Atmospheric Environment 75 (2013) 141–146

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

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

Short communication

The 1970 Clean Air Act and termination of rainfall suppression in a U.S. urban area

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HIGHLIGHTS

- There was a major decrease in particulate emissions after the passage of the Clean Air Act of 1970.
- The reduction in emissions caused a rapid rebound in summer rainfall in the Atlanta region in the late 1970s.
- There was a decrease in summer rainfall of at least 40 mm at affected locales prior to the passage of act.
- The rainfall suppression involved a decrease of heavy-rainfall days.

ARTICLE INFO

Article history:
Received 14 January 2013
Received in revised form
13 April 2013
Accepted 15 April 2013

Keywords:
Precipitation
Particulates
Suppression
Urban
Policy
Pollution

ABSTRACT

The purpose of this paper is to determine the impact of reduced atmospheric particulate resulting from the Clean Air Act of 1970 on changes in summer rainfall in the Atlanta, Georgia USA region. In order to determine if rainfall at nine candidate stations in the metropolitan area was influenced by changes in particulate concentrations within the 1948–2009 period, predicted rainfall characteristics were derived from rainfall frequencies at nine reference stations located more than 80 km from downtown Atlanta. Both parametric and non-parametric tests were used to test for significant differences between observed values and predicted values within 34 overlapping 30-year periods. For the country as a whole, emissions of PM_{10} (i.e. particulates with a diameter less than or equal to 10 μm) decreased by approximately 40% from 1970 to 1975. The reduction in emissions caused a rapid rebound in summer rainfall in the Atlanta region. There was suppression of rainfall over and downwind of the Atlanta urbanized area during 30-yr periods that comprise all or portions of the decades of the 1950s, 1960s, and 1970s. This suppression occurred even while urban-related factors that promote rainfall enhancement were present. During the 1948–1977 suppression period, there was a decrease in rainfall of at least 40 mm at affected locales, which is substantial given that the mean seasonal rainfall was approximately 300 mm. The rainfall suppression involved a decrease of heavy-rainfall days. Atlanta is most likely not a unique case; therefore, particulate-induced rainfall suppression might have occurred over and downwind of other U.S. urban areas prior to the late 1970s.

1. Introduction

Increased atmospheric concentrations of particulates from urban and industrial sources have been implicated in precipitation suppression (Rosenfeld, 2000; Givati and Rosenfeld, 2004; Jirak and Cotton, 2006; Rosenfeld et al., 2007, 2008a, 2008b). In the United States, the passage of the Clean Air Act (CAA) of 1970 caused a dramatic decrease in particulate emissions; from 1970 to 1975, emissions of PM_{10} (i.e. particulates with a diameter less than or equal to 10 μm) decreased by approximately 40% (Fig. 1) (U.S. Environmental Protection Agency, 2012; Chay and Greenstone, 2003). Particulates serve as cloud condensation nuclei (CCN), and increased CCN from fossil-fuel combustion increases the number of cloud droplets while reducing droplet size (Gunn and Phillips, 1957; Coakley et al., 1987). This slows the conversion of cloud droplets into raindrops (Gunn and Phillips, 1957). For example, particulates from fossil-fuel combustion have been shown to suppress precipitation from shallow clouds (Rosenfeld, 2000; Givati and Rosenfeld, 2004; Jirak and Cotton, 2006; Rosenfeld et al., 2007, 2008a). Increased particulate concentrations also can increase the stability of the atmosphere, thereby inhibiting the development of convective clouds (Koren et al., 2004). Given the above information, it seems reasonable to surmise that precipitation suppression over and downwind

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1352-2310/$ – see front matter
http://dx.doi.org/10.1016/j.atmosenv.2013.04.041

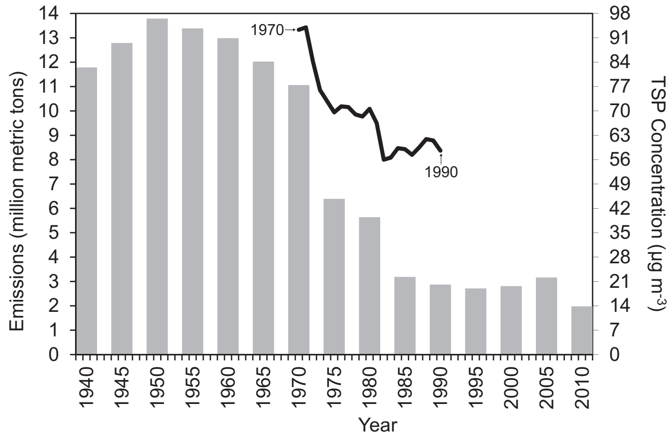

Fig. 1. National PM_{10} emissions from 1940 to 2010 and the mean total suspended particulate (TSP) concentration from 1970 to 1990. PM_{10} emissions from 1940, 1950, 1960, 1970, 1975, 1980, 1985, 1990, 1995, 2000, 2005, and 2010 were obtained from the U.S. Environmental Protection Agency's National Emissions Inventory Air Pollutant Emissions Trends Data. Totals for 1945, 1955, and 1965 were calculated as means from decadal years listed above. TSP concentrations were obtained from Chay and Greenstone (2003), where mean annual TSP concentrations were calculated from data collected at 1000 to 1300 counties.

of U.S. cities occurred prior to the CAA and may have been moderated in the 1970s.

While also establishing standards for carbon monoxide, tropospheric ozone, and sulfur dioxide, the CAA also established a standard for total suspended particulates (TSPs), which are particles ranging in size from approximately 0.1 μm–30 μm in diameter. Standards for PM_{10}, which replaced the TSP standard, and $PM_{2.5}$ (i.e. particulates with a diameter less than or equal to 2.5 μm), were established in 1987 and 1997, respectively. The CAA resulted in a major improvement in particulate air quality from 1971 to 1975 (Chay and Greenstone, 2003) (Fig. 1). The 1950s and 1960s were decades with high particulate emissions and presumably high TSP, PM_{10}, and $PM_{2.5}$ concentrations; thus, clouds over and downwind of urban/industrial areas during those decades should have had more and smaller cloud droplets than did clouds during the past three decades.

Urban areas should affect precipitation, especially summer rainfall, even without any anthropogenic aerosol emissions. Urbanization causes an increase in surface roughness that can lead to convergence downwind of the urban area, and thus enhanced lifting of air needed for cloud formation and development (Hjelmfelt, 1982; Rozoff et al., 2003). Urbanization also results in one or more heat islands within a metropolitan area, and an urban heat island can enhance convection (Baik et al., 2001; Han et al., 2012).

The aim of this paper is to assess the impact of reduced particulate matter resulting from the CAA on changes in rainfall in the Atlanta region. The Atlanta region (Fig. 2) is an optimal region for the assessment. Firstly, the region had high TSP concentrations prior to the passage of the CAA: Fulton County, which is in the center in the center of the Atlanta region, did not meet federal standards for TSPs throughout the 1960 and into the early 1970s

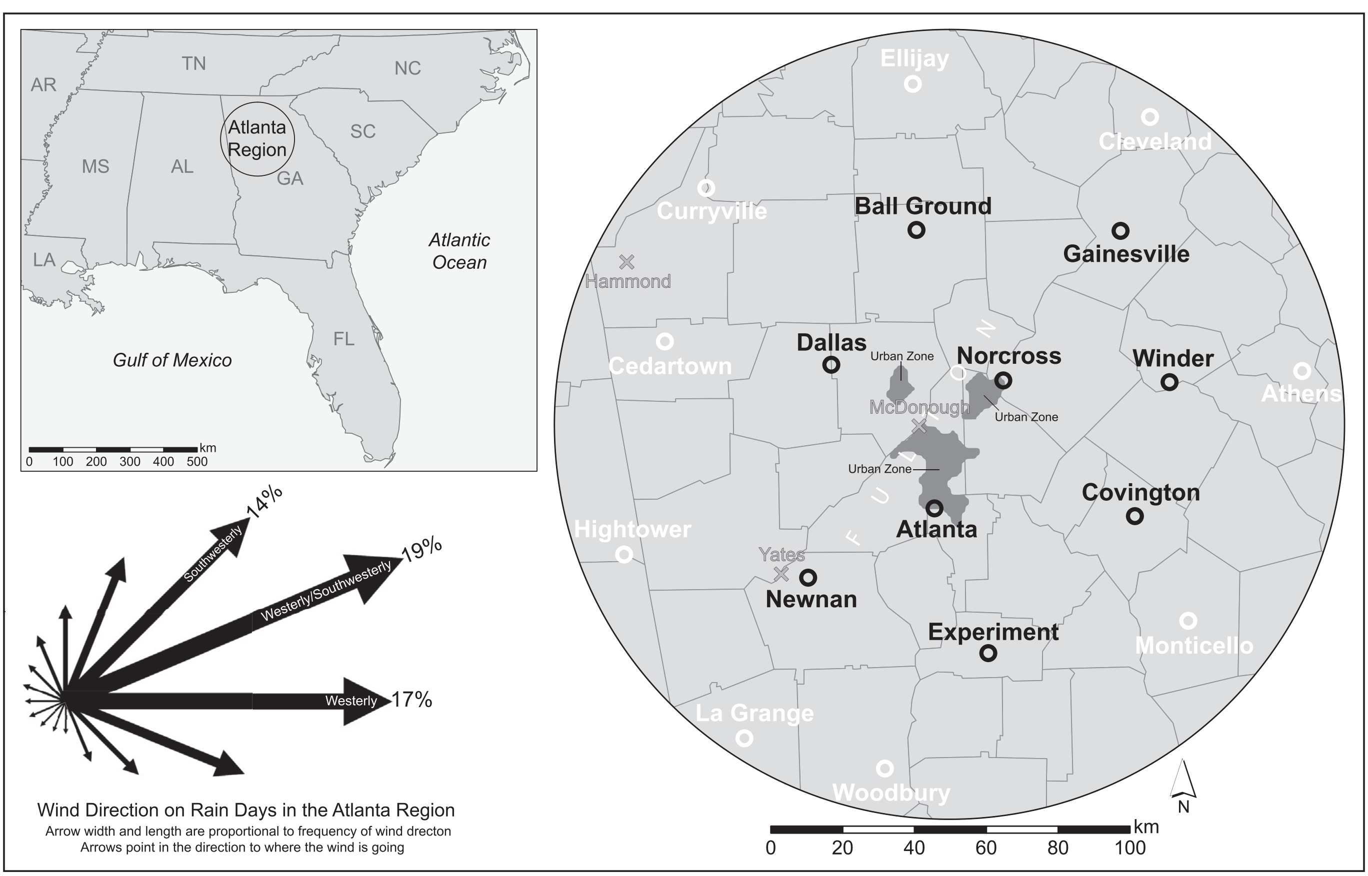

Fig. 2. Location of the study region within the southeastern United States and locations of the nine candidate precipitation stations (black circles), the nine reference precipitation stations (white circles), the three power plants (Hammond, McDonough, and Yates) in operation prior to 1970, and the urban zones of metropolitan Atlanta circa 1973. Also shown are lower-troposphere wind directions on rainfall days at the 18 precipitation stations during the 1948–1977 period. Daily wind data at 850 hPa, 700 hPa, and 500 hPa for grid cells corresponding to the Atlanta region were extracted from the NCEP/NCAR Reanalysis dataset of the Earth System Research Laboratory of the National Oceanic and Atmospheric Administration (Kalnay et al., 1996).