New York – Community-Scale Heath Air Pollution Policy Assessment (NY-CHAPPA) Tool

Model Formulation Document

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Preface

This document describes the formulation of the New York Community-Scale Health and Air Pollution Policy Analysis (NY-CHAPPA) tool, including the various input datasets, model formulation, and references to various processing steps that were implemented during the model development.

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1. Introduction

The goal of the New York Community-Scale Health and Air Pollution Policy Analysis (NY-CHAPPA) tool is to estimate potential changes in concentrations of total fine particulate matter ($PM_{2.5}$) across New York State resulting from changes in emissions, with sufficient geographic detail to provide community-scale results. Changes in annual average $PM_{2.5}$ concentrations resulting from policy scenarios, such as from proposed energy and environmental policies in New York State, can be estimated relative to a base case for each census tract. Health impacts are then estimated for the corresponding changes in concentrations, presented as changes in cases of specific health outcomes and the monetized societal value of these concentration changes. A study evaluating NY-CHAPPA v1.0 was undertaken and is available at https://doi.org/10.26434/chemrxiv-2025-8sbv8.

NY-CHAPPA and related materials are accessible at https://treehug-app.its.unc.edu/chappa/.

This document describes the model design and formulation as of the current version, 2.0, which is appropriate for current analyses. Note that NY-CHAPPA v1.0 has been maintained as an archived but operational model to support the above evaluation study.

The primary difference between NY-CHAPPA v1.0 and NY-CHAPPA v2.0 is that v1.0 uses 2010 census shapes for modeling and receptor placement while v2.0 uses 2020 census tract[1] and census block group[2] boundaries. The change in census shapes leads to differences in both geometry and counts of sources and receptors between the two versions. In total, NY-CHAPPA v2.0 uses 7,282 area source modeling shapes. These modeling shapes include 4,483 single shape census tracts; 21 shapes from multi-part census tracts; 2,761 single shape block groups; and 17 shapes from multi-part block groups.

In addition to the different census data, there are two additional subtle distinctions between NY-CHAPPA v1.0 and NY-CHAPPA v2.0, discussed below.

1. *Population data:* The population datasets are different between NY-CHAPPA v1.0 vs. NY-CHAPPA v2.0. Population estimates by age group for NY-CHAPPA v2.0 were developed for each of the analysis years for all counties in New York State. County-level population data for 2021 was from the U.S. Census Bureau.[3] The Pathways Analysis in the 2025 State Energy Plan assumes total statewide population in 2040 remained flat at 2021 levels, but estimates population shifts within the state based on the most recent available county level projection data from Cornell University's County Projects

[1] U.S. Census Bureau, "cb_2020_36_tract_500k", Cartographic Boundary file for census tract, Cartographic Boundary Files, 2020, https://www.census.gov/geographies/mapping-files/time-series/geo/cartographic-boundary.2020.html, accessed on September 10, 2024.

[2] U.S. Census Bureau, "cb_2020_36_bg_500k", Cartographic Boundary file for census block group, Cartographic Boundary Files, 2020, https://www.census.gov/geographies/mapping-files/time-series/geo/cartographic-boundary.2020.html, accessed on September 10, 2024.

[3] U.S. Census Bureau. County Population Totals and Components of Change: 2020-2024. https://www.census.gov/data/tables/time-series/demo/popest/2020s-counties-total.html#v2023

Explorer.[4] An annual growth rate by county was derived based on the change between the 2021 population data and the 2040 population projections and used to estimate the county level population for each health analysis year.

2. *Tier-based Reporting:* NY-CHAPPA v2.0 can output estimates of total $PM_{2.5}$ concentrations by tier. These values are calculated from the individual precursors concentration from sources assigned to each tier. Due to the interactions between precursors when calculating total $PM_{2.5}$, the by-tier estimates won't sum to match the total census tract-level $PM_{2.5}$ concentration, which considers contributions from all sources before calculating total $PM_{2.5}$. Hence, while the by-tier reports represent a good approximation for the contribution from individual source categories, they should be interpreted with caution.

2. Model Framework

2.1. Overview of the Integrated Models

NY-CHAPPA is a modeling framework that builds on the ZIP Code Air Pollution Policy Assessment (ZAPPA) tool[5] previously developed for New York City. NY-CHAPPA integrates two models — the University of North Carolina at Chapel Hill (UNC)'s Community Air Quality Tools (C-TOOLS)[6] and the U.S. Environmental Protection Agency's (EPA's) CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA).[7]

C-TOOLS projects concentrations of the primary pollutants nitrogen oxides (NO_x), ammonia (NH_3), $PM_{2.5}$, sulfur dioxide (SO_2), and volatile organic compounds (VOCs) that are directly emitted at fine spatial scales in the near-source environment. The air dispersion calculations in C-TOOLS are based on scientifically robust formulations similar to those in regulatory models, but efficiencies are derived from specification of representative meteorological conditions as inputs. Specifically, C-TOOLS has individual algorithms for modeling emissions sources as lines (on-road), point (large stationary) and area (diffuse near surface for all sources except aircraft sources during landing and takeoff cycles which are treated at three different elevations) that

[4] Cornell University. 2018. County Projections Explorer. Ithaca, New York: Cornell Program on Applied Demographics. https://pad.human.cornell.edu/counties/projections.cfm.

[5] Shukla, K., C. Seppanen, B. Naess, C. Chang, D. Cooley, A. Maier, F. Divita, M. Pitiranggon, S. Johnson, K. Ito, S. Arunachalam, (2022). ZIP code-level estimation of air quality and health risk due to particulate matter pollution in New York City, *Env. Sci & Technol*. 2022, 56, 11, 7119–7130, DOI: 10.1021/acs.est.1c07325

[6] https://www.cmascenter.org/c-tools/

[7] https://www.epa.gov/cobra

have been evaluated and applied for multiple applications (Barzyk et al, 2015[8], Isakov et al, 2017[9]; Sorte et al, 2019[10]; Shukla et al, 2022[5]).

The COBRA screening model evaluates how changes in air pollutant emissions and ensuing concentrations result in changes in public health impacts and estimates the economic value of the those impacts. However, in this application, COBRA is used to obtain the transported components of $PM_{2.5}$ from outside the modeling domain into the study domain, and to use the combined change in $PM_{2.5}$ concentrations at the census tract scale to quantify changes in public health impacts and the associated monetized benefits.

ZAPPA integrated C-TOOLS and COBRA through a single web-based interface to assess changes in emissions at a ZIP-code resolution in New York City. NY-CHAPPA was developed by leveraging the approach used by ZAPPA with two distinct advancements:

- Expanding the model area from New York City (NYC) to New York State; and
- Refining the spatial resolution from ZIP code-scale to a highly resolved census tract-scale.

The NY-CHAPPA web interface allows users to upload custom emissions scenarios for a range of years throughout New York State and run a model simulation. The model results are census tract-level changes in $PM_{2.5}$ concentrations, physical health impacts, and monetized societal values associated with the health impacts. In addition to tract-level results, scenario results are available as summary reports that are aggregated by reporting region. The results are available through the web-based interface as text files that users can download and analyze offline.

Note that while NY-CHAPPA evaluates direct emissions of various pollutants as precursors to the formation of $PM_{2.5}$, it only quantifies health impacts due to changes in $PM_{2.5}$ concentrations.

2.2. Input Data

NY-CHAPPA uses the following inputs, which are described in further detail below:

- Meteorological data: Representative hourly meteorological data for a single year (2016).
- Emissions data: Emissions data for base and policy scenarios as point, area and line sources for the different source types. NY-CHAPPA is configured to model changes in emissions for six different years – 2025, 2030, 2035, 2040, 2045 and 2050.
- Population data: Census tract-scale estimates of population from the U.S. Census for each of the six years above.

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[8] Barzyk, T.M., V. Isakov, S. Arunachalam, A. Venkatram, R. Cook, B. Naess (2015). A Near-Road Modeling System for Community-Scale Assessments of Mobile-Source Air Toxics: The Community Line Source (C-LINE) Modeling System, *Environ. Model. Software,* 66:46-56.

[9] Isakov, V., T. Barzyk, E. Smith, S. Arunachalam, B. Naess and A. Venkatram (2017). A Web-based Modeling System for Near-Port Air Quality Assessments, *Environ. Model. Software*, 98:21-34

[10] Sorte, S., S. Arunachalam, B. Naess, C. Seppanen, V. Rodrigues, A. Valencia, C. Borrego, A. Monteiro (2019), Assessment of source contribution to air quality in an urban area close to a harbor: case-study in Porto, Portugal, *Sci. Total Environ,* 662, 347 – 360.

- Health incidence data: Census tract-scale incidence estimates for various health end points including premature mortality and various morbidity conditions.

The meteorological, population, and health incidence data are built into NY-CHAPPA, and users have the option to upload their own emissions data or use the built-in base emissions. Additional information about these inputs is provided in the sections below.

2.3. Model Regions

Emissions sources are modeled for each of eight regions in the state, shown in Figure 1 and listed in Table 1. Local dispersion is calculated separately within each region and then aggregated along with inter-region and out-of-state transport. These eight regions are based on the ten economic regions originally developed for the New York State Regional Economic Development Councils (REDC),[11] but with the following two changes:

- Combine the Western New York and Finger Lakes regions into one region; and
- Combine New York City and Long Island regions along with Rockland and Westchester counties from the Mid-Hudson region to create a new NYC – Long Island – Lower Hudson region.

Combining these regions avoids having urban areas (e.g., NYC or Buffalo) right on the edge of regions or dissecting urban areas and thus avoids boundary issues in the dispersion modeling.

The regions are aggregated counties; a list of counties in each region is provided in Appendix A. $PM_{2.5}$ concentrations from emissions sources within the region are calculated at the census tract scale by C-TOOLS for a set of receptors also within the region. $PM_{2.5}$ concentration contributions from emissions outside of the region are also estimated using COBRA (see Regional Transport Section). Note that while sources are grouped into eight regions for dispersion modeling, the outputs are provided for each of the original 10 regions as defined by REDC. Appendix A also lists the counties in the 10 output regions.

[11] https://www.osc.ny.gov/files/local-government/publications/pdf/osc-economic-regions.pdf

Figure 1. New York State Model Regions Used in NY-CHAPPA.

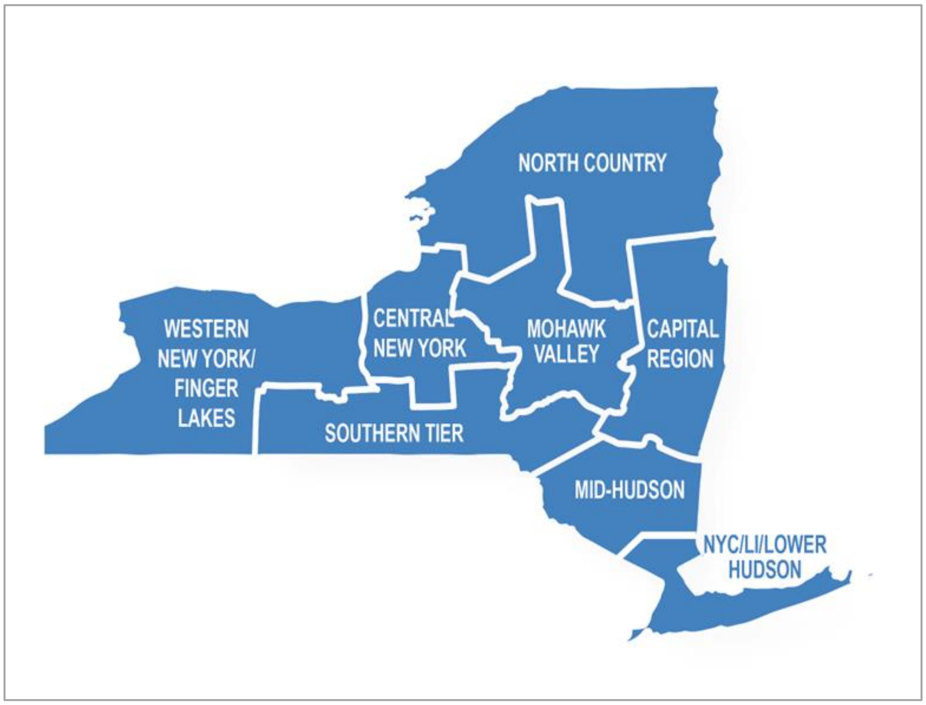

Table 1. Number of Sources and Receptors by NY-CHAPPA Model Region.

NY-CHAPPA Model Region	Counties	Census Tracts	Receptors / Area Sources	Point Sources	Road Sources
Albany / Capital Region	8	282	492	28	44,493
Buffalo / Western NY	14	675	1,159	52	87,870
Mid-Hudson	5	248	549	9	44,702
Ithaca	8	171	426	12	42,673
Mohawk	6	149	326	6	33,017
North Country	7	111	382	12	31,096
NYC / Long Island / Lower Hudson	9	3,058	3,235	70	116,038
Syracuse / Southern Tier	5	217	365	16	30,880

3. Emissions Inputs

NY-CHAPPA emissions input include three source types:

1. **Point sources** are emissions at a given location with specified stack parameters.
2. **Road sources** are line segments with emissions estimates from vehicles driving on the segment.
3. **Area sources** encompass all other types of emissions and are defined at the census tract or census block group level.

To estimate total $PM_{2.5}$ concentrations, emissions in units of tons per year are required for the following pollutants: NH_3, NO_x, primary $PM_{2.5}$, SO_2, and VOCs.

All inputs to CHAPPA are text-based files in comma-separated values (CSV) format. Users of the NY-CHAPPA web tool start by downloading the baseline case emissions as CSV files.[12] Users can then edit those files to adjust the emissions based on their policy scenario. Next, users upload their policy scenario emissions to create a new CHAPPA model run. If users don't need to modify a particular type of source (area, road, or point), they can choose to use the built-in base emissions for their model run, which match the base case data available for download. The built-in base emissions should be considered as sample inputs and users of NY-CHAPPA are recommended to use appropriate data for their study.

All source and receptor geometries discussed below are provided to the dispersion model using the UTM zone 18N projection with WGS 84 datum.

3.1. Point Sources

Point sources refer to large emissions sources (such as power plants or permitted industrial exhaust stacks) that have a defined specific location and stack parameters including stack height, stack diameter, exit temperature, and exhaust velocity. The following sectors are modeled as point sources: fuel combustion – electric utility and fuel combustion – industrial.

Point source locations are pre-defined in the model and new sources cannot be added through input files. Point sources must match the predefined list of point sources included in NY-CHAPPA, developed using permitting and other data for large industrial and electricity generation sources and other sectors defined above in New York State. Users can determine emission rates and stack parameters in the input files[12]. Users are referred to the base point source input file provided on the NY-CHAPPA website for reference. Point sources emissions are matched to the master list based on coordinates (longitude and latitude) and FIPS code. Adding point sources not on the pre-defined list is not currently supported in NY-CHAPPA.

Table 2 specifies the input data requirements for point source emissions.

Table 2. Point Source Input File Format.

Name	Description	Units	Type	Example
longitude	Longitude	degrees	Numeric	-73.874283
latitude	Latitude	degrees	Numeric	42.583249
fips	FIPS code (used to assign source to a region)	n/a	5-digit string	36001
stkhgt	Stack height	feet	Numeric > 0	54.3684
stkdiam	Stack diameter	feet	Numeric > 0	21.0714
stktemp	Stack temperature	degrees F	Numeric > 0	186.3300
stkflow	Stack flow (only used if stack velocity isn't provided)	cubic feet/second	Numeric > 0, can be blank if stack velocity is provided	
stkvel	Stack velocity	feet/second	Numeric > 0, can be blank if stack flow is provided	19.5200

[12] https://treehug-app.its.unc.edu/ny_chappa_v1/reference_input

Name	Description	Units	Type	Example
tier1	Tier 1 code	n/a	Integer, must be either 1 or 2	2
tier2	Tier 2 code	n/a	Integer, can be blank	
tier3	Tier 3 code	n/a	Integer, can be blank	
nh3	Annual NH_3 emissions	tons/year	Numeric >= 0	0.00000000
nox	Annual NO_x emissions	tons/year	Numeric >= 0	0.39520161
pm25	Annual $PM_{2.5}$ emissions	tons/year	Numeric >= 0	0.03436395
so2	Annual SO_2 emissions	tons/year	Numeric >= 0	0.00236898
voc	Annual VOC emissions	tons/year	Numeric >= 0	0.02173383

Before point source emissions can be dispersed, they are processed by C-TOOLS using the following sequence of steps:

1. Delete sources where all emissions are zero.
2. Calculate secondary organic aerosol (SOA) estimates from VOC emissions, using fixed conversion factors consistent with those used in COBRA. See more on this below.
3. Calculate stack velocity from stack flow and diameter if not provided.
4. Convert stack parameters to have units of meters and Kelvin.
5. Define model region based on FIPS code.
6. Match emission sources to list of model point sources; matching is done based on source coordinate and FIPS code. The master list of point sources contains the source's location in modeling coordinates and the assigned meteorological station.
7. Output precursor pollutant emissions for each New York State region in C-TOOLS point source emissions format. This format is a CSV file with the following columns: id, x, y, sf_id, stkhgt_m, stkdiam_m, stktemp_K, stkvel_ms, nox, nh3, pm25, soa, so2. The columns id (unique identifier for each source), x (longitude), y (latitude), and sf_id (meteorological station identifier) are determined in Step 6. Emissions are given in tons/year.

We estimate the formation of SOA using a fixed relationship between SOA and VOC for each Tier 3 emission category, as implemented in COBRA. EPA's 2016v1 platform[13] estimated VOC but did not estimate SOA, so COBRA developed a simple approach to estimate the conversion of VOC to SOA, though this conversion depends on several factors including meteorology and the type of VOC, not captured by the approach used here. COBRA used the 2010 base case inventory of SOA and VOC emissions generated for the Clear Skies Act (CSA) of 2003.[14] For each Tier 3 emission category in this inventory, COBRA provided the ratio of SOA to VOC. There is a total of 268 VOC-to-SOA factors for all emissions sectors, which are taken from the

[13] https://www.epa.gov/air-emissions-modeling/2016v1-platform

[14] U.S. EPA, 2003. Technical Support Document for the Clear Skies Act 2003 Air Quality Modeling Analyses. Research Triangle Park, NC: Office of Air Quality Planning and Standards, Emissions Analysis and Monitoring Division.

COBRA model (version 4).[15] Each combination of Tier 1, Tier 2, and Tier 3 codes has a VOC-to-SOA factor. We then used these Tier 3 category-specific ratios to estimate SOA in the emissions inventory from the 2016v1 platform for use in NY-CHAPPA:

$$SOA_{2016v1,Tier3} = VOC_{2016v1,Tier3} \times \left(\frac{SOA_{CSA,Tier3}}{VOC_{CSA,Tier3}}\right) \quad (1)$$

The C-TOOLS dispersion model is run in point mode (and thus uses the point source dispersion algorithm), using the processed emissions input files described above (see Local Dispersion section). C-TOOLS is run separately for each precursor pollutant and the outputs are annual average precursor pollutant concentrations in μg/m^3 at each receptor from local sources only.

3.2. On-Road Sources

On-road sources in NY-CHAPPA are represented in two categories: major roadways represented as line sources in a roadway network, and smaller roadways represented as area sources.

3.2.1 Development of the Major Roadway Network

The statewide major roadway network used in NY-CHAPPA is predefined, and new major roadways cannot be directly added by users. The network is based on a subset of the road network used in the latest version of the Community Line source (C-LINE) model[16] which starts with the Highway Performance Monitoring System (HPMS) 2016 dataset.[17] The road network was post-processed to ensure that the HPMS input data were valid. This included a simplification of the geometries using the *Simplify* tool in QGIS to remove vertices to a tolerance of 2 meters and splitting multi-line segments into multiple single segments.

The HPMS dataset was filtered to extract only major roads (function class of 5 or less, emissions from smaller roadways with a functional class of 5 and higher were included as areas sources), and the dataset was cleaned to ensure that each road segment had a function class, was classified as either urban or rural, had a speed limit, and had activity in the form of annual average daily traffic (AADT). For segments that were missing any of these key parameters, nearby similar segments were used to provide estimates. In the case where segments didn't have similar segments nearby, statewide average AADT and speed values by road type were used instead. Each segment is assigned to its containing county based on the midpoint of the road segment, so that the road segments can be split up into the 8 regions modeled by NY-CHAPPA (Table 1).

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[15] U.S. EPA, 2020, User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA) Version 4.0, Prepared for the State and Local Climate and Energy Program, June 2020.

[16] Barzyk, T.M., V. Isakov, S. Arunachalam, A. Venkatram, R. Cook, B. Naess (2015). A Near-Road Modeling System for Community-Scale Assessments of Mobile-Source Air Toxics: The Community Line Source (C-LINE) Modeling System, *Environ. Model. Software,* 66:46-56.

[17] https://www.fhwa.dot.gov/policyinformation/hpms/fieldmanual/hpms_field_manual_dec2016.pdf

Road sources in emissions input files must match the pre-defined system road network, as verified by road_id and FIPS code. The user is referred to the base road source input file provided on the NY-CHAPPA website for reference on the system road network.[12]

3.2.2 Road Source Input Data and Data Preparation

Table 3 specifies the input data requirements for road sources.

Table 3. Road Source Input File Format.

Name	Description	Units	Type	Example
road_id	ID to match to system road network	N/A	Integer	1
start_longitude	Road segment starting longitude	degrees	Numeric	-73.925486
start_latitude	Road segment starting latitude	degrees	Numeric	42.749585
end_longitude	Road segment ending longitude	degrees	Numeric	-73.924415
end_latitude	Road segment ending latitude	degrees	Numeric	42.748948
fips	FIPS code (used to assign segment to a region)	N/A	5-digit string	36001
road_type	Road type (informational only)	N/A	Integer: 2 – 5[a]	4
nh3	Annual NH_3 emissions	tons/year	Numeric >= 0	0.02477286
nox	Annual NO_x emissions	tons/year	Numeric >= 0	0.11832313
pm25	Annual $PM_{2.5}$ emissions	tons/year	Numeric >= 0	0.00407769
so2	Annual SO_2 emissions	tons/year	Numeric >= 0	0.00574676
voc_ld[b]	Annual VOC emissions for light duty vehicles	tons/year	Numeric >= 0	0.00917919
voc_hd[b]	Annual VOC emissions for heavy duty vehicles	tons/year	Numeric >= 0	0.00337424

[a] Road types are defined as 2: Rural Restricted Access; 3: Rural Unrestricted Access; 4: Urban Restricted Access; and 5: Urban Unrestricted Access.

[b] VOC emissions are split between light duty and heavy-duty vehicles to allow for calculation of secondary organic aerosol (SOA) (see more on this below).

Road source emissions are processed using the following sequence of steps:

1. Delete sources where all emissions are zero.
2. Calculate SOA from VOC emissions using light duty and heavy-duty conversion factors. We estimate the formation of SOA using a fixed relationship between SOA and VOC for each of these two vehicle types, as implemented in COBRA. The methods are identical to what we described above for point sources in Section 3.1.1.
3. Define model region based on FIPS code.
4. Match sources to master list of road segments; matching is done based on the road_id and FIPS code. The master list of road sources is used to set the source's source-receptor (S-R) matrix ID.
5. Output precursor pollutant emissions for each road segment indexed by the source's S-R matrix ID.

For road sources, the on-road S-R matrix (see Source-receptor Matrix Generation) is used to calculate annual average precursor pollutant concentrations in $\mu g/m^3$ at each receptor.

3.3. Area Sources

Area sources are a collective category of numerous smaller stationary emission sources that are too small to be reported as individual point sources but have a combined impact on air quality. Examples of area sources are commercial and residential buildings, manufacturing facilities, and construction equipment. Consistent with the approach used in the ZAPPA development as described in Shukla et al (2022),[5] NY-CHAPPA modeled the following source sectors as area sources: chemical and allied product manufacturing; fuel combustion – commercial and residential; fuel combustion – electric utility; highway vehicles on local roads, off-highway vehicles; other industrial processes; petroleum storage and transport; solvent utilization; waste disposal and recycling; and miscellaneous other near-surface sources that were not categorized into any of the above.

The tier associated with the emissions for an area source is used to set the modeling height for those emissions. Note that the U.S. EPA, working with the states, develops and reports emissions inventories broken into 14 Tier 1 categories. A complete list of Tier 1, 2, and 3 emissions supported in NY-CHAPPA is available on the NY-CHAPPA portal.[18]

In NY-CHAPPA, area sources were downscaled from regional-scale to census tract-scale, described in Receptors . All area sources are modeled within each tract are modeled using the same geometry, described in the next section.

3.3.1 Area Source Modeling Shapes

For modeling area sources, the geometry of the source is pre-defined and cannot be changed by users. The starting point for NY-CHAPPA's area sources is the geometries of the 5,394 census tracts in New York State (based on 2020 census shapes).[19] For census tracts outside of the five-county New York City area where the area of the census tract is greater than 20 square kilometers, the area sources are modeled using the census block groups inside the census tract. Census tract[20] and block group[21] shapes are based on the US Census shapefiles. There are 919 census tracts in New York State where the area of the tract is greater than 20 sq-km. These tracts contain 2,765 census block groups. Figure 2 below shows the shapes of census tracts or block groups used by NY-CHAPPA.

There are 19 census tract or block groups in New York State that contain multi-part geometries (i.e., they have multiple independent polygons that constitute a single census tract or block group), listed in Table 4. These geometries are split into multiple modeling shapes. Emissions

[18] https://treehug-app.its.unc.edu/chappa/static/web/CHAPPA_emission_tiers.csv

[19] v2.0 was updated to implement 2020 census definitions; NY-CHAPPA previously employed 2010 census definitions.

[20] U.S. Census Bureau, "gz_2010_36_140_00_500k", Generalized Cartographic Boundary file for census tract, TIGER/Line Shapefiles, 2010, https://www2.census.gov/geo/tiger/GENZ2010/, accessed on September 10, 2022.

[21] U.S. Census Bureau, "gz_2010_36_150_00_500k", Generalized Cartographic Boundary file for census block group, TIGER/Line Shapefiles, 2010, https://www2.census.gov/geo/tiger/GENZ2010/, accessed on September 10, 2022.

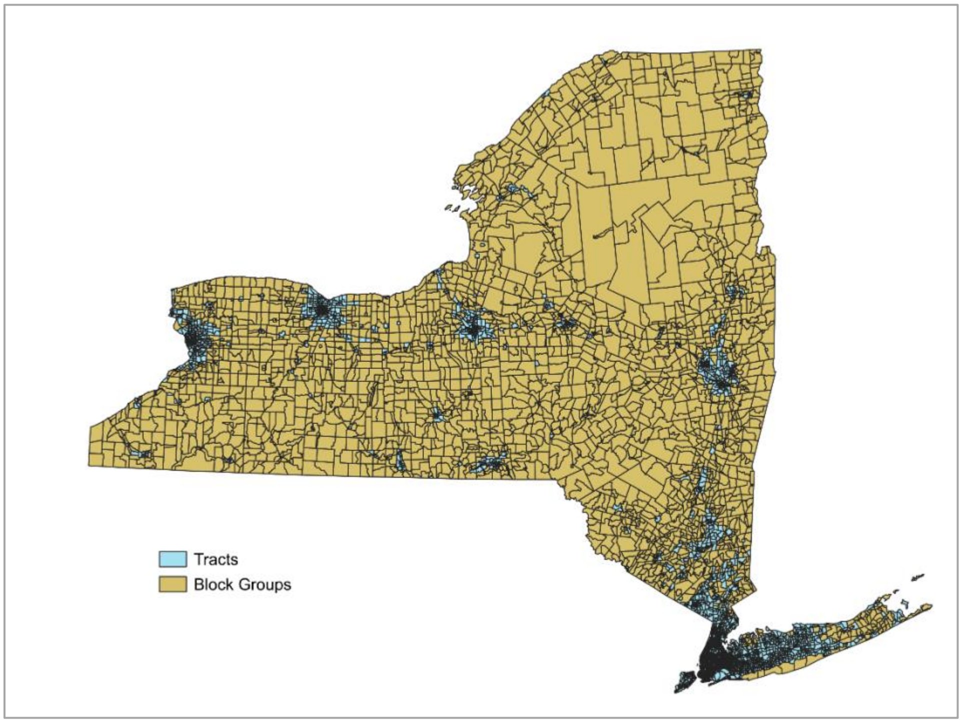
are allocated to each modeling shape based on the area of the shape relative to the overall census tract or block group area.

Table 4. Census Tracts or Block Groups with Multi-part Geometries.

Tract / Block Group ID	Shape Type	# of modeling shapes
36005051600	Census tract	2
36009940000	Census tract	2
360130363002	Block group	2
36029990000	Census tract	4
360450603002	Block group	3
360450603004	Block group	3
360450604005	Block group	3
360459900010	Block group	38
36055990000	Census tract	2
36073990000	Census tract	7
36081099705	Census tract	2
36081990100	Census tract	2
361031350041	Block group	2
361031702023	Block group	2
361031702024	Block group	2
361031907053	Block group	2
361032010011	Block group	4
36103990100	Census tract	3
36117990100	Census tract	10

In total, NY-CHAPPA uses 6,934 area source modeling shapes (see Figure 2). These modeling shapes include 4,087 single shape census tracts; 34 shapes from multi-part census tracts; 2,752 single shape block groups; and 61 shapes from multi-part block groups.

Figure 2. 2020 Census Tracts and Block Groups in New York State Used to Model Area Sources in NY-CHAPPA v2.0.



3.3.2 Area Source Input Data and Data Preparation

Table 5 specifies the input data requirements for area sources.

Table 5. Area Source Input File Format.

Name	Description	Units	Type	Example
geoid	Census tract or block group ID	N/A	11- or 12-digit string	36001000100
tier1	Tier 1 code	N/A	Integer	2
tier2	Tier 2 code	N/A	Integer	1
tier3	Tier 3 code	N/A	Integer	99
nh3	Annual NH_3 emissions	tons/year	Numeric >= 0	0.00072700
nox	Annual NO_x emissions	tons/year	Numeric >= 0	0.24718159
pm25	Annual $PM_{2.5}$ emissions	tons/year	Numeric >= 0	0.10810850
so2	Annual SO_2 emissions	tons/year	Numeric >= 0	1.16766645
voc	Annual VOC emissions	tons/year	Numeric >= 0	0.00363502

Emissions for census tracts larger than 20 square kilometers must be provided at the block group level. NY-CHAPPA doesn't have the ability to allocate user-generated census tract-level emissions for area sources to the block group level for larger census tracts. If a user provides emissions at the block group level but NY-CHAPPA models those block groups at the census tract level, the block group level emissions will be summed to the census tract level as needed.

Both versions of NY-CHAPPA have a refined treatment of aircraft sources to consider elevation of aircraft during landing and takeoff (LTO) activities. Instead of placing all aircraft source emissions at the ground level (which is how they are available and used from the EPA's NEI modeling platform), NY-CHAPPA distributes the emissions at three separate altitudes to better reflect aircraft emissions aloft during LTO. Using emissions estimates of NO_x and CO_2 from the Federal Aviation Administration's Aviation Environmental Design Tool (AEDT)[22] for all airports in New York from a study of 2023 aircraft activity, three altitude bins with corresponding emissions fractions were derived. Emissions from all New York State airports are estimated at 0 meters, 0 to 150 meters, and 150 to 600 meters. Emissions at 0 and 150 meters use the census-based area source shape for all airports. However, for the 150-to-600-meter altitude bin at John F. Kennedy International and La Guardia airports in New York City, custom 11-mile square-shaped polygons centered on the airport location were created at a height of 600 meters to better represent the takeoff and landing emissions associated with those larger airports. For the rest of the airports in New York State, the emissions at the 150 to 600-meter altitude also use the census-based area source shape. The model does not include emissions from cruising altitudes above 600 meters, as is the standard practice for most local-to-regional scale air quality studies.

Area sources in emissions input files must match the predefined census tracts and block groups. The user is referred to the base area source input file provided on the NY-CHAPPA website for reference on the predefined census tracts and block groups.[12]

Area source emissions are processed using the following sequence of steps:

1. Delete sources where all emissions are zero.
2. Calculate SOA from VOC emissions using tier-specific scaling factors provided by COBRA (see more below).
3. Sum emissions by Tier 1 and 2 codes.
4. Define model region based on FIPS code (uses the first 5 digits of the geoid column).
5. Assign modeling height based on Tier 1 code. If no match is found, a height of 0 is used.
6. Match emissions to the master list of area source modeling shapes (mix of census tracts and block groups). The master list of area sources includes factors for splitting emissions for multi-shape tracts and block groups, and is used to set the source's S-R matrix ID.
7. Sum emissions that are provided at the block group level but modeled at the census tract level.
8. Using factors from the master list of modeling shapes, split emissions for multi-shape census tracts and block groups.
9. Output emissions for each area source including S-R matrix ID and modeling height.

We estimate the formation of SOA using a fixed relationship between SOA and VOC for each Tier 3 emission category, as implemented in COBRA. The methods are identical to what we described above for point sources in Section 3.1.1.

For area sources, the area S-R matrix is used to calculate annual average precursor pollutant concentrations in $\mu g/m^3$ at each receptor.

[22] https://aedt.faa.gov/

3.4. Base Case versus Built-in and User-generated Scenarios

NY-CHAPPA includes a default set of base case emissions for the years 2025, 2030, 2035, 2040, 2045, and 2050, developed for NYSERDA. NY-CHAPPA v1.0 has built-in files from a reference case and policy scenario used in a previous study. A description of the reference case and policy scenario is provided in Section II Chapter 1.3 of Appendix G to the New York State Climate Action Council Scoping Plan.[23] NY-CHAPPA v2.0 includes sample data from the "No Action", "Current Policies", "Additional Action", and "Net Zero B" scenarios from the State Energy Plan (SEP)[24].

4. Receptors

The receptor network in NY-CHAPPA was developed to represent modeled $PM_{2.5}$ concentrations for each census tract in New York State. Generally, receptors were placed at the centroid of each census tract. However, for large (greater than 20 square kilometers) census tracts, receptors were placed at the centroids of block groups. For multi-shape tracts and block groups (described above), each shape has its own receptor. For census tracts where there are multiple receptors for different blocks groups and/or shapes, the receptors are averaged to represent $PM_{2.5}$ concentrations for the census tract.

Receptor locations were placed at area centroids for either census tracts or block groups as above. However, receptor locations were corrected in cases where the centroid would fall on or in very close proximity to roadway sources, as that would result in artificially high concentrations from on-road activity. To address receptor locations placed too close to a road, a two-part strategy was used. First, a recursive SQL query was developed to automatically attempt to move receptors further away from their nearest road link. Receptors that were within 30 m of a road link were moved 30 m in the opposite direction of the nearest roadway. For example, if a receptor was located 10 m north of a road oriented in the east/west direction, the receptor was moved 30 m further to the north to then make it 40 m north of that road. When this SQL-based process resulted in receptors still within 30 m of a roadway (possibly a different nearby roadway, especially in census tracts in dense New York City neighborhoods where the spacing between roads is only about 200 feet) those receptors were then moved manually in GIS with a Google imagery base layer to the best possible location, ensuring that receptors are at least 30 m from any road link and remain inside the census shapes they represent.

5. Dispersion and Transport

The total $PM_{2.5}$ concentration at each receptor is a function of two components: (1) the local component from dispersion of local emissions sources and (2) the transported component from outside the region. The following sections describe the local dispersion and regional transport that make up these two components. NY-CHAPPA is configured to estimate total $PM_{2.5}$

[23] New York Climate Action Council, 2022. Appendix G: Integration Analysis Technical Supplement New York State Climate Action Council Scoping Plan, Prepared for NYSERDA, December 2022.

[24] New York State Energy Plan. 2025. https://energyplan.ny.gov/

concentrations at the centroid of each census tract or block group shape (see Receptors Section) to provide a high-resolution estimation of $PM_{2.5}$ concentrations for every census tract in New York State.

5.1. Local Dispersion

Local dispersion of source emissions is modeled by the C-TOOLS reduced-form dispersion model within each model region. C-TOOLS has unique dispersion algorithms for line, point, and area source types, described above, and has been extensively evaluated during its development and in other studies, including in the ZAPPA model for NYC.[5, 16, 25] The dispersion algorithms in C-TOOLS are comparable to AERMOD, as was shown in these studies, including the line source intercomparison study by Heist et al. (2013).[26]

Modeling heights used for area source emissions are based on point source stack heights. Using the point source inventories available through EPA's 2016v1 Emissions Modeling Platform,[27] each of the 470 point source facilities in New York was matched to its corresponding emissions tier (sector), using standard Source Classification Code to tier assignments. Within each tier, the stack heights were averaged at the county level. This produces county- and tier-specific average stack heights, which are then used to model the corresponding tier of area source emissions. A summary of the average tier-specific heights for source groups by each county is provided in Appendix B. The tier definitions are the same as described earlier in the Emissions Inputs section of this document. Note that point source data was not available for all tier/county combinations. Sources without point source-based heights are modeled at the ground level.

The dispersion algorithms for area, point, and road sources are based on the algorithms described in Isakov et al. (2017)[25].

5.1.1 Meteorology

NY-CHAPPA uses meteorological inputs from 29 stations across New York State, shown in Figure 3 and listed in Table 6.

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[25] Isakov, V., T. Barzyk, E. Smith, S. Arunachalam, B. Naess and A. Venkatram (2017). A Web-based Modeling System for Near-Port Air Quality Assessments, *Environ. Model. Software*, 98:21-34, http://www.sciencedirect.com/science/article/pii/S1364815216311367

[26] Heist, D., V. Isakov, S. Perry, M. Snyder, A. Venkatram, C. Hood, J. Stocker, D. Carruthers, S. Arunachalam and C. Owen (2013). Estimating near-road pollutant dispersion: a model inter-comparison *Transportation Research, Part D.,* 25:93-105

[27] https://www.epa.gov/air-emissions-modeling/2016v1-platform

Figure 3. Location of 29 Meteorological Stations in New York State.

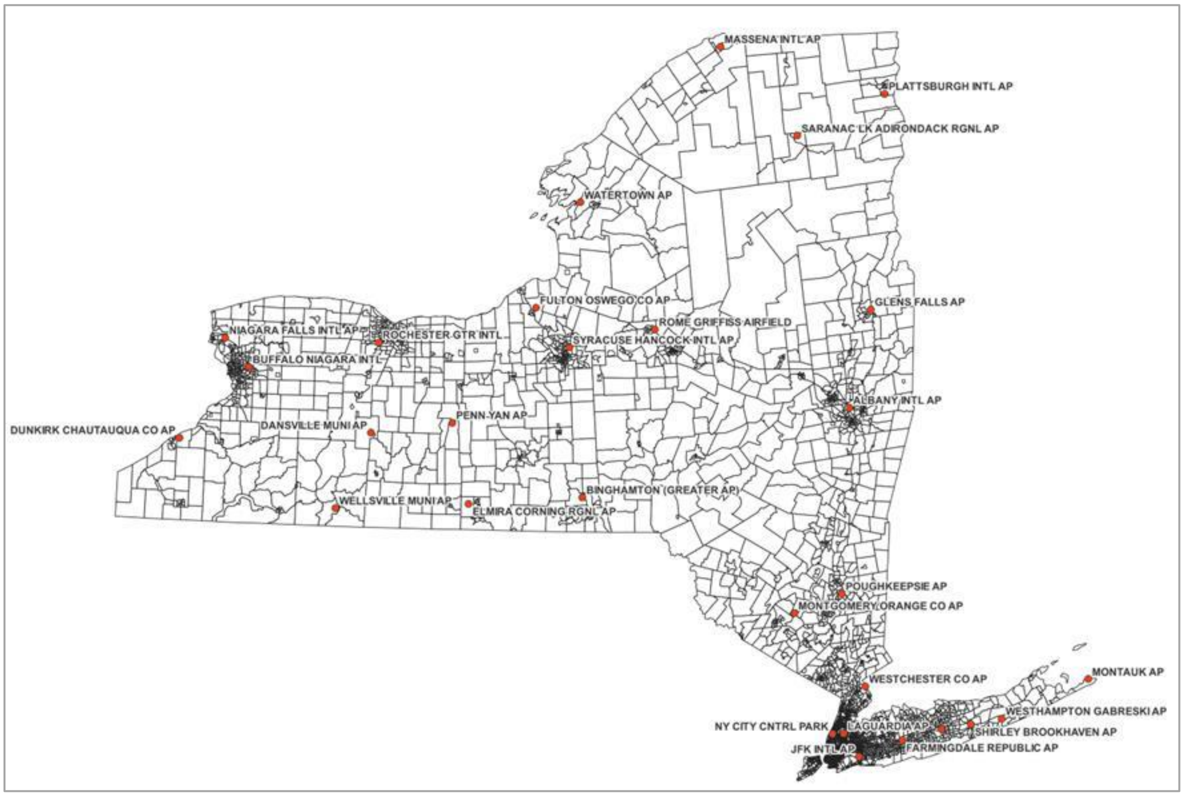


Table 6. List of Meteorological Stations in New York State.

WBAN	Name	Latitude	Longitude
04724	Niagara Falls International Airport, NY, US	43.10830	-78.93818
04725	Greater Binghamton Airport, NY, US	42.20678	-75.97993
04781	Islip Long Island Macarthur Airport, NY, US	40.79389	-73.10181
04789	Montgomery Orange County Airport, NY, US	41.50908	-74.26458
14719	Westhampton Gabreski Airport, NY, US	40.85055	-72.61928
14732	LaGuardia Airport, NY, US	40.77945	-73.88027
14733	Buffalo Niagara International Airport, NY, US	42.93998	-78.73606
14735	Albany International Airport, NY, US	42.74722	-73.79913
14747	Dunkirk Chautauqua County Airport, NY, US	42.49320	-79.27623
14748	Elmira Corning Regional Airport, NY, US	42.15658	-76.90291
14750	Glens Falls Floyd Bennett Memorial Airport, NY, US	43.33849	-73.61024
14757	Poughkeepsie Hudson Valley Regional Airport, NY, US	41.62574	-73.88155
14768	Frederick Douglass Greater Rochester International Airport, NY, US	43.11723	-77.67539
14771	Syracuse Hancock International Airport, NY, US	43.11110	-76.10384
54757	Wellsville Municipal Airport, NY, US	42.10775	-77.98424
54773	Fulton Oswego County Airport, NY, US	43.35037	-76.38316

WBAN	Name	Latitude	Longitude
54778	Penn Yan Airport, NY, US	42.64405	-77.05286
54787	Farmingdale Republic Airport, NY, US	40.73443	-73.41637
54790	Shirley Brookhaven Airport, NY, US	40.82121	-72.86742
64775	Rome Griffiss Airfield, NY, US	43.22417	-75.39563
64776	Plattsburgh International Airport, NY, US	44.63923	-73.46312
94704	Dansville Municipal Airport, NY, US	42.56985	-77.71426
94725	Massena International Airport, NY, US	44.93341	-74.84836
94728	NY City Central Park, NY, US	40.77898	-73.96925
94740	Saranac Lake Adirondack Regional Airport, NY, US	44.39279	-74.20288
94745	Westchester County Airport, NY, US	41.06236	-73.70454
94789	JFK International Airport, NY, US	40.63915	-73.76390
94790	Watertown International Airport, NY, US	43.98872	-76.02609

Hourly meteorology data for the year 2016 for the New York stations were developed by running the EPA's AERMET model.[28] For each station, the hourly meteorology data were processed following the METeorologically-weighted Averaging for Risk and Exposure (METARE) approach[29] to develop a streamlined set of, at most, 100 unique meteorology hours to use in the dispersion model. The actual number of unique hours varies for each of the 29 meteorological stations based on prevalent conditions for the chosen bins in the annual data. Thus, for some stations, we ended with < 100 unique meteorology hours to represent the annual average calculations using the METARE approach.

All point, area, and road sources use meteorological data from their closest meteorological station when modeling dispersion. After the dispersion model calculates hourly concentrations for each of the 100 meteorology hours, the concentrations are averaged using hour-specific weights to estimate the annual average concentrations.

While NY-CHAPPA uses a single year of meteorology from 2016, a sensitivity analysis was conducted to analyze the variability in key meteorology data over time. This includes an analysis of the difference in wind speed and direction, as shown in the wind rose plots for LaGuardia Airport for 2017–2021 (See Appendix C and Figure C-1). These plots show that the annual distribution of wind speed and direction did not change substantially from 2017 to 2021. Similar plots were developed for the other meteorological stations in New York State, and they show a similar lack of variability in wind speed and direction.

We also compared the number of hours with Monin-Obukhov length values in different stability ranges for the years 2016–2021 and shown in Figure C-2 of Appendix C. Monin-Obukhov length

[28] U.S. Environmental Protection Agency, 2024. User's Guide for the AERMOD Meteorological Preprocessor (AERMET), EPA-454/B-24-004, November 2024.

[29] Chang, S.-Y. , W. Vizuete, A. Valencia, B. Naess, V. Isakov, T. Palma, M. Breen, S. Arunachalam (2015). A Modeling Framework for Characterizing Near-Road Air Pollutant Concentration at Community Scales, *Sci. Total Environ., 538:*905-921, http://dx.doi.org/10.1016/j.scitotenv.2015.06.139

is an indication of stability in the atmosphere and the dispersion model relies on this estimate to compute the extent of dispersion. Similar to the wind rose plots shown, the Monin-Obukhov plots also do not show significant year-to-year change at individual stations. The New York City Central Park station has the most interannual variability of all the stations, but even this variation is relatively small for the purposes of this modeling.

Given the lack of substantial interannual variability in wind speed, wind direction, and Monin-Obukhov length, which are key input parameters that drive dispersion in the model, NY-CHAPPA is configured to use a single year of meteorology, 2016.

5.2. Source-receptor (S-R) Matrix Generation

To generate an S-R matrix used to model dispersion of NY-CHAPPA's area and road sources, the dispersion calculations in C-TOOLS are run using emissions inputs of 1 ton per year for an arbitrary pollutant. The outputs of these calculations are S-R matrices where every area and road source and receptor combination has a unique S-R value. This S-R value represents the contribution for the given area or road source to a given receptor. To calculate concentrations from a specific set of input emissions, the S-R value for each area or road source can be multiplied by the source's emissions. This post-processing approach allows NY-CHAPPA to process scenarios much faster than running C-TOOLS for each pollutant. For point sources, C-TOOLS is used to disperse emissions of each precursor because computing time for dispersing individual point sources is relatively modest, compared to modeling area sources.

5.3. Regional Transport

Transported components represent the $PM_{2.5}$ concentrations produced from emission sources outside the modeling region (Figure 4). The transported components are estimated using COBRA by zeroing out all emissions within the modeling region. To estimate the transported component of receptor $PM_{2.5}$ concentrations, NY-CHAPPA has two different options:

a) Automatically calculate transport components during model execution

In this option, NY-CHAPPA automatically calculates transported components based on the provided emissions inputs using COBRA v5.[30] To do this, NY-CHAPPA sums the user's input emissions at the county level and then separate COBRA v5 runs are performed for each modeling region. For each region, emissions for the counties within the region are set to zero, while emissions for all other counties outside the region are defined as the calculated county totals based on user emissions inputs. Emissions for counties outside of New York State use the COBRA v5 default values. The results from COBRA v5 provide estimates of total $PM_{2.5}$ concentrations from sources outside the model region for each county within the region.

b) Upload custom transport components

- In this option, the user can generate their own set of transport components from other sources (e.g., different coarse resolution model or observations) as CSVs and upload them to the model.

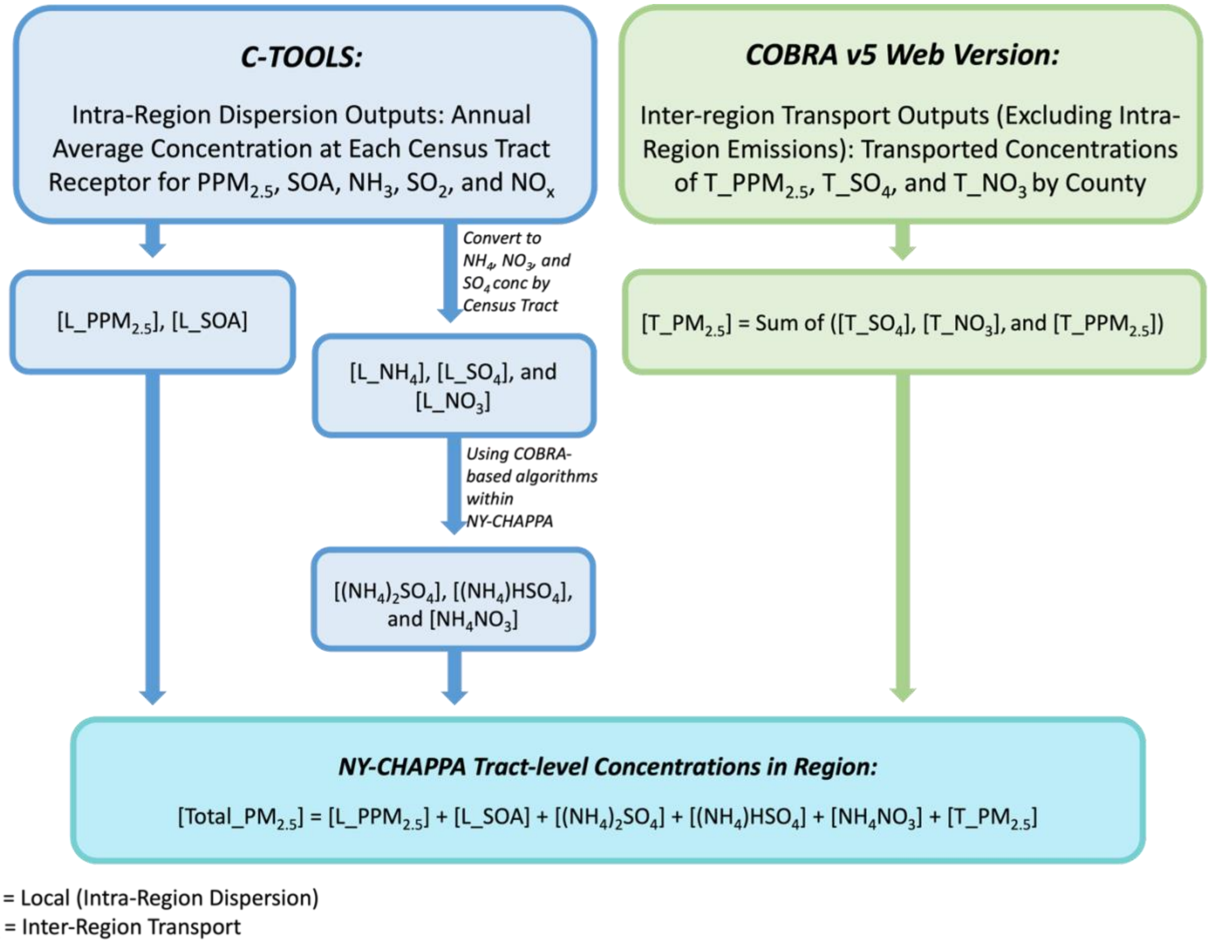
[30] U.S. Environmental Protection Agency. 2025. User's Manual for the CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA), Version 5.2. https://www.epa.gov/cobra/users-manual-co-benefits-risk-assessment-cobra-screening-model

Note that COBRA v5 estimates total transported $PM_{2.5}$ (from both primary emissions and secondary conversion) rather than transported precursor concentrations. The transported $PM_{2.5}$ is then added to the locally produced primary and secondary $PM_{2.5}$ from C-TOOLS to compute total $PM_{2.5}$.

6. Calculation of Total $PM_{2.5}$

Local dispersion modeling of area, point, and road sources produces annual average concentrations in µg/m^3 for NH_3, NO_x, primary $PM_{2.5}$, SO_2, and SOA at each receptor. Next, total secondary $PM_{2.5}$ from local sources is computed for each tract. NY-CHAPPA then estimates the transported $PM_{2.5}$ concentrations from outside the model region into New York State using one of the two methods described in the section above. The total $PM_{2.5}$ concentrations for each census tract is then obtained by adding the transported value for total $PM_{2.5}$ to the local total $PM_{2.5}$ estimate. A schematic of this approach is given in Figure 4 below.

Figure 4. Schematic of the C-TOOLS and COBRA5 Modeling Framework for Estimating $PM_{2.5}$



The sequence of steps in which NY-CHAPPA calculates total $PM_{2.5}$ in each census tract is provided below, where MW = molecular weight.

1. Convert local SO_2 concentration to SO_4

- Local SO_4 = (MW_SO_4 / MW_SO_2) * local SO_2

2. Convert local NO_x concentration to NO_3
   - Local NO_3 = (MW_NO_3 / MW_NO_x) * local NO_x
3. Convert local NH_3 concentration to NH_4
   - Local NH_4 = (MW_NH_4 / MW_NH_3) * local NH_3
4. Calculate Amm_Sulfate, Amm_Bisulfate, remaining SO_4, and Amm_Nitrate from summed SO_4, NO_3, and NH_4 from local sources
5. Secondary $PM_{2.5}$ = Amm_Sulfate + Amm_Bisulfate + remaining SO_4 + Amm_Nitrate + local SOA
6. Total local $PM_{2.5}$ = local primary $PM_{2.5}$ + local secondary $PM_{2.5}$
7. Estimate transported $PM_{2.5}$ from COBRA at a county scale
8. Estimate total $PM_{2.5}$ by adding local $PM_{2.5}$ to transported $PM_{2.5}$ from outside the region

After the total $PM_{2.5}$ concentration is calculated for each census tract for the policy scenario, the base case total $PM_{2.5}$ concentration for the census tract is subtracted to calculate "delta $PM_{2.5}$" in $\mu g/m^3$ for each census tract. The delta $PM_{2.5}$ is the concentration used in the concentration-response functions to calculate health impacts and associated monetized values of health impacts at the census tract level, described below.

7. Calculation of Health Impacts

To calculate public health impacts from the modeled changes in $PM_{2.5}$ concentrations, input data on population and baseline health incidence are needed. These datasets are built into the model and the user does not have the option of uploading their own population and baseline health incidence data. These datasets and approaches for calculating physical health and monetized societal benefits are described in the sections below.

7.1. Population Datasets

Year-specific tract-level population data for the years 2025, 2030, 2035, 2040, 2045, and 2050 are based on 2018 projections from the Cornell University's County Projections Explorer.[31] This is the same dataset used to project energy demand in the Pathways Integration Analysis.[23] The Cornell population projections, which extend through 2040, were projected through 2050 based on linear extrapolation of the population trend in each county from 2025-2040.

7.2. Health Incidence Datasets

Baseline health incidence is required for each health endpoint to determine the change in public health benefits due to changes in $PM_{2.5}$ concentrations. Baseline health data for 2008-2012 was obtained at a sub-county level from New York State Department of Health (DOH) for mortality, asthma emergency room visits, and asthma hospitalizations. Most of the sub-county-level data was not at the census tract level, but rather at aggregations of census tracts developed by DOH to protect patient confidentiality. In cases where the sub-county-level data had between 1 and 4

[31] Cornell University. 2018. County Projections Explorer. Ithaca, New York: Cornell Program on Applied Demographics. https://pad.human.cornell.edu/counties/projections.cfm

cases, the exact number was not provided, and a value of 2.5 (the midpoint of the range) was used instead. For all other health outcomes, sub-county-level data was not available, and the county-level baseline health incidence data from COBRA v4.1 was used.

7.3. Physical Health and Monetized Benefits

To calculate physical health and monetized societal benefits in NY-CHAPPA, concentration-response and economic valuation functions from COBRA v4 for each health endpoint (Table 7) are applied to delta $PM_{2.5}$ concentrations for each census tract.

Table 7. Health endpoints used in NY-CHAPPA.

Endpoint	Incidence data	Incidence data source
Mortality	Mortality, All Cause	Sub-county from DOH
Infant Mortality	Mortality, All Cause	Sub-county from DOH
Nonfatal Heart Attacks	Acute Myocardial Infarction, Nonfatal	COBRA v4.1
Hospital Admits (HA), All Respiratory Direct	HA, All Respiratory	COBRA v4.1
Hospital Admits, Asthma	HA, Asthma	Sub-county from DOH
Hospital Admits, Chronic Lung Disease	HA, Chronic Lung Disease	COBRA v4.1
Hospital Admits, Cardio (except heart attacks)	HA, All Cardiovascular (less Myocardial Infarctions)	COBRA v4.1
Acute Bronchitis	Acute Bronchitis	COBRA v4.1
Emergency Room Visits, Asthma	Emergency Room Visits, Asthma	Sub-county from DOH
Work Loss Days	Work Loss Days	COBRA v4.1

NY-CHAPPA calculates the change in incidence for each health endpoint due to the change in $PM_{2.5}$ concentration in each census tract using the formula in equation (2). The reader is referred to the COBRA user manual[30] for all concentration response functions (CRFs) used in NY-CHAPPA.

$$DeltaIncidence = (1 - e^{-\beta \times AQ}) \times BaselineIncidence \times Population \quad (2)$$

Where:

DeltaIncidence	=	The change in incidence of the health endpoint due to a change in $PM_{2.5}$ concentrations
β	=	The beta coefficient, representing the impact of a change in $PM_{2.5}$ concentrations on the incidence of the health impact
AQ	=	The change in $PM_{2.5}$ concentrations ($\mu g/m^3$)
BaselineIncidence	=	Baseline incidence of the health endpoint
Population	=	County-level population

For the five counties in New York City, city-specific CRFs for emergency room visits for asthma and hospitalizations for cardiovascular events are used, described below. The NYC CRFs have the same functional form as those used in COBRA for these health endpoints.

Emergency Room Visits, Asthma:

- Reference: Ito et al. (2007)[32]
- Incidence Data: Emergency Room Visits, Asthma
- Ages: 0 to 99
- Function: See Equation 2 above
- Beta value: 0.0045328

Hospital Admits, Cardio (except heart attacks):

- Reference: Ito et al. (2011)[33]
- Incidence Data: HA, All Cardiovascular (less Myocardial Infarctions)
- Ages: 40 to 99
- Function: See Equation 2 above
- Beta value: 0.000995

Economic valuation functions used were from COBRAv4.1.

[32] Ito K, Thurston G, Silverman R. 2007. Characterization of PM2.5, gaseous pollutants, and meteorological interactions in the context of time-series health effects models. *Journal of Exposure Science and Environmental Epidemiology*, 17: S45-S60.

[33] Ito K, Mathes R, Ross Z, Nadas A, Thurston G, Matte T. 2011. Fine Particulate Matter Constituents Associated with Cardiovascular Hospitalizations and Mortality in New York City. Unpublished.

Appendix A

Table A-1. Counties used to define modeling regions.

Modeling Region	Counties (FIPS codes)
Capital Region	36001, 36021, 36039, 36083, 36091, 36093, 36113, 36115
Central New York	36011, 36023, 36053, 36067, 36075
Mid-Hudson	36027, 36071, 36079, 36105, 36111
Mohawk Valley	36035, 36043, 36057, 36065, 36077, 36095
North Country	36019, 36031, 36033, 36041, 36045, 36049, 36089
NYC / LI / Lower Hudson	36005, 36047, 36059, 36061, 36081, 36085, 36087, 36103, 36119
Southern Tier	36007, 36015, 36017, 36025, 36097, 36101, 36107, 36109
Western New York / Finger Lakes	36003, 36009, 36013, 36029, 36037, 36051, 36055, 36063, 36069, 36073, 36099, 36117, 36121, 36123

Table A-2. Counties used to define reporting regions.

Reporting Region	Counties (FIPS codes)
Capital Region	36001, 36021, 36039, 36083, 36091, 36093, 36113, 36115
Central New York	36011, 36023, 36053, 36067, 36075
Finger Lakes	36037, 36051, 36055, 36069, 36073, 36099, 36117, 36121, 36123
Hudson Valley	36027, 36071, 36079, 36087, 36105, 36111, 36119
Long Island	36059, 36103
Mohawk Valley	36035, 36043, 36057, 36065, 36077, 36095
New York City	36005, 36047, 36061, 36081, 36085
North Country	36019, 36031, 36033, 36041, 36045, 36049, 36089
Southern Tier	36007, 36015, 36017, 36025, 36097, 36101, 36107, 36109
Western New York	36003, 36009, 36013, 36029, 36063

Appendix B

Table B-1. Average stack heights by Tier for Area Sources.

FIPS	Tier 1	Mean (feet)	Min (feet)	Max (feet)	Count
36001	2	81.7	7.0	200.0	685
36001	4	84.6	17.0	160.0	162
36001	7	118.1	12.0	350.0	517
36001	9	86.8	11.0	171.0	529
36001	10	58.0	28.0	80.0	215
36003	2	28.4	26.5	36.7	86
36003	9	0.0	0.0	0.0	2
36003	10	35.0	35.0	35.0	5
36005	2	62.4	26.0	133.0	271
36005	9	0.0	0.0	0.0	4
36005	10	30.0	30.0	30.0	14
36005	14	30.5	26.0	35.0	4
36007	2	80.6	26.5	91.0	409
36007	7	84.4	34.9	125.0	249
36007	10	15.3	12.0	29.0	229
36009	7	42.5	30.2	53.3	22
36011	2	57.9	43.0	93.0	208
36011	5	95.5	89.3	100.0	47
36011	6	0.0	0.0	0.0	12
36011	7	92.2	23.0	140.0	44
36011	9	38.7	28.5	48.0	46
36011	10	29.6	20.0	30.0	67
36013	2	44.1	36.6	56.0	316
36013	5	39.0	39.0	39.0	31
36013	7	47.7	33.8	138.0	88
36013	10	19.8	3.0	70.0	4
36015	2	75.0	75.0	75.0	61
36015	5	42.0	34.4	43.0	232
36015	7	92.0	30.2	143.0	103
36015	10	10.0	10.0	10.0	66

FIPS	Tier 1	Mean (feet)	Min (feet)	Max (feet)	Count
36017	2	96.2	52.0	125.0	122
36017	7	36.9	33.0	73.6	38
36017	9	22.9	22.9	22.9	1
36019	2	63.8	34.0	75.0	360
36019	4	54.0	36.0	100.0	43
36019	6	120.0	120.0	120.0	1
36019	7	30.2	30.2	30.2	2
36019	10	34.0	34.0	34.0	39
36023	7	38.6	24.0	41.0	13
36025	2	61.6	43.0	70.0	90
36025	7	36.8	26.0	65.0	96
36027	2	56.7	41.0	57.0	229
36027	4	0.0	0.0	0.0	4
36027	7	59.6	14.0	71.0	52
36027	9	52.0	34.1	58.0	8
36027	10	58.0	58.0	58.0	12
36027	14	0.0	0.0	0.0	1
36029	2	71.0	6.0	250.0	1004
36029	4	55.8	4.0	150.0	57
36029	5	132.6	49.0	180.0	97
36029	6	52.0	52.0	52.0	26
36029	7	43.7	4.0	197.0	883
36029	9	34.2	4.0	108.0	240
36029	10	39.6	29.0	46.0	210
36031	2	204.1	127.1	205.0	85
36031	7	135.2	36.0	200.0	289
36031	10	0.0	0.0	0.0	1
36033	2	0.0	0.0	0.0	34
36033	10	0.0	0.0	0.0	62
36035	2	30.8	26.5	35.0	160
36035	7	42.5	32.0	63.6	7
36035	10	0.0	0.0	0.0	27
36037	2	73.1	58.2	80.0	74
36037	7	42.1	42.1	42.1	1

FIPS	Tier 1	Mean (feet)	Min (feet)	Max (feet)	Count
36039	2	14.0	13.0	15.0	33
36039	7	108.9	33.2	155.0	85
36039	9	119.0	26.3	172.0	299
36043	7	47.1	35.6	50.0	9
36045	2	35.7	7.0	95.0	228
36045	7	36.1	30.2	42.1	22
36045	9	12.4	12.0	18.0	417
36045	10	24.4	20.0	30.0	97
36047	2	48.3	25.0	360.0	577
36047	7	37.1	30.2	50.0	23
36047	9	25.5	5.0	40.0	124
36047	10	80.9	30.0	168.0	87
36049	2	56.2	19.0	147.0	121
36049	7	35.9	35.9	35.9	2
36051	2	0.0	0.0	0.0	15
36051	7	15.9	13.0	25.6	24
36053	2	0.0	0.0	0.0	98
36053	7	26.8	22.7	32.4	16
36053	10	21.0	21.0	21.0	51
36055	2	42.0	10.0	60.0	166
36055	4	36.4	29.0	52.0	25
36055	7	44.0	12.0	111.0	401
36055	9	43.6	26.1	60.0	131
36055	10	50.9	21.0	60.0	321
36057	2	37.3	36.0	42.0	178
36057	5	38.0	38.0	38.0	24
36057	7	43.3	8.0	53.0	76
36059	2	58.9	9.0	130.0	457
36059	7	23.8	20.0	33.8	21
36059	9	29.2	11.0	61.4	216
36059	10	0.0	0.0	0.0	28
36061	2	335.6	30.8	544.0	474
36061	7	0.0	0.0	0.0	18
36061	9	22.6	22.3	22.8	13

FIPS	Tier 1	Mean (feet)	Min (feet)	Max (feet)	Count
36061	10	87.0	87.0	87.0	11
36061	14	134.0	134.0	134.0	2
36063	2	99.2	8.0	210.0	330
36063	4	45.9	1.0	103.0	459
36063	5	92.0	92.0	92.0	26
36063	7	33.0	11.0	92.0	219
36063	9	55.0	22.8	103.0	36
36063	10	39.6	2.0	64.0	71
36065	2	33.7	26.5	43.0	123
36065	7	49.2	10.0	88.5	23
36065	9	30.0	30.0	30.0	1
36065	10	26.0	10.0	83.8	82
36067	2	101.7	18.0	210.0	547
36067	4	68.8	44.0	75.0	10
36067	5	18.0	18.0	18.0	32
36067	7	42.8	20.0	108.5	87
36067	9	32.4	24.0	40.0	39
36067	10	20.0	20.0	20.0	4
36069	2	43.2	26.5	50.6	168
36069	4	0.0	0.0	0.0	20
36069	7	103.1	28.0	315.0	174
36069	9	0.0	0.0	0.0	21
36069	10	40.0	40.0	40.0	36
36071	2	40.0	13.0	63.5	359
36071	4	0.0	0.0	0.0	1
36071	5	120.8	38.0	200.0	73
36071	6	16.0	16.0	16.0	7
36071	7	46.2	25.2	65.3	24
36071	9	30.3	12.0	61.4	189
36071	10	33.1	20.0	41.0	56
36073	2	44.0	44.0	44.0	46
36073	7	49.3	49.3	49.3	10
36073	9	0.0	0.0	0.0	1
36075	2	75.3	26.5	134.0	353

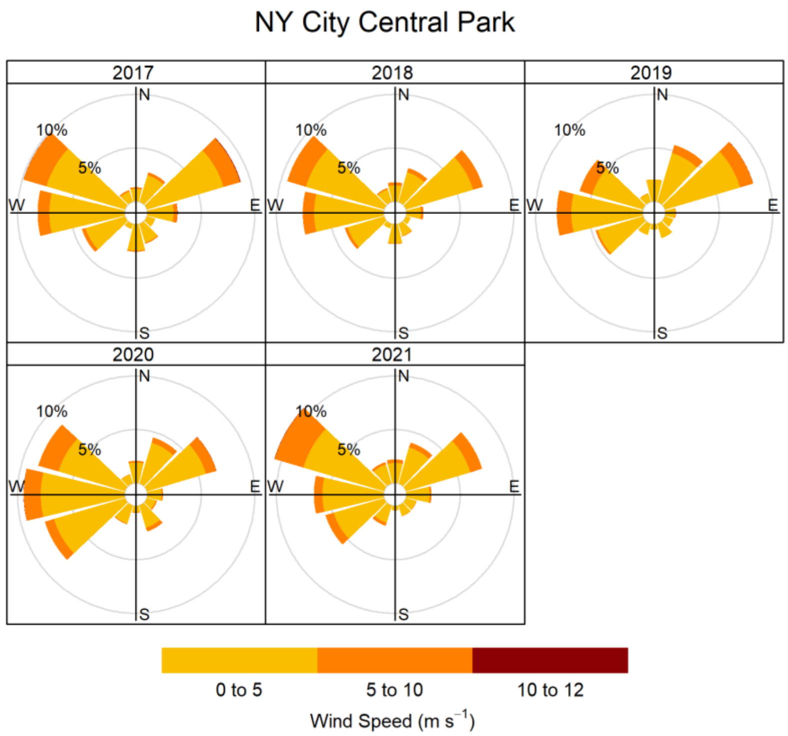
FIPS	Tier 1	Mean (feet)	Min (feet)	Max (feet)	Count
36075	5	127.9	70.0	392.0	110
36075	7	37.5	22.0	72.0	100
36075	9	11.7	10.0	12.0	9
36079	7	32.4	32.4	32.4	2
36081	2	125.6	26.5	352.0	794
36081	4	26.8	22.0	30.0	84
36081	7	57.7	30.2	250.0	15
36081	9	0.0	0.0	0.0	3
36081	10	23.0	23.0	23.0	11
36083	2	44.6	18.0	100.2	386
36083	4	37.7	12.0	85.0	95
36083	7	61.6	34.4	70.0	28
36083	9	23.7	10.0	49.0	191
36085	2	78.5	40.0	193.8	59
36085	9	28.4	16.0	51.0	54
36085	10	49.5	20.0	50.0	100
36087	2	93.2	16.0	273.0	469
36087	4	30.0	30.0	30.0	4
36087	7	32.5	32.5	32.5	4
36087	9	19.0	11.0	31.0	6
36087	10	40.0	40.0	40.0	3
36089	2	62.1	28.0	75.0	471
36089	5	75.7	30.0	111.0	281
36089	7	70.7	30.2	75.0	120
36089	10	17.3	17.3	17.3	1
36091	2	63.9	28.0	100.1	403
36091	4	56.2	11.0	133.0	286
36091	7	48.5	26.0	67.5	29
36091	9	0.0	0.0	0.0	7
36091	10	64.7	22.0	100.0	98
36093	2	73.3	23.0	190.0	514
36093	4	34.6	18.0	54.0	80
36093	7	45.1	14.0	85.0	211
36093	9	21.0	20.0	33.0	65

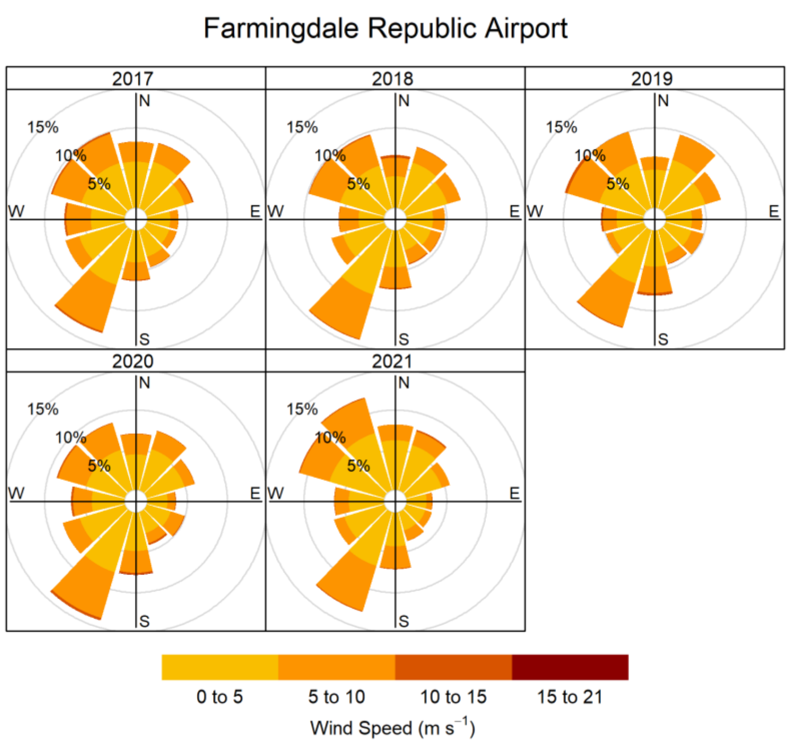
FIPS	Tier 1	Mean (feet)	Min (feet)	Max (feet)	Count
36093	10	15.0	15.0	15.0	6
36095	2	13.0	13.0	13.0	25
36097	2	225.0	225.0	225.0	60
36097	7	33.8	33.8	33.8	1
36099	2	32.1	29.0	40.0	115
36099	7	40.1	30.2	48.7	53
36099	9	26.4	26.4	26.4	3
36099	10	38.8	30.0	50.0	144
36101	2	58.3	8.0	77.0	336
36101	7	35.8	10.0	65.3	793
36101	9	62.0	62.0	62.0	10
36101	10	30.0	30.0	30.0	49
36103	2	29.5	7.0	75.0	483
36103	4	31.9	23.0	36.4	6
36103	5	35.0	35.0	35.0	1
36103	7	59.4	16.0	320.0	215
36103	9	33.2	9.0	45.0	77
36103	10	41.1	27.0	83.8	206
36105	9	44.0	44.0	44.0	1
36105	10	32.0	32.0	32.0	16
36107	7	31.7	29.8	32.7	9
36109	2	129.8	29.7	225.0	312
36109	6	0.0	0.0	0.0	1
36109	7	33.1	32.7	33.2	79
36109	9	14.0	14.0	14.0	12
36111	2	0.0	0.0	0.0	1
36111	7	10.5	10.0	33.8	65
36111	9	41.0	10.0	75.0	42
36113	2	113.7	38.0	223.0	100
36113	7	94.8	10.0	260.0	436
36113	9	113.5	10.0	260.0	510
36113	10	28.0	28.0	28.0	7
36115	2	39.8	29.7	115.0	139
36115	7	54.0	10.0	93.0	149

FIPS	Tier 1	Mean (feet)	Min (feet)	Max (feet)	Count
36115	9	27.4	23.5	29.9	6
36115	14	78.0	78.0	78.0	1
36117	2	83.4	36.6	193.8	52
36117	7	30.9	29.1	33.5	7
36119	2	49.8	29.0	70.0	699
36119	4	37.9	32.0	67.5	25
36119	7	86.2	33.8	100.0	140
36119	9	0.0	0.0	0.0	28
36119	10	40.5	19.0	55.0	20
36121	2	0.0	0.0	0.0	96
36121	5	29.0	27.0	31.0	2
36121	7	30.0	30.0	30.2	25
36123	2	0.0	0.0	0.0	15

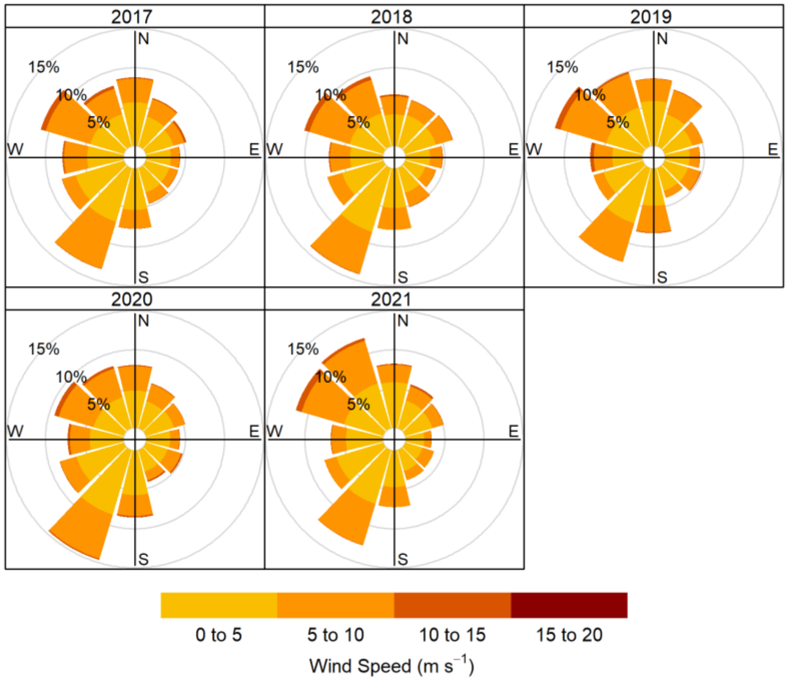
Appendix C

Figure C-1. Wind Rose Plots of Meteorological Data for Select New York State Airports.

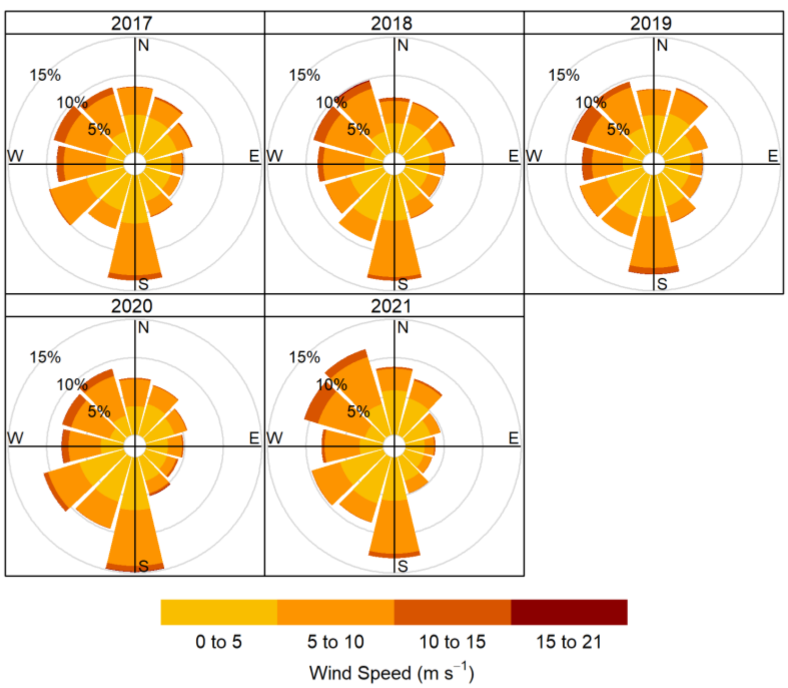


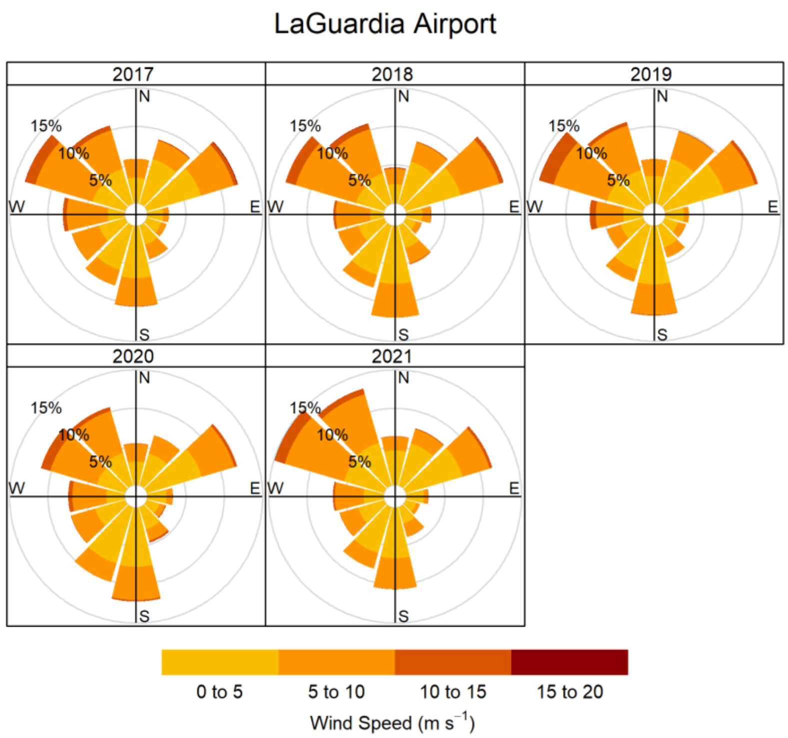


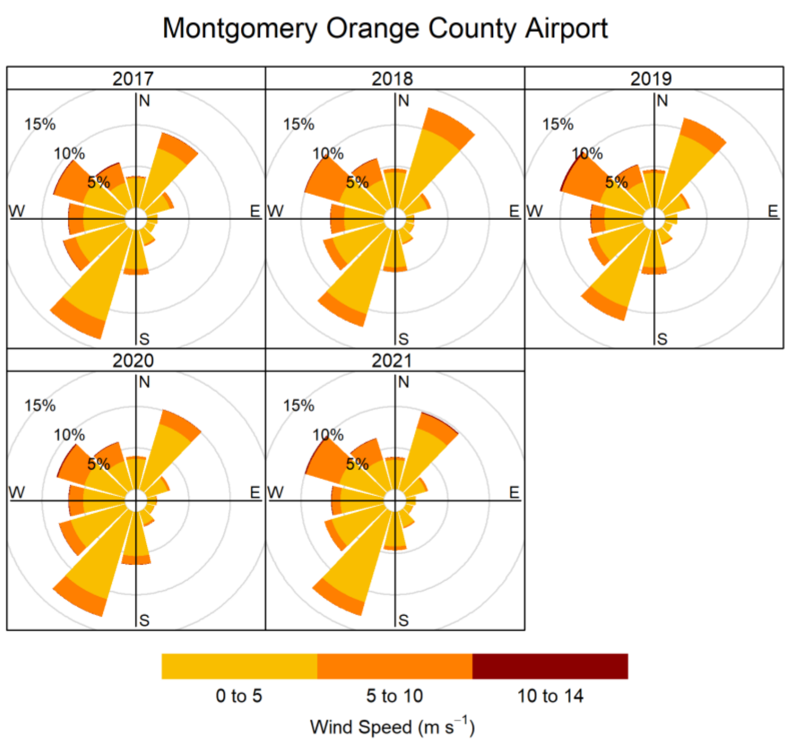
Islip Long Island Macarthur Airport

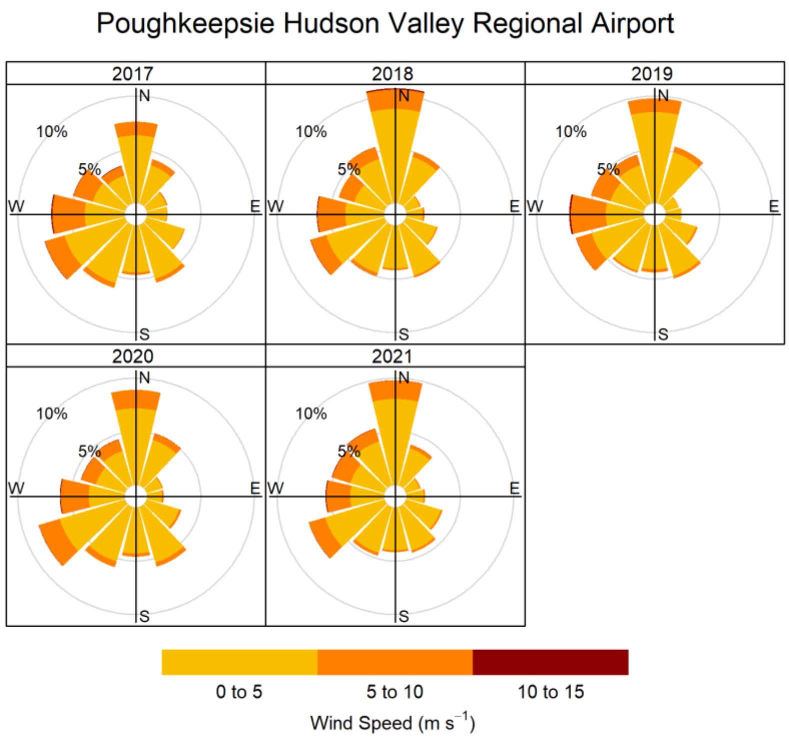


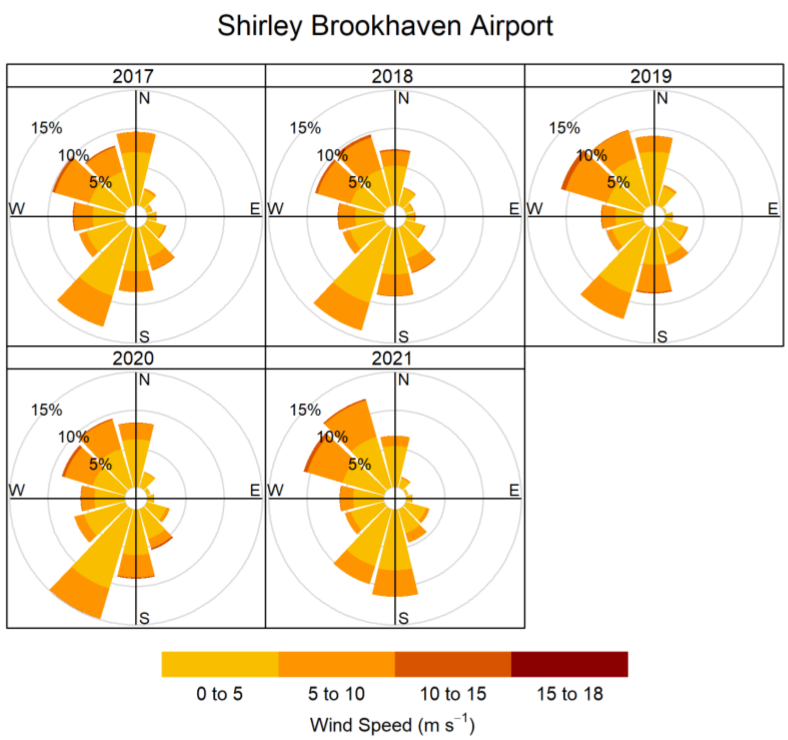
JFK International Airport

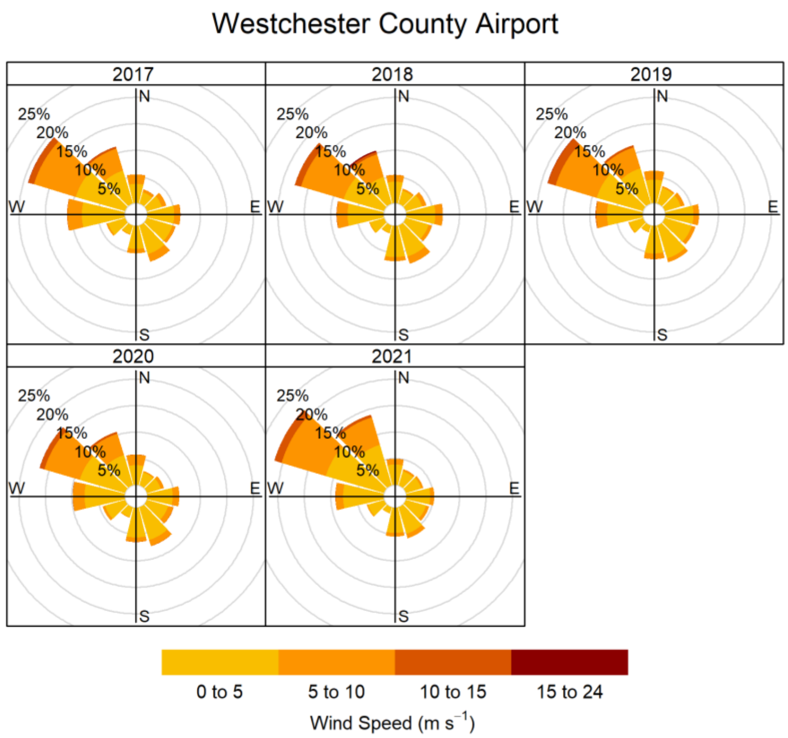



LaGuardia Airport
2017
2018
2019
2020
2021
N
S
E
W
15%
10%
5%
0 to 5
5 to 10
10 to 15
15 to 20
Wind Speed (m s^{-1})


Montgomery Orange County Airport
2017
2018
2019
2020
2021
N
S
E
W
15%
10%
5%
0 to 5
5 to 10
10 to 14
Wind Speed (m s^{-1})


Poughkeepsie Hudson Valley Regional Airport
2017
2018
2019
2020
2021
N
S
E
W
10%
5%
0 to 5
5 to 10
10 to 15
Wind Speed (m s⁻¹)


Shirley Brookhaven Airport
2017
2018
2019
2020
2021
N
S
E
W
15%
10%
5%
0 to 5
5 to 10
10 to 15
15 to 18
Wind Speed (m s⁻¹)


Westchester County Airport
2017
2018
2019
2020
2021
N
E
S
W
25%
20%
15%
10%
5%
0 to 5
5 to 10
10 to 15
15 to 24
Wind Speed (m s⁻¹)

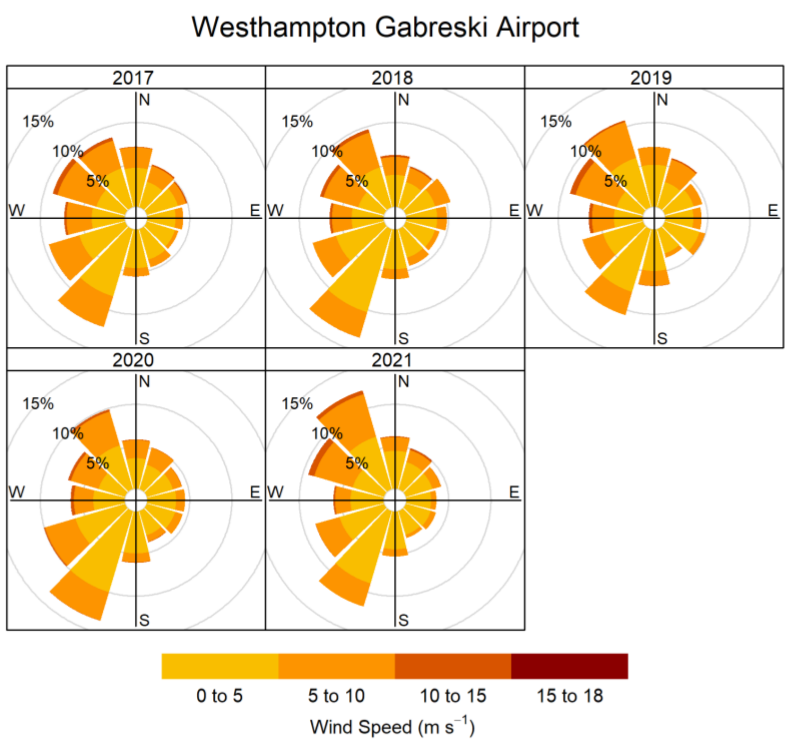

Westhampton Gabreski Airport
2017
2018
2019
2020
2021
N
E
S
W
15%
10%
5%
0 to 5
5 to 10
10 to 15
15 to 18
Wind Speed (m s⁻¹)

Figure C-2. Number of Hours with Monin-Obukhov Length Values in Different Stability Ranges from the Same Select Airports.