NOAA Technical Memorandum NWS WR-217

FORECASTING HEAVY SNOW EVENTS IN MISSOULA, MONTANA

Mike Richmond
National Weather Service
Weather Service Office
Missoula, Montana

May 1992

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

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National Weather Service, Western Region Subseries

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UNITED STATES DEPARTMENT OF COMMERCE
Barbara H. Franklin, Secretary

National Oceanic and Atmospheric Administration
John A. Knauss, Under Secretary and Administrator

National Weather Service
Elbert W. Friday, Jr., Assistant Administrator for Weather Services

This publication has been reviewed
and is approved for publication by
Scientific Services Division,
Western Region

Kenneth B. Mielke, Chief
Scientific Services Division
Salt Lake City, Utah

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MIKE RICHMOND

I. INTRODUCTION

This paper will examine the characteristics of all the heaviest snow events (defined as seven inches or more) that have occurred in Missoula, Montana, over the past 25 years. The events were separated into four categories to aid in pattern recognition. One or more cases from each category is examined in some detail to gain an understanding of what factors may result in heavy snow in Missoula. It is hoped that studying these events will aid in the forecasting of similar ones in the future.

II. PHYSICAL AND CLIMATIC DESCRIPTION OF THE MISSOULA AREA

Missoula is situated in the heart of the northern Rocky Mountains in the west-central part of Montana. The airport, where the Weather Service Office is located, is about five miles east of the confluence of the Bitterroot and Clark Fork Rivers, on a flat valley floor at an elevation of 3197 feet (Fig. 1A). The Clark Fork Valley begins at Missoula and extends about 20 miles west-northwest. The Bitterroot Valley extends about 70 miles due south from Missoula. The Continental Divide is 60 to 80 miles east of Missoula, and the Bitterroot Range is only about 20 miles away to the southwest (Fig. 1B). Mountain elevations in these ranges are generally between 6500 to 9500 feet. These two ranges and the alignment of the Clark Fork Valley have a marked effect on the climate of Missoula.

The accompanying graphs in Fig. 2 show that Missoula has a cool but semiarid climate. Its relatively low annual precipitation average of only 13.29 inches is, in part, due to the presence of the Bitterroot Range to the west and southwest and its interception of much of the moisture in passing weather systems in the mid-latitude westerlies. Missoula's latitude, interior location, and elevation result in wintertime temperatures favorable for snow. Yet, because Missoula is on the downslope side of the Bitterroot Range, the average annual snowfall is a relatively low 47.2 inches. There is one direction in which air flow is directed upslope, albeit gradually; this is from the northwest, due to the alignment of the Clark Fork River Valley. This fact will play an important part in the occurrence of some heavy snowfalls, as will be seen later. Looking at climatic records, most of the snowfalls in Missoula are less than four inches spaced throughout the late fall through early spring months; heavy snowfall amounts of over seven inches are infrequent, occurring on the average of once every three or four years. Thus, unique sets of circumstances must be present for heavy snowfall to occur in Missoula, and an attempt will be made to ascertain these in this Technical Memorandum.

III. DESCRIPTION OF THE 10 HEAVY SNOWFALL CASES

There have been just 10 cases in the past 25 years at WSO Missoula in which snowfall events have totaled seven inches or more. These occurred on the following dates, accompanied by the event total:

CASE	DATE	SNOWFALL TOTAL (inches)
1	07 FEB 75	14.4
2	23 JAN 82	10.1
3	04-05 JAN 80	9.0
4	02-03 JAN 66	9.0
5	27-28 DEC 68	8.5 **
6	23-24 MAY 78	8.1
7	14-15 FEB 86	7.7
8	27-28 DEC 73	7.3
9	23-24 DEC 90	7.0
10	26 FEB 76	7.0

**Excluded from study due to lack of data.

In examining cases like these over a span of many years, the decision on which parameters to study had to encompass both the availability and cost involved in obtaining data. With that in mind, for each case the analyses at the appropriate times of the 850 mb, 700 mb, 500 mb, and 300 mb heights were chosen. The 850, 700, and 500 mb charts all contained the temperature fields, while the 300 mb charts contained the isotach analysis.

The upper-level analyses from the above cases were subjectively determined to fall into four different categories, which will now be described. It should be mentioned first, however, that the 700 mb chart proves to be the most highly significant indicator of snowfall potential in this region due to its representation of synoptic-scale disturbances in the free air flow combined with their interaction with the mountainous terrain.

Category 1

Four of the ten cases fit into this category: Numbers 1, 4, 7, and 8. The main characteristic of this category is a confluent 700 mb flow. The heaviest snow event of all ten cases, case 1, (07 FEB 75) is a good example of this category. The evolution of this case is shown in Figs. 3A-3D and 4A-4D.

In this category, a westerly 700 mb flow with Pacific moisture converges with a colder, drier, more northerly flow from the Canadian interior. Missoula then lies under this area of confluence in a west to northwest flow aloft. This confluent flow is observed at the 500 mb level in each case as well. At the same time, lower level convergence is occurring around an arctic front of colder, drier air moving into western Montana; temperatures at the 850 mb level are generally -2 degrees C or less, cold enough for snow. At the 300 mb level, jet streak dynamics come into play in each case. Briefly, the well-known four-cell pattern of convergence/divergence around a jet streak leading to transverse circulations is observed. In each case, Missoula is in the left-front or right-rear section of a jet streak, areas favorable for upper-level divergence and lower-level convergence (i.e., upward vertical motion).

Moisture for these cases is provided at the 500 and 700 mb levels by cold-core closed lows off the coast. Very cold, dry air streaming out from the Canadian interior into the Gulf of Alaska picks up moisture and energy from the warmer waters, a prime scenario for cyclogenesis. This moisture then circulates into the northwest U.S. in the westerly flow aloft around the low.

Convergence at 850 mb negates the handicap Missoula faces in a more westerly flow aloft of being downslope from the Bitterroot Range. This convergence occurs when cold, dense Continental Polar air flows down from Canada east of the Continental Divide. This colder denser air, if thick enough (i.e., deeper than the elevations of the blocking Continental Divide), will then flow through the passes and gaps of the Rocky Mountains, pushing into the valleys through the river canyons (these are known locally as Hellgate Winds after the Hellgate Gap, where the Clark Fork River Canyon opens up into the Missoula Valley).

Thus, this category is essentially one in which all the factors to support large-scale vertical motion come together and have enough of a moisture source to provide relatively heavy precipitation amounts.

In Figs. 3A-3D, illustrating case 1, the analyses at 00Z on the 7th of February show the different factors developing. All of the factors are in place at 12Z on the 7th, the 850 mb convergence associated with the arctic front (Fig. 4A), the moist and confluent 700 and 500 mb flows (Fig. 4B-C), and the 300 mb dynamics (Fig. 4D). The event of February 7, 1975, began at 08Z, at which time moderate snowfall began at the Missoula airport, and continued for the next 12 hours, leaving an accumulation of over 14 inches.

Category 2

The main feature of this category is a disturbance in a north-westerly flow aloft moving down over Missoula. Both the cases in this category exhibited this at 700 and 500 mb. The two cases in question are numbers 3 (04-05 JAN 80) and 9 (24 DEC 90), both of which will be examined. Figures 5A-5D and 6A-6C illustrate case 9 and the characteristics of this category.

It is common knowledge here at WSO Missoula that weak disturbances in a northwesterly flow aloft almost always produce snow, and quite often Missoula receives more than surrounding stations such as Kalispell or Butte. The configuration of the terrain is partly responsible for this. Since Missoula lies in the Clark Fork Valley, which is oriented northwest-southeast and slopes up to the southeast, precipitation is slightly enhanced if the airflow is also northwesterly.

Case number 3, in January of 1980, produced nine inches of snow. This was brought about by a strong short-wave trough at 700 and 500 mb that moved down from the northwest into western Montana, accompanied by strong cold advection aloft through 500 mb, as well as an arctic outbreak at the surface. This storm actually fits the characteristics of category 1 almost as well, with the exception of a confluent 700 mb flow. The 300 mb jet streak pattern was present, as it actually was in all nine cases. The surface observations show that the brunt of the snowfall occurred with and just after the passage of the low-level arctic front. At the same time, the 700 mb flow was shifting to a more northwesterly direction with the passage of the upper-level trough. Thus, the combination of the low-level convergence and cold advection with a northwesterly flow aloft enhanced snowfall considerably. The low-level trajectories were conducive for precipitation to occur at this time as well. There was a short, over-water trajectory along the British Columbia coast with the short-wave trough at 850 and 700 mb, so ample moisture was picked up from the ocean before the air mass moved into Montana. Water equivalent of the snowfall measured 0.68 inches, generous by Montana standards.

The other case for category 2 was the snowfall of 24 DEC 1990 (case 9). Actual moisture content of this seven inch snowfall was quite low, only 0.26 inches. Looking at the 00Z 500 mb and 700 mb charts (Figs. 5A-B), only very weak short-wave troughs are indicated in the northwesterly flow. However, a strong jet streak at 300 mb (110 + knots) began moving down in the northwesterly flow (Fig. 5C) and enhanced the vertical motion of the 500 mb short wave. By 12Z, the 300 mb jet streak was much closer (Fig. 6D). The majority of the snow fell from 00Z to 22Z on the 24th, during the time of the 300 mb jet streak passage.

Since the flow aloft was entirely over land, and the lower-level air mass was a cold, dry Continental Polar type (850 mb temperature of -16 degrees C (Fig. 6A), moisture was limited. The snow that fell was exceedingly fine and powdery but did accumulate to seven inches. This snowfall was not forecast in any detail because of the innocuous appearance of the short waves at the 500 and 700 mb levels. In fact, Probability of Precipitation (PoPs) percentages in the WSFO Great Falls zone forecast and the WSO Missoula local forecast for the appropriate time period were only 20 percent. Thus, the importance of looking at the upper-level features, and jet streak dynamics in particular, is proven by this case.

Category 3

This category is marked by a very moist and strong west to northwest flow at 700 and 500 mb with warm air advection and "over-running" precipitation. Two of the cases, numbers 2 (23 JAN 82) and 10 (26 FEB 76), fit this category. Figures 7A-7D and 8A-8D show the evolution of case 2.

The lower and mid-level flow is providing warm advection and over-running precipitation and has had a long over-water trajectory, hence, the moisture (Figs. 8A-8C). Colder air with below freezing temperatures is trapped by an inversion in the valleys. At the same time, Missoula lies under the left-front quadrant of a strong 300 mb jet streak (110 knots or more - Fig. 8D). Large quantities of lower and mid-level moisture are moving through an area of enhanced upward vertical motion caused by jet streak dynamics. Terrain enhancement and lower-level convergence do not seem to be a factor in either case since the 850 mb arctic front lies east of the Continental Divide and 500 and 700 mb flows are westerly. All of the snowfall in case 2 occurred after 00Z on 23 JAN 82, when the 700 mb flow became more westerly (Fig. 8B). Warm air advection is illustrated by comparing the temperatures at the 850, 700, and 500 mb levels upstream from Missoula from 12Z on 22 JAN 82 (Figs. 7A-7C) to 00Z on 23 JAN 82 (Figs. 8A-8C).

Thus, it seems that for this category the primary dynamics for heavy snowfalls are caused by warm air advection and so-called "over-running" precipitation, aided by the presence of the vertical motion-favorable quadrant of a 300 mb jet streak.

Category 4

One unusual case (number 6, 23-24 MAY 78) did not fit any of the three previous ones, so it was placed in a category of its own. This category or case, is essentially a convective one and is examined in Figs. 9A-9D. This case fell within the height of the spring convective precipitation maximum in western Montana (Fig. 2). This peak is caused by more efficient surface heating combined with a still active, albeit weaker, westerly flow with embedded baroclinic disturbances.

During this time of the year in western Montana (May-June), a south to southwest flow at 700 mb with an approaching short-wave trough or cold-core low is convectively unstable. Thundershowers will form over the Bitterroot Range to the south and southwest and move into the valleys (including Missoula) in the afternoon and evening hours. This is exactly what happened in this case.

A deep, cold-core low (5450 m height at 500 mb) was moving onshore in the vicinity of Puget Sound. Strong southerly flow at 500 and 700 mb (Figs. 9B-C) combined with increasing cold-air advection led to convective instability over western Montana on the 23rd of May. A slightly diffluent 300 mb flow was present with a speed maximum centered over the Missoula area (Fig. 9D). Surface convergence from the 850 mb level occurred as well, as the winds there were north to northeasterly (Fig. 9A). Temperatures at 850 mb were fairly cool, less than 5 degrees C, with cold advection occurring. Surface temperatures in the early afternoon were in the mid-30s with light rain falling at WSO Missoula. A thunderstorm formed or moved over the WSO, and heavy snow began falling. Evaporative cooling from the downdraft was probably responsible for the change from rain to snow. Over the next five hours, seven inches of snow fell, with a water content of about 0.60 inches, relatively wet for this region.

While this was a most unique event, especially for so late in the season, it is worth documenting in this categorical study so that any future occurrence of this pattern will be recognized as a potential heavy snowfall producer. It is important to remember, however, that this event occurred because of convection during the late spring. This same general upper-level pattern in the winter has not produced a heavy snowfall in Missoula, at least over the last 25 years.

IV. CONCLUSION

The most noticeable characteristic shared by all the heavy snow events was the passage of upper-level (300 mb) jet streaks. These jet streaks supported large-scale upward vertical motions, thereby enhancing precipitation. Beyond that, several different lower-level patterns (especially 700 mb) were able to generate heavy snowfalls in the Missoula area. The following is a summary of the characteristics of each category. Figure 10 contains a simplified average 700 mb pattern for each category. These should aid the forecaster in recognizing patterns favorable for heavy snowfall in Missoula.

<u>Category 1</u>

- West to northwest 500 and 700 mb flow, confluent just upstream with ample moisture from southern branch.
- 850 mb arctic front moving into Missoula providing low-level convergence. Missoula in favorable quadrant of 300 mb jet streak for divergence aloft.
- Negligible cold-air advection at 700 and 500 mb.

<u>Category 2</u>

- Northwesterly flow at 700 and 500 mb levels with an embedded short-wave trough and weak cold air advection.
- Missoula in favorable quadrant of 300 mb jet streak for divergence aloft.

<u>Category 3</u>

- Very moist and strong west to northwest flow at 500 and 700 mb with warm air advection and over-running precipitation.
- Cold air trapped at the surface with below-freezing temperatures.
- Missoula in favorable quadrant of 300 mb jet streak for divergence aloft.

<u>Category 4</u>

- South to southeast 500 mb and 700 mb flow around deep, cold-core low with convective instability.
- Low-level convergence at 850 mb.

- Cool surface temperature (<40 degrees F) with shower or thundershower forming.

- May require evaporative cooling to cause rain to change to snow.

- 300 mb pattern favorable for divergence aloft.

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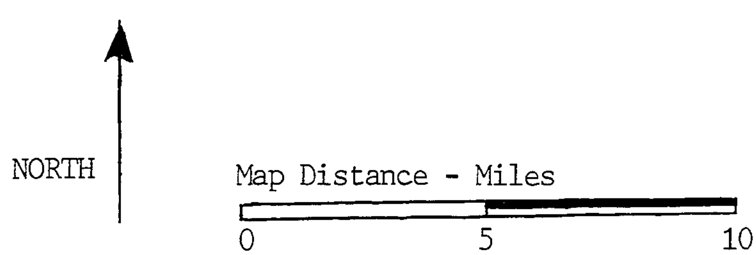


Figure 1A
Missoula Area Map

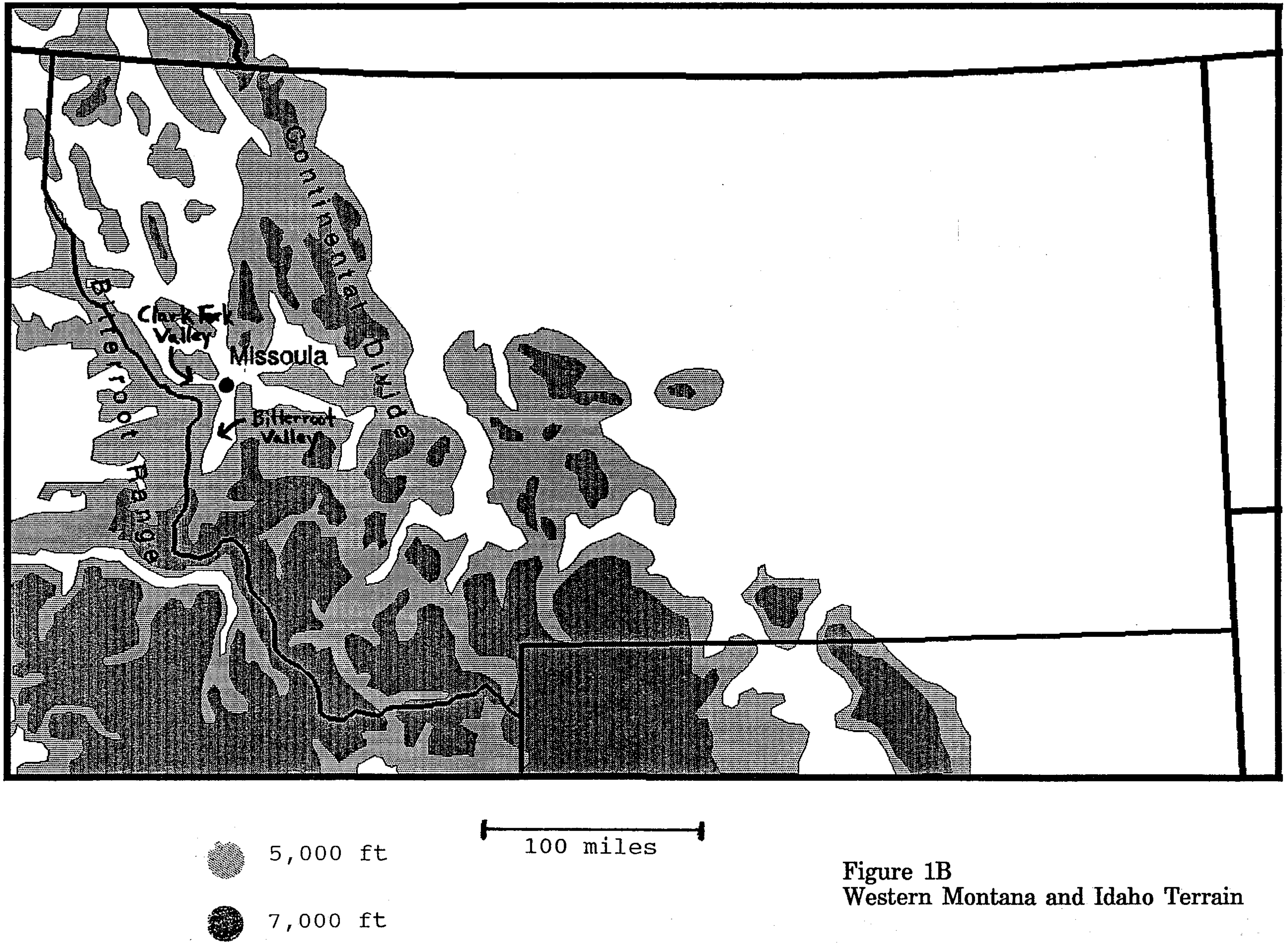
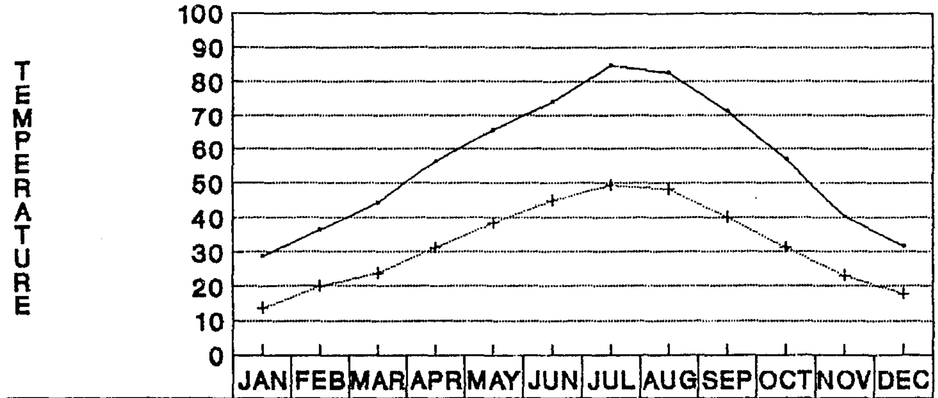


Figure 1B
Western Montana and Idaho Terrain

WSO MISSOULA AVG MONTHLY TEMPERATURES
1961-1990

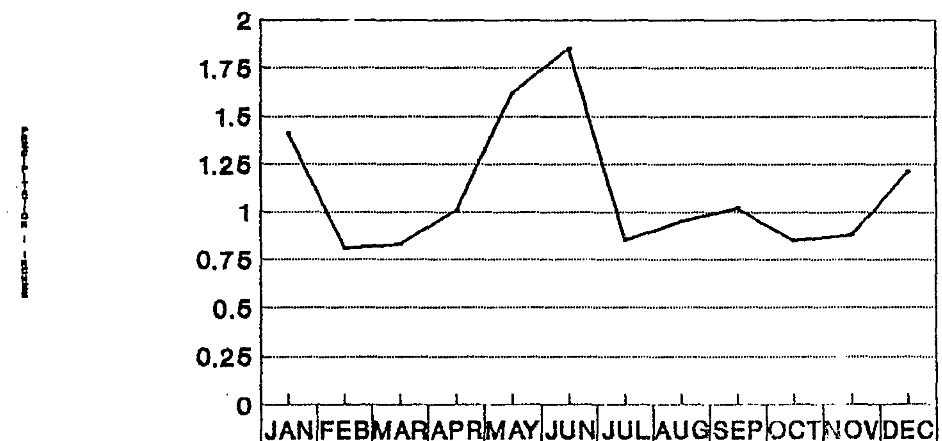


	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
AVG HIGH TEMP	28.8	36.4	44.4	56.5	65.8	74	84.8	82.7	71.3	57	40.4	31.8
AVG LOW TEMP	13.7	19.8	23.8	31.3	38.4	45.1	49.5	48.3	40.1	31.2	23.2	17.9

MONTH

ELEVATION 3197 FEET

WSO MISSOULA AVG MONTHLY PRECIPITATION
1961-1990



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MONTHLY PRECIP	1.41	0.81	0.83	1.01	1.62	1.85	0.85	0.95	1.02	0.85	0.88	1.21

MONTH

ELEVATION 3197 FEET

Figure 2
Missoula Climate Graphs

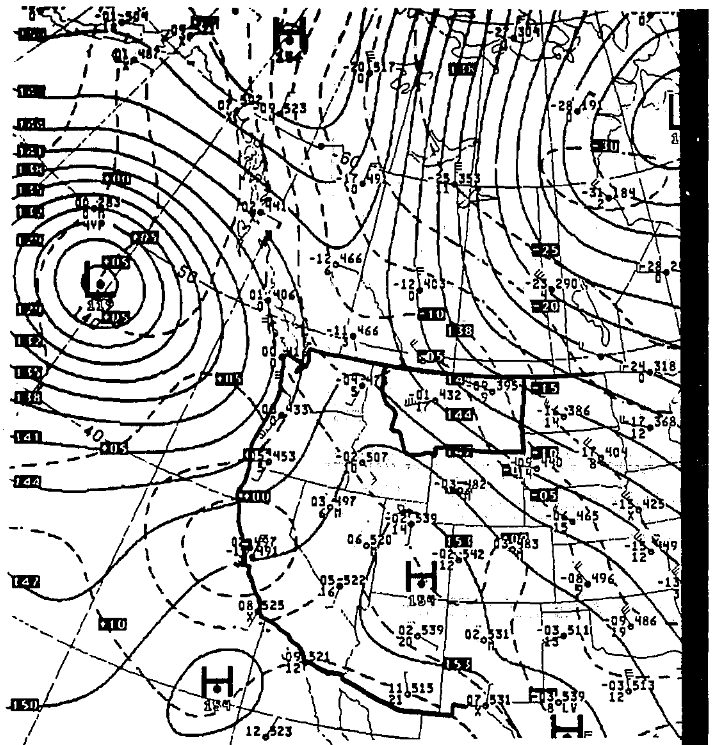


Figure 3A
850 mb Analyses Valid 00Z 07 Feb 1975

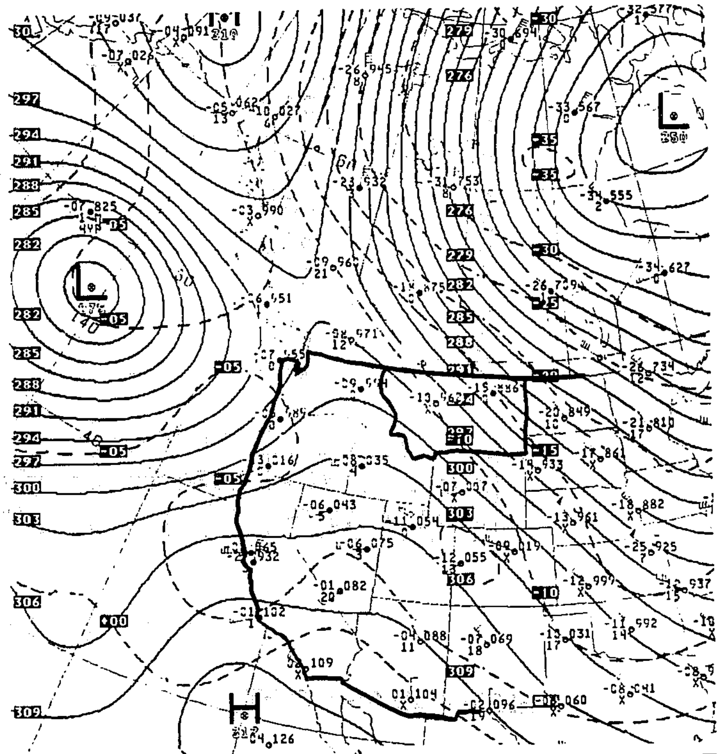


Figure 3B
700 mb Analyses Valid 00Z 07 Feb 1975

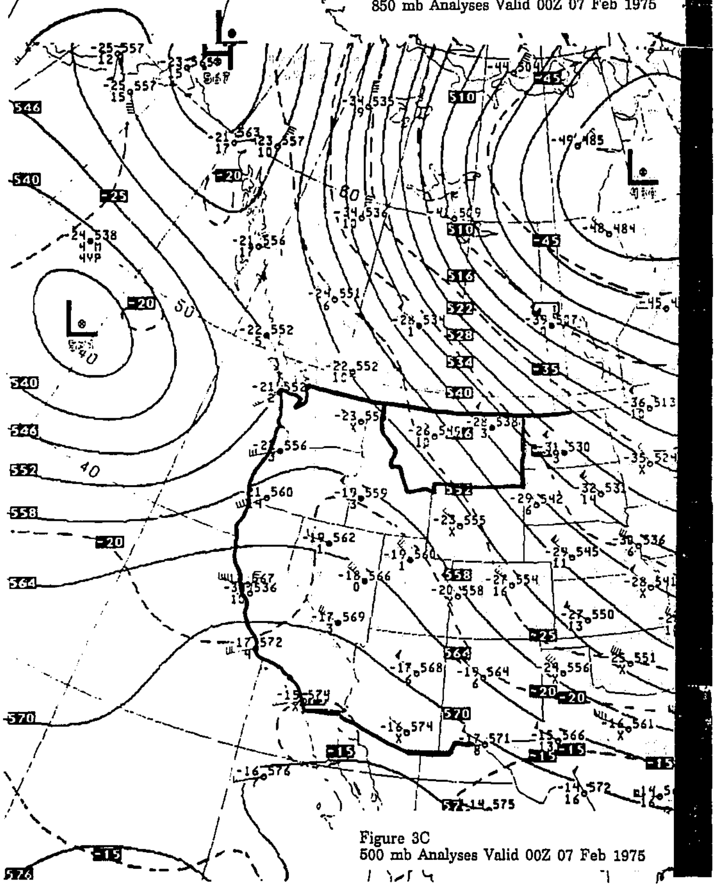


Figure 3C
500 mb Analyses Valid 00Z 07 Feb 1975

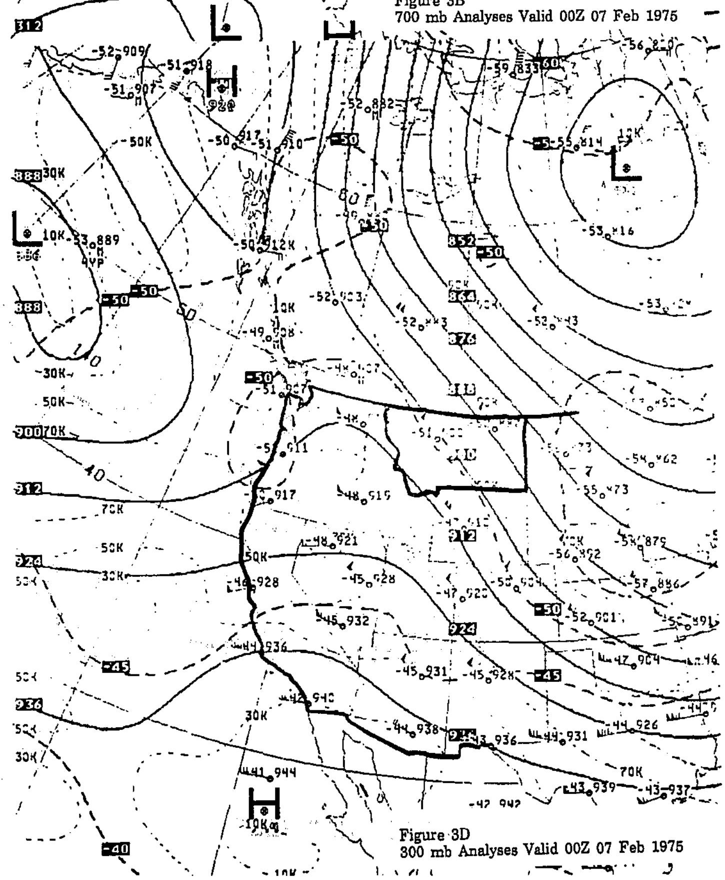


Figure 3D
300 mb Analyses Valid 00Z 07 Feb 1975

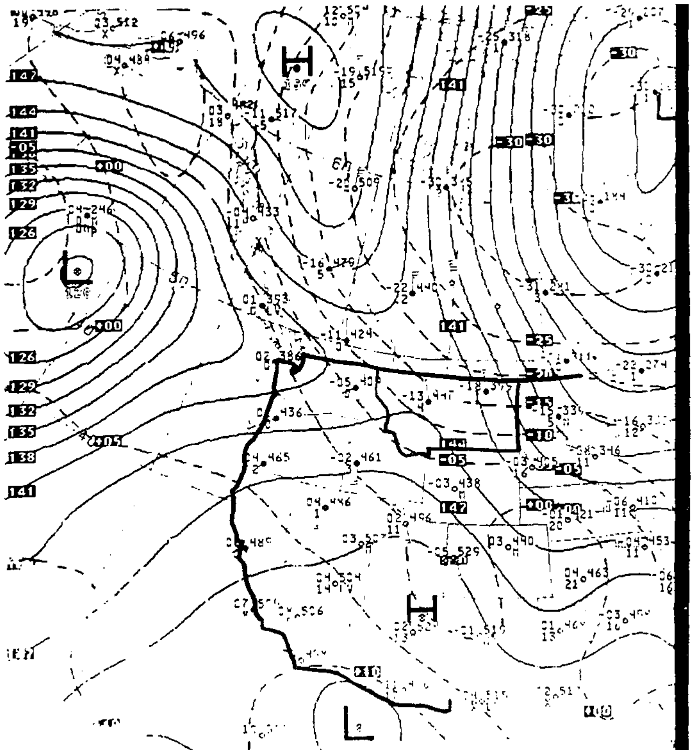


Figure 4A
850 mb Analyses Valid 12Z 07 Feb 1975

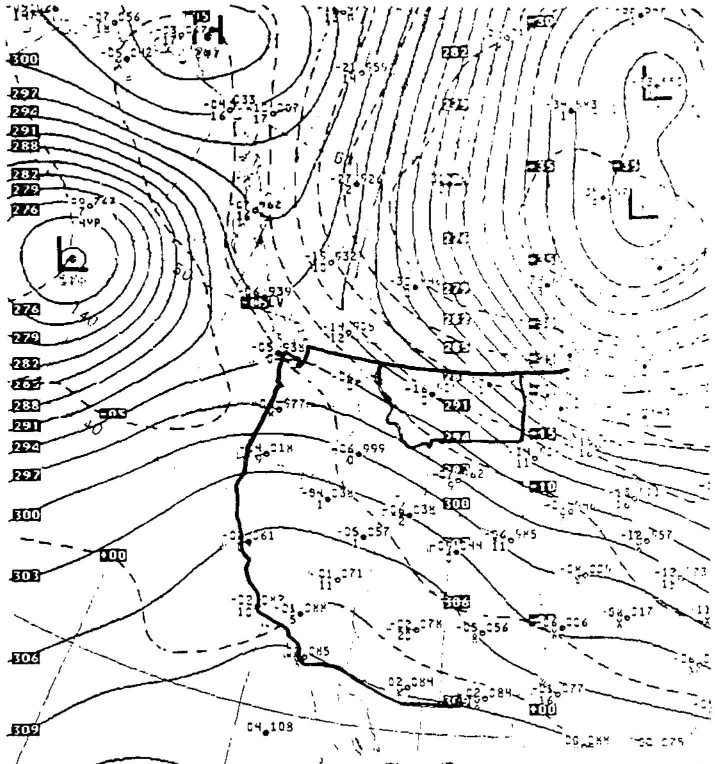


Figure 4B
700 mb Analyses Valid 12Z 07 Feb 1975

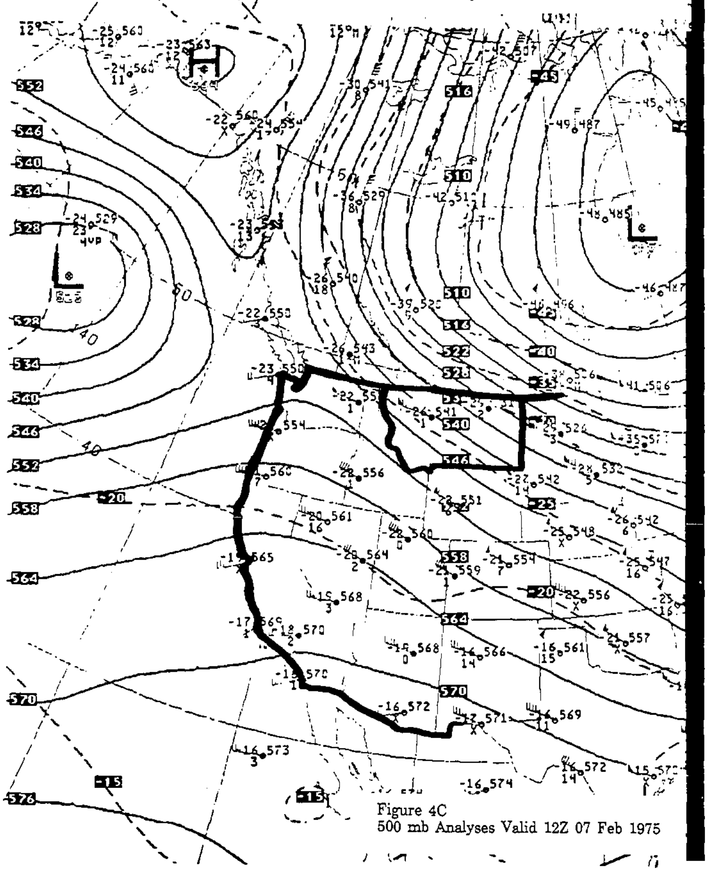


Figure 4C
500 mb Analyses Valid 12Z 07 Feb 1975

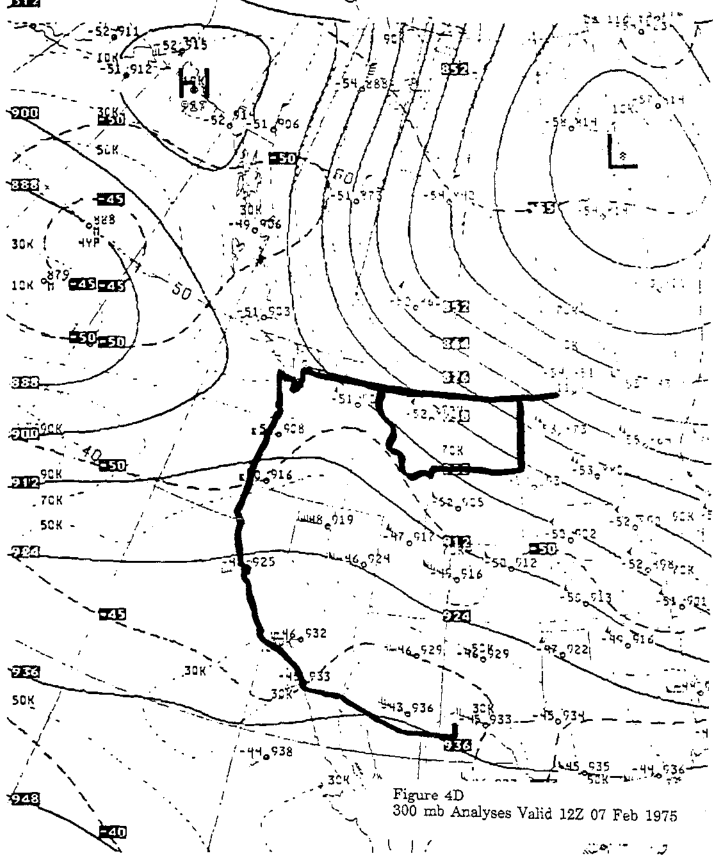


Figure 4D
300 mb Analyses Valid 12Z 07 Feb 1975

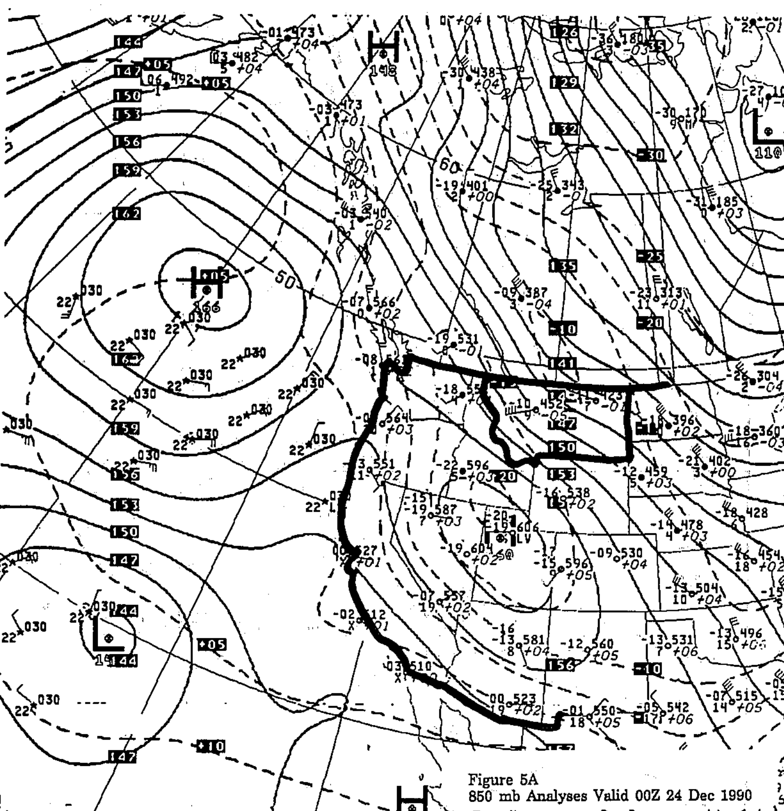


Figure 5A
850 mb Analyses Valid 00Z 24 Dec 1990

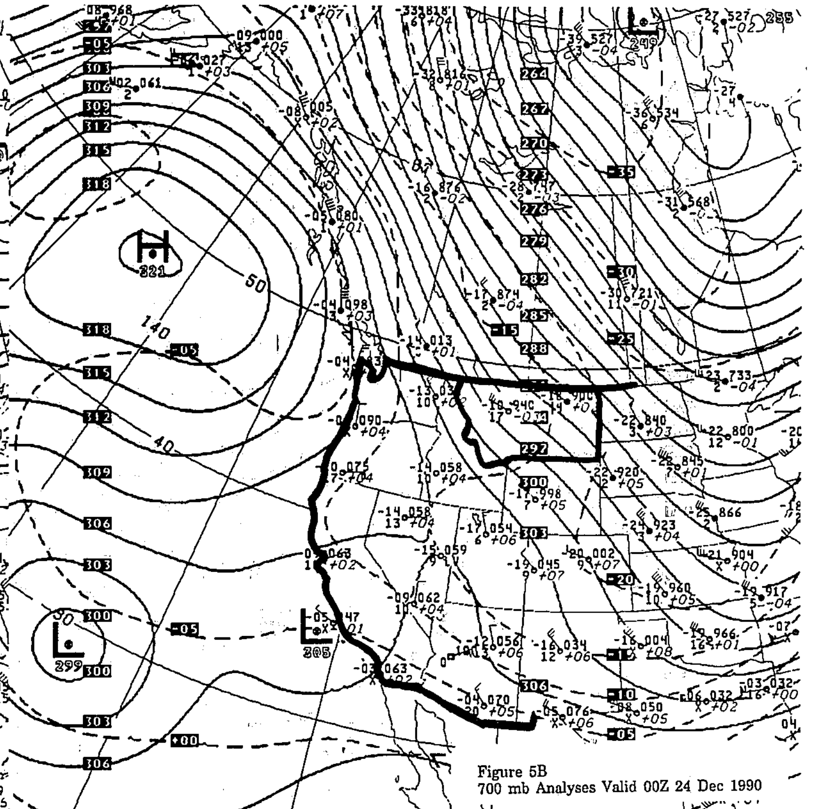


Figure 5B
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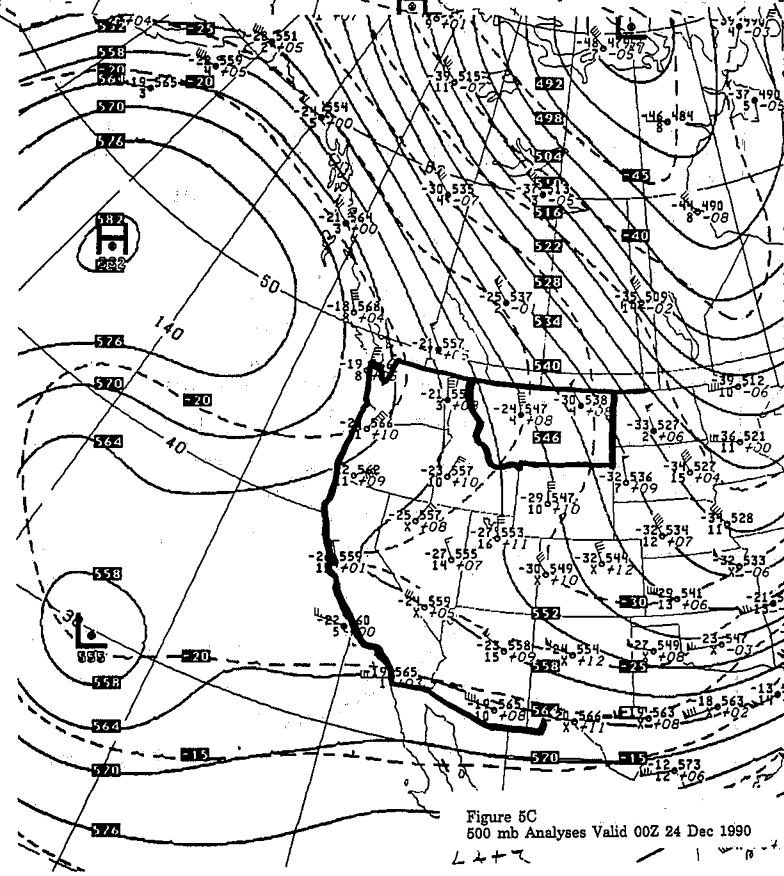

Figure 5C
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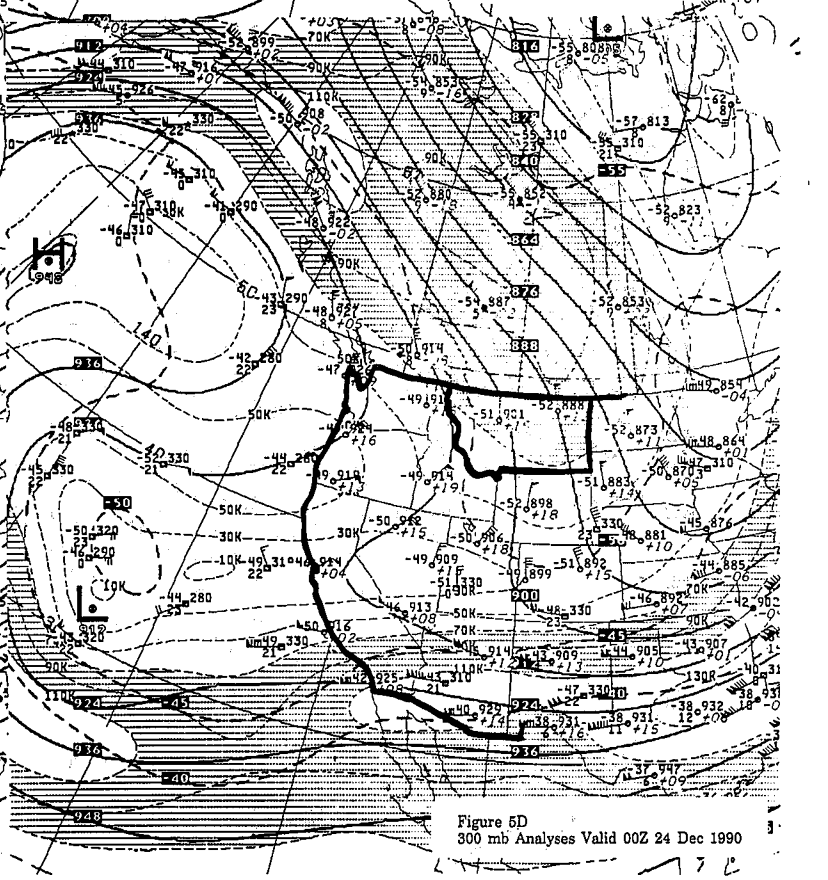

Figure 5D
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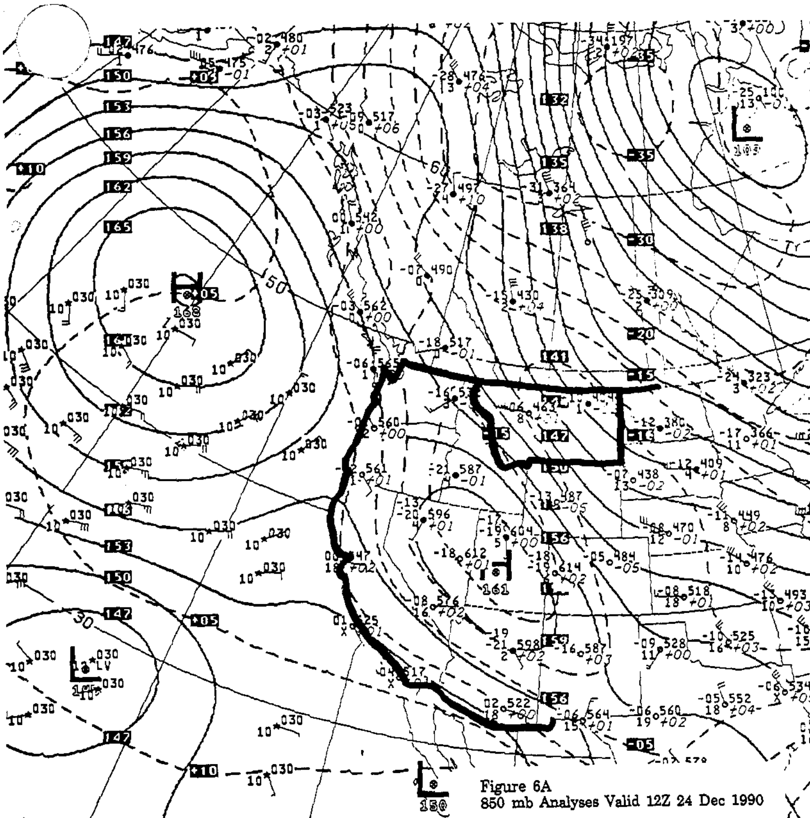

Figure 6A
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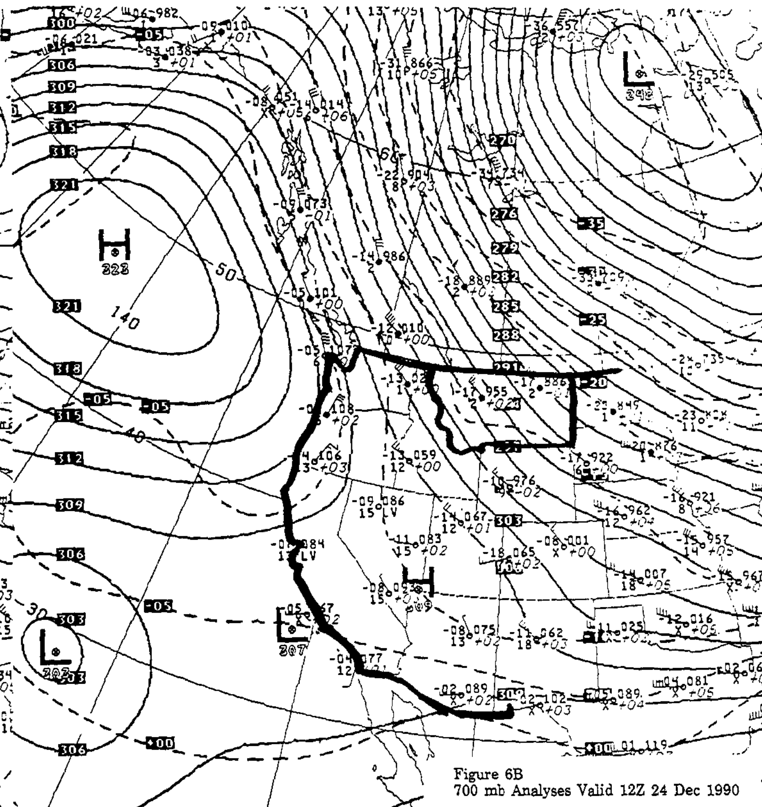

Figure 6B
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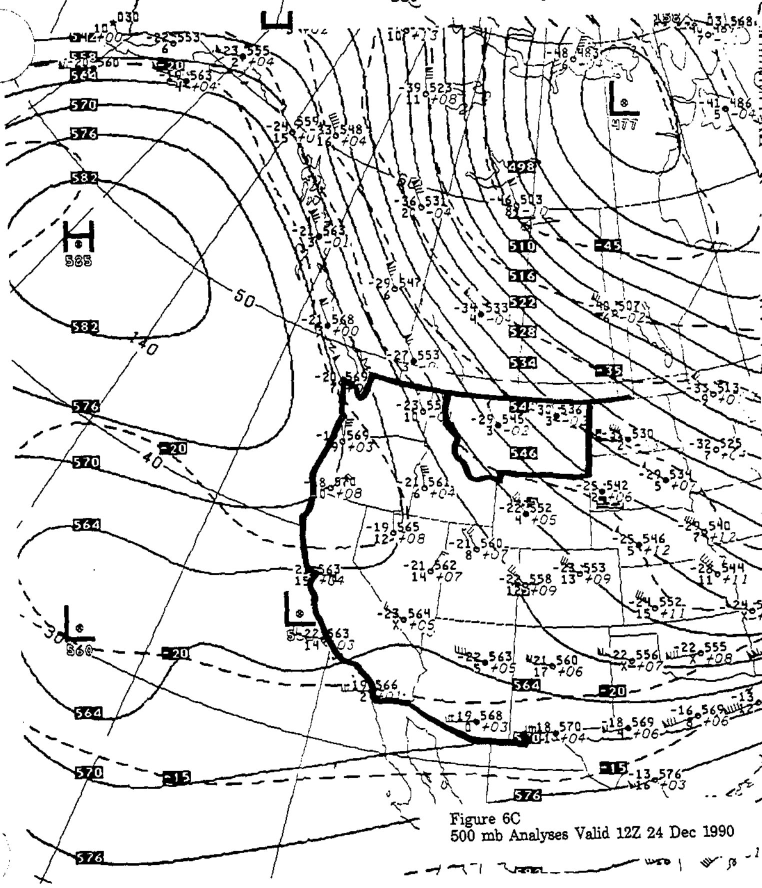

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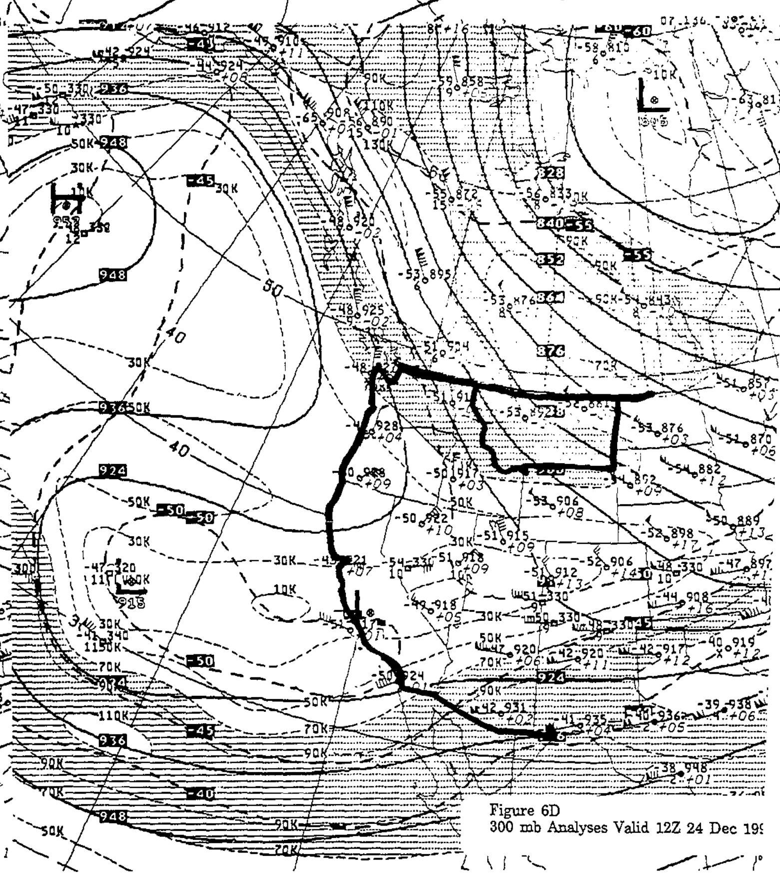


Figure 6D
300 mb Analyses Valid 12Z 24 Dec 19

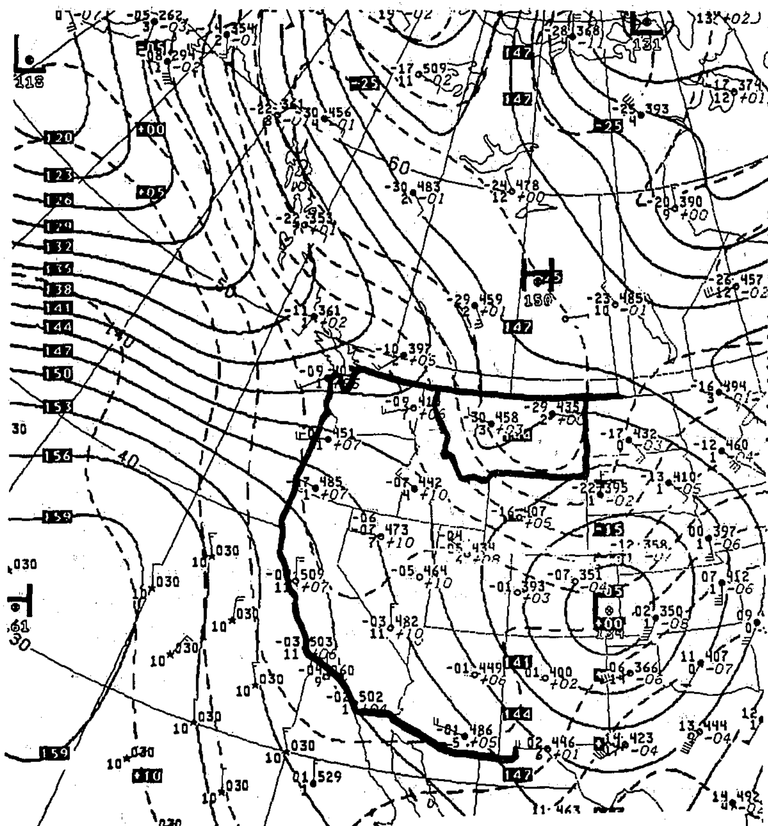


Figure 7A
850 mb Analyses Valid 12Z 22 Jan 1982

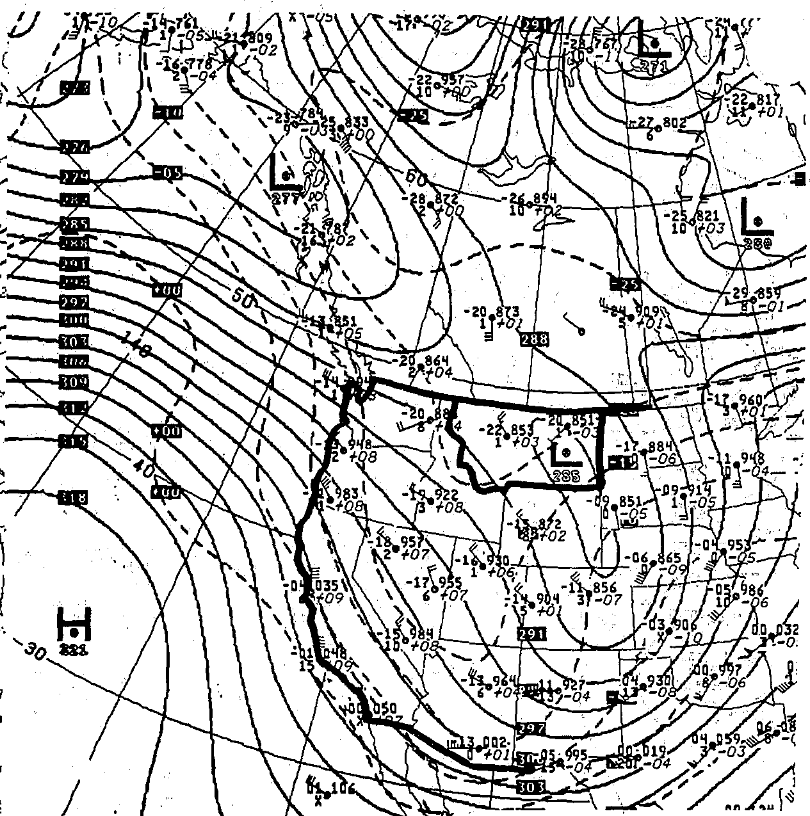
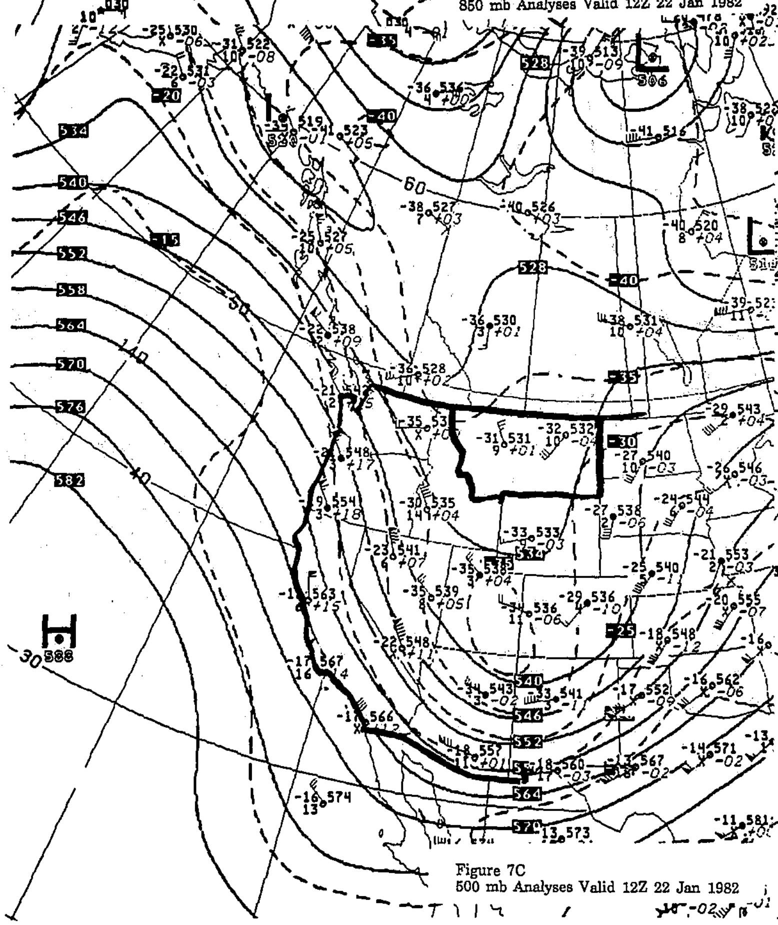


Figure 7B
700 mb Analyses Valid 12Z 22 Jan



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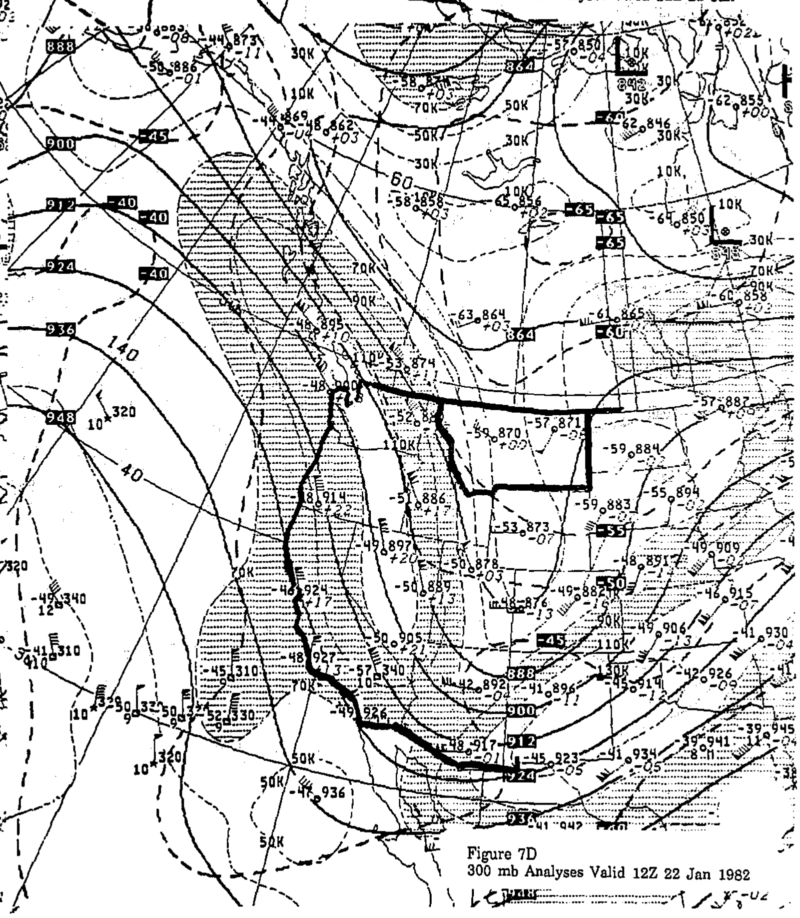

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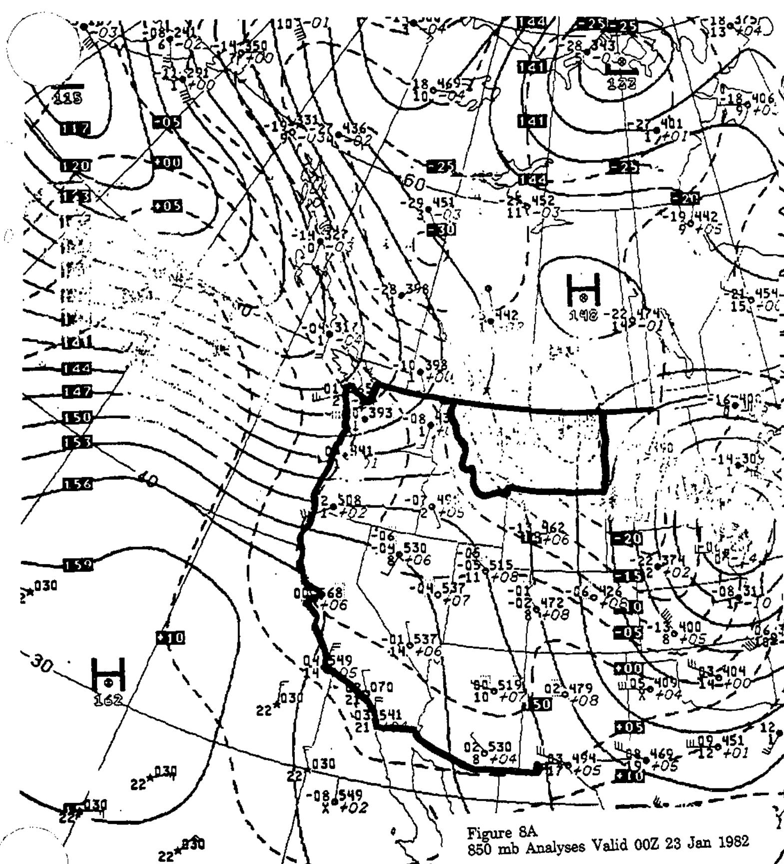

Figure 8A
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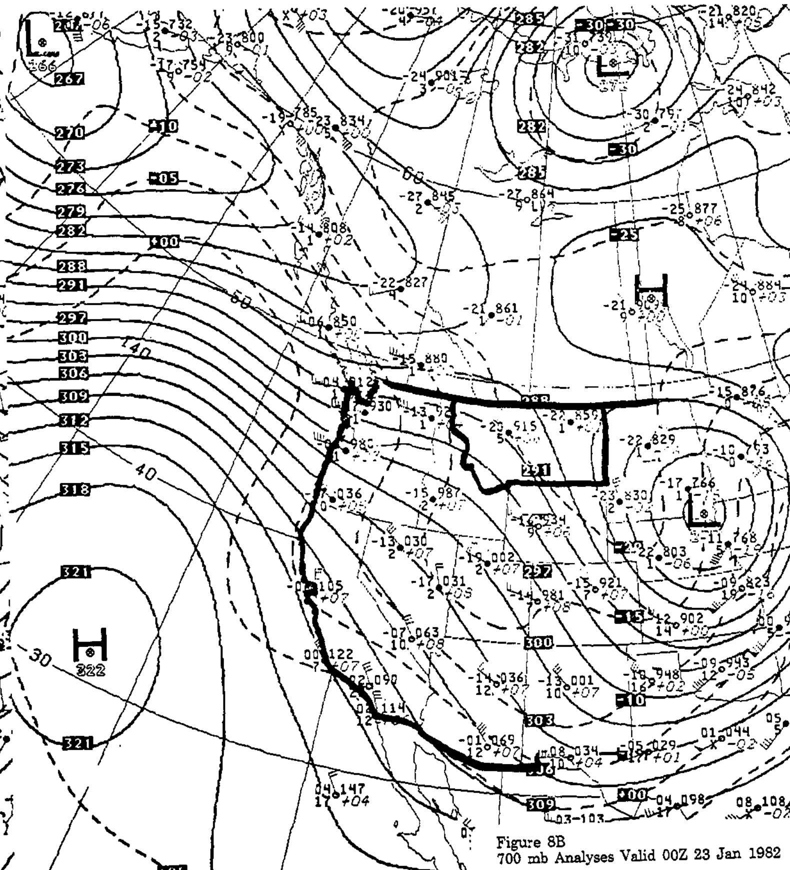

Figure 8B
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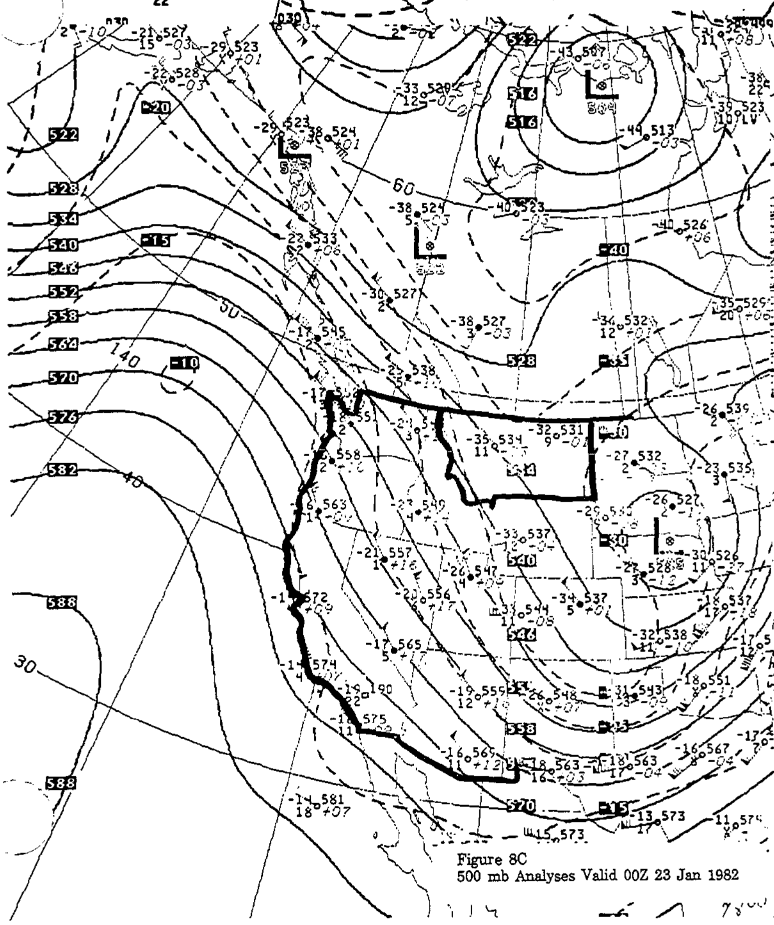

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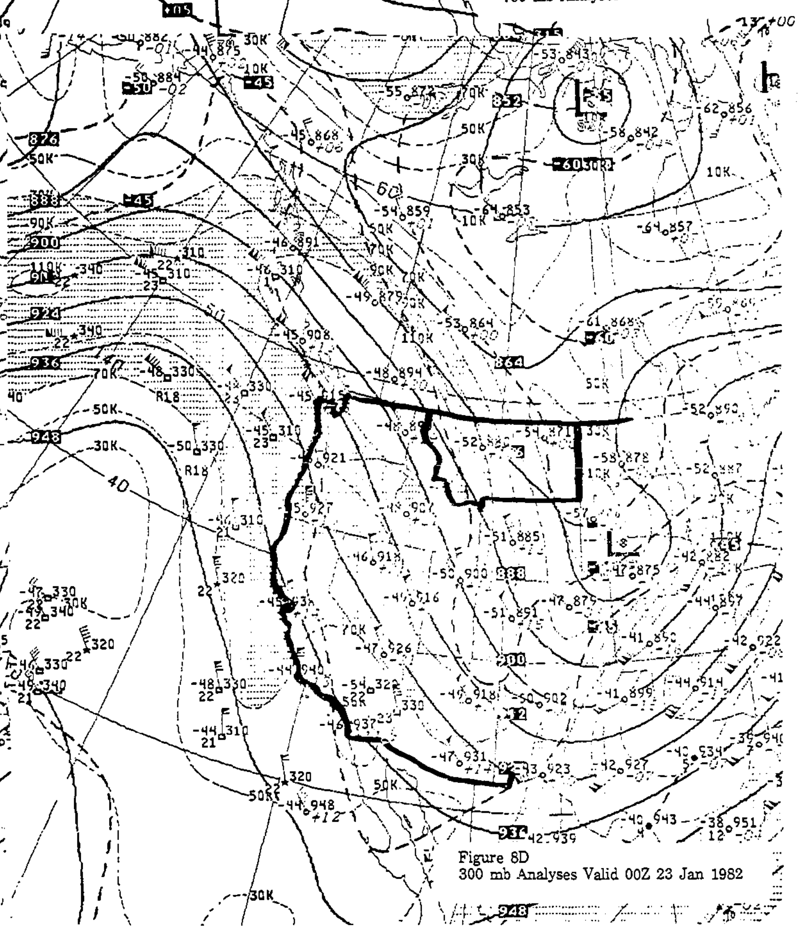

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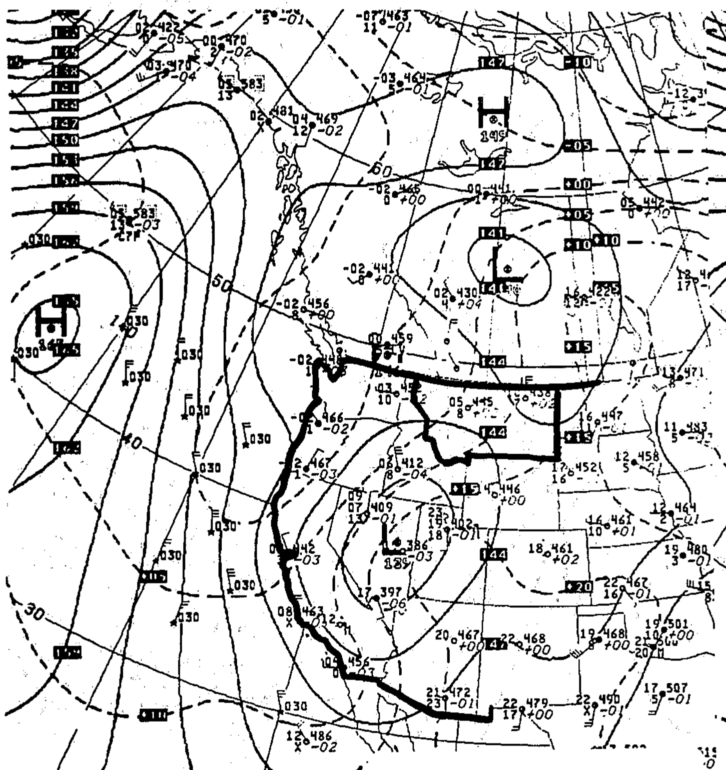

Figure 9A
850 mb Analyses Valid 12Z 23 May 1978

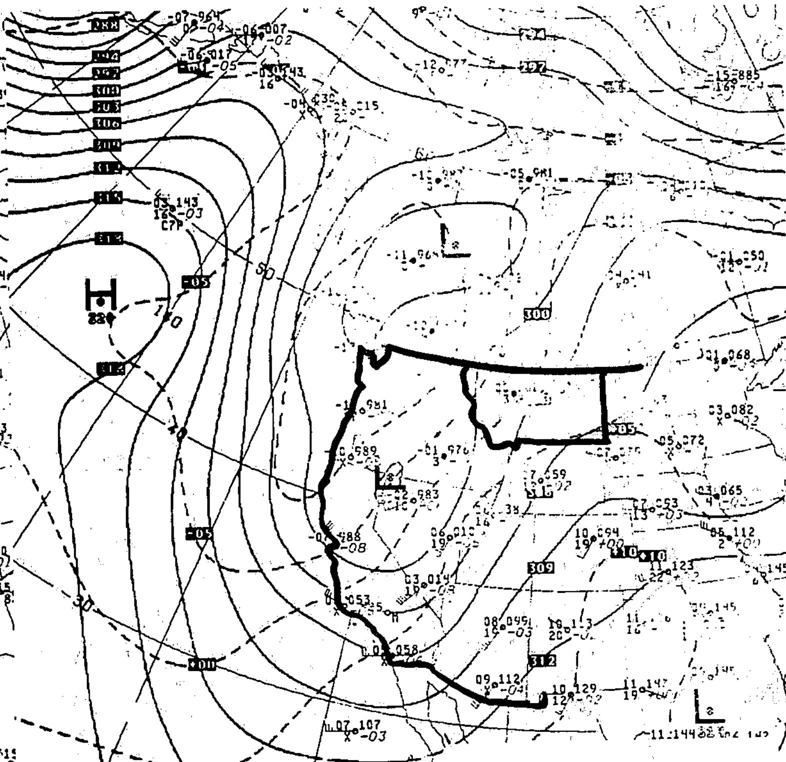

Figure 9B
700 mb Analyses Valid 12Z 23 May 1978

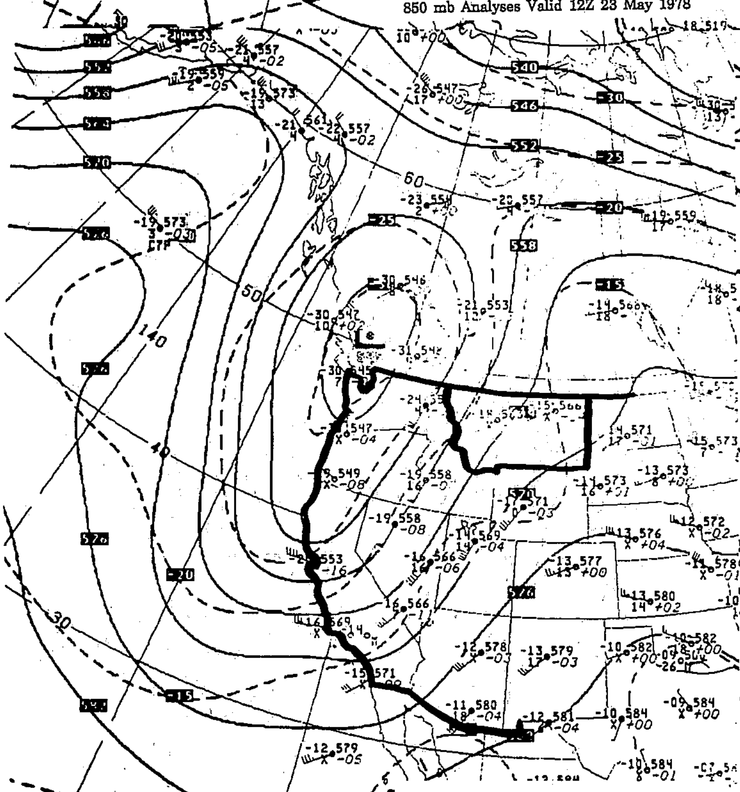

Figure 9C
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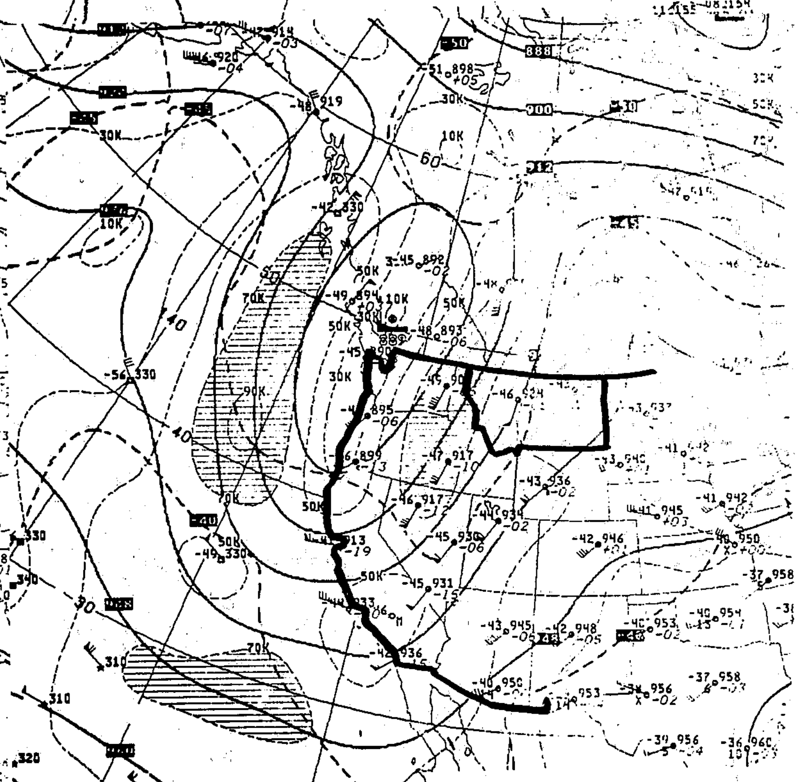

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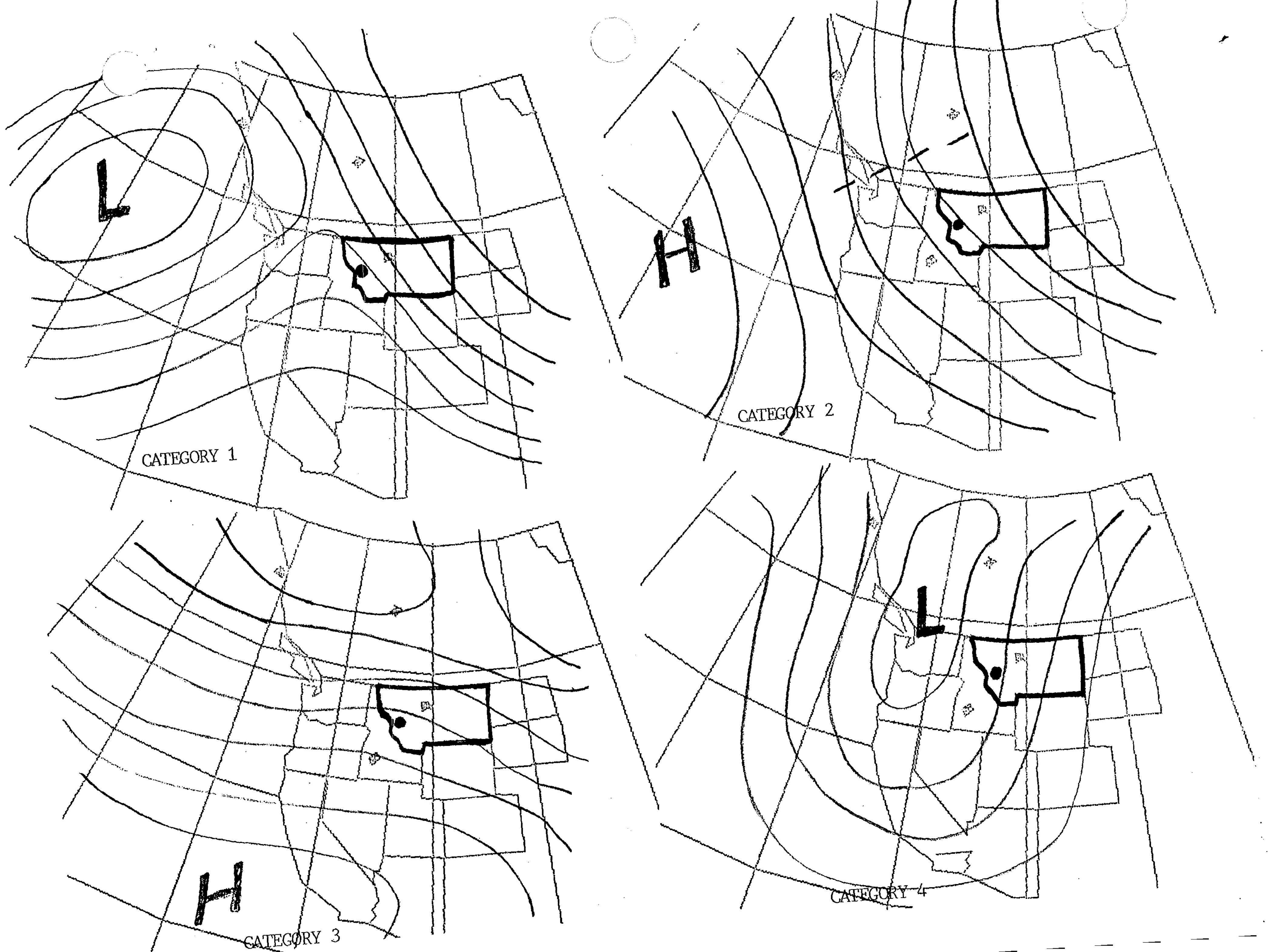

Figure 10

Each Category

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