Bushfire Convection and the Wind field

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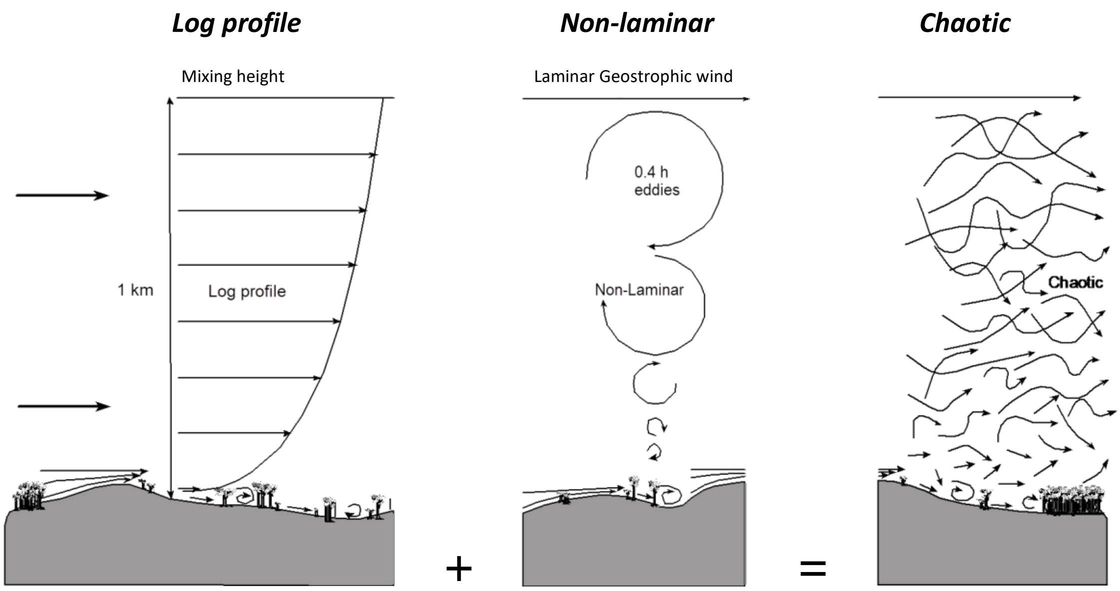
The interaction of wind with atmospheric temperature profiles and the topography, and its influence on bushfire behaviour is a complex subject. In this article I will discuss the interaction of the wind field of a typical dry-season day with the convection of a fire burning over level ground. The resultant pattern of wind around the fire is similar in both grassfires and forest fires, but the strength and extent depends on intensity of the fire.

The wind field is the three-dimensional spatial pattern of wind strength and direction in the air above the ground. It is influenced by differential heating on the ground surface, the change of temperature with altitude, disturbance by vegetation, and interaction with the topography. Let's look at a diagrammatic progression from an average theoretical wind profile to real life.



Log profile *- The average wind speed is assumed to increase in this pattern up to the mixing height (1km). Above the mixing height the geostrophic wind layer is laminar.*

Non laminar *- Within this layer are roll-eddies moving with the prevailing wind. The top eddies are large and slow (e.g. one rotation in 0.4 hr). Closer to the ground they are smaller and faster.*

Chaotic *- The combination of eddies in the prevailing wind produces a wind field that generally increases in speed with height but at any point varies greatly in strength and direction.*

Figure 1. Formation of the wind field

The height of the mixing layer is usually associated with an inversion layer where the temperature of the air is slightly higher than the temperature below. The height of the mixing layer can be low at night and increases during the day as the ground surface warms. Forecasts of the mixing height are provided by the Bureau of Meteorology on a three hourly basis in 7 height classes from <500m to >4,000m, which shows the change in mixing height during the day across Australia and can be accessed on Meteye.

At ground level the wind interacts with the topography and the vegetation. The wind speed generally increases on windward slopes and decreases on lee slopes or forms lee-slope eddies.

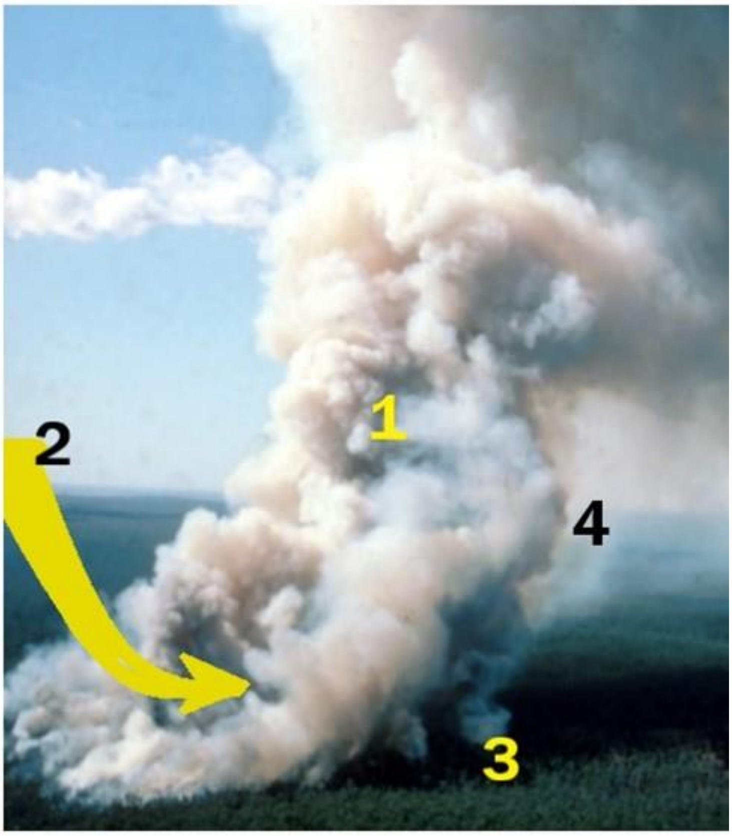
This means that measurements of wind speed and direction near the ground can be very different even when the locations are quite close to each other. Although the mean wind speed over a period of 15-20 minutes may be similar at different locations, the timing and strength of gusts and lulls can be quite different.

Although a fire has no mass and thus does not accelerate, it does grow in size. The convective interaction with the wind field determines whether the fire will increase in rate of forward spread to the full potential for the prevailing weather, or stabilise at some intermediate spread rate.

Interaction of fire convection

A fire transfers energy by convection, radiation and conduction. About 75% of the total energy generated by combustion of grassland and forest fuels is transferred as convective energy, 20% as radiant heat and < 5% as conducted heat. While radiant heat is important in the pre-heating of fuel prior to ignition and personal safety, it is the convective energy that is carried aloft that determines the size and the strength of the convection column.

The interaction of convection with the wind field around an experimental fire is shown in Figure 2. The prevailing wind field pushes the convection column (**1**) forward and its size and strength interacts with the wind speed and direction near the ground. This in turn determines the shape of the fire, the angle of the flames in relation to the fuel bed, and thus the growth of the fire to its potential rate of spread for the prevailing weather conditions.



1. *Rising combustion gasses entrain the prevailing wind and form a barrier to its passage downwind.*
2. *Area of downdraft into the back of the flame-zone.*
3. *Surface winds being drawn towards the flame-zone.*
4. *Wake zone directly downwind of the convection column.*

Figure 2. **Convection column above an experimental forest fire**

The convection column entrains the wind as it rises, but the air entering the flame zone at ground level comes primarily from the up-wind side and creates a downdraft (**2**) behind the flame zone. In Figure 2 the smoke at the centre behind the headfire fire is compressed which, in turn, speeds up the wind near the ground blowing into the back of the flame zone. *(During experiments with large fast moving fires in annual grasslands where there was almost no residual combustion behind the flames we could walk comfortably close to the back of the head fire where the air in this downdraft was smoke-free. Further windward inside the fire was smoky and not nearly as pleasant).*

Surface winds around the head are drawn toward the convection centre (**3**) and draw spot fires toward the headfire.

The convection column acts as a physical barrier to the wind field creating a wake zone (**4)** downwind of the headfire. A generalised schematic of the surface wind in and around a moving fire is shown in Figure 3.

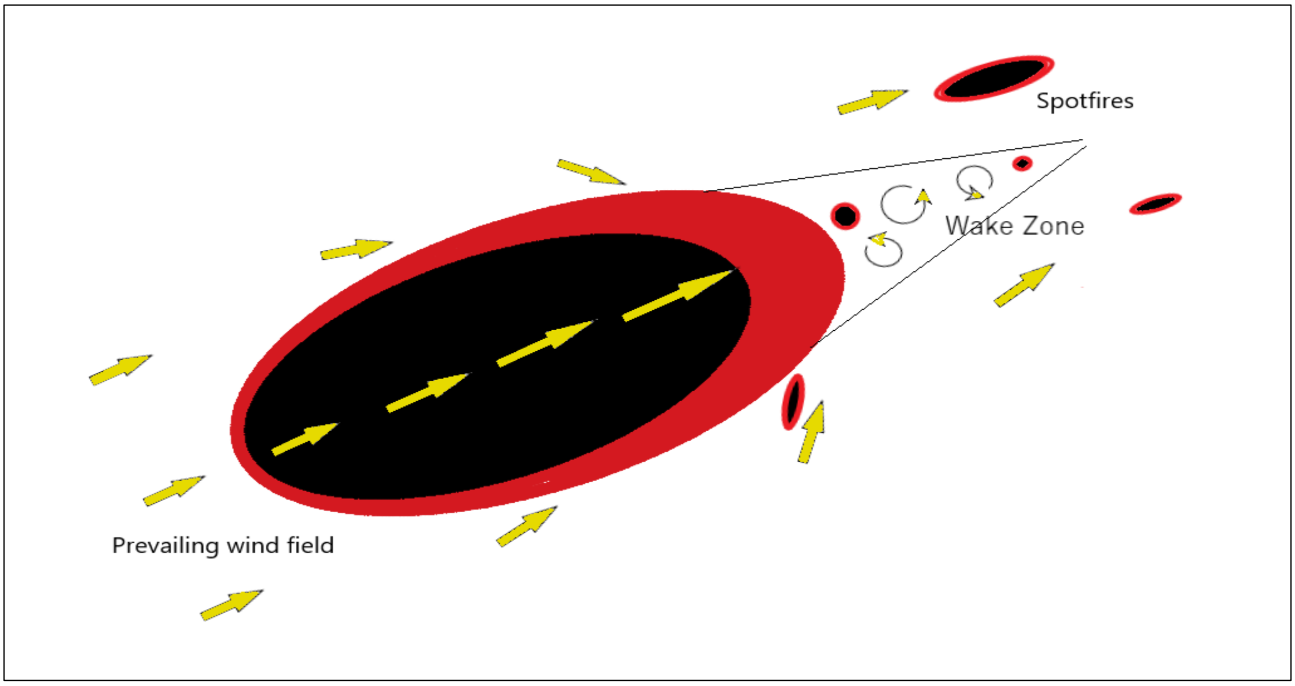


Figure 3: The surface wind field around a moving fire *(length of arrow illustrates relative wind speed)*

The prevailing wind entering the back of fire area speeds up, initially due to removal of surface vegetation, and as it approaches the headfire it is accelerated by the downdraft into the back of the flame zone. Around the flanks wind is drawn towards the flames from both the burnt and unburnt ground at an increasing angle towards the centre of convection at the head fire. In the area of the wake zone immediately in front of the fire very little wind enters the flame front from unburnt ground apart from entrainment of eddies directly into the flames as they rise. However, if there is a pronounced lull in the prevailing wind the convection column will straighten and the convective centre will move back into the burnt area. When this happens the forward spread will stall dramatically and flames will be drawn towards the burnt-out area all around the perimeter. This will persist until there is either an increase in the prevailing wind or the fuels burn out to the point where the convection from the fire area weakens so that the prevailing wind can again push the convection column forward again.

The Wake Zone

A wake zone (Figure 3) will form on all fires that are intense enough to form a convection column. Wind in the wake zone is light and variable and usually associated with light drift smoke. Spot fires are roughly circular and only drawn into the headfire when it is very close. Spot fires to the side or beyond the wake zone respond to the wind strength and direction at their location. This wake effect does not occur when fires are burning very little fuel (e.g. light grasses) and the prevailing wind is able to suppress all convection and blow flames and smoke directly along the ground.

On very large intense forest fires the wake zone may extend several kilometres downwind. This becomes an important safety issue for firefighters and residents in the path of the fire particularly if the convection column also blocks out the sun and it becomes very dark. People in the area often assume that the prevailing wind has dropped and leave safe areas to attack spot fires because they are small and burning quietly. They are totally overwhelmed when the front arrives and are exposed to the full impact of the headfire and the force of the accelerated downdraft driving it.

This phenomenon is difficult to appreciate without first-hand experience so I have included some images taken during the Canberra fires on 18 January 2003 to give some idea of the conditions in front of a major fire.

A. *Fire on Mt Stromlo circa 1500 hr (A. Milgate)*

B. *Fire approaching Duffy @ 1510 hr (Channel 7)*

C. *Convection column circa 1600 hr (T. Jovanovic)*

D. *Conditions at Fisher @ 1603 hr (S. Cheney)*

Figure 4. Images outside and in front of the headfire, Canberra, 18 January 2003

The first pair of images show the first head fire approaching the suburb of Duffy.

Image **A** is the fire burning over Mt Stromlo taken from 8 km north. The wind speed @ 10 m at Canberra airport was 60–70 kmh^{-1}. These flames were not visible on the city side of Mt Stromlo.

Image **B** is the head fire burning towards Duffy through pine forest; conditions in the wake zone 500 m downwind of the head fire are dark, partially illuminated by fire with light winds. Inexperienced firefighters thought they could control the approaching fire.

The second pair of photos were taken around 1600 hr when the fire was at its peak and the second headfire was burning into the suburb of Chapman. Winds at the headfire were estimated to be greater than 80 kmh^{-1} and wind in the associated tornado estimated from damage to be in excess of 200 kmh^{-1}**.**

Image **C** was taken from Shannons Flat NSW, 37 km south of the headfire. The height of the convection column is >10 km, well above the mixing height (approx. 5 km) and the condensation level is energised not only by the fire but also by the latent heat of condensation.

Image **D** was taken 3 km directly downwind of where the head fire entered the suburb of Chapman and is burning houses. Conditions are pitch black with variable wind *(The power grid is down and white dots are emergency home lighting).*

Despite these quite terrifying conditions and the loss of 500 houses only 4 people died. People in both urban and rural areas of the ACT were able to shelter in locations where there was insufficient fuel to support fire immediately around them.

Application

In this section I wanted to provide some insight to the convective structure of both the atmosphere and a bushfire and how they interact. The interaction starts immediately the fire starts to spread and is important to explain how fires develop, the implications for fire suppression, and for fire management by low-intensity prescribed fire.

The intensity of a fire and its convective structure depend on the amount and structure of the fuel. The interaction with the convection column and its effect on fire growth is discussed separately for grassland and forest fuel.

Further reading

Fire Weather: 4. Atmospheric Stability. PMS 425-1, National Wildfire Coordinating Group (1970, Reviewed 2021).