Atmospheric Environment 89 (2014) 392–402

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Size and mass distributions of ground-level sub-micrometer biomass burning aerosol from small wildfires

Rintaro Okoshi [a], Abdur Rasheed [a,1], Greeshma Chen Reddy [a], Clinton J. McCrowey [a], Daniel B. Curtis [a,b,*]

[a] Department of Chemistry and Biochemistry, California State University Northridge, 18111 Nordhoff St., Northridge, CA 91330-8262, USA
[b] Interdisciplinary Research Institute for the Sciences (IRIS), California State University, Northridge, USA

HIGHLIGHTS

- Measured ambient size distributions from three fires near Los Angeles.
- Very high number concentrations, even though fire sizes were small.
- Size varied significantly during the measurements.

ARTICLE INFO

Article history:
Received 26 September 2013
Received in revised form
8 January 2014
Accepted 10 January 2014
Available online 23 January 2014

Keywords:
Biomass burning aerosol
Particulates
Air quality
Southern California

ABSTRACT

Biomass burning emits large amounts of aerosol particles globally, influencing human health and climate, but the number and size of the particles is highly variable depending on fuel type, burning and meteorological conditions, and secondary reactions in the atmosphere. Ambient measurements of aerosol during wildfire events can therefore improve our understanding of particulate matter produced from biomass burning. In this study, time-resolved sub-micrometer ambient aerosol size and mass distributions of freshly emitted aerosol were measured for three biomass burning wildfire events near Northridge, California, located in the highly populated San Fernando Valley area of Los Angeles. One fire (Marek) was observed during the dry Santa Ana conditions that are typically present during large Southern California wildfires, but two smaller fires (Getty and Camarillo) were observed during the more predominant non-Santa Ana weather conditions. Although the fires were generally small and extinguished quickly, they produced particle number concentrations as high as 50,000 cm^{-3} and mass concentrations as large as 150 $\mu g\ cm^{-3}$, well above background measurements and among the highest values observed for fires in Southern California. Therefore, small wildfires can have a large impact on air quality if they occur near urban areas. Particle number distributions were lognormal, with peak diameters in the accumulation mode at approximately 100 nm. However, significant Aitken mode and nucleation mode particles were observed in bimodal distributions for one fire. Significant variations in the median diameter were observed over time, as particles generally became smaller as the fires were contained. The results indicate that it is likely that performing mass measurements alone could systematically miss detection of the smaller particles and size measurements may be better suited for studies of ambient biomass burning events. Parameters of representative unimodal and bimodal lognormal fits to the distributions are provided for reproduction of distributions in aerosol and climate models.

1. Introduction

Biomass burning is a large source of particulate matter and trace gas emissions globally and in the United States (Crutzen and Andreae, 1990; Bond et al., 2004; Reid et al., 2005b, a; Park et al., 2007; Spracklen et al., 2007; Langmann et al., 2008; De Gouw and Jimenez, 2009; Ichoku et al., 2012). Biomass burning aerosol (BBA) particles are thought to have a large impact on human health (Künzli et al., 2006; Naeher et al., 2007) and global climate through

* Corresponding author. Department of Chemistry and Biochemistry, California State University Northridge, 18111 Nordhoff St., Northridge, CA 91330-8262, USA. Tel.: +1 818 677 2479; fax: +1 818 677 4068.
E-mail address: daniel.curtis@csun.edu (D.B. Curtis).
[1] Now at Federal Government Degree College, Jutial Gilgit, Gilgit-Baltistan, Pakistan.

1352-2310/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.atmosenv.2014.01.024

both the direct scattering and indirect cloud nucleation effects (Grant et al., 1999; Haywood and Boucher, 2000; Solomon et al., 2007; Forster et al., 2007). The climate and health effects of BBA depend on particle size, number density, and composition. However, there are significant differences between BBA produced from different fire conditions such as fuel type, combustion temperature, fire phase (flaming versus smoldering), and ambient weather conditions.

An additional uncertainty in the BBA effects is the fact that the emission plume can change over time after being produced (Reid et al., 2005b; Grieshop et al., 2009; Hawkins and Russell, 2010; Akagi et al., 2012). Particle aging can impact climate and health effects by altering the primary aerosol or producing secondary aerosol. Aging is due to both physical and chemical processes, typically involving coagulation of the particles and gas-phase photochemistry driven by sunlight (Capes et al., 2008). The aging process is complicated by factors such as dilution of the plume by surrounding air. Therefore large uncertainties in the climate and health effects of BBA still exist (Solomon et al., 2007; Forster et al., 2007). Particle size distribution measurements of ambient fires can help reduce some of these uncertainties.

An important aspect of biomass burning plumes is that upon exposure to UV light, secondary organic aerosol particles can form due to nucleation of photochemical products of gas-phase reactions. Because these secondary particles are formed from nucleation, they are typically small, but tend to grow in size over time. In addition, gas-phase products can condense onto existing particles and existing particle can coagulate to form larger particles. Several ambient, model, and laboratory studies have observed formation of secondary aerosol in a biomass burning smoke plume (Reid et al., 2005b; Alvarado and Prinn, 2009; Alvarado et al., 2009; Yokelson et al., 2009; DeCarlo et al., 2010; Hennigan et al., 2011; Engelhart et al., 2012; Hennigan et al., 2012). In particular, Engelhart et al. (2012) and Hennigan et al. (2012) observed nucleation of particles upon laboratory exposure of a smoke plume to UV lamps, which increased particle number concentrations by approximately a factor of four within one hour. The secondary particles grew in size from less than 10 nm to approximately 60 nm over several hours. Production of various gas-phase products has also been observed and modeled, ozone in particular (Yokelson et al., 1996; Pfister et al., 2008; Alvarado and Prinn, 2009; Alvarado et al., 2009; Jaffe and Wigder, 2012). As noted by Akagi et al. (2012), if fires occur in locations where ozone concentrations are already relatively high, air quality criteria levels can be violated.

Southern California's dry climate and mountainous terrain lead to numerous wildfire events and recent studies indicate that wildfire frequency, duration, and fire season length have increased in the western United States due to climate change and are expected to continue to change in the future (Westerling et al., 2003, 2006; Jaffe et al., 2008; Westerling and Bryant, 2008). Typical summer meteorological conditions are characterized by southerly or westerly winds with low speed (<10 m s^{-1} on average) and relative humidities of 20–40%. However, late summer and autumn sometimes have the hot, dry Santa Ana conditions, caused by adiabatic warming as dry air from the Mojave desert north and east of Los Angeles descends into the Los Angeles Basin (Westerling et al., 2004). Santa Ana conditions are characterized by high speed (>10 m s^{-1}) northeasterly winds and very low relative humidities ($<10\%$). Santa Ana conditions generally last 2–3 days and occur approximately 10 times per year from autumn into winter. Santa Ana conditions are ripe for wildfires and fires that occur during such conditions often grow quickly to impact a relatively large area.

Ambient measurements of recent fire events in Southern California have been published extensively, but the majority of these measurements were performed during extensive wildfire events that occurred during Santa Ana conditions (Guazzotti et al., 2001; McMeeking et al., 2005a, b; Phuleria et al., 2005; Künzli et al., 2006; Wu et al., 2006; Clinton et al., 2006; Mühle et al., 2007; Verma et al., 2009; Hersey et al., 2011; Wonaschütz et al., 2011; Zauscher et al., 2013). Fewer measurements exist for fires that occur during more typical, non-Santa Ana, weather conditions and for smaller fires that are quickly contained. However, several studies have monitored emissions from intentionally set controlled burns on relatively small scales under more typical weather conditions (Cofer et al., 1988a, b; 1989; Burling et al., 2011; Akagi et al., 2012). In addition to ambient studies, interest in biomass burning aerosol and gaseous emissions has spurred numerous recent laboratory studies of biomass burning (Silva et al., 1999; McMeeking et al., 2009; Hosseini et al., 2010; Akagi et al., 2011; Grieshop et al., 2009; Chakrabarty et al., 2006; Hungershoefer et al., 2008; Lewis et al., 2009; Chen et al., 2006; Burling et al., 2010; Levin et al., 2010; Mack et al., 2010; Engelhart et al., 2012; Hennigan et al., 2011, 2012; Hays et al., 2005, 2002). This study describes ambient size and mass distributions collected during three wildfire events in Southern California. Two events were small and occurred during non-Santa Ana conditions, while one was larger and occurred during Santa Ana conditions, allowing a comparison of the smaller and larger fires under different meteorological conditions.

For the present study, particle size distributions were measured at ground-level during three wildfire events in the Los Angeles area between 2008 and 2010. Size distributions were measured with a Scanning Mobility Particle Sizer (SMPS, TSI, Inc.) across the approximate size range of 20–900 nm. The sampling location was on the campus of California State University Northridge, located near the center of the San Fernando Valley area within the city of Los Angeles. The San Fernando Valley has a population greater than 1,700,000 (United States Census Bureau, 2007–2011 American Community Survey, http://factfinder2.census.gov). Two events, the Getty Fire and Camarillo Fire, were small, burning less than 100 acres (0.4 km^2) each and occurred during non-Santa Ana conditions. The Getty Fire occurred in the Sepulveda Pass area within the city limits of Los Angeles and wind patterns brought the smoke plume from the Camarillo Fire toward heavily populated areas. Despite their small size, the Getty and Camarillo fire events led to very high particle number densities up to 50,000 cm^{-3}. Particle concentrations were higher for the smaller fires than during the larger Marek fire, even though the larger event was closer in proximity and took place during Santa Ana conditions. Therefore, even small fires can impact urban air quality and human health depending on location and weather conditions.

2. Sampling method

2.1. Location

Fig. 1 shows the locations of the fires studied and the sampling location. The inset shows the state of California, with a dot representing the general location of the detailed view. The sampling location was at Citrus Hall on the campus of California State University Northridge (CSUN) at an elevation of 10 m above ground level (approximately 270 m above mean sea level). The site is located at 34°14′20.5″ N latitude and 118°31′39.5″ W longitude near the center of the San Fernando Valley area approximately 33 km northwest of the city center of Los Angeles (DTLA) and 4.5 km northwest of Van Nuys Airport (KVNY). The sampling location was approximately 5 km west, 5 km south, and 6 km north of major interstate freeways (405, 118, and 101, respectively). Fire locations are indicated with triangles on Fig. 1. The Camarillo and Getty fires were small, localized events, while the Marek fire was a