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NWS WR-238

SIGNIFICANT WEATHER PATTERNS AFFECTING WEST-CENTRAL MONTANA

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This publication has been reviewed
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COMPOSITES OF SIGNIFICANT WEATHER PATTERNS AFFECTING WEST-CENTRAL MONTANA

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I. Introduction

As anyone from west-central Montana will admit, severe or extreme weather conditions are not uncommon to that region of the state. Excessive rain, heavy snow, strong winds, and severe thunderstorms have frequented the area through the years, and their accurate forecast is of vital importance. After identifying the dates of the most extreme weather events to occur in Great Falls, Montana since 1949, and examining their corresponding synoptic patterns, the development of composite fields for each scenario was possible, thereby giving an "average" field for each weather phenomenon. With the development of synoptic composites comes a better understanding of these significant weather events. Furthermore, they may serve as a tool for new forecasters, as well as a refresher for current ones.

II. Data

A compact disc, jointly produced by the National Center for Atmospheric Research (NCAR) and the University of Washington, and distributed by the National Climatological Data Center (NCDC), contains archived gridded data for much of the northern hemisphere. A program named COMP (University of Washington, 1990) allows for the compositing of several grid fields of various dates by producing an output file containing mean values and standard deviations. NMCDRAW (Leblang, 1992) contours and displays the gridded analyses over a North America map background, thus making it possible to view synoptic graphics from specific dates. Furthermore, the software allows the user to view the composited gridded data for specific synoptic situations. Finally, LASNMC (Leblang, 1992) allows for the printing of the graphics to a laser printer.

Much information is available on the compact disc. Data includes: gridded files of sea level pressure; 850mb heights, temps and winds; 700mb heights and temps; 500mb heights; 250mb winds; and 200mb heights. Most of this data is given daily at 00UTC and 12UTC. The sea level and 500mb fields from 1946 to 1989 are available, whereas the other fields date back to the early 1960s. Once displayed, editing of the graphics can be done by smoothing out the contours, changing the contour interval, and overlaying fields (although only one field can be overlaid on another and no editing of them is allowed).

III. Methodology

Prior to the creation of composite maps, considerable research was performed. The initial task was to define the significant weather phenomena; rain, snow, wind, and thunderstorms were chosen. The data in this particular study was identified and gathered from the Local Climatological Data (LCD) for Great Falls, MT (NCDC). Daily data from the desired time period was easily obtained from the LCDs. After defining the weather phenomena and finding the dates on which these occurred, the gridded data were looked at carefully in hopes of recognizing specific patterns. For example, flow from a certain direction and basic surface or upper-air features could be distinguishing factors. When these patterns were found, the dates of the significant weather events were grouped accordingly. Without proper sorting, composites would be vague and generally unrepresentative of the situation. Meaningful composites were then produced and analyzed.

IV. Heavy Rain

To begin with, occurrences of heavy rain in Great Falls in a 24 hour period were investigated, with a lower threshold of 1.50 inches chosen. These are fairly rare events, as only 25 cases have met this criteria from 1949 to 1989 (Table 1). Furthermore, 17 of the 25 cases occurred in the spring months of April through June. The latter part of the summer in west-central Montana tends to be warm and dry. The greatest 24 hour rainfall occurred on May 24-25, 1980, when 3.42 inches fell. Incredibly, three of the top eight events happened during an 11 day stretch in 1953. From May 24, 1953 to June 3, 1953 nearly ten inches of rain fell at the Great Falls International Airport, or roughly two-thirds of the annual average. Also, in six of the 24 storms, the air temperature was cool enough to support some rain/snow mix. However, nearly all of the precipitation in these cases was in the form of rain and thus included in this study.

Examination of the 500mb flow at the approximate time of the rain led to the placement of 21 cases into a similar category, with the mean pattern showing a low in northeast Oregon and the trough extending to its south (Fig. 1c). One can also see how this upper-level low develops from the west in the day before the rain and moves over southwest Montana 12 hours after the rain event (Fig. 1a, 1b, 1d). Furthermore, the 500mb field is characterized by a negative tilt trough and southwest diffluent flow over Montana leading up to the rain event. As an approximation, the "12 hours before" composite could represent the onset of the rain and the "12 hours after," the end. The dynamics are favorable for heavy precipitation. The mean sea level pressure field shows a well-developed low-pressure system over northwest South Dakota (Fig. 2c), which weakens and moves off to the east in the day after the rain (Fig. 2d). Prior to the rain, the low intensifies as it moves out of the central Rockies and toward the northeast (Fig. 2a, 2b). The 250mb wind pattern shows a strong jet streak moving down the Pacific coast, prior to the onset of the precipitation, signifying the strengthening of the upcoming storm system and the deepening of the accompanying trough (Fig. 3a). At the beginning of the rain event, the winds continue to be strong on the back side of the trough, creating a slightly negative tilt (Fig. 3b). This increase in storm energy is coupled with diffluence aloft, which shows up clearly on the 250mb wind field in the left-front quadrant of the jet streak. Upward vertical motion is likely enhanced by this diffluence. Twelve hours later, or during the rain event, these strong upper-air features show a deep trough over the western states with a jet max located in southern Nevada (Fig. 3c).

Rain amounts of over two inches in 24 hours are very rare in Great Falls, as there have been only 11 in the 40-year period. Composites of ten of these storms were produced and subsequently compared to the previous study above. The results are similar, with the most noticeable difference being a slightly deeper 500mb trough developing to the west as early as 72 hours before the heavier rain period (Fig. 4a, 4b). This is possibly due to the elimination of the storms of less than two inches from the composite, as some may have had weaker dynamics. In addition, the 250mb winds composite (Fig. 4c) shows slightly stronger winds on the back side of the trough during the heavier rain, signifying the storms' greater intensity.

V. Heavy Snow

The next situation investigated was extreme snowfall amounts in a 24-hour period. A cut-off of six inches was chosen and 54 such cases were found from 1950 to 1989 (Table 2), thus storms of this caliber generally occur a little more than once per year. The largest 24-hour snowfall in Great Falls occurred on April 20, 1973, when 16.8 inches fell.

Of the 54 snow events, 16 have surface features characterized by an arctic front passing southward through Montana, followed by a large area of high pressure originating in the Yukon Territory, Canada. The remaining 38 events are the result of an intense storm system moving out of the central Rockies. These 38 storms can also be divided into two subsets, one with a strong ridge of high pressure over the Mississippi and Ohio River valleys and the other with a strong high to the north in Alberta and Manitoba, Canada. These two cases contain 19 and 18 events, respectively, and will be looked at separately.

Case 1

The 16 arctic front snowstorms (Case 1) are primarily mid-winter events, as all but one occurred between November and March. In addition, they are the least common of the three observed cases and contain the lightest snow amounts, with only four events of more than eight inches. The sea level pressure chart (Fig. 5a) shows very clearly the large area of high pressure, centered over the Yukon, and the arctic frontal boundary cutting approximately through central Montana. Twenty four hours later (Fig. 5b), the high has pushed southward into Montana and the northern plains. Temperature research has further shown that the high is associated with extremely cold air, as temperatures plummeted after the frontal passage. This type of snowstorm is often coined an "Alberta Clipper." The 500mb flow shows a massive low-pressure system located over Hudson Bay and strong northwest flow aloft over western Canada and the Pacific Northwest (Fig. 5c). This type of pattern is typical for bringing Alberta Clippers and cold, arctic air to west-central Montana.

Case 2

Case 2, composed of 19 snowstorms, is characterized by an intense surface low-pressure system moving out of the central Rockies and then being steered into eastern Montana and the western Dakotas by a fairly strong ridge of high pressure over the eastern half of the country. It is primarily a springtime event, as only three of this type occurred prior to February. The heavier snow events fall into this category, including the greatest 24-hour total, 16.8 inches. Of the 19 storms, eight are of 10 inches or more. The sea level pressure composite (Fig. 6a) shows a low centered over southeast Wyoming / north-central Colorado and a high pressure to its east. This scenario produces strong upslope conditions at the surface in west-central Montana, which is perhaps prolonged due to the ridge to the east serving as a blocking feature. The 500mb field (Fig. 6b) shows the trough over the western states and the ridge over the Mississippi and Ohio River valleys. The 850mb chart (Fig. 6c) shows a temperature of approximately -2 Celsius over west-central Montana. At an elevation of 1116m, Great Falls is not much below that level, which has a height of about 1390m. Thus, an 850mb temperature of -2 Celsius shows air cold enough to support snow but also warm enough to hold abundant moisture.

Case 3, with 18 storms, involves a similar low-pressure system centered over the Wyoming / Colorado border but strong high pressure exists in Canada as well. This case had only two storms of at least 10 inches but had seven storms over eight inches, making it more potent than the

Case 1 situation. The sea level pressure composite (Fig. 7a) shows a strong gradient over the north central U.S. and upslope conditions in west-central Montana. Case 3 storms tend to move east quickly, whereas the Case 2 events move more slowly and to the northeast. The 500mb field (Fig. 7b) verifies this characteristic by showing zonal flow across the eastern two-thirds of the country, as compared to Case 2, where the 500mb flow contains higher amplitude waves. Similar to before, the 850mb 0 Celsius isotherm runs through central Montana (Fig. 7c).

In west-central Montana, spring snow storms are often the most severe of the season. During the 40-year span of this study, there were 12 storms of eight inches or more in a two month period from March 15 through May 15. Of these 12 events, nine were Case 2 types. Following is a discussion of these nine spring snow storms.

The sea level pressure composite (Fig. 8a) shows a very intense storm system centered over the Colorado / Wyoming / Nebraska area with strong upslope conditions over west-central Montana. This is similar to Fig. 6a except that the low is more intense. Figure 8b shows a deeper 500mb trough as well. One will notice that, although it has weakened somewhat, the low-pressure center at the surface remains in the same position 12 hours later (Fig. 8c). It is possible that this slow storm motion is responsible for prolonged upslope in the west-central Montana region and, therefore, the high precipitation totals. Furthermore, examination of the 250mb flow (Fig. 8d) shows very strong diffluence aloft, giving added lift.

VI. Strong Winds

The next area of interest was surface winds. Although the very strong, gusty winds associated with severe thunderstorms are common, they are generally not represented on a synoptic scale. It was important to look at sustained winds throughout a given day. Therefore, average daily sustained wind speeds of 30 miles per hour or greater was chosen as the criteria. Because the strongest average winds in Great Falls occur during the winter, the months of November through March were used for this study. From 1963 to 1989, there were 26 such days (Table 3), or roughly one per year. The mean sea level pressure pattern shows a strong gradient between the lower pressures to the north and the higher pressures to the south (Fig. 9a). This pattern, along with the location of the Rockies to the west, results in strong, southwest winds in the Great Falls area. These downslope winds are called chinook winds and are very common in the winter months, with most examples not even considered here as only mean daily winds in excess of 30 miles per hour were investigated. The warming that may occur as a result of the chinook can be shown in the progression of the 850mb heights / temperatures composites (Figs. 9b-c). It is interesting to discover that the 500mb field (Fig. 9d) is very similar to that of Case 1 of the snowstorms (the Alberta Clipper type), and both occur during the winter with huge lows near Hudson Bay. However, crucial differences do exist. Whereas, with the Alberta Clipper, the 500mb flow is from the north with cyclonic curvature to the immediate west of Montana, the chinook winds type has flow from the west, anticyclonic curvature, and much greater heights (giving rise to warm, dry conditions).

An investigation of strong summer-time winds was also undertaken. Average winds are not as strong during the summer so the daily average cutoff was lowered to 25 miles per hour and the year span extended back to 1950. The months of May through September were considered. In the 40-year period, 28 days met this criteria (Table 4). Of the 28 days, only seven occurred during June, July, or August. The high wind occurrence is primarily a late spring or early fall phenomenon. Also, no thunderstorms occurred on any of the high wind days. Thus, the average speeds are not contaminated by thunderstorm gusts. Seventeen of the 28 days had similar synoptic patterns and were composited. The surface composite shows a low pressure to the north and a high pressure over the Pacific Ocean, resulting in a strong pressure gradient from central Washington to central Montana (Fig. 10a). The structure of the isobars implies the passage of a cold front, stretching through eastern Montana to eastern Colorado. Although at first glance it might appear that the winds should be westerly or northwesterly, terrain in the Great Falls area promotes prevailing southwest winds at the surface. The 850mb and 700mb fields show the colder air moving in behind the front, as well as a tight height gradient in the region (Figs. 10b-c). The 500mb composite (Fig. 10d) shows west to southwest flow with a low to the north. Also evident is the shortwave that had passed through west-central Montana shortly before, and this is confirmed through examination of the 500mb fields before and after the winds (not given).

VII. Severe Weather

The final area of study was severe summer weather, and days with thunderstorms accompanied by hail were chosen. From the year 1965 until 1989, 58 such occurrences were recorded at the Great Falls International Airport, 41 of which fall into a similar category (Table 5). The 500mb composite of these 41 cases shows a trough along the Pacific coast, resulting in southwest flow over central Montana (Fig. 11a). The mean sea level composite features a region of lower pressures to the south, stretching from Wyoming to southern Nevada and into Mexico (Fig. 11b). At the time of the severe weather, the pressure in the Great Falls area was at its lowest, and the low in Wyoming was at its most intense stage. Looking at the 850mb temps/heights composite (Fig. 11c), one will notice very warm air at that level, near 20 Celsius over west-central Montana. This is due to strong warm air advection leading up to the severe weather, with cooling afterward. The 250mb winds field shows slight diffluence aloft, thus enhancing the upward vertical motion (Fig. 11d).

VIII. Conclusions

Although no two storm systems are alike, composite maps give a good representation of the general features associated with a specific type of weather. Consequently, they act as an effective tool for forecasters to use. Thanks to the easy access to an abundance of historical gridded data, the development of composites is simple.

In Great Falls, Montana, the changes in a variety of weather conditions come frequently and abruptly. This fact necessitates a solid understanding of each situation, which will unquestionably be aided through the interpretation of meaningful composites.

XI. References

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TABLE 1: Great Falls rain of 1.50 inches or more in 24 hours (1949-1989)

1)	3.42"	May 24-25, 1980	+
2)	3.20"	May 24-25, 1953	
3)	2.74"	August 24-25, 1989	*
4)	2.74"	June 7-8, 1964	
5)	2.43"	April 30 - May 1, 1951	+
6)	2.40"	July 9-10, 1983	
7)	2.40"	May 29, 1953	
8)	2.37"	June 2-3, 1953	
9)	2.29"	June 25-26, 1969	
10)	2.11"	June 1-2, 1954	+
11)	2.09"	June 28-29, 1982	
12)	2.00"	August 15-16, 1985	^
13)	1.94"	May 20-21, 1957	
14)	1.89"	June 24-25, 1965	
15)	1.82"	September 26-27, 1982	+
16)	1.82"	August 19-20, 1974	
17)	1.81"	May 20-21, 1962	
18)	1.73"	September 11-12, 1978	
19)	1.72"	August 9, 1950	
20)	1.67"	May 16-17, 1949	+
21)	1.66"	May 18-19, 1959	
22)	1.64"	May 26-27, 1955	
23)	1.60"	April 25-26, 1986	+
24)	1.51"	July 12-13, 1989	*

All data recorded at the airport

* Data was not available for composite

+ Some snow mixed with rain

^ Did not fit composite pattern

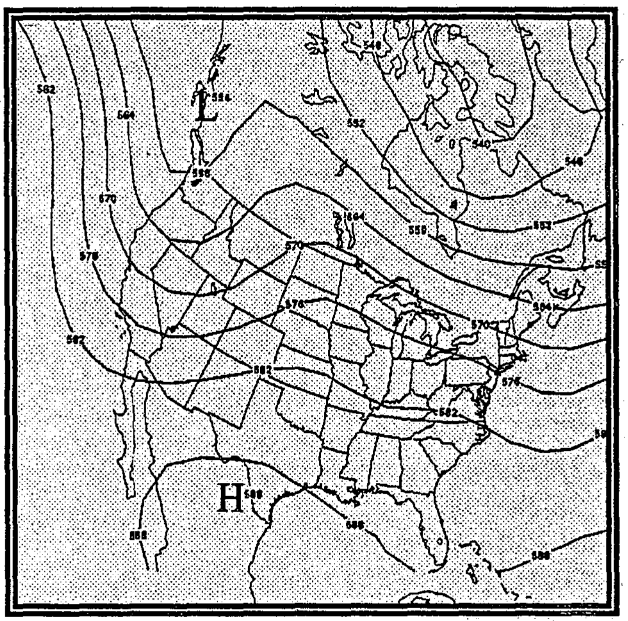

Fig. 1a: 500mb HEIGHTS 24 hours before the rain event. A trough is roughly along the west coast. Winds aloft are from the SSW over Montana.

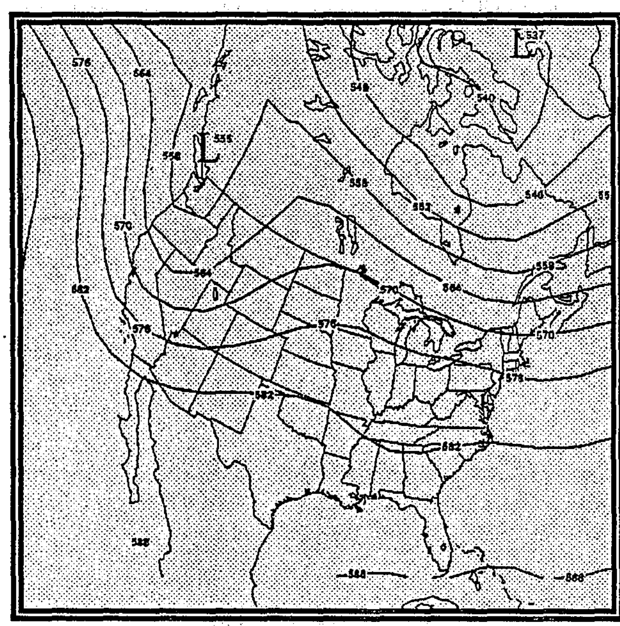

Fig. 1b: 500mb HEIGHTS 12 hours before the rain event. The trough has not moved at this point, however, the low has intensified. SSW winds aloft continue. This approximately represents the onset of the rain.

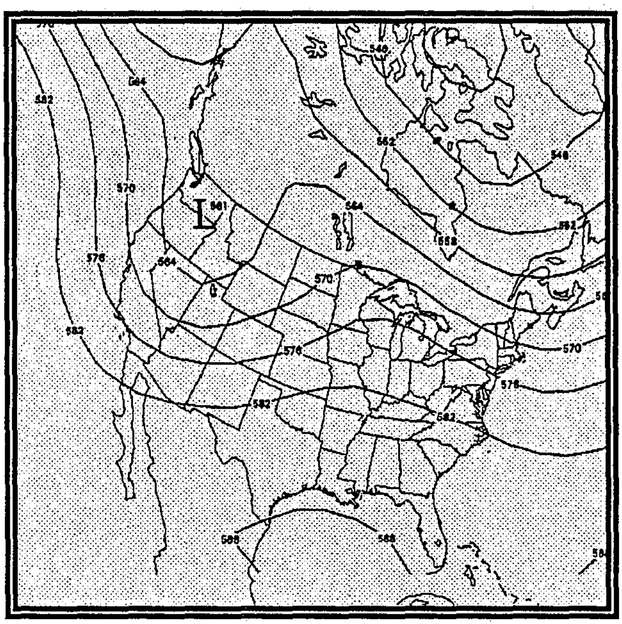

Fig. 1c: 500mb HEIGHTS. The trough is now located over the Great Basin and the low has dug further to the south, bringing south winds aloft. Note the slight negative tilt.

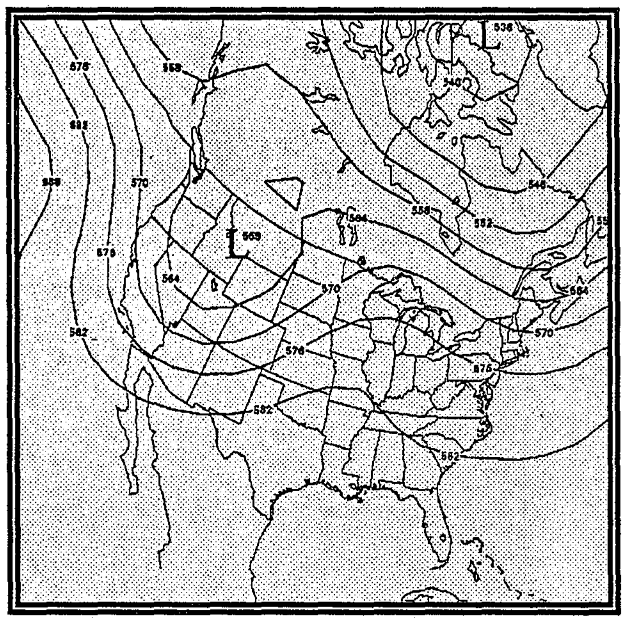

Fig. 1d: 500mb HEIGHTS 12 hours after the rain event. This approximately represents the end of the 24 hour rain period. The low is located over southwest Montana and the trough is no longer negatively tilted.

FIGURE 1: 500mb HEIGHTS (dam) for rain events of 1.50 inches or more.

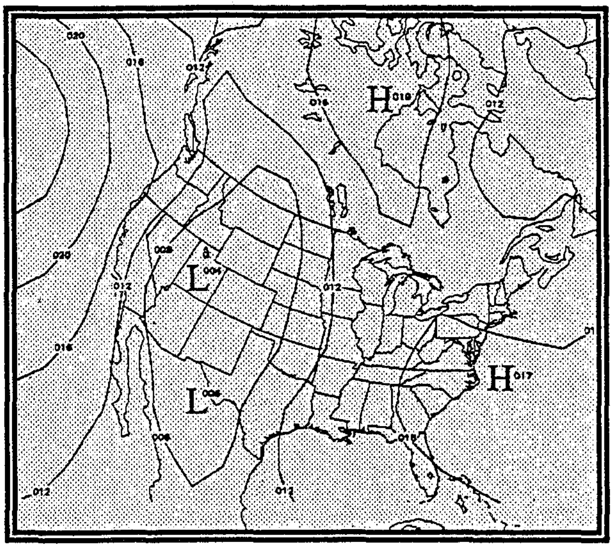

Fig. 2a: SEA LEVEL PRESSURES 24 hours before the rain event. The system is located over Utah and is not yet very well organized.

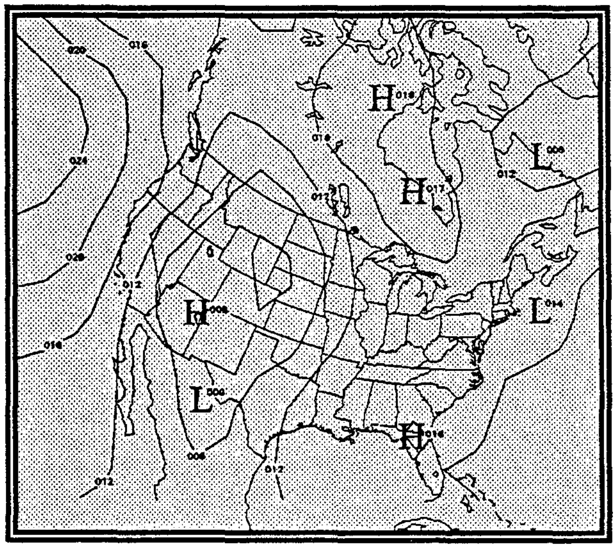

Fig. 2b: SEA LEVEL PRESSURES 12 hours before the rain event. The low has intensified and is moving out of the central Rockies.

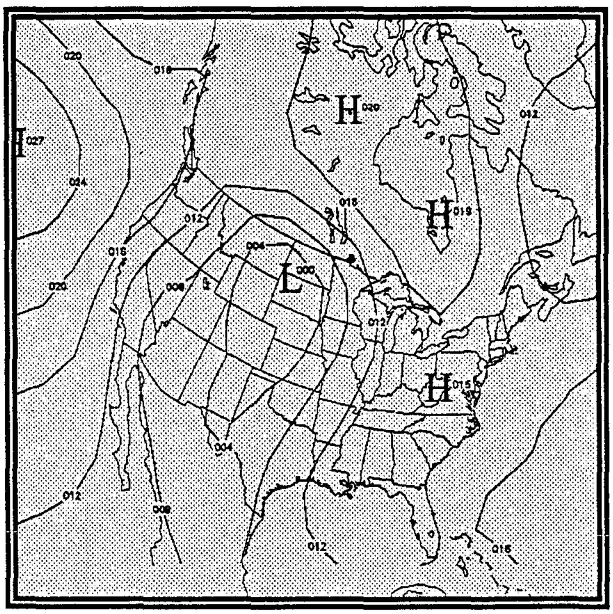

Fig. 2c: SEA LEVEL PRESSURES. The low is centered over northwest South Dakota, giving rise to upslope conditions in west-central Montana.

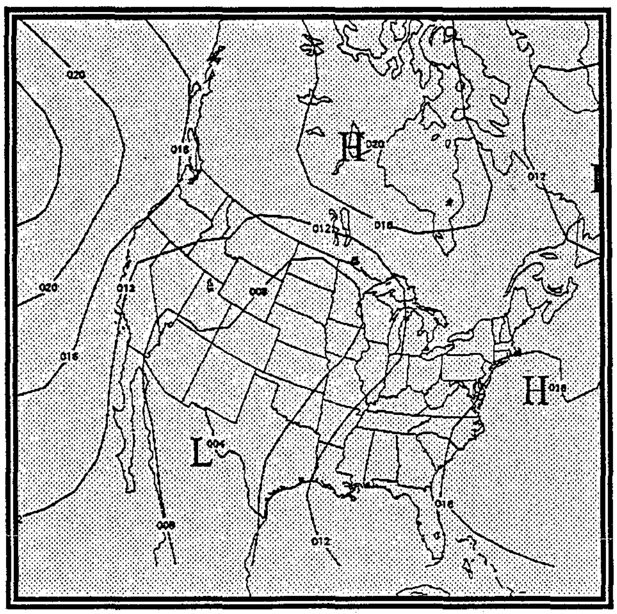

Fig. 2d: SEA LEVEL PRESSURES 24 hours after the rain event. The low has weakened considerably and moved east.

FIGURE 2: SEA LEVEL PRESSURES (mb) for rain events of 1.50 inches or more.

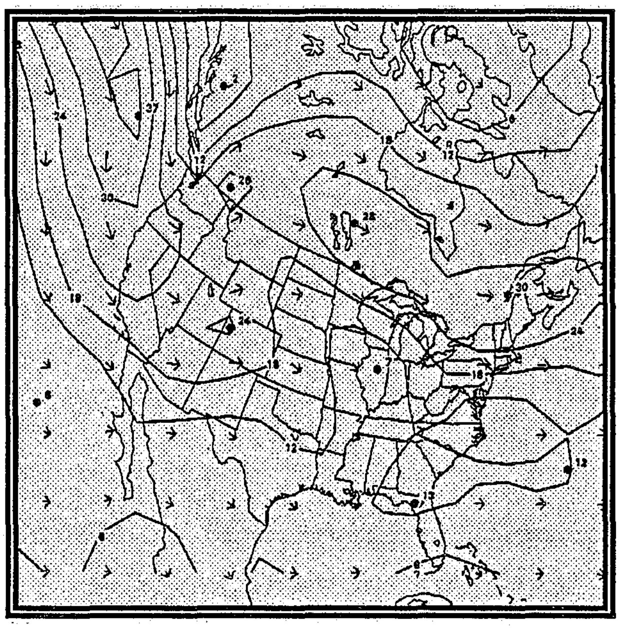

Fig. 3a: 250mb WINDS 24 hours before the rain event. A jet streak is located off of the Pacific northwest coast, on the back side of the trough. This is a sign of the strengthening of the upcoming storm system.

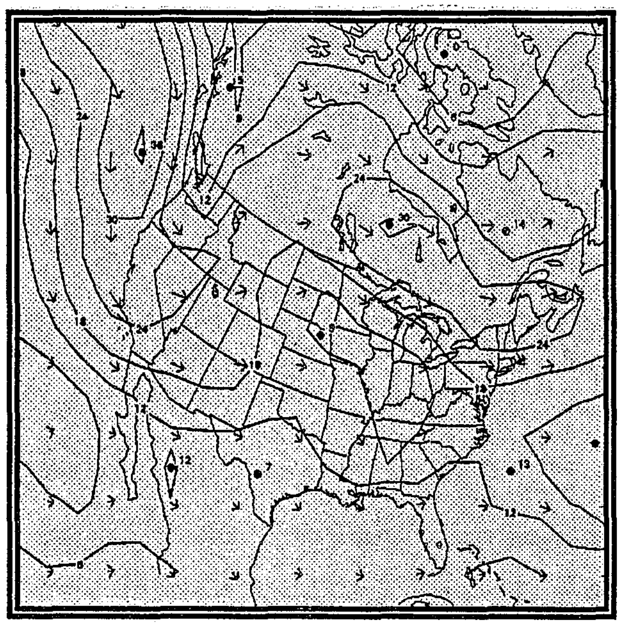

Fig. 3b: 250mb WINDS 12 hours before the rain event. Winds are still strong on the back side of the trough, creating a slightly negative tilt. Diffluence exists over west-central Montana.

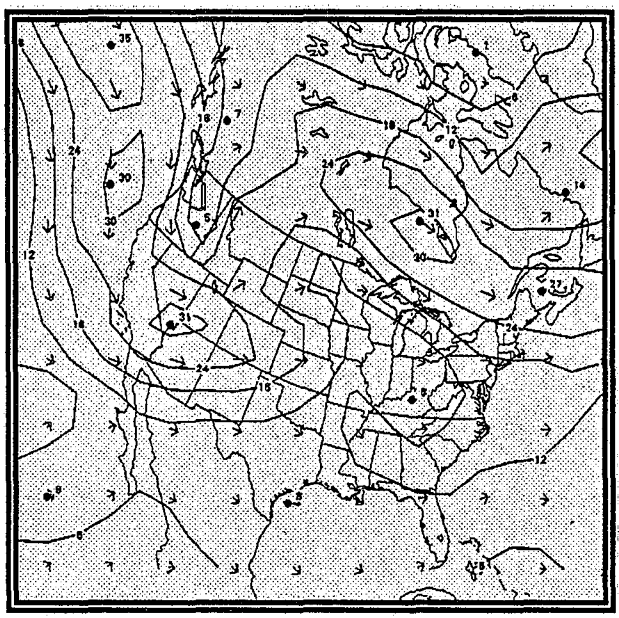

Fig. 3c: 250mb WINDS. A deep trough sets over the western states, and a jet maximum is located over southern Nevada. There is still diffluence aloft, enhancing the lift.

FIGURE 3: 250mb WINDS (m/s) for rain events of 1.50 inches or more.

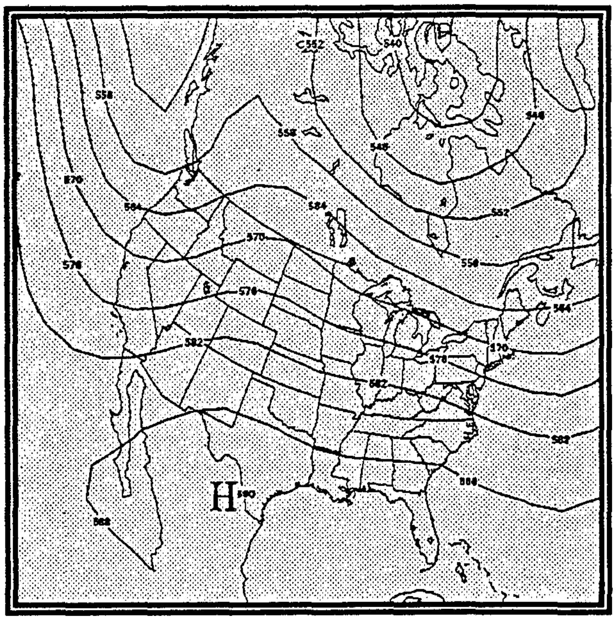

Fig. 4a: 500mb HEIGHTS 72 hours before the heavy rain event. A trough is developing along the west coast. There is SW flow aloft over west-central Montana.

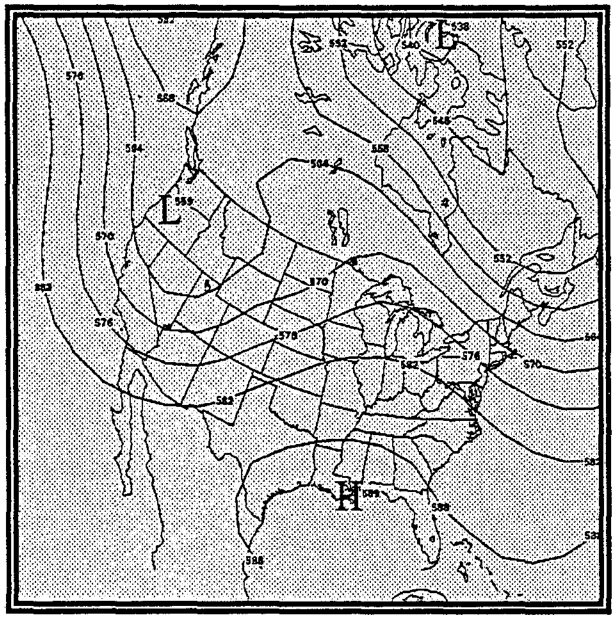

Fig. 4b: 500mb HEIGHTS. The trough is slightly deeper than in Figure 1c for 1.50 inches or greater rainfall.

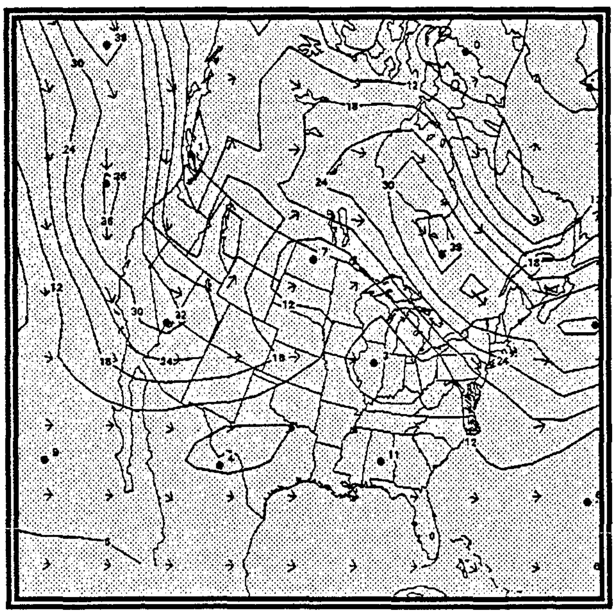

Fig. 4c: 250mb WINDS. Winds on the back side of the trough are stronger than those in Figure 3c for 1.50 inches or greater rainfall.

FIGURE 4: 500mb HEIGHTS (dam) and 250mb WINDS (m/s) for rain events of 2.00 inches or more.

TABLE 2: Great Falls snowfalls of six inches or more in 24 hrs (1950-1989)

CASE 1:

1)	10.2"	January 15-16, 1984	9)	6.9"	January 7, 1962
2)	10.2"	February 21-22, 1982	10)	6.9"	December 3, 1958
3)	8.9"	February 16, 1959	11)	6.8"	April 11, 1986
4)	8.0"	November 11, 1959	12)	6.8"	November 24, 1983
5)	7.4"	December 1-2, 1972	13)	6.6"	March 17, 1950
6)	7.4"	January 2-3, 1966	14)	6.1"	December 23, 1984
7)	7.3"	January 21, 1964	15)	6.1"	December 23, 1977
8)	7.0"	November 26, 1955	16)	6.0"	March 4, 1951

CASE 2:

1)	16.8"	April 20, 1973	11)	8.8"	April 7, 1975
2)	11.5"	March 19-20, 1987	12)	8.6"	May 9, 1983
3)	11.0"	March 28-29, 1977	13)	8.3"	October 3, 1957
4)	11.0"	February 21, 1951	14)	8.1"	February 27, 1953
5)	11.0"	June 7-8, 1950	15)	7.9"	April 2, 1955
6)	10.2"	April 6-7, 1982	16)	6.8"	October, 14, 1975
7)	10.0"	April 25-26, 1976	17)	6.3"	March 27, 1979
8)	10.0"	March 29-30, 1967	18)	6.2"	November 15, 1952
9)	9.0"	February 10, 1978	19)	6.0"	April 7, 1950
10)	9.0"	April 19, 1967			

CASE 3:

1)	11.6"	May 28-29, 1989	10)	7.7"	April 28, 1970
2)	10.3"	April 27, 1989	11)	7.5"	March 19, 1982
3)	9.2"	April 23, 1960	12)	7.1"	October 28, 1972
4)	8.7"	April 5, 1967	13)	6.9"	March 17, 1968
5)	8.6"	January 10, 1988	14)	6.7"	February 26, 1958
6)	8.4"	March 13, 1984	15)	6.4"	October 6, 1985
7)	8.1"	January 6, 1989	16)	6.4"	March 27, 1961
8)	7.9"	February 16, 1952	17)	6.2"	May 10, 1967
9)	7.8"	January 28, 1959	18)	6.1"	September 28, 1954

Note: Gridded data for September 17-18, 1988 snowstorm (8.4") was not available.

All data recorded at the airport

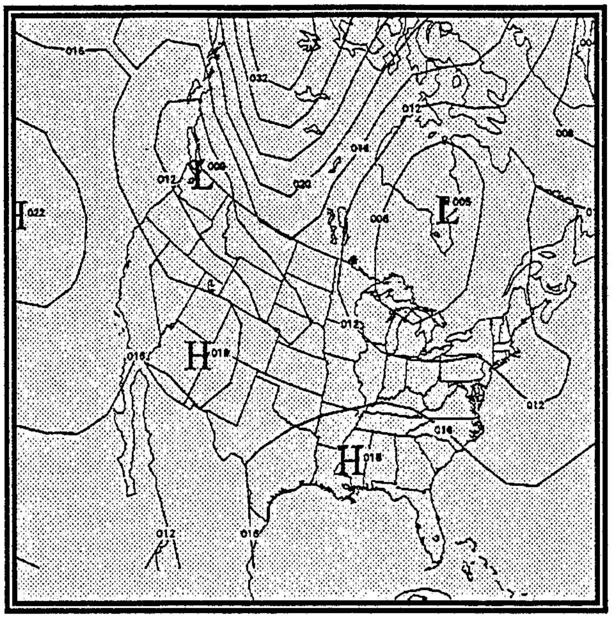

Fig. 5a: SEA LEVEL PRESSURES. An arctic frontal boundary cuts through southcentral Montana. A large high pressure region is to the north.

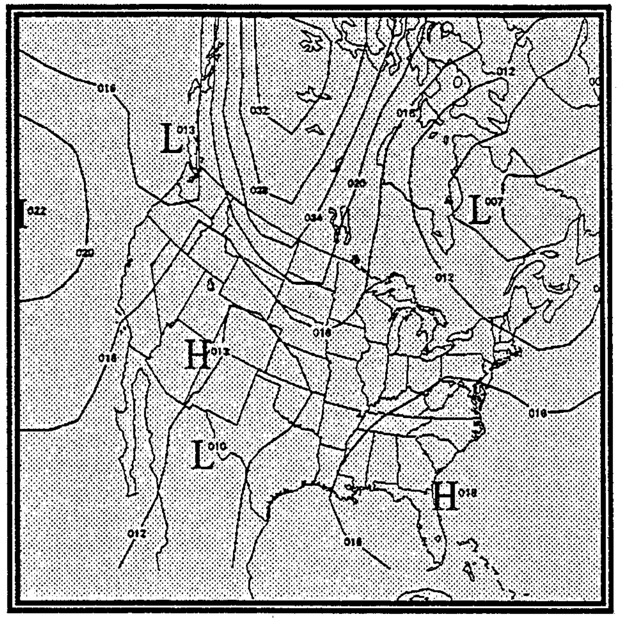

Fig. 5b: SEA LEVEL PRESSURES 24 hours after the Case 1 snow event. An Alberta Clipper has passed through Montana and high pressure is invading the northern plains, as well as much colder temperatures.

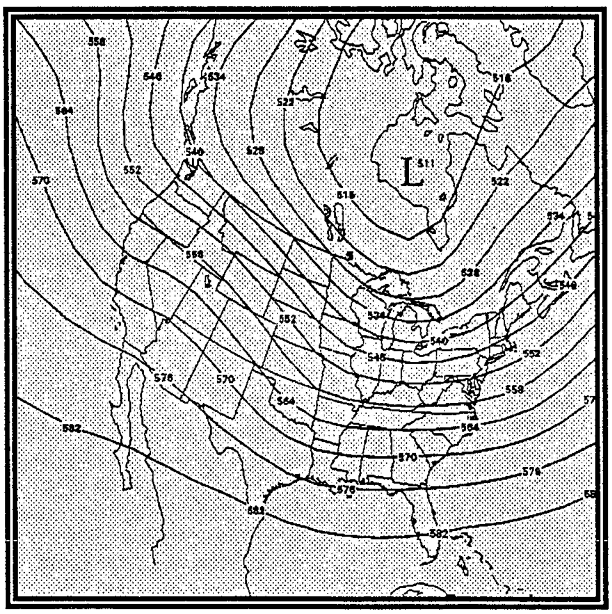

Fig. 5c: 500mb HEIGHTS. A large low is located over Hudson Bay, resulting in WNW flow over west-central Montana.

FIGURE 5: SEA LEVEL PRESSURES (mb) and 500mb HEIGHTS (dam) for Case 1 snow events of six inches or more.

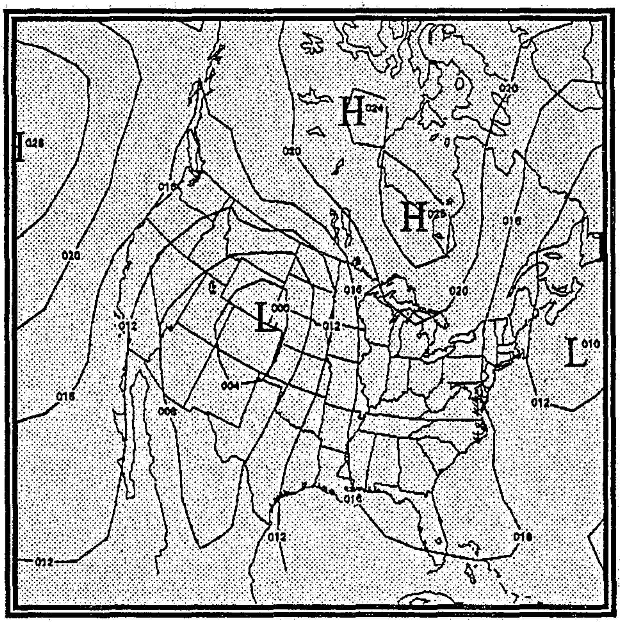

Fig. 6a: SEA LEVEL PRESSURES. Upsloping in west-central Montana is the result of a well developed storm system centered on the CO/WY border. Higher pressure exists over the Mississippi and Ohio River valleys.

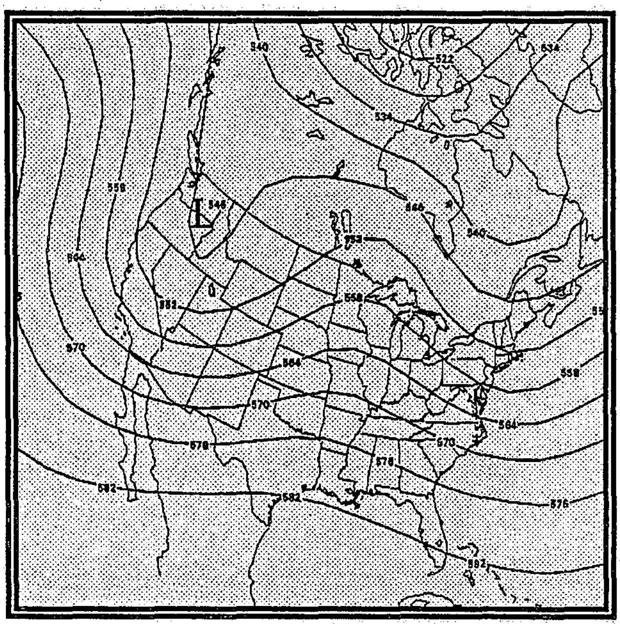

Fig. 6b: 500mb HEIGHTS. A trough is located over the western states and a ridge is to the east, resulting in SSW flow aloft.

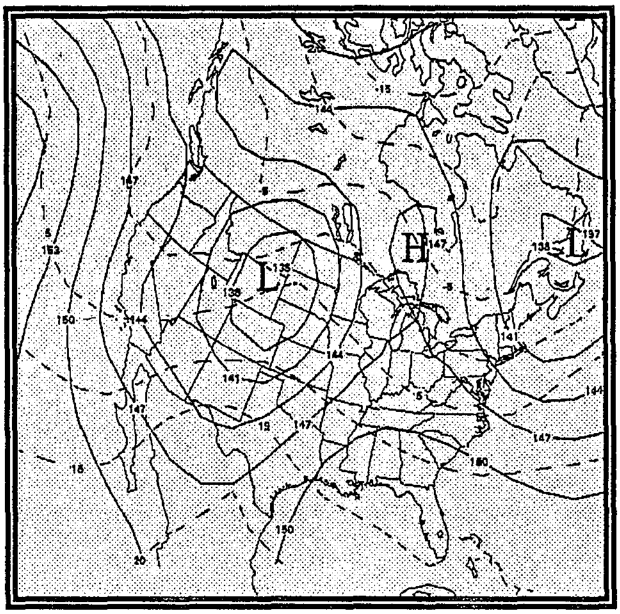

Fig. 6c: 850mb HEIGHTS (solid) and TEMPERATURES (dashed). The temperature over west-central Montana is about -2° Celsius. A low is centered in Wyoming.

FIGURE 6: SEA LEVEL PRESSURES (mb), 500mb HEIGHTS (dam), and 850mb HEIGHTS (dam) & TEMPS (°C) for Case 2 snow events of six inches or more.

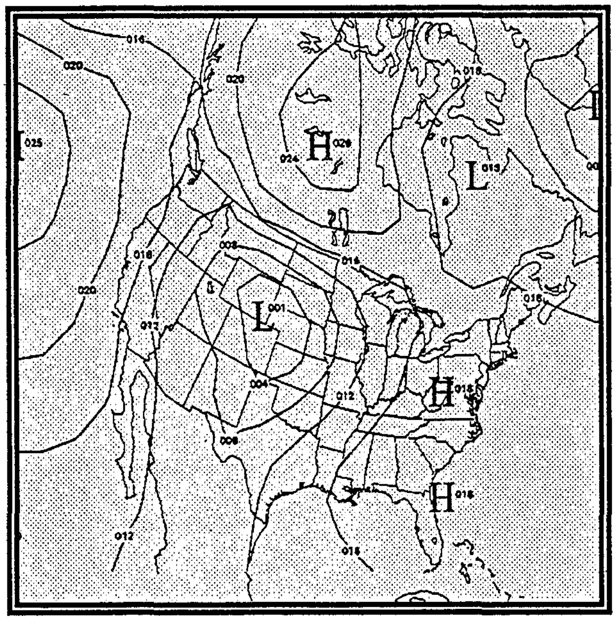

Fig. 7a: SEA LEVEL PRESSURES. A strong low lies on the CO/WY border and a broad high is to the north in Canada. There is a strong pressure gradient in the northcentral U.S. and upslope conditions in west-central Montana.

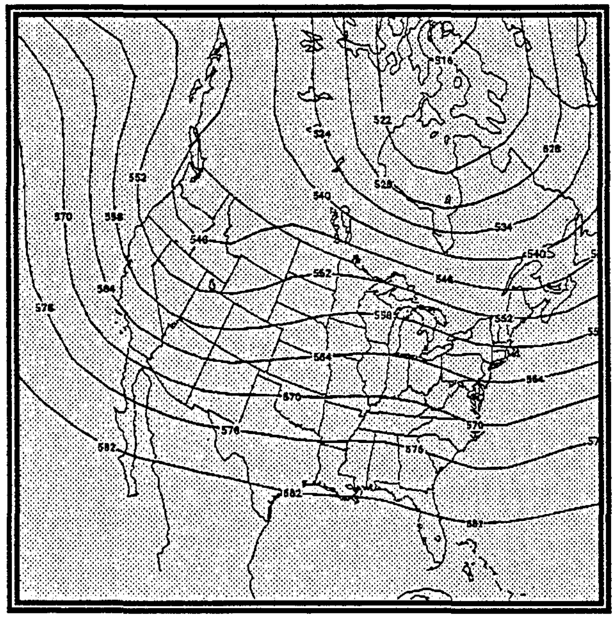

Fig. 7b: 500mb HEIGHTS. A trough lies over the western U.S., with zonal flow over the eastern two-thirds of the country.

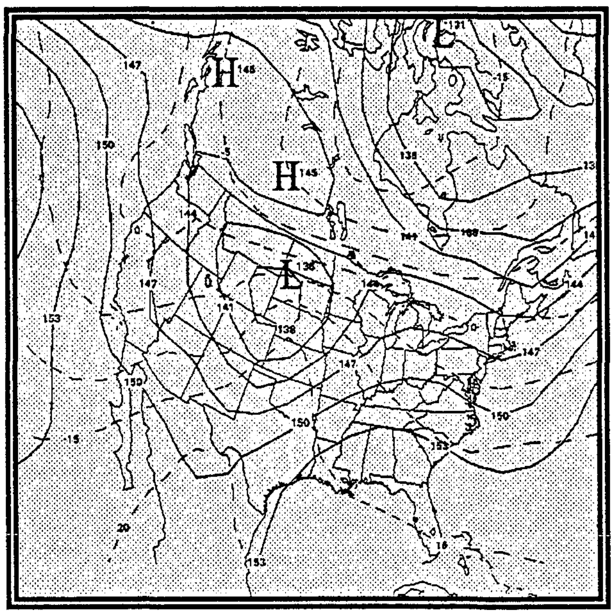

Fig. 7c: 850mb HEIGHTS (solid) and TEMPERATURES (dashed). Similar to Figure 6c, the 0° Celsius isotherm cuts through central Montana. A low is centered in northwest South Dakota.

FIGURE 7: SEA LEVEL PRESSURES (mb), 500mb HEIGHTS (dam), and 850mb HEIGHTS (dam) & TEMPS (°C) for Case 3 snow events of six inches or more.

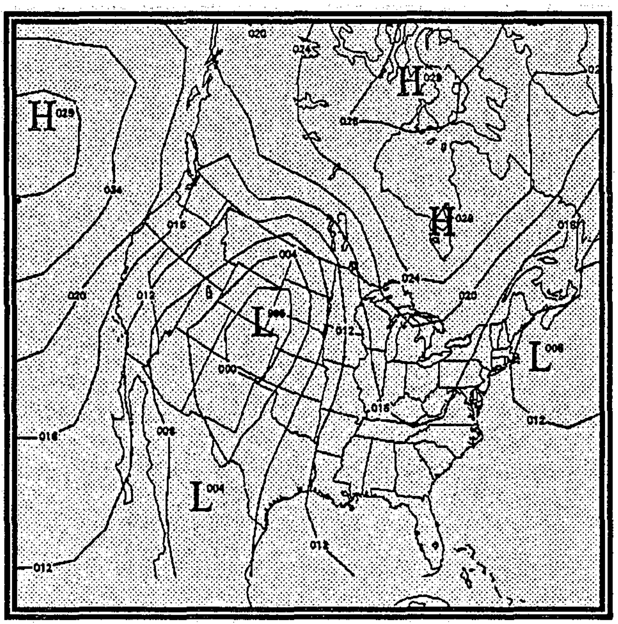

Fig. 8a: SEA LEVEL PRESSURES. An intense low pressure system is located over the CO/WY border. Strong upslope conditions exist in west-central Montana.

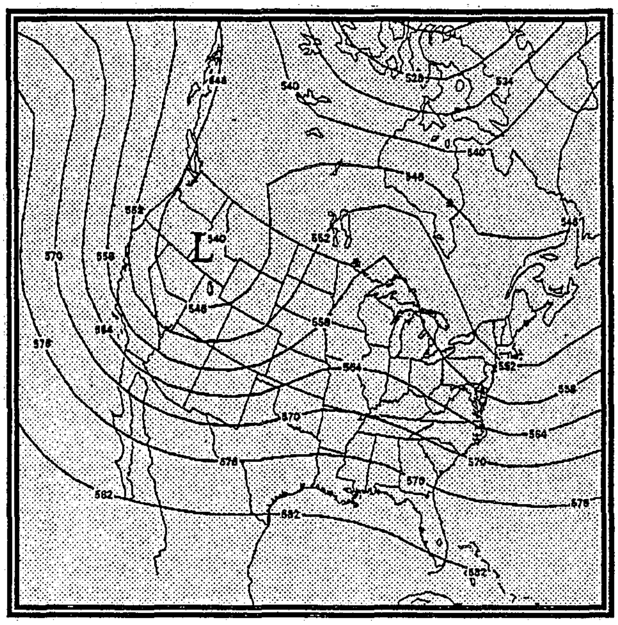

Fig. 8b: 500mb HEIGHTS. The trough is deep, with a low centered in southwest Idaho. A high amplitude ridge is the main feature to the east.

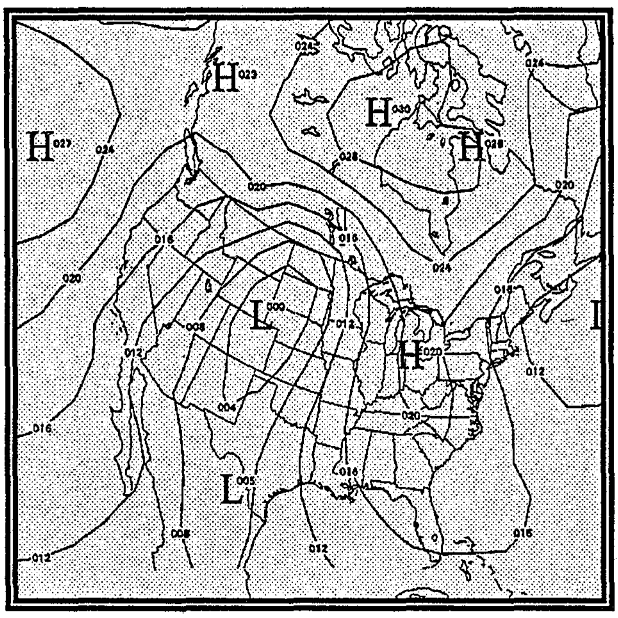

Fig. 8c: SEA LEVEL PRESSURES 12 hours after the heavy Case 2 spring snow event. The low has weakened somewhat but remains in the same position as in Figure 8a. Upslope conditions continue in west-central Montana.

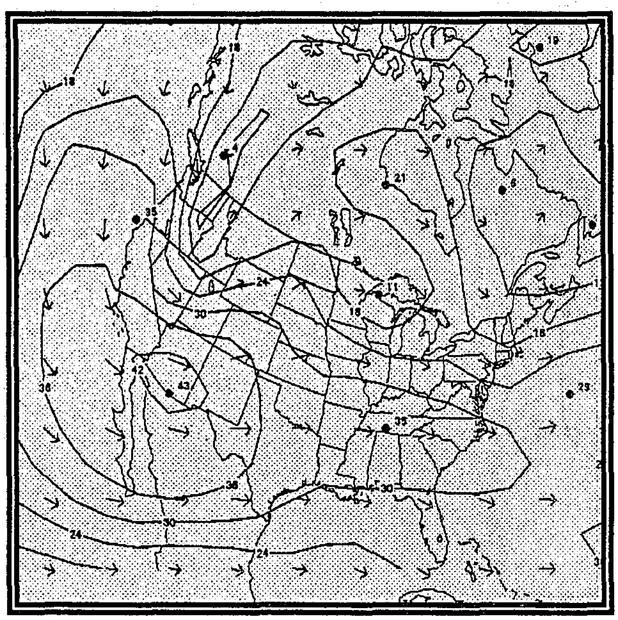

Fig. 8d: 250mb WINDS. A jet maximum is located over southern Arizona and strong diffluence can be found over west-central Montana.

FIGURE 8: SEA LEVEL PRESSURES (mb), 500mb HEIGHTS (dam), and 250mb WINDS (m/s) for heavy Case 2 snow events of eight inches or more from March 15 through May 15.

TABLE 3: Great Falls mean daily winds of 30mph or greater from November through March (1963-1989)

DATE	AVERAGE SPEED(mph) & DIRECTION		FASTEST MILE(mph)
1) January 30, 1989	33.3	SW	42
2) December 6, 1984	31.2	SW	37
3) January 2, 1984	31.4	SW	42
4) December 11, 1980	33.2	SW	48
5) November 7, 1978	30.1	SW	43
6) January 6, 1977	30.5	SW	34
7) February 11, 1976	32.2	SW	45
8) February 8, 1976	34.1	SW	42
9) January 27, 1976	30.8	SW	47
10) December 21, 1974	30.9	SW	51
11) March 5, 1974	33.8	SW	49
12) January 29, 1974	40.0	SW	52
13) January 15, 1974	32.8	SW	55
14) January 13, 1974	32.5	SW	37
15) December 10, 1973	31.2	SW	36
16) December 26, 1972	30.3	SW	50
17) November 30, 1972	32.1	SW	42
18) January 15, 1972	33.8	SW	36
19) January 8, 1972	31.6	SW	45
20) January 4, 1972	33.2	SW	43
21) December 8, 1971	31.6	SW	37
22) November 19, 1971	31.5	SW	42
23) February 3, 1970	30.3	SW	56
24) December 3, 1968	30.5	SW	47
25) December 23, 1963	31.0	SW	42
26) January 19, 1963	31.3	SW	36

All data recorded at the airport

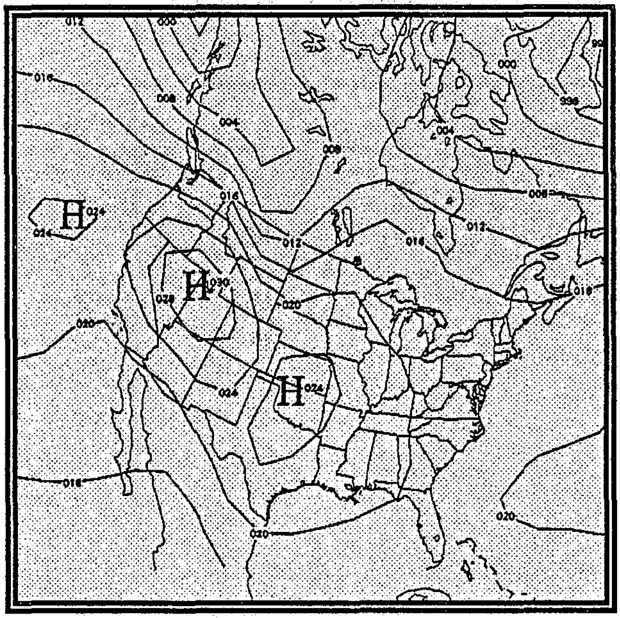

Fig. 9a: SEA LEVEL PRESSURES. A Great Basin high and lower pressures to the north bring a strong gradient to west-central Montana. Southwest, downslope winds result.

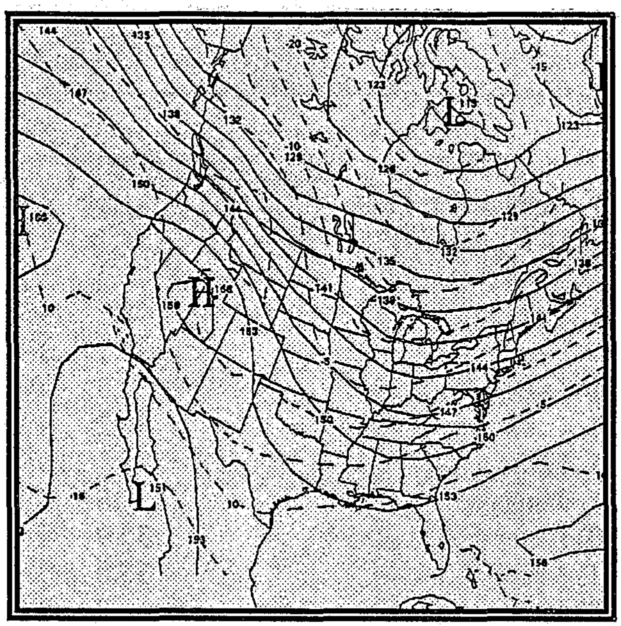

Fig. 9b: 850mb HEIGHTS (solid) and TEMPERATURES (dashed). The isotherms show warming in west-central Montana due to the SW winds.

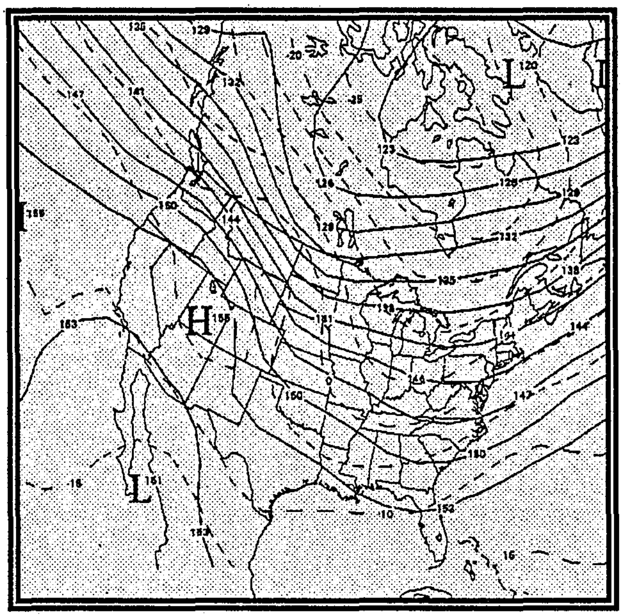

Fig. 9c: 850mb HEIGHTS (solid) and TEMPERATURES (dashed) 12 hours after the strong winter winds. The isotherms show further warming along the east slopes of the Rockies.

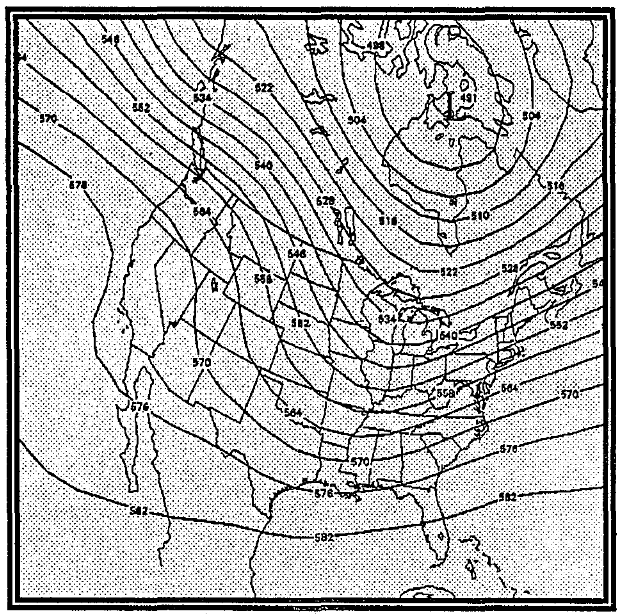

Fig. 9d: 500mb HEIGHTS. A large low is over Husdson Bay. Westerly flow aloft is prominent from the Pacific northwest to British Columbia.

FIGURE 9: SEA LEVEL PRESSURES (mb), 850mb HEIGHTS (dam) &TEMPS (°C), and 500mb HEIGHTS (dam) for strong winter winds of 30mph or greater from November through March.

TABLE 4: Great Falls mean daily winds of 25mph or greater from May through September (1950-1989)

DATE	AVERAGE SPEED(mph) & DIRECTION		FASTEST MILE(mph)
1) May 19, 1989	29.3	SW	43
2) September 6, 1984	29.7	SW	49
3) May 14, 1971	25.0	SW	38
4) September 22, 1970	26.9	SW	42
5) September 25, 1958	28.0	SW	62
6) September 19, 1958	32.9	SW	57
7) September 14, 1958	25.7	WSW	47
8) September 13, 1958	31.3	SW	56
9) June 28, 1958	26.3	SW	47
10) September 7, 1957	25.3	SW	56
11) July 3, 1957	25.6	W	51
12) September 21, 1956	27.0	WSW	38
13) July 7, 1955	25.8	WSW	40
14) May 8, 1955	27.7	WNW	61
15) September 19, 1954	27.6	WSW	49
16) September 18, 1954	25.8	SW	43
17) June 17, 1954	26.8	WSW	50
18) June 16, 1954	25.6	WSW	46
19) September 28, 1953	26.3	WSW	59
20) May 10, 1953	28.5	NW	38
21) May 7, 1953	25.4	SSW	62
22) June 3, 1953	25.6	WNW	57
23) June 22, 1952	30.5	SW	54
24) May 29, 1952	25.7	SW	45
25) May 25, 1951	29.6	W	52
26) May 24, 1951	25.6	WSW	45
27) May 2, 1951	25.6	SW	42
28) May 22, 1950	26.3	SW	56

All data recorded at the airport
Note: On none of these days did thunderstorms occur

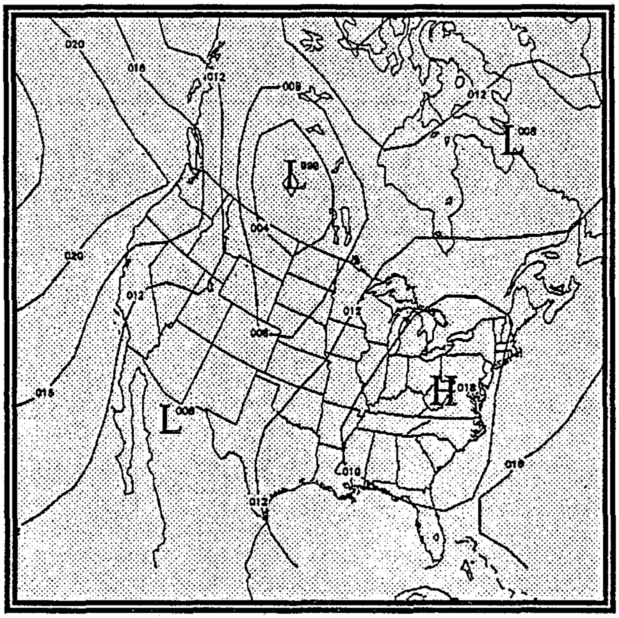

Fig. 10a: SEA LEVEL PRESSURES. A strong pressure gradient exists from eastern Washington to west-central Montana. A cold front stretches from eastern Montana to eastern Colorado.

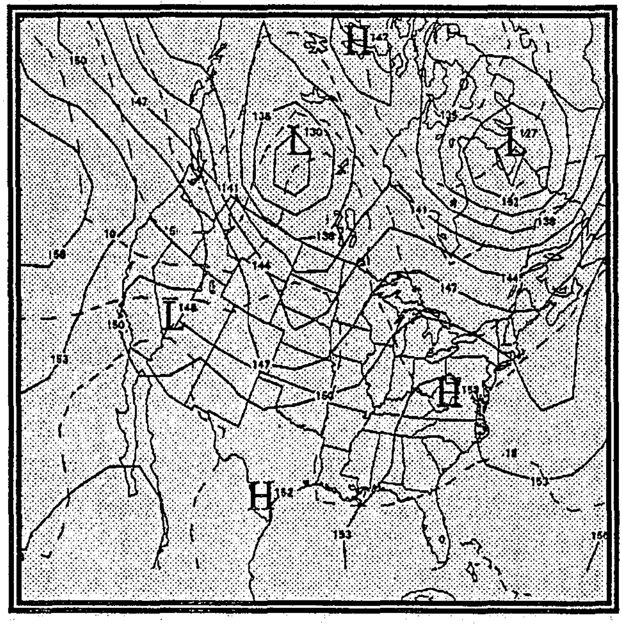

Fig. 10b: 850mb HEIGHTS (solid) and TEMPERATURES (dashed). The isotherms show colder air moving into west-central Montana behind the cold front. The height gradient is strong.

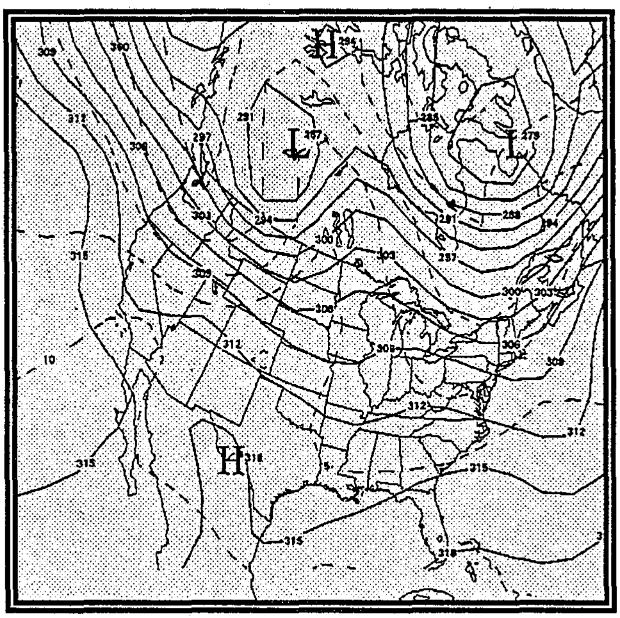

Fig. 10c: 700mb HEIGHTS (solid) and TEMPERATURES (dashed). As in the 850mb field, the height gradient is strong and cold air advection is occurring in west-central Montana.

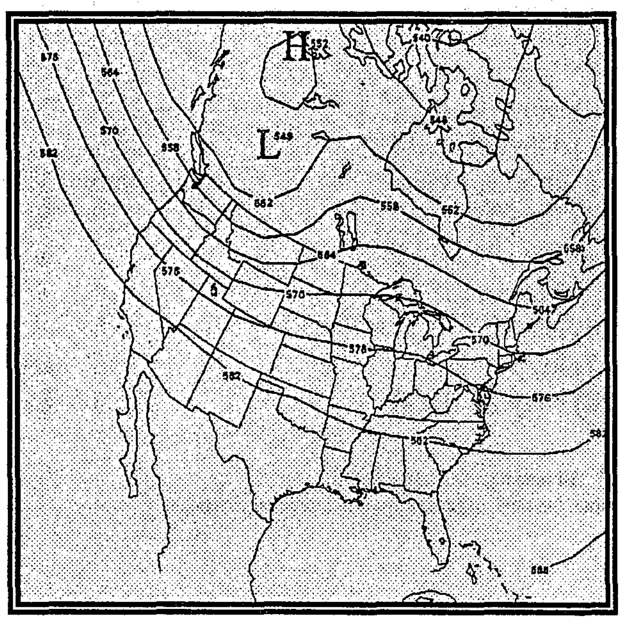

Fig. 10d: 500mb HEIGHTS. The flow aloft is from the WSW in west-central Montana.

FIGURE 10: SEA LEVEL PRESSURES (mb), 850mb HEIGHTS (dam) & TEMPS (°C), 700mb HEIGHTS (dam) & TEMPS (°C), and 500mb HEIGHTS (dam) for strong summer winds of 25 mph or greater from May through September.

TABLE 5: Great Falls thunderstorms with hail (1965-1989)

	DATE	TOTAL PRECIP	SIZE OF HAIL
1)	May 23, 1989	.23"	1/4"
2)	July 5, 1988	.92"	1/2"
3)	July 3, 1988	.30"	1/2"
4)	May 24, 1988	.02"	1/4"
5)	July 24, 1987	.08"	1/2"
6)	July 2, 1987	.22"	1/2"
7)	June 6, 1987	.45"	1/4"
8)	July 26, 1986	.38"	3/8"
9)	June 29, 1986	.30"	1/4"
10)	June 17, 1986	.05"	3/8"
11)	August 7, 1985	.07"	1/4"
12)	May 28, 1985	1.12"	3/4"
13)	July 25, 1983	.25"	1/4"
14)	July 20, 1983	.15"	
15)	August 10, 1982	.21"	1/4"
16)	June 29, 1982	.76"	1/2"
17)	June 28, 1982	1.33"	1/4"
18)	August 3, 1981	.06"	1/8"
19)	July 6, 1981	.41"	1/8"
20)	June 25, 1980	.30"	1/2"
21)	June 12, 1980	.64"	1/4"
22)	June 30, 1979	.28"	1/4"
23)	June 16, 1979	.89"	1/4"
24)	August 22, 1978	.30"	1/2"
25)	June 29, 1978	.17"	3/8"
26)	June 22, 1978	.14"	1/4"
27)	August 27, 1977	.15"	1/4"
28)	August 14, 1977	.37"	1/4"
29)	July 12, 1976	.39"	1/4"
30)	July 11, 1976	1.00"	1/8"
31)	July 6, 1976	.43"	1/2"
32)	June 10, 1976	.07"	3/4"
33)	June 3, 1976	.28"	3/4"
34)	June 30, 1975	.91"	1/2"
35)	August 31, 1971	.32"	3/8"
36)	June 27, 1970	.56"	1/4"
37)	August 6, 1967	.11"	1/2"
38)	July 2, 1966	.77"	1/8"
39)	July 11, 1965	.11"	1/4"
40)	July 9, 1965	.17"	1/4"
41)	June 24, 1965	.70"	3/4"

All data recorded at the airport and only those storms used in composites are listed

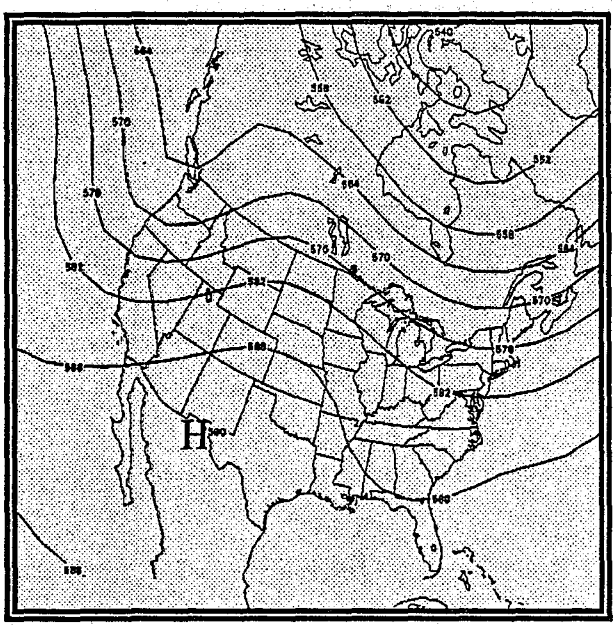

Fig. 11a: 500mb HEIGHTS. A trough over the west coast brings SW flow aloft in west-central Montana.

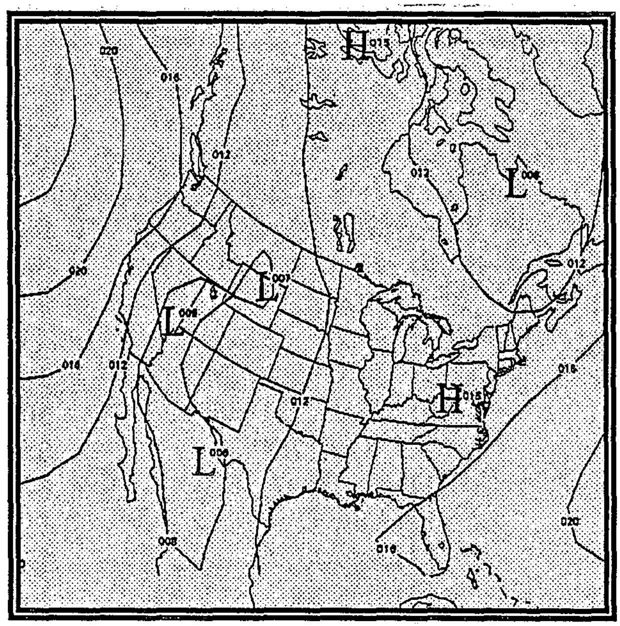

Fig. 11b: SEA LEVEL PRESSURES. Nothing is well-organized, however, lower pressures lie to the south of Montana.

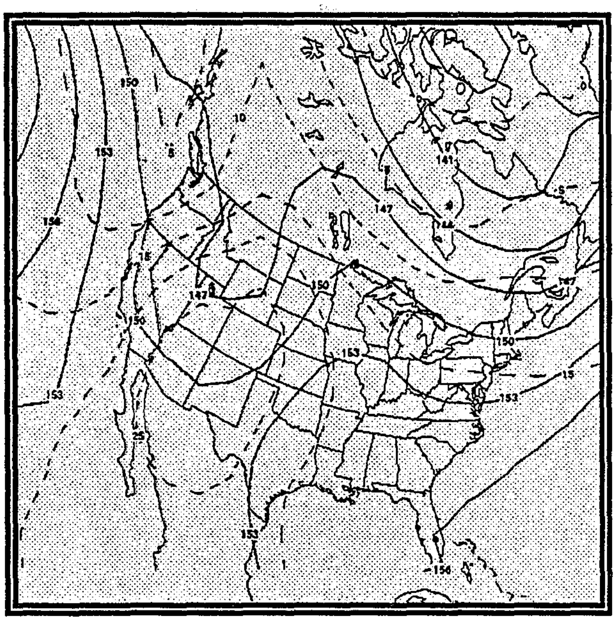

Fig. 11c: 850mb HEIGHTS (solid) and TEMPERATURES (dashed). Very warm air, up to 20 degrees Celsius, lies in west-central Montana. Colder air moves in after the severe weather as the wave moves east.

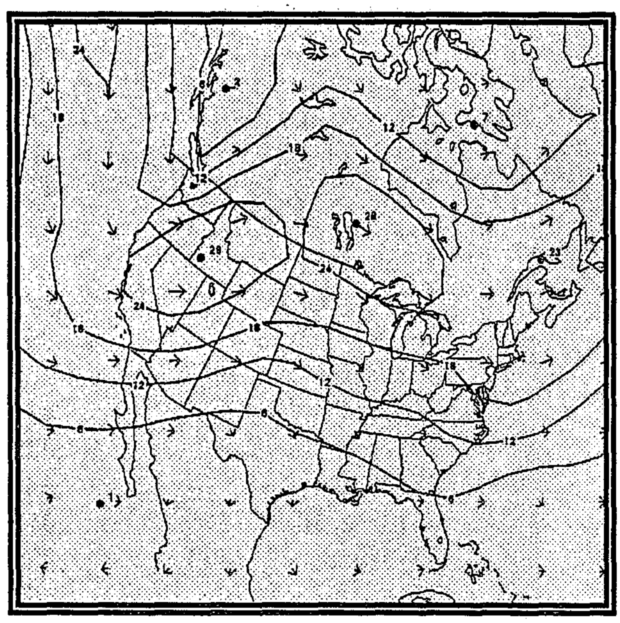

Fig. 11d: 250mb WINDS. Strong SW flow can be seen aloft, as well as slight diffluence.

FIGURE 11: 500mb HEIGHTS (dam), SEA LEVEL PRESSURES (mb), 850mb HEIGHTS (dam) & TEMPS (°C), and 250mb WINDS (m/s) for severe weather events.

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