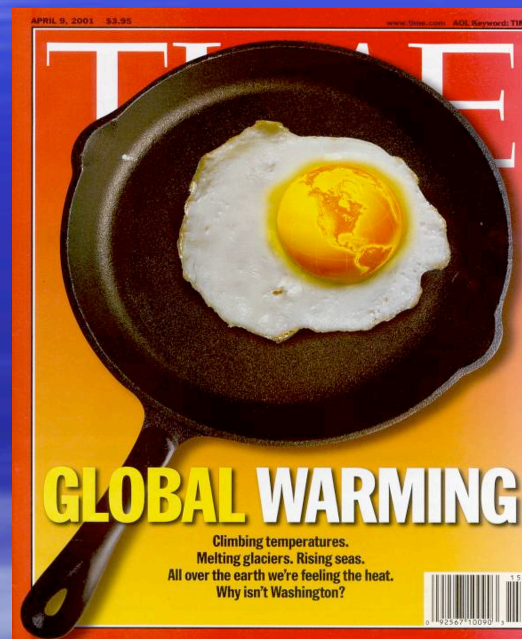
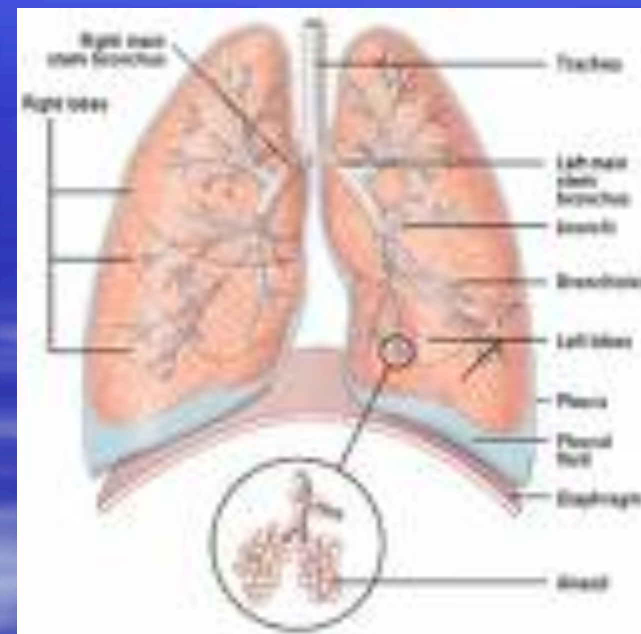
The Health Co-Benefits of Short-lived Climate Forcing Air Pollutants





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Good News First: Co-Benefits

The climate dividend

Lancet Nov. 25, 2009

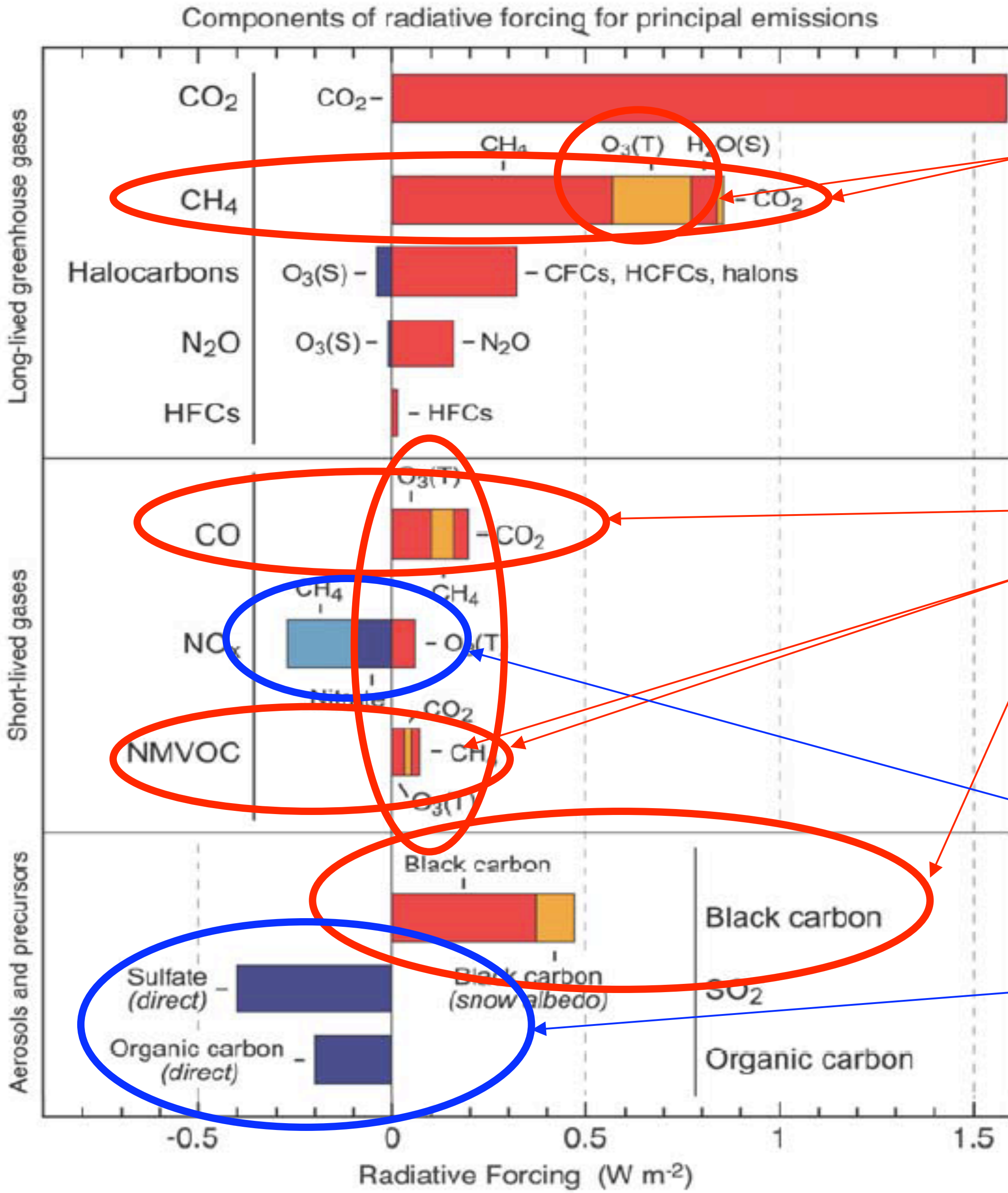
Public health benefits of strategies to reduce greenhouse-gas emissions: health implications of short-lived greenhouse pollutants

Kirk R Smith, Michael Jerrett, H Ross Anderson, Richard T Burnett, Vicki Stone, Richard Derwent, Richard W Atkinson, Aaron Cohen, Seth B Shonkoff, Daniel Krewski, C Arden Pope III, Michael J Thun, George Thurston

Shorter-Lived Climate Forcing Air Pollutants

- Many of the worst-case scenario predictions on greenhouse gas emissions have been surpassed already
- Difficulty in reducing long-lived carbon dioxide (CO_2) has focused attention on short-lived climate forcers
- Reducing short-lived pollutants can have rapid impact on climate and yield large public health benefits

Global warming in 2005 due to all human emissions since 1750



CO_2 is important for climate,
Several of the non-CO_2,
but so are many other
greenhouse gases create
pollutants, including the ones
a good proportion of both
circled that, unlike CO_2, also
their climate forcing and
have significant health as
health damage through
well as climate impacts
the secondary pollutant,

tropospheric ozone

Nitrate, sulphate, and organic carbon particles however, have cooling impacts on climate but are still health damaging

IPCC, 2007

What are the Short-Lived Climate Forcers?

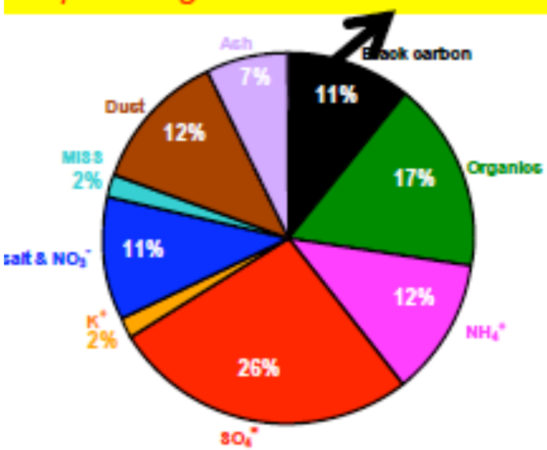
- Some are criteria air pollutants, already under regulatory control
- Major contributors are ozone (O_3) and aerosols (black carbon - BC and sulfate - SO_4)
- Organic carbon also important, but is less studied (always co-emitted with BC – complicates control)
- Climate effects, health effects, spatial distributions and equity issues are different for each pollutant
- Evidence base still far from complete, but the SLCF are attractive policy intervention targets

Black Carbon

- carbon-containing **particulate matter (PM)**
- absorbs light, affects health as PM
- results **from inefficient and incomplete combustion**
- emitted together with CO_2, CO, organic particulate matter (OC), other $PM_{2.5}$, SO_2, NO_X

*Greenhouse Forcing = 3 W/m**2*
*Brown Cloud Masking= -1.5 (+-50%) W/m**2*

Traps sunlight and heats the air



Reflects sunlight and cool

~10%
of global
BC emissions

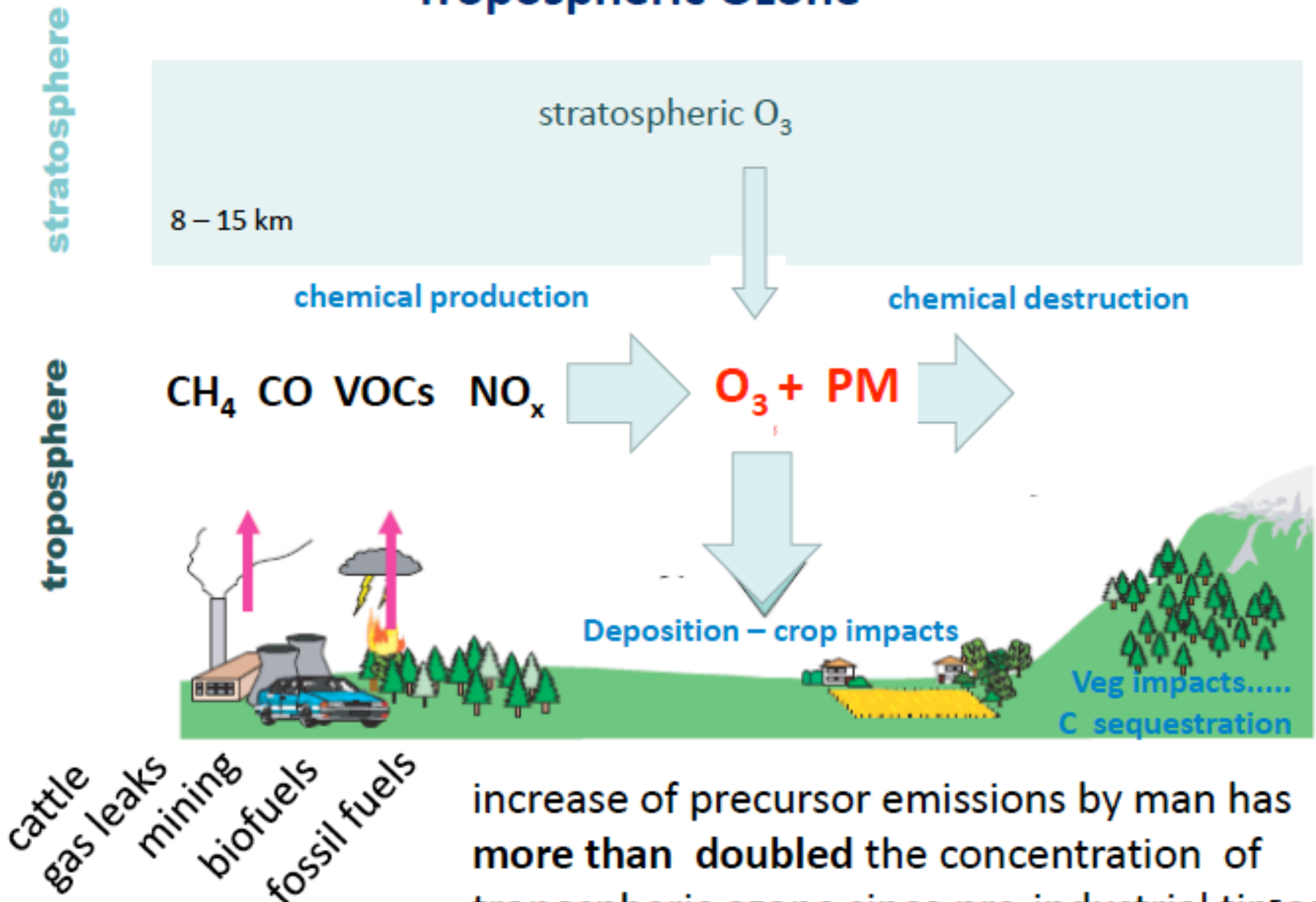
~50%

~60% of the *total* BC emissions is amenable to control

Figure Source: V. Ramanathan, and G. Carmichael, Nature Geoscience, 2008

Slide Source: Carmichael et al. (2011)

Tropospheric Ozone



increase of precursor emissions by man has **more than doubled** the concentration of tropospheric ozone since pre-industrial times!

Slide Source: Carmichael et al. (2011)

Approximate Residence Times

- Ozone usually hours to days (usually <20 days)
- Aerosols usually less than 10 days and can readily be removed by rain
- Means climate effects can occur quickly after reductions – can buy us time!

Evidence of Long-term Health Effects from the USA

- American Cancer Society Subjects enrolled in 1982 1.2 million
- Follow up to 2000
- ACS cohort with 352,000 subjects in 66 Metros (93,000 deaths)
- Central monitor data used per Metro
- Multilevel Cox model with 44 individual terms (smoking) and 14 ecologic terms (e.g. poverty in zip code area or MSA)

INDIVIDUAL LEVEL COVARIATES:

Tobacco smoke variables:

1. Indicator variable for current cigarette smoker,
2. Indicator variable for pipe or cigar smoker,
3. Current smoker's years smoked,
4. Current smoker's years smoked squared,
5. Current smoker's cigarettes per day,
6. Current smoker's cigarettes per day squared,
7. Indicator variable for former cigarette smoker,
8. Former smoker's years smoked,
9. Former smoker's years smoked squared,
10. Former smoker's cigarettes per day,
11. Former smoker's cigarettes per day squared,
12. Indicator variables for starting smoking before or after age eighteen,
13. Number of hours per day exposed to passive cigarette smoke.

Education variables:

▲**Indicator variables for high school completed and more than high school completed, versus high school not completed**

Marital status variables:

▲**Indicator variables for "single" and "other" versus married**

BMI:

▲**BMI and BMI squared**

Alcohol consumption:

▲**Six variables including indicator variable beer, liquor, and wine drinkers and non-responders versus non-drinkers**

Occupational exposure: 

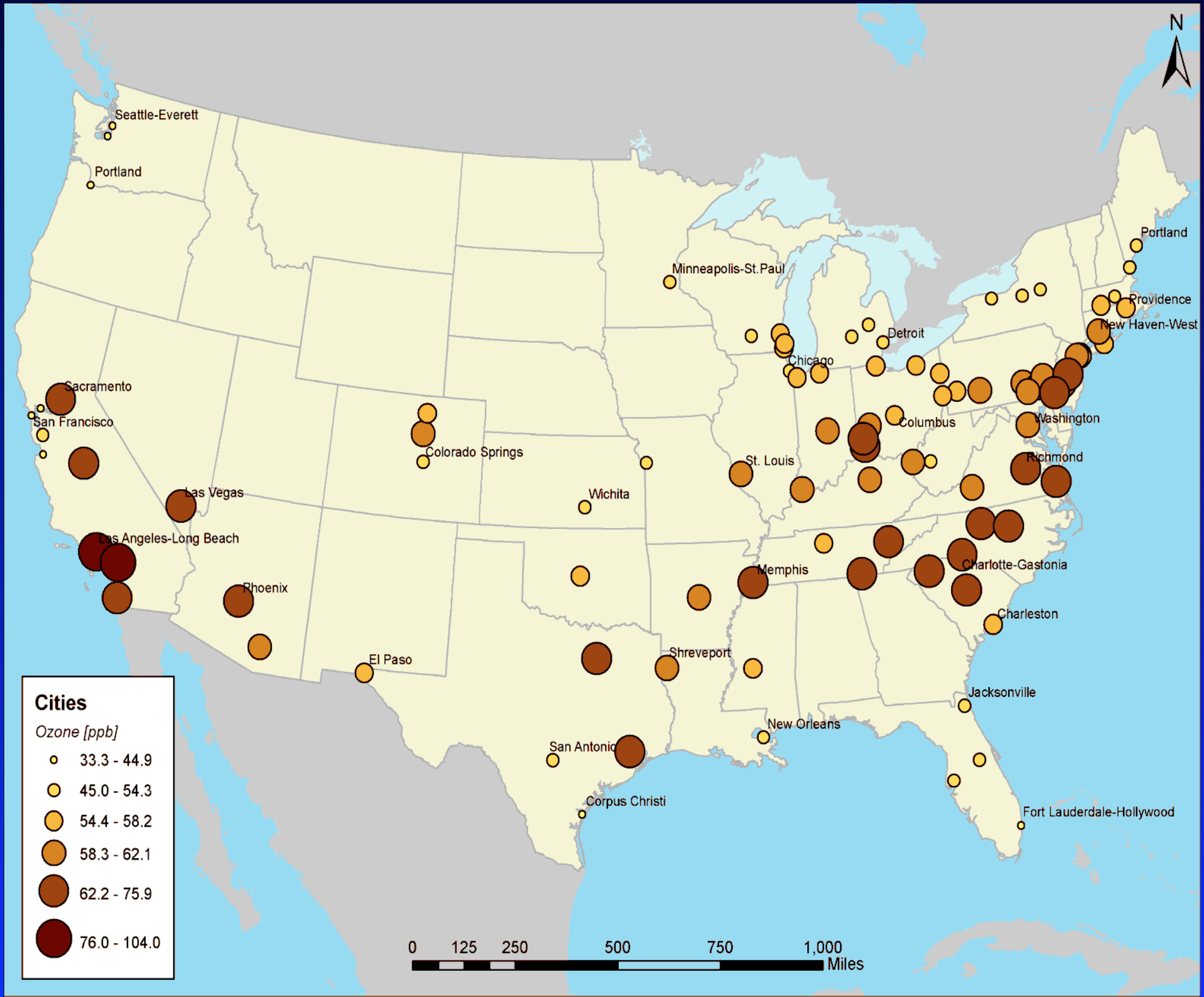
▲A variable that indicated regular occupational exposure to asbestos, chemicals/acids/solvents, coal or stone dusts, coal tar/pitch/asphalt, diesel engine exhaust, or formaldehyde

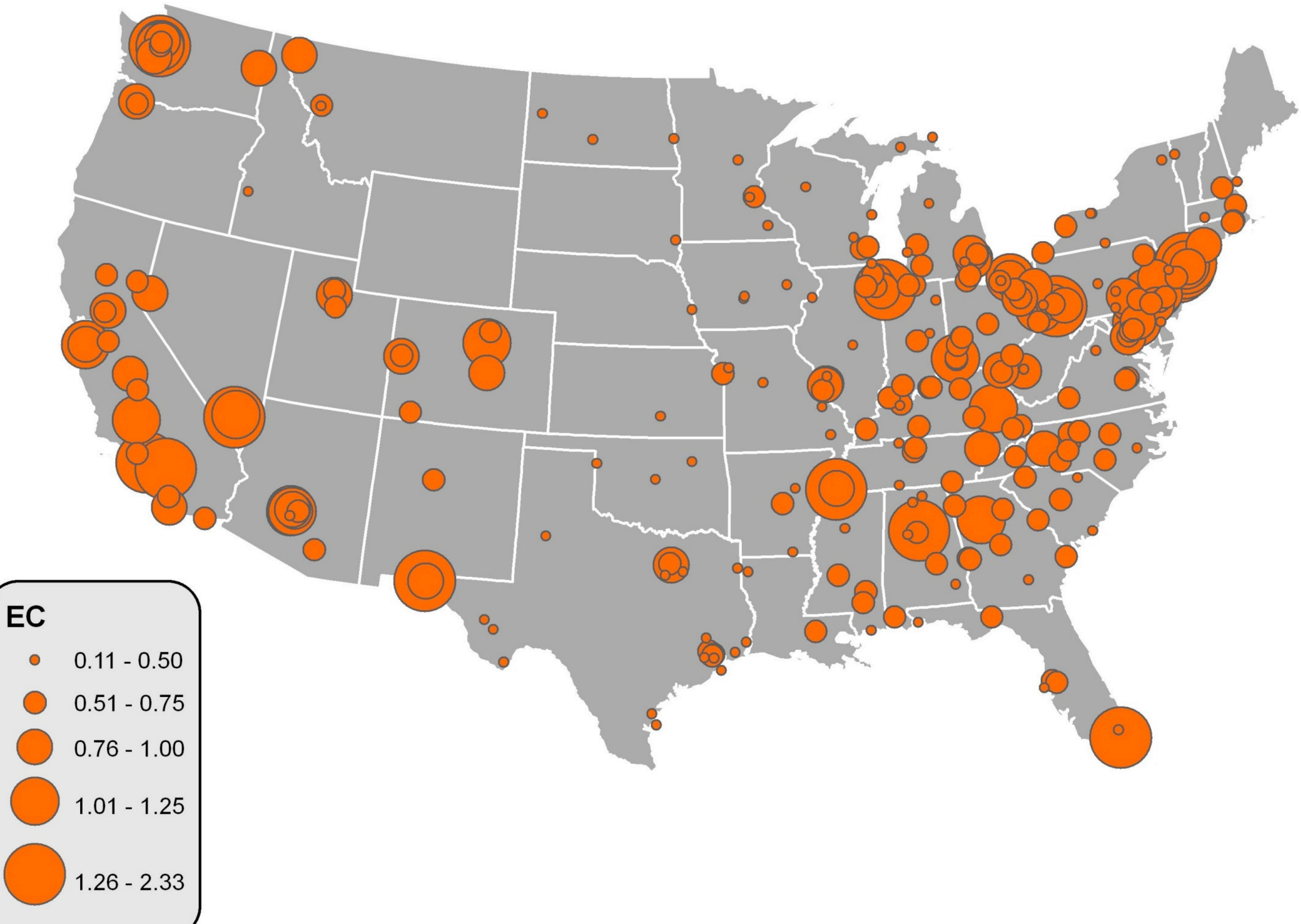
▲9 additional indicator variables that reflected an occupational dirtiness index

Diet:

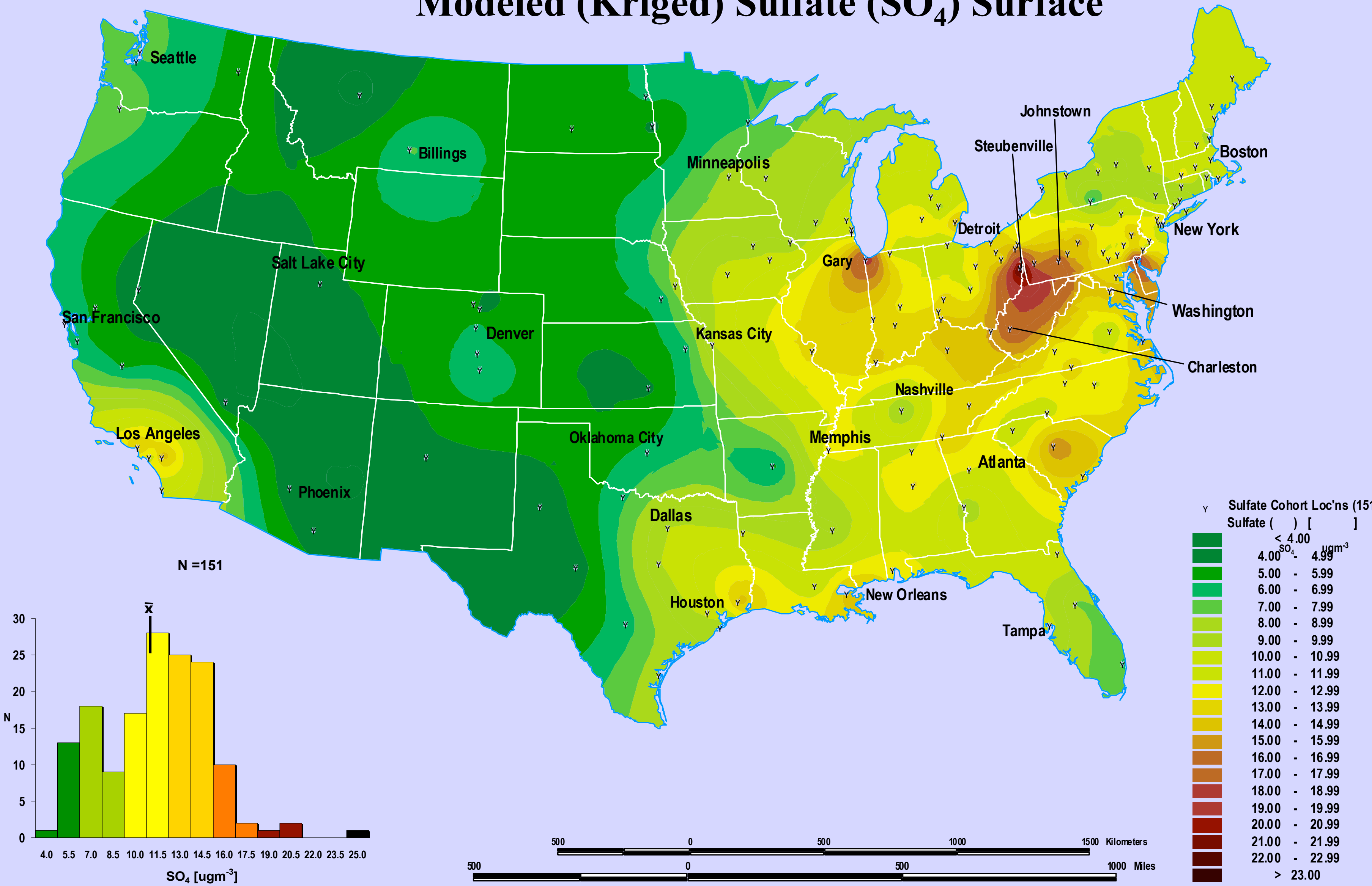
▲Quintile indicator variables for each of two diet indices that accounted for fat consumption an consumption of vegetables, citrus and high-fibe grains were derived based on information given the enrollment questionnaire.

Long-term Ozone Across the US – 1977-2000 – 1-hour Max

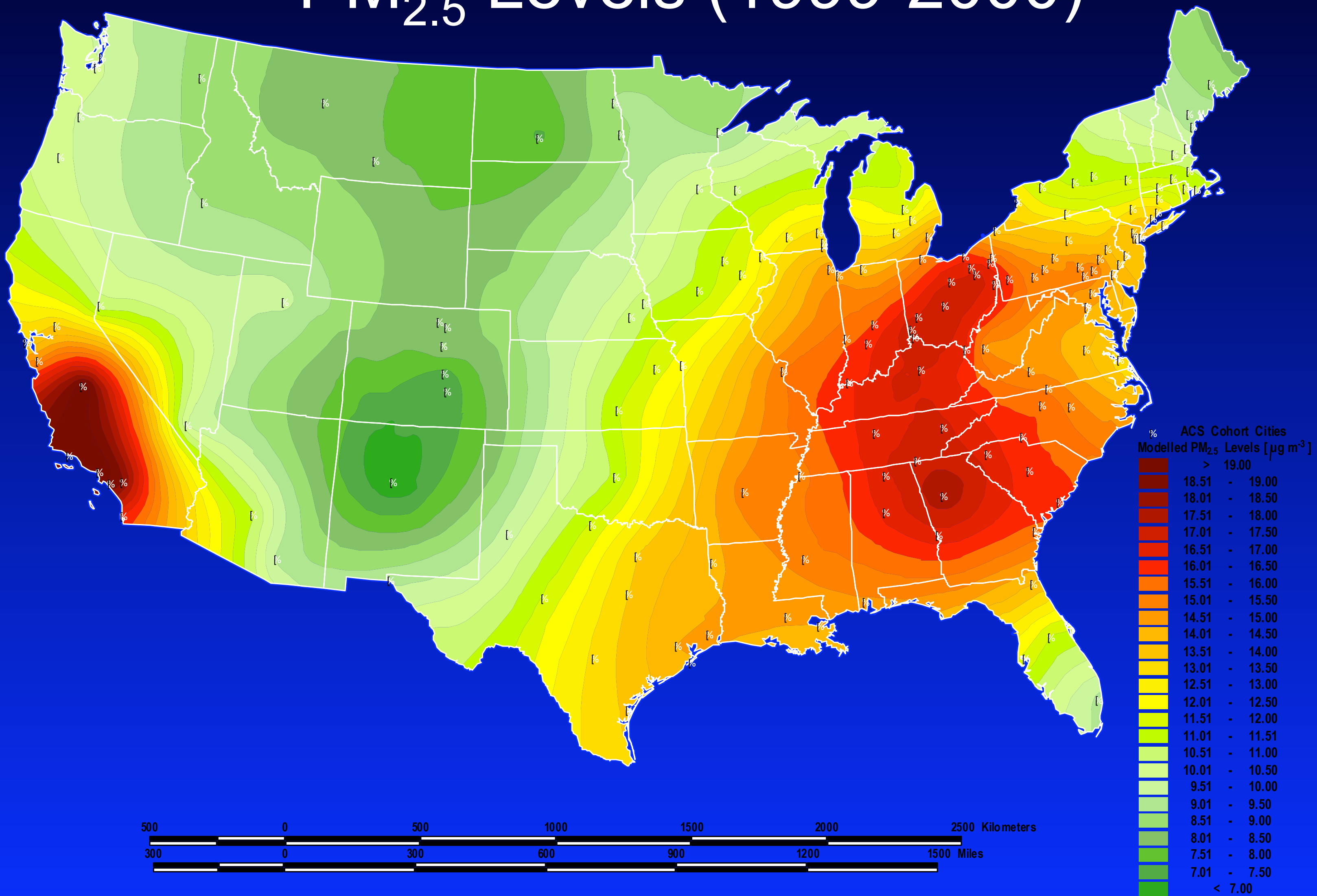



EC
0.11 - 0.50
0.51 - 0.75
0.76 - 1.00
1.01 - 1.25
1.26 - 2.33

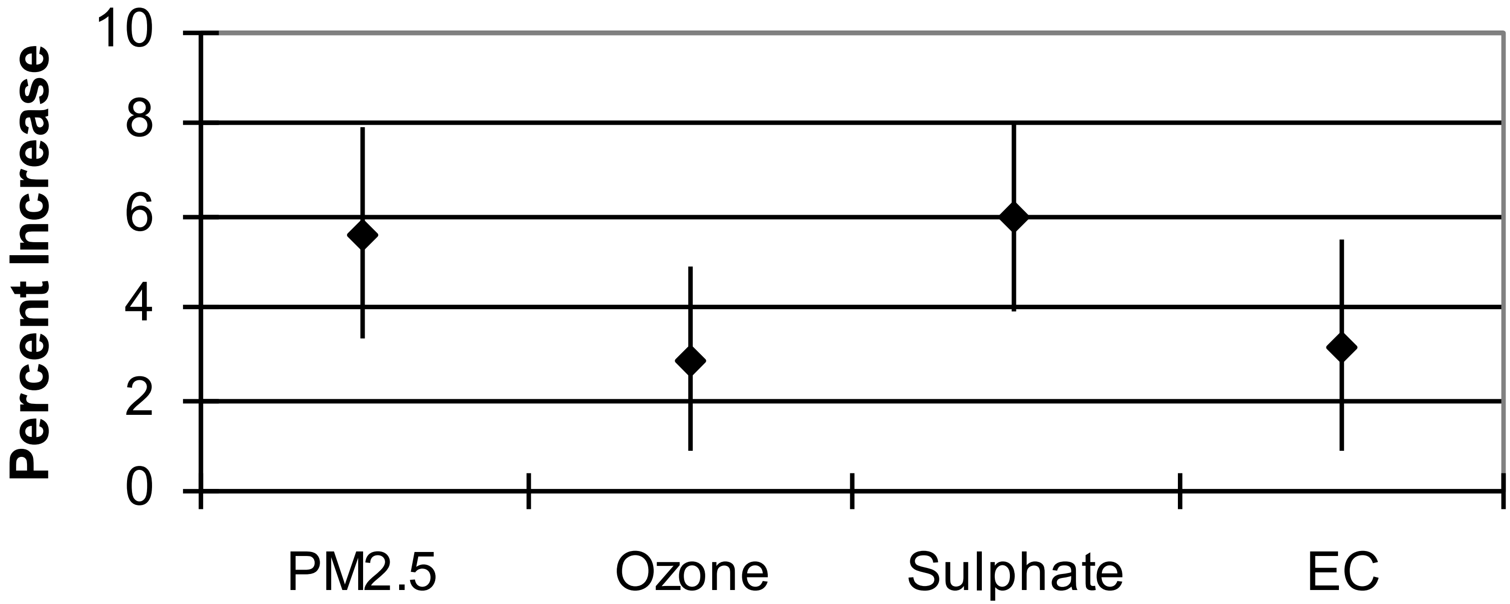
Modeled (Kriged) Sulfate (SO_4) Surface



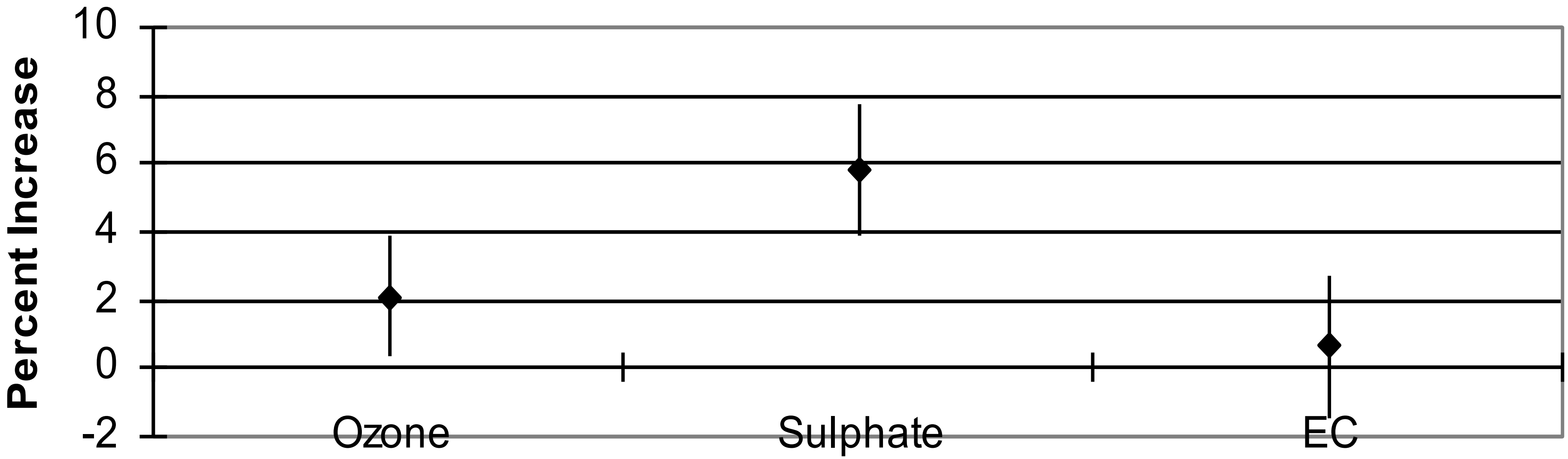
$PM_{2.5}$ Levels (1999-2000)



Percent Increase in Excess Risk Due to Air Pollution (Cardiopulmonary Causes of Death)



Percent Increase in Excess Risk Due to Pollution in Multipollutant Models (Cardiopulmonary Causes of Death)



Evidence of Heat Interactions with Chronic Exposure

The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

Long-Term Ozone Exposure and Mortality

Michael Jerrett, Ph.D., Richard T. Burnett, Ph.D., C. Arden Pope III, Ph.D., Kazuhiko Ito, Ph.D., George Thurston, Sc.D., Daniel Krewski, Ph.D., Yuanli Shi, M.D., Eugenia Calle, Ph.D., and Michael Thun, M.D.

Bottom Line

- Epidemiological evidence suggests health effects from all the short-lived climate forcers
- Interpretation of multi-pollutant models complicated by high correlations ($r \sim 0.6$-0.7 among them)
- Many other studies implicate ozone and BC as contributors to many chronic diseases

Summary of Findings

	Climate	Toxicology	Epidemiology
Sulfate	Cooling	Pure form not toxic	Acute and long-term effects
Organic Carbon	Cooling	Many forms toxic to varying degrees	Acute and long-term effects
Black Carbon	Warming	Pure form moderately toxic	Acute and long-term effects
Ozone	Warming	Pure form very toxic	Acute and long-term effects

UN Assessment Published 2011

Integrated Assessment of Black Carbon and Tropospheric Ozone

- Major Assessment of All Impacts – Indictes Significant Climate, Health, Ecosystem, Food Benefits

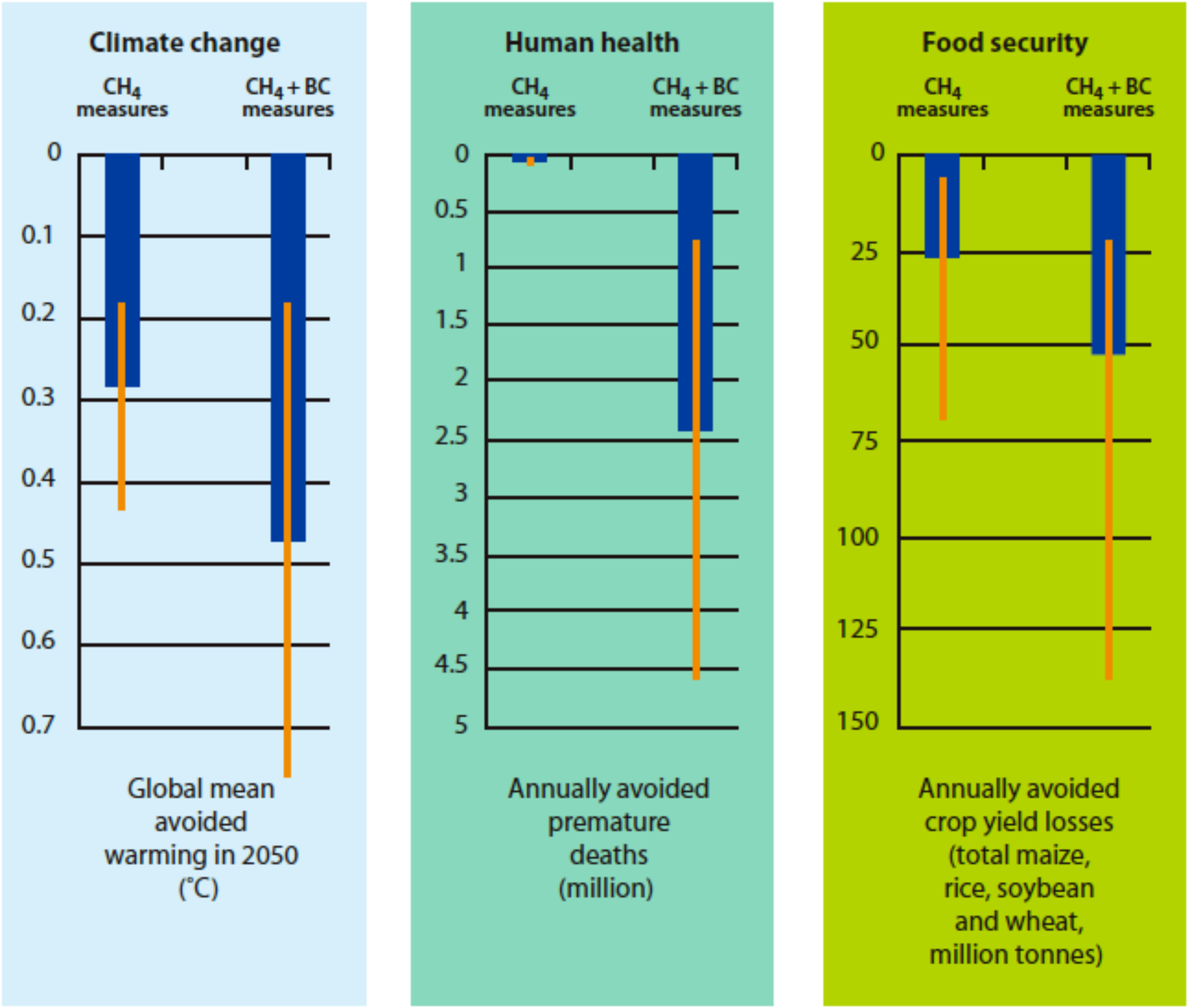


Figure 1. Global benefits from full implementation of the identified measures in 2030 compared to the reference

Regional Breakdown of Mortality Avoided

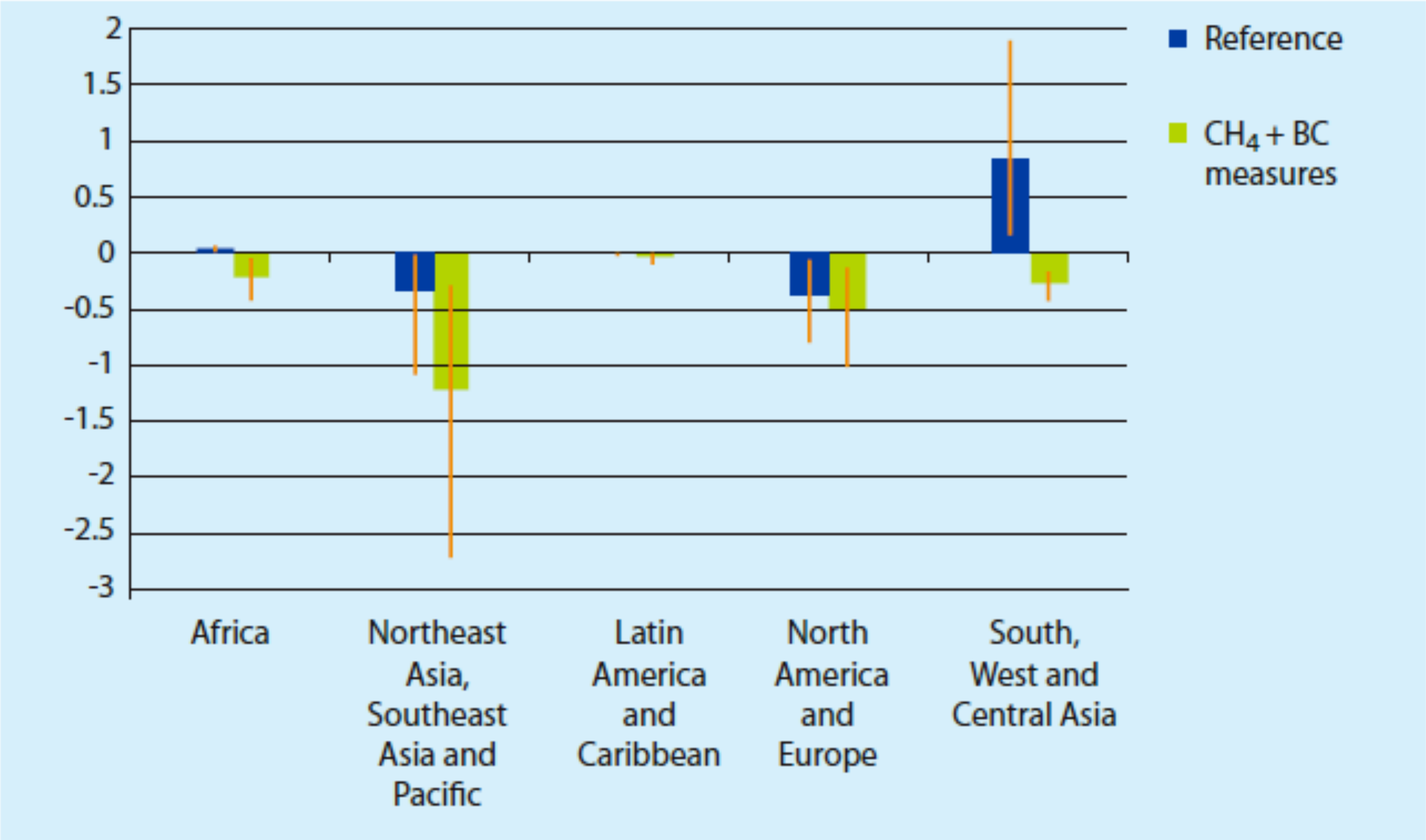
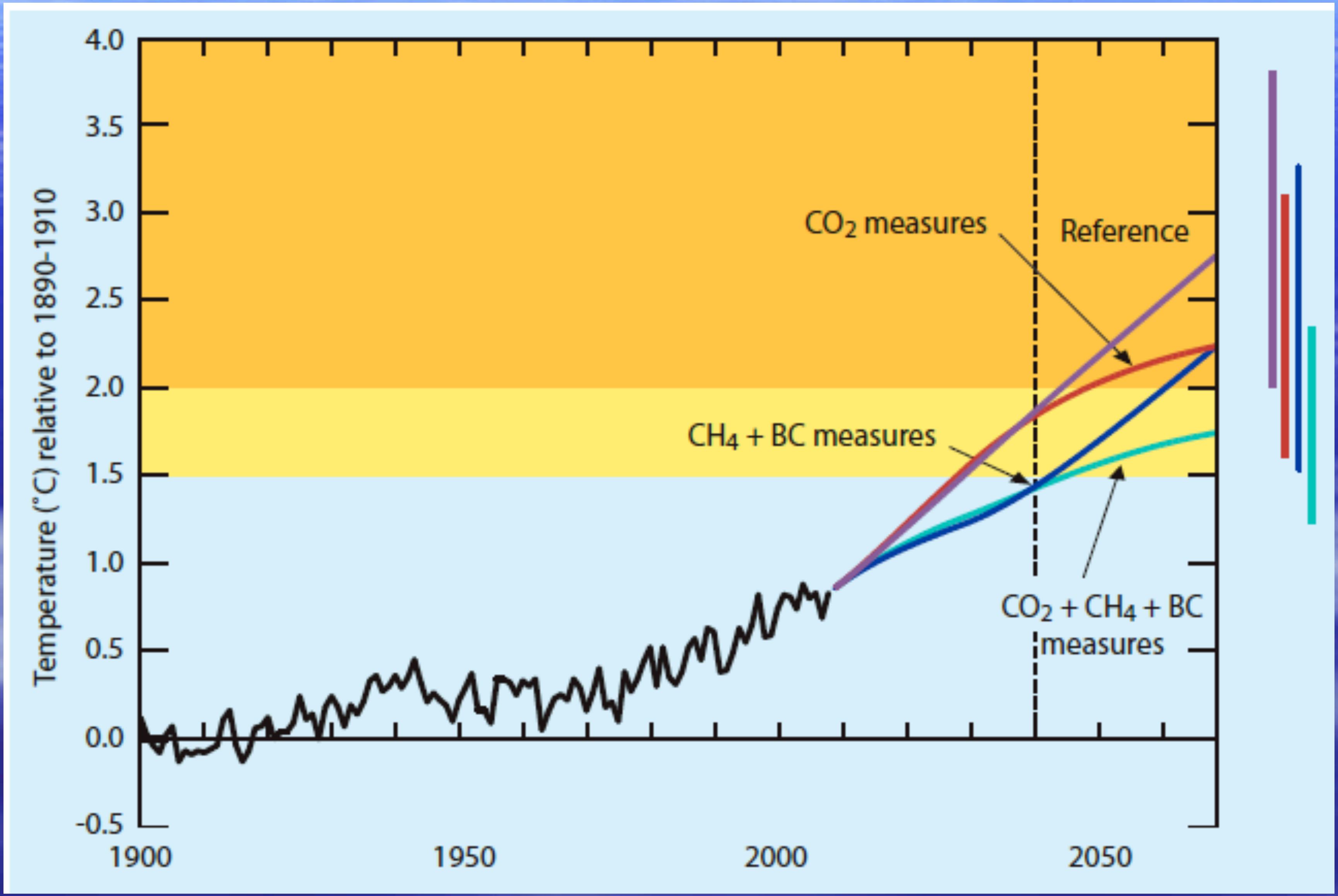


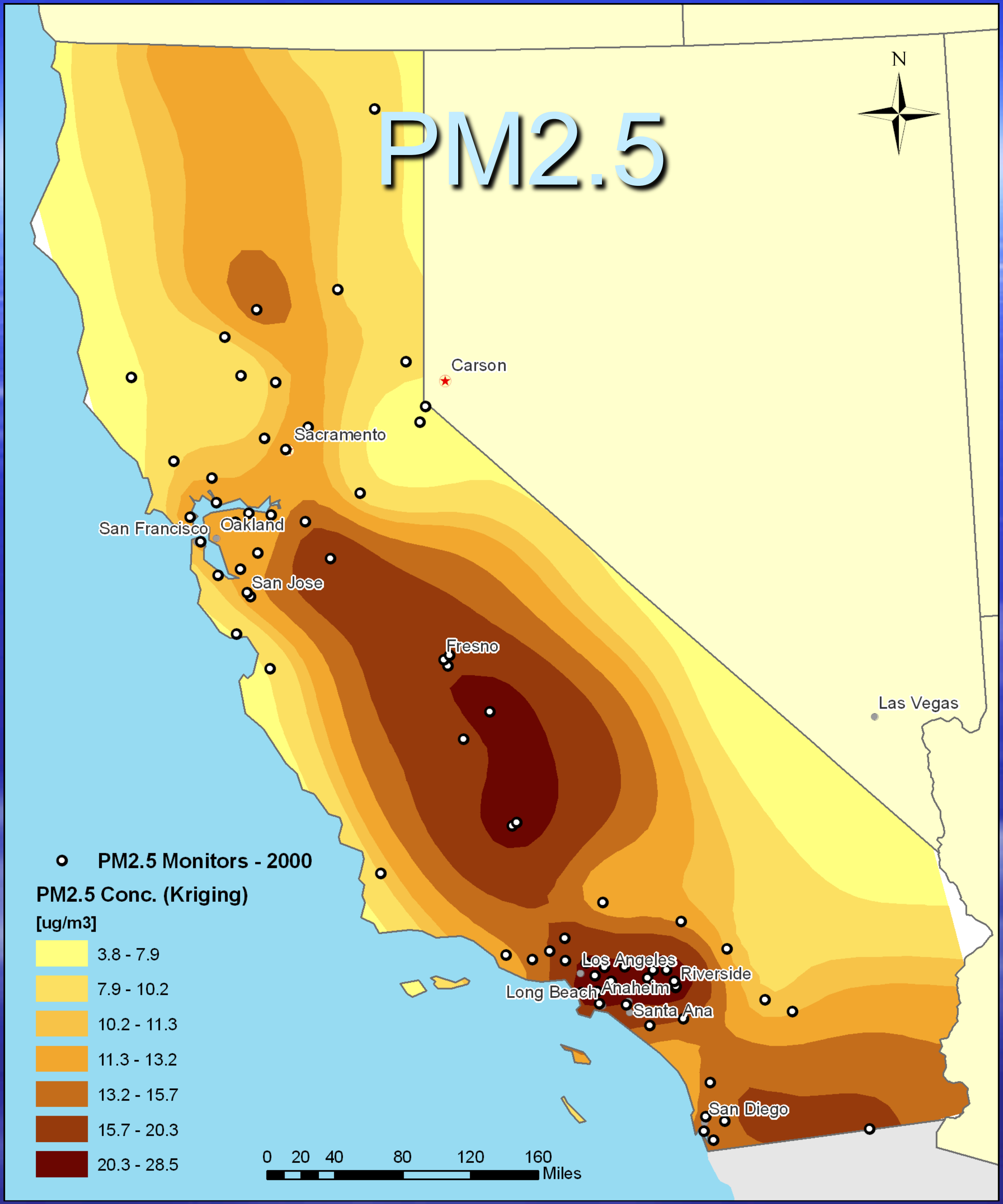
Figure 7. Comparison of premature mortality (millions of premature deaths annually) by region, showing the change in 2030 in comparison with 2005 for the reference scenario emission trends and the reference plus CH_4 + BC measures. The lines on each bar show the range of estimates.

Climate Benefits Near Term



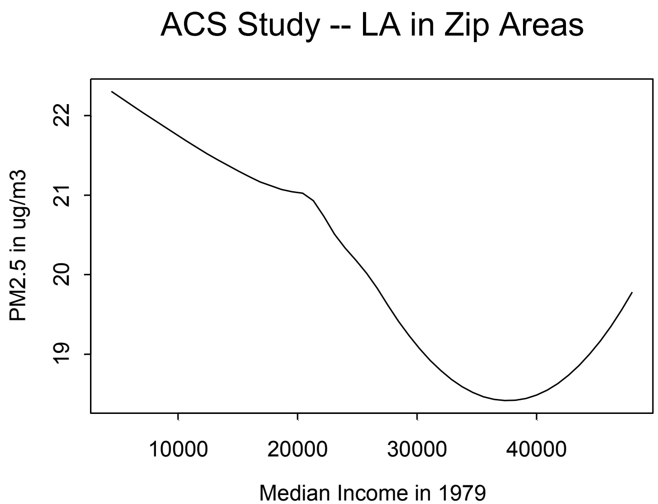
What are the Equity Considerations?

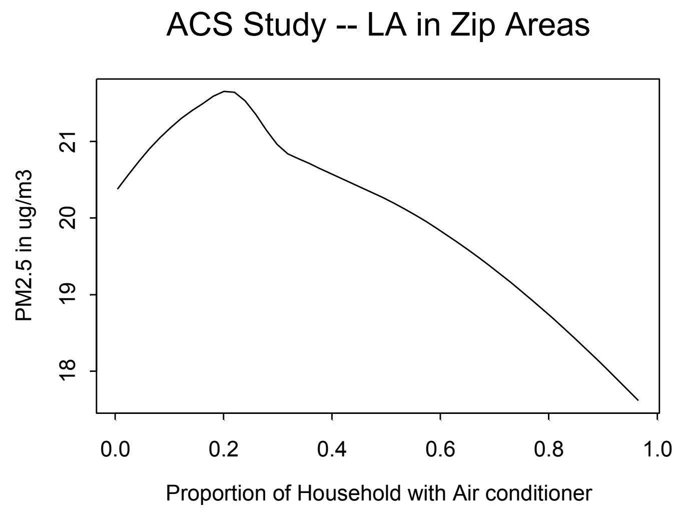
- Different for PM, BC, Sulfate and Ozone
- Spatial scales vary, source contributions and control strategies differ
- Populations affected are different regionally and within cities

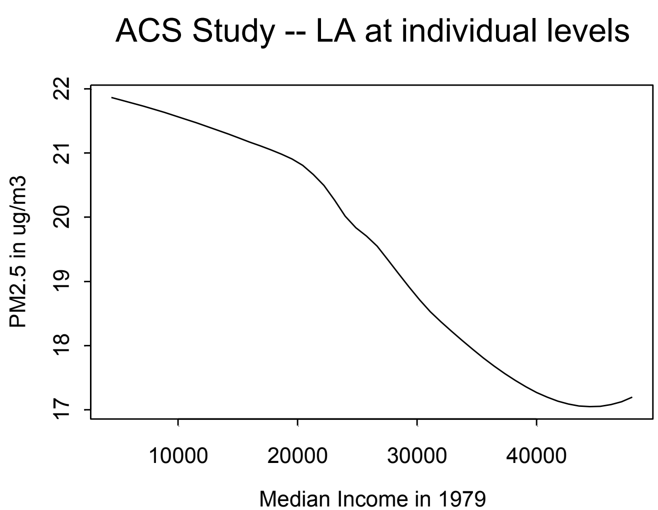


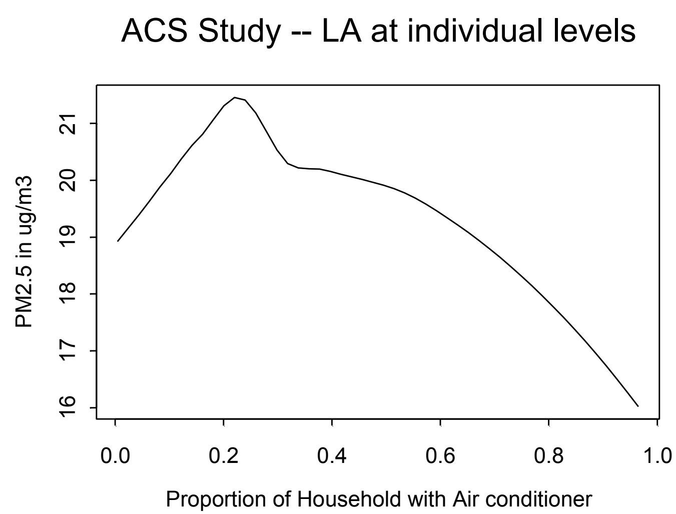
PM2.5
N
Carson
Sacramento
San Francisco
Oakland
San Jose
Fresno
Las Vegas
Los Angeles
Riverside
Long Beach
Anaheim
Santa Ana
San Diego
PM2.5 Monitors - 2000
PM2.5 Conc. (Kriging)
[ug/m3]
3.8 - 7.9
7.9 - 10.2
10.2 - 11.3
11.3 - 13.2
13.2 - 15.7
15.7 - 20.3
20.3 - 28.5
0 20 40 80 120 160
Miles

Wealth and $PM_{2.5}$ Air Pollution Exposure in Los Angeles

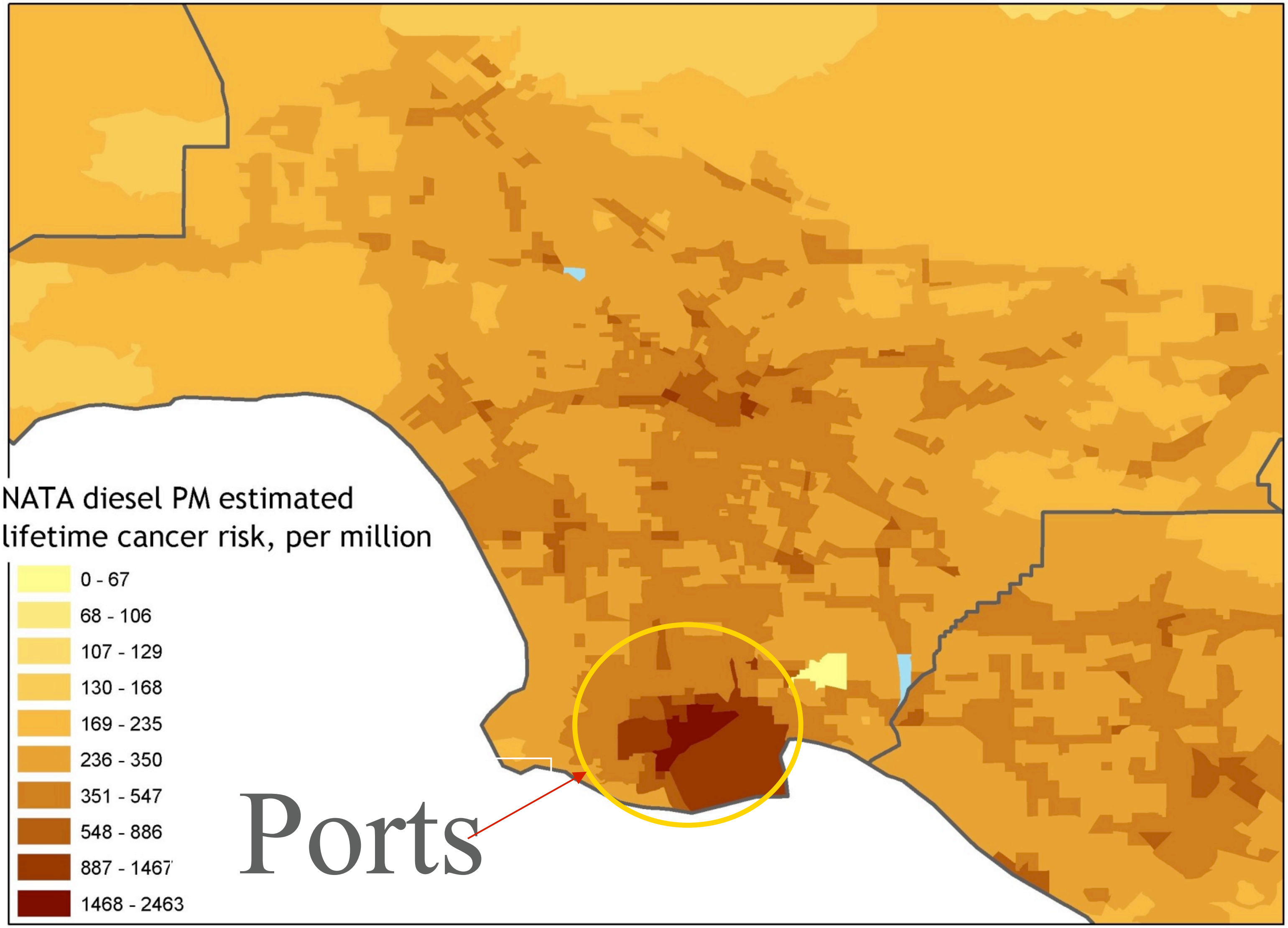




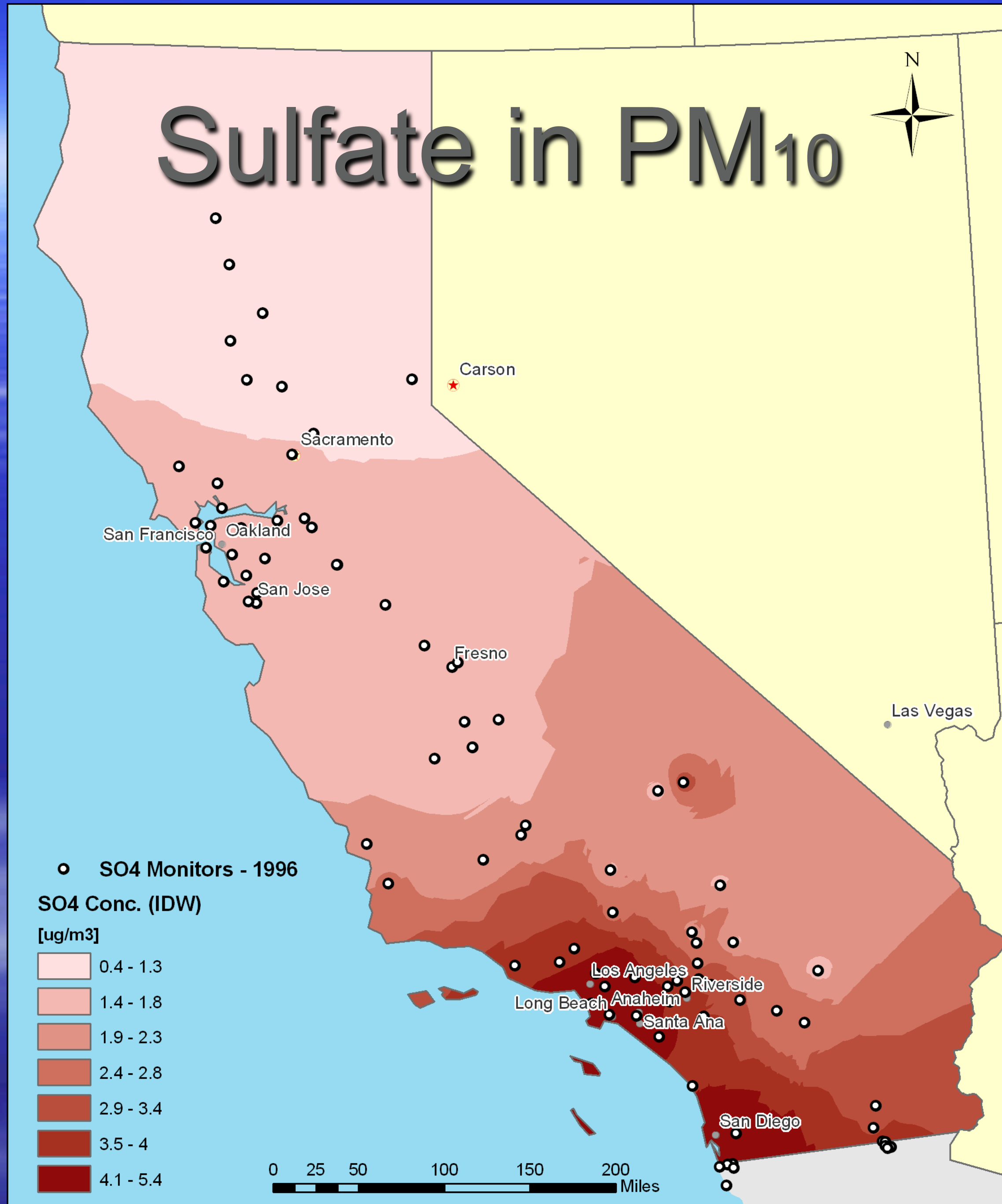




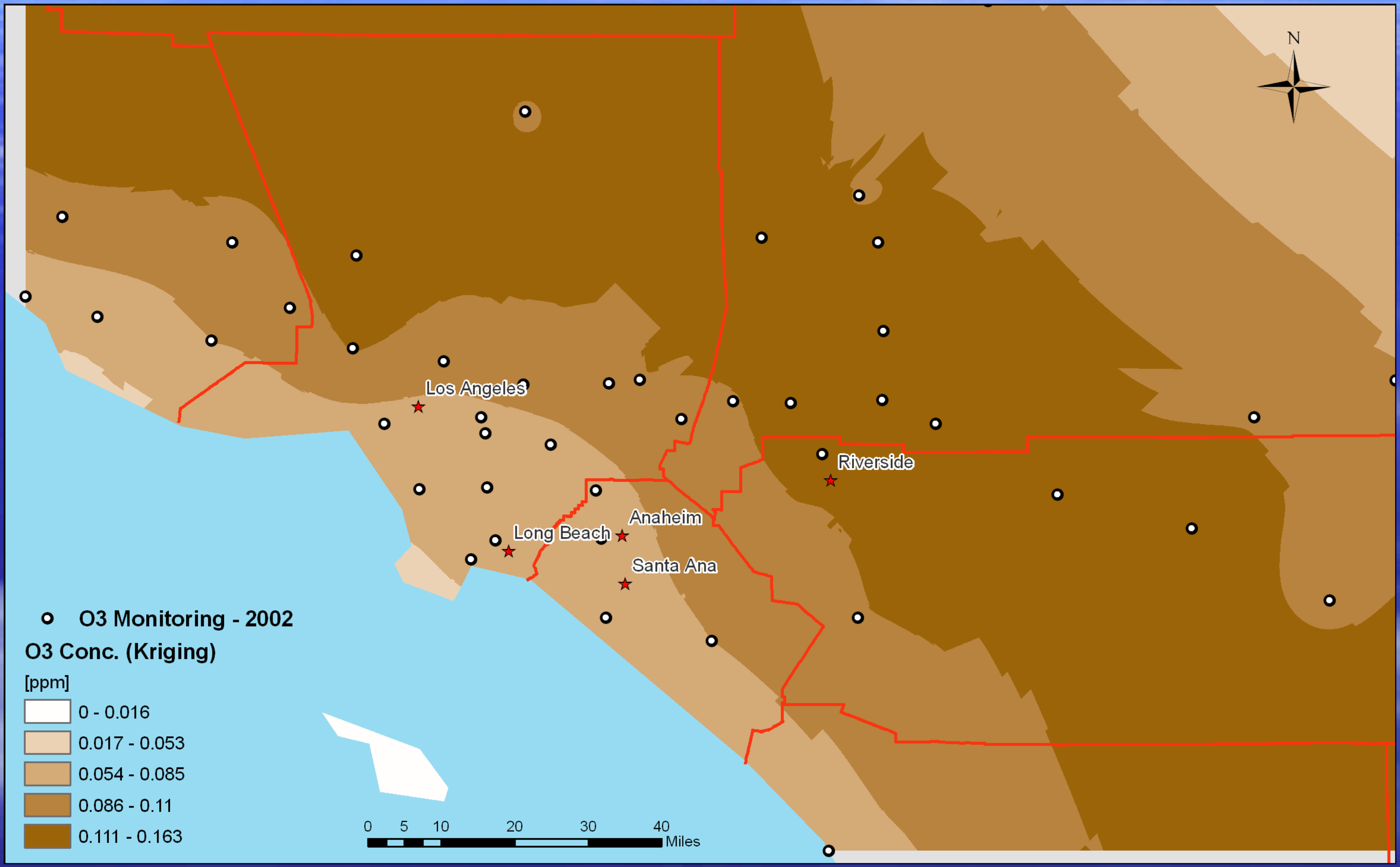
Diesel PM NATA



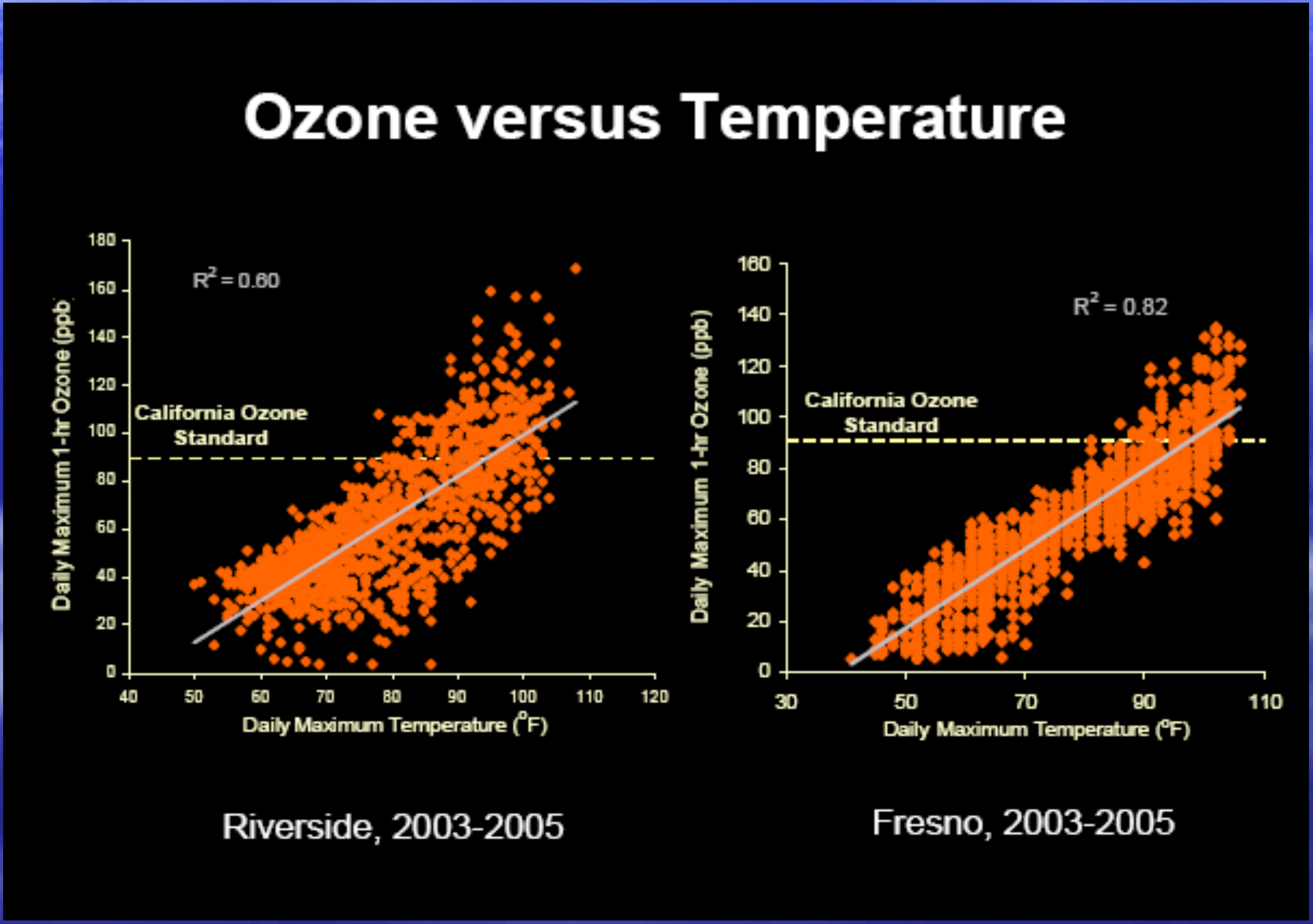
Sulfate in PM_{10}



Ozone


N
Los Angeles
Riverside
Anaheim
Long Beach
Santa Ana
O3 Monitoring - 2002
O3 Conc. (Kriging)
[ppm]
0 - 0.016
0.017 - 0.053
0.054 - 0.085
0.086 - 0.11
0.111 - 0.163
0 5 10 20 30 40
Miles

Ozone Increases with Higher Temperatures



Equity Considerations

Not well understood, but preliminary conclusions:

1. $PM_{2.5}$ and BC tend to have a negative social gradient (worse for poor groups)
2. Ozone probably has a positive social gradient (worse for richer groups)
3. Sulfate more homogeneous locally, but regionally has a negative gradient

Conclusions

- SLCF have become major focus in climate change debates
- BC, sulfate and ozone all have health effects and potential co-benefits
- Reducing sulfate could accelerate warming, while reducing others will probably slow warming
- Equity dimension not well understood, but could be very different for BC, sulfate and ozone
- Controlling SLCFs is essential as a compliment to CO_2 reductions

Acknowledgements

- John Balmes, Kirk Smith, Seth Shonkoff (UC Berkeley), Andy Haines (London School of Tropical Medicine and Hygiene)
- California Air Resources Board, Health Effects Institute, National Institute of Environmental Health Science, Wellcome Trust

Heat and Air Pollution: Ozone

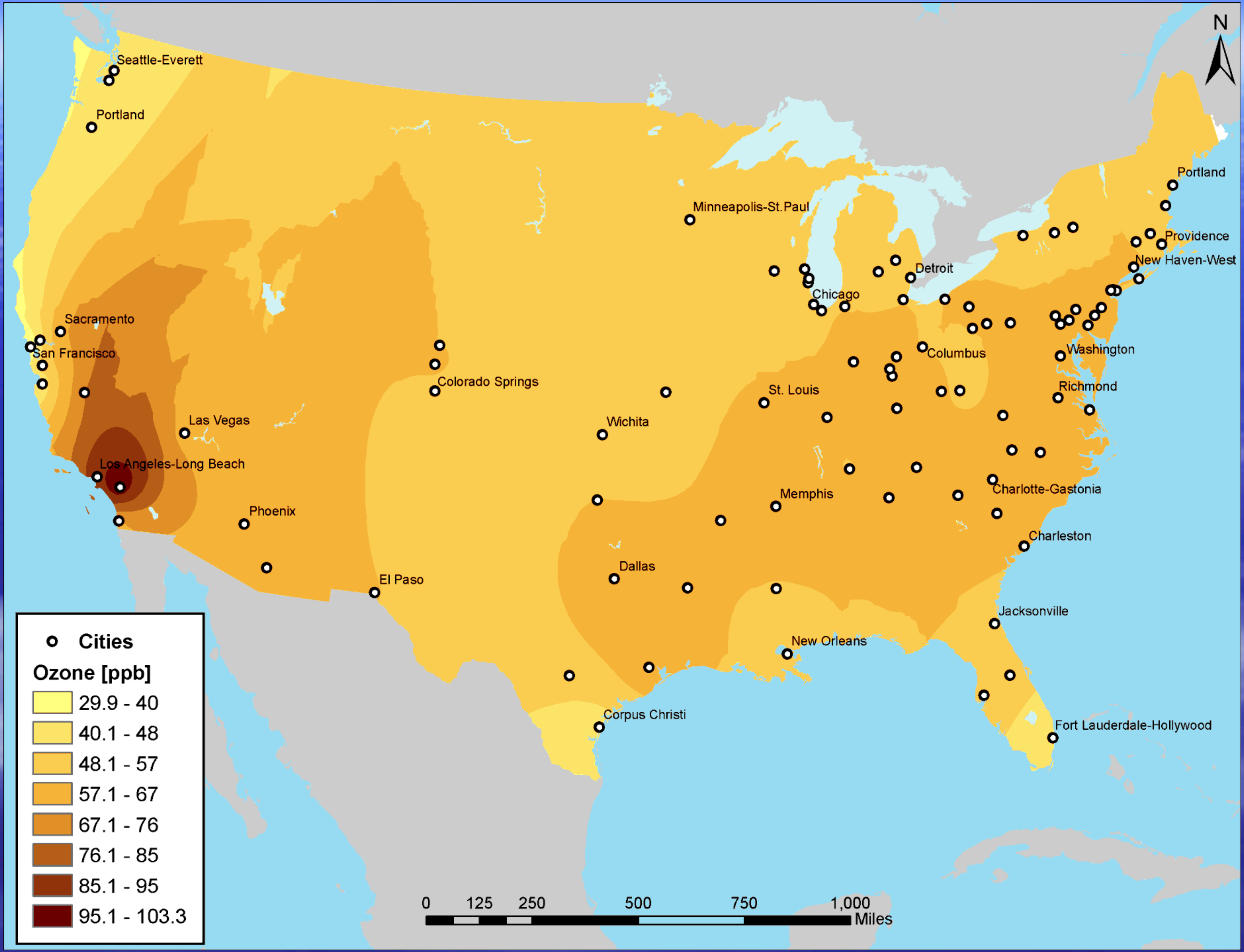
- Higher temperatures, strong sunlight and a stable air mass are ideal for formation of ground level ozone (O_3)
- Difficult to predict, but climate change likely to increase ozone concentrations globally
- In much of the US, a warming of 4 degrees (F) could increase O_3 concentrations by about 5% (US EPA)

Heat and Air Pollution

- Heat waves in Europe in summer 2003 provide a case study of heat-related O_3 impacts on public health
- During the heat waves thousands of excess deaths that occurred above the average recorded for that time of year
- Epidemiological studies of deaths suggest a substantial portion of the mortality attributable to elevated O_3 and particulate levels that occurred during the heat waves
  - 20-50% of the total excess deaths can be attributed to elevated O_3 and particle levels

(Filleul et al.;Johnson et al.)

Ozone Concentrations Across the U.S.



Does Acute Ozone Exposure Interact with Heat?

- "*The results for confounding and/or effect modification by air pollutants on the temperature-mortality association remain mixed*" (Basu 2009)

- With increasing heat and ozone, important to understand interactions

Research Needs

- Toxicology and chamber studies examining effects of heat and ozone (or photochemical mixtures) to determine biology of dose-response under different heat conditions
- Need further epidemiological studies to understand ozone-dose response under hotter conditions
- More generally need better investigation of dose-response shapes because co-benefits vary widely

Sources of Sulfur and Black Carbon

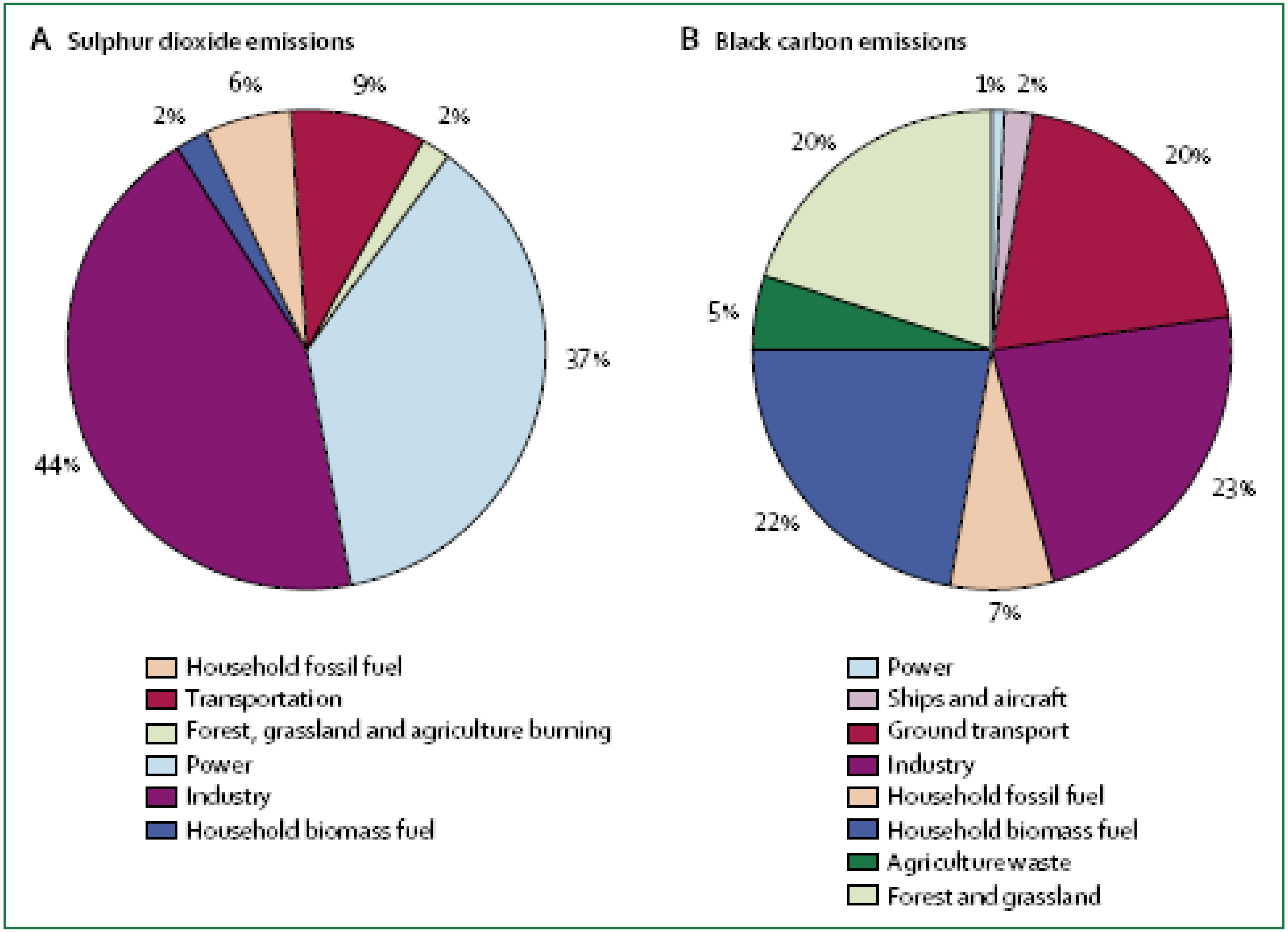


Figure: Relative contributions of human sources to sulphur dioxide (A) and black carbon (B) emissions

Research Needs

- What are the within-city distributions of ozone and black carbon?
- Are health effects different as scale of analysis focuses on smaller areas?
- What are the health effects of pollution mixtures associated with these pollutants?
- What is the global burden of disease from these pollutants?