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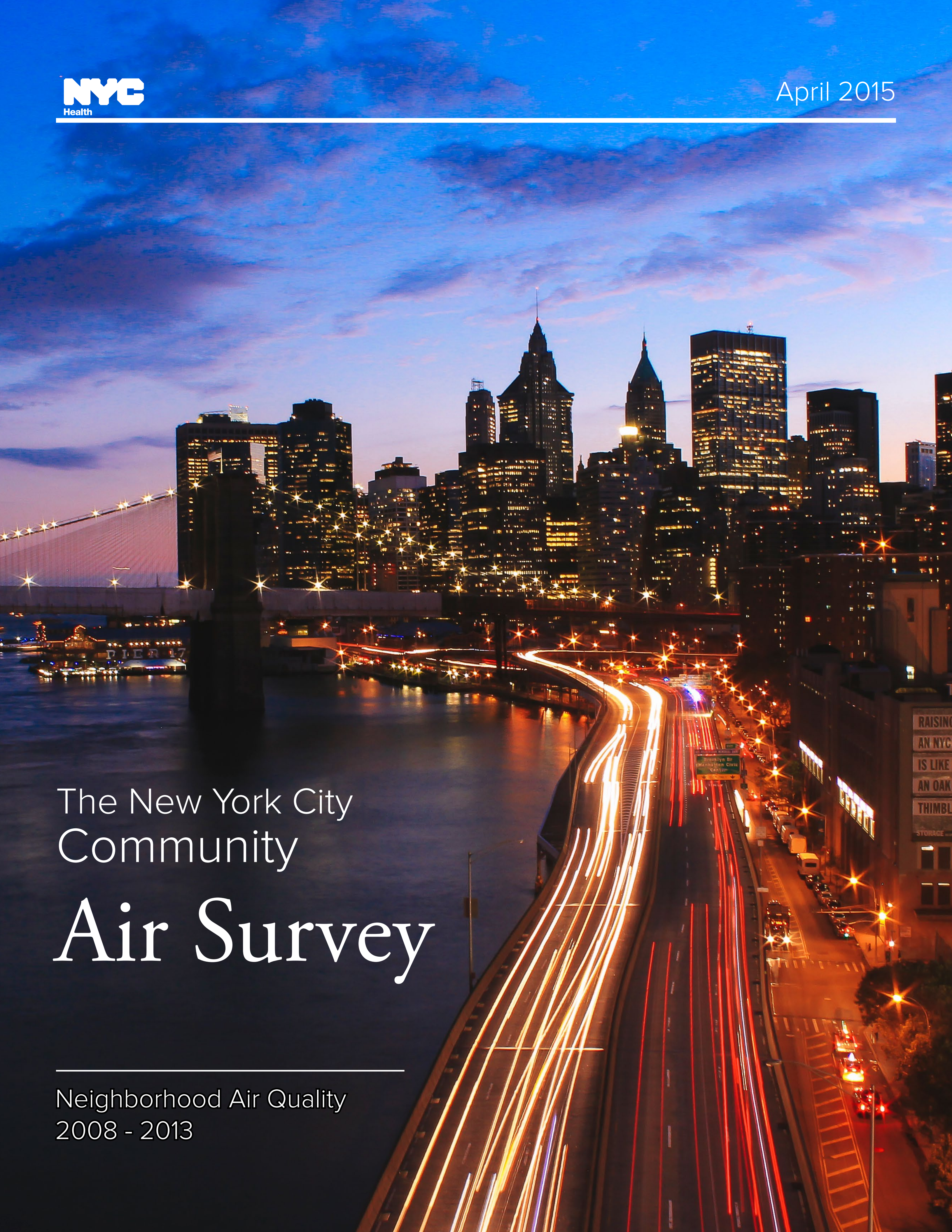

The New York City Community Air Survey

Neighborhood Air Quality 2008 - 2013

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EXECUTIVE SUMMARY

New York City air quality has improved for several decades, but remains a major cause of illness and death. New York City's first long-term sustainability plan (2007) launched several air quality improvement initiatives. One initiative, the New York City Community Air Survey (NYCCAS), is the largest urban air monitoring program in the U.S. NYCCAS is providing data to inform local pollution control measures and track improvements.

This report:

- Describes trends between winter 2008-2009 and fall 2013 in $PM_{2.5}$, NO_2 and wintertime SO_2, major pollutants that affect public health.
- Identifies the sources that still endanger New York City air.
- Maps neighborhood air pollution levels and describes the reasons for air quality differences across the city.

Major findings:

- $PM_{2.5}$, NO_2, SO_2 have all declined over the 5 years by 16%, 19% and 69%, respectively
- Largest declines in SO_2 levels due to regulations in heating oil
- Higher levels of all pollutants continue to be observed in areas of higher traffic density, building density, areas of residual oil boilers, and industrial areas

The report concludes with a summary of the most important remaining pollution sources associated with buildings, traffic and non-road vehicles and equipment. Effective approaches that could reduce pollution from these sources are briefly described. With high densities of people living near emissions sources, preventing air pollution-related deaths and illnesses in New York City will require new strategies to address smaller and more widely distributed sources of air pollution.

BACKGROUND

Air quality in New York City (NYC) has been improving over the past several decades because federal, State, and local measures have reduced pollutants from power plants, building boilers, motor vehicles, and other sources. Still, air pollution remains a major cause of illness and death, particularly among vulnerable residents such as the very young, seniors, and those with preexisting health conditions. The NYC Health Department estimates that fine particles ($PM_{2.5}$), the most important urban air pollutant, cause more than 2,000 premature deaths and 6,000 emergency department visits and hospitalizations from respiratory and cardiovascular disease each year.[1] Research shows that air pollution is also linked to cancer, reduced birth weight, and possibly impaired brain development and function.[2]

New York City created its first long-term plan for environmental sustainability in 2007. One goal was to make NYC's air quality cleaner than that of any large U.S. city. The plan also charged the Health Department with establishing the New York City Community Air Survey (NYCCAS), the largest urban air monitoring program in the U.S. NYCCAS is a collaboration between the Health Department and Queens College to:

- Measure air pollutants that affect public health across the city.
- Identify local emission sources that impact neighborhood air quality.
- Inform the public and city officials on clean air priorities.
- Provide air pollution estimates for health studies.

NYCCAS air monitoring began in December 2008 and focuses on pollutants that pose the most harm to public health. They include the following:

Fine Particles ($PM_{2.5}$)

are tiny airborne solid and liquid particles less than 2.5 microns in diameter. They are also called soot. $PM_{2.5}$ is the most harmful urban air pollutant, small enough penetrate deep into the lungs and enter the bloodstream, worsening lung and heart disease and leading to hospital admissions and premature deaths. $PM_{2.5}$ is also a human carcinogen.[3]

$PM_{2.5}$ can either be directly emitted or formed in the atmosphere from other pollutants. Important local sources include fuel combustion in vehicles, boilers in buildings, power plants, construction equipment, and commercial cooking. $PM_{2.5}$ in NYC's air also comes from outside the city.

Nitrogen Dioxide (NO_2)

is one of a group of pollutants called "oxides of nitrogen" (NO_x). Exposures to NO_2 are linked to increased emergency department visits and hospitalizations for respiratory conditions, particularly asthma. NO_x react with other compounds in the atmosphere to form $PM_{2.5}$ and ozone (O_3). NO_x are produced from a variety of combustion sources in NYC, including motor vehicles, buildings, marine vessels, and construction equipment.

Sulfur Dioxide (SO_2)

in NYC is produced mainly from burning oils with high sulfur content, such as No. 4 or No. 6 oil (also known as residual fuel oil). No. 4 and No. 6 oils in NYC are used mainly to heat buildings and hot water. Some high-sulfur oil is also used to generate electric power and power marine vessels. SO_2 exposures can worsen lung diseases, causing hospitalizations and emergency department visits for asthma and other conditions. SO_2 also contributes to $PM_{2.5}$ in the atmosphere, resulting in exposures downwind of where it is emitted. Local SO_2 emissions declined in recent years, mainly because of NYC regulations to phase out No. 4 and No. 6 oils and State regulation to lower the amount of sulfur allowed in No. 2 distillate heating oil.[4]

The first NYCCAS report, published December 2009 (Figure 1), showed that neighborhoods with many large boilers using heating oil had higher levels of $PM_{2.5}$. SO_2 levels were higher in areas with many buildings heated by Nos. 4 and 6 residual fuel oils. These findings helped spur local regulation to eliminate the use of residual heating oils in NYC buildings by 2030. After the first two years, special studies have measured other pollutants and noise at NYCCAS locations. Results are found at online at www.nyc.gov/health/nyccas.

This report describes trends in $PM_{2.5}$, NO_2 and wintertime SO_2 between winter 2008-2009 and fall 2013, and it identifies the sources that still endanger New York City air. Detailed maps display neighborhoods with high levels of air pollution and the reasons for air quality differences across the city.

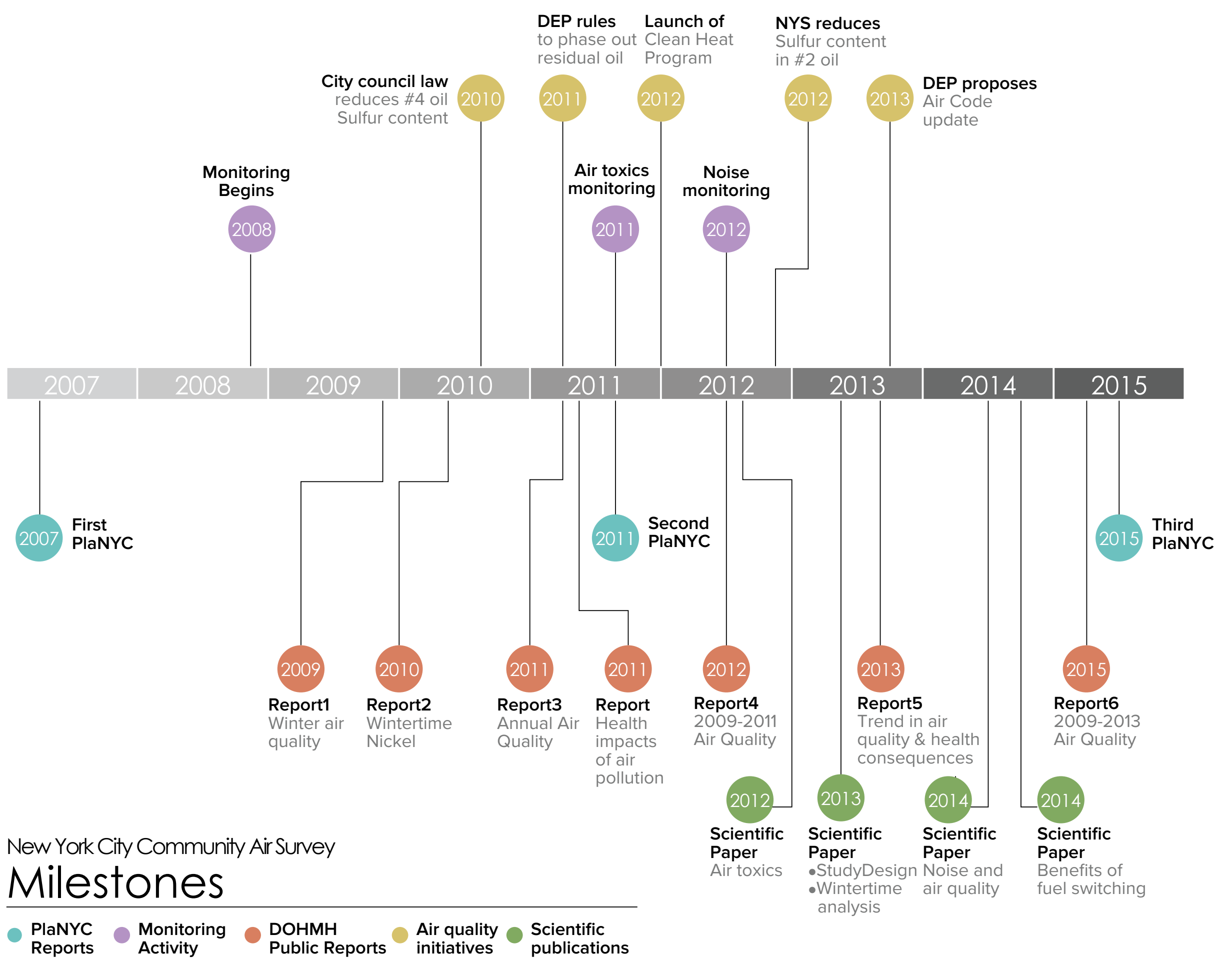

Figure 1: New York Community Air Survey, major milestones.

METHODS

Health Department and Queens College Researchers collected over 2,000 air samples in all city neighborhoods between winter 2008-2009 and fall 2013. Monitoring sites were selected to include the range of traffic conditions, size and number of buildings, and land uses found in NYC neighborhoods. Researchers sampled the air at 150 NYC locations per year during the first two years and 60 to 100 locations per year in subsequent years (Figure 2). Samples were collected in all seasons.

NYCCAS air samplers are mounted on street-side lampposts 10 to 12 feet off the ground. Each sampler uses an air pump and filters to collect $PM_{2.5}$. Passive samplers absorb the gaseous pollutants NO_x, SO_2, and O_3. Laboratory analysis of the filters and passive samplers determines the quantities of pollutants collected and their concentration in air is calculated. Quality control steps included confirming that the sampling pump was operating normally and collecting duplicate and unexposed samples for comparison with study samples.

Air samples were collected at each active NYCCAS site for two weeks in each season. Samples at reference sites located away from potential pollution sources were monitored every two-weeks, year-round. Data from these sites were used to adjust the measurements from street-side sites for citywide changes in air quality over time, mainly from weather conditions. The number of reference sites was reduced from five to three after the first four years.

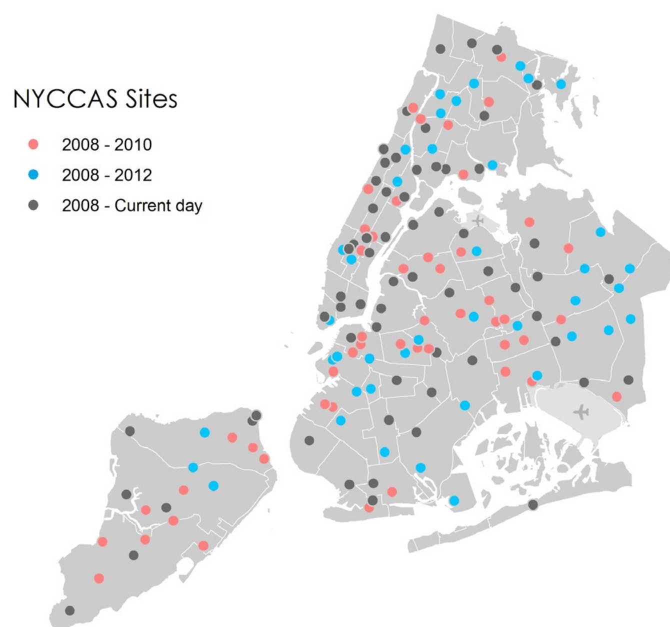

Figure 2: New York City Community Air Survey monitoring locations.

NYCCAS Team Deploys an Air Quality Monitor

NYCCAS data were analyzed using a "land-use regression" (LUR) model. LUR models estimate associations among pollution levels, average traffic, building emissions, land use, and other neighborhood factors around the monitoring sites. These associations were used to estimate the seasonal average air pollution levels at locations across the city, including locations where no measurements were taken. The LUR model is also used to assess sources that appear to contribute most to differences in pollution concentrations.

For more details on methods, visit NYCCAS at nyc.gov/health/nyccas.

RESULTS

Between winter 2008-2009 and fall 2013 - during the first five years of monitoring- $PM_{2.5}$, NO_2, and SO_2 levels all declined. SO_2 levels declined the most, and the difference in SO_2 concentrations between the most and least polluted neighborhoods decreased more than for other pollutants. The neighborhoods with pollution levels higher or lower than average have been fairly consistent over time; these patterns reflect neighborhood differences in emissions from buildings and traffic, which do not change rapidly from one year to the next. The data summarized for each pollutant include:

1. Trend in seasonal average pollutant concentrations by levels of important nearby sources
2. Maps of concentrations estimated by the LUR model. Maps for the first and fifth winter and summer seasons of NYCCAS monitoring are shown in this report. Other maps are available in the appendix. Average pollutant concentrations for each NYC neighborhood are available at www.nyc.gov/health/trackingportal.

PM2.5

At NYCCAS locations monitored each season for five years, seasonally adjusted, street-level $PM_{2.5}$ levels declined by almost 0.5 µg/m³ per year, and by 16% over the five-year period. $PM_{2.5}$ levels tend to be higher in winter and summer than in fall and spring, likely because of increased heating emissions in the winter and increased upwind power sector emissions in the summer cooling season. These seasonal trends are similar to those at rooftop regulatory monitors operated by the New York State Department of Environmental Conservation (NYSDEC).

Despite declining levels, wide differences in concentrations persisted across sites with differences across sites ranging from 8.1 µg/m³ to 21.6 µg/m³, depending on the season. Greater concentrations were consistently measured at sites with higher boiler and traffic emissions (Figure PM-1).

[a]Boiler emissions density estimated within 1000 m and traffic emissions density estimated within 250 m of monitoring sites.

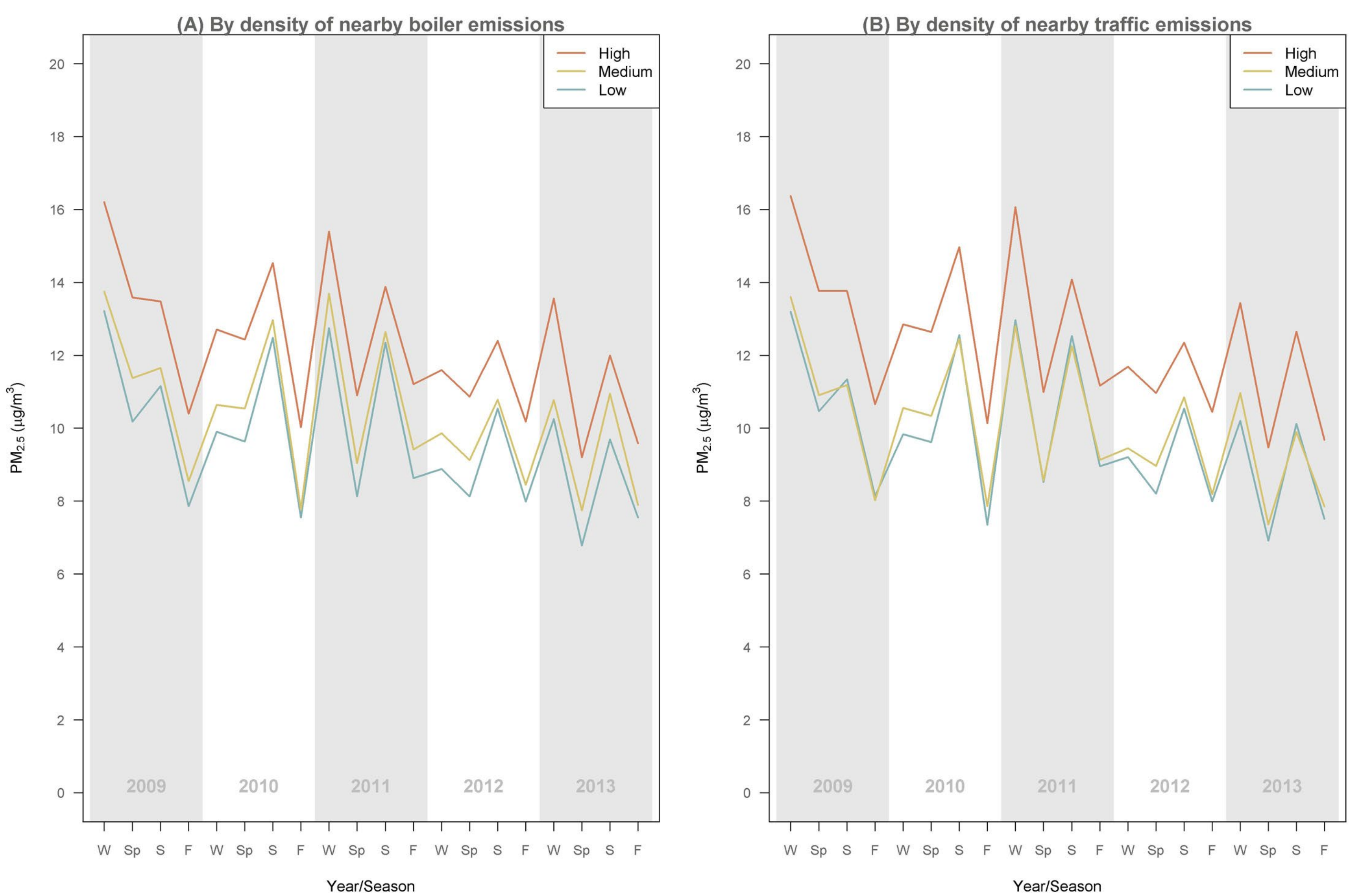

Figure PM-1: $PM_{2.5}$ levels at NYCCAS monitors, by density of nearby boiler emissions (A) and traffic emissions (B).[a]

In the LUR model, the most important predictors of $PM_{2.5}$ concentrations were, in order of importance [b]:

- Emissions from building heat and hot water boilers within 1,000 meters (m).
- Area of industrial land use within 1,000 m.
- Traffic density, weighted by relative emissions rates by vehicle type (car, truck, bus), within 250 m.

Although $PM_{2.5}$ concentrations have declined throughout the city, they remain relatively high throughout much of Manhattan - which has many large buildings and heavy traffic - as well as along major highways and in industrial areas (Figure PM-2).

[b] Sources and methods for emissions indicators are available in appendix.

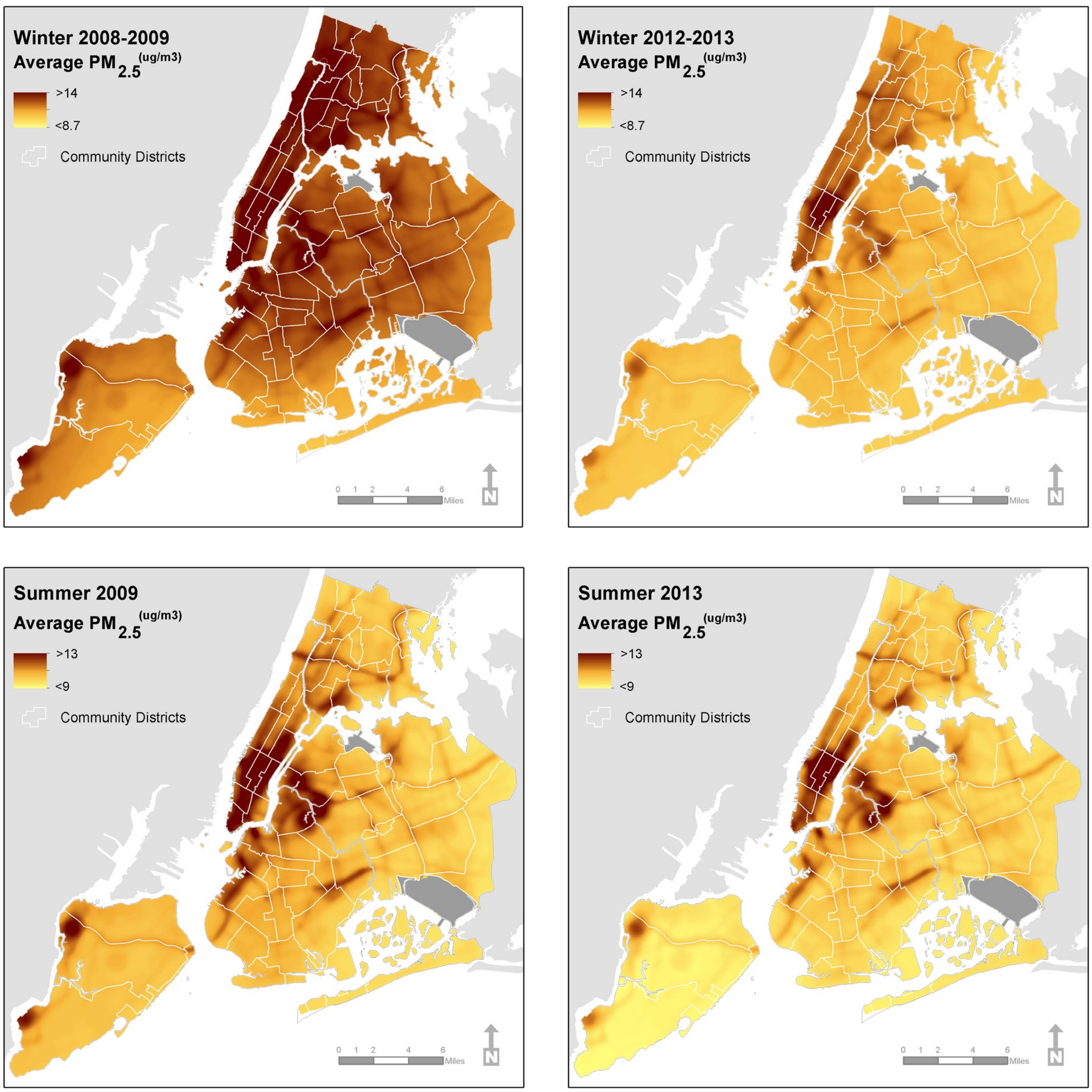

Figure PM-2: $PM_{2.5}$ concentrations, winter and summer, 2009 vs 2013.

NO_2

At NYCCAS locations monitored in each season for five years, seasonally adjusted street-level NO_2 levels declined by 1.3 parts per billion (ppb) per year and by 19% during the five-year period. NO_2 levels tend to be higher in the winter months, likely due to weather conditions and increased heating fuel emissions. These time trends are similar to those at rooftop regulatory monitors operated by NYSDEC.

Citywide NO_2 levels have declined while seasonally adjusted NO_2 concentrations varied by 38 to 67 ppb across monitoring sites, depending on the season. Higher concentrations were consistently measured at sites in areas of higher building density and traffic emissions (Figures NO-1).

[c] Building density estimated within 1000 m and traffic emissions density estimated within 100 m of monitoring

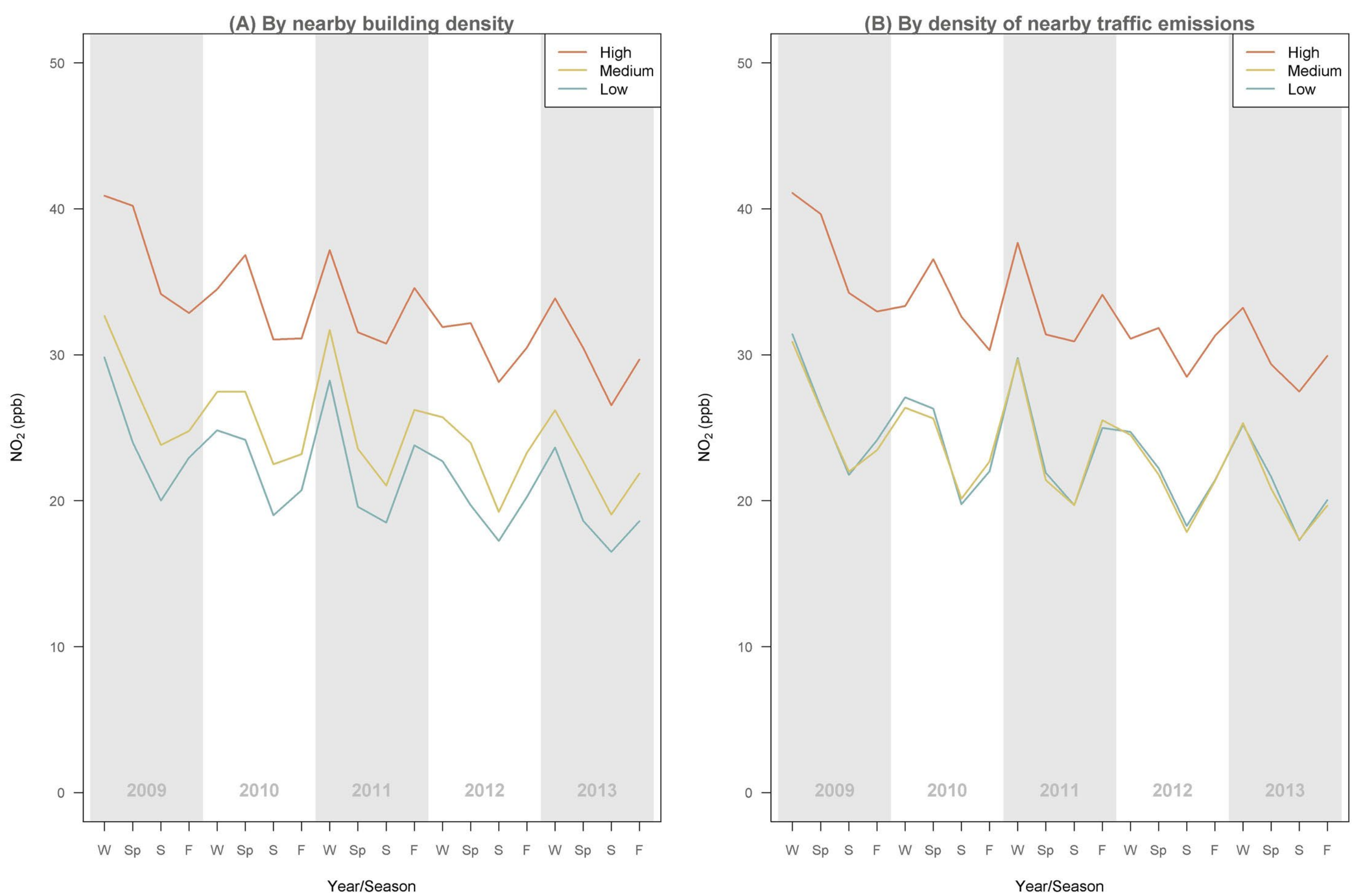

Figure NO-1: NO_2 levels at NYCCAS monitors, by density of nearby buildings (A) and traffic emissions (B).[c]

In the LUR model, the most important predictors of NO_2 concentrations were, in order of importance[d]:

- Area of interior building space within 1,000 m.
- Traffic density, weighted by relative emissions rates and vehicle type (car, truck, bus) within 100 m.
- Percent of impervious surface within 100m.
- Location on a bus route (compared to non-bus route locations).

Although NO_2 concentrations have declined throughout the city, they remain relatively high in the areas of highest traffic and building density in Manhattan, the Bronx and Brooklyn and around major transportation corridors (Figure NO-2).

[d]Sources and methods for emissions indicators are available in appendix.

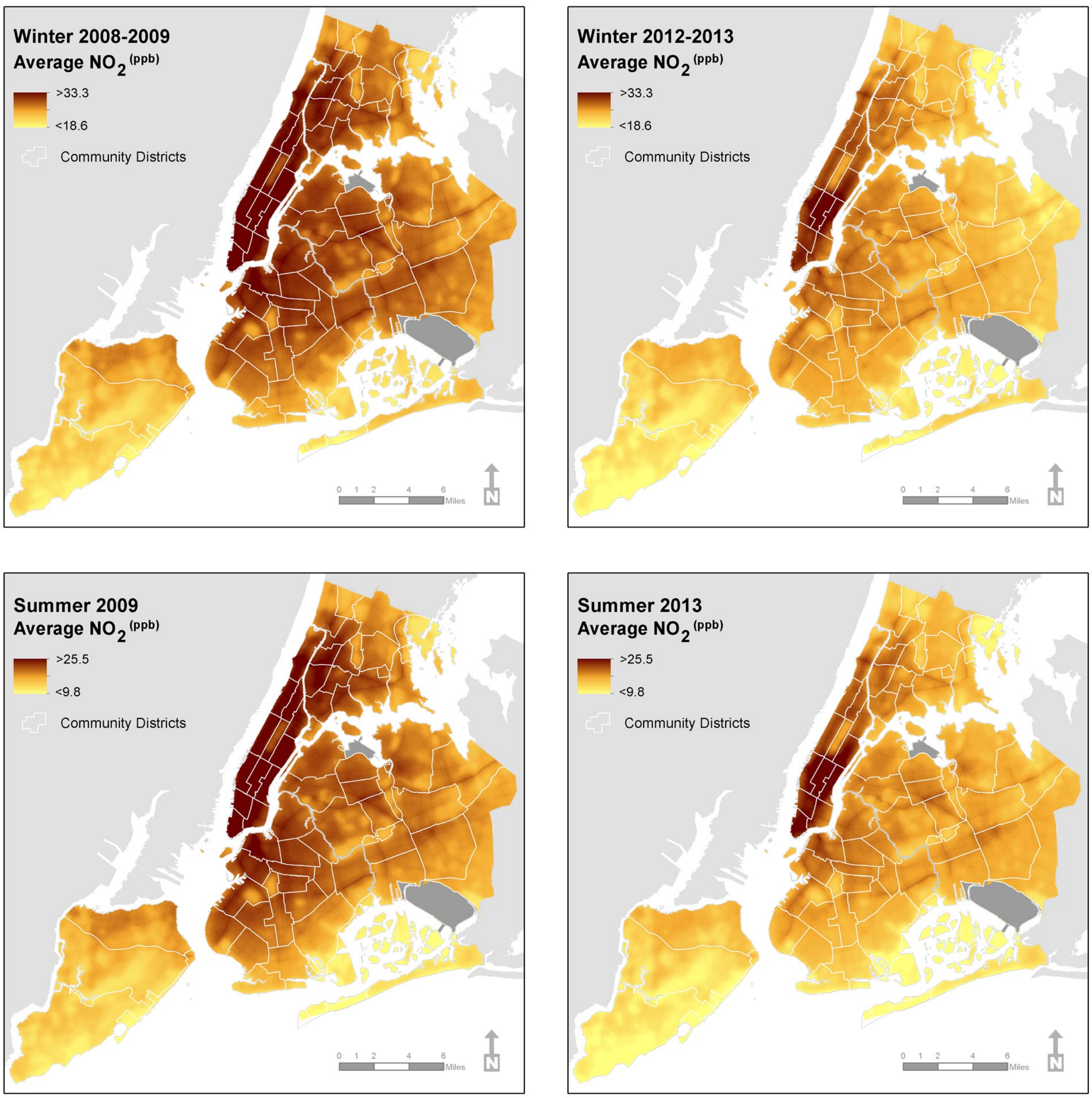

Figure NO-2: NO_2 concentrations, winter and summer, 2009 vs. 2013.

SO_2

At NYCCAS locations monitored each winter for five years, seasonally adjusted street-level SO_2 levels declined by 0.9 ppb per year and by 69% during the five-year period. These trends are similar to those at rooftop regulatory monitors operated by NYSDEC. Seasonally adjusted concentrations varied widely - by 8.5 to 15.8 ppb across monitoring sites, depending on the year. Variation across monitoring sites declined over time, but greater SO_2 concentrations were consistently measured at sites in areas of higher residual oil boiler density and population density (Figure SO-1).

[e]Density of residual oil boilers and nighttime population estimated within 1000 m of monitoring sites. Sources and methods for emissions indicators are available in appendix.

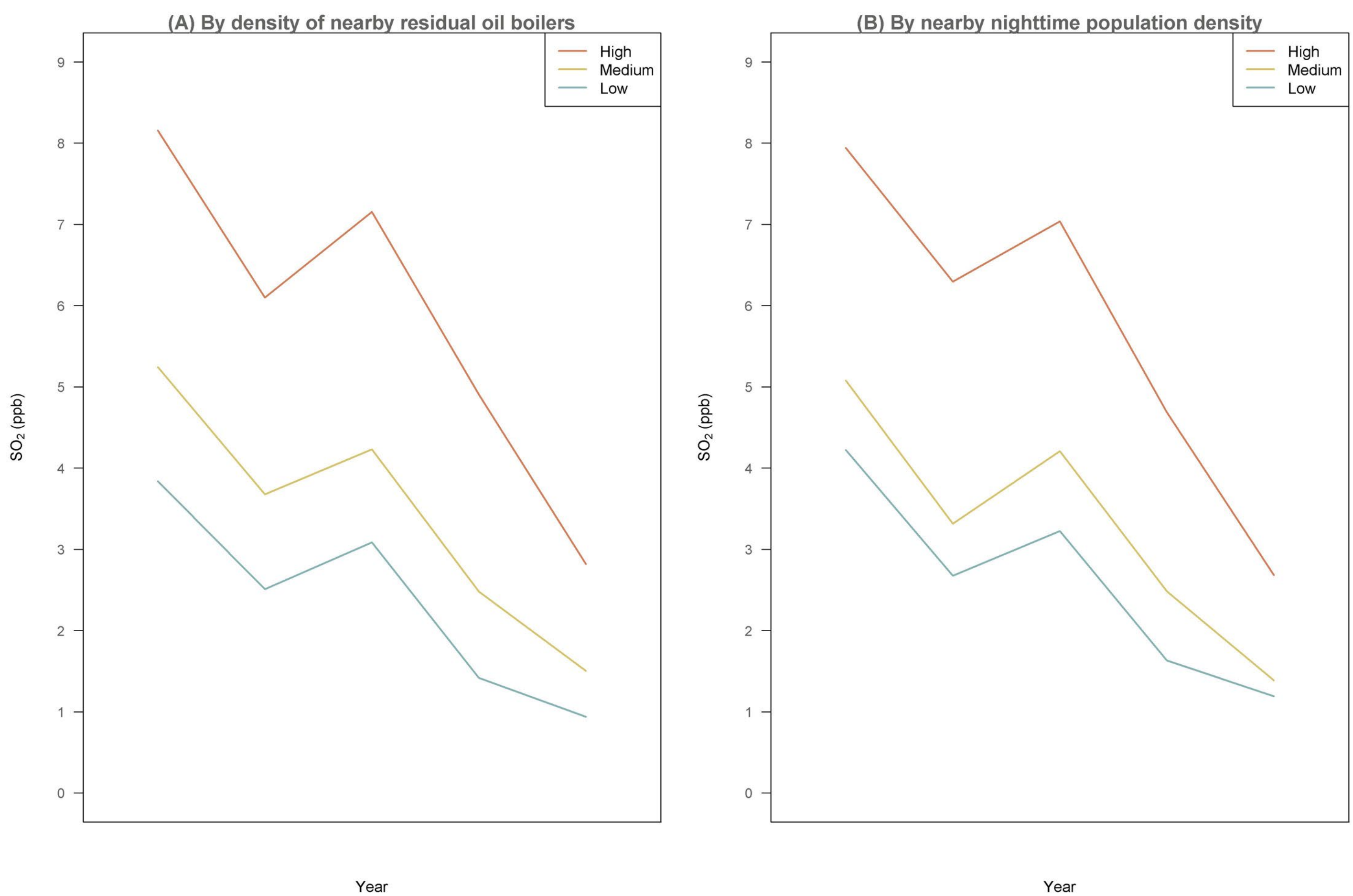

Figure SO-1: SO_2 levels at NYCCAS monitors by density of nearby residual oil boilers (A) and nighttime population (B).[e]

In the LUR model, the most important predictors of SO_2 concentrations were, in order of importance:

- Oil 4/6 density within 1,000 m.
- Nighttime population within 1,000 m.

While SO_2 concentrations have declined significantly across the city, they remain relatively higher in areas with a high density of residual oil boilers, particularly areas of the Upper East and West Sides, northern Manhattan, and the western Bronx (Figure SO-2).

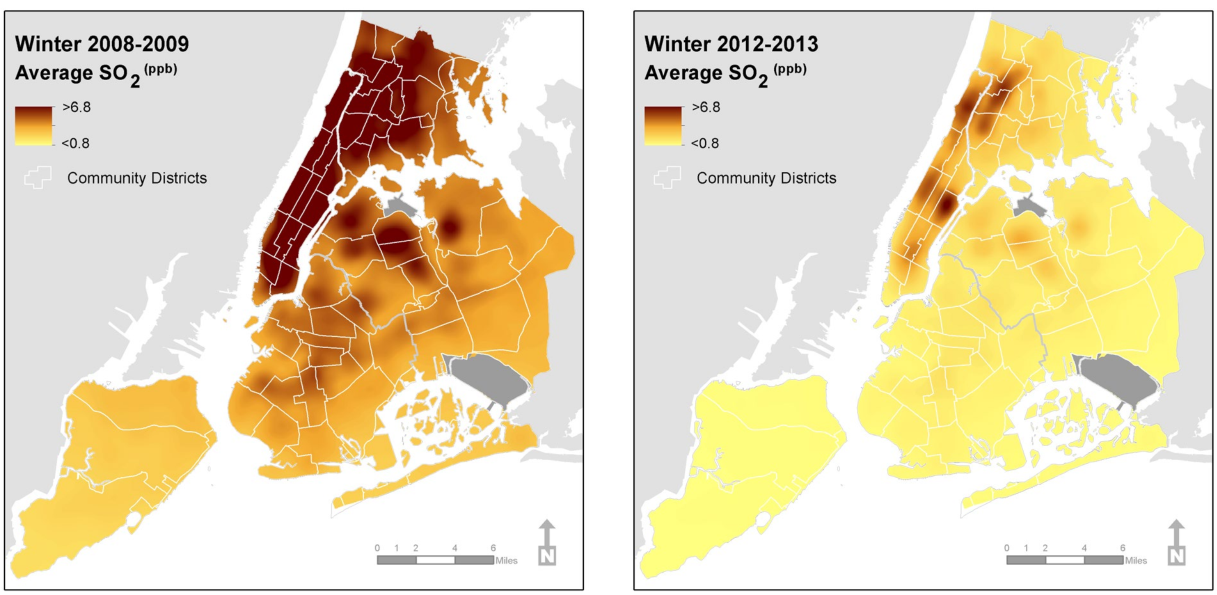

Figure SO-2: SO_2 concentrations, winter, 2008-2009 vs. 2012-2013.

DISCUSSION

Since 2008, NYCCAS has been an integral part of the city's air quality management efforts, providing policy makers with data on air pollution trends, differences in concentrations by neighborhood and sources of harmful emissions. Much of this information has already been used to design strategies to reduce emissions. This report and previous NYCCAS reports have documented large improvements in wintertime SO_2 levels following State and local actions to reduce emissions from high-sulfur heating oil. Existing policies will continue to reduce and eventually eliminate these harmful emissions.

Despite recent air quality improvements, air pollution throughout the city remains at levels harmful to public health, with some neighborhoods suffering disproportionately high exposures. Neighborhoods with higher $PM_{2.5}$ tend to have more boiler and traffic emissions. Areas with increased industrial land use had higher $PM_{2.5}$ levels probably because of increased truck traffic serving the industrial areas of the city as well as emissions from industrial equipment, such as generators and boilers.

Compared to $PM_{2.5}$, about half of which comes from emissions outside the city, NO_2 levels more reflect local sources and are even more variable from place to place. During the first five years of NYCCAS monitoring, average NO_2 levels were 52% and 41% greater in areas of high building density and traffic emissions, respectively. Building density is an indicator of emissions associated with buildings, particularly from heat and hot water boilers. Areas of the city with high building density also tend to have more traffic congestion (such as areas of midtown and lower Manhattan) and emissions from stop-and-go driving and idling in traffic jams. Areas with higher percent impervious surface likely have more emissions, since impervious surfaces tend to be roads, parking lots, and buildings. In areas with little impervious cover, such as parks and suburban areas with lawns, there are fewer emissions sources.

While SO_2 levels declined greatly over five years of monitoring, they remain associated with boilers using No. 4 or No. 6 oil. Nighttime population density is also associated with higher SO_2, likely capturing greater consumption of these high-sulfur fuels in neighborhoods with many large residential buildings, such as the Upper East Side. The strength of the association between density of Nos. 4 and 6 boilers and

SO_2 concentrations has declined, reflecting reductions in emissions as boilers have switched to using cleaner fuels. The disparity between SO_2 concentrations between areas of high and low boiler density declined by 51% between 2009 and 2013. The decline was caused in part by regulations requiring city buildings using residual heating oil boilers to switch to cleaner fuels. A State law also requires reduction in the sulfur content of No. 2 oil, which lowered SO_2 emissions from boilers using No. 2 by more than 99% in winter 2012-2013 compared to winter 2008-2009.

Continued improvements in SO_2 levels are expected as the remaining residual fuel oil boilers in the city convert to cleaner fuels. City regulations will phase out residual fuel oil by 2030. This phase out will also reduce $PM_{2.5}$ emissions, ambient pollution, and harmful health effects.

Air quality improvements during the five years studied in this report, especially falling $PM_{2.5}$ concentrations, are also attributable to other federal and State measures to control emissions from upwind power plants, industrial sources, traffic, and non-road sources. Continued declines in regional sources of air pollution are expected as stricter regulations on carbon emissions from power plants are developed as part of the U.S. Environmental Protection Agency's (EPA) Clean Power Plan (http://www2.epa.gov/carbon-pollution-standards) and tighter fuel economy standards are phased in as part of EPA's Corporate Average Fuel Economy Standards (http://www.epa.gov/otaq/climate/regulations.htm).

New York City's emissions inventory- all sources of a given pollutant- show that building- and traffic-related sources are still the primary local sources of $PM_{2.5}$, NO_x, and SO_2 emissions (Figure 3). Unconverted residual fuel oil boilers are believed to still account for a large portion of SO_2 emissions in New York City. Clean Heat Program efforts to provide assistance, outreach, and financial assistance to buildings for accelerated Nos. 4 and 6 boiler conversions should be continued and increased to accelerate the health benefits from reduced emissions.

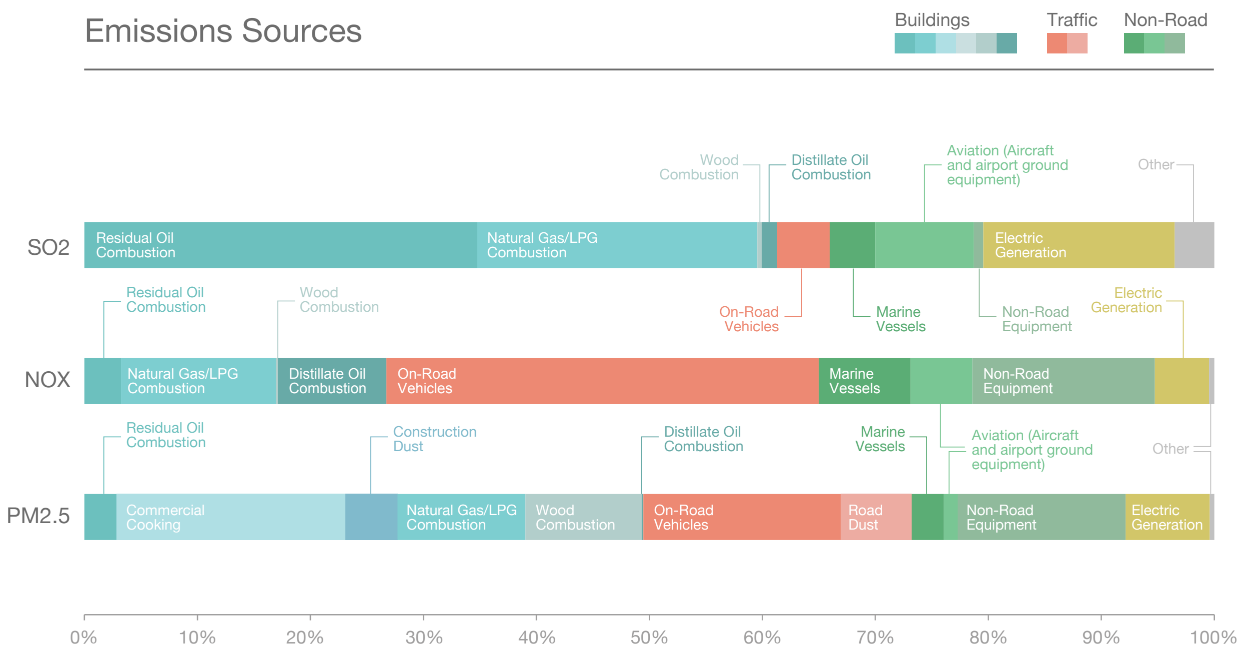

Figure 3: Major sources of $PM_{2.5}$, NO_x, and SO_2 in New York City.[f]

With high densities of people living near emissions sources, preventing air pollution-related deaths and illnesses in New York City will require new strategies to address smaller and more widely distributed sources of air pollution. For example, commercial cooking operations, such as meat charbroiling, produce an estimated 2,000 tons of $PM_{2.5}$ each year, or 20% of all locally emitted primary $PM_{2.5}$. Technologies exist or are in development to control these emissions, and the NYC Department of Environmental Protection has included regulation as part of its updated air code. Additional emissions reductions from buildings and power plants can be realized through conservation and energy efficiency measures proposed through other efforts. For example, the greenhouse gas reduction goals in the Once City Built to Last plan should be pursued not only to help address the risks of climate change but also to reduce harmful air pollutants and bring about a more resilient city.

Further reducing traffic-related pollution is a significant challenge in a busy city like New York and requires a range of approaches. First, policies are needed to shift vehicle fleets to the cleanest possible technology, as is required for City operated fleets by regulation (Local Law 73). For private fleets, especially trucks and buses, older and more polluting vehicles should be replaced and retrofitted through a combination of regulation and incentive programs. Electric vehicles (EVs) should be promoted by expanding charging infrastructure and other EV incentives.

Second, transit services and capacity should be expanded and residential and commercial development should be steered to public transit-friendly neighborhoods. This will reduce reliance on private vehicles, congestion and emissions of both air pollutants harmful to human health and greenhouse gases.

[f] Source: U.S. EPA National Emissions Inventory. 2011 V1, with estimates from boilers burning Nos. 2, 4, and 6 oil replaced with updated estimates reflecting boiler emissions estimated as of December 2014.

Third, increasing bike lanes and pedestrian-friendly streets can lead to improved air quality and increased physical activity. Increasing distance between people and vehicles can reduce exposures among pedestrians, as demonstrated through improved air quality in Times Square after the introduction of a car-free pedestrian plaza.

Finally, reducing vehicle-related emissions can be realized through measures to discourage private vehicle use in the city's most congested, polluted and vulnerable areas. Strategies already in place in other densely populated urban areas should be considered, such as creating low-emissions zones that levy a charge on the most polluting vehicles in the densest areas during the busiest times, congestion- and emission-based tolls, and adjusting parking policies to discourage driving. Revenues from traffic pollution mitigation measures could be used to fund better and more affordable transit and pedestrian and bike infrastructure.

Implementing a diverse and aggressive strategy of reducing emissions will help provide a healthier and more sustainable city for all New Yorkers, including those who live in areas with worse air quality. The city is expanding air quality improvement efforts through its sustainability plan. To learn more, visit http://www.nyc.gov/html/planyc/html/home/home.shtml.

CASE STUDIES

CASE STUDY: AIR POLLUTION AND BIRTH OUTCOMES

The high density of NYCCAS air quality monitors provides a unique opportunity to estimate exposures among NYC residents to better study air pollution's health effects. Recently, Health Department researchers collaborated with academic partners to investigate the impacts of air pollution on the health outcomes of some 250,000 births that occurred in the city between 2008 and 2010. Using data from birth records and NYCCAS and NYSDEC air monitoring data, researchers estimated $PM_{2.5}$ and NO_2 concentrations near each mother's home address during her pregnancy.[5] Figure CS-1 shows the estimated average NO_2 exposures by census tract for mothers who gave birth in NYC between 2008 and 2010. Estimated NO_2 exposures are higher closer to major emissions sources such as roads with high traffic volume or large buildings. These data were used to estimate the effect of air pollution on birth weight of babies born after a full-term pregnancy.[6] The analysis showed that increased levels of both $PM_{2.5}$ and NO_2 in each of the trimesters, as well as for the entire pregnancy, were statistically significantly associated with decreases in birth weight. NYCCAS researchers continue to investigate air pollution's impacts on other birth outcomes, such as preterm birth, gestational hypertension and preeclampsia, as well as the effects of other pollutants, such as the chemical constituents of $PM_{2.5}$.

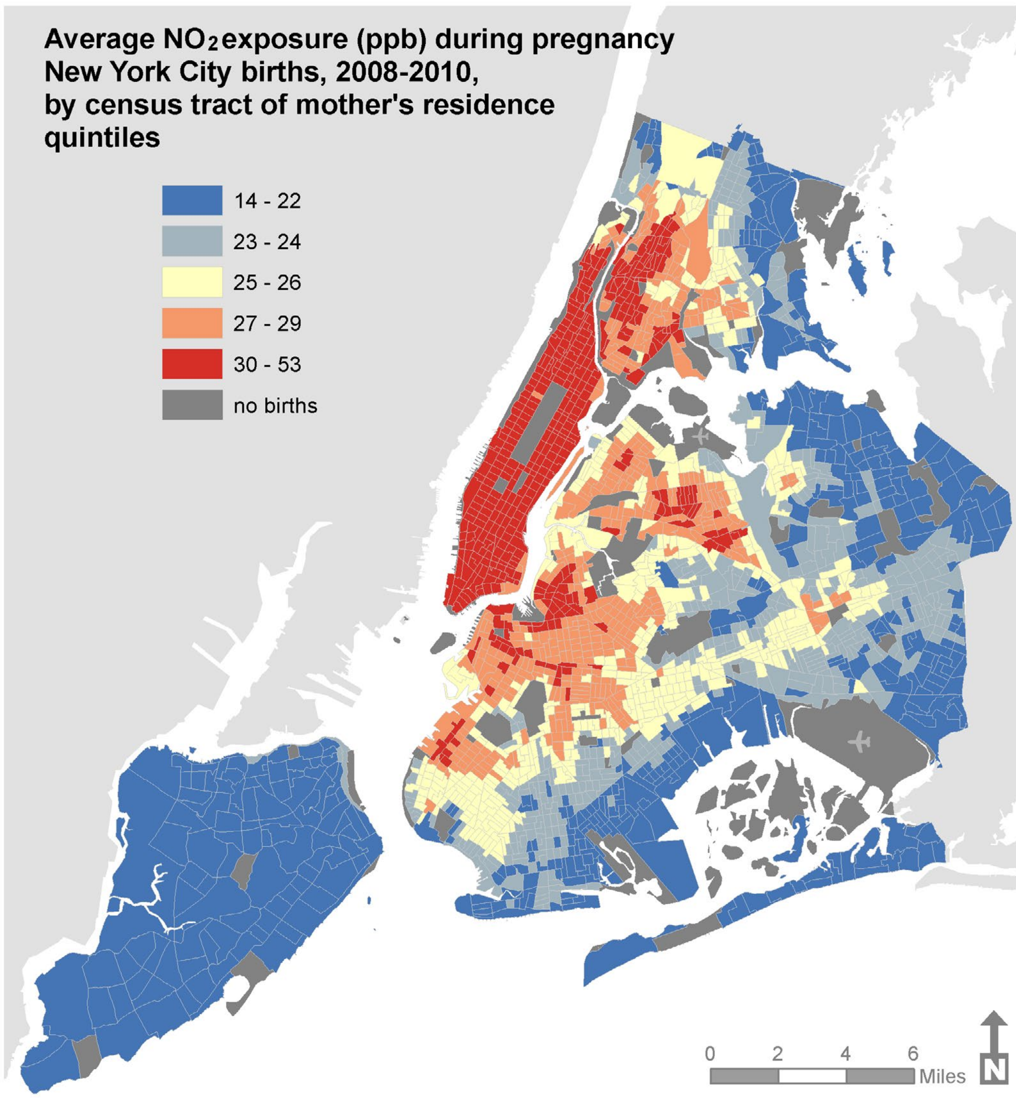

Figure CS-1. Average NO_2 exposure for NYC mothers who gave birth between 2008 and 2010.

CASE STUDY:
TRAFFIC, AIR TOXICS, AND NOISE

Traffic congestion is a familiar part of daily life in New York City and urban areas around the world, negatively affecting the quality of life of commuters and residents alike. Air monitoring data collected by NYCCAS has demonstrated how high traffic density is associated with higher levels of several harmful pollutants including NO_2, $PM_{2.5}$ and black carbon (BC). Additional case studies have evaluated levels of two additional stressors commonly associated with traffic: air toxics and noise.

In spring of 2011, NYCCAS researchers collected measurements of benzene, formaldehyde and other compounds that are in a class of air pollutants commonly known as "air toxics" at 70 street-side and park sites across the city. Air toxics are a class of air pollutants that contribute to increased risk of cancer and other serious health effects. Recent analyses suggest that 49% of New York City residents live in census tracts exceeding the 1 in 10,000 air toxics-attributable cancer risk benchmark, compared with 4.8% of the population nationwide, with the majority of the risk attributed to benzene and formaldehyde exposures.[7,8] Using small passive samplers mounted on city lampposts, researchers found that average levels of benzene and formaldehyde varied by sixfold and twofold, respectively, across New York City monitoring sites (Figure CS-2), and indicators of traffic volume and congestion contributed most to the observed differences. Indicators of fuel burning in buildings

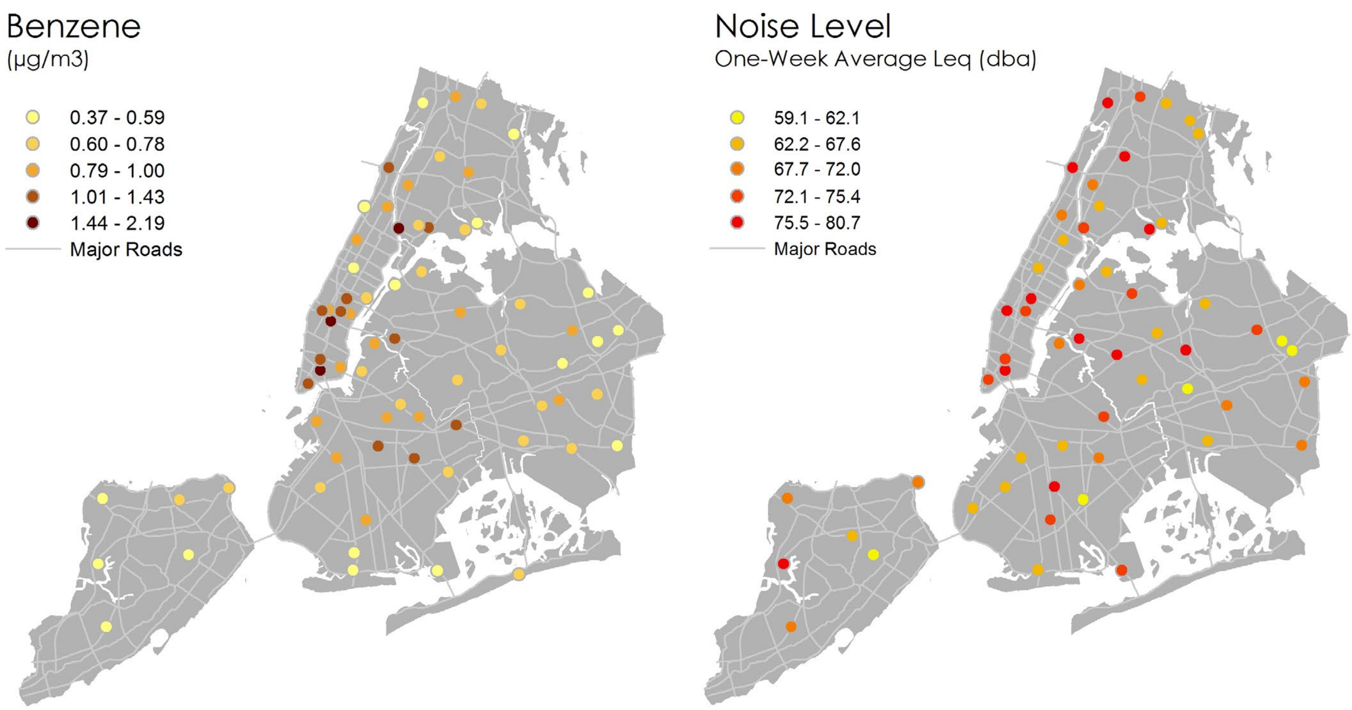

Figure CS-2: Monitored levels of benzene* and noise at sites in NYC.
*Benzene levels adjusted for week-to-week weather differences using central site monitors.

were also associated with higher formaldehyde levels.

Urban dwellers are also exposed to environmental noise from traffic and other sources. A Health Department survey showed that one in five adult New Yorkers experiences noise that disrupts home activities, including sleep, three or more times per week.[9] Some high-poverty neighborhoods experience especially high rates of noise disruption. Ambient noise can cause stress, increase blood pressure and cardiovascular disease risk, disturb sleep needed to maintain health, and interfere with cognitive development in children[10]. To assess levels of outdoor noise throughout the city, in 2012 NYCCAS researchers collected one-week sound pressure measurements at 56 sites using small sound-level meters mounted on city lampposts. Noise at all sites exceeded EPA (55 dBA) and World Health Organization (55 dBA) guidelines to protect health and quality of life and more than half of sites exceeded EPA noise guidelines for hearing loss prevention (70 dBA). Noise levels varied widely (Figure CS-2), with the highest levels occurring during the weekday, daytime hours and in areas of high traffic density within 100 m of the monitoring site. Noise levels also correlated strongly with air pollutants generated by motor vehicles. Reducing emissions of both noise and air pollution from vehicles and other sources would improve health and quality of life in many of our most burdened neighborhoods.

CASE STUDY:

PUBLIC HEALTH BENEFITS OF $PM_{2.5}$ REDUCTIONS DUE TO CONVERSIONS TO CLEANER HEATING FUELS

With cold weather and high population density, the Northeast is the nation's largest consumer of heating oil, using these fuels in building boiler systems year-round for heat and hot water. As noted elsewhere in this and other NYCCAS reports, NYCCAS data have played a critical role in spurring several measures to reduce heating fuel emissions in New York City.

Because multiple interventions are contributing to falling measured $PM_{2.5}$ levels, NYC Health Department researchers and their collaborators used sophisticated model simulations to separately estimate the public health benefits of clean heat measures implemented so far and additional benefits from the complete phase out of high sulfur containing fuels. The analysis had multiple steps:

- Estimating emissions of building boilers before and after City and State regulation using boiler permits and other buildings and emissions data.
- Using a complex air quality computer model that combines emissions information, meteorology data, and simulations of atmospheric chemical reactions to estimate the change in $PM_{2.5}$ concentration that result from the change in boiler emissions.
- Combining modeled output with monitor

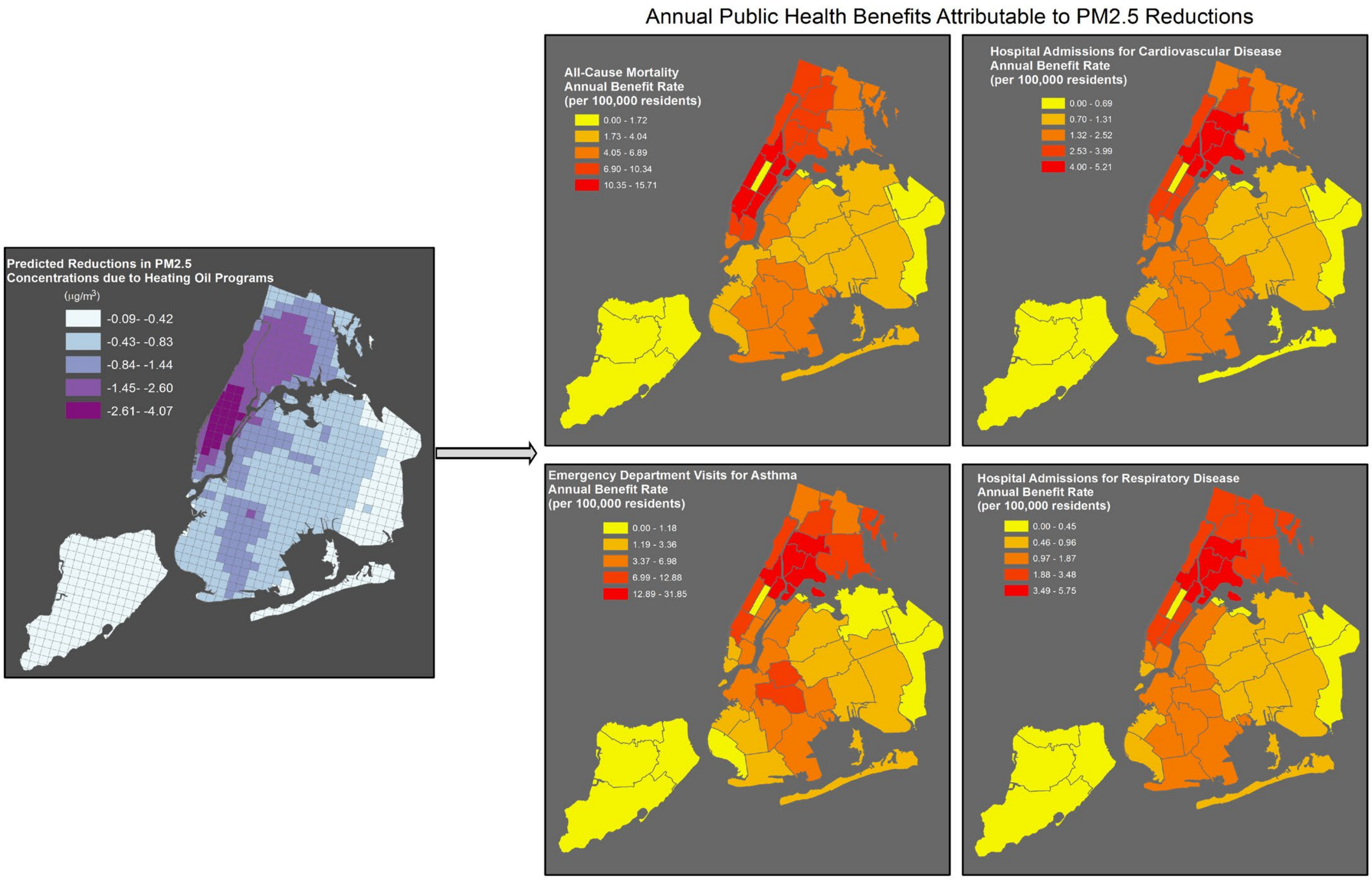

Figure CS-3: Estimated public health benefits of City and State heating oil programs upon full implementation in 2030.[g]

data to more accurately estimate air pollution exposures before and after the regulations.

- Combining $PM_{2.5}$ exposure estimates, neighborhood-level population and health outcome data, and published information on the health risks of $PM_{2.5}$ to estimate avoided health events from clean heat measures by neighborhood.

The study[11] found that by 2030, full implementation of the City and State heating oil regulations could prevent an estimated 290 premature deaths, 180 hospital admissions for respiratory and cardiovascular disease, and 550 emergency department visits for asthma each year (Figure CS-3). This would reduce the city's overall number of deaths caused by $PM_{2.5}$ exposure by more than 10%. Because the city's low-income neighborhoods tend to include higher proportions of vulnerable residents, the largest public health benefits from these programs were found to occur in high-poverty neighborhoods. These findings reinforce the need to accelerate conversions of Nos. 4 and 6 heating oil boilers ahead of regulatory timelines.

[g] Benefit Rate calculated as the number of avoided endpoints divided by the affected population, expressed as per 100,000 residents.

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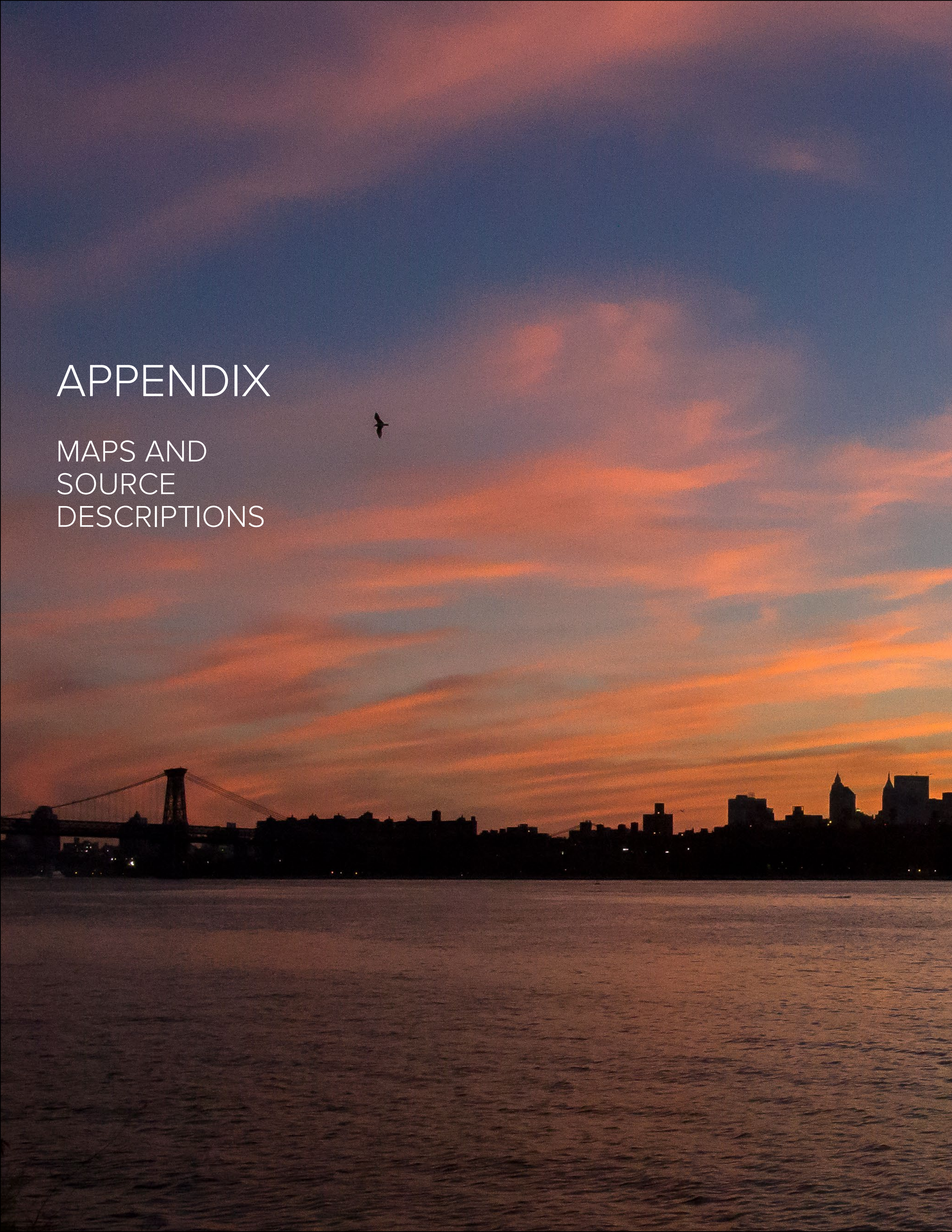
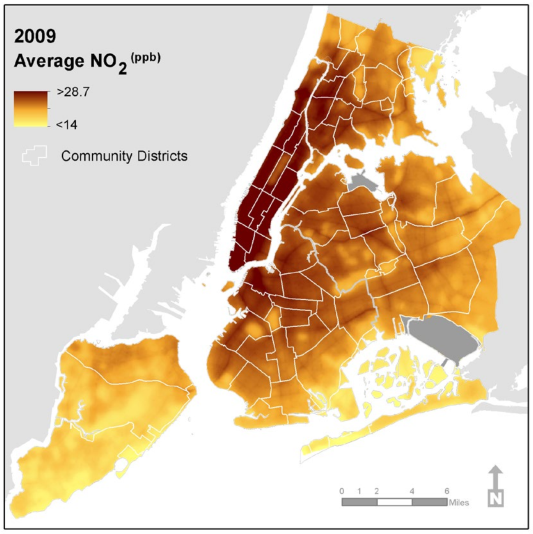
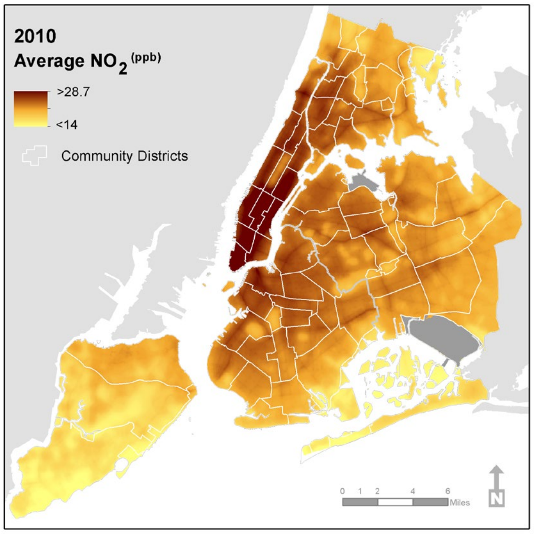
APPENDIX

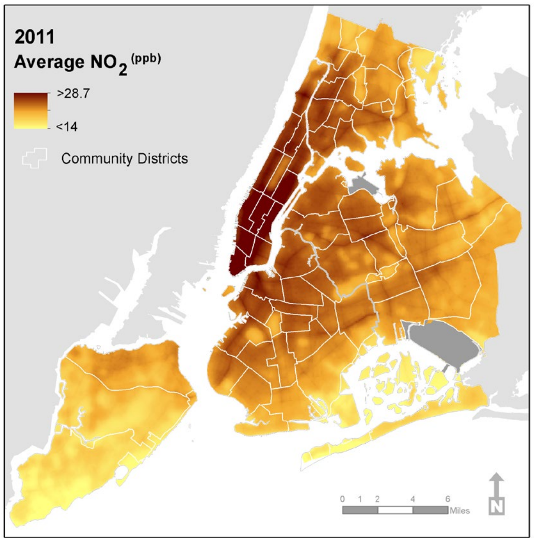
MAPS AND SOURCE DESCRIPTIONS

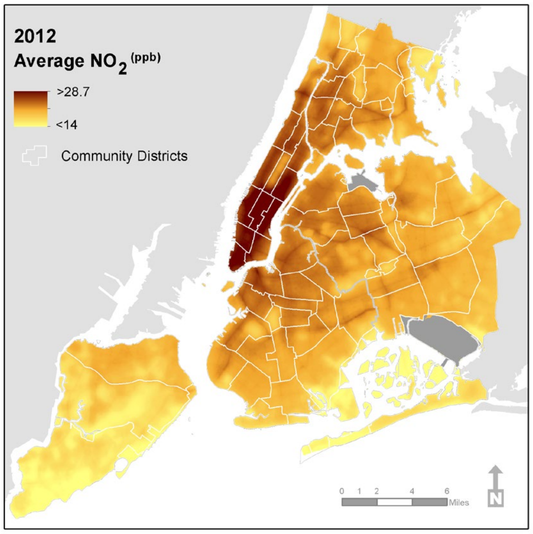


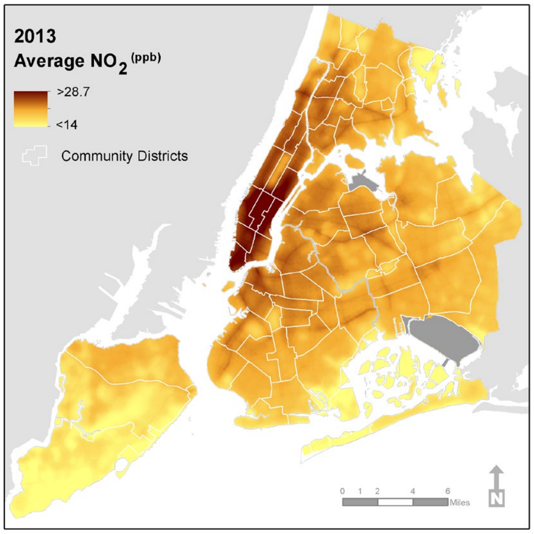
NO2
ANNUAL
AVERAGE



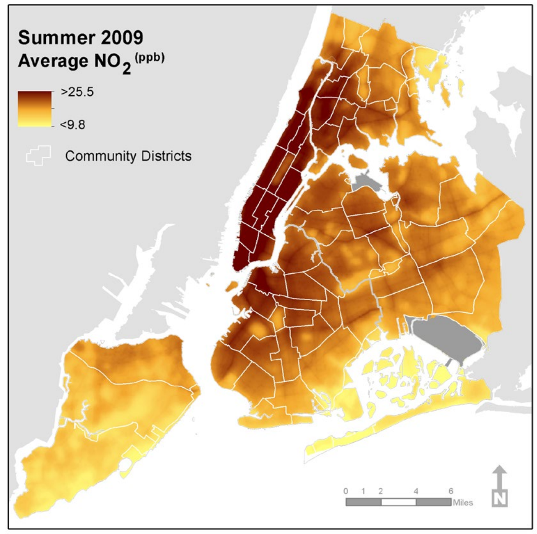


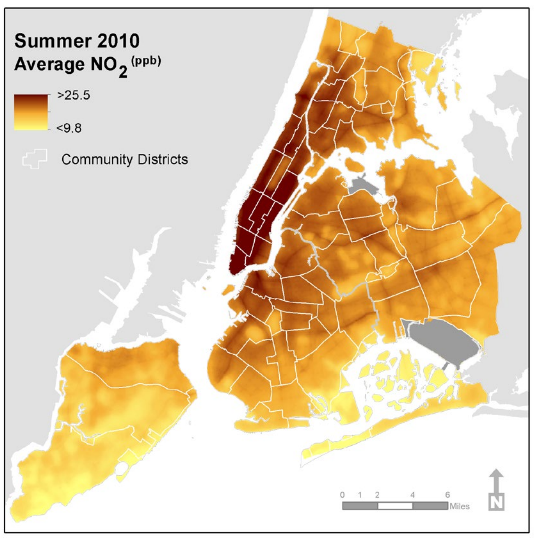


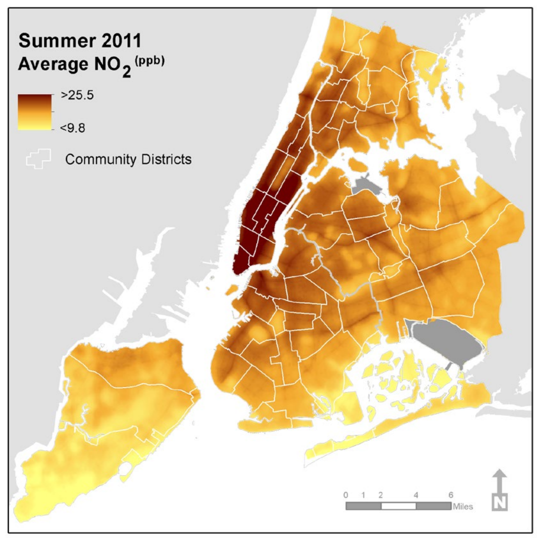


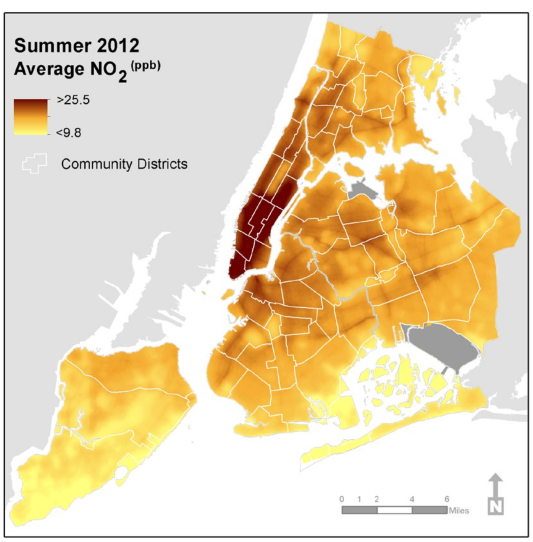


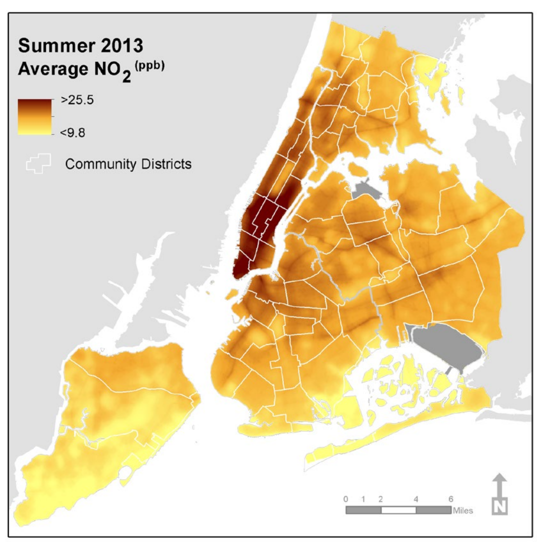
NO2
SUMMER
AVERAGE











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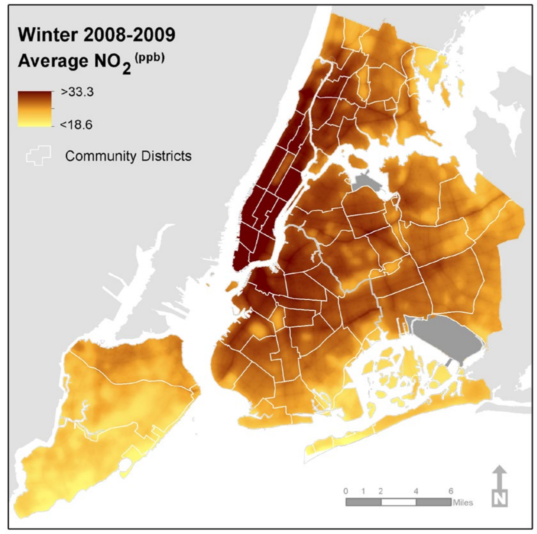
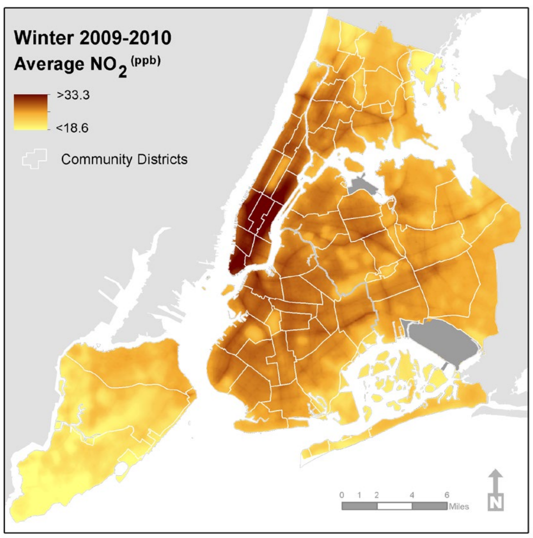
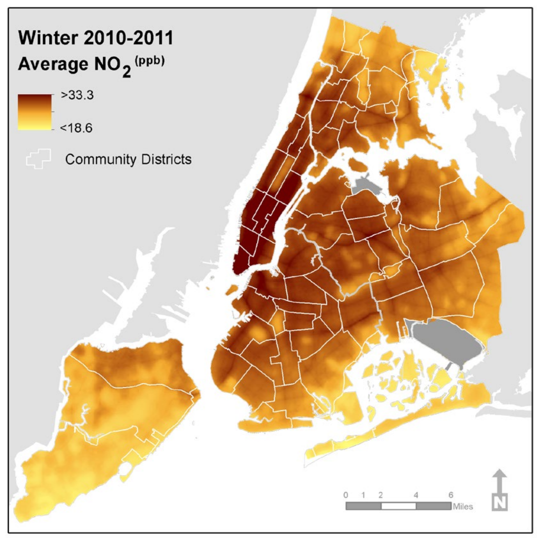
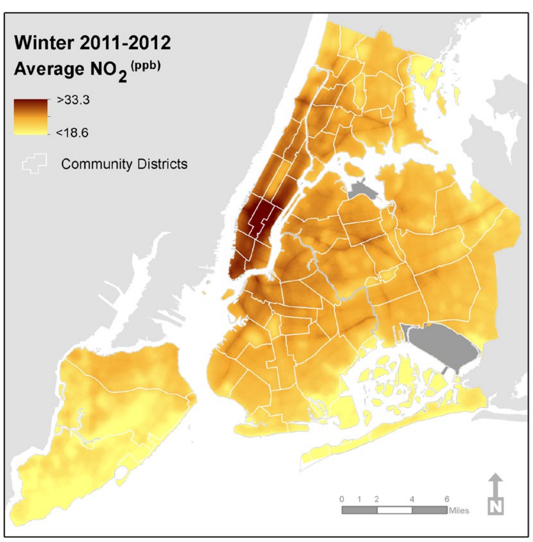
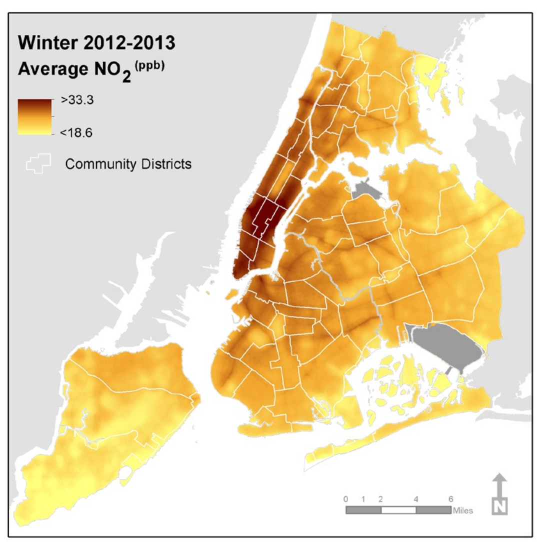


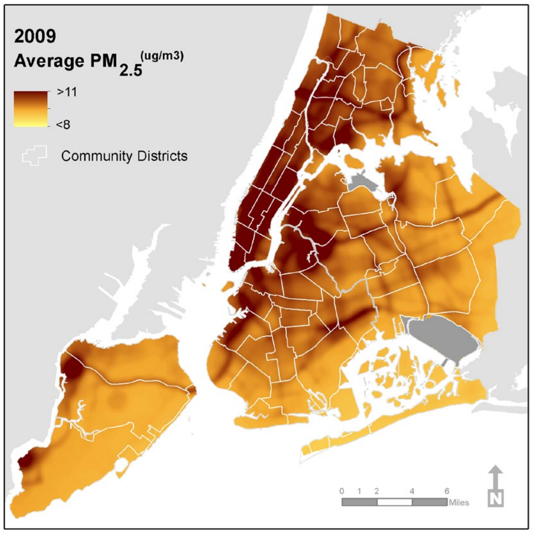


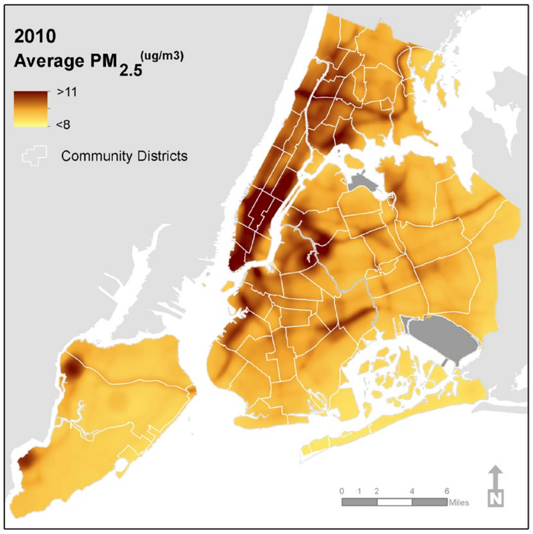


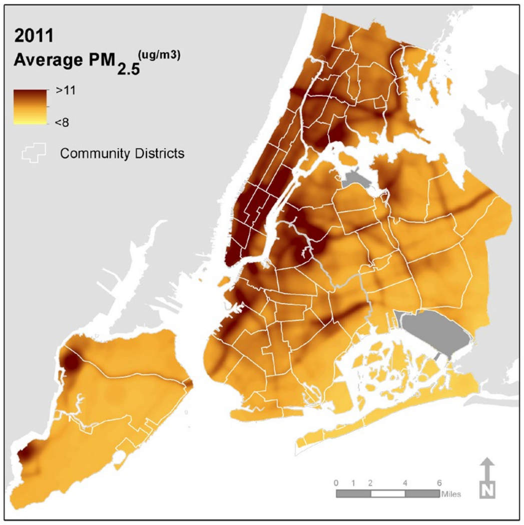


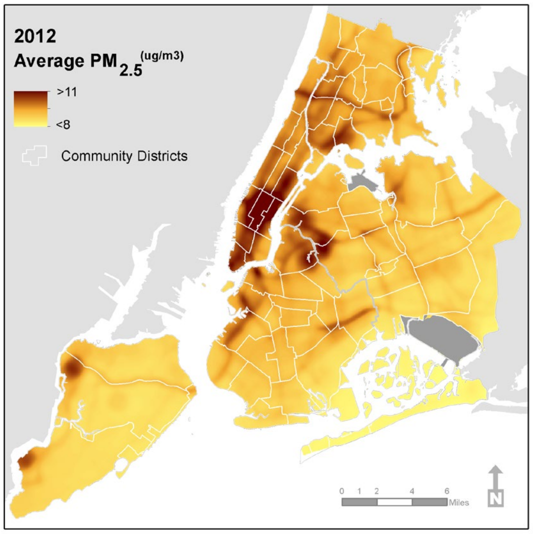


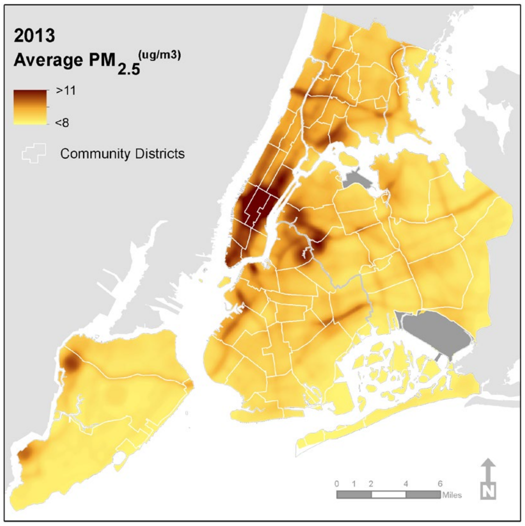
$PM_{2.5}$ ANNUAL AVERAGE



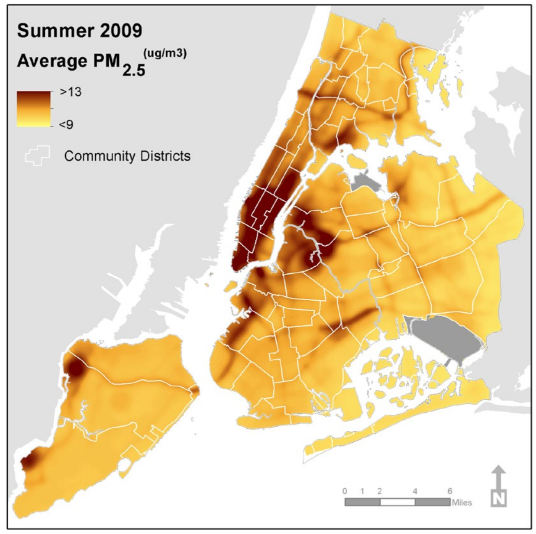


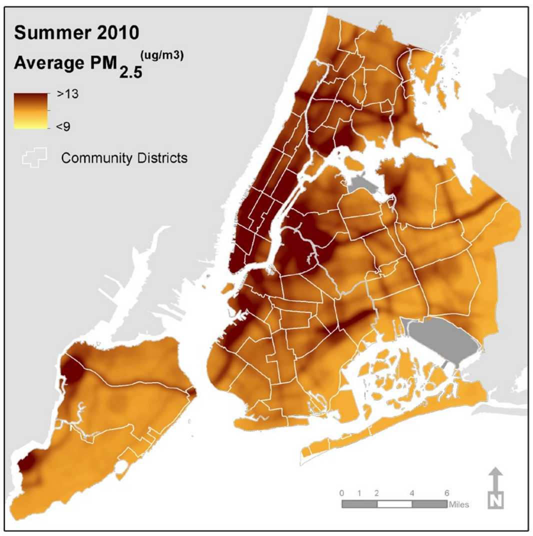


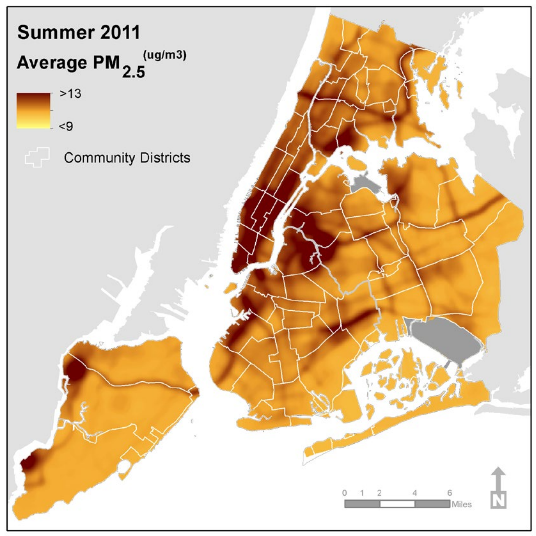


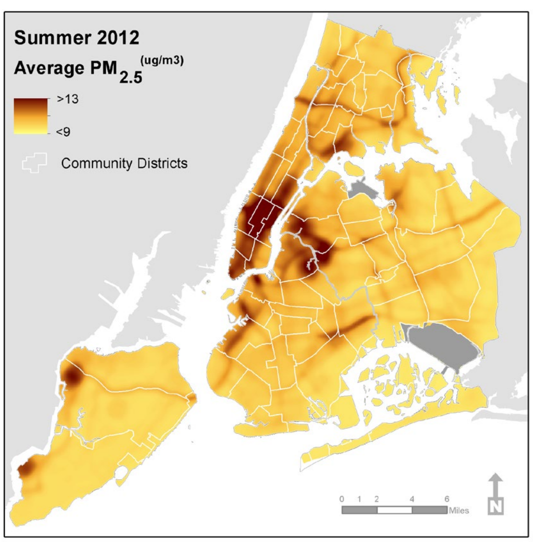


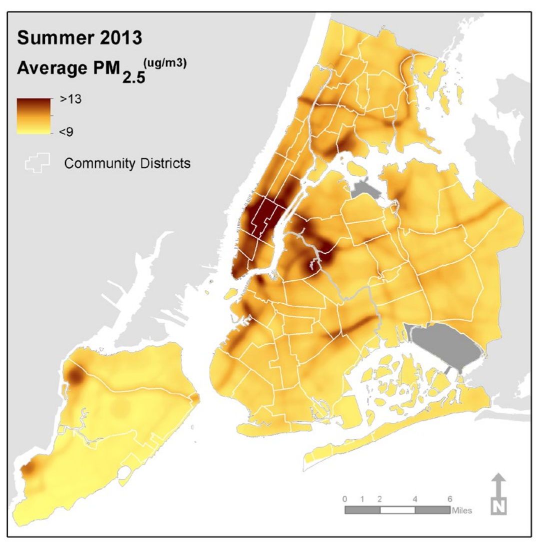
PM2.5 SUMMER AVERAGE



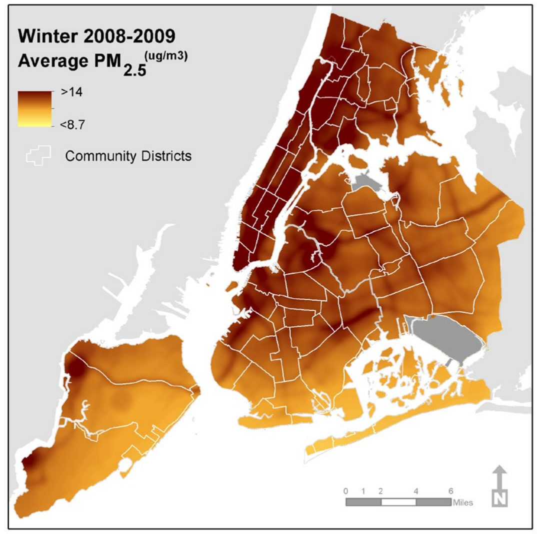


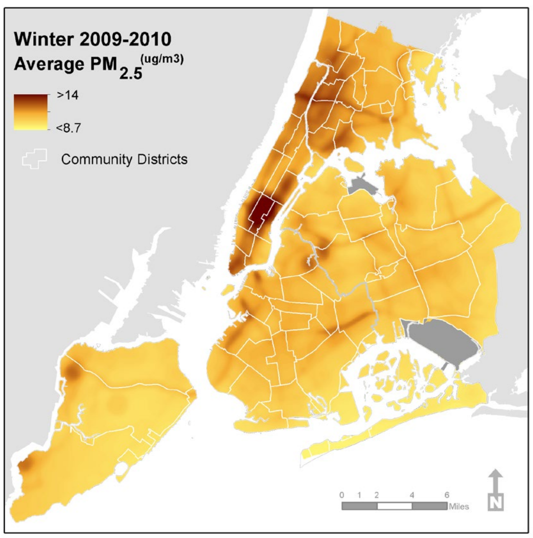


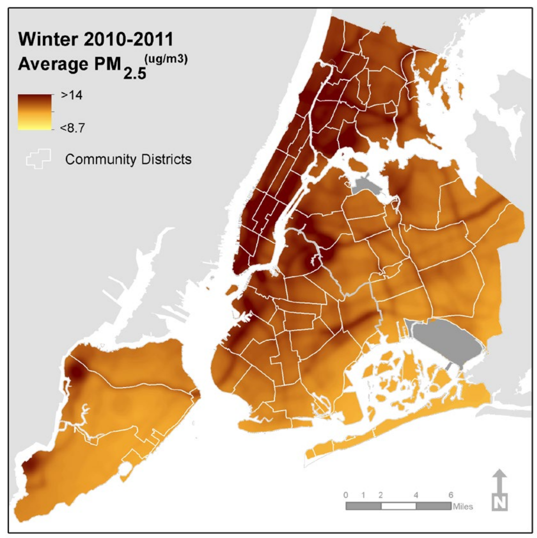


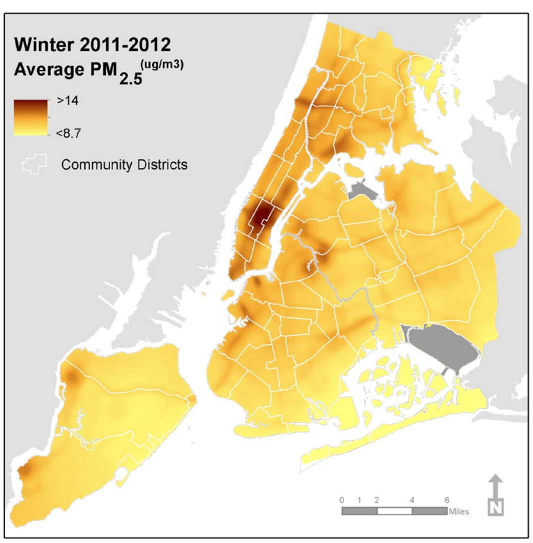


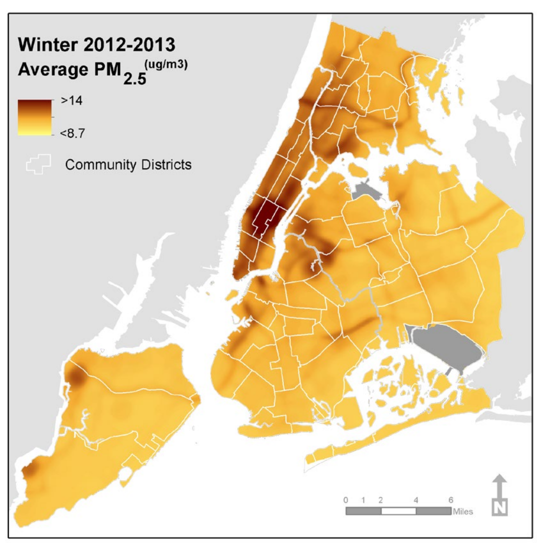
PM2.5
WINTER
AVERAGE











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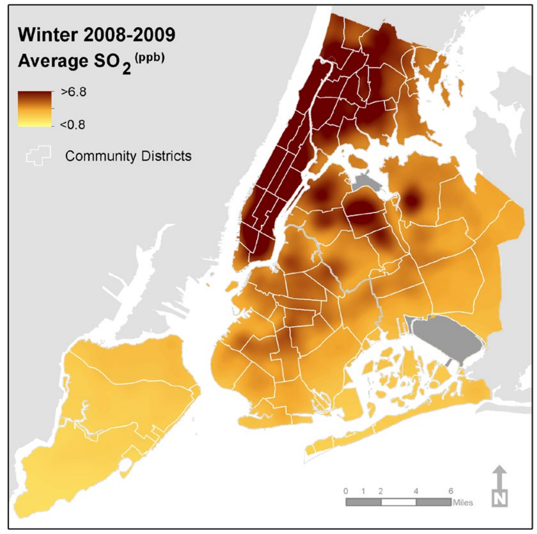

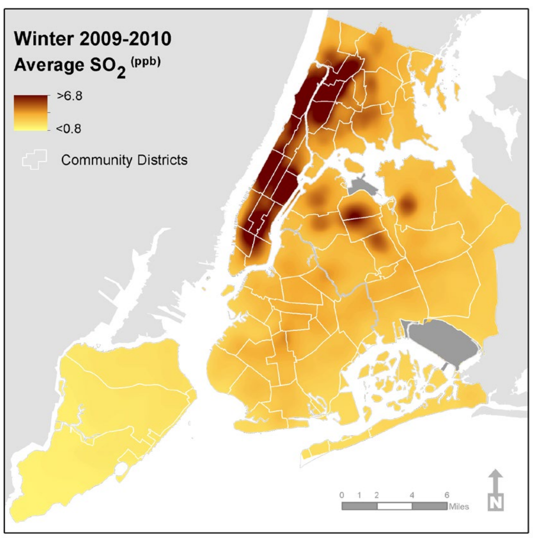

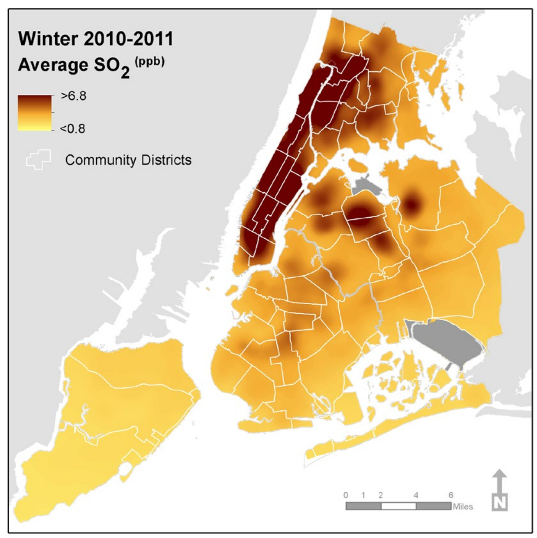

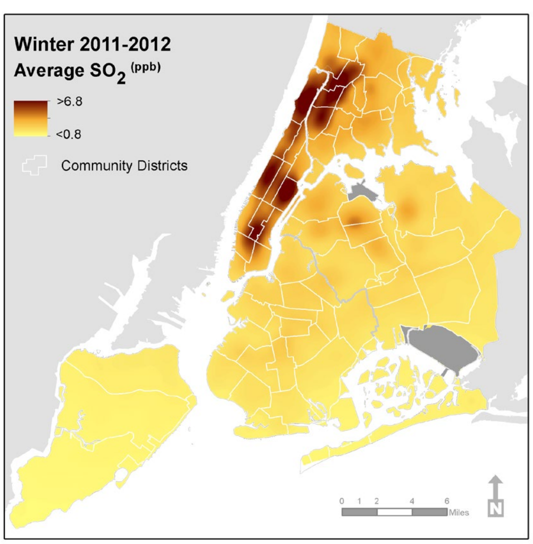

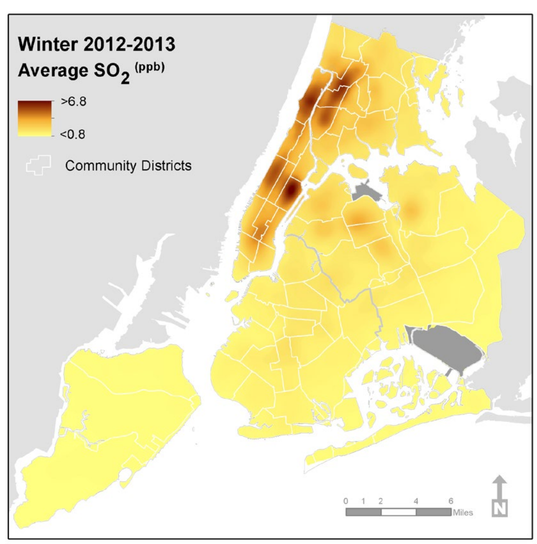

DESCRIPTION OF SOURCE INDICATORS

Density of boiler emissions: Annual building boiler $PM_{2.5}$ emissions were estimated using fuel-specific emissions factors and interior square footage as a proxy for the amount of fuel used. Fuel type, building type and interior square footage were taken from the NYC Department of Environmental Protection boiler registry (2008) where available and NYC Department of City Planning PLUTO dataset and the American Community Survey (2005-2009) for all other buildings.

Area of industrial land use: Industrial land use was estimated from total tax lot area under industrial or manufacturing use according to the NYC Department of Finance. Data Source: NYC Department of City Planning PLUTO Dataset 2007.

Density of traffic emissions: Traffic emissions density was estimated based on annual average daily vehicle miles traveled, weighted by relative emissions factors of each vehicle type (cars, trucks, buses). Data source: New York Metropolitan Transportation Council (2005), NYS Department of Environmental Conservation.

Building Density (area of interior built space): Building density was estimated as the total interior square footage under any usage for all tax lots. Data Source: NYC Department of City Planning PLUTO Dataset 2007.

Density of residual oil boilers: Residual oil boiler density was estimated as counts of boilers over 350,000 BTUs using #4 or #6 heating oil. Data source: NYC Department of Environmental Protection, 2008.

Impervious Surface: Impervious surface was estimated as the percent area identified as land type "impervious". Source: National Land Cover Database 2001,United States Geological Survey.

Nighttime population density: Night-time population counts were modeled using a combination of U.S. Census data, land cover, and administrative data. Data source: Oak Ridge National Laboratory LandScan, 2001.

Location on a bus route: A monitoring site is determined to be on a bus route if it is within 50 feet of a road designated as a bus route. Data source: New York City Transit Authority.

Health