Health responses to changes in PM concentration and composition across New York State from 2005 to 2016

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Background

- Although the United States has been steadily reducing air pollution since the enactment of the Clean Air Act Amendments of 1970, there have been significant changes in air quality particularly with respect to PM$_{2.5}$ during the period since 2000.

- These changes are due in part to the promulgation and enforcement of regulations to reduce emissions from coal-fired power plants and motor vehicles.

- However, there have also been significant economic drivers of changes in emissions as a result of the 2008 recession and the availability of low cost fracked natural gas.
Mitigation strategies

- Reducing emissions for both light- and heavy-duty vehicles and electric power generation
- The NOx SIP (State Implementation Plan) Call (1998) and the NOx Budget Trading Program (2003) as well as the Clean Air Interstate Rule (2009) strongly reduced summertime NOx
- Tier II Tailpipe NOx Emissions Standard
- Particle control traps (2007) and NOx control (2010) for new heavy duty vehicles
- On-road diesel fuel sold after October 1, 2006, was required to have ultra low sulfur concentrations (<15 ppm)
- 2004, Renewable Portfolio Standard, approved by the New York State Public Service Commission, aimed to include a higher proportion of renewable energy sources in the state electricity generation mix
- July 1, 2012, New York State required that all distillate fuels sold within the state for any purpose to be ultralow sulfur
- Beginning in 2010, New York City began forcing a switch from No 6 oil to No 2 for large building heating
- Electricity policy changes in Ontario and the Clean Air Interstate Rule/Cross-State Air Pollution Rules to reduce SO$_2$ and NOx emissions from coal-fired power plants
Economic Effects

Industrial energy sales - New York State

Average Home Heating Oil Prices
Economic Effects

Average Power Plant Operating Expenses

- **Operation expenses (Mills per kWh)**
- **Years (2006-2016)**
- **Fossil Steam**
- **Gas Turbine and Small Scale**

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Economic Effects

United States - Electricity Generation and Fuels

- Other
- Biomass and wood
- Geothermal
- Solar
- Wind
- Hydroelectric
- Nuclear
- Other gases
- Natural gas
- Petroleum coke
- Petroleum liquids
- Coal
- Total
Changing Concentrations: PM$_{2.5}$
PM$_{2.5}$ and ST-Elevation Myocardial Infarction (MI)

Rate of MI associated with each IQR increase in PM$_{2.5}$ concentration

Gardner et al. Particle and Fibre Toxicology 2014, 11:1
http://www.particleandfibretoxicology.com/content/11/1/1

Image from NEJM Resident 360
Triggering of myocardial infarction by increased ambient fine particle concentration: effect modification by source direction

Fig. 1. Eastern United States showing locations of the electric power generating stations and the WSW sector. Dotted line separates the WSW sector into WSW1 (top) and WSW2 (bottom).
RESULTS: The CVD mortality series exhibit strong seasonal trends, whereas the CVD hospitalization series show a strong day-of-week pattern. These outcome series were not correlated with each other but were individually associated with a number of PM$_{2.5}$ chemical components from regional and local sources, each with different seasonal patterns and lags. Coal-combustion–related components (e.g., selenium) were associated with CVD mortality in summer and CVD hospitalizations in winter, whereas elemental carbon and NO$_2$ showed associations with these outcomes in both seasons.

CONCLUSION: Local combustion sources, including traffic and residual oil burning, may play a year-round role in the associations between air pollution and CVD outcomes, but transported aerosols may explain the seasonal variation in associations shown by PM$_{2.5}$ mass.
New York State Accountability Study

Cardiovascular, Respiratory, Respiratory Infectious Disease Hospitalizations and Emergency Department Visits
Aims

1. Estimate the rate of acute cardiovascular, respiratory, and respiratory infectious disease hospitalizations and emergency department (ED) visits associated with increased PM$_{2.5}$ concentrations in the previous 1 to 7 days.

2. Examine whether these relative rates were different BEFORE, DURING, and AFTER the air quality policies/economic changes.

Before 2005-2007

• Ultra-low sulfur in diesel and home heating fuels
• Particle regenerative traps
• Nitrogen oxide controls
• Emission control of power plant
• Economic changes

During 2008-2013

After 2014-2016
Cardiovascular Disease Hospitalizations
Study Population

- SPARCS – All Hospitalizations of NYS residents to non-VA and non-psychiatric hospitals for (ICD9 and ICD10):
  - Cardiac Arrhythmia
  - Congestive Heart Failure
  - Hypertension
  - Cerebrovascular (and ischemic stroke)
  - Ischemic Heart Disease (and myocardial infarction)
  - Chronic Rheumatic Heart Disease
  - Pulmonary Embolism
- \( \leq 15 \) miles of 6 monitoring stations
- \( \geq 18 \) years of age
- \( N = 1,922,918 \)
Methods

- **PM$_{2.5}$ concentrations retrieved from USEPA AQS**
  - 24 hour values from each site
  - Lag day(s) 0, 0-1, 0-2, 0-3, 0-4, 0-5, 0-6

- **Temperature and Relative Humidity**
  - From major airport closest to Buffalo, Rochester, Albany, Bronx, Queens
  - From Central Park weather station for Manhattan

- **Time-stratified Case-crossover Study Design**

- **Conditional logistic regression**
  - Adjusting for natural splines of temperature (4 df) and relative humidity (3 df) at same lag time as PM$_{2.5}$
Excess rate of cardiovascular hospital admissions associated with each interquartile range increase in PM$_{2.5}$ concentration.
Excess rate of **cardiovascular** hospital admissions associated with each interquartile range increase in PM$_{2.5}$ concentration.
Changes by Period

- Annual incidence rate per 1000 persons
- Sites: Albany, Bronx, Buffalo, Manhattan, Queens, Rochester

- Ischemic Heart Disease
  - Excess rate per 6.5 µg/m³ PM₂.₅
  - Before, During, After
  - p = 0.004

- Median PM₂.₅ concentrations (µg/m³)
  - Before, During, After
Excess rate of respiratory infectious disease ED visits associated with each IQR increase in PM$_{2.5}$
Excess rate of respiratory infectious disease hospitalizations associated with each IQR increase in PM$_{2.5}$.
Strengths and Limitations

- **Strengths**
  - Large sample size
  - Six urban locations across the state
    - 3 Upstate
    - 3 New York City

- **Limitations**
  - Exposure misclassification – central site monitor
  - No data on event onset time, only day of admission
Conclusions

- Increased rate of cardiovascular hospitalizations associated with increased PM$_{2.5}$ concentrations
  - Cardiac Arrhythmia
  - Ischemic Stroke
  - Congestive Heart Failure
  - Ischemic Heart Disease
  - Myocardial infarction
- Ischemic Heart Disease relative rates were greater in the AFTER period
- Similar findings with:
  - NYS Respiratory Infectious Disease Hospitalizations and ED visits
  - NYS Respiratory Hospitalizations and ED visits
  - Rochester – Myocardial Infarctions
- May not be confounding by subject characteristics
- Why? Is same mass of PM more toxic?
PM$_{2.5}$ composition – Inter-period differences

Primary Organic Carbon

- **Bronx**
  - KW test p-value = 0
  - Post-Pre p-value:
    - Pre-During = 0.001
    - During-Post = 0
    - Pre-Post = 0

- **Manhattan**
  - KW test p-value = 0
  - Post-Pre p-value:
    - Pre-During = 0.3
    - During-Post = 0.001
    - Pre-Post = 0

- **Queens**
  - KW test p-value = 0
  - Post-Pre p-value:
    - Pre-During = 0
    - During-Post = 0
    - Pre-Post = 0

- **Albany**
  - KW test p-value = 0.93
  - Post-Pre p-value:
    - Pre-During = 1
    - During-Post = 1
    - Pre-Post = 1

- **Buffalo**
  - KW test p-value = 0
  - Post-Pre p-value:
    - Pre-During = 0.002
    - During-Post = 0.08
    - Pre-Post = 0

- **Rochester**
  - KW test p-value = 0
  - Post-Pre p-value:
    - Pre-During = 0
    - During-Post = 0
    - Pre-Post = 0

Concentration (µg m$^{-3}$)

- Pre 2005-2007
- During 2008-2013
- Post 2014-2016
PM$_{2.5}$ composition – Inter-period differences

Secondary organic carbon

**Bronx**

- Pre 2005-2007
- During 2008-2013
- Post 2014-2016

**Manhattan**

- Pre 2005-2007
- During 2008-2013
- Post 2014-2016

**Queens**

- Pre 2005-2007
- During 2008-2013
- Post 2014-2016

**Albany**

- Pre 2005-2007
- During 2008-2013
- Post 2014-2016

**Buffalo**

- Pre 2005-2007
- During 2008-2013
- Post 2014-2016

**Rochester**

- Pre 2005-2007
- During 2008-2013
- Post 2014-2016

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KW test p-value = 0
Post-hoc p-values:
Pre-During = 0
During-Post = 0.012
Pre-Post = 0.014

KW test p-value = 0
Post-hoc p-values:
Pre-During = 0
During-Post = 0.012
Pre-Post = 0.203

KW test p-value = 0.001
Post-hoc p-values:
Pre-During = 0.002
During-Post = 0
Pre-Post = 0.007

KW test p-value = 0.018
Post-hoc p-values:
Pre-During = 1
During-Post = 0.015
Pre-Post = 0.628

KW test p-value = 0.024
Post-hoc p-values:
Pre-During = 0.0121
During-Post = 0.658
Pre-Post = 0.628

KW test p-value = 0
Post-hoc p-values:
Pre-During = 0
During-Post = 0.063
Pre-Post = 0.346
PM$_{2.5}$ sources – Inter period differences

**Gasoline emissions**

- **Bronx**
  - KW test p-value = 0
  - Post-hoc p-values:
    - Pre-During = 0.038
    - During-Post = 0
    - Pre-Post = 0

- **Manhattan**
  - KW test p-value = 0
  - Post-hoc p-values:
    - Pre-During = 0
    - During-Post = 0
    - Pre-Post = 0

- **Queens**
  - KW test p-value = 0
  - Post-hoc p-values:
    - Pre-During = 0.011
    - During-Post = 0.039
    - Pre-Post = 0

- **Albany**
  - KW test p-value = 0
  - Post-hoc p-values:
    - Pre-During = 0.007
    - During-Post = 0
    - Pre-Post = 0

- **Buffalo**
  - KW test p-value = 0
  - Post-hoc p-values:
    - Pre-During = 0.068
    - During-Post = 0.036
    - Pre-Post = 0

- **Rochester**
  - KW test p-value = 0
  - Post-hoc p-values:
    - Pre-During = 1
    - During-Post = 0
    - Pre-Post = 0

Legend:
- Blue: During 2008-2013
- Green: Post 2014-2016
Excess rate of cardiovascular hospitalizations associated with each IQR increase in PM$_{2.5}$ source concentration.
Excess rate of cardiovascular hospitalizations associated with each IQR increase in PM$_{2.5}$ source concentration

* $p<0.016$
Excess rate of cardiovascular hospitalizations associated with each IQR increase in PM$_{2.5}$ source concentration

* $p<0.016$
Excess rate of cardiovascular hospitalizations associated with each IQR increase in PM$_{2.5}$ source concentration

* $p<0.016$
Conclusions

- PM$_{2.5}$ sources associated with increased rates of cause-specific CV hospitalizations:
  - Spark-ignition emissions (GAS)
  - Diesel (DIE)
  - Road Dust (RD), Secondary Nitrate (SN), Residual Oil (RO)
- But not:
  - Secondary Sulfate (SS), Road Salt (RS), Industrial (IND), Biomass Burning (BB), Pyrolyzed Organic Rich (OP), or Aged Sea Salt (AGS), or Fresh Sea Salt (FSS)
- Similar findings for respiratory infectious disease
Synthesis Across Studies

- Increased rates of hospitalizations and ED visits for cardiovascular, respiratory, and respiratory infectious disease associated with increased PM$_{2.5}$ concentrations in the previous 1 to 7 days
- For some outcomes, this relative rate is greater in the AFTER period (2014-2016) than in the DURING (2008-2013) and BEFORE (2005-2007) periods
- Similar findings for ST-elevation myocardial infarction in Monroe County

- Increased rates of CV Hospitalizations associated with increased concentrations of GAS, DIE, SN, RD, RO

- But not SS, RS, IND, BB, OP, FSS, or AGS
Synthesis Across Studies

- **Preliminary hypothesis:** The aerosol is becoming more oxidizing, more SOA formation, with more fresh SOA delivering greater dose of ROS to the lung
  - Could lead to systemic inflammation and other effects contributing to triggering of these events

- Need to evaluate whether further controls past 2016 have impacted, slowed down, or reversed this trend
  - E.g. new vehicle emissions standard in 2017

- Need to evaluate this in other parts of the country with different PM composition and sources, and perhaps different localized air quality policies or actions
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