

Assessing Potential Public Health and Air Quality Impacts of Changing Climate and Land Use in Metropolitan New York

A Study by the New York
Climate & Health Project



Assessing Potential Public Health and Air Quality Impacts of Changing Climate and Land Use

Introduction

Over the coming century, Americans will be confronted by significant environmental changes caused both by a warming global climate and increasing urbanization. Scientists have recently estimated that global average surface temperature may increase by between 1.4 to 5.8 °C (2.4 to 10.4 °F) by 2100 (Intergovernmental Panel on Climate Change, 2001). Simultaneously, human populations are carrying out rapid and substantial conversions of land from natural to human dominated uses. To be responsible stewards of both human health and biological diversity in the coming century, societies need to develop better tools describing and predicting the interactions between these global drivers and the health of the Earth's inhabitants.

The New York Climate & Health Project (NYCHP) is a research group organized to begin addressing these issues locally. Over the past three years, a multi-disciplinary team of investigators from Columbia and other regional universities (see list at the end of this document) has developed and applied a modeling framework to assess potential future public health impacts of climate and land use changes in the New York metropolitan region. Projections of regional climate and air quality have been assessed under alternative scenarios of global climate change and regional land use change, and these projections have then been used in a risk assessment framework to examine potential public health impacts of both extreme heat events and ozone air quality over the coming century.

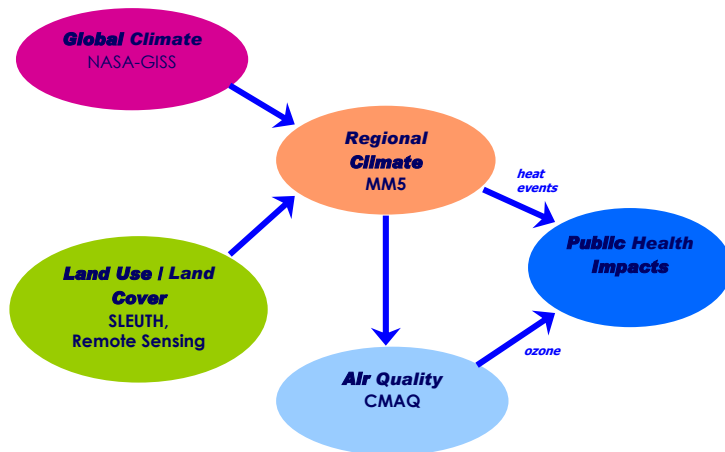


Figure 1. The Integrated Modeling Framework of the New York Climate & Health Project.

To accomplish these goals, the NYCHP team has woven together a diverse set of models and measurements addressing current and future global climate, land use, regional climate, air quality, and human health (Figure 1). A significant innovation of this work has been the “down-scaling” of global climate model outputs to assess regional and urban scale changes, which are more relevant to local policy makers.

Public Health Impact Assessment

The principal research objective of the New York Climate and Health Project was to assess potential future health impacts of climate and land use change for the New York metropolitan region. In the past, the potential effects of climate change have been projected in terms of global or continental-scale temperature and precipitation variation at scales of hundreds of kilometers. The NYCHP conducted public health impact assessments for just the region and for both temperature and ozone, at scales more relevant for adaptive city, county and state planning.

Overall, our results to date using a relatively high growth scenario (the A2 scenario, see below) suggest:

- In a typical summer of the 1990s, about 840 deaths in the NY metro region were heat-related, while approximately 1,300 were ozone-related.
- Under a changing climate, these estimates are projected to increase. Summer heat-related mortality could increase 55% by the 2020s, more than double (129% increase) by the 2050s, and more than triple (258% increase) by the 2080s.
- Areas of relatively high summer temperatures tend to coincide with more densely populated counties in the climate change simulations; the ability to discern these geographic variations is one of the advantages of applying downscaled models for health impact analyses.

- Including the combined effects of warmer summers and warmer winters, net annual temperature-related mortality by the 2050s could be 25% greater than in the 1990s.
- Summer heat-related mortality may exceed ozone-related mortality by the 2050s.
- Climate change alone (ignoring changes in pollution emissions) may increase ozone concentrations across the region and result in a 5% increase in summertime ozone-related mortality by the 2050s.

Even under slower growth assumptions (the B2 scenario, see below), heat-related summer mortality could double by the 2050s (102% increase). If the effect of population growth is included in these B2 projections, the overall impacts of climate changes on regional mortality will be even greater.

Figure 2 illustrates projected increases in each county's summer heat-related mortality for future decades under the A2 growth scenario vs. the 1990s. Urban counties are projected to experience relatively greater increases in summer heat mortality than counties outside New York City.

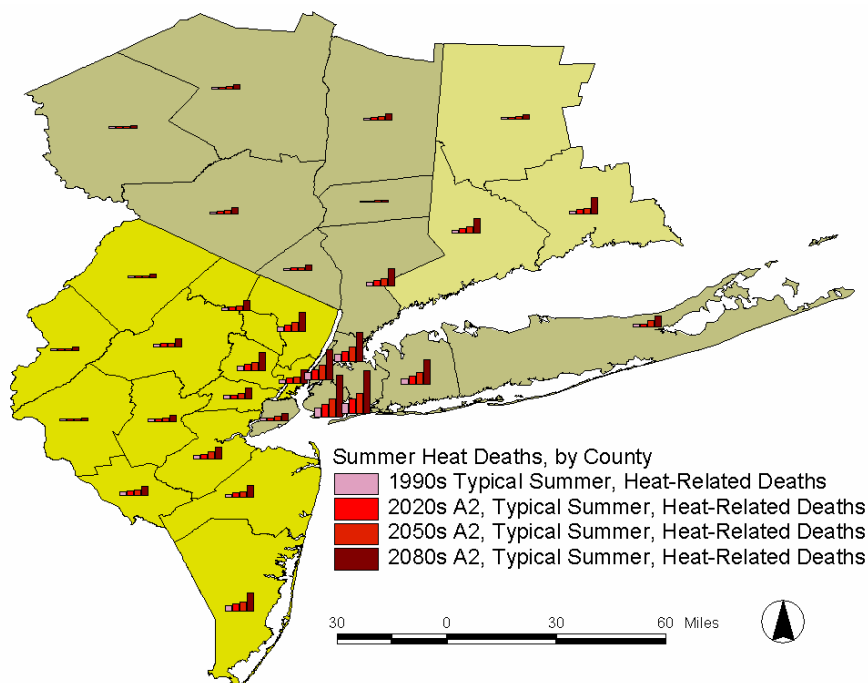


Figure 2. Projected increases in summer heat-related mortality by county, using A2 growth assumptions for future decades as compared to the 1990s.

Approach

The question driving this integrated assessment was: How may health in the region be affected by climate and land-use change, first considering heat stress and air pollution effects on mortality? To put our work into an appropriate context, we defined future scenarios of greenhouse gas emissions, ozone precursor emissions, land use changes and population growth on the basis of two existing growth scenarios published by the Intergovernmental Panel on Climate Change (IPCC). The **A2 scenario** is characterized by relatively high CO₂ emissions (30 gigaton/yr max), weaker environmental concerns, and large population increases (15 billion by 2100). The **B2 scenario** is characterized by medium CO₂ emissions (15gt/yr max), stronger emphasis on environmental issues, and medium population growth (10 billion by 2100). Currently, world CO₂ emissions are about 8 gt/yr from our population of 6.4 billion.

Tropospheric Ozone and Human Health

Ozone is a strong oxidant gas that occurs naturally in the stratosphere (approximately 30-50 km altitude) where it forms a protective layer that filters dangerous ultraviolet radiation from sunlight. In the troposphere (the lowest 10 km of the atmosphere), ozone is an unwelcome pollutant. Inhalation of ozone has been associated with health effects ranging from transient declines in lung function and increased hospital visits for respiratory problems to premature death. Tropospheric ozone is a secondary pollutant (i.e., not directly emitted to a substantial degree) that is formed via complex chemical reactions involving nitrogen oxides, reactive hydrocarbons, and sunlight. Because of the importance of solar radiation and temperature in ozone photochemistry, significant concentrations of ozone in the New York region occur in the warmer months, i.e., May through October. The current national ambient air quality standard for ozone is an eight hour average concentration of 80 parts per billion, a level often exceeded in the New York region.

For modeling runs downscaled from the global to the regional and urban scales, we defined a modeling domain that included the eastern half of the United States. The health impacts domain was defined as the 31 county New York metropolitan region (NYMR), comprised of parts of northern New Jersey, western Connecticut, and southern New York State and Long Island. Within this region, we assessed impacts at a range of grid scales, with the finest scale being 4x4 km.

General circulation model (GCM) outputs were available on an hourly basis from the 1990s through the 2080s. Regional climate and air quality simulations on 36 km grids over the eastern US domain were carried out for the summer months of June-August for five consecutive mid-decadal years (i.e., 1993-97) of the 1990s, 2020s, 2050s, and 2080s. For finer resolution simulations at 12 and 4 km within the NYMR, episodes of high temperature and ozone levels were selected. For assessing public health impacts, we focused the analysis on the effects related to premature mortality.

Global Climate Modeling

Global climate modeling was carried out using the Goddard Institute for Space Studies' coupled atmospheric-ocean global climate model (GISS GCM), version III, with a grid resolution of 4° x 5° latitude and longitude. In this model, computations are made for nine vertical atmospheric layers and thirteen vertical ocean layers with realistic bathymetry. Global climate was simulated for the period 1850-2100 with the IPCC A2 and B2 greenhouse gas forcings. These include projected changes in CO₂, CH₄, N₂O, sulfates, CFC11, and CFC12. Full sets of general circulation model variables from these simulations for the selected 5-year time-periods were provided to the regional climate model groups for use as boundary conditions in their simulations. In addition, the GCM outputs for daily mean temperature at the earth's surface were used directly in health impact analyses within the New York metropolitan region.

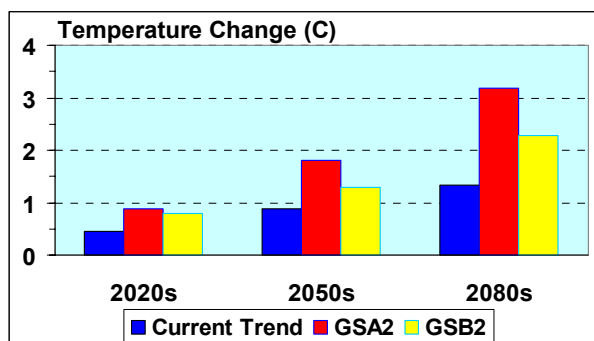


Figure 3 plots surface temperature projections over Central Park for three decades of the 21st century under the A2 and B2 scenarios expressed as changes from model estimates for the 1990s. Decadal values represent tri-decadal averages (e.g., 2020s = average of the 2010s, 2020s and the 2030s). Results show progressive regional warming in both the A2 and B2 scenarios, with stronger climate effects present in the A2 scenario with the greater greenhouse gas forcing. By the 2080s, the projected temperature increases for the region range from 2.0-2.5°C in B2 scenario and 3.0-3.5°C in the A2 scenario.

Figure 3. Projected temperature increases for Central Park, NYC.
("Current Trend" is based on 1900- 2000 data.)

Regional Climate Modeling

To assess regional and local impacts of climate change in the New York metropolitan region, we first had to devise a way to link the global GISS GCM model with a smaller-scale regional climate model, known as MM5. We utilize MM5 simulations driven by the GISS GCM through boundary and initial condition inputs that were performed for the summer seasons (June–August) for five consecutive mid-decadal years (e.g., 1993-1997) in the 1990s, 2020s, 2050s, and 2080s. The MM5 was applied in a nested-grid mode, with an inner grid having a horizontal resolution of 36 km over the eastern U.S. and an outer grid having a horizontal resolution of 108 km covering most of the continental U.S. Figure 4 shows observed and simulated surface temperatures for the 1990s generated from the GISS GCM and by MM5 running at 108 and 36 km scales. Recent MM5 modeling at 4 km has incorporated altered land surface characteristics associated with land use projections for the region. The 36 and 4 km simulations capture some of the spatial detail that is missed at lower resolution, such as over the Appalachian Mountains and the higher temperatures associated with urban areas through the "heat island" effect. Results from these simulations were used to evaluate regional health impacts of temperature extremes and were used to perform air quality simulations.

Preliminary findings from the regional climate work include:

- The MM5 can be used in conjunction with the GCM output to obtain meaningful results for use in regional and local health impact studies, as well as planning future water resource and energy needs.
- For the current climate of the New York metropolitan region, finer-scale (36-km) GISS-MM5 simulations performed better than those of the coarse-scaled GISS GCM and GISS-MM5 at 108km.
- The results of downscaling simulations are highly sensitive to the choice of model physics parameterizations. The differences due to physics options in the region were at times as large ($\sim 2.5^{\circ}\text{C}$) as projected changes for the 2050s.
- Temperature and precipitation validation showed that two model configurations (MIBR and MIGR) compared best to observations in the 1990s over the US. The MIBR configuration performed better than MIGR in simulating the 1990s climate of the metropolitan region.
- The timing of precipitation determines the severity of climate change impacts that can occur in response to changes in the GCM forcing, as CO_2 and other greenhouse gas concentrations increase.
- GISS-MM5 simulations at 4-km resolution with more detailed land-use/land-cover characterization of urban areas and vegetation in the region, show improved representation of the urban heat island.
- GISS-MM5 projections of temperature and precipitation change for the 2050s (IPCC A2 scenario) showed similar patterns across the U.S., although localized differences did exist. For the New York metropolitan region, projected temperature increases in the 2050s showed a range of $2.1\text{--}2.5^{\circ}\text{C}$.

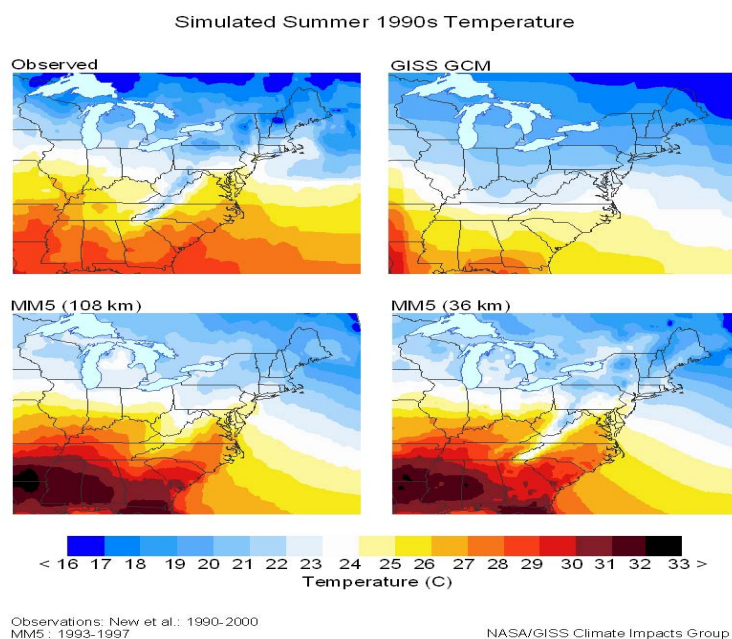


Figure 4. Observed and simulated surface temperatures for the 1990s at alternative scales.

Land Use Modeling

To evaluate future scenarios of urban land use change in the New York metropolitan region, we utilized the SLEUTH program with growth scenarios linked to the SRES A2 and B2 story lines. SLEUTH is an acronym for a set of growth-inducing variables that can be used to define land use change (Slope, Land cover, Exclusion zones, Land use, Transportation, and Hill shading), and it also employs a set of growth parameters (defined by the past patterns of urbanization), and growth rules. The software structure enables one to define future growth as a projection of past growth, as well as define alternative growth scenarios (e.g., slowed conversion, more rapid conversion).

Preliminary modeling work suggests that there could be significant land use and land cover change in the New York metropolitan region during the first half of the 21st century. For example, the Urban Growth Model (UGM) model projects a loss of 47 percent and 67 percent in 2020 and 2050, respectively, of the total non-urban land present in 1990 under the A2 scenario (Figure 5). The rate of conversion slows significantly during the 2020 to 2050 period because the number of available sites (i.e., pixels) becomes limited and instead an increased proportion of the new growth takes place as slower edge growth or transportation corridor related growth. Projected rapid conversion takes place where significant conversion had occurred during the period 1960 to 1990 and where the development potential was high (e.g., areas with relatively flat terrain, access to highways, etc.). As a result, conversion was particularly extensive in eastern Long Island and central New Jersey. The more mountainous and isolated northern parts of the region incurred less development during the study period.

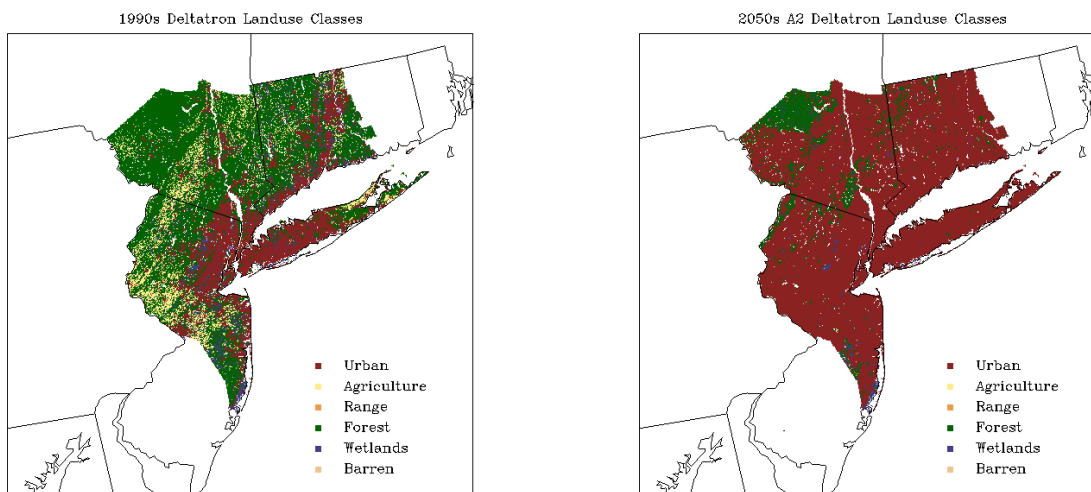


Figure 5. Maps of land use classifications for the 1990s (observed) and 2050s (projected by SLEUTH in the A2 scenario).

We also employed land use projections to alter land surface parameters used as inputs to the regional climate and air quality models. Land surface characteristics derived from satellite (Landsat) imagery—vegetation fraction and albedo—were used to help define predicted changes in urbanization in the 31-county region. Using these land surface qualities, the land use change estimates projected for the region were divided into three urban vegetation categories—low, medium and high density urban.

The model results have utility for both public health exposure and risk analysis. Project work is being planned to use the urban land use model results to develop estimates of future population growth in the suburbanizing parts of the region at the US census tract level (spatial areas defined by approximately 5000 residents). The amount of urban land development in each tract will be associated to a relative increase in population.

Regional Ozone Modeling

For air quality simulations, we use the Community Multiscale Air Quality (CMAQ) model. The GCM/MM5 linked model provides the meteorological inputs needed for the air quality simulations. The outputs from the air quality simulations have been used to evaluate the modeling system against observed ozone data, to project future ozone concentrations throughout the 36 km eastern US modeling domain under different climate scenarios, and for assessing potential public health impacts based within the NYMR.

Climate change can influence the concentration and distribution of air pollutants through a variety of direct and indirect processes, including the modification of biogenic emissions, the change of chemical reaction rates, mixed-layer heights that affect vertical mixing of pollutants, and modifications of synoptic flow patterns that govern pollutant transport. For example, warmer temperatures can result in increased concentrations of photochemical oxidants, while many past studies have revealed the impact of meteorological conditions on episodes of high ozone concentrations.

Using this modeling system under the A2 scenario, we estimated hourly surface ozone concentrations over the 36 km domain for five mid-decadal summers in the 1990s, 2020s, 2050s and 2080s; results for the 1990s and 2050s are shown in Figure 6. This figure illustrates changes that may occur in summertime average daily maximum ozone concentrations due purely to projected climate change (top right panel), due purely to projected emissions changes (bottom left panel) and due to the combined effects of changes in both drivers (bottom right panel).

The most important findings of the air quality modeling and analysis component of the NYCHP are as follows:

- The GCM/MM5/CMAQ system performs well in simulating summertime regional-scale ozone climatology and the frequency and duration of extreme ozone events over the eastern United States under present-day conditions.
- The frequency and duration of extreme ozone events is predicted to increase under the A2 climate scenario for future decades.
- Regional climate change was found to cause significant increases in the simulated 4th-highest summertime 8-hr O₃ concentration in future years. This result implies that it may be important to consider the effects of a changing climate when planning for the future attainment of regional-scale air quality standards such as the U.S. NAAQS that is based on the 4th-highest annual daily maximum 8-hr O₃ concentration.

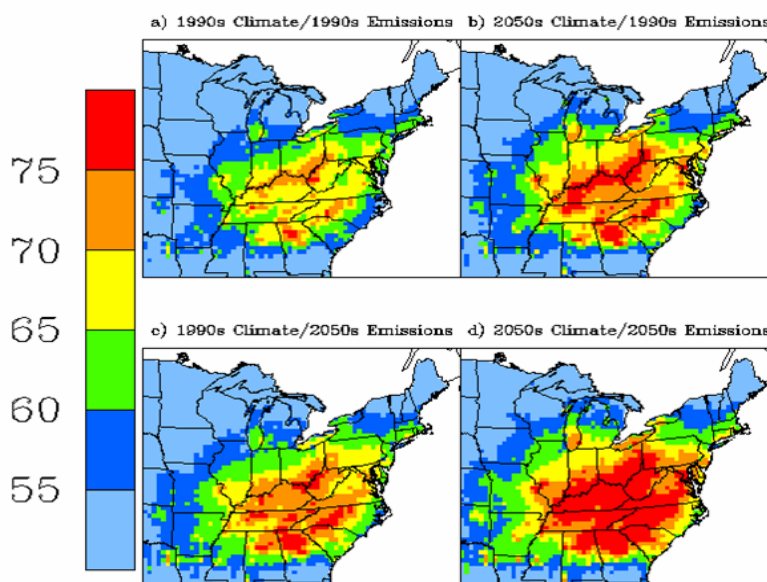


Figure 6. Summertime daily maximum 1-hour ozone concentrations, averaged over five mid-decadal years, from simulations with current/future climate/emissions.

Public Health Impact Assessment Methodology

The principal research objective of the NYCHP was to assess potential future health impacts of climate and land use change for the New York metropolitan region, for projected changes in both temperature and ozone. Future extensions may incorporate other parameters of weather and additional pollutants such as fine particulate matter.

Public health impacts were estimated using a risk assessment framework, with and without assumptions of population growth. Health impacts were assessed for ozone air quality (from simulated 1-hour daily maximum ozone concentrations, in ppb) and ambient temperatures (as daily mean temperatures in degrees Fahrenheit). Future changes in these two environmental stressors as simulated by the NYCHP model system were compared relative to conditions in the 1990s across the region, as taken from meteorological observations at the GCM scale or from interpolated CMAQ ozone and/or MM5 temperature simulations. Concentration-response coefficients for ozone and heat effects were taken from the recent environmental epidemiological literature.

Heat Stress and Human Health

In New York, as in other cities around the world, warm season heat waves can lead to elevated mortality and morbidity rates, especially during extended periods of hot weather that occur early in the season. Since 1998, summertime heat has been the top weather-related cause of mortality in the United States. The elderly and people with pre-existing illnesses are especially vulnerable populations, as are the very young, the bedridden, those living alone, and those with poor access to public transportation or air-conditioning.

Implications for Future Research

The NYCHP has developed an integrated modeling framework for assessing potential public health impacts of climate and land use changes at the regional scale. The results for temperature and ozone presented here illustrate the kinds of research and policy questions that can be explored using this framework. The integrated framework facilitates projections of climate and related health impacts at temporal and spatial scales relevant to local/regional planning. The risk assessment model framework for evaluating climate-related health impacts gives a high degree of transparency and adaptability to the integrated model system, which can be exported to other locales.

Over the next year we plan to continue this study, employing SLEUTH land use model projections at 4 km horizontal resolution to estimate future population density changes in the region. Applying these along with 4 km climate and air quality simulations, the health risk assessment model should be able to discern which local neighborhoods may be most vulnerable to climate-related changes in environmental health in future decades.

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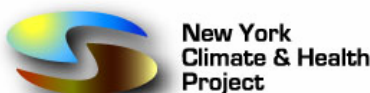
<http://www.geography.hunter.cuny.edu/luca/>

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