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Characteristics of an open-cut coal mine fire pollution event

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HIGHLIGHTS

- An open-cut coal mine fire burning for 45 days impacted nearby populations of 45,000.
- CO, $PM_{2.5}$ and benzene exceeded air quality standards by up to 30 times.
- PM to CO emission ratios suggest char combustion as dominant combustion process.
- Study provides unique data set on emissions from open-cut coal mine fire.

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ABSTRACT

On 9 February 2014, embers from a nearby grass/shrub fire spotted into an unused part of the Hazelwood open-cut brown coal mine located in the Latrobe Valley of Victoria, Australia and started a fire that spread rapidly and extensively throughout the mine under strong south-westerly winds and burned over a period of 45 days. The close proximity of the town to the coal mine and the low buoyancy of the smoke plume led to the accumulation of dense smoke levels in the township of Morwell (population of 14,000) particularly under south-westerly winds. A maximum daily $PM_{2.5}$ concentration of 731 μg m^{-3} and 8-h CO concentration of 33 ppm were measured at Morwell South, the closest residential area located approximately 500 m from the mine. These concentrations were significantly higher than national air quality standards. Air quality monitoring undertaken in the Latrobe Valley showed that smoke from the Hazelwood mine fire affected a wide area, with particle air quality standards also exceeded in Traralgon (population of 25,000) located approximately 13 km from the mine. Pollutant levels were significantly elevated in February, decreased in March once the fire abated and then returned to background levels once the fire was declared safe at the end of March.

While the smoke extent was of a similar order of magnitude to other major air pollution events worldwide, a closer look at emissions ratios showed that the open combustion of lignite brown coal in the Hazelwood mine was different to open combustion of biomass, including peat. It suggested that the dominant combustion process was char combustion. While particle and carbon monoxide monitoring started approximately 4 days after the fire commenced when smoke levels were very high, targeted monitoring of air toxics only began on 26 February (17 days after the fire) when smoke levels had subsided. Limited research on emission factors from open-cut coal mine fires make it difficult to assess the likely concentrations of air toxics emitted during the initial more intense period of the fire.

1. Introduction

On 9 February 2014 a fire started inside an unused part of the Hazelwood open-cut brown coal mine located in the Latrobe Valley of Victoria, Australia. Due to difficulties in putting out the fire, it burned over 45 days and caused a significant air pollution event affecting some 45,000 residents in nearby towns (EPA Victoria 2015a; EPA Victoria 2015b). The Hazelwood mine fire was not a unique event though as worldwide a large number of uncontrolled coal fires have been reported, or in some instance are still burning after more than 50 years (Nolter and Vice 2004; Stracher and Taylor 2004). In the US alone it is estimated that 150 uncontrolled surface and underground coal fires are still burning

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(Finkelman 2004). In Australia, the 'Burning Mountain', a large coal seam in New South Wales has been smouldering for more than 6000 years (Ellyett and Fleming 1974). Similarly in the Jharia Coal Fields in Eastern India, numerous coal mine fires have been burning for more than a century and contribute significantly to increased levels of ambient particles, greenhouse gases and other toxic gases affecting nearby densely populated communities (Sarkar et al. 2007; Pandey et al. 2014; Saini et al. 2016). Extensive underground coal seam fires are also burning in the Wuda coal mining area, China, and despite large efforts in extinguishing the fires, some fire areas are still increasing in size (Kuenzer et al. 2012). In Indonesia, there are 164 inventoried coal fires in East Kalimantan but probably many more are burning presenting a serious risk to Indonesia's ecosystems, population and forest resources (Whitehouse and Mulyana 2004).

Despite the extent of uncontrolled coal fires, only a limited amount of research has focused on the pollutants emitted from coal fires and the human health impacts (Melody and Johnston 2015). Recent research studies have investigated exhaust gases in vents from underground coal mine fires in the US (Hower et al. 2009; O'Keefe et al. 2010; O'Keefe et al. 2011; Engle et al. 2012; Hower et al. 2013) and South Africa (Pone et al. 2007). The results have shown a large spatial and temporal variability in concentrations of gases, some indicating incomplete combustion of the coal and some suggesting a more complete combustion. During incomplete combustion, elevated levels of benzene and aliphatic and aromatic compounds were measured. Research studies focused primarily on greenhouse gas pollutants and other toxic gases (Kuenzer et al. 2007; Pone et al. 2007; Carras et al. 2009; Hower et al. 2009; Day et al. 2010; O'Keefe et al. 2010; Engle et al. 2011, 2012; O'Keefe et al. 2011; Engle et al. 2012; Hower et al. 2013), while information on particulate matter emissions from coal fires is scarce.

Although previous research studies provide some information on potential gases emitted during coal mine fires, these studies have focused on smouldering underground coal mine fires. As these differ from an open-cut coal mine fire especially in terms of available oxygen, emission rates are likely to also differ. Currently available data in the literature on emission characterisation from open-cut coal mine fires are very limited. The current understanding of the combustion of solid fuels such as Victorian brown coal has been focused on burning in furnaces and industrial processes while open combustion is a relatively recent area of concern due to the potential for human exposure and reductions in health.

This paper presents part of the data set of air pollutants that were collected during the Hazelwood mine fire, which presented a unique opportunity to enhance our understanding of the impact on air quality from an open-cut coal mine fire.

2. Methods

2.1. Fire

In January and early February 2014 several lightning strikes started bushfires in forested areas in East Gippsland, Victoria, (approximately 200 kms from Hazelwood mine fire), with 18 active fires being identified on 9 February 2014 (Fig. S1). Due to the hot, dry and windy conditions on that day these fires grew and merged into a 166,000 ha fire complex (850 km perimeter) with other smaller fires affecting a further 10,000 ha. The Hazelwood mine fire started on 9 February 2014 when embers from a nearby grass/shrub fire spotted into the mine. Due to strong south-westerly winds with wind gusts up to 74 km/h, the fire spread rapidly and extensively throughout the mine. By the morning of 10 February 2014, the fire had spread across three levels in the northern batters which were over approximately 2 km long, in the eastern batters which were over approximately 1 km long, and on the floor mine in an approximate area of 0.25 km^2 (Fig. 1) (http://report.hazelwoodinquiry.vic.gov.au/part-two-fire/origin-circumstances-hazelwood-mine-fire/overview). On 13 February 2014 the Hazelwood mine fire was declared to be a hazardous materials incident. The fire was declared under control on 10 March 2014 and declared safe on 25 March 2014, after burning for 45 days. A more detailed sequence of the incident and the response of EPA Victoria and other agencies has been published (Fisher et al. 2015).

2.2. Sampling sites

Air quality monitoring started approximately four days after the fire entered the coal mine and was conducted at multiple locations over varying time periods dictated by the requirement to inform emergency response agencies and the community about air quality in the area. The data was also used to guide incident management responses to manage and reduce smoke impacts in the local community. The locations of all of the air quality monitoring sites are shown in Fig. 2. High quality ambient monitoring was conducted at four fixed locations; Morwell South air monitoring station (AMS) (~0.5 km from the mine), Morwell East AMS (~3 km from the mine), Traralgon AMS (~13 km east from the mine) and Morwell South CSIRO site (~0.5 km from the mine). Short-term particulate matter (PM) continuous monitoring was conducted at an additional four locations in Morwell as well as in Moe (~15 km to the east of Morwell) and Churchill (~11 km to the south of Morwell) using a DustTrak (TSI Inc., USA) and ADR (Thermo Scientific., USA). Roving PM air monitoring was also undertaken to measure the extent of smoke impact across Morwell and other local townships using a DustTrak (TSI Inc., USA). Additional carbon monoxide (CO) measurements were collected in several locations within Morwell.

Volatile organic compounds (VOCs) were monitored at four locations, Morwell South AMS, Morwell East AMS, Maryvale Crescent Preschool (MCP) and Morwell South CSIRO site. Polycyclic aromatic hydrocarbons (PAHs) were measured at Morwell South AMS and Morwell South CSIRO site supplemented by particle chemical speciation at the Morwell South CSIRO site.

2.3. Sampling and analysis methods

Table 1 provides a summary of the measurements conducted, including instrumentation, analysis, frequency of measurements, measurement period and the organisation that made the measurement. Detailed descriptions of the sampling and analysis methods are provided elsewhere (Reisen et al. 2016) and in Supplementary materials. High quality ambient monitoring conducted at the four fixed locations included continuous measurements of criteria pollutants, integrated measurements of air toxics (e.g. VOCs, PAHs), particle chemical speciation of collected filter samples and size-fractionated measurements of particles using a micro-orifice uniform deposit impactor (MOUDI, Model 110-R, MSP Corporation) and HiVol MOUDI (Model 131, MSP Corporation). Continuous particle measurements were conducted by referenced particle monitors (e.g. BAM (Model 5014*i* Beta, Thermo Fisher Scientific Inc.) and TEOM) and light-scattering devices (e.g. Nephelometer, DustTrak and ADR). Collected quartz filter samples were analysed for organic carbon (OC) and elemental carbon (EC) using a DRI Model 2001A Thermal-Optical Carbon analyser with the IMPROVE-A temperature protocol (Chow et al. 2007) and for PAHs following US EPA method TO-9A.