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USEFUL RELATIONSHIPS BETWEEN 500 MB FEATURES AND MAJOR FREEZE EVENTS IN THE LOWER RIO GRANDE VALLEY OF TEXAS

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INTRODUCTION

The Lower Rio Grande Valley of Texas is subject to freezes that severely damage the citrus, sugar cane, and winter vegetable crops. Notable damaging freezes occurred in 1930, 1949, 1951, and 1962--a rate of occurrence that is too infrequent for the development of objective or statistical forecast aids. Yet, the forecaster has a responsibility to forecast these freeze events several days in advance in order to allow the agribusiness interests in the Valley to take action to cut potential losses.

The forecaster must recognize those situations when he will have to deviate from "guidance," since it is likely that the guidance based on statistical methods will not identify rare or extreme events. The forecaster does not necessarily have to accurately (in a conventional sense) forecast minimum temperatures during a severe freeze several days in advance; rather, it is sufficient for him to be able to identify the potential for a severe freeze so that it can be communicated to the agricultural community. The farmers, growers, packers and other agribusiness people take actions commensurate with the assessed freeze potential. For example, a severe freeze threat even at a low confidence level five days in the future could trigger several low-cost actions such as review of resources and accelerated harvesting. As the freeze event time draws closer and the confidence level of a damaging freeze increases, the actions to decrease losses would become more intense, more expensive, and more widespread.

This study was designed to provide the forecaster with guidelines to assist in the subjective evaluation of damaging freeze threats several days in advance.

ARCTIC OUTBREAKS AND THE LOWER RIO GRANDE VALLEY

The impact of severe freezes on agriculture in the Lower Rio Grande Valley is obvious from the citrus production records for the past fifty years (Figure 1). The sharp declines in production as a result of freezes are dominant even when production is plotted on a log scale (other production fluctuations are a result of variables such as cultural practices, acreage in production, and even hurricanes).

The severe freeze of January 1962 destroyed about half the fruit on the trees of the 1961-62 season and about 99 percent of the 1962-63 crop because nearly all bearing wood was destroyed. Minimum temperatures at representative climatological stations in the Valley during the January 1962 freeze are contained in Table 1, along with lows for other selected freeze events referenced in this study.

The surface chart associated with the January 1962 freeze clearly depicted an Arctic outbreak; in fact, the surface anticylone has been termed the greatest anticyclone in the United States history (Ludlam, 1962; Stark, 1962; and USWB Office of Climatology, 1962). A surface chart near the time of maximum strength of the high is shown as Figure 2 and the 500 mb features are shown in Figure 3.

Other freezes have not been as disastrous as the 1962 freeze, but even a lesser freeze event such as the December 1973 freeze when ten percent of citrus production was estimated to have been lost is very important to the Valley agribusiness.

ARCTIC OUTBREAK SYNOPTIC PATTERNS

Although the January 1962 Arctic outbreak set numerous records for high surface pressure and low temperature, the synoptic pattern was not unusual. It exhibited a polar or Arctic outbreak[1] type of anticyclone as contrasted with the anticyclone of a cyclone family series (see Petterssen, 1969). The distinction is important; the major freeze events of the Lower Rio Grande Valley of Texas have all been associated with Arctic outbreaks. Freeze events can occur with an anticyclone of a cyclone family series, but require the radiative cooling conditions of clear skies and light winds. The duration of below freezing temperatures, typically a few hours, is much less than that of the Arctic outbreak, when 68 hours of below freezing temperatures were recorded at Harlingen in the 1962 freeze in the Lower Rio Grande Valley (Young and Peynado, 1962).

The other disastrous freeze of the last fifty years in the Valley was also associated with an Arctic outbreak. The Arctic outbreak of late January and early February 1951 was memorable for both the disastrous freeze in the Lower Rio Grande Valley and the ice storm, common to the Arctic outbreak, which clothed the South with as much as eight inches of ice. The total freeze and ice damages were estimated at $100,000,000 (Harlin, 1952, and Miller and Gould, 1951).

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1. In polar frontal theory, the terms polar and Arctic are not synonymous. To avoid semantic difficulty, the term Arctic will be used throughout the life cycle of the cold air outbreak, although it will change throughout its history from Arctic to polar to, eventually, sub tropical.

The similarities between these two outbreaks and other Arctic outbreaks are sufficiently pronounced to describe, at least tentatively, the characteristic features of the 500 mb synoptic patterns associated with the Arctic outbreaks which produce major freezes in the Lower Rio Grande Valley.

As shown in Figure 4, the 500 mb patterns during the 1951 and 1962 Arctic outbreaks were very similar; a deep polar vortex over Baffin Bay, a major trough over the northern United States with an east-west trough line, zonal flow south of the trough line and northerly flow from a high amplitude ridge north of the trough line. The events preceding these patterns were also very similar. From the breakdown of a high-latitude short wave omega-type block in the long wave ridge, the trough associated with the eastern low moved southward, intensifying while maintaining a general east-west orientation. The combination of the ridge aloft and surface radiative cooling facilitated the development and maintenance of the surface anticyclone, which also began to move southward under the northerly flow aloft. In the four days from 5 Jan to 9 Jan 1962, the surface anticyclone built from a 1025 mb central pressure over the Bering Straits to a 1060 mb high over Alberta.

In both cases, the omega block opened up as the leading trough line moved southward. The closed high circulation of the block became joined with the full latitude long wave ridge over the western coast and the southward moving trough line became linked to the deep low over Baffin Bay.

Another key feature was the cyclogenesis associated with the developing system. In each case, pronounced cylogenesis occurred as the low occupying the mean long wave trough position over the U.S. was ejected. In January 1962, the surface low deepened from 1006 mb central pressure to 980 mb in a 24-hour period with the cyclogenesis.

Cyclogenesis did not occur with the southward moving trough. A consequence of a lack of cyclogenesis was that the cold air was not deflected eastward from its southward trajectory (Means, 1948). The history of the 500 mb and surface patterns from the first appearance of the block for the 1962 outbreak is presented in Figure 5 and the 500 mb sequence for the 1951 outbreak is presented in Figure 6.

The Arctic outbreak of December 1964, a "scare" for the Lower Rio Grande Valley due to the presence of a 1060 mb high over northwestern Canada, also was preceded by an omega block configuration at 500 mb. When the omega block opened in this situation, the closed high moved northward and the leading closed low moved slowly southward before opening up into an east-west trough on 17 December 1964. Figure 7 shows the 500 mb sequence of the outbreak.

In each of these Arctic outbreaks, the 500 mb trough succession over the conterminous U.S. was translational. The existing long wave trough moved eastward and was replaced by the southward-moving intensifying trough. In several other Arctic outbreaks reviewed which produced freezes in the Lower Rio Grande Valley, the 500 mb trough succession pattern was that of discontinuous retrogression. The existing long wave trough was sufficiently strong that the replacement of the existing trough by the southward moving trough occurred within the mean long wave trough position. The mean trough axis shifted westward, a characteristic feature which provides the descriptive name of discontinuous retrogression (see Palmen and Newton, 1969).

The January 1949 Arctic outbreak which produced a damaging freeze in the Lower Rio Grande Valley was one of a series of Arctic outbreaks primarily over the western plateau. January 1949 was the coldest on record in Idaho; many stations averaged 20 degrees F colder than normal (USWB, 1950) during the series of outbreaks. Ice storms were also common with this series of outbreaks (Kiviat, 1949 and the USWB Annual Summaries for 1949).

The strongest outbreak and the one which produced the Rio Grande Valley freeze occurred when the high-latitude omega block opened up; the very strong short wave trough plunged southward rapidly in the northerly flow of the long wave pattern. Again, cyclogenesis did not occur with the southward moving wave. The omega block which preceded the Arctic outbreak is shown in Figure 8.

A discontinuous retrogression sequence in December 1962 produced a record cold wave across the southeastern United States; below freezing temperatures extended to Miami, Florida, and the crop damage was estimated in the hundreds of millions of dollars (USDC-USDA, 1962). The Arctic outbreak was associated with the breakdown of a short wave omega block superimposed on the long wave ridge. The mean long wave trough position was over the Southeast United States so the Arctic outbreak was steered into the Southeast; the lowest temperature in the Lower Rio Grande Valley of Texas during this outbreak was 35°F at Harlingen, Brownsville recorded 40°F as the lowest. Figure 9 shows the omega block stage of the outbreak.

A closed low moving southward from northwestern Canada will also be associated with an Arctic outbreak. This closed low is characterized by trough line oriented north-south or northwest-southeast. The trough is also frequently difluent; stronger gradient and winds exist on the western side with difluence at the trough line. Snellman (1973) noted that these closed lows with difluent, negative tilt troughs were associated with Arctic outbreaks over the plateau. The southward moving low will produce a very sharp, deep mid-continent trough through discontinuous retrogression of an existing trough. The closed low center does not necessarily have to move south of the Canadian border to be associated with an outbreak affecting either South Texas or Florida. Figure 10 shows the sequence at 500 mb during a January 1975 freeze in the Valley.

In the limited sample, the longitude of the closed low and its existing troughline determined the region of the United States to be hardest hit by the Arctic outbreak. In November 1970, a closed low moved southward over Hudson Bay; a major freeze occurred in Florida but not in South Texas. Also, in January 1971 a major freeze occurred in Florida as a result of the leading low of an omega block moving southward over Hudson Bay.

All of the 500 mb synoptic situations described can result in the development of a sharp full-latitude mid-continent trough, frequently with a closed low over the southeastern states. Each major east-west trough associated with a major Arctic outbreak rotated slowly from the east-west orientation to a deep north-south trough over the eastern United

States. The coldest temperatures in the Valley during the 1962 freeze occurred with radiational cooling on the fourth day following frontal passage. This synoptic situation favors the development and maintenance of a slow-moving mid-continent surface high, with continued cold air advection, plus the tendency for formation of a split-off high in southern Texas favors the occurrence of radiational freezes in the Lower Rio Grande Valley.

Several minor freeze events of short duration occurred with the existence of the deep trough or closed low in the southeastern states, regardless of method of formation. The cold advection of an anticyclone within a cyclone family and radiational cooling with very dry air aloft can produce a diurnal temperature range of nearly 50 degrees F.

A USEFUL THEORETICAL CONCEPT

The geopotential tendency equation developed in Holton (1972) is of particular use in this study because it provides insight into areas not addressed in the synoptic descriptions of the Arctic outbreaks. The geopotential tendency equation may be used to relate height changes at 500 mb to vorticity advection at 500 mb and to the differential temperature advection between the surface and 500 mb.

From the geopotential tendency equation, the 500 mb height will fall when there is positive vorticity advection occurring at that point at 500 mb. The magnitude of vorticity advection is normally small along the ridge line and trough line of a 500 mb wave, so the major effect of vorticity advection is to translate the wave without major amplitude changes.

Although 500 mb vorticity products were not available for the Arctic outbreak study, the operational use of vorticity and vorticity advection patterns will provide qualitative estimates of trough movement and the vorticity pattern will assist in the detection of the short waves at high latitudes when the troughs are not obvious in the contour pattern. The 500 mb prog charts may not portray the short wave omega block in the contours, but indications of the block should exist in the vorticity pattern.

The differential horizontal advection of temperature produces the major amplitude changes in a traveling wave. The 500 mb height will fall at a point where cold air advection exists with increasing strength downward; a common situation with a cold front. The strong low-level cold air advection of an Arctic outbreak will produce a rapid deepening of the

500 mb trough; similarly, a pronounced deepening of a 500 mb trough on a prog chart indicates strong surface cold air advection. The 1000-500 thickness and the inferred thickness advection may be used, with caution, to forecast the Arctic outbreak with the related 500 mb features.

DISCUSSION

Several 500 mb synoptic features are common to all major Arctic outbreaks described. The long wave pattern includes a high amplitude ridge over western North America or the eastern Pacific with a deep 500 mb long wave low system centered between Hudson Bay and Greenland. When this long wave pattern exists, the conditions for formation of the Arctic air mass and the potential for its southward movement are favorable. A major short wave embedded in the long wave flow is required for the Arctic outbreak to have a major freeze potential for the Lower Rio Grande Valley; the common rapidly-moving short waves, accompanied by the cyclogenesis and frontogenesis in the lee of the mountains, did not produce a major freeze in South Texas in the limited sample studied.

Two 500 mb short wave configurations were readily identifiable as Arctic outbreak potential; a closed low moving southward over the Prairie Provinces of Canada and the breakdown of a short wave omega block superimposed in the long wave ridge. Typically, a short wave omega block would form in the top of the long wave ridge with the closed high center over the Bering Sea or Alaska. The air mass forming the core of the Arctic outbreak was associated with this closed high.

This air mass in the situations studied remained in place, strengthening slowly, until the short wave omega block opened up. The leading closed low or trough line of the block became connected with the deep long wave low and began to move southward slowly as the block opened. When this occurred, the Arctic air mass of the closed high began to accelerate southward while strengthening rapidly.

The strength and orientation of the existing long wave trough over the United States determined the trough succession pattern. Both discontinuous retrogression and translation were common without apparent significant effect on the strength of the outbreak. The southward moving short wave or closed low moved into the southern portion of the full-latitude long wave trough as the existing trough or closed low was ejected from the mean trough position. The ejected low or trough was characterized by pronounced cyclogenesis; the replacement trough was characterized by a lack of cyclogenesis.

Not all closed highs in the long wave ridge were associated with an Arctic outbreak. The significance of a leading closed low or trough in a block configuration was marked; without a leading trough, the closed high tended to drift toward the northwest without opening up. Another situation where the block did not open up was in the absence of a deep long wave low to the east to steer the short wave southward. The leading trough initially moved southward but then intensified toward the west to form a Rex-type block (see Rex, 1950a and 1950b) over the Gulf of Alaska in one occurrence noted.

The omega block and the southward-moving closed low were not long wave features in the Arctic outbreak studies. A high-latitude long wave omega block did not produce a major Arctic outbreak even though the Arctic high built to 1060-plus pressures on one occasion.

The anticyclones associated with several strong cyclonic winter storms over the northern plains were examined for Lower Rio Grande Valley freeze potential. In each case, the deep surface low was associated with a closed low at 500 mb. The accompanying cold front usually moved through South Texas, but the primary freeze danger was from radiational cooling as the pressure gradient weakened and the skies cleared. None of the major freezes in the Lower Rio Grande Valley have been associated with this synoptic pattern.

Subjectively determined guidelines are difficult to test or evaluate realistically, even with independent or control data. However, a review of several years of winter synoptic charts indicated that when a well-defined short-wave omega block formed, an Arctic outbreak for some portion of the United States was imminent. Similarly, a southward moving short-wave trough or closed low was always associated with a southward moving cold air mass at the surface.

APPLICATION

The significance of the 500 mb features associated with freeze events in the Lower Rio Grande Valley is that they are recognizable several days before the freeze event. Forecasters preparing extended outlooks and agricultural weather forecasts for the Lower Rio Grande Valley should be able to interpret the 500 mb and surface analyses and progs, in conjunction with other synoptic reasoning and centrally prepared guidance, in terms of likelihood of a damaging freeze.

The recognition guidelines for 500 mb patterns which may indicate a freeze are:

1. A short wave omega block superimposed on a long wave ridge through central Alaska with a deep low system between Hudson Bay and Greenland.

2. An east-west trough line over southern Canada or the northern United States with zonal flow and a strong jet to the south and northerly flow to the north of the trough line.

3. A closed low moving southward through the Prairie Provinces of Canada developing into a long wave trough, without cyclogenesis.

4. Discontinuous retrogression of a full-latitude trough over the western United States involving a closed low or major east-west short wave moving southward without cyclogenesis.

5. A sharp full-latitude trough, frequently with a closed low, over the southeastern states.

DATA SOURCES

The sources of meteorological data used in the study were the Daily Weather Maps--Weekly Series, Climatological Data (monthly and annual summaries, and the Daily Series, Synoptic Weather Maps -- Northern Hemisphere Sea Level and 500 Millibar Charts; all published by the Environmental Data Service, Asheville, North Carolina. The author wishes to acknowledge the Texas A&M University Library for their fine facilities and extensive meteorological collection which greatly facilitated this study.

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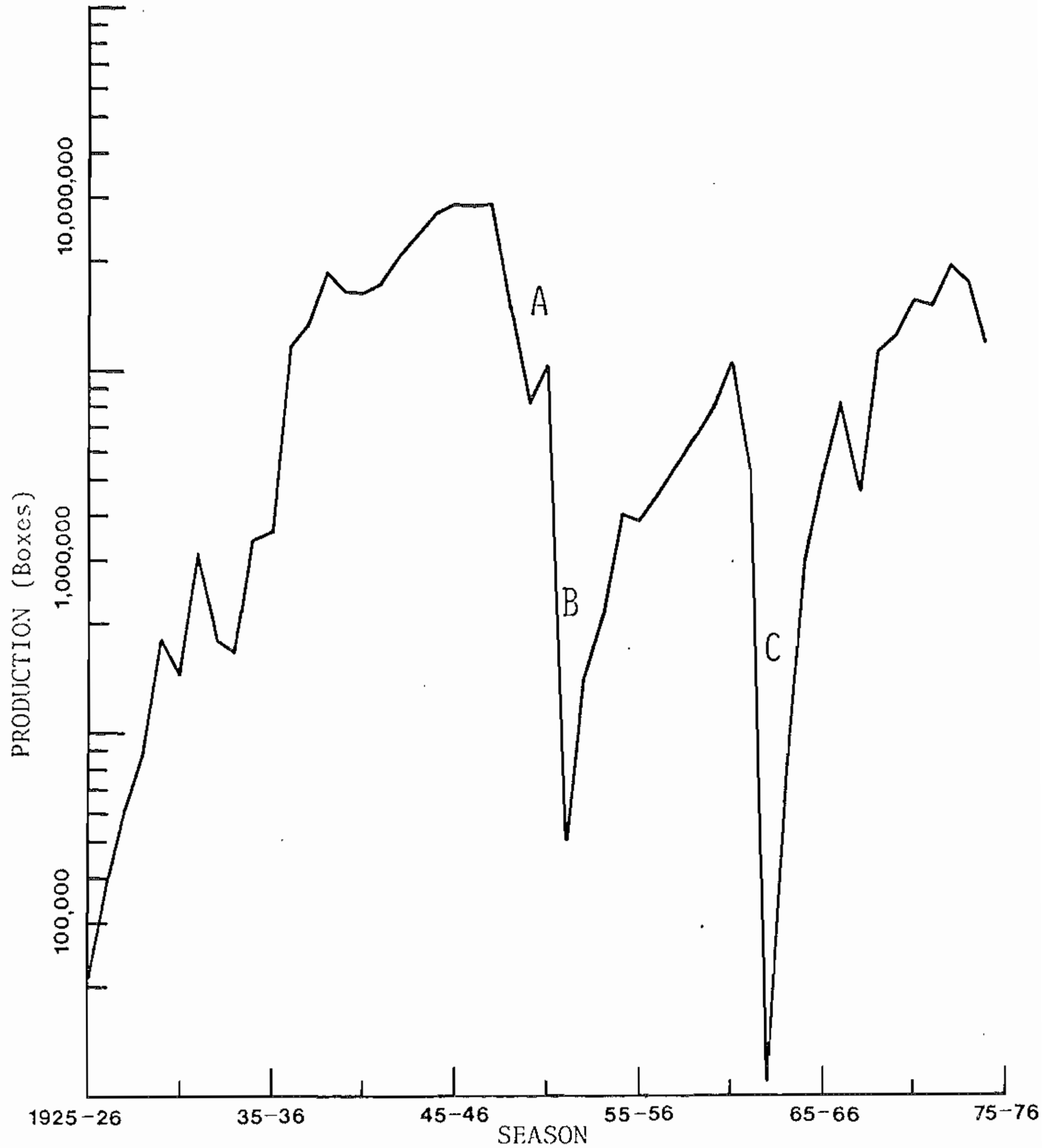

Figure 1. Citrus production of the Lower Rio Grande Valley. The major declines in production, indicated by A, B, and C, were a result of severe freezes with Arctic outbreaks in 1949, 1951, and 1962 respectively. The dollar value of the 1972-73 season was $37,500,000. (Source: Maxwell and Bailey (1963) through 1952-53 and Texas Crop and Livestock Service (1976) for 1953-54 through 1974-75).

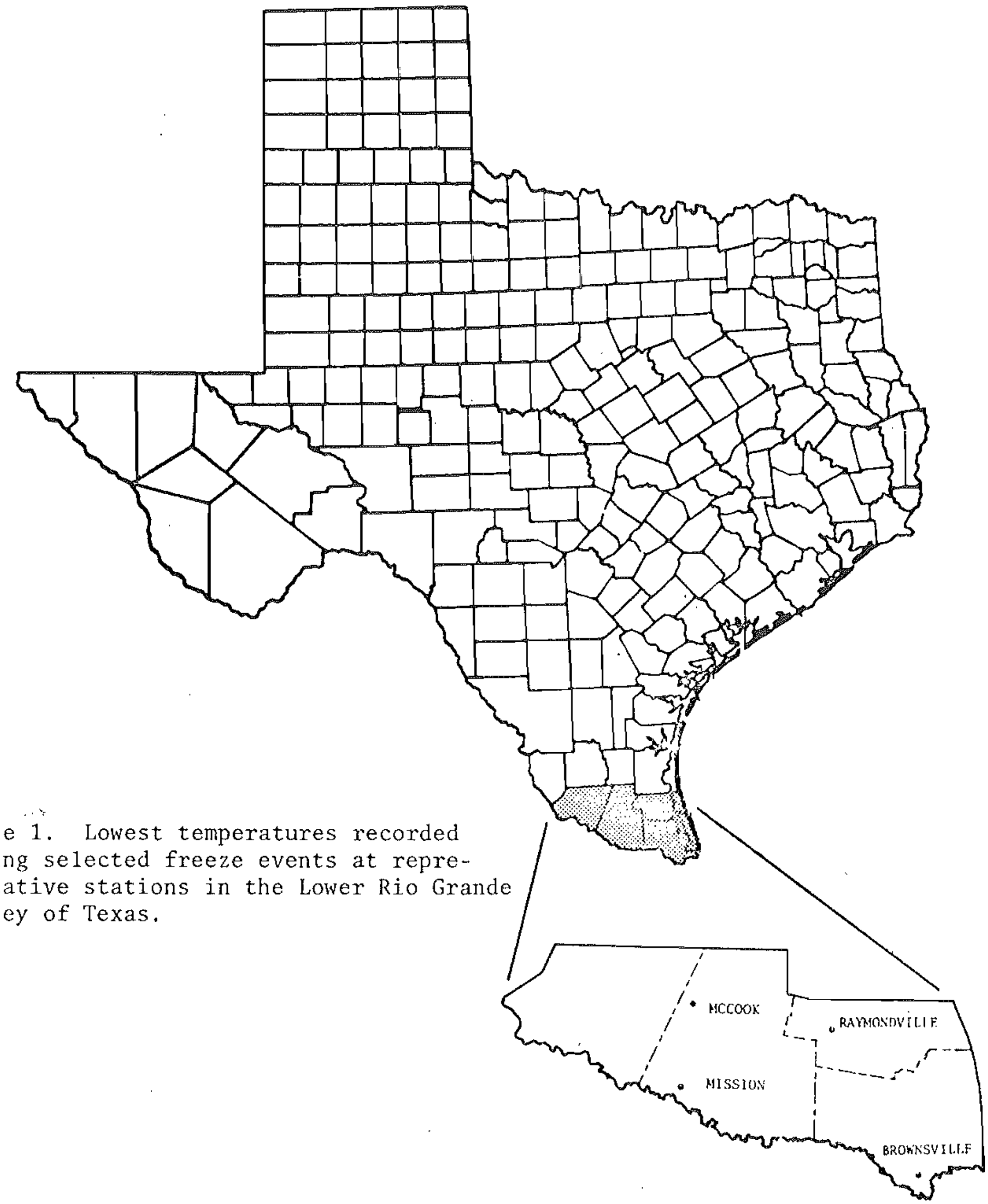

Table 1. Lowest temperatures recorded during selected freeze events at representative stations in the Lower Rio Grande Valley of Texas.

STATION	FREEZE EVENT					
	JAN 49	JAN/FEB 51	JAN 62	DEC 64	DEC 73	JAN 75
Brownsville WSO	23	22	19	32	27	24
McCook	18	16	10	26	21	19
Mission	19	19	18	30	22	24
Raymondville	20	19	14	28	22	23

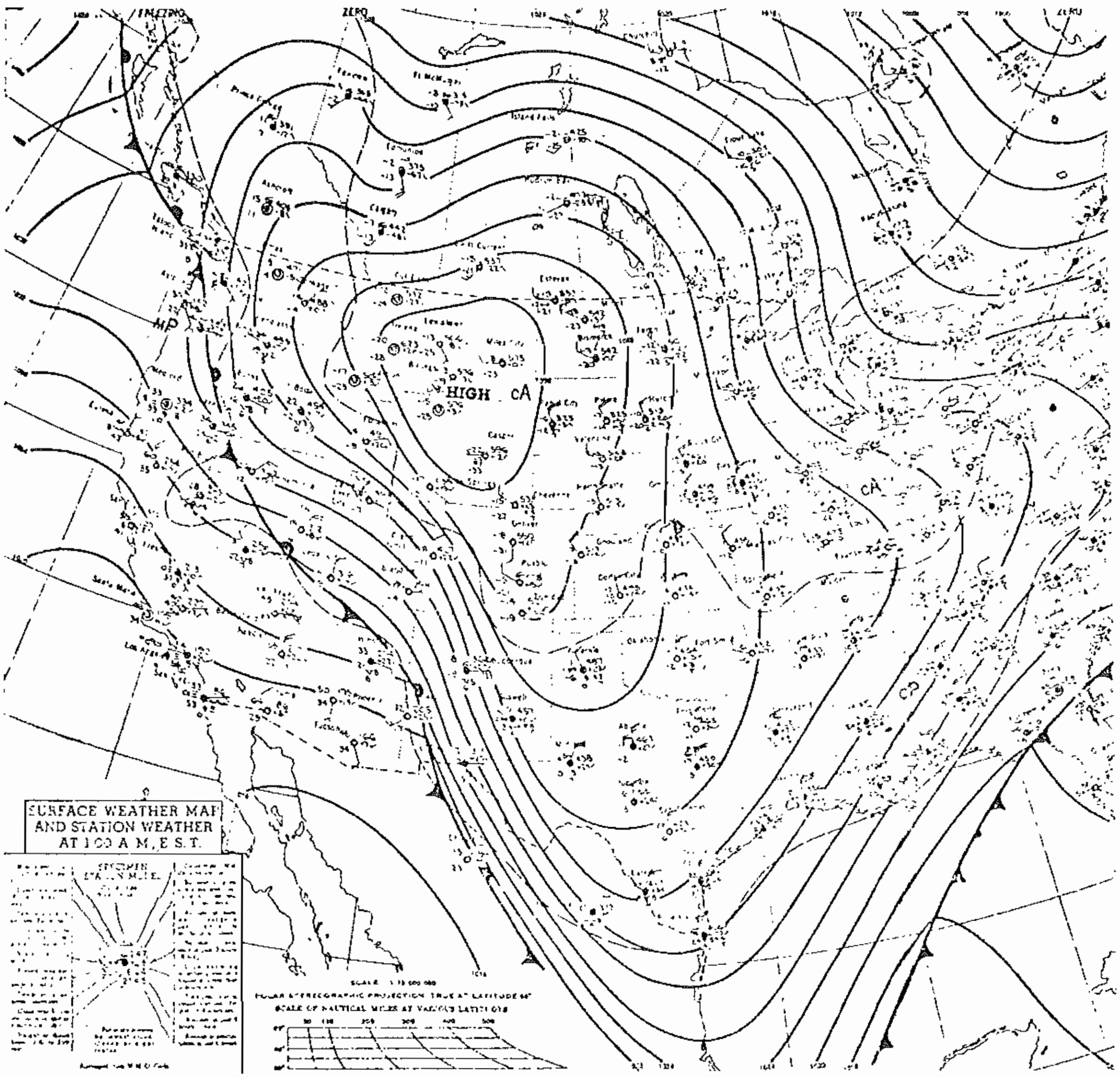

Figure 2. Surface chart, 10/1800Z January 1962. The central pressure was 1060 mb in central Wyoming.

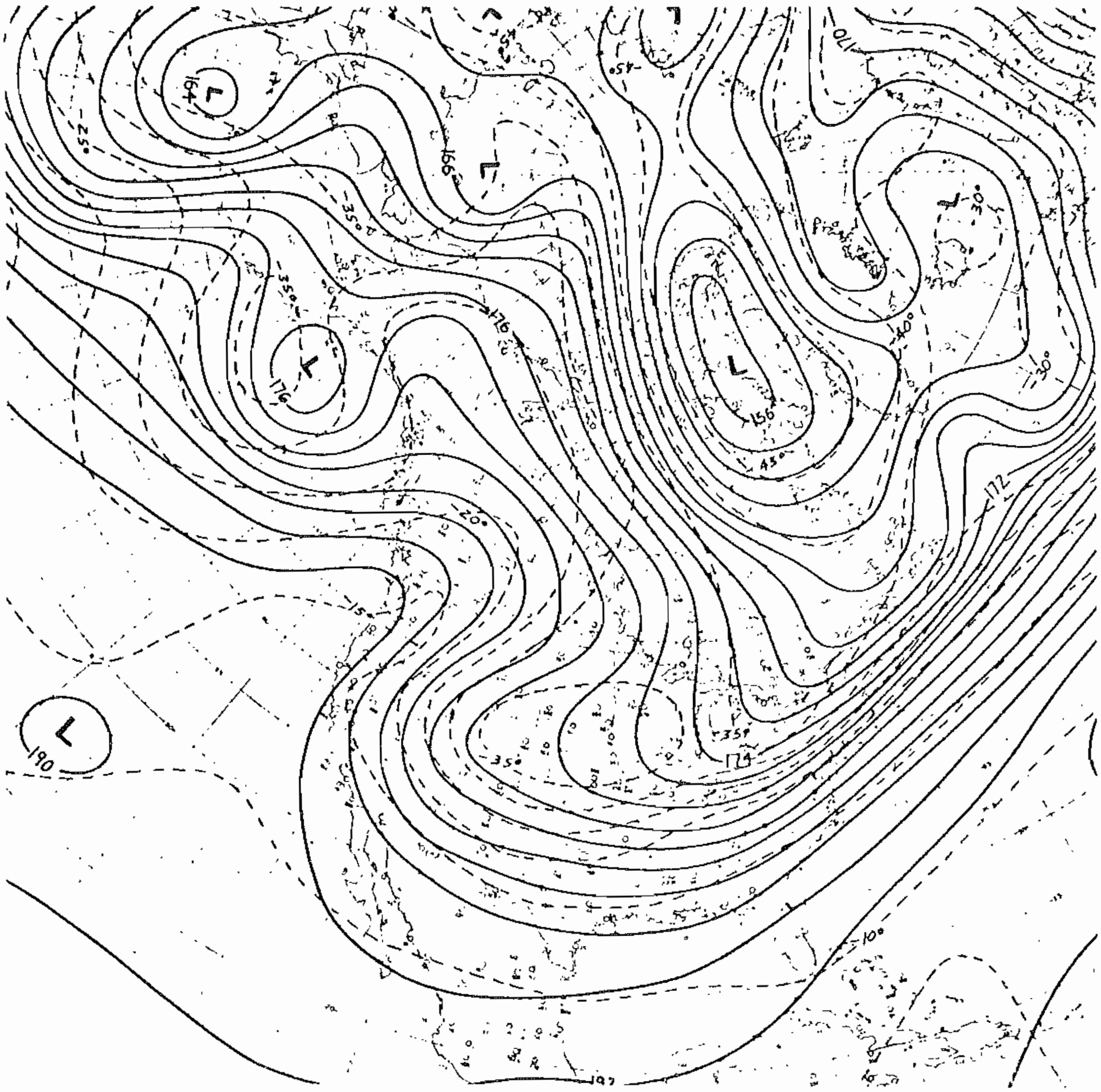

Figure 3. 500 mb, 10/1200Z January 1962.

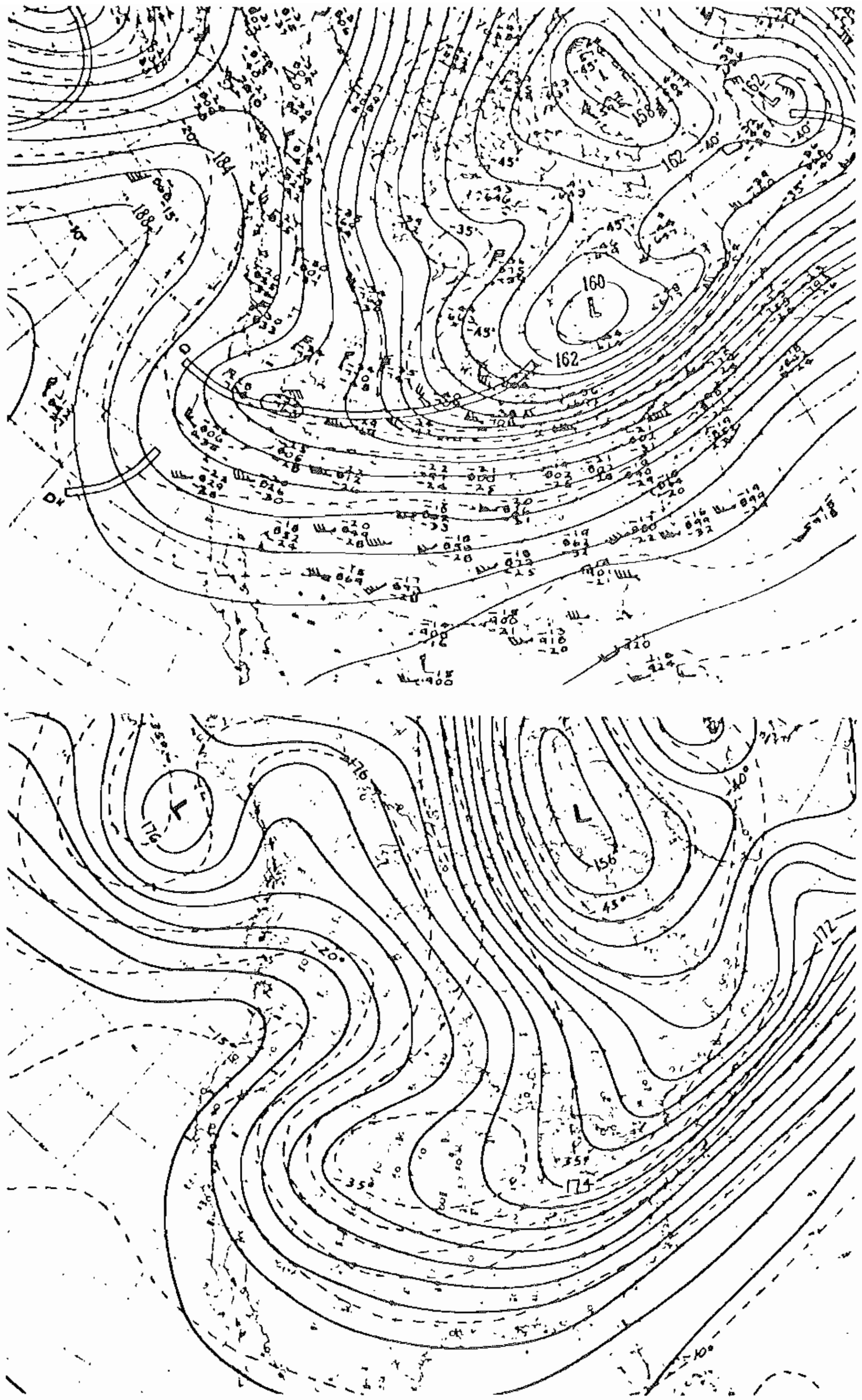

Figure 4. 500 mb, 29/1200Z January 1951 (top) and 10/1200Z January 1962 (bottom). Note the similarity of long wave features.

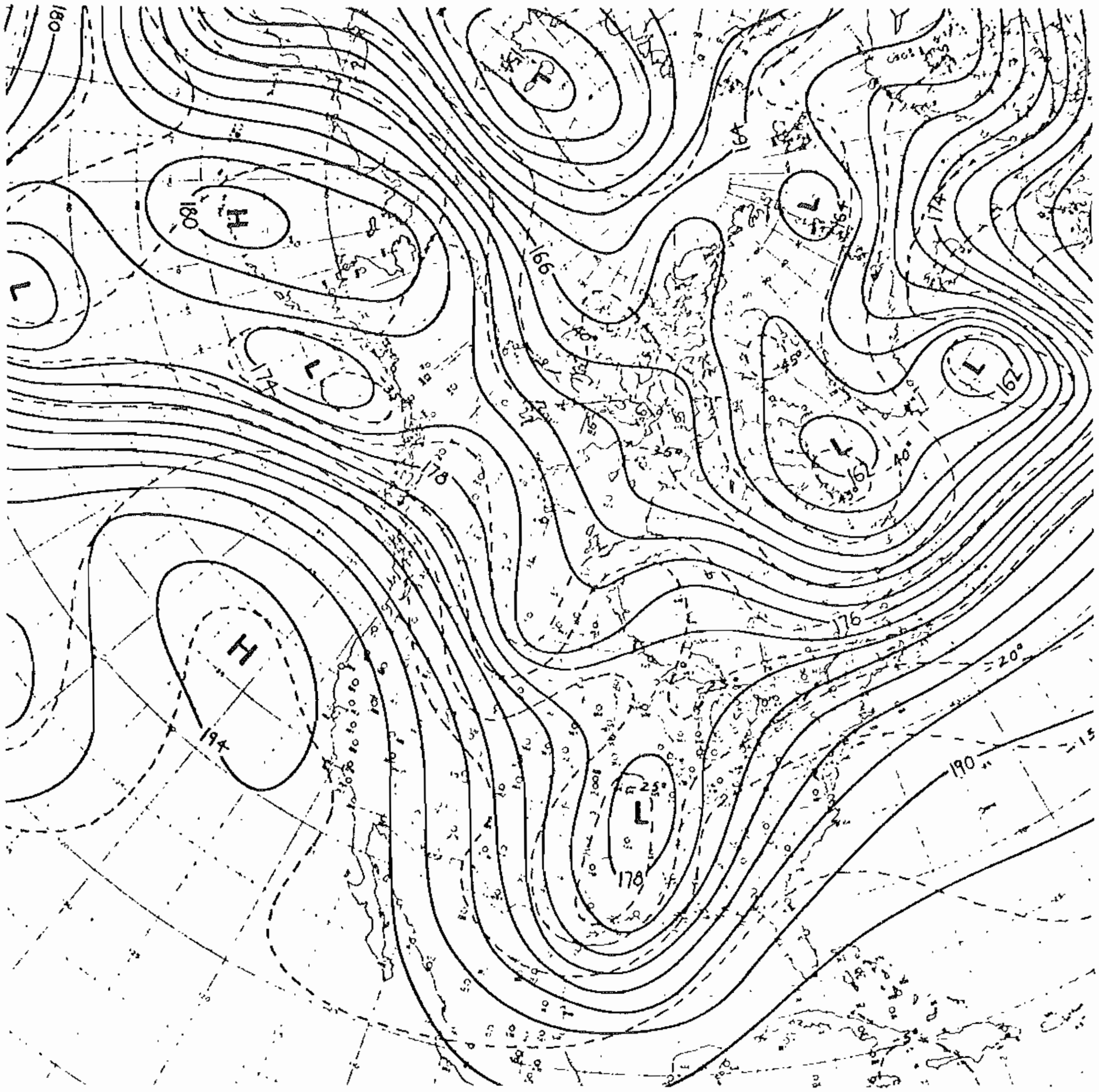

Figure 5a. 500 mb, 6/1200Z January 1962. Note the behavior of the closed high now over the Aleutian Islands during the sequence of events at the 500 mb surface depicted in this series.

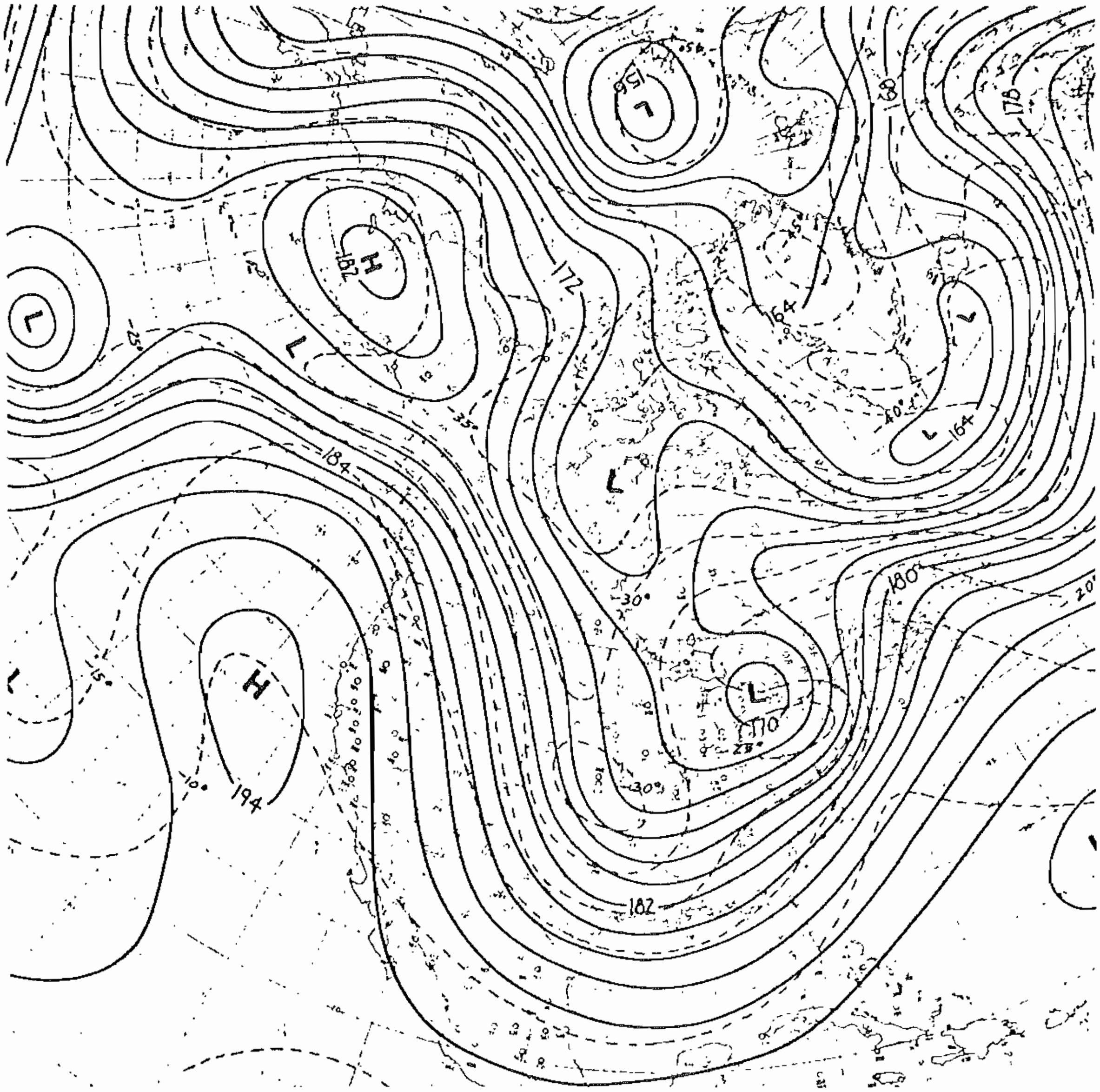

Figure 5b. 500 mb, 7/1200Z January 1962.

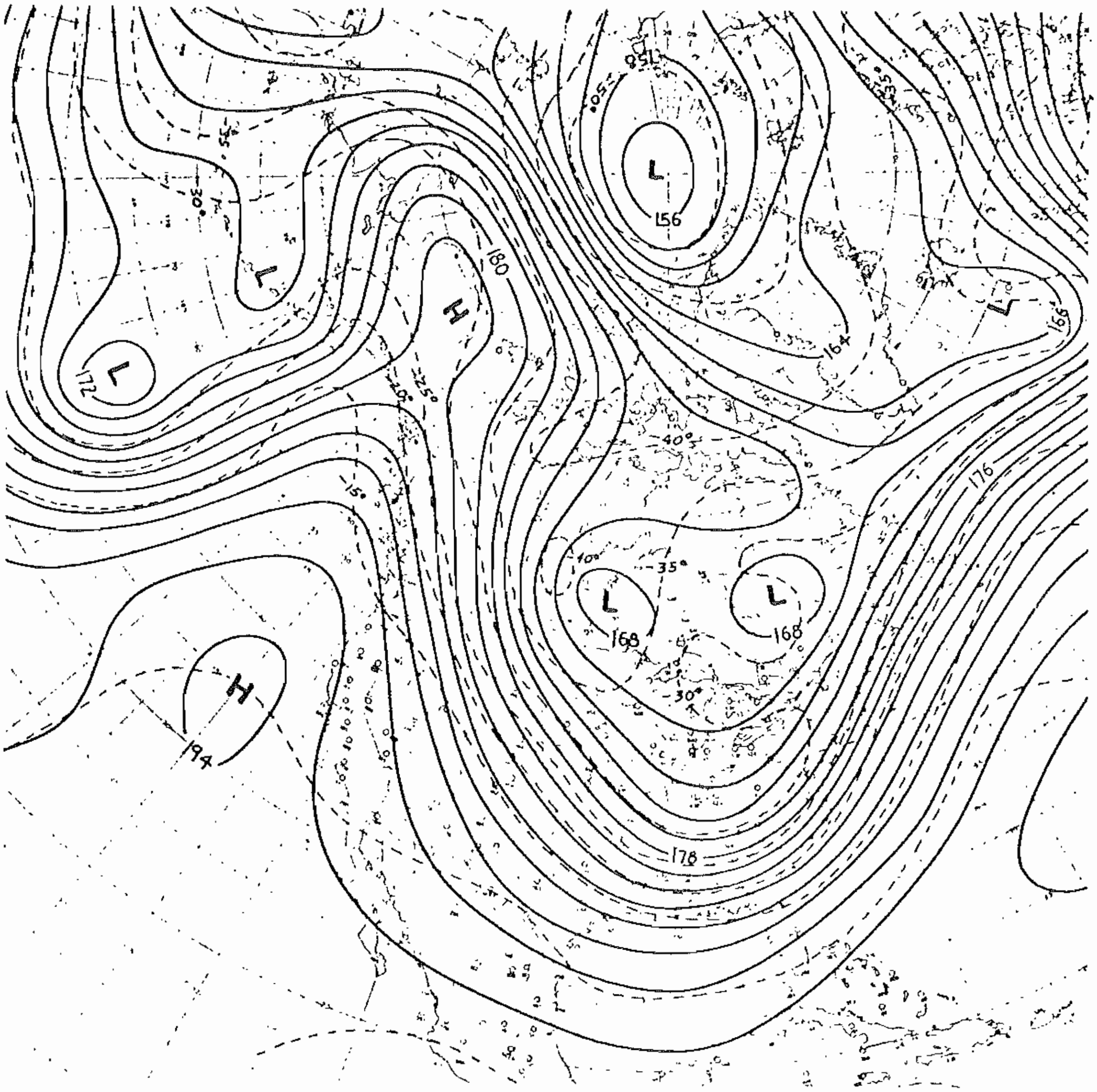

Figure 5c. 500 mb, 8/1200Z January 1962. The short wave omega block superimposed on the long wave Pacific ridge is now readily apparent.

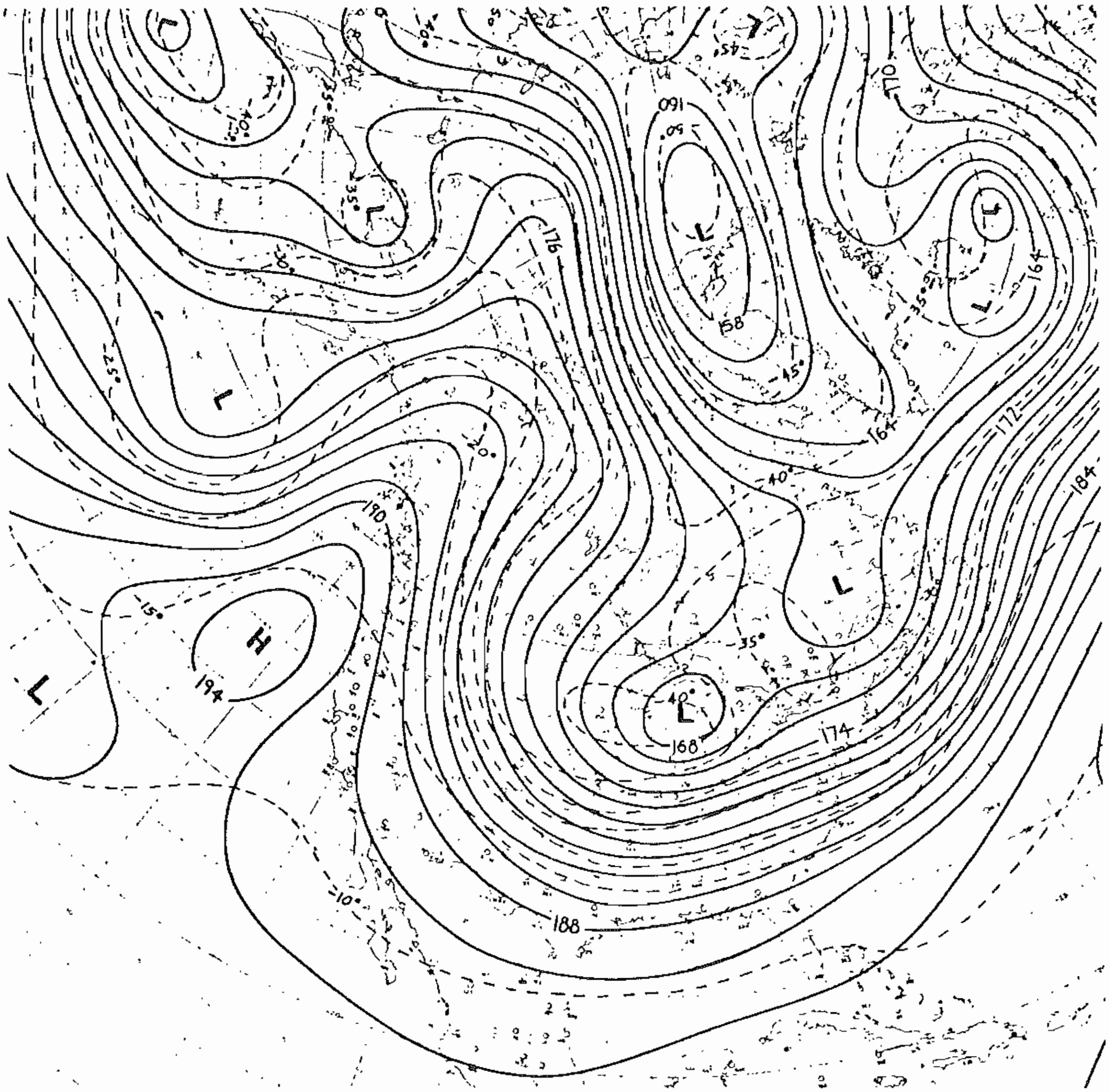

Figure 5d. 500 mb, 9/1200Z January 1962.

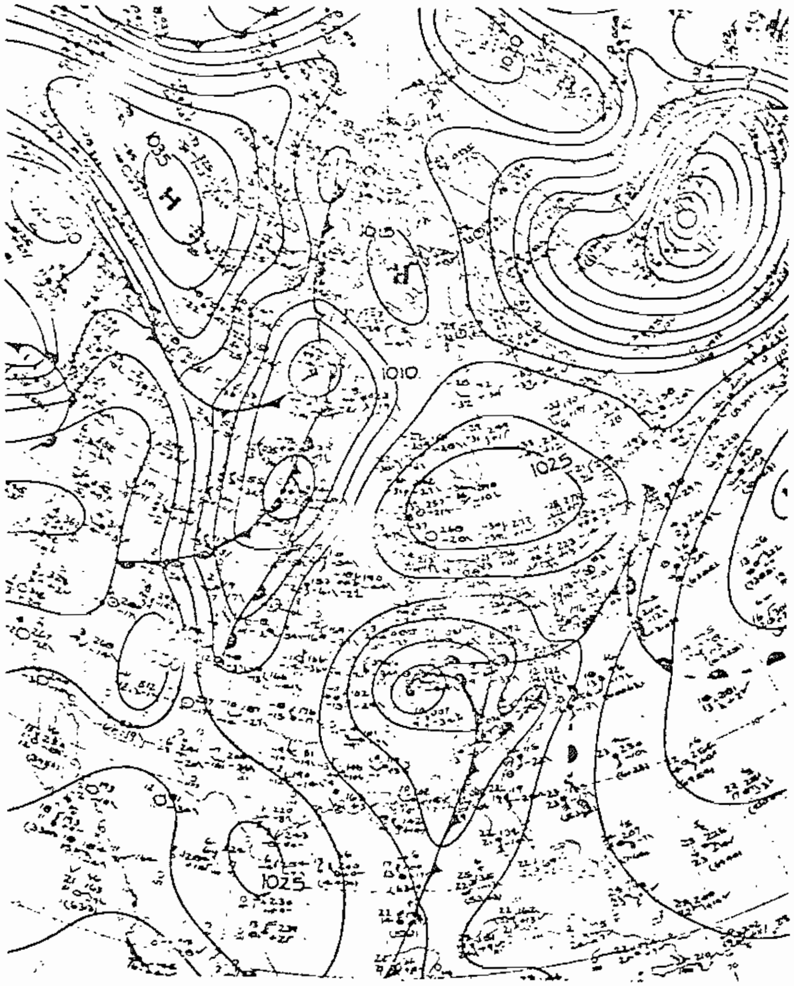

Figure 5e. Surface, 6/1200Z January 1962. Note that the central pressure of the surface high over central Alaska was less than 1040 mb.

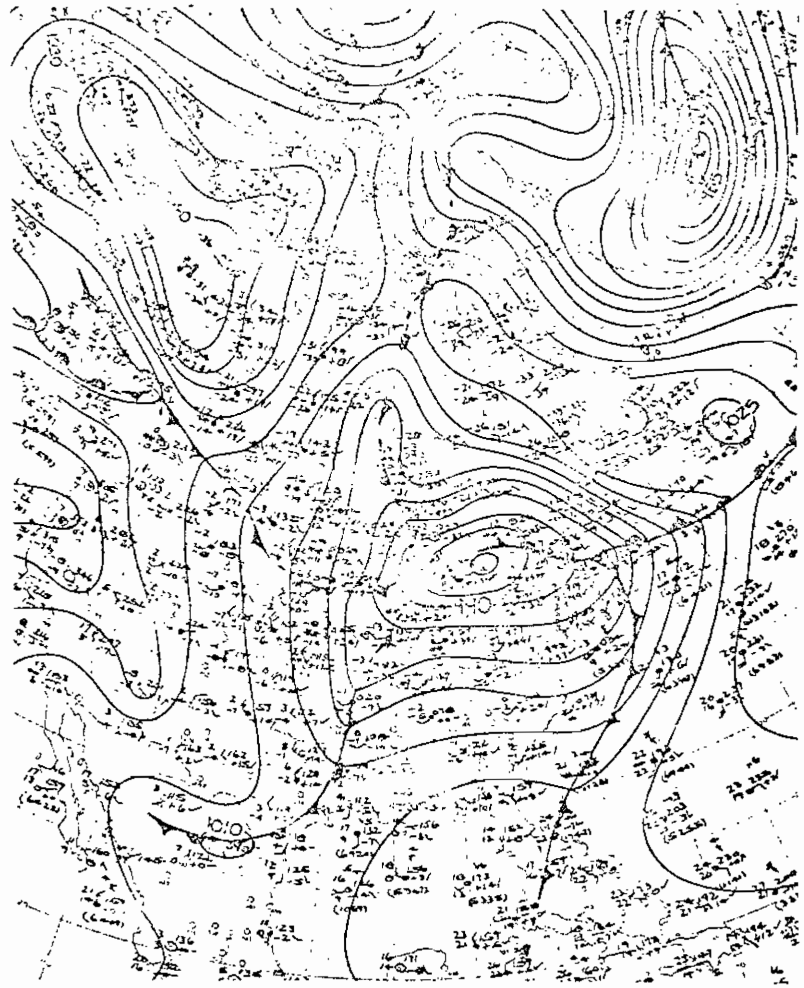

Figure 5f. Surface, 7/1200Z January 1962.

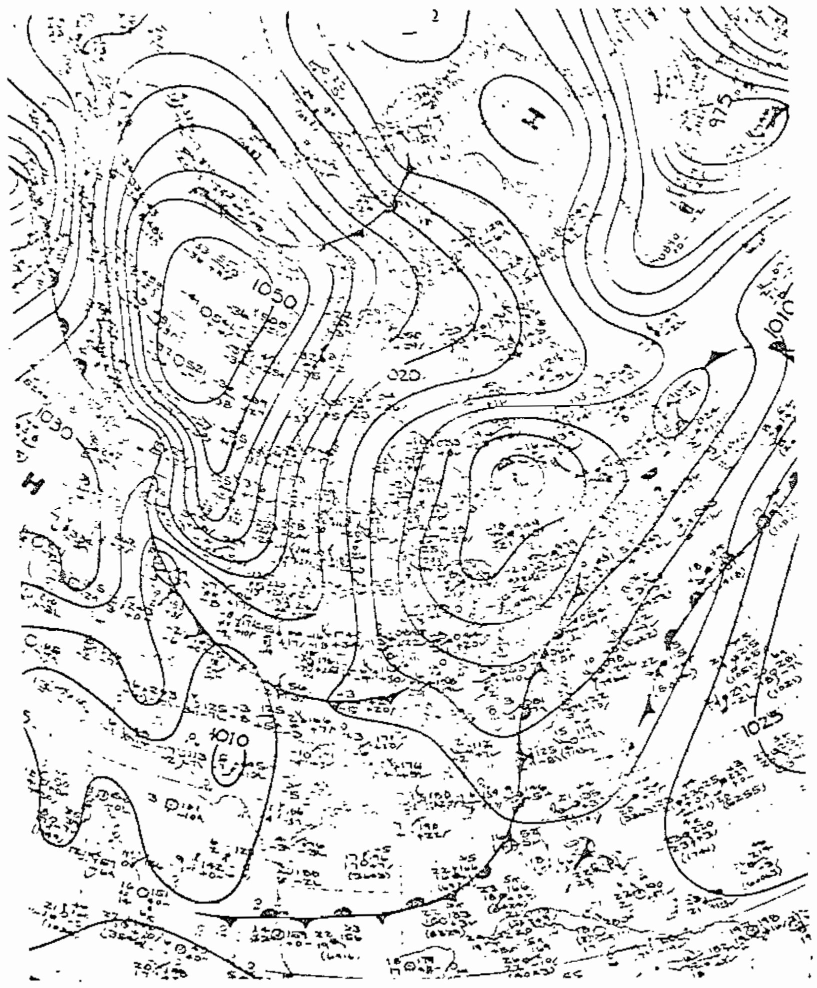

Figure 5g. Surface, 8/1200Z January 1962.

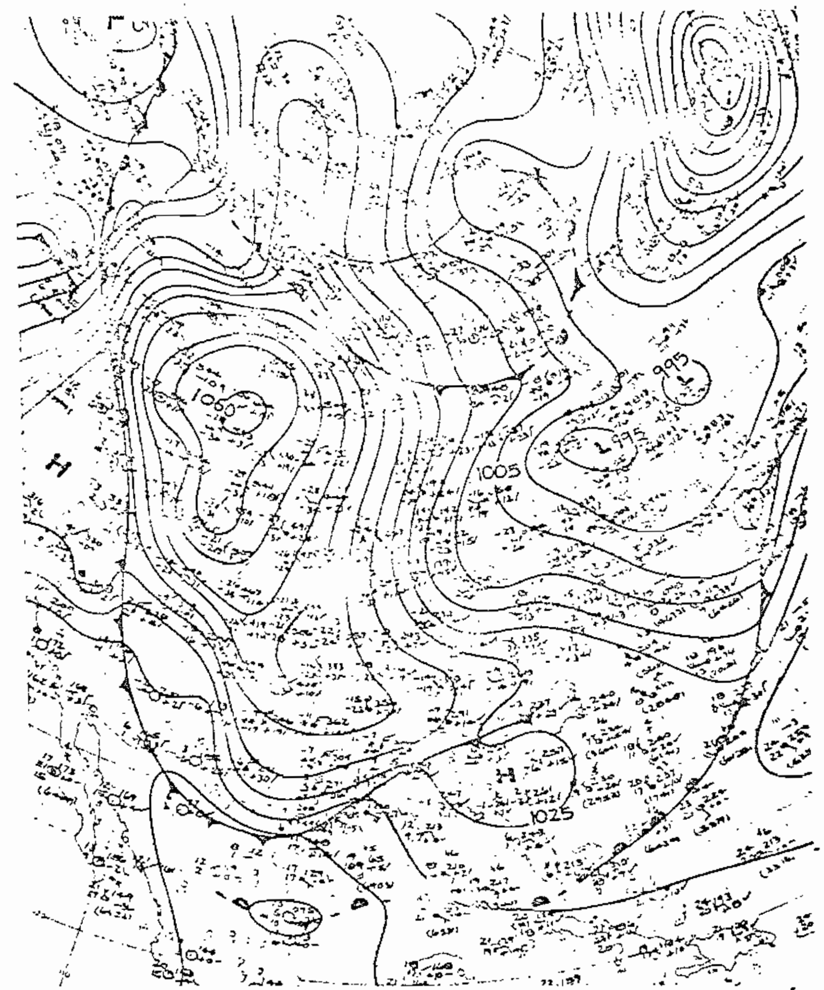

Figure 5h. Surface, 9/1200Z January 1962. Surface pressures of 1060 mb crossed the United States border shortly after 1200Z.

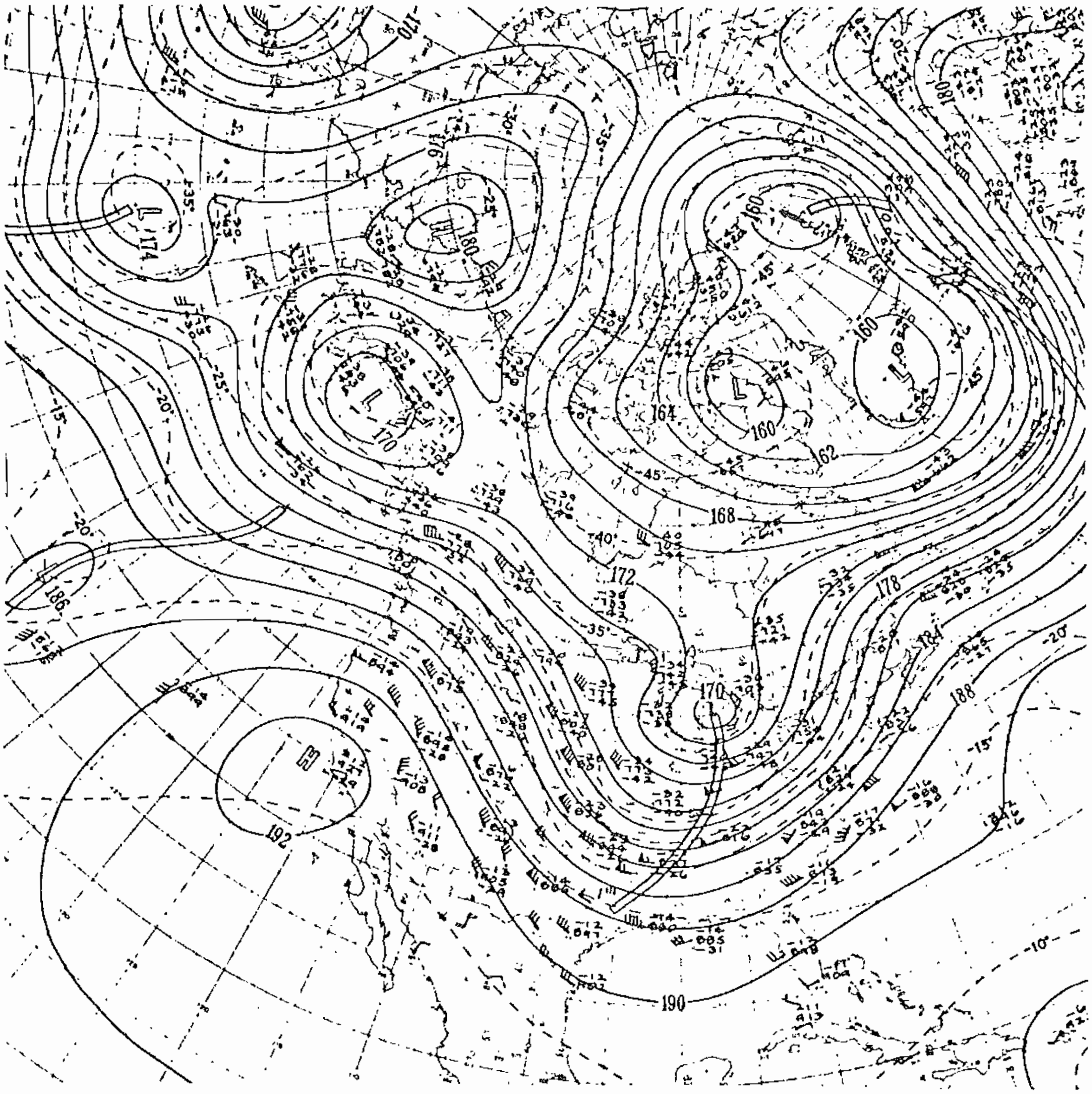

Figure 6a. 500 mb, 24/1200Z January 1951. The maximum surface pressure appearing on the 1200Z surface charts was in excess of 1060 mb in northwestern Canada on 27 Janaury 1951. The surface cold front of the outbreak passed through the Lower Rio Grande Valley on January 29.

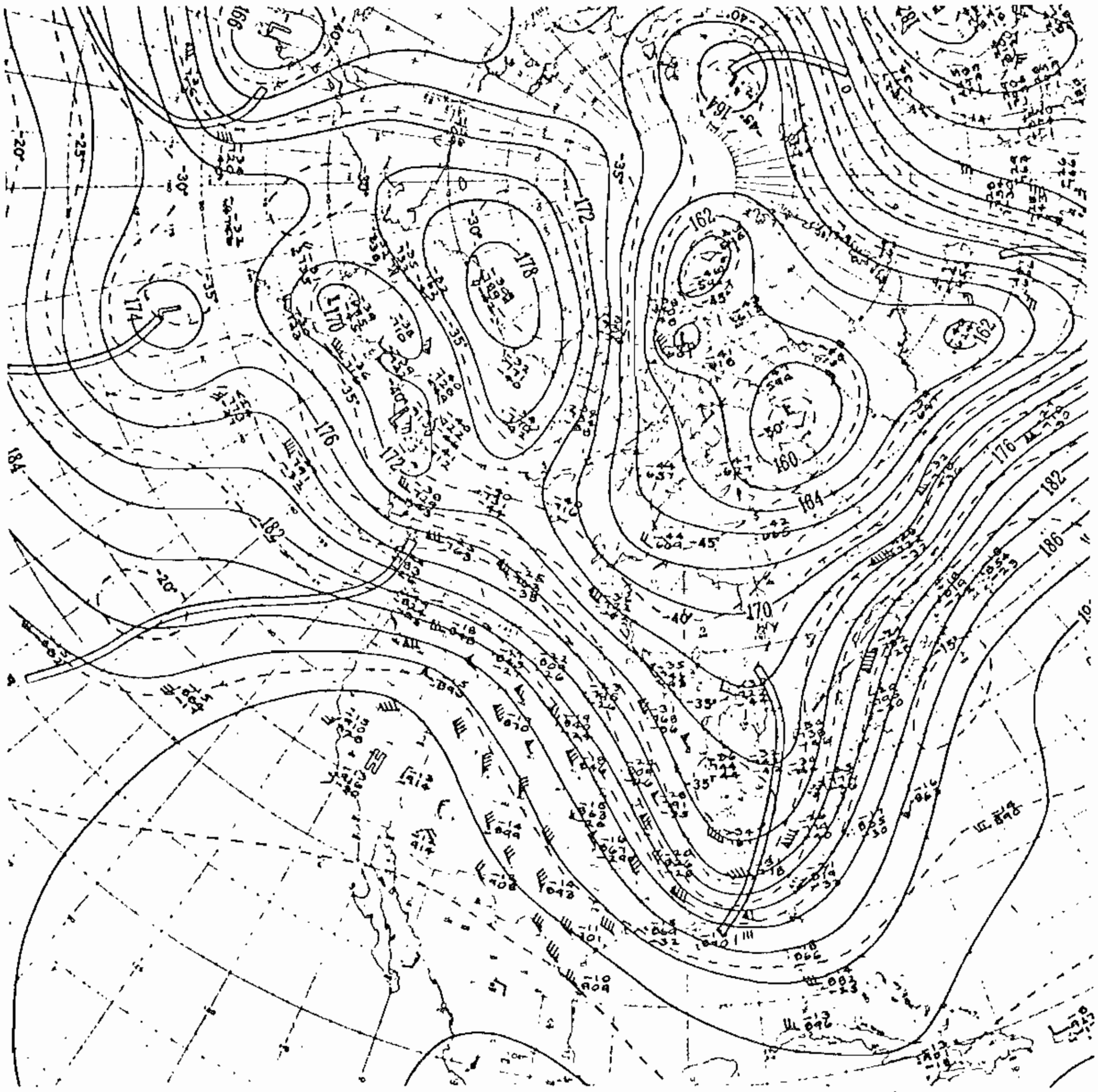

Figure 6b. 500 mb, 25/1200Z January 1951.

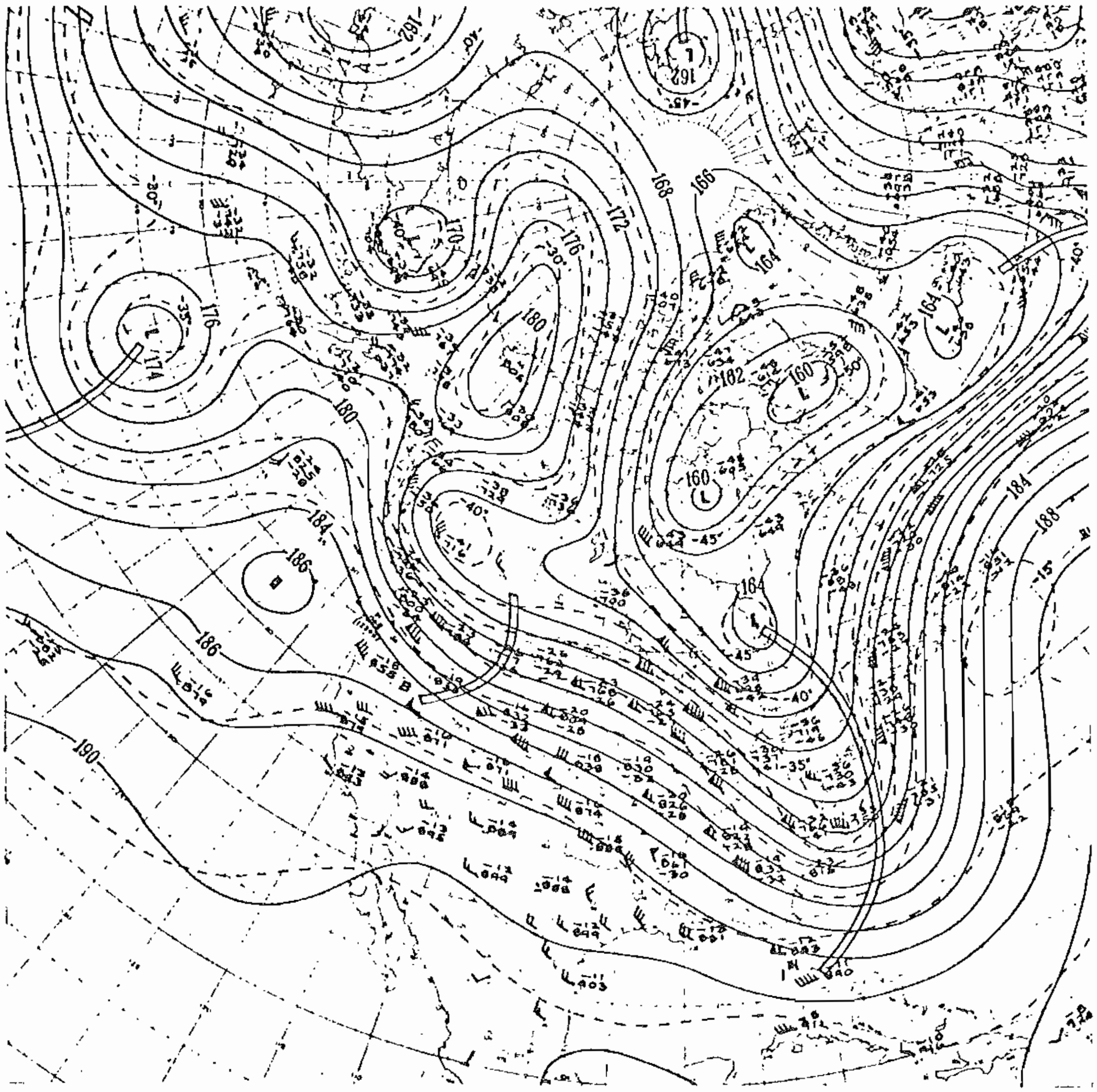

Figure 6c. 500 mb, 26/1200Z January 1951.

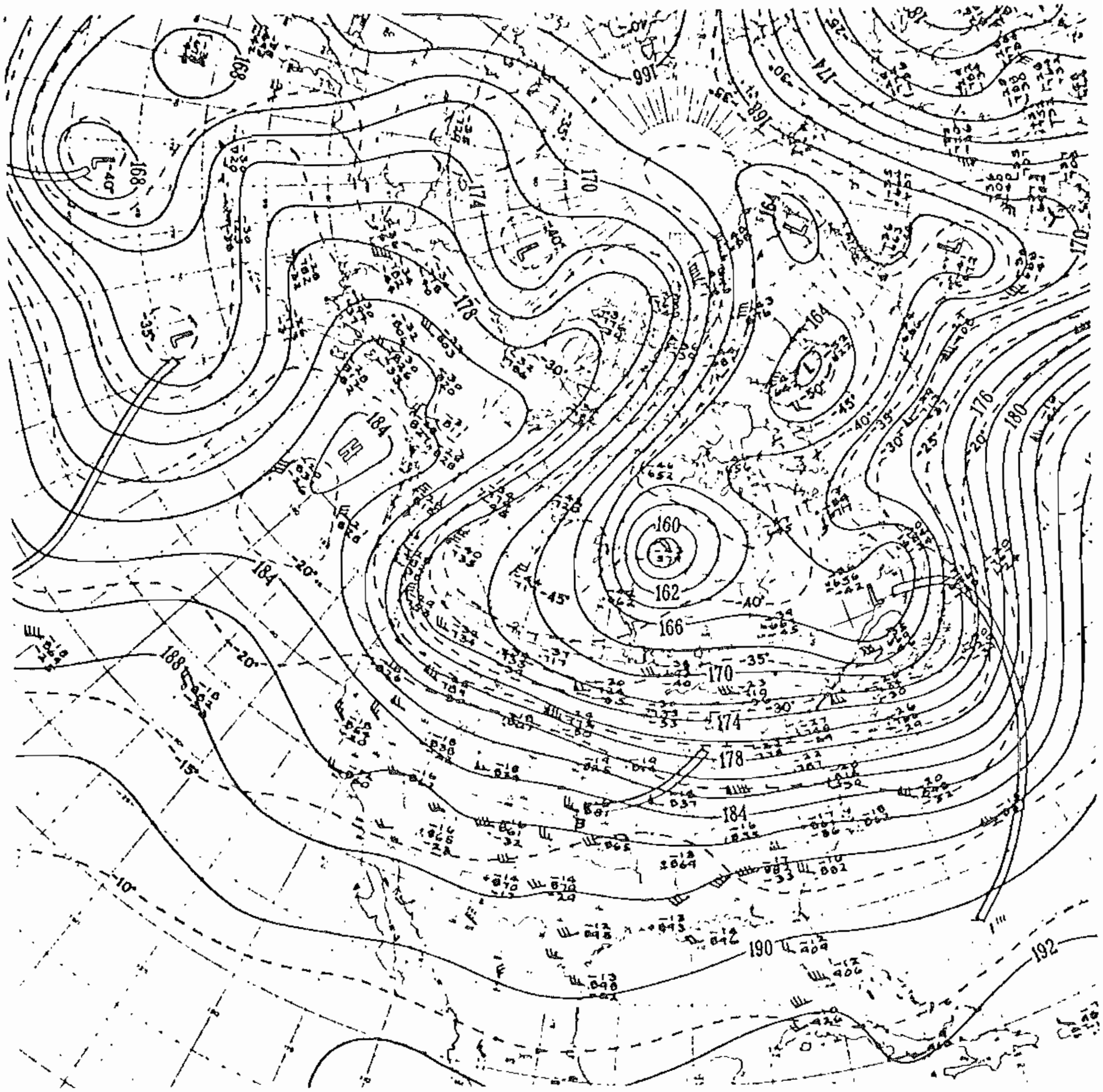

Figure 6d. 500 mb, 27/1200Z January 1951.

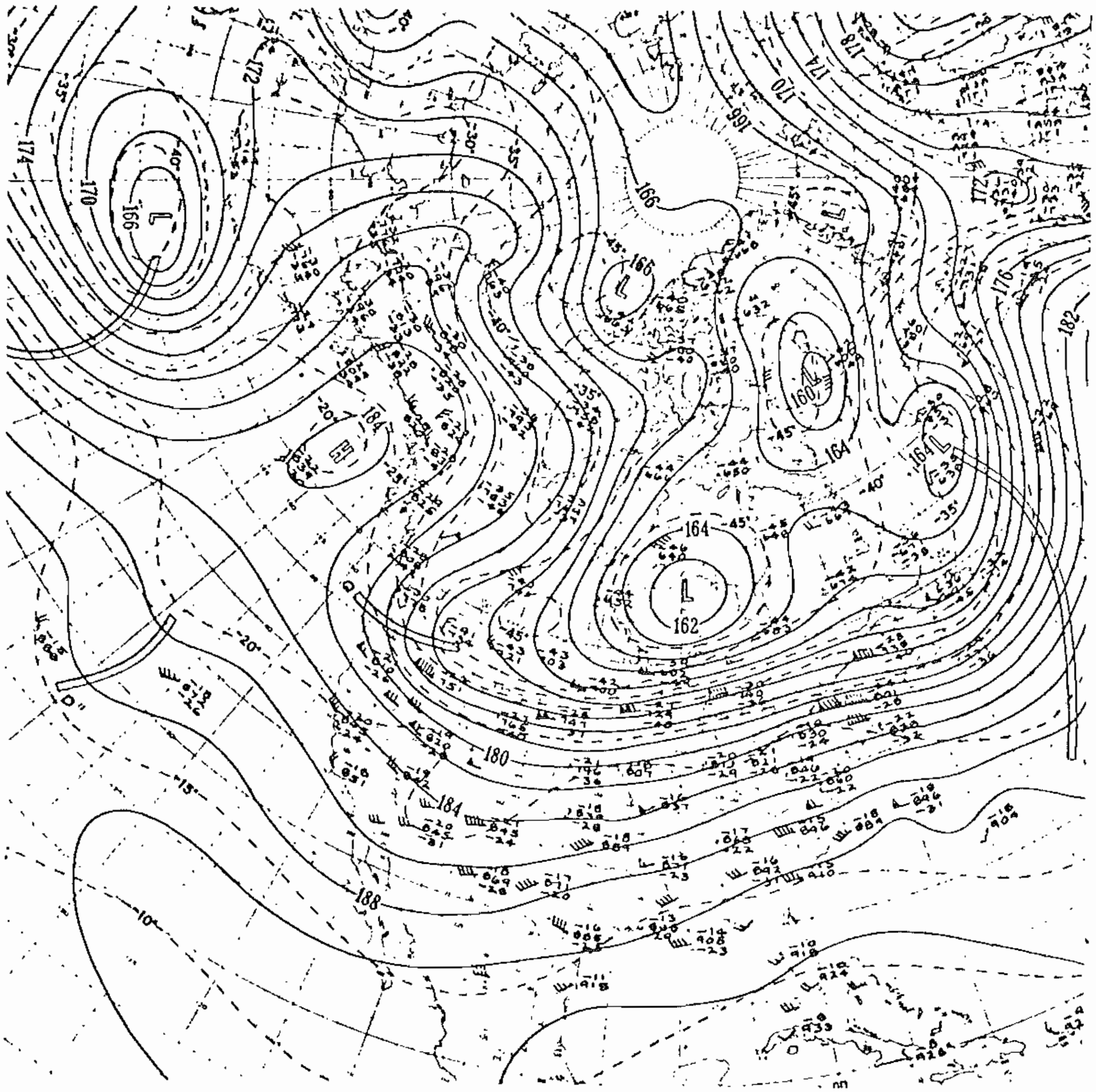

Figure 6e. 500 mb, 28/1200Z January 1951.

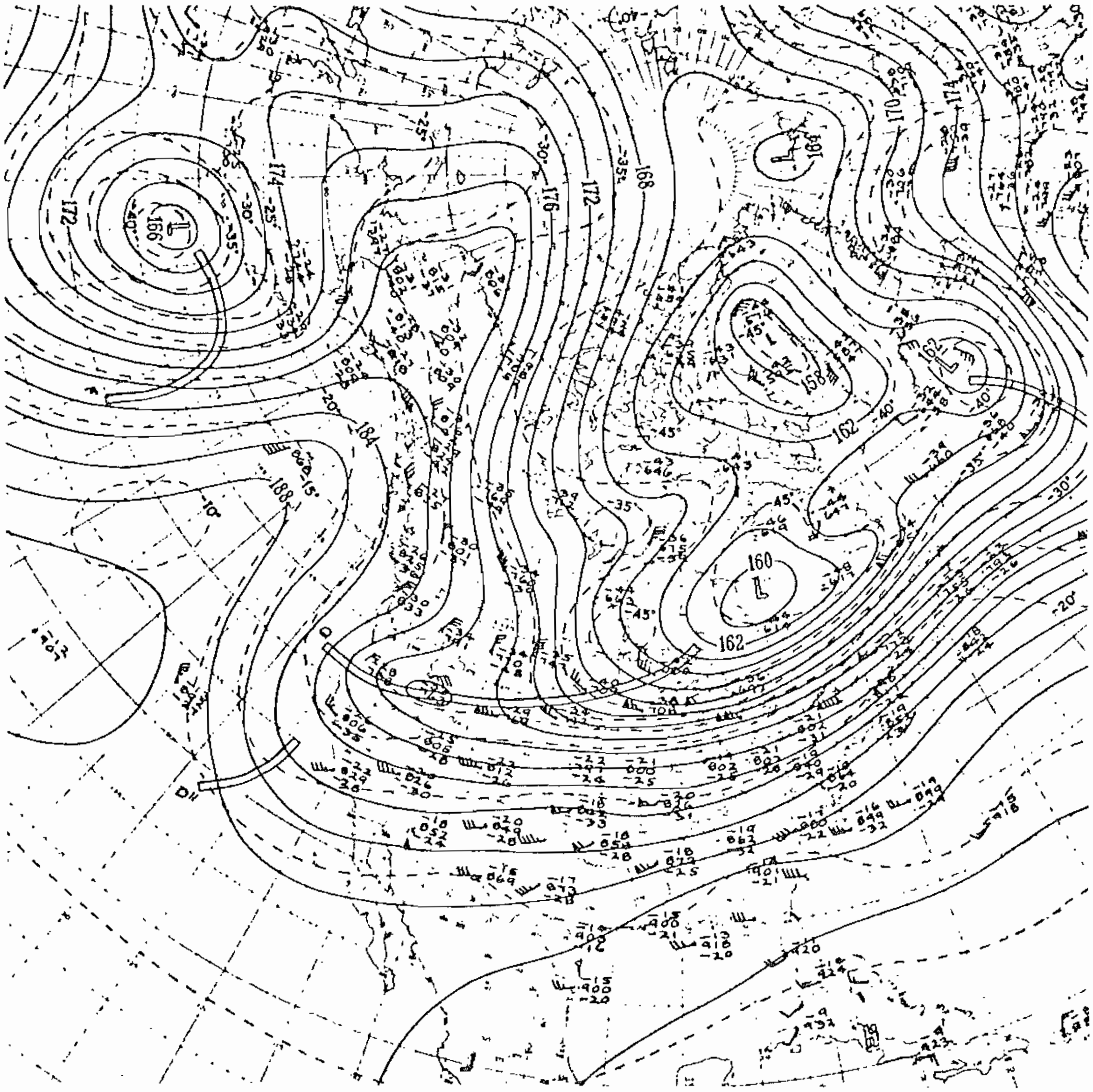

Figure 6f. 500 mb, 29/1200Z January 1951.

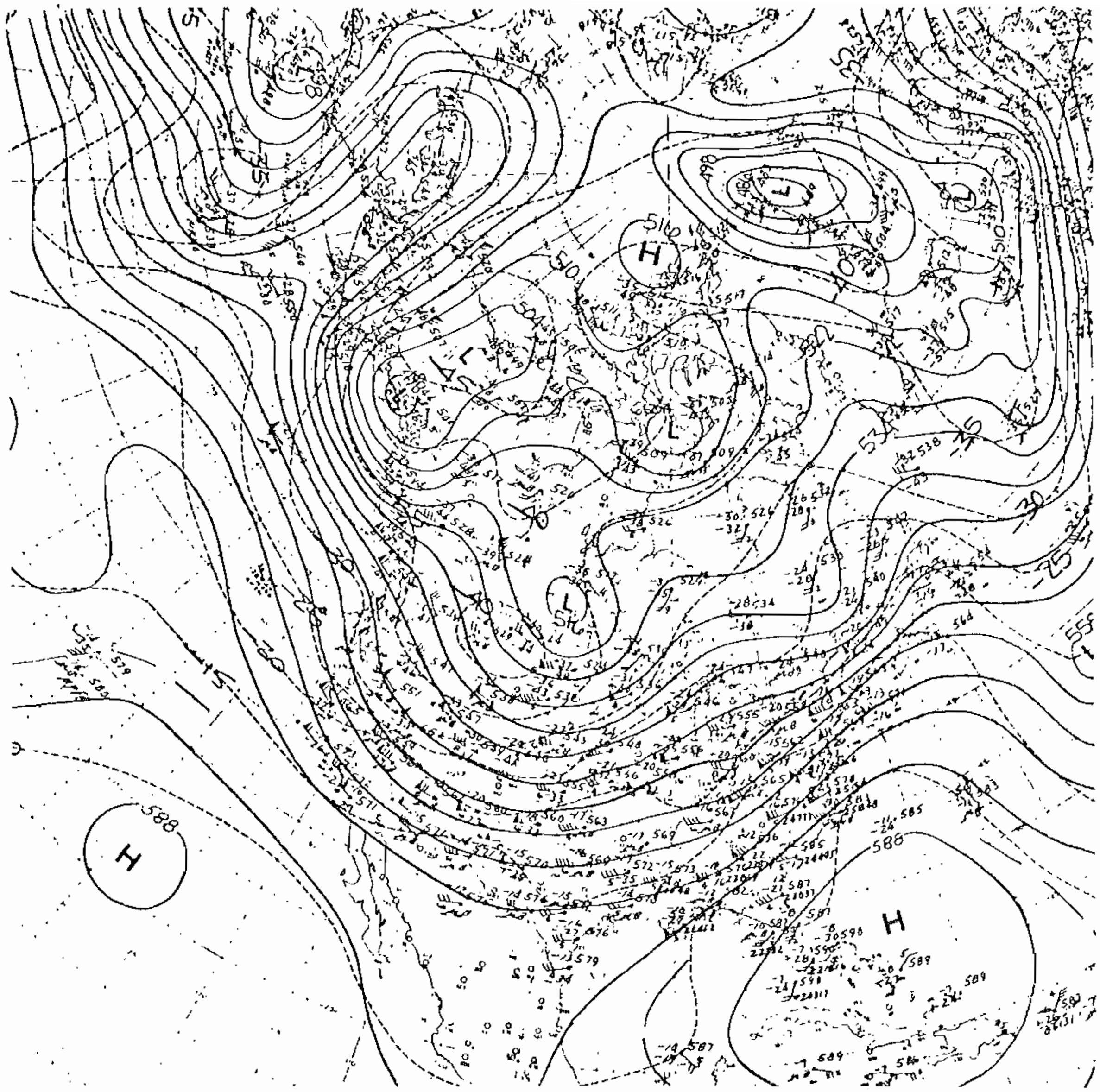

Figure 7a. 500 mb, 12/1200Z December 1964. The surface cold front of the Arctic outbreak passed through the Lower Rio Grande Valley on December 17.

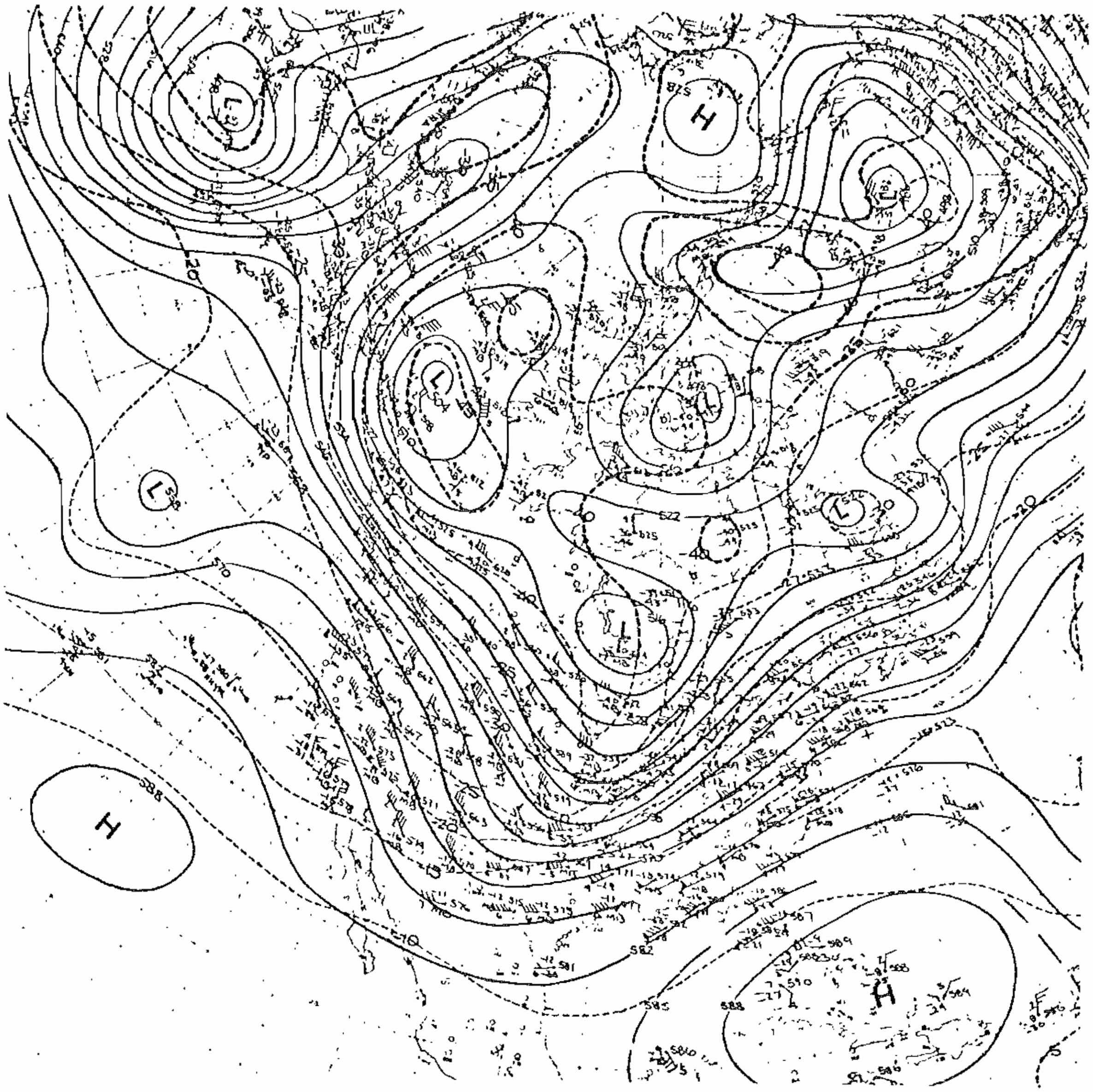

Figure 7b. 500 mb, 13/1200Z December 1964.

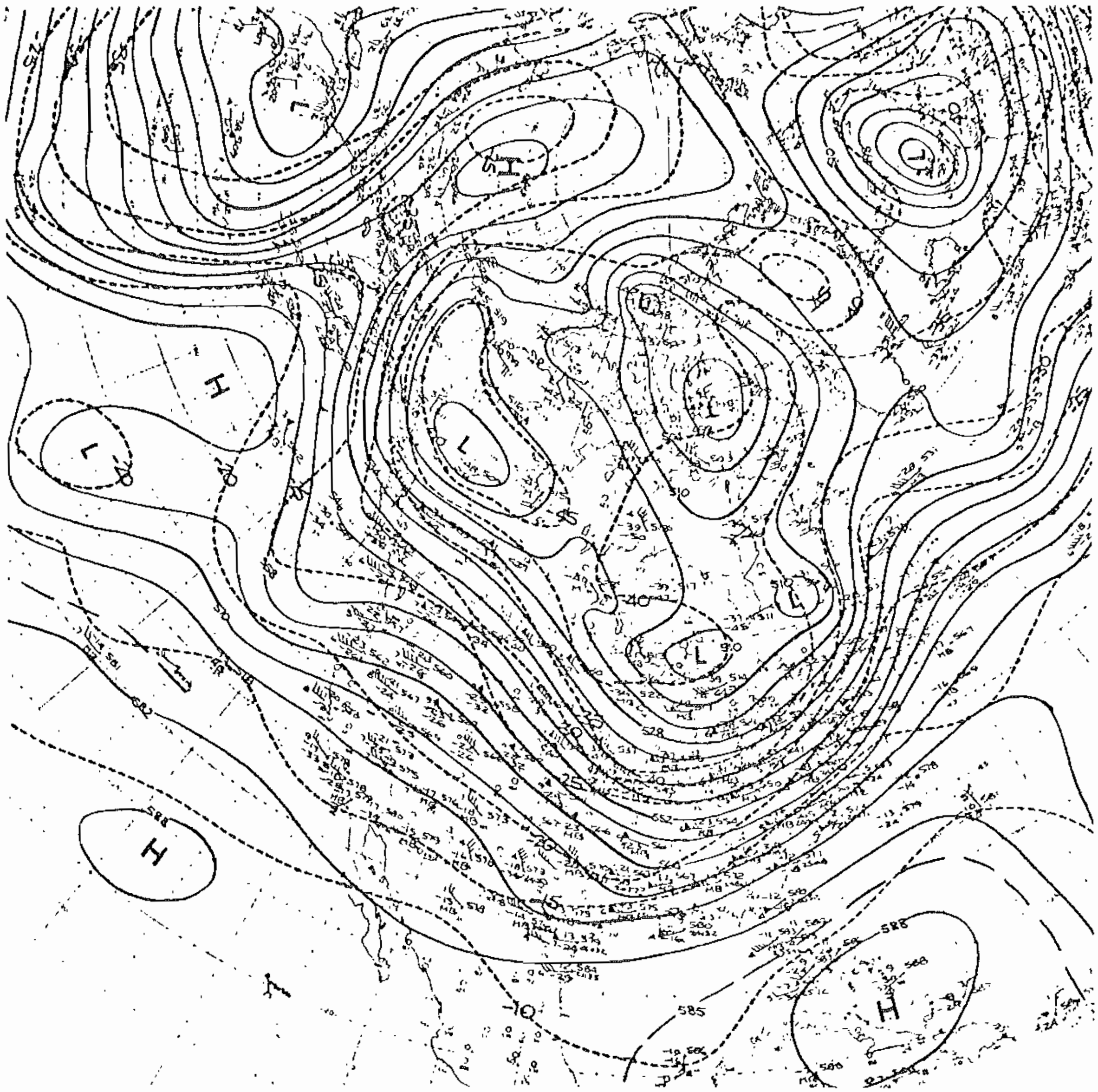

Figure 7c. 500 mb, 14/1200Z December 1964.

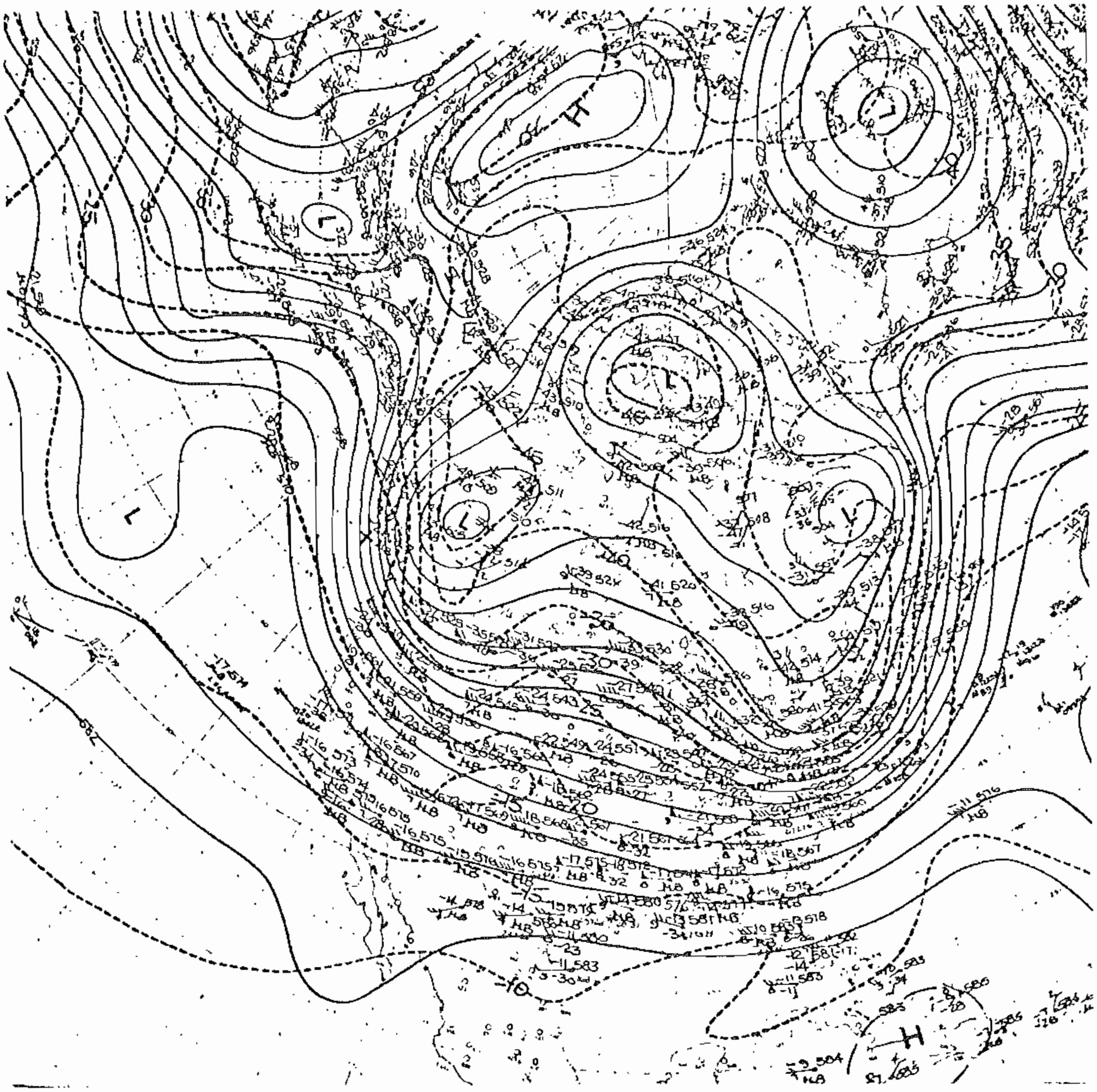

Figure 7d. 500 mb, 15/1200Z December 1964.

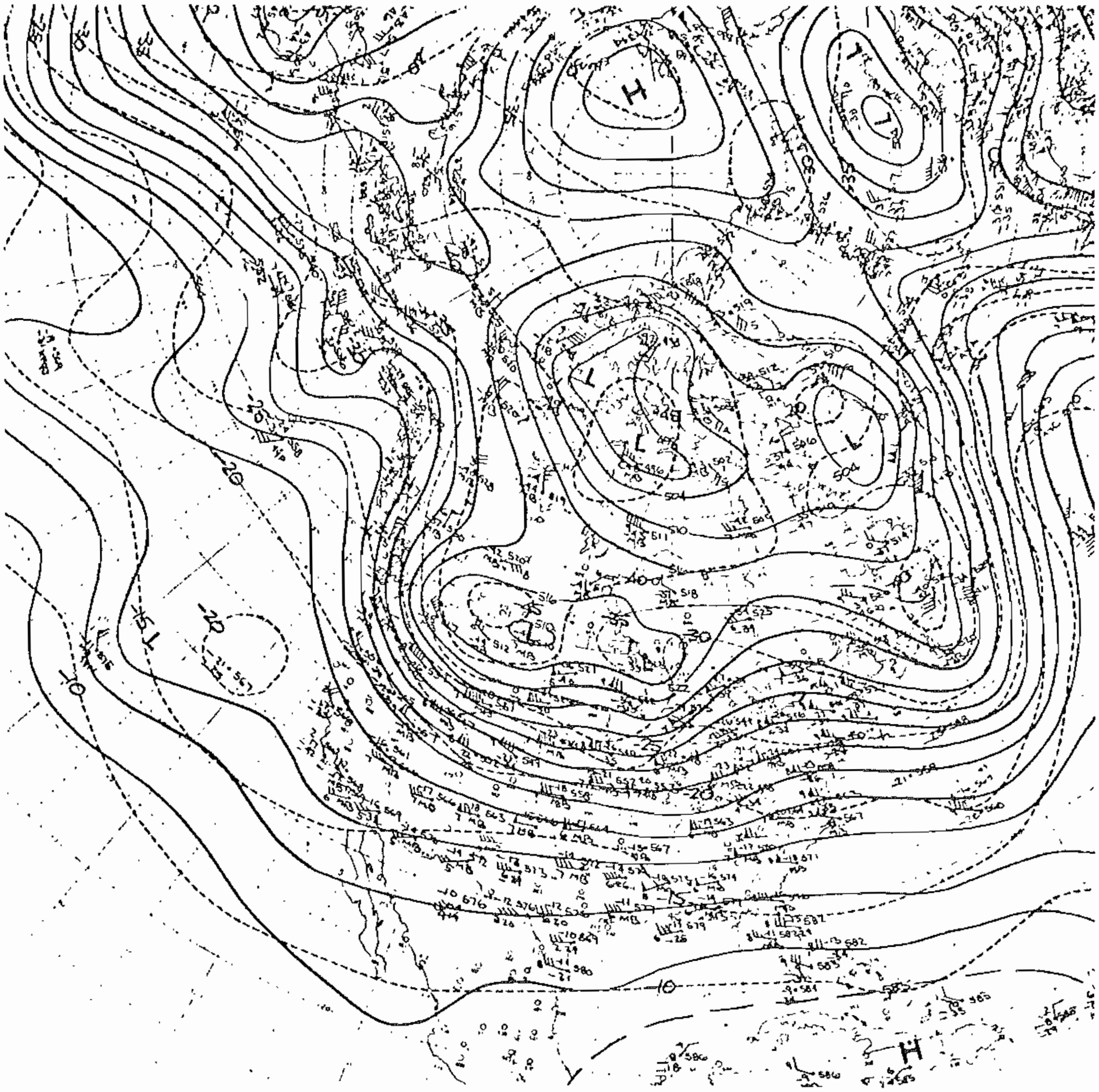

Figure 7e. 500 mb, 16/1200Z December 1964.

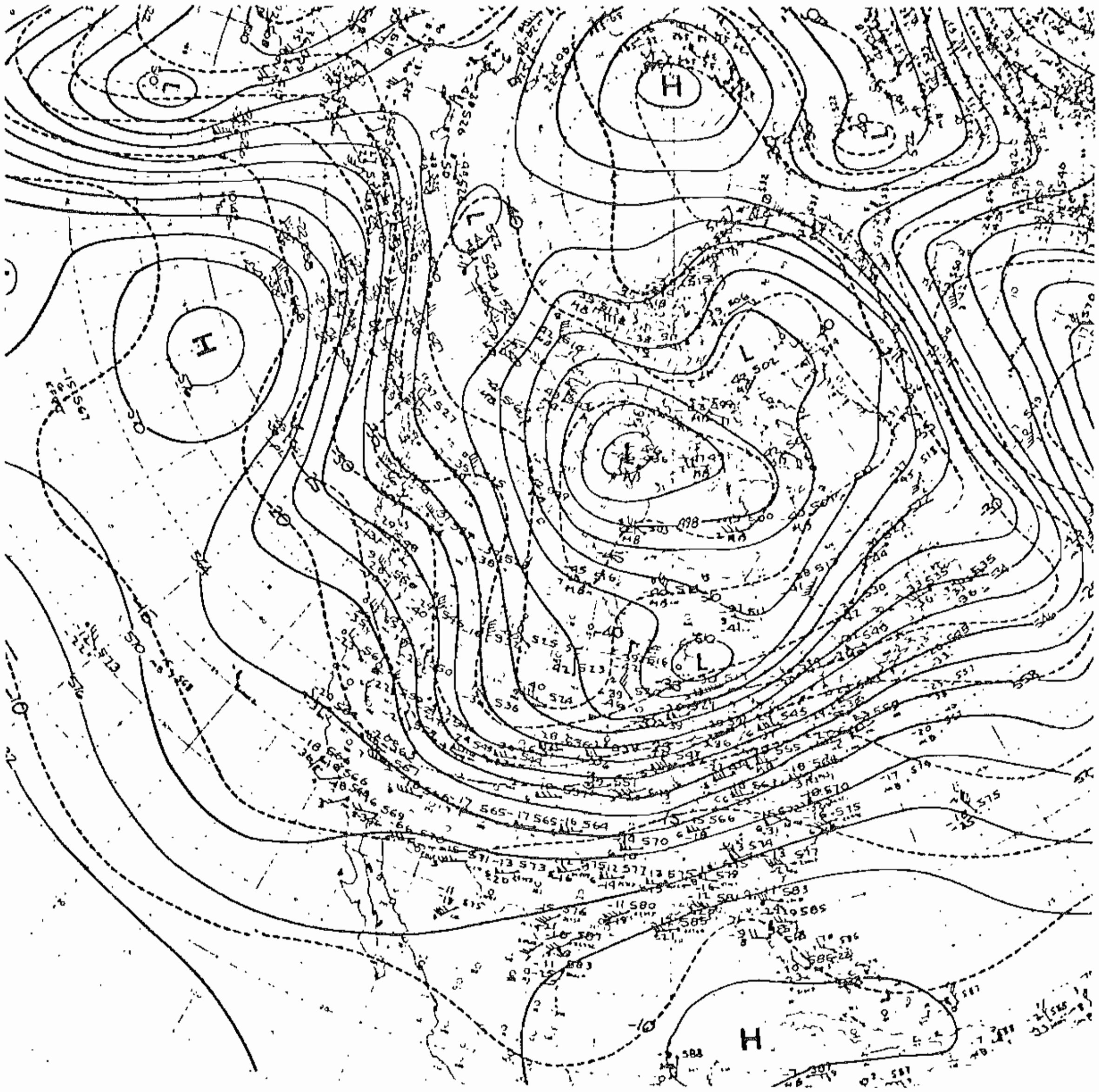

Figure 7f. 500 mb, 17/1200Z December 1964. Note the pressure of the east-west trough line over the Western United States.

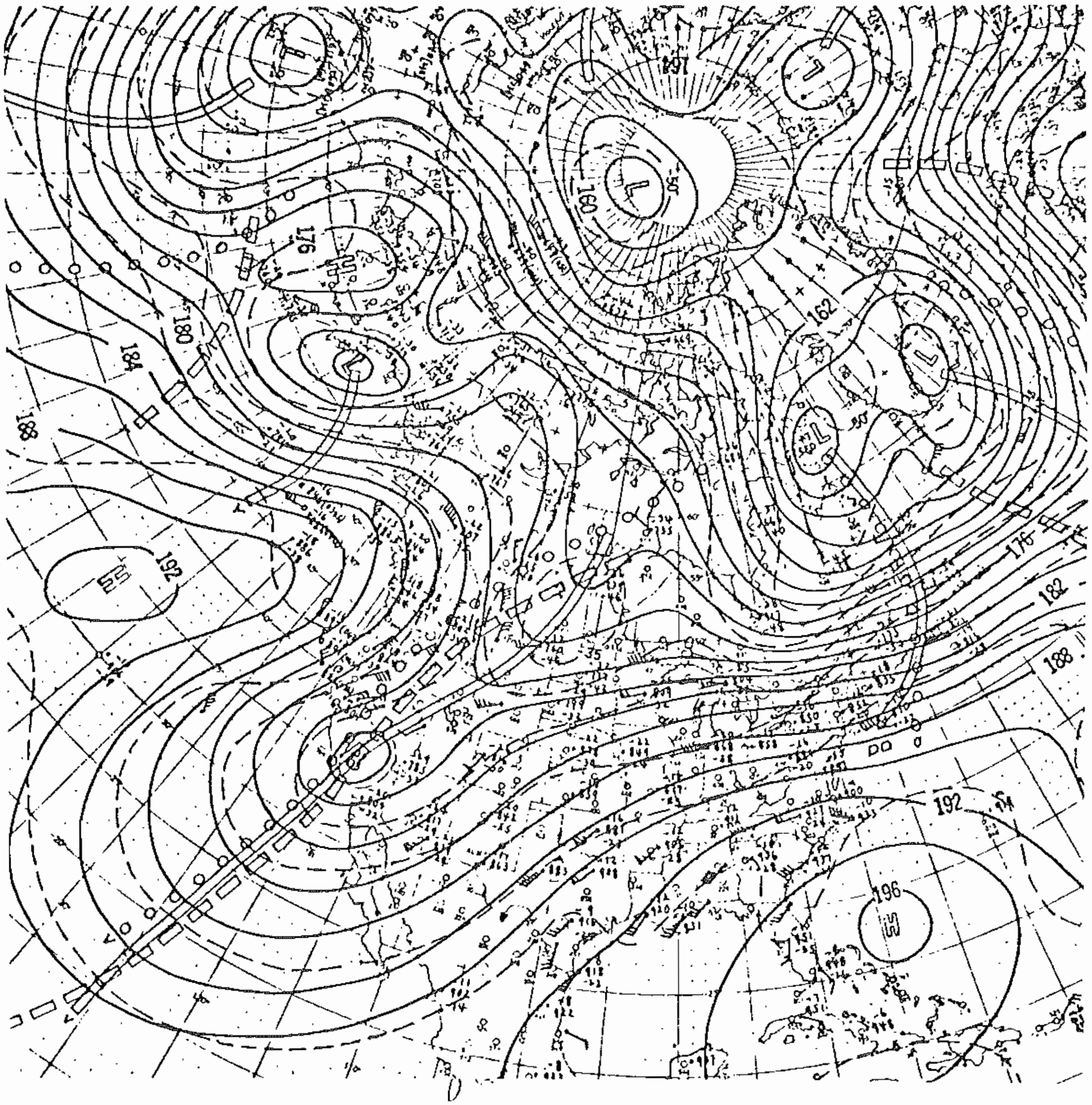

Figure 8a. 500 mb, 25/1200Z January 1949. The freezing temperatures of the Arctic outbreak moved into the Lower Rio Grande Valley on January 29.

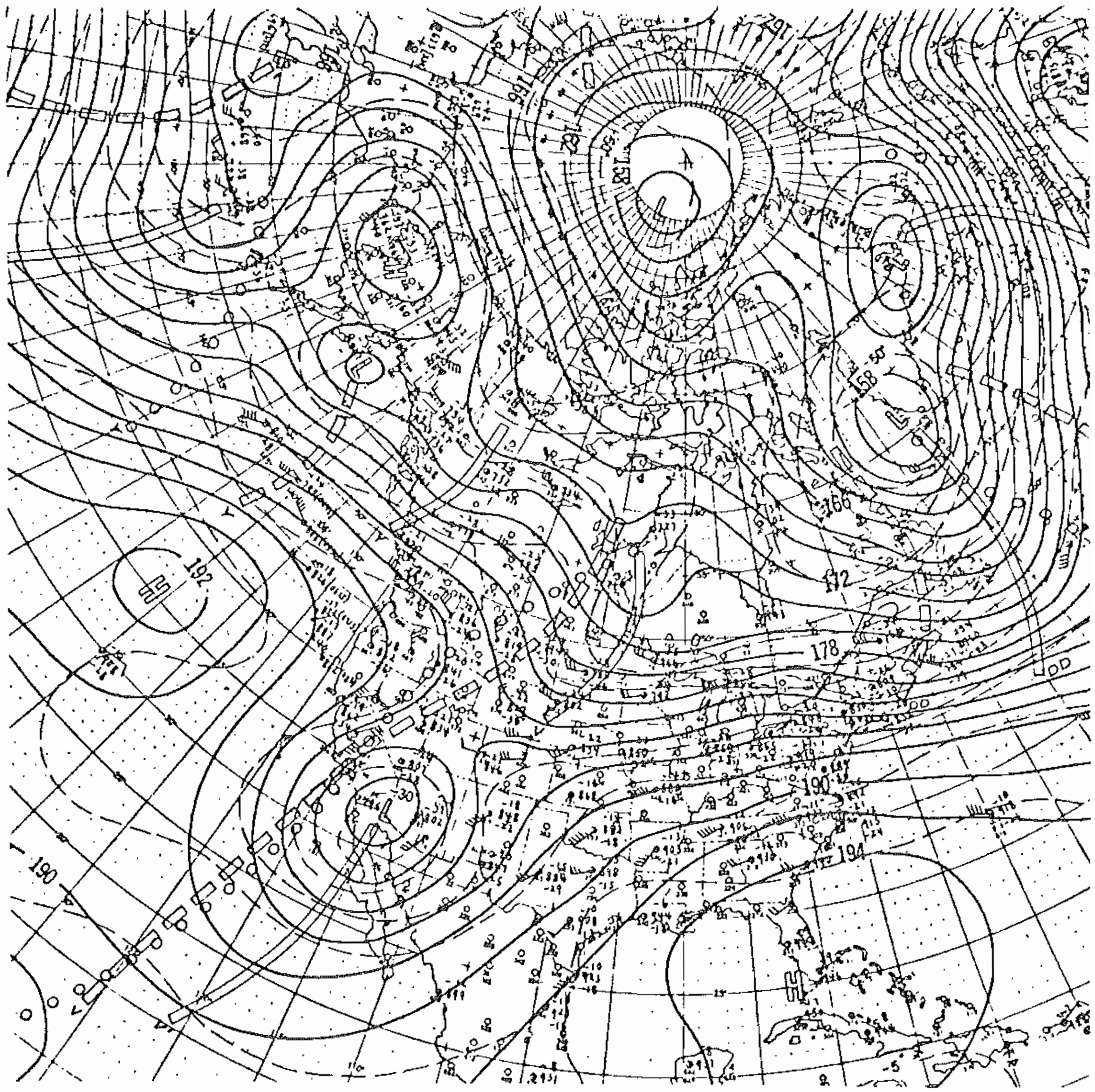

Figure 8b. 500 mb, 26/1200Z January 1949.

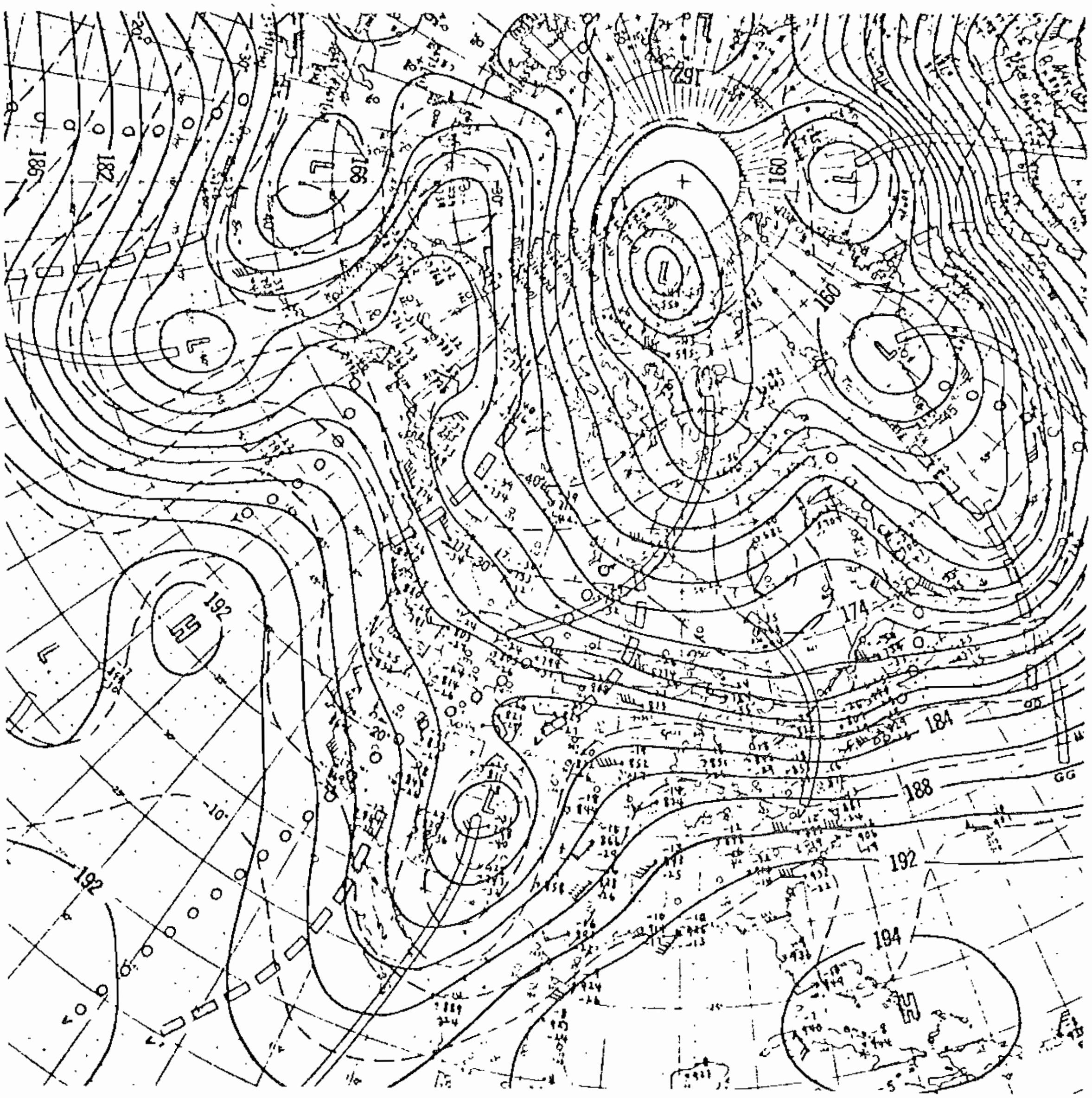

Figure 8c. 500 mb, 27/1200Z January 1949.

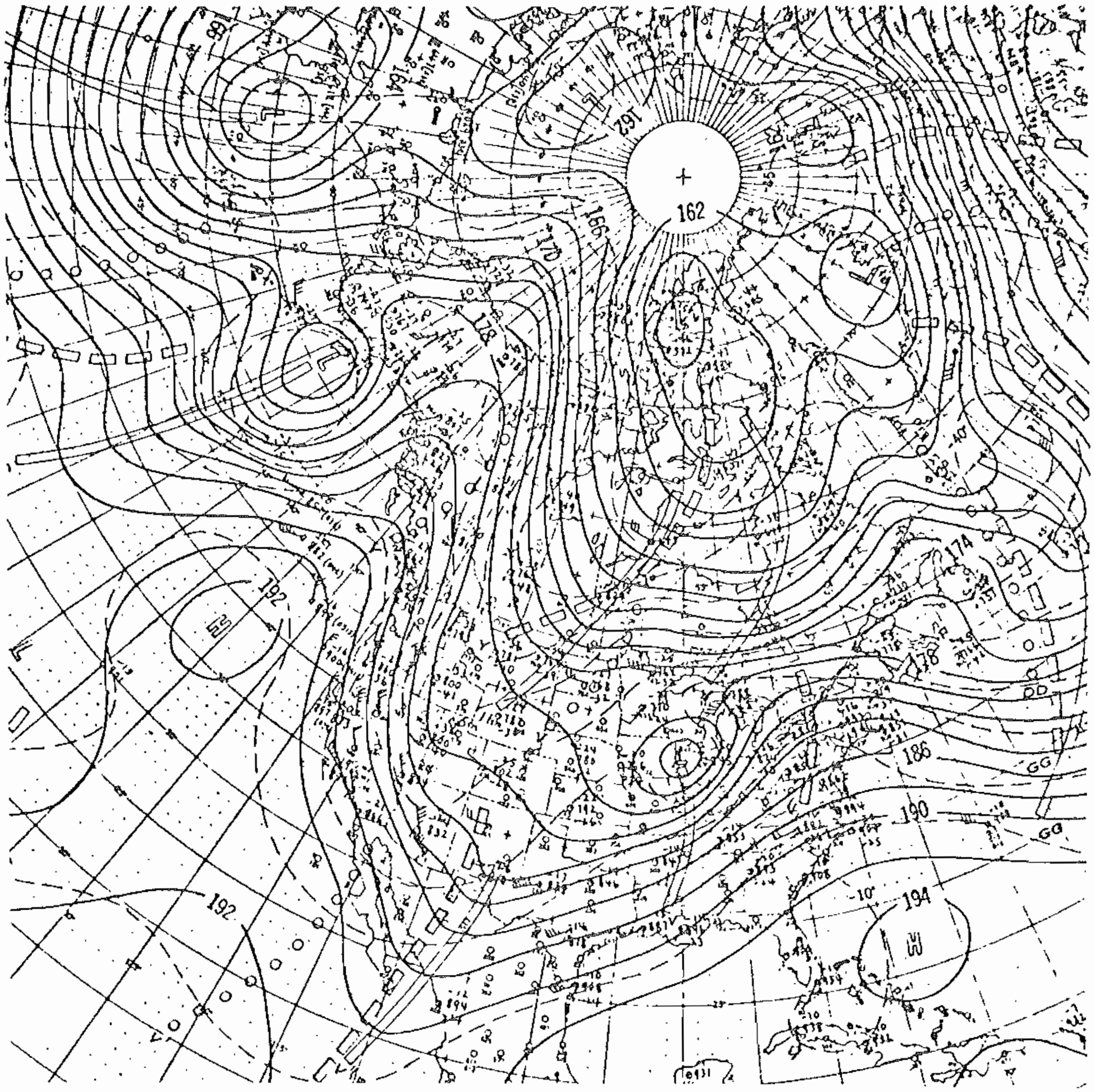

Figure 8d. 500 mb, 28/1200Z January 1949.

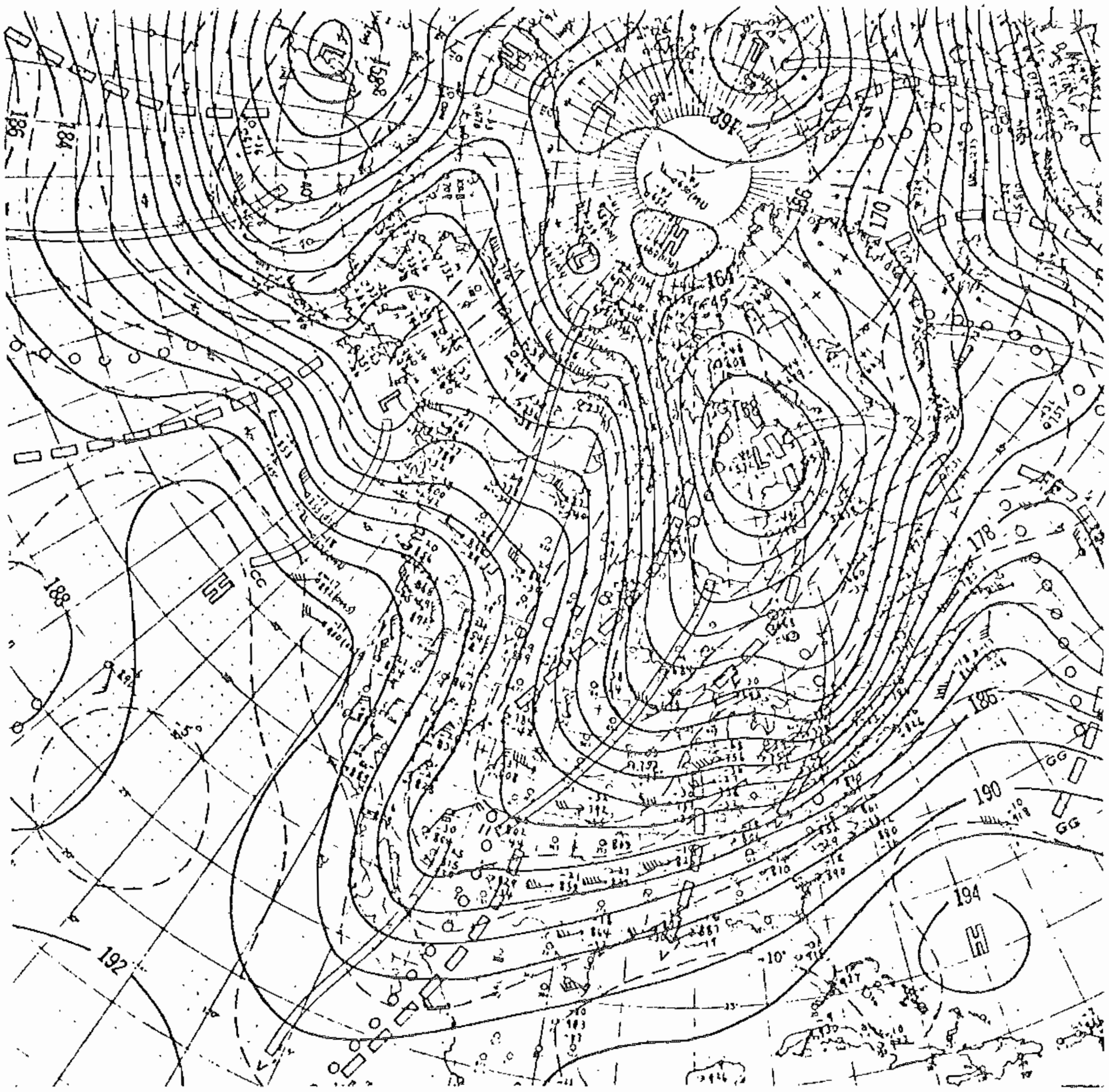

Figure 8e. 500 mb, 29/1200Z January 1949.

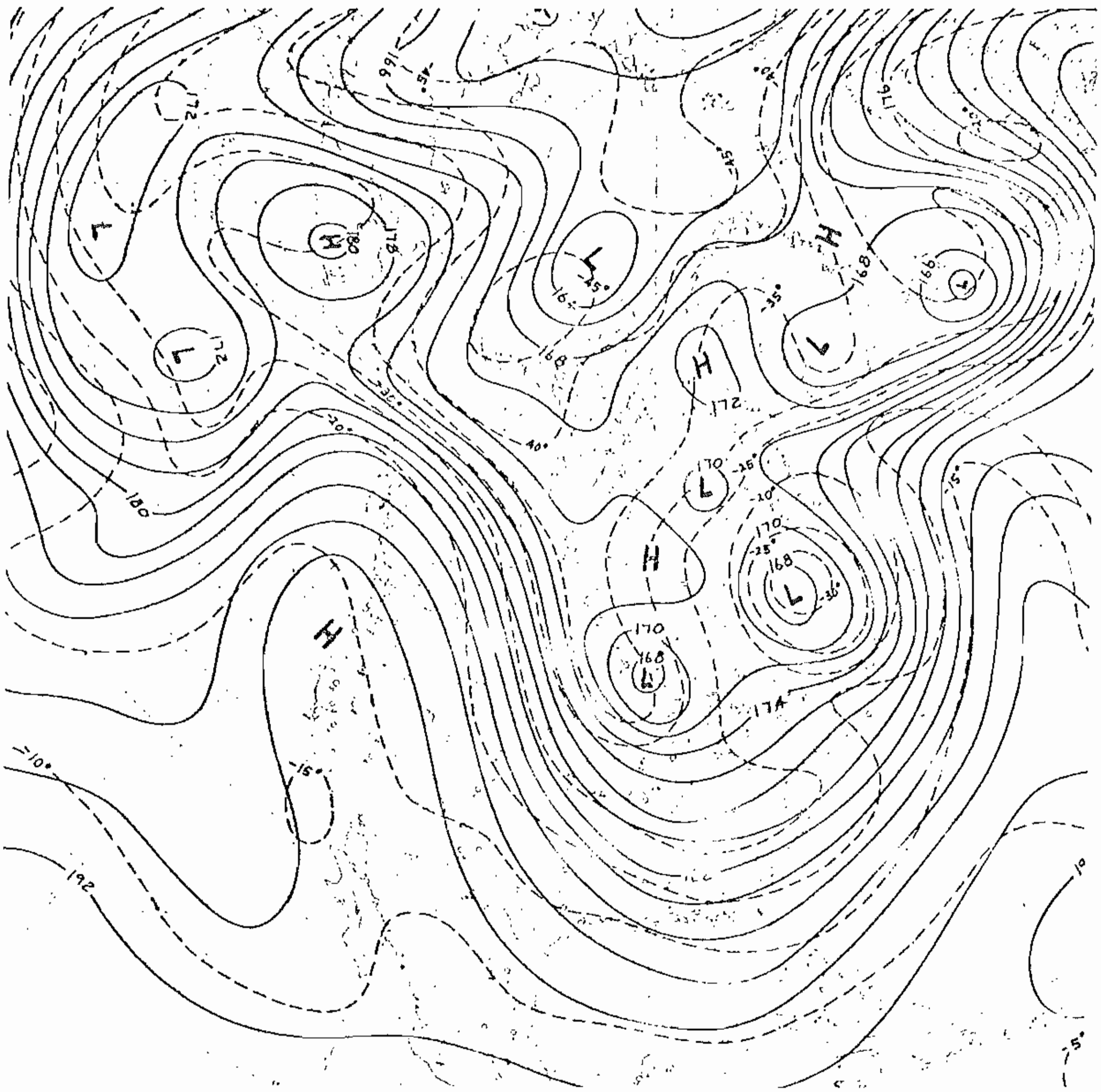

Figure 9. 500 mb, 8/1200Z December 1962. The freezing temperatures of the Arctic outbreak moved into peninsular Florida on December 13. The surface high was centered in central Alaska on 8 December with a 1049 mb central pressure. The positions and intensities of the surface high were: 9/1200Z 1045mb, northwestern Canada; 10/1200Z 1051 mb, northeast Alberta; 11/1200Z 1046 mb, southeast Saskatchewan; 12/1200Z 1041mb, eastern Kansas, and 13/1200Z 1037 mb, Louisiana.

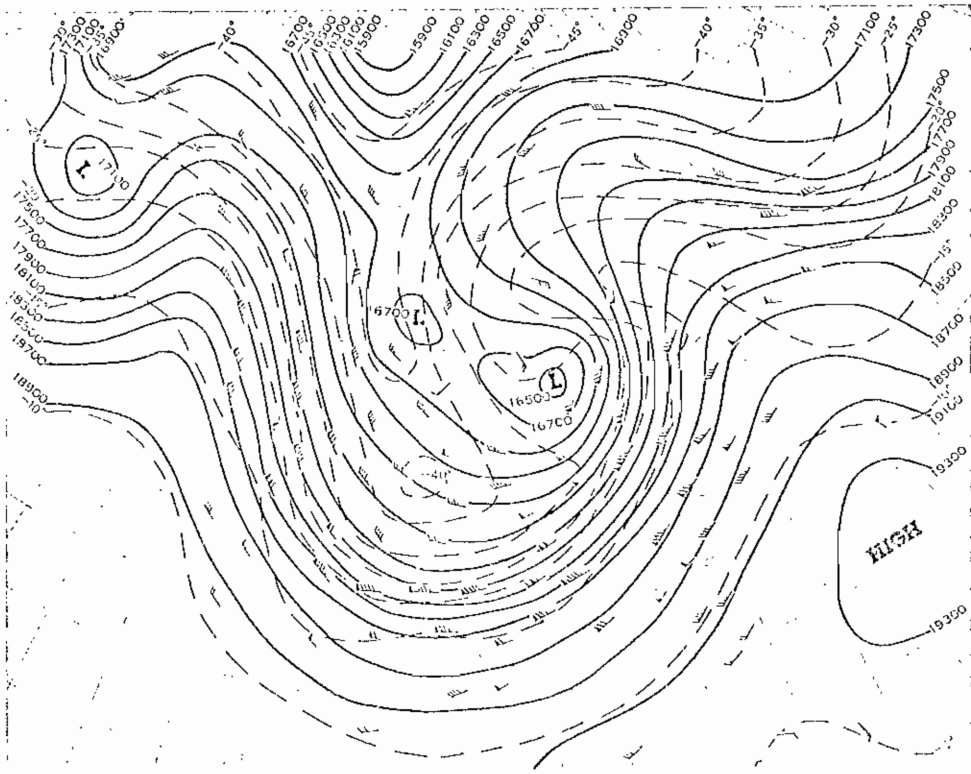

Figure 10a. 500 mb, 10/1200Z January 1975. The freezing temperatures with the Arctic air mass occurred on the evening of January 12 in the Lower Rio Grande Valley. The path of the Arctic high was southeastward through British Columbia to Western Colorado.

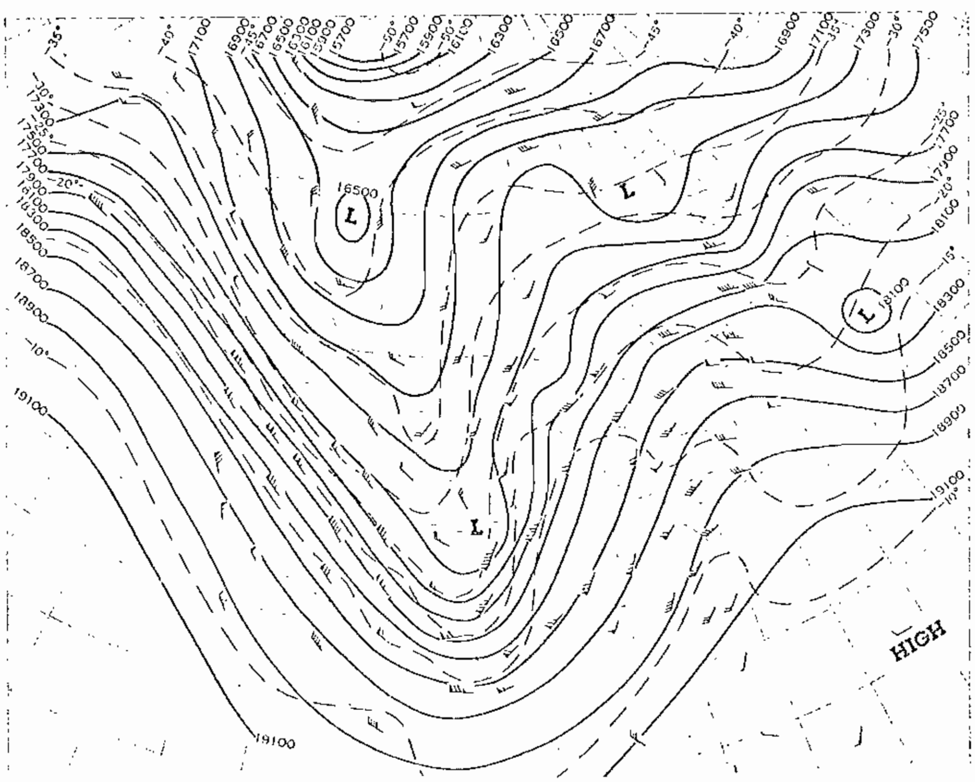

Figure 10b. 500 mb, 11/1200Z January 1975.

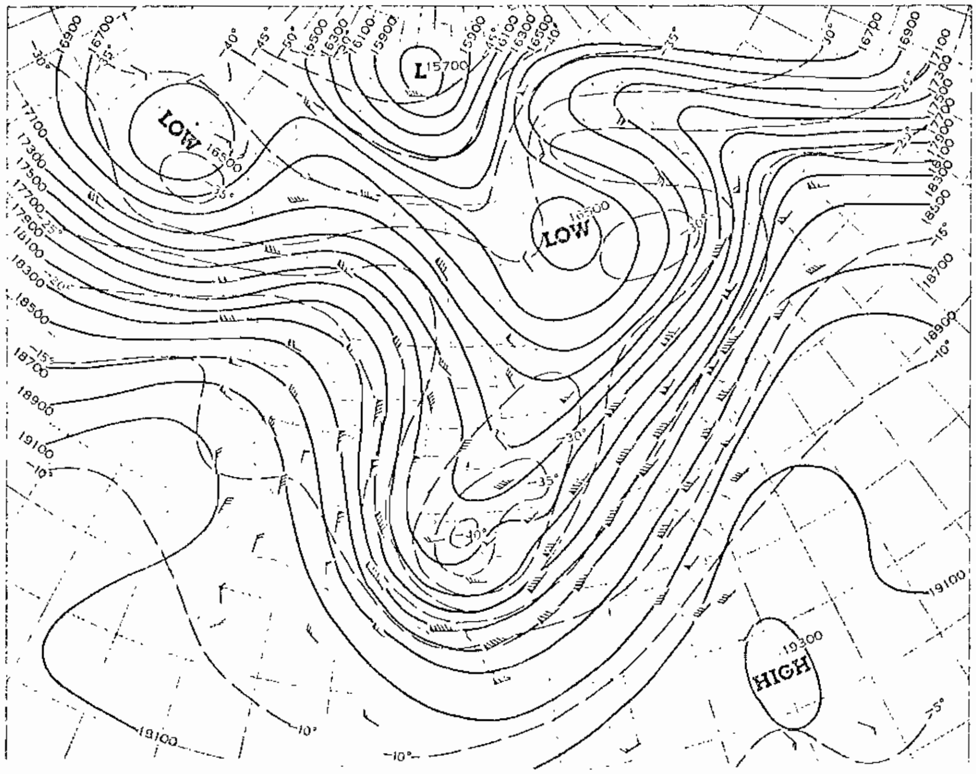

Figure 10c. 500 mb, 12/1200Z January 1975.

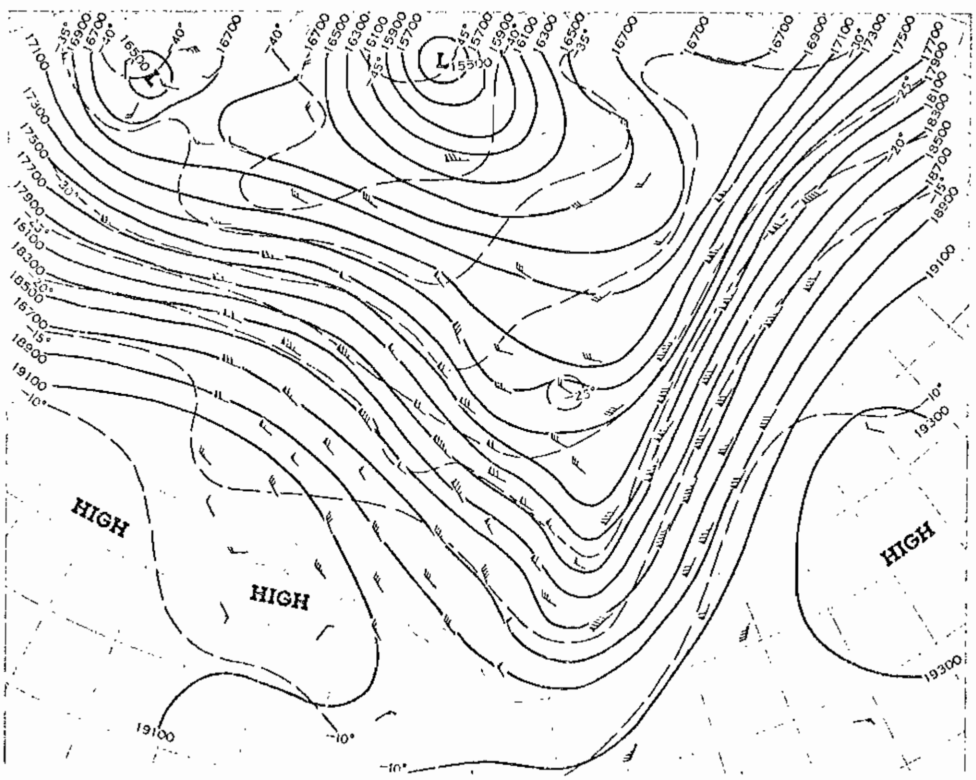

Figure 10d. 500 mb, 13/1200Z January 1975.