Limitations of Red Flag Warning Criteria in the Prediction of Large Fire Growth in Complex Terrain

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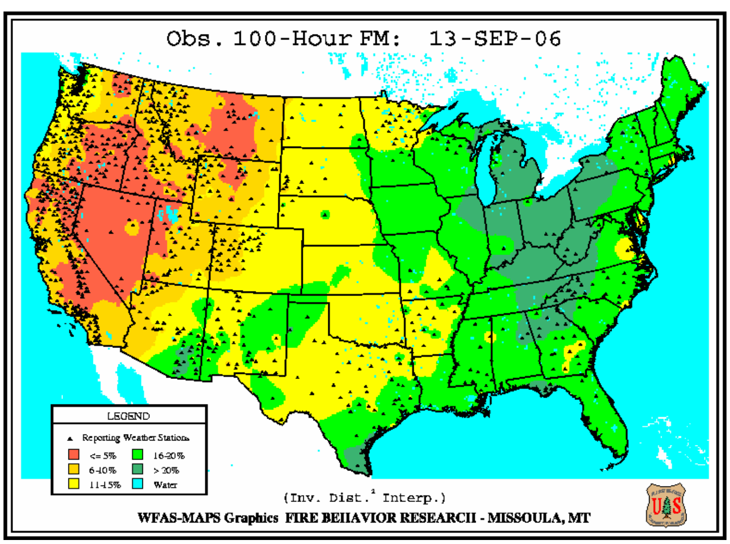
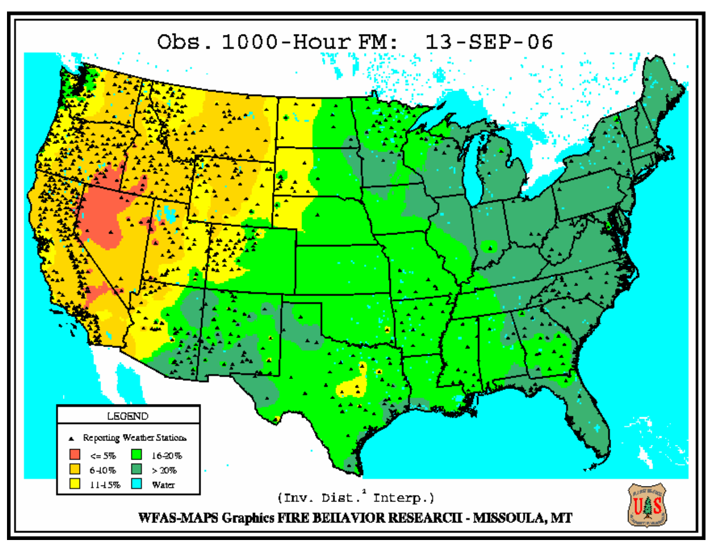
Introduction:

Red Flag Warnings (RFW) are typically issued in response to quantifiable surface parameters, such as wind speed and relative humidity, in an attempt to predict a high probability of dangerous fire growth through verifiable parameters. A "typical" Red Flag Day across southern Montana consists of winds sustained at 15 mph or higher, frequent wind gusts to 25 mph or higher, and relative humidity values less than 20 percent. In addition to the meteorological criteria mentioned, 100 hour fuel moistures of less than 10 percent and 1000 hour fuel moistures of less than 15 percent are also present, resulting in very high or extreme fire dangers. While many fires react vigorously to the aforementioned criteria, there are instances of extreme fire growth during periods of sub RFW surface criteria.

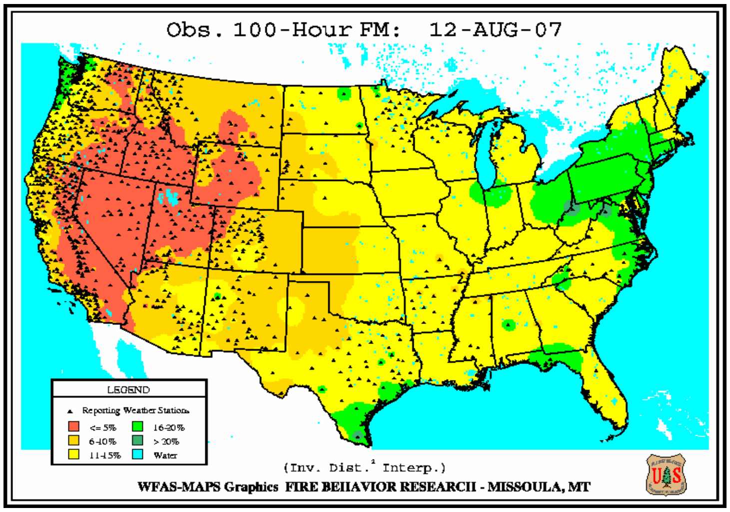
The 2006 Jungle and 2007 Wicked Creek fires over South Central Montana were similar in that they both grew by thousands of acres in a relatively short period of time with comparable topography, fuel's type, and very dry 100 and 1000 hour fuels states (fig.1-4). The fire areas are situated approximately 40 miles apart from one another (fig.5). However, surface weather conditions reported at the time of maximum fire growth were different with each fire. The Wicked Creek fire experienced RFW conditions with a combination of strong winds and low relative humidity values. The Jungle fire did not meet RFW criteria due to light wind speeds but did experience very low relative humidity values. This paper will discuss the meteorological differences between the two fire events, how those differences resulted in similar fire behavior, and why surface based RFW criteria may not always encompass conditions favorable for large fire development.



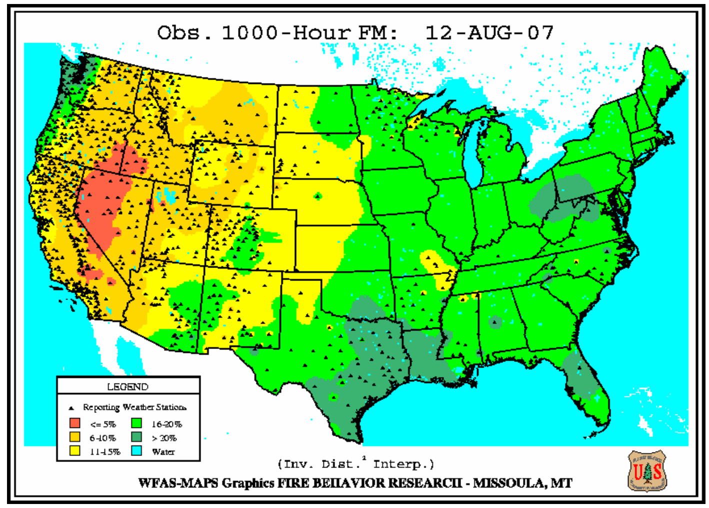
(fig.1) 100 hour fuel moisture Sep 13th 2006. Values for the Jungle fire area less than 5%. (WFAS data)



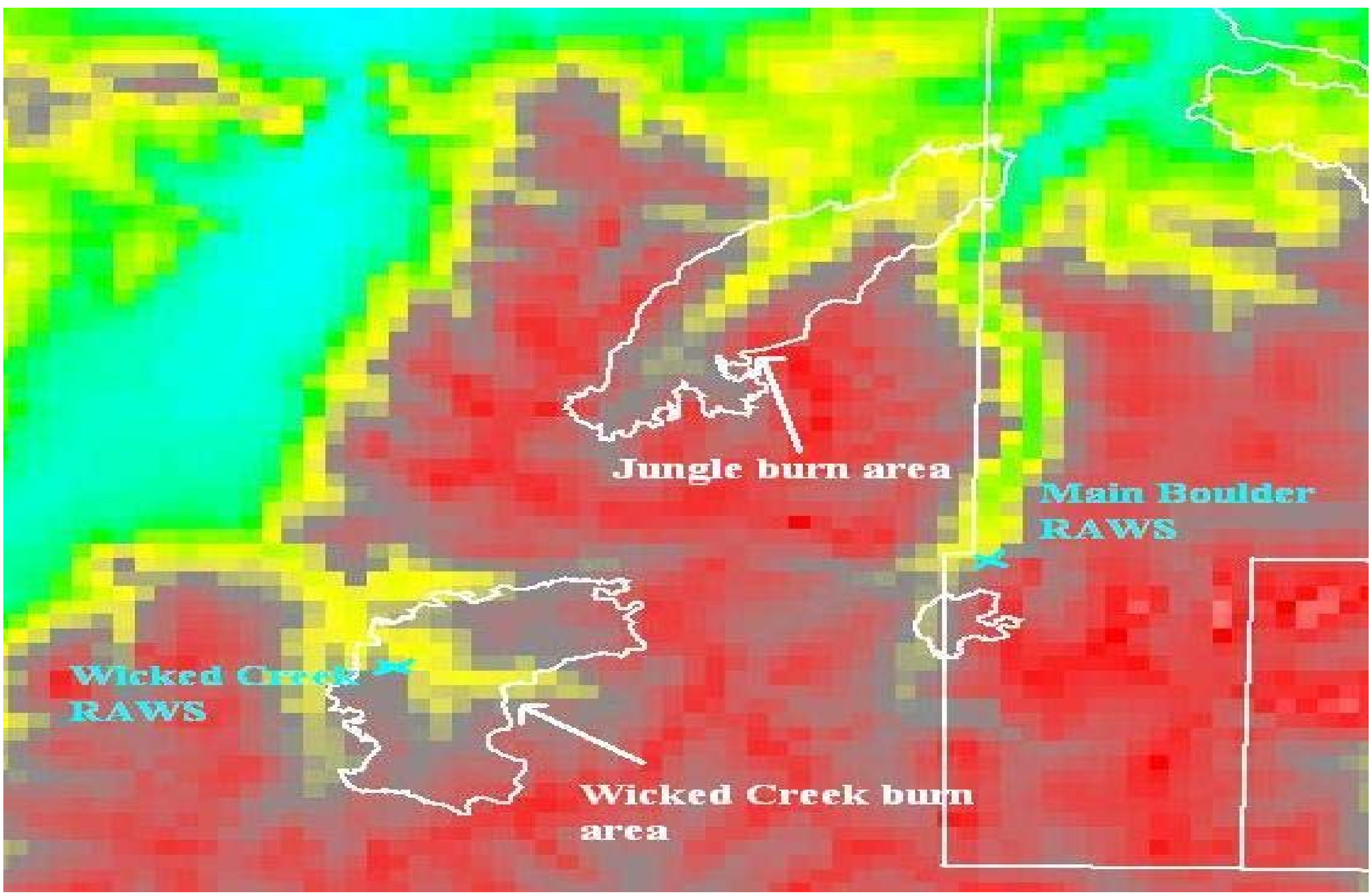
(fig.2) 1000 hour fuel moisture Sep 13th 2006. Values for the Jungle fire area 6-10%. (WFAS data)



(fig.3) 100 hour fuel moisture Aug 12th 2007. Values for the Wicked Creek fire area 6-10%. (WFAS data)



(fig.4) 1000 hour fuel moisture Aug 12th 2007. Values for the Wicked Creek fire area 11-15%. (From WFAS)



(fig.5) Topographical map showing the location of the Jungle and Wicked Creek burn areas and the Wicked Creek and Main Boulder RAWS sites. The Burn areas are approximately 40 miles apart. The elevation of the Wicked Creek Burn area ranges from ~6600ft (yellow) to ~9000ft (light red). The elevation of the Jungle Burn area ranges from ~5400ft (green) to ~10000ft (dark red).

Wicked Creek Fire:

Emphasize fuel type and conditions

The Wicked Creek fire (Elevation 7604ft) is a typical example of a critical fire weather day. During the afternoon and evening hours of August 12th 2007, the fire size increased dramatically from an estimated 800 acres to more than 10,000 acres. The fire was located in steep terrain in the Beartooth and Absaroka mountains of Montana (fig.5). The Wicked Creek RAWS was located in the immediate vicinity of the fire. RFW conditions, per Wicked Creek RAWS, developed around 9 am and continued through 9 pm that evening (fig.6). Winds were sustained as high as 17 mph during this period, with wind gusts reaching 39 mph. Relative humidity values bottomed out at 8 percent around 5 pm. With strong wind speeds reported from 9 am to 9 pm on the 12th, dramatic fire growth should be expected. This case is clearly a critical fire weather day with prolonged single digit relative humidity values and wind gusts approaching 40 mph, representing what a forecaster would normally describe as a typical RFW case.

Time(GMT)	Temperature °F	Dew Point °F	Relative Humidity %	Wind Speed mph	Wind Gust mph	Wind Direction	Quality check
2:01	75.0	16.9	11	14	31	SSW	OK
1:01	77.0	13.9	9	15	39	S	N/A
0:01	78.0	17.0	10	16	36	S	OK
23:01	80.0	13.4	8	13	36	S	OK
22:01	81.0	16.9	9	16	31	S	OK
21:01	79.0	17.8	10	17	35	SSW	OK
20:01	77.0	18.5	11	16	30	SE	OK
19:01	81.0	25.5	13	17	26	SSE	OK
18:01	78.0	24.9	14	12	23	SSE	OK
17:01	75.0	25.8	16	11	32	SSE	OK
16:01	72.0	24.8	17	15	25	SSE	OK
15:01	69.0	23.7	18	17	27	SE	OK

(table 1) Wicked Creek RAWS (Elevation 7604ft) observations near Wicked Creek fire August 12th 2007

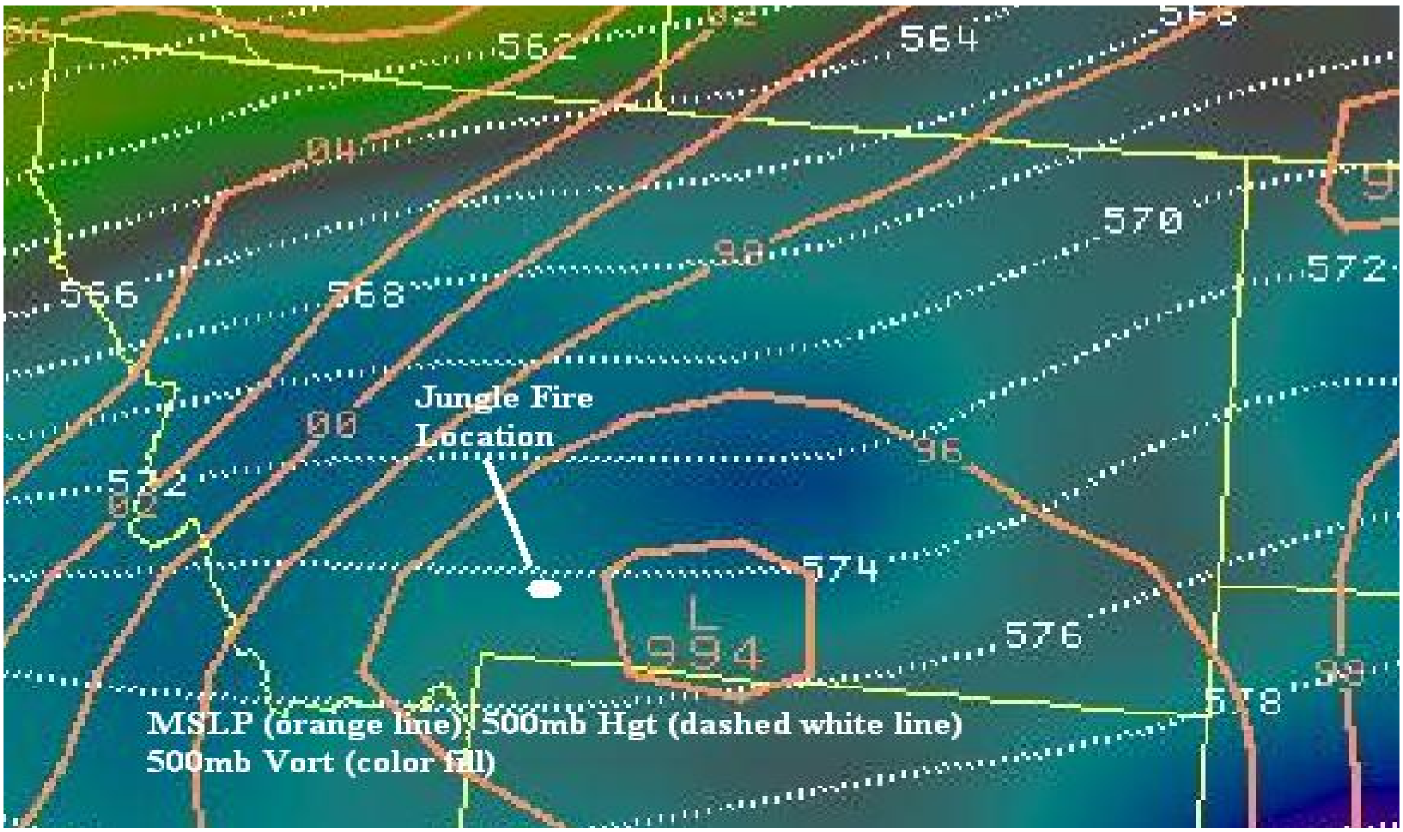
Time(GMT)	Temperature °F	Dew Point °F	Relative Humidity %	Wind Speed mph	Wind Gust mph	Wind Direction	Quality check
4:00	61.0	27.7	28	1	4	N	OK
3:00	61.0	26.8	27	1	2	SE	OK
2:00	69.0	25.0	19	1	4	ESE	OK
1:00	75.0	24.2	15	2	7	S	OK
0:00	79.0	24.0	13	4	10	SSW	OK
23:00	82.0	24.4	12	4	12	S	OK
22:00	85.0	22.3	10	4	11	S	OK
21:00	87.0	23.8	10	4	10	S	OK
20:00	85.0	19.9	9	3	10	ESE	OK

(table 2) Main Boulder RAWS (Elevation 5700ft) observations near Jungle fire September 13th 2006

Jungle Fire:

Emphasize fuel type and conditions

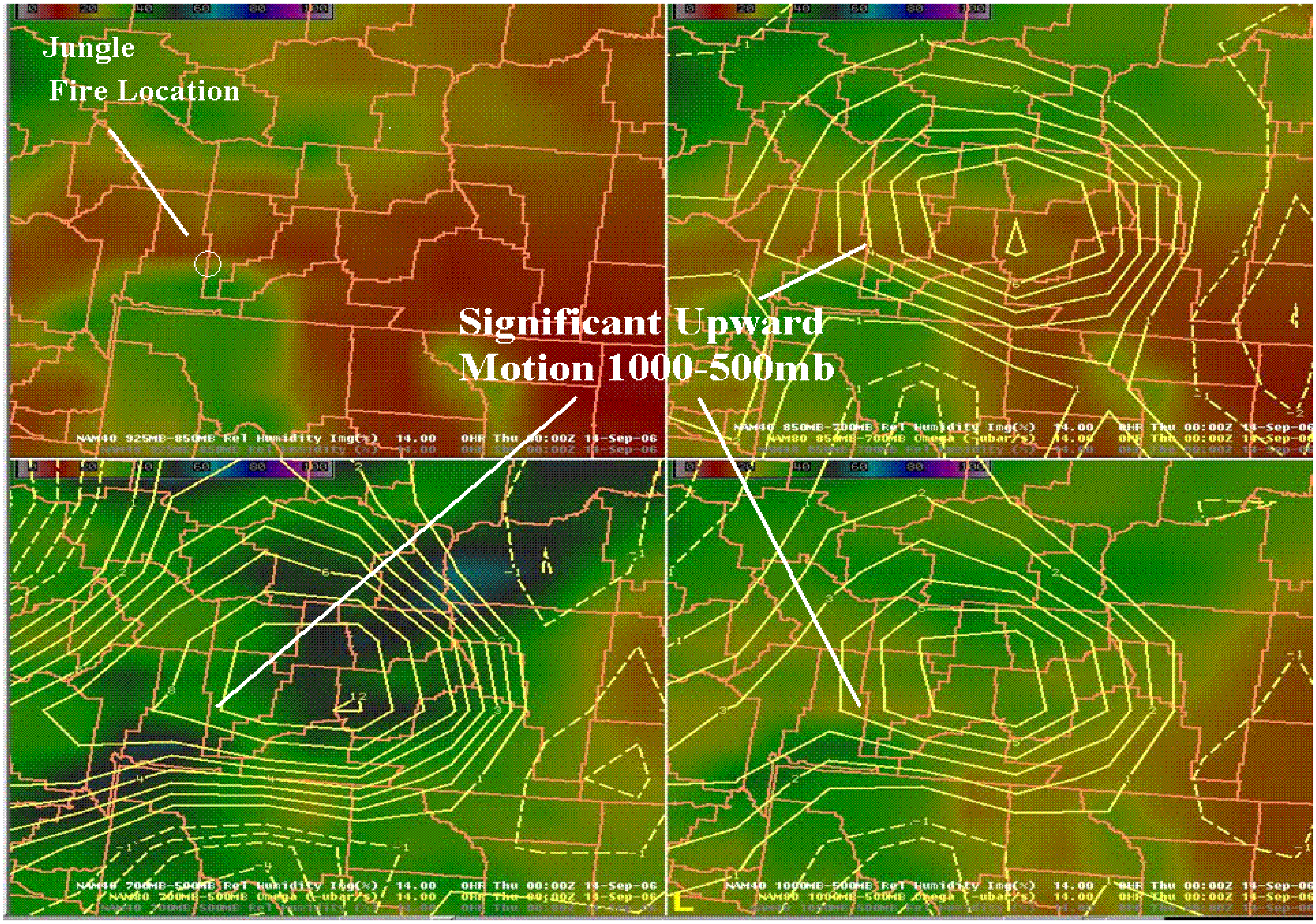
The Jungle fire (Elevation 5700ft) is an example of a less typical critical fire weather day. On the morning of September 13th 2006, the fire was reported to be 5,000 acres. Explosive fire growth occurred late in the day. In a few hours during the late afternoon and early evening of September 13th**,** the fire grew to a reported 30,000 acres. The fire was located in the steep terrain of the Boulder River valley, an area known for strong channeled southwest winds (fig.5). The Main Boulder RAWS was the closest observation site to the fire and was located in the adjacent Boulder River Valley 14 miles east-southeast of the fire. Despite being in an adjacent river valley, conditions at the Main Boulder RAWS were representative of general conditions in the valleys along the north side of the Beartooth and Absaroka Mountains. These valleys are all susceptible to strong south to southwest wind events. During the afternoon and early evening hours of the 13th, RFW conditions failed to materialize at the Main Boulder RAWS (table 2). Relative Humidity values dropped to around 9 percent. However, the surface pattern was not synoptically supportive of strong winds, and sustained wind speeds were only as high as 4 mph and gusts only reached 12 mph during the extreme fire growth period. Winds of this magnitude hardly seem indicative of what the Gallatin National Forest reported as a run of 9 miles by the fire, between 5 pm and 830 pm, down the Boulder River Valley that evening. Clearly, the surface observations and surface pressure pattern do not support such a run (fig.6). However, it is possible that once extreme fire growth began, the fire induced much stronger winds locally which resulted in the rapid spread down the valley.



(fig.6) September 14/00z AWIPS image of MSLP (solid orange line), 500mb height (dashed white line), and 300mb wind speed imaged (green ~100kts to dark blue ~50kts). Surface low over the area resulting in weak pressure gradient, not supportive of strong gradient winds.

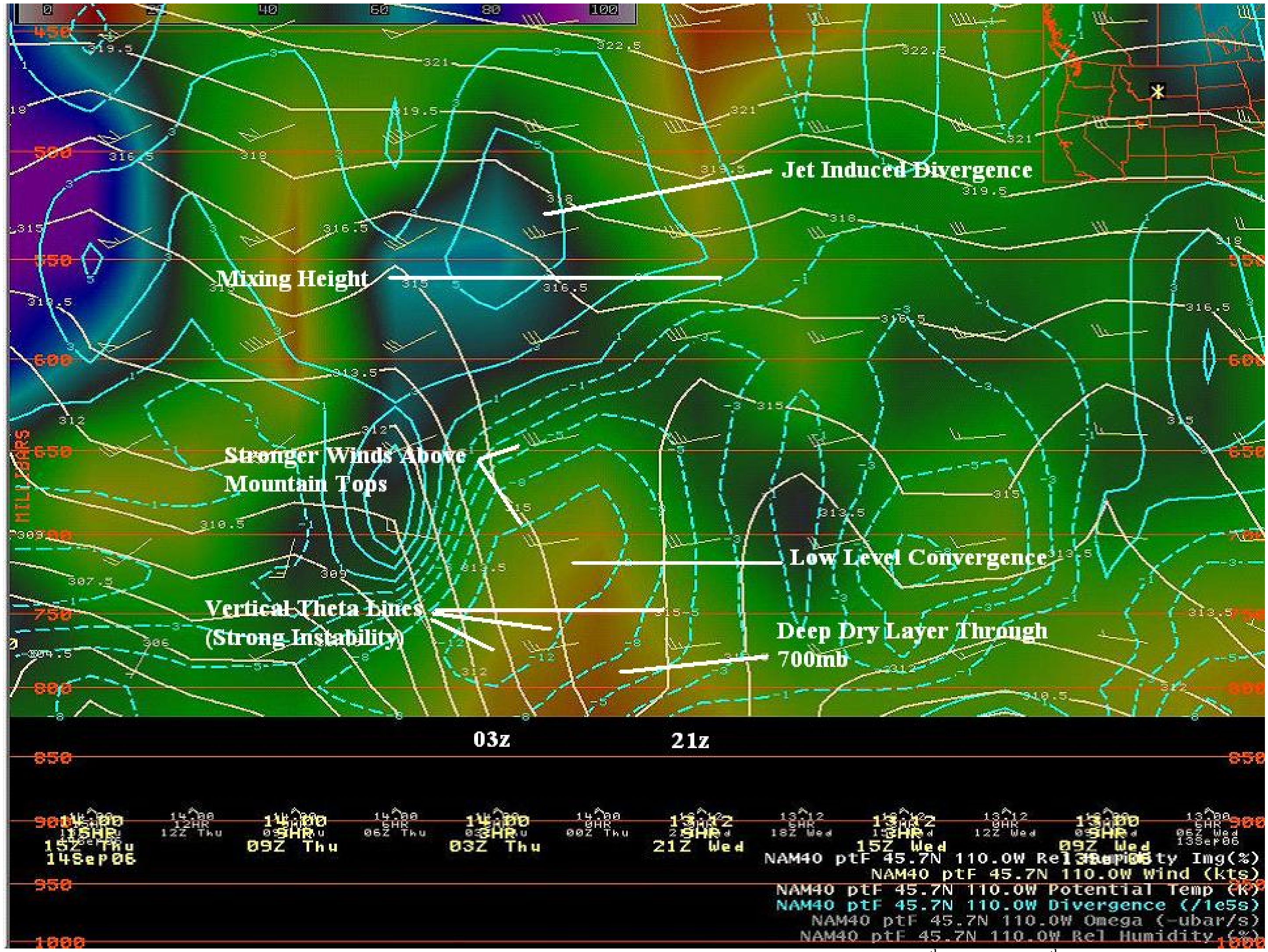
The explosive fire growth of the Jungle fire, absent of strong synoptic winds, presents a problem in terms of the Red Flag Warning criteria as well as a quandary to the operational forecaster trying to predict potentially hazardous fire weather conditions. So the question becomes, how can a fire behave in a severe manner without the aid of strong surface winds, and what should the operational forecaster look for to anticipate this potential?

The 14/00z NAM40 initialization showed an area of 35kt southwesterly winds moving over the fire at 700mb. The NAM40 00z forecast soundings suggest mixing to 550mb which should have allowed these stronger winds to mix down easily into the southwest to northeast oriented valley where the fire was located. However, based on the Main Boulder RAWS observations, mixing of higher level winds to the surface did not occur. There is also a strong upward motion signature in the 14/00z NAM40, centered just northeast of the fire location and extending southwest over the Boulder River valley at 00z (fig.9). This positive omega layer extends from the surface through about 500mb.



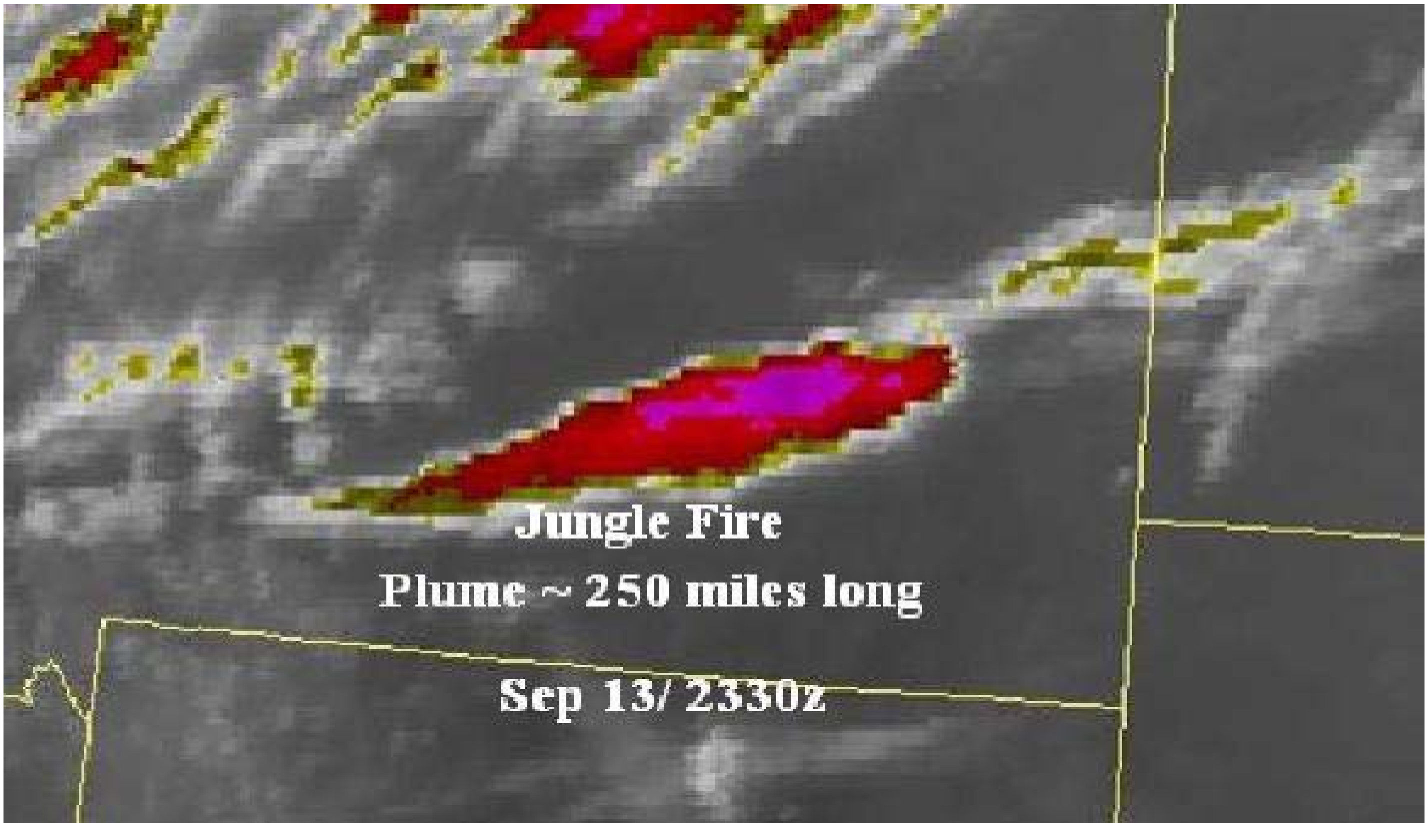
(fig.7) Four panel display of 14/00z NAM40 layer omega (upward motion solid yellow lines) and relative humidity (color background, orange color <20%). Clockwise from upper left : 925-850mb, 850-700mb, 1000-500mb, 700-500mb.

A NAM40 Time/Height cross section from the same time, centered at the fire location during the time of the extreme fire growth, shows jet induced upper level divergence with lower to mid level convergence in place over the fire location (fig.8). This is the likely cause of the significant upward motion over the fire area. The upward motion worked to prevent the stronger winds aloft from mixing down into the valley preventing stronger surface winds. At the same time this upward motion impacted the fire itself, helping to generate plume dominant effects by providing enhanced ventilation (i.e. the Chimney Effect). The enhanced vertical ventilation likely resulted in strong surface inflow winds adjacent to the fire that fed the rapid growth and spread of the fire, absent stronger synoptically generated surface winds. Ascent in this manner is a key component in the convective forecasting process, but appears to be a rarely considered component in operational fire weather forecasting or RFW consideration.



(fig.8) NAM40 Time/Height cross section over the Jungle fire highlighting the period between 13th 21z and 14th 03z when extreme fire growth occurred. Divergence (solid blue line), Convergence (dashed blue line), Theta (solid brown line), Pressure Levels (in red on left), Relative Humidity (background image : orange <20%).

Observations from witnesses at the fire site, and supported by KBLX WSR-88D and GOES Satellite imagery, show a massive smoke plume extending from the fire site into the upper troposphere, and subsequently being advected to the northeast by upper level winds (fig.9). While the stronger 700mb winds did not mix to the surface, the effect of the stronger southwest winds moving across the steep valley likely aided in the ventilation process, as well as contributing to fire propagation itself through spotting to the northeast of the main fire. Once the fire became plume dominant, its behavior became self contained, aided by terrain effects in the steep Boulder River valley.



(fig.9) Goes IR image of smoke plume from the Jungle fire 2330z September 13th 2006. At this time the plume was approximately 250 miles long. The plume impacted aviation interests as far east as Chicago during the following 12 hours.

Conclusion:

While most fires will react explosively to typical RFW surface based criteria, there are times when explosive growth occurs absent some facet of this criteria. It may be that mid level forcing plays a significant role in these cases, as it appears to have done on the Jungle fire. Unfortunately, discreet RFW criteria do not directly encompass factors such as upward motion or mid level forcing. Although fire weather forecasters certainly have discretion to warn for any condition that could result in extreme fire behavior, reliance on RFW criteria that fails to encompass other than the most quantifiable weather elements may result in dangerous fire activity developing without prior warning. Attention to pattern recognition and reliance on forecaster experience with previous fires can mitigate some of the potential for under forecast explosive fire growth events.

Forecaster awareness of, and attention to, the application of mid and upper level analysis should be considered by the fire forecaster as an important element in reducing the potential for unwarned, high impact fire events. Jetstream interactions, including jet induced upper level divergence coincident with lower to mid level convergence, and deep layer instability are some of the factors that should, in combination with very low relative humidity levels, key the operational forecaster to the potential for plume dominant fire activity. This is even in the absence of strong lower level winds. While this doesn't mean to imply that a Red Flag Warning should necessarily be issued based only on these factors, at the very least it should prompt further examination. A mention in the fire weather forecast of factors that could lead to enhanced fire activity can be invaluable to users, even if no Red Flag Warning is issued.