

September 26, 2013



New York City Trends in Air Pollution and its Health Consequences



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Acknowledgments

The contributors are grateful to colleagues from City and State agencies that provided logistical support and advice. The New York City Community Air Survey contributors also appreciate the contributions of Anna Tilles, Jordan Werbe-Fuentes, Jonah Haviland-Markowitz, Rolando Munoz, Steves Vanderpool, Jung Kim, Victoria Vele, Sarah Walters, Kathryn Lane, and Grant Pezeshki.

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Executive Summary

Air pollution is one of the most important environmental threats to the health of New York City residents. To improve the health of its residents, in 2007 New York City launched its first sustainability plan, PlaNYC, which included a collection of measures designed to improve local air quality.

One component of PlaNYC's air strategy was the launch of the New York City Department of Health and Mental Hygiene's New York City Community Air Survey (NYCCAS), which measured street level air pollution at 150 locations from 2008-2010 and at 100 locations from 2010-2013. Results from the first year of monitoring (2009) showed that levels of air pollutants important to public health, specifically fine particles ($PM_{2.5}$), sulfur dioxide (SO_2) and nickel (Ni), were higher in areas that have high density of buildings with boilers burning fuel oil, particularly residual fuel oil (grades No. 4 and No. 6 heating oils). Since then the city has taken action to eliminate residual oil from our buildings, combining regulations that will phase out their use with resources for building owners provided through the city's Clean Heat program. Additional New York State restrictions on the sulfur content of No. 2 oil and citywide limits on the sulfur content of No. 4 oil were also implemented in 2012 to reduce heating related emissions.

This report summarizes results of NYCCAS air quality monitoring conducted since December 2008. As of winter 2012-2013, wintertime SO_2 levels have declined by 69% while levels of nickel in fine particulate matter (an indicator of residual oil combustion) have declined by 35%. Neighborhoods with the greatest reductions in emissions from boiler conversions and fuel sulfur restrictions saw the greatest improvement in air quality, with almost two-fold greater improvements in SO_2 and Ni levels than seen in neighborhoods with fewer building boiler conversions.

In addition, routine regulatory air monitoring (conducted by the New York State Department of Environmental Conservation as required by federal clean air regulations) in New York City has recorded a 23% improvement in annual average city-wide $PM_{2.5}$ concentrations in 2009-11 relative to 2005-2007. These reductions are likely due to the reduced emissions from local heating sources, combined with state and federal actions to reduce emissions from regional and national sources. These improvements are estimated to contribute to 780 fewer deaths, 1,600 fewer emergency department visits for asthma, and 460 fewer hospitalizations for respiratory and cardiovascular disease annually. We estimate that 25% fewer $PM_{2.5}$ -attributable deaths occurred in 2009-2011 than would have occurred had there been no improvements in $PM_{2.5}$ levels. Due to declining concentrations, New York City has moved from seventh place among the nation's nine largest cities for $PM_{2.5}$ levels as recently as 2008-2010 to fourth place in 2011-2012, achieving the largest decline in levels among largest cities since 1999-2001.

These findings indicate that targeted efforts included in PlaNYC, in concert with state and federal efforts, have improved air quality levels in New York City and have led to substantial public health benefits for city residents. Further action is still needed to improve air quality, as it is estimated that current (2009-2011) levels of $PM_{2.5}$ still cause annually more than 2,000 deaths, 4,800 emergency department visits for asthma, and 1,500 hospitalizations for respiratory and cardiovascular disease. Continued efforts to reduce emissions are needed, particularly from traffic related sources, where action such as congestion mitigation and low emission vehicle adoption will lead to further improvements in the city's air.

Introduction

PlaNYC Launched a New Era of Local Action to Improve Air Quality

Despite improvements since the 1970s, air pollution remains a serious health threat for New York City residents. The Health Department has estimated that ambient levels of fine particles (PM_{2.5}) in 2005-2007 contributed to over 3,000 deaths in New York City annually.¹ With the most local emissions per square mile of fine particles (PM_{2.5}), or soot, of any large U.S. city,² and a dense population that includes many who are vulnerable to the effects of air pollution, more local action was needed to reduce levels and improve the health of New Yorkers. In 2007 the city launched its first sustainability plan, PlaNYC, which included 127 initiatives to accommodate one million new residents over the next decade, improve environmental quality, and create a more livable city. PlaNYC set the ambitious goal of making New York City's air quality the cleanest air of any big city in the U.S., and set in motion a comprehensive agenda to reduce emissions from sources such as cars and trucks, buses, power plants and buildings.

PlaNYC recognized the need for a comprehensive citywide, year-round study of air quality across New York City neighborhoods to more effectively target local emissions. The Health Department's New York City Community Air Survey (NYCCAS) was launched in December 2008 in cooperation with Queens College to provide data on street-level concentrations of harmful air pollutants across the city and identify sources driving differences in neighborhood air quality.³ The results of this monitoring have been used to guide city air quality improvement strategies, provide

exposure estimates for health effects research, and provide New Yorkers with information on harmful pollutant levels in their communities.

Results from NYCCAS documented impacts of heating oil emissions, especially from residual oil, on neighborhood concentrations of fine particulate matter air pollution (PM_{2.5}), sulfur dioxide (SO₂) and nickel, spurring laws, regulations, and voluntary efforts to switch to cleaner heating fuel.

Since then, significant emissions reductions have been realized from a variety of sources, including heating fuel, power plants, and motor vehicles. This report first describes changes in wintertime air pollution levels since the start of NYCCAS monitoring in December 2008, examining associations with reduced emissions from heating fuel in particular. It then reports on how citywide PM_{2.5} levels have changed since the launch of PlaNYC and estimates the public health benefits of these improvements.

Cleaner Fuel for Heat and Power

It was estimated that in 2005 approximately 10,000 buildings in New York City burned Nos. 4 and 6 heating oil, the most polluting of heating fuels, that emit more PM_{2.5}, SO₂, nickel and other pollutants than alternative heating fuels. These buildings, accounting for 1% of the total buildings in the city, were estimated to produce more PM_{2.5} emissions than all the on-road vehicles citywide. Additionally, NYCCAS monitoring in the winter of 2008-2009 found that sites in with high densities of No. 4 and No. 6 boilers had 2.5 times higher SO₂ levels and 4 times higher nickel levels than

¹ <http://www.nyc.gov/html/doh/downloads/pdf/eode/eode-air-quality-impact.pdf>

² Relative to cities with greater than 1,000,000 residents. Source: US EPA 2008 National Emissions Inventory (available at: <http://www.epa.gov/ttn/chief/net/2008inventory.html>), US Census County Database (available at: <http://www.census.gov/support/USACdataDownloads.html#LND>)

³ <http://www.nyc.gov/html/doh/html/environmental/community-air-survey.shtml>

those with low nearby residual oil boiler density. $PM_{2.5}$ levels were found to be 33% higher near sites with high oil burning density (No. 2, No. 4, and No. 6) than sites with lower density.

To address this important local source, the city worked with state officials to secure passage of a state law that reduced the sulfur content of No. 2 oil to 15 ppm — a 99% reduction. The City Council then passed and the Mayor signed Local Law 43 of 2010, which lowered the sulfur content of No. 4 oil from 3,000 parts per million (ppm) to 1,500 ppm and required all heating oil to contain 2% of renewable biodiesel. Regulations were then adopted by the city in 2011 to phase out the use of No. 6 heating oil by 2015 and No. 4 heating oil by 2030. The goal of this two-part phase-out was to achieve significant near-term pollution reduction while minimizing costs to building owners. Reducing sulfur content in heating fuels reduces harmful emissions of both $PM_{2.5}$ and SO_2 .

The Clean Heat program, launched that same year, is a partnership between the city, the Environmental Defense Fund, and the New York City Energy Efficiency Corporation that seeks to encourage early adoption of cleaner fuels by providing technical and financial assistance to building owners. Since the program's launch, nearly 2,700 buildings have converted to cleaner fuels, with approximately 75% of those buildings converting to one of the two cleanest fuels, natural gas or ultra-low sulfur No. 2 oil. Conversion rates to natural gas were particularly strong as buildings sought to take advantage of the lower costs of gas relative to fuel oil, which began in 2008 as a result of significant expansion of regional gas supply.

Through these regulatory measures and market forces, since the winter of 2008-9 there has been major progress in shifting to cleaner heating fuels. Consumption of No. 6 heating oil has dropped by 29% since 2009, from 228 million gallons per year to 161 million gallons in 2012.⁴ After taking weather into account, this drop in No. 6 oil consumption amounts to a 16% reduction.

The reduction in heavy oil consumption in buildings from 2008 to 2012 mirrored earlier reductions that occurred in the power sector. From 2005 to 2008, operators of local power plants that were able to utilize either heavy oil or natural gas increasingly burned natural gas to take advantage of its increasingly competitive price. As a result, during this time period, the amount of heavy oil utilized for power generation in New York City decreased from 30% of the total fuel mix to only 2%. Although this fuel switching and the resulting air quality benefits occurred prior to the launch of NYCCAS monitoring, and therefore are not a component of the neighborhood level analysis conducted since 2008, it is important to note the contribution of cleaner burning power plants in improving New York City's air quality, which helped reduce $PM_{2.5}$ levels described later in this report.

⁴ 2013 Inventory of New York City Greenhouse Gas Emissions. Does not include weather adjustments.

New York City Community Air Survey (NYCCAS): Methods

NYCCAS is the first-ever comprehensive survey of street-level air quality across New York City. By monitoring many locations in all seasons across all neighborhoods of the city, NYCCAS studies place-to-place differences in air pollution levels, the major sources that predict these differences, and tracks changes in air quality over time. From December 2008 through December 2010, pollutants were measured at 150 locations citywide, for two weeks in each season of the year. Since 2010 these measurements have been taken at 100 locations. The survey measures common pollutants that are harmful to the respiratory and cardiovascular systems, cause increases in symptoms, emergency department and hospital admissions and even death. Pollutants routinely measured include fine particulate matter (PM_{2.5}), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), ozone (O₃), black carbon (BC), and metals constituents of PM_{2.5}.^{5,6}

NYCCAS results were used to track changes in two pollutants related to heating oil emissions -- Nickel (Ni), a component of fine particles (PM_{2.5}) from burning residual (No. 4 and 6) oil, and sulfur dioxide (SO₂) a pollutant from burning sulfur containing oil -- since NYCCAS began neighborhood air monitoring in the winter of 2008-9 through the winter of 2012-2013.

We first examined trends in the yearly winter average concentrations of each pollutant across all 100 NYCCAS monitoring sites that collected samples in each of the five winter seasons from 2008-9 through 2012-13. Average temperatures during the same five winter seasons were also compared, because more heating emissions occur with colder temperatures.

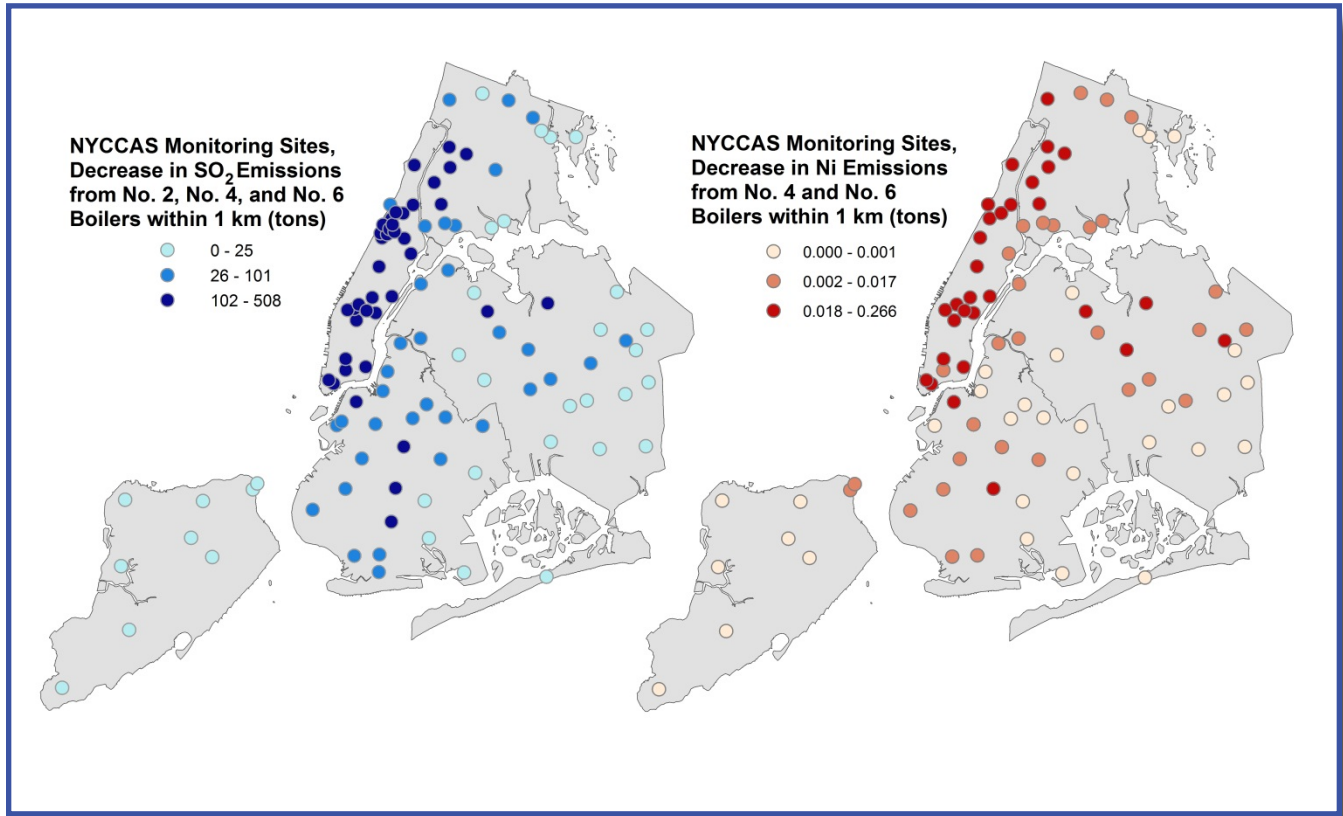
To compare changes in pollutants over time in different parts of the city, we used data from two winters with comparable average temperatures, 2008-9 and 2012-13. We compiled information from permits issued by the New York City Department of Environmental Protection and estimated changes in SO₂ and nickel emissions from boilers citywide in each winter due to completed boiler conversions and new regulations that restricted the sulfur content of Nos. 2 and 4 oil. These building-level changes in SO₂ and nickel emissions were then summed to estimate the change in emissions around each NYCCAS monitoring site. Figure 1 shows the location of NYCCAS sites monitored in both years and the estimated reduction in emissions within a one-kilometer radius. We then calculated average changes in monitored concentrations between winter 2008-9 and in winter 2012-13 for sites in three categories-- low, medium, and high emissions reductions -- and then compared them to evaluate how air quality levels changes in areas near large emissions reductions relative to those with little to no emissions reductions. All SO₂ and Ni concentrations were adjusted for regional weather and emissions using PM_{2.5} levels measured at a background location in Staten Island.

Inhaled PM_{2.5} worsens heart and lung disease, causing hospital admissions and deaths. Nickel (Ni) content in PM_{2.5} is a marker of emissions from residual oil burning and PM_{2.5} with higher Ni content may have greater health effects. SO₂ can exacerbate asthma and, along with PM_{2.5}, contributes to other respiratory illnesses and exacerbation of heart disease. Airborne SO₂ also reacts to form acid, sulfates, PM_{2.5}, and other harmful pollutants.

⁵ More information on these pollutants and health effects at <http://www.epa.gov/airquality/urbanair/>

⁶ More information on NYCCAS methods is available at <http://www.nature.com/jes/journal/v23/n3/abs/jes2012126a.html>

Figure 1: NYCCAS sites sampled in 2008-9 and 2012-3 winters and estimated annual SO₂ and Ni emission reductions



Clean Heat Policies are Improving Winter Air Quality

Over the past five winters, the average SO₂ concentration at NYCCAS monitors declined by 69% from 5.6 ppb to 1.7 ppb. Notably, comparing the 2011-12 and 2012-13 winters, concentrations continued to fall, even though the latter winter was considerably colder (Figure 2). Substantial reductions in estimated concentrations have occurred across the city (Figure 3). The reduction in concentrations was greater at locations with more reduction in nearby emissions from boiler conversions and cleaner fuel (Figure 4). As a result, the gap in SO₂ concentrations between locations of high and low density of Nos. 2, 4, and 6 boilers fell by 46%.

Figure 2: Change in wintertime average SO₂ concentrations across all NYCCAS monitoring sites

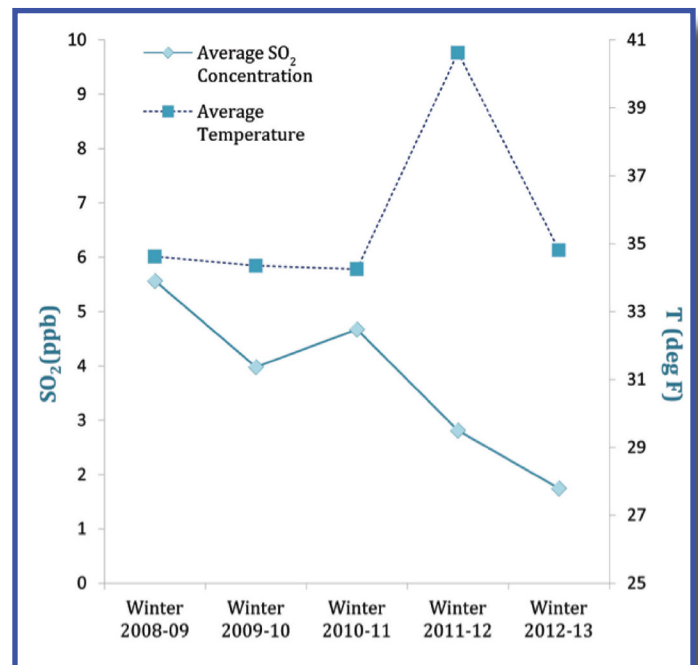


Figure 3: Estimated SO₂ Concentrations, winter 2008-2009 and winter 2012-2013

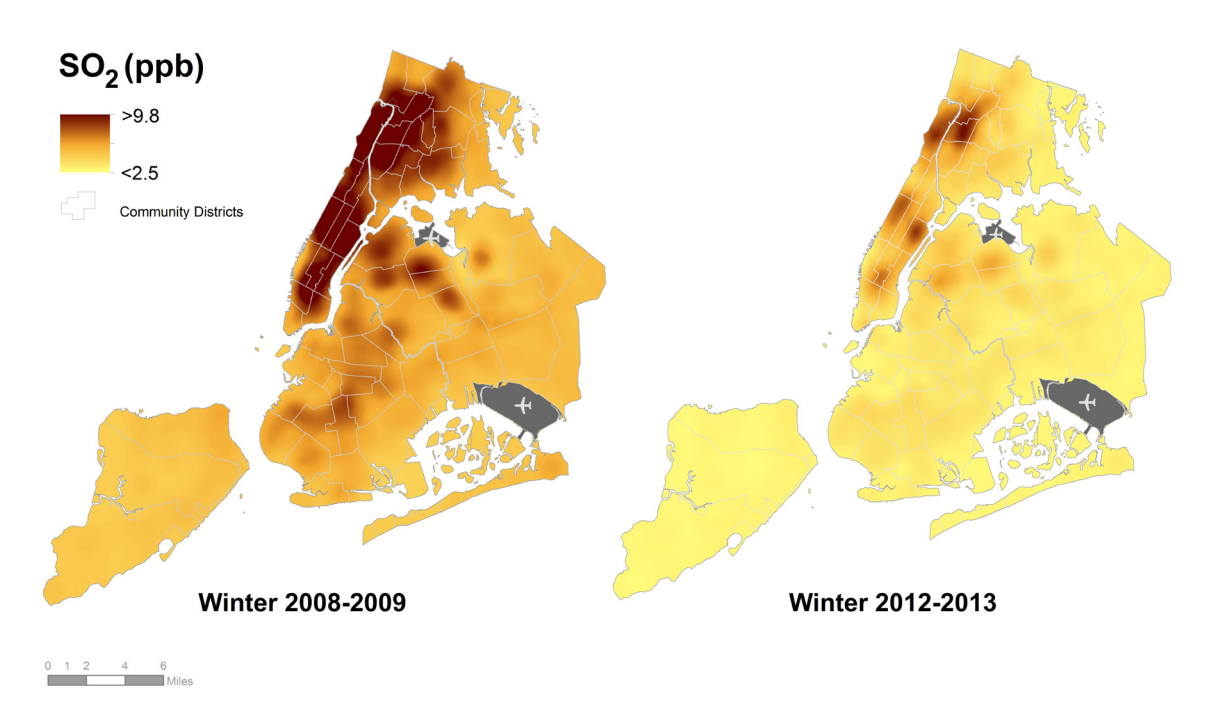
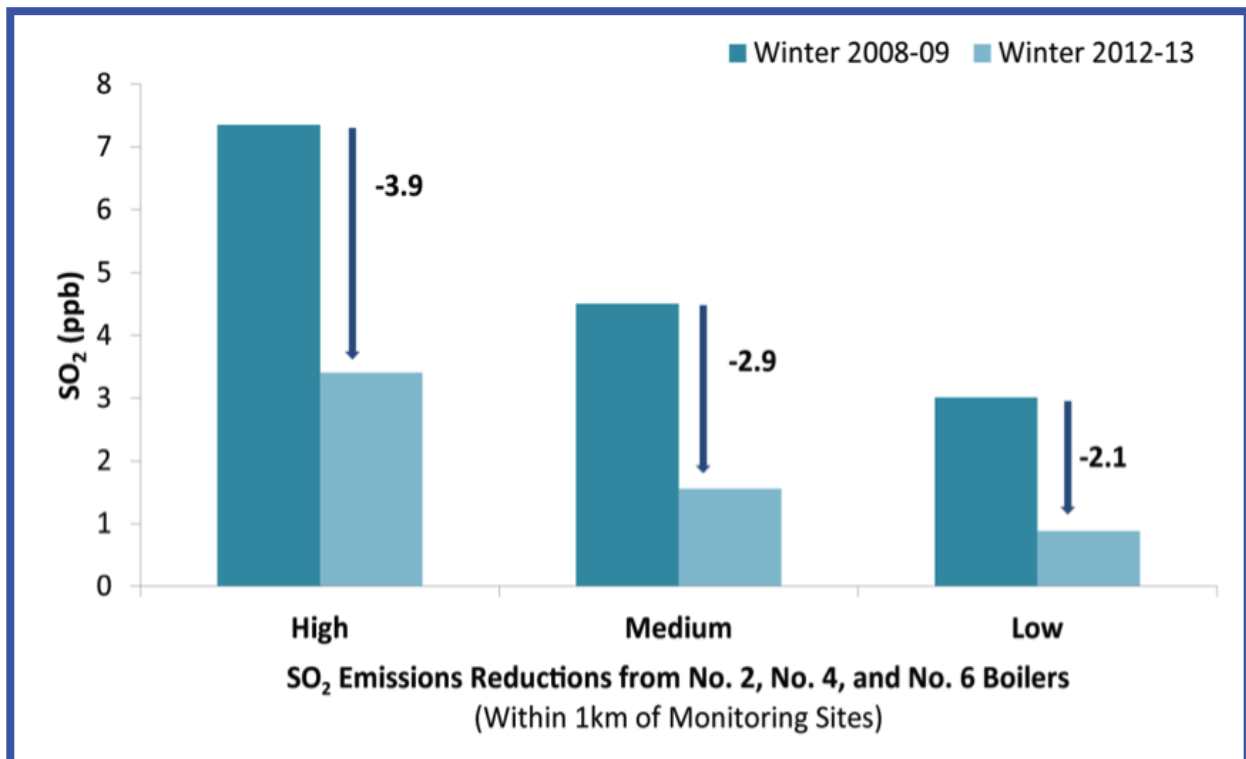


Figure 4: Ambient SO₂ levels fell the most at locations with the most nearby emission reductions.*



*Change in emissions is based on the mass of SO₂ emissions reductions estimated to have occurred from Nos. 2, 4 and 6 boilers within 1km of sampling locations from winter 2009-9 and winter 2012-13. Each category includes one-third of sampling sites.

Nickel in $PM_{2.5}$ is a marker of emissions from residual oil burning and $PM_{2.5}$ with higher Ni content may have greater health effects. Citywide concentrations of Ni also fell between winter 2008-9 and winter 2012-13, with average reductions of 4.8 nanograms per cubic meter (ng/m^3) or 35% (Figure 4). Ni concentrations were somewhat higher in the more seasonably cold winter of 2012-3 compared to the unusually warm winter of 2011-2 and remained substantially higher in some Manhattan and Bronx neighborhoods where Nos. 4 and 6 boiler density is highest (Figure 6). Sites near the most conversion activity experienced a greater average reduction in Ni concentration (3.7 ng/m^3) than those near fewer conversions (1.9 ng/m^3) (Figure 7). The gap in concentrations between locations of high and low density of Nos. 4 and 6 boilers fell modestly (9.4%).

Figure 5: Change in wintertime average Ni concentrations across all NYCCAS monitoring sites

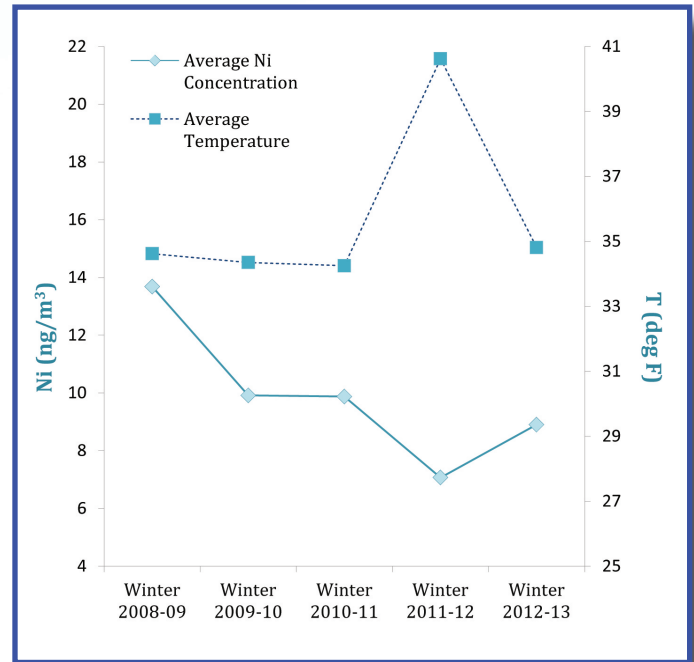


Figure 6: Estimated Ni Concentrations, winter 2008-2009 and winter 2012-2013

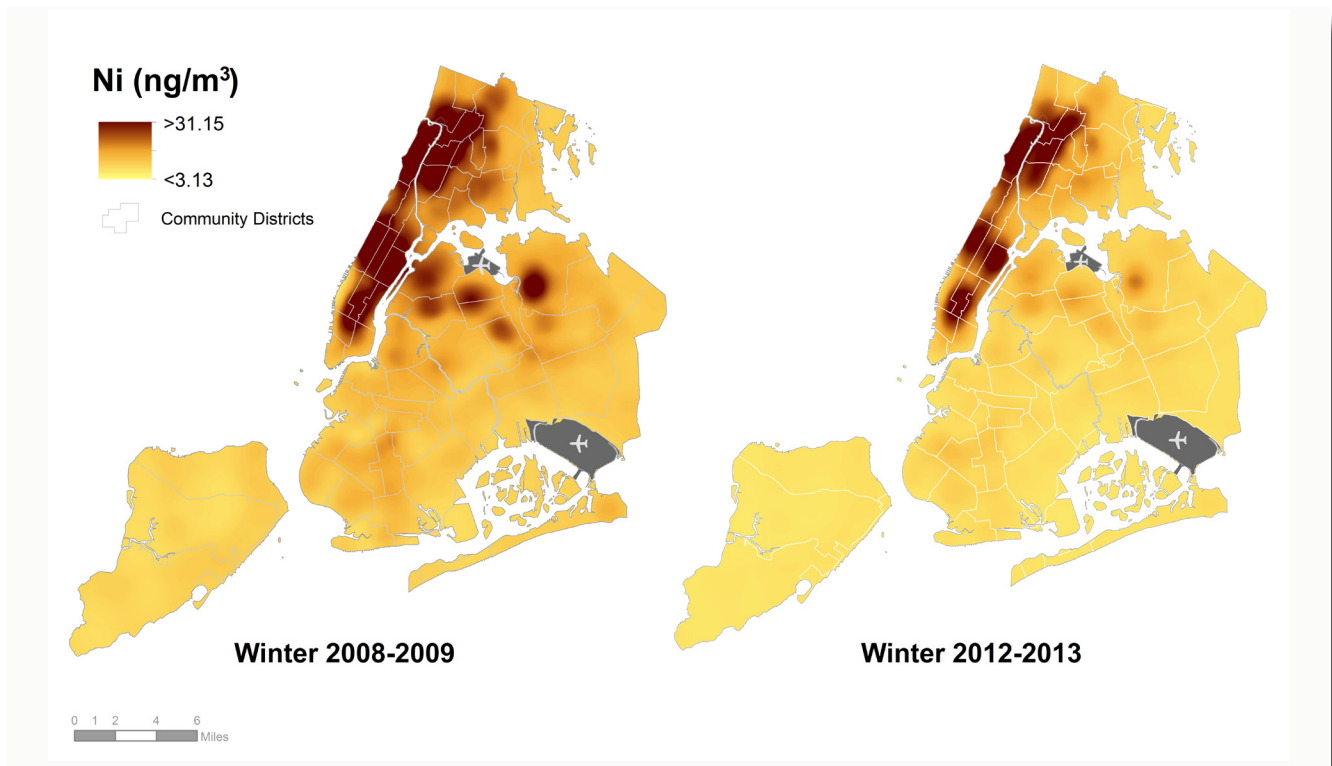
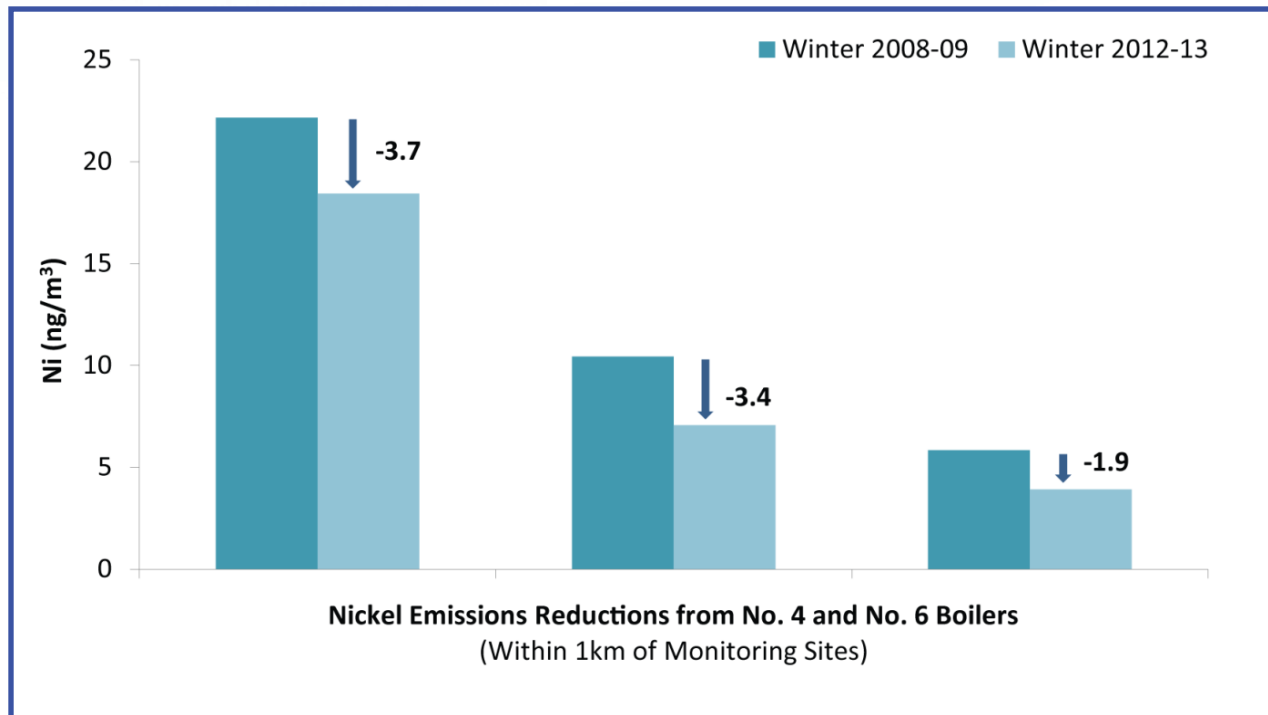


Figure 7: At monitoring sites near high density of emissions reductions from Nos. 4 and 6 boilers, ambient Ni levels were reduced by almost twice as much compared to sites with low density of nearby emissions reductions.*



*Change in emissions is based on the mass of nickel emissions reductions estimated to have occurred from Nos. 4 and 6 boilers within 1km of sampling locations from winter 2009-9 and winter 2012-13. Each category includes one-third of sampling sites.

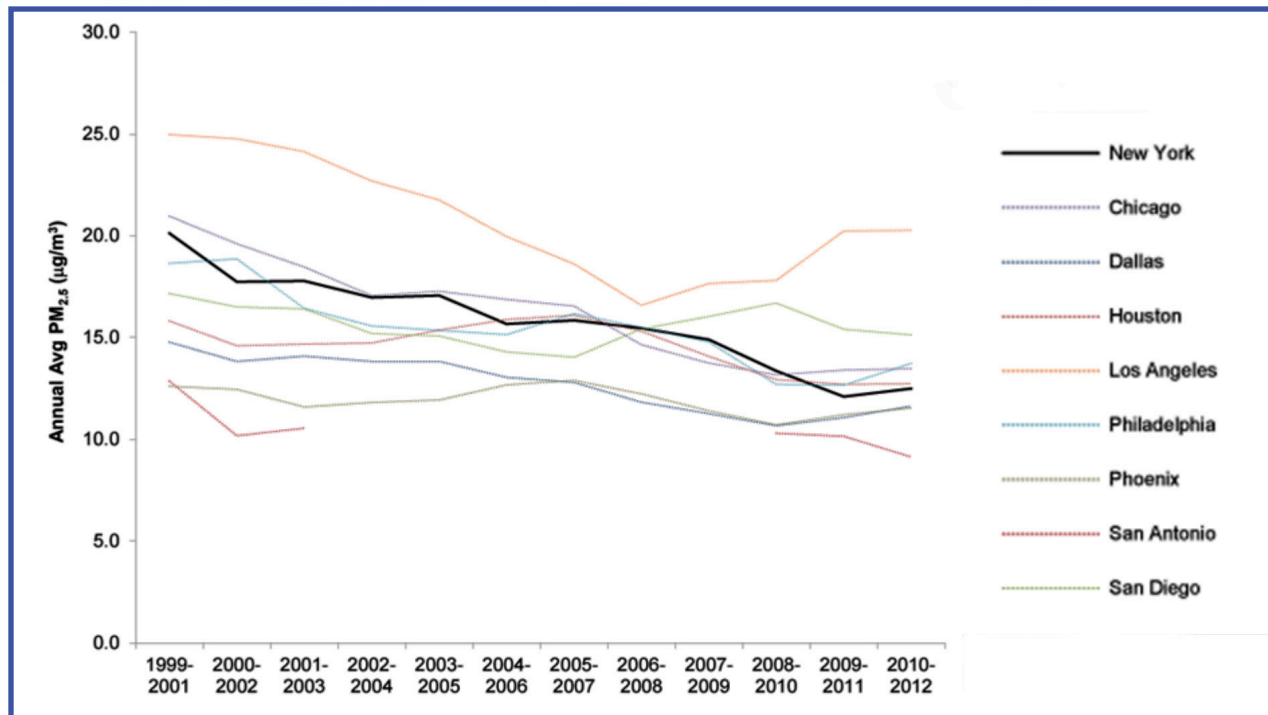
Progress Towards the PlaNYC Clean Air Goal

Since 2000, New York City's overall air quality has continued a trend of improvement that began in the 1970s. Based on routine air quality monitoring by the New York State Department of Environmental Conservation to comply with EPA regulations, $PM_{2.5}$ concentrations have fallen (Figure 8) thanks to reductions in emissions from upwind power plants, industrial sources, trucks and other vehicles, and construction equipment to meet a variety of federal, state, and local regulations.

In 2007, PlaNYC set the goal of achieving the cleanest air (based on $PM_{2.5}$ concentrations) of any of the largest U.S. cities. Since then, local emission control initiatives have included

the fuel oil regulations described in this report, greening of the municipal fleet with more hybrids and electric vehicles, reducing emissions from school buses, and expanding access to cleaner transportation by enhancing the city's pedestrian, biking, public transit networks and through zoning changes to promote transit-friendly development. Emissions have also been reduced by market-driven shifts to natural gas in the heating and power sector due to declining natural gas prices. These measures, combined with continued federal and state programs, have resulted in significant progress toward the PlaNYC goal. Our ranking among the nine largest cities in the U.S. has improved from seventh place as recently as 2008-10 to fourth place in 2010-2012, with New York City showing the most improvement among large cities since 1999-2001 (Figure 1).

Figure 8: Trends in 3-year average $PM_{2.5}$ concentrations in New York City relative to other large U.S. cities.*



* $PM_{2.5}$ concentrations calculated as rolling 3-year average of maximum annual average reported from all monitors within each city. Source: EPA Air Quality System

Estimated Health Benefits of Cleaner Air

In a prior report, we estimated that in 2005-2007, $PM_{2.5}$ levels in New York City contributed to over 3,100 deaths, over 2,000 hospitalizations for cardiovascular and respiratory disease, and 6,000 emergency department visits for asthma annually.⁷ Applying the same methods used previously, we estimated the number of annual deaths and health events avoided by improvements in $PM_{2.5}$ concentrations in 2009-2011 relative to 2005-2007 concentrations, when average annual citywide levels of $PM_{2.5}$ declined by 23%. If these improvements are

sustained, we estimate an average of 780 fewer $PM_{2.5}$ -attributable deaths per year than would have occurred had concentrations remained at 2005-2007 levels, or a reduction of 25% (Table 1). Similarly, we estimate that 1,600 emergency department visits for asthma and 460 hospitalizations for respiratory and cardiovascular are avoided each year as a result of reductions in $PM_{2.5}$. Each of these benefits is expected to continue so long as air pollution levels remain at these levels. Despite this progress, current exposures to ambient $PM_{2.5}$ still contribute each year to approximately 2,300 premature deaths, 4,800 emergency department visits for asthma, and 1,500 hospitalizations for respiratory and cardiovascular disease (Table 1).

⁷ Air Pollution and the Health of New Yorkers. Available at: <http://www.nyc.gov/html/doh/downloads/pdf/eode/eode-air-quality-impact.pdf>

Table 1: Estimated annual health events avoided due to reductions in ambient PM_{2.5} in 2009-2011 relative to 2005-2007 and current annual PM_{2.5}-attributable health burden (2009-2011)

Endpoint	Age Group	Avoided Annual Incidences due to Improvements, 2005-2007 vs. 2009-2011 (Number, 95% Confidence Interval (CI))	2009-2011 Annual Health Burden (Number, 95% CI)	Percent of incidences avoided due to improvements (Number, 95% CI)
Mortality, All Cause ⁸	30 and older	780 (530,1000)	2,300 (1600,3000)	25.30%
Emergency Department Visits for Asthma ⁹	Under 17	620 (370,860)	1,900 (1100,2600)	24.60%
	18 and older	960 (590,1320)	2,900 (1800,4000)	24.90%
Hospitalizations-Cardiovascular ¹⁰	40 and older	200 (45,360)	640 (150,1100)	23.80%
Hospitalizations-Respiratory ^{11,12}	20 and older	260 (90, 420)	880 (370,1400)	22.80%

Remaining Challenges

New York City's air quality improvements demonstrate the value of using data to set priorities and inform our clean air efforts. Despite progress to date, air pollution in New York City remains at levels that are an important cause of serious illness and premature mortality. Clearly, further action is needed to protect all New Yorkers, and particularly the city's children, seniors, and vulnerable populations. Ozone levels have not improved substantially

since the launch of PlaNYC (Figure 9), following trends seen in other major U.S. cities. Since ozone is formed downwind from major sources of nitrogen oxides (NOx), reduced NOx emissions in metro area counties upwind of New York City will be required to bring down ozone levels in the city. Reductions in NOx emissions in the most congested areas of the city will, in turn, reduce ozone levels in those downwind neighborhoods in the outer boroughs and beyond. Regional efforts to expand cleaner transit modes and reduce traffic congestion are needed to address the ozone problem across the metro area.

⁸ Effect estimate: Krewski et al. 2009. Extended Follow-Up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality. HEI Research Report 140. Health Effects Institute. Boston, MA.

⁹ Effect estimate: Ito et al 2007. Characterization of PM_{2.5}, Gaseous Pollutants, and Meteorological Interactions in the Context of Time-Series Health Effects Models. Journal of Exposure Science and Environmental Epidemiology. 17:S45-S60

¹⁰ Effect estimate: Ito et al 2010. Fine Particulate Matter Constituents Associated with Cardiovascular Hospitalizations and Mortality in New York City. Environmental Health Perspectives. Doi:10.1289/ehp.1002667

¹¹ Effect estimate: Zanobetti et al. 2009. Fine Particulate Air Pollution and its Components in Association with Cause-Specific Emergency Admissions. Environmental Health. 8:58.

¹² Effect Estimate: Moolgavkar SH. 2000. Air Pollution and Hospital Admissions for Chronic Obstructive Pulmonary Disease in Three Metropolitan Areas in the United States. Inhalation Toxicology. 12(Supp4):75-90.

Figure 9: Trends in summertime ozone concentrations

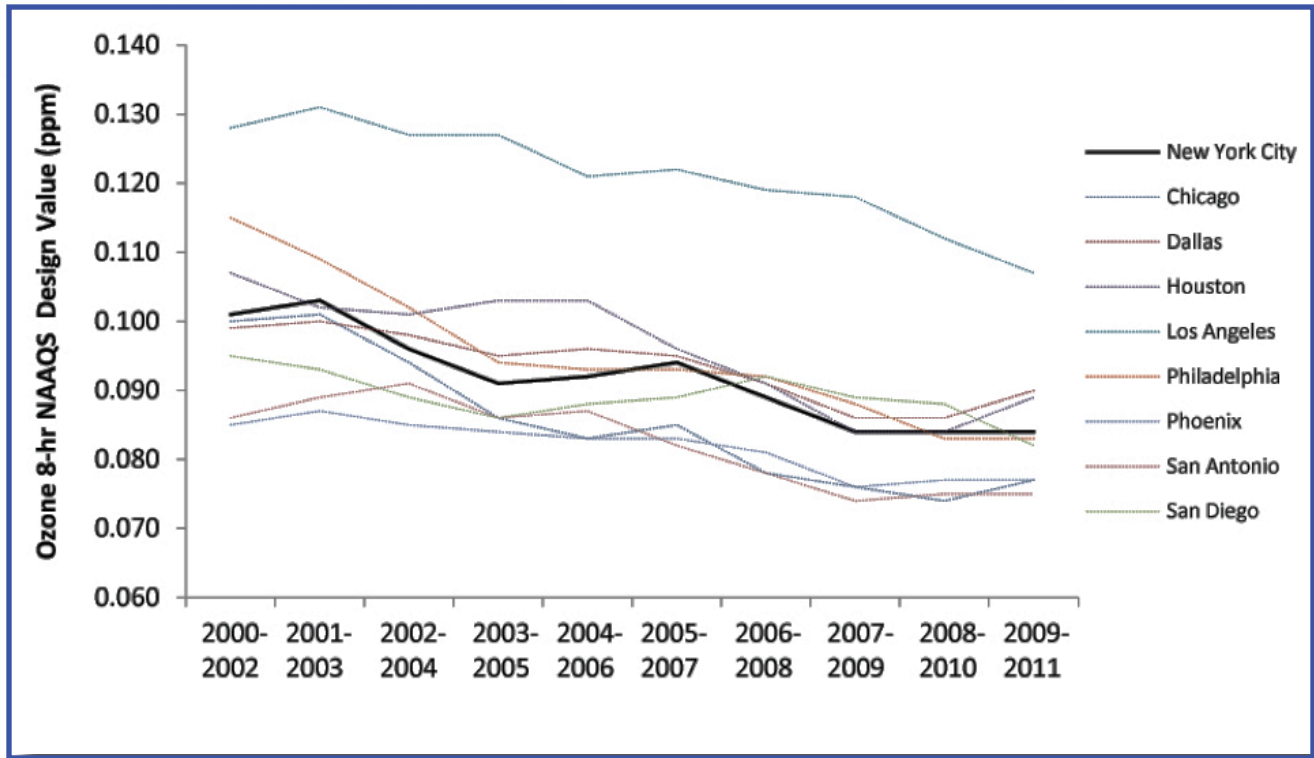
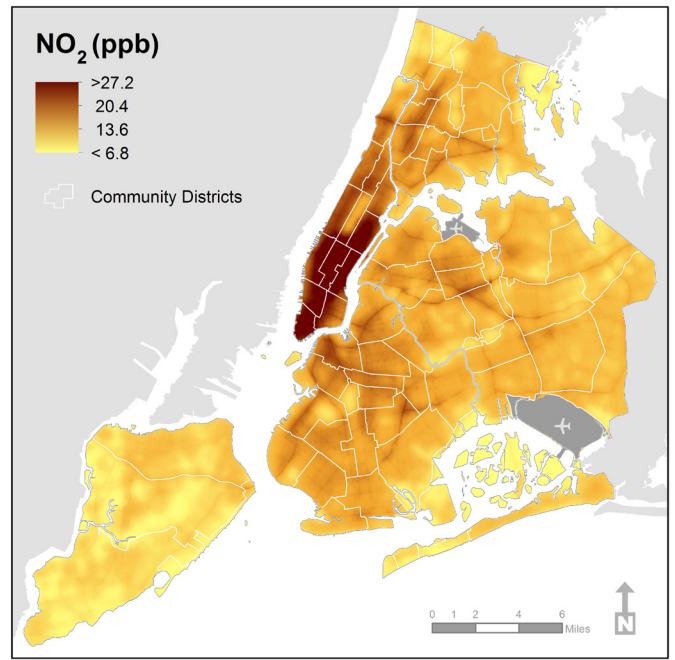


Figure 10: Estimated NO₂ Concentrations, Summer 2012



Since the beginning of NYCCAS, NO₂ levels have also improved, with citywide average levels decreasing by 16% in the summer (summer 2009 vs. summer 2012) and 18% in the winter (winter 2008-9 vs. winter 2010-2012). These improvements have been due to a variety of stationary and mobile source programs, including benefits from changes in heating oil. However, levels remain elevated throughout the city and particularly in areas of high traffic density (Figure 10).

Further improvements in NO_x and other traffic-related pollutants such as PM_{2.5}, BC, and benzene will require continued and expanded local, regional and federal efforts to address on-road sources which account for approximately 10%

¹³ EPA 2008 National Emissions Inventory. Available at: <http://www.epa.gov/ttn/chief/eiinformation.html>

of $PM_{2.5}$ emissions and 25% of NOx emissions locally.¹³ Similarly, these sources contribute to levels of carcinogenic pollutants such as benzene, which are found to occur at high levels in areas of high traffic density. Increased efforts to reduce congestion and adopt low-emission vehicles are needed.

There continue to be emissions from local sources. Among those with the fewest emissions controls, commercial cooking contributes to 16% and road dust contributes 9% of locally emitted $PM_{2.5}$.¹⁴

Continued monitoring and analysis of air quality levels throughout the city will help us track changes over time and evaluate the impacts of environmental policies. For example, ongoing monitoring of the molecular components of $PM_{2.5}$ will help better characterize the sources that contribute to poor air quality. Neighborhood saturation studies, like the one described in the

appendix of this report, will help better evaluate air quality interventions occurring in specific neighborhoods. Ongoing health effects analyses will increase our understanding of the risks of air pollution exposures and how combined exposures to multiple pollutants affect the health of New Yorkers.

This report has focused on changes in air quality over the past five years, particularly around changes in heating oil. There are many other initiatives in PlaNYC to improve air quality. To learn more, visit: <http://www.nyc.gov/html/planyc2030/html/home/home.shtml>.

¹⁴ More information on levels of benzene and other air toxics in New York City available at: <http://www.ehjournal.net/content/11/1/51>

