Initial Analysis of Meteorologically Adjusted Sulfate Trend and the Implication of the Recent Economic Slowdown

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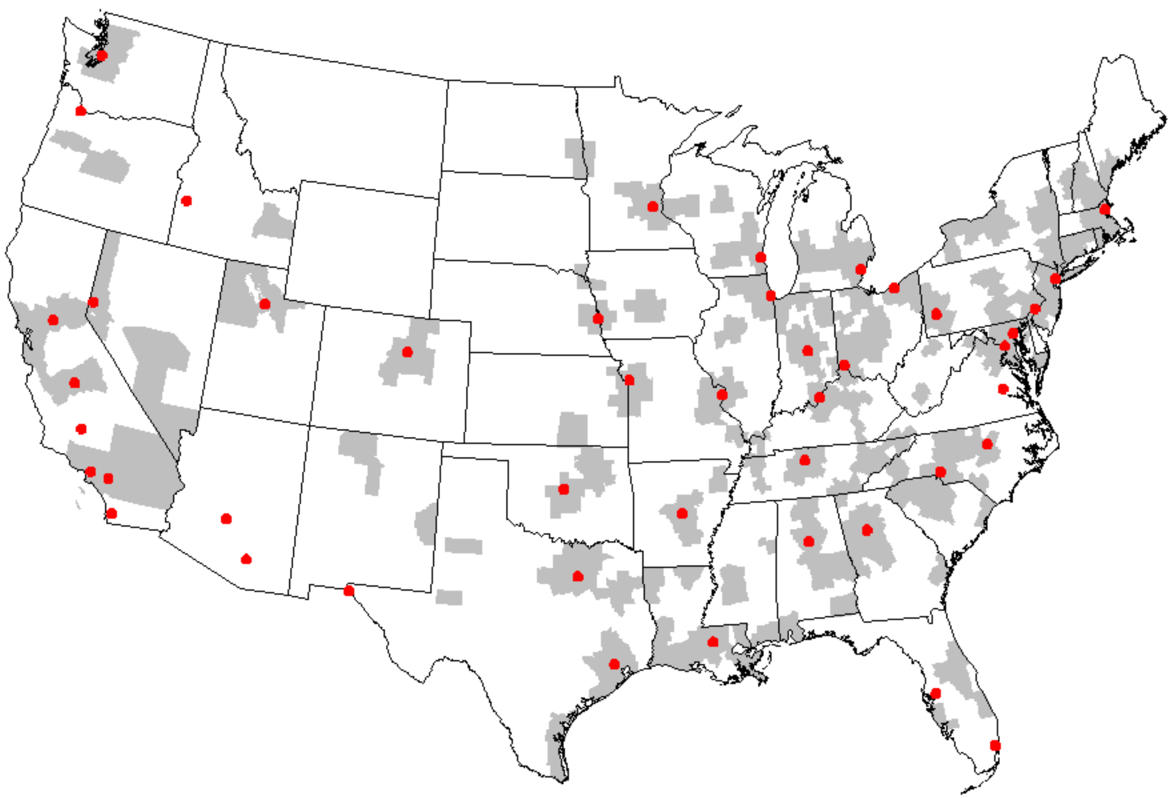
Introduction

- The **intent** of this study is to examine whether the recent **economic slowdown** had an impact on the **accelerated decrease in sulfate concentrations** observed in 45 major cities in the US **in 2008 and 2009.**

NATIONAL URBAN SULFATE TREND STUDY AREAS

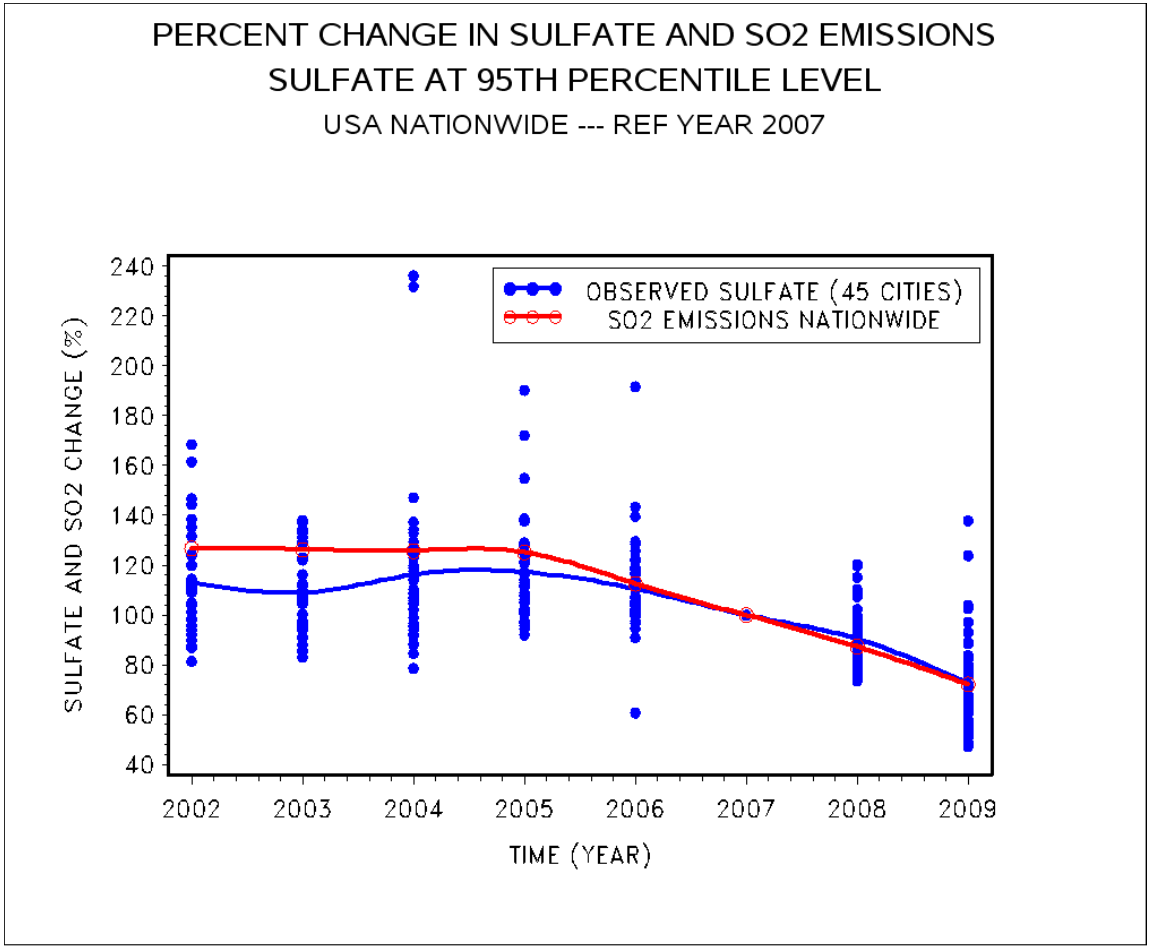
45 SELECTED URBAN AREAS

COLOR CODE: GREY SHADE=CBSA RED DOTS=MONITOR LOCATION



Percent Change in Annual 95th Percentile Sulfate Concentrations and SO_2 Emissions Nationwide

Data: US EPA 2010



Introduction

- **Combustion** of sulfur-containing **fossil fuels**, such as coal and oil, **leads to**

  ---> **SO_2 formation**, and **oxidation of SO_2**
  ---> **formation of sulfate aerosols** in ambient air.

Introduction

- **Fossil fuel consumption** is also **closely related to various economic activities**: such as:
  - **electric power usage,**
  - **industrial production**,
  - **transportation**, etc.

Introduction

- Since **sulfate is a function of SO_2 emissions and meteorology**, a **meteorological adjustment** technique was applied to estimate the **influence of "atypical" meteorological conditions on sulfate** concentrations.

Introduction

- Comparing the meteorologically-adjusted sulfate trend with observed SO_2 emission changes can shed light on whether the accelerated sulfate decline in 2008 and 2009 is a result of:
    - **Non-conducive meteorological conditions**, and/or
    - Reduced SO_2 emissions due to **control measures**, and/or
    - Reduced SO_2 emissions due to **lower power demand in an economic slowdown**, or
    - Some or all of the above.

Data

- In this study, **24-hour-average sulfate data** collected by the Chemical Speciation Network (CSN) from **2002 to 2009** in **45** major urban areas were analyzed. The data collection frequency was **1-in-3 days.**

Data

- 2002-2009 **meteorology data** from National Climatic Data Center (NCDC) were also acquired for meteorological adjustment analysis.
  - Daily maximum temperature,
  - daily average relative humidity,
  - wind speed,
  - dew point,
  - precipitation, and
  - one day pollutant transport distance.

Data

- In this study, the **annual heat input to** electric power generating units (**EGU**) nationwide was used as a **surrogate** to reflect yearly electric **power demand**.
- Thus, long-term **SO_2 emissions** and **heat input** data from Acid Rain (ARP) and Clean Air Interstate Rule (CAIR) programs, together with
- National **Industrial Production Index** data published by Federal Reserve

  were all used in this analysis.

Analysis Approach

- Since sulfate is a function of SO_2 emission and meteorology, thus,

  $S = f(e,m)$, and difference is partitioned into:

$$\Delta S_i = \Delta S(m_i - M)\Big|_{e=e_i} + \Delta S(H_i - H_{07})\Big|_{m=m_i} + \Delta S(C)_i$$

  - where S = sulfate, e = SO_2 emissions,

    m = meteorology, M = mean m,

    H= heat input to EGU,

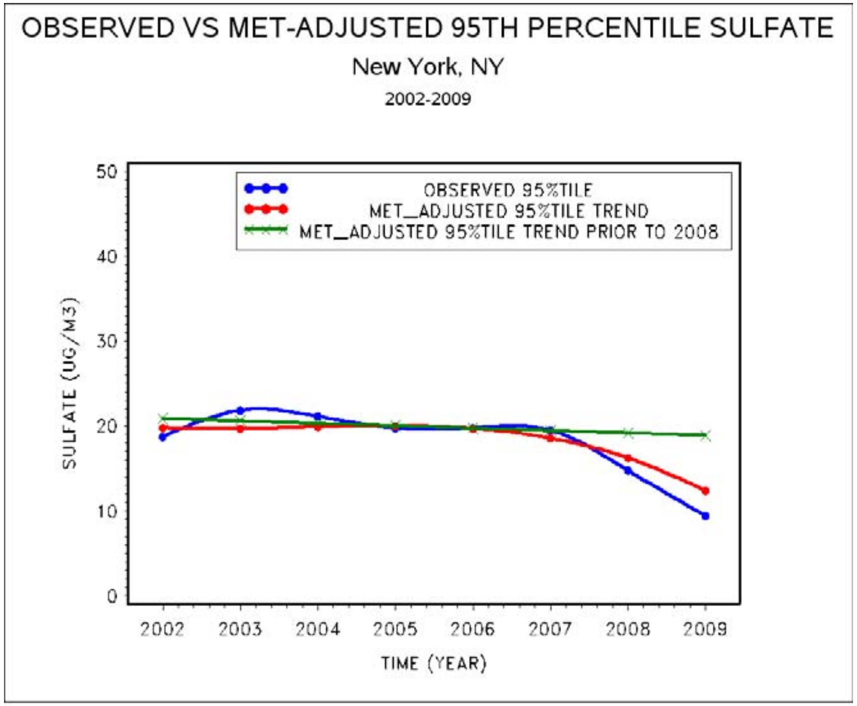
    C = "emission controls"

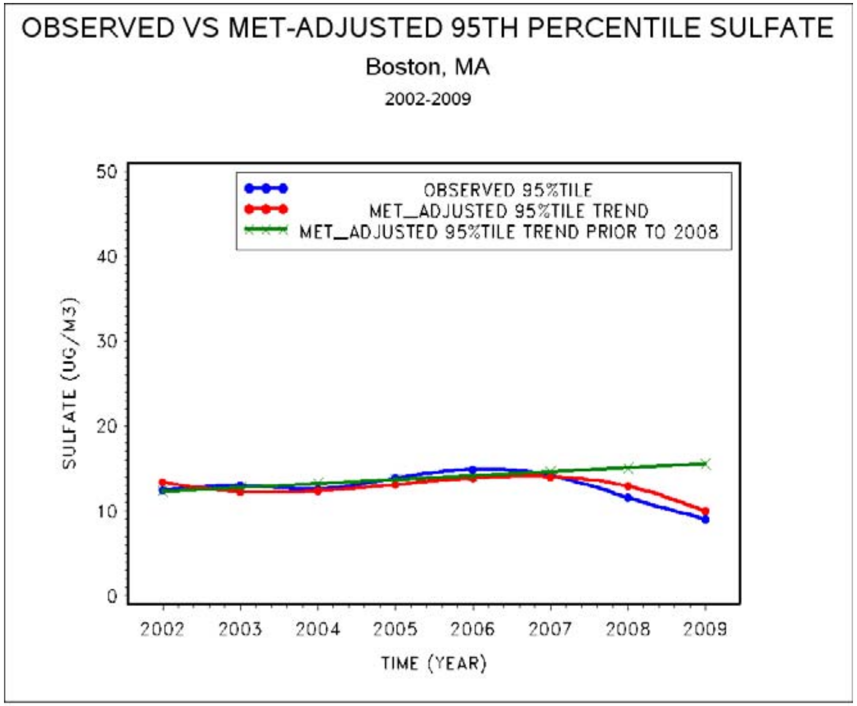
    i = year i, 07 = 2007

Analysis Approach

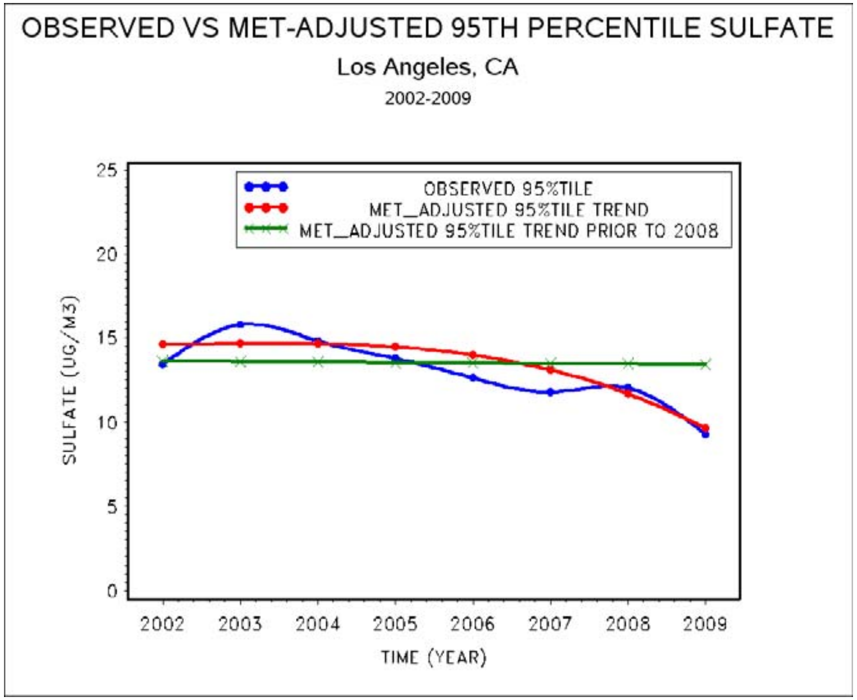
- The **Annual 95th percentile** of **sulfate** concentration due to deviation from **typical meteorological condition** observed **in 2002-2009** were **adjusted** using a quantile regression model.
- The **expected value** of the **sulfate** concentration for 2009 was **estimated by** a **linear regression** of the **meteorologically adjusted 2002-2007 sulfate** concentrations (i.e., the data before the economic slowdown).

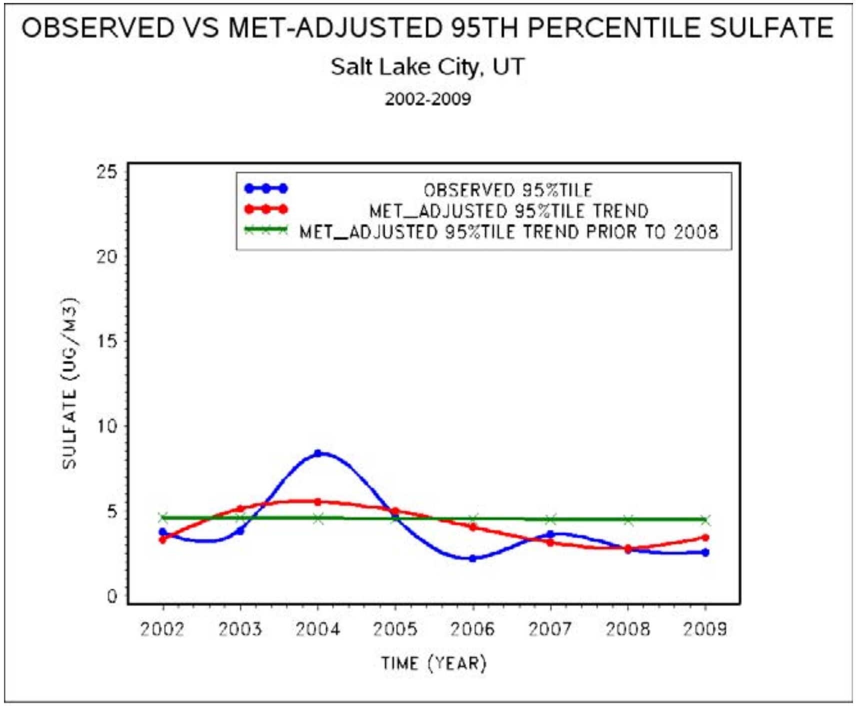
2002-2009 Sulfate Decrease in Eastern US Due to Meteorology and Emission Changes



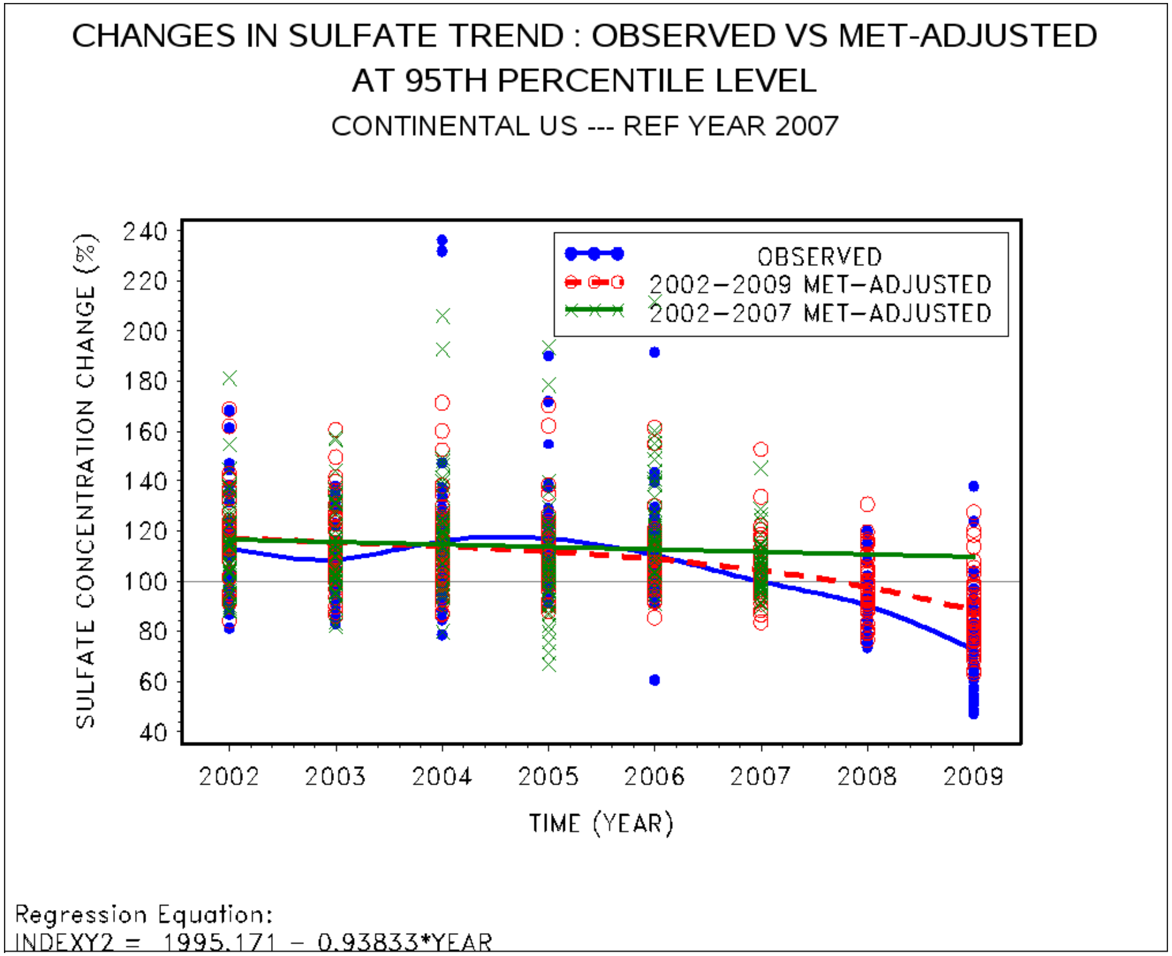


2002-2009 Sulfate Decrease in Western US Due to Meteorology and Emission Changes





Changes in 95th Percentile Sulfate 45 Major Urban Areas, Nationwide



Observed and Meteorologically Adjusted Sulfate Trends

- Comparing the **meteorologically adjusted** with the **observed** sulfate trends in 45 major urban areas, we find that **a significant amount** of the observed **sulfate decrease** between 2007 and 2009 could **not** be explained by **non-conducive meteorological conditions**.

Analysis Approach

- Since **heat input data to EGU** nationwide was used as a **surrogate** to **electric power demand**, sulfate difference due to SO_2 emission changes were partitioned into two parts:
  - **(a)** due to **heat input difference** between year *i* and year 2007;
  - **(b)** due to '**emission controls'** between year *i* and year 2007.

Analysis Approach

- Since sulfate **adjustment** due to **EGU heat input deviation from 2007 level** was done under its **annual meteorological conditions**, its value may have some **'year-specific' influence due to meteorological difference between year *i* and 2007**.

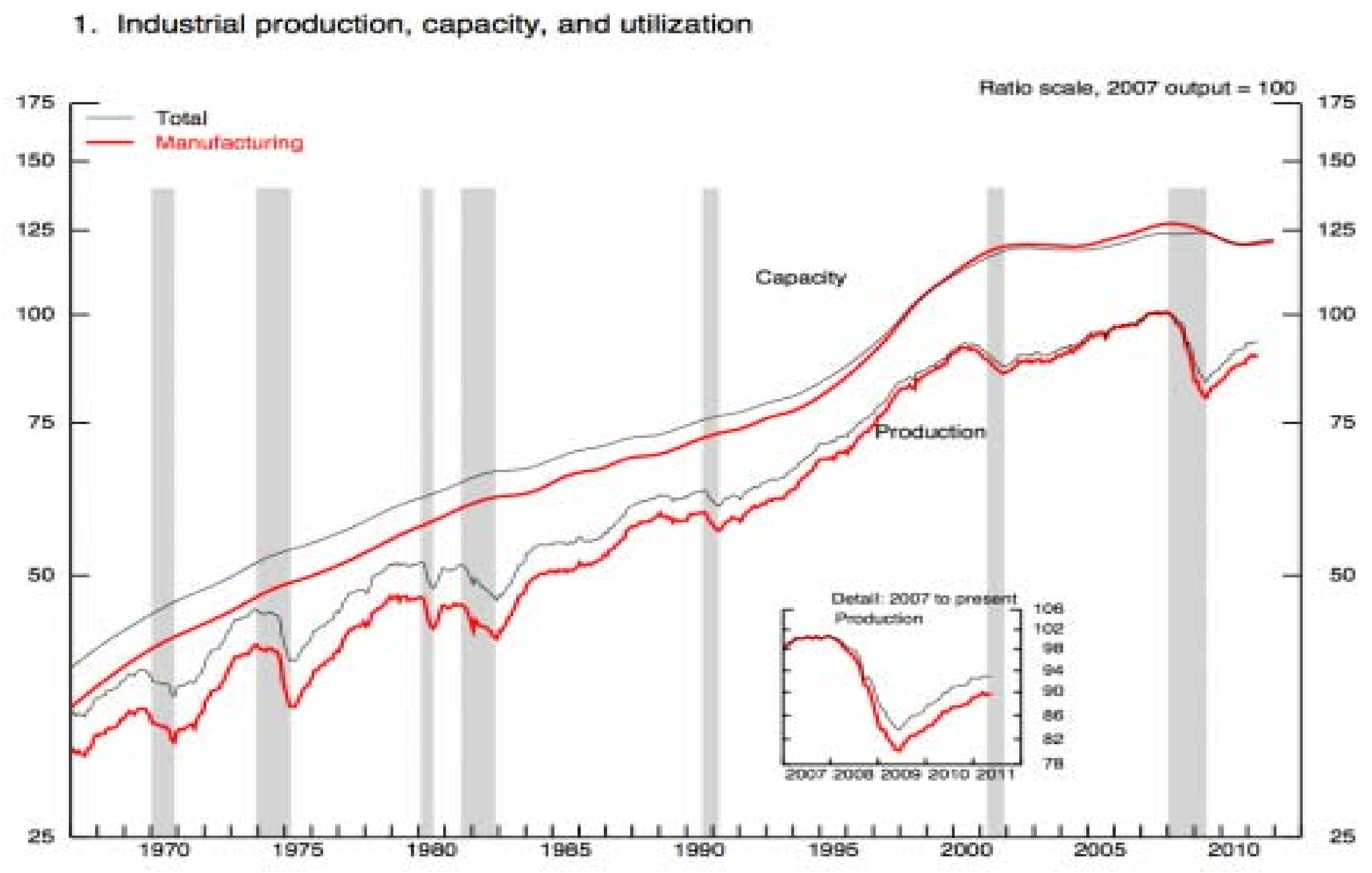
Analysis Approach

- Long-term **relationship** between national **SO_2 emissions** and **economic growth** as reflected in:
  - **industrial production** and
  - **electric power demand** were also analyzed.

Analysis Approach

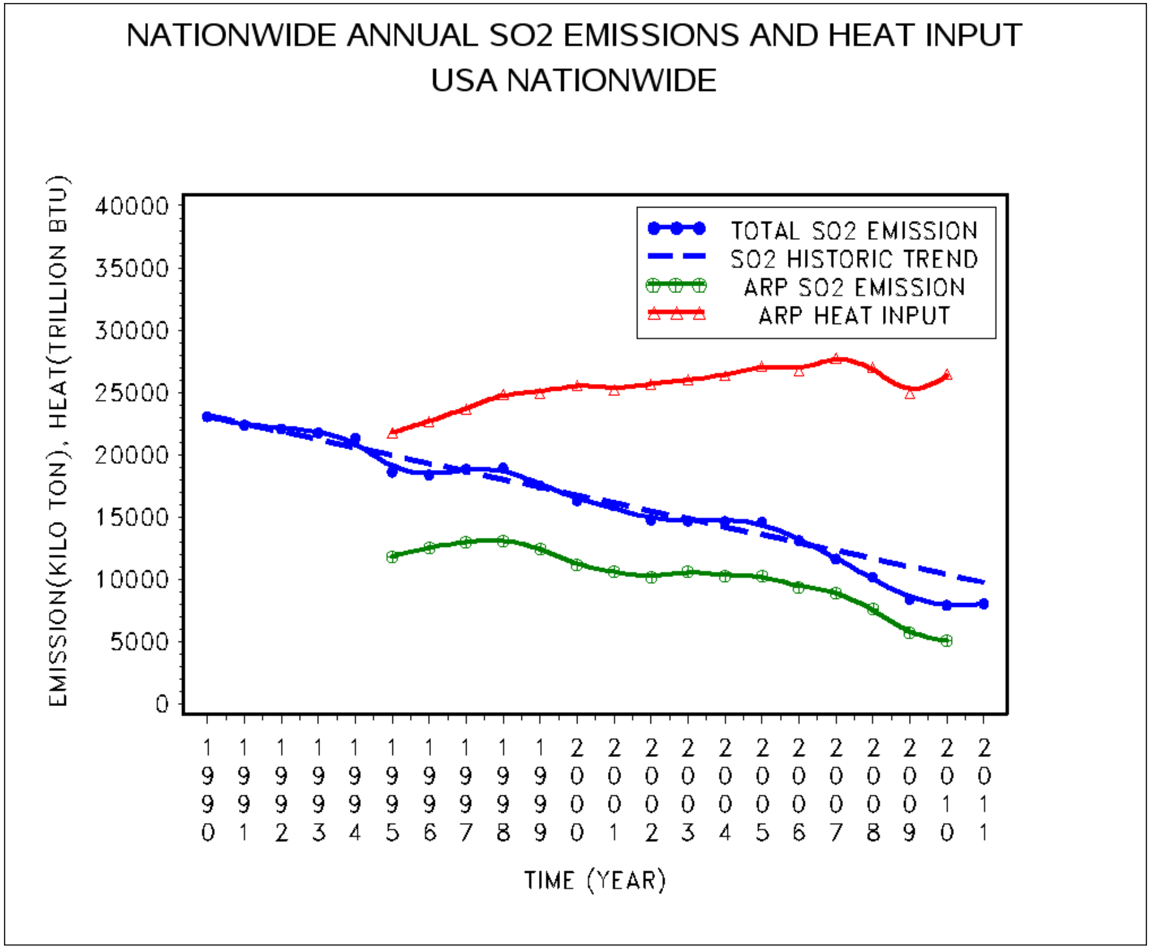
- **Trends** of **SO_2 emissions**, **EGU heat input data** and **Industrial Production Index** in the past decades were **analyzed** to uncover the **general relationship** among them in the past decades.

Federal Reserve's Monthly Index of Industrial Production



SO_2 Emissions and Heat Input Trend Nationwide

Data: US EPA 2010, 2011



SO_2 Emissions, EGU Heat Input, and Industrial Production Trends

- In the past 20 years, we see a continuous **upward trend** in both the national **Industrial Production Index** and **heat input** to EGU **all the way up to 2007**.
- At the same time, a **steady decline** in the long-term **SO_2 emission trend** was also observed. SO_2 emissions nationwide have **decreased** steadily by approximately **50%** over the **last 20 years**.

SO_2 Emissions, EGU Heat Input, and Industrial Production Trends

- Contrasting these trends demonstrates that **regulations** to curb excessive SO_2 emissions in the past two decades **did not prevent economic growth** as reflected in **industrial production** and **electric power usage**.

Sharp Decline in Sulfate and SO_2 Emissions in 2008-2009

- An average of **30% decline in sulfate and SO_2** emissions nationwide in 2009 from its 2007 level, however, was found to **coincide** with a **20% decrease in Industrial Production Index** and a **10% drop in EGU heat input during** the 2008-2009 **economic slowdown**.

Calculation of Lower Power Demand Impact on Accelerated SO_2 Emission Decline

Data: US EPA 2010

- **A calculation** based on SO_2 emission and heat input data of ARP suggests that approximately **28% of the SO_2 emission decrease** nationwide **between 2007 and 2009** can be attributed to **lowered power demand in** the 2008-2009 **economic slowdown**.

Calculation of Lower Power Demand Impact on Accelerated SO_2 Emission Decline in 2007-2009

Data: US EPA 2010

- This calculation is based on ARP SO_2 Emissions and heat input data.
- SO_2 Emission Rate (ER) -- ton/mmBTU

  $ER = E / H$, where E -- SO_2 Emissions; H -- Heat Input
- Heat Input (H) to EGU difference between 2007 and 2009

  $D_H = H_{09} - H_{07}$
- Assume $ER_{09} = ER_{07}$, then the SO_2 Emission changes attributable to difference in heat input to EGU between 2007 and 2009 becomes

  $DE_H = ER_{07} * D_H = E_{07}*(H_{09} – H_{07})/ H_{07}$
- Total observed SO_2 emission difference between 2007 and 2009

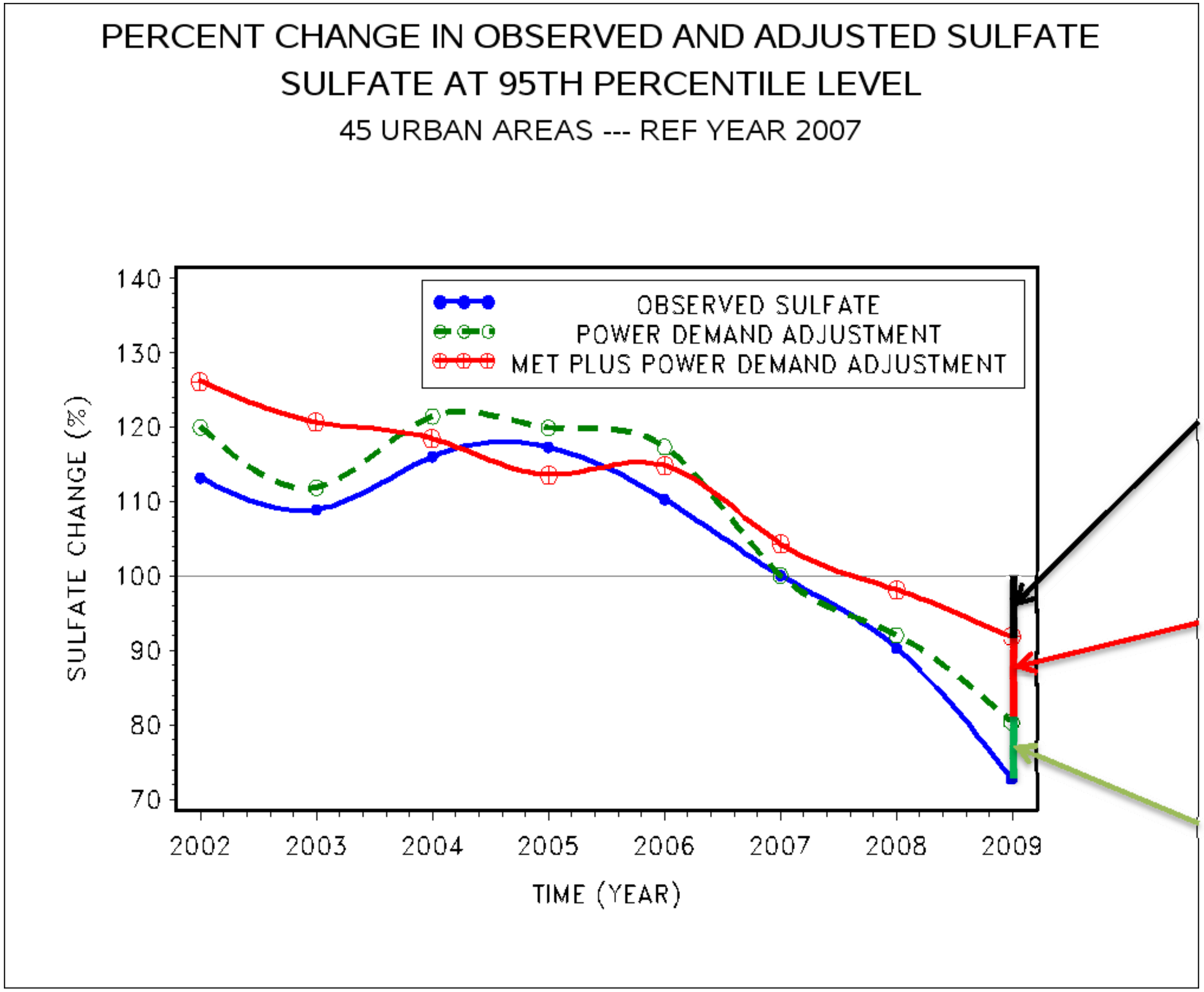
  $DE = E_{09} - E_{07}$
- Percent SO_2 Emission changes between 2007 and 2009 due to heat Input to EGU difference

  $R = 100\% * DE_H / DE =$ **27.8%**

Assessing the 2008-2009 Sharp Decline in 95 Percentile Sulfate

- Since SO_2 is the precursor to ambient sulfate formation, this analysis suggests that the **accelerated decline in sulfate** concentrations **in 2008 and 2009** was essentially attributed to:
  - **non-conducive meteorology by ~40%,**
  - **SO_2 emission controls by ~30%** under Federal programs (e.g., ARP, CAIR and other measures) **and**
  - **reduced power demand by ~30%** during **economic slowdown** in 2008 and 2009.

Percent Change in 95 Percentile Sulfate Concentrations



Due to SO2 Emission Controls

Due to Non-Conducive Meteorology

Due to Lower Power Demand

Summary and Discussions

- **2002-2009 sulfate data in 45 major urban areas** in the US have been **analyzed**.
- The results indicate that the **major factors** responsible for the **accelerated sulfate decline** observed in most urban areas in the US **in 2008 and 2009** were:
  - **Non-conducive meteorology (~40%)**,
  - SO_2 **emission controls (~30%),** and
  - **Lower power demand (~30%)** during the economic slowdown.

Summary and Discussions

- **Comparing the long-term trends** of SO_2 emissions with EGU heat input and industrial production nationwide, **I found**:
  - **Regulations** to curb excessive SO_2 emissions **in the past** have **improved sulfate air quality but did not prevent growth** of industrial production and electric power usage nationwide.
  - An **accelerated decline in sulfate and SO_2 emissions in 2008 and 2009** was caused in a large part by a **lower demand for power during the economic slowdown** as evidence by a 10 percent drop in EGU heat input and 20% drop of industrial production nationwide.

Summary and Discussions

- However, since the sulfate data from the CSN Network are relatively short, the national SO_2 emissions are based on the tri-annual NEI inventory data, the **uncertainty** of this analysis could be large.
- Further study of economic impact on air quality using longer data records, such as O_3, NO_x and SO_2, are needed.
- This report is only a draft. A research paper is under development.

Acknowledgement

- Special thanks to my colleagues: Pat Dolwick, Joe Tikvart, Neil Frank, David Mintz, and Venkatesh Rao of US EPA for the helpful discussion and good suggestions they gave me in preparing this talk.

- Thank you for your attention!
- Any questions?