Atmospheric Environment 86 (2014) 58–67

Contents lists available at ScienceDirect

Atmospheric Environment

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

The impact of meteorological parameters on urban air quality

Nicole R. Ramsey*, Petra M. Klein, Berrien Moore III

University of Oklahoma, USA

HIGHLIGHTS

- Comparison of ozone concentrations from two hot, dry years and two cool, wet years.
- Hot, dry summers experience higher monthly minimum and maximum ozone concentrations.
- Hot, dry years have three times as many exceedance days as cool, wet years.
- Human exposure to harmful levels of ozone is doubled during hot, dry years.

ARTICLE INFO

Article history:
Received 15 July 2013
Received in revised form
6 October 2013
Accepted 6 December 2013
Available online 1 January 2014

Keywords:
Ozone concentrations
Climate change
Urban air quality
Health impacts
Oklahoma City

ABSTRACT

Previous studies have shown that global climate change will have a significant impact on both regional and urban air quality. As air temperatures continue to rise and mid-latitude cyclone frequencies decrease, the overall air quality is expected to degrade. Climate models are currently predicting an increased frequency of record setting heat and drought for Oklahoma during the summer months. A statistical analysis was thus performed on ozone and meteorological data to evaluate the potential effect of increasing surface temperatures and stagnation patterns on urban air quality in the Oklahoma City Metropolitan area.

Compared to the climatological normal, the years 2011 and 2012 were exceptionally warm and dry, and were therefore used as case study years for determining the impact of hot, dry conditions on air quality. These results were then compared to cooler, wetter summers to show how urban air quality is affected by a change in meteorological parameters. It was found that an increase in summertime heat and a decrease in summertime precipitation will lead to a substantial increase in both the minimum and maximum ozone concentrations as well as an increase in the total number of exceedance days. During the hotter, drier years, the number of days with ozone concentrations above the legal regulatory limit increased nearly threefold. The length of time in which humans and crops are exposed to these unsafe levels was also doubled. Furthermore, a significant increase was noted in the overnight minimum ozone concentrations. This in turn can lead to significant, adverse affects on both health and agriculture statewide.

1. Introduction

Tropospheric ozone is one of the leading photochemical pollutants in the atmospheric boundary layer. Because of the photochemical nature of ozone production, the largest concentrations typically occur during the early to mid-afternoon hours when incoming solar radiation is maximized (Bloomer et al., 2010). Reciprocally, the lowest concentrations generally occur during the overnight hours due to scavenging of ozone through reactions with nitrous oxide and volatile organic compounds (Böhm et al., 1991). Many studies, including Logan (1985), have shown that monthly average ozone concentrations reach a maximum between March and August and a minimum during the winter. This broad six-month period of elevated ozone concentrations from spring through summer has increased over time. Between 1990 and 1994, ozone concentrations in the United States peaked during the summer months but now elevated ozone concentrations have been noted earlier (Bloomer et al., 2010).

High ozone days, or days in which the maximum eight-hour (8-h) ozone concentration is greater than 75 ppb, in the Oklahoma City (OKC) region often occur when conditions are hot and sunny and winds are light out of the south, southeast, or east (Association of Central Oklahoma Governments, 2008). This connection between certain meteorological parameters and elevated ozone concentrations has been well documented in the literature for other study areas. In general, an increase in surface temperature and a decrease

* Corresponding author.
E-mail address: nicole.r.ramsey@ou.edu (N. R. Ramsey).

1352-2310/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.atmosenv.2013.12.006

in wind speed are both associated with higher ozone values (Bloomer et al., 2010; Camalier et al., 2007; Ngan and Byun, 2011). One of the primary formation mechanisms for ozone is via photochemical processes. Therefore, the presence of sunlight and the amount of available radiation are important in determining the rate of ozone formation (Logan, 1985; Arya, 1999). Furthermore, an increase in relative humidity is usually associated with an increase in cloud cover and a decrease in atmospheric stability, which in turn reduces the photochemical processes that are vital to the formation of ozone (Camalier et al., 2007). Similarly, higher rainfall values result in lower ozone concentrations because rainfall acts as a pollution ventilation mechanism via the removal of ozone from the lower atmosphere (Ludwig and Shelar, 1978; Tarasova and Karpetchko, 2003; Banta and Coauthors, 2005).

This influence of meteorological parameters on ozone concentrations will become increasingly important as the climate changes. A study conducted by Fang et al. (2013) showed that when the emission of air pollutants is held constant, higher ozone concentrations could be expected over populated regions due to climate change during the 21st century. Wu et al. (2008) showed that an increase in the frequency of stagnation periods is expected during the 21st century. Furthermore, a decrease in mid-latitude cyclone frequency across southeast Canada along with a weakening in the global circulation will lead to a decline in the number of frontal passages moving through the United States (Wu et al., 2008; Fang et al., 2013). This has significant ramifications on ozone concentrations and air quality since frontal passages are a major source of pollution ventilation. General circulation models also predict that an increase in the number of heat waves will lead to an increase in surface temperature and a decrease in cloud cover. This is expected to cause ozone concentrations in polluted areas to increase by 1 to 10 parts per billion (ppb) (Jacob and Winner, 2009). An increase in temperature is also expected to result in a 12-day increase in the total number of days during which the 8-h ozone concentrations exceed 80 ppb (Murazaki and Hess, 2006).

The U.S. Environmental Protection Agency (EPA) is in charge of reducing air pollution and improving air quality in the United States with the goal of protecting humans and animals from elevated exposure to harmful pollution levels. The National Ambient Air Quality Standards (NAAQS) were designed by the EPA to limit the anthropogenic emission of ozone and five other harmful pollutants (United States Environmental Protection Agency Office of Air Quality Planning and Standards, 2012). Nonattainment designations are subsequently determined by taking the "annual fourth highest daily maximum 8-h concentration, averaged over 3 years" (United States Environmental Protection Agency, 2011). If this value is greater then 75 ppb, that region will be designated as a non-attainment area and will be required to reduce pollution concentrations below the legal limit. Similarly, the World Health Organization (WHO) advises that 8-h ozone concentrations should remain below 50 ppb in order to satisfactorily protect humans from the harmful effects of ozone (World Health Organization, 2011).

Elevated surface ozone concentrations can cause harm to human health and agricultural productivity. Short-term exposure to ozone concentrations above the EPA's 1-h ozone regulation standard further results in chest tightness, dry coughing, and rapid and shallow breathing (Beckett, 1991). At high concentrations, surface ozone can lead to increases in respiratory ailments, hospitalizations, and morbidity among children and the elderly (Beckett, 1991). Fang et al. (2013) showed that changes in ozone concentrations due to climate change could increase premature mortality from respiratory diseases in people over 30 by 6300 deaths. Increased ozone concentrations also negatively affect the stomatal conductance of wheat crops, resulting in a substantial relative yield loss (Van Dingenen et al., 2009). Wheat, one of the primary crops produced in Oklahoma (United States Department of Agriculture, 2011), is extremely sensitive to ozone exposure. Avnery et al. (2011) showed that wheat is more sensitive to frequent exposure to high ozone concentrations then it is to long-term exposure to moderate ozone concentrations. In this study, ozone was found to inhibit wheat growth by reducing the amount of photosynthesis and the number of physiological functions that the plant can undergo. This weakens the plant, decreases the quality of the crop, and reduces the amount of crop yield.

The harmful effects of elevated ozone concentrations will become increasingly important since climate models are predicting warmer, drier, more stagnant conditions to become more prevalent in the OKC Metropolitan area over the next century (Jacob and Winner, 2009). Surface ozone concentrations are exacerbated under warm, dry, stagnant conditions, so a shift towards these weather patterns could result in dangerously high ozone concentrations during the summer months. By comparing ozone concentrations during cooler, wetter years against those from warmer, drier years, this research shows how ozone concentrations and the number of exceedance days could evolve under a changing climate if emission rates and patterns are not adapted. The data and methods used in this study, as well as a discussion of the meteorological and air quality patterns observed during the ten-year (10-y) study period from 2003 to 2012, are described in Section 2. Based on the trends noted in these patterns, four case study years were selected and discussed in detail in Section 3, followed by conclusions in Section 4.

2. Data and methods

The Oklahoma Mesonet is a network of 120 automated stations that monitor upwards of seventeen different meteorological parameters in 5-min intervals statewide (McPherson and Coauthors, 2007). Three monitoring sites, Norman, Minco, and Spencer, are located in the greater OKC Metropolitan region (Fig. 1) and were used during this study to collect data on temperature, wind speed, wind direction, relative humidity, solar radiation, and precipitation. In order to determine how variations in meteorological parameters under a changing climate will influence ozone concentrations in OKC, climate data from the Oklahoma Mesonet were analyzed from 2003 to 2012. Fig. 2 shows how 2004 and 2007 were unseasonably cool and wet compared to the climatological average while 2011 and 2012 were unseasonably warm and dry compared to the climatological average, especially during the summer months. These four years were selected as case study years to serve as proxies for the two different climates: cool and wet (2004 and 2007) and warm and dry (2011 and 2012). Similarly, the average monthly radiation was much higher and the dewpoint temperature was much lower during the peak summer months in the warm, dry years compared to the cool, wet years (not shown).

The EPA maintains the Air Quality System (AQS) database, which includes air quality data collected by both the EPA, and state, local, and tribal governments, and uses it to monitor air quality and pollution levels (United States Environmental Protection Agency, 2013). Out of more then 10,000 monitoring stations nationwide, six state-maintained, ozone-monitoring stations are located in and around the OKC Metropolitan region (Fig. 1). The southern most monitoring site, Goldsby, is located in a rural setting on land used for agricultural purposes. OSDH, or OKC Central, is an urban site located in the heart of downtown. The remaining four stations, Yukon, OCC, Choctaw, and Moore, are located in a suburban setting on land zoned for either residential or commercial use. Throughout the 10-y study period, OCC, OSDH, and Choctaw have the highest