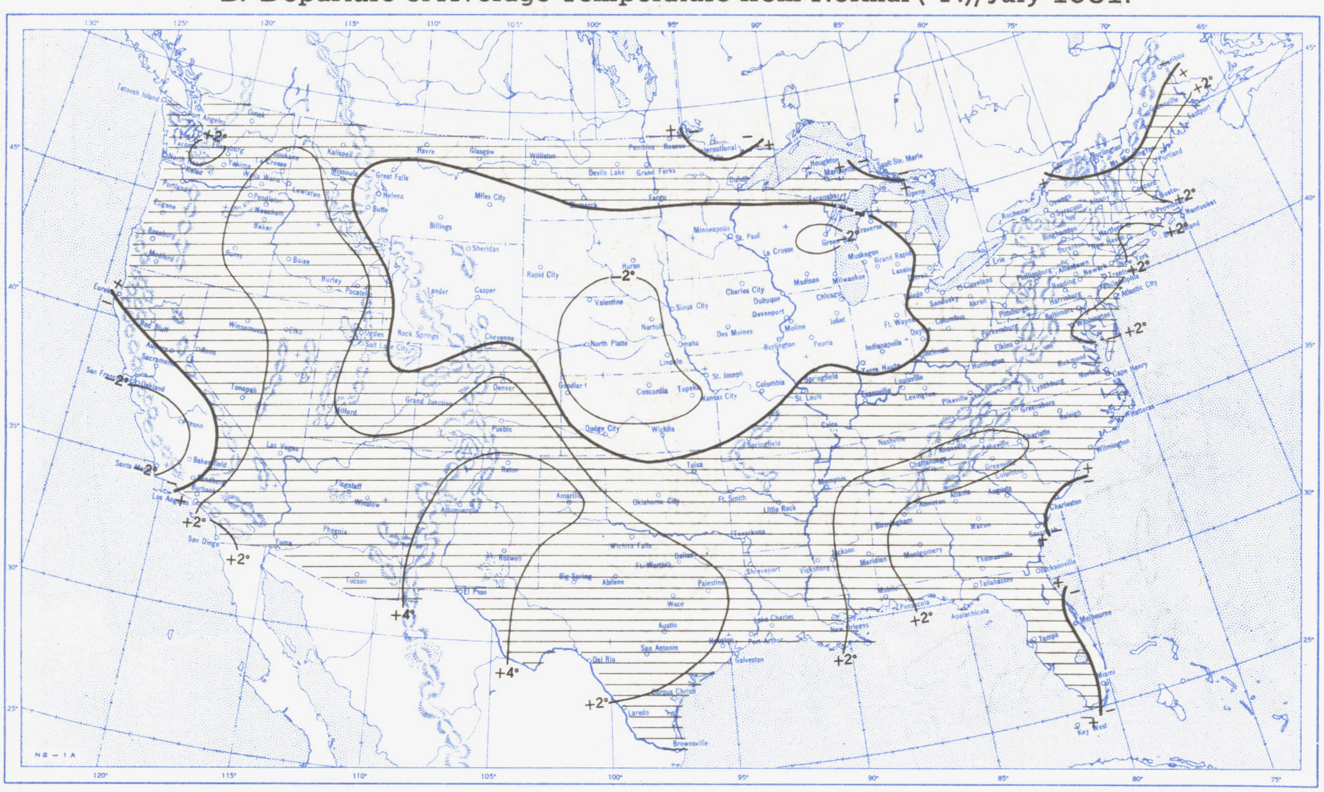
Chart I. A. Average Temperature (°F.) at Surface, July 1951.

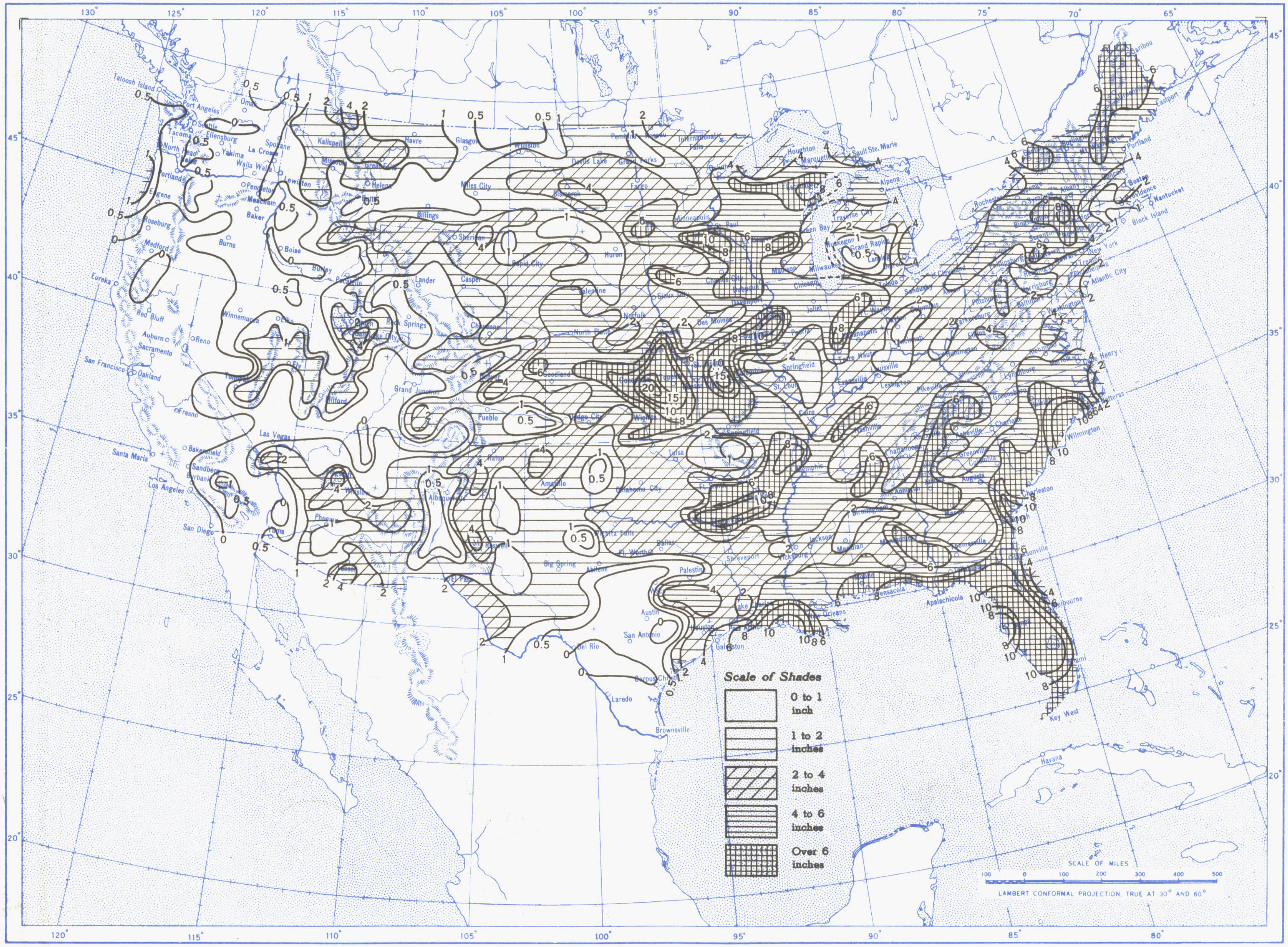


B. Departure of Average Temperature from Normal (°F.), July 1951.



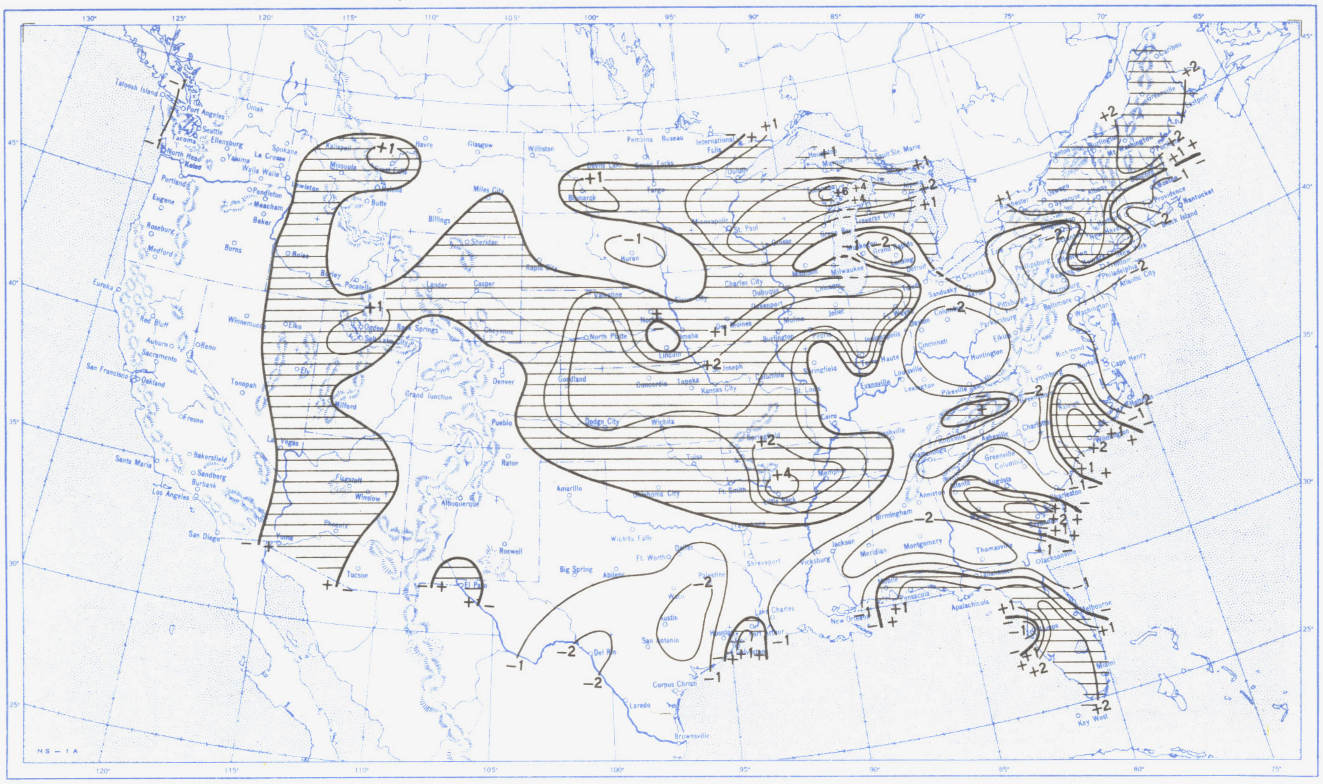
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), July 1951.

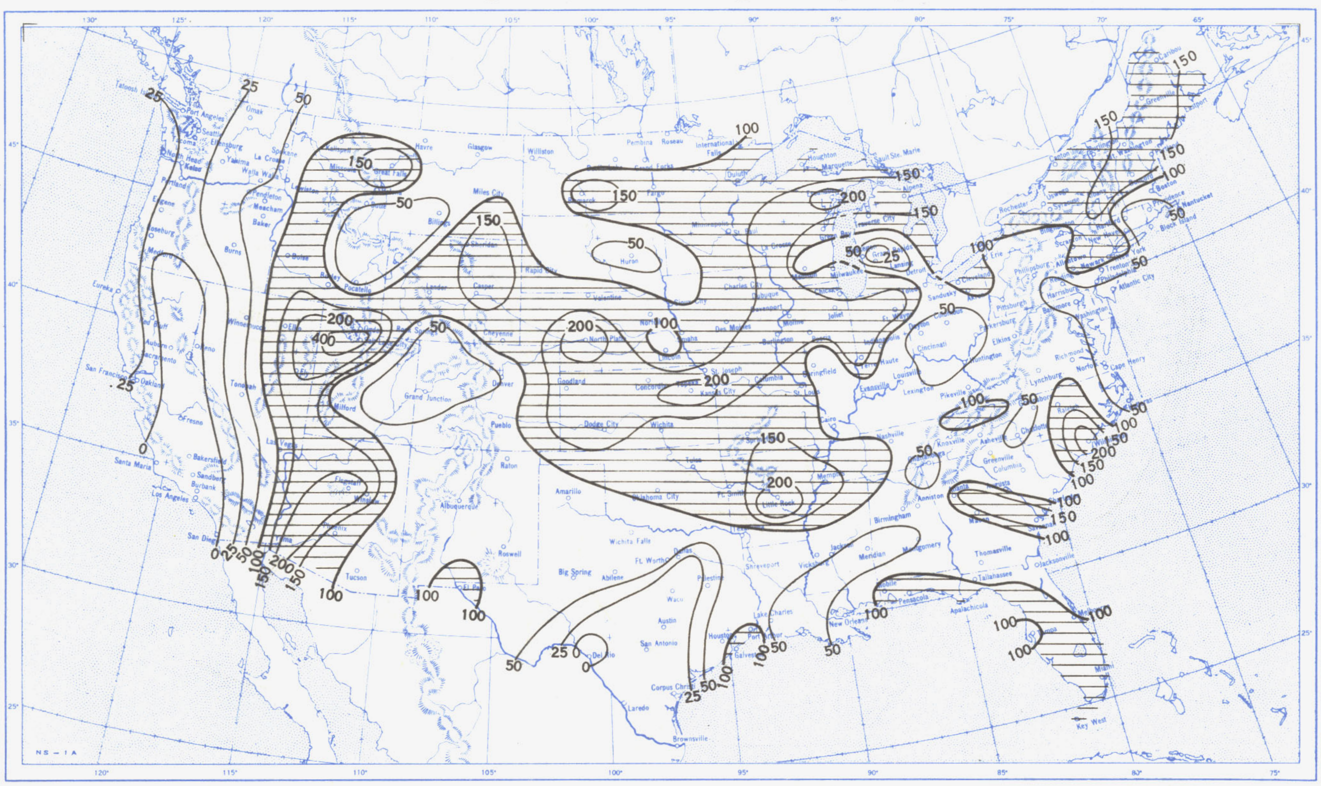


Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), July 1951.

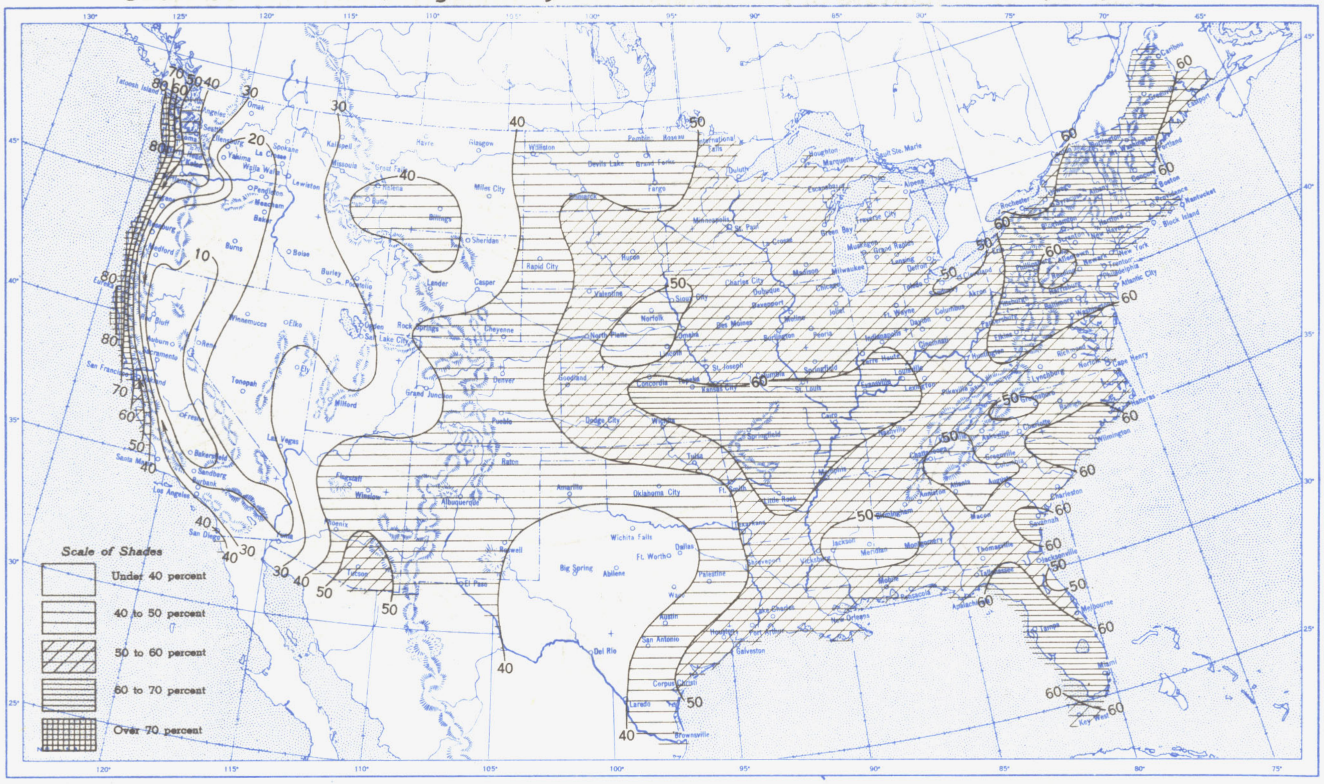


B. Percentage of Normal Precipitation, July 1951.

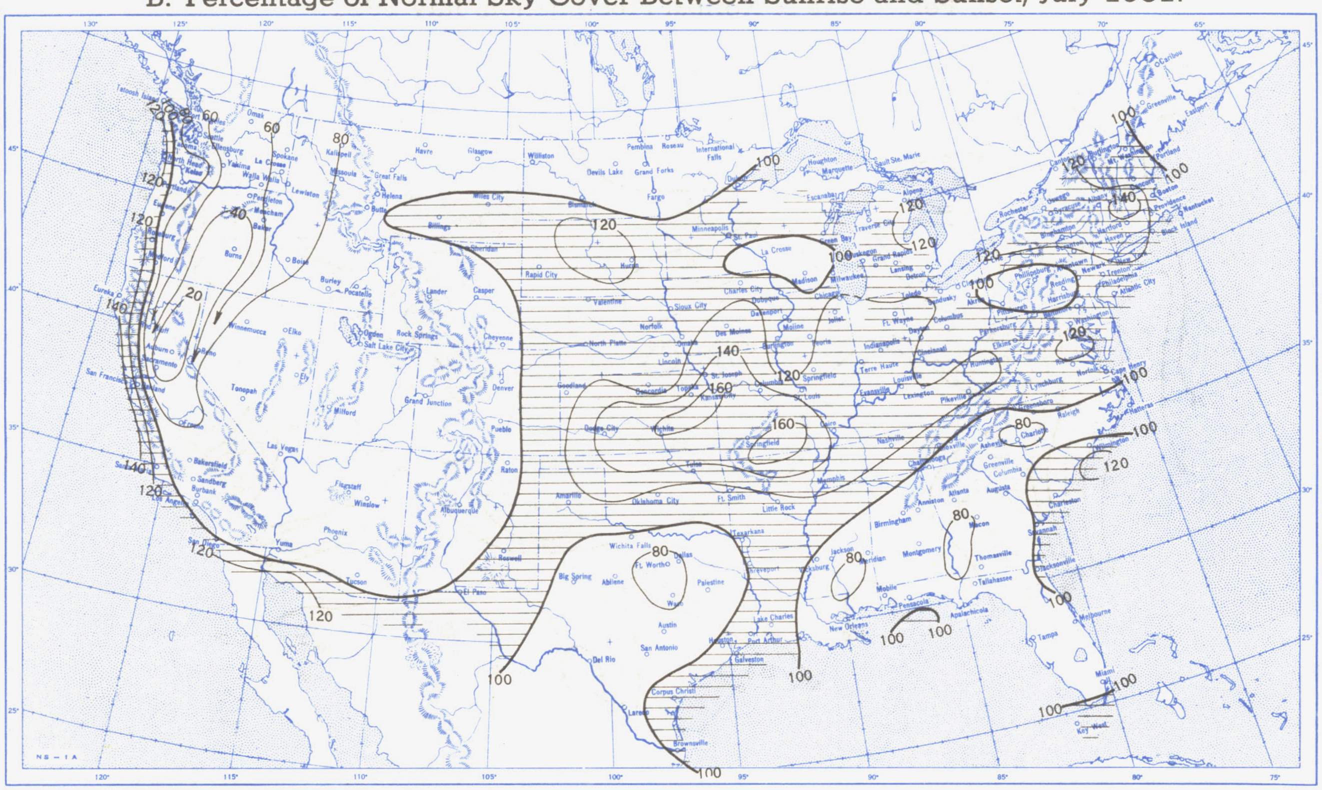


Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, July 1951.

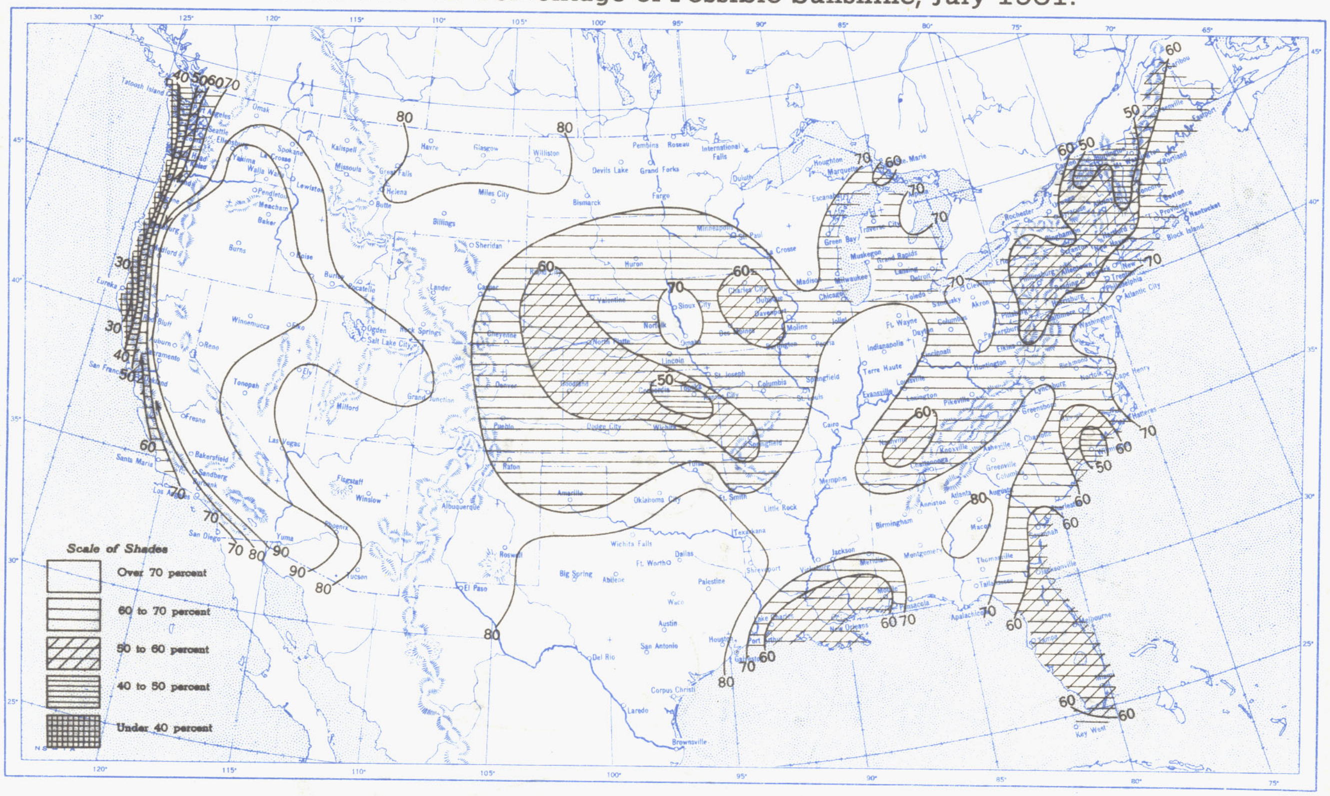


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, July 1951.

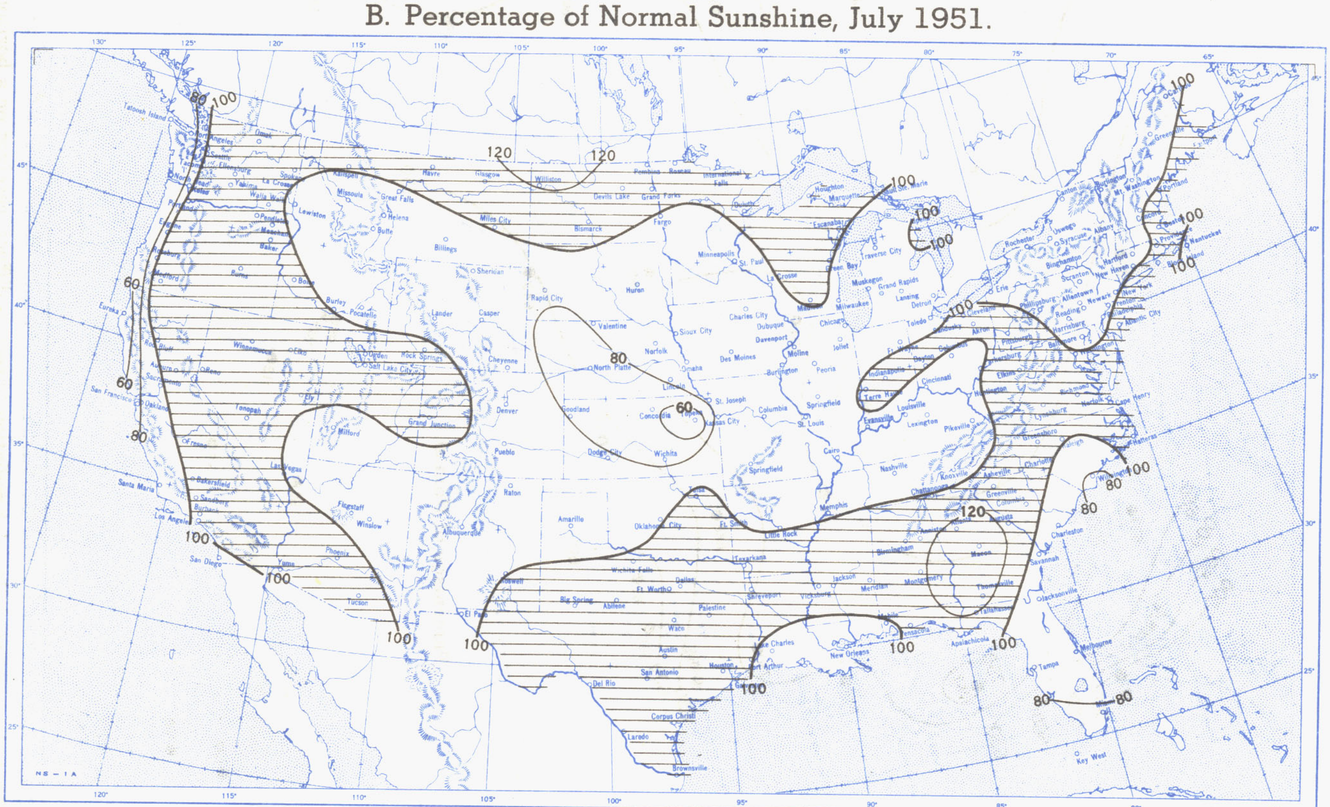


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, July 1951.



B. Percentage of Normal Sunshine, July 1951.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, July 1951. Inset: Percentage of Normal

Average Daily Solar Radiation, July 1951.

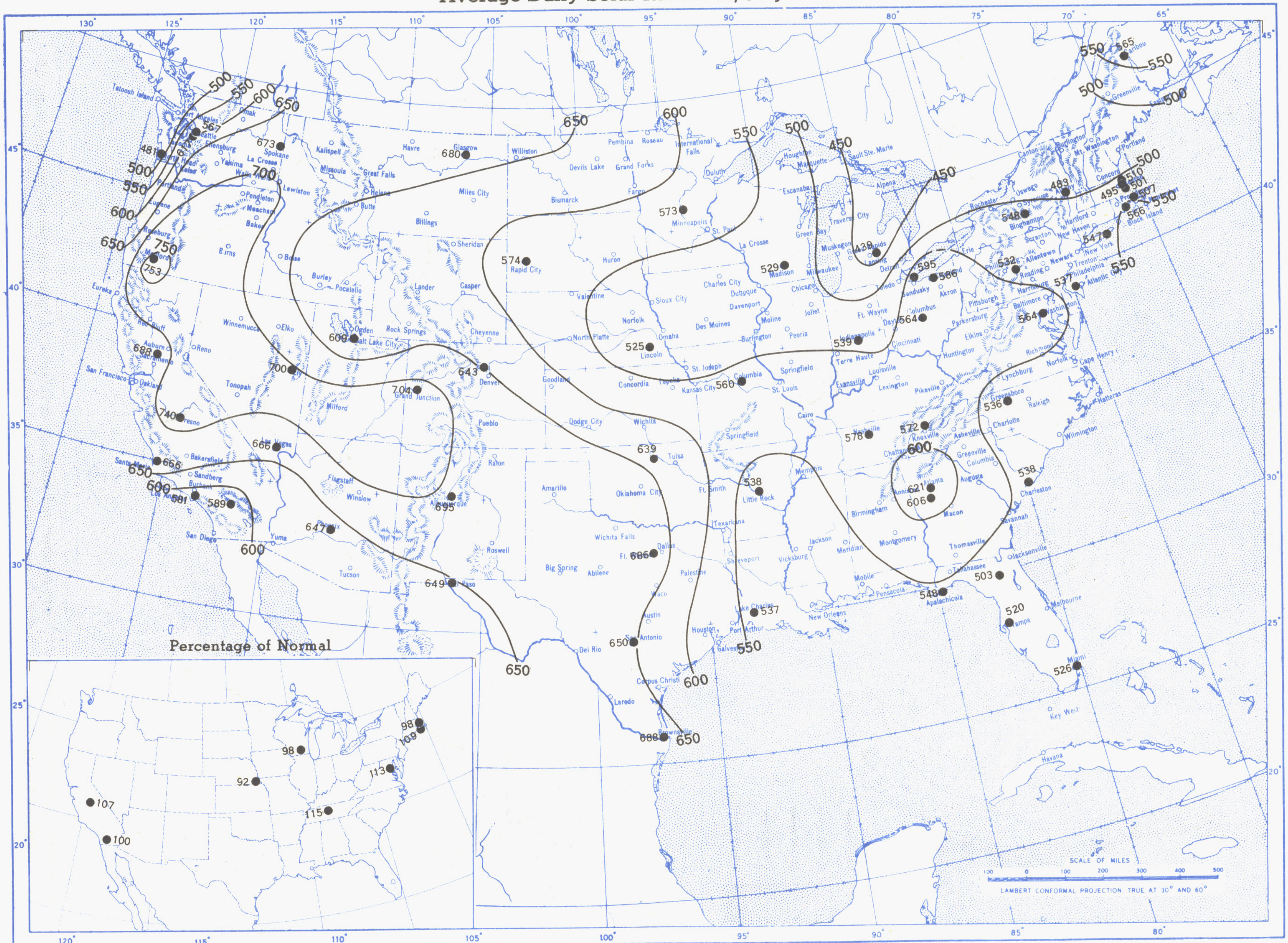
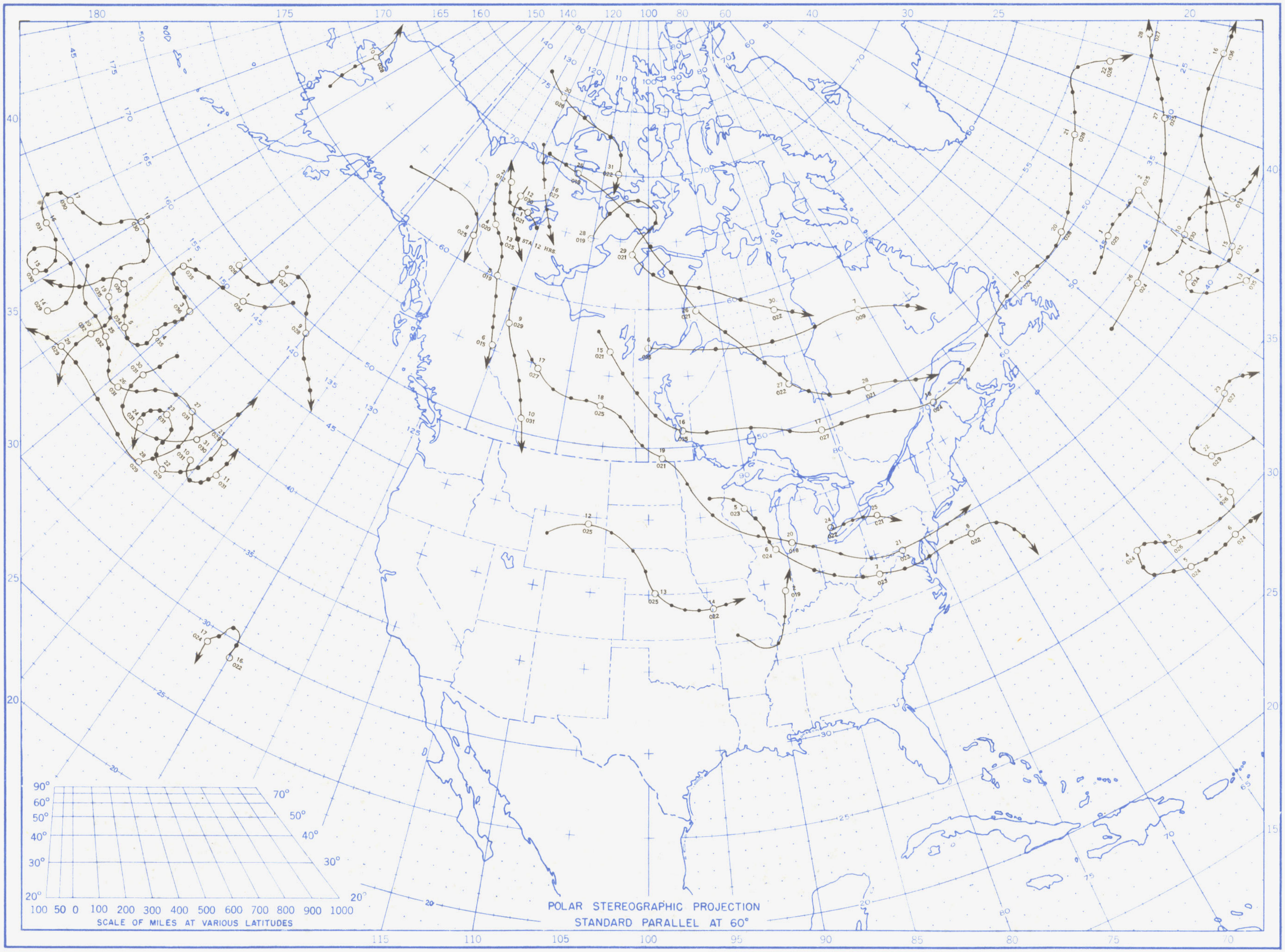


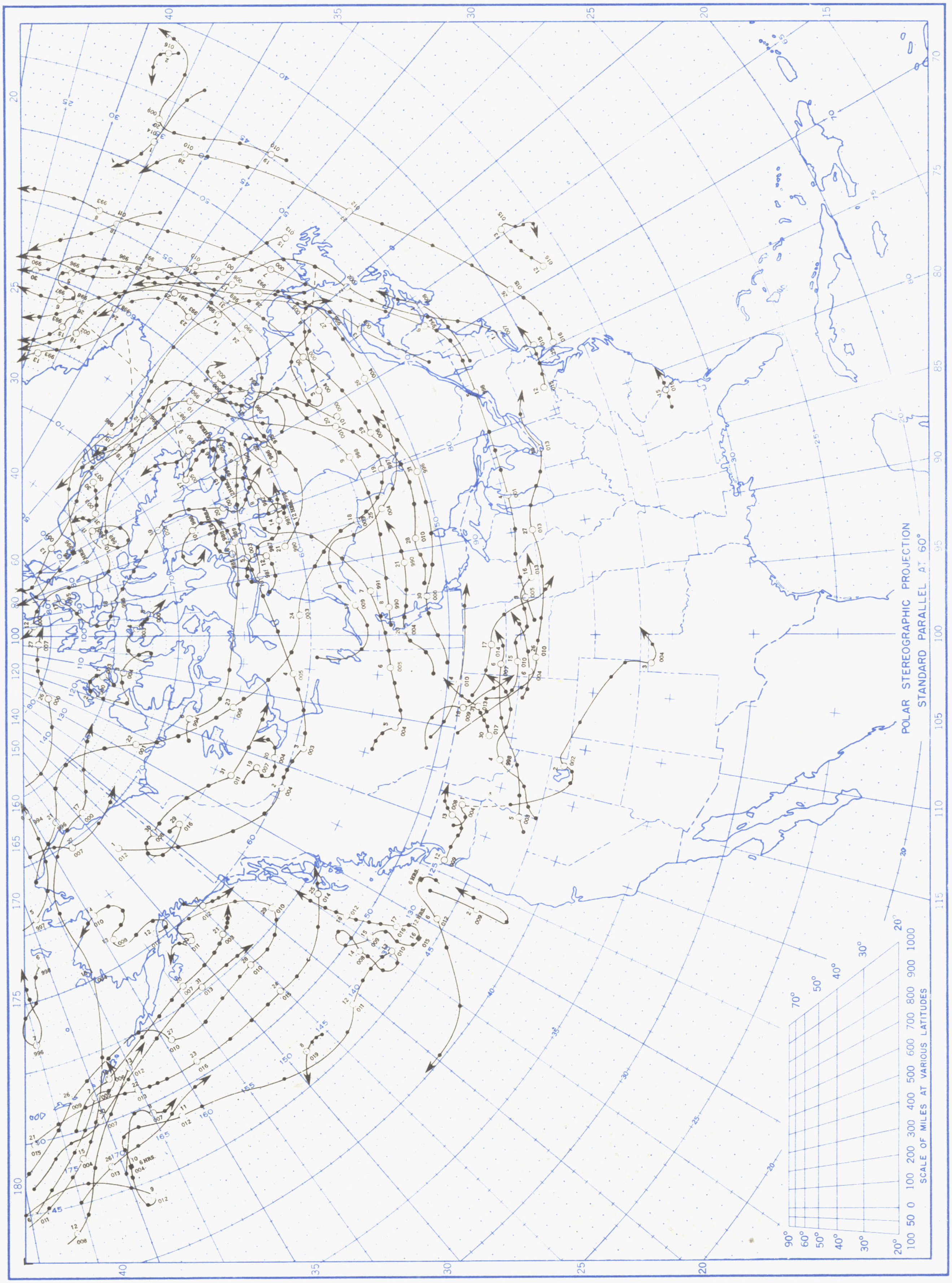
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates obtained from supplementary data for which limits of accuracy are wider than for those data shown. Normals are computed for stations having at least 9 years of record.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, July 1951



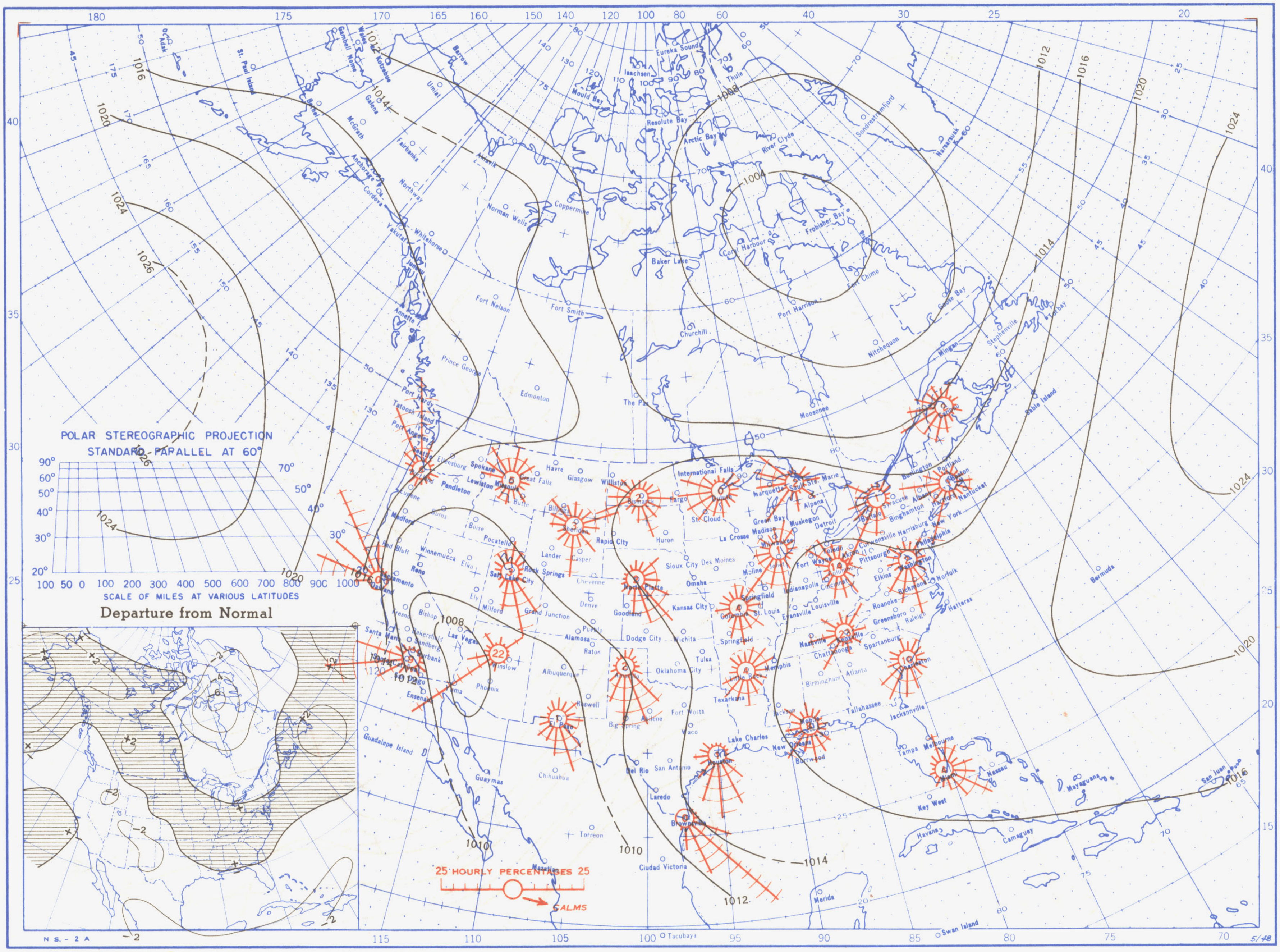
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, July 1951.



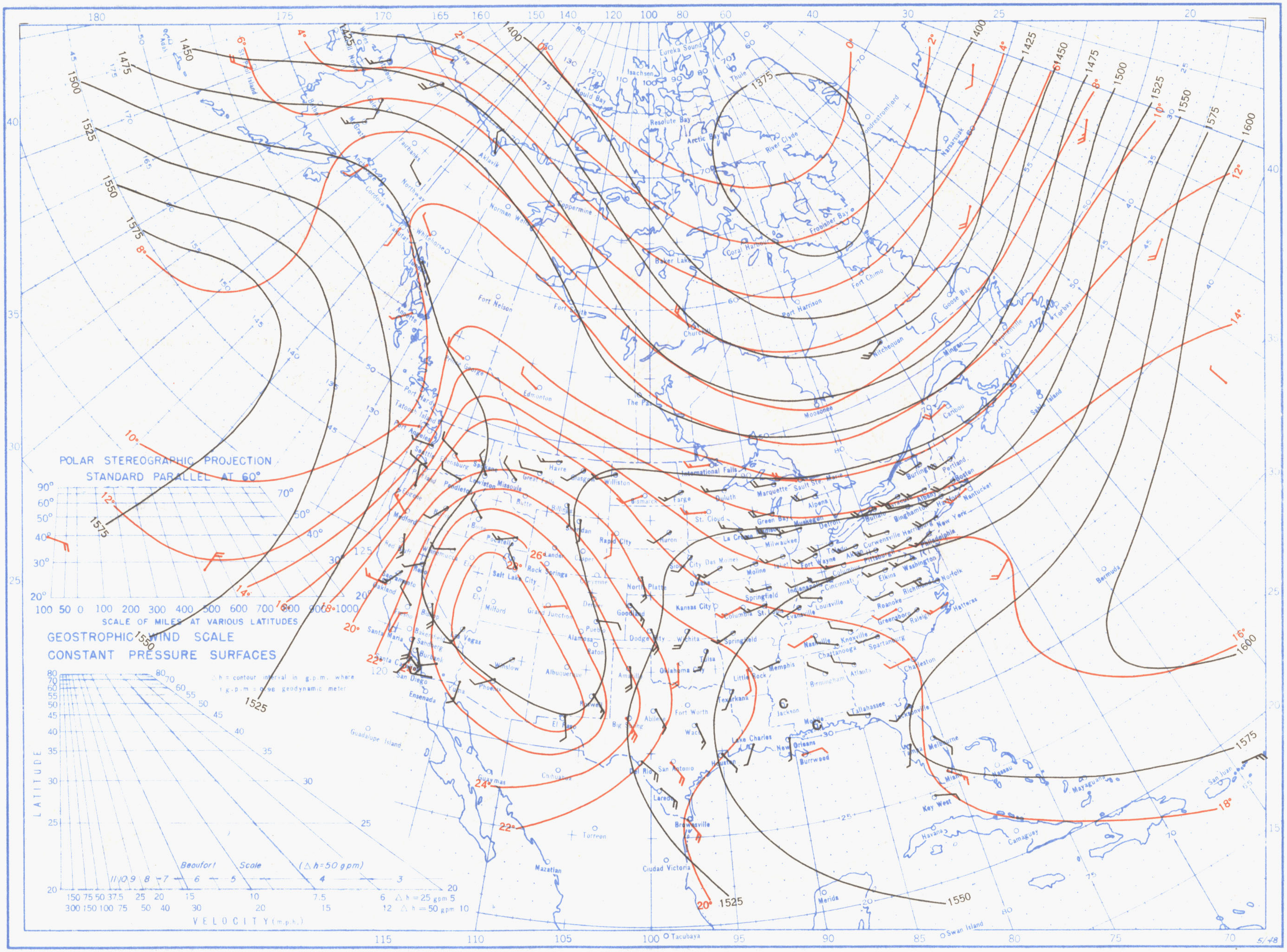
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, July 1951. Inset: Departure of Average Pressure (mb.) from Normal, July 1951.



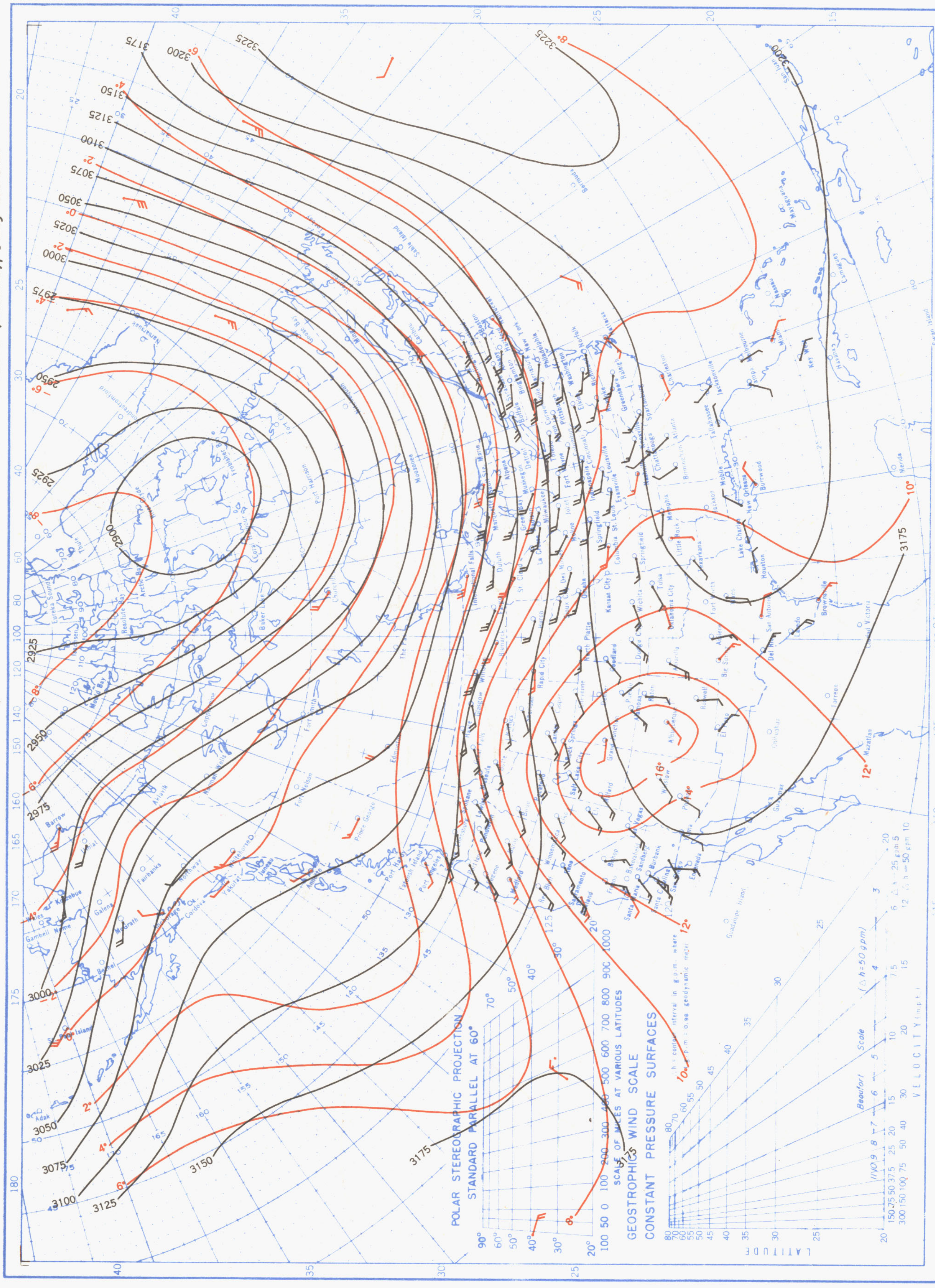
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid from map readings for 20 years of the Historical Weather Maps, 1899–1939.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), July 1951.



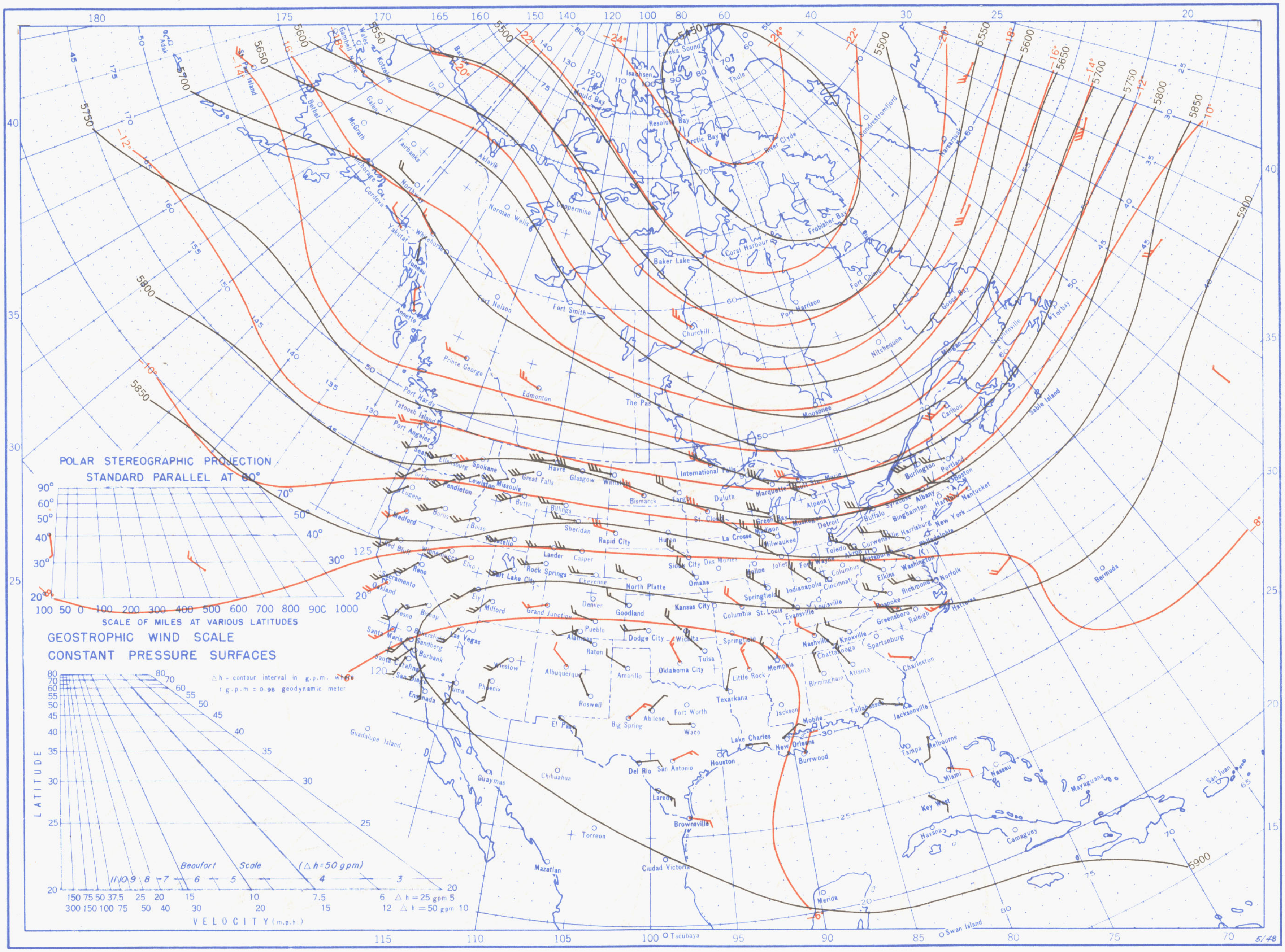
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m.. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), July 1951.



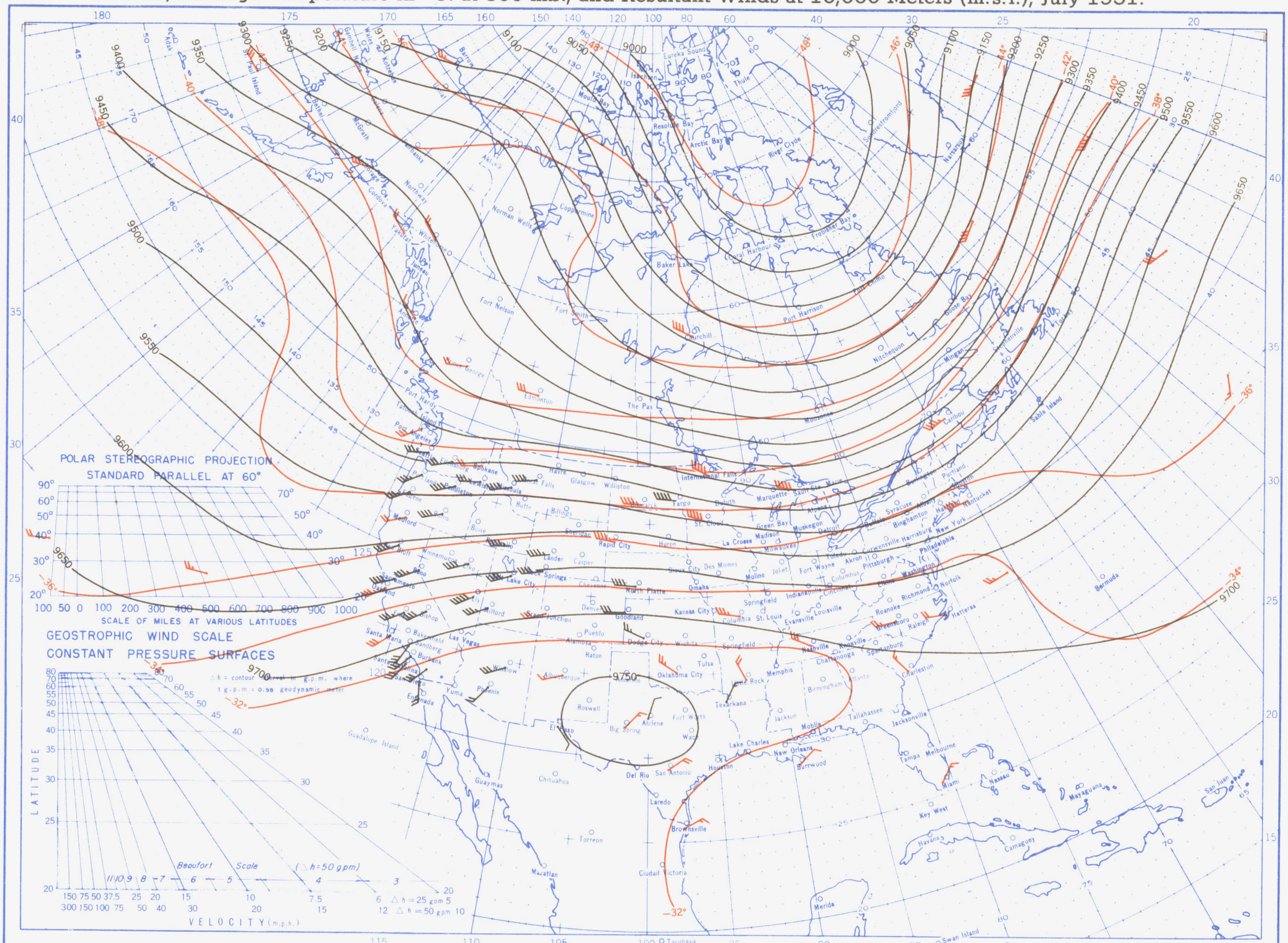
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), July 1951.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), July 1951.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.