SECTION II.—GENERAL METEOROLOGY.

THE DISTRIBUTION OF SNOWFALL IN CYCLONES OF THE EASTERN UNITED STATES.[1]

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[Dated, Harvard University, Cambridge, Mass., June 12, 1914.]

The distribution of snowfall in cyclones may be studied in a general way with weather-maps, but more in detail with the original reports of the coöperative observers of the Weather Bureau in addition. Through the kindness of Mr. P. C. Day, Chief of the Climatological Division of that bureau, the writer was enabled to examine the original records for the eastern United States covering two snowstorms, February 10–14, 1899, and February 20–23, 1912. In charting the snowfall for each day of these periods, many of the observations could not be used because the snowfall had been recorded only for the storm as a whole. However, these records were employed in drawing the charts of the total snowfall of each storm reproduced as figures 6 and 11. The daily snowfall records are homogeneous to the extent that the observations were generally taken within two or three hours of sunset each day. On account of the strong winds accompanying the two snowstorms, the snow was badly drifted and packed in many places, thus rendering the observations subject to large local errors. However, the use of 800 to 1,000 stations for each storm in preparing the charts, probably eliminated many such irregularities. These storms will be discussed in detail after a general consideration of cyclones and snowfall.

Cyclones and snowfall.

In winter most of the precipitation of the eastern United States is produced chiefly by the forced ascent of converging winds about the centers of cyclones. Loomis (1) found that the centers of the precipitation areas of cyclones generally lie near the center and on the east side or front of the cyclone. On this side the winds are rising more strongly than behind, for the cyclone, moving as a wave, meets the winds in front and draws away from those behind. Mr. W. G. Reed, in a study of the cyclonic distribution of rainfall in the United States (2), found that the area of heaviest precipitation usually occurred on the side of the cyclone track which was nearer a large source of moisture. Thus, in the eastern United States, the combined effect of the motion of the storm and the positions of the Great Lakes and Atlantic Ocean generally locates the region of greatest precipitation in the northeast quadrant of cyclones.

With proper temperature conditions the previously-mentioned distribution of precipitation applies to snowfall. Active condensation taking place below 32° F. forms snow crystals, which reach the ground if they are not entirely melted or evaporated on the way. Mr. W. A. Bentley of Jericho, Vt., has made a great many photomicrographs of snow-crystals (3). He classified these not only according to form but also on the basis of their cloud associations and the cyclonic quadrant in which they occurred. The two principal forms of snow-crystals are the tabular and the branching, stellate forms. The former seem to be associated with the upper clouds and the latter with the lower ones. Perfect crystal forms occur most frequently in the west half of the cyclone. In the east half broken and unsymmetrical forms are produced by turbulent winds and melting. Many flakes passing through clouds of undercooled liquid drops become coated with granular ice and fall to the earth rapidly. A similar heaviness is produced when snowflakes partly melt in a warm stratum and freeze in a cold layer of air. In the center of a cyclone, all forms may occur.

Turning now to snowfall amounts, in the region of the warm southerly winds on the southeast side of a cyclone, heavy snowfall does not usually occur. Thus snowstorms in the eastern United States are generally confined to the northwest halves of cyclones. The heaviest snowfall occurs as near the center and as much to the northeast as temperatures permit. Any melting of the snow in the air or on the ground reduces the apparent depth of snowfall. So the greatest depth of snowfall is not necessarily reported from the region of greatest precipitation in the form of snow, but generally from farther north where with perhaps less precipitation the snow-cover formed was less dense.

This cyclonic distribution of snowfall is strongly modified by local topography. Winds blowing from water to land in winter are cooled in several ways: (1) by radiation to the cold land—or snow—surface; (2) by mixture with cold air; (3) by expansion in forced ascent, when friction diminishes the wind velocity and when the winds are forced to rise with increasing altitude of the land. Such effects tend to intensify cyclonic snowfall or to cause snowfall beyond the limits of the precipitation produced by cyclonic action. Thus, the immediate leeward shores usually have more snow than areas a short distance inland. The expansion of air rising on the windward sides of mountains also augments cyclonic snowfall. The warming by compression as the wind descends on the leeward sides has the opposite tendency.

Snow storm of February 10–14, 1899.

The two snowstorms shown on the appropriate weather-maps and the accompanying charts are intense examples of the usual distribution of snowfall in winter cyclones. The storm of February 10–14, 1899 was preceded by very cold weather over the central and northeastern United States. As a result of the strong temperature gradient between the Central States and the Gulf of Mexico, a convectional circulation was established in which a cyclone gradually developed. This cyclone moved from Florida northeastward, sweeping the entire Atlantic coast with its northwestern half. On account of the accompanying low temperatures, the precipitation was mostly snow. (See the Daily Weather Map of the United States for the dates in question.)

Figure 1 shows the snowfall from sunset February 9 to sunset February 10, 1899. The snowfall indicated in the Lake region was locally produced by the on-shore winds from the Lakes. That of the central Mississippi and lower Ohio valleys was probably the result of weak cyclonic action. The snowfall of the Gulf States occurred in the southern convectional circulation. The next day

[1] This work was presented as part of the requirements for the degree of Doctor of Philosophy in Climatology at Harvard University, May, 1914.

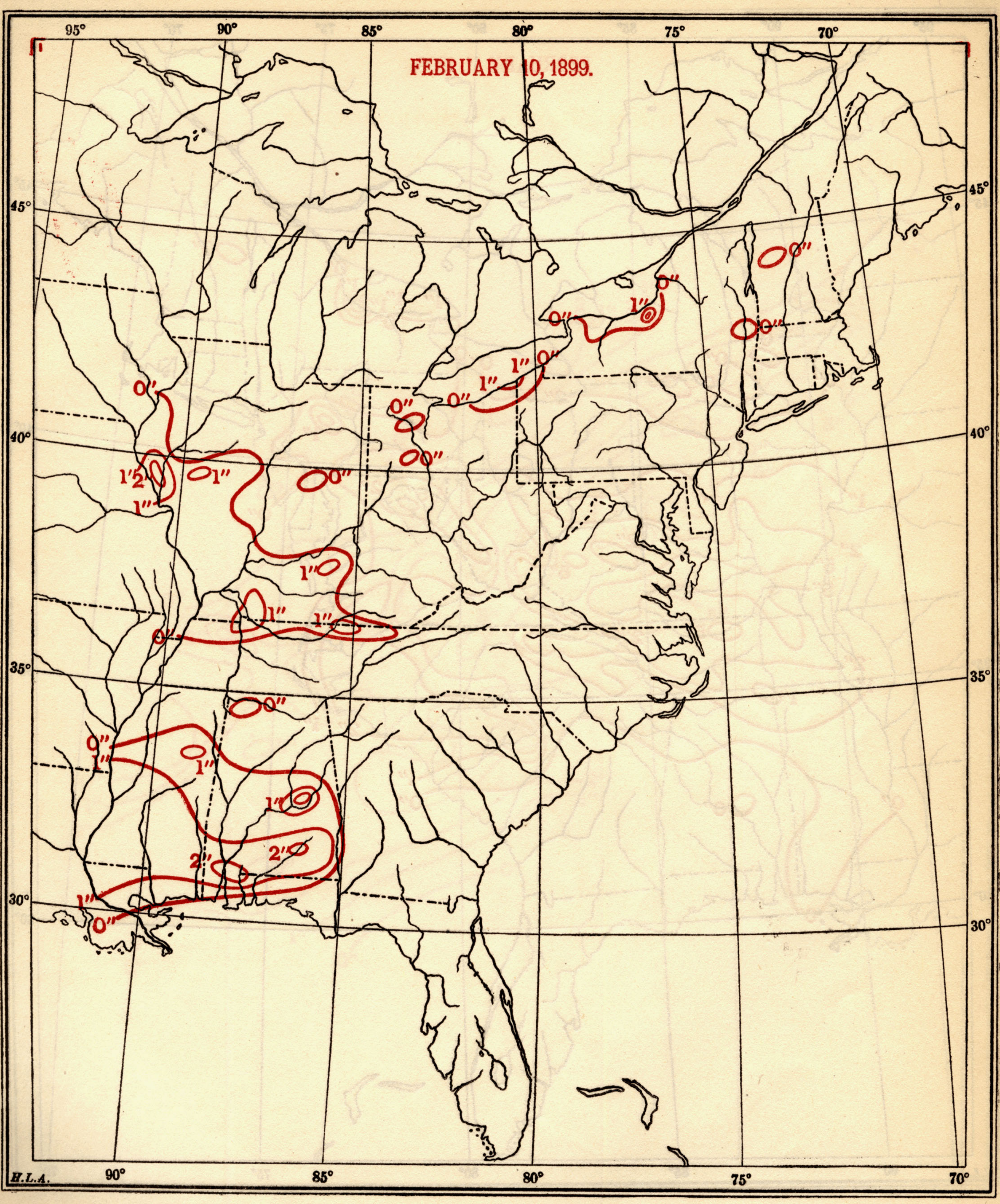

FIG. 1.—Snowfall over the eastern United States from sunset on February 9 to sunset on February 10, 1899. (Depths in inches.)

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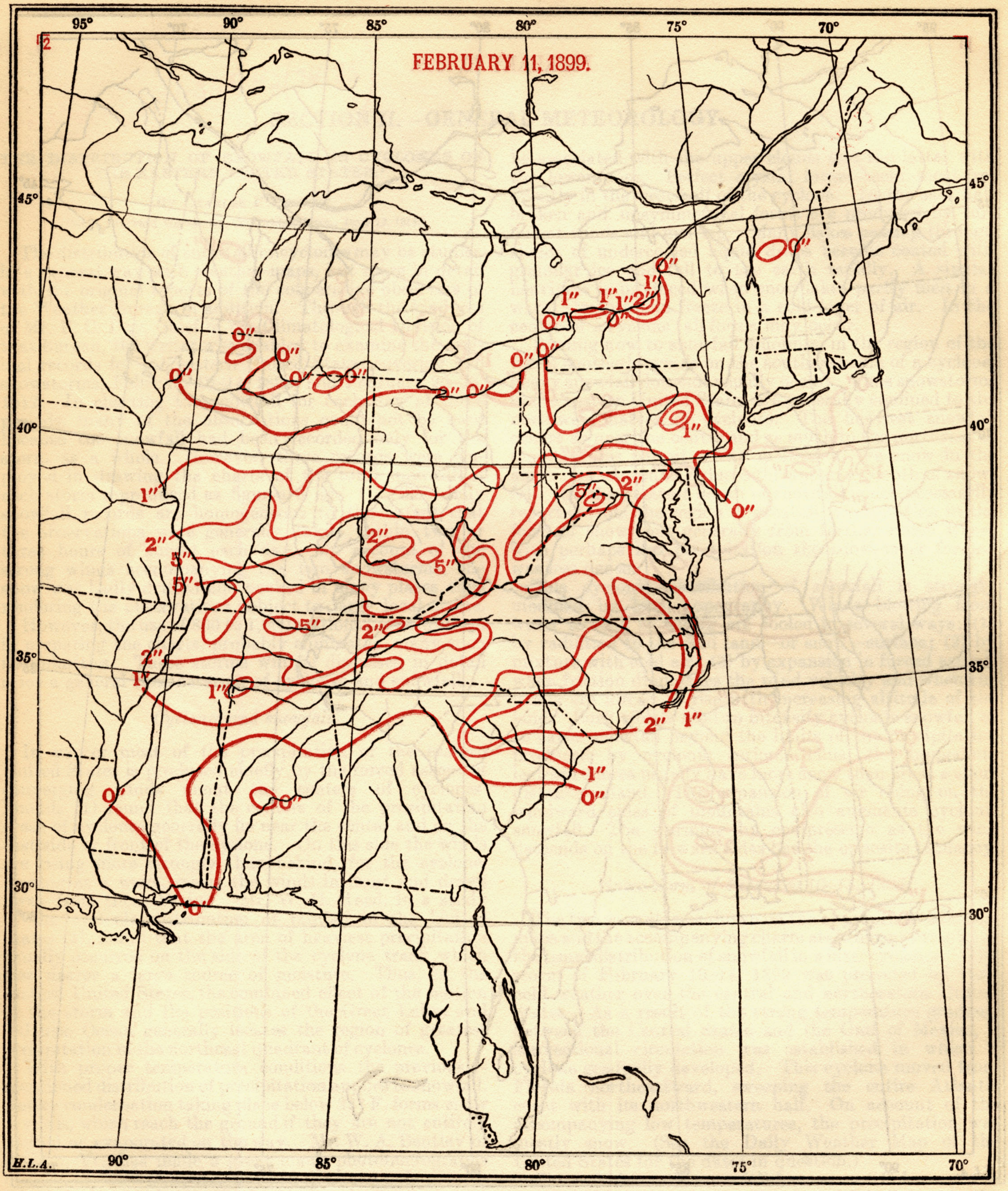

FIG. 2.—Snowfall over the eastern United States from sunset on February 10 to sunset on February 11, 1899. (Depths in inches.)

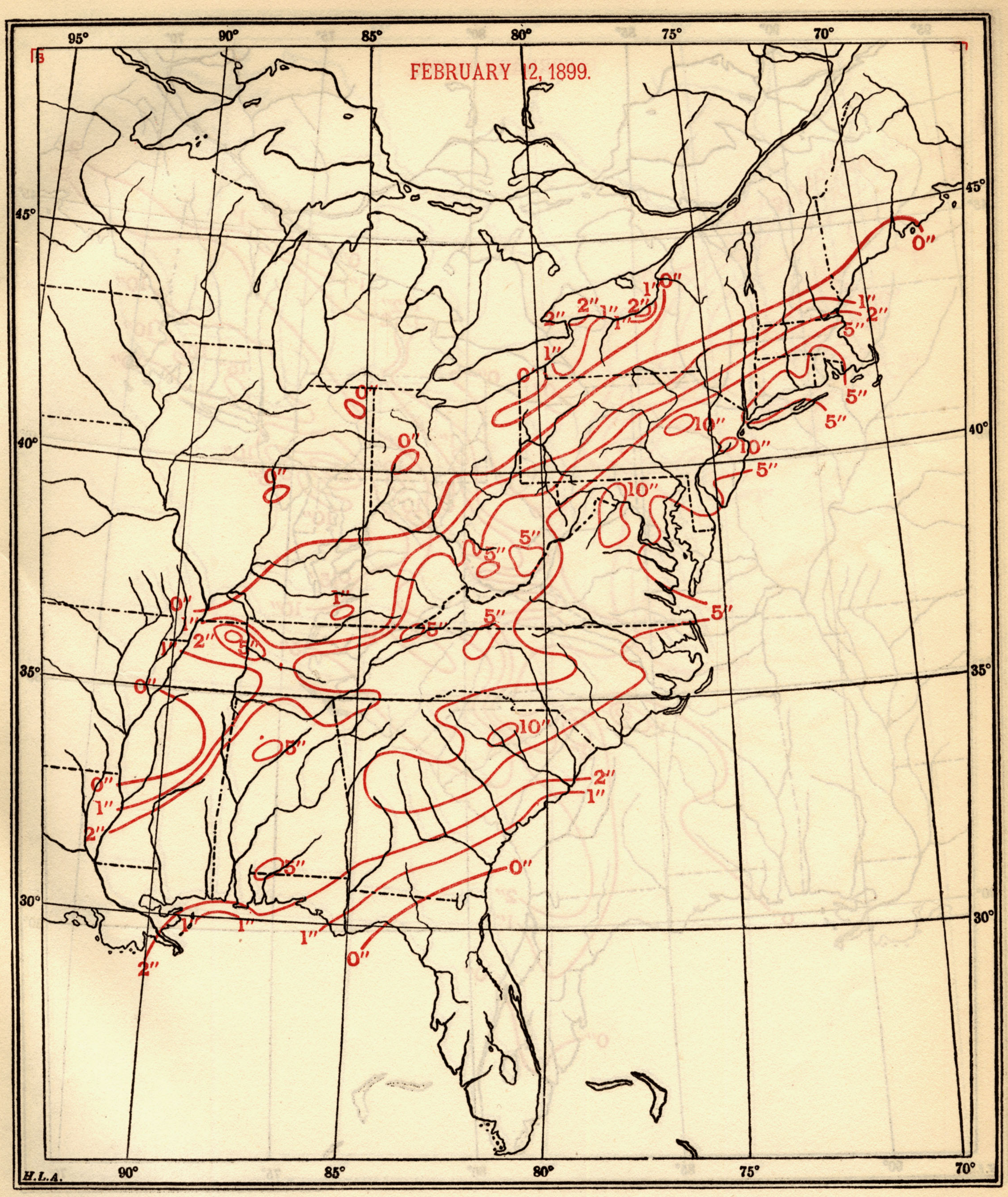

FIG. 3.—Snowfall over the eastern United States from sunset on February 11 to sunset on February 12, 1899. (Depths in inches.)

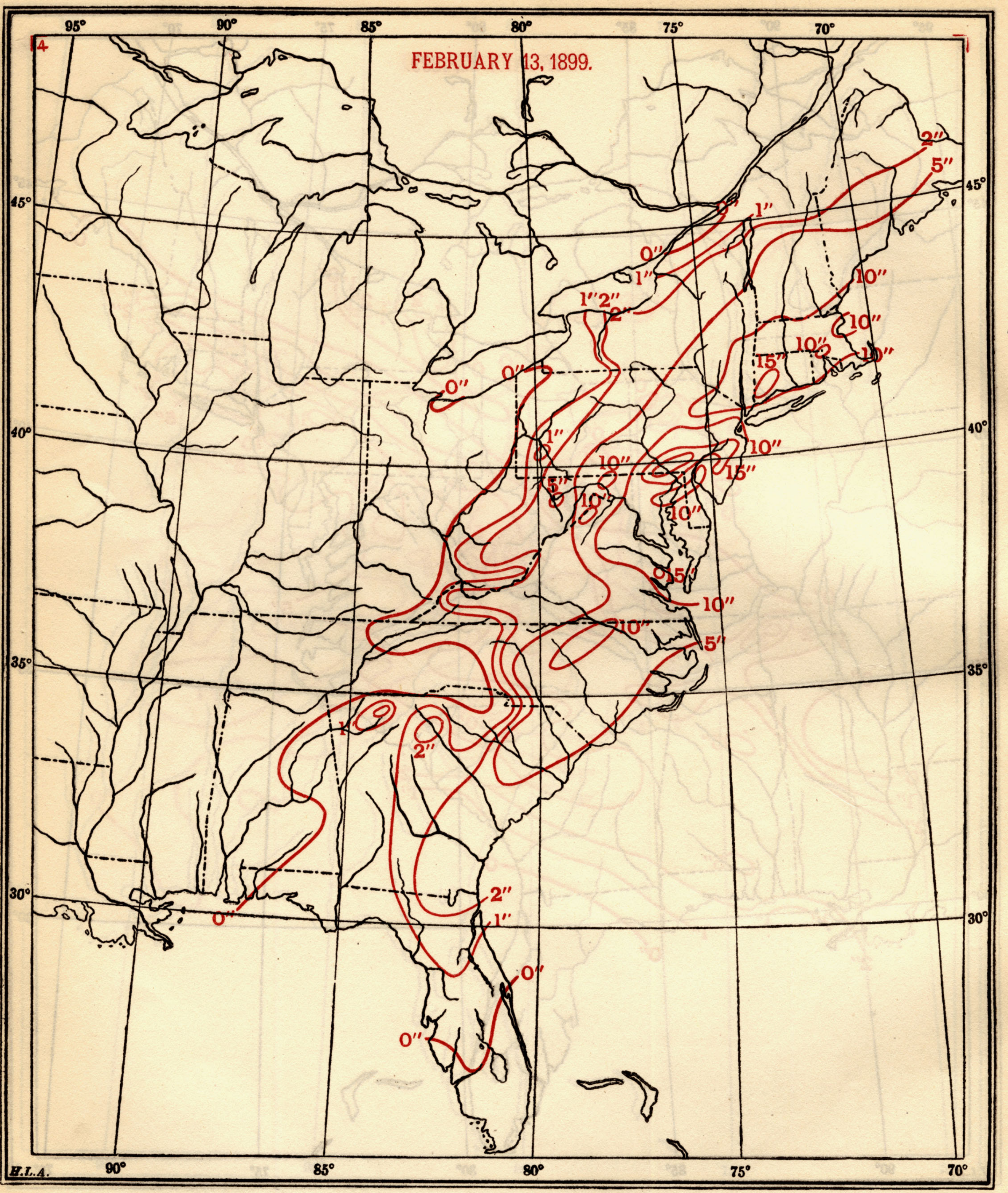

FIG. 4.—Snowfall over the eastern United States from sunset on February 12 to sunset on February 13, 1899. (Depths in inches.)

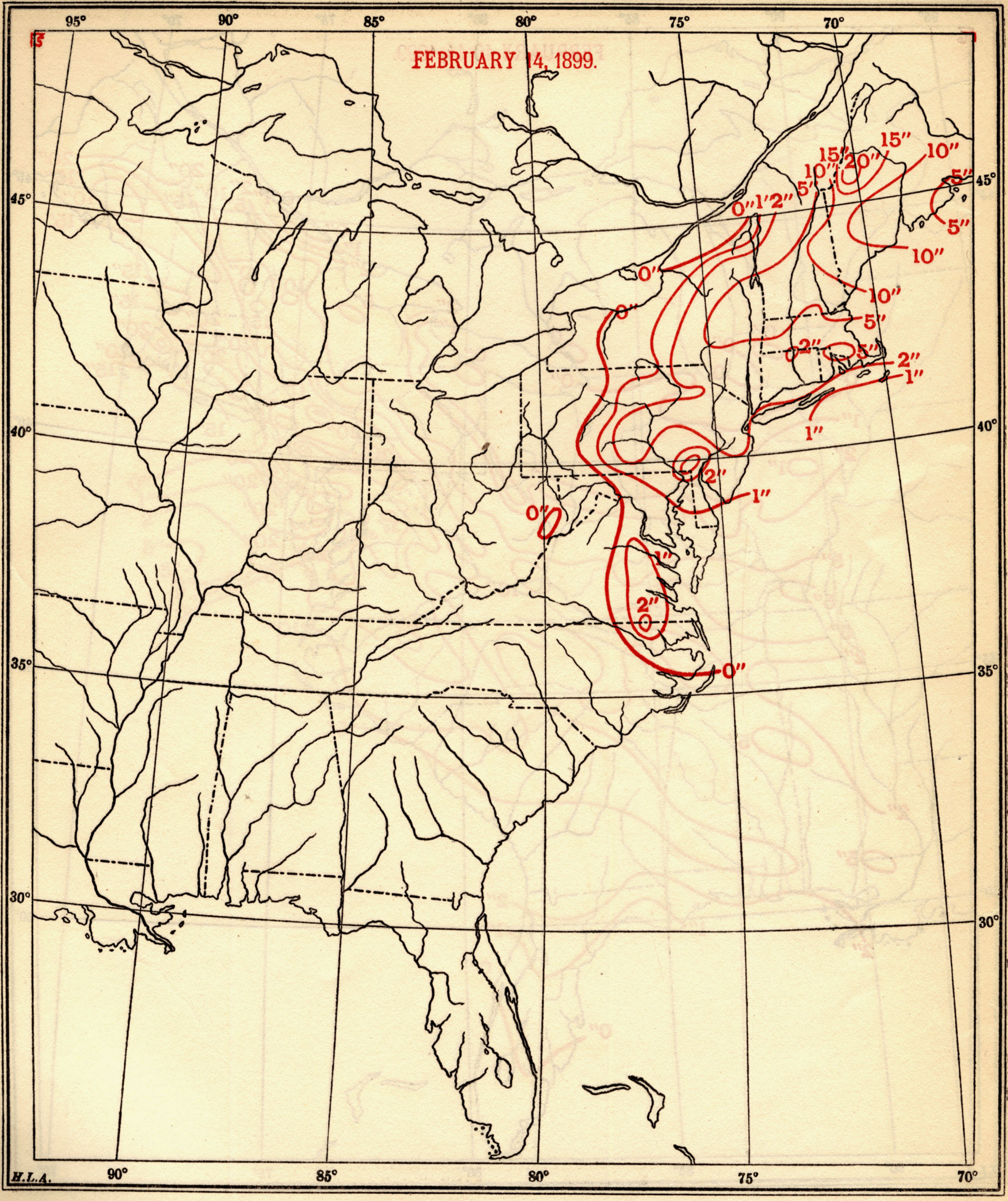

Fig. 5.—Snowfall over the eastern United States from sunset on February 13 to sunset on February 14, 1899. (Depths in inches.)

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Fig. 6.—Total snowfall over the eastern United States for the storm of February 10–14, 1899. Two maxima of 44 inches each occurred in south-central New Jersey and in southeastern Pennsylvania. (Depths in inches.)

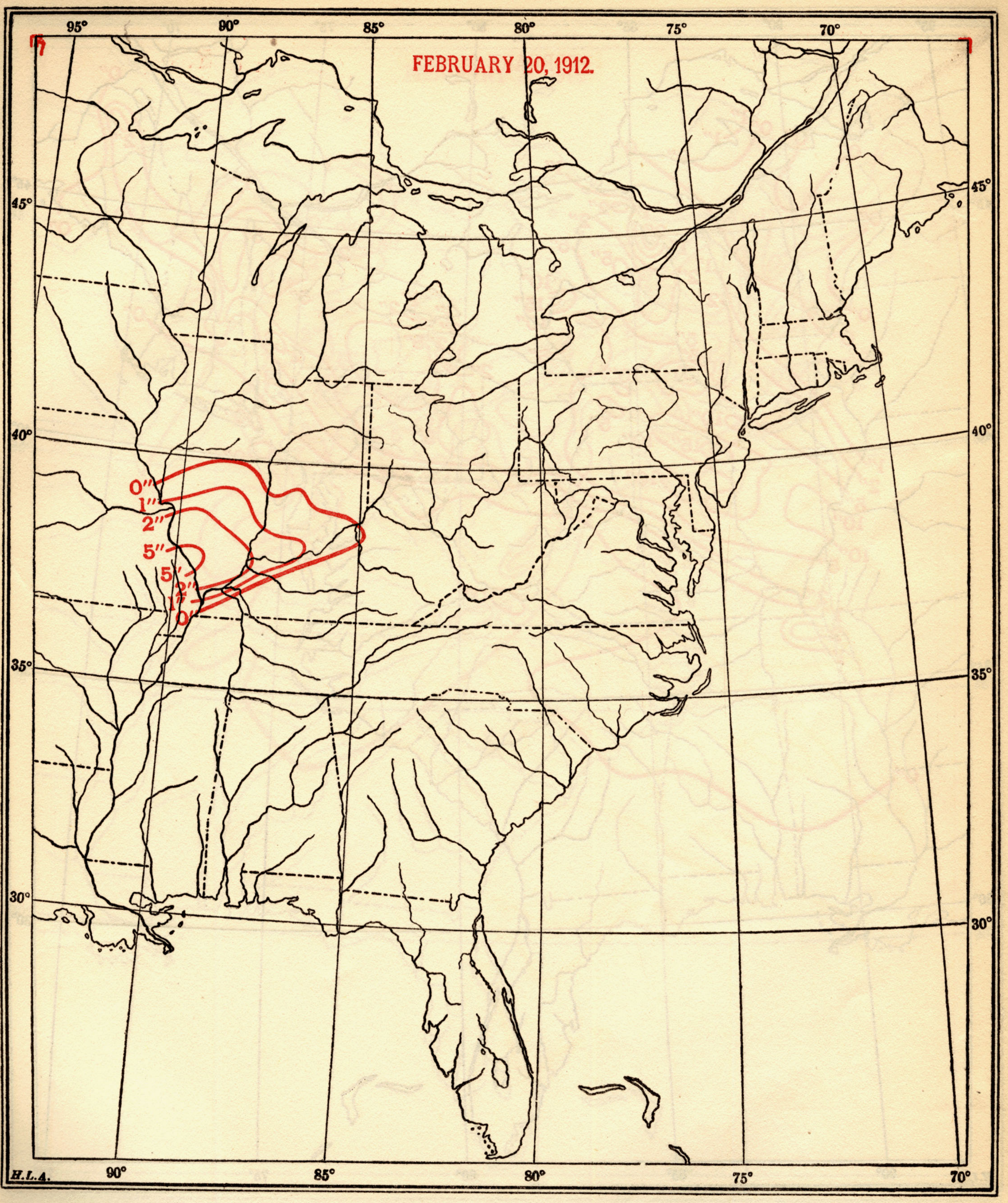

FIG. 7.—Snowfall over the eastern United States from sunset on February 19 to sunset on February 20, 1912. (Depths in inches.)

FIG. 8.—Snowfall over the eastern United States from sunset on February 20 to sunset on February 21, 1912. (Depths in inches.)

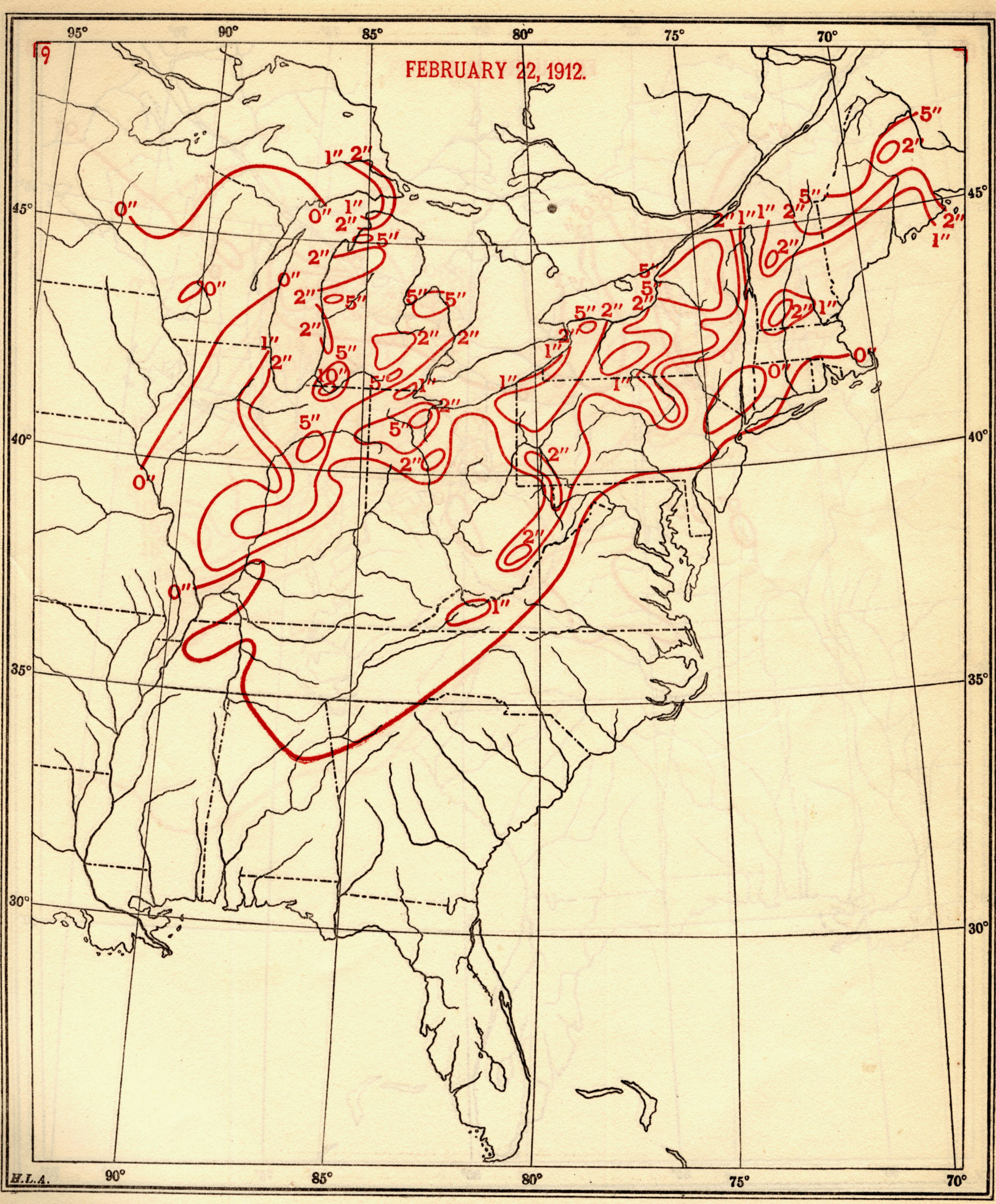

FIG. 9.—Snowfall over the eastern United States from sunset on February 21 to sunset on February 22, 1912. (Depths in inches.)

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FIG. 10.—Snowfall over the eastern United States from sunset on February 22 to sunset on February 23, 1912. The fall over Lakes Huron and Michigan shows the advance of another cyclone. (Depths in inches.)

FIG. 11.—Total snowfall over the eastern United States for the storm of February 19-23, 1912. The belt of maximum fall is 150-200 miles north of the track of the Low center (Depths in inches.)

(figure 2) the snowfall in the south was interrupted during a temporary rise of temperature, but that in the Ohio valley increased in intensity as the pressure fell. By the morning of the 12th, the southern cyclone had appeared and in connection with it, snow was falling over a large area (figure 3). The snowfall as it began over the Middle Atlantic States is described as having come from a hazy sky. No. 405 of Mr. Bentley's (4) photographs of snow crystals shows the small tabular snow-crystals which fell in Jericho, Vt., on February 13, 1899 (5). As the cyclone increased in strength and moved up the coast the snowfall area became more localized and the snowfall heavier (see U. S. Daily Weather Map, February 13, 8 a. m., and figure 4). By February 14 at 8 a. m. the cyclone had advanced to Nova Scotia and snow had stopped falling over most of the eastern United States, as is evident from figure 5.

Figure 6 shows the distribution of the snowfall of the whole storm. Two maxima of 44 inches each occurred in south-central New Jersey and in southeastern Pennsylvania. Depths of more than 30 inches were reported from southeastern Massachusetts, eastern Pennsylvania, Delaware, eastern Maryland and northern Virginia. Thus, the snowfall was at a maximum where the strongest pressure gradient occurred and where local topography had the greatest cooling effect on the snow-bearing winds. The distribution of snowfall in this storm is characteristic of the northeast snowstorms of the Atlantic coast,—the heavy snowfall being generally confined to a belt about 200 miles wide along the coast.

Snowstorm of February 20–23, 1912.

The snowstorm of February 20–23, 1912, attended a well-developed elliptical cyclone which moved in a nearly straight path from the western Gulf States to the Gulf of St. Lawrence. In front of the cyclone was the characteristic sirocco with heavy rain and thunderstorms; in the rear followed the cold-wave with snowflurries, and on the north, was the heavy northeast snowstorm. The isotherm of 32° F. passed in a general northeast-southwest direction through the center of the cyclone, dividing the rain- from the snow-area. Far in front, with the usual southward bend of the 32° isotherm, the snowfall area (figure 7) extended south of the track of the center of the cyclone. Nearer the center, rain fell. (See U. S. Daily Weather Map for February 21, 1912, 8 a. m.)

The snowfall chart for February 21 presented in figure 8 shows the large southward extent of the light snowfall of west-wind snow-flurries. Figure 9 for the next day shows this area farther east. The central Appalachians are marked by heavier snowfall on the windward side and none on the leeward. Likewise the western Adirondacks had more snowfall than the eastern: this was the reverse of the conditions of the day before, when an east wind was bringing the snow. On February 23 (fig. 10) the west winds of the eastern Great Lakes made heavy snowfall on the leeward shores and mountains. Around Lakes Huron and Michigan, snowfall with southerly winds was beginning with the advance of another cyclone.

Taking the storm as a whole (fig. 11), the snowfall, although patchy, occurred in belts as was the case in February, 1899. The belt of maximum snowfall was, on the average, 150 to 200 miles north of the track of the center of the cyclone. In this belt the heaviest snowfall, 30 inches, occurred on the west shore of Lake Huron, most of it falling on the 21st with the easterly gale. The next heaviest snow, 24 inches, fell on the southeast shore of Lake Michigan with a north and northwest wind (6). Thus, both areas of maximum snowfall were located where cyclonic and local effects made the strongest combination.

SUMMARY.

As illustrated by the great snowstorms of February 10–14, 1899 and February 20–23, 1912, the distribution of snowfall in cyclones of the eastern United States is controlled by cyclonic action, temperature, topography and proximity to large sources of moisture. This distribution is roughly as follows:

1. The snowfall is spread over a wide territory on each side of the track of the cyclonic center.
2. The heaviest snowfall comes with northeast winds and occurs in a belt about 100 to 200 miles north of the track.
3. The northwest winds in the southwest quadrant sprinkle light snowfall over the country to a distance of about 300 miles south of the track of the center of the cyclone.
4. The effects of local topography and geography make the distribution of snowfall patchy.

The writer wishes to acknowledge the courtesy of Mr. R. H. Weightman of the Forecast Division, U. S. Weather Bureau, in sending tracings of some of the 8 p. m. weather maps.

REFERENCES.

(1) Contributions to Meteorology, 1882.
(2) Monthly Weather Review, 1911, pp. 1609–1616.
(3) Monthly Weather Review, May 1901; do., Ann. Sum. 1902.
(4) Monthly Weather Review, Ann. Sum. 1902, Plate II (XXX–119).
(5) Detailed accounts of this storm and its human effects are given in the Monthly Weather Review, February 1899, and in the Weather Bureau Climate & Crop Reports, February 1899, for the different States.
(6) For a study of snowstorms with reference to wind direction and cyclonic action see A. B. Crane, Snowstorms at Chicago. Am. Met. Journ. 1892, pp. 63–66.

ON THE INFLUENCE OF THE DEVIATING FORCE OF THE EARTH'S ROTATION ON THE MOVEMENT OF THE AIR.(1)

[Communicated to the International Meteorological Congress at Chicago, Ill., August, 1893.][1]

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(Dated Statens Meteorologiska Centralanstalt, Stockholm, 1893. Revised by the author, June, 1914.)

I. ON RELATIVE MOTION IN GENERAL.

Let there be a system of material particles or points at which observers are stationed; the earth's surface constitutes such a system. An observer at one point of this system can detect a motion of the other points only by means of the changes in their mutual distances and directions and will thus conclude that the whole system is at rest. This perception of motion among the particles of a system is called relative motion.

Now suppose the whole system of material particles to include not only the earth but also the whole solar system; then all motions are considered as relative to this system, which as a whole is supposed to be at rest.

If the system include the whole universe, then the latter must necessarily be considered as at rest. Since we have no more general system of points, therefore, motion relative to the universe as a whole is the most general of which

[1] See MONTHLY WEATHER REVIEW, February, 1914, 42: 93.