THUNDERSTORM ANALYSIS In the NORTHERN ROCKY MOUNTAINS

by

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PROJECT Skyfire

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE
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INTRODUCTION

Lightning-caused fires are a continuing serious threat to forests in the northern Rocky Mountain area. More than 70 percent of all forest fires in this area are caused by lightning. In one 10-day period in July 1940 the all-time record of 1,488 lightning fires started on the national forests in Region 1 of the U.S. Forest Service.[2/]

Project Skyfire was planned and organized to study the causes and characteristics of lightning storms and to see what steps could be taken to decrease the great losses caused by lightning fires. One important phase of Project Skyfire is the study and analysis of the weather phenomena associated with the formation and growth of lightning storms. A better understanding of these factors is valuable to both the forester and the meteorologist. In the Project Skyfire research program,analyses are being made of the specific characteristics of individual lightning storms and the general characteristics of storms during an entire fire season. This paper presents an analysis of thunderstorm development and characteristics in the northern Rocky Mountains for the 1955 fire season (July and August).

OPERATIONS

The area being studied by Project Skyfire is closely identified with Region 1 of the U.S. Forest Service and includes 16 of its national forests. Certain strategically located lookouts in this region were chosen to be the 15 Skyfire stations, and two additional outlying stations were established at the Russell Mountain Lookout in Wallowa-Whitman National Forest in eastern Oregon and at Mt. Washburn Lookout in Yellowstone National Park. These last two stations were chosen to observe the storms moving into the area from the southwest and southeast quadrants. All Skyfire lookout stations were manned during the main fire season, July and August.

In addition to their training for regular duties in fire detection and control, the Skyfire observers were instructed to measure and record the dry and wet bulb temperatures, wind speed and direction, and cloud types and movement at three observation times daily: 0800, 1200, and 1630 MST. From weather measurements they computed the burning index (a numerical measure of

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1/ Research meteorologist, U.S. Weather Bureau, Washington, D.C. He has collaborated in Intermountain Station's fire research program since 1954.

2/ Includes Montana, Idaho north of the Salmon River, northeastern Washington, Yellowstone National Park, and northwestern South Dakota.

fire danger) daily for their station, and recorded the time of beginning and ending, location and movement, and the number of cloud-to-ground lightning strikes in each thunderstorm during each 24-hour period within a 20-mile radius of their tower.

In addition to the 17 Skyfire stations, more than 80 weather stations were operated in this area during the fire weather season. Some of these stations were in Glacier National Park and on Indian reservations, and most of them were operated by Forest Service personnel. At these stations the dry and wet bulb temperatures, wind speed and direction, and fuel moisture were measured. The burning index was computed and the data recorded for the 1630 MST observation time together with the maximum cumulus activity for the afternoon and the time of beginning and ending of lightning for the 24-hour period in their district. The network of weather stations and the Skyfire stations were connected by radio to a central radio station in Missoula, Montana, where weather reports were received daily at 1700 MST. Regular teletype weather data and facsimile maps were available at the Weather Bureau Airport Station in Missoula.

ANALYSIS OF DATA

Distribution of storms over the entire area during the 1955 season (fig. 2) shows greater frequency of storms on the east side of the Continental Divide. Yellowstone National Park and Gallatin National Forest had the greatest frequency; fairly even distribution occurred over the other national forests east of the divide. West of the divide, the Nezperce, Bitterroot, and Lolo Forests, or the southern section, had more lightning storms than other areas. This concentration in the southern sections is in agreement with the general topography and the windflow.

Distribution of the reported initial times of lightning storms is shown in figure 3. The largest number of storms began during the late afternoon and evening (1400-2200 MST); the second largest number began about midnight; and the least number began in the early morning hours.

Distribution of the number of lightning strikes reported by the 17 Skyfire stations is shown in figure 4. The greatest total number of lightning strikes was recorded at the Sliderock and Double Arrow Lookouts in the Lolo National Forest, Mt. Washburn Lookout in Yellowstone, Gisborne Lookout near the Priest River Experimental Forest, and Cold Springs Lookout in the Nezperce National Forest. The number of strikes per storm is rather evenly distributed over the entire area. The seasonal average of lightning strikes per storm for the entire area was 35.

A calendar of the lightning storm activity is shown for the months of July and August 1955 (tables 1 and 2). These tables record the lightning activity and the precipitation both east and west of the Continental Divide. Comments in the "Remarks" column indicate the type of storm and list the more significant meteorological features. Some of the more interesting storms are treated in detail later in this paper, but a few general comments on the whole season follow here.

Table 1.--Lightning activity, July 1955

DATE	WEST OF DIVIDE		EAST OF DIVIDE		REMARKS
	ϟ	PRECIP.	ϟ	PRECIP.	
1					} COLD LOW ALOFT EXCEPT FOR BREAKS ON JULY 2 AND 7-8 (July 1-11)
2					
3					
4					
5	+	M	+	L	
6	⊕	H	⊕	M	UPPER LEVEL TROUGH MOVED ACROSS AREA
7	O	H	O	M	
8	—	L	+	L	
9	⊕	M	+	L	
10	+	M	+	M	
11	+	M	+	M	
12	O	L	—	M	SCATTERED AIRMASS OR TOPOGRAPHICAL
13	—	L	+	L	" " " "
14	O	O	+	L	" " " "
15	+	L	+	L	DEEPENING SURFACE LOW - FRONTAL ZONE
16	⊕	L	+	L	" " " " "
17	+	M	+	L	COLD FRONTAL PASSAGE
18	+	L	+	M	" " "
19	O	O	+	L	SCATTERED AIRMASS OR TOPOGRAPHICAL
20	+	L	+	L	" " " "
21	+	L	+	L	" " " "
22	⊕	M	+	M	" " " "
23	⊕	M	+	M	" " " "
24	⊕	M	⊕	L	COLD LOW ALOFT
25	⊕	M	⊕	M	" " "
26	O	L	—	L	" " " } COLD FRONTAL PASSAGE (July 26-27)
27	⊕	M	+	M	" " " } UPPER TROUGH MOVED ACROSS AREA (July 27-28)
28	O	L	+	M	
29	O	L	—	L	
30	O	L	O	O	WEAK FRONTAL PASSAGE
31	O	L	O	O	" " "

Explanation of symbols: lightning, 0 none; - few isolated storms; + considerable activity over parts of area; ⊕ widespread activity; precipitation, 0 none; L trace - 0.10 inch; M 0.11 - 0.50 inch; H more than 0.50 inch.

July was characterized by considerable lightning activity and also by heavy precipitation, especially in the first part of the month. Total rainfall from October 1 through June in the Priest River area had been unusually low, but precipitation in early July was sufficient to reduce the fire danger greatly; it remained low until near the end of the season.

The period from July 1 to 11 was associated with a persistent deep cold low aloft and quite moist air at all levels. A frontal zone with deepening surface pressure was evident July 15 and 16, and was followed by a cold frontal passage on the 17th. Another period with a cold low aloft appeared July 24-28, but this time the moisture seemed to be confined more in the higher levels. This period was associated with a surface cold frontal passage July 26-27 and with the passage of an upper trough July 27-28. Most of the storms in the first part of the month were lower level storms accompanied by considerable precipitation. Many storms east of the divide from July 12 to 21

Table 2.--Lightning activity, August 1955

DATE	WEST OF DIVIDE		EAST OF DIVIDE		REMARKS
	ϟ	PRECIP.	ϟ	PRECIP.	
1	O	O	+	O	WEAK FRONTAL ZONE
2	–	O	–	L	COLD LOW ALOFT-LOCAL HIGH LEVEL MOISTURE
3	O	O	–	L	
4	O	O	O	O	
5	O	O	O	O	
6	O	O	–	O	
7	+	L	O	O	COLD FRONTAL PASSAGE
8	+	L	+	L	" " "
9	O	O	O	O	
10	O	O	O	O	
11	O	O	O	O	COLD FRONTAL PASSAGE
12	O	O	+	L	" " "
13	O	O	+	L	
14	+	O	⊕	M	COLD LOW ALOFT
15	+	L	⊕	L	COLD FRONTAL PASSAGE
16	O	L	O	L	" " "
17	O	O	O	O	
18	+	O	–	O	COLD LOW ALOFT - HIGH LEVEL MOISTURE
19	+	L	+	L	COLD FRONTAL PASSAGE-HIGH LEVEL MOISTURE
20	O	O	–	O	" " " " " "
21	O	O	O	O	
22	O	O	–	O	
23	O	O	O	O	
24	O	O	+	L	COLD TROUGH ALOFT - HIGH LEVEL MOISTURE
25	⊕	L	⊕	L	" " " AND INSTABILITY
26	O	O	+	L	" " "
27	O	O	O	O	
28	O	O	O	O	
29	O	O	O	O	
30	O	O	O	O	
31	O	O	O	O	COLD FRONTAL PASSAGE

Explanation of symbols: lightning, 0 none; - few isolated storms; + considerable activity over parts of area; ⊕ widespread activity; precipitation, 0 none; L trace - 0.10 inch; M 0.11 - 0.50 inch; H more than 0.50 inch.

and west of the divide after the 17th probably were airmass or orographic. The storms from July 22 through July 28 were higher level storms. A weak frontal zone was present on July 30-31, but the air was too dry and stable for any activity except some light precipitation.

There was less lightning storm activity in August than in July. The storms were of the high-level type and were usually associated with little or no precipitation. The periods of August 7-9, 14-16, and 18-19 were associated with cold fronts. In the last period, a cold low aloft was also in evidence. The period of August 24-25 was associated with a well developed cold low aloft with the moisture and instability concentrated in the higher levels.

CHARACTERISTIC SOUNDINGS

A tabulation of the upper air data at the standard levels was made for Boise, Spokane, Medford, and Tatoosh Island. Mean soundings were computed for various periods of storm activity and corresponding periods with little or no activity. The results for Spokane are shown in figure 5. In the set of diagrams on the upper right, the solid lines refer to the temperature and dew point profile for the period July 5-11. These soundings show considerable moisture at all levels and extremely low temperatures at the 500- and 400-millibar levels. The computed bases of clouds would be quite low. The conventional Showalter Stability Index for this mean sounding is +2. While there may be some question about the interpretation of the exact numerical value of the stability index when applied to a mean sounding, the relative values of the stability indices computed for a series of mean soundings should furnish considerable information on the comparative degree of stability.

Except for a break July 7-8, this period was characterized by widespread storm activity and moderate to heavy rainfall, and the bases of the storm clouds were low. The mean sounding for the July 12-14 (B) period shows decided warming at all levels with generally lower relative humidities. While the over-all stability has not changed much, there has been pronounced drying above the 500-millibar level, which could inhibit buildup of the convective activity to sufficient heights for storms to develop. During this particular period, no storm activity occurred in the northwestern section around Spokane.

The mean sounding for the July 15-17 (C) period shows adequate moisture at all levels and a stability index of +1. This sounding shows considerable heating in the lower levels rather than the cooling aloft that occurred in the July 5-11 period. Thunderstorms and considerable precipitation appeared during this period. The mean sounding for the corresponding period July 18-21 (D) shows a very dry and stable airmass with no chance for convective activity; no storms occurred during that period.

The mean sounding for the period of July 22-25 (E) shows possible activity. However, some additional lifting by either frontal or orographical action would be necessary to produce thunderstorm activity. In any case the cloud bases would be high (above 10,000 feet). There were scattered storms in this period. The mean sounding for the period of July 26-31 (F) shows fairly high relative humidity, but increased stability due to cooling in the lower levels. The stability index was +6 in contrast to +1 in period (E).

The mean sounding for the first part of August (G) shows a very dry and stable airmass (stability index of +7) with little chance of any thunderstorm activity. The sounding for August 3 (H) shows no definite indication of activity except for the drop in temperatures at the 500- and 400-millibar levels. The moisture seems insufficient for thunderstorms, but scattered storms were observed; the moist tongue may have been quite narrow and may not have shown on the Spokane sounding. Soundings (I) and (J) (August 19 and August 7-9) do not show a sufficient amount of moisture or instability to produce thunderstorms. The stability indices were +2 and +4. In these periods, additional lifting apparently was provided by frontal lifting. The bases of any indicated storms would be rather high.

The sounding for August 25 (L) shows little indication of activity below the 500-millibar level; the conventional stability index was +6. However, the layer between the 500- and 400-millibar levels shows high relative humidity and considerable instability. This was also shown on the corresponding soundings at Boise. The mean sounding for the period of August 17-September 9 (except for the two periods of August 19 and August 25) shows a very dry and stable airmass (stability index of +7).

Similar mean soundings computed for Boise are shown in figure 6. As in the data for Spokane, a comparison of the mean soundings for the period of July 9-11 (A), which had considerable activity, and for the period of July 12-15 (B), which had little or no activity, shows the presence of very cold air in the higher levels and considerable moisture at all levels in the first period; there was a decided warming at all levels and much drier air above the 500-millibar level in the latter period. The two sets of readings show little change in the stability index.

In the mean sounding for the period of July 16-18 (C), the stability index was 0 as compared to a value of +8 in the mean sounding for the corresponding period July 18-19 (D), which had little or no activity. There was definitely drier air in the lower levels in the latter period. Similarly the mean sounding for the period of July 20-25 (E), associated with widespread lightning activity and precipitation, shows a stability index of -1, while the mean sounding for the corresponding period of July 26-31 (F) with no activity, shows decided drying and increased stability (index of +6).

The mean sounding for the period of August 7-9 (G), which was associated with scattered storm activity, shows a stability index of 0 with the moisture concentrated in the upper levels. The mean sounding for the periods of August 1-7 and 9-14 (H), with no activity, shows much drier air at all levels and increased stability (index of +4). The mean sounding for the period of August 24-26, associated with widespread lightning activity, shows the moisture concentrated above the 700-millibar level. This mean sounding suggests that additional lifting, probably orographical, will be necessary to set off the storm activity. Individual soundings will be discussed later in a case history of this period. The mean soundings for the three periods of August 17-23, August 26-31 (J), and September 1-5 (L), which had no thunderstorm activity, show extremely dry and quite stable air. The mean sounding for the period of September 5-7 (K), which had scattered high level storms, shows the moisture and instability concentrated above the 500-millibar level.

Careful analysis of upper air conditions is essential in the understanding and forecasting of thunderstorm and lightning activity. In this and similar mountainous areas, the moisture and instability at higher levels are extremely important. In any consideration of stability, not only the current soundings but the possible modifications by advection and vertical motions must be considered; these modifications include the advection of warmer or colder air and moist or dry air, lifting caused by surface frontal action or the passage of upper fronts or troughs, and mixing processes. Another lifting mechanism quite important in this area is the orographical lifting when the airflow is in the proper direction. Another factor in this upper air analysis is the moist tongues that may be too narrow to be observed on any existing radiosonde stations. A possible remedy for this difficulty is to watch the surface moisture at key high elevation stations.

CASE HISTORIES OF STORMS

July 1-11.--Upper air soundings during this period showed considerable moisture at all levels, and rather low stability. Instability was increased by the presence of extremely cold air at the 500- and 400-millibar levels. Figure 7 shows the 500-millibar contours and isotherms for 2000 MST on July 1, 2, 3, and 4, the location of the 300-millibar jet stream axis, and the 300-millibar low center. The low storm activity on July 2 is associated with the breakup of the cold low aloft and the warming of the air over the area on that day. Return of the cold air aloft, as indicated by the -20°C. isotherm, coincides with the new storm activity on July 3. These storms were accompanied by low ceilings and considerable precipitation. Since there was little change in either the map or the activity on July 5, the map for that day is not shown. Figure 8 shows similar charts for 2000 MST on July 6, 7, 8, and 9. The decided reduction in storm activity on July 7-8 is reflected in the breakup of the cold low aloft on those days. Renewed storm activity, with the return of the cold low aloft, is indicated on the map for July 9. Storm activity continued with little change in the upper level patterns on July 10 and 11, but maps for these days are not shown.

July 21-23.--This period was characterized by a low pressure trough at the surface through Nevada and eastern Oregon and Washington, with a high pressure area gradually moving southward east of the divide. The pattern aloft at both the 500- and 300-millibar levels (fig. 9) shows a high pressure area over the southwest with southwesterly flow at most levels over the Skyfire area. The 300-millibar sequence shows a new jet stream axis appearing on the evening of July 21; the wind at Spokane increased to 80 knots at 35,000 feet at 0200 MST on July 22. After this maximum was reached, the axis of the jet stream remained over the area but the speed decreased to about 60 knots by the middle of that afternoon.

Figure 10 shows an interesting sequence of storms moving across the area from the southwest during the night of July 21-22. This was a very narrow band of storms. On July 22, altocumulus castellatus appeared about 0800 MST. During the afternoon the convective cells were seen to build up to about 20,000 feet and then to dissipate above this level. Inspection of the soundings at Spokane (fig. 11) shows high relative humidity from 12,000-18,000 feet, but dry air above 23,000 feet at the 0800 MST observation time. By the time of the 2000 MST sounding, the air column showed drying down to 18,000 feet. This lack of buildup during the afternoon may well have been due to this extremely dry layer aloft. The vertical shear of the wind alone seems not to be sufficient between the 18,000- and 25,000-foot levels to be responsible for the breakdown of the convection. The thunderstorms that reappeared later during the night of July 22 probably were associated with the adiabatic layer just above the 500-millibar level.

August 2.--Local thunderstorms occurred in the Colville National Forest about 50 miles to the north of Spokane. Figure 12 shows the 500- and 300-millibar charts for 2000 MST on August 1, 2, and 3. The cold air at the 500- and 300-millibar levels can be seen on the chart for August 2. Figure 13 shows the time cross section of the wind, temperature, and dew point profiles for Spokane. The change in the wind profile shows existence of a strong jet stream axis with the isotach center passing across the area. In this situation the storms occurred as the isotach center passed over the area. The actual soundings do not reveal sufficient moisture for thunderstorm activity, but it must be remembered that the storms were quite localized, and the moist tongue may have been quite narrow and not in evidence on the Spokane sounding.

August 24-25.--Figure 14 shows another interesting progression of storms from the south and west across the area during the evening of August 24 and the morning of August 25. The 500- and 300-millibar charts are shown in figure 15. The general circulation is from the southwest. The time sequences of the temperature and dew point profiles at both Spokane and Boise are shown in figure 16. The interesting feature is the moisture and instability at high levels. This is evident on the Boise sounding for 0800 MST on the 24th, with a nearly dry adiabatic lapse rate from 500 to 400 millibars and near saturation above the 540-millibar level. This condition progressed to the north and northeast and is evident at Spokane on the 0800 MST sounding of August 25. The lapse rate is dry adiabatic between 525- and 495-millibar levels and nearly dry adiabatic up to the 400-millibar level. The air is nearly saturated from the 600- to 400-millibar layer.

JET STREAM

Possible relationships between the high level jet stream and the occurrence of thunderstorms have been considered for some time. Presence of zones of high winds and strong wind shears and associated vertical currents may influence the stability of the atmosphere considerably.

The position of the main jet stream axis at the 300-millibar level was recorded daily along with the occurrence or nonoccurrence of lightning or thunderstorm activity (fig. 17). The larger area outlined in this figure represents the area used to define whether a jet stream was present. Any reports of thunderstorm or lightning activity at any of the Skyfire stations, the fire weather stations, regular Weather Bureau, or CAA reporting stations in the smaller outlined area were recorded.

A summary of results shows 27 days with no jet stream axis in the area; there was storm activity on only 8 of these days. Of the 41 days when jet stream axis was present, 30 days had storm activity.

Further analysis shows that on the 19 days when the major jet stream was located to the north and west, thunderstorms occurred on 12 days but not on the other 7 days. Of the 11 days when the jet stream was overhead, thunderstorms occurred on only 7 days. On all the 11 days when the jet stream had passed on across the area, thunderstorms occurred.

While there seems to be some correlation between thunderstorm occurrence and presence of the large scale or hemispheric jet stream, as indicated on the 300-millibar chart, a more useful approach would be to consider zones of high winds local in nature and of short duration. These local wind maxima can be detected on the upper level wind reports at the individual stations. Time cross sections of the local winds at Spokane for the months of July and August 1955 are shown in figures 18 and 19; similar time cross sections for the local winds at Great Falls for July and August are shown in figures 20 and 21. The periods of storm activity (indicated by the + symbol at the top of the diagram) are associated with the zones of high winds and wind shear. On some days no major jet stream axis was indicated on the 300-millibar chart, but the local wind diagram indicated zones of high winds and wind shear.

There are some instances of strong local winds and wind shear zones with no storm activity. Vertical motions induced around these local high winds and shear zones cannot produce storm activity if insufficient moisture is present or if the atmosphere is too stable. More research is needed to obtain data about the fine structure of the wind speed around these zones of high wind and possible induced vertical motions near these zones.

COLD LOW ALOFT

One of the most important factors in thunderstorm occurrence in this area is the influence of the cold low aloft off the Northwest coast. The advection of cold air at high elevations often produces the instability necessary for the formation of thunderstorms to the east of this cold low. Displacement of this cold low to the south and east or the eastward movements of minor waves or troughs must be watched very carefully for the development of thunderstorms. When there is a major displacement of this cold low eastward across the area with a sufficient moisture supply in the middle and upper layers, the thunderstorms usually move rapidly with high level bases, and little or no precipitation reaches the ground.

SUMMARY

This paper reports and discusses in detail the occurrence and movement of thunderstorms during the 1955 fire season in the northern Rocky Mountain area and the meteorological conditions associated with these storms. The important meteorological factors are the moisture patterns in both the lower and upper levels, the temperature and wind profiles, the instability of the airmass, and the lifting mechanisms.

Thunderstorms during this season are discussed with reference to geographical distribution, time of occurrence, number of lightning strikes, amount of associated precipitation, and storm movement.

Various types of thunderstorms and the associated meteorological conditions are pointed out in this paper. Some storms are of a local airmass type in which surface heating and orographic lift are the important factors. This type of storm prevailed in the eastern portions of the region. Other storms were associated with the passage of surface or higher level cold fronts.

The main association of the jet stream with thunderstorm activity is somewhat indirect. The strong vertical wind shear associated with the major jet axis and its displacement is definitely connected with vertical motions in the atmosphere. The best condition for storm development probably is found with the superposition of divergence aloft over a low level convergence pattern.

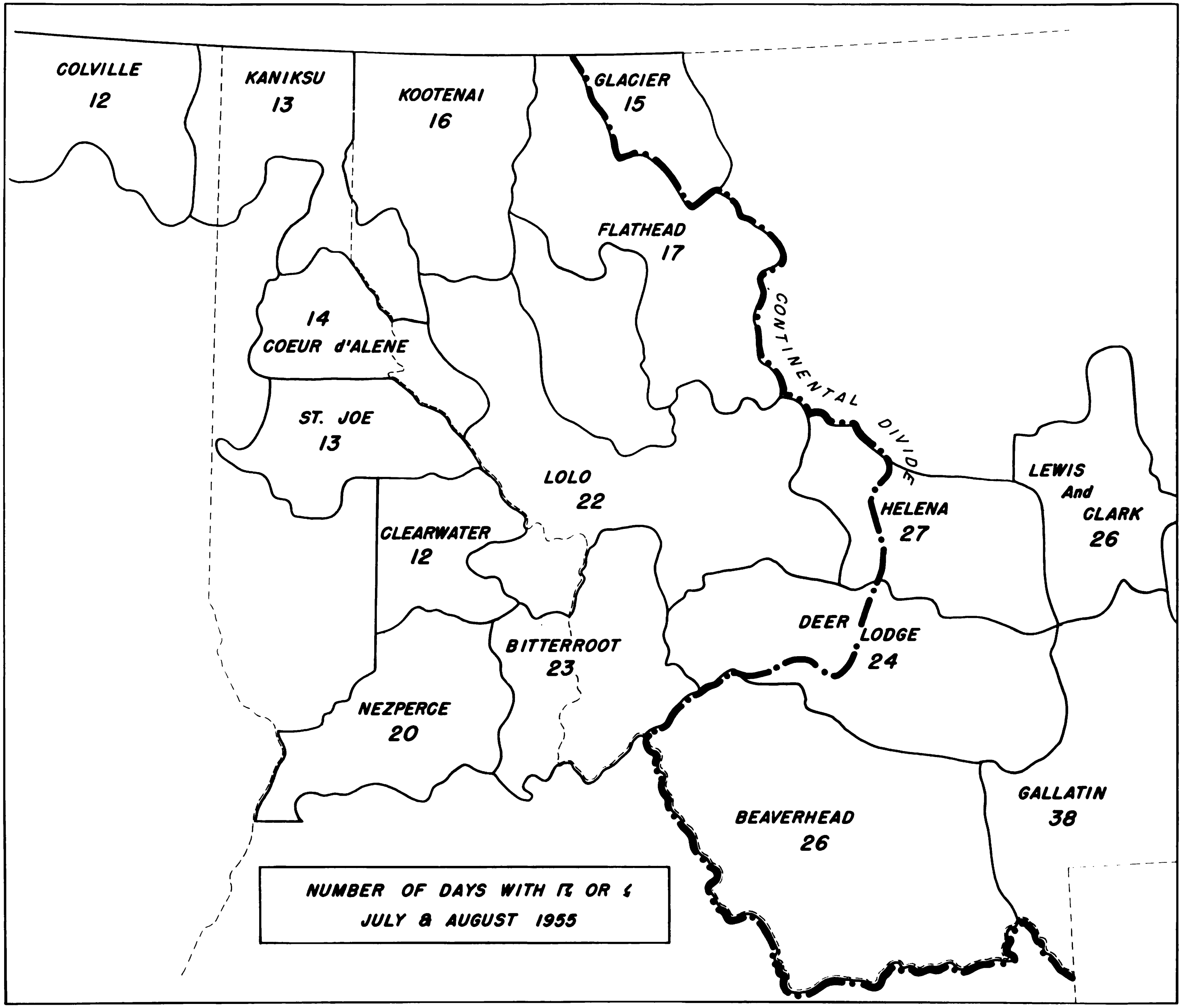


Figure 2.--Distribution of lightning storms over observation area.

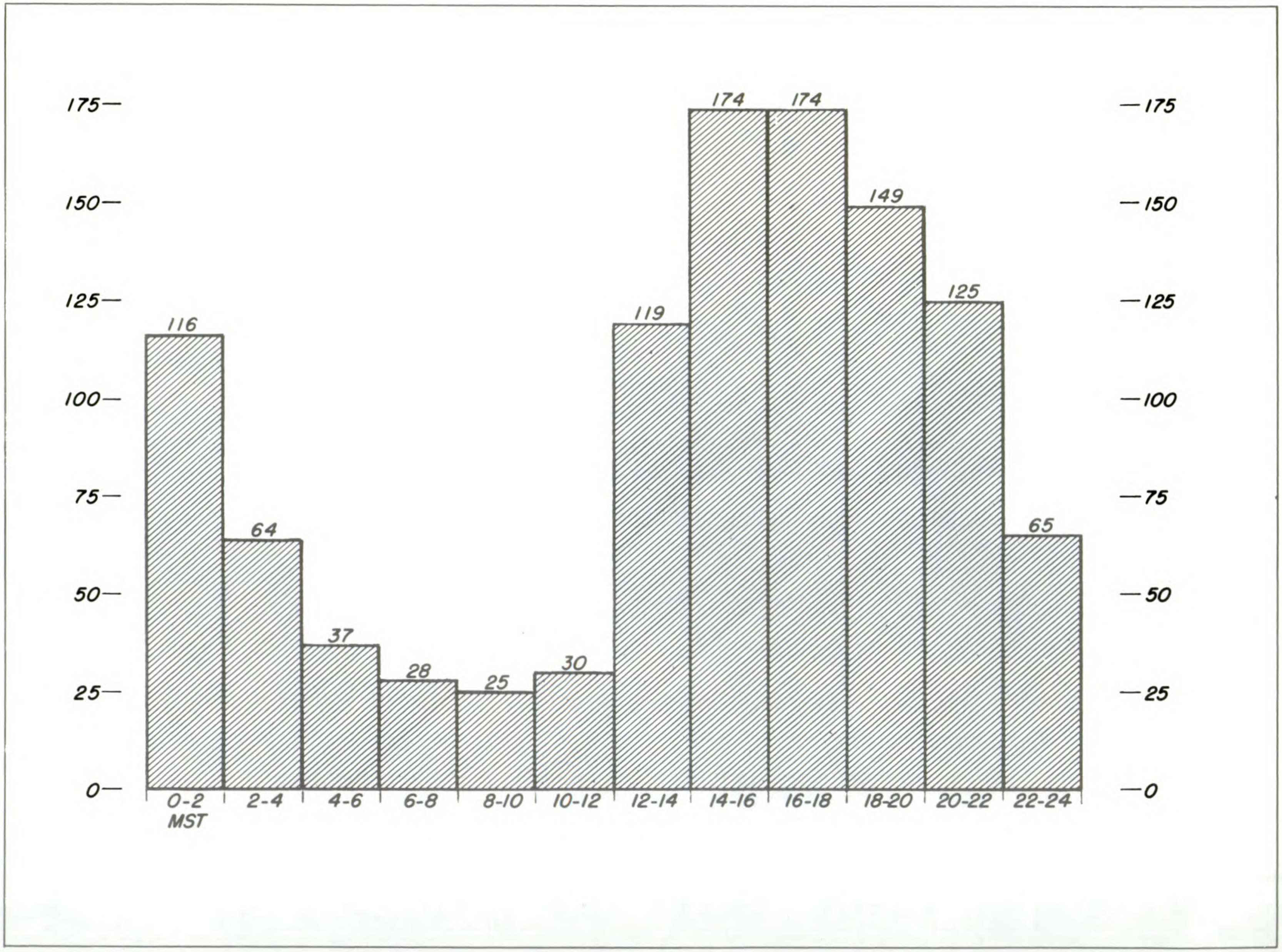


Figure 3.--Time-frequency of initial lightning over Project Skyfire area, July and August 1955.

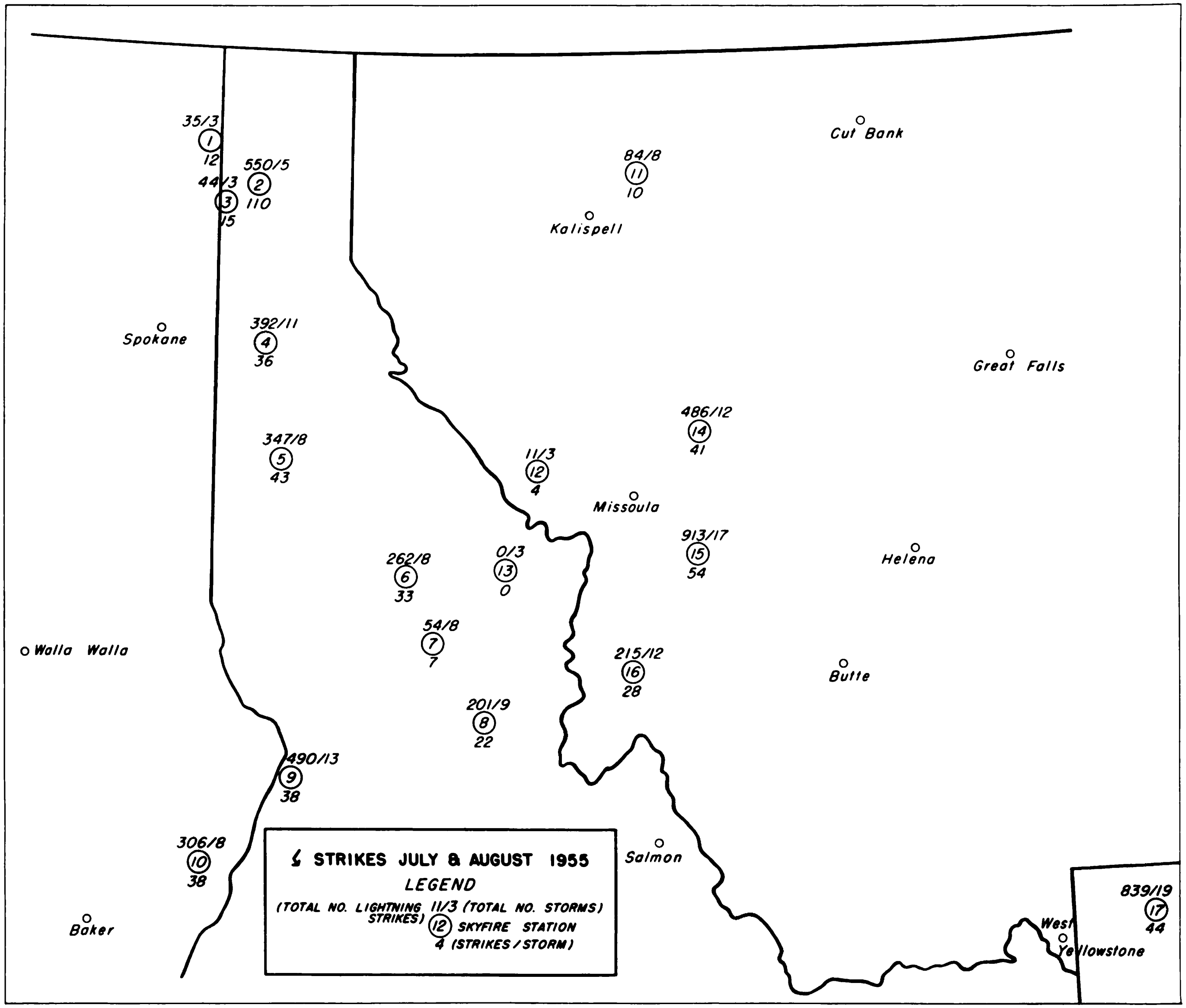


Figure 4.--Distribution of lightning strikes, July and August 1955.

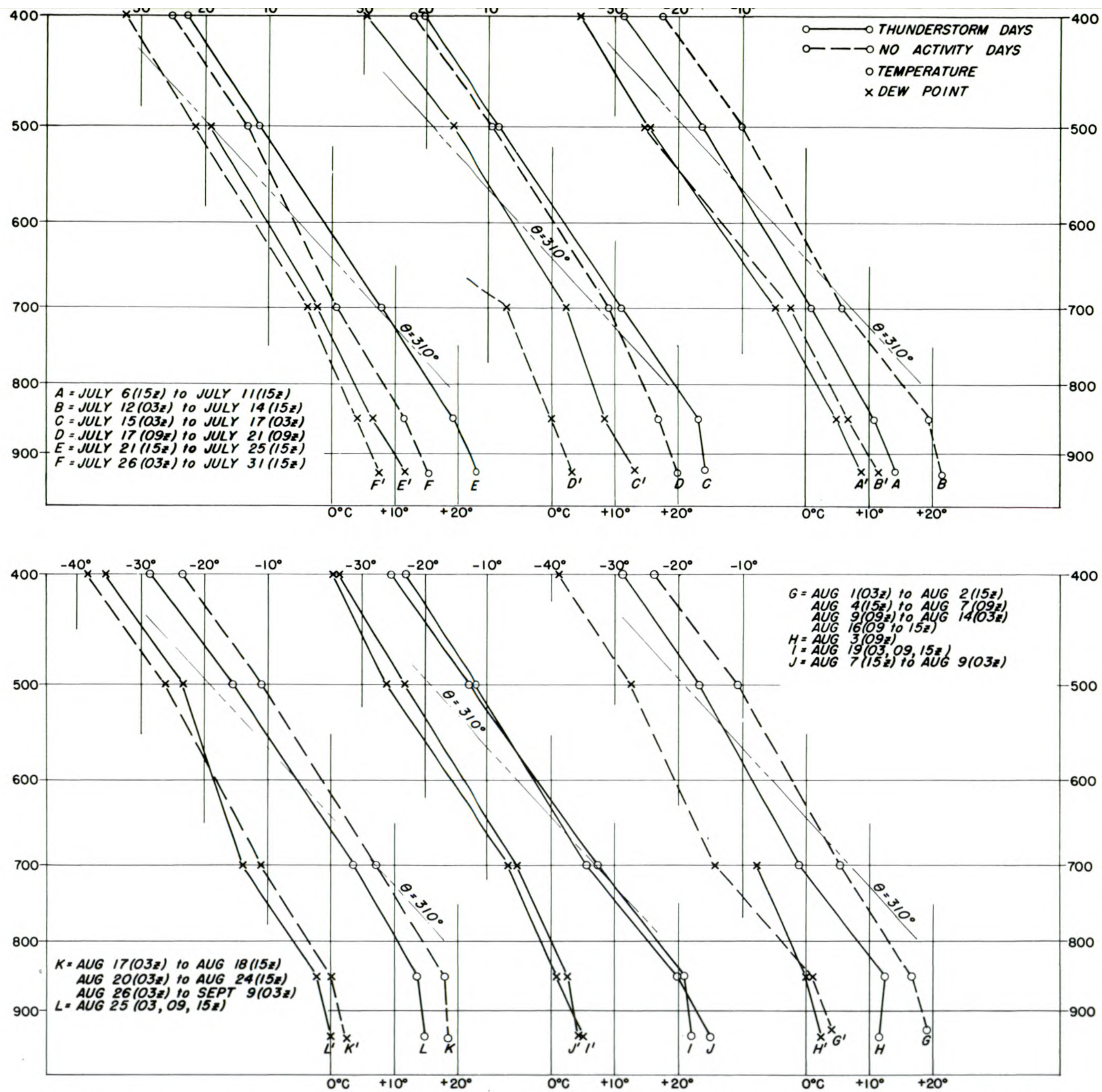


Figure 5.--Characteristic soundings at Spokane for periods of thunderstorm activity and periods of no activity.

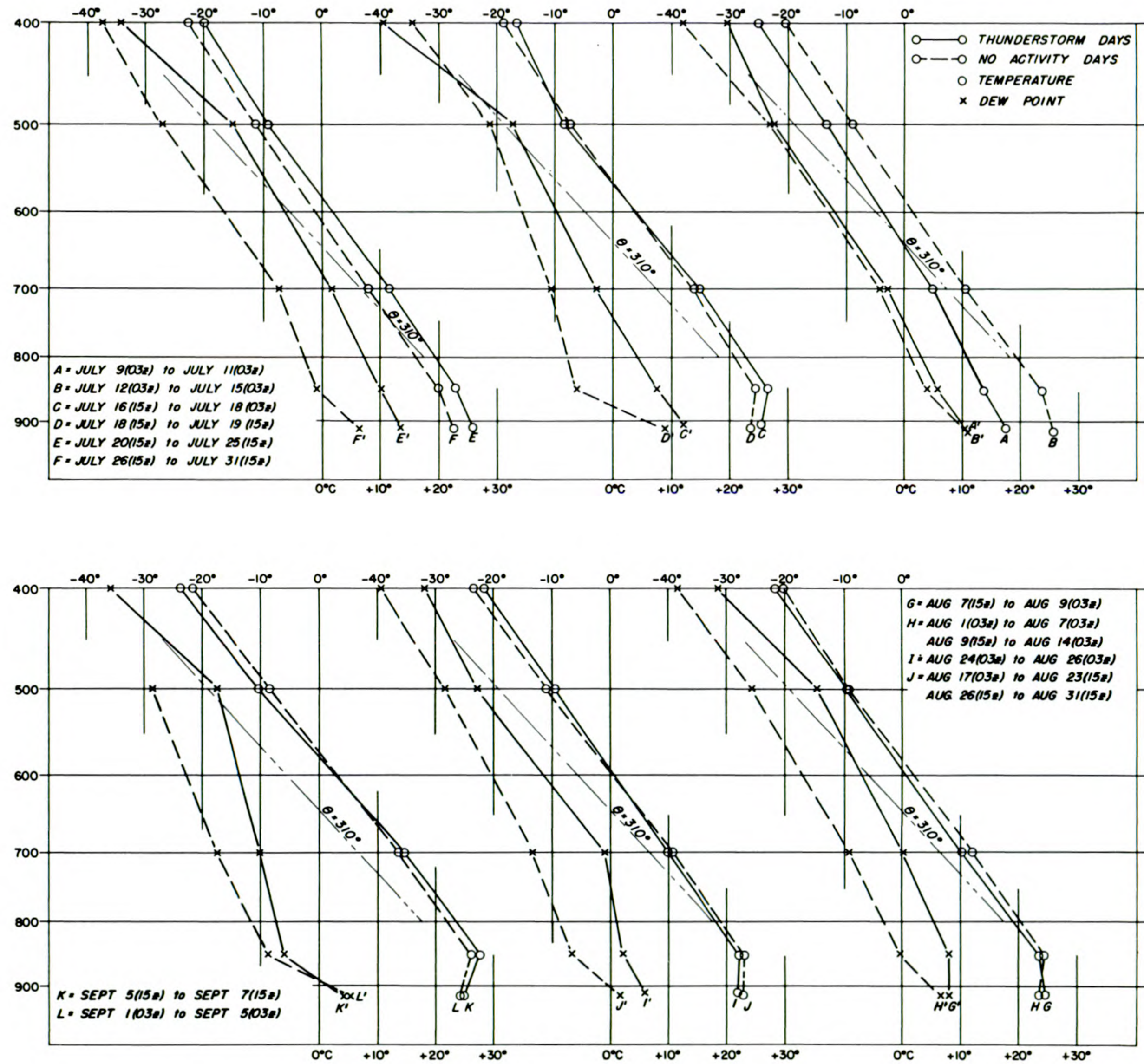


Figure 6.--Characteristic soundings at Boise for periods of thunderstorm activity and periods of no activity.

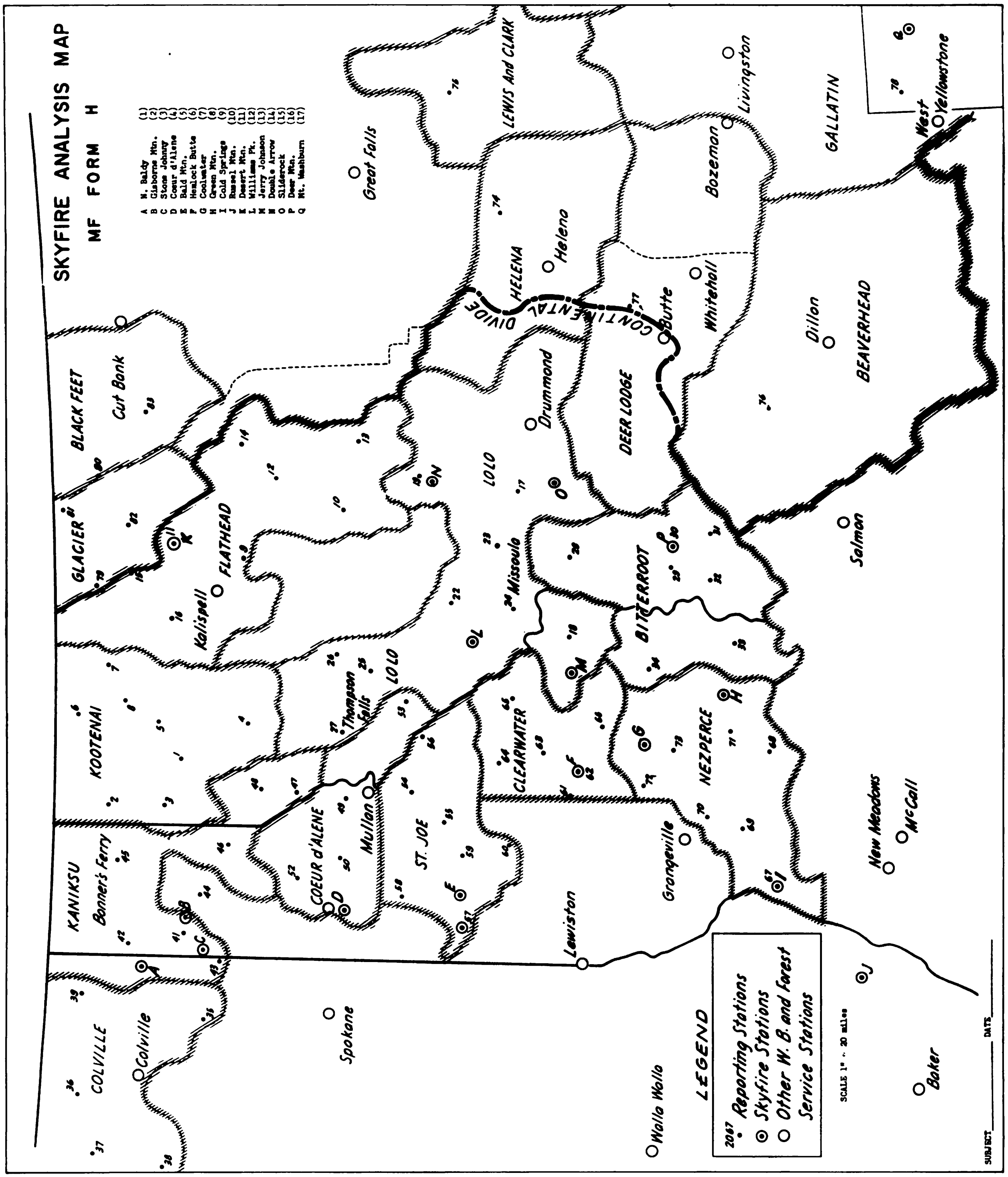


Figure 1.--Weather Stations in Project Skyfire area.

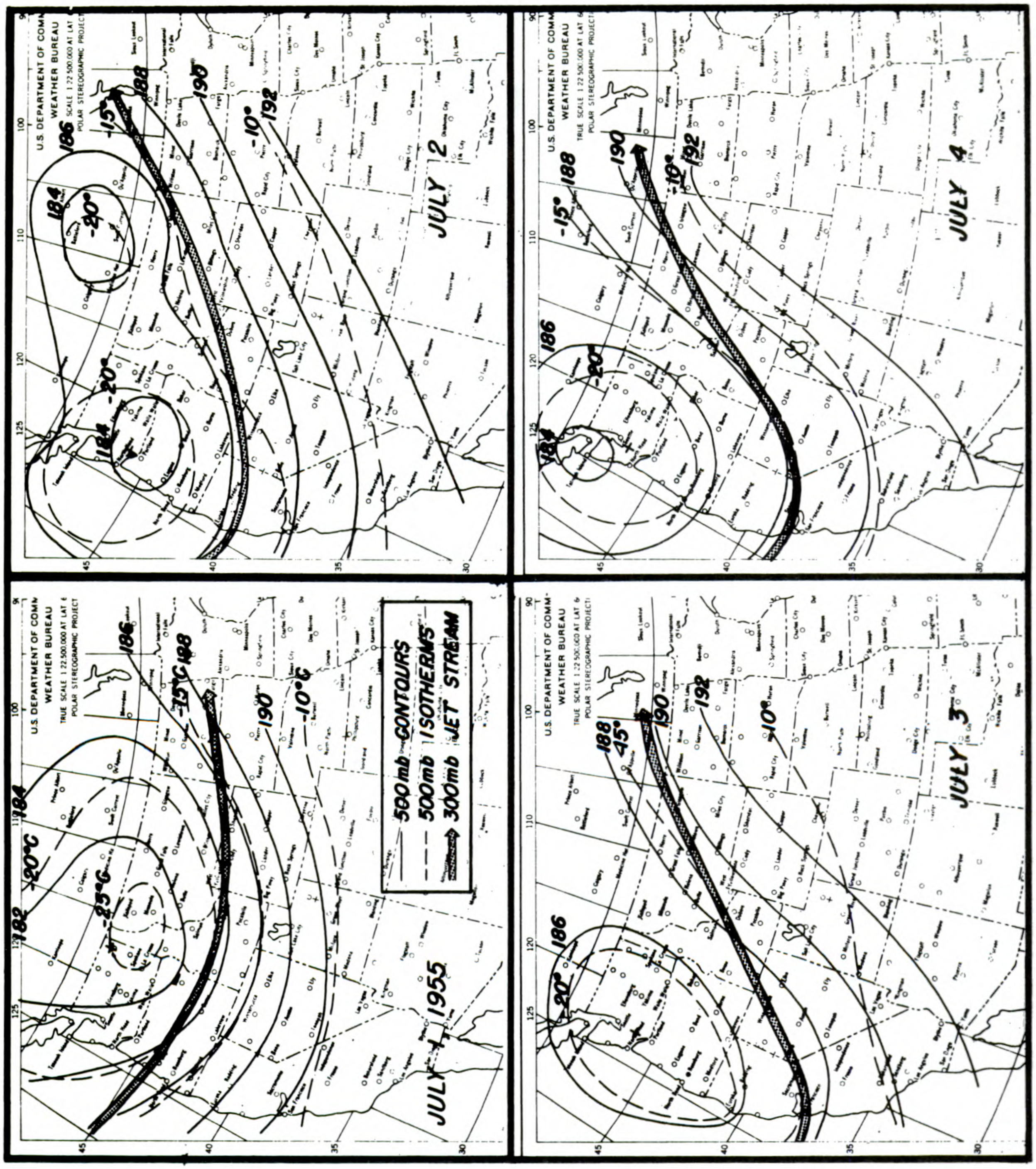


Figure 7.--500-MB charts for July 1-4, 1955.

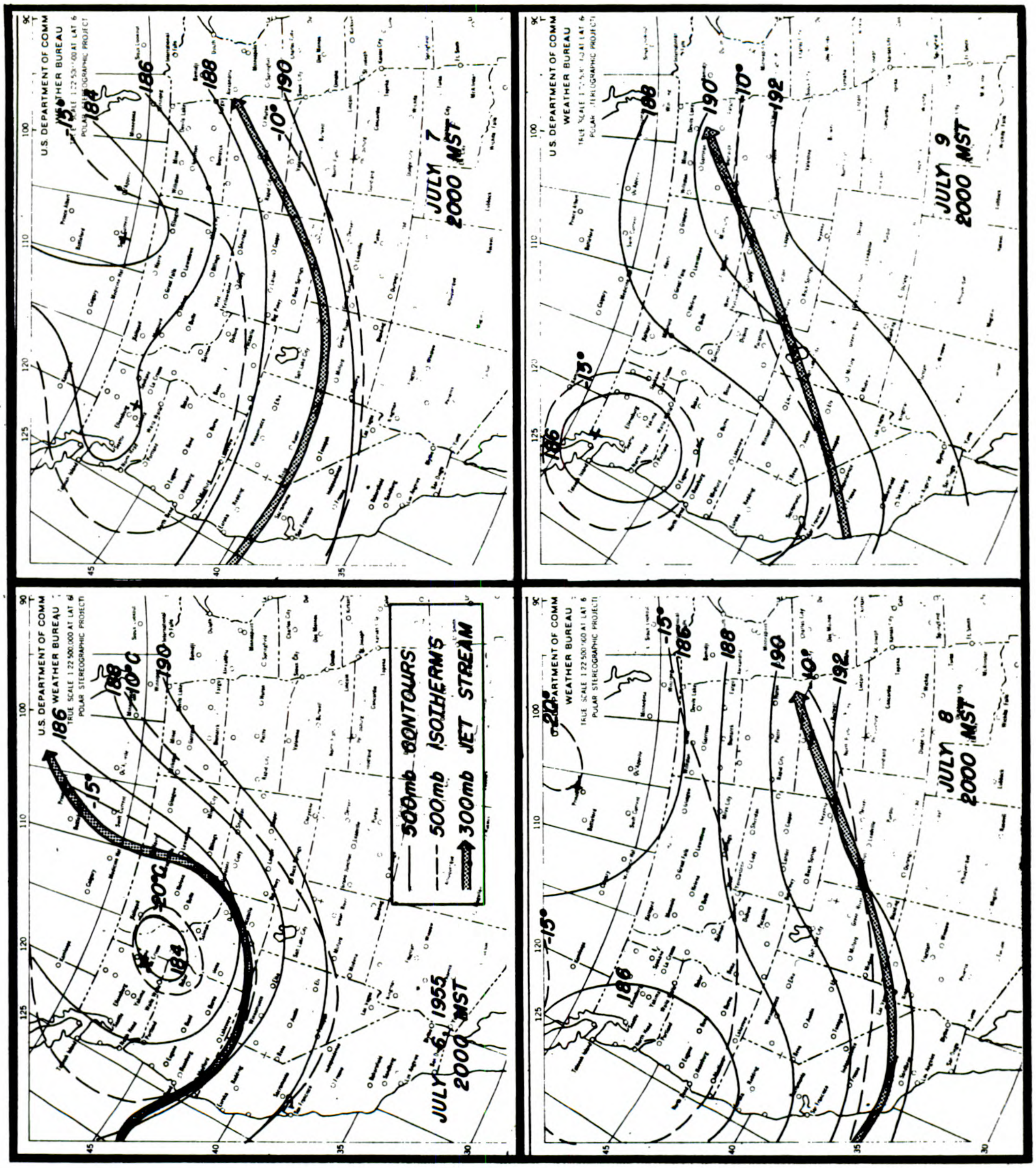


Figure 8.--500-MB charts for July 6-9, 1955.

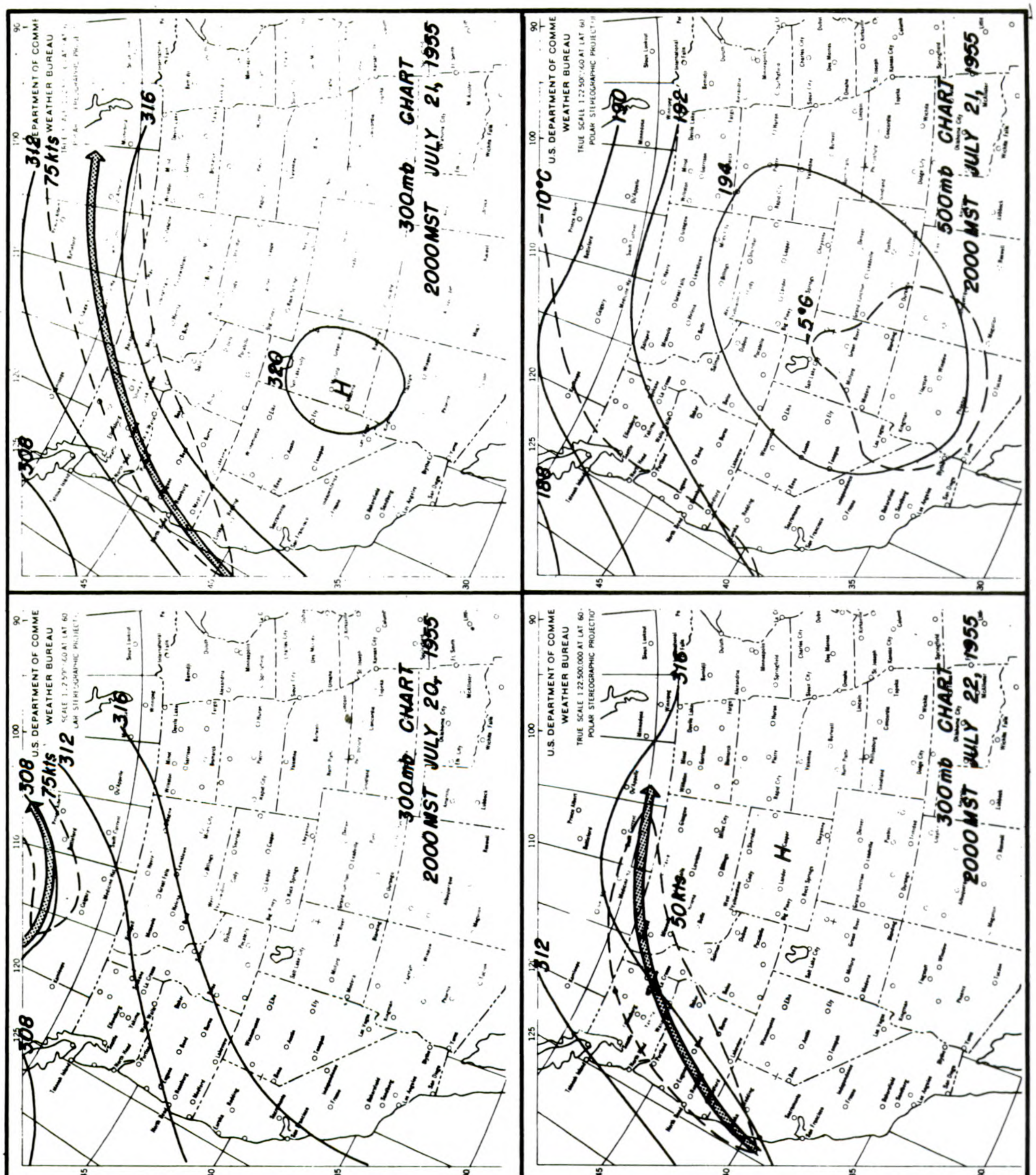


Figure 9.--500- and 300-MB charts for July 20-22, 1955.

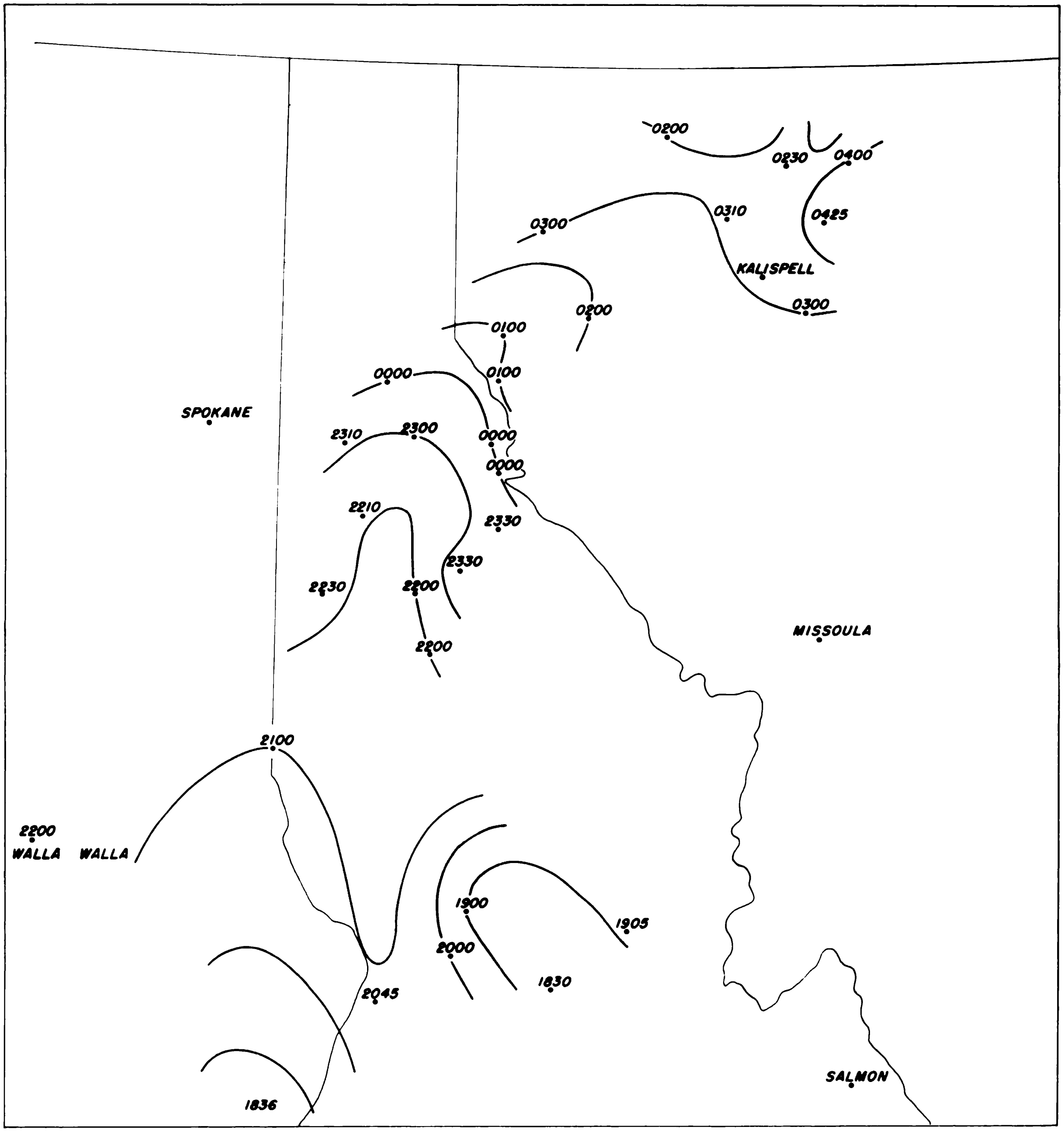


Figure 10.--Isochrones of initial lightning July 21-22, 1955.

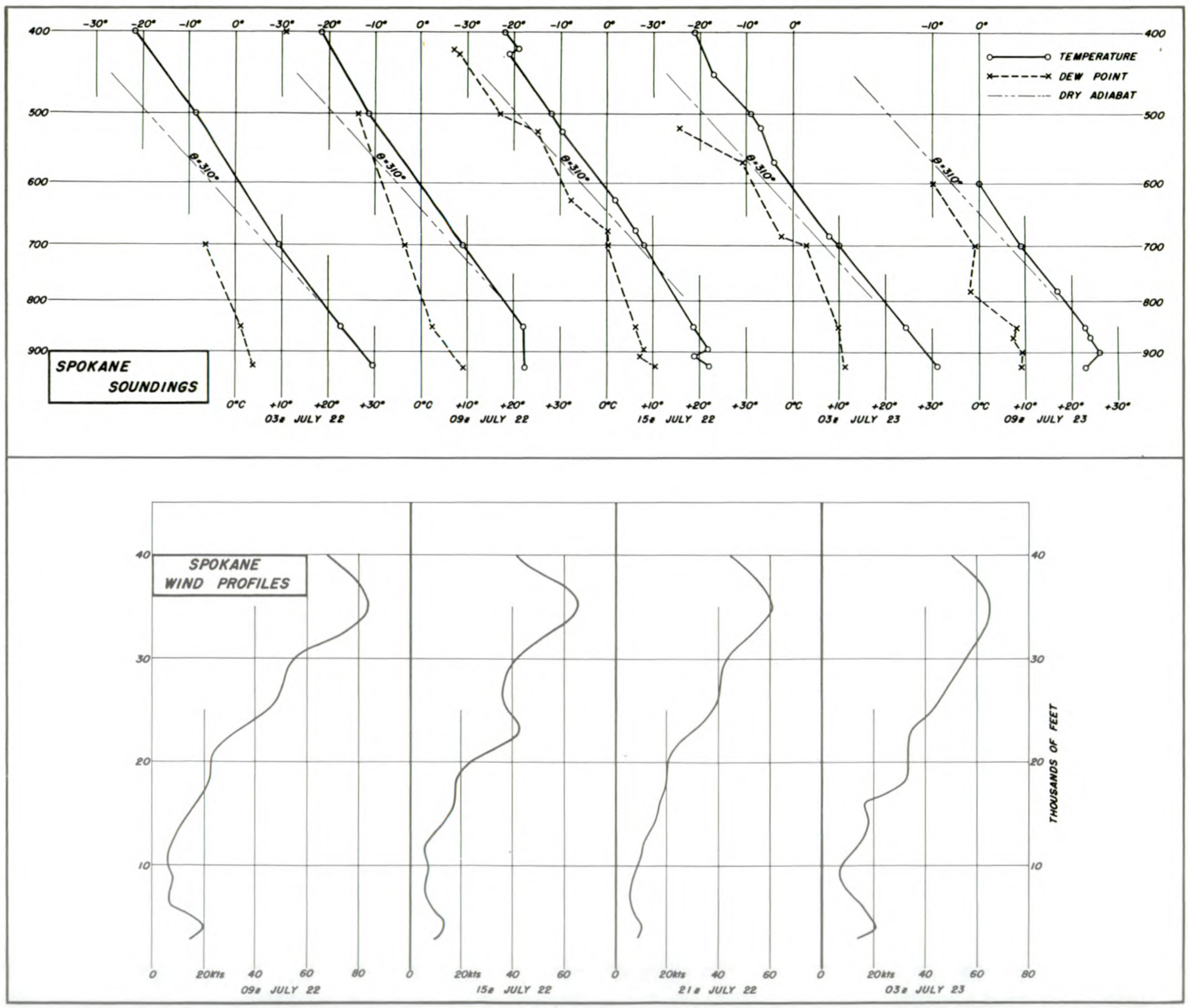


Figure 11.--Temperature, dew point, and wind profiles at Spokane, July 22-23, 1955.

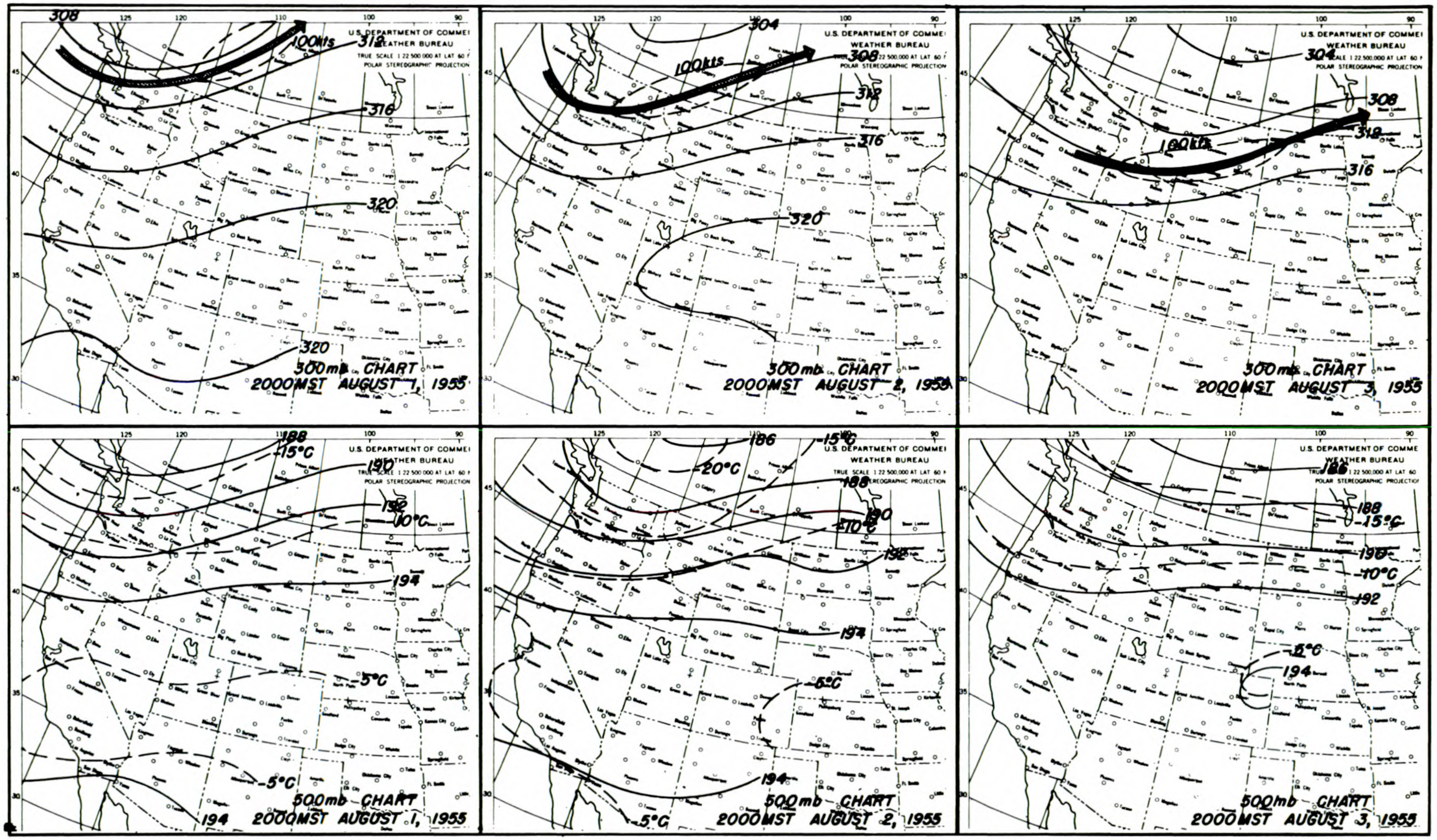


Figure 12.--500- and 300-MB charts for August 1-3, 1955.

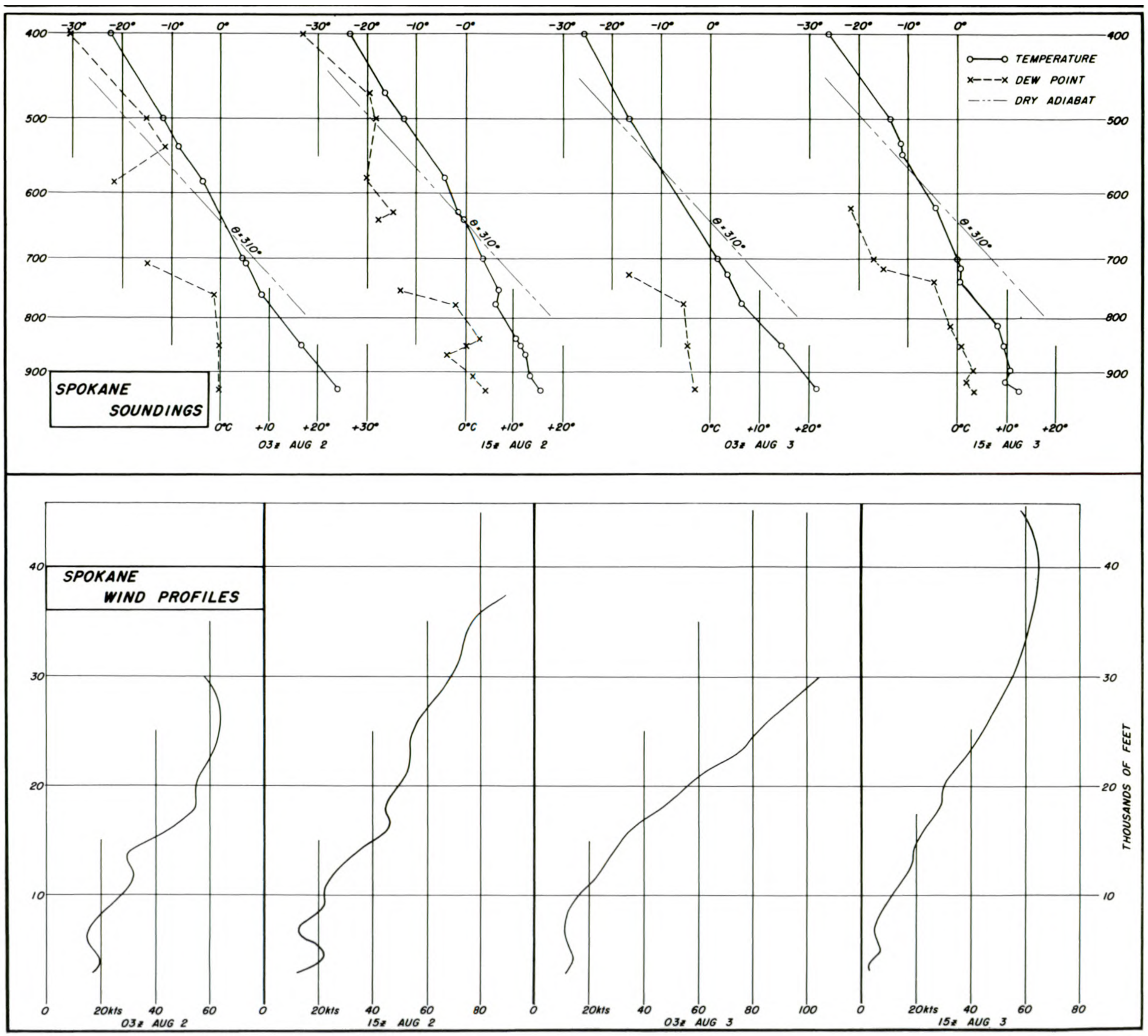


Figure 13.--Temperature, dew point, and wind profiles at Spokane for August 2-3, 1955.

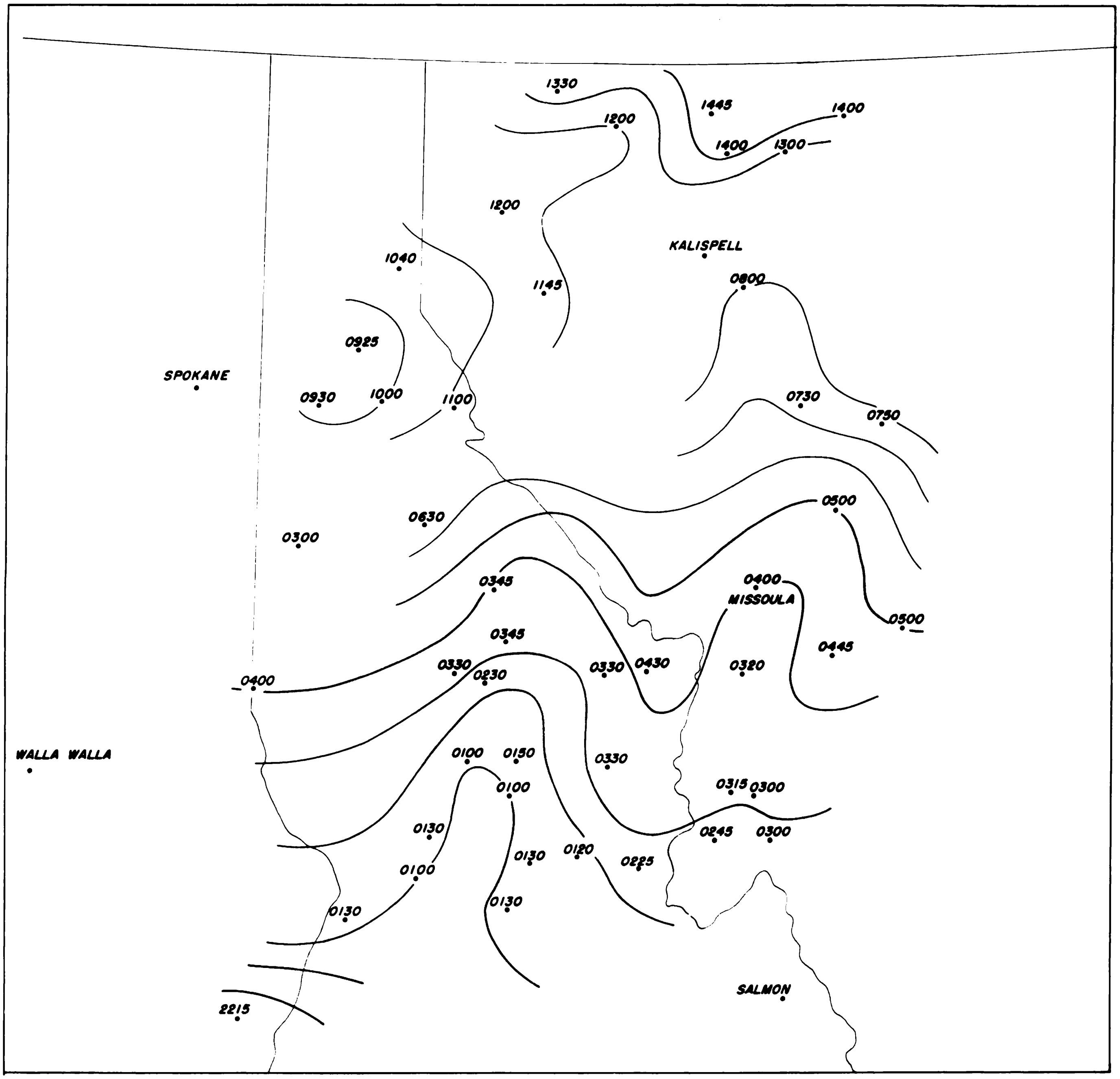


Figure 14.--Isochrones of initial lightning August 24-25, 1955.

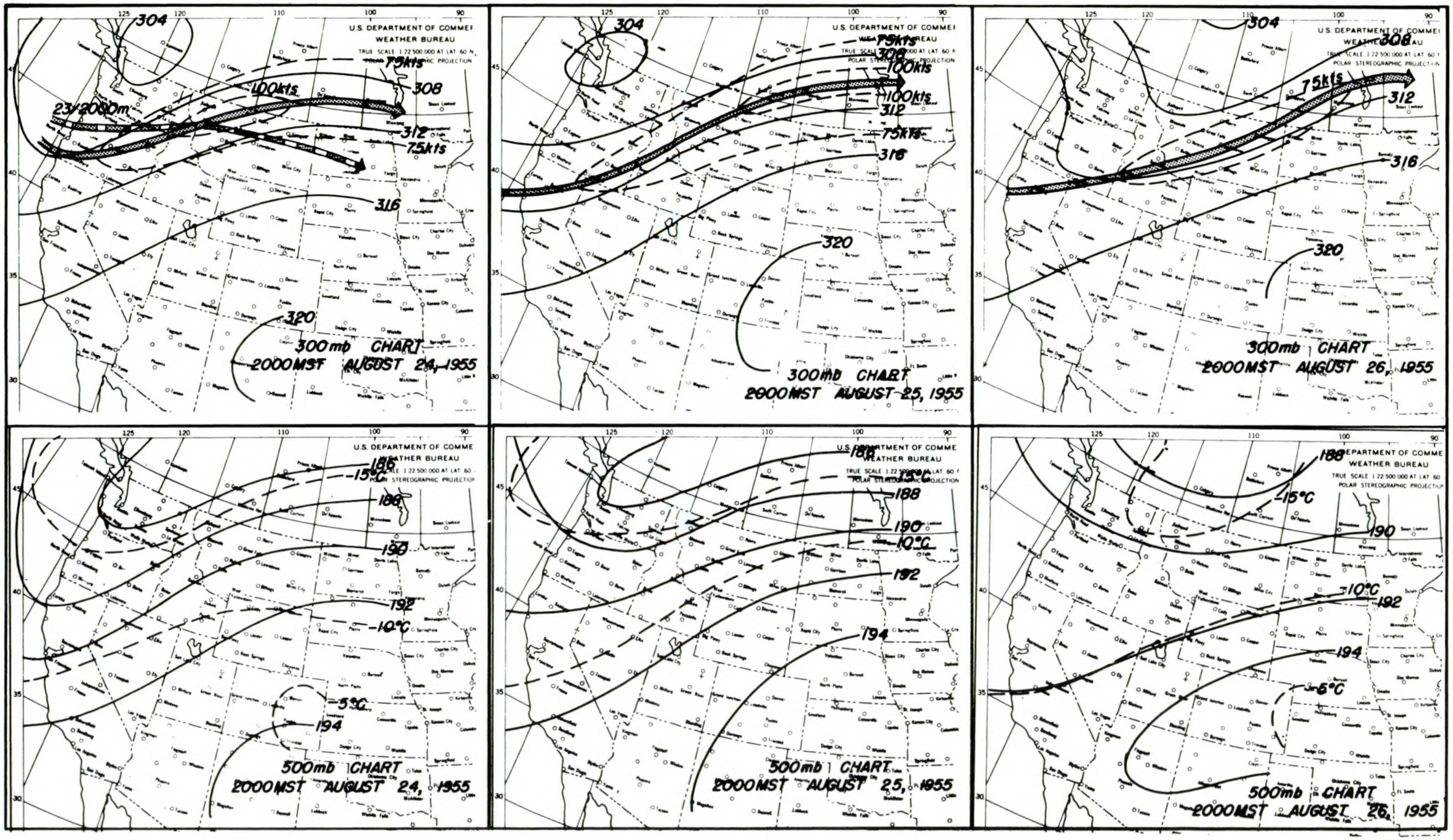


Figure 15.--500- and 300-MB charts for August 24-26, 1955.

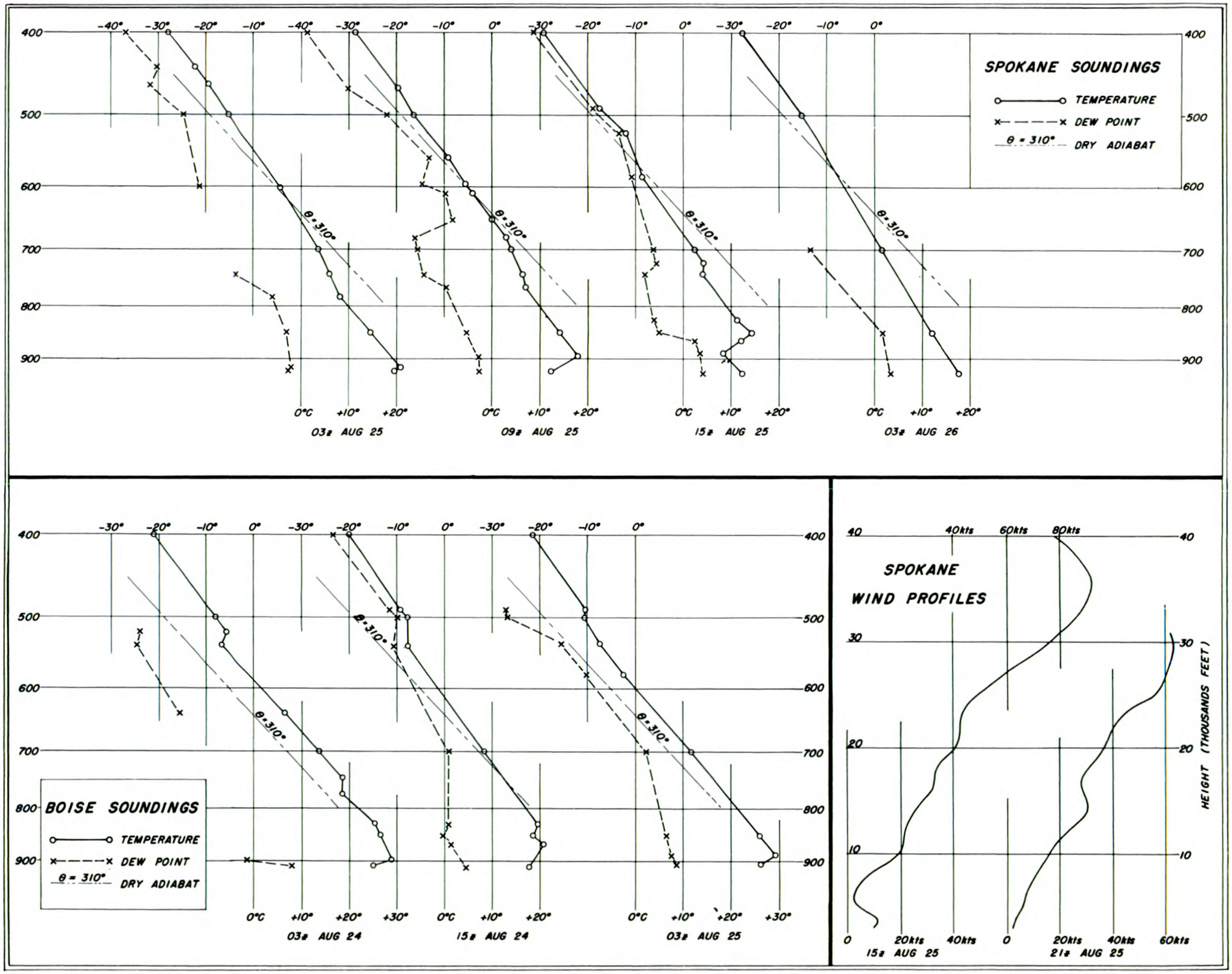
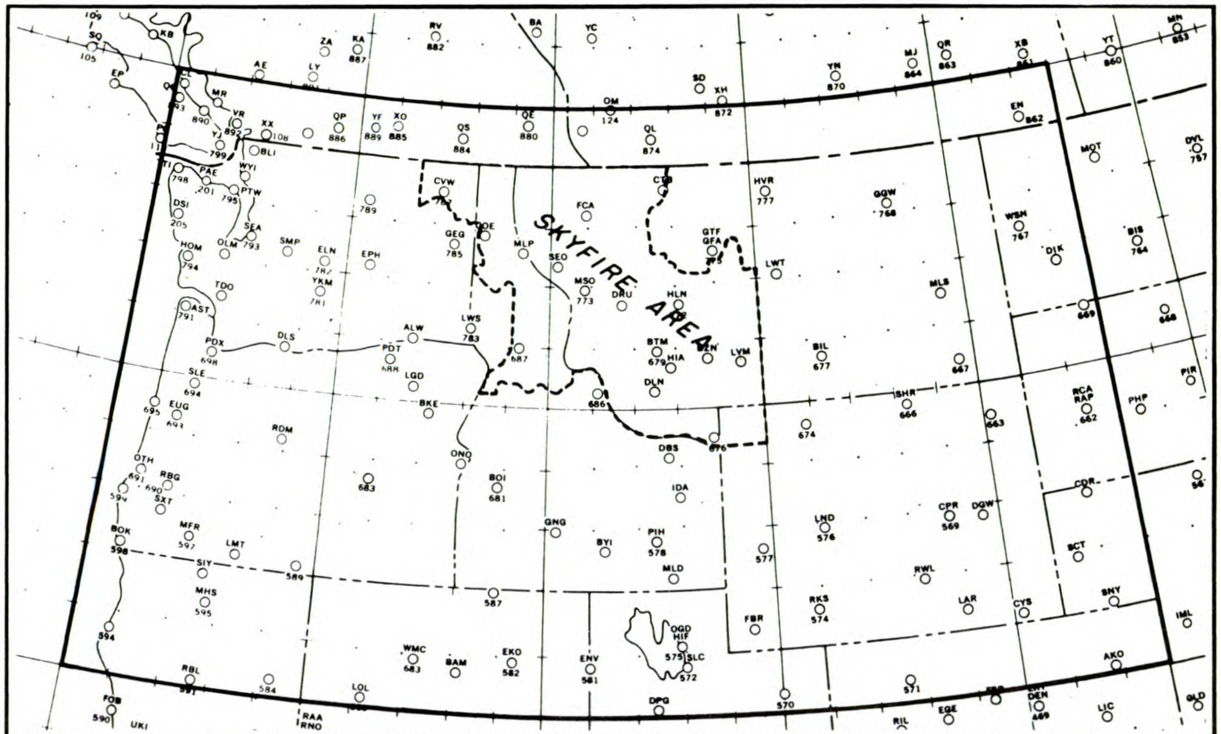


Figure 16.--Temperature, dew point, and wind profiles at Spokane and Boise for August 24-26, 1955.



	☈	NO ☈
NO JET IN AREA	8	19
JET IN AREA	30	11
JET TO N & W	12	7
JET TO S & E	11	0
JET OVERHEAD	7	4

Figure 17.--Jet stream-thunderstorm summary, July 4-September 9, 1955.

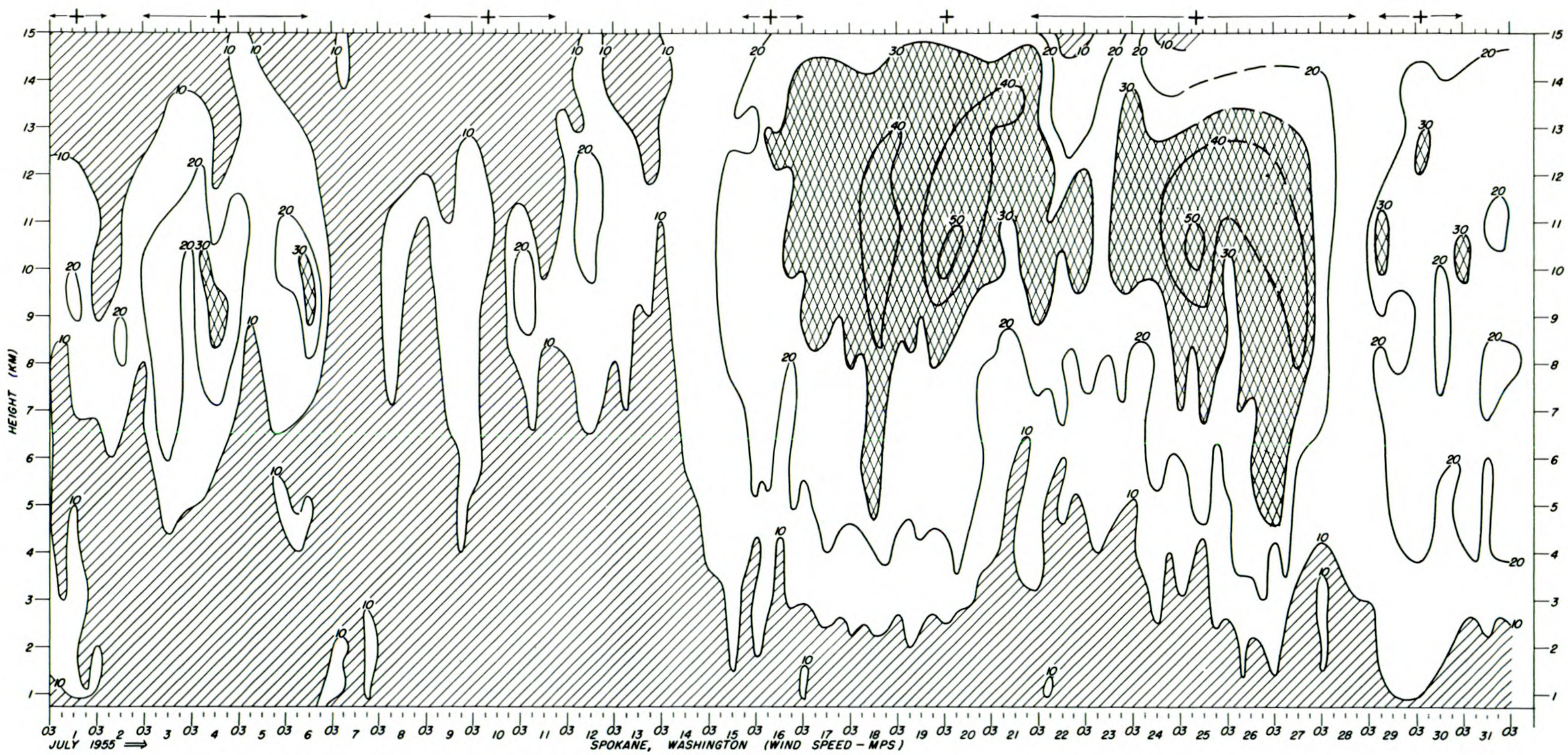


Figure 18.--Time cross section of upper-level winds at Spokane for July 1955. "+" at top indicates thunderstorm period.

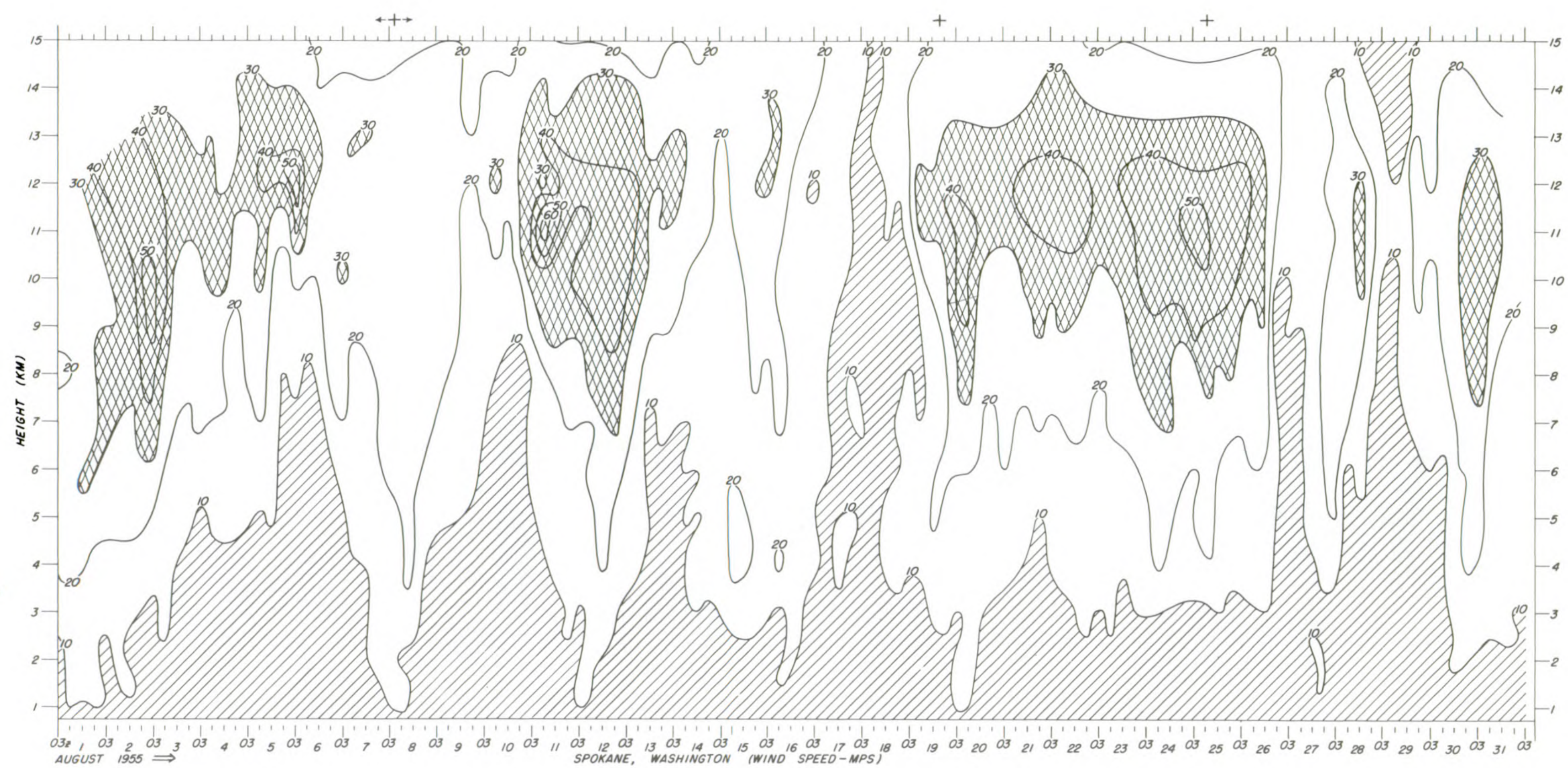


Figure 19.--Time cross section of upper-level winds at Spokane for August 1955. "+" at top indicates thunderstorm period.

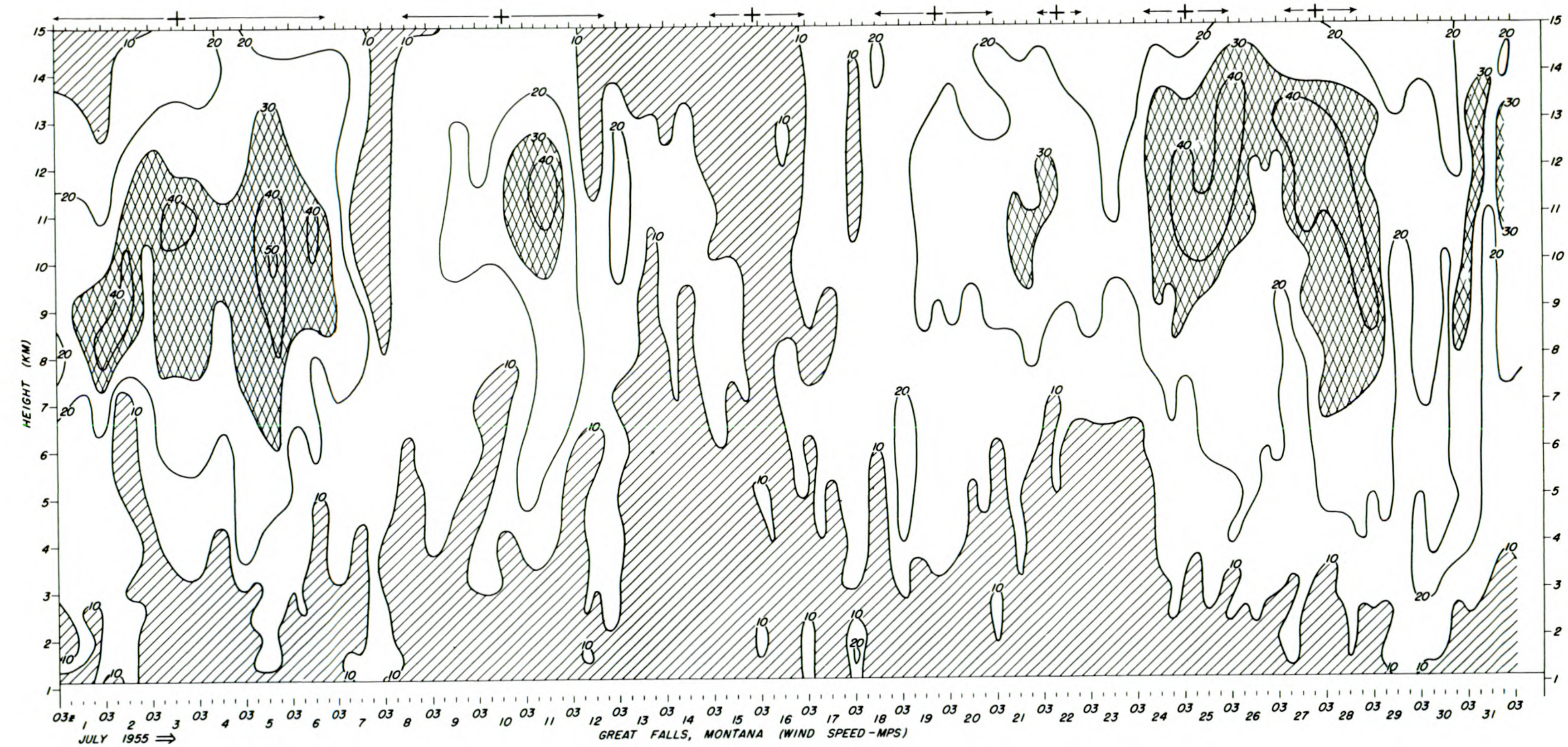


Figure 20.--Time cross section of upper-level winds at Great Falls for July 1955. "+" at top indicates thunderstorm period.

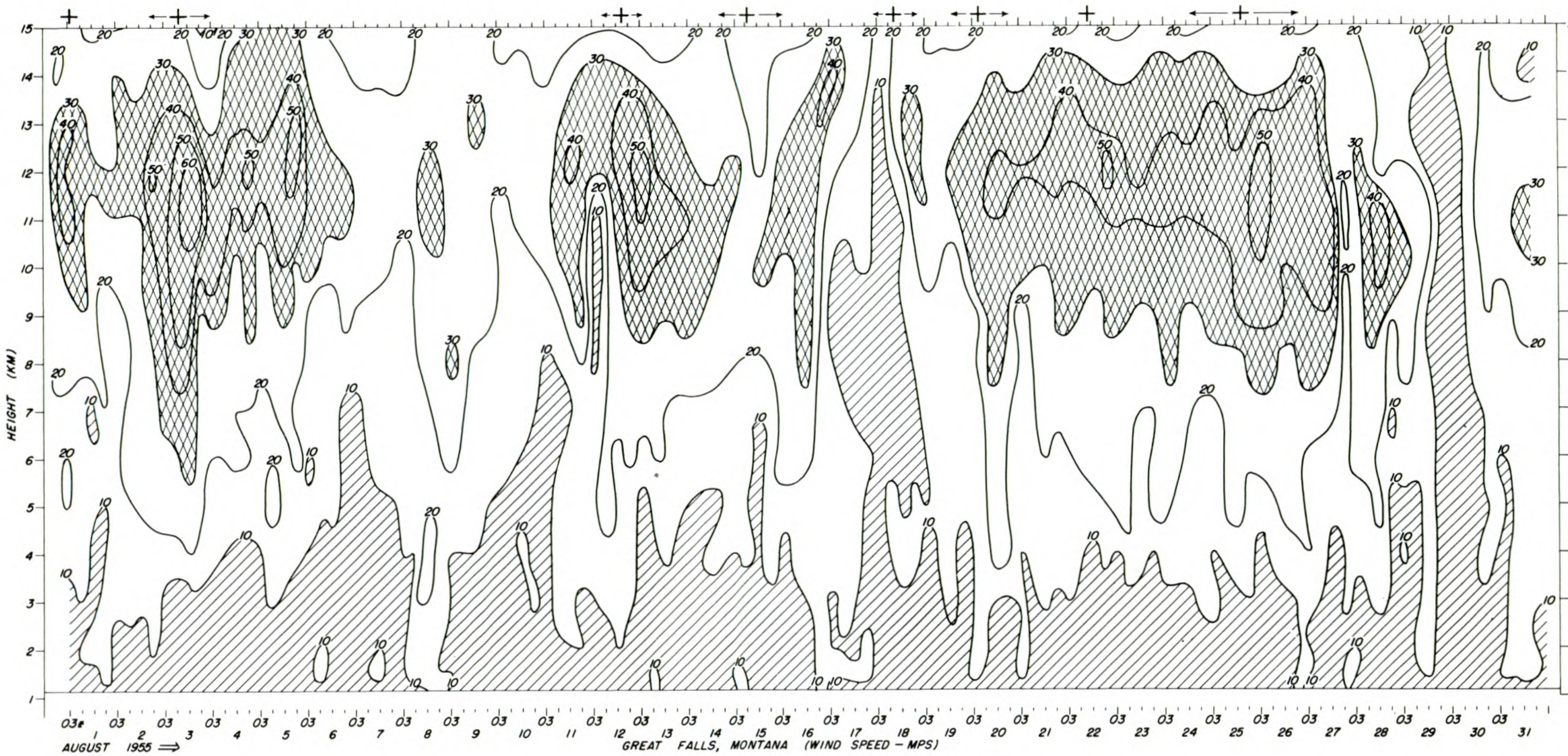


Figure 21.--Time cross section of upper-level winds at Great Falls for August 1955.
"+" at top indicates thunderstorm period.