Atmospheric Environment 44 (2010) 678–687

Contents lists available at ScienceDirect

Atmospheric Environment

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

Analysis of the effects of combustion emissions and Santa Ana winds on ambient ozone during the October 2007 southern California wildfires

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ARTICLE INFO

Article history:
Received 22 June 2009
Received in revised form
5 November 2009
Accepted 6 November 2009

Keywords:
Air pollution
Ozone
Wildland fires
Meteorology
Santa Ana winds

ABSTRACT

Combustion emissions and strong Santa Ana winds had pronounced effects on patterns and levels of ambient ozone (O_3) in southern California during the extensive wildland fires of October 2007. These changes are described in detail for a rural receptor site, the Santa Margarita Ecological Reserve, located among large fires in San Diego and Orange counties. In addition, O_3 changes are also described for several other air quality monitoring sites in the general area of the fires. During the first phase of the fires, strong, dry and hot northeasterly Santa Ana winds brought into the area clean continental air masses, which resulted in minimal diurnal O_3 fluctuations and a 72-h average concentration of 36.8 ppb. During the second phase of the fires, without Santa Ana winds present and air filled with smoke, daytime O_3 concentrations steadily increased and reached 95.2 ppb while the lowest nighttime levels returned to ~0 ppb. During that period the 8-h daytime average O_3 concentration reached 78.3 ppb, which exceeded the federal standard of 75 ppb. After six days of fires, O_3 diurnal concentrations returned to pre-fire patterns and levels.

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1. Introduction

Tropospheric ozone (O_3) is a naturally occurring greenhouse gas formed during photochemical reactions between nitrogen oxides (NO_x), carbon monoxide (CO) and volatile organic compounds (VOCs) (Finlayson-Pitts and Pitts, 2000). Since the Industrial Revolution, global background O_3 concentrations have been growing due to increasing emissions of O_3 precursors from fossil fuel combustion, industrial activities and wildland fires (Crutzen and Andreae, 1990; Sitch et al., 2007; Goldammer et al., 2009). At the end of the 19th century in Europe, and likely elsewhere in the Northern Hemisphere, O_3 levels were less than10 ppb (Guiherit and Roemer, 2000). At present, across that hemisphere, average annual O_3 concentrations are typically 40–50 ppb, with 50–60 ppb frequently occurring in mid-latitudes (Brasseur et al., 2001; Oltmans et al., 2006), including western regions of the United States (CASTNET, 2007; Jaffe and Ray, 2007). Since O_3 causes serious human health problems, it is listed as a federally and state-regulated air pollutant with a primary 8-h standard set at 75 ppb (http://www.epa.gov/air/ozonepollution/standards.html).

Emissions from combustion engines are a major contributor to O_3 precursors (Finlayson-Pitts and Pitts, 2000) and result in high O_3 concentrations in suburban, rural and remote areas downwind of the pollution source areas (Bytnerowicz et al., 2007). The highest O_3 concentrations occur in urban agglomerations with dense traffic, such as the Los Angeles Basin, where the term “photochemical smog” was coined in the 1950s as O_3 levels sometimes exceeded 500 ppb (Seinfeld and Pandis, 1998). Since the introduction of reformulated gasoline and the advent of strict controls on emissions ambient levels of O_3 in southern California rarely exceed 150 ppb (Bytnerowicz et al., 2008). In urban areas, O_3 concentrations have a clearly defined diurnal cycle with a minimum in early morning and a maximum in late afternoon. Such a pattern results from the daytime photochemical O_3 production combined with O_3 loss by dry deposition and reaction with nitric oxide (NO) after sunset when photochemical reactions stop. In locations where NO concentrations are high at night, such as urban areas or in the vicinity of major transportation routes, the nighttime drop of O_3 concentrations may be very pronounced, often resulting in a complete O_3 disappearance (Seinfeld and Pandis, 1998).

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1352-2310/$ – see front matter Published by Elsevier Ltd.
doi:10.1016/j.atmosenv.2009.11.014

Biomass burning results in elevated O_3 concentrations in adjacent downwind areas as photochemical reactions are fed by the NO_x, CO and VOC emissions. There are many examples of elevated concentrations related to wildland fires in various areas of the World (Goldammer et al., 2009). Production of O_3 from fires depends on the age of fire plume. Fresh plumes have thick smoke inhibiting photochemical reactions and contain high NO concentrations, effectively titrating O_3. Old plumes typically have less dense smoke allowing for photochemical reactions and O_3 generation from the abundant precursors such as NO_2, VOCs and CO (Urbanski et al., 2009). Intense wildfire periods can significantly increase surface O_3 levels in remote areas of the western United States (Jaffe et al., 2008). Increases of O_3 concentrations in areas downwind from the October 2007 southern California wildfires resulted in increased frequency of violations of the U.S. federal air quality standard for O_3 during that period of relatively low photochemical activity (Pfister et al., 2008).

In southern California, wildland fires commonly occur during Santa Ana wind conditions. Santa Ana winds are blustery, dry and warm blowing into southern California from the Mojave Desert. These winds develop when the desert is cold, and thus they take place during the cool season (October through March). When high pressure builds over the Great Basin in Nevada, the cold air begins to sink and is forced downslope, compresses and warms at a rate of $\sim 10\ ^{\circ}C\ km^{-1}$. As the temperature rises, the relative humidity drops, the air picks up speed and is channeled through passes and canyons into southern California (http://www.atmos.ucla.edu/~fovell/ASother/mm5/SantaAna/winds.html).

Information gained from a detailed analysis of the ambient O_3 concentrations is important for understanding potential air quality problems caused by wildland fires. Such fires may become more intense and frequent in the western United States as the climate warms up (Westerling et al., 2006). Improved information on the effects of fires on air quality is crucial for air resources and land managers of the federal, state and local agencies deciding on a potential use of prescribed (controlled) fires as a tool for fuel reduction and mitigation of catastrophic fire effects. Prescribed burning has to be carefully planned and applied to assure compliance with the federal and state air quality standards (Arbaugh et al., 2009).

The objective of this study was to provide an analysis of ambient O_3 during the October 2007 southern California fires at a remote receptor site from a perspective of detailed changes of meteorological conditions. Such analysis was supported by characterization of ambient O_3 at several air quality monitoring sites in the general area of the fires. We were mostly interested if these fires produced violation of the national O_3 air pollution standard, and how the Santa Ana winds influenced the distribution of ambient O_3 in the area affected by the fires.

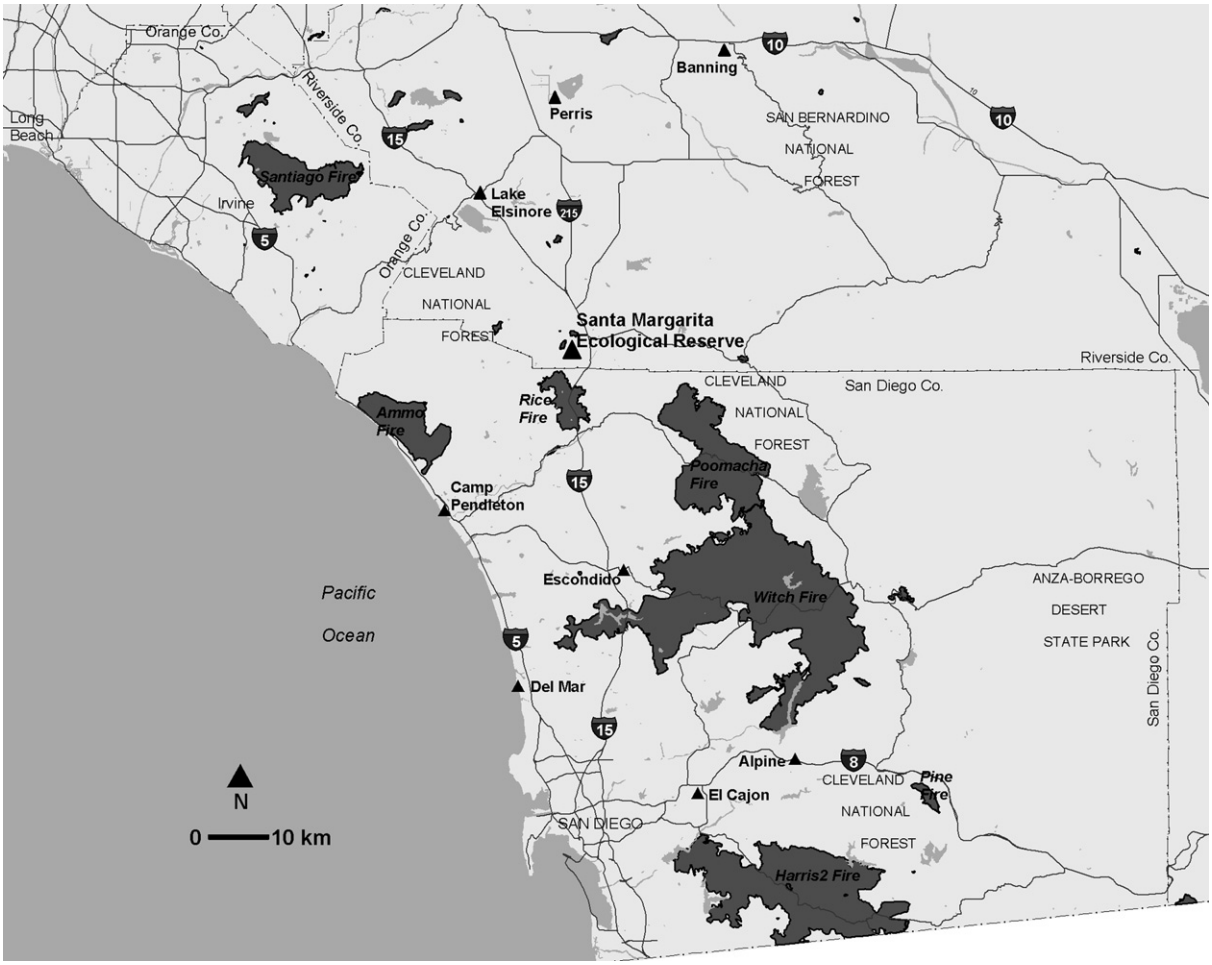

Fig. 1. October 2007 wildland fires and locations of the Santa Margarita Ecological Reserve (SMER) and other selected air quality monitoring stations in San Diego and Riverside counties.