Retrospective and Future Analysis of Air Quality In and Downwind of New York City
DRAFT White Paper
December 1, 2017

Purpose

A research program to address the needs outlined in this White Paper would serve four broad and overlapping purposes aimed at developing a better understanding of air pollutant emissions and transformations in the New York City metropolitan region:

1) Provide a retrospective analysis in the New York City (NYC) region that assesses the impacts of historical air pollution control programs and shifts in electricity generation patterns to inform future air quality and energy policy.
2) Better understand the specific features of ground-level ozone photochemical formation and transport downwind of NYC over Long Island Sound that are responsible for on-going violations of national ozone air quality health standards.
3) Develop a new case study of air pollution in a large urban area and downwind region (New York City/Long Island Sound) that complements studies elsewhere in the U.S. (e.g., Denver/Front Range, Chicago-Milwaukee/Lake Michigan, Houston-Galveston/Gulf of Mexico, Baltimore-DC/Chesapeake Bay) and can further support validation of current and future satellite measurements.
4) Investigate the future implications of wildfire plumes originating from distant locations on the Northeast's air quality as local and regional anthropogenic emissions continue to decline.

Some fundamental questions to be addressed include:

1. How have air pollution programs changed atmospheric chemistry in and around NYC since the 2004 International Consortium for Atmospheric Research on Transport and Transformation (ICARTT), and do photochemical air quality models capture these changes?
2. In light of regional NOx reductions from power plants in the eastern U.S., what is the current relative influence of ozone and precursor transport into the NYC metro area from source regions in the Ohio Valley (long-range), Northeast Corridor (mid-range), and NYC metro area (local)?
3. Do current emission inventories (NOx, VOC) used in air quality regulatory modeling for the NYC region adequately reflect ground-based and aircraft observations, both quantitatively and temporally, during high ozone episodes?
4. Have shifts in distributed electricity generation within the NYC region created localized high emission spikes (e.g., NOx, $PM_{2.5}$, air toxics) on hot summer days when electricity demand is highest?
5. How do photochemical processing and meteorology of polluted air masses over Long Island Sound influence observed high ozone concentrations along coastal Connecticut other downwind areas?

6. Does the NYC metro area urban air shed share similar attributes with other urban regions influenced by over-water transport of polluted air masses that would help inform air quality program decisions?
7. What is the future potential impact under a warming climate of long-range pollutant transport in wildfire plumes on the Northeast's air quality as anthropogenic emissions continue to decrease?

Introduction

The New York City (NYC) Combined Statistical Area (CSA) is the largest CSA by population in the United States, with over 23 million people living across portions of Connecticut, New Jersey, New York, and Pennsylvania.[1] While air pollution levels have dropped over the years across much of the United States, the New York City (NYC) metropolitan area and surrounding region continue to persistently exceed both past and recently revised federal health-based air quality standards for ground-level ozone. In addition, urban residents can be exposed to higher levels of health damaging fine particle and air toxic pollutants concentrated at "hot-spots" in close proximity to high-density traffic and other local air pollution sources. These air quality problems afflict the health and well-being of the 23 million people living in the urbanized area comprised of NYC and surrounding counties in NY State, northern NJ, western CT and northeastern PA, as well as additional populations in downwind CT, RI, MA, NH, and ME.

The location of New York City proper relative to Long Island Sound, the density of its air pollution sources, and the southwest to northeast air pollution transport flow makes this region unique. It is therefore somewhat surprising in light of the region's large population and persistent air pollution problems that it has received relatively little recent research attention compared to other parts of the U.S. It does, however, have a robust research history that can provide a useful reference point to gauge the effectiveness of past pollution control programs as well as market- and regulatory-driven shifts in the electric generation sector.

In May 2017, the Northeast States for Coordinated Air Use Management (NESCAUM) with support from the New York State Energy Research and Development Authority organized the "New York City Metro Area Energy & Air Quality Data Gaps Workshop" at Columbia University's Lamont-Doherty Earth Observatory that brought together energy and air quality planners, researchers, non-profits, and industry to share information on current activities at the interface of New York's air quality and energy programs.[2] The workshop's goal was to identify data gaps that hinder informed decision making aimed at improving air quality and public health in the greater NYC urban area, as well as in downwind areas affected by air pollution transported from and through the NYC area. Topics included data gaps that present challenges for air quality planning in the New York City metro region as well as a discussion of energy programs underway or planned in New York City and State that have implications for future air quality.

Key data gaps identified by workshop participants included 1) understanding changes in atmospheric chemistry over time and relating the changes to regulatory programs, 2) better understanding of the dynamics of air pollution transported over Long Island Sound, 3) improving transportation emission estimates (e.g., on-road mobile source NOx inventories), 4) improving

[1] https://en.wikipedia.org/wiki/Combined_statistical_area

[2] A number of speaker presentations and poster abstracts from the workshop are available at http://www.nescaum.org/documents/nyc-metro-area-energy-air-quality-data-gaps-workshop.

emissions and activity profiles of distributed generation sources (e.g., stationary diesel generating units), and 5) understanding public exposure to air pollutants at local scales (e.g., neighborhood).

Many of these data gaps cut across the general areas outlined at the beginning of this White Paper and expanded upon in the following sections. The following discussion includes specific policy-relevant research questions and recommendations from the workshop that have been supplemented with additional suggestions generated in subsequent conversations between atmospheric scientists and NESCAUM after the workshop.

Potential Research Activities to Address Planning Needs

1) Retrospective analysis of regulatory air program effectiveness since ICARTT 2004

Air quality in the New York City region has contributions from the eastern U.S. through long-range transport (e.g., ozone and its precursors), as well as inter-region (Northeast Corridor) and local influences. As a result, pollution control strategies and energy use shifts occurring on regional and local scales can influence NYC's air quality. Examples of these include regional reductions in nitrogen oxides (NOx) from fossil fuel power plants, coal power plant retirements with shifts to natural gas, implementation of state renewable energy portfolio standards and energy efficiency programs, potentially more local electric generation with emission spikes on hot summer days, and a cleaner on-road vehicle fleet as newer cars meeting more stringent tailpipe standards have displaced older, more polluting vehicles.

Somewhat unique to the NYC region, there is an extensive historical data set collected during the 2004 International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) field campaign that provides a reference point with which to evaluate changes in the formation and downwind transport of air pollution resulting from historical air pollution control programs and electric generation shifts occurring over the intervening years. In the summer of 2004, several separate field programs within ICARTT intensively studied the photochemical, heterogeneous chemical and radiative environment of the troposphere over the northeastern U.S. (including NYC) and outflow regions to the North Atlantic Ocean. The results of this study encompassed 68 papers published in 2007 in two special issues of Journal of Geophysical Research-Atmospheres (Part 1, v111, D23 and part2, v112, D10), with Fehsenfeld et al. (2006) providing a broad overview of the effort.

Approximately 13 years have passed since the ICARTT field study was conducted in 2004. The photochemical environment over and downwind of the New England area has changed over that time due to pollution control programs and structural changes in the electric generating industry. ICARTT 2004 now provides the opportunity to use its historical data sets for comparison with a new set of measures that would include vertical profile and synoptic-scale spatial distributions of aerosols and gases downwind of NYC.

An initial effort is underway with a small number of aircraft flights by the University of Maryland (UMD) being conducted during the 2017 and 2018 ozone seasons (about 6-8 flights currently planned). These flights are collecting VOC, NOx, and aerosol-related measurements over Long Island Sound. The ICARTT data sets and more recent UMD flights (and measurements by other researchers that could occur in 2018) would provide a basis for investigating historical trends over Long Island Sound and at higher altitudes not completely captured by on-shore surface measurements. They may also provide information on how well

surface monitors along the Long Island Sound shoreline reflect pollutant species and chemistry occurring over water and at higher altitudes (important for downwind transport assessments). Questions that could be investigated include:

- What are the surface level OH and HO_2 radical budgets in the region, and what are their implications for ozone and secondary $PM_{2.5}$ formation, thus regulatory control strategies?
- Has the vertical atmospheric chemistry (i.e., pollutant profiles with height) in and downwind of NYC changed since the ICARTT measurements? If so, can these be attributed to regulatory programs and energy transitions?
- Do precursor pollutant ratios in the vertical profiles provide useful information on trends in ozone sensitivity to past and current VOC and NOx control programs?
- Do the ICARTT measurements and more recent flights provide an adequate baseline for assessing future changes in air quality resulting from energy transitions? Are there anticipated indicator species not in the present data sets that could be added to current monitoring programs or field campaigns?
- Can near-shore surface pollutant measurements along Long Island Sound provide reasonably representative information in lieu of over-water measurements?

2) *Improved understanding of ground-level ozone formation and transport over Long Island Sound*

During New York City's most severe ozone episodes, air pollution is transported in a southwest to northeast direction all along the Northeast corridor, carrying air pollution from upwind areas (both within and outside of the Northeast Corridor) into the City and then across Long Island Sound. The relatively cool waters of the Sound confine the pollutants in a shallow and stable marine boundary layer. Afternoon heating over coastal land creates a sea breeze with a southerly component carrying air pollutants onshore from the confined maritime layer, resulting in high ozone concentrations along the Connecticut coast and at times farther east into Rhode Island and Massachusetts. At times, the high ozone pollution plume can extend even farther downwind, with observed 8-hour ozone concentrations exceeding national air quality standards as far away as the Maine coastline, including Acadia National Park (see recent example in Figure 1). Inland winds from the west prevent sea breeze penetration and can sometimes contribute to the formation of a convergence zone that can further concentrate ozone along the coast.

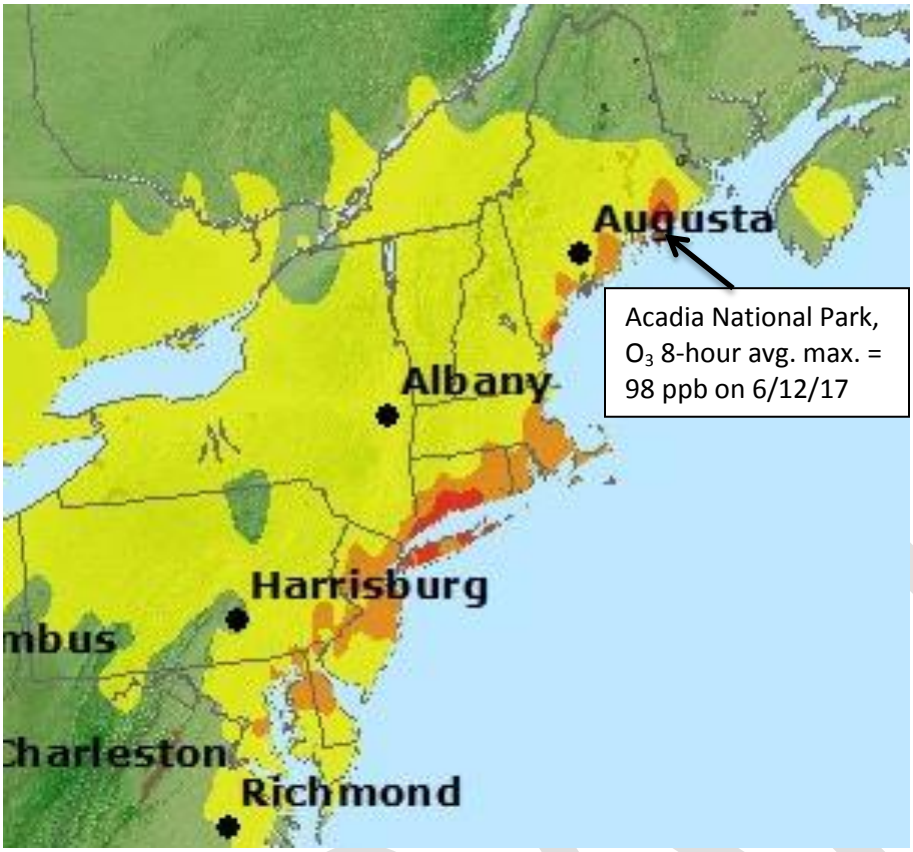

Figure 1. Maximum 8-hour average ozone in Northeast U.S., June 12, 2017.
Source: U.S. EPA, AIRNow, https://cfpub.epa.gov/airnow/index.cfm?action=airnow.mapsarchivecalendar

The transport of pollution from continental to marine environments results in characteristic average vertical profiles of pollutants. From the ICARTT 2004 measurements, Lee et al. (2011) present a detailed analysis of the transport and photochemistry during a high ozone event on July 20 and 21, 2004, which includes WRF-Chem photochemical modeling. Figure 2 shows their analysis of data from aircraft flights using an ozone lidar.

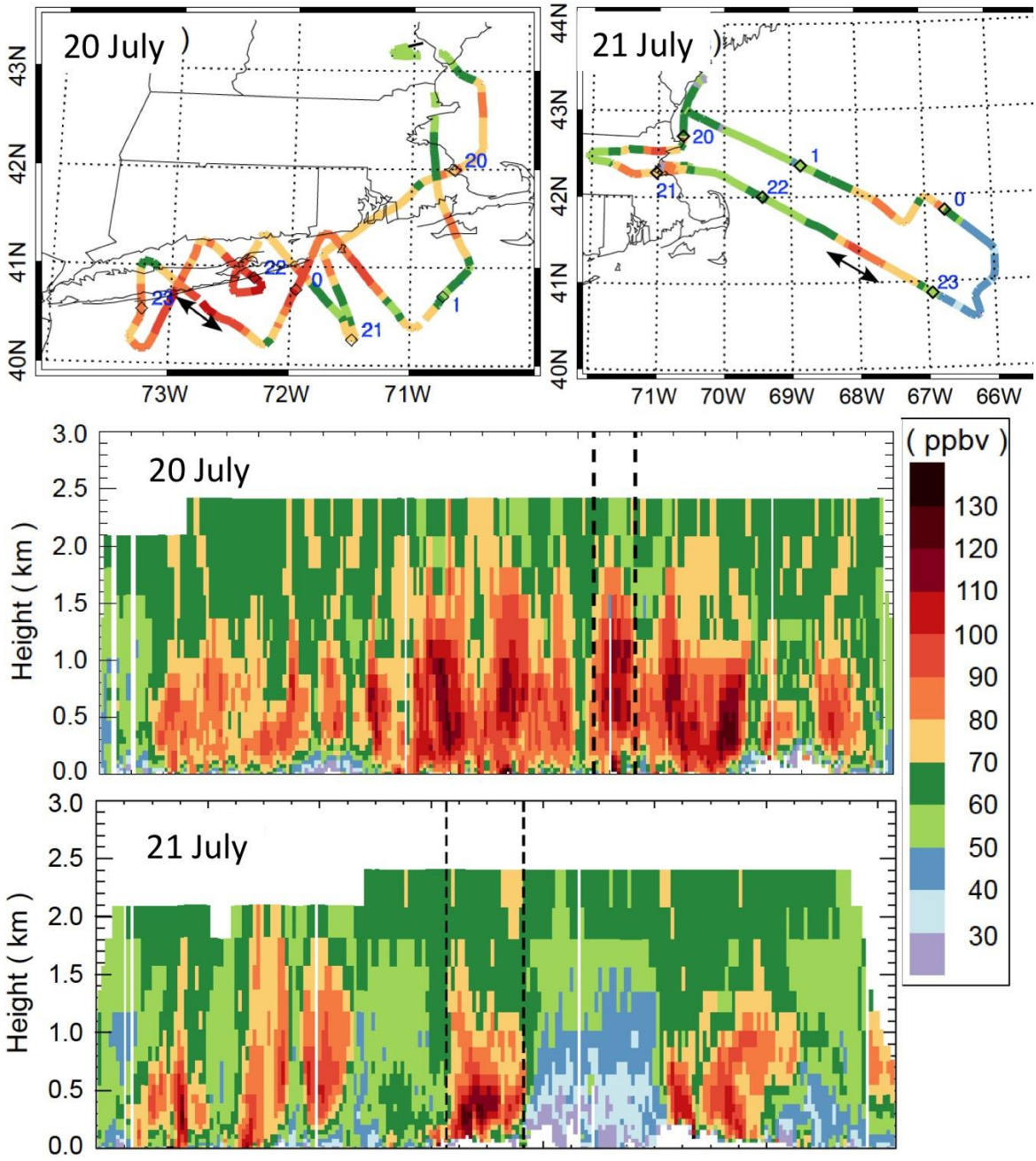

Figure 2. (top) Flight tracks of the DC-3 aircraft on 20 and 21 July color-coded by measured ozone mixing ratios vertically averaged from near surface to about 1.5 km. (bottom) Vertical distributions of observed ozone mixing ratios during the flights. The double-headed arrows in the upper plots correspond to the periods between the dashed lines in the lower plots. (Figure adapted from Lee et al., 2011).

The ozone produced within the plumes transported from NYC is clearly apparent in both the horizontal (upper figure panels) and in the vertical distributions (lower figure panels). Qualitatively, the pollution plumes transported from NYC are well defined by the data from both aircraft platforms. However, the transport has very complex details, which Lee et al. (2011)

discuss in the context of their photochemical modeling; some of those details include:

- The measured urban plumes extended vertically up to about 2 km near New York City, but not as high (1–1.5 km) over the stable marine boundary layer (MBL) over the North Atlantic Ocean.
- Generally a steep gradient is seen below about 0.5 km observed by in situ measurements of vertical profiles during aircraft flights, indicating that the urban plume is decoupled from the MBL (e.g., see Fig. 6a of Lee et al. (2011)).
- The similarity of ozone concentrations measured near the source regions on July 20 and measured far downwind on July 21 indicates that the ozone plumes were efficiently transported in the lower atmosphere over the North Atlantic Ocean without significant influence of ozone loss processes.
- The layered structure of the lower troposphere in the marine environment results in a great deal of complexity in transport, which is driven by the vertical shear in wind speed and direction. Figures 9 - 13 of Lee et al. (2011) show this complexity in great detail, with a continental plume well defined in the horizontal and vertical, separating into separate plumes transported in different directions at different altitudes after entering the marine environment.

A key research problem is understanding the sources and temporal emission profiles of the ozone precursors NOx and VOCs captured within the marine environments, and how it photochemically evolves with downwind transport over Long Island Sound. The NYC metropolitan area has a large concentration of mobile sources, and heavy-duty on-road vehicles (i.e., diesel trucks) are relatively less controlled than other mobile sources. Furthermore, area sources, such as small diesel engines and oil-fired boilers in large commercial and residential buildings, are difficult to account for in emission inventories used in air quality modeling. While these area sources are individually small, a dense collection of them in the metropolitan region can result in collectively large emissions, and their similar activity patterns can create high peak-day emissions not captured in models that may use daily averages based on total emissions occurring during a season or year.

At the May 2017 New York City Metro Area Energy & Air Quality Data Gaps Workshop, meeting participants discussed a number of research recommendations to address questions relevant to a better understanding of the NYC regional ozone problem. These include the following:

Recommendation 1: More fully assess existing monitored air pollutant data sets from the Photochemical Assessment Monitoring Stations (PAMS) network. The 1990 Clean Air Act Amendments required enhanced research-oriented monitoring in areas classified as serious non-attainment for the then existing 1-hour ozone standard. The PAMS network was required to achieve the following:

- Provide data to evaluate control strategies
- Provide pollutant and metrological data for photochemical grid models
- Provide data to evaluate source emission impacts
- Provide data to detect trends
- Provide data to support attainment designations and maintenance plans

- Provide data to evaluate exposure to air toxics

Historical PAMS data have been collected at sites in NY, NJ and CT within or near the NYC region. Several workshop participants noted that the PAMS data sets have not to date been fully assessed, and that the PAMS set of volatile organic compounds (VOCs) (e.g., non-polar hydrocarbons from gasoline) may not be representative of a more complex VOC mix, such as oxygenated VOCs from consumer products. A more comprehensive assessment of the PAMS data along with additional measurements of an expanded set of VOCs (see Recommendation 2 below) could help address the following questions:

- What fraction of the VOC reactivity in the region can be attributed to PAMS compounds, and how has this changed over time?
- Are there changes in VOC speciation over time that have implications for enhanced or diminished formation of organic carbon fine particulate matter ($PM_{2.5}$) species at the local and regional scales?
- If a VOC reactivity change has occurred, does it have implications for the sensitivity of ground-level ozone formation in the local NYC area and downwind transport over Long Island Sound, hence an impact on regulatory strategies to reduce ozone?
- Do current regulatory air quality models used for simulating ozone and $PM_{2.5}$ formation adequately represent the key VOC species observed in the PAMS data set?
- Are there detectable VOC species trends in the NYC area from low sulfur fuel oil requirements and energy technology conversions from fuel oil to natural gas? For example, have air toxics changed significantly over the years in the NYC area, and if so, can they be attributed to changes in fuel types and characteristics?
- Have consumer product VOC emissions overtaken transportation-related VOCs in the NYC region due to requirements to reduce VOC volatility of transportation fuels? If so, what are the implications of this for $PM_{2.5}$, ozone, and air toxic reduction strategies?

Recommendation 2: Better quantify VOC and other species not previously measured that may indicate changing roles in emission source sectors relevant to ozone and $PM_{2.5}$ formation as a result of historical VOC control measures.

A number of biogenic and consumer product VOCs along with their oxygenated products and related species in the atmosphere have previously been difficult to measure, but analytical instrumentation techniques have improved over time. Better quantification of these species and derived atmospheric products would help inform the need to revise chemistry mechanisms in air quality models that have not previously incorporated these more reactive species because of the historical dominance of mobile source VOCs. Also, routine speciated measurements of NOy and chemically related groups are now feasible, although demanding, and obtaining these measurements would better reflect atmospheric reactivity and ozone/$PM_{2.5}$ production chemistry. Activities under this recommendation would seek to apply more recent analytical techniques to measuring atmospheric species in answering the following questions:

- What are the atmospheric species to measure in order to determine the relative abundance of mobile vs. non-mobile VOCs in NYC? Possible candidate species may include more oxygenated larger VOCs and siloxanes (these are more specific to consumer products).

- What is the relative importance in the NYC region of biogenic VOCs and their oxidized products in the atmospheric chemistry of ozone and $PM_{2.5}$?
- What are the NOy speciation and organonitrate levels in the region, and do air quality models reasonably reflect their atmospheric reactivity and role in ozone/$PM_{2.5}$ formation?

Recommendation 3: Develop a better understanding of meteorological conditions over Long Island Sound, their influence on the evolution and transport of pollution plumes, and the adequacy of near-shore meteorological measurements to represent conditions over Long Island Sound.

There is a dearth of meteorological measurements over the Long Island Sound. Additional resources would provide important input information for air quality modeling used in planning and forecasting. The City University of NY (CUNY) has lidar instruments within NYC. New York State has developed a state-wide MESO-scale NETwork (MESONET) capable of providing high-quality weather and climate data. Several MESONET sites are or will be located within NYC, and many of these are enhanced with vertical profilers to measure vertical wind profiles up to 3 km, vertical temperature and moisture profiles, and sky conditions. EPA is also now requiring hourly mixed layer height measurements at PAMS sites. A key data gap is whether these sites provide adequate meteorological information to support air quality modeling forecasts downwind after pollutant transport over Long Island Sound. A temporary pilot site located within (to the fullest extent practicable) Long Island Sound would help answer the following questions:

- Are on-shore profile measurements adjacent to Long Island Sound consistent with vertical structure over Long Island Sound?
- As seen by the meteorological measurements, do air quality models contain sufficient vertical resolution to adequately predict chemical evolution and transport of pollution plumes over water?
- Is there a strong sea breeze effect influencing shoreline pollutant levels transported over water in Long Island Sound, and if so, are air quality planning and forecasting models capable of capturing these on high pollution days?

Recommendation 4: Investigate the adequacy of mobile source emission inventories currently used by air quality planners to appropriately estimate NOx and VOC emissions from the transportation sector in the NYC region.

Since the 1960s, there have been large reductions in motor vehicle tailpipe emissions, with new cars today ~400x cleaner than pre-control vehicles. Along with technology advances, other factors are influencing transportation emissions over time, such as changing durability of the control technologies and different vehicle operating conditions, which can include the influence of driver behavior and operational (including illegal) bypasses of emissions control equipment during on-road driving.

The dramatic changes in vehicle emissions over time may not be adequately captured in current mobile source emission inventory estimates, such as EPA's MOtor Vehicle Emission Simulator (MOVES). For example, recent studies suggest U.S. passenger vehicle NOx emissions may be overestimated by ~2 times in EPA's MOVES. It is not clear, however, whether this large discrepancy is found across all cities, and an assessment specific to the NYC region is needed to

determine the adequacy of the current mobile source NOx emissions inventory. This is a significant issue for air quality planners, as air quality modeling suggests that ground-level ozone is highly sensitive to transportation NOx emissions.

In addition to NOx, the rapid decreases in transportation VOC emissions are shifting the urban VOC budget away from energy (e.g., gasoline, diesel) to non-energy related sources (e.g., coatings, adhesives, consumer products, vegetation). If the VOC species mix in and around NYC is changing, it has implications for the reactivity of the evolving VOC composition in the formation of ground-level ozone and organic carbon $PM_{2.5}$.

Potential questions to address include:

- Do field measurements and/or fuel-based estimates of NOx emissions in the NYC region reasonably agree with estimates from MOVES used in air quality modeling?
- If transportation VOC emissions have significantly declined, are the other non-energy VOC sources adequately quantified in emission inventories used for air quality planning?
- Can current mobile source inventory models such as MOVES adequately capture prospective pollution changes from transitioning the mobile source fleet in the NYC region to electric and alternative-fueled vehicles?

Recommendation 5: Better quantify the temporal profile and quantity of NOx emissions in the NYC region, especially on high-electric demand days during the summer, that also establishes a baseline for evaluating impacts of future changes in electric generation in New York State and adjacent areas.

Even when current emission inventories may reasonably quantify the magnitude of air pollutant emissions in the NYC region, the temporal profile of those emissions, if not also appropriately captured, can have implications for air quality and energy policy. Inadequate temporal profiles of NOx emissions in regulatory air quality models, for example, can affect the perceived effectiveness of NOx versus VOC controls at reducing ground-level ozone.

Furthermore, as energy transitions occur in the NYC area, such as potential shifts to more local-scale microgrids and increased time-of-day demand periods for electric vehicle (EV) recharging, a baseline is needed to evaluate how these future energy-related shifts may affect air quality. These changes can have profound benefits in the region by shifting generation away for relatively dirtier fossil fuels, like residual oil, but may also have potential costs as more disbursed sources and changes in the timing of emission peaks to serve shifting demand can increase pollutant exposures in local populations, even if the new source is cleaner relative to a displaced pollution source that may have been much farther away.

Areas to investigate can include:

- Do time-resolved remote-sensing measurements of NOx and aerosol profiles in the NYC region during periods of high electric demand (e.g., hot summer days with high a/c load) agree with air quality model profiles? This will also inform air quality and energy planners on whether distributed diesel generation, a potentially high polluting source sector operating only over short periods to meet peak electric demand, is a significant public health concern in the NYC region.

- Can measurements of temporal pollutant profiles in the NYC region provide a baseline to inform assessments of the potential health benefits and costs in shifting to a more distributed generation system that fosters cleaner generation technologies but in closer proximity to population centers?
- Can measurements of temporal pollutant profiles in the NYC region provide a baseline to inform assessments of potential health benefits and costs of increased EV recharging in the NYC region in the event the region's electric demand profile changes over time to support EV recharging patterns?

Recommendation 6: Develop a better understanding of the historical trend in atmospheric formaldehyde concentrations.

New York City and State monitoring indicates that while many pollutants of concern have been decreasing over time as a result of pollution control programs and shifts in energy use, one important air toxic, formaldehyde, appears to be increasing. The reasons for this trend are not fully understood. One possible explanation related to energy trends is a postulated increase in secondary formation of formaldehyde as a by-product of increased natural gas and biofuel combustion. An alternative explanation (or in addition to) is that secondary formaldehyde formation in the atmosphere has become more rapid in recent years as a result of NOx reduction programs. Formaldehyde can also be a useful indicator species in conjunction with NOx for assessing the relative effectiveness of NOx versus VOC control measures, and in evaluating changes in atmospheric chemistry over time as a result of pollution control programs. Research questions to address include:

- Why have formaldehyde concentrations increased in the New York City region while many other air pollutants are decreasing?
- Do measured trends in formaldehyde concentrations relative to NOx levels provide information to air quality planners on the effectiveness of past pollution control programs, and give an indication of their future effectiveness?
- Will increased natural gas combustion in distributed generation systems (e.g., microgrids) in the NYC region have implications for public exposure to formaldehyde?

3) Complementary urban and regional measurements to further support infusion of current and future satellite measurements

Capabilities of remote sensing observations relevant to air quality have progressed significantly since the ICARTT 2004 study. For example, daily measurements by the Ozone Monitoring Instrument (OMI) since its 2004 launch on NASA's Aura satellite have been used to show regional changes in NO_2 emissions (e.g., Tong et al., 2015; de Foy et al., 2016). Passive remote sensing observations from satellites and aircraft can provide broad spatial coverage, but it is challenging to infer near-surface concentrations of pollutants from them because the measurements are sensitive to integrated atmospheric column amounts. The DISCOVER-AQ mission (NASA, 2013) included field campaigns in four different air quality environments in the U.S. to improve capability for inferring air quality from satellite measurements. The campaigns included airborne measurements of in-situ vertical profiles, airborne mapping of remote sensing column amounts, and surface measurements of in-situ concentrations and remote-sensing columns at multiple times per day. This measurement approach along with high-resolution air

quality modeling has shown the value of such integrated observations for interpreting the 4-D evolution of air quality at urban and regional scales (e.g., Goldberg et al., 2014).

An emphasis of DISCOVER-AQ was preparing for upcoming satellite air quality measurements, including geostationary observations from the Tropospheric Emissions: Monitoring of POllution (TEMPO) instrument over North America (Chance et al., 2013), the Geostationary Environmental Monitoring Spectrometer (GEMS) over East Asia (Kim, 2012), and the Sentinel-4 mission over Europe (Ingmann et al., 2012). These missions will all provide hourly measurements of tropospheric column nitrogen dioxide, formaldehyde, ozone, and aerosol optical depth at spatial resolutions on the order of 7 km. In addition, the recently launched follow-on to OMI, TROPOspheric Monitoring Instrument (TROPOMI), will continue the OMI daily global data record at a 7 km spatial resolution, which is approximately 10x finer than OMI. The high spatial resolution of these measurements and the hourly revisit from the geostationary observations are anticipated to enable watershed advances in air quality management. Truly realizing such advances will require integrating the new observations with traditional air quality monitoring networks, research-grade monitoring instruments, and high-resolution air quality models. DISCOVER-AQ is a prototype for such integration.

An integrated strategy similar to that used in DISCOVER-AQ has recently been used in smaller campaigns focused narrowly on specific air quality issues, including the 2017 Lake Michigan Ozone Study in the Chicago-Zion-Sheboygan area, the 2017 NASA Student Airborne Research Program (SARP) in Los Angeles, and the 2017 Ozone Water-Land Environmental Transition Study (OWLETS). These studies included airborne mapping measurements by the Geostationary Trace gas and Aerosol Sensor Optimization (GeoTASO) instrument (Nowlan et al., 2016), in-situ vertical profiles of NO_2 and O_3 (and HCHO when possible), and ground based column measurements of O_3, NO_2, and HCHO from Pandora spectrometers. GeoTASO and a sister instrument called the GEO-CAPE Airborne Simulator (GCAS) were developed as test beds for the geostationary instruments. GCAS was a core component of DISCOVER-AQ and previous GeoTASO campaigns in the U.S. have been conducted over Los Angeles, Texas, Colorado, and Lake Michigan. Pandora was developed as a validation instrument for OMI measurements and in partnership with US EPA and the European Space Agency (ESA) is now emerging as a routine continuous column measurement for air quality monitoring and satellite validation within the U.S. and Europe (Herman et al., 2009). OWLETS also included Pandora and limited airborne measurements, but primarily featured ground-based tropospheric ozone lidar measurements at two near-coastal sites (one over water and one over land) to attempt to capture details in the temporal evolution and vertical structure of ozone plumes in a land-water interface region of the lower Chesapeake Bay. These ozone lidars were developed by NASA and its partners through the Tropospheric Ozone Lidar Network (TOLNet) activity (Newchurch et al., 2016).

NASA is considering deployment of some or all of these measurement assets as part of collaborative integrated air quality studies in the vicinity of Long Island Sound and the northeast transport corridor, e.g., Washington-Baltimore-Philadelphia-New York. As in previous campaigns, the remote sensing measurements would provide unique perspectives to the science including above-ground pollutant concentrations, regional transport, and diurnal variation. The NYC/Long Island region provides a robust test case for satellite observations due to its complex emissions profile (temporally and spatially) and the higher land/sea spatial resolution challenge within the relatively narrow and confined Long Island Sound. The partner measurements of

ozone, nitrogen dioxide, and formaldehyde vertical profiles and partner high-resolution meteorological and chemical modeling will provide valuable information for developing more refined retrieval algorithms for TEMPO and companion missions. Occurring in summer 2018, the campaign would also provide a timely early-validation opportunity for TROPOMI measurements. Ultimately, the integrated strategy strengthens the science. The remote sensing measurements will directly contribute to addressing Recommendations 3-6 of Research Activity 2 in this document. Results of the study will provide regional air planners with a better current understanding of ozone formation sensitivity in the NYC region to VOC and NOx emissions. Comparison to other urban areas where land/water interactions play a role in pollution transformation and transport (e.g., Lake Michigan, Chesapeake Bay, Houston Ship Channel/Gulf of Mexico) may help identify common or unique features among these regions that could be important in analyzing future satellite measurements.

4) Influence of wildfires on air quality in NYC region under a changing climate

Using co-located observations of particulate matter and the National Weather Service Hazard Mapping System smoke data, Brey and Fischer (2016) estimated 10-20% of days in the Northeast Corridor with 8-hour ozone concentrations above 75 ppb also had smoke present, with a similar proportion for the more recent 70 ppb ozone air quality standard. Studies of smoke plumes from forest fires in Quebec found influences on ozone and aerosol levels in the Northeast (Colarco et al., 2004; DeBell et al., 2004; Kang et al., 2014). Dreessen et al. (2016) analyzed a June 2015 event in Maryland where a wildfire plume originating in Saskatchewan influenced ozone and aerosol levels in the Mid-Atlantic region, including contributing to exceedances of the 70 ppb national ozone air quality standard. They noted that "wildfire smoke may be an increasing fractional contribution to high O_3 days, particularly in light of increased wildfire frequency in a changing climate, lower regional emissions, and tighter air quality standards." During late May 2016, surface ozone monitoring sites in and around the NYC region saw large ozone enhancements that were not consistent with typical meteorological conditions conducive to ozone formation within the region. Figure 3 shows the significant difference in ozone between the air quality forecast for May 25, 2016 (left side) and the measured concentrations in that day (right side). A number of Northeast states (CT, MA, NJ, RI) analyzed several high ozone days during this period as "exceptional events" according to guidance from the U.S. EPA to exclude their monitored ozone data from determinations of compliance with ozone air quality standards. The technical support documentation for the "exceptional events" determination indicated a strong influence from a large wildfire plume originating in the Fort McMurray, Alberta area.

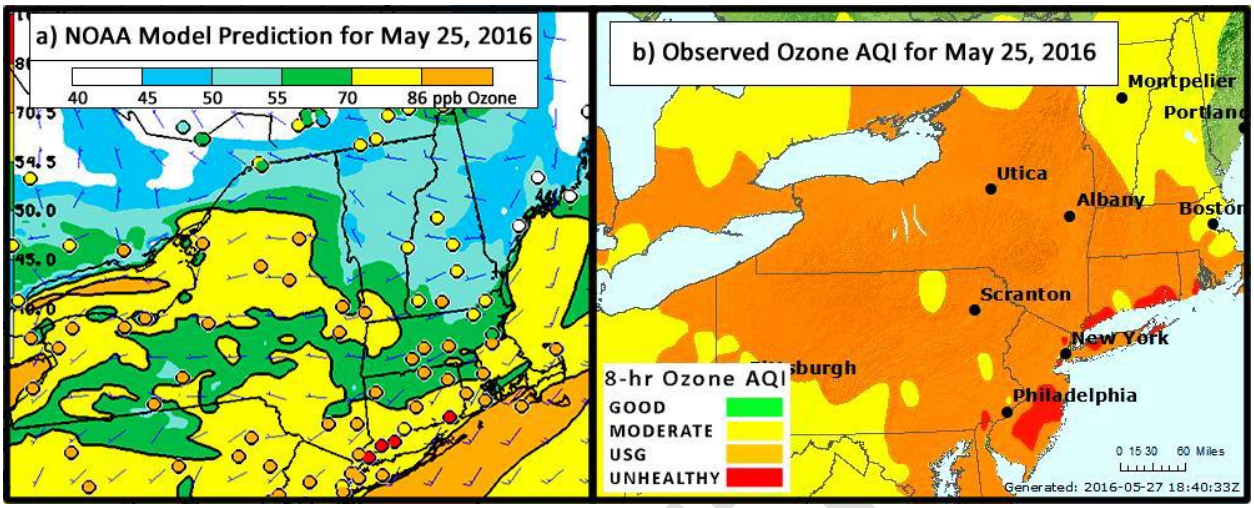

Figure 3. NOAA model forecasted AQI values for May 25th, 2016 (a) and the observed ozone AQI values (b). Figure 1a shows the early morning forecast (isopleths) for the day of May 25th including wind fields and actual observed ozone AQI levels at monitoring sites (circles) in the northeast. Figure 1b shows the extent of the observed ozone levels. Note that Figure 1a color scheme for monitors match the color scheme in figure 1b. (Figure taken from CT DEEP, May 2016 Ozone Exceptional Event Analysis, Technical Support Document, Draft for Public Review, April 2017.)

The interactions of wildfire plumes with urban pollution are complex (McKeen et al., 2002, Bein et al., 2008, Jaffe and Wigder, 2012). With observations and predictions of more frequent and larger wildfires in North America under increasingly dry conditions (Westerling et al., 2006, Moritz et al., 2012), it is important to gain a better understanding of how wildfire smoke influences air quality in the Northeast, and how current or future regional and local pollution control measures may mitigate the air quality impacts.

References

Bein, K.J., Yongjing, Z., Johnston, M.V., and Wexler, A.S. (2008), Interactions between boreal wildfire and urban emissions, J. Geophys. Res., 113, D07304, doi:10.1029/2007JD008910.

Brey, S.J. and Fischer, E.V. (2016), Smoke in the City: How Often and Where Does Smoke Impact Summertime Ozone in the United States?, Environmental Science and Technology, 50, 1288-1294, doi:10.1021/acs.est.5b05218.

Chance, K., Liu, X., Suleiman, R. M., Flittner, D. E., Al-Saadi, J., and Janz, S. J. (2013), Tropospheric emissions: monitoring of pollution (TEMPO), Proc. SPIE 8866, Earth Observing Systems XVIII, 8866, 88660D-1–88660D-16, doi:10.1117/12.2024479.

Colarco, P.R., Shoeberl, M.R., Doddridge, B.G., Marufu, L.T., Torres, O., and Welton, E.J. (2004), Transport of smoke from Canadian forest fires to the surface near Washington, D.C.: Injection height, entrainment, and optical properties, J. Geophys. Res., 109, D06203, doi:10.1029/2003JD004248.

De Foy, B., Lu, Z., and Streets, D.G. (2016), Impacts of control strategies, the Great Recession and weekday variations on NO_2 columns above North American cities, Atmos. Envt., 138, 74-86, doi:10.1016/j.atmosenv.2016.04.038.

DeBell, L.J. et al. (2004), A major regional air pollution event in the northeastern United States caused by extensive forest fires in Quebec, Canada, J. Geophys. Res., 109, D19305, doi:10.1029/2004JD004840.

Dreessen, J., Sullivan, J. and Delgado, R. (2016), Observations and impacts of transported Canadian wildfire smoke on ozone and aerosol air quality in the Maryland region on June 9–12, 2015, J. Air & Waste Assn., 66, 842-862, doi:10.1080/10962247.2016.1161674.

Fehsenfeld, F. C., et al. (2006), International Consortium for Atmospheric Research on Transport and Transformation (ICARTT): North America to Europe—Overview of the 2004 summer field study, J. Geophys. Res., 111, D23S01, doi:10.1029/2006JD007829.

Goldberg, D.L, Loughner, C.P., Tzortziou, M., Stehr, J., Pickering, K.E., Marufu, L.T., and Dickerson, R.R. (2014), Higher surface ozone concentrations over the Chesapeake Bay than over the adjacent land: Observations and models from the DISCOVER-AQ and CBODAQ campaigns, Atmos. Env., 84, 9-19, doi:10.1016/j.atmosenv.2013.11.008.

Hermann, J., A. Cede, E. Spinei, G., Mount, M. Tzortziou, and N. Abuhassan (2009), NO_2 column amounts from ground-based Pandora and MFDOAS spectrometers using the direct-sun DOAS technique: Intercomparisons and application to OMI validation, J. Geophys. Res., 114, D13307, doi:10.1029/2009JD011848.

Ingmann, P., Veihelmann B., Langen, J., Lamarre, D., Stark, H., and Courrèges-Lacoste, G.B. (2012), Requirements for the GMES Atmosphere Service and ESA's implementation concept: Sentinels-4/-5 and -5p, Rem. Sens. Env., 120, 58-69, doi:10.1016/j.rse.2012.01.023.

Jaffe, D.A. and Wigder, N.L. (2012), Ozone production from wildfires: A critical review, Atmos. Envt., 51, 1-10, doi:10.1016/j.atmosenv.2011.11.063.

Kang, C.-M., Gold, D., and Koutrakis, P. (2014), Downwind O_3 and $PM_{2.5}$ speciation during the wildfires in 2002 and 2010, Atmos. Envt., 95, 511-519, doi:10.1016/j.atmosenv.2014.07.008.

Kim, J. (2012), GEMS (Geostationary Environment Monitoring Spectrometer) onboard the GeoKOMPSAT to Monitor Air Quality in high Temporal and Spatial Resolution over Asia-Pacific Region, in: EGU General Assembly Conference Abstracts, edited by: Abbasi, A. and Giesen, N., Vol. 14, EGU General Assembly Conference Abstracts, 22–27 April 2012, Vienna, Austria, 4051.

Lee, S.-H., et al. (2011), Modeling ozone plumes observed downwind of New York City over the North Atlantic Ocean during the ICARTT field campaign, Atmospheric Chemistry and Physics, 11(15), 7375-7397, doi:10.5194/acp-11-7375-2011.

McKeen, S.A., et al. (2002), Ozone production from Canadian wildfires during June and July of 1995, J. Geophys. Res., 107, D14, 4192, doi:10.1029/2001JD000697.

Moritz, M.A., Parisien, M.-A., Batllori, E., Krawchuk, M.A., Van Dorn, J., Ganz, D.J., and Hayhoe, K. (2012), Climate change and disruptions to global fire activity, Ecosphere, 3(6):49, doi: 10.1890/ES11-00345.1.

NASA (2012), DISCOVER-AQ Science Objectives, https://www.nasa.gov/mission_pages/discover-aq/science/index.html (accessed October 27, 2017).

Newchurch, M.J., et al. (2016), TOLNet – A Tropospheric Ozone Lidar Profiling Network for Satellite Continuity and Process Studies, EPJ Web of Conferences 119, 20001, doi:10.1051/epjconf/201611920001.

Nowlan, C.R., et al. (2016), Nitrogen dioxide observations from the Geostationary Trace gas and Aerosol Sensor Optimization (GeoTASO) airborne instrument: Retrieval algorithm and measurements during DISCOVER-AQ Texas 2013, Atmos. Meas. Tech., 9, 2647-2668, doi:10.5194/amt-9-2647-2016.

Tong, D.Q., et al. (2015), Long-term NOx trends over large cities in the United States during the great recession: Comparison of satellite retrievals, ground observations, and emission inventories, Atmos. Envt., 107, 70-84, doi:10.1016/j.atmosenv.2015.01.035.

Warneke, C., et al. (2006), Biomass burning and anthropogenic sources of CO over New England in the summer 2004, J. Geophys. Res., 111, D23S15, doi:10.1029/2005JD006878.

Warneke, C., et al. (2016), Instrumentation and measurement strategy for the NOAA SENEX aircraft campaign as part of the Southeast Atmosphere Study 2013, Atmos. Meas. Tech. Discuss., 9, 3063–3093, doi:10.5194/amt-9-3063-2016.

Westerling, A.L., Hidalgo, H.G., Cayan, D.R., and Swetnam, T.W. (2006), Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity, Science, 313, 940-943, doi:10.1126/science.1128834.