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Short communication

Atmospheric patterns in relationship with observed ozone concentrations in the Phoenix, Arizona, metropolitan area during the North American Monsoon

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ABSTRACT

Phoenix, Arizona is a designated ozone nonattainment area by the United States Environmental Protection Agency (EPA) and is susceptible to unhealthy ozone during the summer North American Monsoon. This study identifies common July and August synoptic environments linked with daily exceedances and non-exceedances of the EPA National Ambient Air Quality Standard (NAAQS). Results indicate a common weather pattern for exceeding the NAAQS consisting of 1) an amplified high-pressure ridge over the Four Corners region causing 500 hPa heights to often exceed 5910 m, 2) surface afternoon temperatures typically rising over 40 °C, 3) lighter wind speeds in the planetary boundary layer (PBL) under four ms^{-1}, and 4) a distinct and persistent light easterly flow regime from 700 to 500 hPa. The last feature would counter local mountain-valley winds in the upper PBL to promote ozone accumulation aloft and subsequent fumigation. Conversely, non-exceedance days are associated with 1) West Coast troughing and 500 hPa geopotential heights between 5.9 and 21.4 m lower, 2) afternoon PBL temperatures on average 0.8 °C–2.2 °C cooler, 3) faster afternoon westerly flow at 925 and 850 hPa over four ms^{-1}, and 4) westerly flow in general at and above 925 hPa, aligning with the daytime mountain-valley circulation. Furthermore, a secondary non-exceedance pattern was identified. This less frequent pattern has moist southeast flow and is recognized for bringing widespread convective storm activity to central Arizona, including the PNA, based on prior research.

1. Introduction

Ground-level ozone is one of six criteria air pollutants deemed by the U.S. Environmental Protection Agency (EPA) to pose a risk to health and the environment. In an effort to regulate pollution levels the EPA has imposed pollutant specific National Ambient Air Quality Standards (NAAQS). Areas found to not meet pollutant standards are considered to be in nonattainment. The Phoenix-Mesa Mean Statistical Area (MSA) is designated as nonattainment for ozone (PNA hereafter) and occupies nearly 13,000 km^2 in south-central Arizona (Fig. 1). At the time of this study, the PNA had 20 regulatory monitors sited at a mix of urban, suburban, and rural locations. Terrain is complex in the PNA with elevation for monitoring sites varying between 258 and 1582 m at the Buckeye ("BU") and Humboldt Mountain ("HM") sampling locations, respectively.

In 2015, the EPA lowered the ozone NAAQS to its latest adjustment, which is based on a daily maximum 8-h average concentration (labeled as DMO8 in this study), from 75 parts per billion (ppb) to 70 ppb. Consequently, there is an expectation for more frequent daily ozone exceedances as the standard drops closer to mean concentrations typically observed in the PNA during the summer North American Monsoon (NAM) (Adams and Comrie, 1997) in the months of July and August (Fig. 2). Since the PNA hosts a significant population numbering over four million residents as of 2015 (U.S. Census Bureau, 2017) and ozone may have detrimental health consequences for the general public (e.g., Owens et al., 2017), it is vital for predictive purposes that we achieve a better understanding of atmospheric conditions supportive of unhealthful levels of surface ozone in this region.

Historically, meteorological forecasting in the southwest U.S. during the NAM phenomenon poses challenges due to a wide variation in atmospheric conditions throughout the season (Adams and Comrie, 1997; Sheppard et al., 2002). For example, marked intra-seasonal spatial differences for summertime precipitation have been observed to take place that is caused by the monsoon circulation intermittently deviating

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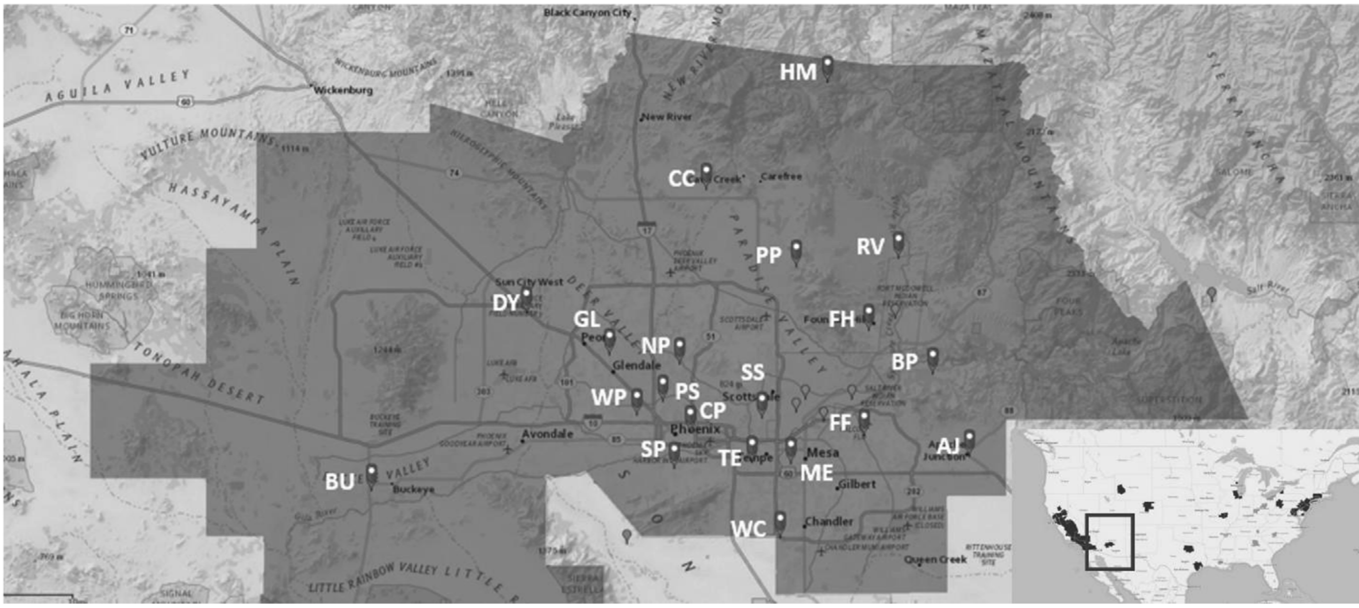

Fig. 1. Phoenix-Mesa MSA ozone nonattainment area (PNA) boundary (dark shade) with the 20 regulatory ozone monitors (listed in white letters) used in study denoted as balloon markers. Ozone monitors are overlaid with topography to highlight the complex terrain. Inset map of United States shows the PNA (within box) relative to other U.S. ozone nonattainment areas (dark polygons). Maps generated from EPA's website (https://epa.maps.arcgis.com/apps/webappviewer/index.html?id=5f239fd3e72f424f98ef3d5def547eb5&extent=-146.2334,13.1913,-46.3896,56.5319, EPA, 2017).

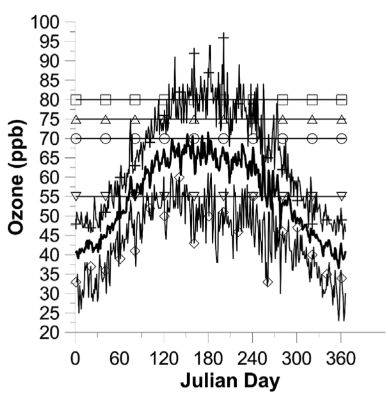

Fig. 2. Annual plot showing the 2006 to 2016 PNA mean (bold black line), maximum observed (plus sign), and minimum observed (diamond) DMO8 values. Additionally, the EPA 1997, 2008, and 2015 NAAQS ozone standards are indicated (square, triangle, and circle, respectively). Mean, maximum, minimum curves calculations are based only on the highest reporting daily DMO8 in the 20-monitor network for a given day. The NAM season covers the months of July and August and is the focus of this study.

over relatively short periods thereby affecting moisture, temperature, winds, and overall atmospheric instability (e.g., Shi et al., 2012). Specifically, the monsoon consists of "breaks" and "bursts" (Carleton, 1986) in regional rainfall. Drawing a parallel to "breaks" and "bursts" in monsoonal precipitation, it is likely that changing atmospheric patterns would dictate local pollution levels. Therefore, this study's main goal is to identify favorable atmospheric conditions and patterns when high DMO8 values are observed during NAM (i.e., July and August) in the PNA.

2. Data

Meteorological and air quality data are available for NAM from 2006 to 2016 within the PNA. There were 682 days possible over the study period representing 11 monsoon seasons; however, selection of days for review were limited to those having: 1) at least one DMO8 observation in the PNA, 2) 12Z (0500 LST) and 00Z (1700 LST) radiosonde profiles (i.e., mandatory levels between surface and 300 hPa), and 3) ozone precursor readings, including oxides of nitrogen (Monks et al., 2015) and carbon monoxide (Yamasoe et al., 2015). A modest reduction in potential study days occurred from missing radiosonde wind observations, primarily in the years 2010 and 2011, compounded by some gaps in daily precursor representation as only days with all 24-hourly observations were analyzed. Consequently, data inclusion restrictions resulted in 509 out of 682 possible days (74.6 percent) for evaluation.

Radiosondes are launched in the Phoenix-Mesa MSA regularly only during the monsoon (i.e., mid-June through late September) by the local water/power utility, Salt River Project, in conjunction with the National Weather Service Forecast Office Phoenix. Location of launch site is centrally located within the PNA in an urbanized area (33.45N, −111.95W) and is close to the Tempe monitor (TE in Fig. 1). Data are available via the National Oceanic and Atmospheric Administration/ Earth System Research Laboratory radiosonde database (ESRL, 2017).

The Phoenix 12Z and 00Z radiosonde data establishes the vertical atmosphere represented when new daily ozone production begins (i.e., after sunrise) and again near the typical late afternoon peak in ozone concentrations (e.g., Ellis et al., 1999; Shutters and Balling, 2006). Although the use of an afternoon radiosonde launch during the monsoon could produce local "convective contamination" concerns (Giaiotti and stel, 2007), the local meteorological conditions are specifically required for this study to determine the association with ozone concentrations within the PNA.

Radiosonde variables considered were geopotential height, temperature, dewpoint, wind speed, and wind direction at the following levels: Surface, 925, 850, 700, 500, 400, and 300 hPa. Three additional variables were derived. First, the parameter "dewpoint depression" was calculated for its relationship to cloud cover approximation (Vasques, 2011), since cloud cover affects solar insolation received at the surface and interferes with the photochemistry necessary for new ozone production (e.g., Wayne, 1987). The second and third derived variables were zonal (U) and meridional (V) wind components to replace and overcome the difficulties in using a single wind direction (0°–360°) in statistical analyses.