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Response of the summertime ground-level ozone trend in the Chicago area to emission controls and temperature changes, 2005–2013

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HIGHLIGHTS

- O_3 in Chicago did not decline during 2005–2013, despite reductions in NO_x emissions.
- Since 2008/2009, O_3 formation has become more sensitive to VOC emissions.
- Concentrations of reactive VOCs increased significantly after 2008/2009.
- Meteorological conditions explain about 53% of the O_3 variance.

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ABSTRACT

Despite strenuous efforts to reduce the emissions of ozone precursors such as nitrogen oxides (NO_x), concentrations of ground-level ozone (O_3) still often exceed the National Ambient Air Quality Standard in U.S. cities in summertime, including Chicago. Furthermore, studies have projected a future increase in O_3 formation due to global climate change. This study examines the response of summertime O_3 to emission controls and temperature change in the Chicago area from 2005 to 2013 by employing observations of O_3, O_3 precursors, and meteorological variables. We find that meteorology explains about 53% of the O_3 variance in Chicago. O_3 mixing ratios over Chicago are found to show no clear decline over the 2005–2013 period. The summertime ground-level O_3 trend consists of a decrease of 0.08 ppb/year between 2005 and 2009 and an increase of 1.49 ppb/year between 2009 and 2013. Emissions of NO_x and concentrations of NO_2 have been decreasing steadily from 2005 to 2013 in the Chicago area. Concentrations of volatile organic compounds (VOCs) in Chicago, however, have more than doubled since 2009, even though emission inventories suggest that VOC emissions have decreased. We believe that O_3 production in Chicago became more sensitive to VOCs starting in 2008/2009 and may have switched from being NO_x-limited to VOC-limited. The warmer climate since 2008 has also contributed to the increasing ozone trend in the Chicago area. Increased attention should be paid to improving the quantification of VOC sources, enhancing the monitoring of reactive VOC concentrations, and designing VOC mitigation measures.

1. Introduction

Despite strenuous efforts over a period of almost 25 years since the passage of the U.S. Clean Air Act Amendments (CAAA) of 1990, large areas of the U.S., particularly urban areas, continue to experience elevated summertime ozone (O_3) concentrations. These high concentrations aggravate asthma and other respiratory conditions and may lead to premature death, especially of people with pre-existing heart and lung disease. Because of these effects, the costs for medication, doctor visits, emergency department visits, and hospital admissions add to the economic burden of U.S. cities and their residents. Sensitive vegetation can also be harmed by elevated O_3 levels. In addition, O_3 plays a critical role in

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photochemical reactions that control the lifetimes of other air pollutants. Regulatory initiatives by the U.S. Environmental Protection Agency (U.S. EPA), in concert with state and tribal agencies, have driven down emissions of the O_3 precursors nitrogen oxides (NO_X) and volatile organic compounds (VOC), and yet summertime O_3 concentrations have not shown a corresponding downward trend in many locations. Why is this? And what is the prognosis for air quality improvement in a world of increasingly limited and expensive emission controls, a growing population, and a warming climate? This study examines the experience in Chicago over the period 2005–2013.

The National Ambient Air Quality Standards (NAAQS) for O_3 were codified in their current form in 1997 as an 8-h concentration of 0.08 parts per million (ppm) or 80 parts per billion (ppb)—rounded to 84 parts per billion (ppb) for compliance purposes—defined as the annual fourth-highest daily maximum value, averaged over three years. In 2008, the level was reduced to 75 ppb. These values applied to both primary (for the protection of public health) and secondary (for the protection of public welfare) standards. At present, as part of its mandatory five-year review, U.S. EPA is considering revising the standard again, down to somewhere in the range of 60–70 ppb. In 2012, U.S. EPA made final designations on compliance with the 2008 O_3 standard. The greater Chicago area—consisting of eight Illinois (IL) counties (two of them partial), two northwest Indiana (IN) counties, and one southeast Wisconsin (WI) county (partial)—was designated to be in marginal nonattainment, based on monitoring data, state recommendations, and related technical information.

In order to reduce O_3 concentrations nationwide and to achieve compliance with the NAAQS, several initiatives were triggered by the 1990 CAAA with the aim of reducing emissions of O_3 precursors. Because NO_X is an important precursor of O_3, efforts were made to restrict NO_X emissions from on-road vehicles and fossil-fuel-burning power plants. Vehicle NO_X emissions declined nationwide due to implementation of the requirements of the 1990 CAAA, especially after the more-stringent Tier 2 standards were phased-in between 2004 and 2009 (Dallmann and Harley, 2010; McDonald and Gentner, 2013). The State Implementation Plan (SIP) Call was issued in 1998 with the objective of cutting NO_X emissions so that summertime O_3 levels would be lowered (http://www.epa.gov/airmarkets/progsregs/nox/noxsipcall.html). Furthermore, the Clean Air Interstate Rule (CAIR) was introduced in 2005 for 27

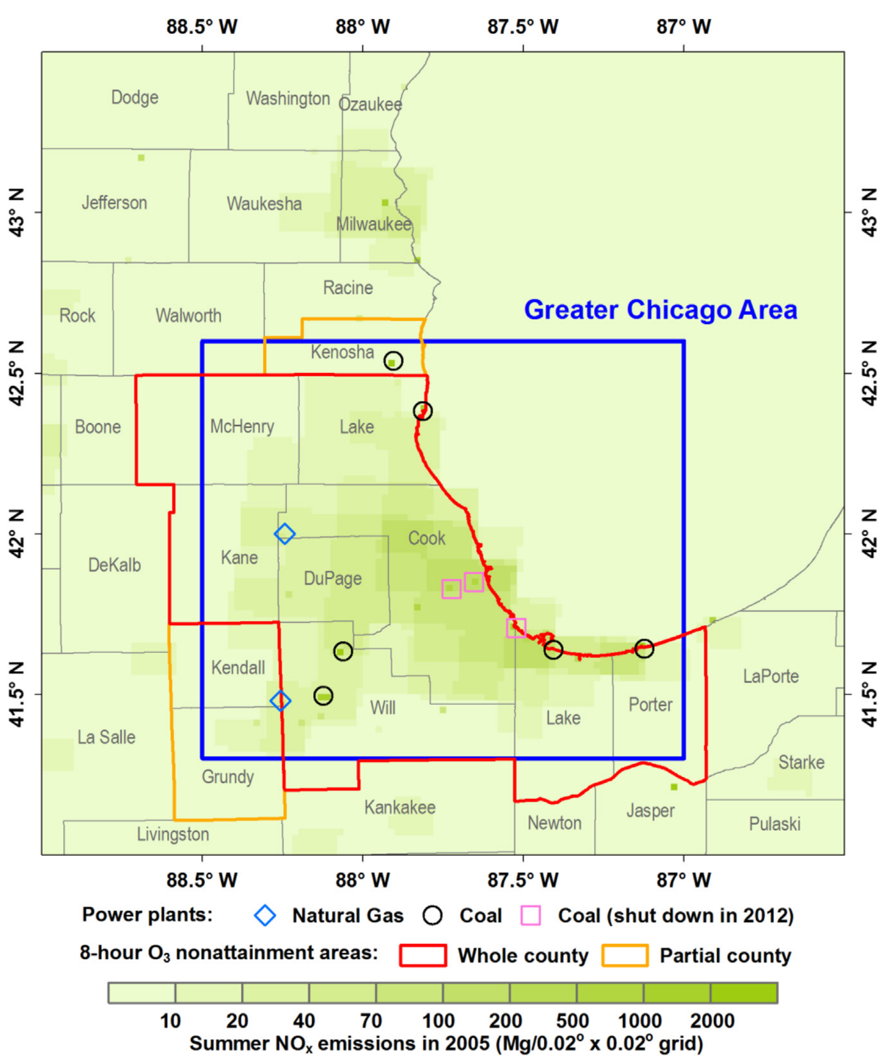

Fig. 1. Summertime NO_x emissions in 2005 in Chicago and surrounding regions from Xing et al. (2013) at 0.02° × 0.02° resolution. The greater Chicago area is enclosed by the blue box. The red line encloses whole 8-h O_3-nonattainment counties; partial O_3-nonattainment counties are enclosed by orange lines. Blue diamonds mark the locations of large natural-gas-burning power plants, black circles are large coal-burning power plants, and pink squares are the three coal-burning power plants that were shut in 2012. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)