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Impact of the New South Wales fires during October 2013 on regional air quality in eastern Australia

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HIGHLIGHTS

- We analyze the impact of the NSW fire episode during October 2013 on regional air quality.
- Specific emission factors are derived from FTIR measurements.
- This event resulted in 10 days'exceedences of air quality standards for $PM_{2.5}$.
- The CHIMERE CTM shows good performance in the simulation of the fire pollution levels.
- The fire emissions'diurnal and vertical profiles influence significantly the peak values.

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ABSTRACT

Smoke plumes from fires contain atmospheric pollutants that can be transported to populated areas and effect regional air quality. In this paper, the characteristics and impact of the fire plumes from a major fire event that occurred in October 2013 (17–26) in the New South Wales (NSW) in Australia, near the populated areas of Sydney and Wollongong, are studied. Measurements from the Fourier Transform InfraRed (FTIR) spectrometer located at the University of Wollongong allowed a calculation of specific emission factors (EFs) in terms of grams per kilogram of dry fuel burned: 1640 g kg^{-1} of carbon dioxide; 107 g kg^{-1} of carbon monoxide; 7.8 g kg^{-1} of methane; and 0.16 g kg^{-1} of nitrous oxide. These EFs have then been used to calculate daily fire emissions for the NSW fire event using the APIFLAME emissions' model, leading to an increase of 54% of CO emitted compared to calculations with EFs from Akagi et al. (2011), widely used in the literature.

Simulations have been conducted for this event using the regional chemistry-transport model (CTM) CHIMERE, allowing the first evaluation of its regional impact. Fire emissions are assumed well mixed into the boundary layer. The model simulations have been evaluated compared to measurements at the NSW air quality stations. The mean correlation coefficients (R) are 0.44 for PM_{10}, 0.60 for $PM_{2.5}$ and 0.79 for CO, with a negative bias for CO (−14%) and a positive bias for $PM_{2.5}$ (64%). The model shows higher performance for lower boundary layer heights and wind speeds. According to the observations, 7 days show concentrations exceeding the air quality Australian national standards for PM_{10}, 8 days for $PM_{2.5}$. In the simulations, 5 days are correctly simulated for PM_{10}, 8 days for $PM_{2.5}$. For PM_{10}, the model predicts 1 additional day of exceedance (one false detection). During this fire episode, inner Sydney is affected during 5 days by PM exceedances, that are mainly attributed to organic carbon in the model simulations.

To evaluate the influence of the diurnal variability and the injection heights of fire emissions, two additional simulations were performed: one with all fire emissions injected below 1 km (CHIM_1 km), since satellite observations suggest low injection for this fire case, and one with a diurnal profile (CHIM_diu) adjusted to best match surface observations closest to the fires. CHIM_1 km displays less bias and root mean square error, and CHIM_diu presents a good agreement for hourly statistics for stations where peaks of PM are well captured, but enhances the differences when a peak is overestimated by the model. This sensitivity analysis highlights significant uncertainties related to these two key fire

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parameters (which add up to uncertainties on emissions), resulting in variations on concentrations of PM and CO.

1. Introduction

Emissions from fires have a significant influence on atmospheric composition, due to the quantity of trace gases and aerosols injected during combustion (e.g. Andreae and Merlet, 2001). These emissions can impact locally, regionally and globally the air quality, the radiative budget and the meteorology (Bowman et al., 2009; Langmann et al., 2009; IPCC, 2013). In Australia, bushfires are well known natural hazards, with 54 Mha burned each year on average since 1997 (Giglio et al., 2010). Less well known is that the death toll from air quality impacts may exceed those killed directly in the fires (Johnston et al., 2011; 2013). Fires are more commons in the north, where the tropical savanna is affected every year by fires, but the southeast, where there is the majority of the population (7,3 millions inhabitants in New South Wales), is also regularly affected by extreme fire events (Gupta et al., 2007; Paton-Walsh et al., 2010; Dirksen et al., 2009). During the bushfire seasons (October–February) of 1993–94 and 2002–03 for instance, more than 2,200,000 ha were burned. Moreover, australian bushfires are predicted to increase with higher temperatures as a consequence of climate change, with an increase of 25% of the fire risk in New South Wales (Pitman et al., 2007).

Among many pollutants released in smoke plumes from fires, fine particles as PM_{10} and $PM_{2.5}$ (particles with an aerodynamical diameter smaller than 10 μm and 2.5 μm respectively) can penetrate deeply into the respiratory system and provoke higher risks of mortality and morbidity (Pope III and Dockery, 2006; Johnston et al., 2012). In this context, the World Health Organisation guidelines (followed by the air quality standards from the National Environment Protection Measure (NEPM) of Australia) has set to 50 μg m^{-3} and 25 μg m^{-3} the daily mean maximum concentration of respectively PM_{10} and $PM_{2.5}$. From 1994 to 2007 in Sydney, 59%–90% of PM exceedances were due to fires (Johnston et al., 2011). The precise estimation of atmospheric composition in terms of key pollutants resulting from those fires is thus essential to analyse their air quality impact. For this purpose, numerical simulations by chemistry-transport models (CTM), providing 3-dimensional distributions varying with time, are used.

Fire emissions are accounted for using inventories provided on regional or global scales (van der Werf et al., 2006; Wiedinmyer et al., 2011; Mieville et al., 2010; Turquety et al., 2014). However, uncertainty on these emissions remains high, estimated to up to a factor of 5 for total carbon release, due to different methodologies and uncertainties on burned area products or emission factors (Schultz et al., 2008). Other studies have pointed out the uncertainty associated with the use of daily emissions computed with polar-orbiting satellite fire products (Wang et al., 2006; Sessions et al., 2011). Another key input for modeling fires is the injection height, which has an impact on the fire plume transport and chemistry (Sessions et al., 2011; Paugam et al., 2015).

Modelling fires in Australia are often conducted with global CTMs, i.e at low resolution, and for long range transport (Dirksen et al., 2009) or emissions calculation purposes (Paton-Walsh et al., 2010). In an epidemiological study, Johnston et al. (2012) use a global CTM associated with satellite observations to estimate global PM exposure to smoke from fires. Although many fire regional studies with CTM have been undertaken in other populated areas of the world (for instance Hodzic et al. (2007); Konovalov et al. (2011) in Europe), there are few in Australia and more particularly in the Sydney region. However, air quality monitoring needs finer resolutions than global models.

The purpose of this study is to evaluate air quality impairment by a major bushfire event in Australia, more particularly in New South Wales, using regional chemistry and transport simulations. Therefore, an analysis of the main fire characteristics (*i.e.* area burned, type of vegetation, emission factors), the resulting emissions and the pollution plume simulated is conducted.

The New South Wales (NSW) bushfires during October 2013 were a series of wildfires that burned in rural NSW and brought thick smoke plumes over population centres in Sydney (4.3 millions inhabitants) and Wollongong (290,000 inhabitants). The fires followed the warmest September on record for New South Wales, according to the Australian Bureau of Meteorology, with a daily mean temperature of 19.1° C at Sydney (3.6 ° C above the average). The first of the fires started around the 13th October, but serious fires broke out in the Greater Blue Mountains Area to the west of Sydney on the 17th October and 18th October and were largely extinguished by 28th October 2013 (these fires have been detected by satellite and rain radars observations, see Fig. 1a and b). During this time, high fuel loads and hot, dry and windy conditions led to large fires with a total burned area of 118 thousand hectares (i.e. more than 15% of the total burned for the year 2013), two fatalities and 248 properties lost. Two of the most significant fires during this time were the State Mine fire, which started during explosives training in a military area near Marrangaroo on the 16th October 2013 (the dense aerosol plume was precisely detected by the Australian Bureau of Meteorology rain radar as seen on Fig. 1b), and the Hall Road fire, which was ignited by power-lines near Balmoral in the Southern Highlands.

The State Mine fire grew into a major fire by 17th October and the smoke plume from this fire blanketed the densely populated Sydney metropolitan area on the afternoon of the 17th October causing poor air quality including highly elevated PM_{10} values. An estimated area of 56,500 ha was burnt.

The Hall Road fire broke containment lines on 17th October and the resulting smoke plume extended over large parts of the Illawarra region, including Wollongong (about 35 km from this fire) (see Fig. 1). Wollongong was impacted by the fires again in the early hours of 19th October, when a temperature inversion trapped smoke plumes close to the ground for several hours, resulting in peak concentrations of carbon monoxide (CO) in excess of 4 ppm (CO average levels of 124.5 ppb according to Buchholz et al. (submitted)). By the time the Hall Road fire was extinguished, the New South Wales Rural Fire Service estimated that over 15,600 ha had been burnt.

In this paper, the impact on air quality of this series of bushfires in October 2013 in the Australian New South Wales is studied using a combination of in situ observations and chemistry-transport modeling. We first present the available measurements of the smoke pollution over the region of Sydney and Wollongong, as well as the emission factors derived using a trace gas analyser based on Fourier transform spectroscopy. These measured concentrations of key pollutants are then compared to those predicted by the regional chemistry-transport model CHIMERE, with a focus on air