NOAA Technical Memorandum NWS WR-208

METEOROLOGICAL FACTORS CONTRIBUTING TO THE CANYON CREEK FIRE BLOWUP SEPTEMBER 6 AND 7, 1988

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

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I. INTRODUCTION

The Canyon Creek Fire was ignited by lightning on June 25, 1988, within the Scapegoat Wilderness Area of Montana's Lolo National Forest. The fire was initially allowed to burn unconstrained in accordance with guidelines set forth in the Scapegoat-Danaher Fire Management Plan (1982). The National Weather Service's Fire Weather Office in Missoula, Montana, provided weather information for the initial decision process, allowing the fire to play its natural role in the wilderness, and throughout the summer and fall for management decisions concerning this fire.

During the life of the Canyon Creek Fire, four major wind events resulted in rapid fire growth (See Fig. 1). The fire increased in size to 10,000 acres on July 22. Strong winds on August 9 drove the fire to 33,000 acres. On August 29, the fire increased to 51,200 acres as it was again fanned by gusty winds. The most significant run began on the evening of September 6. By daybreak on September 7, the fire had quadrupled in size and encompassed more than 240,000 acres. The firestorm had moved through 180,000 acres of private, state, and federal lands in one 16-hour period, mostly at night.

The drought of 1988 conditioned the wildlands of the northern Rockies, providing an environment conducive to large fire growth. Meteorological events that produce periodic strong winds occur fairly frequently during the summer in Montana. The weather systems that pushed the Canyon Creek Fire's first three major runs were not atypical. The last and most dramatic run occurred under an uncommon and unusual combination of meteorological events. This paper will document those events.

II. TOPOGRAPHY

The Scapegoat Wilderness Area is mountainous and rugged with elevations ranging from around 4,500 feet to over 8,500 feet. The area is mostly timbered with various coniferous tree species. The Continental Divide cuts through the eastern third of the wilderness. The timberline is generally around 7,200 feet, with much of the Continental Divide above the timberline.

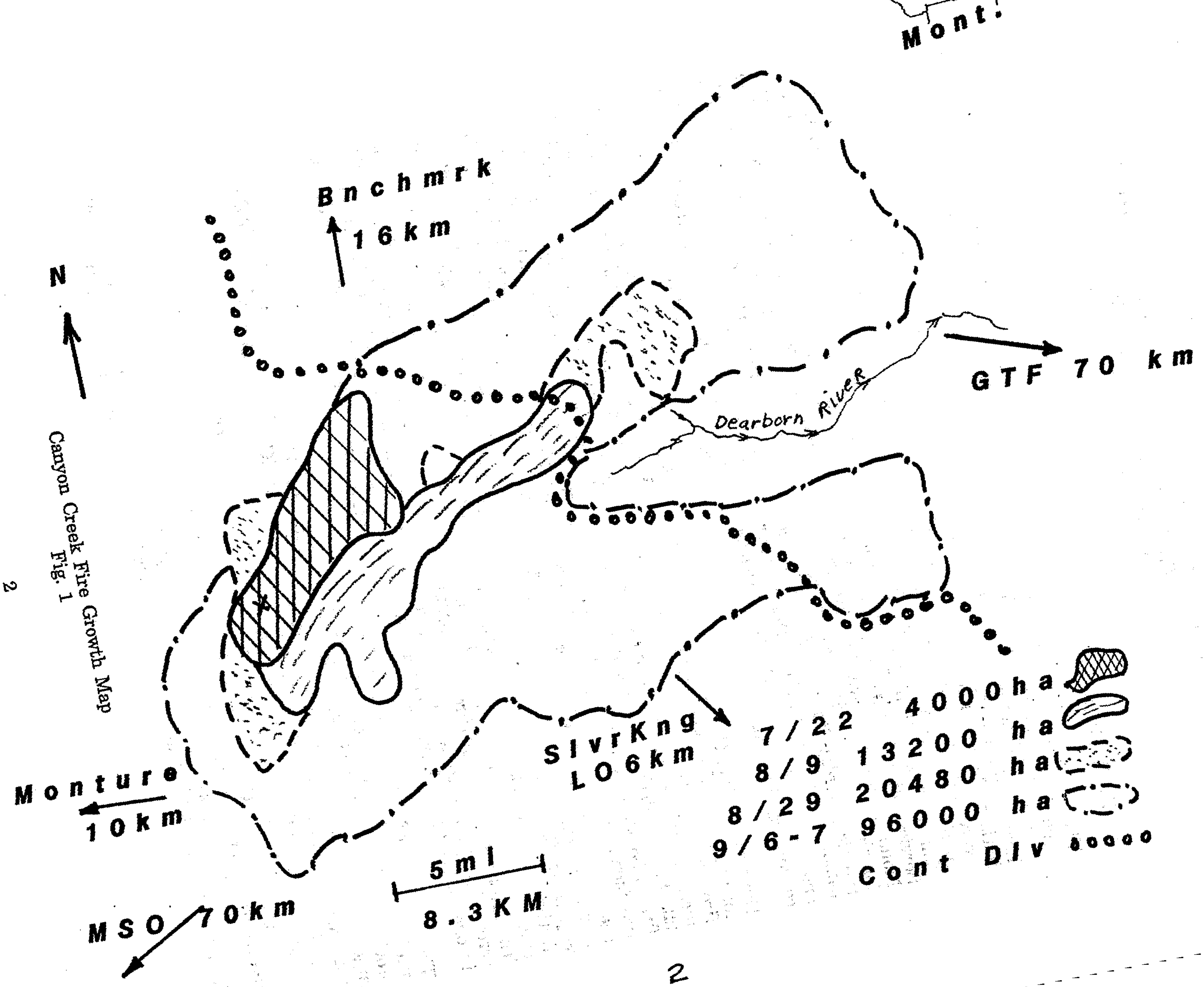
A portion of the Dearborn River drainage was unburned during the major fire run of September 6 & 7, providing a conspicuous void in the burn pattern (see Fig. 1). The Dearborn River is contained within a major drainage on the east slopes of the Continental Divide. This drainage is flanked to the south and west through much of its upper reaches by a predominant ridge line which is part of the Continental Divide. The unburned area was spared by a combination of sheltering effects, primarily by the high ridge line to the south, and the previously burned area up-wind that provided a partial fire break.

III. CLIMATOLOGY AND LONG-RANGE FORECASTS:

1. Climatology

A. Winds

Winds throughout Montana west of the Continental Divide are normally light



Canyon Creek Fire Growth Map
Fig. 1

during the summer and early fall. The average wind speed in Missoula is 6.6 mph in August, and 6.0 mph in September. Along the east slopes of the Continental Divide winds are stronger throughout the year. Average wind speed in Great Falls is 10.3 mph during August, and 11.4 mph in September.

Normally, strongest surface winds occur during the afternoon hours from spring through summer and fall in the Northern Rockies. This is a result of a number of atmospheric processes, including solar induced convective forces, and turbulent mixing in the lower atmosphere. Winds usually decrease at night, even under unusual weather situations.

Whenever the synoptic scale circulation pattern provides discontinuities in the air masses, i.e., fronts and/or low-level jet streams, then very often the synoptic scale features will overpower local processes. The duration of strong wind events associated with frontal passages is typically in the range of a few hours before to a few hours after frontal passage. When systems slow down or become stationary, it is usually because of a weakening in the pressure gradient and/or an achieved balance in other dynamic forces, and winds are neither persistently strong nor gusty.

B. Precipitation and Lightning

The climate of the Scapegoat and contiguous Wilderness areas is characterized by cold, snowy winters, cool, wet springs, and warm, dry summers. Average precipitation in the area ranges from 40 to 60 inches per year (USDA-SCS, 1977). Snowfall is heavy, especially in areas along and west of the Continental Divide. Snowfall accumulation is distributed fairly uniformly from November through March. Rainfall in May and June provides about 25 percent of the annual precipitation.

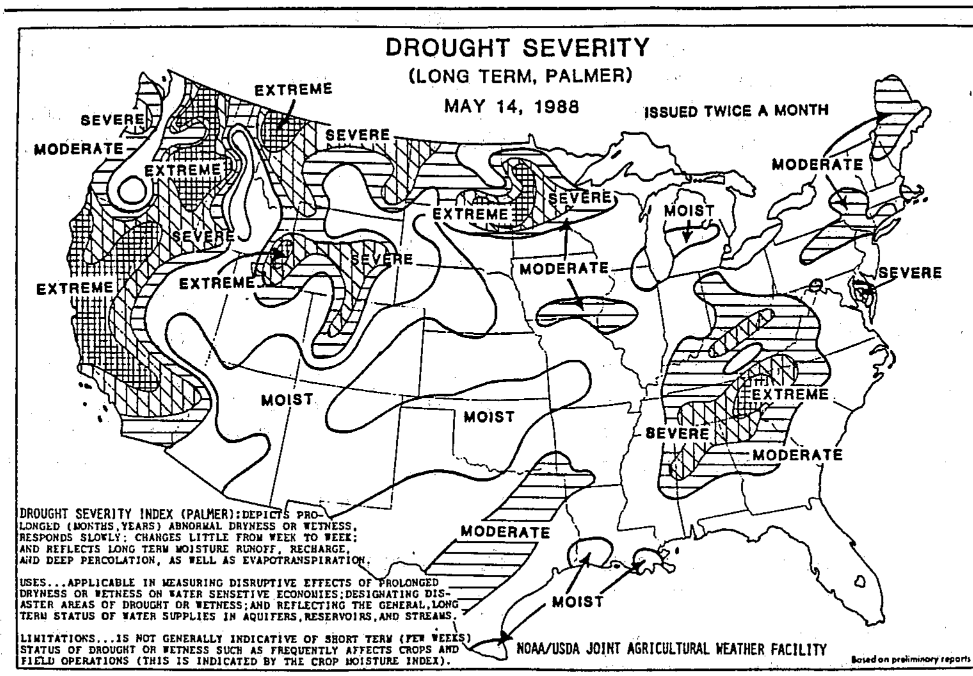
The area west of the Continental Divide receives more moisture as it is primarily affected by weather systems of Pacific origin. Areas east of the Continental Divide are drier as much of the moisture from Pacific systems is precipitated out in the upslope flow on the west side.

Thunderstorms are common during the summer months (six to ten per month), with most storms being accompanied by some precipitation. Dry lightning, though not a common event, occurs most often during July and August. Lightning is responsible for an average of only three detectable fire starts annually within the Scapegoat-Danaher Fire Management Zone (Bailey, 1989).

C. Drought

The Palmer Drought Severity Index (PDSI) was developed to identify the onset, severity, and duration of a drought expressed as a departure of weather conditions from the norm (Palmer, 1965). It was initially derived to describe moisture conditions in the Great Plains, but has subsequently been applied to all regions of the United States. It is essentially a soil moisture accounting algorithm, calibrated to relatively homogenous hydrologic areas. The PDSI seems to provide an indication of potential fire severity as it indirectly reflects fine fuel moisture and the moisture content of large dead fuels.

The northern Rocky Mountains experienced drought conditions in 1987 and 1988. Mid-May (1988) PDSI charts (Fig. 2) indicated the northern Rocky Mountains were in severe to extreme drought. Drought conditions intensified by early July, and the moisture content of wildland fuels dried to unseasonably low levels.



Palmer Drought Chart, May 14, 1988

Fig. 2

Extended drought periods have an important impact on wildfire danger, and the occurrence and severity of large fires (Davis, 1959). The most significant effect may be the critical drying of large dead forest fuels. When the large dead fuels are extremely dry, their contribution may create fire intensity sufficient to cause soil damage, contribute to crown fires, and sustain fire during occasional moist periods. The moisture content in the smaller size class of fuels (less than one inch diameter) is important to the initiation and spread of a fire. During the long days of summer, lack of precipitation allows smaller fuels to dry to critical levels, thereby providing receptive fuel beds that easily kindle and sustain ignitions.

Normally, much of the western United States experiences a break in the warm, dry summer weather during the second or third week of August. This break occurs as low-pressure systems move southeast out of the Gulf of Alaska and across the Pacific Northwest and northern Rockies, bringing wetting rains and cooler temperatures. This break has been referred to as the "August Singularity" (Christopherson, 1980) and occurs with notable frequency. Climatological records for Missoula show it has occurred 23 times in the last 30 years. This weather event normally signals the end of the summer fire season. Fuels moistened by the wetting rains are prevented from drying to dangerous levels, primarily because of the shorter days (fewer hours of sunshine) of late summer. Many of the significant fire years in the northern

Rockies (1967, 1973, 1979, 1984, and 1988) occurred when this break in the weather did not develop until the last few days in August or early September. The break in 1988 did not come until after September 7.

2. Long-Range Forecasts

On July 11, a "Fire Analysis Team" comprised of U.S. Forest Service officials met to evaluate the risks and benefits of allowing the Canyon Creek Fire to continue in prescription status. The Fire Weather Unit at the National Weather Service's Missoula office provided long-range weather forecasts for both the 30-day and 90-day outlook periods for western Montana. These forecasts were based upon guidance prepared by the Climate Analysis Center Prediction Branch and were one of many inputs that contributed to the decision to allow the fire to continue unconstrained.

The 30-day outlook for July indicated near normal precipitation and near or a little below normal temperatures. The 90-day outlook for July through September indicated below normal temperatures and near or slightly above normal precipitation. There are many factors that are considered in the formulation of the extended-range forecasts, including climatology, sea surface temperatures, etc. (Harnack, 1986). Because the long-range forecasts were indicating a trend of cooler temperatures with more moisture, which is consistent with the normal August break in the weather, Missoula Fire Weather Forecasters felt comfortable advising the "Fire Analysis Team" based on this trend.

IV. SETTING THE SCENE - METEOROLOGICALLY

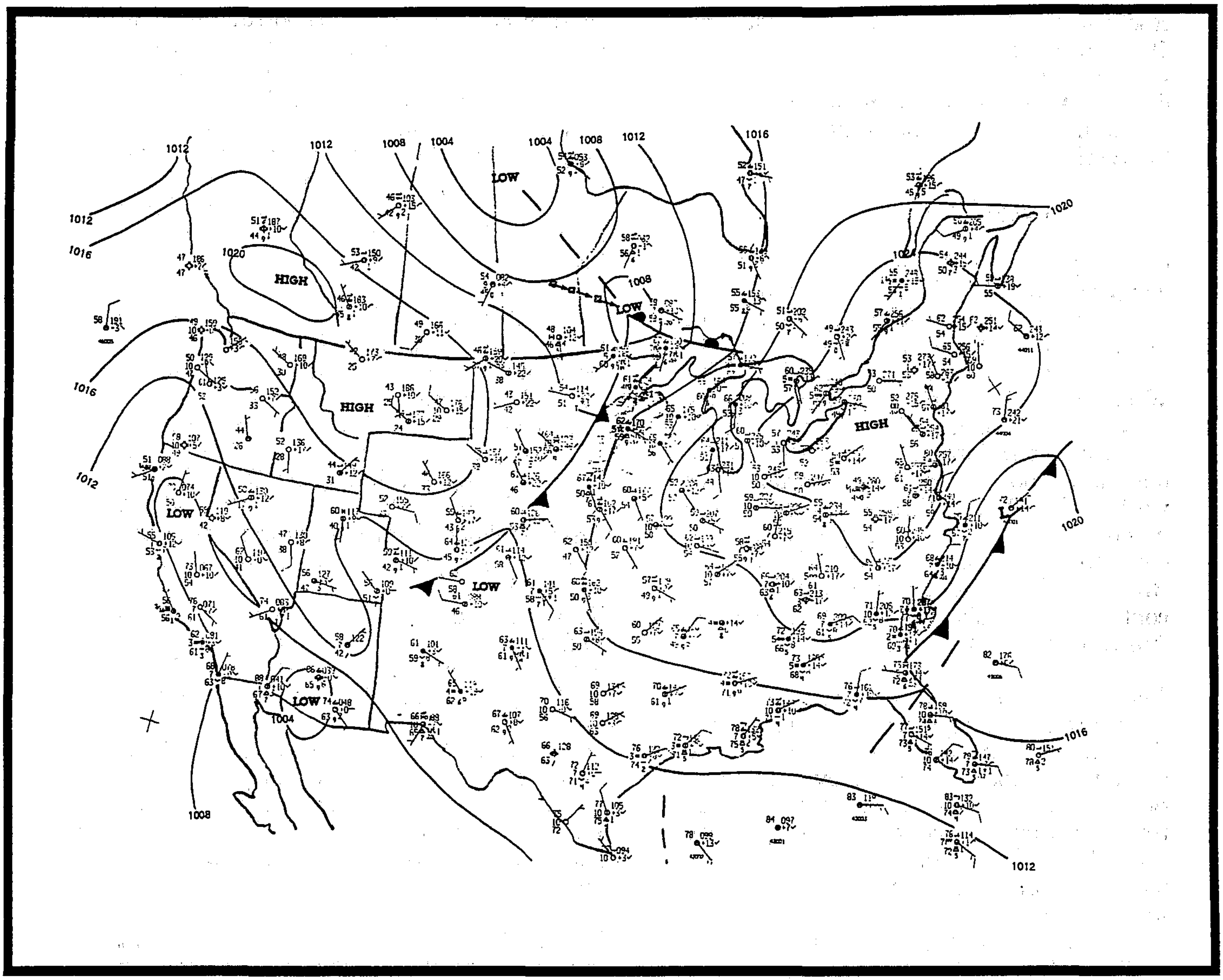
On August 29, a relatively dry Pacific front moved across Montana. West winds in excess of 30 mph (reported by field observers) pushed the fire across a constructed containment line and out of the Scapegoat Wilderness Area. Aerial and infrared mapping on the 30th of August showed the fire had grown to over 51,000 acres. The fire had exceeded prescription parameters and was declared a WILDFIRE during the early morning hours.

By September 1, high pressure in the upper troposphere had developed over northern Alberta, Canada and extended south into Nevada. On the surface, high pressure was building over eastern Montana, with a thermally induced low-pressure area developing northward from California into Oregon (Fig. 3 and 4). This established an east-to-west pressure gradient force over western Montana.

The east winds induced by this pattern had two significant effects on the fire. First, the east side of the fire was being pushed back onto itself, thereby aiding suppression efforts. On the western sections of the fire, control problems escalated. The east winds pushed the fire into unburned islands within the fire line, and also spread fire to the west and south outside of previously established control lines.

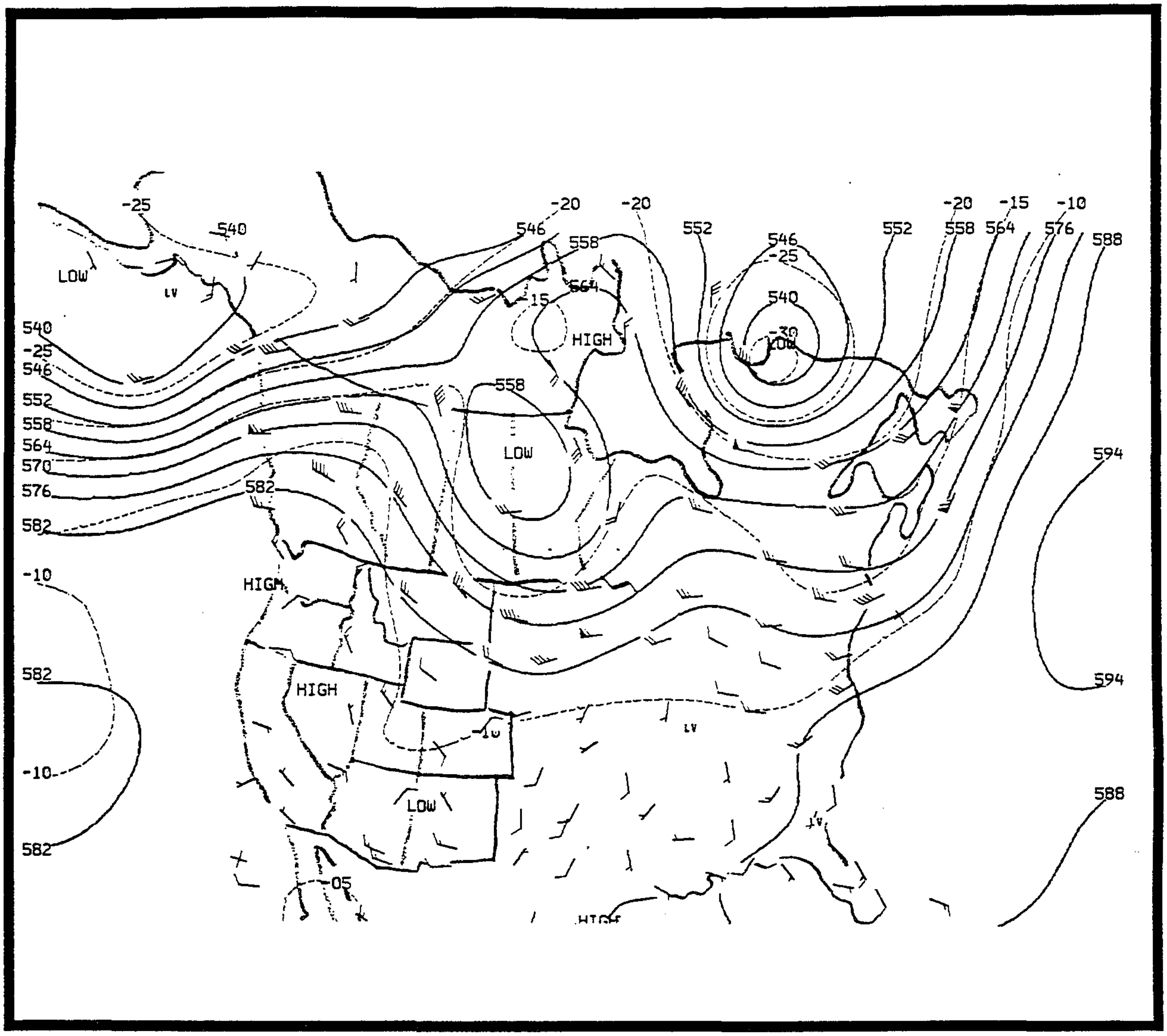
The east winds persisted for three days, but on September 4, the weather pattern began to change. As the surface high pressure center moved east into the Dakotas, pressures began to fall along the lee slopes of the Continental Divide. The development of the "Lee-Side Trough" decreased the pressure gradient forces in the fire area. Winds were generally light and primarily slope-induced for nearly 24 hours.

The fire perimeter for the morning of September 5, (Fig. 5) shows the effects of three days of east winds, most significantly on the western portions of the fire. By mid-day on the 5th, west



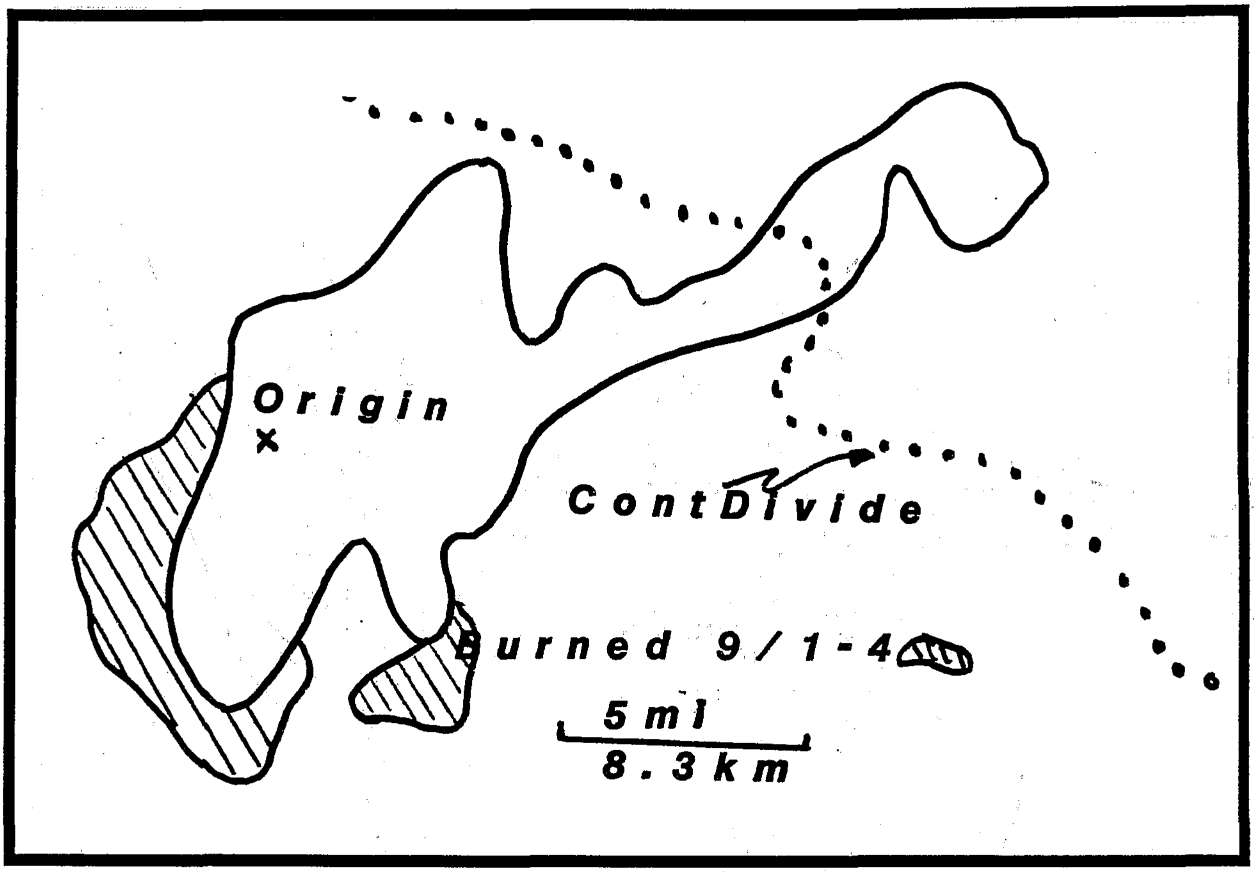
Surface Analysis, 1200 UTC, September 1, 1988

Fig. 3



500 mb Chart, 1200 UTC, September 1, 1988

Fig. 4



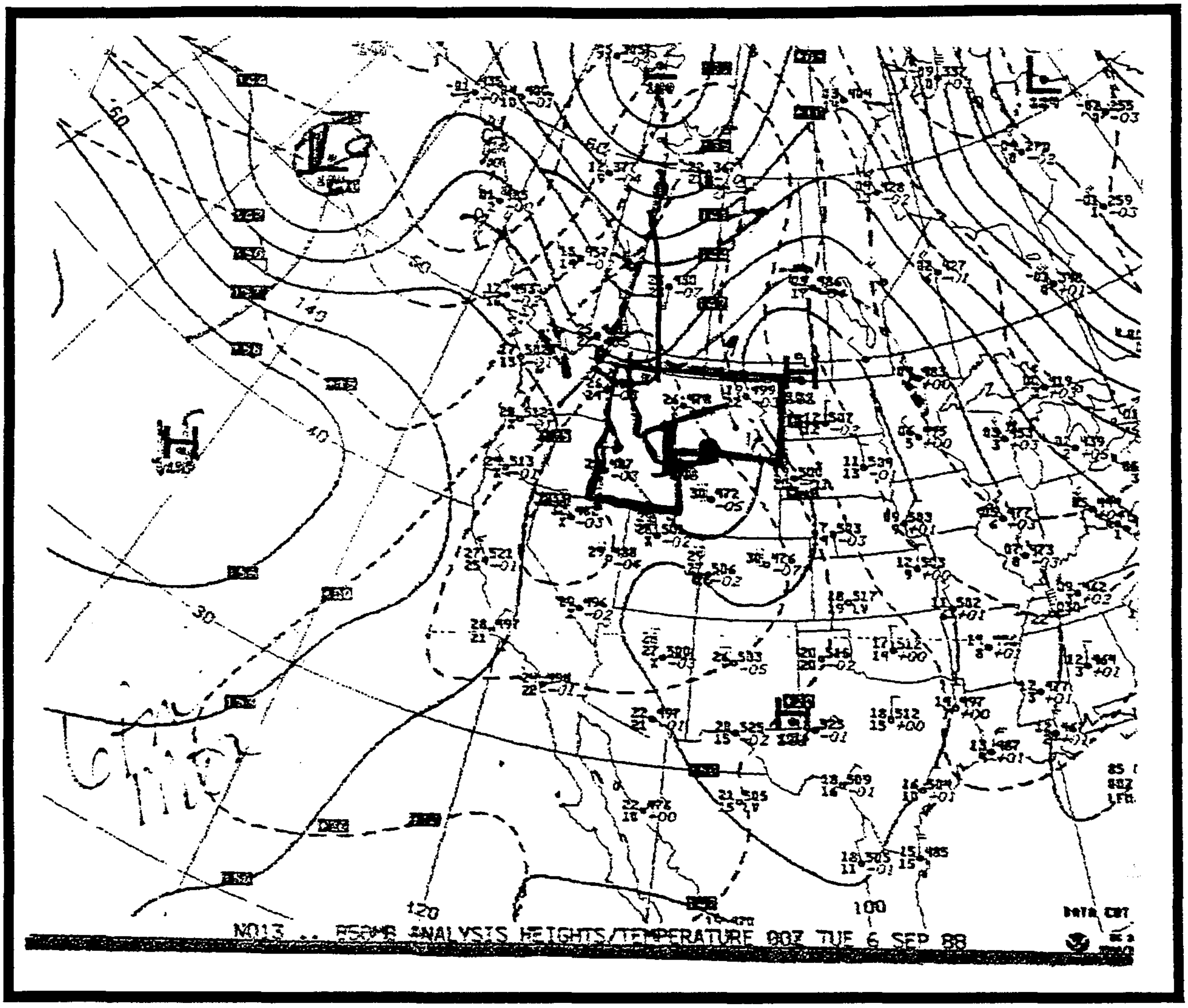
Fire Perimeter, September 5, 1988

Fig. 5

winds began to increase on the western portion of the fire. East of the Continental Divide, winds were still out of the east, but were light.

By the evening of September 5, a complex pattern of weather events was evolving. A surface wave began to form from a low pressure center over northern Alberta. This can be seen on the 850 mb chart for 0000 UTC, September 6 (Fig. 6). The fire area was in the warm sector, and low-level (850 mb) southwesterly winds increased to over 30 kts during the night. The air mass became progressively more unstable as cool air advection aloft began to override the warm, dry air at the surface. These meteorological factors, combined with physical factors of the fire environment, were developing into a "Blow-Up" situation for the Canyon Creek Fire. At 0500 UTC on September 6, (11:00 p.m. on September 5) a field observer on the fires west zone reported 9% relative humidity in a drainage bottom. Areas of unburned timber within the fire ignited, exhibiting extreme fire behavior throughout the evening and into the early morning hours of the 6th.

The weather pattern during the first five days of September was of extreme significance to the events that followed.



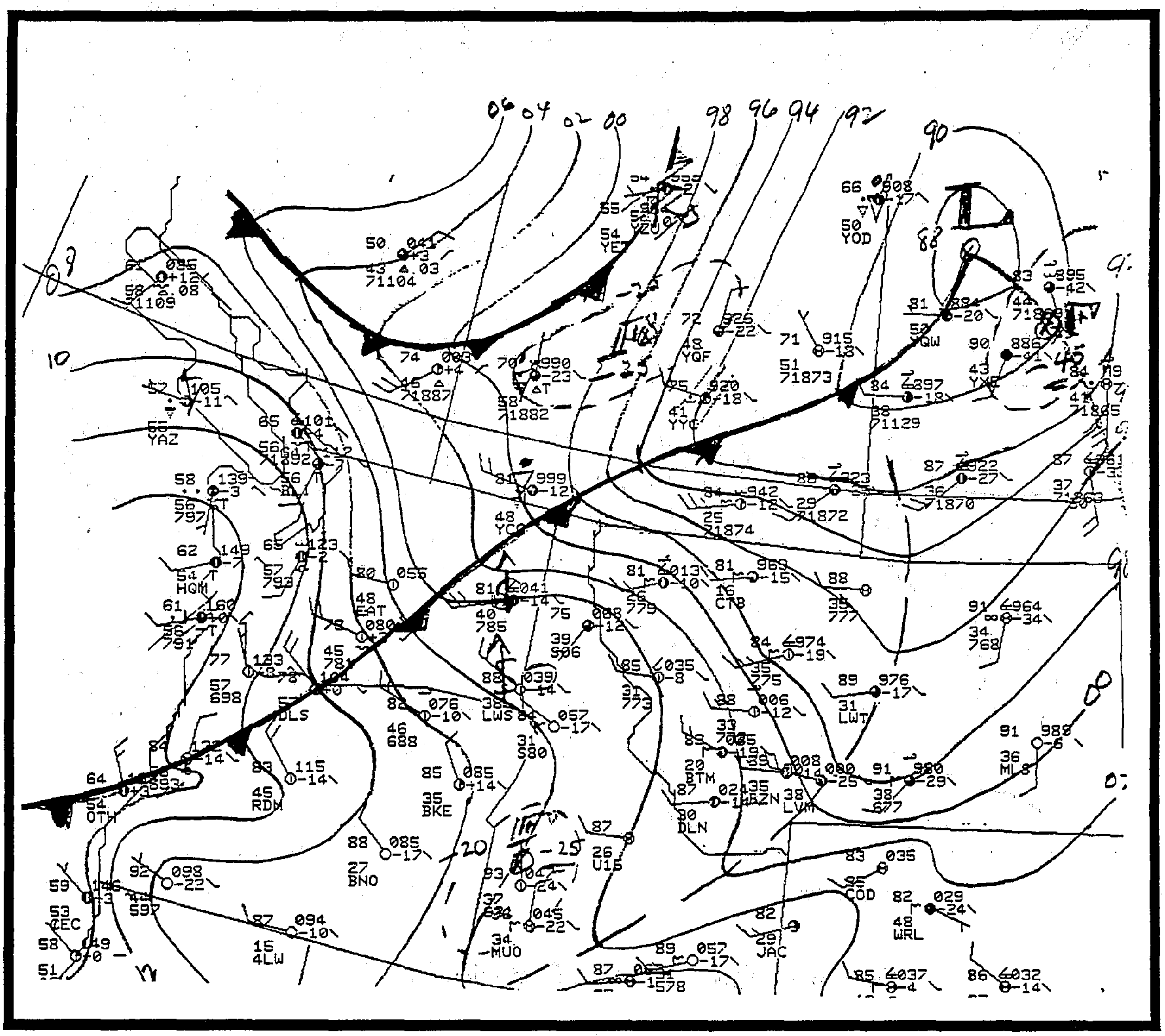
850 mb Analysis, 0000 UTC, September 6, 1988

Fig. 6

V. "BLACK TUESDAY AND ASH WEDNESDAY" -- SEPTEMBER 6 AND 7

By the morning of September 6, the fire was estimated at a little over 57,000 acres... a modest increase of around 6,000 acres in five days. A large percentage of this increased acreage was on the southwest side of the fire. Equally significant, however, was the amount of area within the fire perimeter that was hot due to reburn during the three-day period of east winds and the wind reversal of September 5.

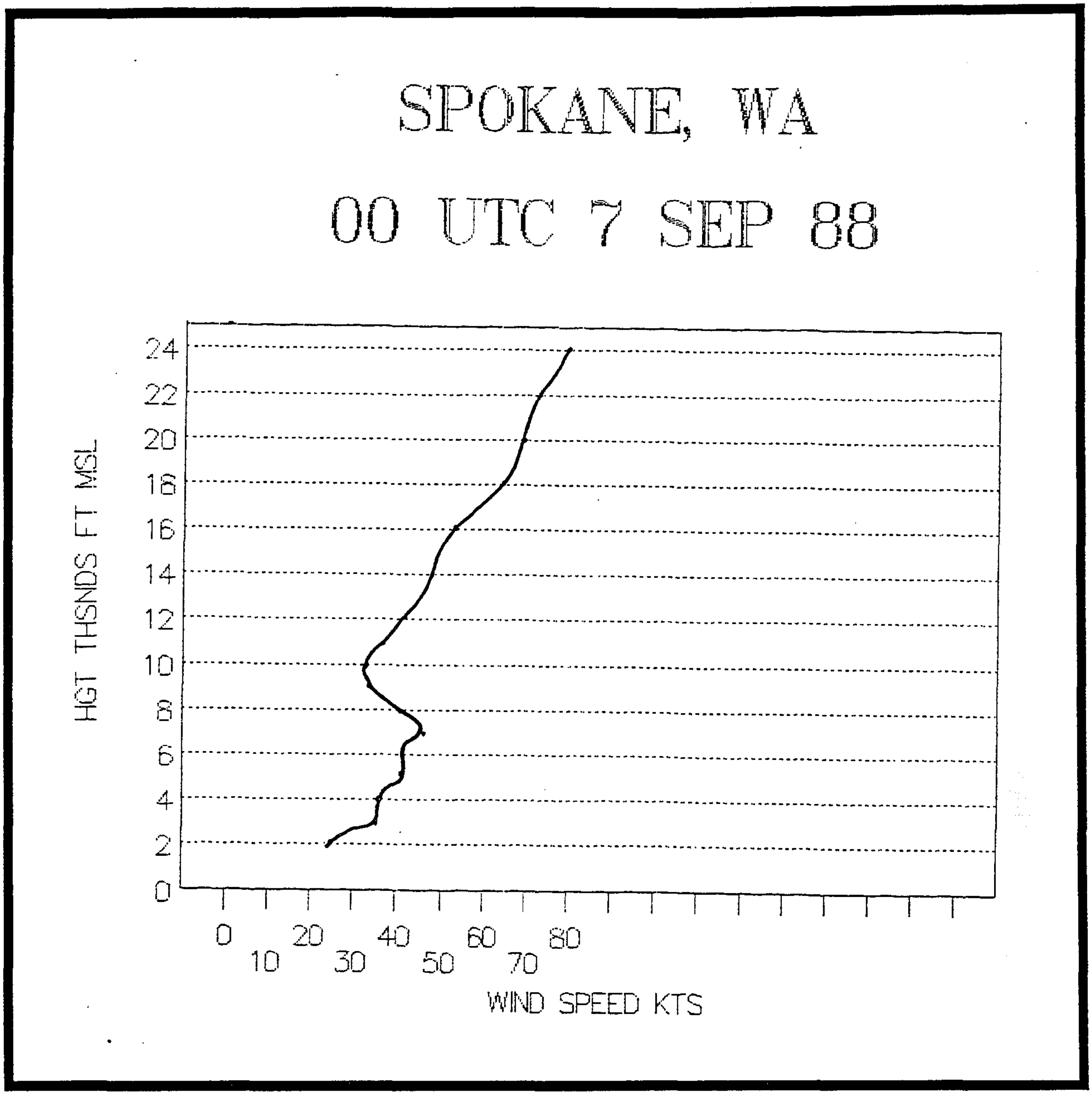
The surface weather chart for 0000 UTC on September 7, (6:00 p.m. on September 6) (Fig. 7) shows two frontal systems moving toward western Montana from the



Surface Chart, 0000 UTC, September 7, 1988

Fig. 7

northwest. The first was apparent only in the dew-point field; the second, a cooler continental push. In the upper levels, winds were quite strong and increasing. Winds measured on the 0000 UTC, September 7, atmospheric sounding at Spokane, Washington (Fig. 8) indicated a low-level jet of nearly 45 knots near 7,000 ft. MSL. At 24,000 feet (400 mb), winds were 75 knots.



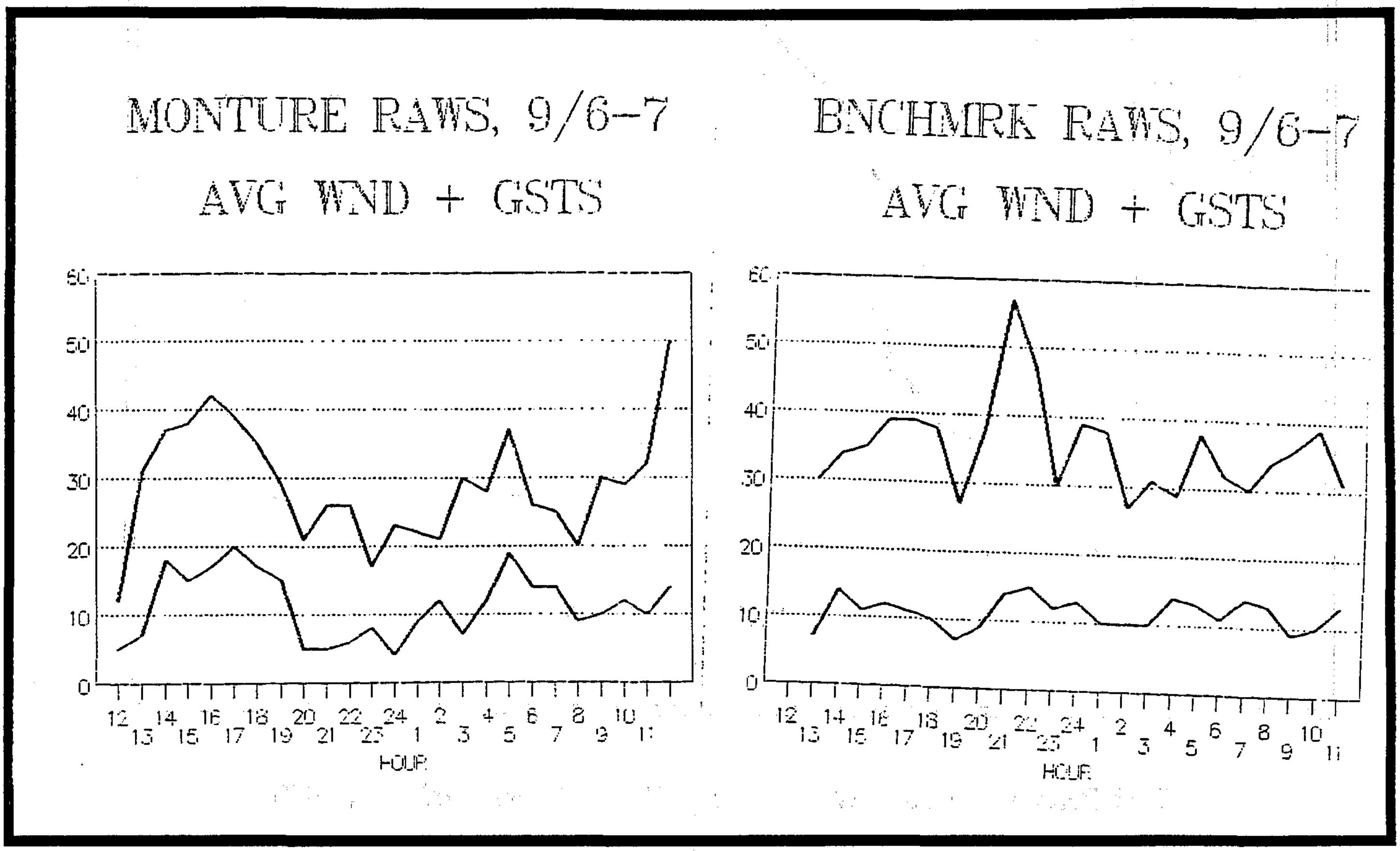
Wind Profile, Spokane, Washington, 0000 UTC, September 7, 1988

Fig. 8

On September 6, westerly surface winds increased on the fire's east zone during the mid-afternoon, and on the west zone by late afternoon. The trough, in the lee of the Rockies, moved east and pressure gradient forces increased. Surface winds in portions of the east zone of the fire were reported as erratic, 20 to 30 mph, with gusts up to 50 mph.

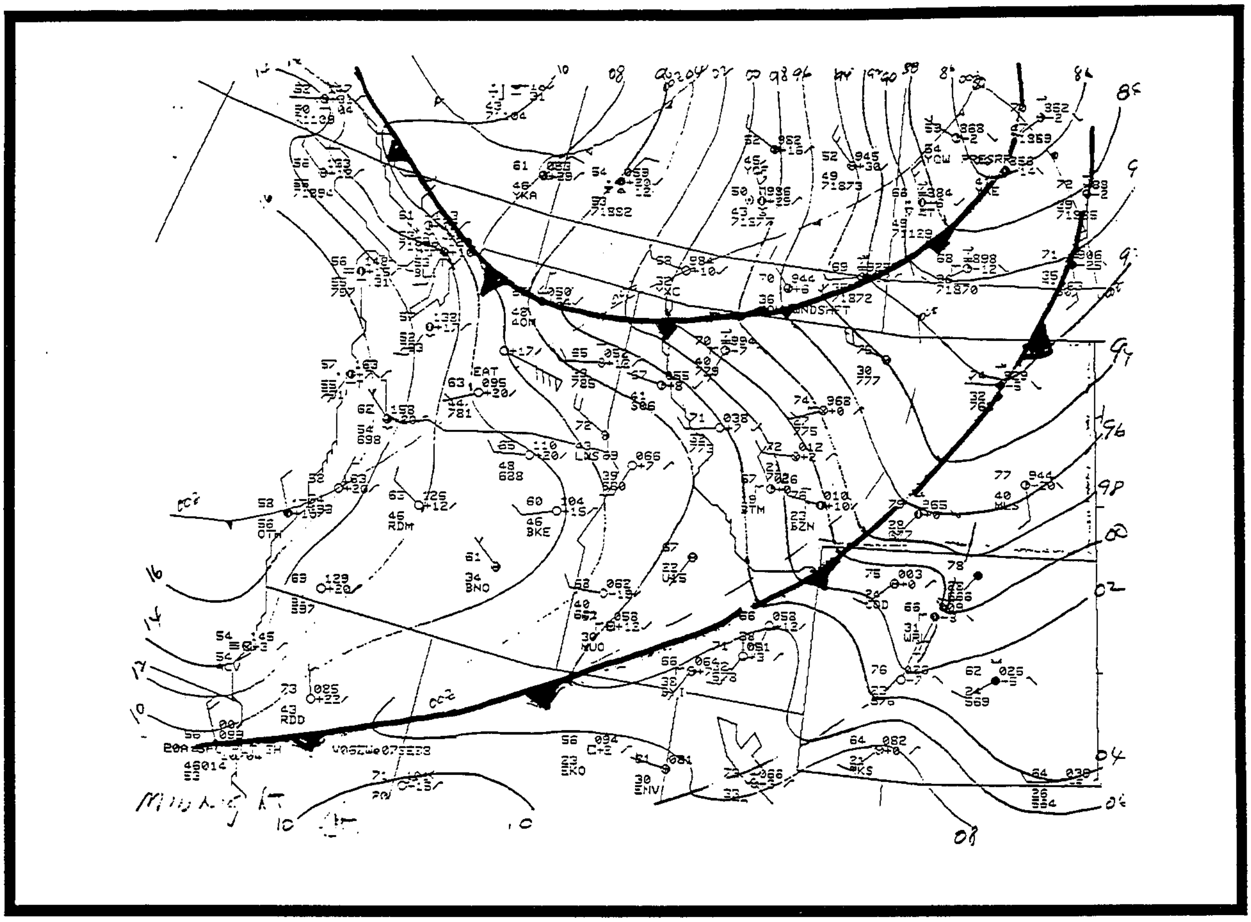
The first front moved across the fire area during the evening hours of September 6. This front was difficult to track due to the lack of a good mesoscale data network, as well as the usual problems associated with frontal movement in mountainous terrain (Saucier, 1965). Reports from the Monture and Benchmark Remote Automatic Weather Stations (RAWS) and Silver King Lookout were consistent, all reporting strong west winds throughout the night. Winds averaged 15 to 20 mph with gusts between 40 and 60 mph (Fig. 9).

Characteristic air mass changes at the surface were not apparent with the first frontal passage. This is most likely due to active mixing caused by the wind, with contributions from the tremendous energy release in the lower atmosphere by the fire. During the 16-hour blowup, an average of 160 acres a minute were consumed. Temperatures at the RAWS sites remained above 60 F and humidity below 40 percent throughout the night. Closer to the fire, observers reported temperatures in the mid-70s (F) and humidity in the mid-teens at 0900 UTC on September 7 (3:00 a.m. MDT).



Observed Winds, Monture and Benchmark RAWS Sites
September 6 and 7, 1988

Fig. 9



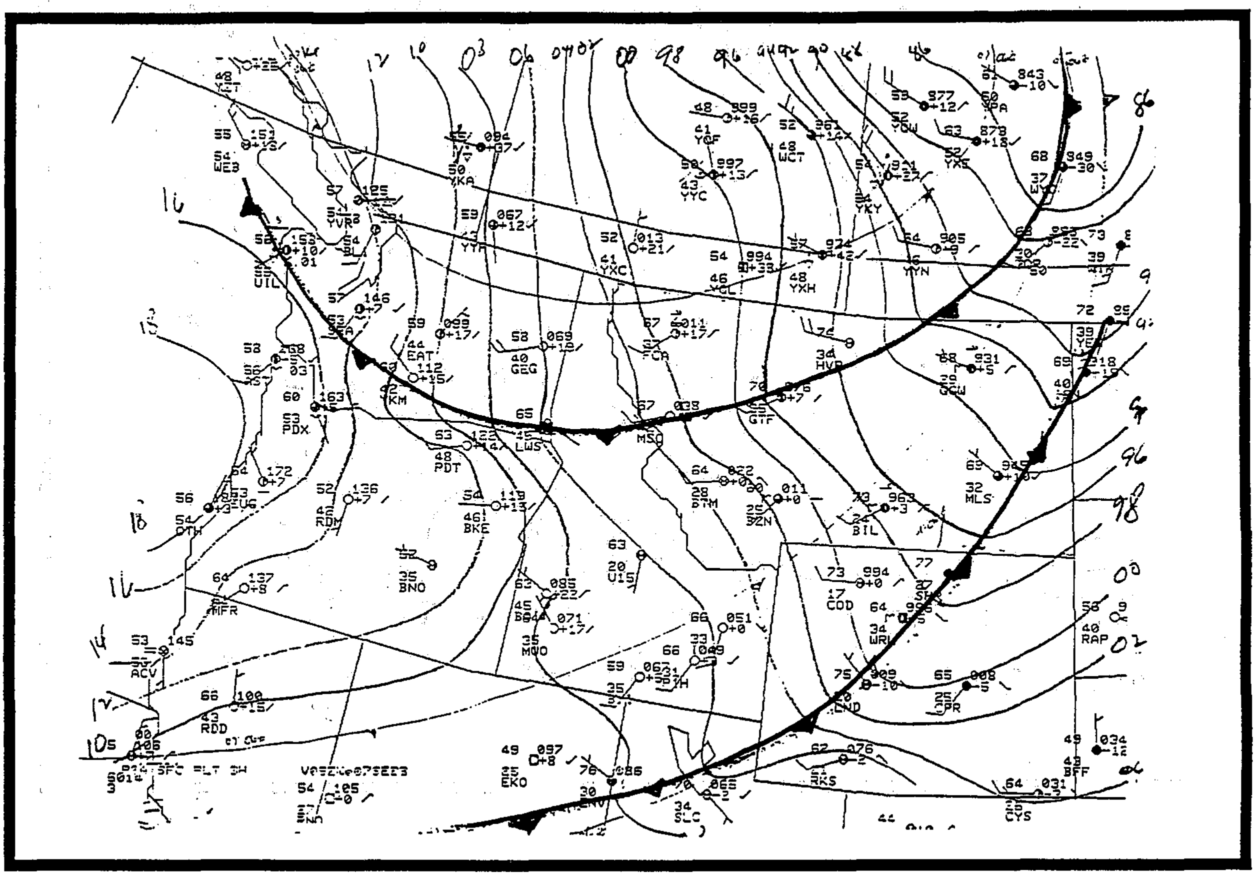
Surface Analysis, 0600 UTC, September 7, 1988

Fig. 10

The surface analysis for 0600 UTC on September 7, (12:00 a.m. MDT) (Fig. 10) showed the second (polar) frontal system moving into northwestern Montana. By 1:00 a.m. MDT, ash began falling on the Great Falls, Montana airport, over 50 miles east of the fire. By 0900 UTC (3:00 a.m. MDT), the front had moved over the fire area (Fig. 11). Visibility was restricted at Great Falls to five miles by smoke and falling ash through the remainder of the night. Rapid pressure rises, along with a slight wind shift, reported in the 7:00 a.m. MDT surface weather observation signaled the weak frontal passage at Great Falls.

The 500 mb chart for 0000 UTC September 7, (Fig. 12) shows the polar jet stream moving south with a 50 knot speed maximum approaching northern Idaho. The 1200 UTC, September 7, 500 mb chart (Fig. 13) indicated a wind speed maximum of nearly 100 knots approaching the fire area.

The 1200 UTC (6:00 a.m. MDT) September 7 sounding from Great Falls (Fig. 14) shows a shear layer between 12,000 and 14,000 feet with winds increasing from 25 knots to 50 knots. Below this shear layer, a lower level wind maximum of 35 knots existed between



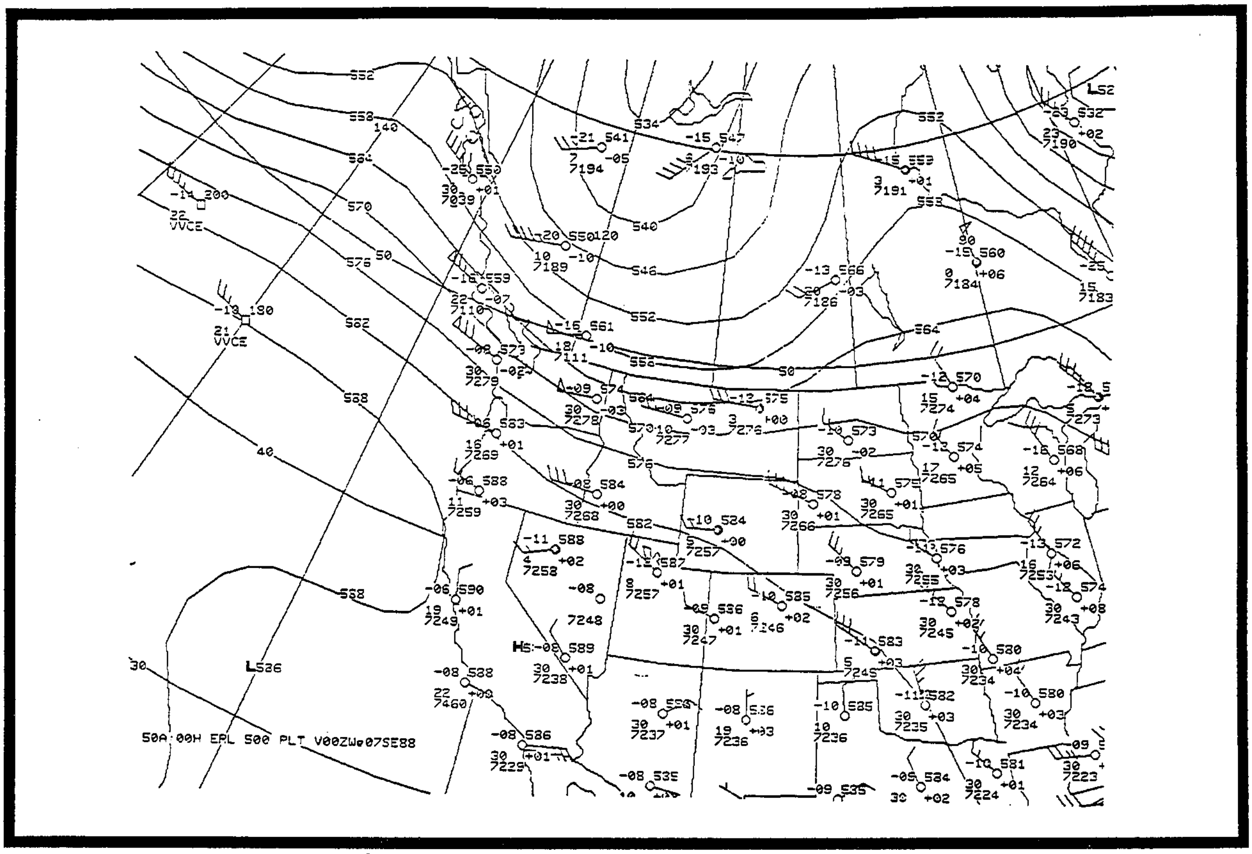
Surface Analysis, 0900 UTC, September 7, 1988

Fig. 11

8,000 and 9,000 feet, near mountaintop level. A subsidence inversion was just above the shear zone, and most likely associated with the right front quadrant of the jet stream (Reiter, 1963). This inversion was significant as it helped substantiate, on a much larger scale, the unusually warm and dry conditions that existed throughout the night over the fire.

The subsidence-type of inversion just above mountaintop level has also been identified as fundamental in the development of "Foehn" type strong mountain downslope winds (Klemp and Lilly, 1976). The compressional warming associated with the strong downslope flow on the east slopes of the Continental Divide contributed to both the rapid rate of spread and intensity of the fire.

The secondary frontal boundary oriented on an east-west line remained nearly stationary over the fire area through mid-day on September 7. Strong westerly surface winds continued along the east slopes of the Continental Divide. Visible imagery from a polar-orbiting satellite (Fig. 15) showed the frontal boundary



500 mb Chart, 0000 UTC, September 7, 1988

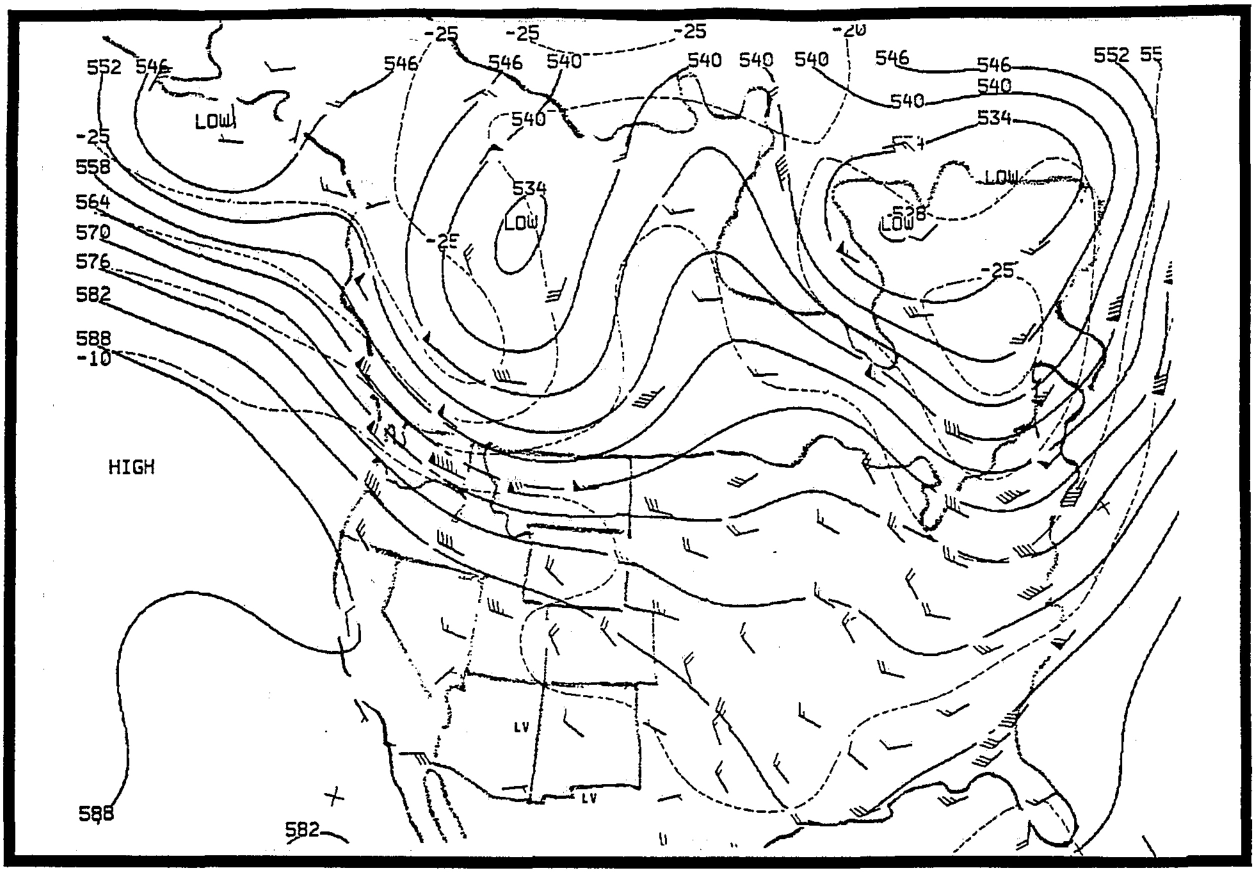
Fig. 12

across the fire area and a spiral smoke plume downwind of the fire. The interesting spiral configuration of the smoke plume is indicative of a core of strong winds near the surface, i.e., a low-level jet stream. The satellite photograph showed fires further south in Idaho and in Yellowstone Park being influenced by the strong, westerly winds south of the polar front and jet core.

By 1200 UTC (6:00 a.m. MDT) on September 7, the fire had concluded its major run. Although the winds were still strong on the surface and aloft, the fuels along the eastern head of the fire were so sparse and discontinuous that further spread was limited (Morris, 1989).

VI. SUMMARY

The factors of fuels, topography, and weather all contributed to the Canyon Creek Fire's momentous spread on September 6 and 7. An in-depth evaluation of the role of topography and fuel supply on this fire is best left to other subject-matter experts. It is sufficient to say that fuels were available and ready to burn, both as a result of the age and class of trees, condition of the forest environment, and the precedent dry weather conditions. The complex topography played a significant role in the fire growth, and the final fire shape, size, and burn pattern.



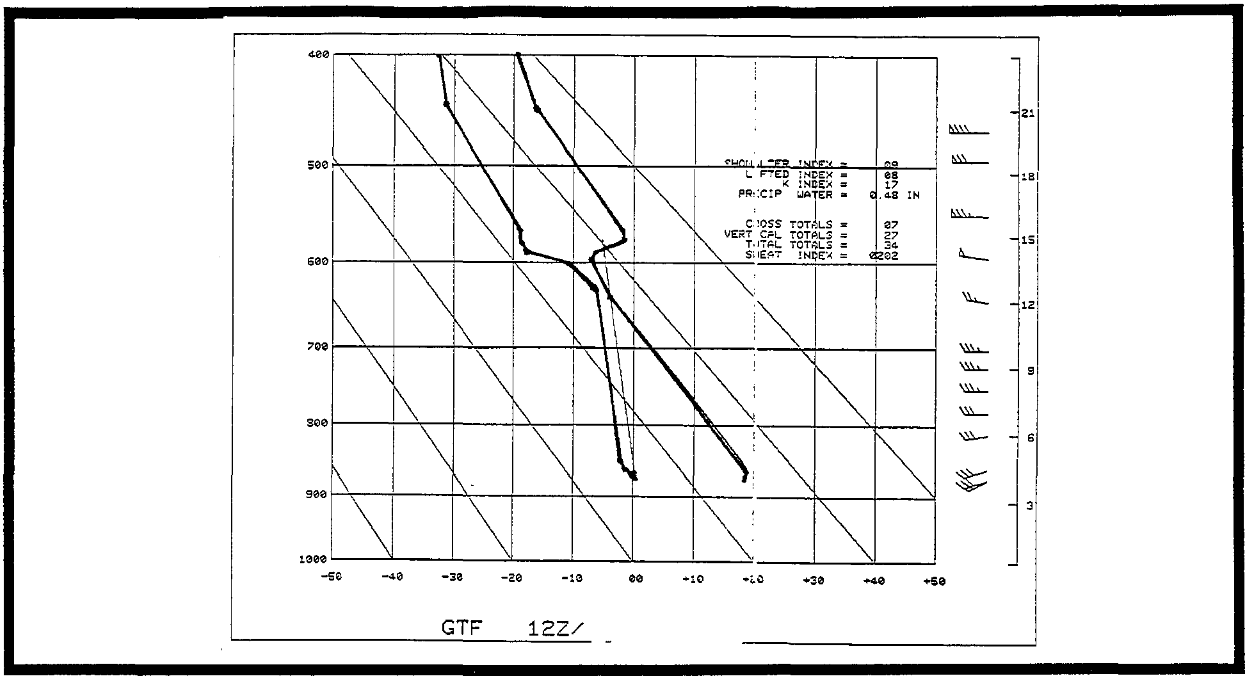
500 mb Chart, 1200 UTC, September 7, 1988

Fig. 13

The east winds that occurred on both sides of the Continental Divide during the few days prior to September 6 were rather unusual, as winds from that quadrant are not a common or persistent event in western or central Montana. Climatology for Great Falls, located on the east slopes of the Continental Divide, showed that an average wind direction in September is from the southwest. West of the Divide in Missoula, wind directions are normally from the northwest.

The east winds on those portions of the fire located west of the Divide were "downslope" in nature, that is, warm and dry. These winds were topographically channeled and enhanced, providing fire growth on the southwest side of the fire. Additionally, these winds pushed the fire back into unburned areas within the perimeter, thereby increasing active burning within the interior of the fire. With a significant amount of active fire on the southwest flank, and many areas within the fire perimeter fanned into activity, the stage was set for the dramatic spread that took place on September 6 and 7.

The wind pattern associated with the fire run of September 6 and 7, was unusual in strength, timing, and persistence. The southern migration of the polar jet stream influenced a number of factors, including the speed and timing of the frontal systems that effected the fire. As the jet lowered in elevation over the fire area,



Great Falls Atmospheric Sounding, 1200 UTC, September 7, 1988

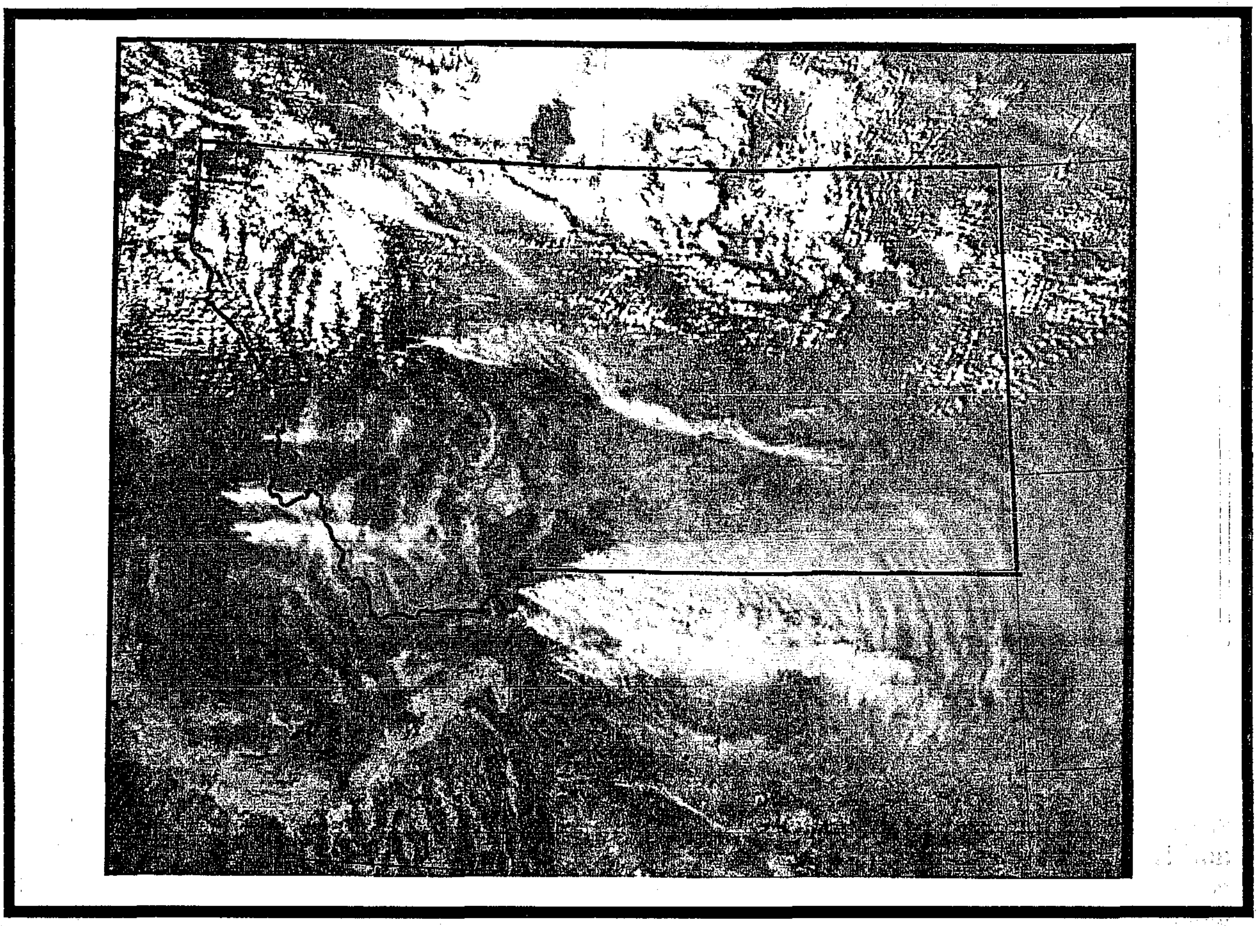
Fig. 14

surface winds increased significantly. In addition, the jet provided a further contribution to fire activity through the warming (resulting from active low-level mixing) and the compression effects as the winds were forced over the terrain. The effects in the wind pattern can be seen in recorded data from nearby observation sites:

1. Great Falls (Fig. 16): The average wind speed of 19 mph on September 6, was nearly 175 percent of the monthly average of 11.3 mph. From midday on the 6th to midday on the 7th, the average wind speed was about twice the monthly average. This is especially noteworthy because of the persistence of the strong winds throughout the night.

2. Missoula (Fig. 17): The average wind speed of 10.2 mph (170 percent of normal) on September 6, was significant, especially when we note that winds were less than 5 mph until after midday. The average wind speed for Missoula in September is only 6.0 mph. On September 7, the average wind speed was 16.7 mph, approaching nearly three times the monthly average. Again, this is even more meaningful because the strong winds persisted throughout the night.

Topography, both west and east of the Continental Divide, played an important role in the wind's influence on the fire. West of the Divide, the rough, broken mountainous terrain was a factor in increasing the mixing depth at night (due to terrain induced turbulence), bringing the stronger winds aloft to the surface. The winds were most likely increased by terrain forced convergence of the airflow. Finklin (1973) noted a similar behavior in the wind field at night as it effected the dramatic Sundance Fire run in North Idaho on September 1, 1967. The "downslope" effect east of the Divide is a



Satellite Photograph, 1800 UTC, September 7, 1988

Fig. 15

well-documented occurrence and was most likely amplified by the location and strength of a low-level jet stream.

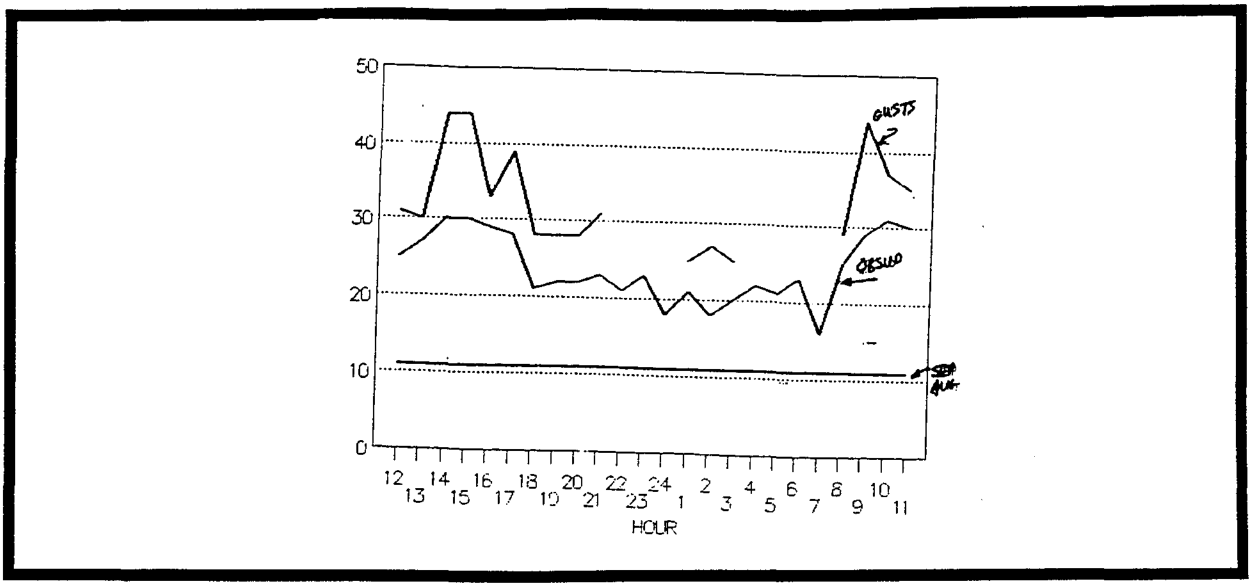
VII. CONCLUSIONS

Wind-driven fires can be easily recognized by their characteristic shape (Anderson, 1983). It is obvious by a casual examination of the fire growth map (Fig. 18) for September 6 and 7, that the Canyon Creek fire was driven by the wind. Topographic discontinuities were factors in the unburned area within the Dearborn River drainage on the east half of the fire.

The meteorological events that contributed to the explosive overnight growth of the fire were singularly significant and collectively unique. The four major events were:

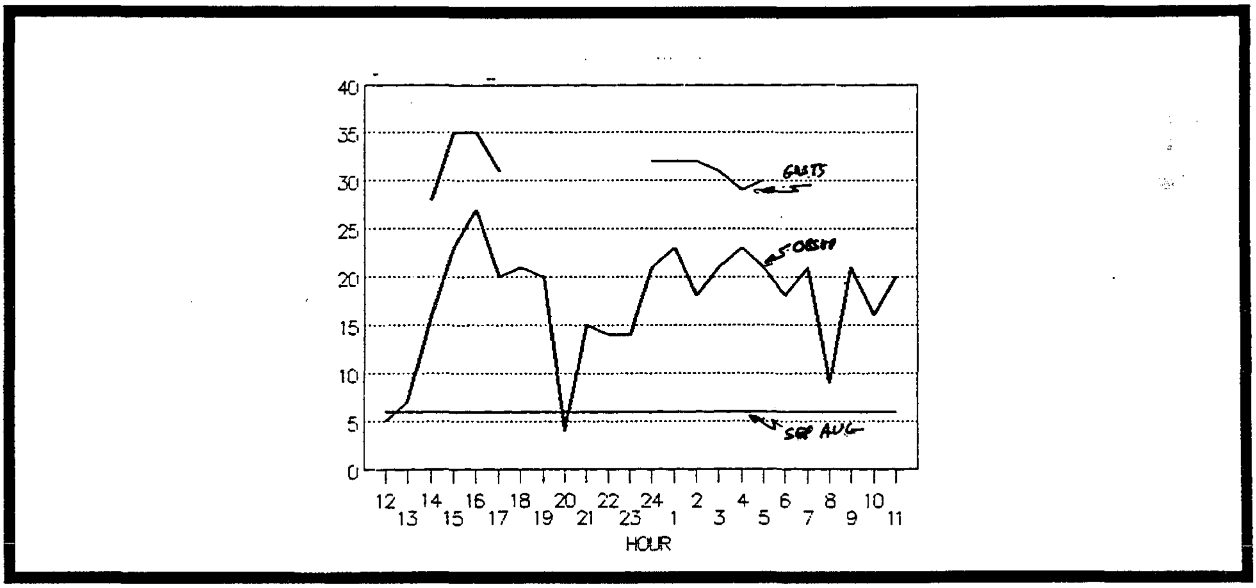
1. Long-term drought unrelieved by usual late summer rains;

2. Three days of east winds in an area that has predominate west winds;



Observed Wind, Great Falls, Montana, September 6-7, 1988

Fig. 16



Observed Wind, Missoula, Montana, September 6-7,1988

Fig. 17

3. The passage of two dry frontal systems within twelve hours accompanied by persistent strong west winds;

4. The occurrence of a low-level jet stream that moved over the fire area and remained stationary for over 12 hours.

The combination of these meteorological events imposed on an environment ripe with fuels, and in favorable topography, produced and enhanced the spectacular and devastating fire growth of the Canyon Creek Fire on September 6 and 7, 1988.

VIII. ACKNOWLEDGEMENTS

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Canyon Creek Fire, Final Fire Size

Fig. 18

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