THE WEATHER AND CIRCULATION OF APRIL 1954[1]

A Month With a Confluent Jet Stream

WILLIAM H. KLEIN
Extended Forecast Section, U. S. Weather Bureau, Washington, D. C.

CONFLUENCE AND THE THERMAL GRADIENT

The most striking feature of the general circulation of April 1954 was the extremely strong poleward temperature gradient which prevailed along the northern border of the United States, as indicated by the zonal orientation and crowding of isotherms in this area on the monthly mean charts for sea level (Chart I-A) and upper levels from 850 to 300 mb. (Charts XII-XV). The anomalies of temperature at sea level (Chart I-B) and for the layer from 1000 to 700 mb. (fig. 1) show that this month's meridional temperature contrast was much greater than the April normal. Figure 1 highlights the contrast between abnormally warm conditions in the southern three-quarters of the United States and extremely cold temperatures (as much as 12° C. below normal) in practically all of Canada. On many days of the month a quasi-stationary polar front extended across the northern United States, separating cold Canadian air from warm tropical and Pacific air masses to the south. A good example of such a situation is the synoptic chart for 1330 EST, April 6, reproduced in figure 2. That such situations recurred frequently throughout the month is implied in figure 3, which shows a concentration of surface fronts in the northern part of the United States, where they were located about two-thirds of the time.

The abnormally strong meridional temperature gradient in the northern United States was located in, and downstream from, a zone of intense confluence of the type first described by Namias [1]. Figure 4 shows that the monthly mean wave pattern at 700 mb. was markedly out of phase in the Pacific, where a low latitude trough complex near the Hawaiian Islands was surmounted by a well developed blocking ridge in the Bering Sea. The magnitude of the height anomaly (+460 ft.) in this ridge is the second greatest observed in this area in April during our 22-year period of record. Downstream from this ridge stronger than normal northerly flow from the west coast of Alaska to Hudson Bay carried extremely cold Arctic air into

[1] See Charts I-XV following p. 109 for analyzed climatological data for the month.

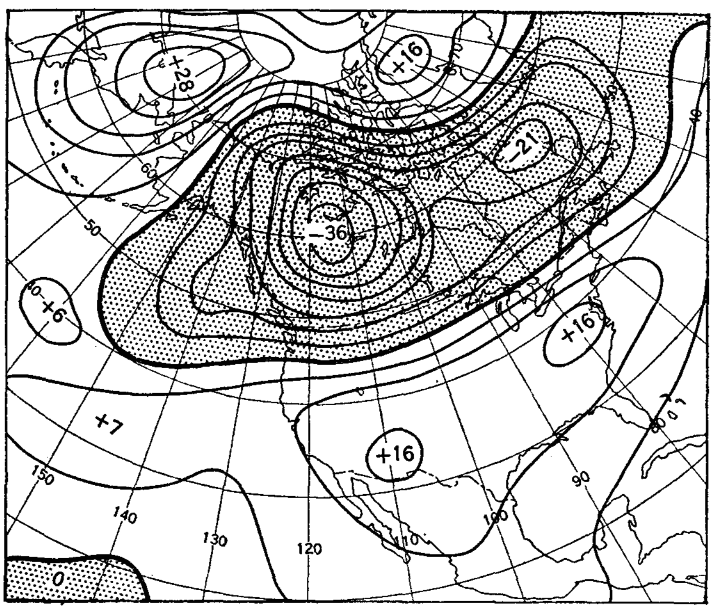


FIGURE 1.—Departure from normal of mean thickness (700–1000 mb.) for March 30–April 28, 1954, analyzed for intervals of 50 ft. with centers labeled in tens of feet. Below normal thicknesses (shaded) covered nearly all of Canada, with center of −360 ft. corresponding to mean virtual temperature about 12° C. below normal. Note warmth in most of United States with abnormally strong temperature gradient along northern border.

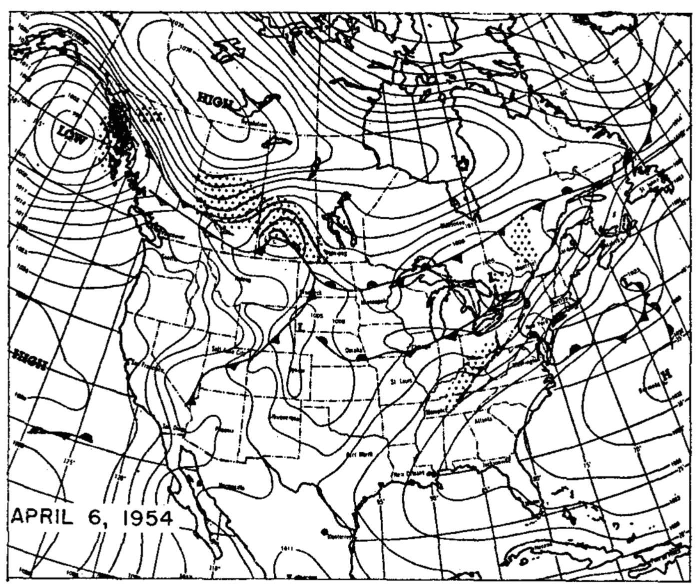


FIGURE 2.—North American synoptic weather map for 1330 EST, April 6, 1954. This daily map is typical of conditions which prevailed during the month (Chart XI) with polar anticyclone in Yukon, Low in Gulf of Alaska, strong Bermuda High, and concentration of fronts in northern United States and southern Canada.

Canada. This cold stream from the north was deflected sharply eastward along the northern border of the United States as it flowed alongside warm air carried in a broad southwesterly current from low latitudes of the Pacific and North America. Recurrence of this differential advection at frequent intervals throughout the month intensified the thermal gradient along the northern border of the United States. Concentration of the solenoidal field in this confluence zone probably resulted in acceleration of the westerlies at middle latitudes throughout the troposphere. A mechanism for such a process of transformation from potential to kinetic energy has been suggested in previous papers [2, 3].

THE JET STREAM

The existence of stronger than normal west winds at the 700-mb. level at middle latitudes from the Gulf of Alaska eastward to the mid-Atlantic may be inferred from the lines (dashed) of equal height anomaly in figure 4, since heights were below normal in Canada and southern Greenland but above normal in a broad zonal band to the south. It is illustrated more graphically, however, in figure 5, showing the geographical distribution of monthly mean 700-mb. wind speed and its departure from normal. Note the well defined axis of maximum wind speed extending eastward from Puget Sound across the northern Border States of the United States and the Maritime Provinces of Canada and thence northeastward across the Atlantic. Within the axis of this 700-mb. "jet stream" wind speeds averaged from 12 to 18 m. p. h. above their normal values (fig. 5b). There were actually two centers

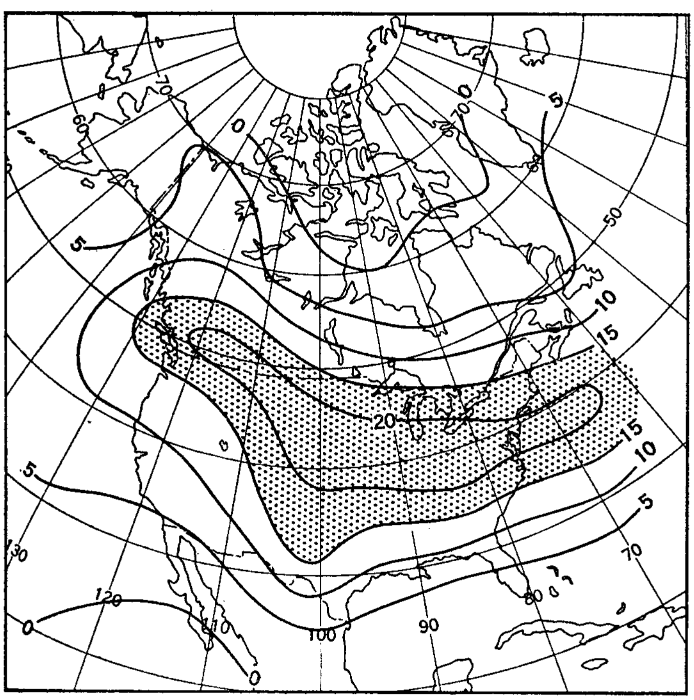


Figure 3.—Number of days in April 1954 with surface fronts (of any type) located within square areas with sides approximately 430 nautical miles. Frontal positions taken from *Daily Weather Map* for 1330 EST. Areas where fronts were present on 15 or more days are shaded. Note great frequency of fronts in northern United States.

of confluence producing this extensive zone of above normal wind speeds. The dashed line in figure 5A shows that a secondary axis of maximum wind speed curved anticyclonically around the blocking ridge in the Bering Sea and split into two branches, one joining the principal middle latitude jet stream in the southeast Gulf of Alaska and the other contributing to a confluence zone in the western Great Lakes. From here a single well developed 700-mb. jet continued downstream in a broad cyclonic sweep almost to the west coast of Europe. Within this current, maximum monthly mean wind speeds of almost 40 m. p. h. were observed in Maine.

The monthly mean circulation at the 200-mb. level (fig. 6) was similar in its broad-scale features to the corresponding circulation at 700 mb. (figs 4 and 5), although several weak troughs and ridges which appeared at the lower level were smoothed out of the upper level picture. An out-of-phase pattern in the mid-Pacific, with a high-latitude ridge north of a low-latitude trough was still apparent at 200 mb. The resulting confluence downstream is well depicted by the merger of two separate jet streams, one from the northwest and one from the southwest, in the southeast Gulf of Alaska, followed by a progressive increase of wind speed along the jet axis in the northern United States to a maximum of over 90 m. p. h. near Lake Ontario.

One of the most interesting aspects of figure 6 is the weak and disjointed nature of the subtropical jet stream normally found at low latitudes almost vertically above the subtropical high pressure belt at sea level [4]. This subtropical jet was best developed over the Atlantic and North Africa but completely absent over North America. Instead, the 200-mb. jet stream across the northern United States was closely associated with the mean polar front since it was located near the regions of greatest meridional temperature gradient in the lower troposphere (fig. 1), of maximum frequency of surface fronts (fig. 3), and of strongest wind speeds at 700 mb. (fig. 5). According to Palmén [4] it is rare for this "polar front jet" to show up so clearly on a mean chart, to the complete exclusion of the "subtropical jet". In fact this is the first month, except for midsummer, that this condition has been noted since regular preparation of monthly mean 200-mb. isotach charts for this series of articles was inaugurated in July 1952 [5].

The contrast between this month's 200-mb. circulation and the normal condition is illustrated visually in figure 7. The April 1954 jet axis was located about 20° of latitude north of the axis of maximum wind speed on the normal map for April at the 13-km. level (approximately 200 mb.) [6]. Since this normal was prepared primarily by extrapolation procedures without benefit of any of the observational data of the past decade, its accuracy is questionable. The location of the jet stream on the 200-mb. mean map for April 1953 [7] has therefore been included for comparison. The difference in jet location between April 1954 and April 1953 is almost as striking as the difference between

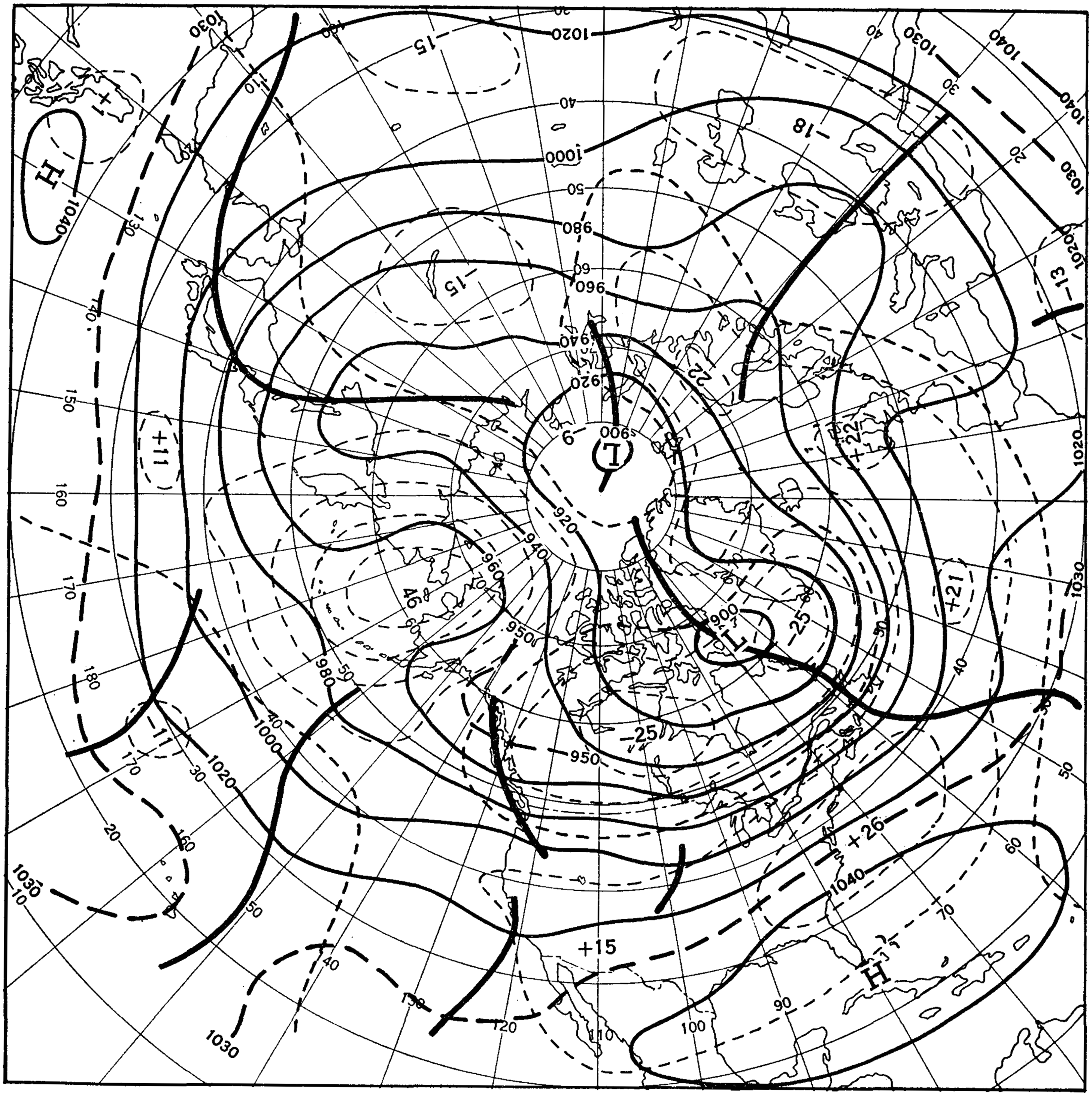


Figure 4.—Mean 700-mb. contours and height departures from normal (both in tens of feet) for March 30–April 28, 1954. High index and confluence in North America, with above-normal heights in all portions of the United States except the northern border but below-normal heights throughout Canada, were accompanied by a low-index, blocking type of circulation in the Pacific.

this month and the long-period normal. Figure 7 also depicts the location of the axis of the 700-mb. jet stream (dashed lines) for both April 1954 and the recently revised April normal [8]. At this level too, this month's axis of maximum wind speed was displaced well north of its normal position. It is also interesting that the jet stream at 200 mb. was slightly south of its counterpart at 700 mb., as is normally the case.

INDEX CONSIDERATIONS

It has been pointed out by Willett [9] that, for the winter half-year in the Northern Hemisphere, the poleward gradient of mean virtual temperature between sea level and 700 mb. is negatively correlated with the zonal westerlies at sea level but positively correlated with the zonal westerlies at the 3-km. (700-mb.) level. This relationship fit the observed circulation rather well this month, when the abnormally strong meridional temperature gradient previously described was accompanied by a zonal index 1.3 m. p. s. below normal at sea level but 0.7 m. p. s. above normal at 700 mb. In other respects, however, this month's circulation was quite different from Willett's ideal low index state. For example, the sea level polar easterlies were weaker than normal, the subtropical easterlies were stronger than normal, and the latitude of the strongest westerly winds was displaced north of its normal position (fig. 8). All the preceding characteristics refer to the Western Hemisphere as a whole. In order to obtain a clearer picture of the general circulation for this month (and probably for all months) it is necessary to consider the index in its more regional aspects.

Throughout the Pacific and western North America typical low index conditions prevailed at sea level (Chart XI) with the Aleutian Low weakened and split into two centers, the polar High as much as 14 mb. stronger than normal, and the subtropical High pressure belt weaker than normal. Aloft a split jet stream and above normal wind speeds at low latitudes were also typical of low index. In eastern North America and the Atlantic, however, an opposite type of circulation, characteristic of high index, prevailed. A single intense Icelandic Low surmounted well developed Azores and Bermuda Highs, the latter with mean pressure 7 mb. above normal (Chart XI inset). Between these centers of action a strong belt of westerlies prevailed at all levels from sea level to 200 mb. Such a sharp contrast between low index in one region and high index in an adjoining region should probably accompany any jet stream produced in a confluence zone, downstream from an out-of-phase pattern of the long waves. The Rossby-Rex hypothesis that the initiation of blocking requires a strong jet upstream from the block also implies a regional differentiation of index [10]. Thus uniform high or low index conditions around the entire hemisphere are seldom observed, and an index loses much of its utility when applied to the entire hemisphere rather than to quadrants or sectors.

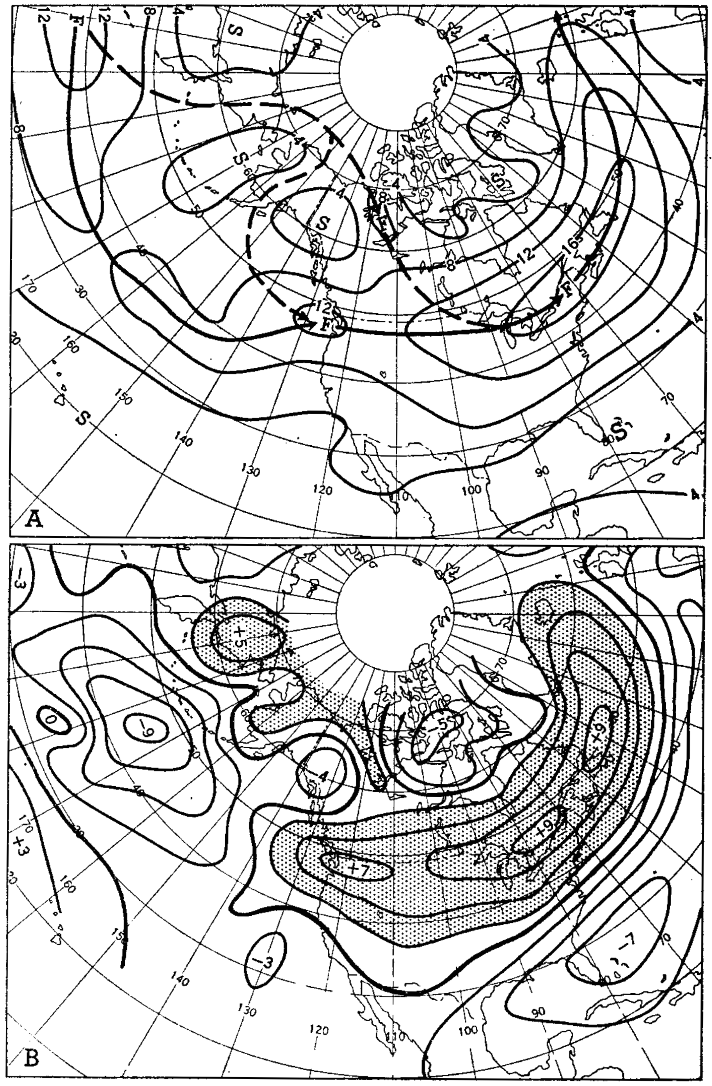


Figure 5.—(A) Mean 700-mb. isotach and (B) departure from normal wind speed (both meters per second) for March 30-April 28, 1954. Solid arrows indicate average position of the 700-mb. jet stream, which was south of its normal location and weakened in the Pacific, but north of normal and greatly intensified in North America and the Atlantic. Dashed lines delineate secondary axes of maximum wind speed around blocking ridge in Bering Sea.

TRACKS OF ANTICYCLONES AND CYCLONES

The individual anticyclone and cyclone tracks shown in Charts IX and X have been summarized in figure 9. Many cold polar anticyclones originated in the monthly mean High over Alaska and the Yukon (Chart XI) and moved southeastward, steered by the strong northwesterly flow aloft. They all curved sharply eastward, however, upon approaching the confluence zone along the United States-Canadian border, some to the north over southern Hudson Bay, but more to the south in the region of maximum anticyclonic vorticity aloft. Thus the well defined anticyclone track from the Lower Lakes across New England and the mid-Atlantic was parallel to and to the right of the axis of the mean jet stream at both the 700-mb. and 200-mb. levels. A few offshoots of the eastern Pacific High also entered the United States during the month, only to stagnate and dissipate in the Great Basin.

Most of the cyclones traversing North America originated in the quasi-stationary Low in the Gulf of Alaska or in the trough to its south (Charts X and XI). After entering British Columbia many of the storms moved east across southern Canada to Labrador before curving northeastward toward Iceland (fig. 9B). The parallelism between this principal storm track and the axis of the 700-mb. jet stream (fig. 5A) is striking. The former was located about 5° of latitude to the left (looking downstream) of the latter, in the region of maximum cyclonic shear. A similar relation has been pointed out on many previous occasions in this series of articles (for example see [5, 7]). A secondary storm track extended in normal fashion from Colorado through Lake Superior to southern James Bay, where it merged with the principal track across

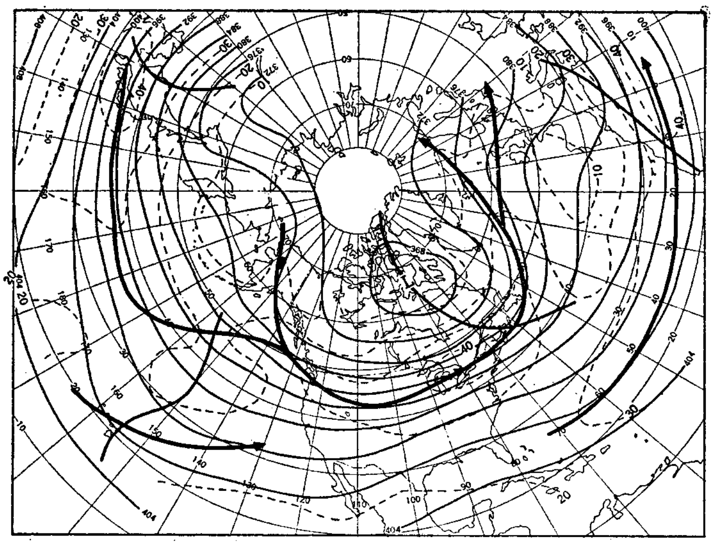


FIGURE 6.—Mean 200-mb. contours (in hundreds of feet) and isotachs (dashed, in meters per second) for March 30–April 28, 1954. Solid arrows indicate the average position of the 200-mb. jet stream. Outstanding feature is absence of normal subtropical jet in North America and prominence of polar front jet in northern United States.

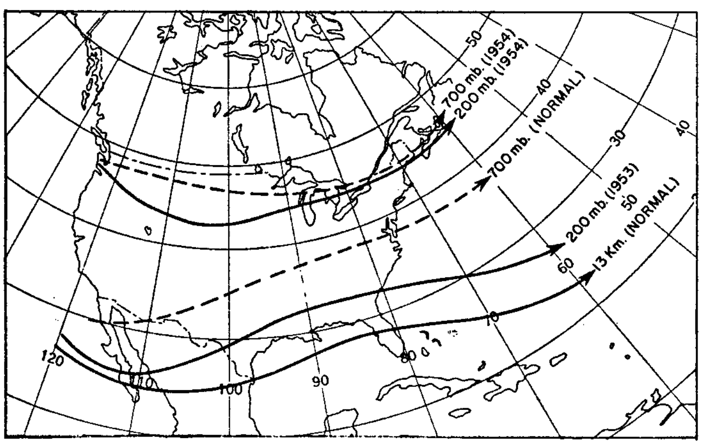


FIGURE 7.—Location of axes of April jet streams in North America at 200 mb. (solid lines) and 700 mb. (dashed lines) for 1954, 1953, and the long-period normal. At both levels this year's jet was well north of the normal April position.

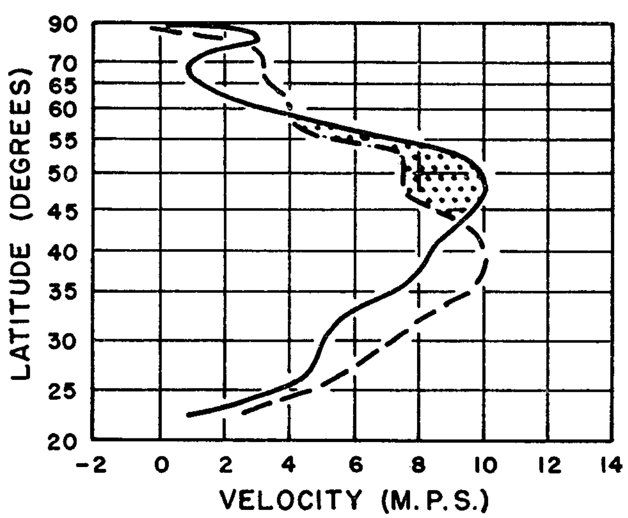


FIGURE 8.—Mean 700-mb. zonal wind speed profile in the Western Hemisphere for March 30–April 28, 1954, with normal April profile dashed and area of positive anomaly shaded. The west wind maximum at 48° N. was about 10° north of normal.

southern Canada. It is noteworthy that fewer cyclones took the former than the latter route, in contrast to the normal April situation when storms are more frequent in the central United States than they are north of the border [11]. Another secondary storm track stretched from the vicinity of Cape Hatteras northeastward to the mid-Atlantic, passing some 300 to 400 miles south of Nova Scotia and Newfoundland, along the left-hand margin of the Gulf Stream. It is difficult to rationalize this track on the basis of any of the monthly mean charts since it was located south of the upper level jet stream in a region of abnormally strong ridge conditions at both sea level and 700 mb. Apparently this track was made up by fast-moving relatively weak storms of small dimension which left virtually no impress on the monthly mean pattern. It is notable, however, that a storm track of this sort is normally observed during April, when the sea surface temperature gradient between the warm Gulf Stream and the cold Labrador current is particularly strong [11].

THE WEATHER

Surface temperatures in the United States during April averaged below normal in the Northwest, near normal in the extreme Northeast, and above normal in the remainder of the country (Chart I–B). The below-normal temperatures were produced primarily by intrusions of cold cP air carried in stronger than normal northeasterly flow at sea level around an abnormally intense monthly mean High in the Yukon (Chart XI). This cold air was "contained" in the north, unable to penetrate the country to any appreciable degree, because of abnormally fast westerlies in the confluence zone along the northern border. As a result most of the migratory anticyclones which entered the United States from Canada were of the glancing variety, moving rapidly eastward across the northern United States. Note also the close coincidence between the line of zero surface temperature anomaly in Chart I-B and the axis of the 200-mb. jet stream in figure 6. Another important factor contributing to abnormal warmth in the eastern United States was the unusual development of the Bermuda High, which made this month's sea level map (Chart XI) look more like the July than the April normal. Stronger than normal southerly and southwesterly flow around the westward extension of this High dominated the entire eastern half of the United States and combined with ridge conditions aloft to produce temperatures that averaged as much as 6° F. above normal in a large area (Chart I-B).

Precipitation was subnormal in most of the United States during April (Chart III) since the principal storm track was north of the border, anticyclonic vorticity was pronounced, and fast westerlies intensified the rain shadow effect of the Rockies in the Northern and Central Plains. Above normal amounts were recorded in some areas of the northern United States, in the vicinity of the confluence zone and jet stream aloft and in the area of maxi-

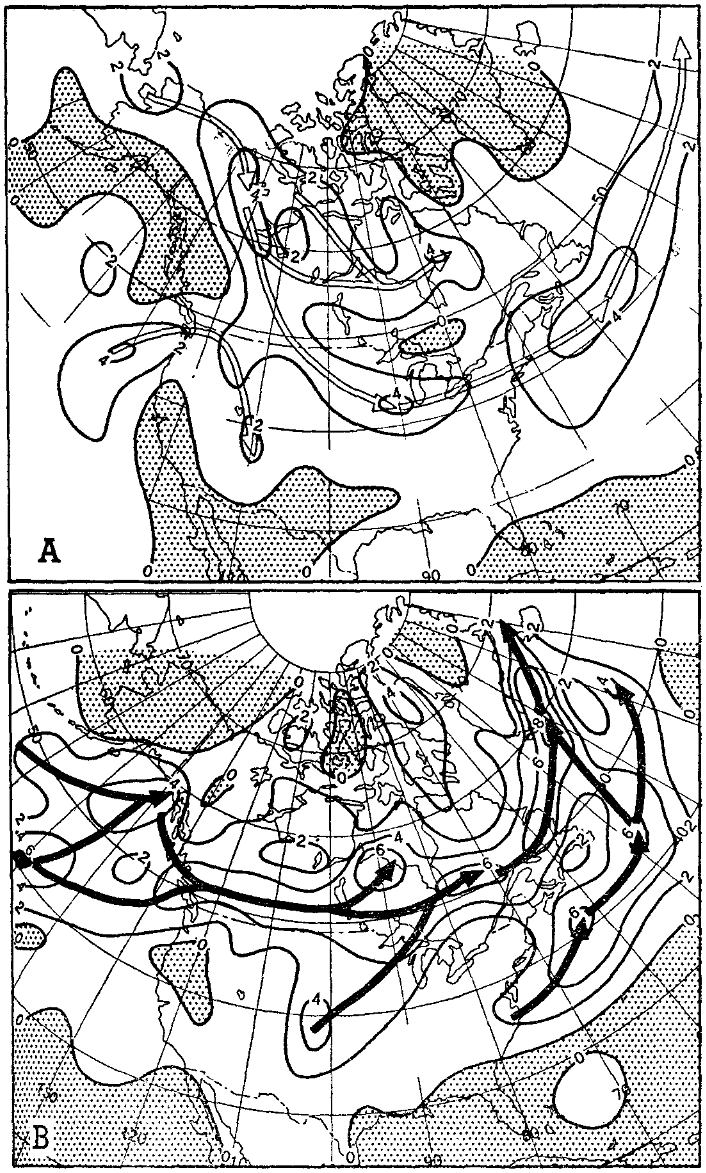


Figure 9.—Frequency of anticyclone passages (A) and cyclone passages (B) (within 5° squares at 45° N.) during April 1954. Well defined anticyclone tracks are indicated by open arrows and cyclone tracks by solid arrows. Cyclone track just north of Canadian-United States border and thence northeastward to Iceland was located in the area of cyclonic shear to the left of the jet stream. Polar anticyclones were unable to penetrate the southern United States because of abnormally fast westerlies along the northern border.

mum frequency of fronts at the surface. Heaviest precipitation fell in the Upper Mississippi Valley, where a few Colorado Lows and southerly flow ahead of a small scale mean trough at 700 mb. produced as much as twice the normal amount. Fast westerlies and trough conditions at 700 mb. were responsible for heavy rain along the north Pacific Coast, while some coastal storminess contributed to heavy amounts in New England.

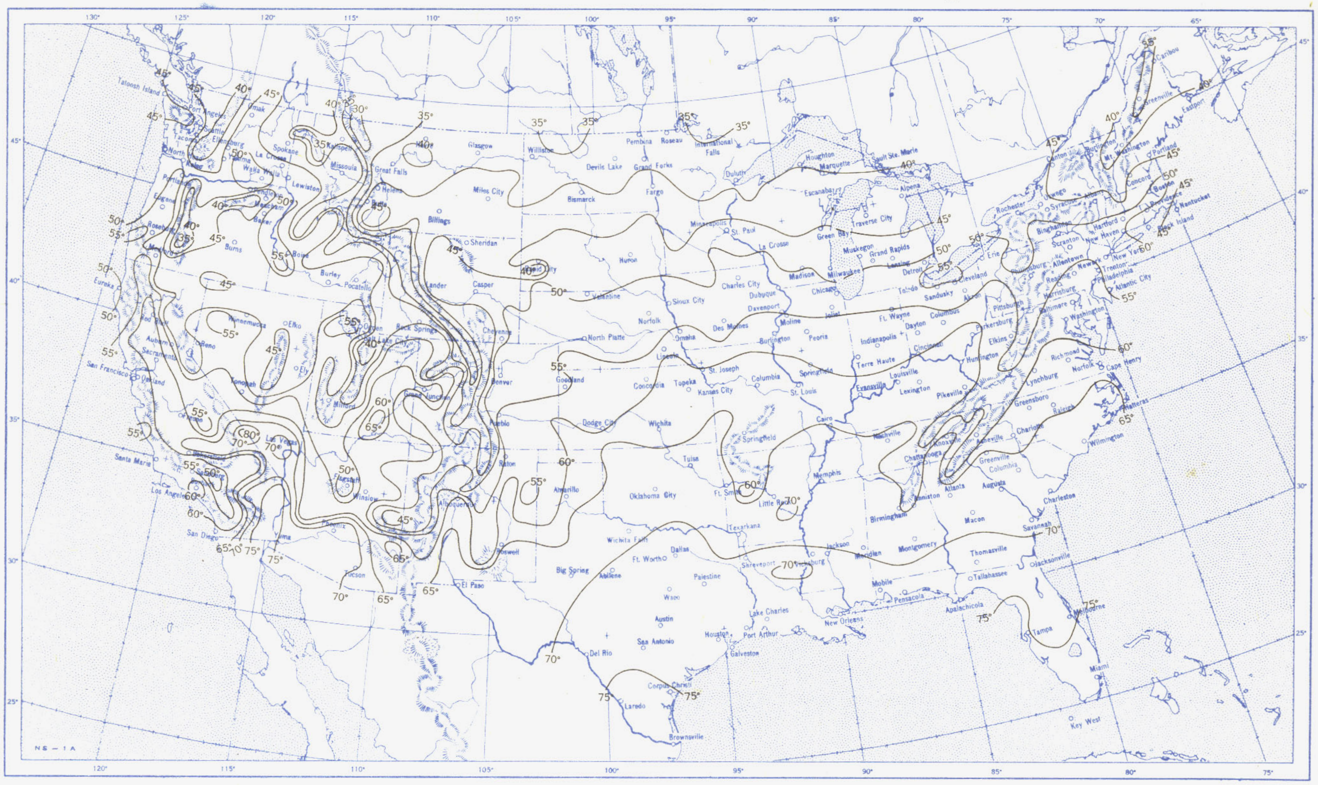
The most newsworthy precipitation of the month fell in Texas where Statewide amounts averaged 122 percent of normal. This relieved a serious drought in a State which had only half its normal rainfall during the preceding 5 months and the lowest on record for the first 3 months of 1954. The moisture for this heavy precipitation was carried from the Gulf of Mexico by stronger than normal southeasterly monthly mean wind components at both sea level and 700 mb. This moisture was released in a region of high frequency of surface fronts (fig. 3), many of which stagnated for several days. The Texas rains were not directly associated with surface cyclones or an upper level jet stream. On the contrary, the westerlies were so far north that the customary rain shadow effect was negligible and a weak onshore flow, more typical of summer, prevailed.

REFERENCES

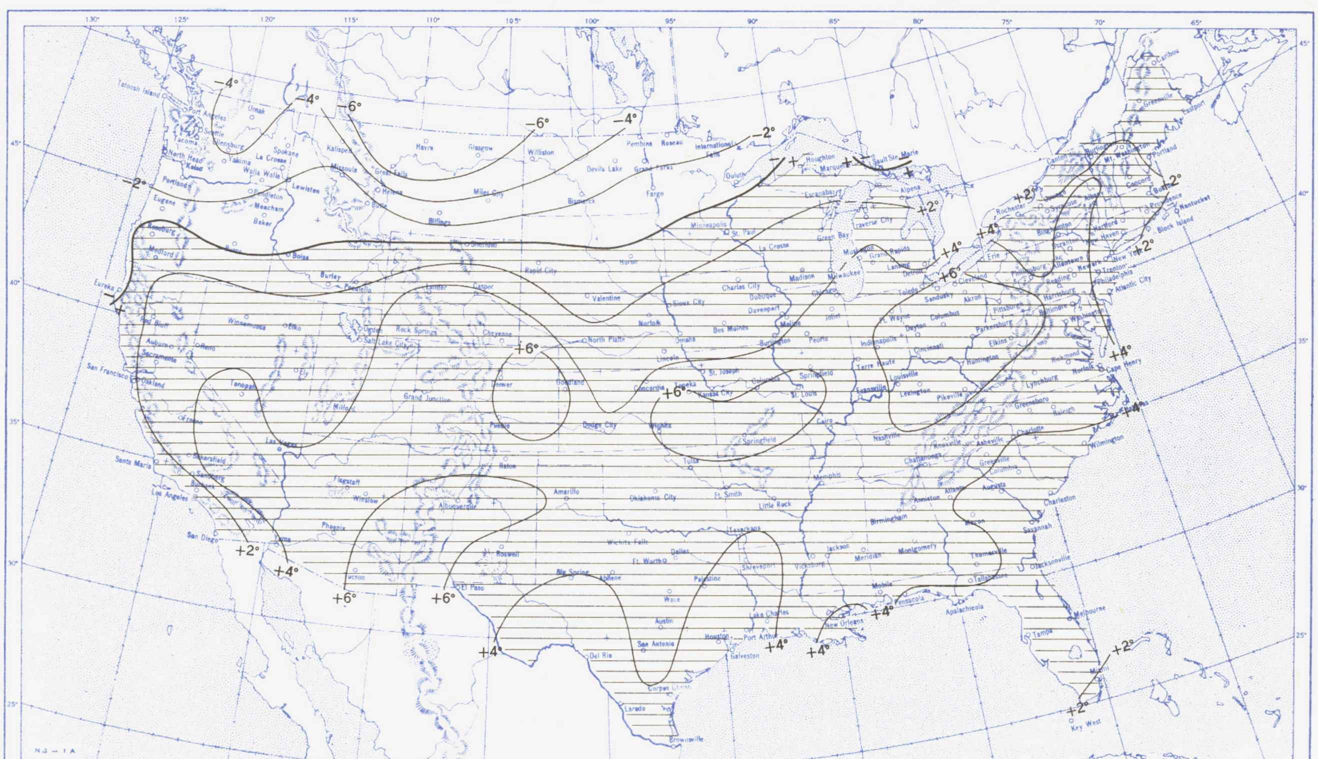
1. J. Namias, "Physical Nature of Some Fluctuations in the Speed of the Zonal Circulation," *Journal of Meteorology*, vol. 4, No. 4, Aug. 1947, pp. 125–133.
2. J. Namias and P. F. Clapp, "Confluence Theory of the High Tropospheric Jet Stream," *Journal of Meteorology*, vol. 6, No. 5, Oct. 1949, pp. 330–336.
3. P. F. Clapp and J. S. Winston, "A Case Study of Confluence as Related to the Jet Stream," *Journal of Meteorology*, vol. 8, No. 4, Aug. 1951, pp. 231–243.
4. E. Palmén, "The Role of Atmospheric Disturbances in the General Circulation," *Quarterly Journal of the Royal Meteorological Society*, vol. 77, No. 333, July 1951, pp. 337–354.
5. W. H. Klein, "The Weather and Circulation of July 1952—A Month with Drought," *Monthly Weather Review*, vol. 80, No. 7, July 1952, pp. 118–122.
6. U. S. Weather Bureau, Northern Hemisphere Isograms of Wind Speed and Stream Lines, Upper Levels, (Unpublished, based on *Normal Weather Maps, Northern Hemisphere, Upper Levels*, 1944.)
7. W. H. Klein, "The Weather and Circulation of April 1953—A Cold, Stormy Month with a Low Index Circulation," *Monthly Weather Review*, vol. 81, No. 4, Apr. 1953, pp. 115–120.
8. U. S. Weather Bureau, "Normal Weather Charts for the Northern Hemisphere," *Technical Paper* No. 21, Washington, D. C., 1952.
9. H. C. Willett, "Patterns of World Weather Changes," *Transactions, American Geophysical Union*, vol. 29, No. 6, Dec. 1948, pp. 803–809.
10. J. S. Winston, "The Weather and Circulation of February 1952—A Month with a Pronounced Index Cycle," *Monthly Weather Review*, vol. 80, No. 2, Feb. 1952, pp. 26–30.
11. W. H. Klein, Principal Tracks of Cyclones and Anticyclones over the Northern Hemisphere, U. S. Weather Bureau, 1954 (Unpublished).

U. S. GOVERNMENT PRINTING OFFICE: 1954

Chart I. A. Average Temperature (°F.) at Surface, April 1954.



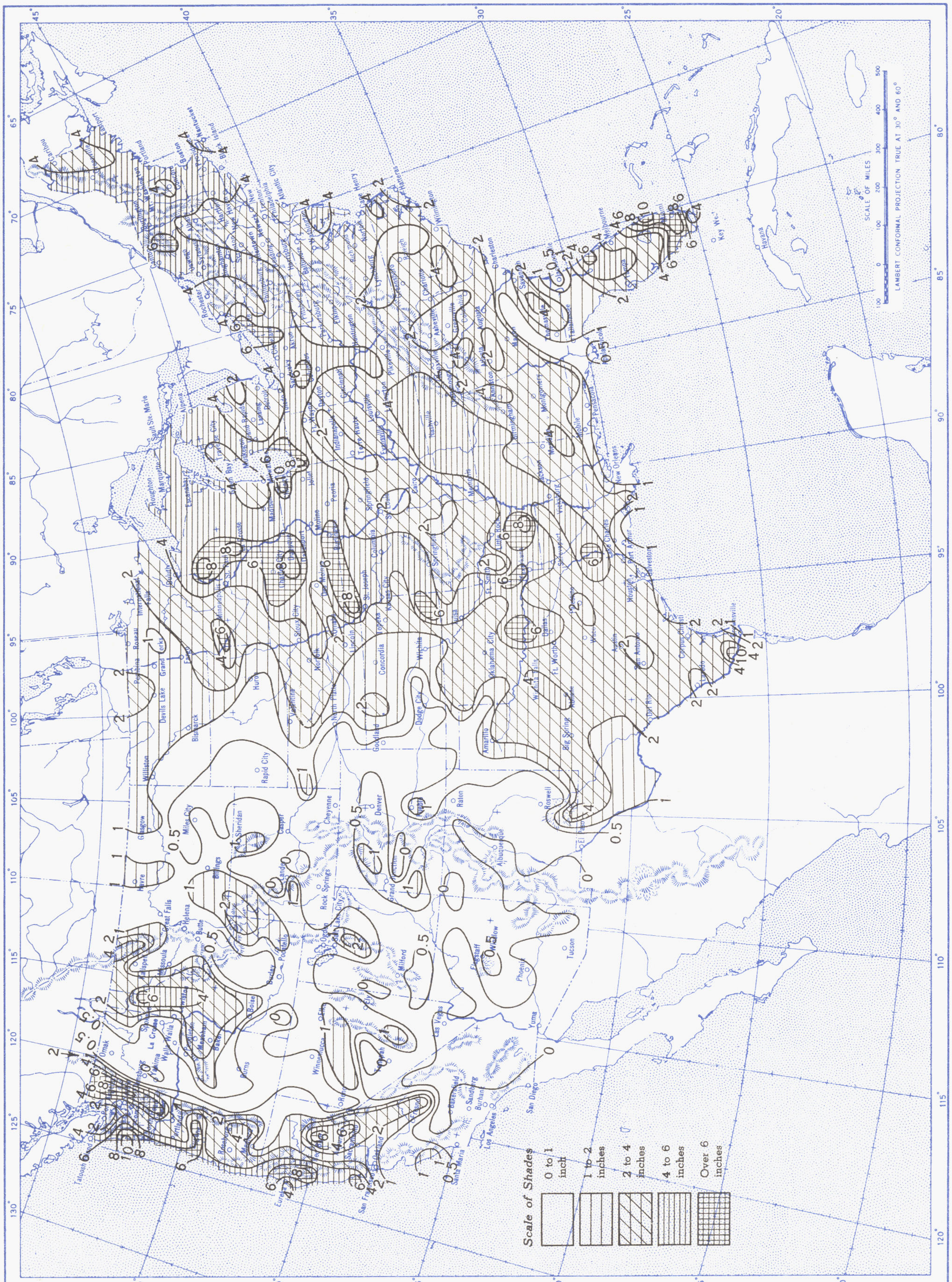
B. Departure of Average Temperature from Normal (°F.), April 1954.



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.

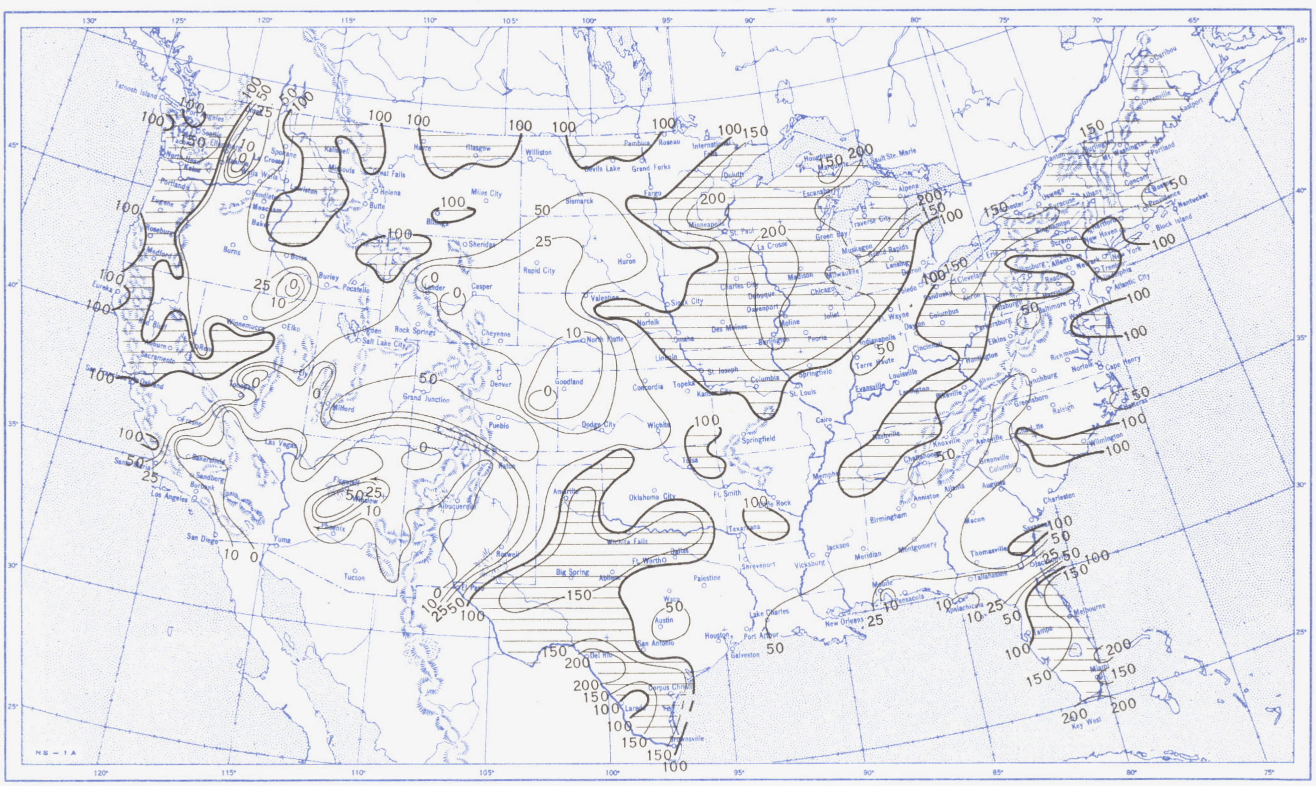
Chart II. Total Precipitation (Inches), April 1954.



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

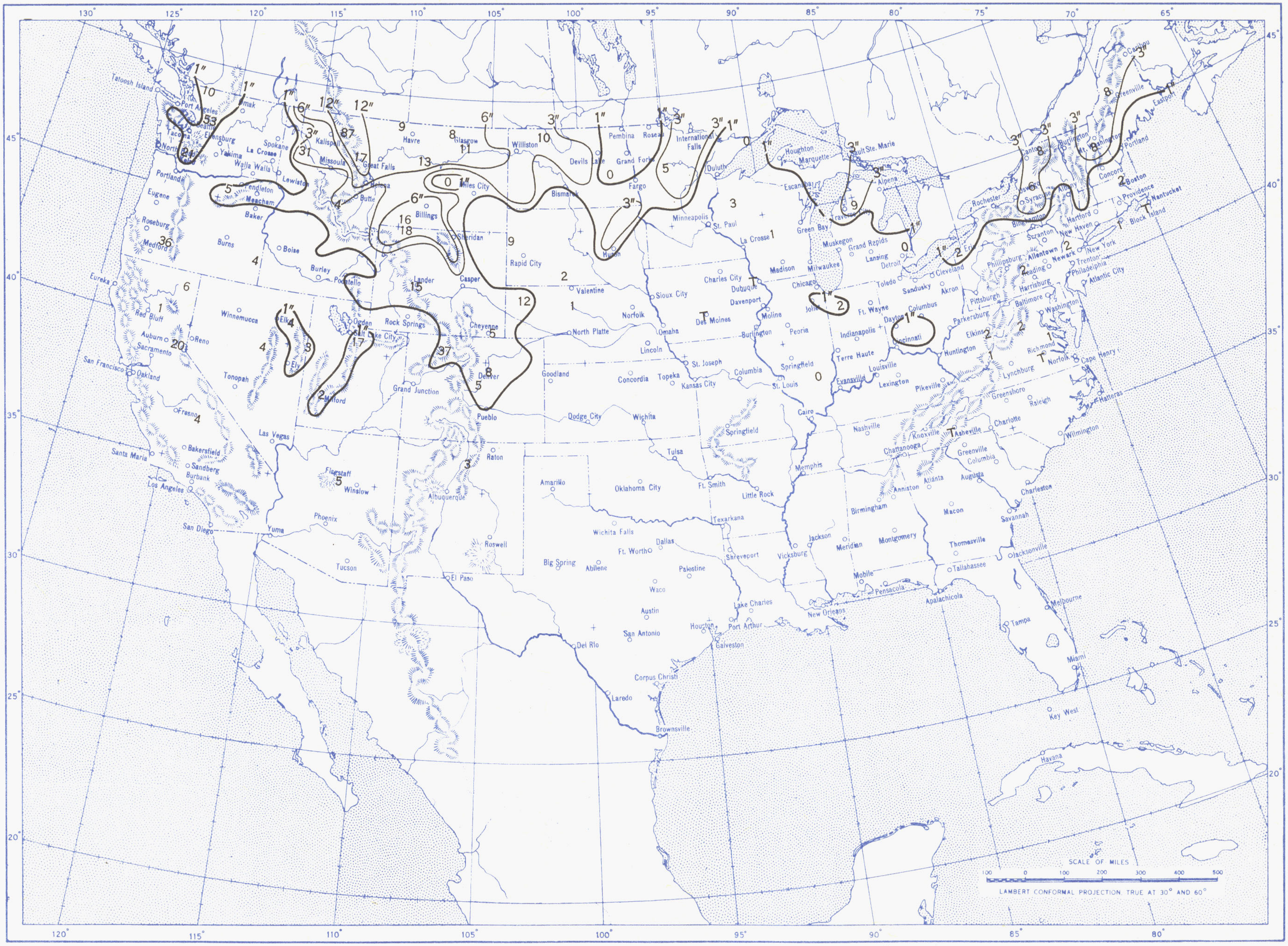
Chart III. A. Departure of Precipitation from Normal (Inches), April 1954.

B. Percentage of Normal Precipitation, April 1954.



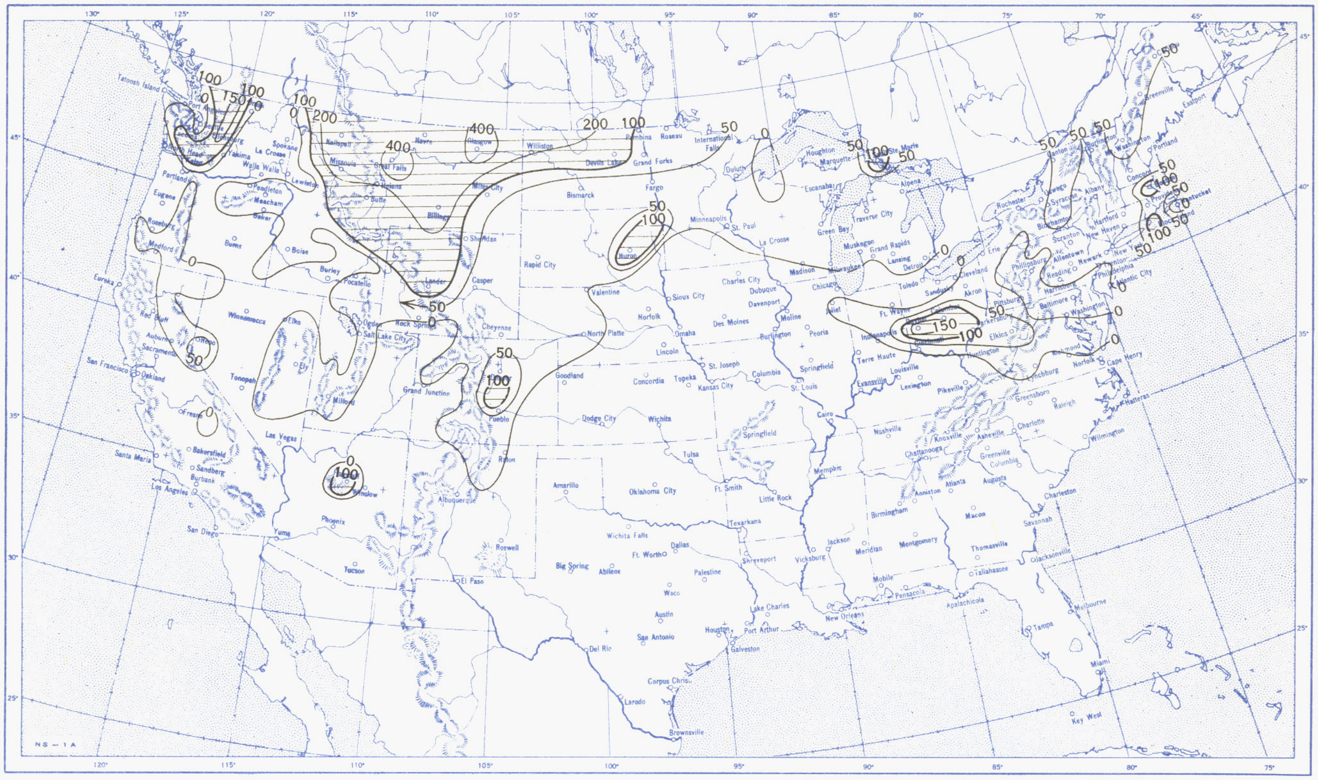
Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart IV. Total Snowfall (Inches), April 1954.

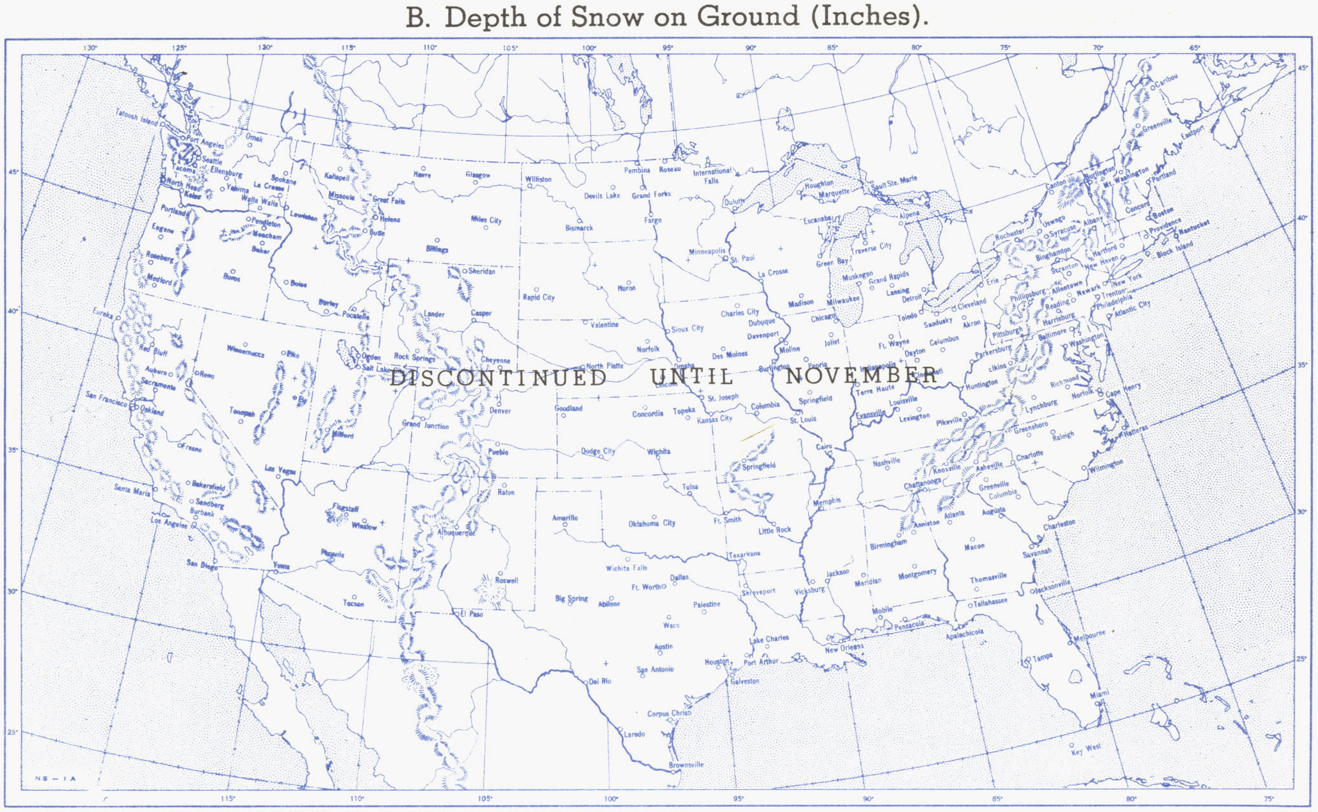


This is the total of unmelted snowfall recorded during the month at Weather Bureau and cooperative stations. This chart and Chart V are published only for the months of November through April although of course there is some snow at higher elevations, particularly in the far West, earlier and later in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

Chart V. A. Percentage of Normal Snowfall, April 1954.

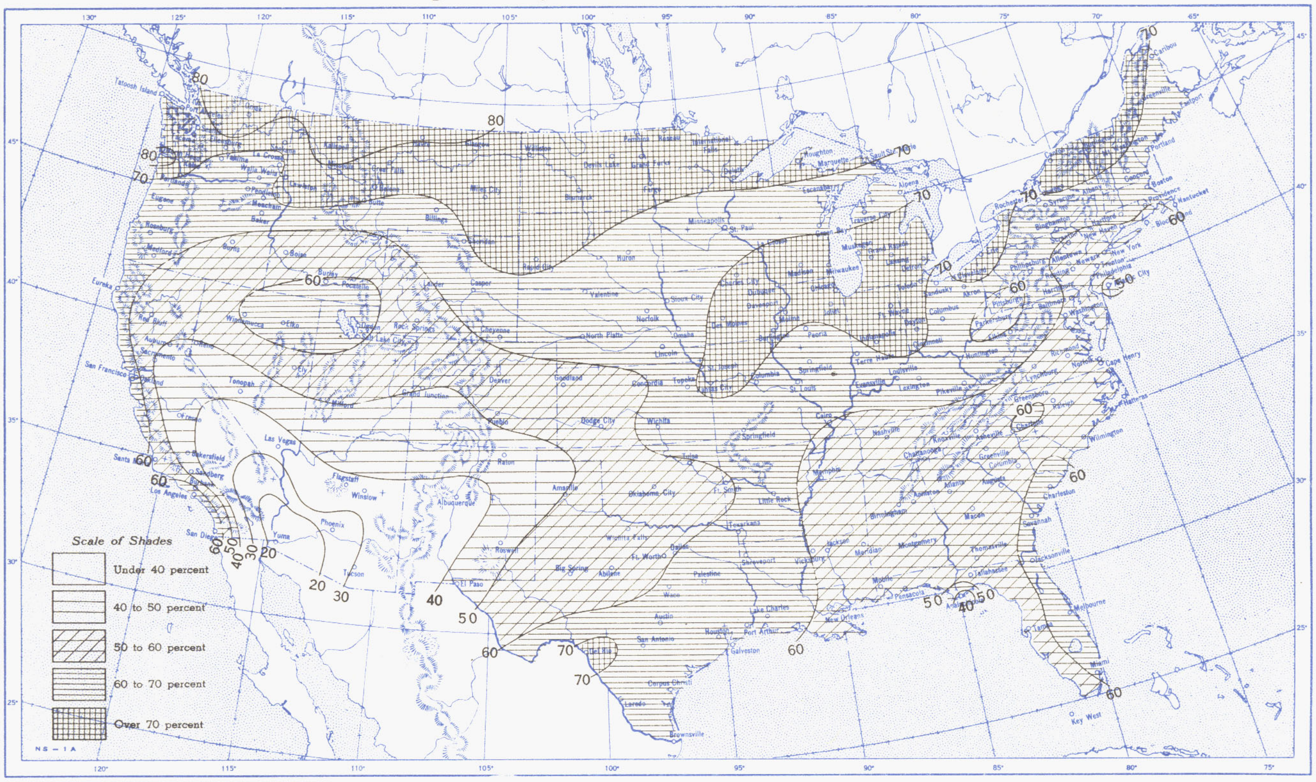


B. Depth of Snow on Ground (Inches).

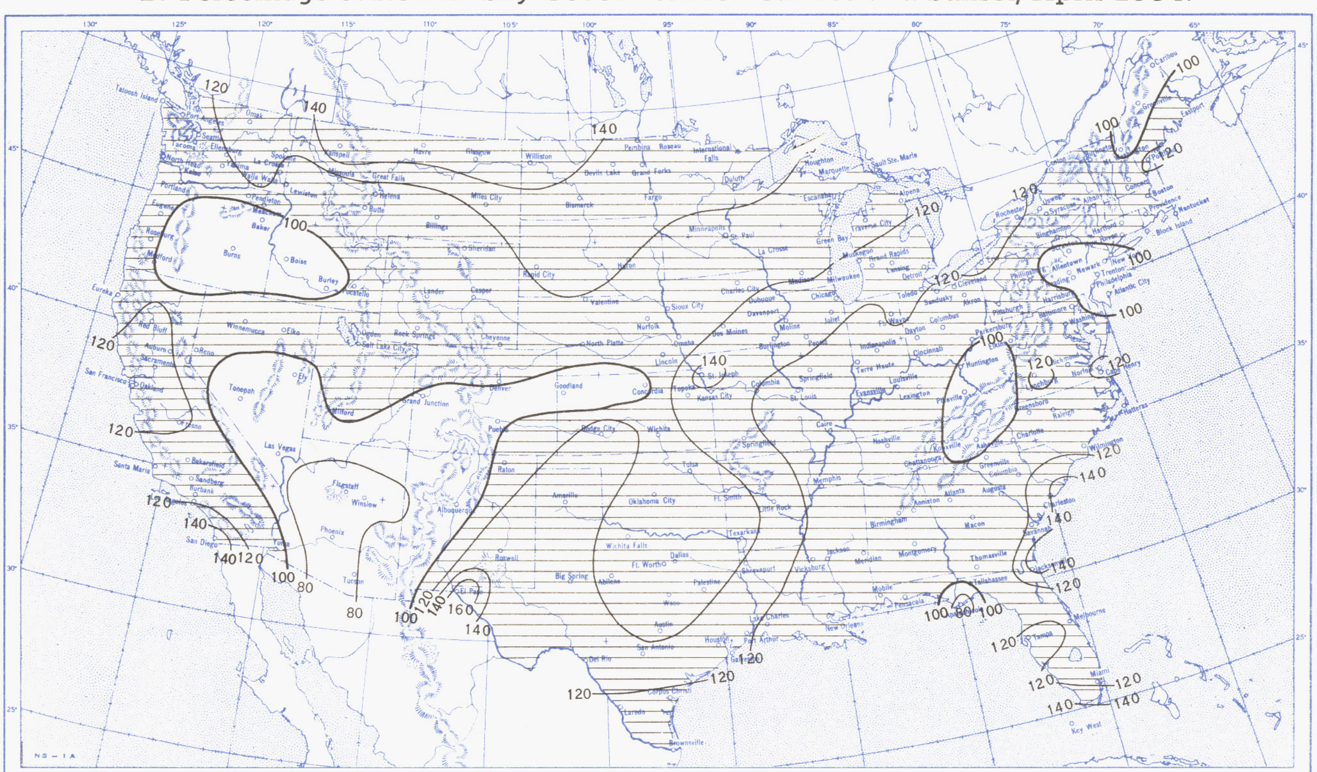


A. Amount of normal monthly snowfall is computed for Weather Bureau stations having at least 10 years of record.
B. Shows depth currently on ground at 7:30 a. m. E. S. T., of the Tuesday nearest the end of the month. It is based on reports from Weather Bureau and cooperative stations. Dashed line shows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

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, April 1954.

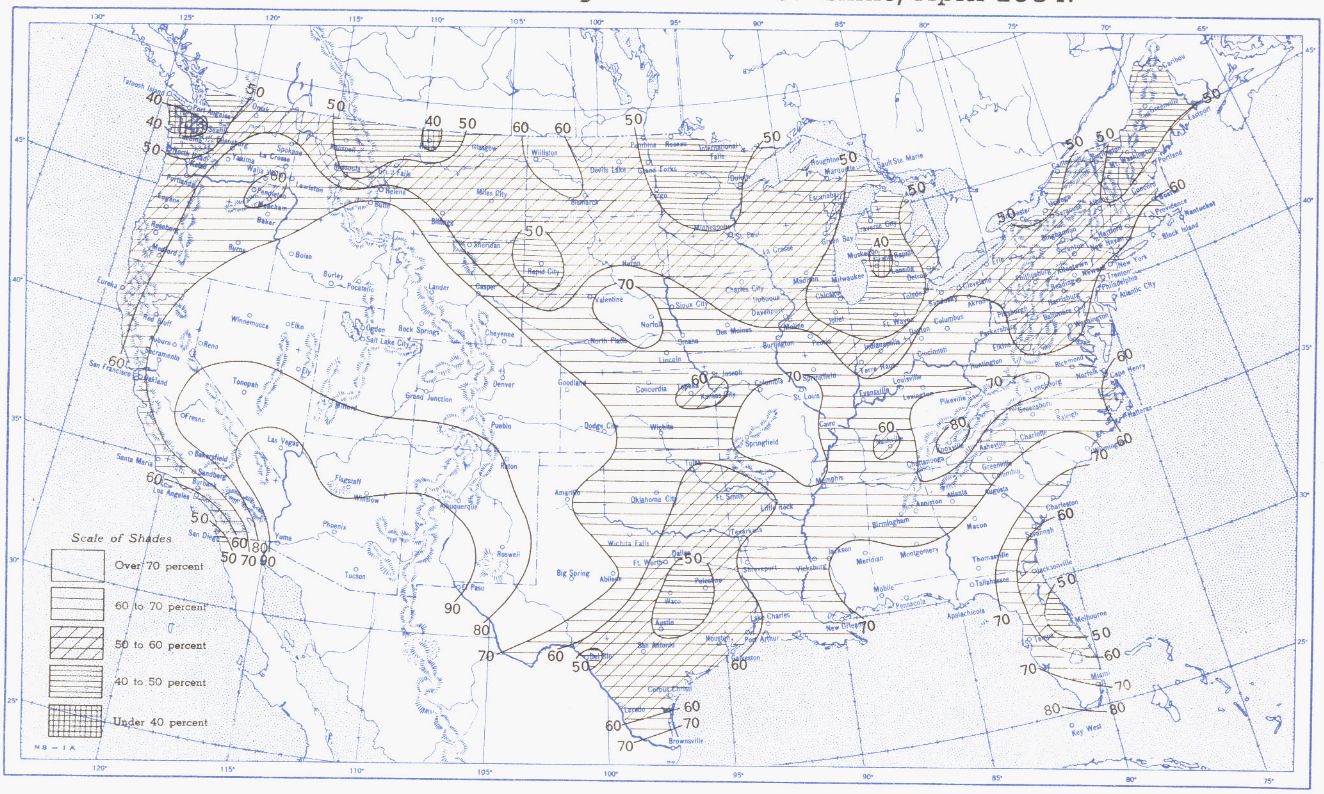


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, April 1954.

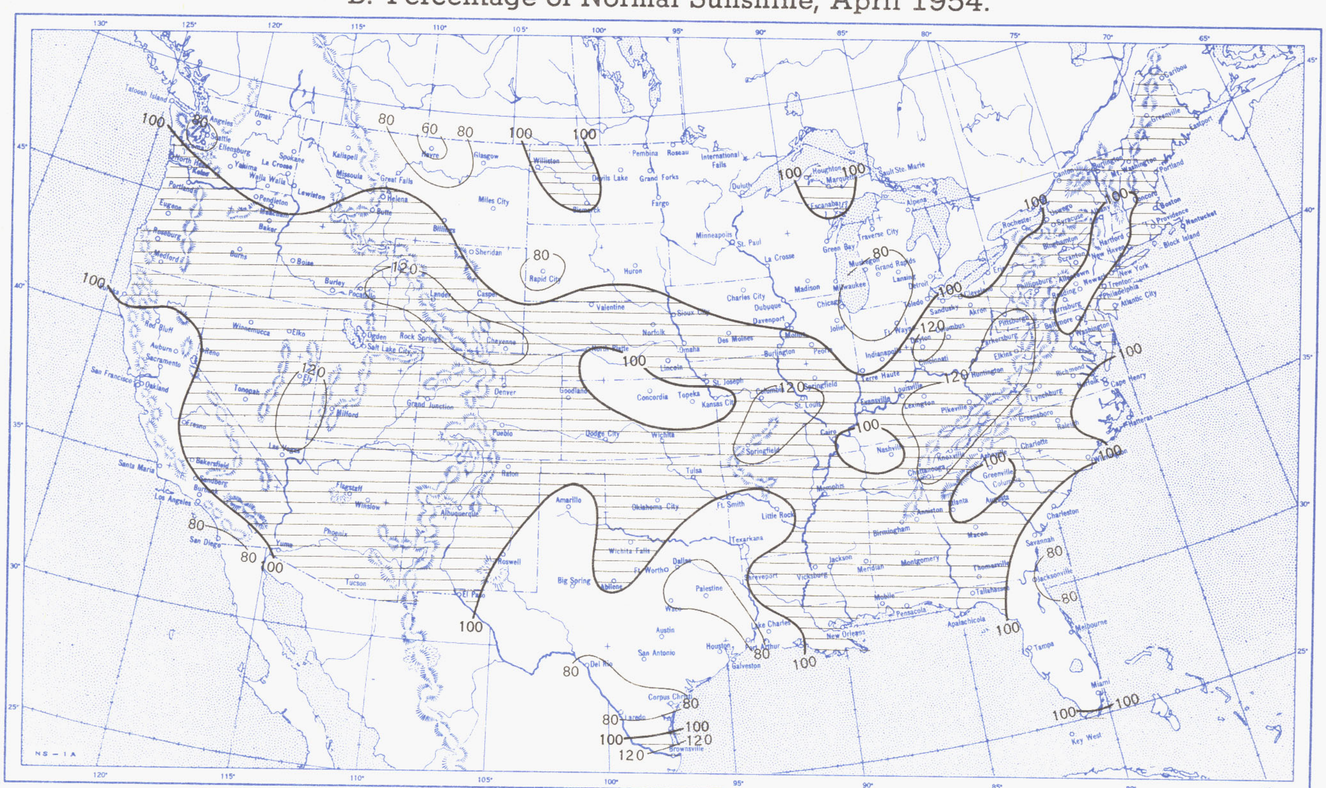


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, April 1954.



B. Percentage of Normal Sunshine, April 1954.



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, April 1954. Inset: Percentage of Normal Average Daily Solar Radiation, April 1954.

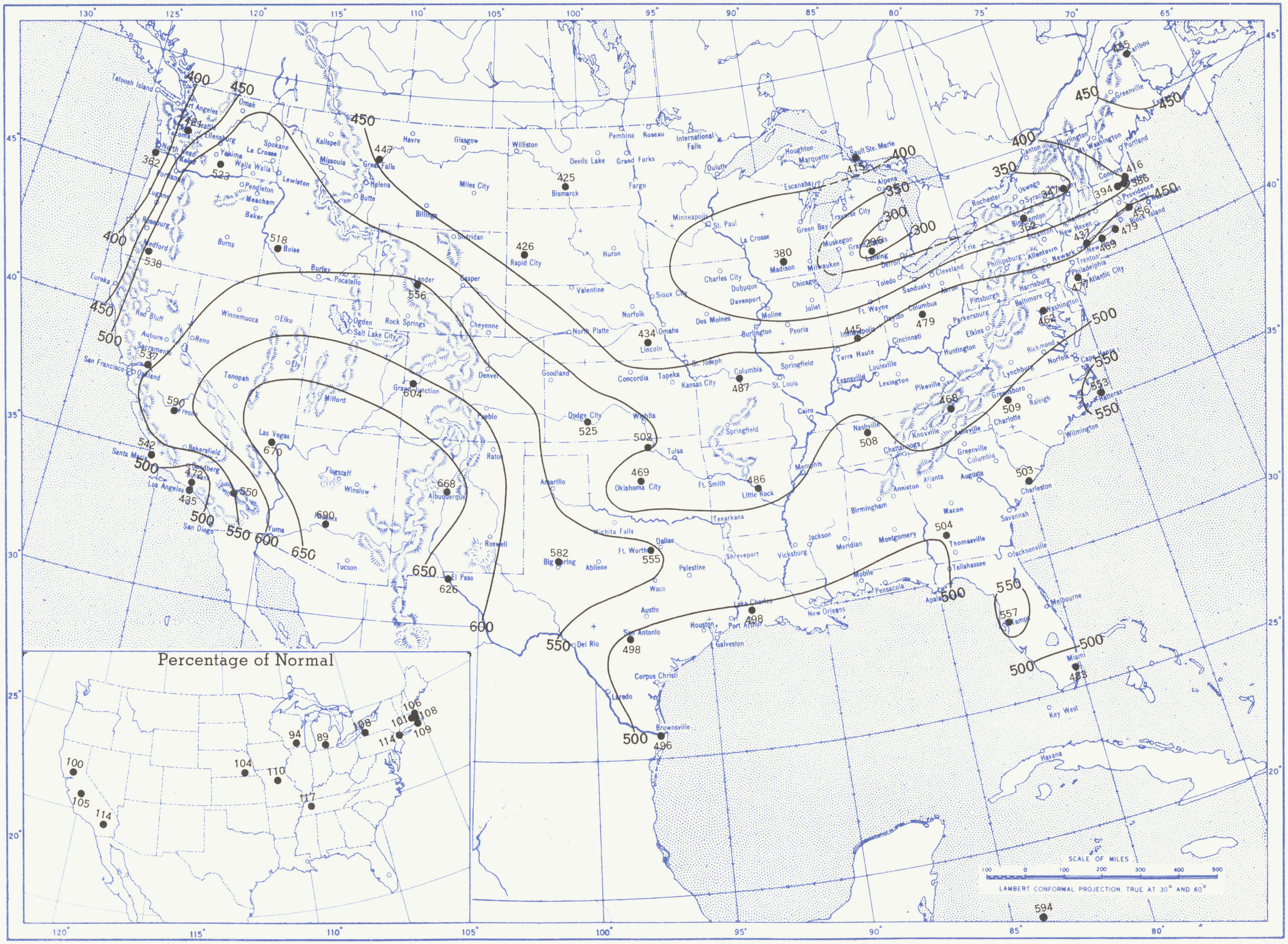


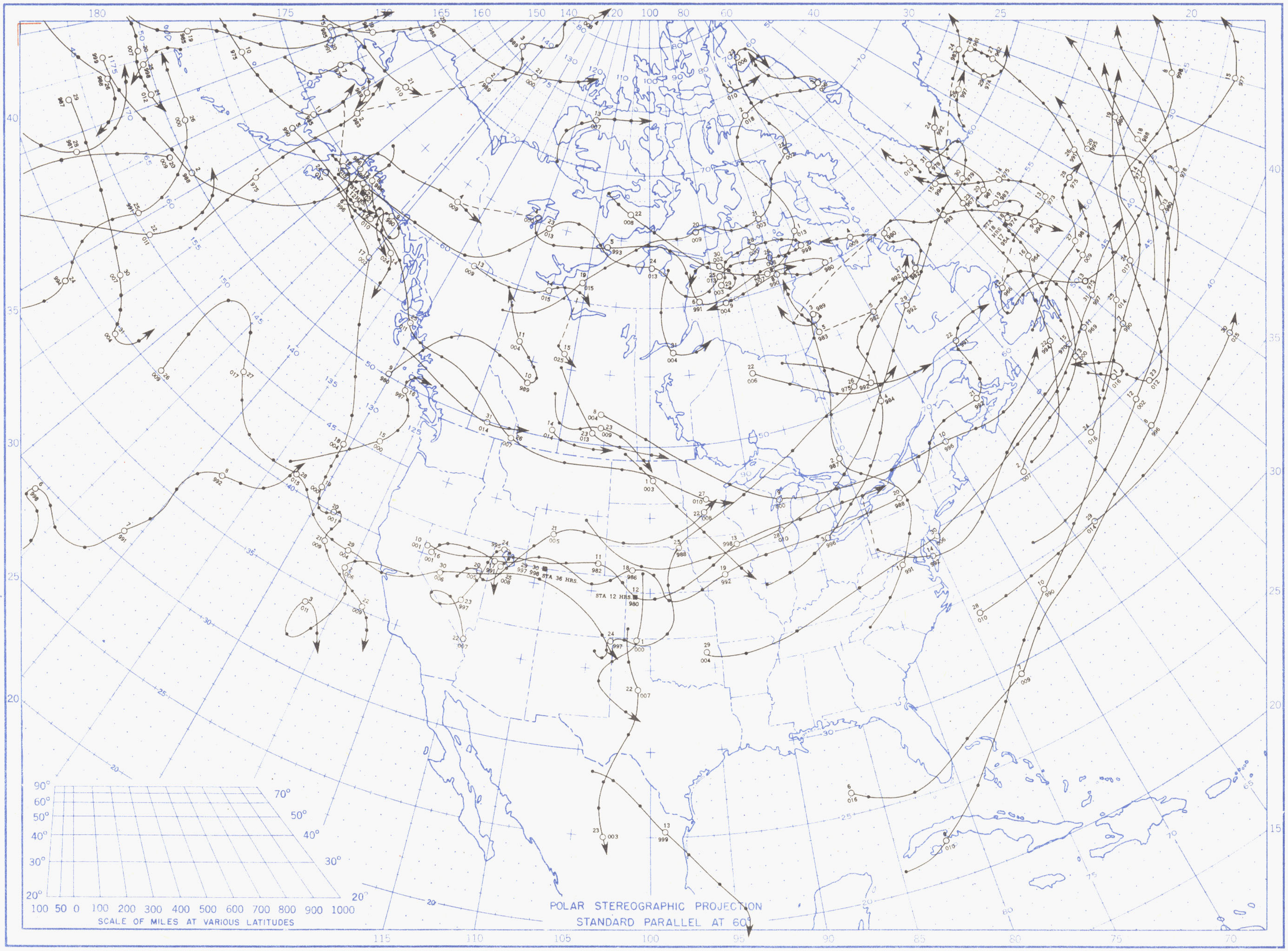
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm.$^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown.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

Chart IX. Tracks of Centers of Anticyclones at Sea Level, ~~April~~ MARCH 1954.

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.

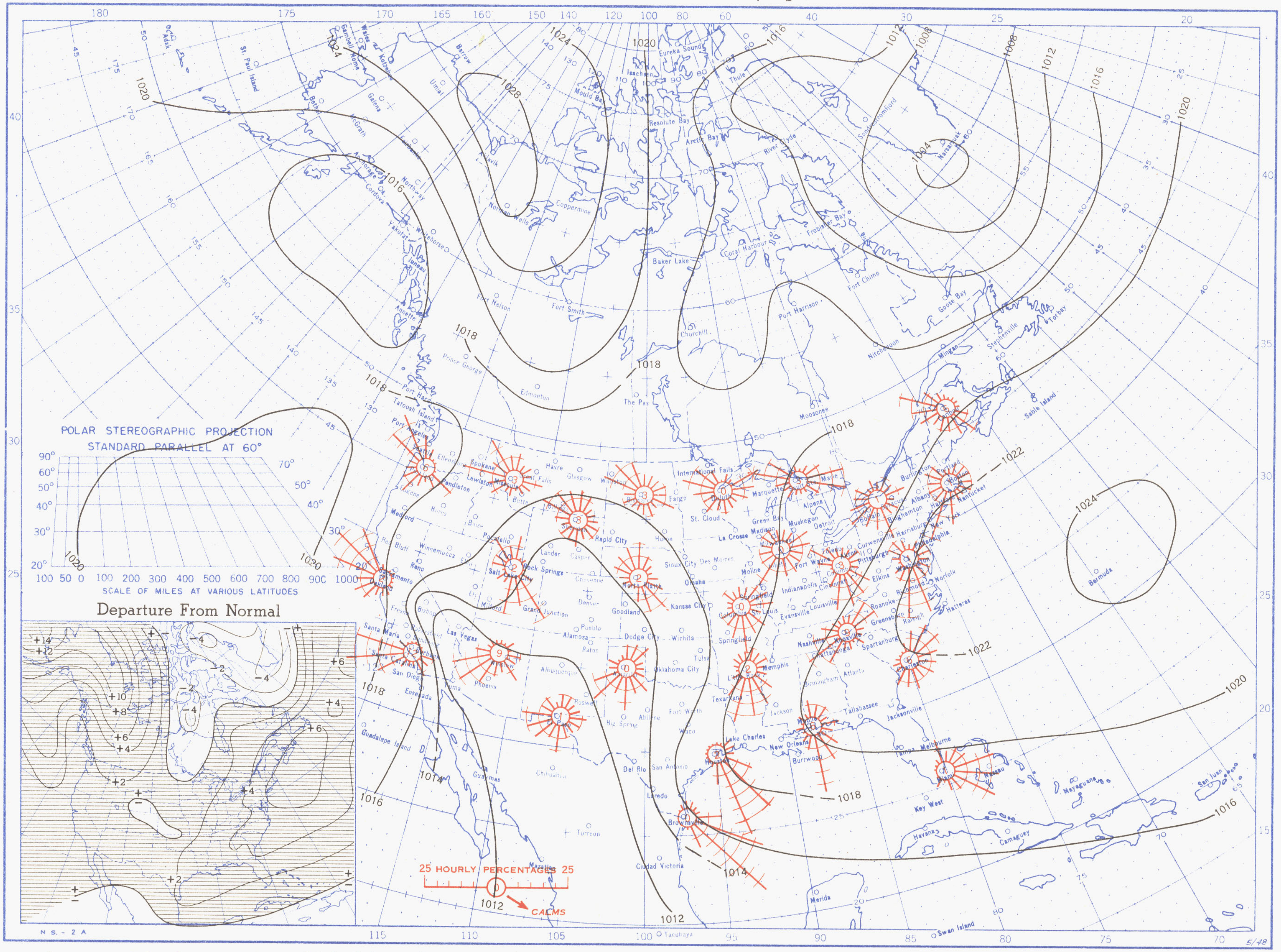
Chart X. Tracks of Centers of Cyclones at Sea Level, ~~April~~ MARCH 1954.

(See Mar 1954 for Apr.)



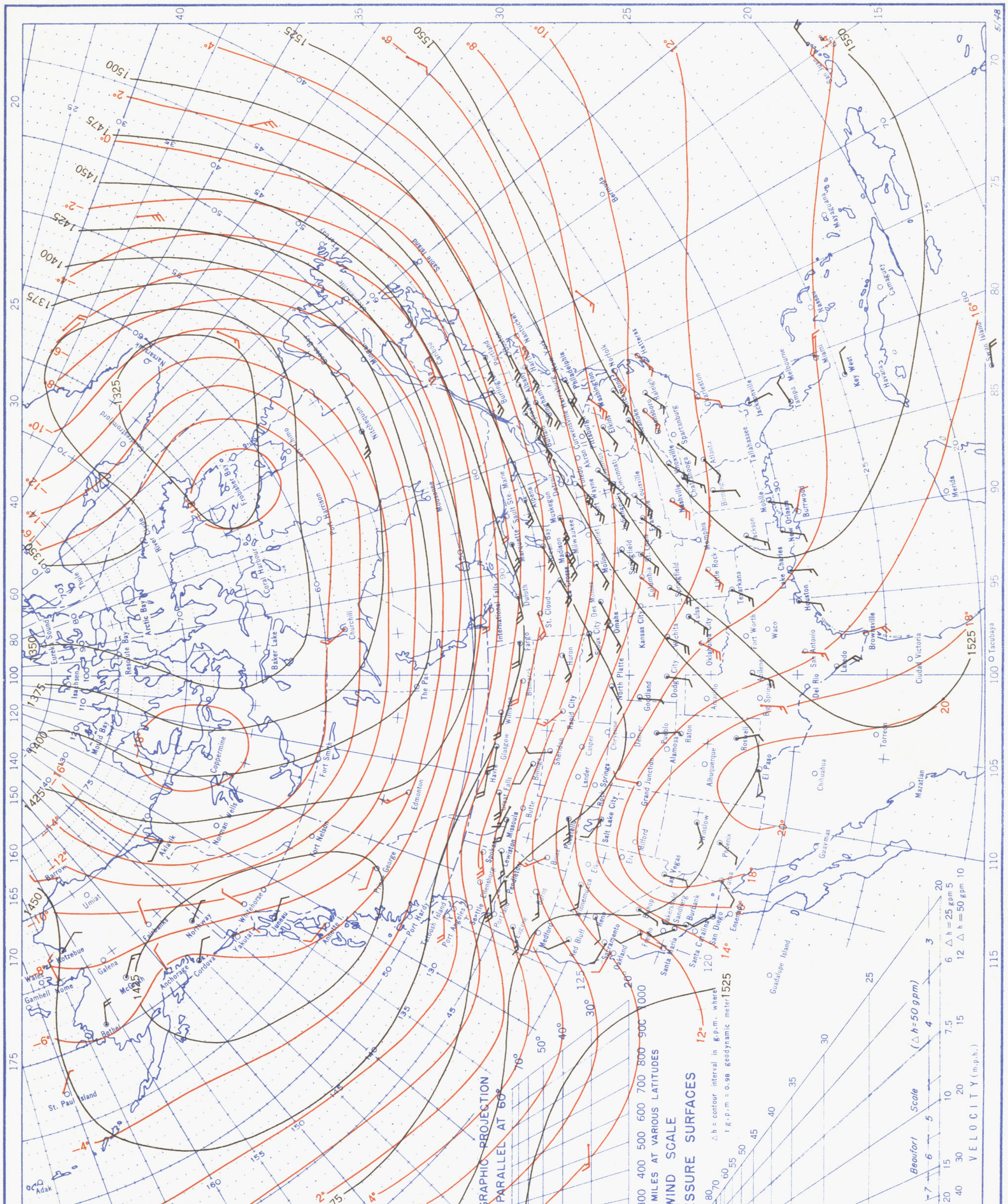
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, April 1954. Inset: Departure of Average Pressure (mb.) from Normal, April 1954.



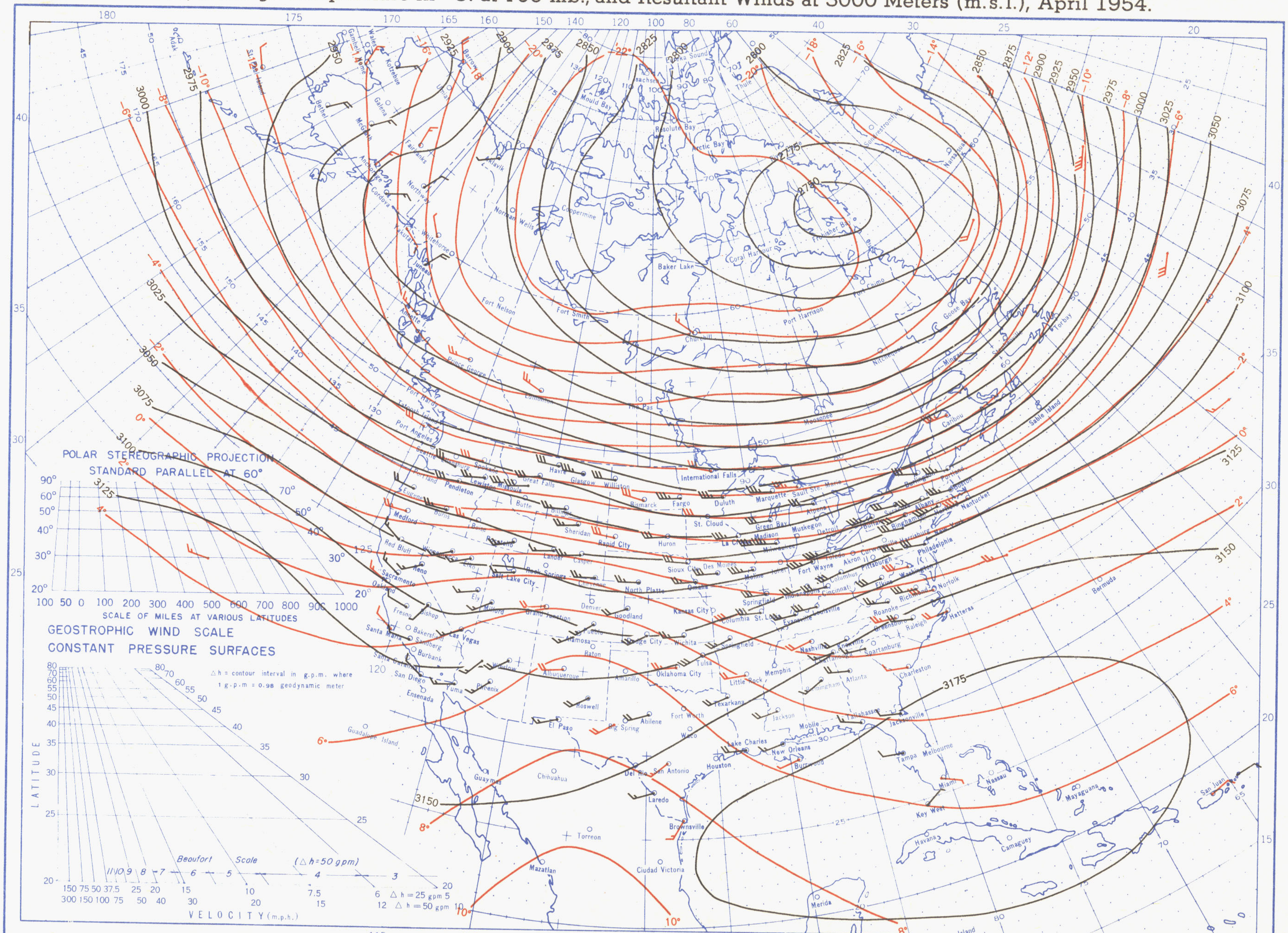
Average sea level pressures are obtained from the averages of the 7:30 a.m. and 7:30 p.m. E.S.T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

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.), April 1954.



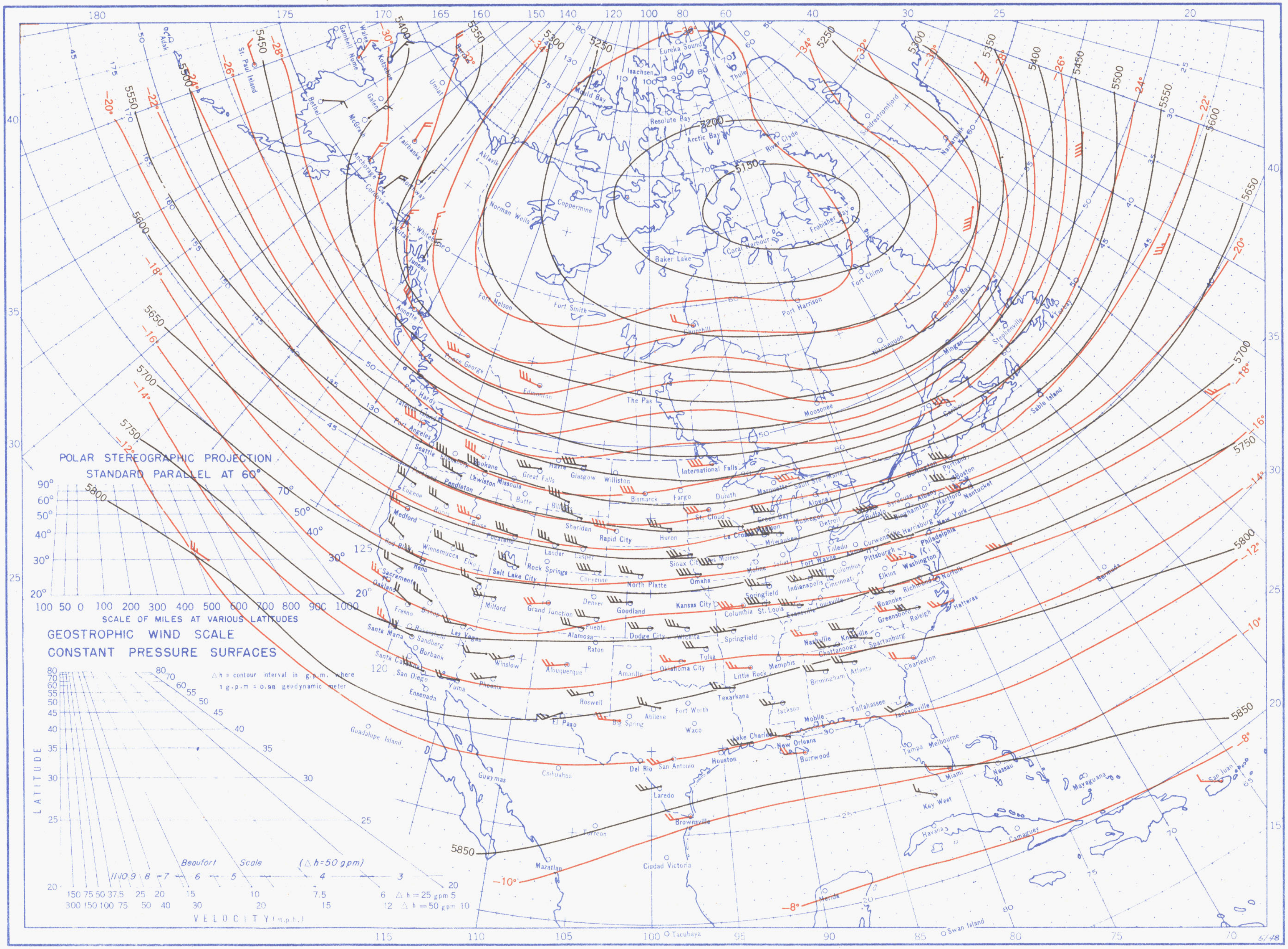
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

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.), April 1954.



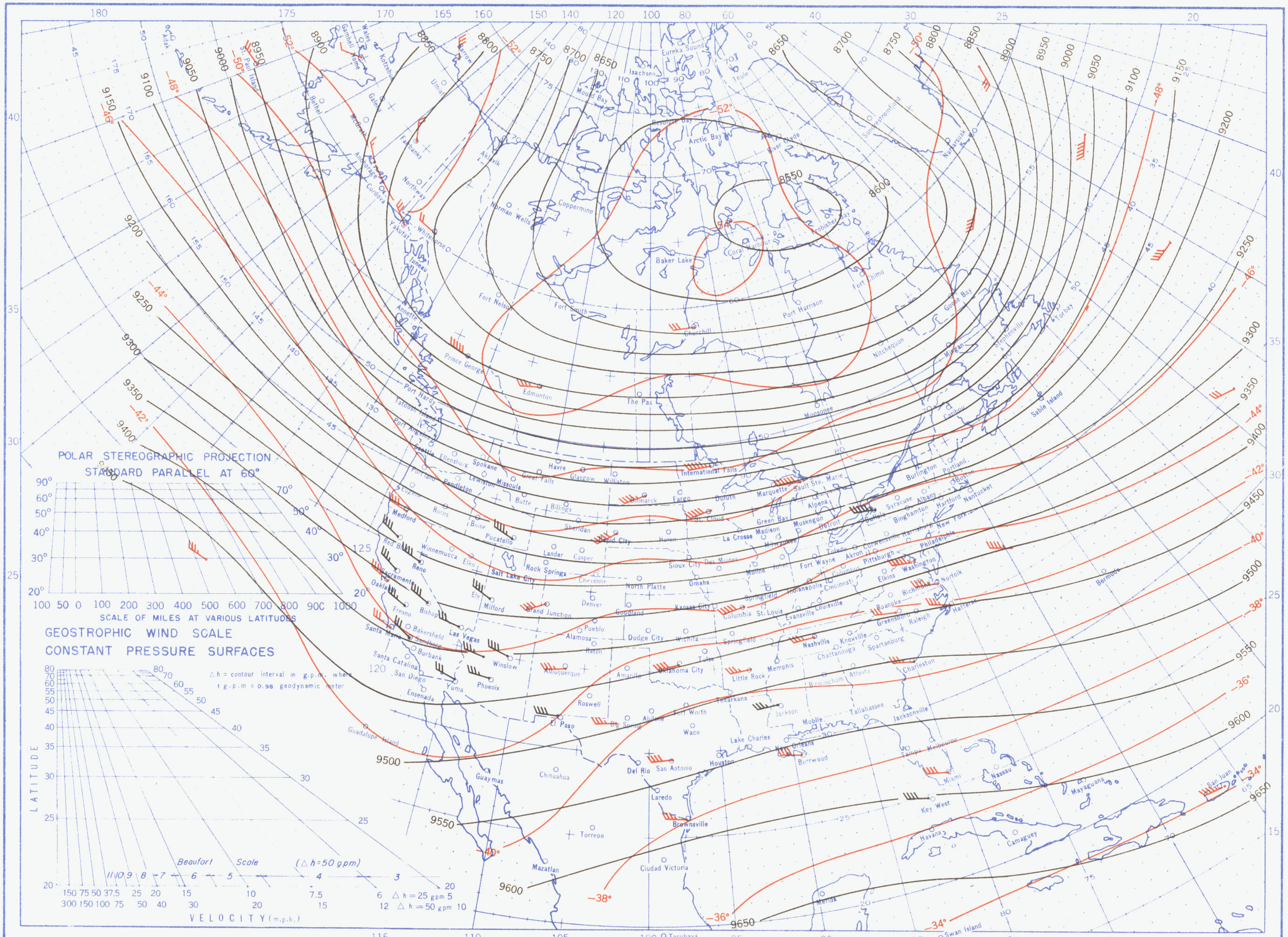
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

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.), April 1954.



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. Wind barbs indicate wind speed on the Beaufort scale.

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.), April 1954.



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. Wind barbs indicate wind speed on the Beaufort scale.