Accountability Case Study: Detroit

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Goal and Approach

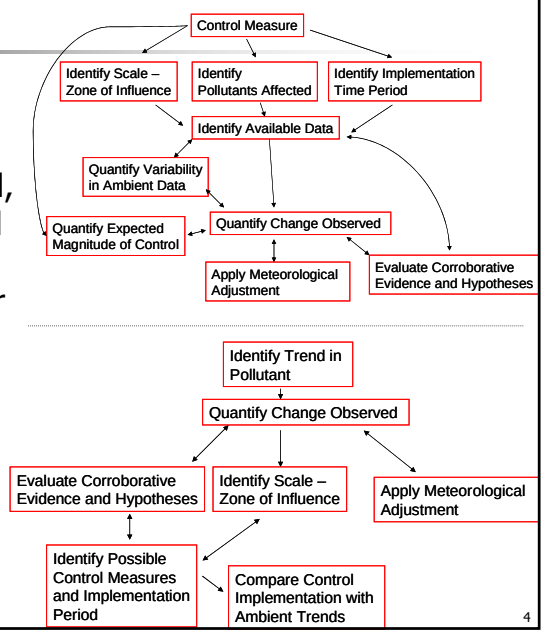
- The goal of this project was to identify and potentially quantify changes in ambient air quality due to known regulations
- A detailed technical approach was assembled
- Detroit was selected as an initial case study area, focusing on:
  - SO_2 regulations due to the acid rain program
    - Expected to impact SO_2, possibly $PM_{2.5}$ and sulfate
  - NO_x regulations due to the NO_x SIP call
    - Expected to impact NO_x and ozone, but not nitrate (regulation is summer only)
  - Other programs also impact these emissions, though the above ones are likely the greatest year-to-year impact

NO_x and SO_2 Regulations

- SO_2 regulations occurred as part of the acid rain program (Title IV) in 1995 and 2000 in Michigan and throughout U.S.
- NO_x regulations occurred as part of the SIP call (OTR) in 1995, 1999 and 2003, though the focus was on the Northeast. *Michigan was affected in 2004, though the extent of compliance/exclusions is not known.*

Approach

- Two methods:
  1. Identify control measures (NO_x SIP call, acid rain program) and evaluate ambient trends before and after
  2. Analyze ambient data for significant decreases in concentrations and attempt to connect to controls



Conceptual Model for SO_2

- Scale: both local and regional, so intra-urban differences are likely; local sources may confound trends at some monitors
- Emissions reductions occur somewhat gradually, except for a large decrease in 1995; a long time series will be needed to identify trend, though the decrease in 1995 may be significant enough to see with a smaller time series
- Emissions reductions are expected to be significant enough to identify a trend in the long-term ambient data
- Other pollutants/issues tied to this regulation include deposition, $PM_{2.5}$, sulfate and visibility

Conceptual Model for NO_x

- Scale: local and regional influences both important. Intra-urban differences are likely, and local sources, especially mobile, should confound trends at some monitors.
- NO_x from power generation in Detroit is ~ 40% of the total in the NEI, so changes in VMT and shipping/rail emissions may confound decreases due to the regulation
- Emissions reductions occurred in Michigan only in 2004, and changes may not be significant enough to see without a long time series
- Emissions reductions may or may not be significant enough to identify a trend and may be obscured by increase in mobile emissions; long-term data are needed, and additional analyses such as segregation by wind direction or ratio with other species may be needed to elucidate any trend
- Other species tied to this regulation include ozone; nitrate and $PM_{2.5}$ are not expected to be affected since regulation is for summer only when nitrate is extremely low in concentration

NEI = national emission inventory
VMT = vehicle miles traveled

Expectations

- Large controls or long data sets will be needed, i.e., a large reduction in total emissions of a pollutant or 6-10 years of data. Long data sets are necessary to establish trends above the "noise" of interannual variability due to meteorology, fluctuations in emissions, etc.
- Pollutants that are regional (NO_x, sulfate, PM) may be difficult to quantify trends without long data records since they are so widespread spatially
- Urban-Rural site pairs are useful to segregate local and regional impacts
  - Rural site=few local sources, representative of regional impact
  - Urban site=many local sources, representative of local impact

Data and Expectations

- There are few long continuous data records at a given site in Detroit
- While some pollutants have data in the last few years, the records likely do not cover enough years prior to a regulation to quantify the change
- Due to the long data records, the best opportunities in Detroit for accountability are ozone, SO_2, and TSP metals (though no known regulations have been promulgated for the latter)
- Rural-urban pairs for Detroit are typically not available.
  - Best option is for SO_2.
  - Speciated $PM_{2.5}$ sites from IMPROVE are too far away and may not be subject to same transport patterns as Detroit.

Executive Summary of Results

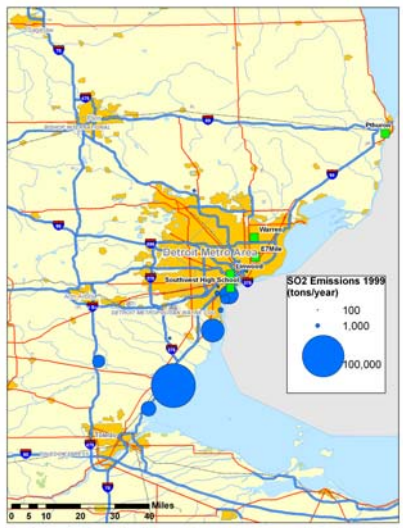
- Several key pollutants were examined to determine the affect of the NO_x SIP call on ambient concentrations
  - Pollutants included NO_x, SO_2, O_3, $PM_{2.5}$, benzene, TNMOC, and CO
  - Ratios of pollutants were also examined to assess the impact of meteorology and to differentiate NO_x originating from mobile or stationary sources
- Results
  - Gradual decreasing trend in SO_2 1993-2005 (agrees with emissions information); significant decrease in 1995 when emissions were significantly reduced.
  - Similar decreasing trend in SO_4^{2-}
  - No conclusive trend in NOx was seen
  - Meteorologically adjusted O_3 shows decrease from 1997 to 2005
  - Data were sufficient, though more NOx data, as well as NOy, are needed to better elucidate and quantify trends

Hypothesis Example: SO_2

- SO_2 reductions due to Acid Rain program should reduce SO_2 more than other pollutants between 1995 and 2001
- Therefore a long-term trend of decreasing SO_2 from 1993 on should be seen at all sites in Detroit
- Data for SO2 available 1993-2005
- Extent of local controls not well known
- Regional controls should affect concentrations, so meteorology may play a role
- In addition to SO2, regulations should impact secondary affects including particulate sulfate, visibility, and acid deposition

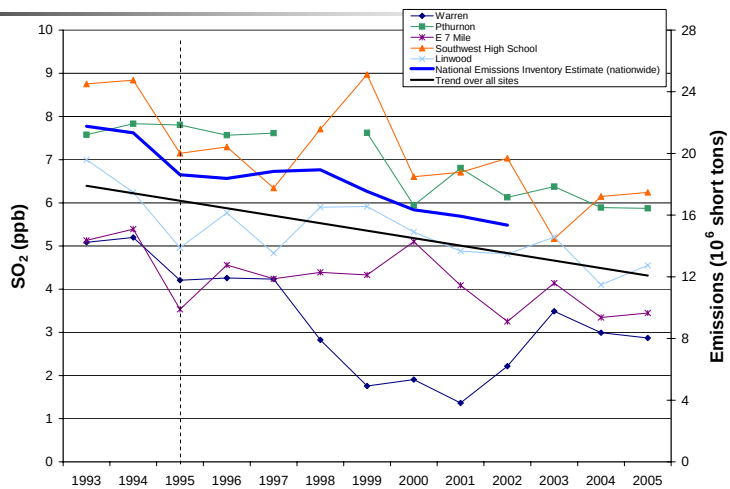
SO_2 sites and emissions

- Large SO_2 point sources to the south within ~ 45°
- In Linwood area, also major shipping and diesel traffic at point facilities
- Meteorology important since there may be persistent lake effects on wind direction
- National Emissions Inventory trends data available for nation-wide SO_2 (1993-2002); yearly emissions from electric generating facilities available 1995-2005



Trends in annual average SO_2 concentrations

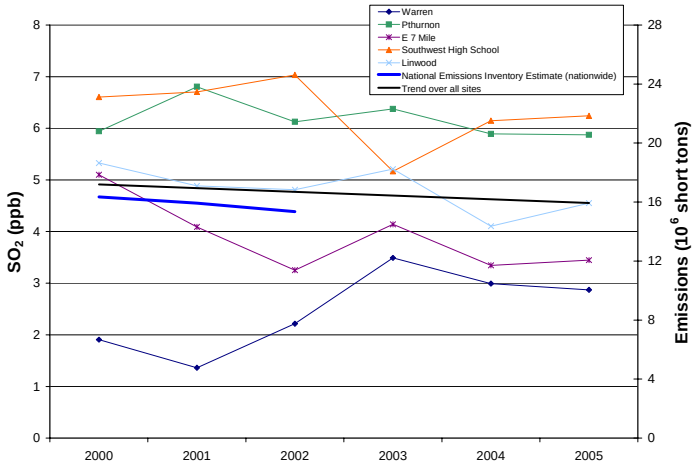
Decrease of 28% between 1994 and 2002 in emissions corresponded with 30% decrease in ambient SO_2



- Statistically significant decrease from 1993 to 2005
- No statistically significant trend from 2002 to 2005
- Emissions trends are similar to ambient trends
- Pt Huron removed for 1998 due to sudden increase/decrease in concentrations

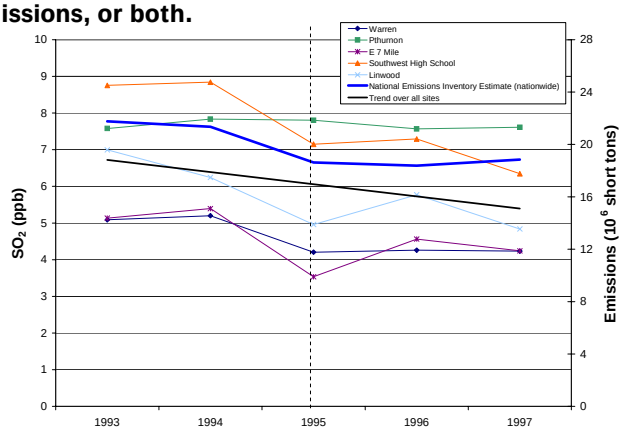
Importance of long data record 1 of 2

If previous chart was prepared for only 2000-2005, the long term decrease in ambient SO_2 would not be clear



Importance of long data record 2 of 2

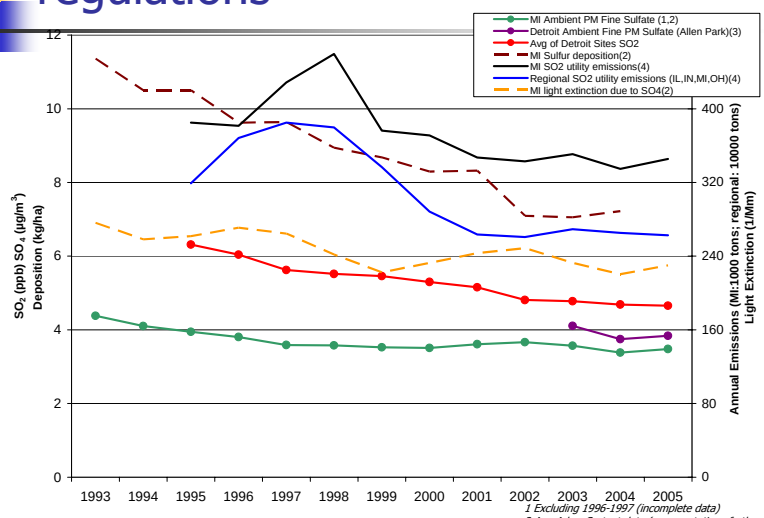
- However, if examining data from 1993 through 1997, during the large decrease in emissions in 1995 (~20% decrease), a trend in ambient concentrations is still evident
- **Thus, we need either long-term data, a very large decrease in emissions, or both.**



Multipollutant effects of SO_2 regulations

- SO_2 regulations resulted in decrease in SO_2 emissions
- Similar trends also observed in secondary sulfur species, including:
  - 24% decrease in sulfate concentrations in Ann Arbor (1991-1003 to 2003-2005) and 7% decrease in Allen Park (2001-2003 to 2003-2005)
  - 36% decrease in total S deposition in Ann Arbor (1991-1993 to 2003-2005)
  - 17% decrease in light extinction due to sulfate
- 14% decrease in MI SO_2 emissions from electrical generating and 26% decrease in emissions region-wide (IL,IN,OH,MI) (1995-1997 to 2003-2005)
- 26% decrease in Detroit average SO_2 (1993-1995 to 2003-2005)

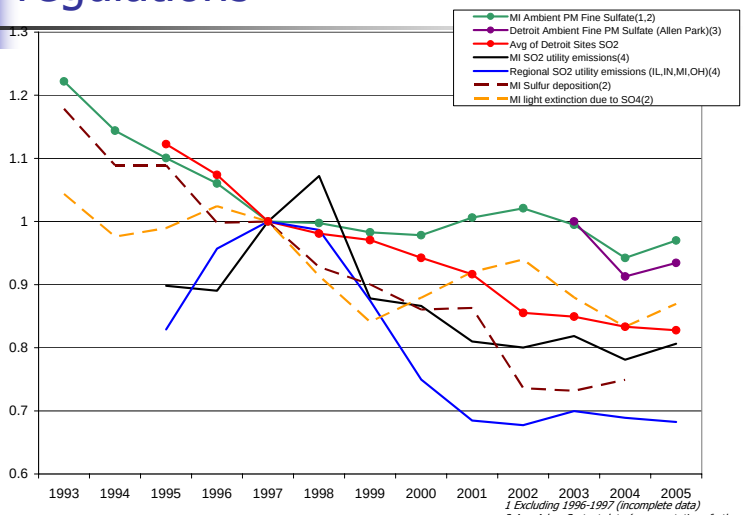
Multipollutant effects of SO_2 regulations



1 Excluding 1996-1997 (incomplete data)
2 Ann Arbor Castnet data (representative of other MI sites)
Light Extinction calculated from b=(3)f(RH)[SO_4^{2-}]
3 STN network
4 Utility Emissions from
http://www.epa.gov/airmarkets/emissions/prelimarp/index.html

- All values are three-year back averaged, excluding emissions data

Multipollutant effects of SO_2 regulations



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- Same as previous slide, normalized to 1997

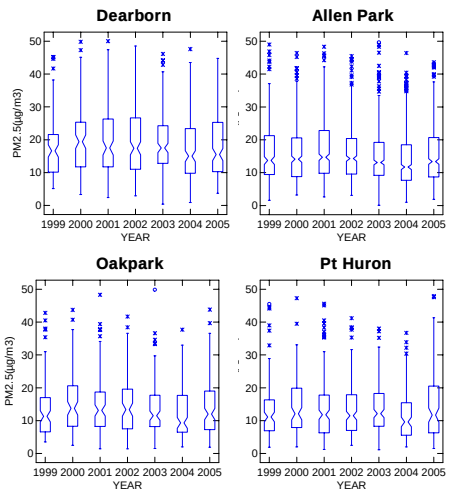
$PM_{2.5}$

- $PM_{2.5}$ concentrations may have been affected by the decrease in SO_2 (decrease in sulfate)
- $PM_{2.5}$ data are only available for 1999 to 2005, when SO_2 decreases were smaller year-to-year
- Sulfate data are only available starting in 2001, when SO_2 decreases were small, so meteorology/transport "noise" will likely dominate trends

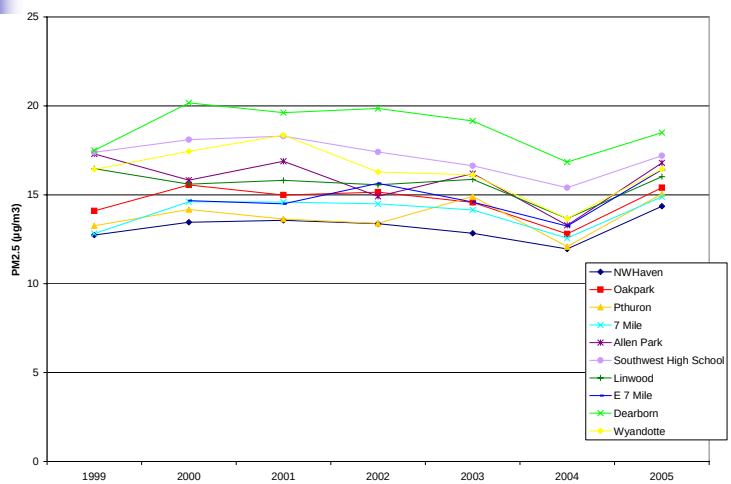
Trends in $PM_{2.5}$ 24-hr average concentrations

No trend observed in $PM_{2.5}$ concentrations

- Lower concentrations in 2004 due to decrease in sulfate that is likely meteorologically driven
- Similar trend at all sites (see time series, next slide)

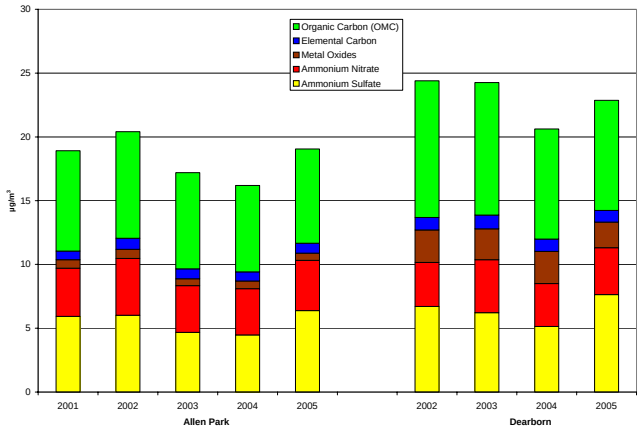


Trend in $PM_{2.5}$ annual averages



Trends in $PM_{2.5}$ Speciation

- As expected, no significant trend in sulfate is seen between 2001-2005, similar to SO_2 trends
- Sulfate decreases in 2002 to 2004 but increases in 2005; decrease likely from meteorology



OMC = 1.8 * OC
Metal Oxides =
2.2*Al+2.19*Si+1.63*Ca+2.42*Fe+1.94*Ti

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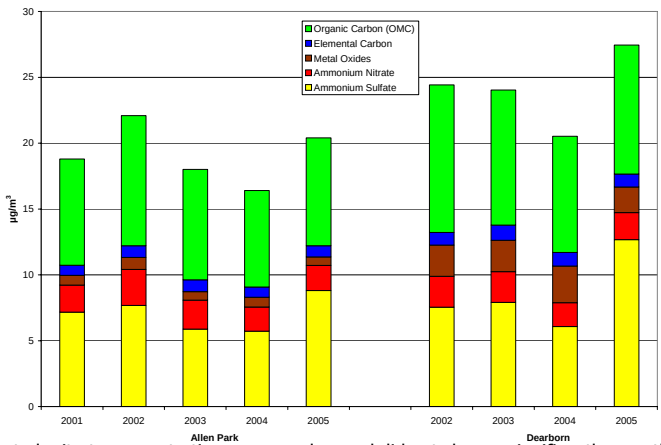
Trends in summer $PM_{2.5}$ Speciation (June-August)



OMC = 1.8 * OC
Metal Oxides =
2.2*Al+2.19*Si+1.63*
Ca+2.42*Fe+1.94*Ti

- As expected, nitrate concentrations are very low and did not change significantly over this time period
- Since nitrate is minimal in Detroit in summer, NO_x SIP call cannot be expected to have much of an effect
- Sulfate and OMC exhibit same temporal trend as PM (decrease 04,increase 05)
- Other components showed no trend

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SO_2 Conclusions

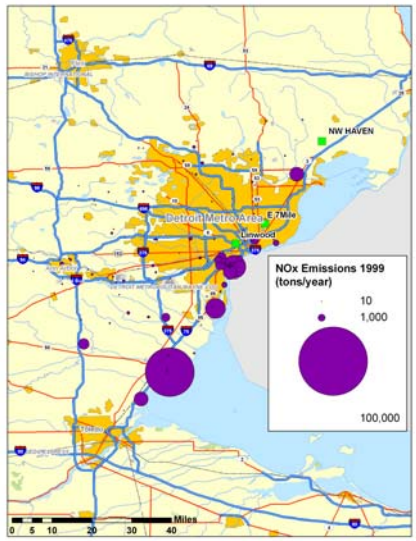
- Large decrease in emissions (~15%) from 1994 to 1995 shows corresponding decrease in ambient concentrations of SO_2 (17%)
- Decreases in emissions from 1994 to 2002 (28%) were coincident with decrease of 30% in ambient SO_2
- Steady decrease through 2000 also reflected in ambient SO_2 data, but not sufficient to show decrease in $PM_{2.5}$ data between 1999 and 2005
- Small decreases after 2000 may not be enough to be statistically significant in ambient data (i.e., noise from meteorology and impact of local sources become more important than large-scale reductions)
- Sulfate shows a similar decreasing trend as SO_2
- Long data record was critical, as changes after 1995 may not have been large enough to capture with a smaller data record

Expectations: NO_x SIP Call

- NO_x SIP call should reduce NO_x more than other pollutants, during 1995, 1999, and 2003/2004
- *Michigan required to start in 2004, did some facilities comply in 2003? Did all comply in 2004?*
- NOx from electricity generation in Detroit is less than from mobile sources, about 40% of the total (NEI, 2002)
- Increases in VMT for gasoline and diesel (plus shipping/rail) as well as changes in electricity usage (i.e., 2003-2004 were cooler) may confound non-mobile source NO_x trends
- Extent of local controls not well known
- Regional controls may also affect concentrations, so meteorology may play a role
- Overall the emission reductions may not be significant enough to identify a trend with limited data and may be confounded by increasing mobile NO_x

Location of NO_x sites

- Data available for 1993-1998 for NW Haven and 2002-2005 for Linwood and E 7 Mile
- Linwood NO_x concentrations expected to be dominated by point source emissions from the southwest, by mobile from the west and north, and Canada (likely mobile) to the east
- E 7 Mile NO_x concentrations expected to be dominated by mobile source emissions in all directions
- NW Haven outside of influence of urban mobile sources and removed from point sources as well; likely representative of regional concentrations



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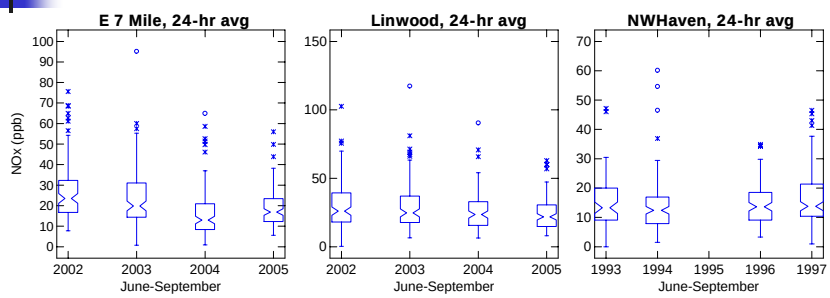
NO_x trends by year (summer)



- Only 4 years of data, may not be sufficient to identify trend
- E 7 Mile shows significant decreases in NO_x concentrations in 2003 and 2004, followed by increase in 2005. These changes may be meteorologically driven rather than emission driven.
- Linwood did not show any trend, despite being closer to point sources. More analysis is needed to understand point source emission trends
- NW Haven showed no change in concentrations in response to 1995 regulations, though site is likely dominated by mobile/regional emissions
- Hourly data was also examined; no year to year trend across sites was evident for all hours, nighttime hours, or daytime hours
- NO temporal patterns are similar to NO_x

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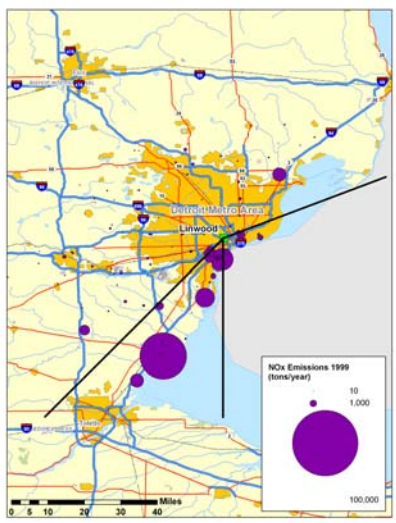
Wind direction analysis

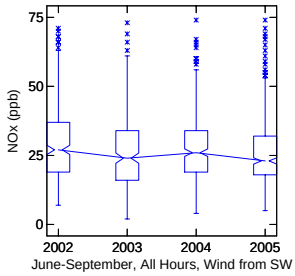
- NO_x concentrations overall did not show a decrease in response to the NO_x SIP call.
  - This is probably due to the large mobile contribution that was not impacted by the SIP call
- Therefore, to see a change in concentrations, need to isolate point source contribution by
  - Using wind direction to identify when concentrations are affected by different areas
    - Data excluded if wind speed is less than 2 m/s as this is essentially "calm" and not indicative of a particular direction
  - Looking at nighttime concentrations, when mobile source emissions are lowest
  - Concentrating on sites with greater percent of point source emissions (i.e., closer to sources or with less mobile impact)
- Also need to test null hypothesis: concentrations from area without significant point sources should not show change in concentration

Wind direction analysis

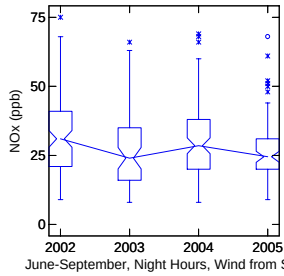
- Focus on Linwood site, expected to be more heavily impacted by point source emissions
- Most sources align to the southwest of Linwood site
  - Data selected when wind direction was from 180° – 225° to isolate these sources
  - Divided remaining data into two sets to verify hypothesis:
    - From Detroit area, not from point source direction, morning area - *expected to be mobile dominated, no change in concentrations*
    - From Canada, all hours - *no emissions info*



Isolating point source Influence



June-September, All Hours, Wind from SW

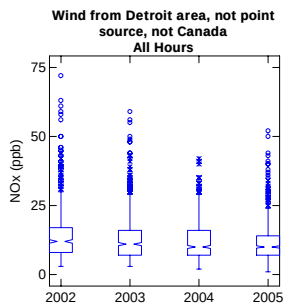


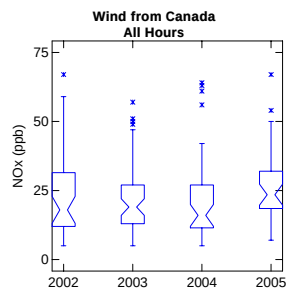
June-September, Night Hours, Wind from SW

No met data available at Linwood, so E7MI data used

- Linwood NO_x
  - Calm hours excluded (wind speed ≤ 2m/s)
  - Wind direction of 180° – 225° degrees
  - Values above 75 ppb excluded from graph to focus on medians
- No consistent year to year trend in NOx concentrations for all hours or just night hours when using only wind from the SW

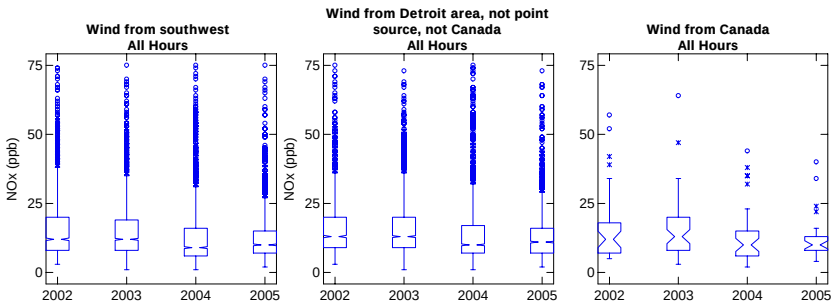
Non-point source Directions





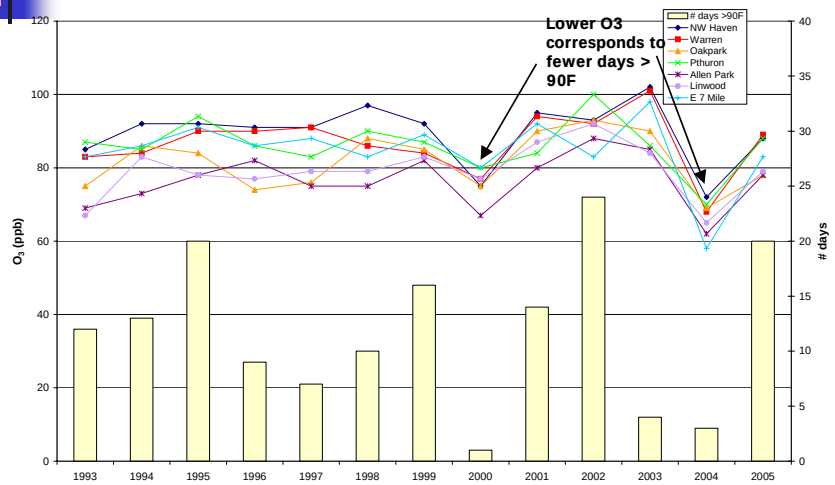
- As expected, when wind direction is not from direction of major point sources, no decrease in concentrations from 2002-2003 is seen
- Other changes likely due to meteorology?

E7 Mile Wind Direction Analysis



- No consistent trend seen at East 7 Mile
- NO_x concentrations dominated by mobile sources at this site

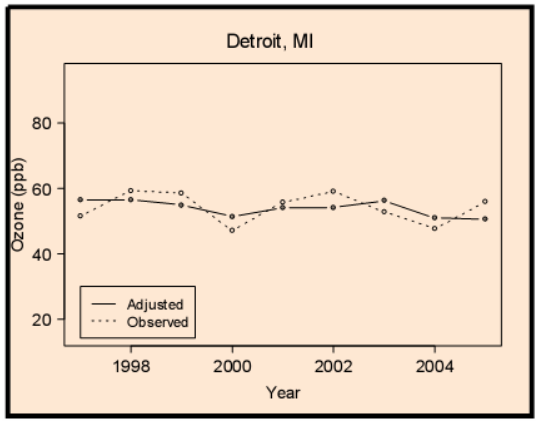
NO_x SIP call impact on O_3



- *Ozone concentrations need to be adjusted for differences in meteorology year to year*

Met-adjusted ozone

- Average ozone shows decreasing trend from 1997 after adjustment for meteorology



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Other analyses

- Segregation of NOx by hour
  - Morning vs. Non-Morning
  - Try to isolate impact of mobile emissions during rush hour
- Segregation of NOx by day of week
  - Weekday vs. Weekend
  - Again, try to isolate impact of mobile emissions which have a different day of week trend than point sources
- Ratio analysis
  - Benzene:NOx
  - TNMOC:NOx
  - SO2:NOx
  - By taking the ratio of NO_x to other species that are mobile source dominated, may be able to determine trend in NO_x, assuming mobile source species (benzene, TNMOC) did not change much between years
- No consistent trend seen when using these additional analyses

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NO_x Conclusions

- Insufficient data for analysis of impact of 1995 regulations
- When using all data, no impact of 2003/04 regulations is seen, since electrical generation is not the dominant source of NOx in the area, so changes in emissions are likely obscured by mobile emissions
- Several analyses were tried to isolate an electrical generation source
  - Although methods are believed to be robust, no affect of NOx SIP call seen
  - NOy would be more useful for these analyses
  - A longer time frame of data is critical to observing the impact of emissions changes on ambient concentrations

Next Steps

- Use additional emissions data if available
  - Are other long-term annual SO2 emissions data available for Michigan?
  - Are there changes in emissions inventory methodologies that can be reconciled?
- Conduct multipollutant source apportionment with PMF, including STN PM2.5, HAPs and VOC data where available
- This will help us understand common sources of PM, HAPs and other species