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Optimization of Multipollutant Air Quality Management Strategies

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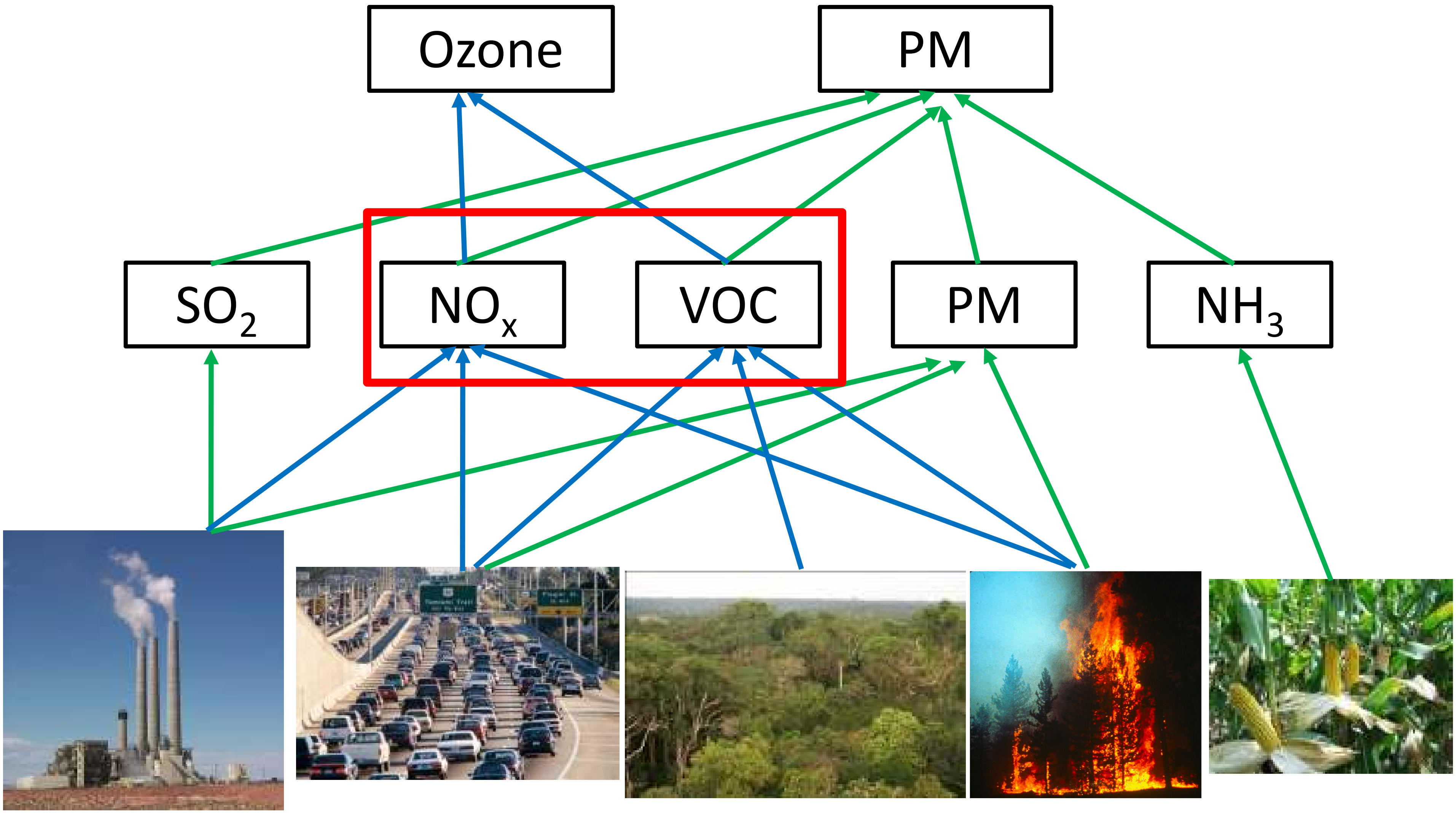
Emission Sources of Ozone and Particulate Matter (PM)



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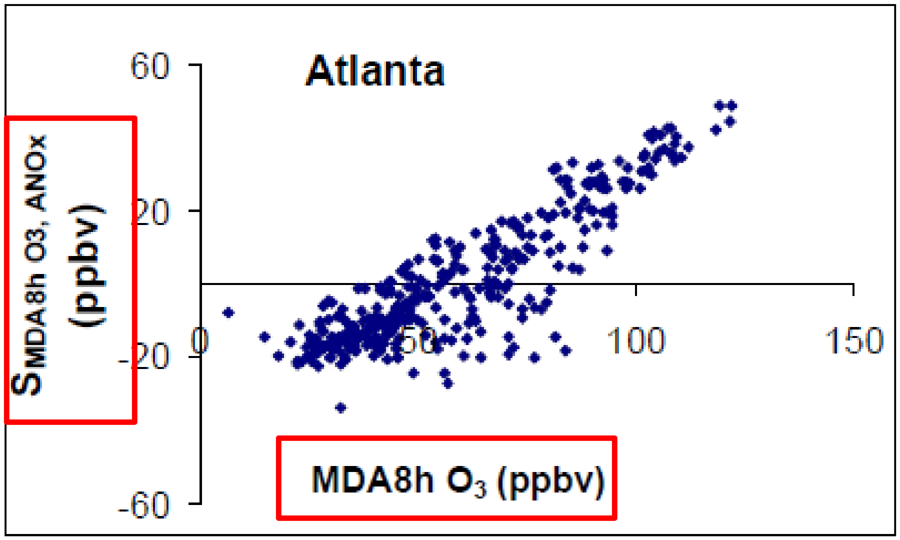
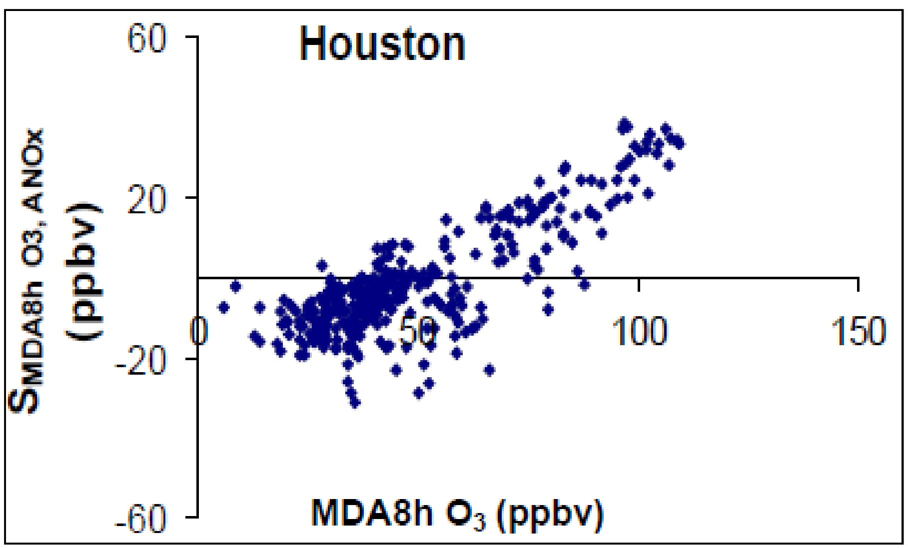
Responses of Ozone to Reductions in Anthropogenic NOx Emissions





First - order sensitivity :

$$S_{MDA8hO3,ANOx} = E_{ANOx} \frac{\partial C_{MDA8hO3}}{\partial E_{ANOx}}$$

Positive sensitivity =>
Reductions in ANOx decrease MDA8h ozone

Negative sensitivity =>
Reductions in ANOx increase MDA8h ozone

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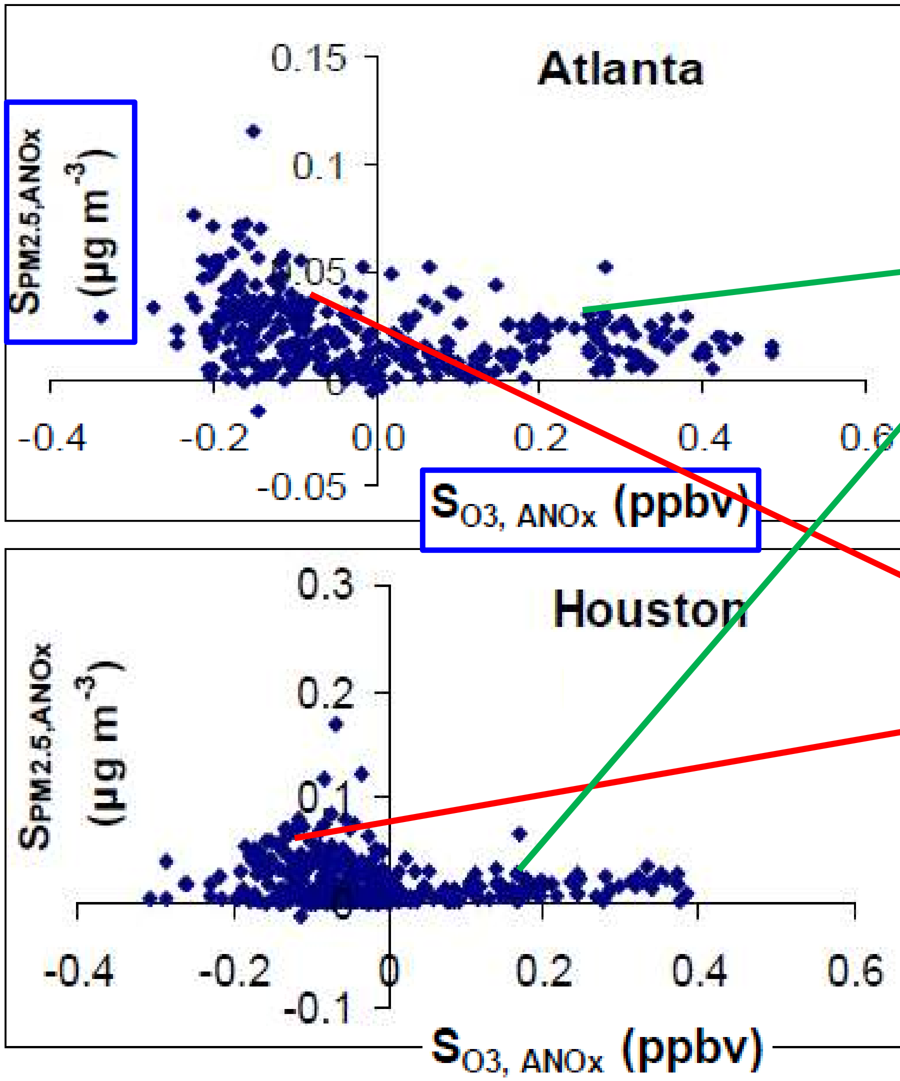
Cross-Responses of Ozone and Total $PM_{2.5}$ to Reductions in Anthropogenic NOx Emissions



Reductions in ANOx emissions decrease both total $PM_{2.5}$ and MDA8h ozone concentrations

Reductions in ANOx emissions decrease total $PM_{2.5}$ but increase MDA8h ozone concentrations

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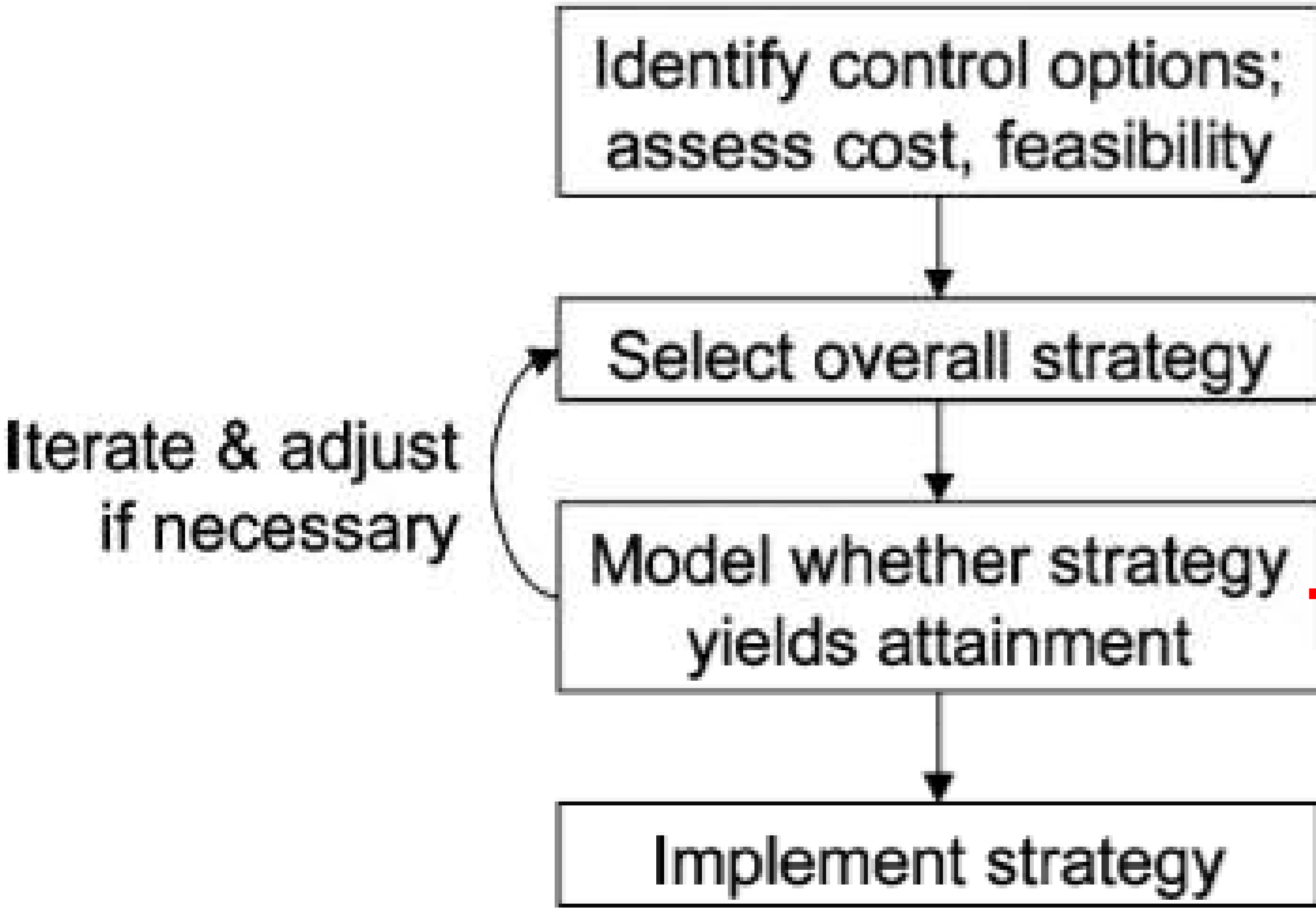
Traditional Framework for Developing State Implementation Plan (SIP) in the U.S.



Air Quality Modeling

Cohan et al., 2007

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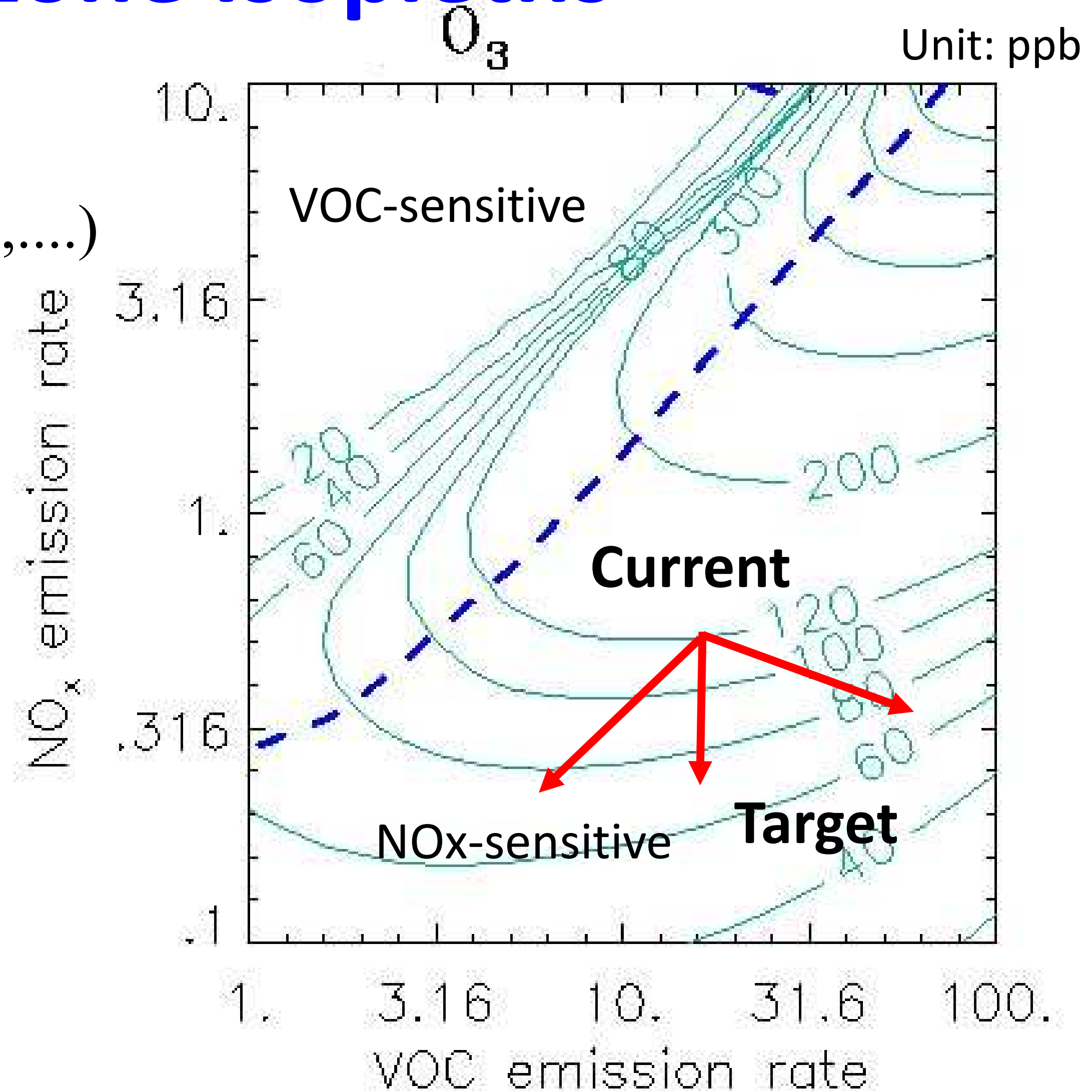
Ozone Isopleths

$$[O_3] = f(NOx, VOC, met., ...)$$



http://www-personal.umich.edu/~sillman/ozone.htm

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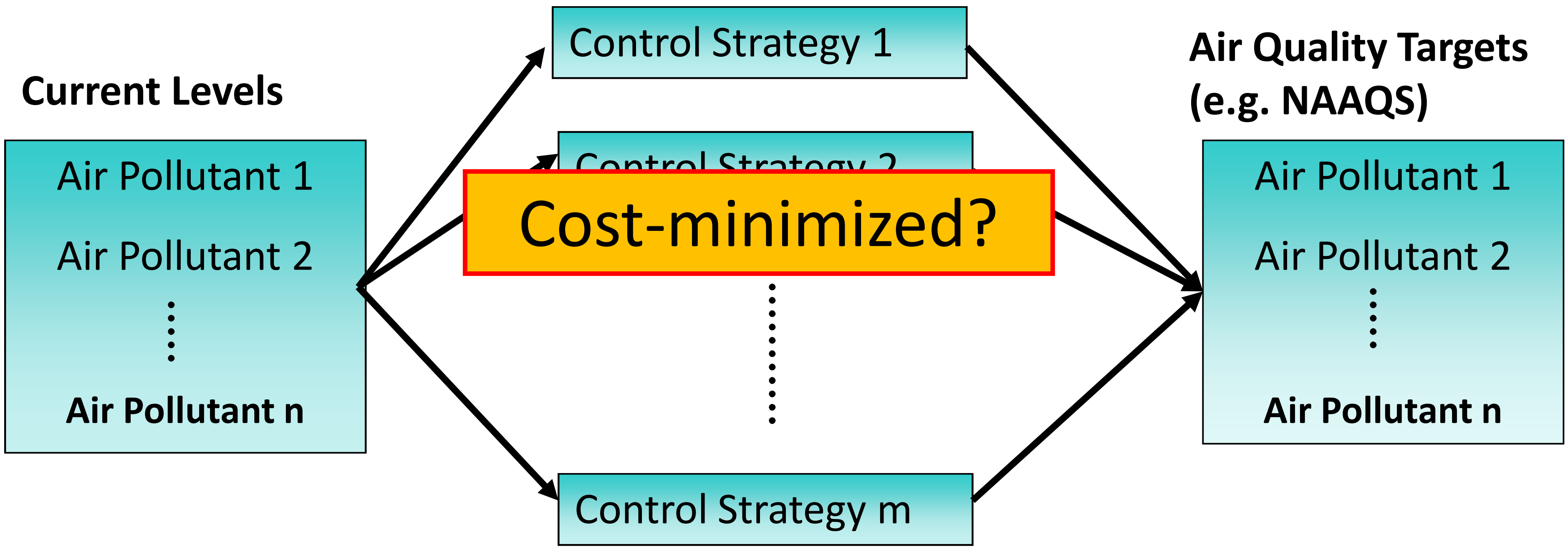
Air Pollution Control Strategies for Multi-Pollutants and Multi-Locations



Challenge:

Air pollutants at different locations have different responses to changes in precursor emissions from common sources.

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Objective - I

Development of a decision-making model which identifies optimal (i.e., least-cost) control strategies for:

- achieving multipollutant air quality targets
- at multiple locations simultaneously

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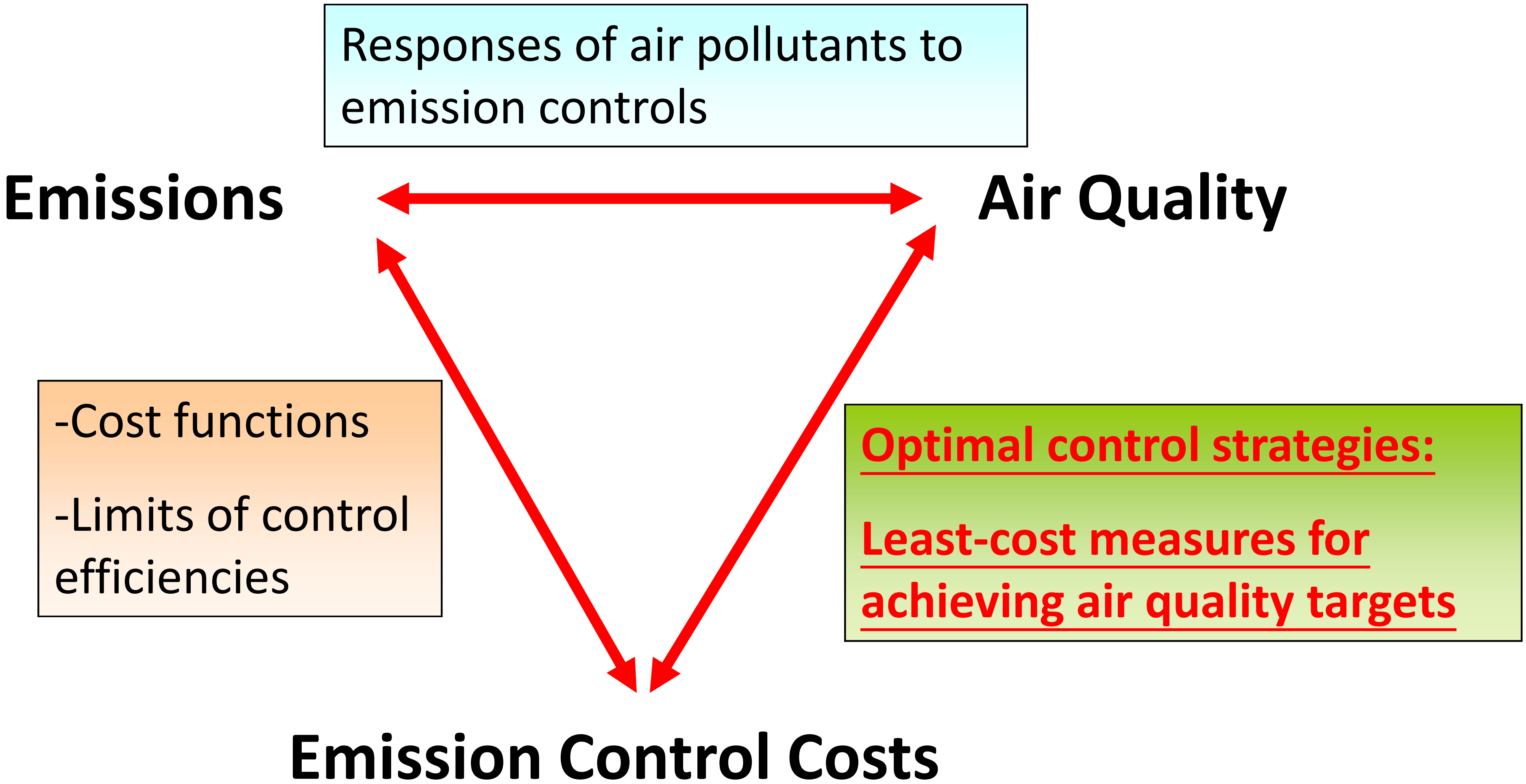
What We Need to Optimize Air Quality Management Strategies?



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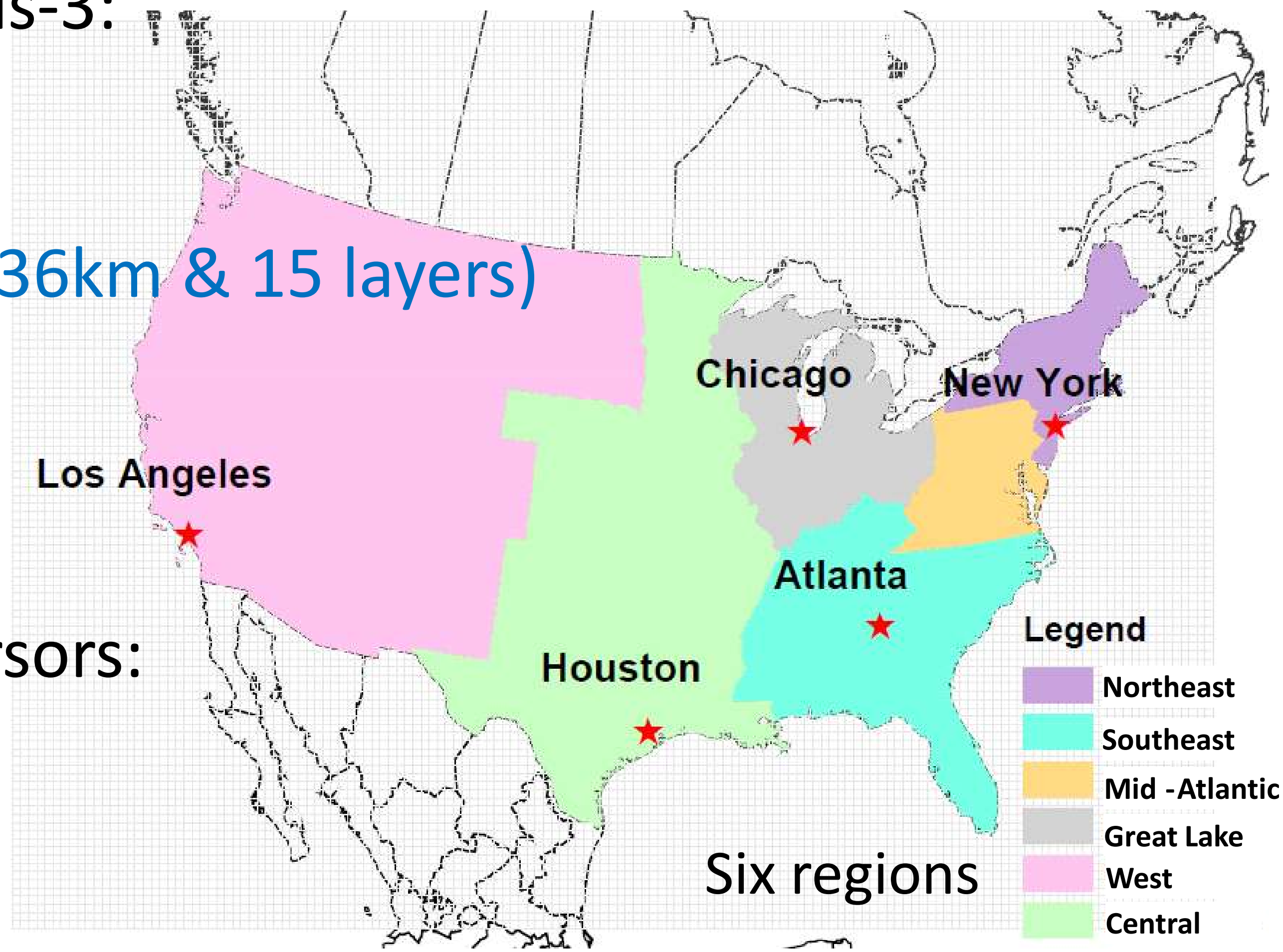
Modeling Domain and Setup

- U.S. EPA Models-3:
  - WRF
  - SMOKE
  - CMAQ-DDM (36km & 15 layers)
- Two pollutants:
  - ozone
  - $PM_{2.5}$
- Regional precursors:
  - SO_2
  - NO*x*
  - VOC
- Local primary $PM_{2.5}$



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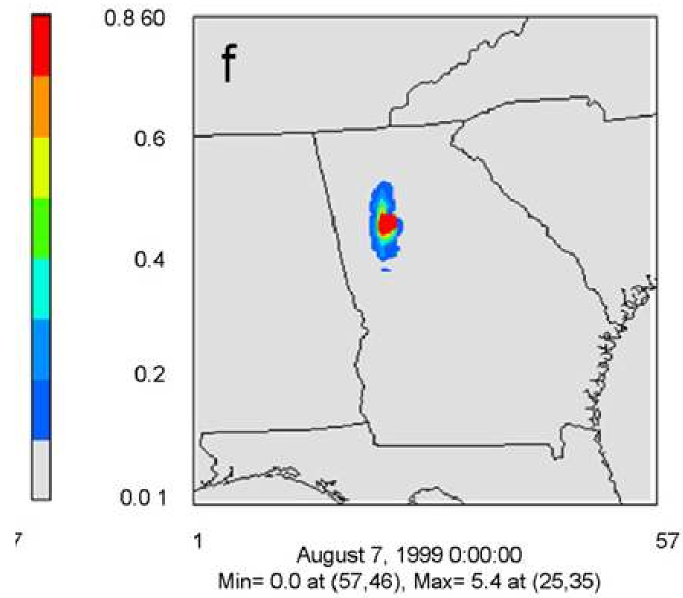
Assumptions

1. First-order sensitivities:

$$C_{i,new} \approx C_{i,\,prior} + \Delta\varepsilon_j \underline{S_{i,j}} + \cancel{H.O.T} \quad \Rightarrow \quad S_{i,j} \approx \frac{\partial C_i}{\partial \varepsilon_j}$$

2. Ignore co-benefits of emission reductions for multiple precursors

3. Primary $PM_{2.5}$ emissions only have local effects on air quality: Metropolitan Statistical Area (MSA)



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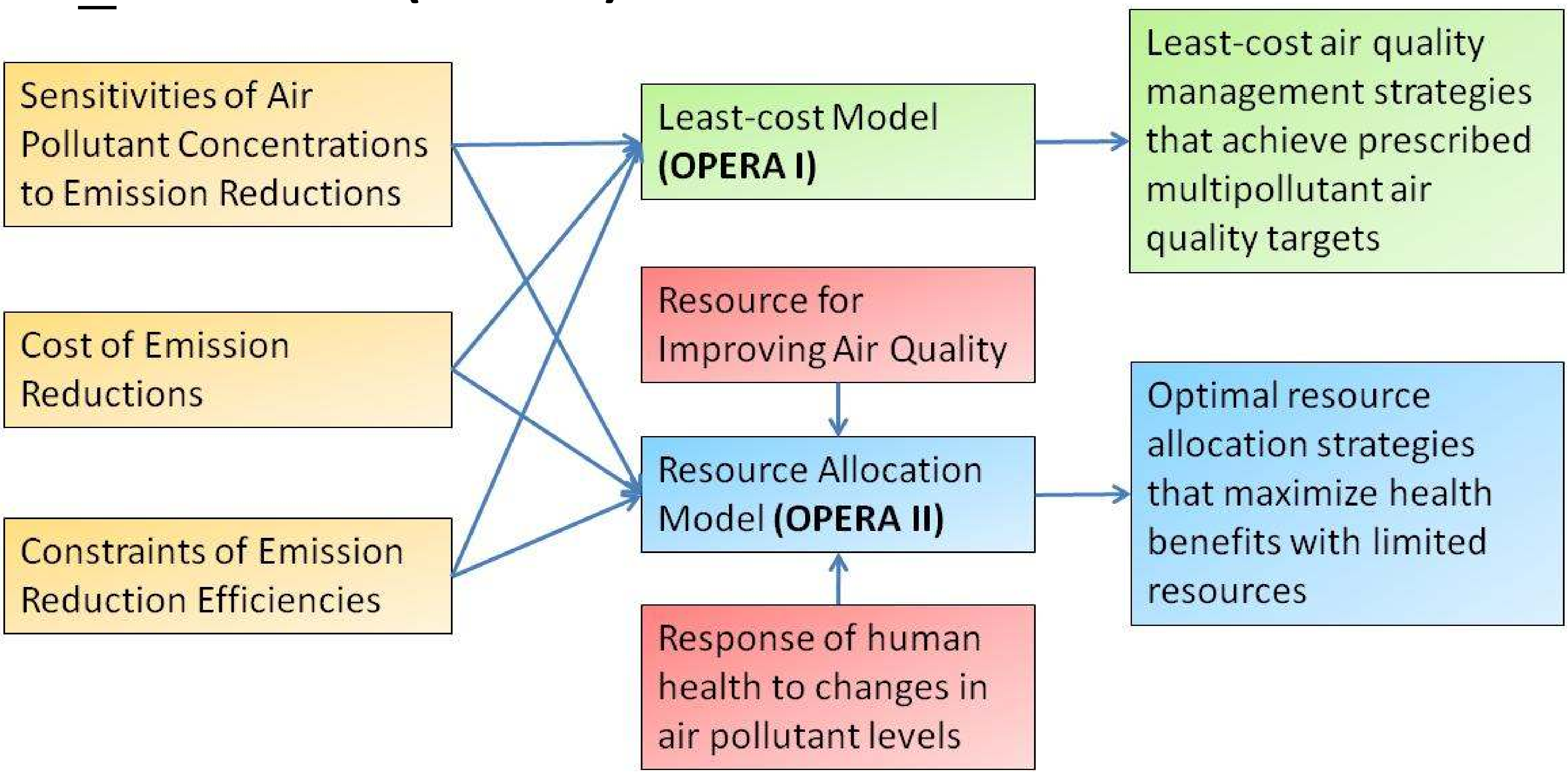
Developing AQ Management Strategies

OPtimal Integrated **E**mission **R**eduction **A**lternatives **(OPERA)**



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OPERA-I Least-Cost Model

Minimize $$\sum_{i,j} Cost_{i,j}\left(\Delta\varepsilon_{i,j}\right) + \sum_{k} Cost_{primary\_PM2.5,k}\left(\Delta\varepsilon_{primary\_PM2.5,k}\right)$$

Subject to:

Ozone target

$$\sum_{i,j} \Delta\varepsilon_{i,j} S_{O_3,i,j,k} \geq C_{O_3,prior,k} - \underline{C_{O_3,target,k}}$$

PM$_{2.5}$ target

$$\sum_{i,j} \Delta\varepsilon_{i,j} S_{PM_{2.5},i,j,k} + \Delta\varepsilon_{primary\_PM_{2.5},k} C_{primary\_PM_{2.5},k} \geq C_{PM_{2.5},prior,k} - \underline{C_{PM_{2.5},target,k}}$$

$$\left(\begin{array}{l} 0 \leq \Delta\varepsilon_{SO_2,j} \leq R_{SO_2,j} \\ 0 \leq \Delta\varepsilon_{NOx,j} \leq R_{NOx,j} \\ 0 \leq \Delta\varepsilon_{VOC,j} \leq R_{VOC,j} \\ 0 \leq \Delta\varepsilon_{primary\_PM_{2.5},k} \leq R_{primary\_PM_{2.5},k} \end{array}\right)$$

Constraints for emission control efficiencies

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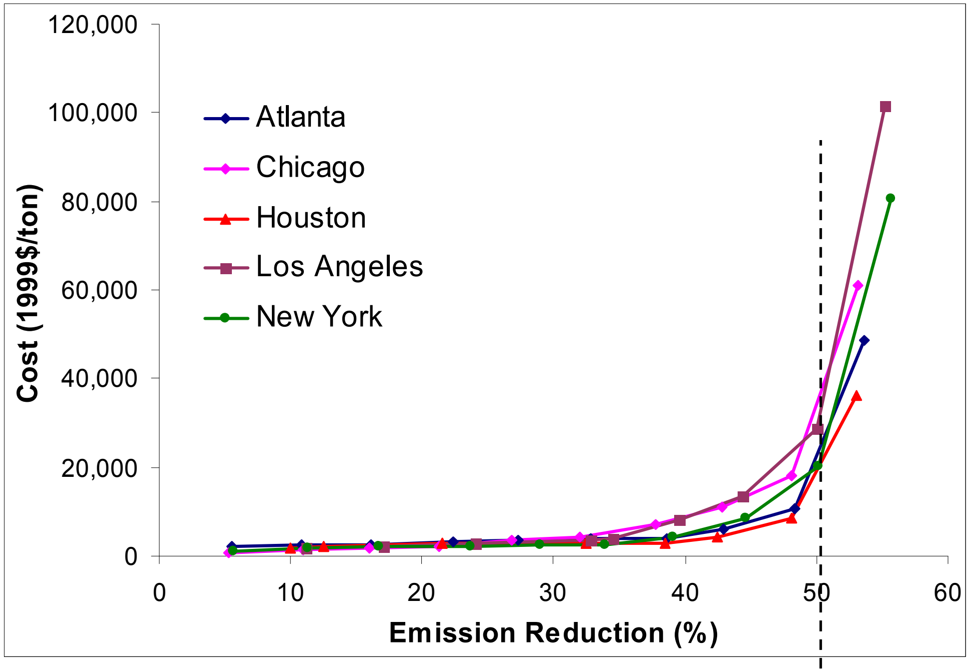
Per-ton Cost of Primary $PM_{2.5}$ Emission Reductions



AirControlNET v4.1 1999 EI (*E.H. Pechan & Associates*, 2006)

↓

EPA Control Strategy Tool (CoST), 2007-2009 EI

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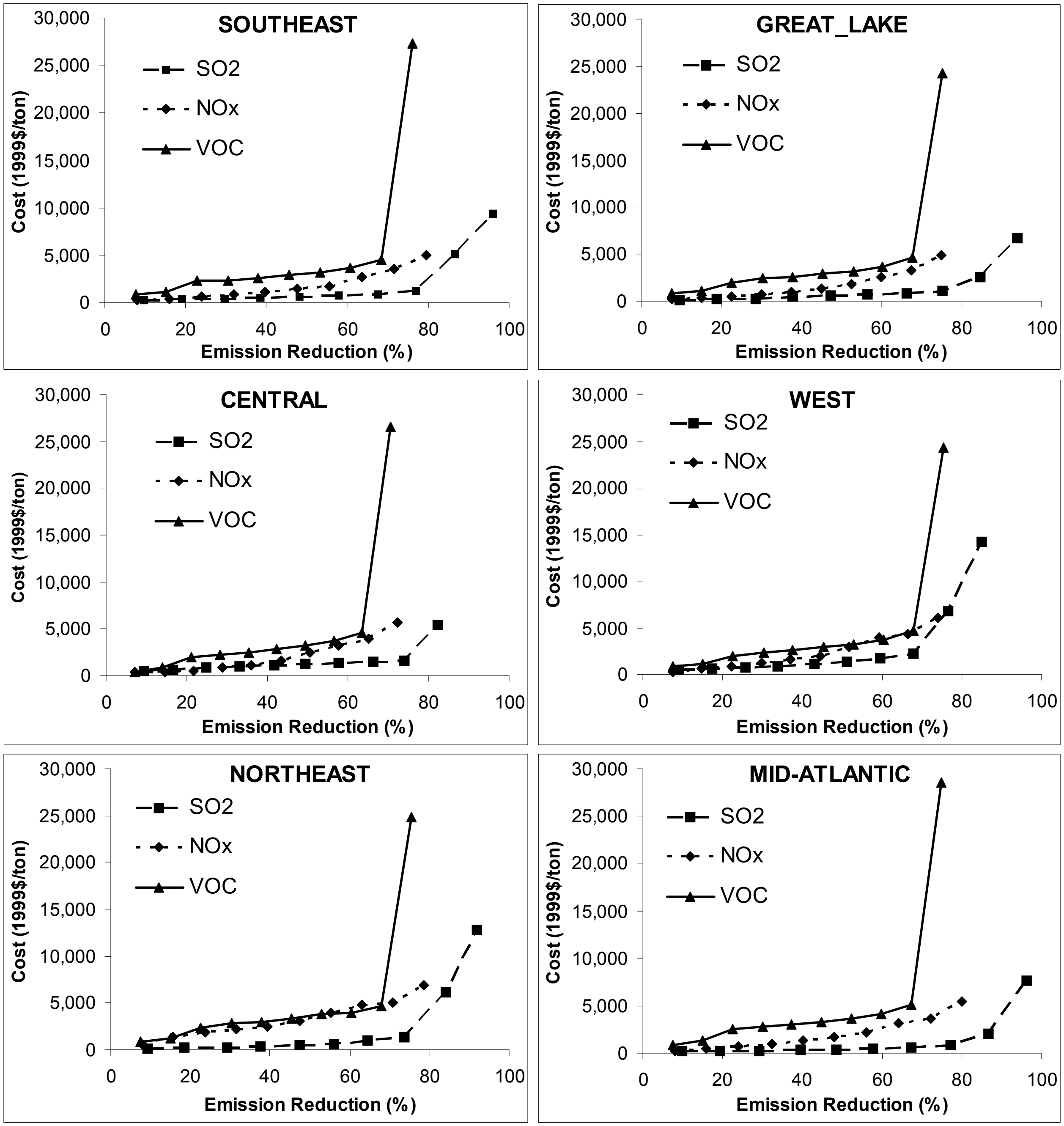

Per-ton cost (1999$) of anthropogenic SO_2, NO_x and VOC emission reductions (%, relative to total controllable emissions) from the six regions

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Objective - II

Development of an optimal **resource allocation model** for maximizing human health benefits attributed to air pollutant emission control:

- Maximizing human health benefits considering resource (i.e., budget) limit

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OPERA-II Resource Allocation Model

Decreases in total mortality due
reductions in pollutant concentrations

maximize

$$\sum_{i=1}^{n} \underline{\Delta mortality}_{\,i}$$

Subject to:

$$\sum_{j=1}^{p} Cost_{j,k}\left(\Delta\varepsilon_{j,k}\right) \leq R_k \qquad k = 1,\ 2,..,m$$

$$0 \leq \Delta\varepsilon_{j,k} \leq U_{j,k}$$

$$\Delta mortality_i = population \cdot y_0 \cdot \left(e^{\beta \cdot \Delta X} - 1\right)$$

where ***i***, ***j*** and ***k*** present the MSAs, precursors and regions, respectively.
n, ***p*** and ***m*** are the number of MSAs, precursors and regions, respectively

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Age-averaged Mortality Rate (y_0)

Age	Population Proportion[1]	Mortality rate[2] (per 100 people per year)	Proportion * Mortality rate
<1	0.014	0.687	0.009
1-4	0.055	0.030	0.002
5-14	0.146	0.030	0.004
15-24	0.139	0.093	0.013
25-34	0.136	0.106	0.014
35-44	0.163	0.192	0.031
45-54	0.135	0.408	0.055
55-64	0.087	0.998	0.087
65-74	0.066	2.454	0.162
75-84	0.045	5.636	0.253
>85	0.016	13.541	0.210
Age-weighted mortality rate (per 100 people per year)			0.841

[1] http://wonder.cdc.gov/

[2] Environmental Benefits Mapping and Analysis Program (BenMAP) User's Mannual Appendices, 2008, Abt AssociatesInc Prepared for Office of Air Quality Planning and Standards of U.S. Environmental Protection Agency

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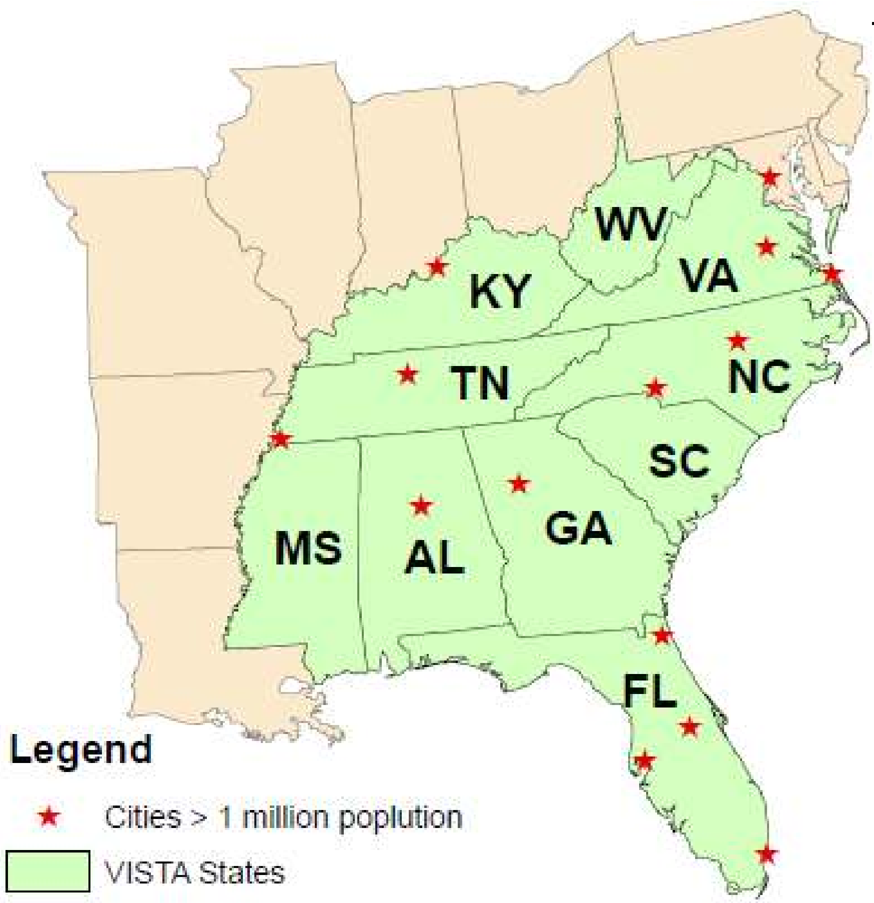
OPERA-II Modeling Domain and Cities



MSA	Population[1] (as of 2009)
1. Miami-Fort Lauderdale-Pompano Beach, FL	5,547,051
2. Washington-Arlington-Alexandria, DC-VA-MD-WV	5,476,241
3. Atlanta-Sandy Springs-Marietta, GA	5,475,213
4. Tampa-St. Petersburg-Clearwater, FL	2,747,272
5. Orlando-Kissimmee, FL	2,082,421
6. Charlotte-Gastonia-Concord, NC-SC	1,745,524
7. Virginia Beach-Norfolk-Newport News, VA-NC	1,674,498
8. Nashville-Davidson-Murfreesboro-Franklin, TN	1,582,264
9. Jacksonville, FL	1,328,144
10. Memphis, TN-MS-AR	1,304,926
11. Louisville/Jefferson County, KY-IN	1,258,577
12. Richmond, VA	1,238,187
13. Birmingham-Hoover, AL	1,131,070
14. Raleigh-Cary, NC	1,125,827

[1]http://www.census.gov/popest/metro/metro.html

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Schedule of Tasks

Task	Year 1				Year 2				Year 3			
	0-3 mos	3-6 mos	6-9 mos	9-12 mos	12-15 mos	15-18 mos	18-21 mos	21-24 mos	24-27 mos	27-30 mos	30-33 mos	33-36 mos
Conduct WRF meteorological simulations	•	•	•	•								
Develop emission control cost functions			•	•								
Prepare emission inventory and conduct smoke emission processing			•	•	•	•	•	•				
Conduct CMAQ-DDM air quality simulations and sensitivity analyses			•	•	•	•	•	•	•	•		
Develop air quality management strategies using OPERA I & II						•	•	•	•	•	•	•
Prepare final report and papers								•	•	•	•	•

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Expected Results

- Assessment of the effectiveness of emission reductions from various U.S. regions as well as local primary $PM_{2.5}$ emission reductions for improving multipollutant air quality in polluted urban areas.
- Development of two decision-making models,
  - a least-cost model (OPERA-I) for identifying optimal (i.e., least-cost) multipollutant air quality management strategies
  - a resource allocation model (OPERA-II) for maximizing health benefits considering limitations of resources and emission controls.
- Education promotion.