THE WEATHER AND CIRCULATION OF MARCH 1951

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The most striking feature of the 700-mb. circulation during March 1951 (fig. 1) was the extensive area of positive height anomaly extending from middle latitudes in the Atlantic Ocean and eastern North America northwestward into the Canadian and Siberian Arctic and thence southward through the Bering Sea into the Pacific Ocean. The centers of +560 feet near the North Pole and +450 feet in the Davis Strait were the largest height anomalies in the entire Northern Hemisphere. At lower latitudes in the Atlantic there was a deep trough almost directly south of the abnormally strong ridge in Greenland and the northern Atlantic. This pattern of a ridge latitudinally superimposed over a trough, or positive height anomaly north of negative height anomaly, is characteristic of pronounced blocking action, where warm anticyclonic conditions prevail in subpolar regions and cold cyclonic conditions exist at lower latitudes. This blocking pattern was almost duplicated, with somewhat less intensity, over the east-central Pacific where the Aleutian-Bering Sea ridge with an anomaly of +330 feet was directly north of the deep trough (anomaly of −160 feet) west of the Hawaiian Islands. Most of these fea-

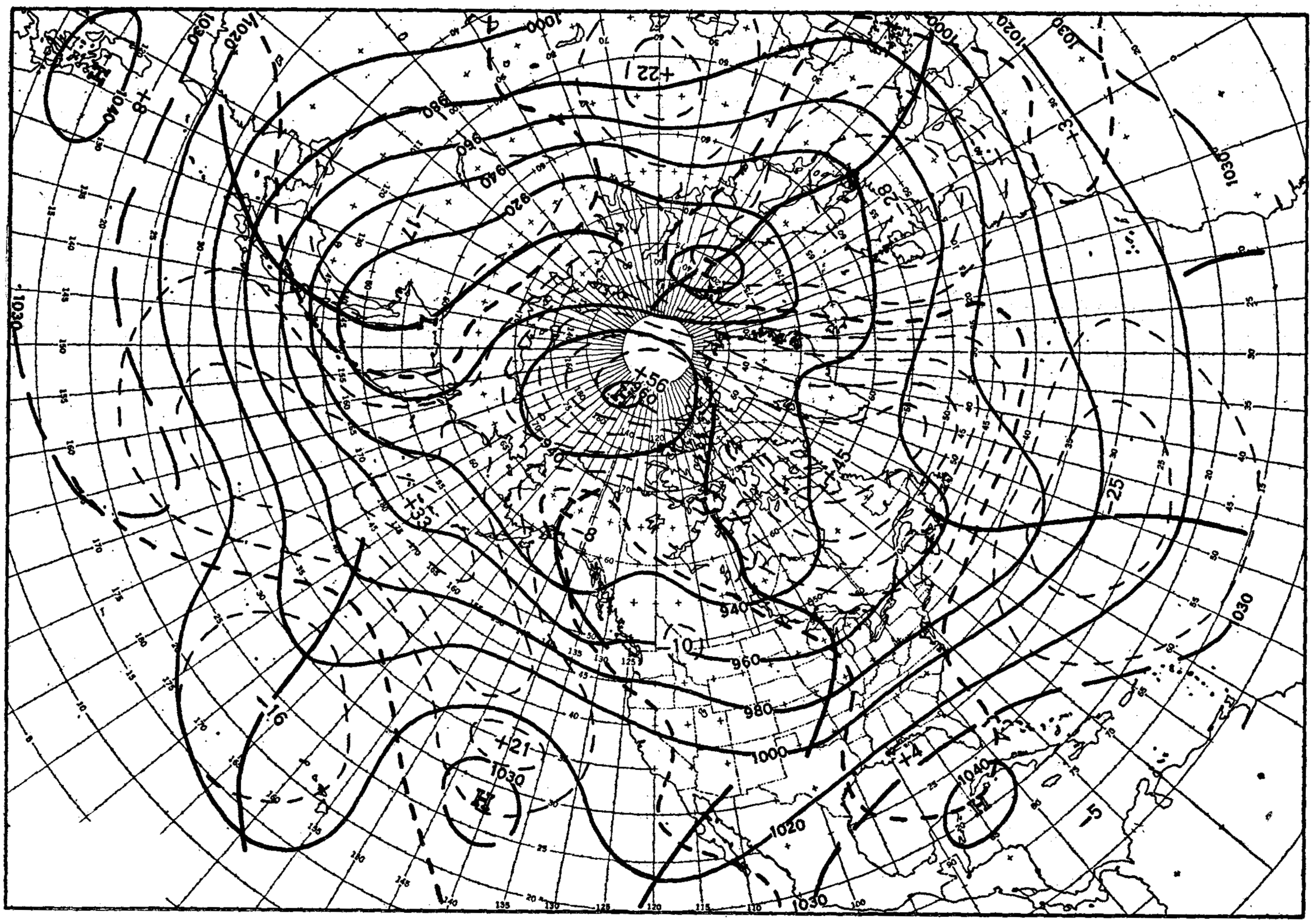


FIGURE 1.—Mean 700-mb. chart for the 30-day period February 27–March 28, 1951. Contours at 200-ft. intervals are shown by solid lines, intermediate contours by lines with long dashes, and 700-mb. height departures from normal at 100-ft. intervals by lines with short dashes with the zero isopleth heavier. Anomaly centers and contours are labeled in tens of feet. Minimum latitude trough locations are shown by heavy solid lines.

tures were also in evidence at sea level and higher levels (Charts XI–XV).[1] The pressure anomaly at sea level (Chart XI inset) was as striking as the 700-mb. anomaly with above normal pressures covering a vast area north of latitude 45°.

These patterns were associated with very weak westerlies in temperate latitudes in the Atlantic and Pacific. This is graphically illustrated in figure 2 where the average Western Hemisphere 700-mb. zonal wind speed profile for the month and the normal for March are shown. It is noteworthy that wind speeds in March 1951 were weaker than normal at all latitudes north of 25° N. except for the zone between 55° and 60° which was slightly above normal. In fact at about latitude 42°, where the westerlies normally have their peak speed in March, this month's speed was 4 m/sec below normal. Also, the maximum speed of the westerlies was located about 5° of latitude farther south than normal.

This sluggish nature of the westerlies during March 1951 was associated with a pronounced index cycle which lasted about five weeks from late February until late March. The index cycle, whose phases have been described by Rossby and Willett [1], is a period in which the temperate-latitude westerlies decline from comparatively high values to low values and then recover again. There are often relatively short-term fluctuations of this type, but Namias [2] has applied the term to cycles lasting several weeks. Namias pointed out the tendency for an index cycle to occur during late February and March in the period which he studied. The year 1951 was no exception to this rule as can be seen from the graph of the 5-day mean temperate-latitude 700-mb. zonal index shown in figure 3. Note how the westerly speed dropped from a peak of 12.7 m/sec (more than 2 m/sec above normal) on February 16 to a low of 4.6 m/sec (about 5 m/sec below normal) on March 12. Recovery soon followed as the index again climbed above the normal to reach a value of 11.1 m/sec on March 23.

A more complete picture of the nature of this index cycle is given by the 700-mb. wind speed time section in figure 4. This chart depicts the variation of the 5-day mean zonal wind speed in the Western Hemisphere with both latitude and time during February and March 1951. It is clear that the initial slowdown in the westerlies at middle latitudes occurred as the major westerly belt, which had been near latitude 45° early in February, gradually shifted northward after the first week of February reaching polar regions by the first week of March. Thus, by February 23 a minimum speed of only 4.5 m/sec was found at latitude 40°. A weak band of maximum westerlies was in evidence at lower latitudes as the main westerly stream progressed north of latitude 55° late in February. However, they remained weak until the disappearance of the fast westerlies at higher latitudes. Then as easterly winds dominated the subpolar regions,

[1] See Charts I–XV following p. 60 for analyzed Climatological Data for the month.

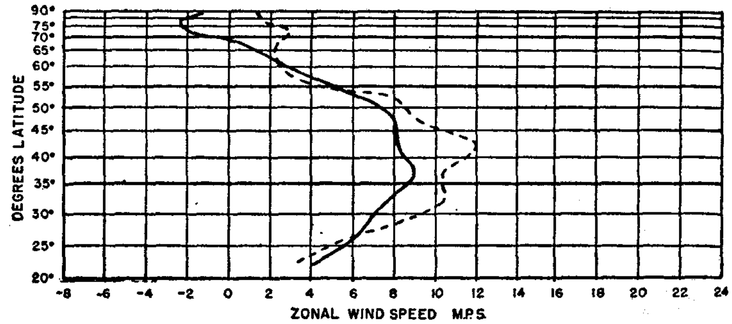


FIGURE 2.—Monthly mean 700-mb. geostrophic zonal wind speed profile in m/sec averaged from 0° westward to 180° longitude. Solid curve is for March 1951, dashed line is March normal.

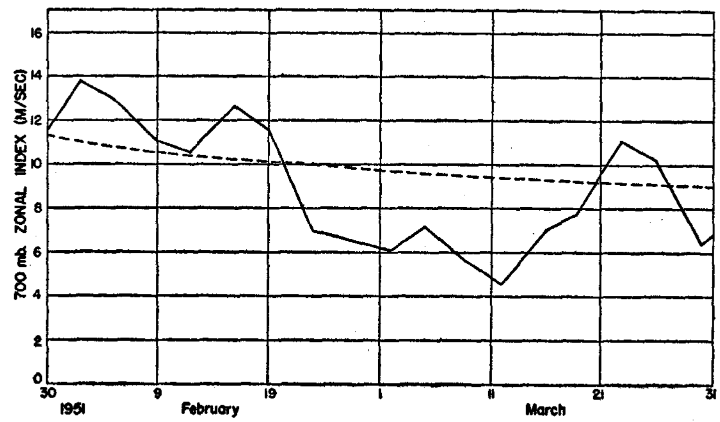


FIGURE 3.—Variation of temperate-latitude zonal index (average strength of zonal westerlies in m/sec between 35° N and 55° N.) at 700 mb. over the Northern Hemisphere from 0° westward to 180° longitude. Solid line connects 5-day mean zonal index values (plotted at middle of 5-day period) for February and March 1951. Dashed line shows variation of normal zonal index values for February and March.

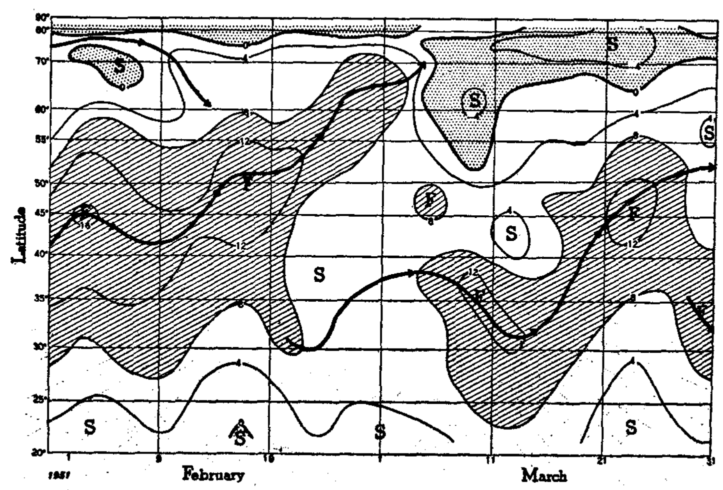


FIGURE 4.—Time-latitude section of 5-day mean zonal wind speed (averaged from 0° westward to 180° longitude) in m/sec at 700 mb. for February and March 1951. Isopleths are drawn at intervals of 4 m/sec. Areas with speeds greater than 8 m/sec are shaded with hatching; areas with negative speeds (easterlies) are shaded with dots. Maximum speed centers are labeled F, minima are labeled S. Heavy arrowed line marks latitudinal position of axis of maximum wind speed with time.

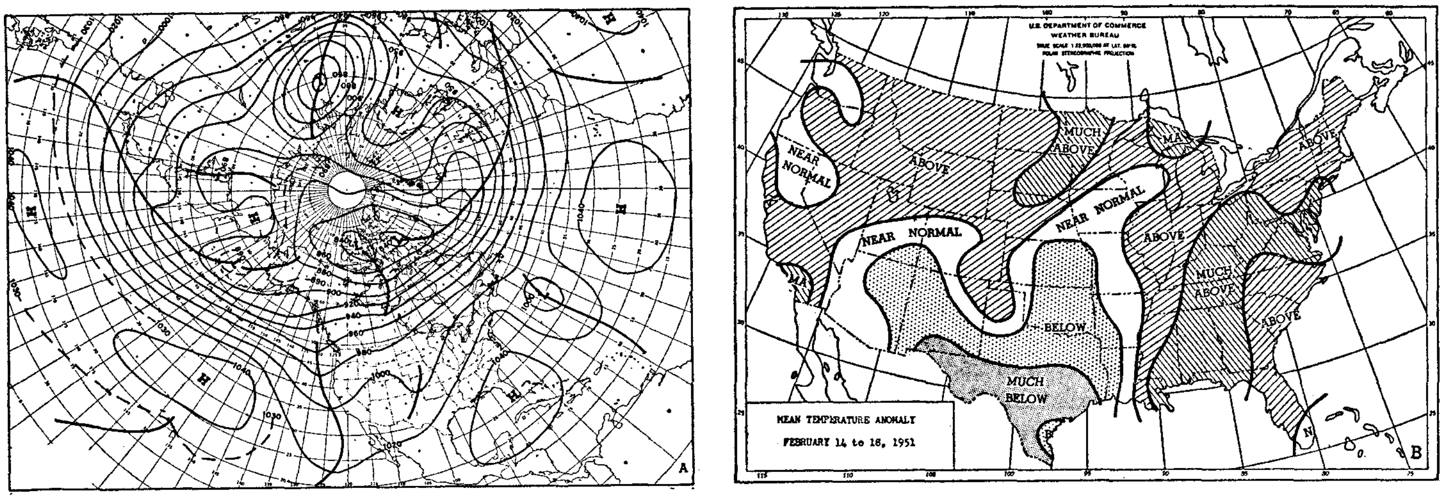


FIGURE 5.—(A) 5-day mean 700-mb. chart for period February 14–18, 1951. Contours at 200-ft. intervals are shown by solid lines, selected intermediate contours by dashed lines, and minimum latitude trough lines by heavy solid lines. (B) 5-day mean surface temperature anomaly over United States for period February 14–18, 1951 analyzed in terms of above and much above normal, near normal, and below and much below normal. The classes above, below, and near normal are so defined that they each normally occur one-fourth of the time at each station; and the classes much below and much above, one-eighth of the time.

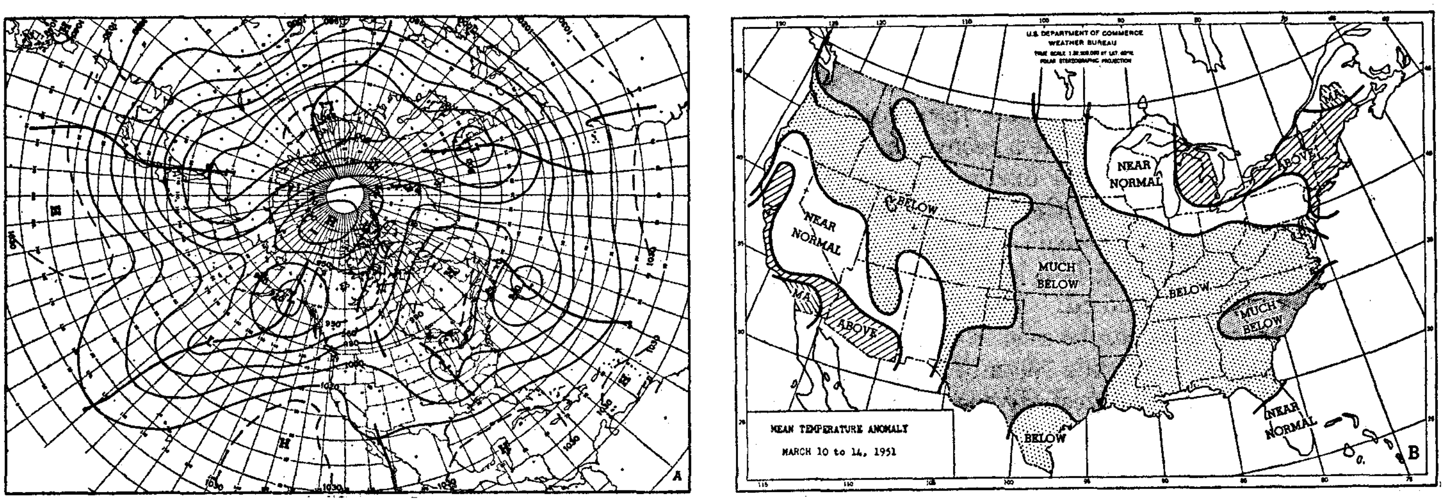


FIGURE 6.—(A) 5-day mean 700-mb. chart, March 10–14, 1951. (B) 5-day mean surface temperature anomaly over United States, March 10–14, 1951.

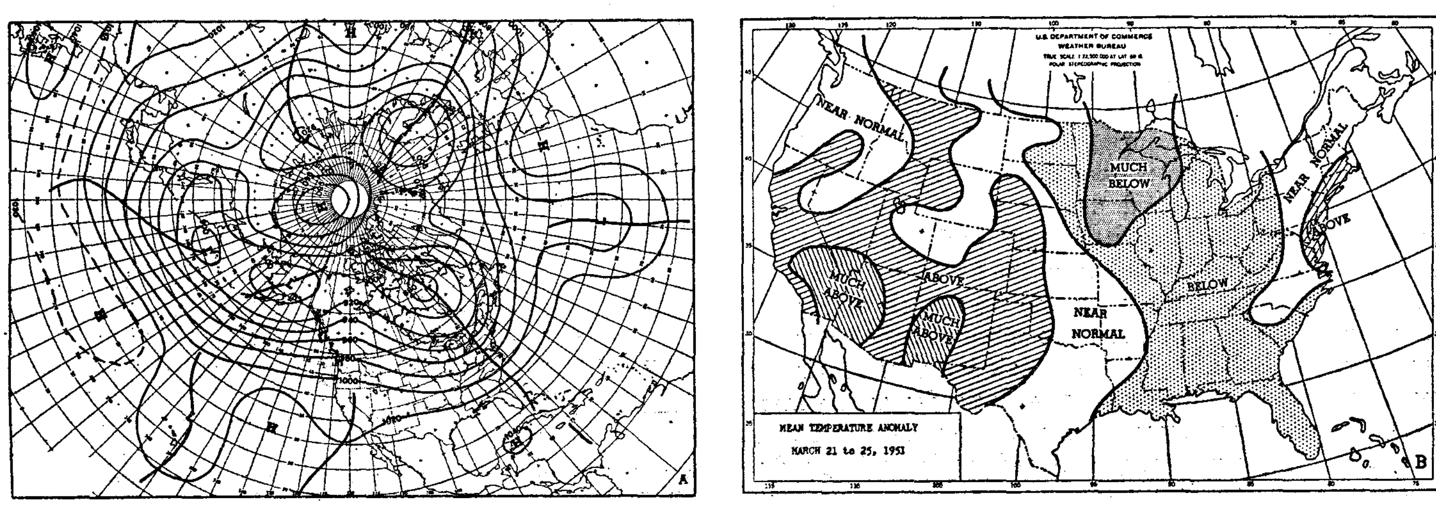


FIGURE 7.—(A) 5-day mean 700-mb. chart, March 21–25, 1951. (B) 5-day mean surface temperature anomaly over United States, March 21–25, 1951.

the lower latitude westerlies strengthened, reaching a peak of about 13 m/sec by March 10. These westerlies moved southward as far as latitude 32° by March 13, while the speed between latitudes 40° and 45° dropped to 3 m/sec. The westerlies then progressed northward again reaching a peak at latitude 45° by March 23. At the end of the month it appeared as though the westerlies were splitting once again and that another index cycle was beginning in April.

To illustrate the synoptic patterns associated with the various phases of this index cycle, three 5-day mean 700-mb. charts have been selected, and are shown in figures 5A, 6A, and 7A. Also, the corresponding 5-day mean surface temperature anomalies for the United States are presented in figures 5B, 6B, and 7B to demonstrate the temperature patterns associated with the phases of this cycle. Figure 5A shows the 700-mb. 5-day mean map centered at February 16, the high index point at the beginning of the cycle (figs. 3 and 4). Note the fast flat westerlies from the Pacific across Canada and out over the Atlantic with well-developed subtropical high cells to the south. Several low latitude troughs including a cut-off Low east of Bermuda and an easterly wave extending southwestward from the Hawaiian Islands were also present. As a result of this circulation pattern temperatures over the United States were predominantly on the warm side with below-normal temperatures only in portions of the South and Southwest (fig. 5B).

The extreme low index phase of the cycle, which occurred in the period centered at March 12 (figs. 3 and 4), is illustrated in figure 6A. Huge warm Highs dominated eastern Canada and the Canadian Arctic, while cold Lows were located along latitude 40° N. in the east-central Pacific, Illinois, and the western Atlantic. Deep cyclonic vortices were also located over the Gulf of Alaska and the British Isles. It is interesting to note that the lower latitude vortices and their associated troughs were located in approximately the same positions as the monthly mean troughs on the February 700-mb. chart [3] and the March chart (fig. 1). This indicates that low latitude cyclonic activity during an index cycle may be favored where pre-existing large-scale troughs (of the type found on a monthly mean chart) are located. It would seem quite natural that when fast westerlies deteriorate the cold polar air previously contained at high latitudes should drop southward into already established lower latitude troughs. Returning to figure 6A, it is seen that as a consequence of the low latitude cyclonic vortices there were pronounced westerlies in the subtropics, and the subtropical high cells in the Caribbean and the Atlantic were weak and displaced to the south. Turning now to figure 6B the effect of this low index circulation on temperature is immediately apparent. Temperatures were below, and much below, normal over almost the entire United States except in the Northeast, where warm oceanic easterly drift prevailed, and in the extreme Southwest.

It is interesting to note that the westerlies over the Eastern Hemisphere were strong and well-organized in a relatively simple wave pattern during both the low phase of the index cycle (fig. 6A) and the month as a whole (fig. 1). Thus, it would appear that the index cycle occurred over only the Western Hemisphere during February–March, 1951.

Figure 7A shows the 5-day mean 700-mb. circulation at the recovery point of the cycle (figs. 3 and 4), the period centered at March 23. The westerlies were once again organized in simple fashion at middle latitudes. The major vortex over North America had shifted northward to its more normal position near Hudson Bay. However, cut-off low latitude troughs still persisted near Hawaii and in the Atlantic (although now somewhat farther east). In fact the eastern Atlantic picture showed blocking characteristics which contributed to a lowering index again at the end of March. The temperature anomaly in figure 7B reflects the recovery from the extreme cold of the low index state (fig. 6B). Cold air was confined to the eastern half of the country under the northwesterly flow to the rear of the full-latitude trough in the eastern United States.

The effects of blocking action and the low index state are seen in the erratic nature of the cyclone tracks in Chart X. Note the frequent stalling of storms, rapid accelerations and decelerations, peculiar changes in direction, and frequent occurrence of motion toward the north and northwest. A notable example of this was the storm which started along the Gulf Coast on the 12th, traveled north-northeastward to Lake Ontario by the 15th, stalled for a day as it was blocked, and then accelerated rapidly toward the southeast into the region of the deep Atlantic trough (fig. 1). Blocking action was also responsible for the complete lack of storms moving eastward over the Atlantic out of Canada. The only storms which did go onto the Atlantic from North America crossed the east coast of the United States near the northern boundary of the lower latitude westerly belt.

The rather frequent cyclonic activity through central and eastern sections of the United States resulted in excessive precipitation in much of the East and Midwest (Chart III, A and B). The cyclogenetic area in the Central Plains east of the Continental Divide was associated with the stronger-than-normal thermal gradient (Chart I inset) in that region and the cyclonic vorticity in the trough extending northeastward from Oklahoma (fig. 1). Minnesota, Iowa, and Wisconsin were most affected by these storms. Much of the precipitation there fell in the form of snow with amounts totaling between 30 and 50 inches (Chart IV). These amounts were more than 400 percent of normal (Chart V–A) and even on March 27 (Chart V–B) there were still between 12 and

35 inches left on the ground. By the end of the month serious flooding in Iowa streams had begun as mild weather began melting the huge snow cover and copious rains added to the already excessive water supply on the ground.

The heavy precipitation in southern Texas (Chart III–B) was associated with the low latitude trough near Lower California and stronger-than-normal southerly flow off the Gulf of Mexico at sea level (Chart XI and inset). Much of the very heavy rainfall in Louisiana, Mississippi, and Alabama occurred with squall-line thundershowers in the closing days of the month as the major trough developed strongly in the eastern part of the country. (See article by Miller in this issue.)

Subnormal precipitation in the Southwest occurred under northwesterly flow aloft (fig. 1). The western Plains were also dry as somewhat stronger-than-normal northwesterly flow crossed the Divide. The dry area in Oklahoma and Arkansas is difficult to explain from the upper-level pattern. This area was located to the southeast of most of the cyclones (Chart X) and to the northwest of the squall line activity late in the month.

The average temperatures for March were below normal (Chart I and inset) throughout an extensive area of the United States from the Pacific Northwest to the Ohio Valley. The blocking ridge in the Atlantic and the accompanying westward displacement of the trough in Canada to the west of Hudson Bay (fig. 1) forced the cold polar outbreaks to drop into the United States quite far to the west. Chart IX shows that no anticyclones crossed from Canada into the United States east of North Dakota. The coldest area was the Northern Plains where temperatures averaged as much as 12° F. below the March normals (Chart I inset). Strong easterly continental drift of polar air at the surface (Chart XI and inset) contributed to this very cold weather in the Northern Plains and also to the cold conditions in the Pacific Northwest. It is not surprising then that cyclonic activity in the Northwest in the first 10 days (Chart X) resulted in snowfall which was very excessive for the area (Charts IV and V–A). This cyclonic activity was quite clearly associated with the trough in the northeast Pacific, the below normal heights in the area, and the stronger-than-normal northwesterly flow onto the Washington-Oregon coast (fig. 1).

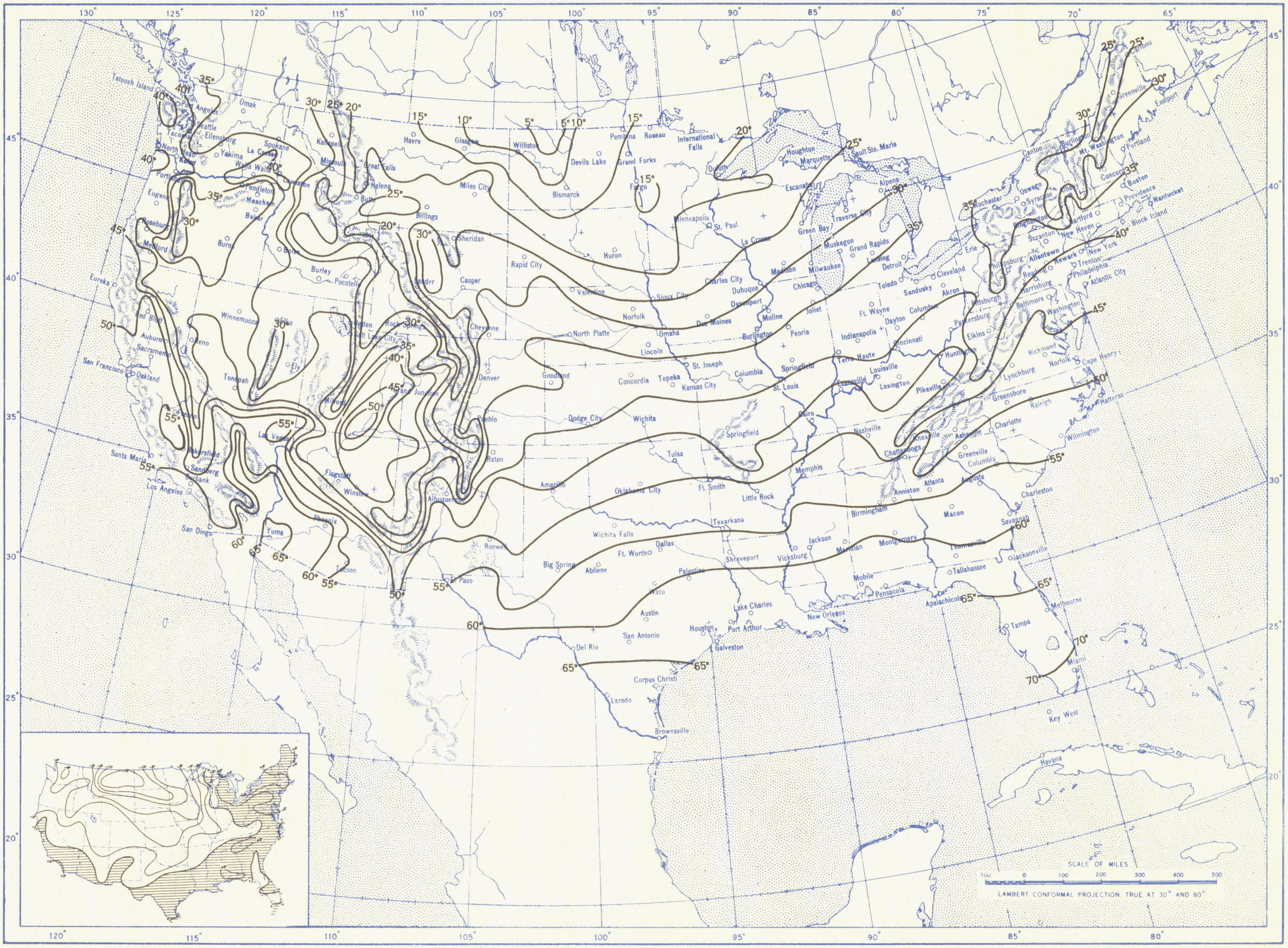
The only area where temperatures were outstandingly above normal was in the Northeast where the strong easterly drift relative to normal associated with blocking caused a predominance of warm maritime flow into the region at both sea level (Chart XI inset) and aloft (fig. 1). The Southeast averaged just slightly on the above normal side even though the cold air swept into that area at and following the bottom of the index cycle (figs. 6B and 7B). However, extreme warmth early in the month while the subtropical ridge was well-developed led to the averages being slightly above the normal. This ridge (with heights just slightly above normal) was a feature of the monthly mean circulation (fig. 1).

The Hawaiian Islands received some of their heaviest rainfall on record in March 1951. Many stations on the Islands reported totals ranging from 200 to 700 percent of normal for the month. This was a result of the marked cyclonic activity associated with the deep low latitude trough to the west of Hawaii (fig. 1). As was mentioned earlier this trough was one of the major centers of action during the index cycle.

REFERENCES

1. C.-G. Rossby, and H. C. Willett, "The Circulation of the Upper Troposphere and Lower Stratosphere," *Science*, vol. 108, No. 2815, December 10, 1948, pp. 643–652.
2. J. Namias, "The Index Cycle and its Role in the General Circulation," *Journal of Meteorology*, vol. 7, No. 2, April 1950, pp. 130–139.
3. W. H. Klein, "The Weather and Circulation of February 1951," *Monthly Weather Review*, vol. 79, No. 2, February 1951, pp. 35–38.

Chart I. Average Temperature (°F.) at Surface, March 1951. Inset: Departure of Average Temperature from Normal (°F.), March 1951.

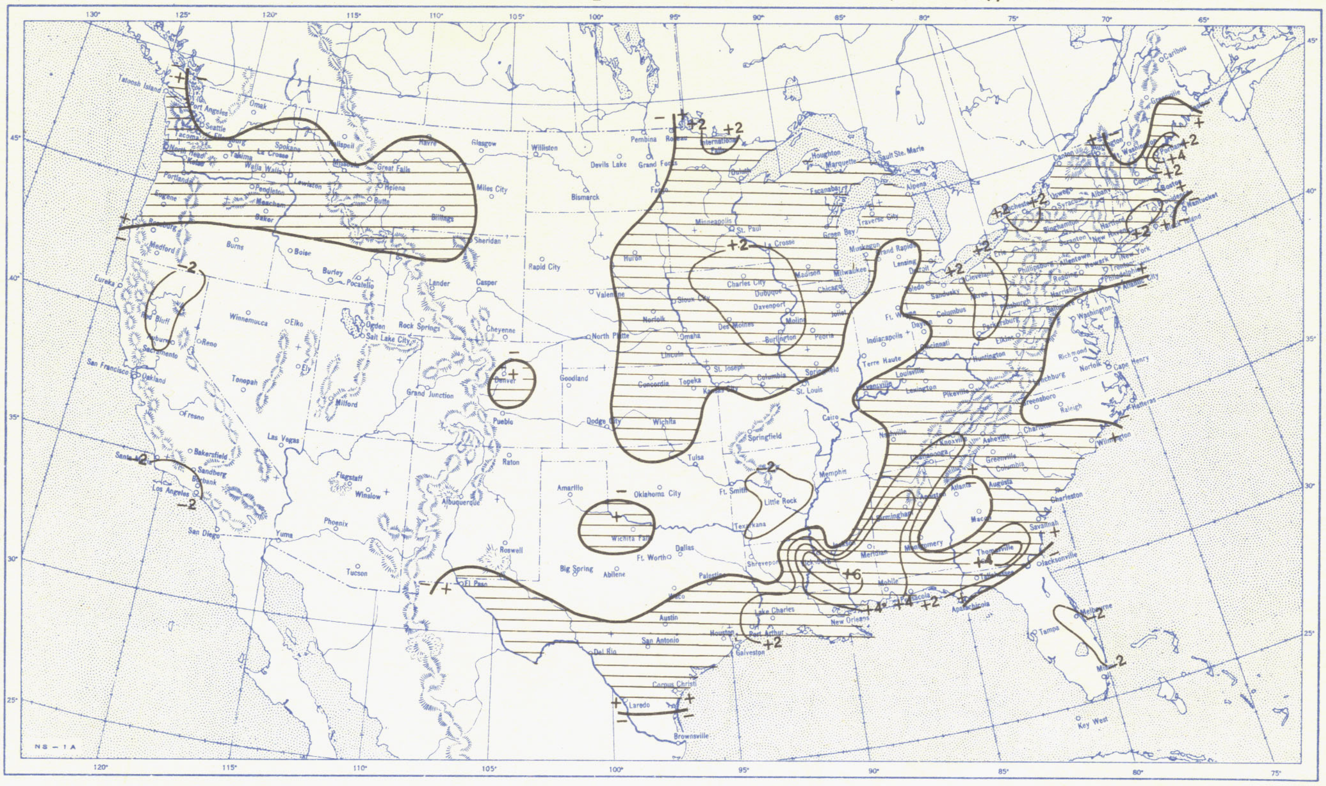


Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively. Normal average monthly temperatures are computed for Weather Bureau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

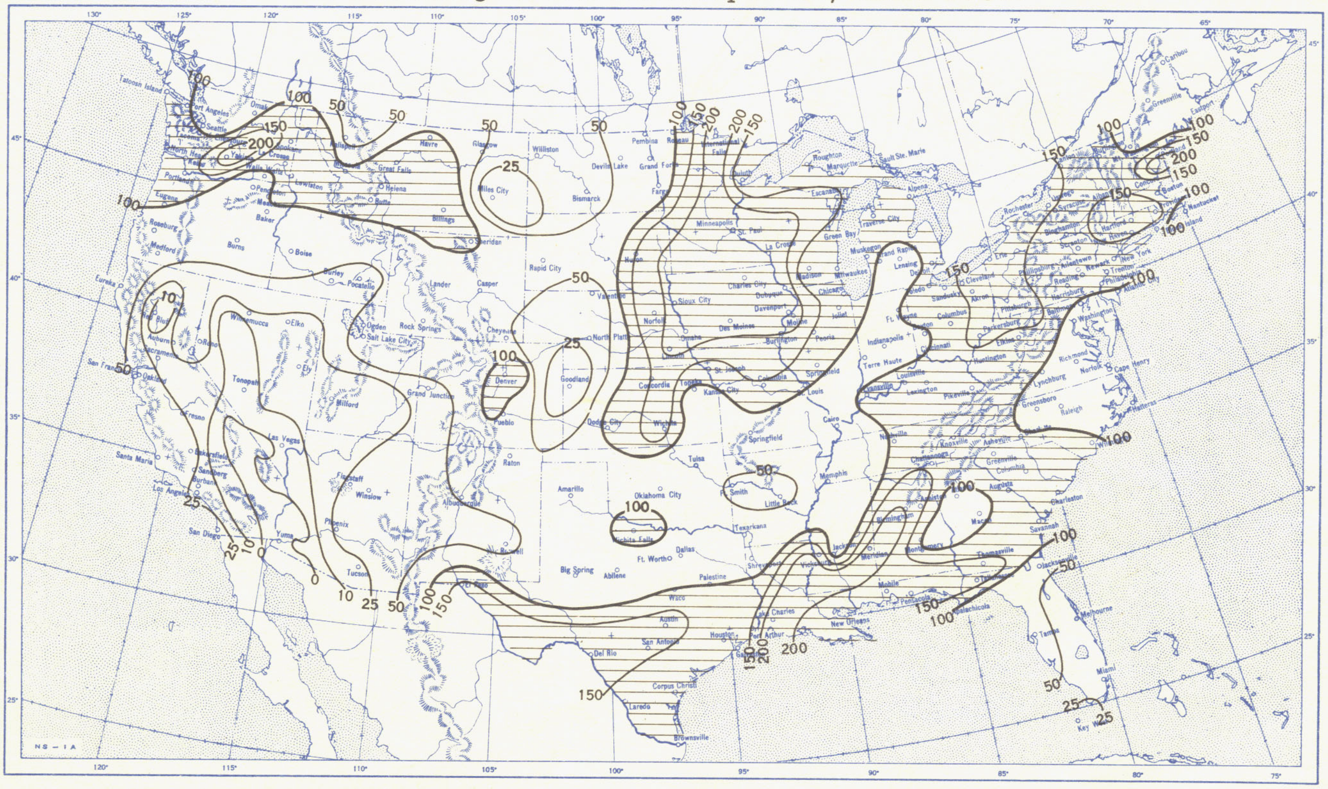
Chart II. Total Precipitation (Inches), March 1951.

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

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



B. Percentage of Normal Precipitation, March 1951.

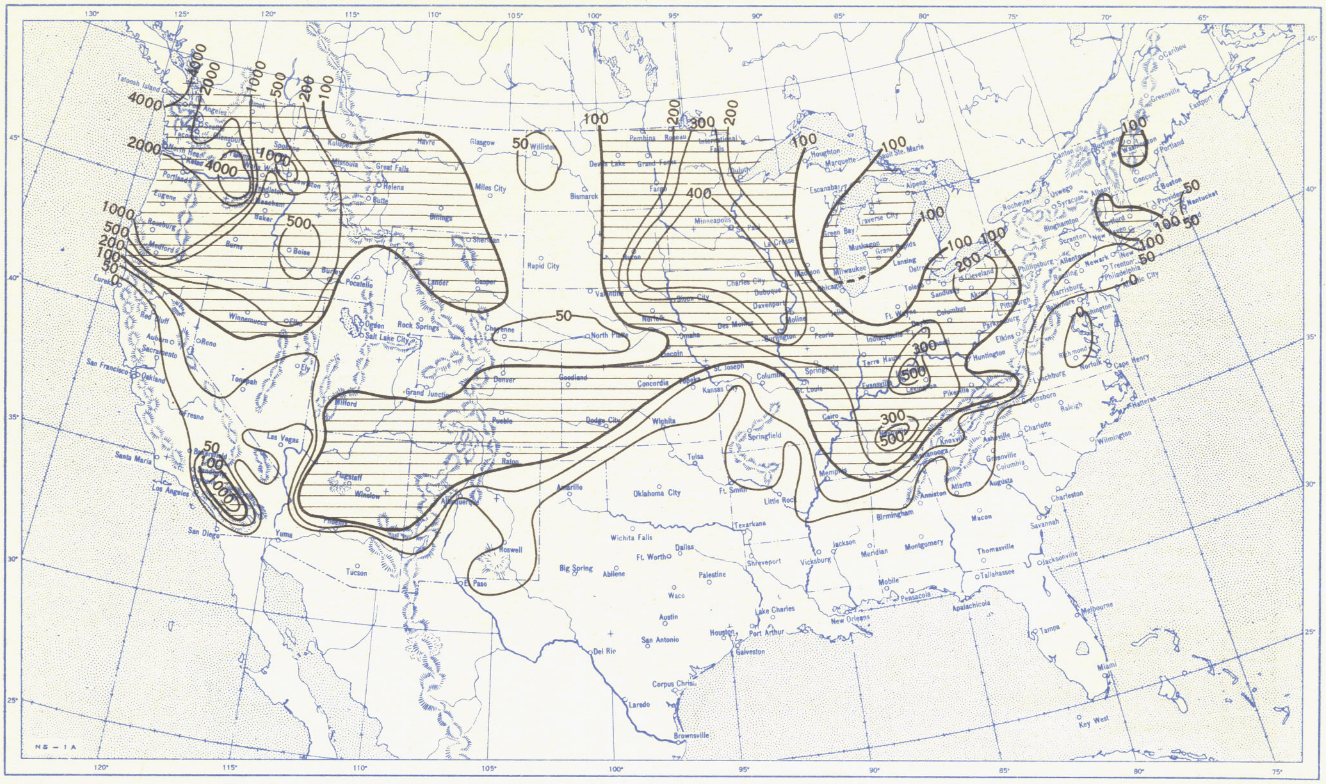


Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart IV. Total Snowfall (Inches), March 1951.

This is the total of unmelted snowfall recorded during the month at Weather Bureau and cooperative stations. This chart and Chart V are published only for the months of November through April although of course there is some snow at higher elevations, particularly in the far West, earlier and later in the year.

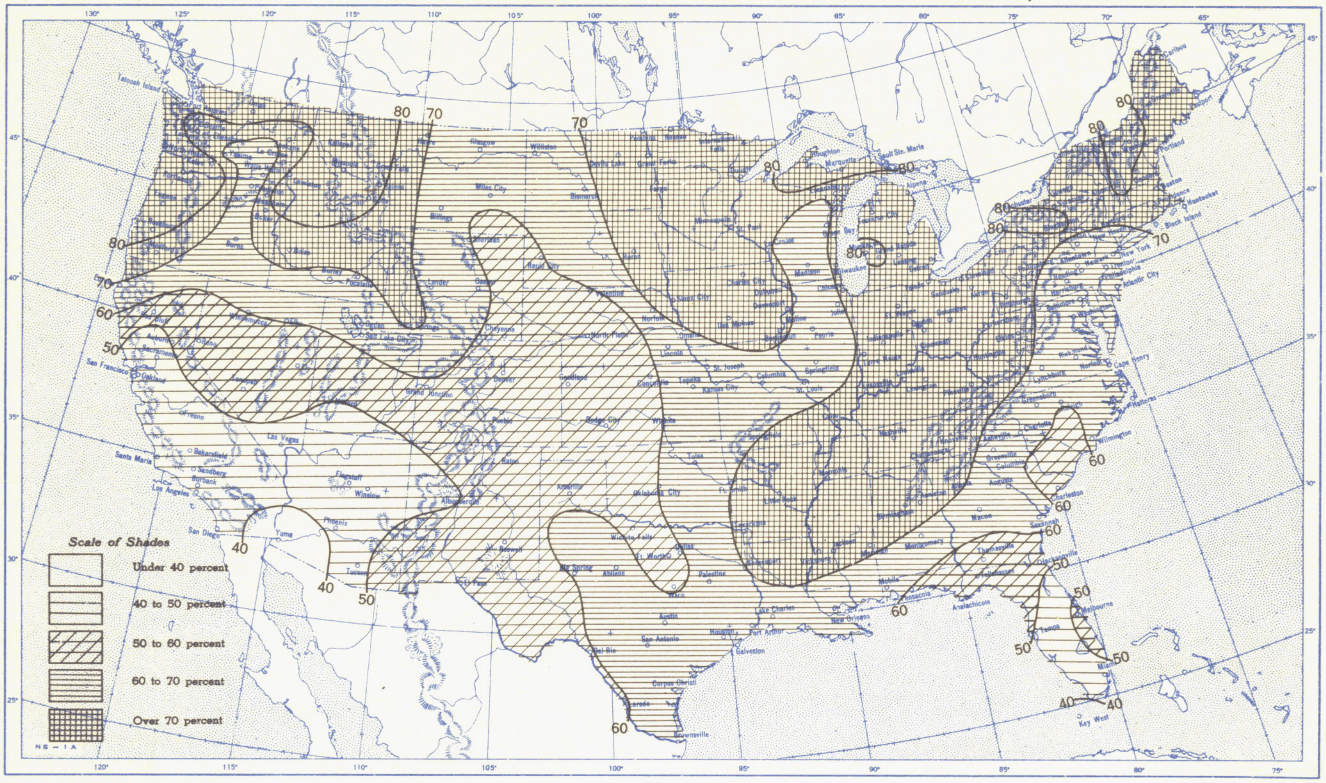
Chart V. A. Percentage of Normal Snowfall, March 1951.



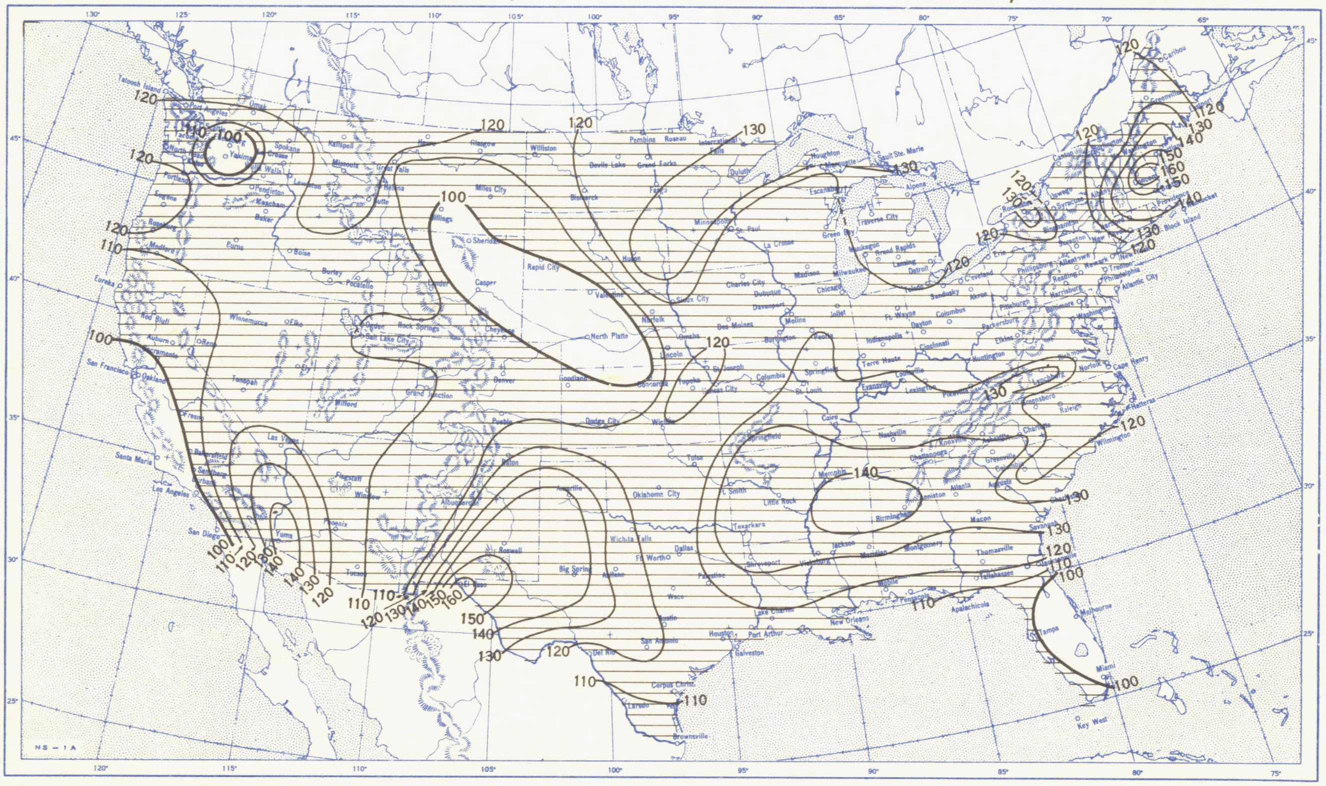
B. Depth of Snow on Ground (Inches), 7:30 a. m. E. S. T., March 27, 1951.

A. Amount of normal monthly snowfall is computed for Weather Bureau stations having at least 10 years of record.
B. Shows depth currently on ground at 7:30 a. m. E. S. T., of the Tuesday nearest the end of the month. It is based on reports from Weather Bureau and cooperative stations. Dashed line shows greatest southern extent of snowcover during month.

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

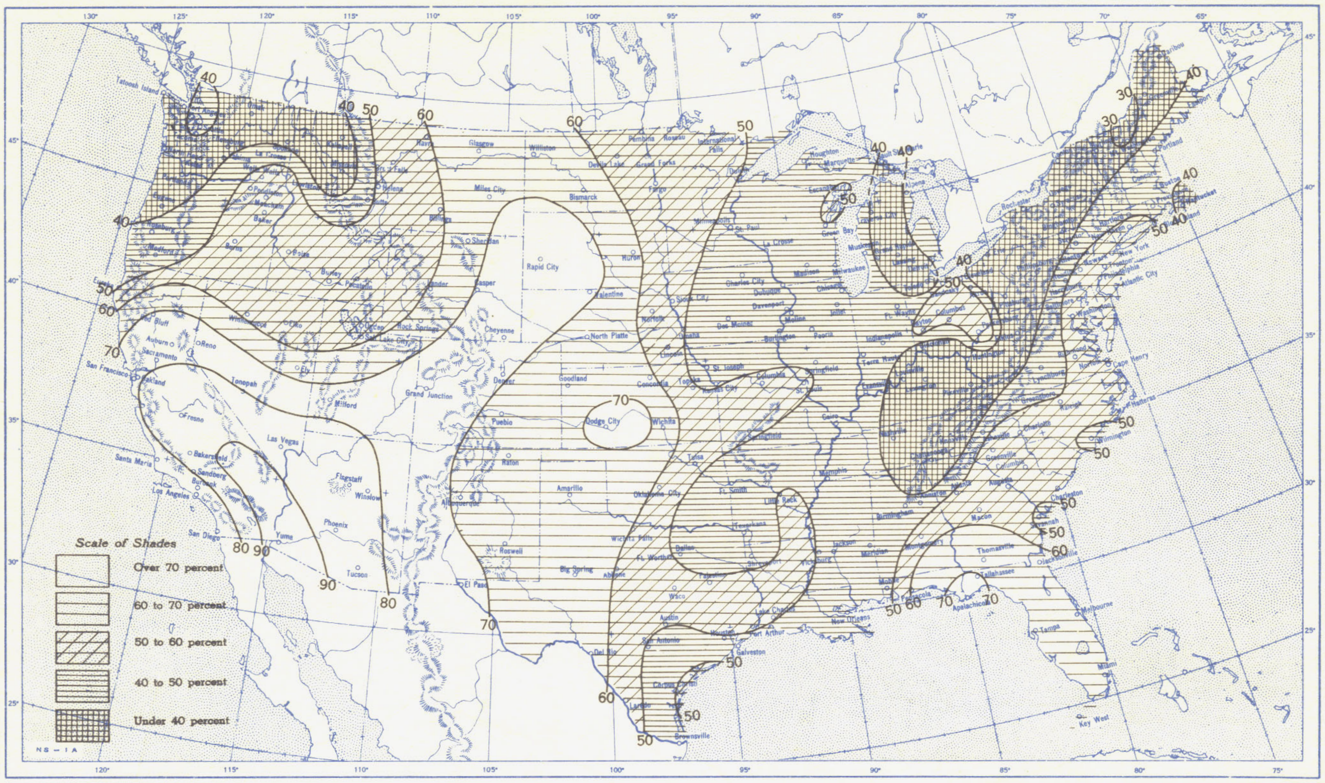


B. Percentage of Normal Sky Cover between Sunrise and Sunset, March 1951.

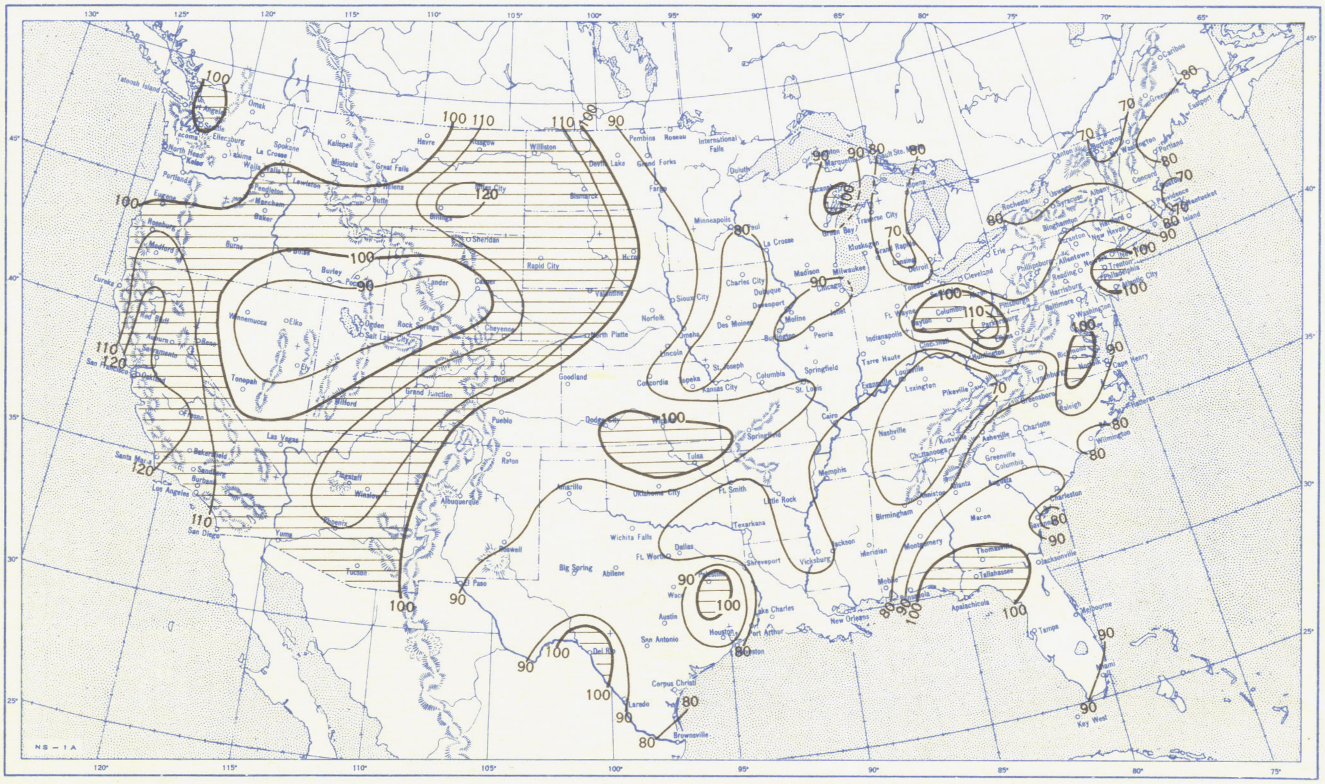


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

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



B. Percentage of Normal Sunshine, March 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, March 1951. Inset: Percentage of Normal Average Daily Solar Radiation, March 1951.

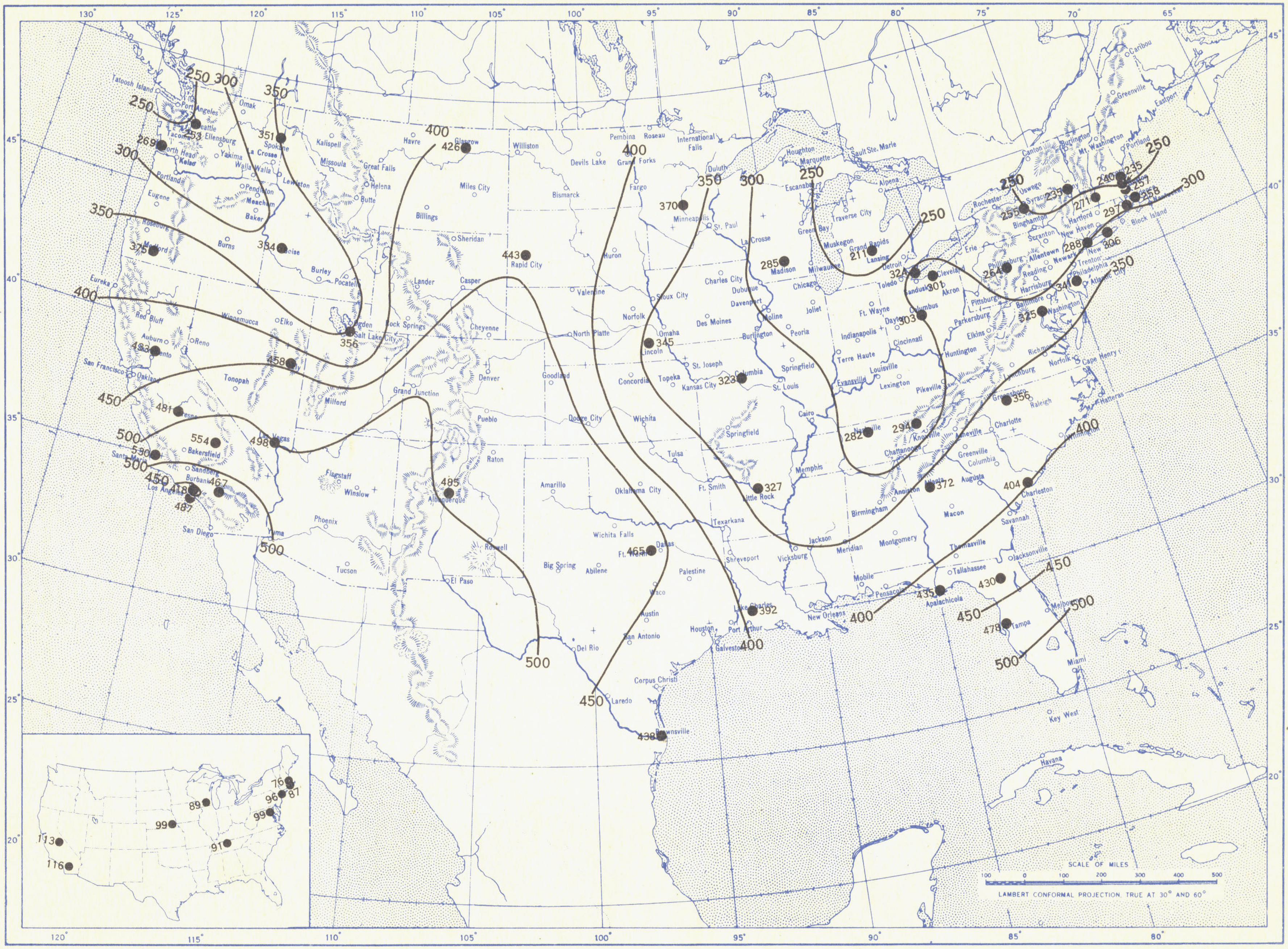
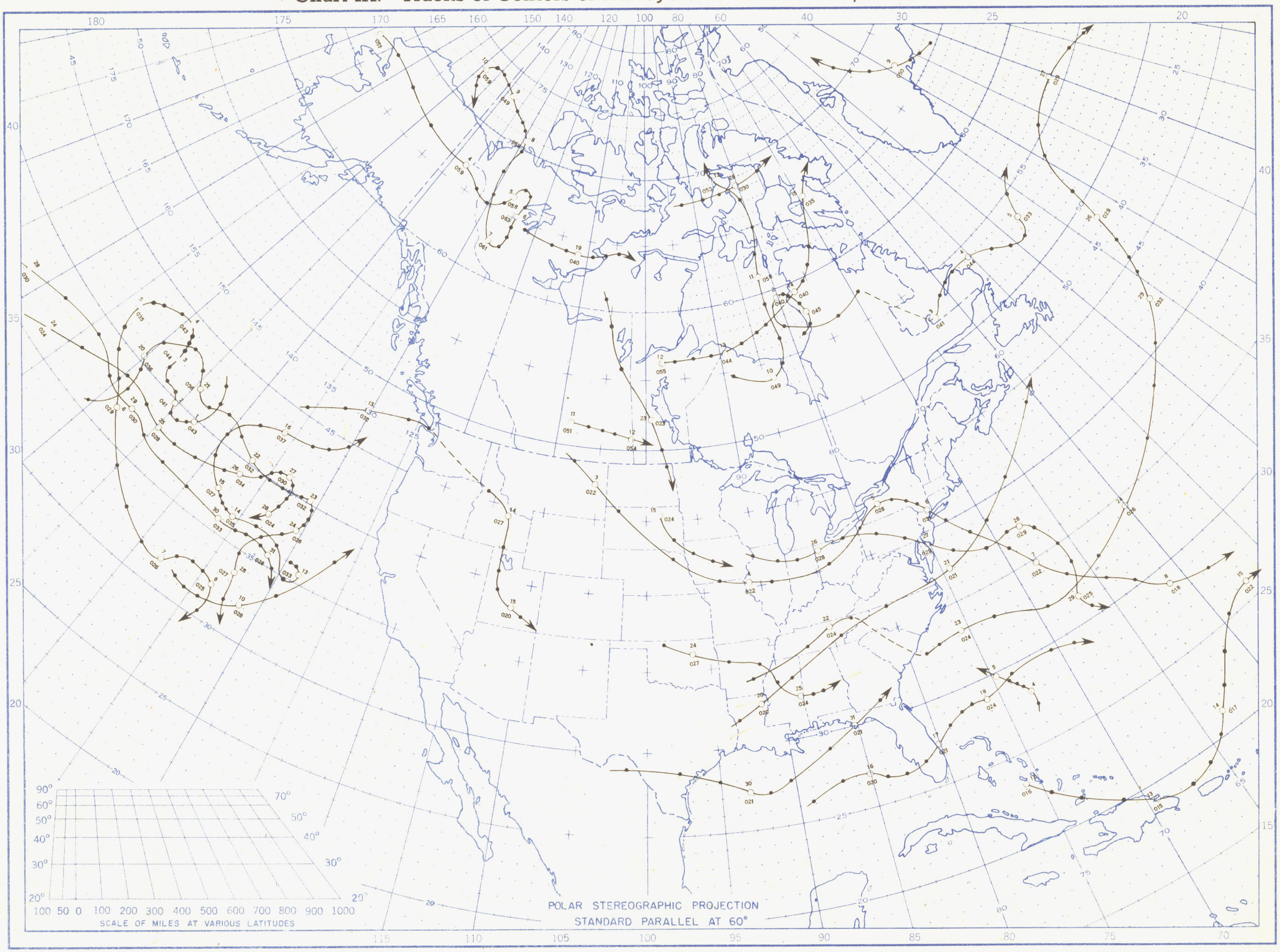


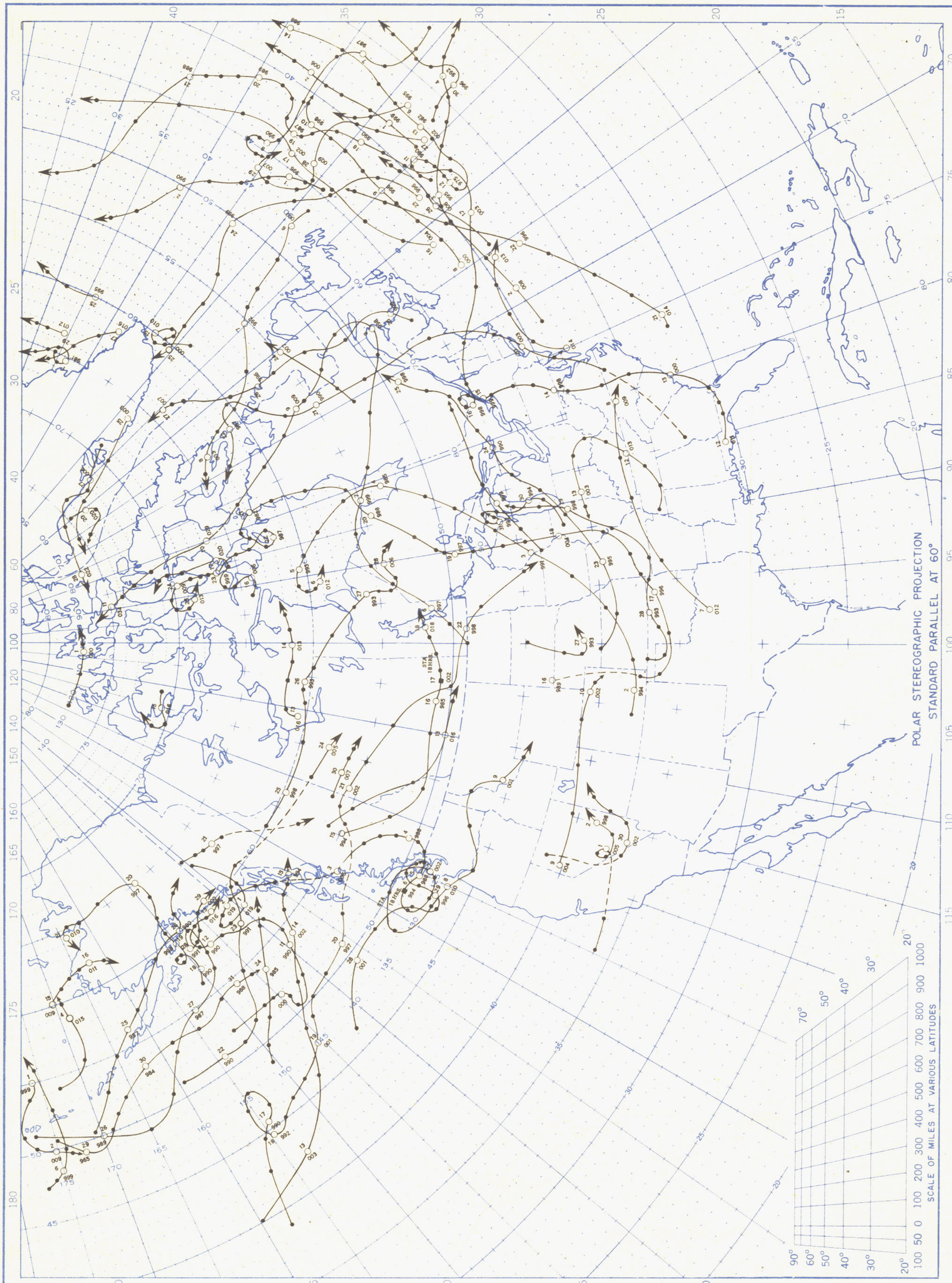
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates obtained from supplementary data for which limits of accuracy are wider than for those data shown.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

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



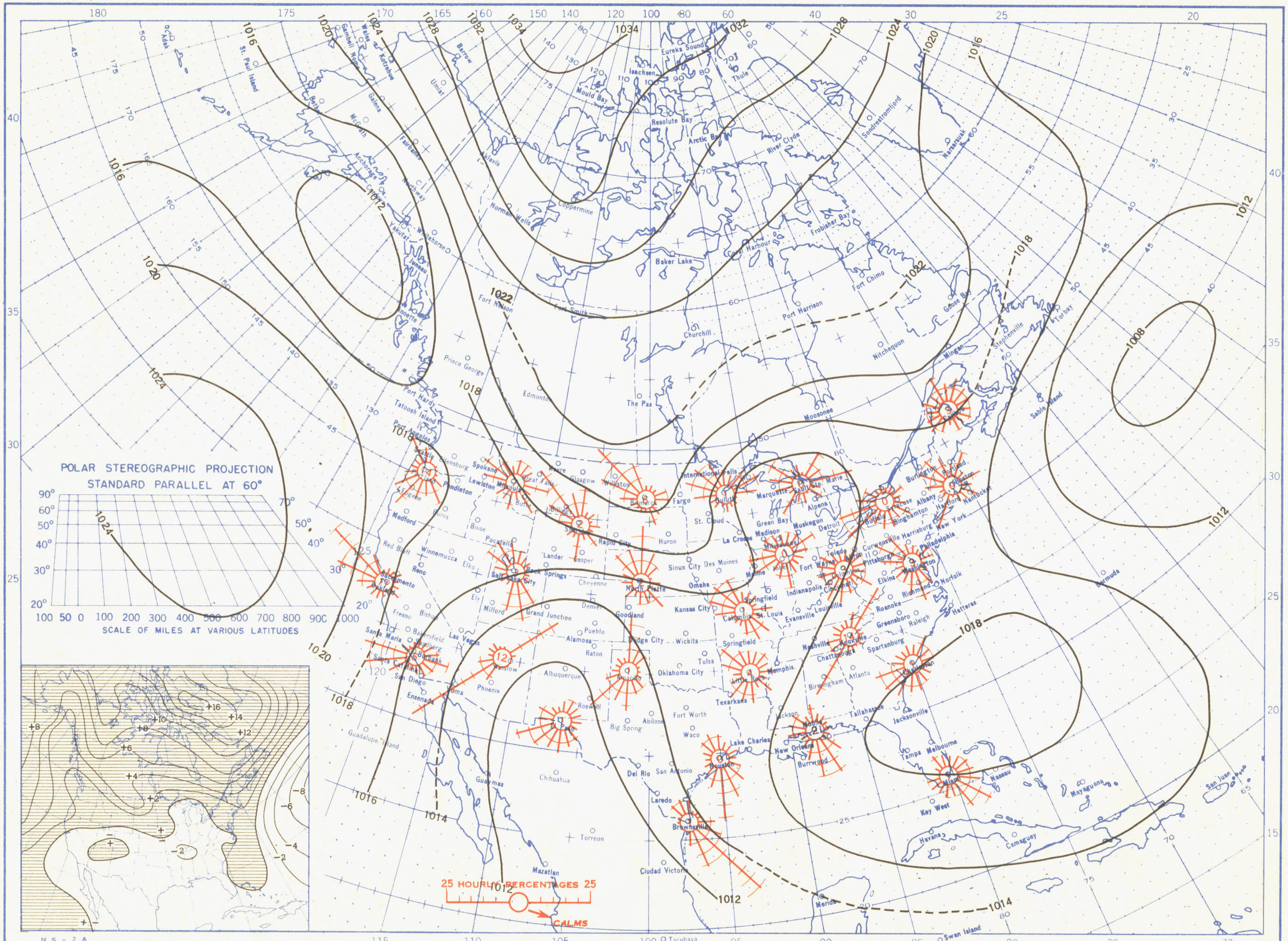
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position.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

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



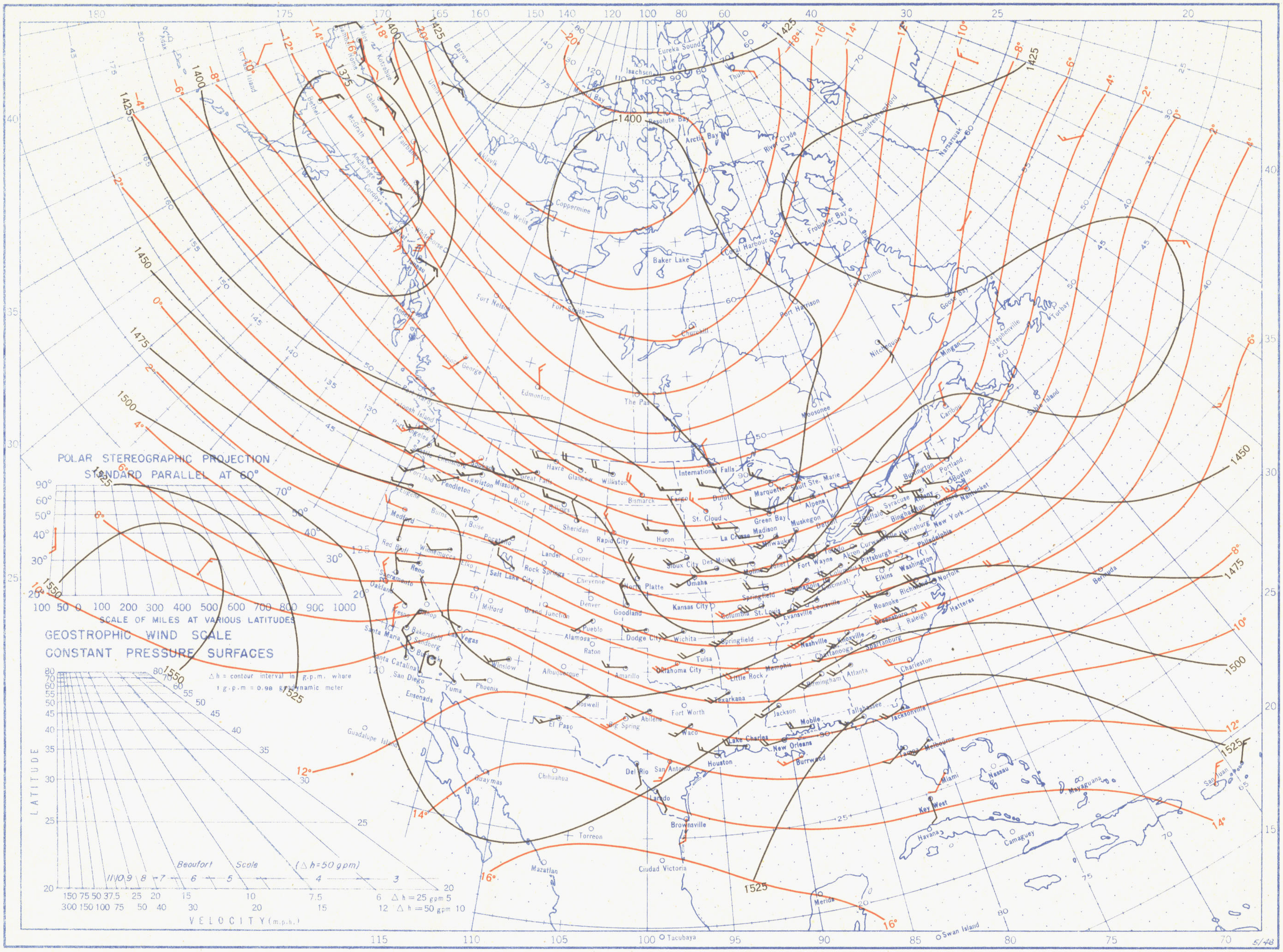
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

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



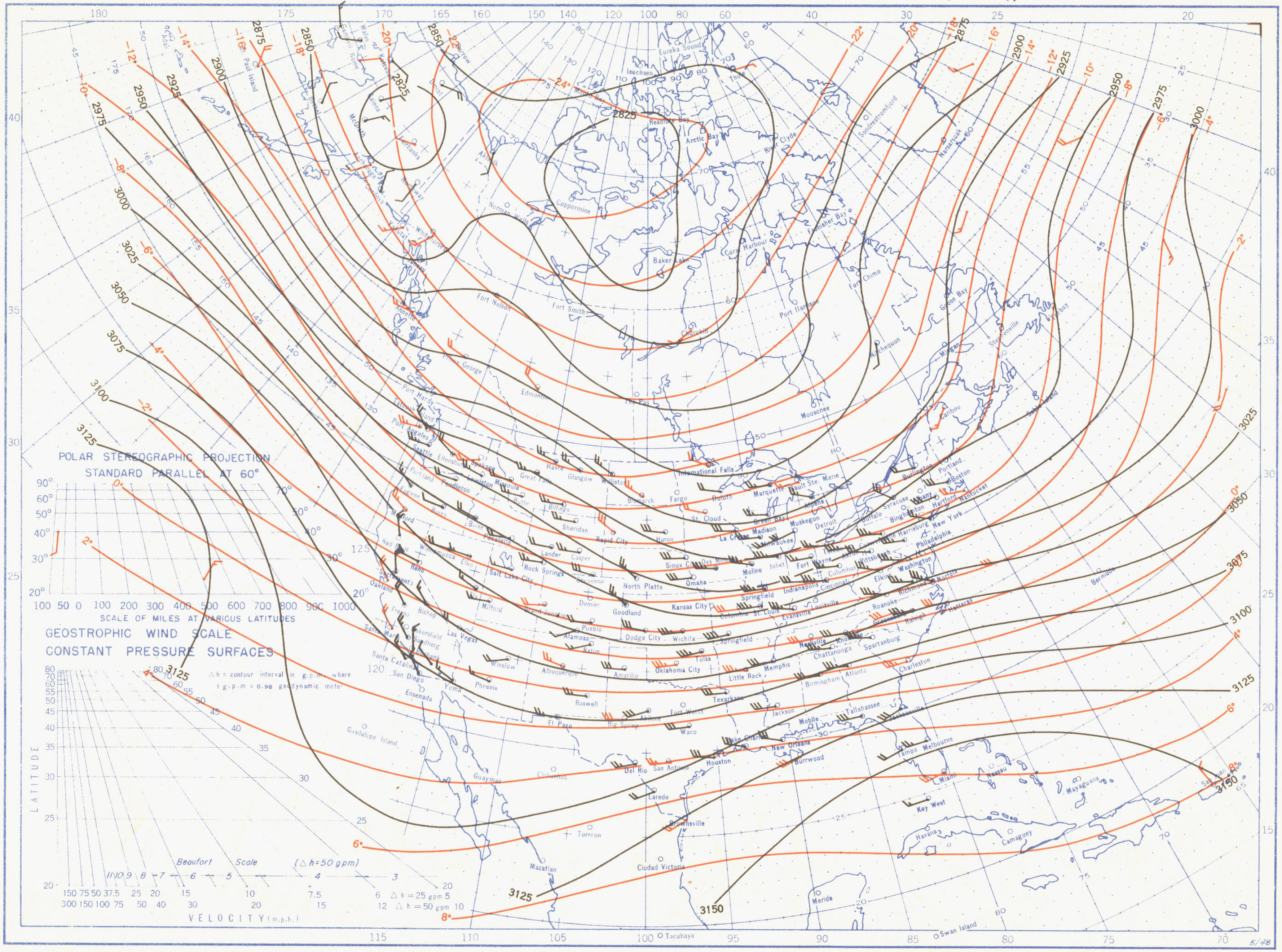
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections 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.), March 1951.



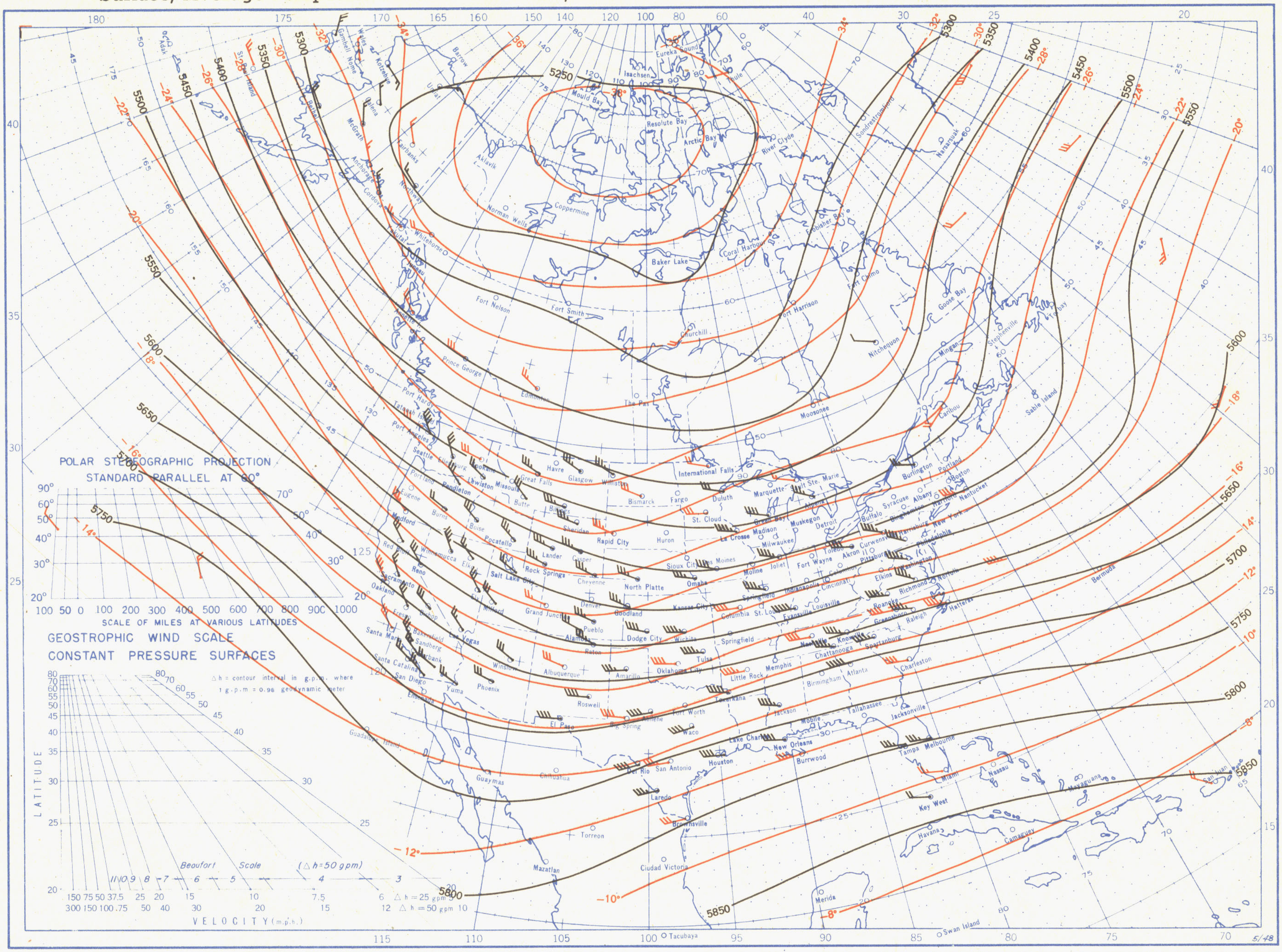
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

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.), March 1951.



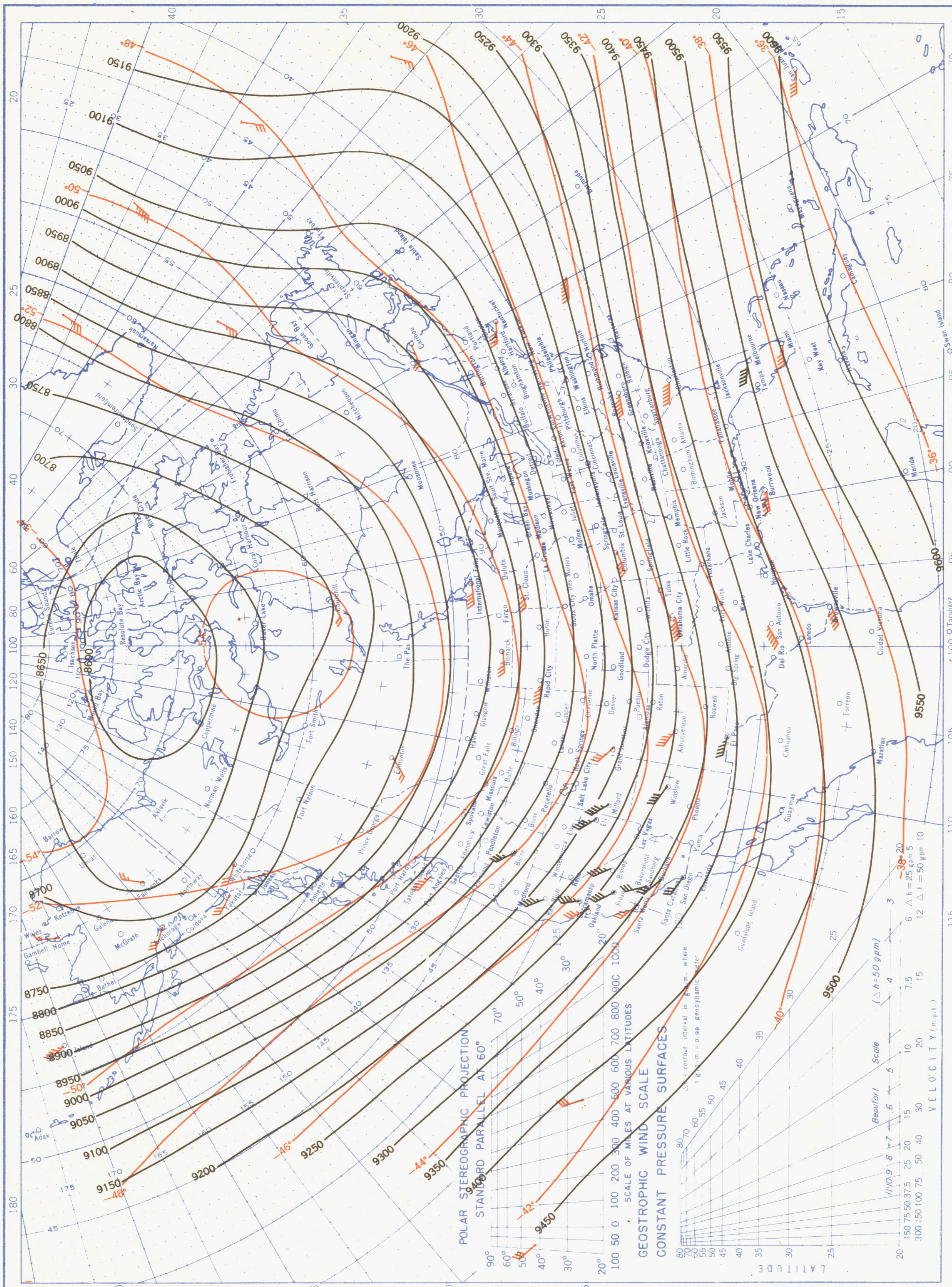
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

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.), March 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.), March 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.