A Multi-Site Time Series Study of Hospital Admissions and Fine Particles:
A Case-Study for National Public Health Surveillance

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EPA Workshop October 17 2007

Sponsored by the EPA, CDC Center of Excellence, and NIEHS

A NATIONAL SYSTEM FOR TRACKING POPULATION HEALTH

- **Multiple government databases contain massive amounts of information on the environmental, social, and economic factors that determine health**
- **Research on population health could be rapidly advanced by:**
  - **integrating these existing databases**
  - **bringing to bear new statistical models that would describe major threats and their causes**
- **These integrated databases and new analysis tools would create a national system for population health research**

Air pollution and health: Fundamental questions

- Is there a risk at current levels?
- How can we estimate it?
- How big is the risk?
- What causes it?

Health Effects Fine Particles: Objectives

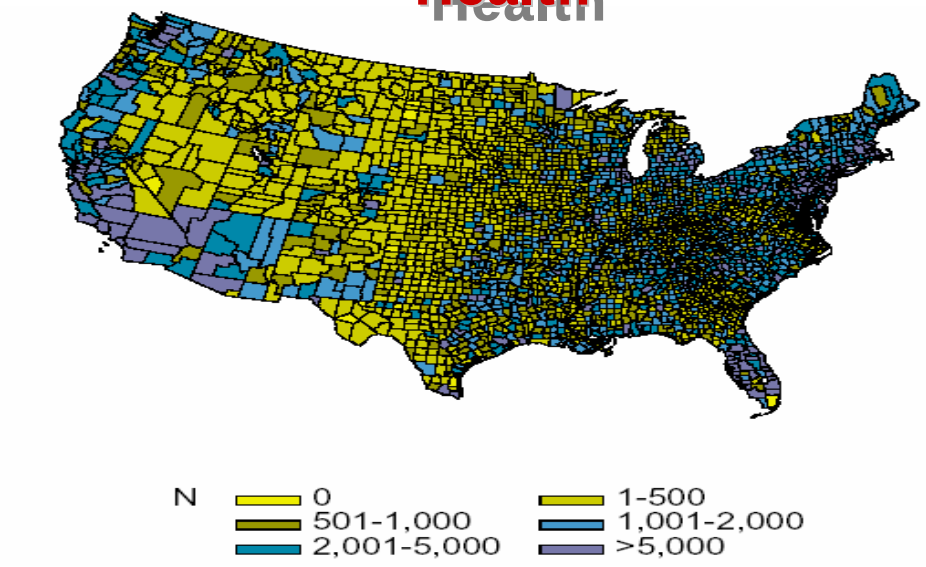
1. assemble a national database of time series data for the period 1999-2005 on hospital admissions rates for cardiovascular and respiratory diseases, fine particulates, and weather for 204 US counties
2. develop state-of-the-art statistical methods
3. estimate maps of relative risks of hospital admissions associated with short-term changes in fine particles
4. illustrate how integration and analysis of national databases can lead to a national health monitoring system

Integrating National Data Sources

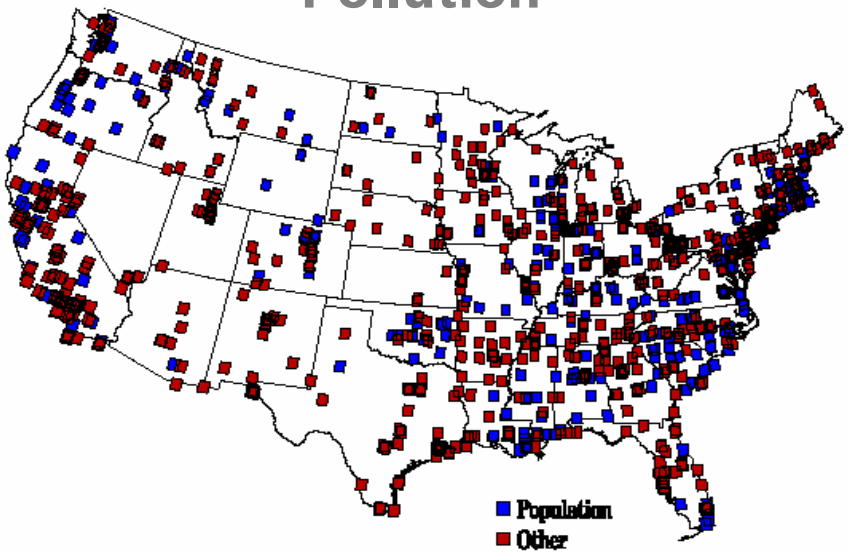
- **NCHF:** 48 million identification numbers
- **MCBS:** subset of 15,000 Medicare participants with additional information on risk factors
- **AIRS:** air pollution monitoring network
- **NOAA:** weather monitoring network
- **US Census:** location characteristics

Integrating national data bases

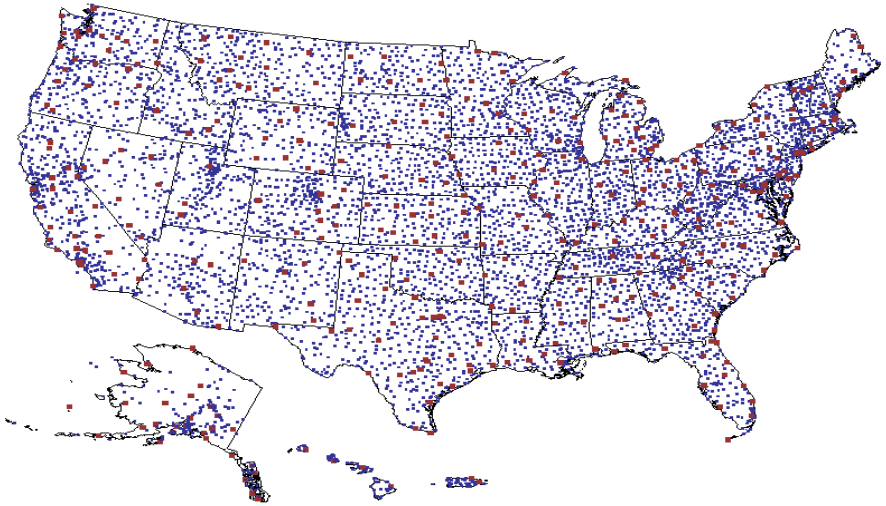
Health



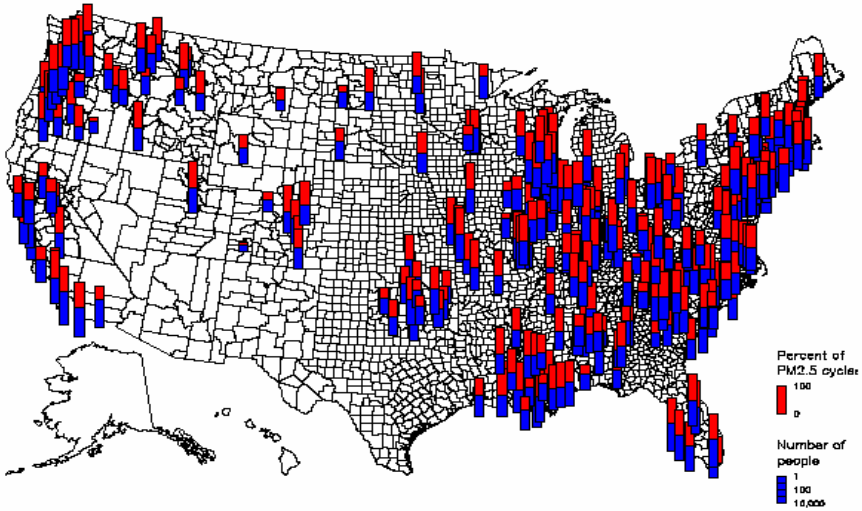
Pollution

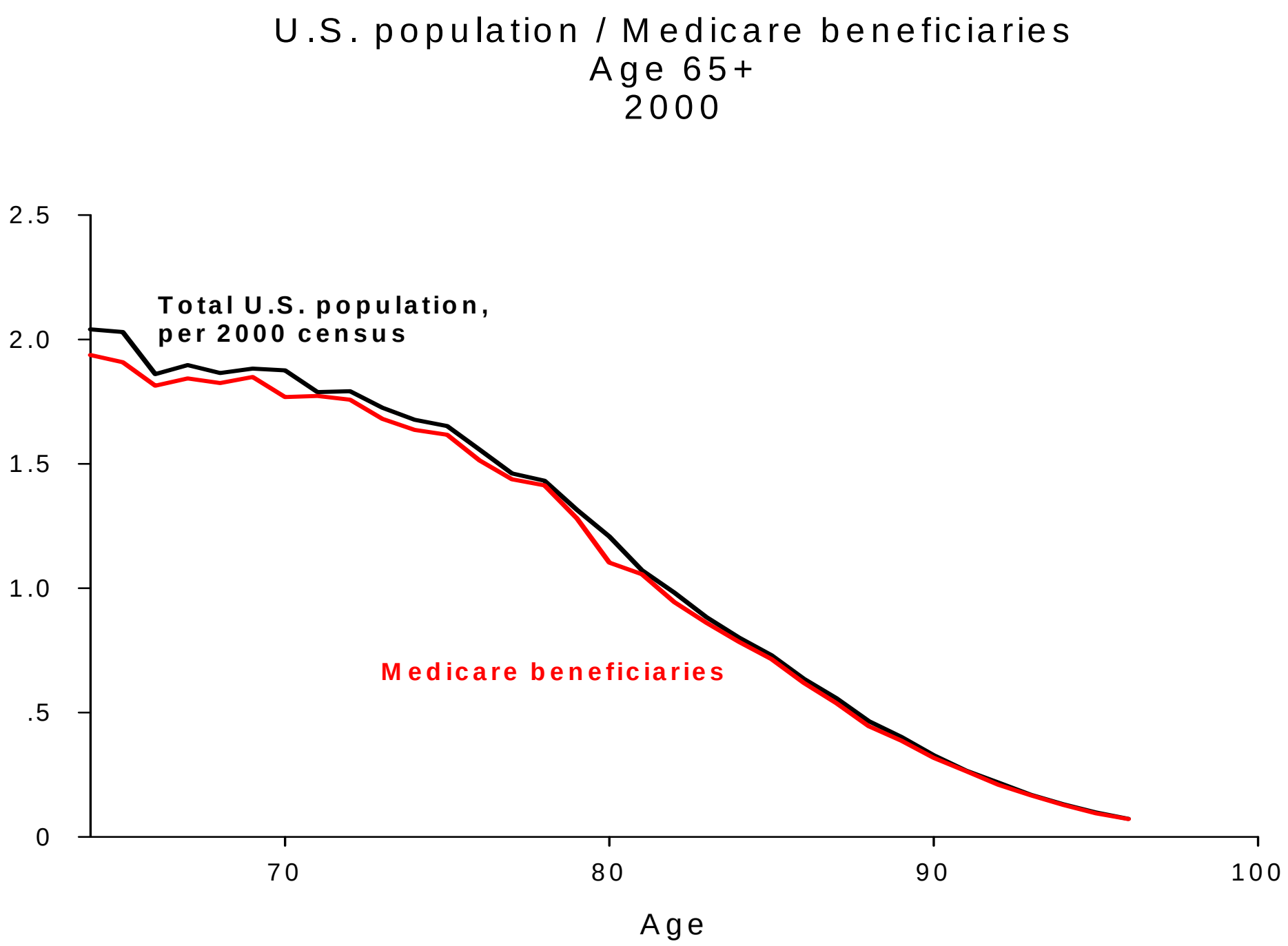


Weather



204 counties with matched data

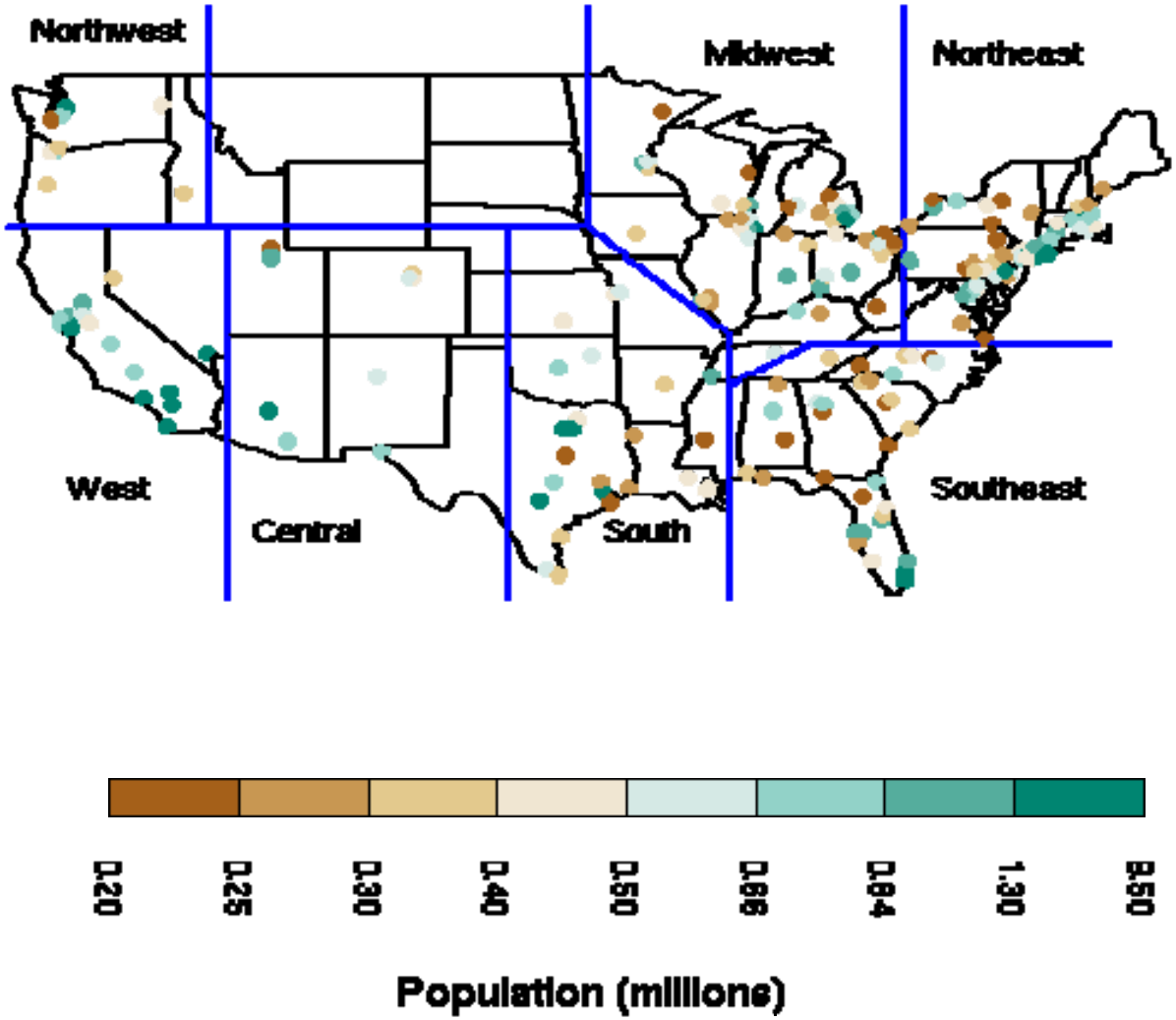



U.S. population / Medicare beneficiaries
Age 65+
2000
2.5
2.0
1.5
1.0
.5
0
Total U.S. population,
per 2000 census
Medicare beneficiaries
70
80
90
100
Age

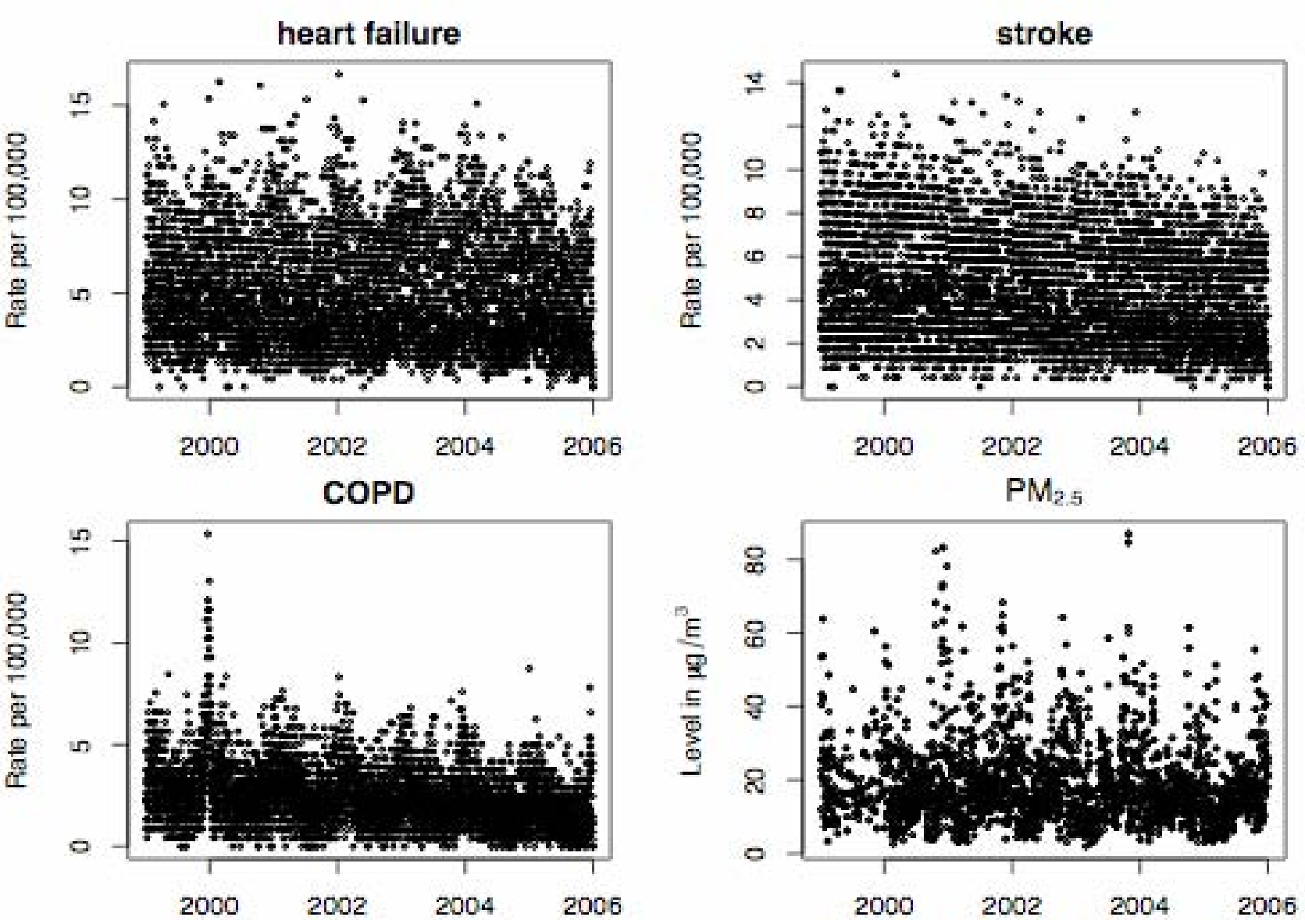
National Medicare Cohort (1999—2005)

- National study of fine particles ($PM_{2.5}$) and hospital admissions in Medicare
- Data include:
  - Billing claims (NCHF) for everyone over 65 enrolled in Medicare (~48 million people),
    - date of service
    - treatment, disease (ICD 9), costs
    - age, gender, and race
    - place of residence (ZIP code/county)
  - Approximately 204 counties linked to the air pollution monitoring

MCAPS study population: 204 counties with populations larger than 200,000 (11.5 million people)



Daily time series of hospitalization rates and $PM_{2.5}$ levels in Los Angeles county (1999-2005)



Multi-site time series studies

- Compare day-to-day variations in hospital admission rates with day-to-day variations in pollution levels within the same community
- Avoid problem of unmeasured differences among populations
- Key confounders
  - Seasonal effects of infectious diseases and weather

Statistical Methods

- **Within city**. Semi-parametric regressions for estimating associations between day-to-day variations in air pollution and mortality controlling for confounding factors
- **Across cities**. Hierarchical Models for estimating:
  - national-average relative rate
  - Regional-average relative rate
  - exploring heterogeneity of air pollution effects across the country

Challenges

- For any given city, we try to estimate a small pollution effect relative to confounding effects of trend, season and weather
- Strong role of other time-dependent factors
- High correlation between non linear predictors
- Sensitivity of findings to model specifications

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The Journal of the American Medical Association

$PM_{2.5}$ → **Hospital Admissions**

ORIGINAL CONTRIBUTION

Fine Particulate Air Pollution and Hospital Admission for Cardiovascular and Respiratory Diseases

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Aidan McDermott, PhD
Scott L. Zeger, PhD
Jonathan M. Samet, MD

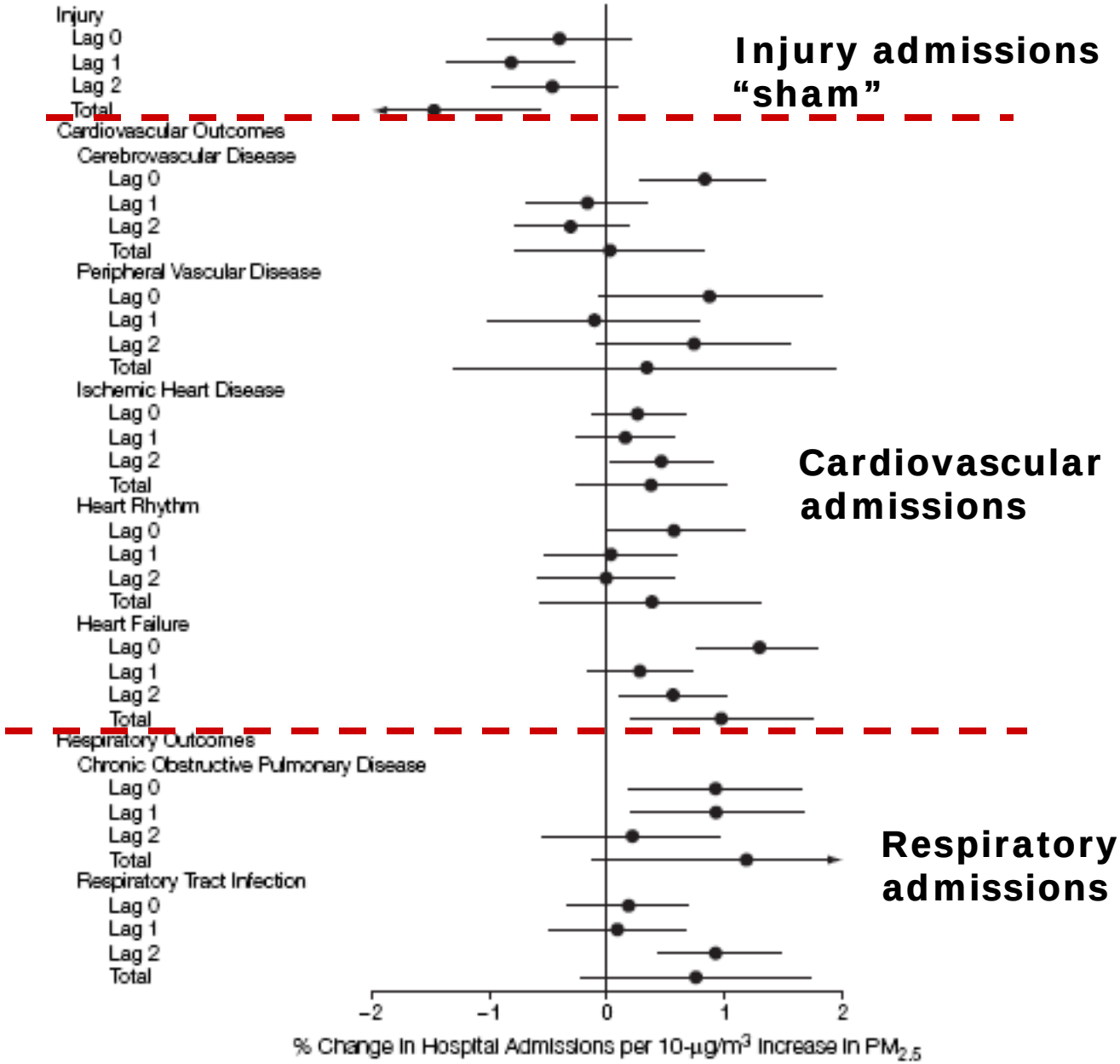
Context Evidence on the health risks associated with short-term exposure to fine particles (particulate matter ≤2.5 μm in aerodynamic diameter [$PM_{2.5}$]) is limited. Results from the new national monitoring network for $PM_{2.5}$ make possible systematic research on health risks at national and regional scales.

Objectives To estimate risks of cardiovascular and respiratory hospital admissions associated with short-term exposure to $PM_{2.5}$ for Medicare enrollees and to explore heterogeneity of the variation of risks across regions.

Design, Setting, and Participants A national database comprising daily time-series data daily for 1999 through 2002 on hospital admission rates (constructed from

March 8 2005

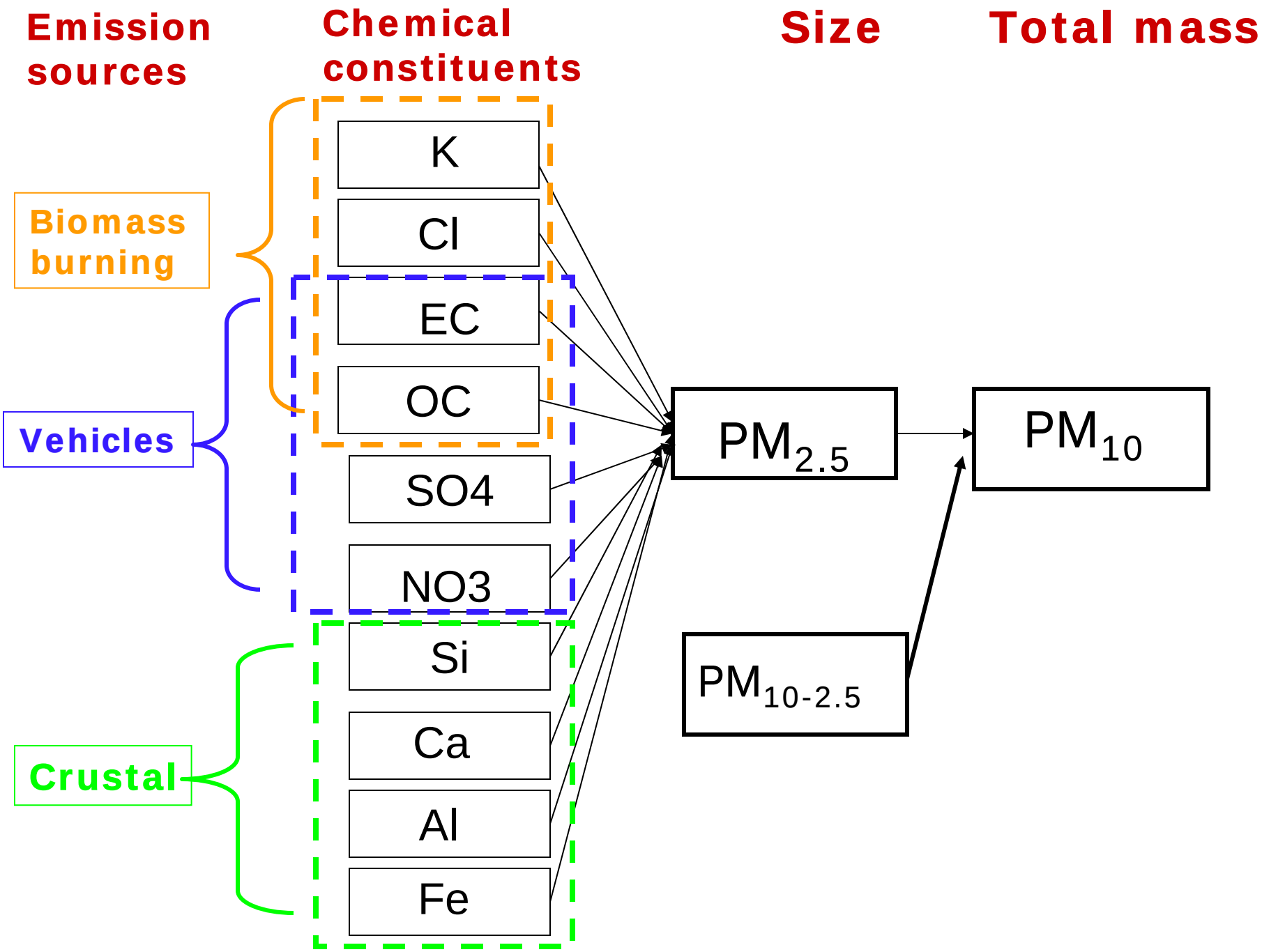
Figure 2. Percentage Change in Hospitalization Rate by Cause per 10-μg/m³ Increase in $PM_{2.5}$ on Average Across 204 US Counties



New Scientific Questions

What are the mechanisms of PM toxicity?

- **Size?**
- **Chemical components?**
- **Sources?**


Emission sources
Chemical constituents
Size
Total mass
Biomass burning
Vehicles
Crustal
K
Cl
EC
OC
SO4
NO3
Si
Ca
Al
Fe
PM2.5
PM10-2.5
PM10

Air pollution and health: Questions and (some) answers

- **Is there a risk?**
  - Multi-site time series studies such as NMMAPS (1987—2000) provide strong evidence of short-term association between air pollution and mortality
  - Preliminary results from Medicare data (1999—2002) indicate that current air pollution levels still affect health
- **How can we estimate it?**
  - National datasets are powerful resources for assessing the health effects of air pollution
  - Statistical models that can integrate information across space and time
  - National average estimates for the effect of PM are robust to various model formulations and statistical methods

Reproducible research

- We want to reproduce previous findings
  - "Did you do what you said you did?"
- Test assumptions, robustness of findings; check methodology
  - "Is what you did any good?"
- Implement and test new methodology
  - "I can do it better!"

NMMAPSdata R Package - Mozilla Firefox

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http://ihapss.biostat.jhsph.edu/data/NMMAPS/R/

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iHAPSS
Internet-based Health & Air Pollution Surveillance System

NMMAPSdata R Package

Publications | Software | Data | Rweb | iHAPSS

NMMAPSdata R Package

Current version: 0.3-4

The NMMAPSdata R package contains daily mortality, air pollution, and weather data originally assembled as part of the National Mortality, Morbidity, and Air Pollution Study (NMMAPS).

There is a technical report available which contains a brief overview of the package and contains examples of multi-city time series analysis of air pollution and mortality.

- The files simple.R, seasonal.R, and tdlm.R referenced in the report contain example code and functions for reproducing NMMAPS analyses.

Database summary information

- Time frame: January 1, 1987 -- December 31, 2000
- Causes of death: Total non-accidental, CVD, respiratory, pneumonia, COPD, accidental
  - Age categories: < 65, 65--74, >= 75
- Pollutants: PM_{10}, $PM_{2.5}$, CO, O_3, SO_2, NO_2
- Weather: Temperature, dewpoint temperature, relative humidity
- Number of Cities: 108

More detailed information about the database can be found on the IHAPSS website at http://www.ihapss.jhsph.edu/.

Package requirements

- R version 1.9.0 or higher.
- bzip2 compression capability. Most people will *not* have to worry about this since R comes with bzip2 compression capability by default. However, on some Unix-like systems it is possible that the version of R was compiled without it. NMMAPSdata will give an error when the package is loaded if bzip2 capability is not present.
- Approximately 380MB of disk space to store the package.

For **Unix**, **Linux**, and **Mac OS X** users, there is a source package available.

Done

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seasonal-techreport.pdf

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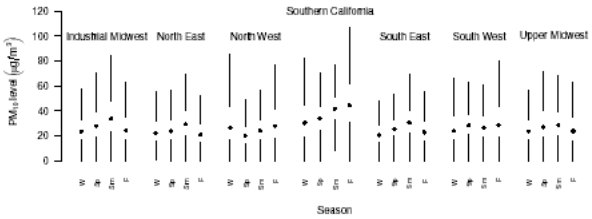

Figure 2: Boxplots of regionally averaged daily PM_{10} levels (in $\mu g/m^3$) by season.

	Winter	Spring	Summer	Fall
PM_{10} only (100 cities)	$0.15_{(-0.08,0.39)}$	$0.14_{(-0.14,0.42)}$	$0.36_{(0.11,0.61)}$	$0.14_{(-0.06,0.34)}$
with SO_2 (79 cities)	$0.24_{(-0.12,0.60)}$	$0.05_{(-0.44,0.55)}$	$0.47_{(-0.04,0.97)}$	$0.15_{(-0.21,0.51)}$
with O_3 (72 cities)	$0.21_{(-0.05,0.47)}$	$0.21_{(-0.08,0.51)}$	$0.32_{(0.04,0.59)}$	$0.01_{(-0.28,0.29)}$
with NO_2 (68 cities)	$0.18_{(-0.15,0.51)}$	$0.15_{(-0.22,0.51)}$	$0.34_{(-0.04,0.72)}$	$0.16_{(-0.18,0.51)}$

Table 3: Seasonal PM_{10} estimates in two-pollutant models.

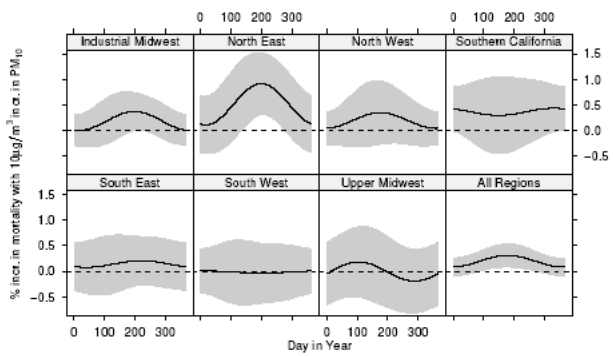

Figure 3: National and regional seasonal curves estimated from the sine/cosine model for lag 1 PM_{10}. Gray regions indicate pointwise 95% posterior intervals.

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```
x <- 1:ndays
B <- periodicBasis(x, 1, ndays, intercept = TRUE, ortho = FALSE)

bc <- extractBetaCov(r, pollutant = "pm10")
initTLNise()
g <- tlnise(bc$beta, bc$cov, regionInd, prnt = FALSE, labelY = names(r),
            intercept = FALSE, seed = 54321)
pooledRegion <- matrix(g$gamma[,1], byrow = TRUE, ncol = ncol(regionInd),
                       nrow = nrow(g$theta))
pooledRegionSD <- matrix(g$gamma[,2], byrow = TRUE, ncol = ncol(regionInd),
                         nrow = nrow(g$theta))
b <- B %*% pooledRegion
zero <- matrix(0, nrow = ndays, ncol = 7 * 3)
curveRegion <- lapply(1:ncol(pooledRegion), function(i) {
    B <- zero
    ## This is weird
    B[, seq(i, 7 * 3, 7)] <- periodicBasis(x, 1, ndays, intercept = TRUE, ortho
= FALSE)
    s <- sqrt(diag(B %*% g$Dgamma %*% t(B)))
    cbind(b[,i], b[,i] - 2*s, b[,i] + 2*s)
})

## Overall estimate
initTLNise()
g <- tlnise(bc$beta, bc$cov, rep(1, NROW(bc$beta)), seed = 12345, prnt = FALSE)
V <- diag(B %*% g$Dgamma %*% t(B))
b <- B %*% g$gamma[,1]
curve <- cbind(b, b - 2*sqrt(V), b + 2*sqrt(V))

## data(regions)
regionFullNames <- c("Industrial Midwest", "Northeast", "Northwest",
                     "Southern California", "Southeast", "Southwest",
                     "Upper Midwest")
## regionFullNames <- with(regions, description[match(regionNames, value)])

## Plot
Y <- rbind(do.call("rbind", curveRegion), curve) * 1000
conf <- Y[,2:3]
rng <- range(Y) + c(-1, 1) * .05
y <- Y[,1]
nRegions <- length(curveRegion) + 1
x <- rep(1:ndays, nRegions)
g <- ordered(rep(c(regionFullNames, "All Regions"), each = ndays),
             levels = c(regionFullNames, "All Regions"))

## trellis.device(dev = x11, height = 5, width = 8, color = FALSE)
p <- xyplot(y ~ x | g, as.table = TRUE, subscripts = TRUE, type = "l",
            panel = function(x, y, subscripts, ...) {
                llines(x, Y[subscripts, 2], lty = 3, lwd = 2)
                llines(x, Y[subscripts, 3], lty = 3, lwd = 2)
                panel.xyplot(x, y, ...)
                panel.abline(h = 0, lty = 2)
            },
            strip = strip.custom(bg = 0),
            ylim = rng, layout = c(4, 2),
            ylab = list(expression(paste("% increase in mortality with ",
                "10-", mu, "g/", m^3," increase in ", PM[10])), cex = 0.9),
            xlab = "Day in year",
            scales = list(alternating = 1, tck = c(0.8, 0))
            )
print(p)
:
```

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Discussion

- Linking national databases and developing statistical methods that can properly analyze these them, are essential steps for a successful national public health tracking system
- Because of the small risks to be detected and the large number of potential confounders, single-site studies are generally swamped by statistical error
- A national system, that routinely analyze data from multiple locations in a systematic fashion, is a very promising approach for tracking population health

Explosion of Information
e.g.
large databases
on population health and exposure
to potentially toxic agents

Expertise in:

- **Integration of complex databases**
- **Statistical Methods**
- **Reproducibility**

More confusion

More knowledge and
Better health risk assessment

Acknowledgments

- **Our team:**
  - R. Peng
  - S. Zeger
  - J. Samet
  - A. McDermott
  - M. Bell
  - L. Pham
- **Our sponsors:**
  - EPA
  - JHU CDC Center of Excellence
  - NIEHS