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Unusual Phenomena in an Extreme Bushfire

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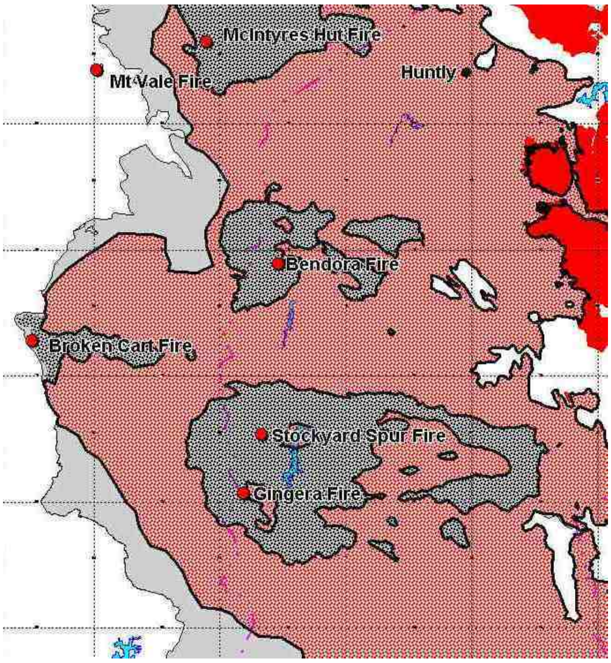

Figure 1: The circles mark the locations of fire ignitions on 8th January 2003. The map includes a 10 km grid for scale. Black stippling indicates areas burnt up to the morning of 18th January, red stippling indicates areas burnt on 18th January, and grey shading shows areas burnt afterwards. The location of Huntly is also shown.

Abstract

Fires burning to the west of Canberra on 18th January 2003 generated a series of cumulonimbus, or pyrocumulus, clouds that may have exacerbated windspeeds as they approached suburban Canberra. Powerful whirlwinds were generated, at least one of which might have been a genuine tornado. In places, fires are reported to have emerged with an intensity that appeared unsustainable by the local vegetation. This suggests that pyrolysed gases might have been able to escape from the incomplete combustion at the fire front in sufficient concentration to ignite and burn elsewhere.

1 Introduction

Lightning strikes during a storm on 8th January 2003 started a number of fires in mountainous countryside West of Canberra, as illustrated in Figure 1. The rugged terrain and the remoteness of these fires made them difficult to extinguish and the fires spread relatively slowly, averaging about 2 km per day over the first 8 days. On 17th January the fire-spread was more rapid, but was still not showing particularly unusual features. The 18th January was different. At one stage, the fires advanced more than 10 km in 45 minutes, entering the west of Canberra. Four people were killed and about 500 homes were destroyed.

Figure 2: Part of the pyro-cumulonimbus created by the fires.

Figure 3: A view of the fires approaching Canberra.

The heat generated by the fires as well as the water vapour released in the combustion products were sufficient to generate cumulonimbus, or pyrocumulus, clouds that rose to a maximum height of about 16 km [6, 8]. Aspects of this are illustrated in Figures 2 and 3. Canberra's 'firestorm' involved some highly unusual phenomena, possibly unprecedented in Australia's recorded bushfire history, that may take some time to be fully understood, let alone predicted with any degree of reliability.

The 'firestorm' was partly distinguished by the appearance of powerful whirlwinds. One, in particular, left a trail of damage as it travelled about 16 km from a point in the mountains west of Canberra to finally enter some of the suburban areas. Figure 4 shows part of the pattern of damage caused to pine trees near

Figure 4: The pattern of felled trees in this aerial photograph (21st January 2003 by AAM Photographics, Sydney) demonstrates the initial passage of a powerful whirlwind, or possibly a fire-induced tornado, running diagonally across the picture.

the whirlwind's inception. It could be that this was a genuine tornado, generated from the growing storm above and touching down where the damage was seen, although there is no truly conclusive evidence to prove this. A very substantial body of hot combustion products might have been able to generate a similar powerful rotation from below, in the same way that air above hot ground is able to generate whirlwinds, albeit greatly strengthened by heat from the combustion. The path of damage from the vortex is not continuous, having a gap of 2.1 km, which would be consistent with a tornado lifting off the ground and touching down again.

Broader details of the fire on and before 18th January have been outlined elsewhere. A commission of inquiry and the various submissions to it (all available online [5]) report some of the information. Other articles describe the atmospheric conditions on the day [8] as well as some aspects of the fire's development [6]. Based on an estimated average fuel consumption of 3 kg per square metre, McRae [6] points out that the fire released the energy equivalent of about 350 kilotonnes of TNT, not explosively of course but distributed over the afternoon of 18th January.

While the scale of the fire on that afternoon was dramatic, this article focuses mainly on two phenomena that were observed by individuals facing the fire in the field. In at least three separate incidents, flames were seen to propagate across open, heavily grazed grassland areas, with a size and intensity that appeared unsustainable by the local vegetation. Another observation was made of a continuous sheet of fire burning *like oil on water* [1] about a metre above ground in a large open area, also with insufficient local vegetation to sustain such a fire.

These observations were made in stressful life-threatening situations and conditions were obviously not ideal for scientific observation. There are relatively few accounts of these phenomena available and subjective estimates might not be reliable. Linescan data from aircraft do not offer frequent enough detail to either back up or contradict the accounts. On the other hand, the observers are experienced fire-fighters reporting events that seem inexplicable in terms of normal fire behaviour [4].

2 Flames where there was little to burn

Three remarkable encounters with the fire on 18th January are hard to explain in terms of the combustion of local vegetation alone. Two of these occurred in a region near 'Huntly property', where drought and grazing by cattle and sheep had left fields with almost no vegetation to burn, apart from relatively modest and sparse plantings of trees as windbreaks and long dry grass beside a road where grazing had not taken place. The geographical area is shown in Figure 5.

Figure 5: Map including the area of the Huntly property. The events described in sections 2.1 and 2.2 occurred near the points marked **C** and **D**, respectively. Grid lines are 1 km apart with contours marking every 20 m of elevation.

Figure 6: An aerial photograph shortly after flames passed through the Huntly property, near the point marked **C** in Figure 5.

2.1 Neil Cooper's experience

Recognising the potential danger posed by long grass beside the road, Neil Cooper, an experienced firefighter and coauthor of this paper sought refuge by taking his 4WD vehicle into a heavily grazed region about 75 metres from the road. The fact that there was little to burn locally is reinforced by his finding that he was unable to ignite a backburn fire to diminish the fuel load further, although there were strong winds at the time which would not have helped.

In spite of this a fire rapidly engulfed the field with flames to a height of about 2 metres. Partly sheltered by being inside his vehicle, Mr Cooper managed to escape the flames only by returning quickly to the road which was then relatively safe because the grass had already been burnt away. The vehicle was severely damaged by the fire. A detailed report of the incident exists [1]. The photograph shown in Figure 6, taken about 10 minutes after this incident, shows the general area in which these events took place.

2.2 Matt Dutkiewicz's experience

About two kilometres northwest of the place where Neil Cooper took refuge, Matt Dutkiewicz was leading a fire-tanker crew in preparing to protect an occupied farm cottage in a location that overlooks the Murrumbidgee river valley. The team felt confident of being able to control the situation because '*there was nothing to burn*' apart from a wind-row of trees 50 metres away.

However, after observing '*flames 'more than 200 metres high'* *racing down the* [Murrumbidgee] *gorge*' it became clear that something highly unusual was happening. Shortly before the fire arrived, the team experienced '*a gust of wind that broke most of the wind row in half*'. The heat of the fire seems to have been very intense:

> '*The heat was so intense that it cracked the mirrors. We activated our protection sprays but most of the water seemed to evaporate before it reached us. The floor of the truck was so hot that it burnt our knees through our overalls.*' [9]

2.3 Phil Koperberg's experience

In another incident Phil Koperberg (Commissioner of the NSW Rural Fire Service) described seeing flames 10 metres tall crossing a region in Canberra where a fire in 2001 had destroyed a large area of pine plantation. The trees had been cleared leaving only stumps and relatively sparse clumps of grass [3].

2.4 Continuous flame over nearly bare ground

After his experience summarised in section 2.1 above, Neil Cooper returned in a replacement vehicle to the ACT Forests depot in Canberra only to find himself again in danger of being cut off by fire. The depot was mostly surrounded by pine of varying ages, much of which was already burning or catching fire.

The only 'unburnable' region was an open area of about 50 metres square locally called 'the oval' which was effectively bare because of sustained drought. However this turned out not to be safe at all. Mr Cooper saw it covered in a continuous sheet of flame, as if it was '*oil burning on top of water and that the whole area was alight at once, i.e. it had no front as such*' [1].

3 The role of gas or pyrolysed vapour

The obvious question that the above descriptions raise is: how can a flame cross a region with insufficient fuel to support such a flame? The question actually assumes that the fuel is solid. If a fuel is present in the form of gas, vapour or even very fine vegetable matter lofted above the ground as a form of powder, then such a fuel can be highly mobile and could burn anywhere that it finds itself in sufficient concentration to be able to ignite.

The normal situation in bushfires seems to be that little unburnt gaseous or vapourised fuel manages to escape the fire. Nevertheless much of the combustion takes place in the form of gas or vapour burning with the oxygen of the air. If the oxygen is abundant then all gasous fuel would tend to be burnt. However, it is possible that situations could arise when the oxygen supply is insufficient to burn all of the gaseous fuel, at least at a local level within some part of the fire. If the residual fuel vapour is able to cool down sufficiently, perhaps exchanging its heat with vegetation that has not yet pyrolysed, it can reach a point at which it would be too cold to burn even when further oxygen becomes available.

The details of how this might have happened are obviously uncertain, at the moment, but the presence of combustible vapourous pyrolysis products (probably having a relatively high mean molecular weight) is consistent with all of the observations listed in section 2. A brief description in terms of nonuniformly premixed gaseous flames is in order.

3.1 Flame propagation in a nonuniform mixture

The speed of propagation of a gaseous premixed flame varies with the proportions of the mixture between the rich flammability limit and the lean flammability limit. Between these limits is the stoichiometric proportion in which fuel and oxidant are both fully consumed by the exothermic oxidation reaction. On

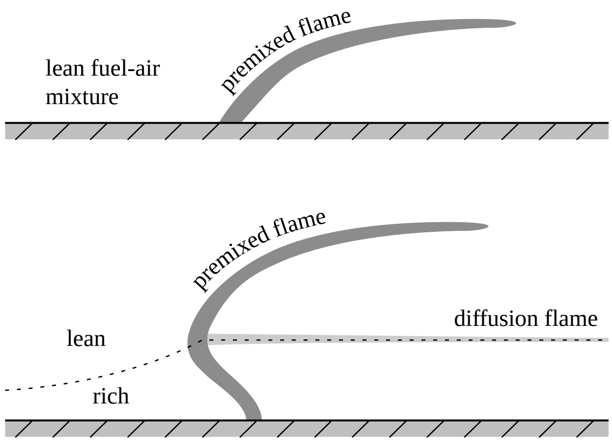

Figure 7: Sketches of flames travelling through a nonuniform mixture of fuel above ground. If the mixture is fuel-rich near the ground (lower diagram) a diffusion flame forms along the path of stoichiometry after the passage of the lean and rich premixed flame branches.

the lean side of stoichiometry unburnt oxidant remains after all fuel is consumed in a premixed flame and on the rich side, unburnt fuel remains.

If gaseous fuel is present above the ground in sufficient concentrations for the mixture to fall between the flammability limits, then two possibilities arise, as sketched in Figure 7. Because air is present in abundance at sufficient height above the ground, the mixture must always be lean at some height. Different forms of flame behaviour can therefore be expected if the mixture remains lean all the way down to the ground or if the mixture becomes rich in fuel close to the ground, in which case there must also be some level at which the mixture is stoichiometric.

In the former case, when the mixture is entirely lean, a propagating flame will consume all of the fuel, after which gaseous combustion must cease leaving only hot combustion products and some residual unburnt oxygen. The shape of the flame would be curved by the fact that the flame propagates faster in some parts of the mixture (closer to stoichiometry) than in others.

In the latter case, the flame in fuel-lean regions leaves unburnt oxygen and in fuel-rich regions it leaves unburnt fuel. Behind the leading premixed flame branches the fuel and oxidant meet at high temperature where they must continue to burn in a diffusion flame. This is the structure of a triple flame, well-known in gaseous combustion studies (see for example [2]). The flames are curved because the propagation speed tends to be highest near stoichiometry.

Such flames are entirely consistent with the field observations outlined above. The case of the flame resembling 'oil on water' would arise if fuel vapour was rich near the ground. After premixed flame branches pass, the diffusion flame would burn relatively passively as a continuous sheet of flame, with no edge, until the fuel beneath it is consumed.

Two other notable features of these flames are worth mentioning. Firstly, premixed flames tend to have high temperatures leaving very hot burnt gases behind them. The chemical kinetics of such flames requires a chain-branching process to occur which is strongly inhibited below about 1400 K [7]. Temperatures would therefore tend to be in the range of about 1400 K to 2000 K, with the highest temperature arising near stoichiometry.

Secondly, the heating of the gas also causes a large volumetric expansion through the flame (by a factor of about 5 to 8). In the curved premixed flame front arising in a nonuniform mixture this expansion pushes aside the gases in front of the flame. As well as enhancing its overall speed of propagation [2], this must have the effect of creating a strong wind immediately before the arrival of the flame, as was reported by Matt Dutkiewicz [9].

3.2 Flame in the Murrumbidgee gorge

The report of '200 metres high flames' racing down the Murrumbidgee valley (section 2.2 [9]) is noteworthy. It is difficult to judge actual speeds and heights, but such high flames are remarkable. The evidence is not sufficient to be conclusive, but if relatively dense pyrolysed gases were present on the Huntly property it is also very likely that they were present in the valley below. The rapid spread of the fire in this region, at least, might have been greatly enhanced, if not led, by unburnt gases from other regions in the overall spread of the fire.

4 Tornado or whirlwind?

To the knowledge of the authors the kind of tornado or powerful whirlwind that accompanied the Canberra bushfire has not been recorded in any other Australian bushfire to date. The fire spread very rapidly, possibly enhanced by semi-independent gaseous flame propagation.

4.1 Pyro-cumulonimbus

As well as generating large volumes of hot fire products, these fires must have produced considerable quantities of water as a byproduct of the combustion. Thus, although the relative humidity of the unburnt air was as low as 4% on the day, the products of the fires were full of moisture. This would have helped to generate the unstable atmosphere in which large quantities of moisture-laden hot air and combustion products rose into the stratosphere in a full-scale cumulonimbus cloud. It is conceivable that the storm was intense enough to generate a tornado. Although direct evidence for this is not available, it is a curcumstantial possibility.

4.2 Fire-driven whirlwind

Another possibility may be connected with gaseous combustion. The region immediately west of the damage shown in Figure 4 includes a basin of about 1 square kilometre. If unburnt pyrolysed gases had gathered in this basin they would have burnt very rapidly, at some stage, generating a large volume of hot products spread over a wide area that would certainly have risen in the form of a whirlwind of great intensity, probably adding to the cumulonimbus cloud. Again there is no direct evidence available for this.

Of course, the actual event might have been enhanced, if not actually caused, by a combination of these factors.

5 Discussion

Every now and then a fire in the landscape occurs under conditions of severe drought and wind, such as the 1939 Black Fires in Victoria, the Hobart Fires of 1967, the Ash Wednesday Fires in Victoria and South Australia in 1983 and the 2003 Canberra Fires. The 2003 fires were started by lightning in the mountains to the west of Canberra and ten days later reached suburban parts of Canberra with considerable destructive power.

The propagation of large flames over areas with very little vegetation and the generation of powerful whirlwinds (possibly a tornado in connection with a large pyro-cumulonimbus) seem to have made this fire quite unusual. This does not mean, of course, that it could not happen again. Indeed, had conditions been different, the experiences described in section 2.2 might have happened within suburban Canberra itself. This makes it all the more important to reach an understanding of the causes of such phenomena, which must be a prerequisite for knowing how they might have been avoided or controlled.

Fire-spread over vegetation that apparently could not sustain such a fire must require the importation of combustible material (most probably in the form of gaseous pyrolysis products) from elsewhere. How such gases can escape the wind-blown fire and embers where they were generated needs further investigation and modelling.

A related question must arise in understanding the nature of such gases and the ways in which they could have gathered elsewhere in sufficient concentrations to burn. Furthermore, the consequences of such burning, probably very rapidly over relatively large geographical areas, are not yet known, although powerful and potentially destructive atmospheric interactions are likely, as well as greatly enhanced overall rates of fire-spread.

There may also be alternative explanations, not relying on the presence of unburnt gaseous pyrolysis products. These could include: mass ignition by spotting; and combustion of organic material that might have been lofted above the ground in the form of a dust. There is insufficient space in this short article to discuss these possibilities more fully and a more detailed future publication is planned.

More detailed modelling and study of bushfires and the gas-solid, thermodynamic and chemical interactions in vegetation and the atmosphere above it are needed to help to gain a fuller understanding.

6 Acknowledgements

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