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Potential Impacts of Climate Change on Air Quality and Human Health

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Overview

- Sources, characteristics and health impacts of key air pollutants
- Ways that climate can affect air pollution
- Case study: health impact assessment for climate change and air quality in NYC metro region.
- Who is vulnerable?
- Five year research plan

Background

- The mixtures of air pollutants produced by burning of fuels can
  - Adversely affect human health
  - Promote climate change
- In addition
  - Climate can influence air pollution, resulting in direct health effects
  - Climate can affect other aspects of air quality, including smoke from agricultural or wild fires, and aero-allergens like pollen and mold spores

Criteria Pollutants:

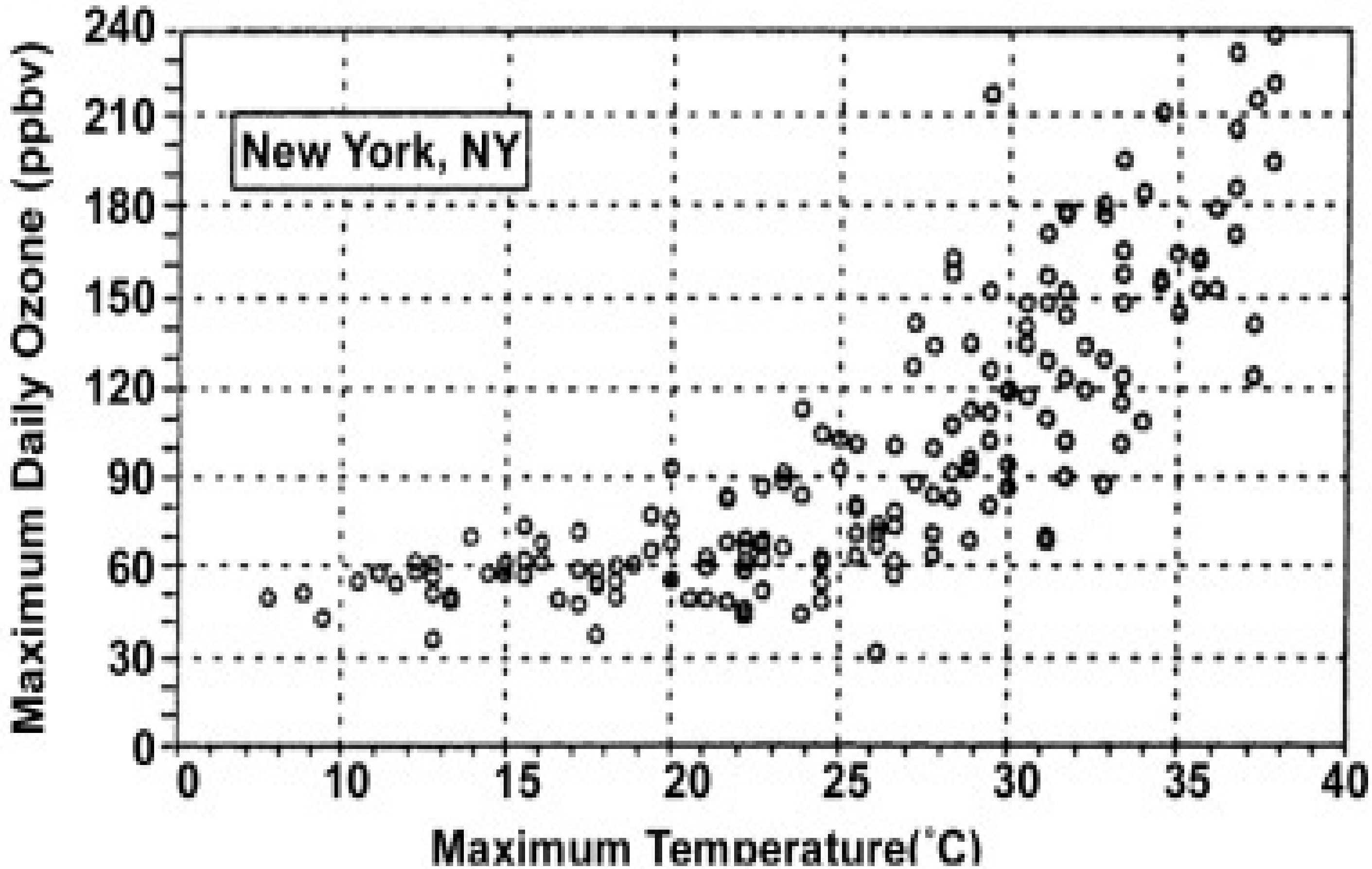
Ubiquitous Pollutants of Human Health Concern

- **Carbon monoxide (CO)**
- **Nitrogen dioxide (NO_2)**
- **Lead (Pb)**
- **Sulfur dioxide (SO_2)**
- **Ozone (O_3)**
- **Particulate matter ($PM_{2.5}$, PM_{10})**

"National Ambient Air Quality Standards (NAAQS)"

Ozone – O_3

- Secondary pollutant, formed via photochemical reactions in the atmosphere from NO_x and VOCs in the presence of sunlight
- Strong oxidant that damages cells lining the respiratory system
- Wide range of health impacts have been observed
- Concentrations often highest downwind of source regions
- Concentrations can be reduced by control of NO_x and VOC emissions, especially from motor vehicles and power plants



Source: US EPA (1991); in Kleinman and Lipfert, 1996.
Note threshold~90° F (32° C)

Particulate Matter - PM

- Both primary emissions (combustion, mechanical processes) and secondary formation (atmospheric reactions and transformations of primary gaseous pollutants)
- Wide range of particle sizes
- Wide range of physical/chemical properties
- Wide range of health impacts, including premature death
- Control by filtration, electrostatic precipitation, and reduction of precursor gases

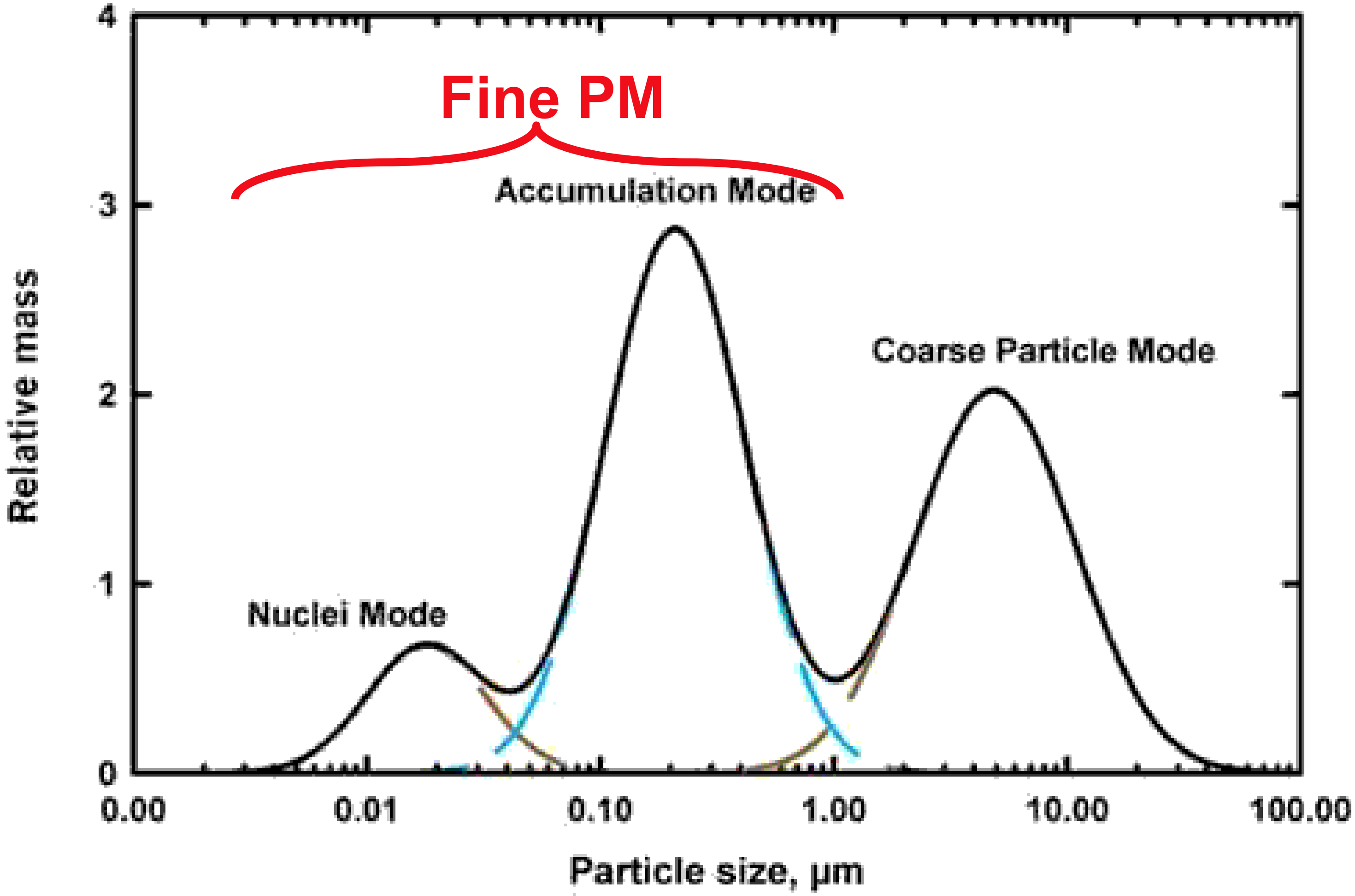
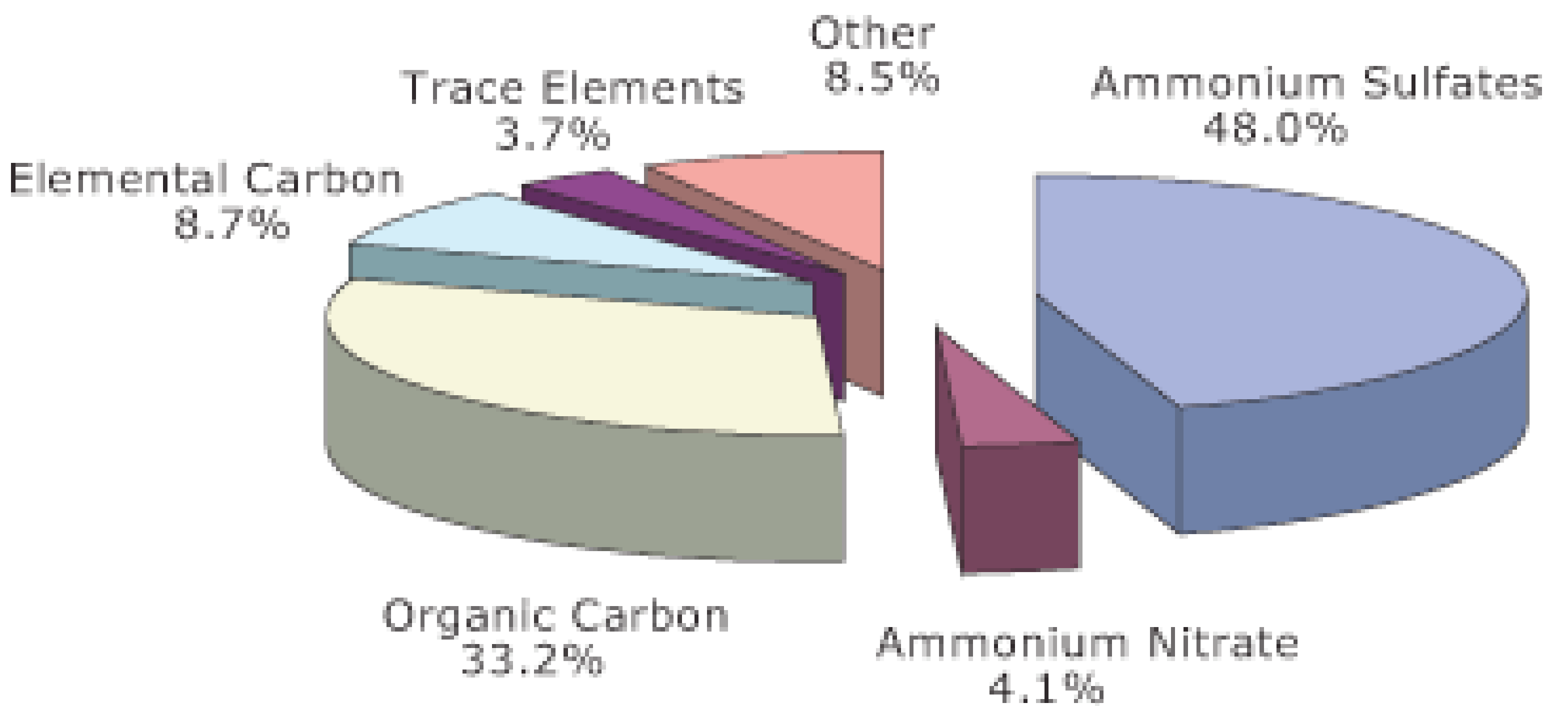


Figure 1: Typical urban particulate matter size distribution

Fine Particle Composition



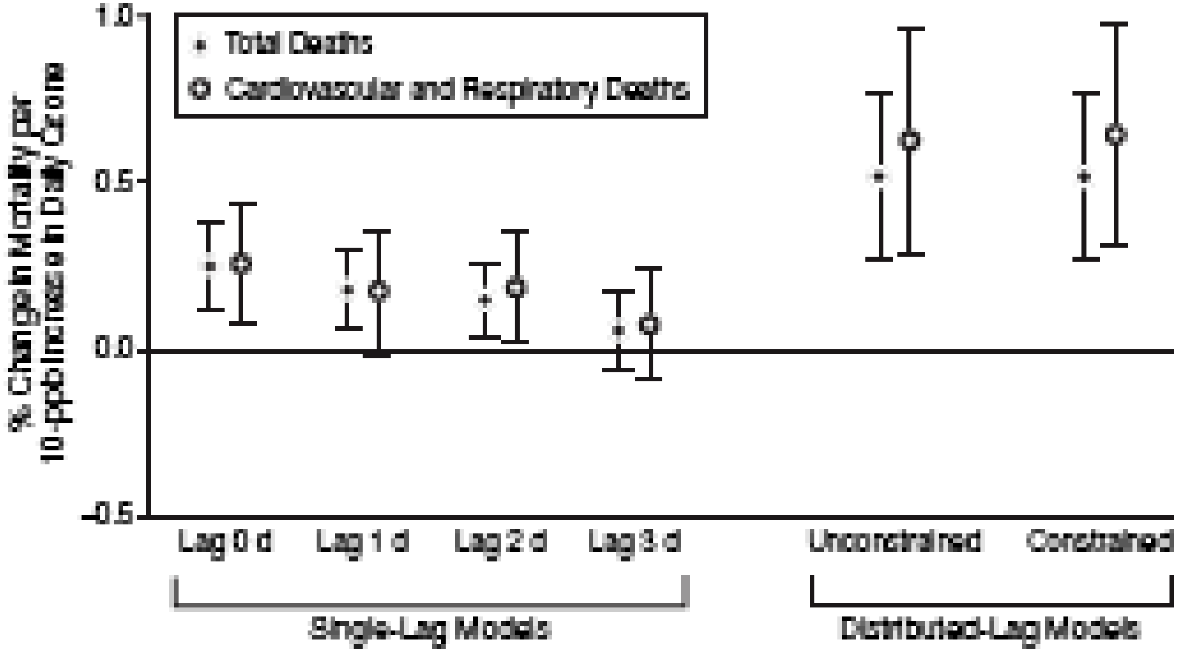
Annual average fine particle data for 2001 from the Look Rock station of the Tennessee Valley Authority. Source: http://www.tva.gov/environment/air/ontheair/fine_particles_smokies.htm

Health Effects of Air Pollution

- Historical experience provides strong evidence for causal relationship between air pollution and premature death
- Modern epidemiology studies have consistently found significant associations
- Two primary epidemiologic study designs:
  - **Time series studies of acute effects**
  - **Cohort or cross-section studies of chronic effects**
- Let’s look in more detail at ozone and particles

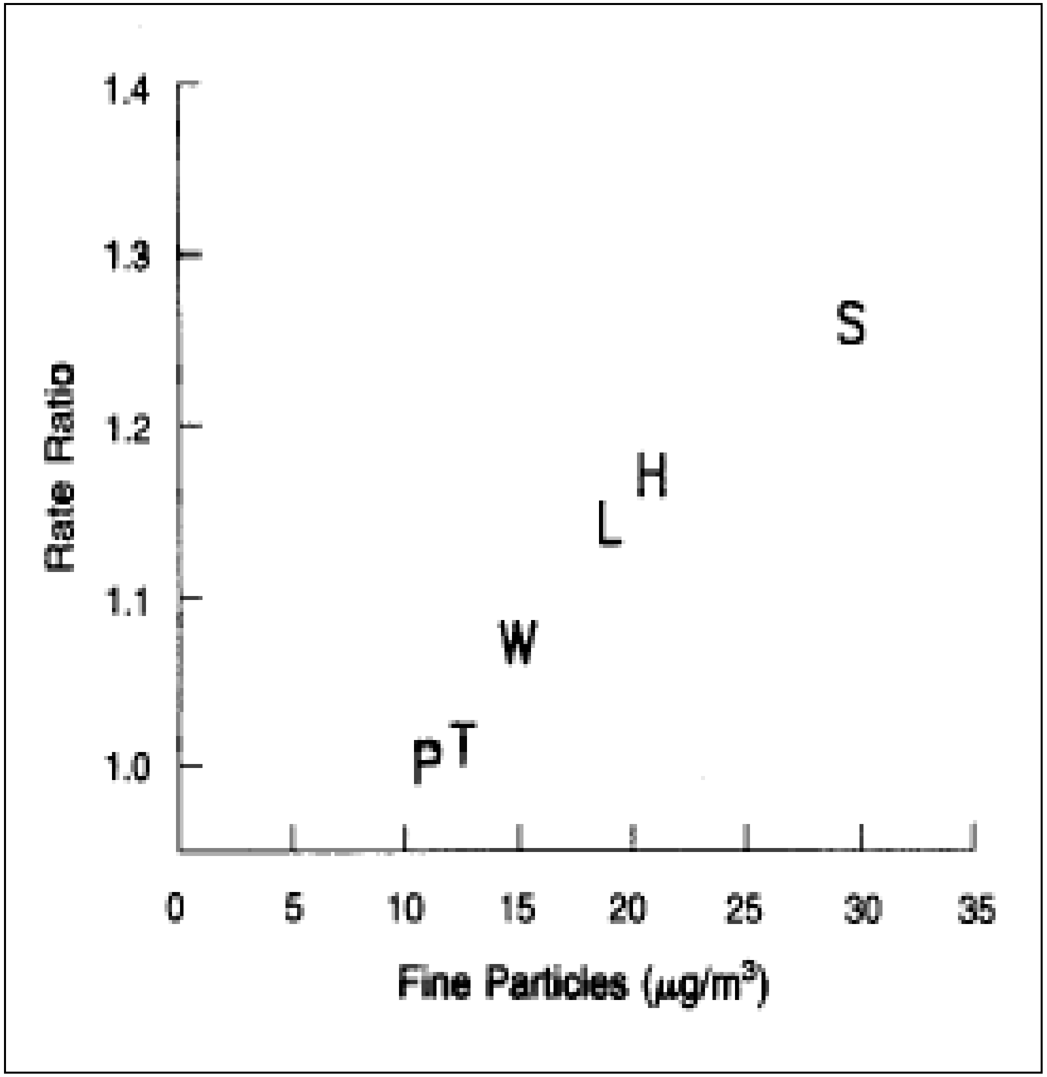
Recent studies have confirmed that ozone is associated with daily mortality

Figure 1. Percentage Change in Daily Mortality for a 10-ppb Increase in Ozone for Total and Cardiovascular Mortality, for Single-Lag and Distributed-Lag Models



The single-lag model reflects the percentage increase in mortality for a 10-ppb increase in ozone on a single day. The distributed-lag model reflects the percentage change in mortality for a 10-ppb increase in ozone during the previous week. Error bars indicate 95% posterior intervals.

Bell et al., JAMA 2004



Long-term average concentrations of fine particle air pollution were associated with mortality rates, controlling for individual-level risk factors across six U.S. cities.

Results from Harvard Six Cities Study. Dockery et al., NEJM, 1993.
Findings later confirmed and extended by Pope et al., 1995; 2002, etc.

Health Effects Summary

- Outdoor levels of six air pollutants are regulated in the U.S. based on national standards that are assumed to avoid adverse health impacts
- Ozone and fine particles dominate current health concerns
- Many health effects have been associated with currently-observed distributions of ozone and fine particles, but mortality is most prominent among them
- Mortality impacts for fine particles tend to dominate most health impact assessments

How might Climate Change Affect Air Pollution?

- Formation reactions for secondary pollutants generally happen faster at high temp and with greater sunlight
- Biogenic precursor emissions increase at higher temp

- Some particle species may volatilize at higher temperatures (e.g. nitrates, organics)

- Regional air mass patterns over time and space may change, altering stagnation and clearance events
- The mixing height of the lower atmosphere may change, affecting dilution of pollution emitted at the surface

→ Use Coupled Climate/Air Quality Models to Investigate

Case Study: Integrated health impact assessment for climate change and air quality in NYC metro region

Linking models for global and regional climate, land use and cover, and air quality,

examine the potential public health impacts of heat and air pollution under alternative scenarios of climate change and regional land use in the 2020s, 2050s, and 2080s in the NYC metropolitan region.

…grew out of MEC regional assessment (Rosenzweig, Solecki et al)

Approach

Develop an integrated modeling system that links changes in global climate, regional climate, land use, and emissions, to project future ozone and heat at policy-relevant geographic scales

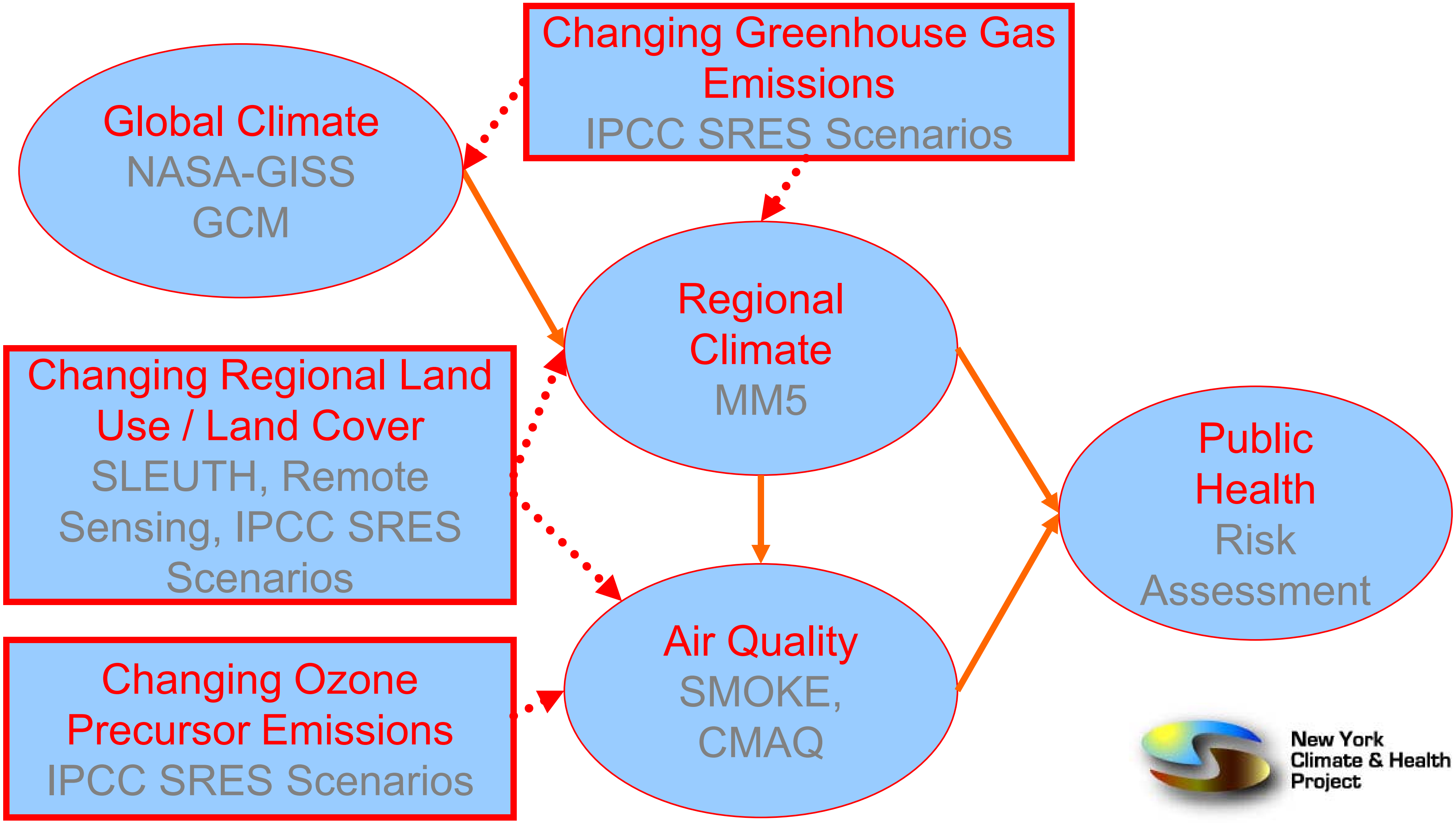
Develop exposure-response functions for temperature and ozone using historical data from the NYC metro area

Run the models using alternative greenhouse gas growth scenarios

Combine to assess potential mortality risks in the NYC metro area in the 21st century

Funded by USEPA STAR grant

Integrated Modeling System



New York Climate & Health Project

The Study Team:

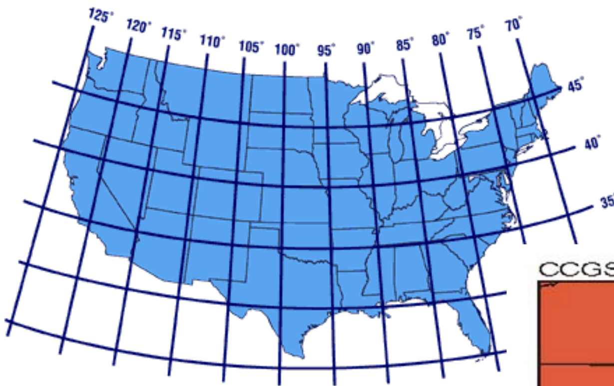
Health: Patrick Kinney (PI), Joyce Rosenthal, Kim Knowlton, Mailman School of Public Health, Columbia University; NRDC

Climate: Cynthia Rosenzweig, Richard Goldberg, Barry Lynn, NASA-Goddard Institute for Space Studies; David Werth & Roni Avissar, Duke University

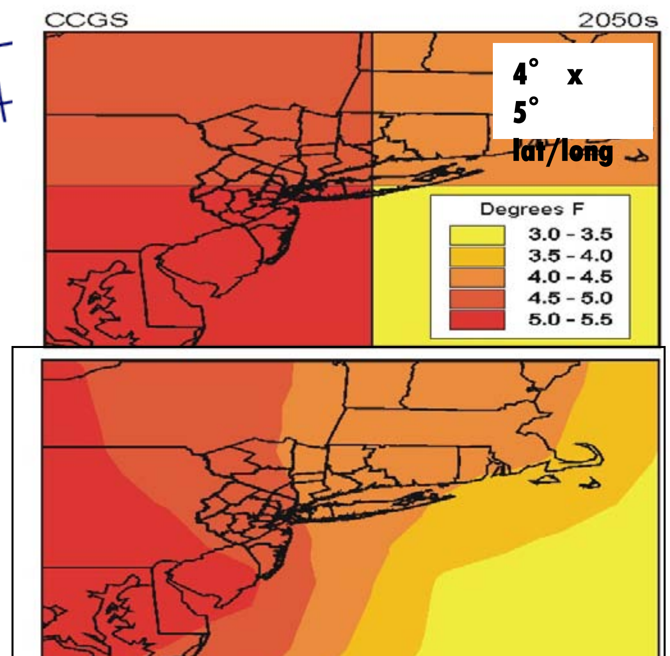
Land use/remote sensing: William Solecki, Jennifer Cox, Hunter College Geography Dept; Christopher Small, Lamont Doherty Earth Observatory;

Air quality: Christian Hogrefe, SUNY Albany; Michael Ku, Kevin Civerolo, NY State Dept Environ Conservation; Tracey Holloway, Earth Institute and University of Wisconsin-Madison; Michelle Bell, Yale

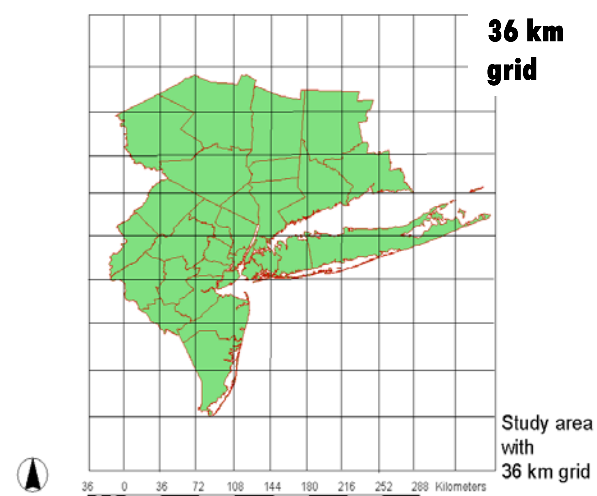
Downscaling of projections was a key objective



- **Scale:**
  global **(4° x5°) vs.** ***regional*** **(36 km)**?
- How to project ***regional & local*** health impacts?



Source: C Rosenzweig & R Goldberg, NASA/GISS



Model Setup

GISS coupled global ocean/atmosphere model driven by IPCC greenhouse gas scenarios (“A2” and “B2”)

MM5 regional climate model took initial and boundary conditions from GISS GCM, and run on 2 nested domains of 108 km and 36 km over the U.S.

CMAQ is run at 36 km to simulate ozone

1996 U.S. Emissions processed by SMOKE and – for some simulations - scaled by IPCC scenarios

Simulations periods : June – August 1993-1997
June – August 2023-2027
June – August 2053-2057
June – August 2083-2087

Citation: Hogrefe, C., B. Lynn, K. Civerolo, J.-Y. Ku, J. Rosenthal, C. Rosenzweig, R. Goldberg, S. Gaffin, K. Knowlton, and P. L. Kinney (2004), Simulating changes in regional air pollution over the eastern United States due to changes in global and regional climate and emissions, *J. Geophys. Res.*, *109*, D22301, doi:10.1029/2004JD004690.

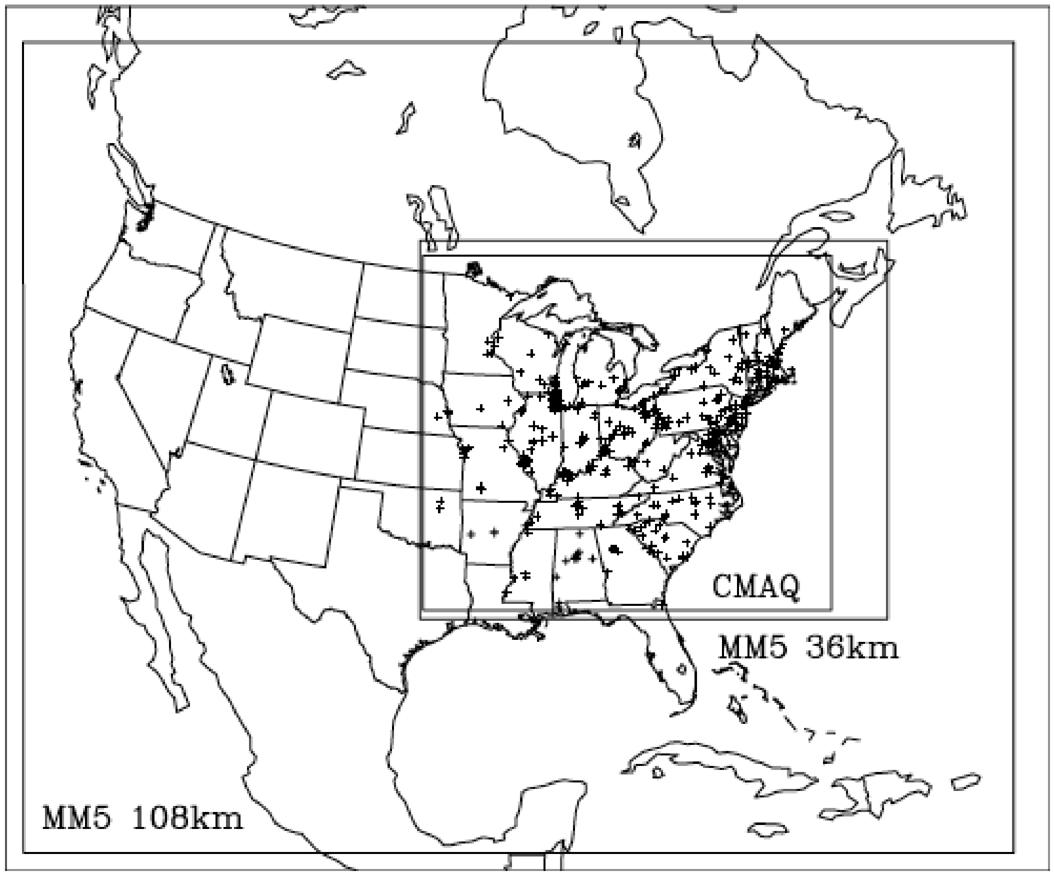


Figure 1. Map showing the 108- and 36-km MM5 modeling domains, the CMAQ modeling domain, and the locations of 428 O_3 monitors (pluses) used to calculate spatial averages over the CMAQ modeling domain.

Hogrefe et al., *J. Geophysical Research*, 2004

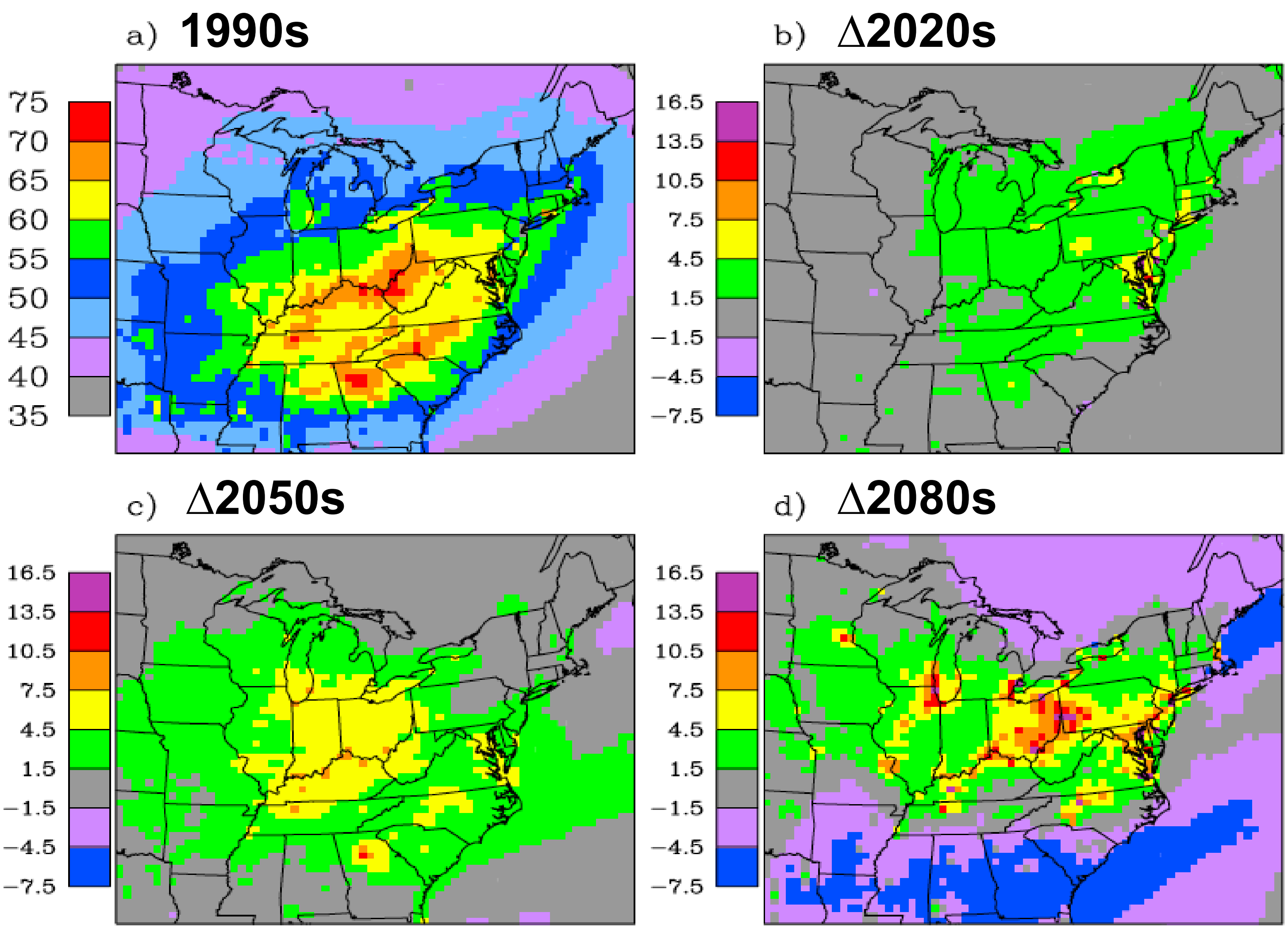
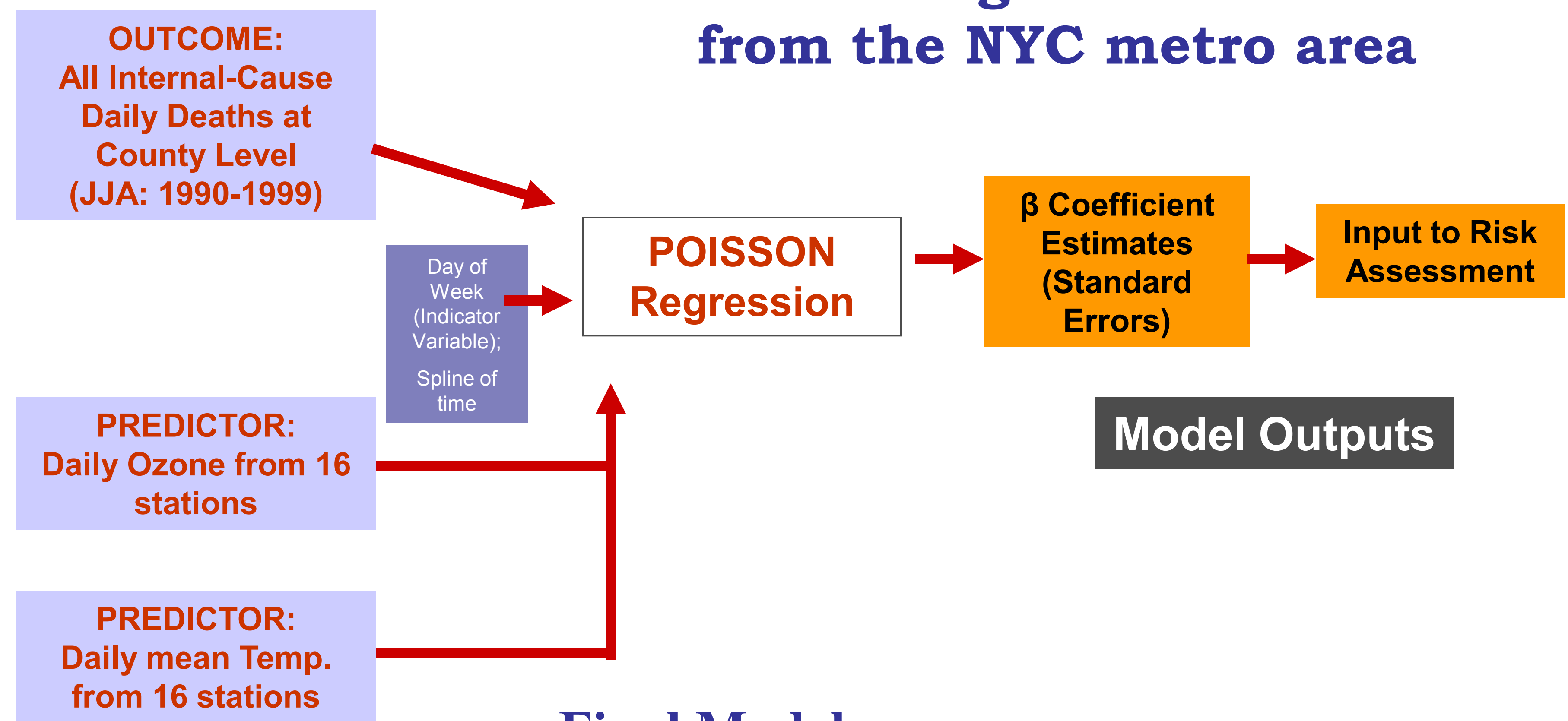


Figure 2. (a) Summertime average daily maximum 8-hour O_3 concentrations for the 1990s and changes in summertime average daily maximum 8-hour O_3 concentrations for the (b) 2020s, (c) 2050s, and (d) 2080s A2 scenario simulations relative to the 1990s, in parts per billion. Five consecutive summer seasons were simulated in each decade.

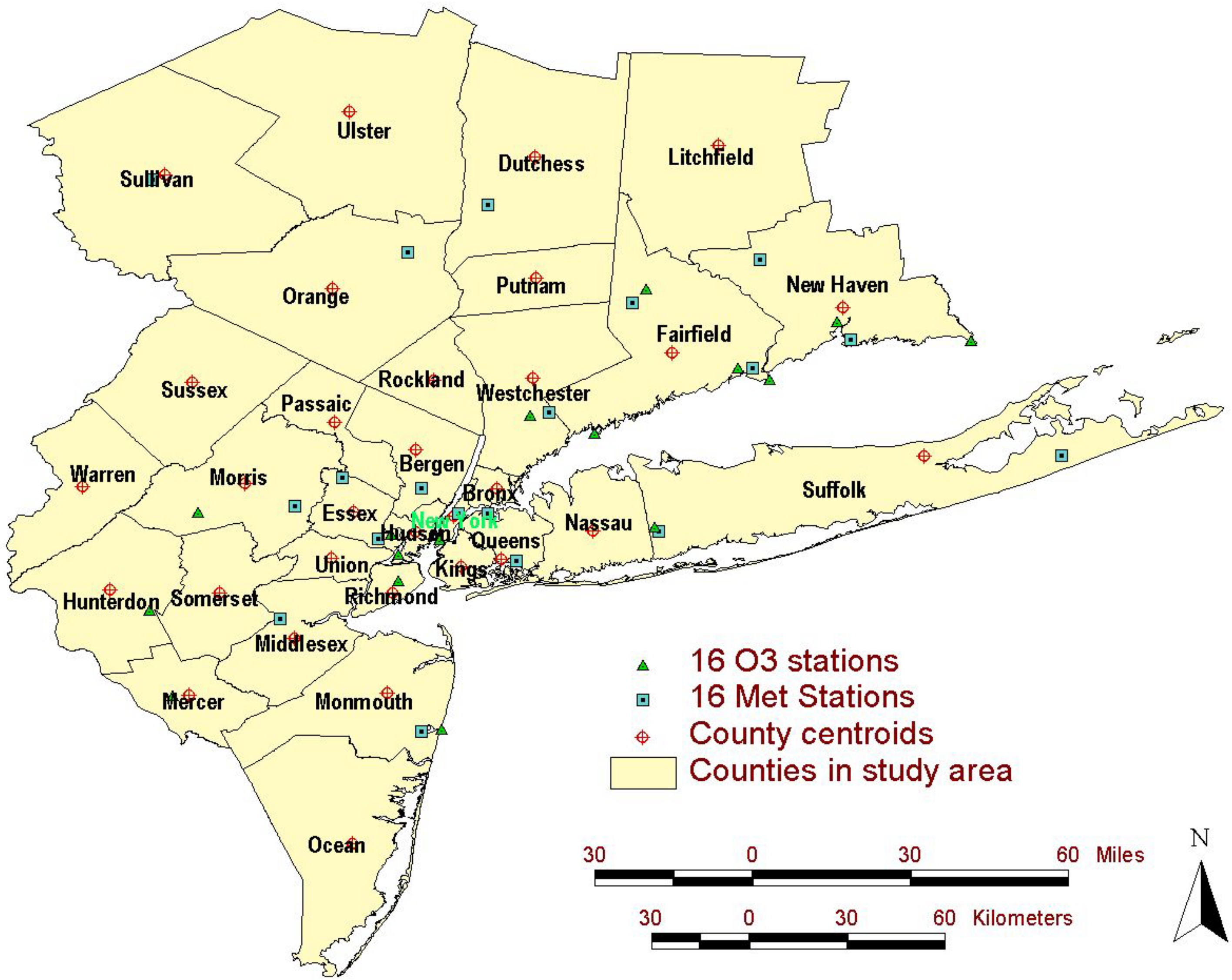
Develop exposure-response functions for temperature and ozone using historical data from the NYC metro area

Model Inputs

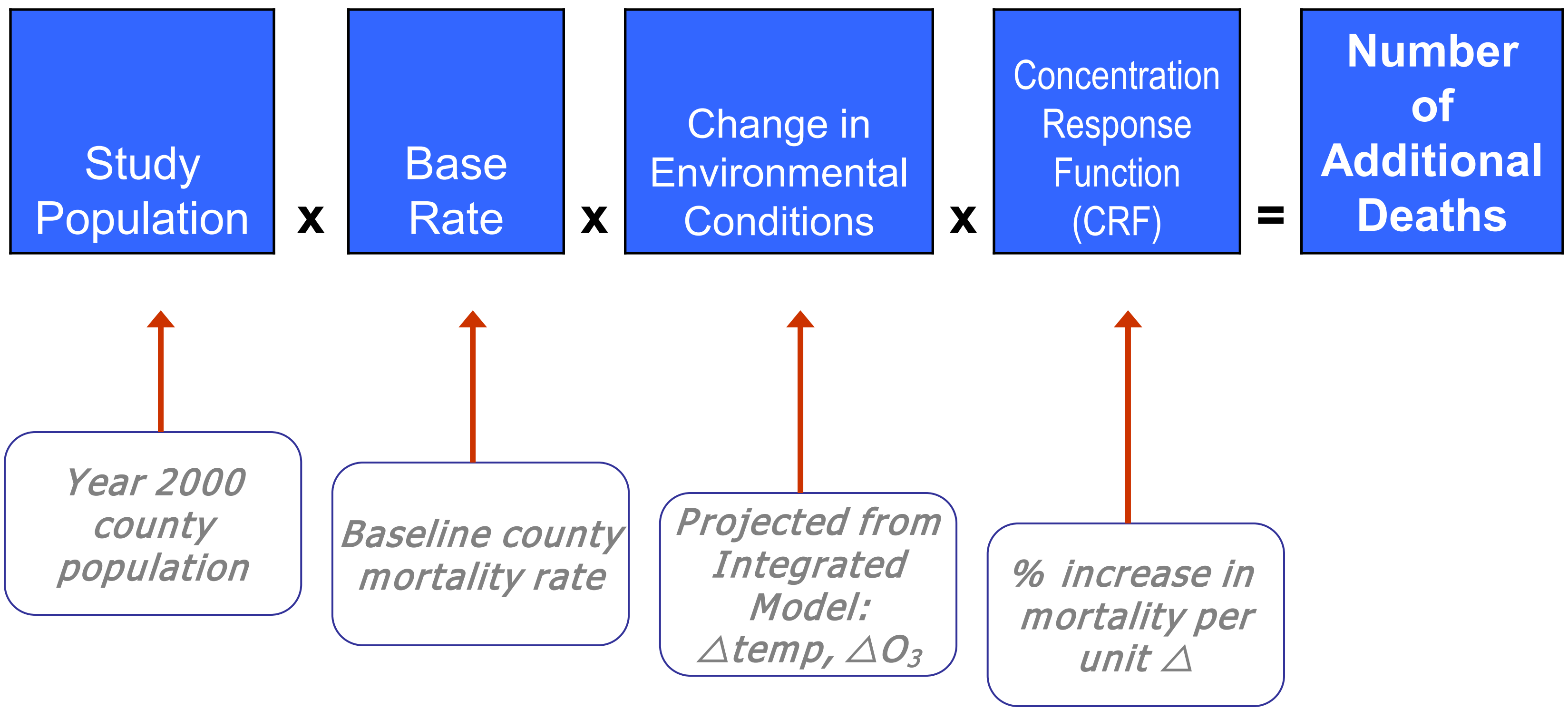


Final Model:

log (daily deaths)= DOW + spline(time)+ b1(mean Tlag0)1-3 + b2(max O3 lag0-1)


Ulster
Sullivan
Dutchess
Litchfield
Orange
Putnam
New Haven
Fairfield
Sussex
Rockland
Passaic
Westchester
Warren
Morris
Bergen
Bronx
Essex
New York
Hudson
Queens
Nassau
Suffolk
Union
Kings
Hunterdon
Somerset
Richmond
Middlesex
Mercer
Monmouth
Ocean
16 O3 stations
16 Met Stations
County centroids
Counties in study area
30 0 30 60 Miles
30 0 30 60 Kilometers
N

Health Impact Assessment



Modeled changes in:

Mean 1-hr max O3 (ppb) **O3-related deaths (%)**

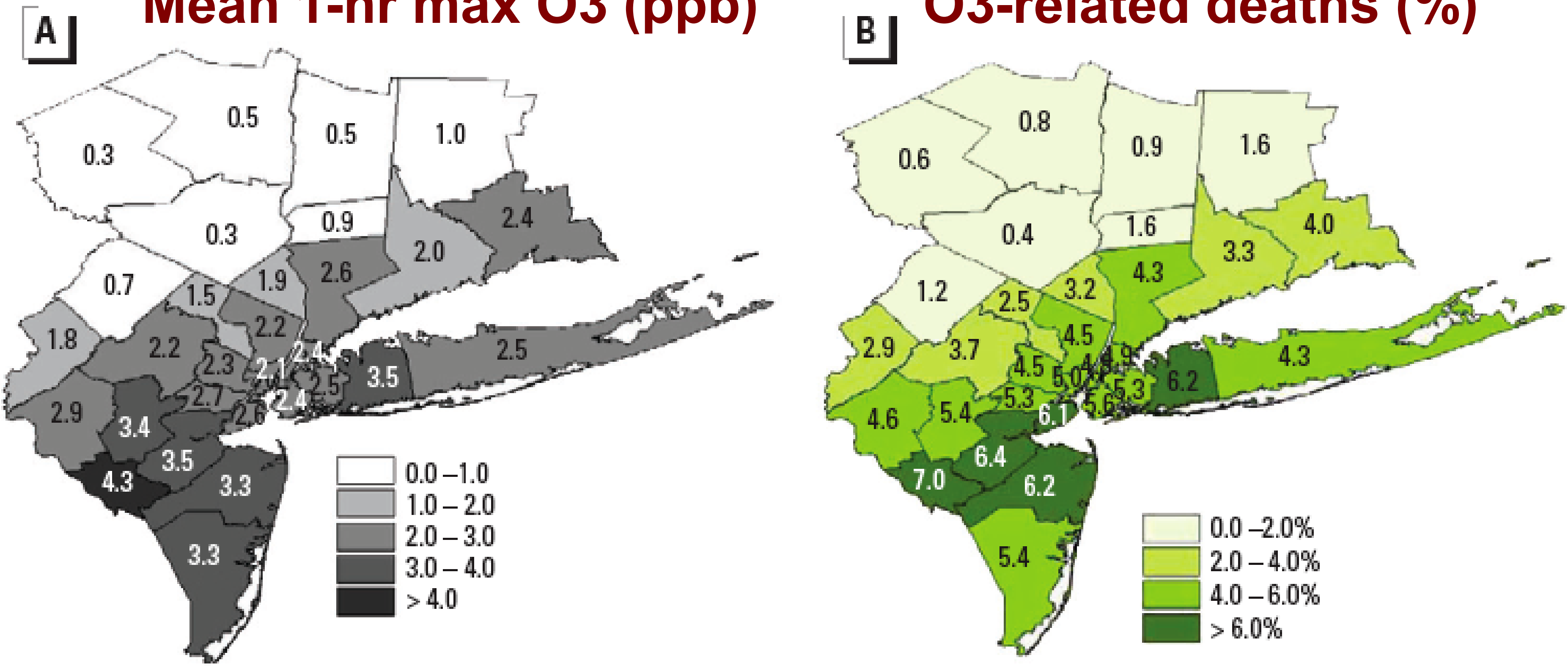
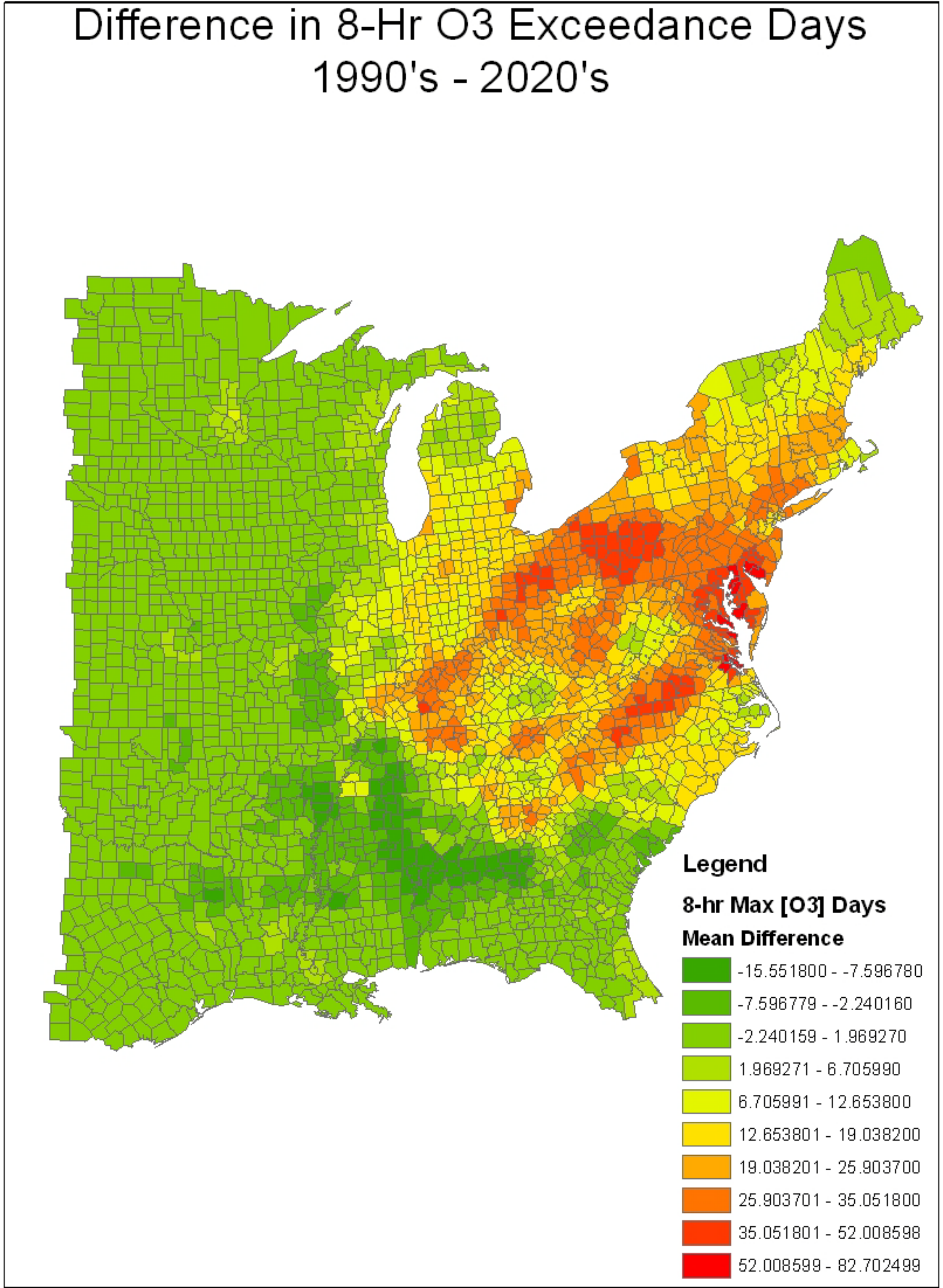


Figure 2. Estimated changes in O_3 and associated summertime mortality in the 2050s compared with those in the 1990s for M1, where climate change alone drives changes in air quality. (*A*) Changes in mean 1-hr daily maximum O_3 concentrations (ppb). (*B*) Percent changes in O_3-related mortality.

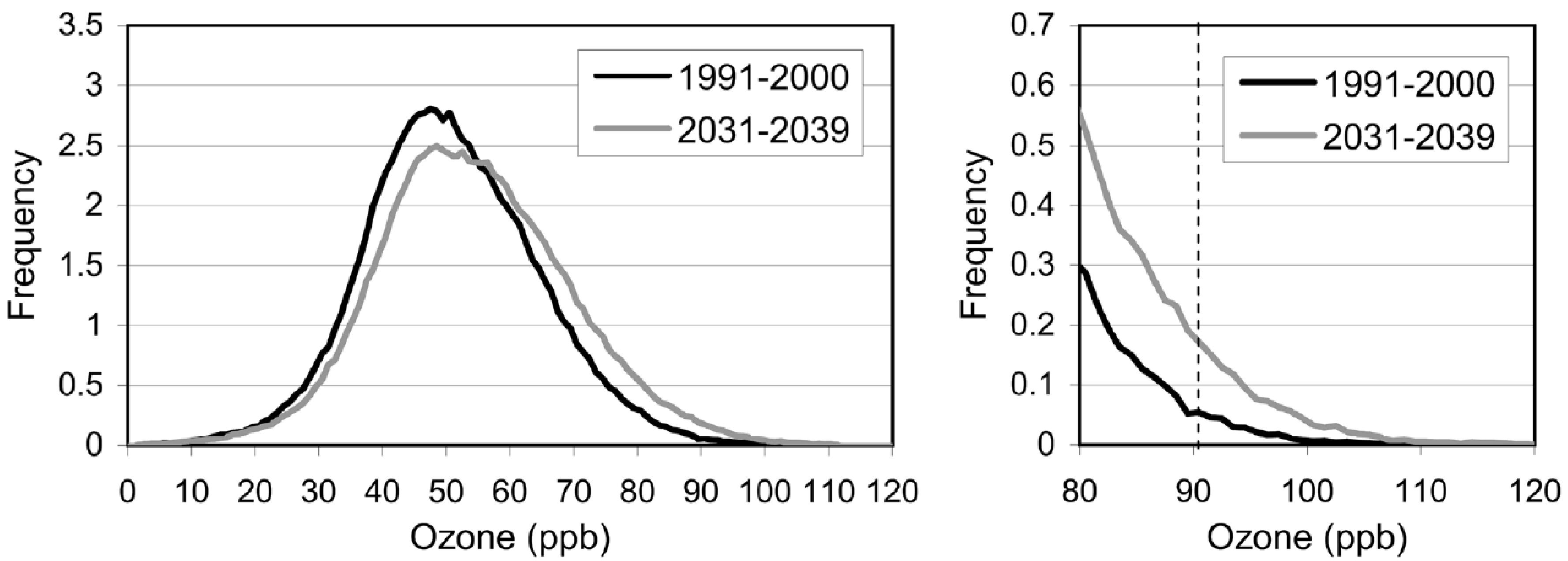
Knowlton et al., Environ Health Perspec, 2004

Ongoing work:

Examining the distribution of ozone and heat extremes at the county level across the entire 36 km domain.



Upper tail of ozone distribution is more sensitive to climate



Frequency distribution of the simulated daily ozone maxima averaged over southern Germany during summer (June-August) for the years 1991-2000 and 2031-2039. Right side: zoom of the high-ozone portion of the curve. From Forkel and Knoche 2006.

Case Study Summary

- Health impact assessment was carried out to examine effects of climate change on air quality and resulting human health
- Holding precursor emissions constant, increased ozone-related acute mortality was modeled under 2020s, 2050s, and 2080s climate
- Multiple uncertainties should be kept in mind

Summertime Average O3 Change
2090s -1990s A1 Climate Scenario

Murazaki and Hess, 2006 JGR

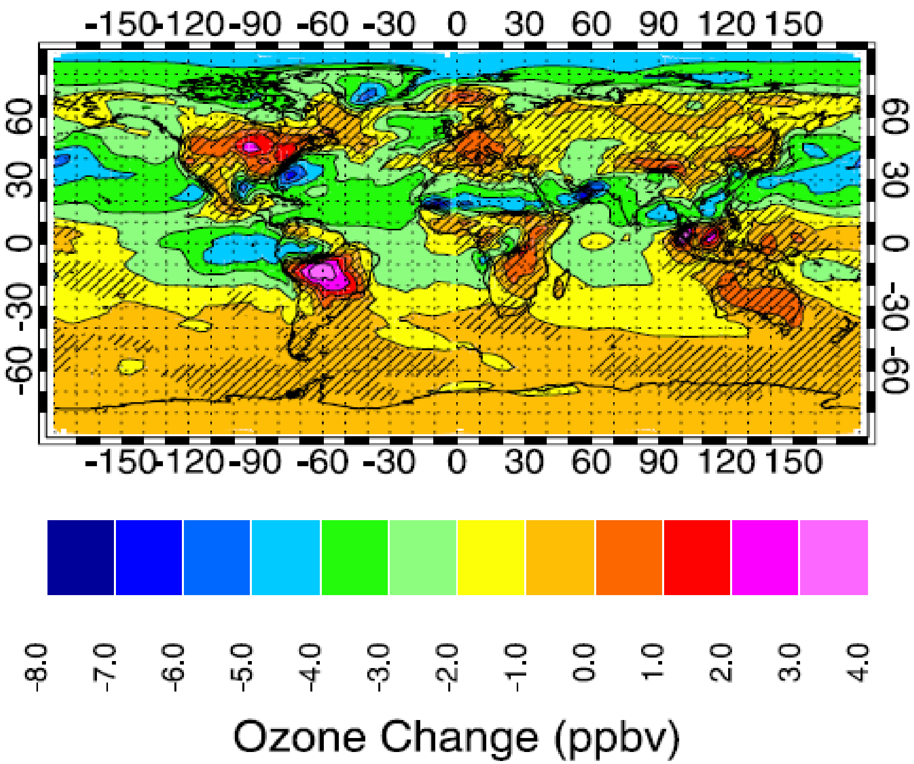


Figure 1. Change in surface ozone (ppbv) during JJA between 2091–2099 and 1991–1999 where the hatched area shows where the results are not significantly different (see text).

Summertime 95th Percentile O3 Change
2050s -1990s A1 Climate Scenario

Nolte et al., 2007, Submitted

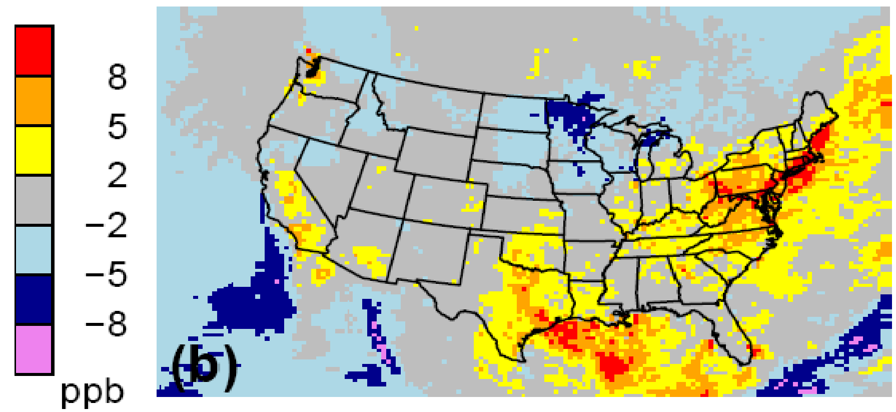


Fig. 5. (a) 95th percentile of CMAQ modeled daily maximum 8-h average (MDA8) ozone concentrations (ppb), Jun–Aug (left) and Sep–Oct (right), PB; (b) Difference (FB−PB) in 95th percentile MDA8 ozone, JJA and SO; (c) Difference (FC−PB) in 95th percentile MDA8 ozone, JJA and SO.

Beyond climate, future air pollution concentrations will depend on:

- Anthropogenic Emissions
- Intercontinental Transport
- Land Use

Further, future pollution-related health impacts will depend on future population, age, health status, etc.

Summary

Results from coupled climate/chemistry modeling studies are consistently projecting a “climate penalty” for ozone in the continental U.S., though the magnitude, timing and spatial extent vary considerably across models, scenarios, etc.

Results are beginning to emerge for fine particles

Effects are complex: some climate changes favor increased air pollution; others favor decreased air pollution; some could go either way → justifies use of modeling systems designed to address these complexities

Who’s Vulnerable?

Ozone and fine particle concentrations are gradually declining in urban areas in the U.S. and western Europe, due to aggressive emissions control efforts

Though observations are sparse, concentrations appear to be increasing in developing-world settlements

Epidemiologic findings imply that the old, young, and infirm are most sensitive to air pollution-related health effects.

Poverty is a major risk factor for ill-health

These observations imply that developing world populations will be particularly vulnerable

Five-Year Research Plan

Since modeling results vary across individual studies, there is a need for multi-model, multi-center ensemble studies using global-to-regional climate and air pollution model systems

Examine distributions of changes for full suite of gaseous and chemical species

Develop downscaled projections in urban areas in both the developed and developing world

Build the observational database for air pollution and health outcomes in developing world cities