DISCOVER-AQ

The Benefit of Historical Air Pollution Emissions Reductions during Extreme Heat

An examination of the climate penalty factor phenomenon—as temperatures increase, air pollution worsens.

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Baltimore, Maryland

Thermometer in the shade on the hottest day of the summer shows a 122 degree heat index during research hours.

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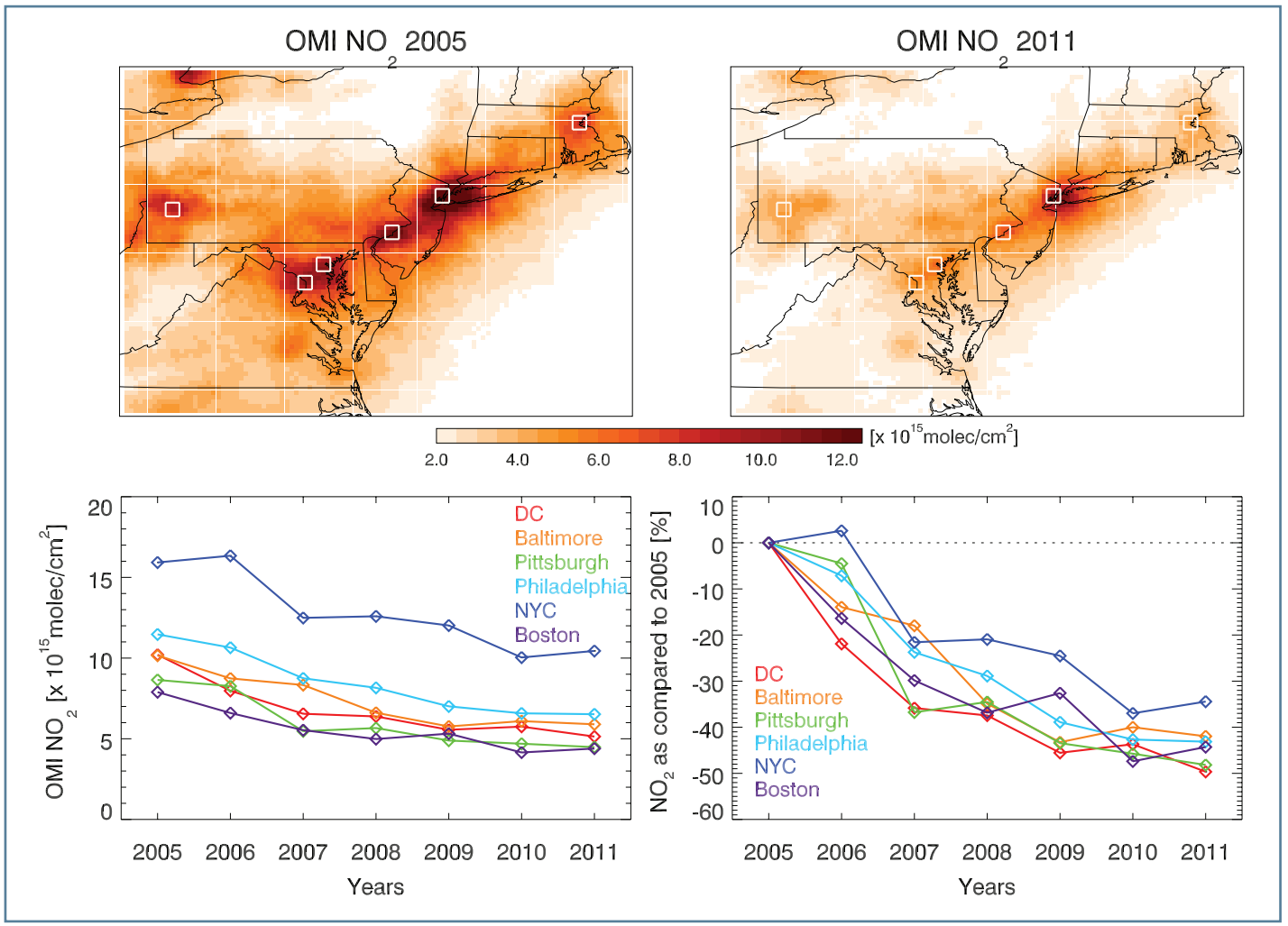

Figure 1. OMI annual average tropospheric NO_2 column throughout the Mid-Atlantic in 2005 (top left) and 2011 (top right), for select cities from 2005 to 2011 (bottom left), and percent change from 2005 for select cities (bottom right).

As air pollution emissions have been reduced in the United States over the past few decades, surface air quality has improved. However, future climate change is expected to dampen the benefit of emissions reductions. Air quality model results show air pollution worsens as temperatures increase,[1-4] and observations confirm a correlation of high temperature and events with high air pollution levels.[5-7] This phenomenon is termed the climate penalty factor.

Various meteorological, photochemical, and emissions processes describe the positive correlation between temperature and ozone (O_3).[8-10] Bloomer et al.[5] noted that the climate penalty factor is reduced as air pollution emissions decrease, and He et al.[10] determined that a third of the climate penalty factor is due to an increase in power plant emissions as a result of an increase in energy demand on hot summer days. Here, we examine the impact of historical air pollution emissions reductions on surface O_3 during unseasonably hot summer days, which are favorable for O_3 production and may become more typical due to climate change. This allows us to isolate the effects of emissions reductions from climate variability.

Hot, Hot, Hot in July

Maryland in July 2011, a historically hot month, is used as a backdrop for this study. The United States experienced extreme heat during July 2011, which coincided with the DISCOVER-AQ Maryland field campaign. Nationally, July 2011 was the fourth warmest July on record. The Baltimore–Washington metropolitan area experienced its hottest month in recorded history in July 2011, and the Baltimore–Washington International (BWI) airport recorded 24 days with temperatures at or above 90 °F during July 2011. The hot temperatures experienced in July 2011 may be more prevalent in the future under a globally warming world.

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If emissions did not change since 2002, then half of the days in July 2011 would have been classified as O_3 exceedence days for much of the Mid-Atlantic.

The hot, stagnant weather conditions in July 2011 contributed to unhealthy air pollution levels. In Maryland, 14 code orange days (maximum 8-hr average O_3 >75 parts per billion by volume, ppbv) and three code red days (maximum 8-hr average O_3 >95 ppbv) were recorded. However, it could have been much worse without historical emissions reductions inside and outside Maryland.

Historical Emissions Reductions

Air pollution emissions regulations have been put in place with the goal of achieving attainment of healthy air, as defined by the U.S. Environmental Protection Agency's (EPA) National Ambient Air Quality Standards. In 1998, the nitrogen oxides (NO_x) State Implementation Plan (SIP) Call Rule was finalized to require 22 states and the District of Columbia to regulate NO_x emissions to mitigate O_3 transport. The NO_x SIP Call Rule was fully implemented by May 31, 2004, and included rules pertaining to the NO_x Budget Trading Program. Since then, additional court-orders and state regulations went into effect to further improve surface air quality. Nationwide, NO_x anthropogenic emissions have been reduced by 37% between 2002 and 2011 as reported by EPA's National Emissions Inventory (NEI).

Past emissions reductions have been detectable from space.[11] The Ozone Monitoring Instrument (OMI) onboard the NASA Aura satellite detects column integrated O_3, or the number of molecules of O_3 between the instrument and Earth's surface. However, it is difficult to discriminate the amount of the O_3 column that is at "nose level" as most of the column is in the stratosphere (e.g., "ozone layer") and ultraviolet (UV) wavelengths of light, which are used for detecting and measuring O_3, are strongly obscured by atmospheric scattering, which limits their ability to reach Earth's surface.

OMI also measures nitrogen dioxide (NO_2), an O_3 precursor. Column integrated NO_2 is typically reported in units of molecules per unit area of the Earth's surface. Decreases in NO_2 column content have been evident throughout the United States, including the Mid-Atlantic, as shown in Figure 1. For example, OMI detected tropospheric NO_2

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column has decreased by about 40% over the Washington, DC, metropolitan area between 2005 and 2011. These reductions have occurred as air pollution emissions regulations have been adopted and implemented inside and outside Maryland, resulting in healthier air for everyone to breathe.

The benefits of regional reductions in air pollution emissions on surface O_3 concentrations are evident at ground monitoring stations. In order to isolate the influence of emissions from climate variability, we examine the number of O_3 exceedance days to high temperature days. Figure 2 depicts the number of days when the temperature reached 90 °F or higher at the BWI Airport and the number of days surface O_3 exceeded the current EPA standard (maximum 8-hr average O_3 >75 ppbv) at any monitoring site in Maryland for each year from 1980 to 2013. In 1980, Maryland experienced double the number of O_3 exceedance days based on the current standard (maximum 8-hr average O_3 >75 ppbv) than hot days (maximum temperature ≥90 °F). As numerous air pollution emissions reductions regulations took effect in the 2000s, the difference between the number of hot days and number of O_3 exceedance days decreased. In fact, Maryland experienced more hot days than O_3 exceedance days over the past five years, as shown in Figure 2 (2009–2013).

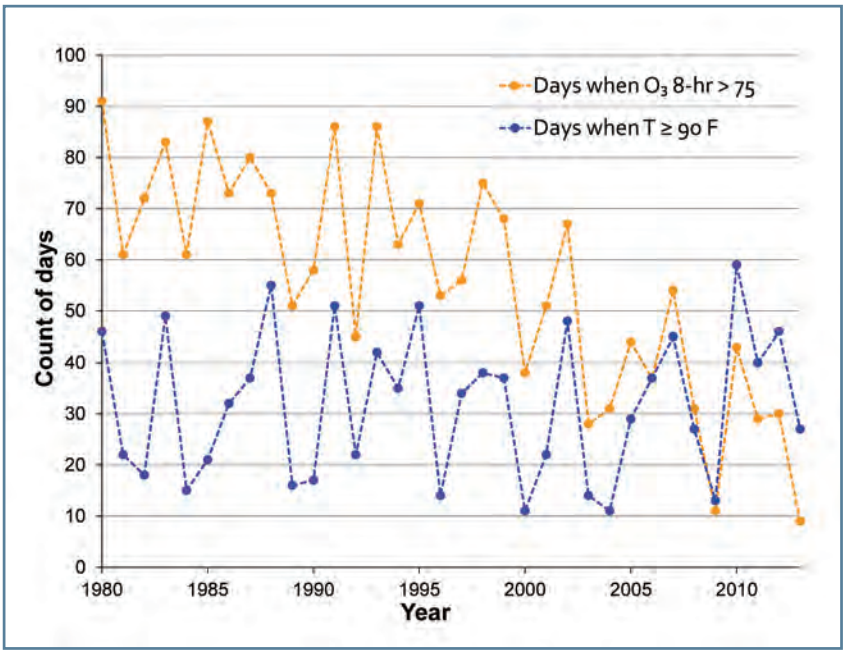

Figure 2. Number of days maximum 8-hr average O_3 exceeded the current EPA O_3 standard (>75 ppbv) from all monitored data collected in Maryland (orange) and the number of days daily maximum temperature reached 90 °F or above (blue) from 1980 to 2013.

CMAQ Model Simulation Results

To investigate the benefit of anthropogenic emissions reductions since the NO_x SIP call during a historically hot month (July 2011), the Community Multi-scale Air Quality (CMAQ) model[12] was run with emissions appropriate for 2002 and 2011. Both simulations use July 2011 meteorology, biogenic emissions, and lightning emissions, so the only difference in the two CMAQ simulations is the anthropogenic emissions inputs. This modeling approach removes the uncertainty in the role of climate variability impacting O_3 concentrations,

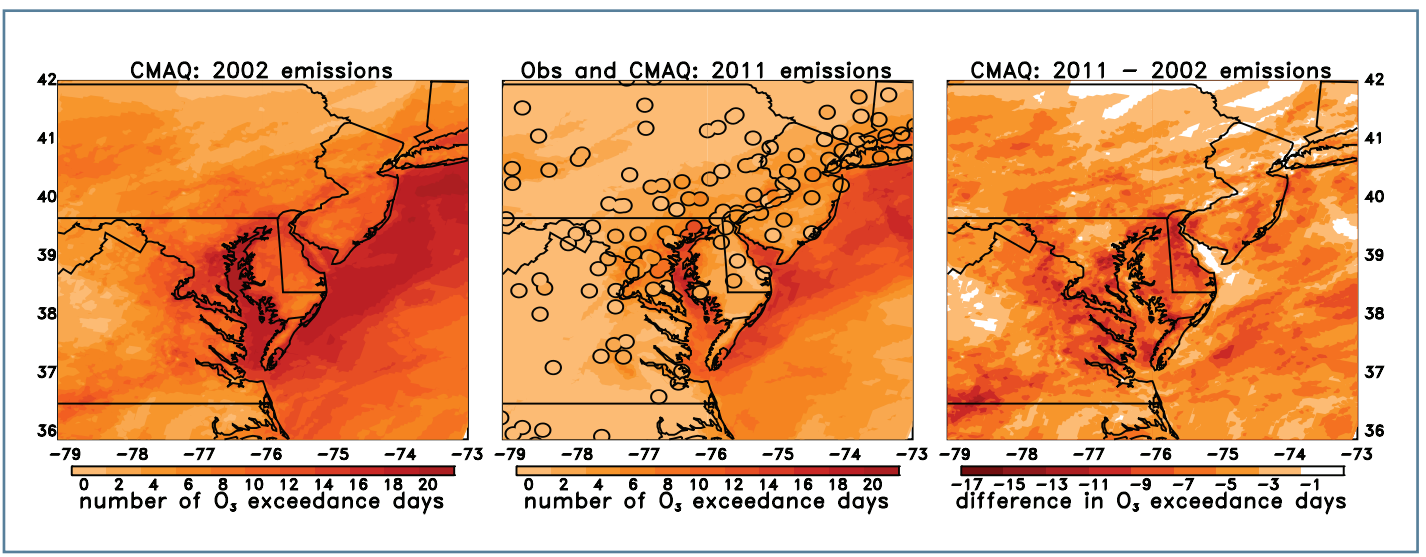

Figure 3. Number of O_3 exceedance days (>75 ppbv) for July 2011 from a CMAQ simulation using anthropogenic emissions appropriate for 2002 (left), a CMAQ simulation with anthropogenic emissions appropriate for 2011 with observations overlayed on-top (center), and the difference in number of O_3 exceedance days between the CMAQ simulations using 2011 and 2002 emissions (right).

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so a comparison between the two model runs reveals only the benefit of the historical anthropogenic emissions changes (air pollution emissions regulations) on surface air quality.

Results presented here are from a 4-km domain covering the Mid-Atlantic that was nested down from 36- and 12-km domains. See Refs. 13–17 for details on the implementation and inputs used in the CMAQ simulation using anthropogenic emissions appropriate for 2011. CMAQ anthropogenic emissions inputs appropriate for 2002 were created by processing the EPA 2002 NEI with the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system.[18]

Results from the two CMAQ simulations, shown in Figure 3, indicate that if emissions did not change since 2002, then half of the days in July 2011 would have been classified as O_3 exceedence days for much of the Mid-Atlantic. Air pollution emissions reductions since 2002 likely prevented 3–11 O_3 exceedance days throughout Maryland during this historically hot month. Averaged over the entire month of July, simulated maximum 8-hr average O_3 with 2002 emissions is 3–9 ppbv higher than the simulation with 2011 emissions.

Summary

The benefit of recent regional emissions reductions regulations for meeting the O_3 standard is clear for the Mid-Atlantic. Emissions reductions between 2005 and 2011 reduced NO_x loading by approximately 40% in Maryland, as detected by the OMI. These regional emissions reductions have decreased the amount of O_3 exceedance days during hot, stagnant meteorological episodes (i.e., when O_3 production is favorable). The emissions reductions between 2002 and 2011 likely prevented 3–11 O_3 exceedance days throughout Maryland in July 2011, a month that experienced record breaking heat. The meteorological conditions Maryland experienced in 2011 may become typical under a globally warming world and should be considered when implementing future air quality plans. **em**

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