HEAT ADVISORY

How Global Warming Causes More Bad Air Days

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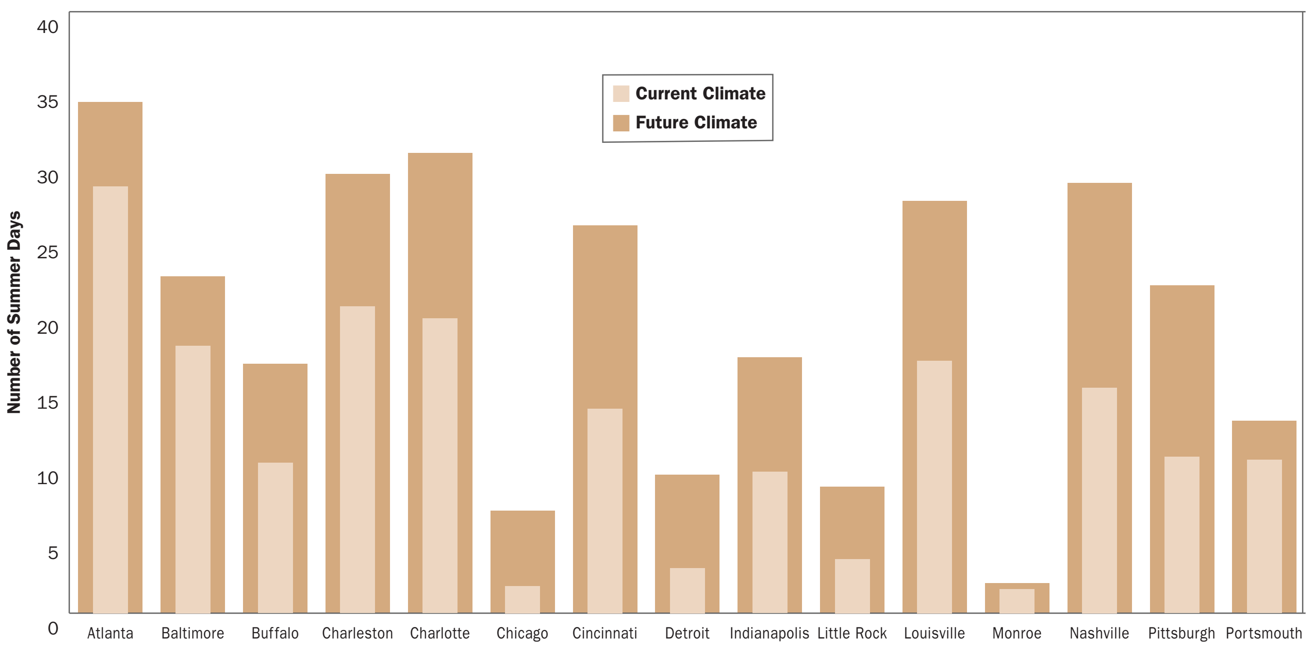
As global warming causes hot summer days to get hotter, concentrations of an air pollutant called ozone increase—forming lung-damaging pollution commonly known as smog. This report presents a comprehensive new analysis by medical experts at the Johns Hopkins University's Bloomberg School of Public Health and Columbia University's Mailman School of Public Health in collaboration with University at Albany SUNY, Yale University, and the University of Wisconsin-Madison. The analysis assesses how much smog levels could rise over the eastern United States because of global warming—and what that could mean for public health.

Smog is formed when pollutants from vehicles, factories, and other sources mix with sunlight and heat, which means that key air quality measures are highly sensitive to temperature. Researchers project under a climate change scenario that by mid-century people living in 15 cities in the eastern United States would see a 60 percent increase—from 12 to almost 20 days per summer—in the average number of days exceeding the health-based 8-hour ozone standard established by the U.S. Environmental Protection Agency (EPA) (see Figure ES-1). The number of unhealthy "red alert" days would double. Correspondingly, these citizens would enjoy, on average, nearly 20 percent fewer healthy air days in future summers because of global warming (see Figure ES-2).

Measured over 1-hour and 8-hour periods, ozone levels are ranked on a color-coded air quality index established under the Clean Air Act to determine the threat to public health. On red alert days, everyone—particularly children and people with asthma—is advised to limit outdoor activity.

FIGURE ES-1
Changes in Number of 8-Hour NAAQS Exceedance Days per Summer Due to Global Warming



On average across all the cities, there were 12 8-hour NAAQS exceedance days per summer for the current climate, and nearly 20 8-hour NAAQS exceedance days per summer for the future climate.

The findings mean that many more people would be forced to restrict outdoor activities. Those with asthma and other respiratory troubles face the most serious threats.

Examples of projected city-specific consequences include:

▶ Nashville, Tennessee, would see almost 14 more red alert summer days.

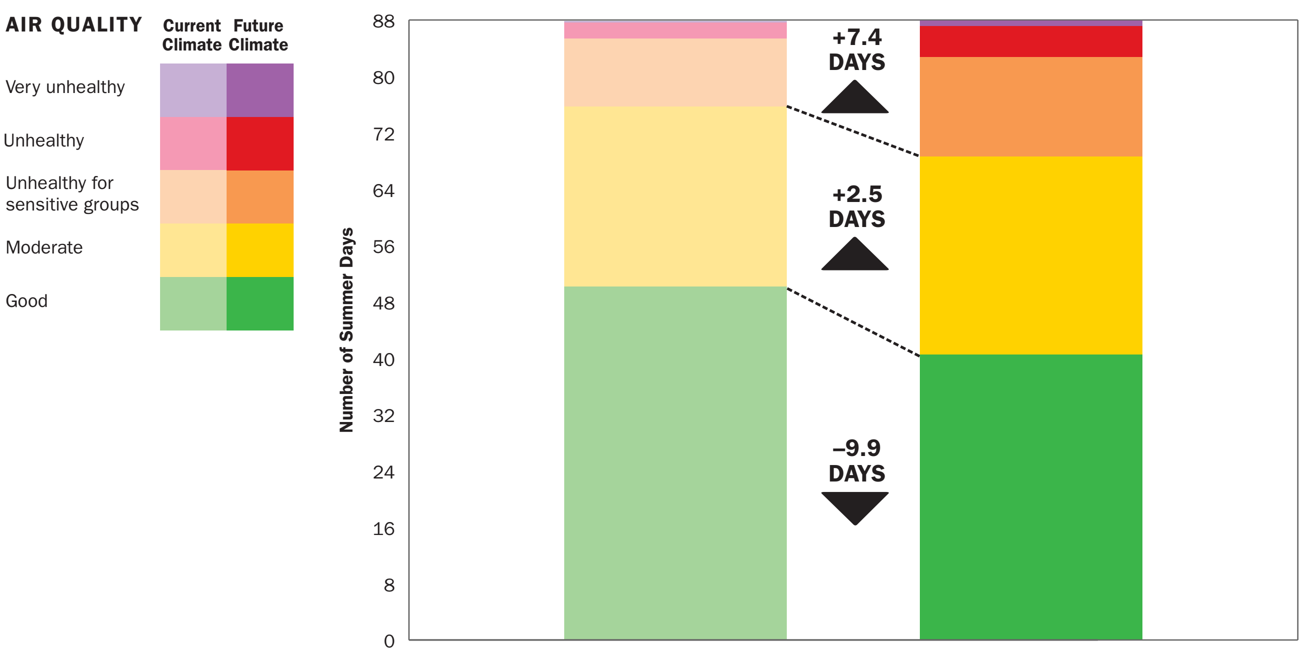
▶ Cincinnati, Ohio, would see a 90 percent increase (from 14 to 26) in the number of days when ozone levels exceed the health-based 8-hour air quality standard set by the EPA.

▶ Louisville, Kentucky, would see the highest rise among the study cities for asthma hospital admissions of people under 65 and mortality because of elevated ozone due to global warming.

▶ Portsmouth, New Hampshire, would see two "purple alert" days per summer—the most severe, and rare, health advisory issued, which calls for everyone to limit outdoor activities.

Higher smog levels trigger asthma attacks and make it difficult to breathe, particularly for children and the elderly. For people who have asthma, smog pollution can increase their sensitivity to allergens. And because carbon dioxide levels also are elevated, allergenic plants, such as common ragweed, produce more pollen.

FIGURE ES-2
Changes in Number of Healthy and Unhealthy Summer Days Due to Global Warming



Researchers project that by the middle of the century, people living in 15 cities in the eastern United States would see a 20 percent decrease in the number of healthy summer days and a 60 percent increase in the number of unhealthy summer days as a result of climate change.

Smog is a serious problem, and not only in the 15 cities studied for this report. More than 100 million Americans live in counties that do not comply with health-based air quality standards for ozone. Ozone is a persistent environmental health problem, despite the significant efforts that have been made to control emissions since enactment of the Clean Air Act in 1970.

Future air pollution control strategies should address heat-trapping pollution, such as carbon dioxide, as well as the pollutants that are direct precursors to ozone. Otherwise, the Clean Air Act's goal to provide all Americans with clean, healthy air to breathe could choke, and many Americans will suffer preventable illnesses—even death.

CHAPTER 1

Climate Change and Air Pollution

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More than 100 million Americans currently live in counties that do not comply with health-based air quality standards for ground-level ozone, commonly known as smog. Although many types of air pollution have been reduced in the United States since the 1970 Clean Air Act, improvements in ozone pollution levels have slowed since the 1990s. As a result, smog has become a persistent environmental health problem that can aggravate allergies and respiratory illness, particularly in children and the elderly.

What's more, ozone levels are more sensitive to temperature and weather than other air pollutants, suggesting that global warming could worsen the health risks from ozone. Rising temperatures across the eastern United States will increase smog, and this in turn could mean more hospital admissions from respiratory illnesses such as asthma.

In short, the increase in air pollution brought on by global warming may choke the Clean Air Act's goal to provide all Americans with clean, healthy air to breathe.

OZONE AS AN AIR POLLUTANT

Air pollution is the contamination of air by gases and particulates. Air pollutants result from both natural and human activities.[1] Human causes of air pollution include the burning of fossil fuels for transportation and power generation, industrial processes, and garbage incineration. Examples of air pollutants emitted by both natural processes and human activities include aerosols, nitrogen oxides, nonmethane volatile organic compounds, carbon monoxide, carbon dioxide, and methane.

The U.S. Environmental Protection Agency (EPA) has identified six types of air pollutants as "criteria" pollutants that are harmful to the public health and the environment:

- Carbon monoxide (CO)
- Lead (Pb)
- Nitrogen dioxide (NO_2)
- Ozone (O_3)
- Particulate matter (PM)
- Sulfur dioxide (SO_2)

OZONE PRECURSOR POLLUTANTS

Nitrogen oxides (NO_x) are produced from fossil fuel combustion by motor vehicles and by power plants and other industries. Nitrogen oxides are highly reactive gases that form when fuel is burned at high temperatures. Nitrogen oxides include various nitrogen compounds, principally nitrogen dioxide (NO_2) and nitric oxide (NO). The major mechanism for the formation of NO_2 in the atmosphere is the oxidation of NO. A suffocating, brownish gas, nitrogen dioxide is a strong oxidizing agent that reacts in the air to form corrosive nitric acid, as well as toxic organic nitrates. It also plays a major role in the atmospheric reactions that produce ground-level ozone (or smog).

Volatile organic compounds (VOCs) and oxides of nitrogen (NO_x) are precursors of ozone and are emitted from a variety of human and natural sources. Volatile organic compounds are produced by fossil fuel combustion, petroleum refining, surface coating (for example, painting), and the use of solvents. Another major source of these volatile compounds is natural forests and vegetation. Plant species responsible for biogenic VOC emissions of isoprene and monoterpenes vary by region of the country and include oak, maple, citrus, hickory, spruce, fir, eucalyptus, and pine. These biogenic emissions play a crucial role in ozone formation. In fact, in some regions, biogenic emissions of VOCs are greater than anthropogenic emissions. Therefore, increases in biogenic VOCs caused by higher temperatures could have a significant impact on ozone concentrations.

Sources: Seinfeld, J.H., and Pandis, S.N, *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*, John Wiley & Sons, New York, 1998; and Guenther, A., et al., *Natural emissions of non-methane volatile organic compounds, carbon monoxide, and oxides of nitrogen from North America,* Atmospheric Environment 34(12-14, 2000): pp. 2205–2230.

There are currently no federal regulations limiting emissions or concentrations of carbon dioxide, the heat-trapping pollutant primarily responsible for global warming.

Under the Clean Air Act, National Ambient Air Quality Standards (NAAQS) are established for these criteria air pollutants at levels designed to protect public health. There are currently no federal regulations limiting emissions or concentrations of carbon dioxide, the heat-trapping pollutant primarily responsible for global warming.

What Is Ozone?

Ozone is a colorless gas that is present in both the upper atmosphere (stratosphere) and the lower atmosphere (troposphere). Stratospheric ozone forms a protective layer around the earth that absorbs harmful ultraviolet radiation (UV-B). Nearer to the ground, in the troposphere, a significant amount of ozone is formed when its chemical precursors—nitrogen oxides (NO_x) and volatile organic compounds (VOCs)—interact in the atmosphere in the presence of heat and sunlight.[2]

Global emissions of nitrogen oxides are associated mainly with human activities: fossil fuel use, biomass burning, and aircraft. Natural sources for NO_x include microbial activity in soils, lightning, and transport from the stratosphere.[3] Both ozone and particulate matter formed in the atmosphere (secondary aerosols) may share common precursor species such as NO_x (see *Ozone Precursor Pollutants,* above).

As stratospheric ozone is depleted, more ultraviolet radiation reaches the earth's surface, where it can affect tropospheric ozone, especially in polluted regions that have abundant ozone precursor gases. This is because heat and ultraviolet light are required in the chemical reaction between NO_x and VOCs to form ozone.

Patterns of ozone concentrations on the earth's surface are affected by a number of factors, including emission densities, seasonality, changing weather conditions, and atmospheric transport. Ozone, along with its precursors, can be carried hundreds of miles from the original pollution source by wind and weather (called *atmospheric transport*). Temperature, cloudiness, and atmospheric transport modify the impact of UV-B. And changes in the chemical composition of the atmosphere, including aerosols, will have an impact on ozone concentrations.[4]

Ozone Levels in the United States

According to the EPA, ozone levels have decreased over the past 10 to 25 years as a result of emission controls mandated by the Clean Air Act. However, the downward trend is slowing.[5] What's more, an EPA ozone report says:

> *Nationally, 2003 was a good year for ozone air quality. Much of the good news can be attributed in part to favorable weather conditions across many parts of the nation. . . . For the eastern half of the country, the height of ozone season (June through August) was cooler and wetter than normal; therefore, it was less conducive to the formation of ozone than in past years.*[6]

In fact, the EPA says that the number of summertime days above 90 degrees Fahrenheit is one of the indicators of conditions favorable to ozone formation. Despite improving air quality and downward trends in most criteria pollutants, ozone will become more challenging to grapple with in a warmer atmosphere. Even if further reductions in air pollution emissions are achieved, what happens if global warming brings hotter and dryer summers over much of the United States? How might such warmer temperatures alter ozone air pollution—the most weather-sensitive pollutant—and what are the resulting health risks?

Even if further reductions in air pollution emissions are achieved, what happens if global warming brings hotter and dryer summers over much of the United States?

CLIMATE CHANGE EFFECTS ON AIR POLLUTION

Theoretically, global warming has the potential to increase average ambient concentrations and the frequency of episodes of ozone pollution. As stated in a health report of the U.S. National Assessment on Climate Change, climate change may affect people's exposure to air pollutants by affecting weather, anthropogenic emissions (human-caused), and biogenic emissions (caused by living organisms), and by changing the distribution and types of airborne allergens.[7] Local temperature, precipitation, clouds, atmospheric water vapor, wind speed, and wind direction influence atmospheric chemical processes, and interactions occur between local and global-scale environments.

If the climate becomes warmer and more variable, air quality is likely to be affected for three reasons.[8]

First, weather influences the dispersal and ambient concentrations of many pollutants, in addition to its effects on chemical reaction rates. For example, large high-pressure systems often create a temperature inversion, trapping pollutants in the boundary layer at the earth's surface. It has been suggested that with climate change we are likely to see more instances of very hot weather combined with increases in air-pollutant concentrations.[9]

Second, higher temperatures increase ozone formation when precursors are present. This relationship is nonlinear, with a stronger correlation seen at temperatures above 32 degrees Celsius (90 degrees Fahrenheit). Ozone and nonvolatile secondary PM will generally increase at higher temperatures because of increased gas-phase reaction rates. Interannual temperature variability in California, for example, can increase peak O_3 and 24-hour average $PM_{2.5}$ by 16 percent and 25 percent, respectively, when other meteorological variables and emissions patterns are held constant.[10]

Third, woody plants, especially, emit important biogenic volatile organic compounds called *isoprenes.* Isoprene production is controlled primarily by leaf temperature and light. And biogenic VOC emissions are so sensitive to temperature that an increase of as little as 2 degrees Celsius (or 3.6 degrees Fahrenheit) could cause a 25 percent increase in emissions.[11] Therefore, temperature increases could raise ozone levels, in part from vegetative emissions, by increasing the concentration of precursor compounds.

Recent Observations of the Climate-Ozone Relationship

In the eastern United States and in Europe, most days when the levels of ozone exceed air quality standards occur in conjunction with slow-moving high-pressure systems around the summer solstice.[12] This is the period of greatest sunlight, when solar radiation is most intense and air temperatures are high. Episodes of high levels of ozone last three to four days on average and extend over a large area—greater than 600,000 square kilometers (or roughly 230,000 square miles).

During 1995 and 1998, the United States saw relatively high levels of ozone, probably due in part to hot, dry, and stagnant conditions. But in 2003, the United States experienced one of the cleanest ozone years in recent history. The reason had much to do with the unusually cool and wet summer in the eastern United States.

CHAPTER 2

Results of Climate Change Projections

Global warming is caused primarily by carbon dioxide from power plants, vehicles, and other sources. These emissions cause a buildup of carbon dioxide in the atmosphere, which keeps the sun's heat from escaping. This thickening blanket of heat-trapping pollution is raising temperatures all over the world.

Since the late 1950s, the global average surface temperature has increased by 1 degree Fahrenheit. Snow cover and ice extent have diminished, sea level has risen on average by 4 to 8 inches during the past century, and ocean heat content has increased.[13] Although natural climate variability may play a role in these changes, it cannot explain the magnitude, rate, and pattern of the changes. Panels of leading scientists assembled by the National Academy of Sciences and the Intergovernmental Panel on Climate Change have concluded that emissions of heat-trapping gases that have accumulated in the atmosphere are primarily responsible for the warming seen during the past 50 years.

Recognizing the issue, Congress set a mandate in 1990 for the U.S. Global Change Research Program to conduct a national assessment of the impacts of climate variability and change. This assessment integrates, evaluates, and interprets the findings of the program and discusses the scientific uncertainties associated with such findings. It also analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity. The report also analyzes current trends in global change, both human-caused and natural, and projects major trends for the next 25 to 100 years.[14] Midrange estimates for future climate change from the National Assessment report are a global mean warming of 5.5 degrees Fahrenheit and a sea level rise of 18 inches by the year 2100. Increased variability in the hydrologic cycle (more floods and droughts) is expected to accompany global warming. The rate of change in climate is faster now than in any period in the past 1,000 years.[15]

The climate models used in the national assessment forecast that the average warming across the United States will be in the range of 5 to 9 degrees Fahrenheit by the end of the twenty-first century. According to the assessment, summer conditions in New York might be more like those now experienced in Atlanta, summers in Atlanta might be more like those now experienced in Houston, and future summers in Houston might be more like those in Panama.[16]

For much of the eastern United States, increases in the heat index (which combines heat and humidity into an effective temperature) are estimated to be more extreme, in the range of 5 to 15 degrees Fahrenheit.[17] Minimum summer temperatures in the Northeast and mid-Atlantic regions are anticipated to rise by 5 degrees Fahrenheit, with summer maximum temperatures projected to increase by 2 to 11 degrees Fahrenheit. In wintertime, minimum temperatures are estimated to rise by 4 to 12 degrees Fahrenheit.[18]

LINKING CLIMATE AND AIR QUALITY MODELS

The ozone/health analysis in this report builds on the results of the climate change ozone model of the New York Climate and Health Project, based at Columbia University. That study is evaluating the effects of changing global climate and land-use on regional climate, air quality, and public health in the tri-state New York metropolitan region. The study aims to quantify the implications of global warming for regional air quality using the following methodology (see Appendix for more detailed information).

Summer conditions in New York might be more like those now experienced in Atlanta, summers in Atlanta might be more like those now experienced in Houston, and future summers in Houston might be more like those in Panama.

First, researchers validated the model results against observations for current climate conditions. The model simulations captured quite well the regional-scale ozone climatologic and longer-term fluctuations. The authors concluded that the model "is a suitable tool for the simulation of summertime surface temperature and ozone air quality conditions over the eastern United States in the present climate."[19] This evaluation of the modeling system against historical data is a critical step, ensuring confidence in the results as well as establishing a foundation for future projections of ozone air pollution.

Next, researchers looked at ozone concentrations for five consecutive summer seasons, starting in 1993. To evaluate future air quality, a scenario of heat-trapping gas emissions described by the United Nation's IPCC Special Report on Emissions Scenarios was used for the projections of climate in the 21st century. Researchers compared the ozone concentrations for the 1990s with climate simulations for three periods in the future, holding constant all other human contributions to ozone pollution. Average summertime daily maximum ozone concentrations in the eastern United States increased by 2.7 parts per billion (ppb) for a five-year span in the 2020s, 4.2 ppb for a five-year span in the 2050s, and 5.0 ppb for a five-year span in the 2080s.[20] In addition, both the frequency and the duration of extreme ozone events increased over the eastern United States.

The researchers then applied these climate-based increases in regional ozone to 15 cities in the eastern United States to arrive at projections for daily 1-hour maximum ozone concentrations, daily 8-hour maximum ozone concentrations, and daily average ozone concentrations for the 2050s.

OZONE POLLUTION PROJECTIONS OVER THE EASTERN UNITED STATES

Hourly ambient concentrations were estimated for each of 15 cities in the eastern United States for June 1 to August 31 for each of the following summers (Figure 2-1):

- Current climate: 1993, 1994, 1995, 1996, 1997
- Future climate: 2053, 2054, 2055, 2056, 2057

Note that this work investigated the effect of changes in climate and not changes in anthropogenic emissions. Thus, the corresponding increases in ozone levels are in response to changes in climate (for example, higher temperatures) rather than changes in anthropogenic emissions. (The model accounts for changes in biogenic emissions as a function of temperature.) This research was not intended to provide realistic estimates of future ozone concentrations, but rather the increase in ozone in direct response to changes in climate, holding anthropogenic emissions constant.

Other factors can influence regional ozone concentrations. These include changed boundary conditions (*i.e.,* ozone concentrations and other conditions at the edge of the modeling domain) and changed anthropogenic emissions within the modeling domain. Previous studies have implicated the growing contribution of global emissions and intercontinental transport of precursors affecting ozone levels in the United States.

The results of the model show, however, that regional climate change may be equally important in determining future attainment of regional air quality standards, which is based on extreme concentration events.[21] (However, it should be noted that future studies using fully coupled, multi-scale dynamics-chemistry models are needed to account for all interactions between emissions, climate, and air quality on

FIGURE 2-1
Map of Cities Analyzed in This Climate Change Study

TABLE 2-1
Changes in Ozone Concentrations (Levels with Future Climate-Levels with Current Climate)

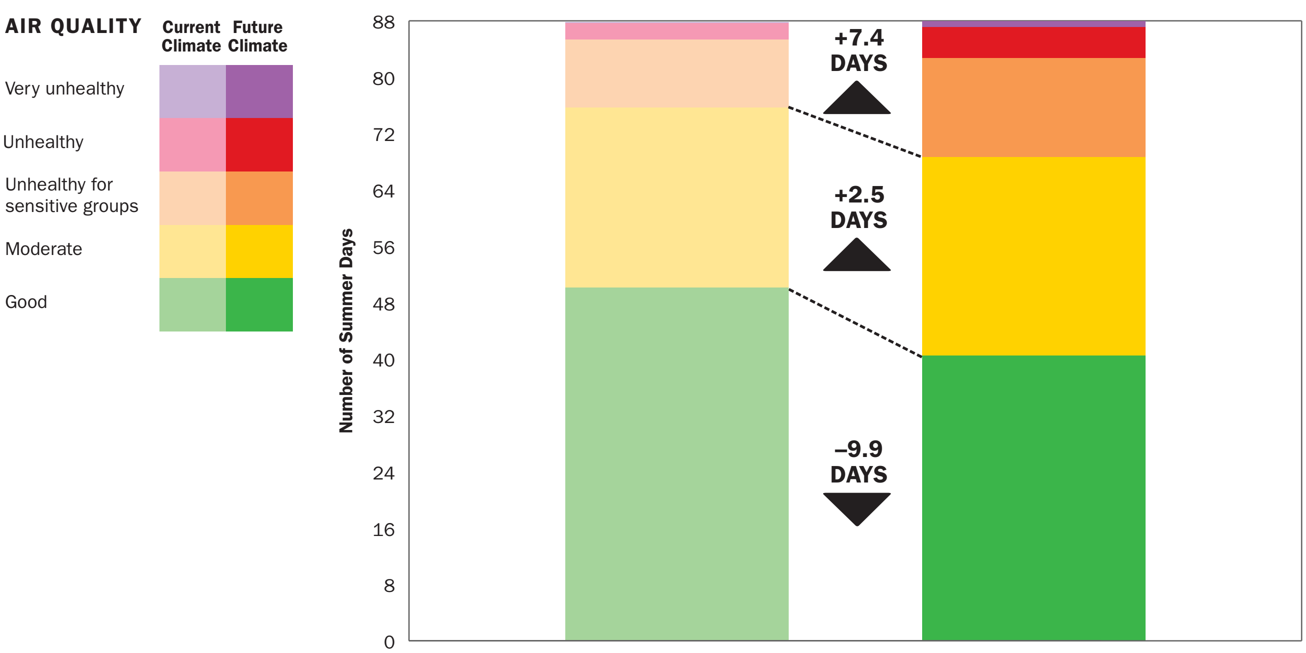
	Average Increase	Smallest Increase	Largest Increase
Daily average	3.7 ppb (8.1%)	–0.01 ppb (–0.02%)	6.4 ppb (13%)
Daily 1-hour maximum	6.3 ppb (9.2%)	0.58 ppb (1.1%)	9.6 ppb (14.3%)
Daily 8-hour maximum	5.7 ppb (9.2 %)	0.48 ppb (0.9%)	9.0 ppb (13.7%)

both regional and global scales and to investigate the relative impacts of various factors on regional air quality in a comprehensive manner for a range of climate and emission scenarios.)

Ozone levels averaged across the five future summers were compared to averages for five current summers. On average across the 15 cities, the daily average ozone levels increased 3.7 ppb, although there was substantial spatial variation (Table 2-1).

Table 2-1 shows the increase in ozone levels for several concentration measures. The elevated temperatures caused higher daily 1-hour maximum and daily 8-hour maximum ozone concentrations for all cities. The daily average for all cities was also raised by the climate change scenario, except for Monroe, Louisiana, which had basically the same daily average (0.01 ppb lower daily average for the climate change scenario). The largest increase in ozone levels for these cities was for Louisville, Kentucky, and the smallest increase was for Monroe, Louisiana, for all three concentration metrics listed in Table 2-1.

FIGURE 2-2
Number of Summer Days in Each Ozone Action Category for 15 Cities in the Eastern United States



Researchers project that by the middle of the century, people living in 15 cities in the eastern United States would see a 20 percent decrease in the number of healthy summer days and a 60 percent increase in the number of unhealthy summer days as a result of climate change.

Cities with higher existing pollution levels had larger increases in ozone. The largest increases are estimated to occur in Ohio, Indiana, Kentucky, West Virginia, and central North Carolina. The lowest increases in ozone levels take place in New Hampshire and Louisiana.

NAAQS Exceedances Results

The primary National Ambient Air Quality Health Standards (NAAQS) are established to protect human health with an adequate margin of safety. In 1997, the U.S. Environmental Protection Agency (EPA) proposed revisions to the NAAQS for ozone, adding a daily maximum 8-hour standard of 80 ppb and phasing out the daily hourly maximum standard of 120 ppb.[22] These changes were prompted by evidence from epidemiological, controlled human exposure, and toxicological studies. This research identified adverse health effects at ozone concentrations less than the existing 1-hour NAAQS and indicated that the 8-hour averaging time better reflects how human health is affected by ambient ozone.

We calculated the number of NAAQS exceedance days for each of the 10 summers for each city for both the 1-hour and the 8-hour NAAQS standards. Our aim was to estimate how the anticipated number of exceedance days would differ under the future climate scenario. An *exceedance day* occurs when ozone levels go above the regulatory standard; however, attainment is calculated using several years' worth of measurement data. In other words, an area could exceed the regulatory standard on a given day but still be within the standard, depending on the concentrations found on other days. However, an increase in the number of exceedance days would bring more areas into noncompliance.

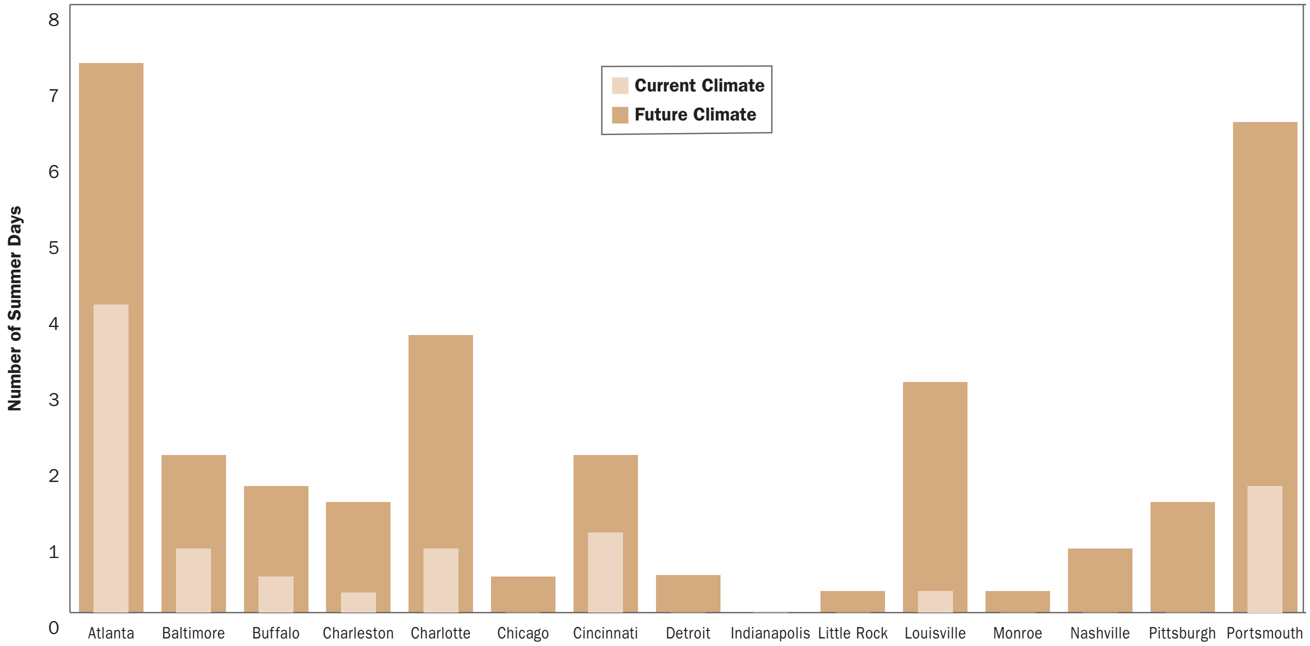
This research identified adverse health effects at ozone concentrations less than the existing 1-hour NAAQS and indicated that the 8-hour averaging time better reflects how human health is affected by ambient ozone.

Under the future climate calculation, all cities had more, or the same number, of exceedance days than under the current climate for both regulatory standards. Figures 2-3 and 2-4 depict the number of NAAQS exceedance days for each city for the 1-hour and 8-hour NAAQS, respectively. The light bars represent the average number of exceedance days per summer for the current climate, and the dark bars represent the number of exceedance days that would occur under the future climate.

For the 1-hour NAAQS, Indianapolis showed no estimated exceedance days under the current climate, whereas Chicago and Detroit averaged only 0.4 exceedance days. But all these cities had more exceedance days for the 2053 to 2057 summers. The largest increase was 4.8 additional exceedance days per summer for Portsmouth. On average across the 15 cities, there were 0.6 1-hour NAAQS exceedance days per summer for the current climate, compared with 2.0 for the future climate. Cities with higher preexisting ozone levels exhibited the largest increases in the number of exceedance days.

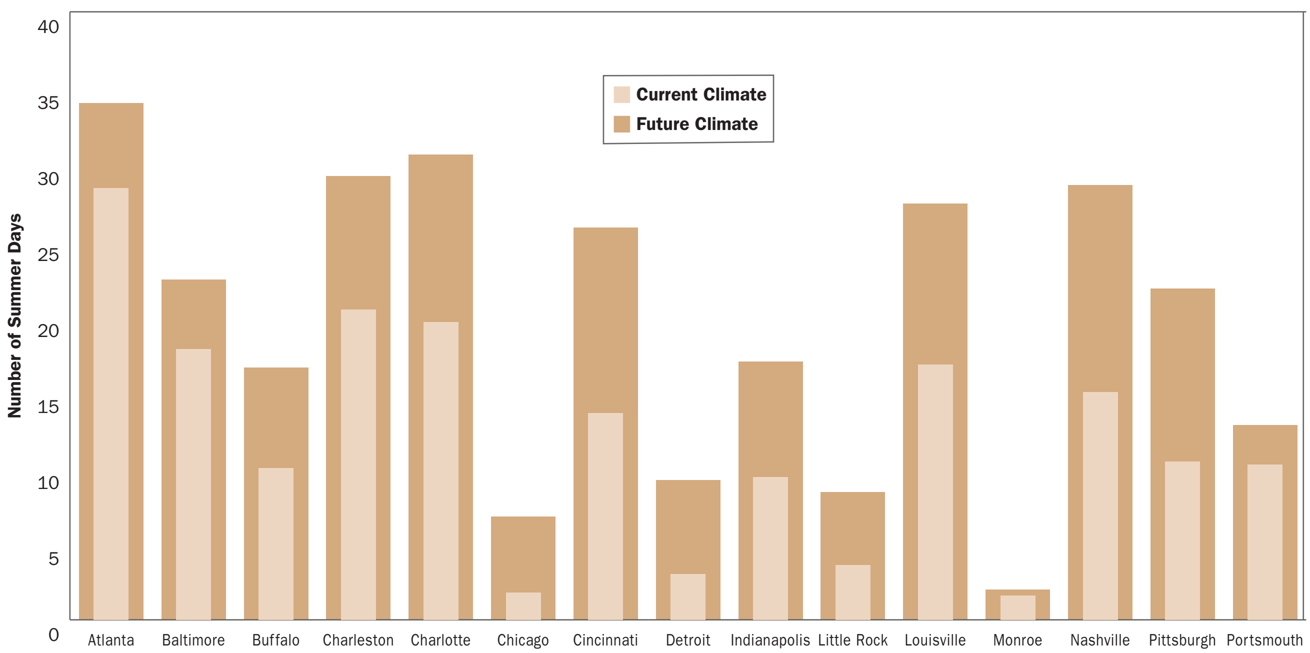
For both the current and the future climate, all cities had more, or the same number, of 8-hour NAAQS exceedance days as 1-hour NAAQS exceedance days. This is anticipated given that the 8-hour standard is expected to be more stringent than the original requirement.[23] On average across all the cities, there were 12.1 8-hour NAAQS exceedance days per summer for the current climate, as simulated by the modeling system, and 19.5 for the future climate. The largest increase was for Nashville, which went from 15 exceedance days to 28.6.

FIGURE 2-3
Number of 1-Hour NAAQS Exceedance Days per Summer



On average across the 15 cities, there was one 1-hour NAAQS exceedance days per summer for the current climate, compared with two 1-hour exceedance days per summer for the future climate. Cities with higher preexisting ozone levels exhibited the largest increases in the number of exceedance days.

FIGURE 2-4
Number of 8-Hour NAAQS Exceedance Days per Summer



On average across all the cities, there were 12 8-hour NAAQS exceedance days per summer for the current climate, and nearly 20 8-hour NAAQS exceedance days per summer for the future climate. The largest increase was for Nashville, which went from 15 to almost 30 exceedance days.

Increased Ozone Action Days

The Air Quality Index (AQI) provides an overall assessment of the health impacts of outdoor air with respect to several pollutants. The index is calculated by assigning an individual index to each of several pollutants (O_3 8-hour, O_3 1-hour, PM_{10}, $PM_{2.5}$, CO, SO_2, and NO_2) and then assigning the highest of these individual indices as the overall AQI for that day. The AQI can range from zero to 500, with zero representing the best air quality and 500 the worst. The AQI levels for ozone are listed in Table 2-2. Similar strata exist for the other pollutants.

Health advisories in the form of ozone alert days are evaluated by forecast ozone concentrations. An ozone *advisory* is issued when the ozone forecast has an orange AQI, whereas an ozone *alert* is declared when the ozone forecast has a red AQI. An ozone *health alert* is issued for code purple, although this is a rare occurrence.

We estimated the number of days under each AQI category for both climate scenarios and each city (see Figure 2-5). No city had maroon-level AQIs under either climate scenario. Even under the current climate, 42 percent of the summer days in these cities have moderate or unhealthy ozone concentrations, with an AQI of yellow or worse. Under the climate change scenario, 54 percent of the days have moderate or unhealthy ozone levels. The climate change scenario changed the distribution of AQI categories, with more days in each of the less healthy categories (yellow, orange, red, and purple) and fewer days in the good ozone levels category (green).

Every city had the same or more days with unhealthy ozone levels in the future climate.

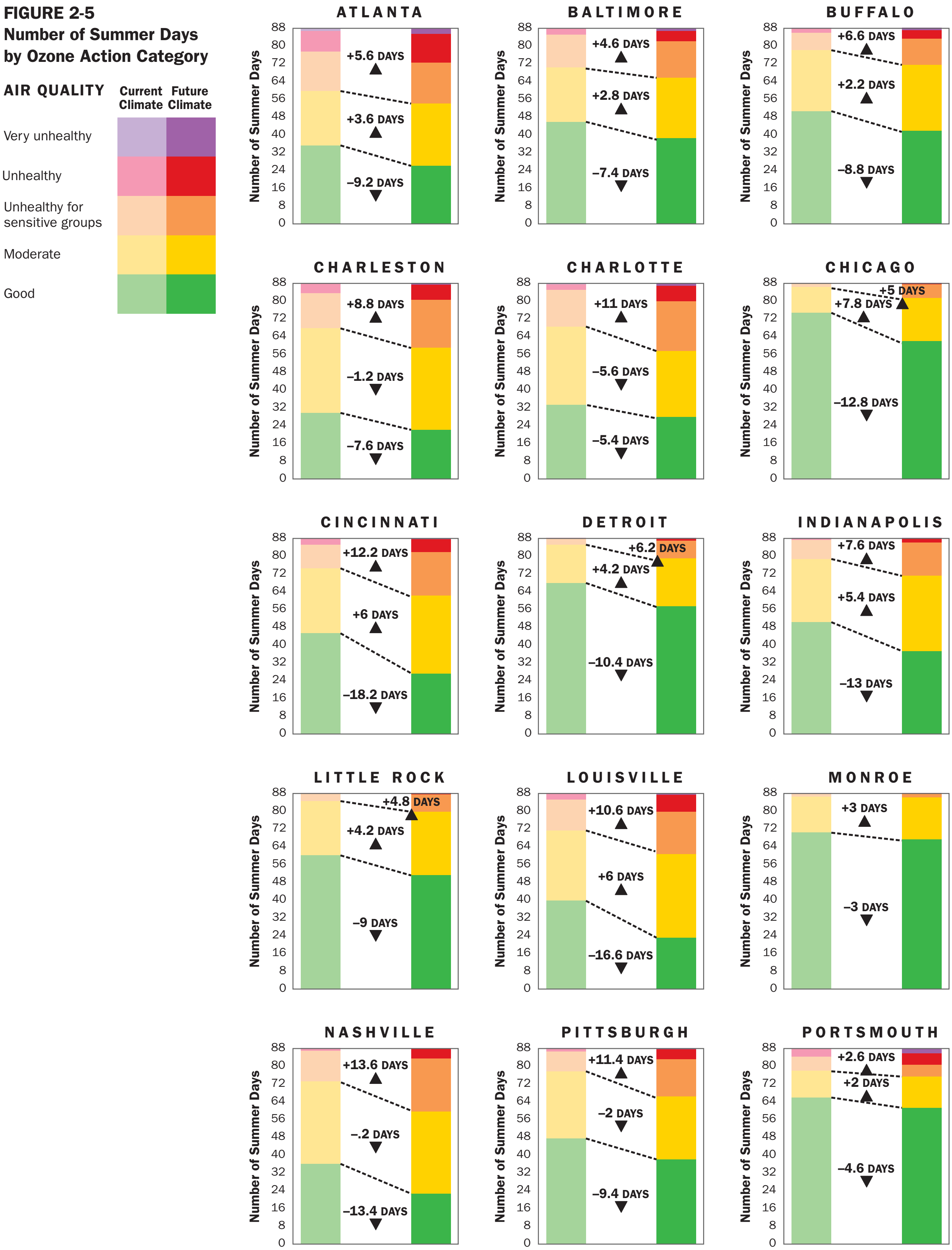
Every city had the same or more days with unhealthy ozone levels in the future climate. City-specific distributions of AQIs for each scenario are shown in Figure 2-6. All three of the cities without red or higher AQI levels in the current scenario (Chicago, Detroit, and Little Rock) reach red levels with the future climate. Three of the eight cities without purple-level AQIs under the current climate (Buffalo, Nashville, and Pittsburgh) reach those high ozone levels under the future scenario.

TABLE 2-2
Air Quality Index Levels for Ozone

AQI	O_3 (8-hour ppb)	O_3 (1-hour ppb)	Air Quality	Color Code	Health Advisory
0–50	0–64	0–84	Good	Green	None
51–100	65–84	85–124	Moderate	Yellow	Unusually sensitive people should consider limiting prolonged outdoor exertion.
101–150	85–104	125–164	Unhealthy for sensitive groups	Orange	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.
151–200	105–124	165–204	Unhealthy	Red	Active children and adults, and people with respiratory diseases, such as asthma, should avoid prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion.
201–300	125–374	205–404	Very unhealthy	Purple	Active children and adults, and people with respiratory disease, such as asthma, should avoid all outdoor exertion; everyone else, especially children, should limit outdoor exertion.
301–500	375+	405+	Hazardous	Maroon	

Source: Bey, I., et al., *Global modeling of tropospheric chemistry with assimilated meteorology: Model description and evaluation*, J. Geophys, Res., 2001.

FIGURE 2-5
Number of Summer Days by Ozone Action Category



INCREASES IN ALLERGENIC POLLEN

Allergic diseases affect approximately 17 percent of the U.S. population and cost the health care system $18 billion per year. Nearly 40 million people suffer from hay fever, resulting in almost four million lost days of work and school.[24] Asthma is a severe form of allergic disease, and from 1980 to 1994 the Centers for Disease Control and Prevention (CDC) estimated that the number of preschool-aged children with asthma increased as much as 160 percent.[25]

It has been suggested that climate change will increase exposure to natural allergens (see *Rationale for the Interrelationship Between Air Pollution and Allergens That Induce Respiratory Allergy,* below). In Europe, the flowering (and hence pollen release) of birch trees has trended to earlier dates in spring over a 40-year data record that is highly correlated with warming trends.[26] Climate change could therefore shift the timing and distribution (and, potentially, the allergenicity) of pollen, with subsequent effects on the occurrence and severity of asthma and allergic reactions.

One of the most predictable aspects of global warming is the ongoing increase in atmospheric carbon dioxide (CO_2) and changes in seasonality. Both aspects will affect the biomass of plants, making them larger at maturity and consequently able to produce more pollen, a result that may significantly increase human exposure to allergenic pollen.[27] Besides increased pollen production, some plant species have also shown higher allergenic content in samples collected from sites with higher daily mean temperature. Further research is needed to confirm these results in other allergen-containing plants.[28]

It has been suggested that climate change will increase exposure to natural allergens.

In addition to being the principal gas associated with climate change, carbon dioxide is also the sole supplier of carbon for photosynthesis. Because 95 percent of all plant species are deficient in the amount of CO_2 needed to operate at maximum efficiency, the recent rise in atmospheric CO_2 and future projected increases have already stimulated plant growth, and should continue to, with the degree of stimulation being temperature dependent.[29] This stimulation, however, includes undesirable as well as salutary plant species.

RATIONALE FOR THE INTERRELATIONSHIP BETWEEN AIR POLLUTION AND ALLERGENS THAT INDUCE RESPIRATORY ALLERGY

Three compelling reasons provide a rationale for the interrelationship between air pollution and allergens as a cause of respiratory allergies. First, components of air pollution can interact with pollen grains, leading to an increased release of antigens characterized by modified allergenicity. Second, components of air pollution can interact with allergen-carrying particles. Some of these are derived from plants and can reach small airways with inhaled air, inducing asthma in sensitized people. And third, components of air pollution—especially ozone, particulate matter, and sulfur dioxide—have an inflammatory effect on airways, causing increased permeability and easier penetration of pollen allergens in the mucous membranes, and subsequent interaction with the immune system.

Source: D'Amato, G., et al., *The role of outdoor air pollution and climatic changes on the rising trends in respiratory allergy*, Respir Med 95(7, 2001): pp. 606–611.

The undesirability of plants can extend to impacts on human health. In general, plants are recognized as directly affecting health through allergenic reactions, contact dermatitis, mechanical injury, and internal poisoning. How, then, have past or projected changes in atmospheric carbon dioxide and/or temperature mediated the growth of such plants?

Overall, our current understanding regarding the interaction of plant biology, rising carbon dioxide, and public health remains limited. However, preliminary growth chamber and greenhouse investigations have indicated a significant stimulation in the growth and pollen production of common ragweed (*Ambrosia artemisiifolia*) in response to recent and projected CO_2 concentrations.[30] (CO_2 concentrations increased from 280 ppmv, or parts per million by volume, at the end of the 19th century to 375 ppmv currently; CO_2 concentrations are projected to rise to 600–720 ppmv by the end of the 21st century.) Although this information is intriguing, its application to *in situ* environments is unclear since these investigations were conducted under optimal, indoor conditions and did not consider the issue of increased air temperature.

Elevated CO_2 and temperature resulted in threefold and sixfold increases in peak pollen production and seasonal pollen production.

To further investigate the interactions between ragweed biology and climate change, an urban-rural transect (sample area) differing in temperature and CO_2 concentration was used to determine ragweed sensitivity to climate. From 2000 and 2001, measurements from weather stations along the transect indicated that average daily (24 hour) values of CO_2 concentration and air temperature within an urban environment were 30–31 percent and 1.8–2.0 degrees Celsius (or 3.4–3.6 degrees Fahrenheit) higher than those at a rural site (Table 2-3).[31] These results are consistent

TABLE 2-3
Temperature, CO_2 Variability, and Ragweed Pollen Production from Rural to Urban Areas in Baltimore

Site Description	[CO_2]	+Avg. (°C)	Pollen Peak	Pollen Sum.
2000				
Rural farm site, control	386±19.0 b		211 c	1751 b
County park, semi-rural	398± 5.5 b	+0.7 c	481 b	1881 b
Baltimore suburb	461±35.1 a	+1.0 b	724 a	6537 a
Downtown Baltimore	489±44.1 a	+1.8 a	NA	NA
2001				
Rural farm site, control	389±18.1 b		228 b	2294 b
County park, semi-rural	399±21.9 b	+0.6 c	338 b	3262 b
Baltimore suburb	501±55.9 a	+1.1 b	845 a	13204 a
Downtown Baltimore	511±46.6 a	+1.9 a	729 a	12138 a

Source: Ziska LH et al. *Cities as Harbingers of climate change: Common ragweed, urbanization and public health.* Journal of Allergy and Clinical Immunology, 111: 290–295.

Location and description of data collection sites along the rural/urban transect. Data are average concentration of atmospheric carbon dioxide (p.p.m.v.±SE), and average increase in daily temperature (+Avg., °C) relative to the rural farm site. All data were determined as daily (24-h) averages along an urbanization gradient from day of year DOY 93–DOY 270 for 2000 and 2001. DOY 93–DOY 270 correspond approximately to the growing season for common ragweed at this latitude. NA: Although meteorological data were taken, permission from city authorities to grow ragweed was not given for downtown Baltimore (Science Center) in 2000. Data were analyzed for each year using a one-way ANOVA with site (i.e. CO_2/temperature gradient) as the classification variable. Different letters within a column for a given year indicate significant differences as determined by Fisher's protected lsd ($P<0.05$).

with most short-term (50–100 year) Intergovernmental Panel on Climate Change projections regarding climate change.

Remaining meteorological variables (wind speed, humidity, light, rainfall) did not differ consistently between urban and rural areas. As expected, urban ozone values were high (relative to the accepted standards of the EPA); however, a separate sensitivity analysis to ozone was conducted for the same seed lot of ragweed used in this study. This analysis indicated that the time of pollen release was not affected by the effect of urban ozone levels on ragweed biomass or reproductive growth.[32]

Therefore, it seems likely that the CO_2 and temperature increases associated with urbanization were the principal drivers associated with the earlier flowering times, greater aboveground biomass, and increased pollen production observed in common ragweed.[33] These urban-induced increases in CO_2 and temperature (compared to the rural plots) resulted in threefold and sixfold increases in peak pollen production and seasonal pollen production.

Although the current research examined only a single species, empirically, urban-induced effects related to CO_2 and/or temperature would also be expected to alter seasonal pollen production of other allergenic plants, including tree and grass species.

Climate change has the potential to alter expected improvements in ozone air quality (and possible allergenic pollen) over much of the United States, and significant health implications could follow.

CONCLUSIONS

Since the Clean Air Act of 1970, air pollution across the United States has improved for many pollutants, but unhealthy levels persist. Ground-level ozone pollution is the most temperature- and weather-sensitive air pollutant, and improvements in ozone levels have slowed since the 1990s. More than 100 million U.S. citizens live in counties that are noncompliant with current EPA ozone standards, thereby making ozone pollution a persistent environmental health challenge.

Although the future may bring more stringent limits on emissions of precursors of ozone (namely, NO_x and VOCs), implying a hopeful scenario for ozone air quality in the United States, this optimism assumes no change in future climate. Many other variables, of course, are also important. Examples included international transport of precursor pollutants (thus, future emissions from Asia will need to be considered), changes in land use, and technological advancements.

Climate projections for the United States include warmer summer temperatures and mid-continental droughts. Holding ozone precursor emissions constant to isolate the effects of global warming, a model system based on a climate change-only scenario shows an average ozone increase of 4 ppb across the eastern United States by the mid-2050s. Additionally, ragweed pollen and other allergens respond to increases in both temperature and CO_2 levels.

In short, climate change has the potential to alter expected improvements in ozone air quality (and possible allergenic pollen) over much of the United States, and significant health implications could follow. Future air pollution projections must therefore address heat-trapping pollutants like carbon dioxide as well as a multitude of determinants of other air pollution emissions. Without such considerations, future health risk estimates will be inaccurate, and preventable illness and deaths will occur.

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CHAPTER 3

Projections of Health Effects Resulting From Climate Change

Inhaled ozone causes an inflammatory response, manifested by increased airway permeability and bronchial hyperactivity. In controlled clinical studies, breathing ozone has been linked to reduced pulmonary function, increased cough, and chest tightness. There is a marked and unpredictable individual variability in sensitivity to ozone. What's more, there is some evidence that ground-level ozone might worsen the effects of allergens in people with asthma.[34]

In vitro animal studies of acute ozone exposure have shown increased airway permeability and inflammation, as well as morphological, biochemical, and functional changes such as decreased host defense functions.[35] Reduced lung function and physical performance, increased airway reactivity, and acute inflammation have been found at exposure levels as low as 80 parts per billion (ppb).[36]

HEALTH EFFECTS OF OZONE

Outdoor work, play, and exercise increase the amount of air pollution people inhale. During morning and evening rush hours, peak levels of pollutants from vehicle exhaust are emitted, and after daytime temperatures rise (and given a sunny day with ample UV-light reaching the ground), the high numbers of people returning from work and school result in high population exposure. And children engaged in after-school sports, or adults exercising after work, magnify exposure to ozone. Other health effects of ozone include an increase in hospital admissions and even premature mortality. Ozone exposure has also been linked to school absenteeism and restricted activity days.

Exacerbating Asthma

Exposure to ozone heightens the sensitivity of asthmatics to allergens and impairs lung function, especially in children and the elderly.[37] In many places, including Atlanta and Mexico City, ozone has been linked to increased hospital admissions for lower respiratory infections and asthma in children.[38]

Alternative transportation policies put in place during the 1996 Olympic games in Atlanta reduced vehicle exhaust and related air pollutants by about 30 percent. During that time, the number of acute asthma attacks fell by approximately 50 percent, and pediatric emergency admissions dropped 19 percent. Decreased traffic density during the games, especially during the critical morning periods, was

VULNERABLE POPULATIONS

Young children, the elderly, and those with preexisting respiratory problems are at most risk from adverse health effects of air pollution.

Children

Evidence is mounting that children are especially susceptible to ill effects of ozone (O_3). Children spend significantly more time outdoors, particularly during summer when ozone levels are highest. Children also spend more time exercising, and their higher ventilation rate brings more pollution deep into the lungs. Infants' lungs are not fully developed at birth. The new tissue that grows during childhood is more sensitive to air pollutants. Also, unlike adults, children are less able to rid their bodies of harmful toxins.

Even at low levels of ambient ozone, children with severe asthma using maintenance medication are particularly vulnerable to O_3 and are at a significantly increased risk of experiencing respiratory symptoms. A 50 ppb increase in O_3 corresponded to a 35 percent increase of self-reported wheezing and 47 percent increase in those reporting chest tightness. It is also possible that ozone air pollution may actually lead to the development of asthma in children, as opposed to simply exacerbating existing disease. Controlling for the level of activity in children playing after-school sports, the relative risk of developing asthma was 3.3 times higher in communities with high ozone, versus low-ozone-polluted communities in a study from Southern California. Also, the fall in acute asthma events (approximately 50 percent reduction), as well as decrease in emergency room and hospital admissions of children during the Atlanta Olympics, paralleled a drop in traffic-related ozone pollution.

The Elderly

Breathing ability diminishes over time, and therefore, even the healthy elderly are at an increased risk from exposure to ozone and other air pollutants, which further reduces their lung function. Ozone pollution, for example, also increases susceptibility to infections such as the flu and pneumonia, which are especially dangerous for the elderly. The elderly tend to have more difficulty clearing particles from their lungs, and their immune system is more susceptible to be compromised by air pollution.

In addition, ozone can significantly worsen the condition of people with chronic bronchitis and emphysema, and since most of these diseases occur in the elderly population, the elderly are at special risk for exposure to ozone. The association between daily variations in ozone and cause-specific mortality was found to be higher in the warm season and among persons aged 65 years or over.

The Predisposed *(people with existing chronic cardiac and respiratory disease such as chronic obstructive pulmonary disease (COPD) and asthma)*

Air pollution facilitates the development of allergies in predisposed subjects and the worsening of symptoms in subjects that are already allergic. Exposure to NO_2 and ozone may prime the eosinophils to subsequent activation by inhaled antigen in atopic subjects, and result in increased airway reactivity to nonspecific and specific broncho-constrictor agents. Ozone exposure has both a priming effect on allergen induced responses as well as an intrinsic inflammatory action in the nasal airways of allergic asthmatics.

In summary, whether they are vulnerable to environmental health dangers because of age, developmental stage, a preexisting health condition, or economic situation, these vulnerable populations bear the brunt of public environmental health problems.

Sources: Gent, J.F., et al., *Association of low-level ozone and fine particles with respiratory symptoms in children with asthma,* Jama, 2003. 290(14): p. 1859–67; McConnell, R., et al., *Asthma in exercising children exposed to ozone: A cohort study,* Lancet, 2002. 359(9304): p. 386–91; Friedman, M.S., et al., *Impact of changes in transportation and commuting behaviors during the 1996 Summer Olympic Games in Atlanta on air quality and childhood asthma.* Jama, 2001, 285(7): p. 897–905; Edwards, P., *Climate change, air pollution and your health,* 2001, 92(3): p. suppl-24; Goldberg, M.S., et al., *Associations between daily cause-specific mortality and concentrations of ground-level ozone in Montreal, Quebec,* Am. J. Epidemiol., 2001, 154(9): p. 817–26; Burnett, R.T., et al., *Association between ozone and hospitalization for acute respiratory diseases in children less than 2 years of age,* Am. J. Epidemiol., 2001, 153(5): p. 444-52; and D'Amato, G., et al., *Respiratory allergic diseases induced by outdoor air pollution in urban areas,* Monaldi Arch. Chest. Dis., 2002. 57(3-4): p. 161–3.

associated with a prolonged reduction in O_3 pollution and significantly lower rates of childhood asthma events.[39]

There is some recent evidence that ozone triggers and worsens asthma attacks. In fact, recent data suggest that even at low levels of ambient ozone (and controlling for ambient fine particle concentration), children with severe asthma using maintenance medication are particularly vulnerable to O_3 and are at a significantly increased risk of experiencing respiratory symptoms.[40] The researchers found that O_3 was significantly associated with respiratory symptoms and the use of rescue medication among those using maintenance medications. A 50 ppb increase in O_3 corresponded to a 35 percent increase in self-reported wheezing and a 47 percent increase in those reporting chest tightness.[41]

It is also possible that ozone air pollution may actually lead to the development of asthma in children, as opposed to simply exacerbating existing disease. Controlling for the level of activity in children playing after-school sports, the relative risk of developing asthma was 3.3 times as high in communities with high ozone as in communities with low ozone.[42]

It is also possible that ozone air pollution may actually lead to the development of asthma in children, as opposed to simply exacerbating existing disease.

Morbidity and Mortality

Levels of sulfate have been found to significantly correlate with relative humidity in the summer. The concentration of resultant acid aerosols was a strong predictor of summer hospital admissions for respiratory causes. On peak pollution days, summertime haze (composed of mostly ozone and acid aerosols) was associated with about half of all respiratory admissions.[43] Over a 15-year period, daily mortality was associated with hot days in summer and high ozone levels in Philadelphia.[44]

Both chronic and acute exposures to fine particles cause increased mortality.[45] Furthermore, concurrent hot weather and particulate air pollution can have interactive impacts on health.[46] A coordinated project in 12 European cities has found that the effects of sulphur dioxide and black smoke on mortality were stronger during the summer.[47]

Recent studies have examined the health effects of exposure to extreme heat and air pollution to determine whether there are potential synergistic effects related to simultaneous exposure. One study found interactions between high levels of sulfur dioxide and high temperature (30 degrees Celsius) in Athens, Greece.[48] Another study found that mortality during the Belgium heat wave of 1994 was correlated with mean daily temperature and 24-hour ozone concentration from the previous day.[49]

A devastating 2003 heat wave killed an estimated 15,000 people in France in a matter of weeks.[50] In England and Wales, more than 2,000 excess deaths were reported from August 4 through August 13. Approximately one-fourth to one-third of those deaths have been attributed to ozone and particulate air pollution (especially ozone), which shot up in concentration along with the soaring temperatures.[51] The extent to which the severity of the European heat wave falls far outside the current distribution of weather is consistent with expectations of future climate change scenarios.[52]

HEALTH EFFECTS OF OZONE POLLUTION INCREASES OVER THE EASTERN UNITED STATES

The study described in Chapter 2 of this report also examined the impacts of climate change on ozone levels and subsequent mortality effects using the air pollution modeling system described earlier to compare future and current ozone levels in 15 cities in the eastern United States. This study provides insight into only one of the ways in which climate change could adversely affect human health.

Short-term exposure to ozone has been linked to numerous adverse health effects, such as hospital admissions and emergency department visits, worsening of asthma, and decreased lung function.[53] We estimated the change in morbidity and mortality from elevated ozone levels caused by climate change. We estimated the relationship between ozone and morbidity and mortality using meta-analysis and a large-scale time-series analysis.

Increases in Respiratory Illnesses

Ozone has been linked to numerous other adverse health outcomes, such as hospital admissions, the onset of adult and childhood asthma, emergency room visits, respiratory symptoms, and lost days from work or school, as well as ecological and human welfare effects such as material damage.[54] We provide the following estimates of changes in hospital admissions as examples. These results by no means cover the full range of ozone-related health impacts.

Findings of the study report both an increase in hospital admissions and mortality as a result of ozone-related pollution.

Because epidemiological studies can differ in their concentration-response functions, we show estimates calculated using the results from a variety of studies based in the United States. Table 3-1 shows the percent increase in hospital admissions of the elderly for pneumonia, chronic obstructive pulmonary disease (COPD), and respiratory causes. Table 3-2 gives the percent increase in asthma-related hospital admissions for the non-elderly. Results are provided for the average increase in cause-specific hospital admissions across all the cities, as well as the

TABLE 3-1
Percent Increase (95% Confidence Intervals) in Hospital Admissions for the Elderly (≥ 65 Years of Age)

Condition	Average Across All Cities (Confidence Interval)	Largest City-Specific Effect (Confidence Interval)	Epidemiological Study
Pneumonia	1.4 (0.6,2.1)	2.4 (1.2,3.7)	Moolgavkar et al. 1997
	1.0 (–0.2,2.3)	1.8 (–0.4,4.0)	Schwartz 1994a
	2.0 (1.0,2.9)	3.4 (1.7,5.1)	Schwartz 1994b
COPD	1.0 (–0.2,2.3)	1.8 (–0.4,4.0)	Moolgavkar et al. 1997
	2.1 (0.6,3.6)	3.6 (1.0,6.3)	Schwartz 1994b
Respiratory	1.0 (–0.03,2.0)	1.7 (–0.6,3.5)	Schwartz 1995
	2.7 (0.8,4.6)	4.7 (1.4,8.1)	Schwartz 1995

Sources: Moolgavkar, S.H., E.G. Luebeck, and E.L. Anderson, *Air pollution and hospital admissions for respiratory causes in Minneapolis-St. Paul and Birmingham.* Epidemiology, 1997. 8(4): p. 364–70; (a) Schwartz, J., *PM10, ozone, and hospital admissions for the elderly in Minneapolis-St. Paul, Minnesota.* Arch Environ Health, 1994. 49(5): p. 366–74; (b) Schwartz, J., *Air pollution and hospital admissions for the elderly in Detroit, Michigan.* Am J Respir Crit Care Med, 1994. 150(3): p. 648-55; and Schwartz, J., *Short term fluctuations in air pollution and hospital admissions of the elderly for respiratory disease.* Thorax, 1995. 50(5): p. 531–8.

TABLE 3-2
Percent Increase (95% Confidence Intervals) in Asthma Hospital Admissions for the Non-Elderly (≤ 64 Years of Age)

Condition	Average Across All Cities	Largest City-Specific Effect	Epidemiological Study
Asthma	2.7 (0.8,4.7)	4.8 (1.5,8.2)	Sheppard 2003

Source: Sheppard, L., *Ambient air pollution and nonelderly asthma hospital admissions in Seattle, Washington, 1987–1994*, in *Revised Analyses of Time-Series Studies of Air Pollution and Health*, H.E. Institute, Editor. 2003, Health Effects Institute: Washington. p. 227–230.

largest city-specific effect, which is estimated for Louisville, Kentucky, the city with the largest increase in ozone concentrations.

Table 3-3 presents a summary of the following findings: starting with the IPCC Special Report on Emissions Scenarios (SRES) using the A2 scenario, and the Goddard Institute for Space Studies Global Climate Model (GISS-MM5), linked to the Community Multiscale Air Quality Model (CMAQ) and ozone dose-response functions for human mortality and morbidity, for the years 2053–2057.

The World Health Organization and the World Resources Institute estimated that nearly 700,000 deaths per year are related to air pollution and that about 8 million avoidable deaths will occur worldwide by 2020.

Increases in Mortality

The overall estimates from these meta-analysis studies, expressed as the percentage increase in daily mortality for a 10 ppb increase in daily O_3, are as follows:

- 0.9 percent (95 percent confidence interval, CI = 0.6,1.2 percent)
- 1.4 percent (CI = 0.8,2.0 percent) considering only studies that allow nonlinear associations between temperature and mortality
- 1.1 percent (CI = 0.3,1.9 percent)
- 1.0 percent (CI = 0.6,1.4 percent)[55]

Although meta-analyses can measure an overall effect of the relationship between ozone and health, they are subject to potential publication bias in which studies that show a null or negative association are less likely to be formally published, and thus are not included in the meta-analysis. Additionally, the individual studies can use different study designs, leading to inconsistencies.

We estimated the percent increase in mortality for these 15 cities based on elevated ozone levels from climate change using several epidemiological studies (see

TABLE 3-3
Summary of Findings (see text)

Average temperature increase	3°–6.5°F (1.5–3.5°C)
Average daily ozone increase	4.2 ppb
Average mortality increase	0.28–0.36%
City with greatest increase (mortality)	0.42–0.62%
Average asthma hospital admissions	2.7%
City with greatest increase (asthma)	4.8%

TABLE 3-4
Increases in Total Mortality From Elevated Ozone Levels in Response to Climate Change

Epidemiological Study	Overall Increase (Confidence Interval)	Largest Increase (Louisville) (Confidence Interval)	Smallest Increase (Monroe) (Confidence Interval)
Levy et al., 2001	0.36% (0.22,0.51)	0.62% (0.37,0.87)	0.00% (0.00,0.00)
Stieb et al., 2003	0.28% (0.08,0.49)	0.43% (0.12,0.73)	0.02% (0.01,0.04)
Thurston & Ito, 2001	0.34% (0.20,0.49)	0.52% (0.30,0.75)	0.03% (0.02,0.04)

Sources: Levy, J.I., et al., *Assessing the public health benefits of reduced ozone concentrations.* Environ Health Perspect, 2001. 109(12): p. 1215-26; Stieb, D.M., S. Judek, and R.T. Burnett, *Meta-analysis of time-series studies of air pollution and mortality: update in relation to the use of generalized additive models.* J Air Waste Manag Assoc, 2003. 53(3): p. 258-61; and Thurston GD, Ito K. Epidemiological studies of acute ozone exposures and mortality. J Expo Anal Environ Epidemiol 11:286–94(2001).

Table 3-4). Calculations were made according to the original metric used in the epidemiological study (for example, daily 1-hour max).

The actual number of deaths corresponding to these percent increases will depend on the population and mortality rates in the 2050s. In addition, these results are subject to whether the concentration-response relationships hold in future scenarios.

Reducing emissions from older coal-fired power plants in the United States could save 18,700 deaths, 3 million lost work days, and 16 million restricted-activity days each year.

STEPS TO REDUCE THE HEALTH EFFECTS OF OZONE POLLUTION

Reducing fossil fuel emissions to decrease global warming will have the additional benefit of lowing particulate matter and ozone, reducing the number of premature deaths and morbidity. Reducing emissions from older coal-fired power plants in the United States could save 18,700 deaths, 3 million lost work days, and 16 million restricted-activity days each year.[56] In 1997, the World Health Organization and the World Resources Institute estimated that nearly 700,000 deaths per year are related to air pollution and that about 8 million avoidable deaths will occur world-wide by 2020.[57]

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APPENDIX: MODEL DESCRIPTION AND EVALUATION

A linked climate/air quality modeling system developed by the New York Climate and Health Project (Hogrefe et al., 2004) was used to derive ozone concentrations under climate change. The modeling system included the GISS global climate model (National Aeronautics and Space Administration), the MM5 meteorological model (Penn State/United Corporation for Atmospheric Research), the CMAQ Model (U.S. Environmental Protection Agency), and the SMOKE emissions processor (MCNC Supercomputing Center.)

Regional weather for the modeling was derived by coupling the MM5 meso-scale model to the Goddard Institute for Space Studies (GISS) 4° X5° resolution General Circulation Model (GISS-GCM).[58,59] The IPCC A2 emission scenario drove the GISS global climate model. MM5 was applied in a nested-grid mode with an inner grid of 36-km resolution over the eastern United States. These regional climate fields, along with the SMOKE-processor emissions simulations for five summer seasons, 1993–1997, were used for air quality simulations, which were performed using version 4.2 of the Community Multiscale Air Quality model (CMAQ).[60]

The EPA 1996 National Emissions Trends (NET96) were used as the emissions inventory and processed by the Sparse Matrix Operator Kernel Emissions Modeling System (SMOKE).[61] Temperature-dependent biogenic emissions of ozone precursors were estimated by the Biogenic Emissions Inventory System, Version 2 (BEIS2).[62] Mobile source emissions were estimated by Mobile 5b model.[63]

To evaluate the modeling system's ability to reproduce present-day ozone climatology, model predictions were compared against hourly surface ozone observations for 1993–1997, which were obtained from the EPA AIRS data system from 428 monitors located in the eastern U.S. modeling domain. The modeling simulations indicate that the regional average ozone concentration in the eastern United States would increase by 4.2 ppb above 1990s levels by the 2050s; however, ozone changes showed regional variation.[64]

Note that the ozone estimates for the current climate do not represent actual observed ozone air quality with respect to NAAQS. Although the model evaluation performed by Hogrefe et al. (2004) showed that the modeling system generally captured spatial and temporal patterns as well as the frequency and duration of extreme ozone events over the entire domain, differences in absolute extreme concentrations certainly do exist at a number of locations.[65] For example, Birmingham, Boston, Chicago, and Harrisburg are currently in non-attainment for the 1-hourozone standard based on observations, although no 1-hour exceedance days were estimated by the CGM/MM5/CMAQ modeling system.

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