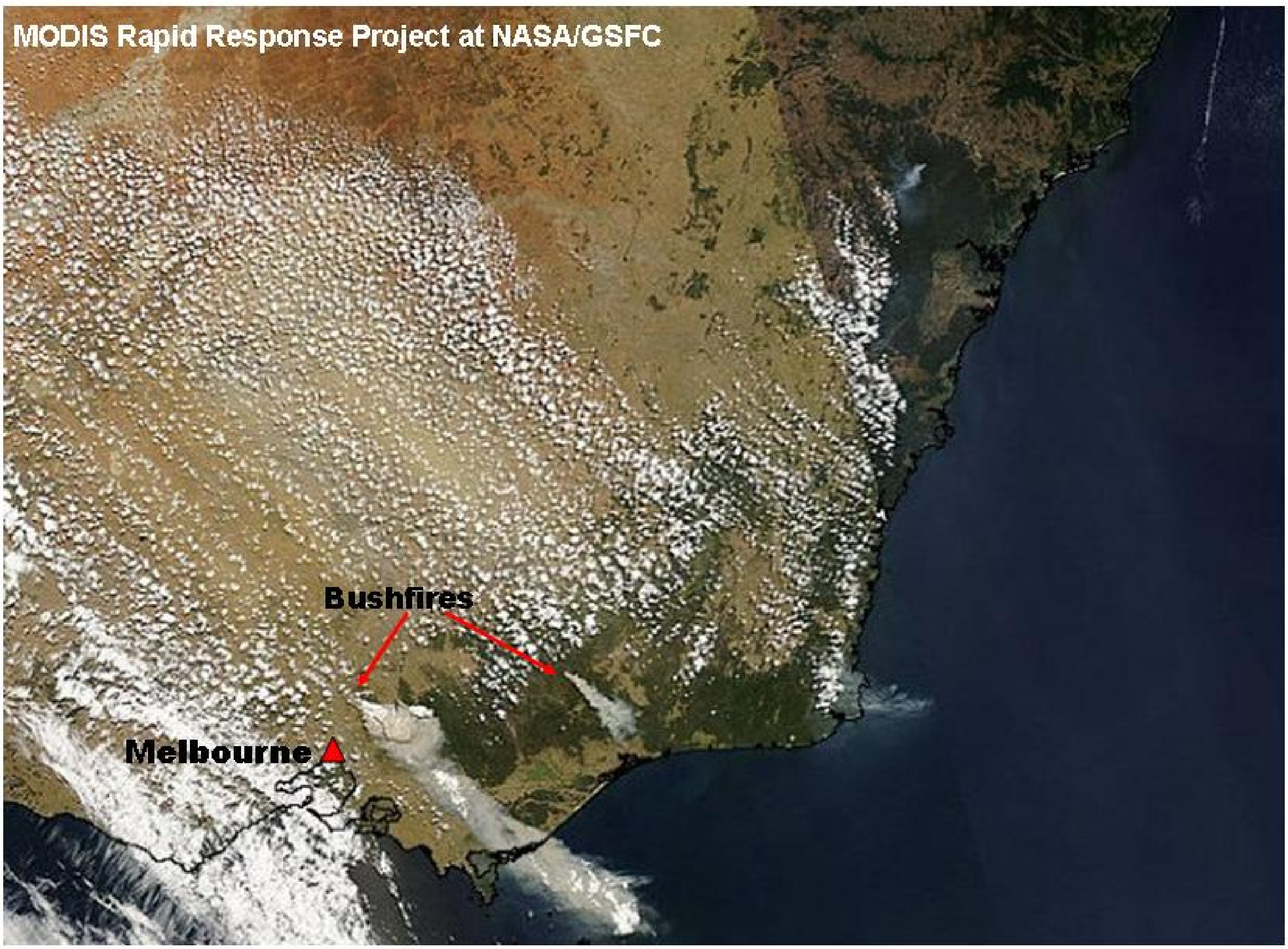
Fire Weather Case Study

Victoria, Australia Bushfires

"Black Saturday" February 7, 2009



Smoke plumes over Victoria, Australia on February 7, 2009

Background Information:

Australia experienced a natural disaster of historic proportion on February 7, 2009 when bushfires swept across the state of Victoria. These fires killed 173 people, destroyed more than 2,000 homes and burned 421,000 hectares (1,040,312 acres). Most of the fatalities occurred in a few small communities where people were either trapped in their homes or perished in their cars trying to flee rapidly moving flames.

Victoria is located in the southeastern corner of Australia and is the smallest mainland state (figure 1). Although small, Victoria contains many diverse climatic areas, ranging from semi-arid and hot in the northwest, to temperate and cool along the coast. The Victorian Alps, in the northeast, are the coolest part of Victoria. The Alps extend east-west through the center of the state and rise to almost 2,000 meters (6,500 ft). Melbourne is Victoria's capital and largest city and is home to over 70% of the state's population.

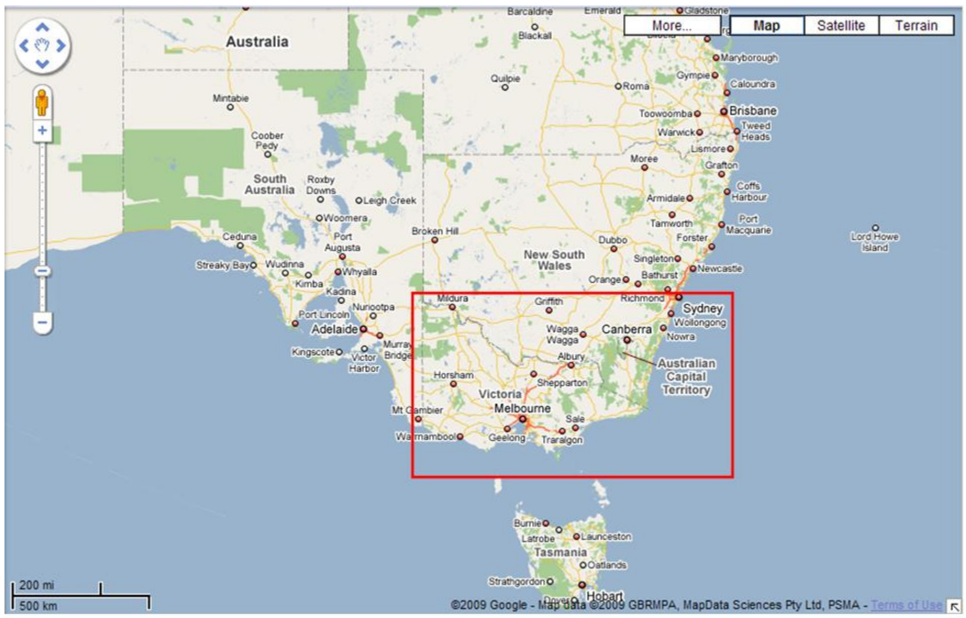


Fig. 1 Melbourne area located in southeast Australia

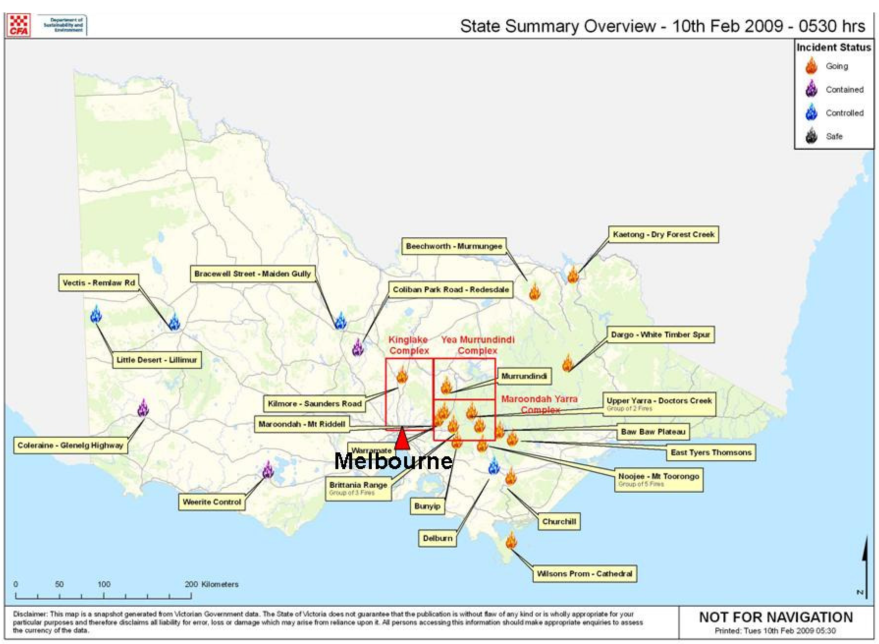


Fig. 2 Location of major fires in the Melbourne area

More than two dozen large fires ignited on February 7, 2009, most of which were located north and east of Melbourne (figure 2). Downed power lines ignited many of these fires, but a few were thought to be arson caused.

Case Study Objective:

The intent of this report is to analyze weather conditions on February 7, 2009 to determine whether a 'critical fire weather pattern' contributed significantly to the extreme fire behavior observed on these fires. Extreme fire behavior is often exhibited when there is a sudden increase in fireline intensity and/or rapid fire spread rates preclude direct control or upset existing suppression plans. 'Critical fire weather patterns' are defined as atmospheric conditions that encourage extreme fire behavior resulting in large and destructive wildland fires.

Weather Discussion:

An intense heat wave gripped much of Australia prior to the outbreak of the bushfires. A strong 500 hPa (500 mb) ridge of high pressure persisted over southern Australia between January 25th and February 7th (figure 3). Meanwhile, the surface pressure pattern (figure 4) consisted of high pressure east of Melbourne over the ocean with low pressure centered over the Western Australian desert. The combination of high pressure in the upper atmosphere and low pressure over interior Australia produced hot, dry and windy weather throughout Victoria.

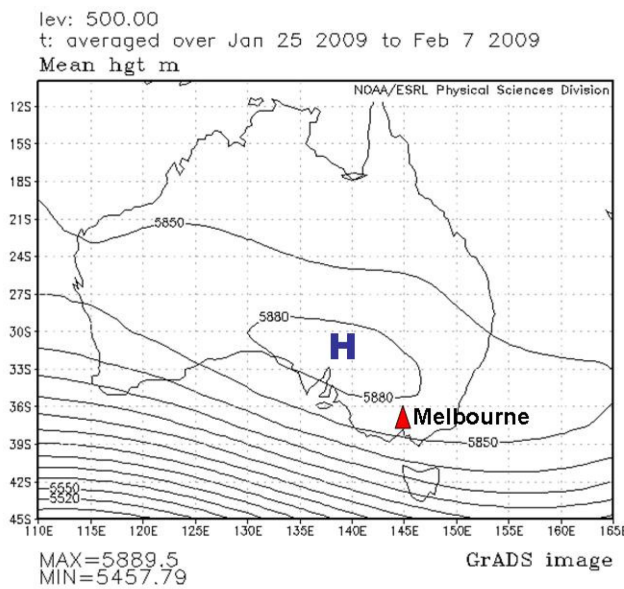


Fig. 3 500 hPa Pressure Pattern Jan 25 – Feb 7, 2009

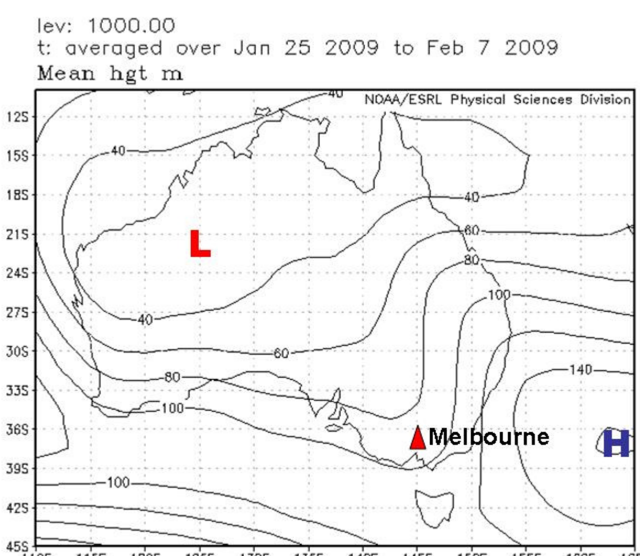


Fig. 4 Surface Pressure Pattern Jan 25 – Feb 7, 2009

During this time period, maximum temperatures were consistently 35-42 degree C (95-108 degree F) and minimum relative humidity was in the 10-20% range. Peak wind gusts of 45-55 km/hr (25-35 mph) were reported at Melbourne a few days prior to the bush fire outbreak. These conditions resulted in intense drying of wildland fuels, making them extremely susceptible to ignition.

The upper air weather pattern on February 7, 2009 was similar to that which had been experienced the previous two weeks. High pressure at 500 hPa was centered along the southeastern Australian coast near Sydney (figure 5). The center of the high was approximately 5891 meters with the 5880 meter contour line, extending across much of eastern Australia and well into the interior. These heights indicated that this was a strong area of high pressure in the upper atmosphere, but not unusually strong for the Australian summer. Meanwhile, a low pressure system was rapidly moving from west to east over the Southern Ocean toward Tasmania. An upper trough from the center of the system / low extended northward to the southwestern Australian coast. The center of the upper low was at least 5160 meters, indicating it was particularly strong for summer.

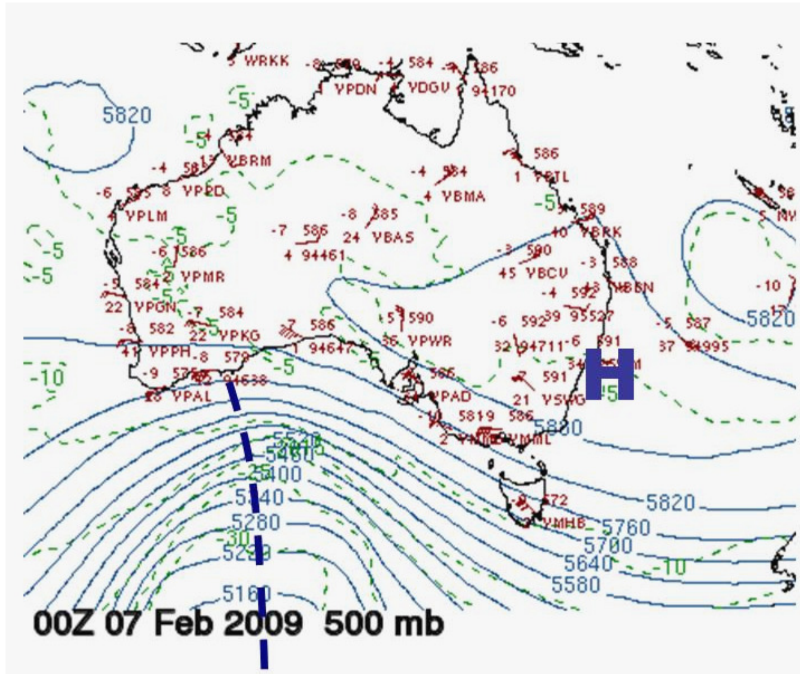


Fig. 5 500 hPa (500 mb) chart 07 Feb 11 AM EDT

The surface pattern (figure 6) showed high pressure (centered between New Zealand and Australia) and a cold front over the Southern Ocean moving east toward Victoria and Tasmania. A surface thermal trough was located ahead of the front extending from Western Australia to the southeastern corner of Victoria. This thermal trough was most likely caused by intense heating of the ground, resulting in lower surface pressure.

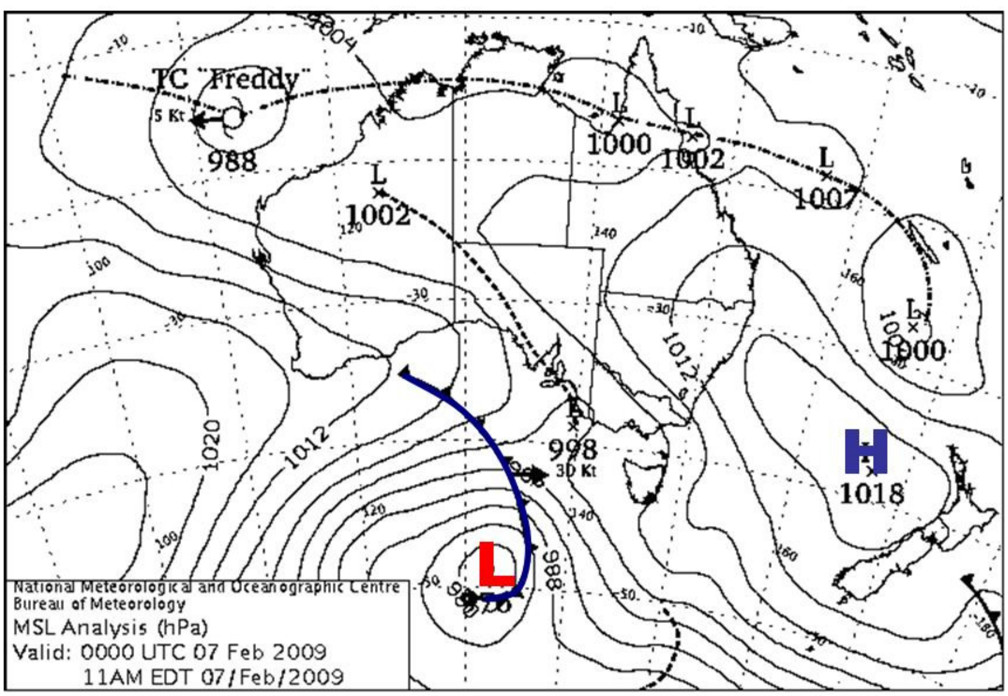


Fig. 6 Surface pressure pattern 07 Feb 11 AM EDT

Victoria was situated between these two pressure centers, west of the high pressure center and east of the upper trough. A transition zone between pressure patterns often experiences extreme weather conditions, such as gusty winds and hot temperatures.

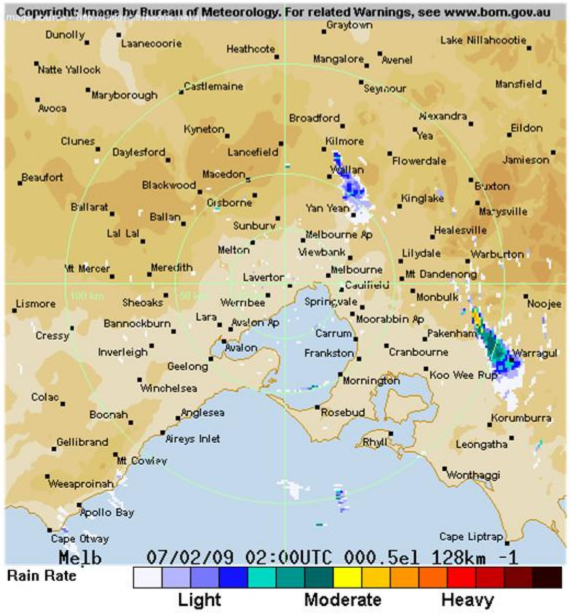


Fig. 7 Smoke plumes on Melbourn

The first fires, as depicted by Melbourne weather radar (figure 7), were already well established at 1300 EDT to the north and southeast of Melbourne in the vicinity of Kilmore (Kilmore East Fire) and Pakenham (Bunyip Fire). Orientation of the smoke plumes indicates a general wind flow from northwest to southeast.

The 2000 EDT radar map (figure 8) showed numerous fires in an arc from the north to southeast of Melbourne, with a greatly expanded area of smoke. Winds were still pushing the smoke toward the southeast.

Fig. 8 Smoke plumes on Melbourne radar at 8 PM EDT

Critical Weather Elements:

There are four critical weather elements common to large and destructive wildland fires: 1) low atmospheric moisture / relative humidity, 2) strong wind, 3) unstable air, and 4) drought. Low relative humidity must always be present for development of large and intense wildland fires. (Note: Regional values can vary between 15% and 40%, depending upon fuel model.) In addition to low relative humidity, either strong wind or unstable air must also be present.

Drought is often associated with large timber fires, but is not necessary for large grass fires. We will now examine how many of these elements were present during Victoria's February 7th fires.

1) Low Atmospheric Moisture:

Dry air in lower levels of the atmosphere (i.e. low relative humidity) significantly lowers the moisture content of fuels, making it easier for them to ignite and carry fire. Low relative humidity (RH) increases the probability of spotting as firebrands are lofted into the air and fall in unburned fuel, resulting in new fire starts.

Figure 9 is a graphic of the RH at 925 hPa (925 mb) or approximately 700 meters ASL over southeastern Australia at 1700 EDT on February 7th. It shows a band of very dry air across Victoria with RH of less than 20 percent.

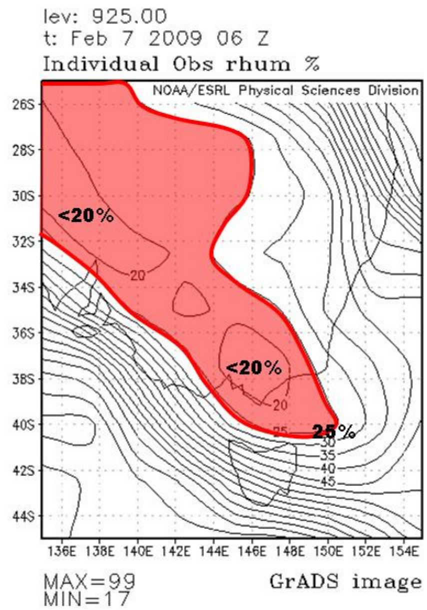


Fig. 9 Very dry air over Victoria, Aus at 5 PM EDT

Figure 10 charts the February 2009 daily maximum temperature and 1500 EDT RH at Melbourne Airport. February 7th was clearly the hottest and driest day of the month with a maximum temperature of 46.8 degree C (116 degree F) and RH of 10 percent. Average February maximum temperature is only 26.5 degree C (80 degree F) and average 1500 RH is 44%. The 46.8 degree C set an all-time daily maximum record at Melbourne Airport.

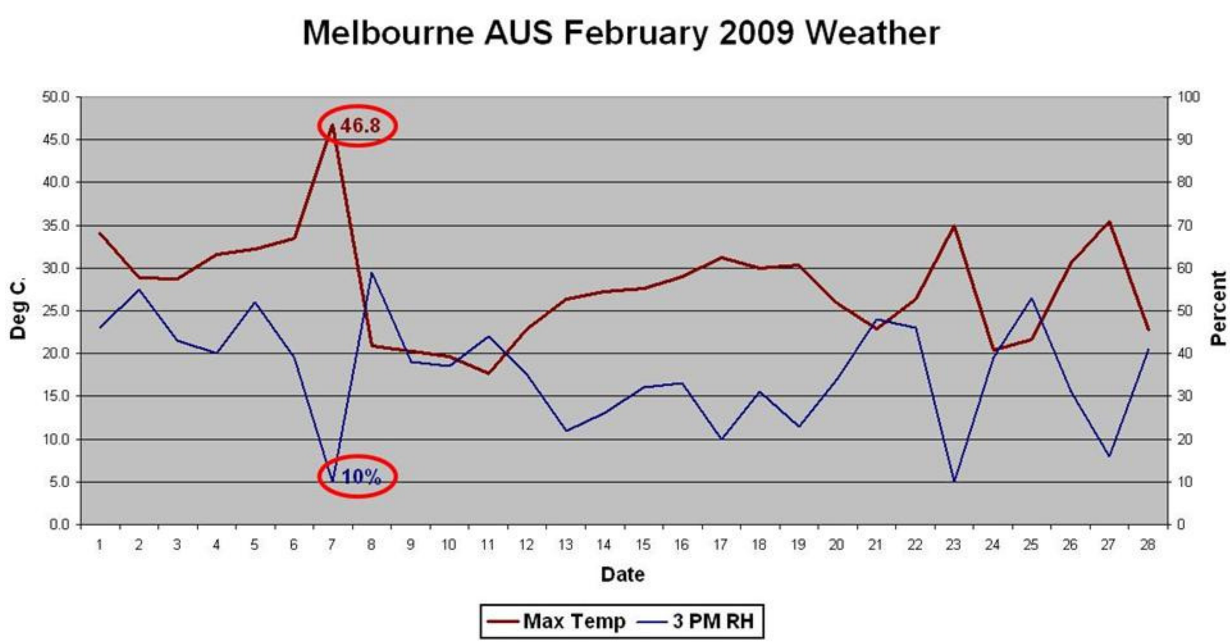


Fig. 10 Melbourne, Aus February Max Temp and 3 PM RH

The combination of hot temperatures and low relatively were truly exceptional. Thus, it can be concluded that:

<u>Low atmospheric moisture was a critical element in extreme fire behavior experienced during the Victoria Bushfires</u>.

2) *Strong Wind:*

Extreme burning conditions have been associated with strong frontal, thunderstorm and foehn winds. Wind affects wildland fires in a number of ways. Wind:

1) supplies additional oxygen to the fire, increasing fire intensity
2) preheats fuels ahead of the fire, and
3) increases rate of spread by carrying heat and burning embers to new fuels.

Strong wind produces wind-driven fires.

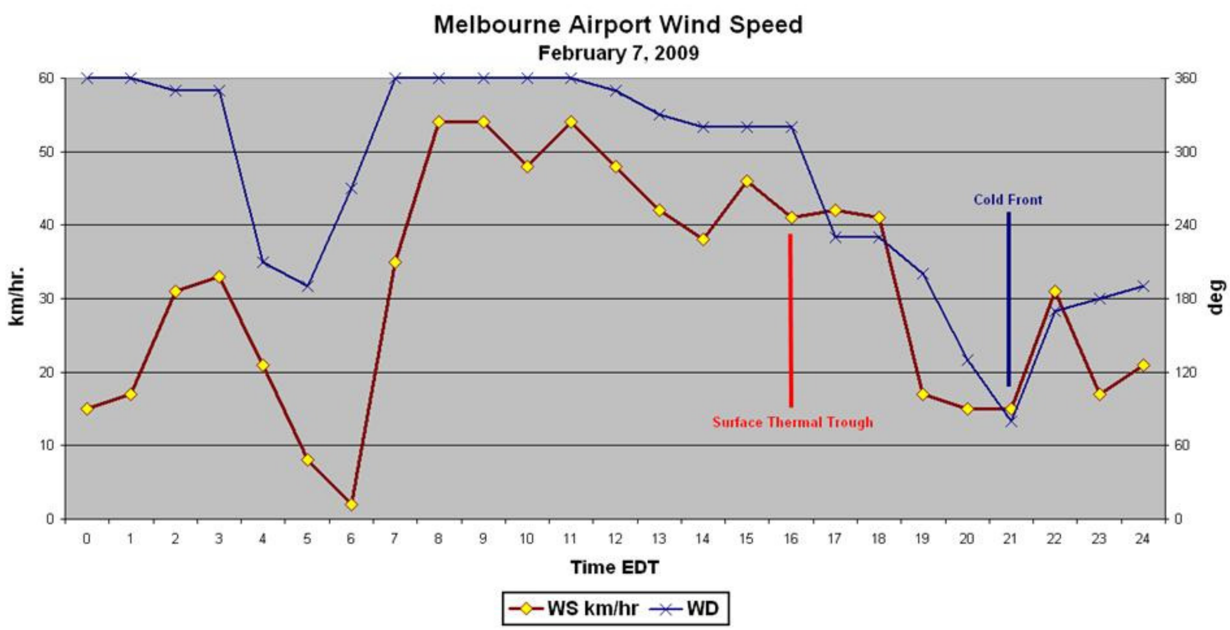


Fig. 11 Melbourne Airport Wind Feb 7, 2009

Wind at Melbourne Airport on February 6th was primarily from the south at 15-25 km/hr. A southerly wind at Melbourne Airport is typical during the summer months and results in moderating temperatures and RH, as these winds originate from the Southern Ocean. At about 2300 EDT on February 6th the wind shifted to the north and steadily increased until reaching a peak of 33 km/hr at 0330 EDT on the 7th (figure 11). It then reverted back to a south and southwest wind until 0600 EDT. At 0630 EDT, the wind abruptly shifted back to the north again and dramatically increased to 35 km/hr. By 0730 EDT, the wind was blowing at 46 km/hr with gusts to 70 km/hr. Meanwhile, the RH plummeted to 20%. Strong northwest to north winds of 40-55 km/hr with gusts as high as 81 km/hr continued to blow through 1600 EDT. During this period, RH remained extremely low, generally less than 10% and as low as 4%.

Around 1630 EDT, the surface thermal trough moved across Melbourne Airport and wind direction shifted to the southwest. RH increased to 20-30%, but the wind still continued to blow hard at 35-50 km/hr. It wasn't until 1900 EDT that the wind significantly diminished to 15-25 km/hr. The surface cold front moved through Melbourne Airport at 2100 EDT. RH rapidly increased to 80% or more by 2200 EDT. Thus, the period of strong wind and low RH on February 7th lasted approximately 16 hours, from 0600 EDT until 2200 EDT. It was during this timeframe that the numerous bushfires north and east of Melbourne Airport exhibited extreme fire behavior and experienced the greatest growth.

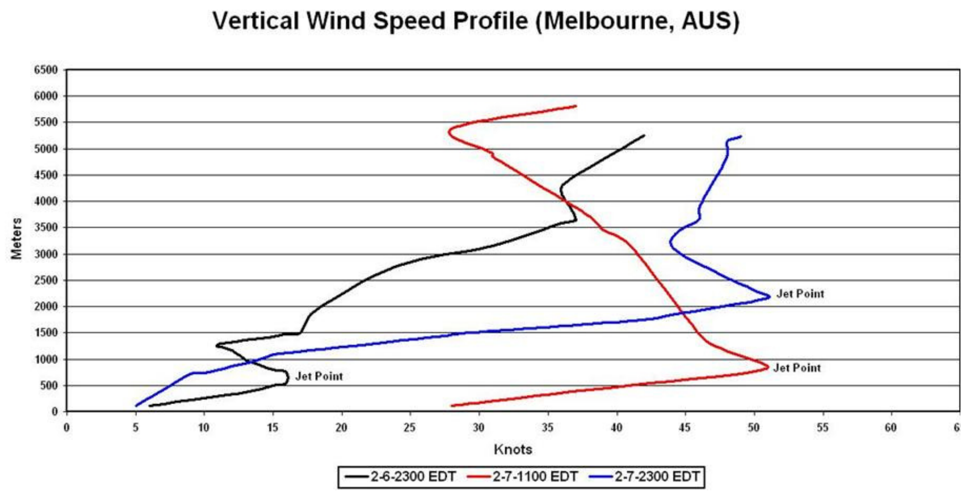


Fig. 12 Vertical wind speed profile Feb 6 – 7, 2009

The presence of a low level jetstream (figure 12) was captured by Melbourne Airport radiosonde at 1100 EDT on February 7th, just prior to the large outbreak of wildland fires north and east of the airport. Surface wind speed was 28 knots (52 km/h) with a 51 knot (94 km/h) jetstream maximum located at an elevation of 829 m. At 2300 EDT surface wind speed dropped to 6 knots (11 km/h), with the 50 knot (93 km/h) jetstream maximum elevated to 2162 m.

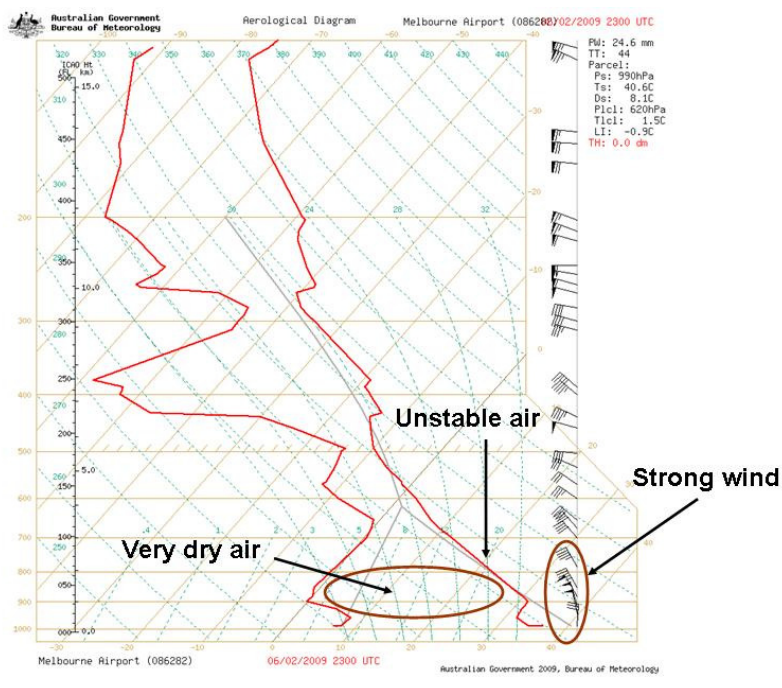


Fig. 13 Melbourne Airport radiosonde 07 Feb 11 AM EDT

Byram (1954) classified this wind profile as a Type 3-c, which can be very dangerous. However, with fires burning at or near the jetstream point elevation (500-1000 meters), the vertical wind profile would show strongest winds at the surface with decreasing winds aloft. This changes Byram's wind profile to 1-a, which he states is, "the most dangerous type from the standard of personal safety and erratic and unpredictable fire behavior." With this wind profile, rapid rates of spread (ROS) are experienced with development of fire whirls and long range spotting. A towering convection column is likely to form.

The Skew-T / Log-P diagram (figure 13), created using February 7th 1100 EDT Melbourne Airport radiosonde data, clearly indicates the presence of strong wind and very dry air in lower levels of the atmosphere which surfaced during the heat of the day.

Strong wind was definitely a critical element in the extreme fire behavior experienced during the Victoria Bushfires.

3) Unstable Air:

Unstable air enhances vertical motion in the atmosphere. As with wind, upward movement of air increases combustion by supplying more oxygen to a fire. It also enhances vertical growth of the smoke column. As height and strength of the smoke column increases, the potential for gusty surface winds, dust devils and fire whirls also increases. Spotting may become profuse all around the fire as large firebrands are lifted in the smoke column. Unstable air increases the probability of plume-dominated fires.

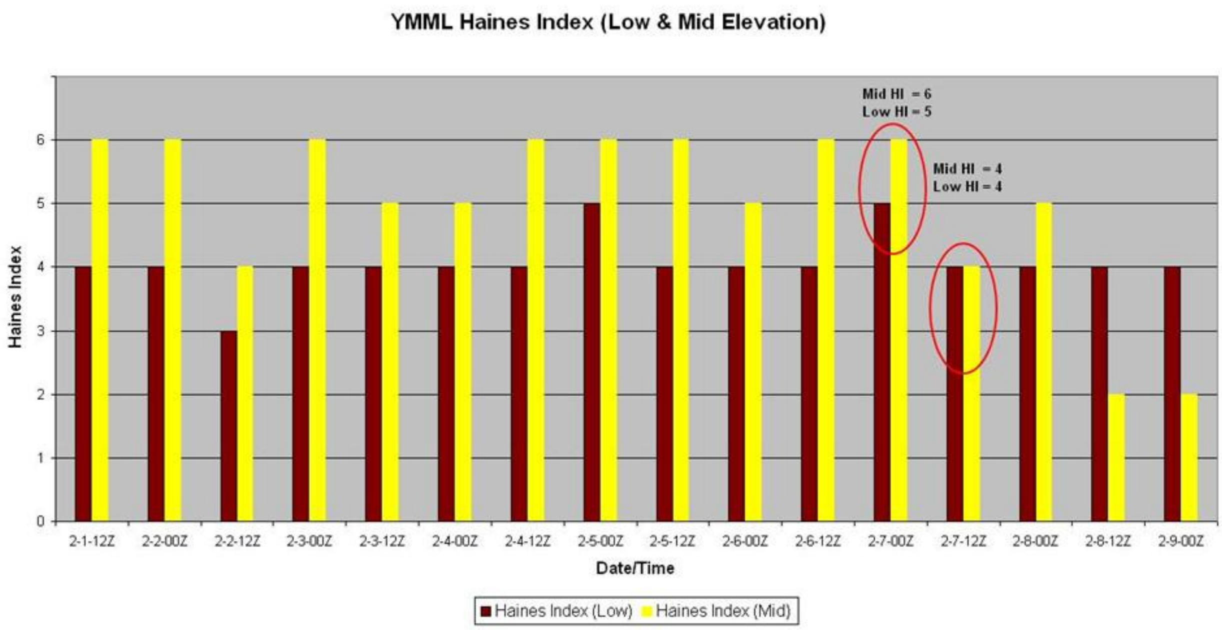


Fig. 14 Melbourne Airport Haines Index (Low and Mid Elevation)

The Haines Index (Haines 1988, Werth and Ochoa 1993) is a good indicator of unstable air. It combines stability and dryness of the lower atmosphere into an index that correlates well with large fire growth. The Index ranges between 2 and 6. Values of 2 and 3 are indicative of moist, stable air. Values of 5 and 6 indicate dry, unstable air. Low and mid-elevation Haines Index values for the Victoria bushfires (figure 14) were calculated using Melbourne Airport radiosonde data for 00Z (1100 EDT) and 12Z (2300 EDT). The mid-level Haines Index was primarily a 6 prior to the fire siege, indicating a long period of unusually dry, unstable air over Victoria.

Meanwhile, the low-level index was moderately stable and moist. On the morning of February 7th the mid-level index was 6 and the low-level was 5, indicating a deep layer of dry, unstable air through the 70 hPa level (3146 m). Both the low and mid-elevation Haines Index values dropped to a 4 by 2300 EDT that evening due to passage of a cold front that brought more stable and moist air inland from the Southern Ocean.

The low and mid-level Haines Index indicate that unstable air was a critical element in the extreme fire behavior experienced during the Victoria Bushfires.

4) ***Drought:***

Drought affects fuel availability by lowering moisture content of both live and dead fuels, making them more combustible. Drought conditions are NOT a prerequisite for fires to occur and spread, but there is a close relationship between drought conditions, large wildland fires and extremely difficult fire suppression.

The long-term Australian drought condition prior to the outbreak of bushfires is shown in Figure 15. It displays 20-month rainfall deficiencies between June 1, 2007 and January 31, 2009, showing severe deficiency in much of Victoria and South Australia. The rainfall percentile ranking was in the lowest 5-10% of the historical record. A drought of this length would certainly lower moisture content of dead and live vegetation.

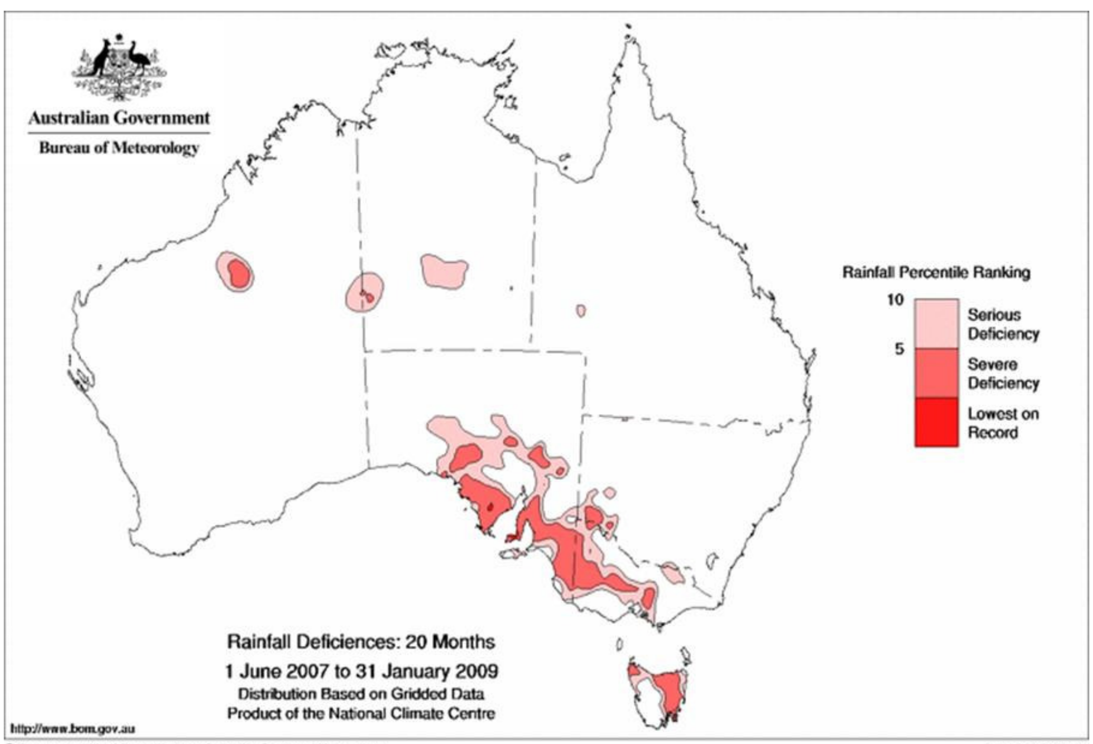


Fig. 15 Rainfall Deficiency 1 June 2007 to 31 January 2009

Figure 16 displays Melbourne monthly precipitation from February 2008 through January 2009. Nine of the twelve months were much drier than usual, and twelve-month total precipitation was only 69% of average. December 2008 was wet, but January 2009 was particularly dry with only 1.6 mm recorded, or only 4% of normal.

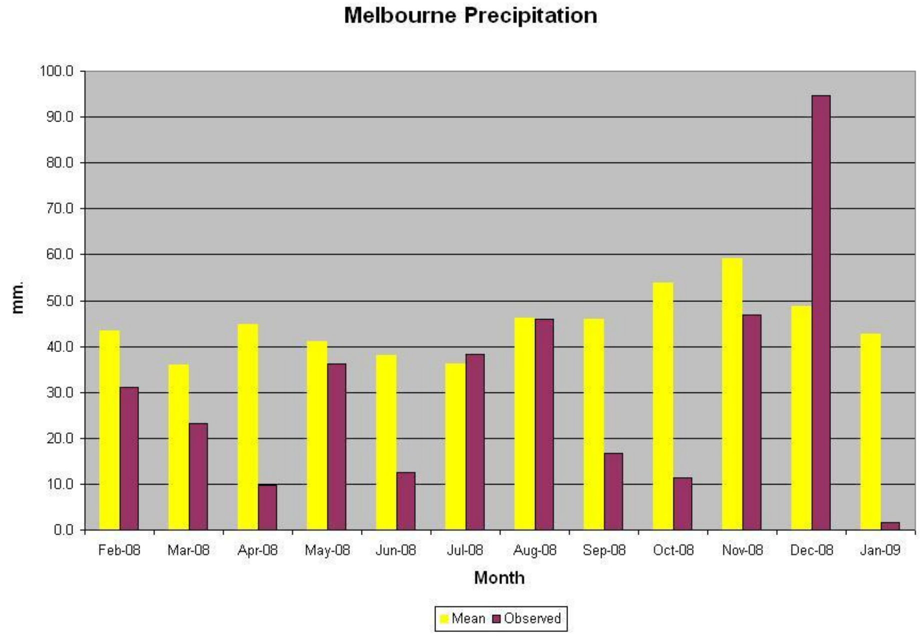


Fig. 16 Melbourne precipitation Feb 2008 to Jan 2009

Drought was a critical element in the extreme fire behavior experienced during the Victoria Bushfires.

In summary, all four critical weather elements were present during the Victoria Bushfires.

Critical Fire Weather Pattern:

A 'critical fire weather pattern' is defined as the atmospheric conditions that encourage extreme fire behavior resulting in large and destructive wildland fires. In this section, we will determine whether a critical fire weather pattern significantly contributed to the February 2009 Victoria bushfires and, if so, what that critical weather pattern was.

The concept of critical fire weather patterns has been around for many years, but it has been not been operationally used in fire weather forecasting. While individual weather elements are highlighted in fire weather forecasts, they are not connected to cyclical large-scale atmospheric patterns that continually change on a daily and seasonal basis.

The first publication concerning critical fire weather patterns was "Synoptic Weather Types Associated with Critical Fire Weather" by Schroeder et al. (1964). This study covered the United States (except Alaska and Hawaii) and concluded that **"periods of critical fire weather are associated with relatively few weather patterns."**

"Predicting Major Wildland Fire Occurrence" by Ed Brotak and William Reifsnyder (1977) detailed the relationship between central and eastern United States wildland fires and surface frontal systems and upper level troughs and ridges.

"Wildfire Behavior Associated with the Upper Ridge Breakdown" by Nicholas Nimchuk (1983) documents the relationship of the breakdown of an upper level ridge with extreme fire behavior conditions in western Canada.

All of these publications connect weather elements known to be associated with large destructive wildland fires (i.e. strong surface winds, unusually low relative humidity, unstable air) to specific upper level and surface pressure patterns.

One of the best documented critical fire weather patterns is 'Breakdown of the Upper Level Ridge' by Nimchuck (1983) and Werth and Ochoa (1993). There are three defining factors of this pattern:

1. a strong upper level ridge at 500 hPa (500 mb) that is moving eastward
2. an advancing upper level trough from the west
3. a surface cold front and/or surface thermal trough situated between the upper level ridge and upper level trough

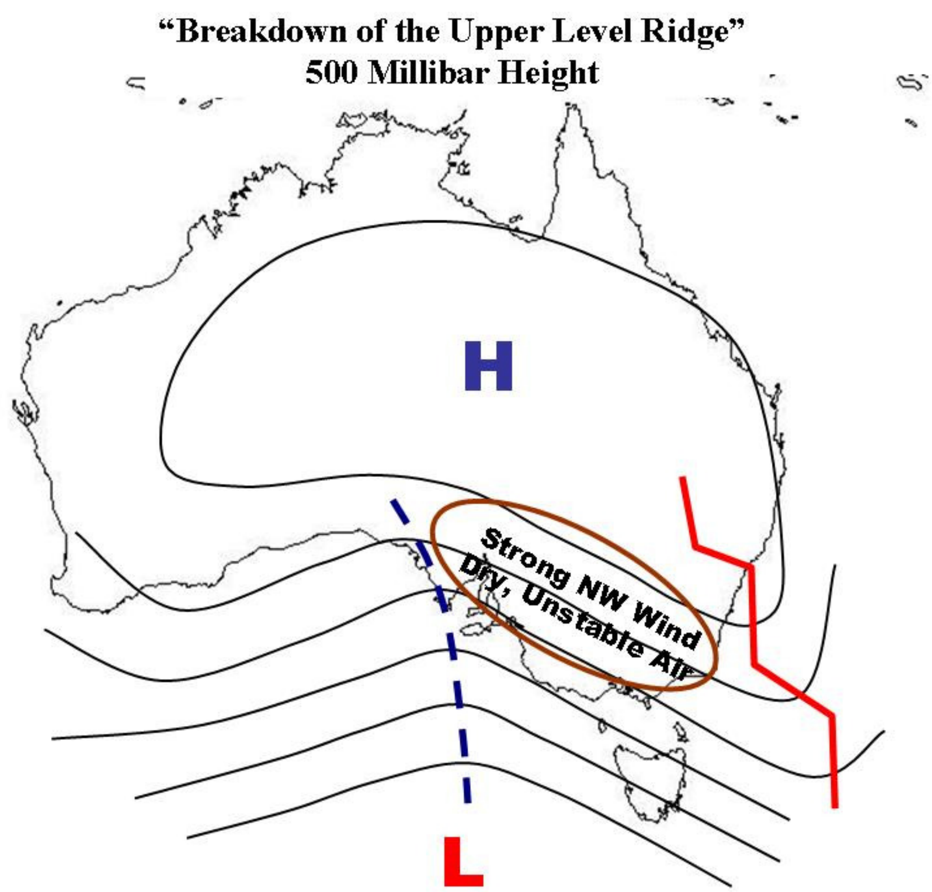


Fig. 17 Critical Fire Weather Pattern – 500 hPa Level

This pattern, combined with low atmospheric moisture and long-term drought, is a recipe for sudden and extreme fire behavior. This summer-weather pattern typically produces hot temperatures, very low relative humidity, unstable air, strong gusty wind, and possible dry lightning. Individually, each of these weather elements can cause fire problems but, when combined, can frequently produce large and destructive fires.

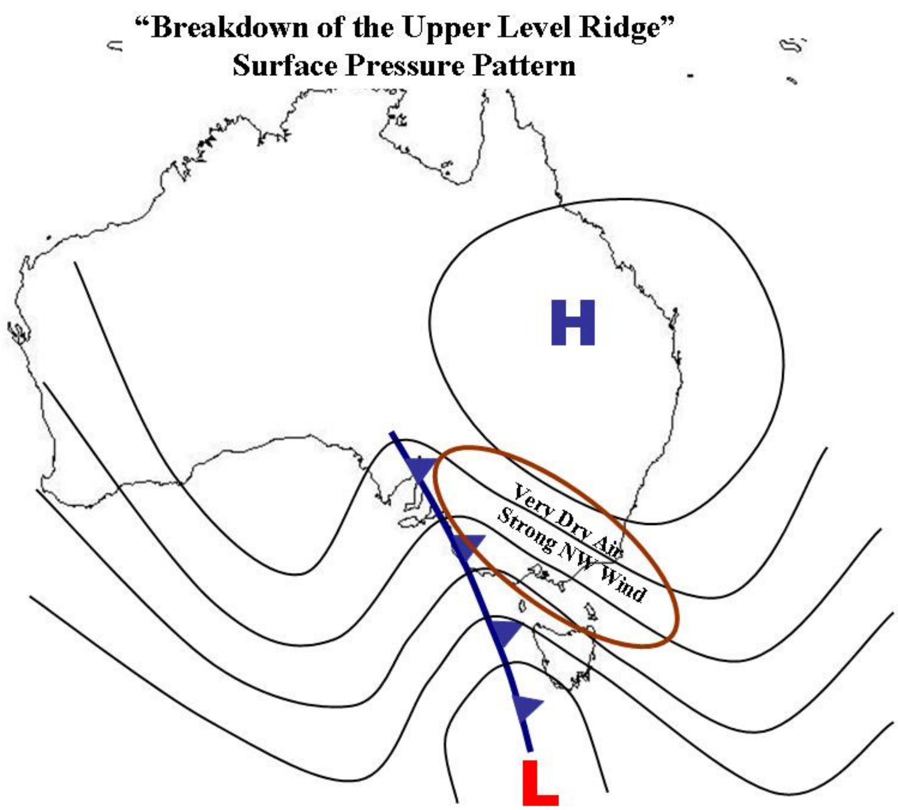


Fig. 18 Critical Fire Weather Pattern – Surface Pressure

Victoria's upper level and surface weather maps (figures 5 and 6) for February 7, 2009 are markedly similar to those shown for an idealized Australian version of the 'Breakdown of the Upper Ridge' critical fire weather pattern (figures 17 and 18). The weather and fire behavior documented by firefighters and the public during this wildland fire siege are consistent with extreme weather associated with this pattern.

Summary:

Australia experienced bushfires of historic proportion on February 7, 2009, killing 173 people, destroying over 2,000 homes, and burning 421,000 hectares (1,040,312 acres) in the state of Victoria.

Based on the weather pattern of the day, observed surface weather data, and eyewitness accounts, it can be concluded with a high level of confidence that a 'Breakdown of the Upper Ridge' critical fire weather pattern significantly contributed to the severity these bushfires.

Acknowledgements:

The author would like to thank Tony Bannister and Kevin Parkyn (Victorian Region Office, Australia Bureau of Meteorology), Rick Ochoa (Predictive Services, National Interagency Fire Center, Boise Idaho) and John Saltenberger (Predictive Services, Northwest Geographic Area Coordination Center, Portland Oregon) for reviewing the document and providing insightful comments. I also thank my wife, Victoria for her considerable help in editing and formatting this case study. The time and effort these individuals provided is very much appreciated.

References:

Australian Government Bureau of Meteorology.

Brotak, E.A.; Reifsnyder, W.E. 1977: Predicting major wildland fire occurrence. Fire Management Notes. 38: 5-8.

Byram, G. M., 1954: Atmospheric conditions related to blowup fires. Sta. Pap. 35. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 34 p.

Fires and Incidents: Australia County Fire Authority. http://www.cfa.vic.gov.au/about/history/about_black_saturday.htm (Feb. 7, 2012)

Haines, D.A., 1988. A lower atmospheric severity index for wildland fire. National Weather Digest. 13: 23-27.

Nimchuk, N. 1983: Wildfire behavior associated with upper ridge breakdown. Report T/50. Edmonton, AB: Alberta Energy and Natural Resources, Forest Service. 45 p.

Stories from the Fire Front: Australian Broadcasting Corporation.

Schroeder, M.J. et al. 1964. Synoptic weather types associated with critical fire weather. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 493 p.

Victoria Bushfires: The Australian Newspaper. http://www.theaustralian.com.au/in-depth/victoria-bushfires (Feb. 7, 2012)

Werth, P.A.; Ochoa, R. 1993: The evaluation of Idaho wildfire growth using the Haines Index. Weather and Forecasting. 8(2): 223-234.

Author of this study:

Paul Werth, Fire Weather Meteorologist
Weather Research and Consulting Services, LLC
Battle Ground, Washington USA