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NOAA Technical Memorandum NWS WR-172

FORECASTING HEAVY SNOW AT WENATCHEE, WASHINGTON

Salt Lake City, Utah
December 1981

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

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

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Weather Service Office
Wenatchee, Washington
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ABSTRACT

An examination of past cases indicates that strong warm advection was the principle characteristic of the majority of heavy snows at Wenatchee. Further examination of these cases revealed that a high probability of heavy snow existed when temperatures at the 850- and 700-mb levels in the cold air in advance of the warm advection were below specific critical values.

The only other well defined heavy snow pattern occurred during Arctic outbreaks associated with strong southward moving upper troughs or closed lows. These cases featured cold advection with heavy snow developing in easterly upslope flow against the Cascade range.

I. INTRODUCTION

Heavy snow, defined as 4" or more in 12 hours or 6" or more in 24 hours, occurs on the average of three times each winter at Wenatchee. It is frequent enough and has sufficient impact on area activities that public safety agencies desire advance warning of this event. Experience indicates that for a heavy snow warning to be effective it must be issued during daytime working hours. A warning of heavy snow expected to begin early tomorrow morning, for example, would have to be issued the previous day to provide any benefit. Therefore, the forecaster needs to recognize well in advance those situations that could lead to heavy snow.

An examination of all heavy snow cases at Wenatchee during the period 1965-1980 indicates that most heavy snows occurred under two well defined patterns. The vast majority occurred when strong warm advection was associated with an incoming Pacific storm and a cold airmass existing over the Columbia River Basin. Temperatures at 850- and 700-mb levels in the cold air were below definite threshold values in nearly all cases prior to heavy snow cases. Heavy snow rarely occurred when temperatures were above these values. Most of the remaining heavy snow cases occurred with Arctic outbreaks. The potential for heavy snow in these latter cases depended upon the strength of the trough or closed low associated with the Arctic outbreak and the required upward motion indicated by strong positive vorticity advection and orographic lifting.

II. CLIMATOLOGY OF HEAVY SNOW AT WENATCHEE

Wenatchee is located at the confluence of the Wenatchee and Columbia Rivers in a rather deep valley with valley floor elevations ranging from 650 to 1200 feet. The Waterville Plateau rises to an elevation of about 3000 feet a few miles to the east while the Wenatchee Range rises to nearly 7000 feet immediately to the south and southwest. In winter this valley traps and holds cold air with temperatures near or below freezing. The warmer, moist air associated with Pacific storms usually passes over the top of the trapped cold air. Frozen precipitation often occurs under these conditions. Similar conditions prevail in all the deeper valleys along the Cascade east slope.

During the 16-year period 1965-1980, a total of 50 heavy snows occurred at the the Wenatchee WSO. The seasonal frequency varied from none during the 1966-67 and 1976-77 winters, to six heavy snows during the 1968-69 and 1971-72 winters. Forty heavy snows occurred in December and January, six in November and four in February. Snowfalls during the storms exceeded 6" in 60% of the storms. Five storms exceeded 10" and one storm produced 18" during a 24-hour period. The average storm duration was 14 hours and most storms met the heavy snow criteria of 4" in a 12-hour period.

Strong warm advection was the principle factor in 42 of the 50 heavy snow cases. Cold advection with easterly upslope flow accounted for five of the cases. No significant temperature advection existed in the three remaining cases. These three non-advection cases, all of which produced snowfalls just meeting the heavy snow criteria, had only one common factor--the presence of a southwesterly 500-mb jet over the area.

III. WARM ADVECTION SNOWSTORMS

Warm advection storms usually produced heavy snow along the entire Cascade east slope and often over much of eastern Washington. Previous studies by Younkin [1] and Woerner [2] note the importance of warm advection to heavy snows over the Pacific Northwest. The physical reasoning connecting upward vertical motion to warm advection is shown in the adiabatic equation for vertical velocity (see Petterssen):

$$w = - \frac{\frac{\partial T}{\partial t} + V \frac{\partial T}{\partial s}}{\gamma_w - \gamma}$$

where w = vertical velocity, positive upward

$\frac{\partial T}{\partial t}$ = local temperature change

$V \frac{\partial T}{\partial s}$ = temperature advection term along streamline, negative with warm advection

γ_w = wet adiabatic rate when air saturated

γ = current lapse rate

The numerator of this equation states that for upward vertical motion to develop, the temperature advection term, $V\frac{\partial T}{\partial s}$, must be greater in absolute value than the local temperature change, $\frac{\partial T}{\partial t}$. Therefore, a good upward motion field is most likely in a warm advection pattern driven along by strong winds.

The colder an airmass temperature is prior to the beginning of warm advection the stronger the advection pattern is. Consequently, an investigation was made to see if there were critical airmass temperatures in the cold air prior to the onset of heavy snow. Table 1 shows the average temperature at the 850- and 700-mb levels at the beginning and end of all warm advection heavy snow cases for which data were available (33 out of the 42 heavy snow cases).

Table 1: Average temperatures at beginning and end of warm advection heavy snows. Spokane sounding. Temperatures C°.

LEVEL	AVERAGE TEMP. @ BEGINNING	AVERAGE TEMP. @ END	AVERAGE CHANGE	MEAN DECEMBER / MEAN JANUARY
700 mb	-16.0	-6.6	+9.4	-7.0 / -11.9
850 mb	- 7.7	+0.3	+8.0	-2.2 / -5.0

These upper-air temperatures were obtained from Spokane (GEG), the nearest radiosonde station representative of the Wenatchee environment. The table also contains the normal temperature values at these levels for December and January [3]. The data show that these temperatures averaged about 5°C below normal at the start of the warm advection and warmed an average of 8-9°C during the snow-fall period. In addition, the following precedent conditions were noted:

1. In all cases the 700-mb temperature was -10°C or lower at the beginning of the warm advection.

2. In all but one case the corresponding 850-mb temperature was -4°C or lower.

Since heavy snow rarely occurred during warm advection patterns when airmass temperatures were greater than these values, these temperatures indicate threshold temperatures that the forecaster should consider in deciding whether or not to forecast heavy snow for Wenatchee.

The speed of the advecting wind during heavy-snow periods was also investigated for critical values. In all warm-advection heavy snows, the 500-mb winds exceeded 50 knots and the 500-mb jet axis was located over or just south of the state of Washington. Wind directions ranged mainly between SW and NW. When the advecting wind at 500 mbs was less than 50 knots or if the 500-mb jet axis was north of the state during the warm advection, little or no precipitation occurred, even in cases where the initial airmass temperatures were favorable and well below critical values. It is important that the warm advection and strong advecting winds occur simultaneously for heavy snow to occur.

Other factors, such as the strength of positive vorticity-advection, the location of a surface low-center with respect to the area of heavy snow, etc. were not reliable indicators of heavy snow. Positive vorticity advection of varying degrees was present with warm advection snows, but it was not necessarily very strong. Goree [4] and Brown [5] state that in heavy snow cases east of the Rocky Mountains, heavy snow is nearly always confined to areas to the left (usually north) of the path of the surface low center. At Wenatchee this is not the case with most warm-advection heavy snows since the associated surface low usually moves inland across southern British Columbia. The reason for this is surely related to topographical influences. Cold air that is trapped in deep valleys cannot be easily swept out by the warmer air in the southern sector of storms so precipitation remains as snow rather than rain.

The question of rain versus snow can arise especially early and late in the snow season. However, during December and January, if the 850- and 700-mb temperatures are below the critical values stated above, snow occurs even if the surface temperature is several degrees above freezing when the precipitation begins.

The numerical predictions from NMC have often been helpful in forecasting the development and timing of warm-advection snows. The LFM progs are especially helpful and easy to use since warm advection is depicted by the intersections of the thickness contours and surface isobars. Snow usually starts when the warmer thickness values begin to penetrate eastern Washington. Satellite pictures over the Pacific have been useful in detecting developing warm-advection patterns and in checking the validity of initial LFM thickness analyses.

IV. COLD ADVECTION SNOWSTORMS

Strong troughs moving southward and associated with Arctic outbreaks provide the only other well defined pattern associated with heavy snow at Wenatchee. Heavy snow fell when the lower level winds shifted to a northeast direction driving moist air upslope against the Cascades. Wenatchee is especially well situated to receive heavy snow under northeast flow since a high mountain ridge lies immediately to the southwest of the city. While it is common for Wenatchee to be the only station to observe heavy snow in eastern Washington, in this type of flow, heavy snow will often fall along much of the lower Cascade east slope. Most other regular reporting stations in eastern Washington, such as Omak, Yakima, and Spokane, are not in topographically favored areas to receive heavy snow with northeasterly flow.

In order for heavy snow to occur strong positive vorticity-advection must exist with the trough. Absolute vorticity values on the order of 16×10^{-5} per second or greater were associated with the troughs that produced heavy snow. Snow with this type of flow is usually light and fluffy so that 4" or more can accumulate in a short time but will not have much liquid water content. If the southward moving trough develops into a closed low which stalls in the Wenatchee vicinity, then snowfall will be of a longer duration and may spread over a larger area of eastern Washington.

Cold advection snow at Wenatchee begins when the low level wind, up through 850 mb, shifts to a northeast direction. LFM and FOUS numerical guidance provide good indications of the development of strong southward moving troughs and the timing of lower level flow changes to northeast.

V. EXAMPLE OF A WARM ADVECTION HEAVY SNOW; DECEMBER 2, 1980

This storm began shortly after midnight on December 2 and dropped 6-10" of snow in the Wenatchee area by mid-afternoon. Precipitation totaled .93" with a snowfall of 6" at the Wenatchee WSO. Pragborn Field (EAT), a short distance from the WSO at an elevation of 1250', received 10" of snow. Heavy snowfall was general over much of eastern Washington.

Figures 1-4 show the upper-air patterns at 850-, 700-, and 500-mb levels as they evolved beginning at 12Z, December 1. At that time (Figure 1) a deep, cold airmass lay over eastern Washington with a 700-mb temperature of -14°C at Spokane (GEG), well below the critical value for heavy snow. The 850-mb temperature of -3°C was marginal compared to temperatures usually present prior to the onset of heavy snow (i.e., -4°C or lower). However, it was considered close enough so that a heavy snow warning was issued for Wenatchee in the afternoon of December 1. The 00Z December 2 upper-air data (Figure 2) showed strong warm advection beginning over Oregon with southwest flow existing over Washington. The 500-mb jet, which was over southern Oregon earlier, was moving northward. By 12Z December 2 (Figure 3) the strongest warm advection at 700 mb was over southern Washington moving northeastward under the 500-mb jet which had shifted northward over Washington. By 00Z December 3 (Figure 4) the warm tongue at 850- and 700-mb levels was over eastern Washington. The snow had tapered off in the Wenatchee area by this time. The Spokane 700-mb temperature had warmed 11°C and the 850-mb temperature had warmed 5°C during the heavy snow period.

The LFM prog series, based on initial data for 12Z December 1, is given in Figure 5. The progs showed the developing warm advection pattern. Note the intersections of 1000-500-mb thickness isopleths and surface isobars. Strong warm advection is indicated on the 00Z and 12Z, December 2 prog panels. These progs also forecast the 500-mb jet to move northward over Washington as the short-wave trough over British Columbia phased in with the eastward moving trough in the southern branch of the westerlies.

VI. EXAMPLE OF A COLD ADVECTION HEAVY SNOW; NOVEMBER 18-19, 1978

Snow began just before noon on November 18 and continued into November 19. Six inches of snow fell at Wenatchee WSO, 12" fell at the southern edge of town, and three to four feet of powdery snow was reported at higher elevations southwest of Wenatchee. Snowfall in the Columbia Basin, away from the mountains, ranged from 2-5".

Figures 6-8 show the upper-air patterns at 850-mb and 500-mb levels as they evolved during this storm. At 12Z, November 18, (Figure 6), an upper-level trough was dropping southward over British Columbia. The leading edge of the Arctic air at 850 mb was near the Canadian border at this time. The Arctic front with a wind shift to northeast moved into Wenatchee just before noon on the 18th and snow commenced at that time. Low level winds became strong easterly as the trough drifted southward. A low-pressure center developed near the mouth of the Columbia River (Figures 7 and 8). Temperatures at the 850-mb level dropped from -2 to -13°C at Spokane during the period of snowfall. The surface temperature at Wenatchee dropped from the mid 30s at the beginning of the snow to the mid 20s by the afternoon of November 18.

The LFM prog series, based on initial data for 00Z November 18, Figure 9, forecast the 500-mb trough to move southward from British Columbia into Washington during November 18. This motion was associated with strong, positive vorticity advection. The associated surface progs also indicated the development of strong northeasterly winds.

VII. SUMMARY

Strong warm-air advection over an existing cold airmass is responsible for the majority of heavy snows at Wenatchee. The prestorm criteria are: 1. 850-mb temperature at Spokane -4°C or lower in cold air preceding the warm advection. 2. 700-mb temperature -10°C or lower. Heavy snow will occur if significant warm advection occurs during the following 12-18 hours which will raise temperatures at these levels an average of 8°C. The warm advection must be associated with a 500-mb jet lying over or just south of Washington with wind speeds 50 knots or greater. Positive vorticity advection accompanies these storms but is variable in intensity and not necessarily strong. The position of the surface low center is not critical and usually moves inland north of Wenatchee. Snow begins soon after the warm advection at 700- and 850-mb levels reaches eastern Washington. The snow ends or tapers off when the axis of the warm tongue passes east of the Wenatchee. Heavy snow associated with warm advection is usually general along the entire Cascade east slopes and eastern Washington.

Cold air advection associated with Arctic outbreaks is responsible for most of the remainder of heavy snow cases at Wenatchee. A favorable flow pattern for this type of heavy snow is a southward moving 500-mb trough with strong positive-vorticity advection occurring in eastern Washington. Absolute vorticity values in the trough were on the order of 16×10^{-5} per second or greater. Snow begins when lower level winds become northeasterly. Heavy snowfall with this type is often fluffy and confined to the immediate upslope area of the Cascades with Wenatchee commonly the only reporting station receiving heavy snow.

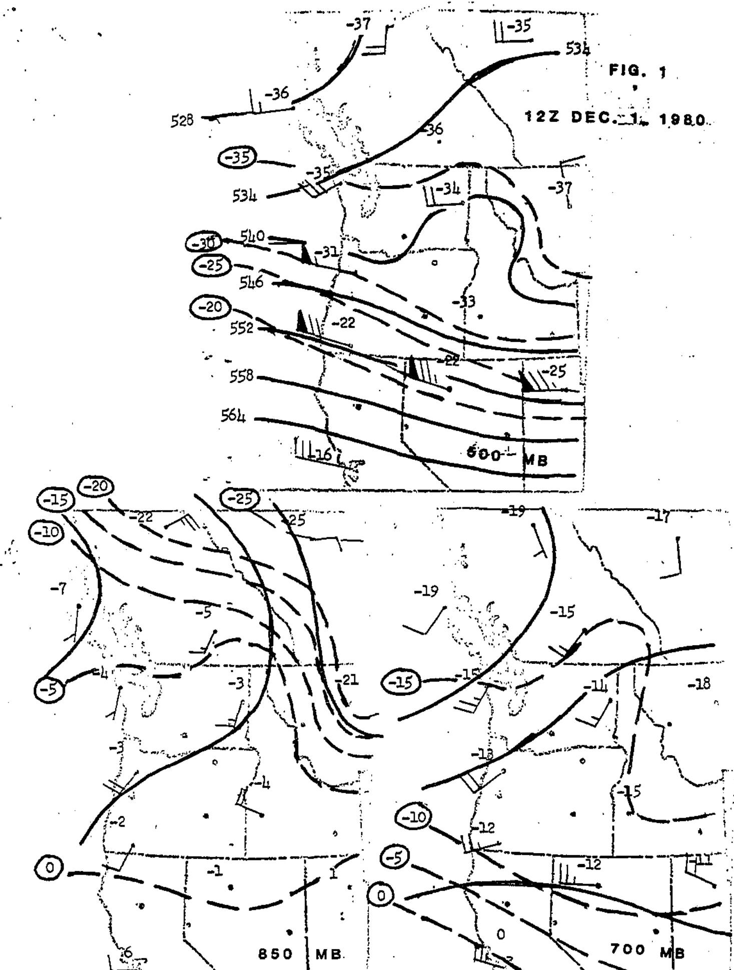

FIG. 1
12Z DEC. 1, 1980

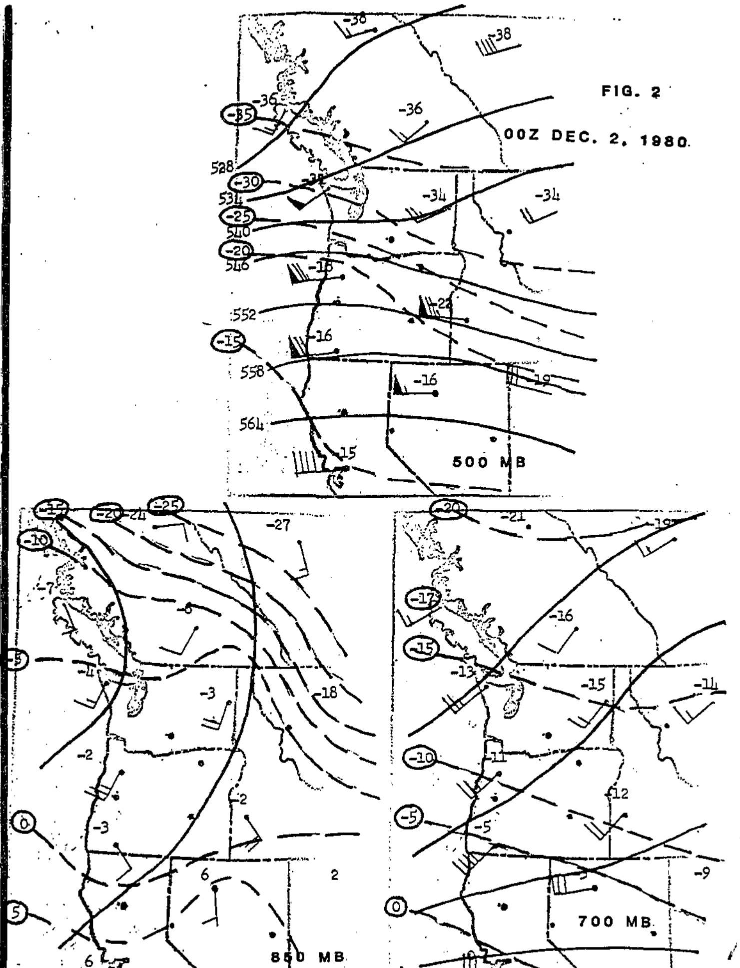

FIG. 2
00Z DEC. 2, 1980

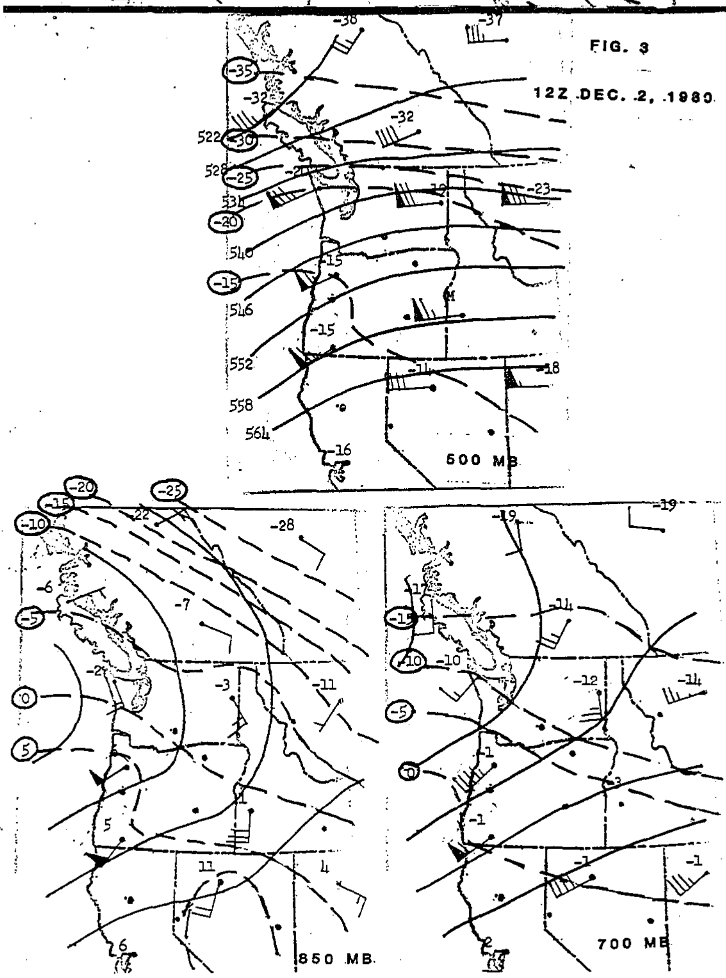

FIG. 3
12Z DEC. 2, 1980

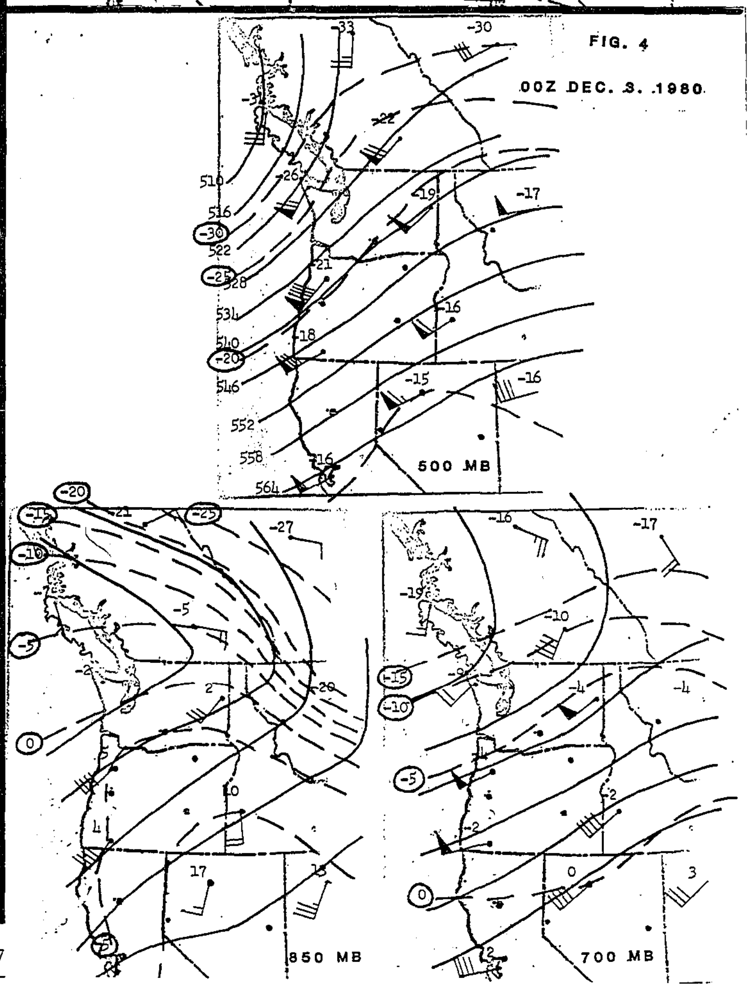

FIG. 4
00Z DEC. 3, 1980

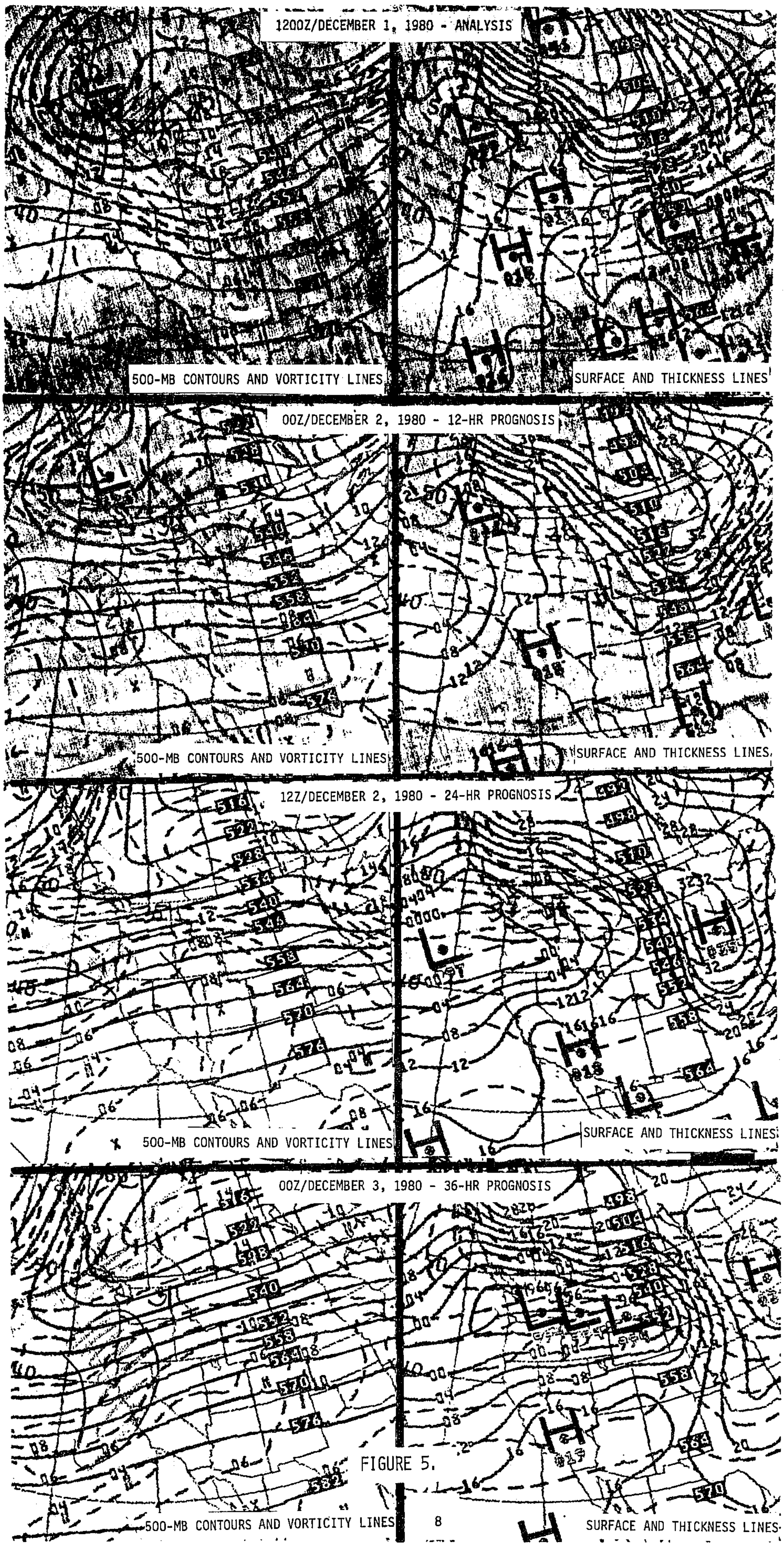
1200Z/DECEMBER 1, 1980 - ANALYSIS
500-MB CONTOURS AND VORTICITY LINES
SURFACE AND THICKNESS LINES
00Z/DECEMBER 2, 1980 - 12-HR PROGNOSIS
500-MB CONTOURS AND VORTICITY LINES
SURFACE AND THICKNESS LINES
12Z/DECEMBER 2, 1980 - 24-HR PROGNOSIS
500-MB CONTOURS AND VORTICITY LINES
SURFACE AND THICKNESS LINES
00Z/DECEMBER 3, 1980 - 36-HR PROGNOSIS
500-MB CONTOURS AND VORTICITY LINES
SURFACE AND THICKNESS LINES

FIGURE 5.

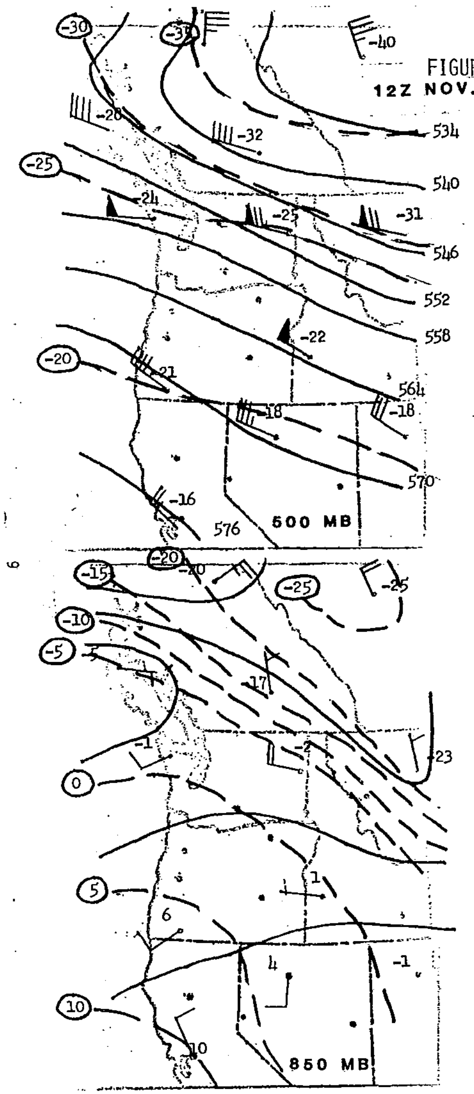

FIGURE 6
12Z NOV. 18, 1978

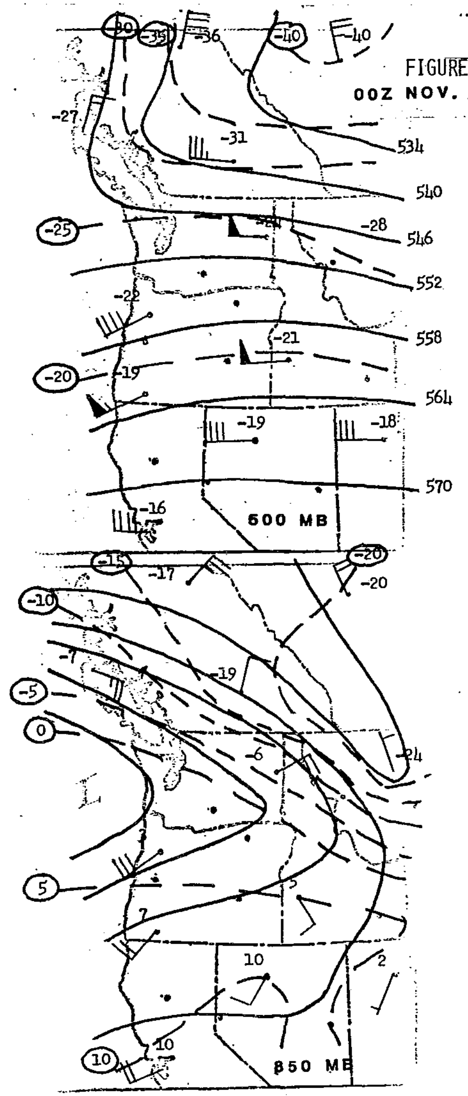

FIGURE 7
00Z NOV. 19, 1978

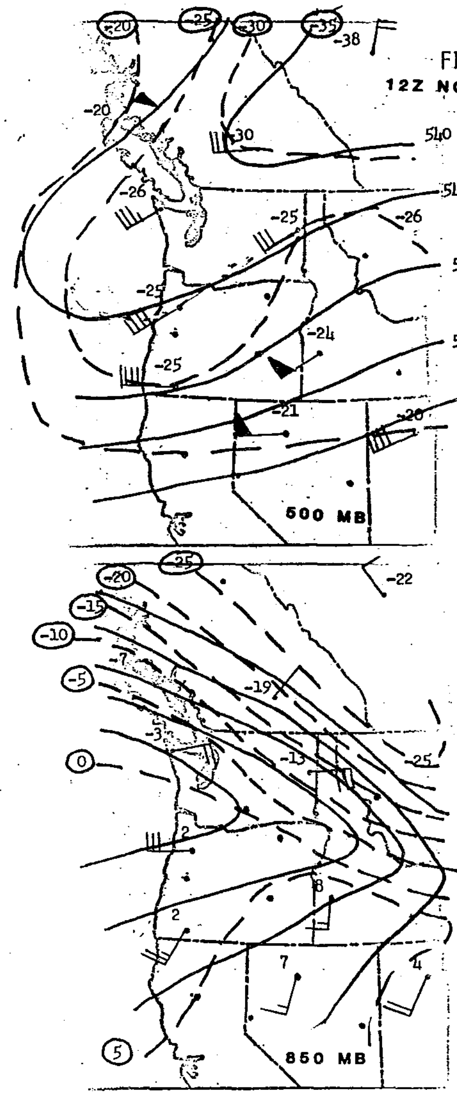

FIGURE 8
12Z NOV. 19, 1978

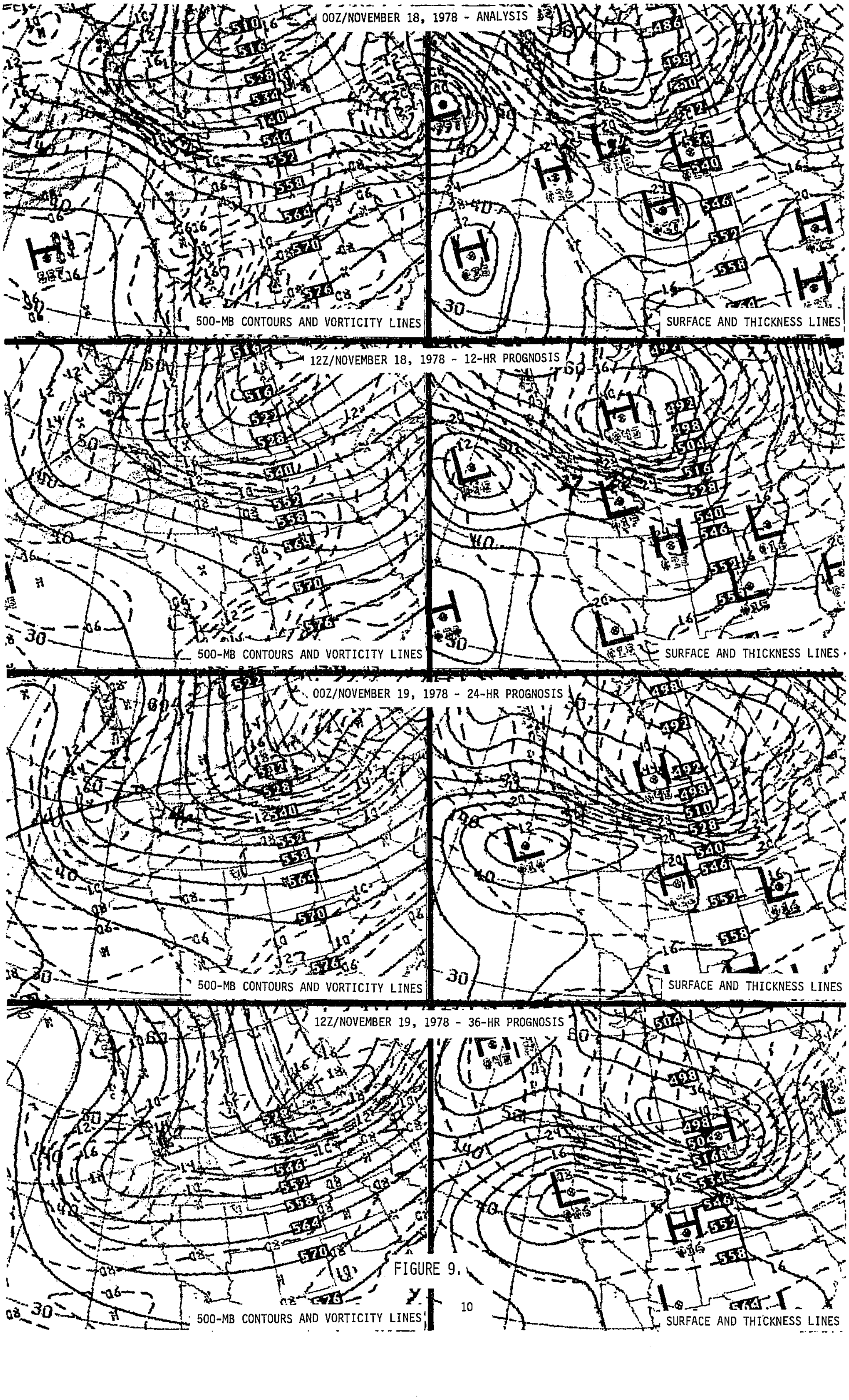
00Z/NOVEMBER 18, 1978 - ANALYSIS
500-MB CONTOURS AND VORTICITY LINES
SURFACE AND THICKNESS LINES
12Z/NOVEMBER 18, 1978 - 12-HR PROGNOSIS
500-MB CONTOURS AND VORTICITY LINES
SURFACE AND THICKNESS LINES
00Z/NOVEMBER 19, 1978 - 24-HR PROGNOSIS
500-MB CONTOURS AND VORTICITY LINES
SURFACE AND THICKNESS LINES
12Z/NOVEMBER 19, 1978 - 36-HR PROGNOSIS
500-MB CONTOURS AND VORTICITY LINES
SURFACE AND THICKNESS LINES

FIGURE 9.

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