
# Particulate Matter Science for Policy Makers: A NARSTO Assessment

## Assessment Co-Chairs:

*Peter H. McMurry*, University of Minnesota

*Marjorie Shepherd*, Meteorological Service of Canada

*James Vickery*, U.S. Environmental Protection Agency

## Assessment Authors:

More than *30 leading authorities* from academic, governmental, and private sector organizations


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# NARSTO

- A multi-stakeholder entity:

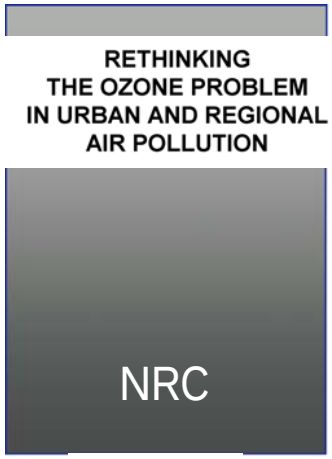
  *government, private sector, academia*

- A multi-national entity:

  *Canada, Mexico, U.S.*

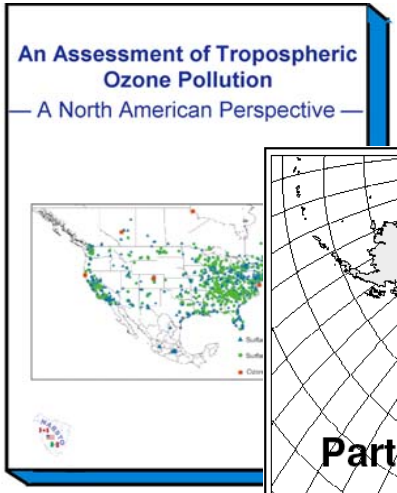
- Carries out periodic *policy-relevant science assessments* on air pollutants including **particulate matter (PM)** and **ozone**

# NARSTO,
# who we are and what we do

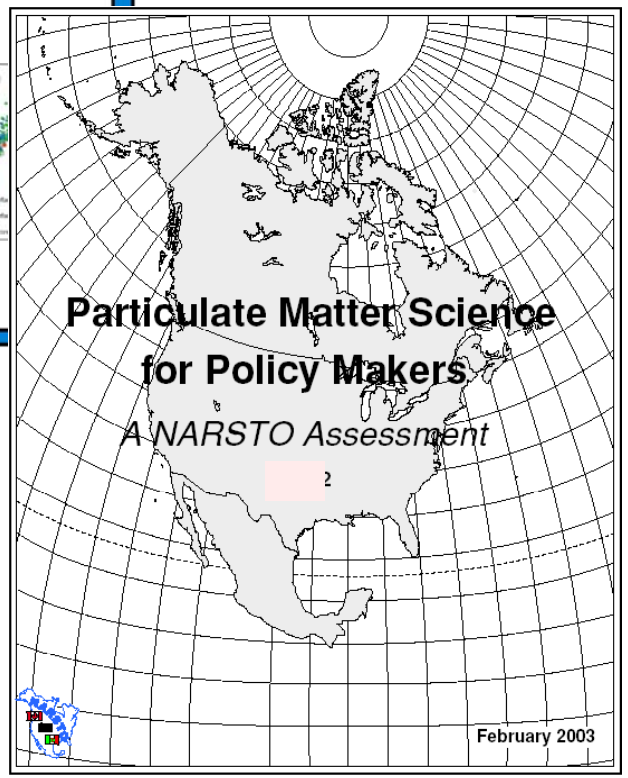



1991


1995




2000




2003

# Purposes of this PM Assessment

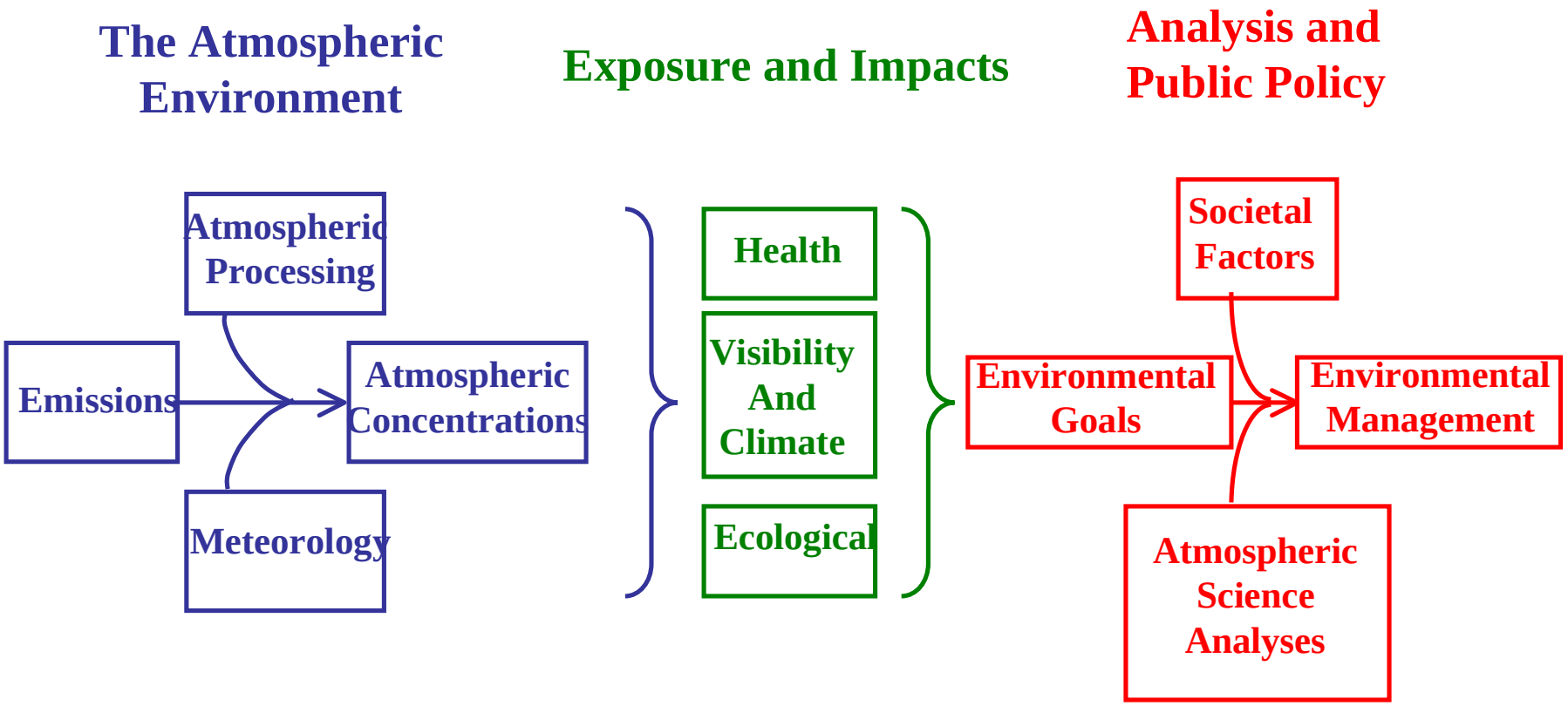
- To interpret complex and new atmospheric science so that it is useful for the *management* of particulate air pollutants

- To *inform exposure and health scientists* as they continue to investigate causal hypotheses

# Approach

- Survey science needs of *policy makers*
- Prepare PM Assessment
  - Executive Summary (4 pages)
  - Synthesis for Policy Makers (50 pages)
  - 11 science chapters: implications for policy makers (600 pages)
    - Effects context; human health, visibility, and climate
    - Factors that influence atmospheric concentrations
    - Modeling tools to manage PM
    - Conceptual models of 9 regions
    - Recommended research to fill key information gaps
- Peer review by NARSTO community
- External tri-national relevancy review
  - NAS (US), Royal Society (Canada), FUMEC (Mexico)

# Framework for Informing Management of PM



# Chapters and Lead Authors

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| 2. Health Context | R. McClellan, B. Jessiman |
| 3. Atmospheric Processes | S. Pandis |
| 4. Emissions | G. Hidy, D. Niemi, T. Pace |
| 5. Measurements | F. Fehsenfeld, D. Hastie, P. Solomon, J. Chow |
| 6. Spatial & Temporal PM | C. Blanchard |
| 7. Receptor Methods | J. Brook, E. Vega, J. Watson |
| 8. Chemical Transport Models | C. Seigneur, M.Moran |
| 9. Visibility | I. Tombach, K. McDonald |
| 10. Conceptual Models | J. Vickery |
| 11. Recommended Research | P. McMurry |

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| • Chap. 4. | Jason West |
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| • Chap. 8. | P. Amar, Jason West, R. Villasenor |
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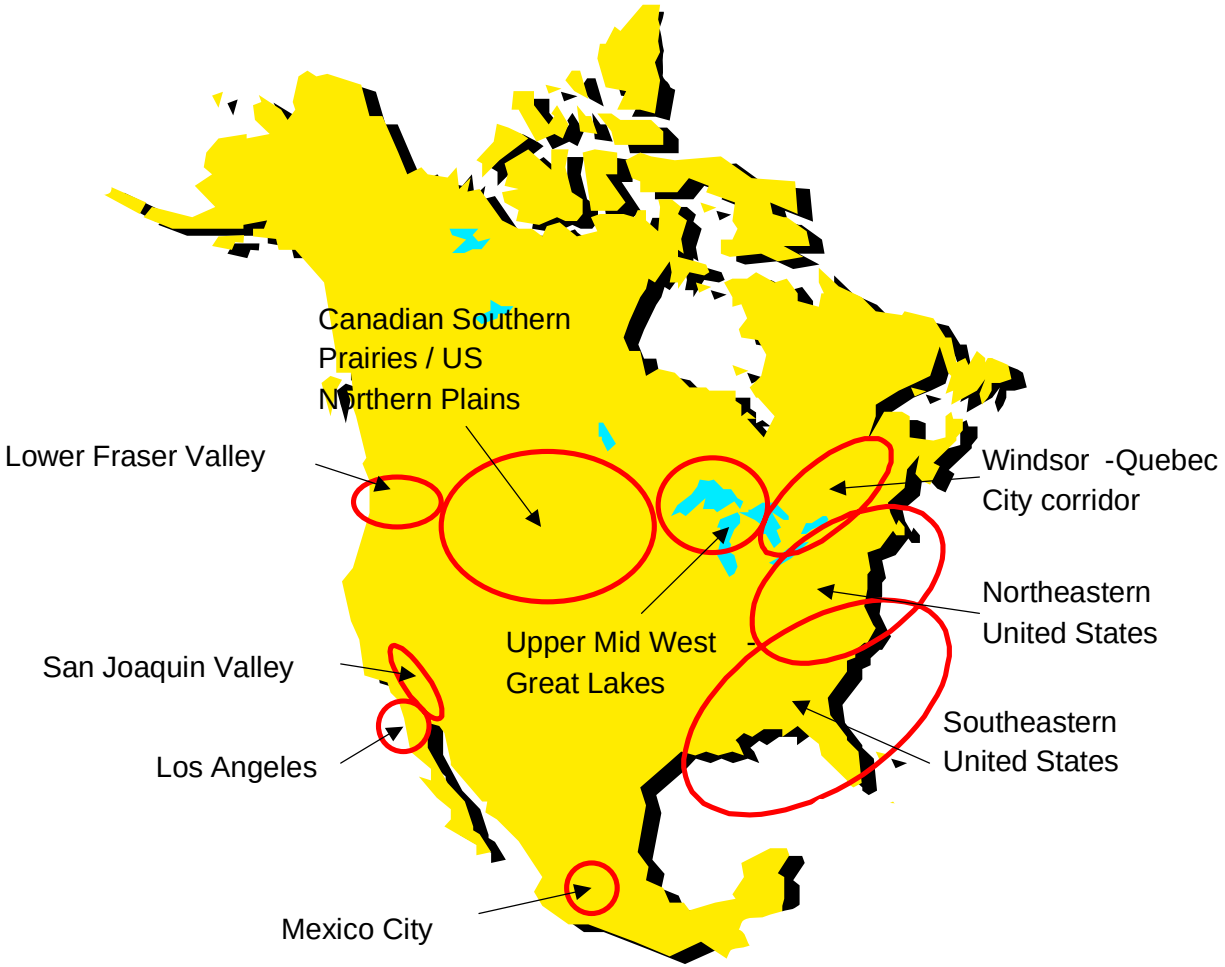
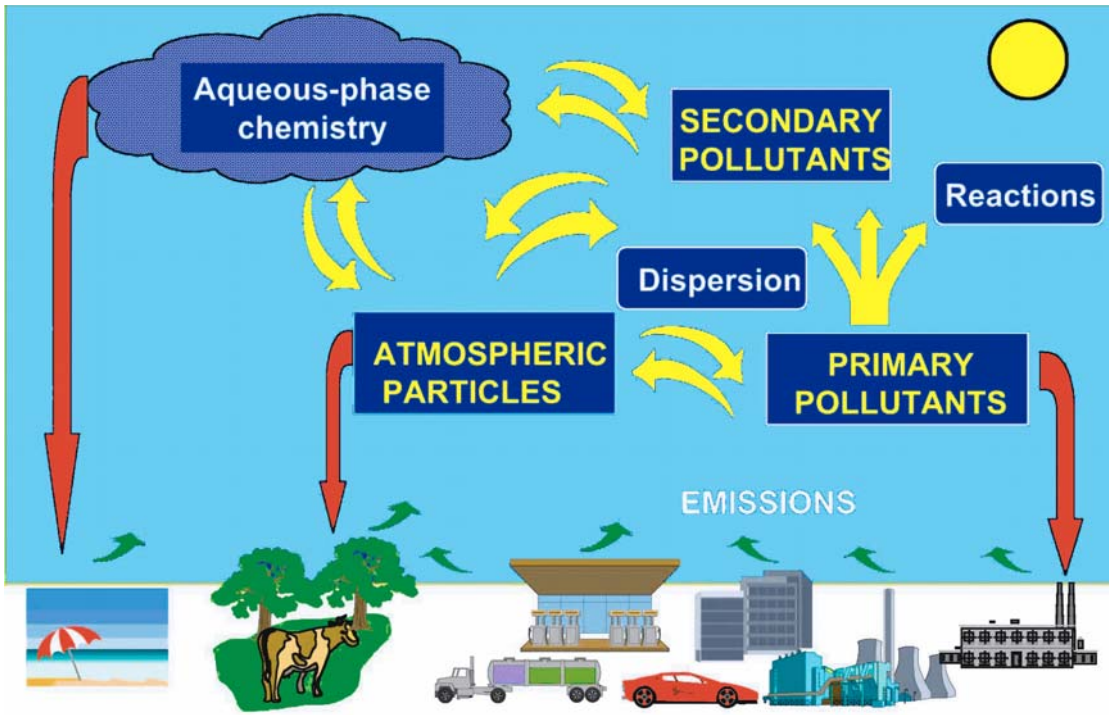
# *Conceptual models* for nine representative areas



# *Conceptual models* and their policy relevance

Synopses of the best understanding of the influence of emissions, meteorology and atmospheric processes on ambient $PM_c$ concentrations



# Simplified Conceptual Model for the Northeast United States

## The Atmospheric Environment

### Atmospheric Processing of $PM_{2.5}$ (Key drivers of peak PM)

- Summer sulfate driven by gas-phase production
- Aqueous production of sulfate is oxidant limited and non-linear
- The small level of $NO_3$ is ammonia limited and controlled by $SO_4$ availability. Lots of $HNO_3$ available
- Little information, but majority of OC is estimated to be secondary in origin

Emissions
Manmade/ Natural
Gas/Particle

### Meteorology (Conditions common to peak PM)

**$PM_{2.5}$**

- Strong seasonal (rural to urban) gradient noted
- Gas phase $SO_4$ favored by stagnant summer periods with high oxidant production
- Year-to-year variability in wet deposition cleansing.

### Atmospheric Concentration (Of typical peak PM)

| **$PM_{2.5}$** | **$PM_{10}$** |
|---|---|
| **Concentration**<br>**Annual:**<br>• Rural 5-10 μg/m³<br>• Corridors of Ohio River Valley and Coastal Ozone Plain near and just over 15 μg/m³. NYC >15 μg/m³<br>**24hr**<br>• Seldom above 65 μg/m³ except for Pittsburgh area.<br>**Seasonality**<br>• Summer > winter by factor of ≈ 1.5-2.5 across region, but reverse for Phil. & NYC (Summer = 0.9 Winter) | **Concentration**<br>**Annual**<br>• 30-50 μg/m³ at large urban areas<br>**24 hr:**<br>• 80-150 μg/m³ at large urban areas<br><br>Downward trend 1999 15-18% lower than 1990l |
| **Composition**<br>**Peak**<br>$SO_4$ ≈ 60-80%<br>**Average.**<br>$SO_4$ ≈ 55-65%<br>OC ≈ 25-30%<br>**Rural (Summer)**<br>$SO_4$ ≈ 60-75%<br>OC ≈ 20-30%<br>$NO_3$+BC+Soil ≈ 10%<br>**Urban (Winter)**<br>OC ≈ 30-35%<br>$SO_4$ ≈ 25-35%<br>$NO_3$ ≈ 15-25%<br>BC+Soil ≈ 5-15% | |

## Analysis & Policy Implications

### Policy Implications for $PM_{2.5}$ (Simple Summary Insights)

- Median $SO_4$ continues to drop from 1990 levels due to acid rain controls, but peaks remain.
- Summer sulfate not neutralized, but is in winter so greater nitrate response to winter sulfate drop.
- Regional transport in summer from Ohio River Valley important. Reduction in regional and local $SO_2$ beneficial.
- Local $SO_4$, OC and $NO_3$ in coastal urban areas important in winter. Need to consider how to reduce OC.
- Winter nitrate increase will partially offset sulfate decreases, and is ammonia limited.

### Sources (Estimates of contribution from source apportionment)

**$PM_{2.5}$ (% mass)**

- Coastal Urban Corridor
  - Local $SO_4$ ≈ 10%
  - Regional $SO_4$ ≈ 50%
  - Motor Vehicles ≈ 25-30%
  - Residual oil burning 4-8%
  - Soil 6-7%
  - Biogenic OC's (included in Motor Vehicles)
- Rural
  - Summer $SO_4$ = 2-4 times Winter $SO_4$
  - Summer OC = 2 times Winter OC
- Urban
  - Summer $SO_4$ ≈ Regional $SO_4$
  - Winter $SO_4$ = 2 times regional $SO_4$
  - Winter OC = 4-5 times regional OC

## Atmospheric Concentration

(Of typical peak PM)

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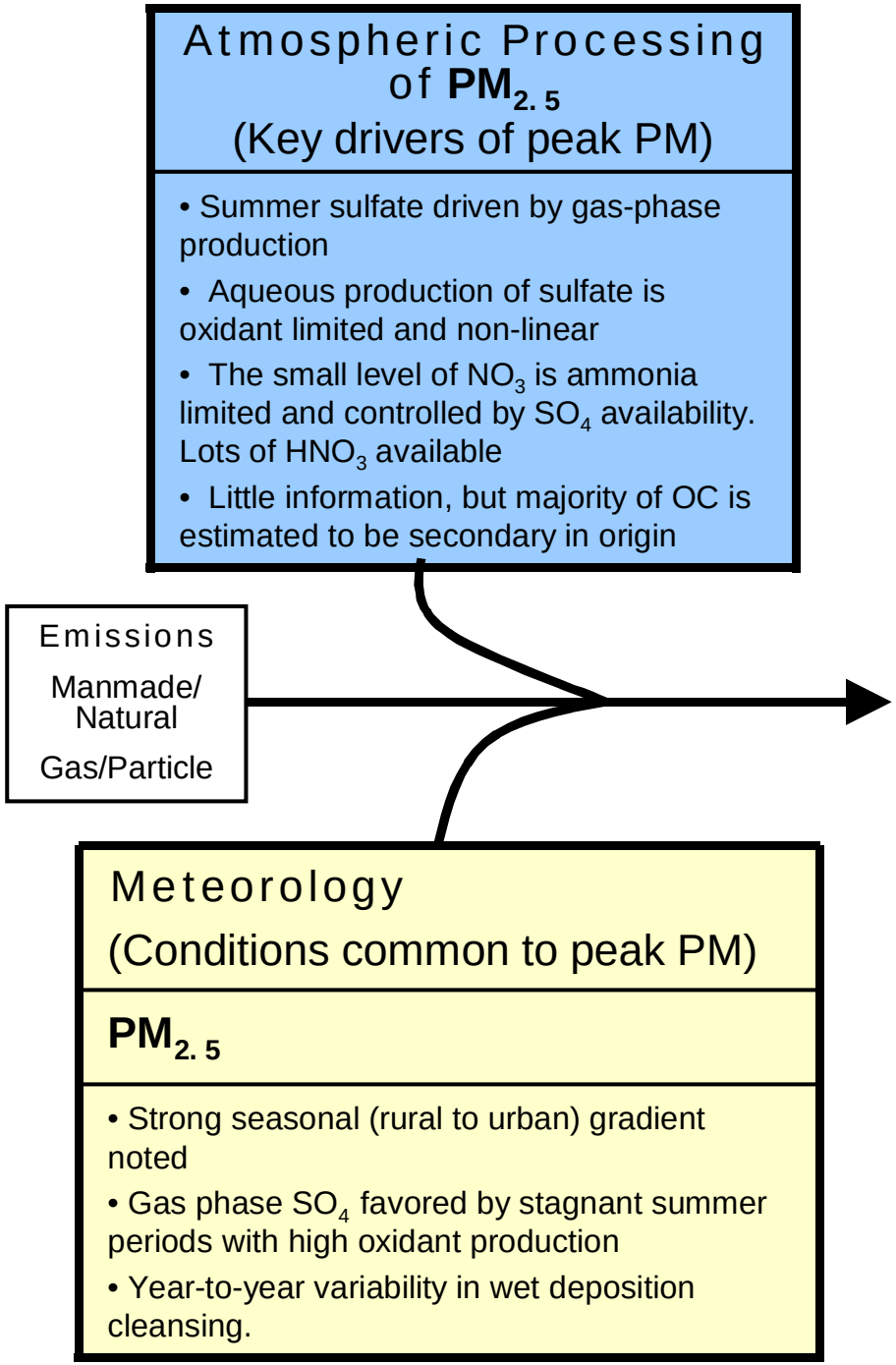
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# Policy Questions Frame Synthesis

- PQ1. Is there a significant PM problem and how confident are we?
- PQ2. Where there is a PM problem, what is its composition and what factors contribute to elevated concentrations?
- PQ3. What broad, pollutant based, approaches might be taken to fix the problem?
- PQ4. What source specific options are there for fixing the problem given the broad control approaches above?
- PQ5. What is the relationship between PM, its components, and other air pollution problems on which the atmospheric science community is working?

- - - - - - - - - - - - - - - - - - - - - - -

- PQ6. How can progress be measured? How can we determine the effectiveness of our actions in bringing about emissions reductions and air quality improvements, with their corresponding exposure reductions and health improvements?
- PQ7. When and how should implementation programs be reassessed and updated to adjust for any weaknesses, and to take advantage of advances in science and technology?
- PQ8. What further atmospheric sciences information will be needed in the periodic reviews of national standards?

# Conclusions - 1

- $PM_{2.5}$ levels persistently greater than existing standards have been observed in urban areas throughout North America
  - On average, greater than 2/3 of $PM_{2.5}$ is traceable back to an thropogenic sources
- $PM_{10}$ levels greater than existing standards are observed in specific parts of North America
  - S trong influence of fugitive and open source e missions

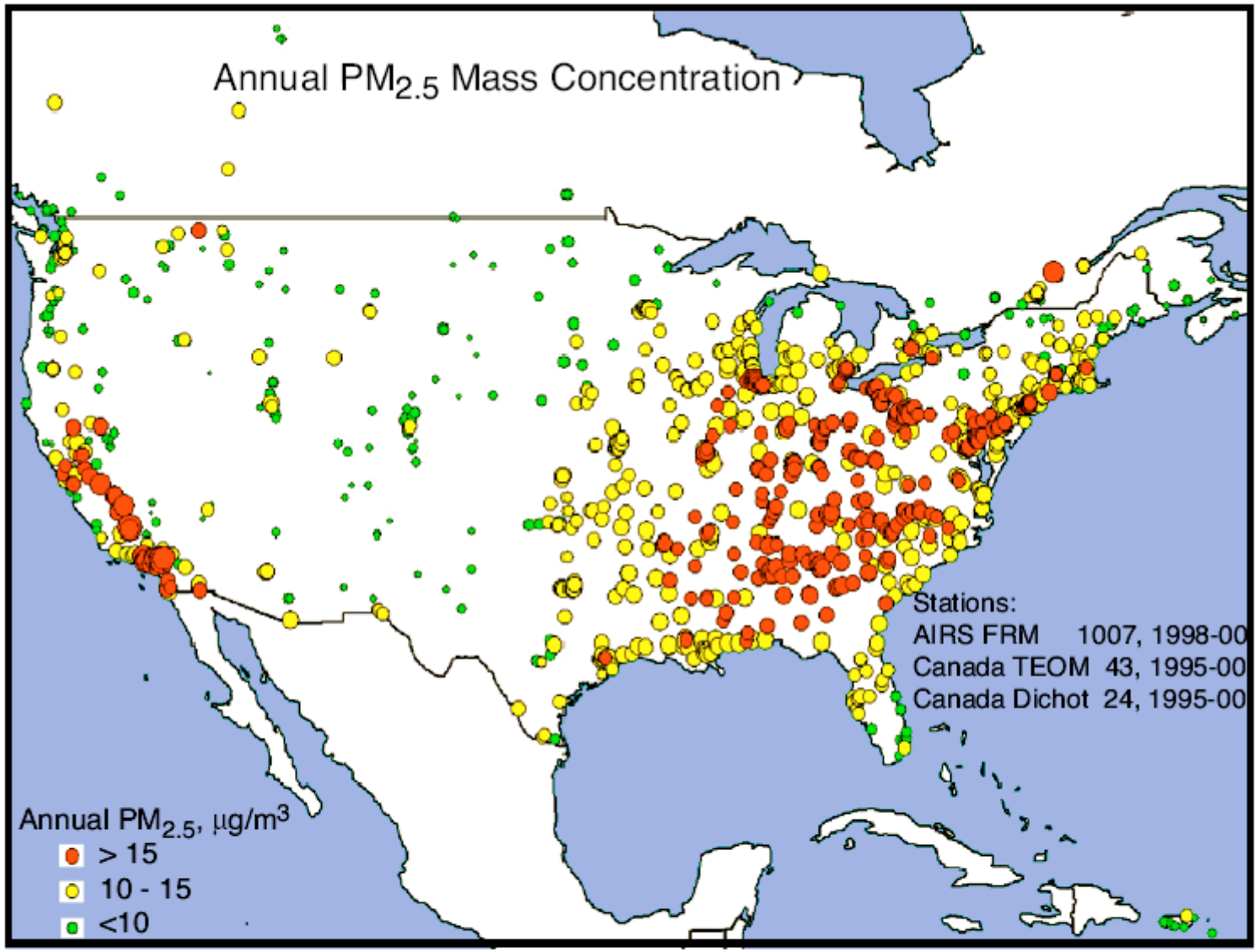



Figure 6.7. Average $PM_{2.5}$ concentrations. The U.S. data are from FRM monitors at sites in the EPA AIRS database for July 1998 through July 2000. Canadian data are from TEOM and dichotomous samplers operating from 1995 through 2000. The currently available data from sites in Mexico represented less than one year of sampling and were excluded from the computation of annual averages. Spot diameter varies in proportion to concentration. (Source: R. Husar, pers. comm.).

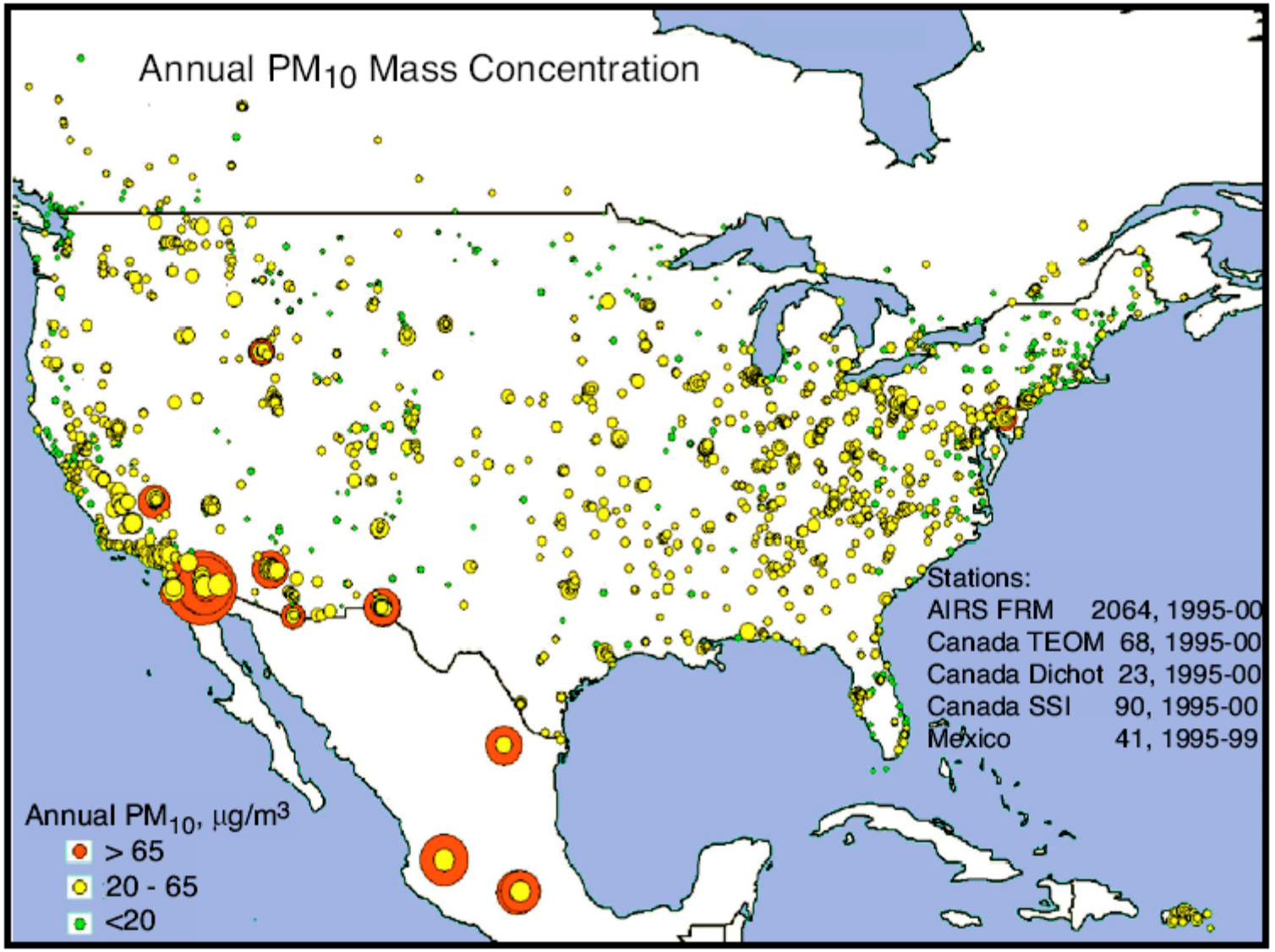



Figure 6.3. Average annual $PM_{10}$ mass concentrations. The U.S. data are from sites in the EPA AIRS database. Canadian data were provided by Environment Canada. $PM_{10}$ data were available for five cities in Mexico. Spot diameter varies is proportion to concentration. (Source: R. Husar, pers. comm.).

# Conclusions - 2

- Origins and properties of PM vary with time-of-year and by region
  - Management strategies will likely vary with region
  - Strategies will likely address both local and regional contributions

# Conclusions - 2 continued:

- $PM_{2.5}$ includes a complex mixture of chemicals

| | Min. | Max. | Avg. |
|---|---|---|---|
| Sulfate | 7% | 47% | 24% |
| Nitrates | 4% | 37% | 13% |
| Ammonium | 3% | 20% | 13% |
| Black Carbon | 2% | 22% | 10% |
| Organic Carbon | 11% | 41% | 27% |
| Soil | 2% | 25% | 7% |
| Other | 0% | 23% | 6% |

  - Of these, organic carbon is the most complex, and our understanding of its origins (manmade and biogenic), atmospheric behavior, and composition is the most poorly understood

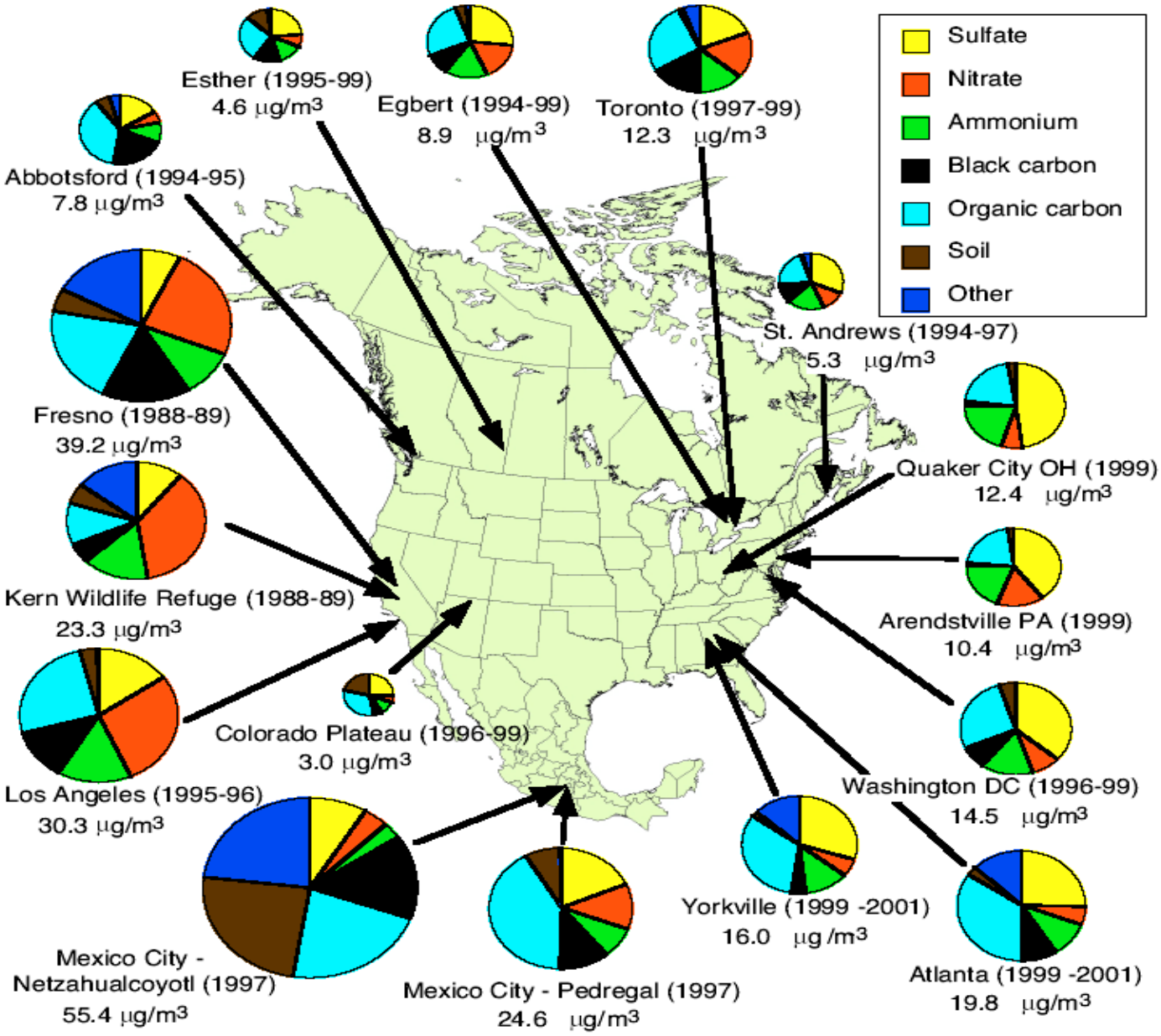



Figure 6.12. Composition of $PM_{2.5}$ at representative urban and rural locations. The urban sites are Toronto, Washington DC, Atlanta, Mexico City, Los Angeles, and Fresno. Averaging periods and average $PM_{2.5}$ mass are indicated. All sites have at least one year of sampling except Mexico City, for which the average was

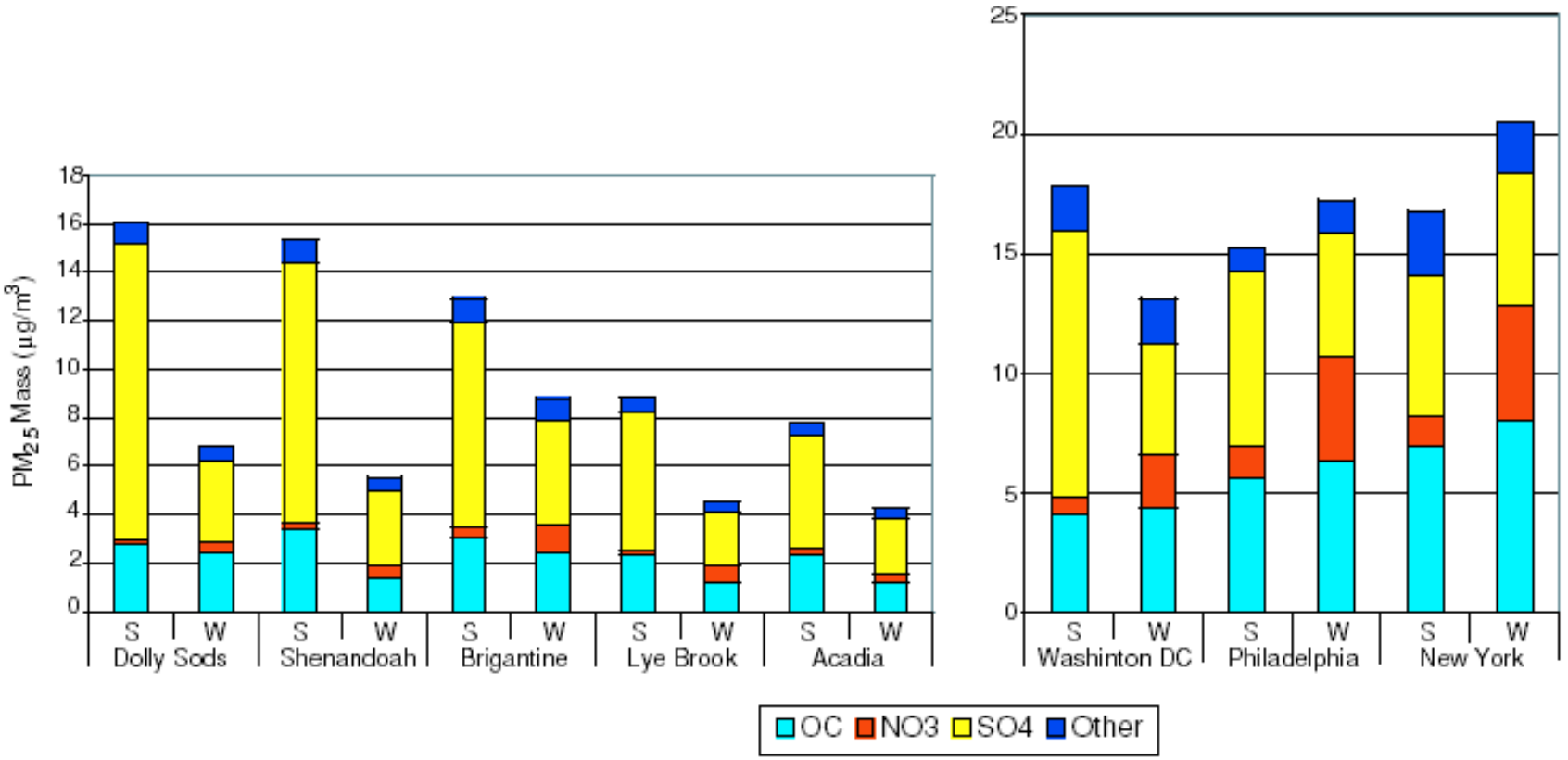



Figure 10.28. Reconstructed Fine Mass partitioned into the individual components: (a) rural sites (left) and (b) urban sites (right), where S=summer and W=winter.

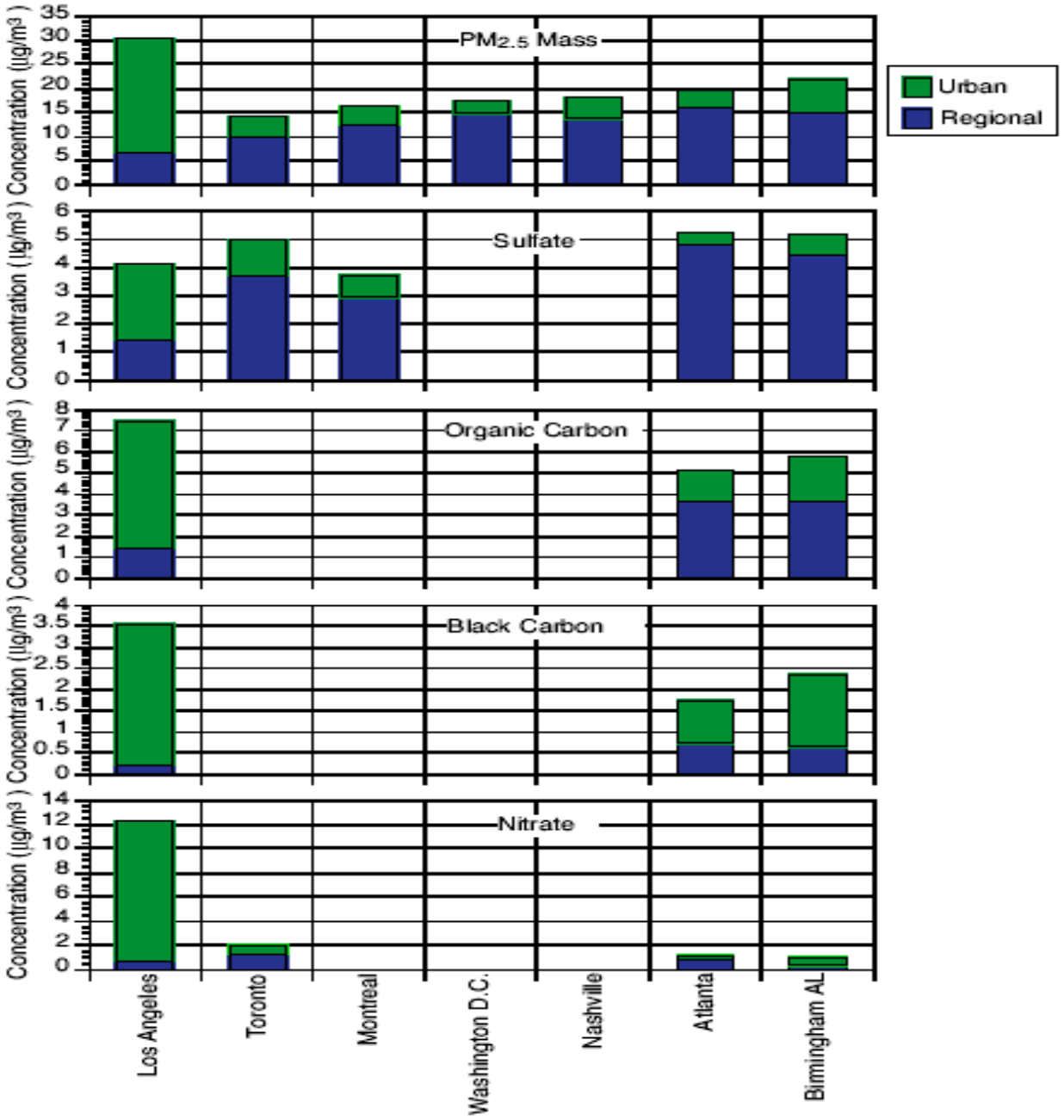
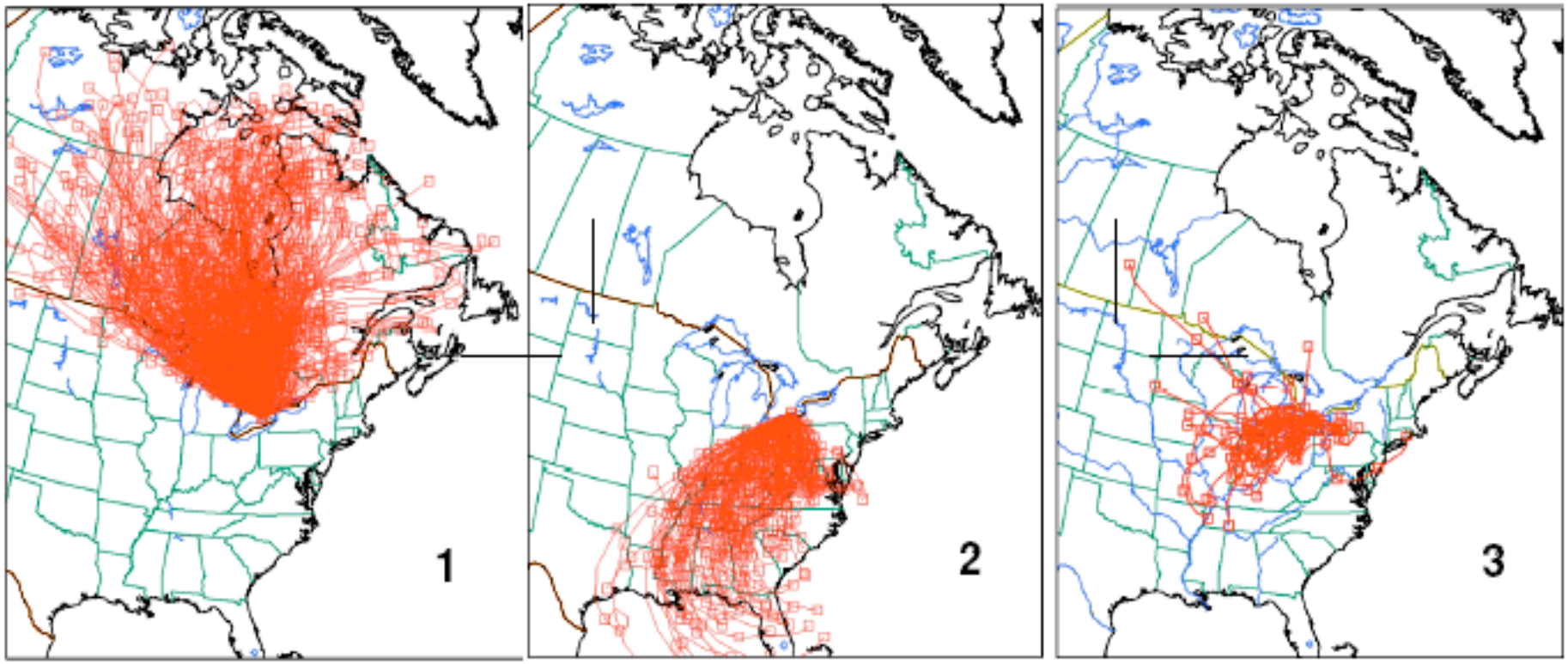



Figure 6.15. Comparisons of average $PM_{2.5}$ mass and species concentrations at

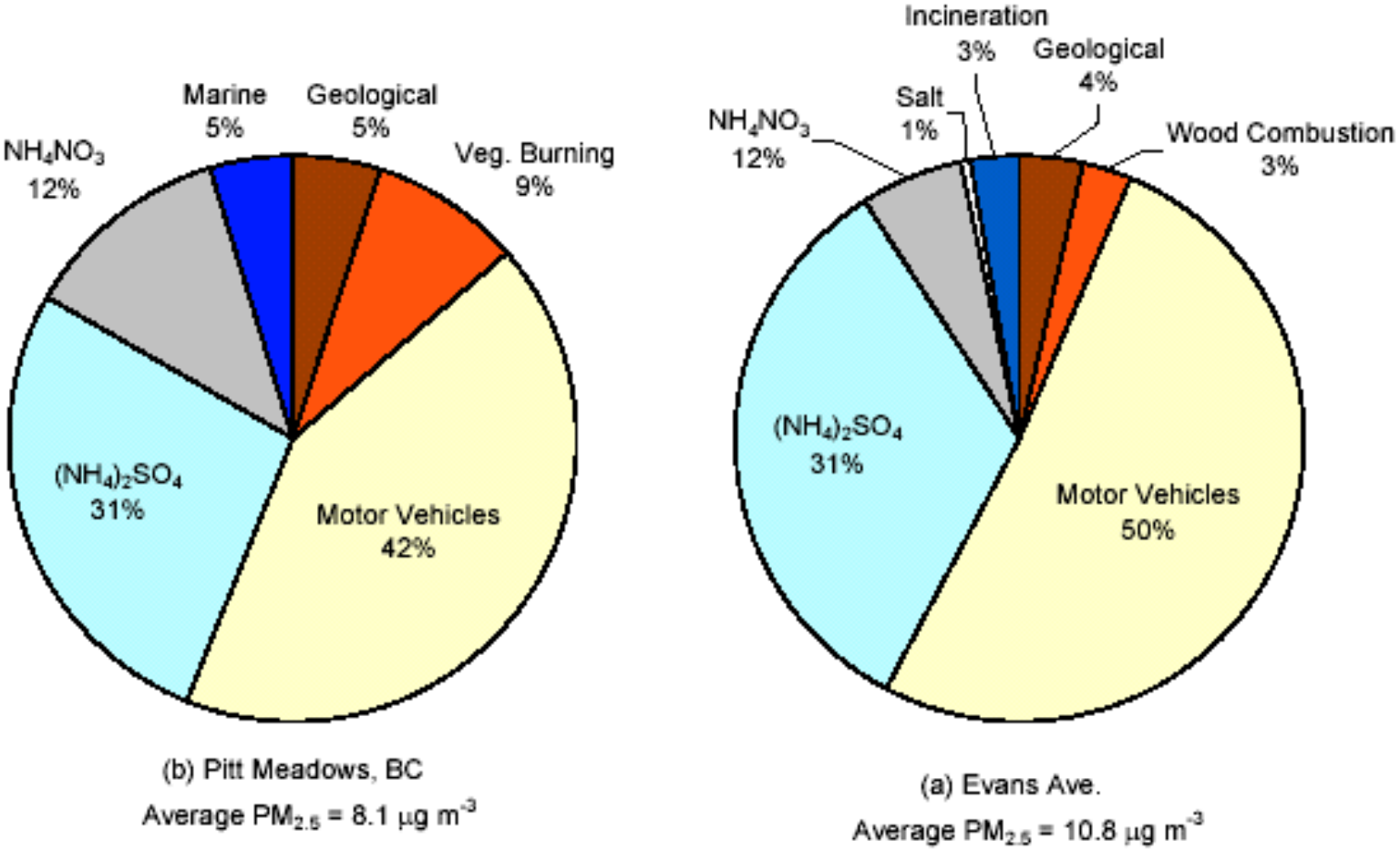
# Conclusions - 3

- Receptor models and chemical transport models are useful mathematical tools for identifying PM management strategies
  - Part of a corroborative analysis
  - The power and accuracy of such models is likely to improve significantly in the future, as our understanding of atmospheric aerosols improves




igure 7.4. Three-day back-trajectories arriving at Simcoe, ON, during May-September of 1998 and 19
ere sorted by transport sector. Back-trajectories represent the most probable path that the air mass follow
n route to Simcoe. The sectors shown represent: 1) northerly flow over predominantly Canadian sour
egions, and 2) southerly flow over U.S. source regions. Six-hr average $PM_{2.5}$ from a TEOM were 6.7 ±6
g/m$^3$ (±1SD) for sector 1 and 22.4 ±11.7 µg/m$^3$ for sector 2. Sector 3 includes trajectories corresponding
$M_{2.5}$ >30 µg/m$^3$, that could not be classified into either of the other sectors because they cross over regior
he cut-off value of 30 was used because it is approximates the Canadian standard for 24-hr average PM
see Chapter 1 for details). The unclassifiable high-concentration cases (sector 3) were associated with ve

**Figure PQ.3: (from Bloxam et al., 1997).** CMB source contribution estimates for $PM_{2.5}$ in the Vancouver and Toronto urban areas of Canada (average for twenty-six 24-hr observations from July-August 1993).



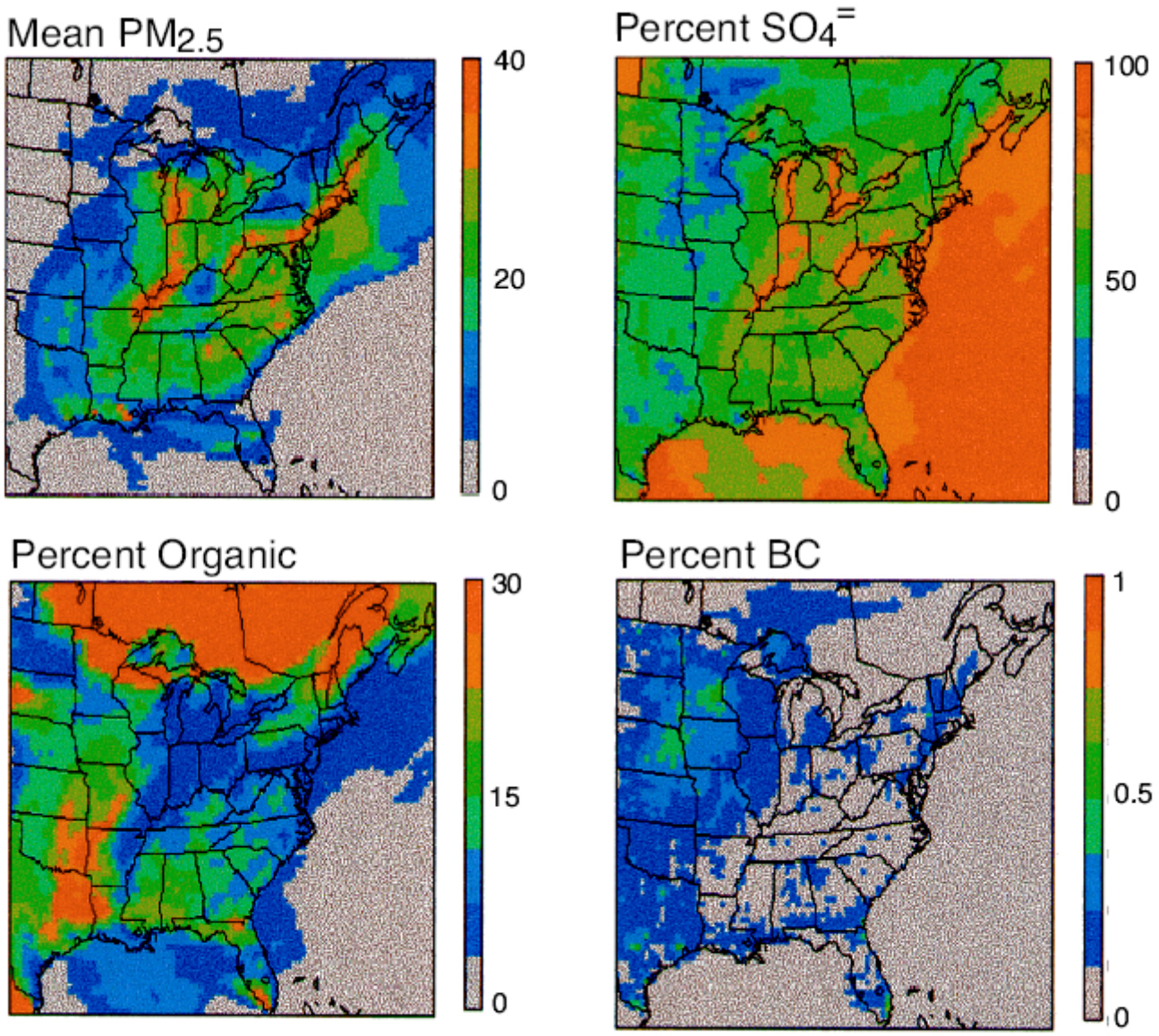



Figure 8.7b. Application of two distinct CTMs (AURAMS and Models-3/CMAQ) to northeastern North America: (b) 24-hr average surface-level $PM_{2.5}$ mass concentration field ($\mu g/m^3$) and sulfate, OC, and BC percentage contribution fields on 13 July 1995, simulated by Models-3/CMAQ.

Table S.3 (8.2). Levels of confidence in aspects of chemical transport model simulations.

| CTM Aspect | Confidence Level [a] | CTM Aspect | Confidence Level [a] |
|---|---|---|---|
| **PM Mass Components** | | **Gases** | |
| PM ultrafine | VL | $SO_2$ | H |
| PM fine | M | $NO_x$ | H |
| PM coarse | M | $NH_3$ | M |
| **PM Composition** | | VOC | M |
| Sulfate | M - H | $HNO_3$ | M |
| Nitrate | M | $O_3$ | M |
| Ammonium | M | **Spatial Scale** | |
| OC primary | L | Continental | L |
| OC secondary | VL | Regional | M |
| BC | L | Urban | L - M |
| Crustal | L | **Temporal Scale** | |
| Water | L | Annual | L |
| Metals, biologicals, peroxides | VL | Seasonal | L |
| | | Episodic | M |

[a] H: high, M: medium, L: low, VL: very low

# Conclusions - 4

- There is an interrelationship between PM and other air pollution problems
  - Ozone
  - Visibility impairment and climate change
  - Acid deposition

➢ Management strategies should consider these interrelationships

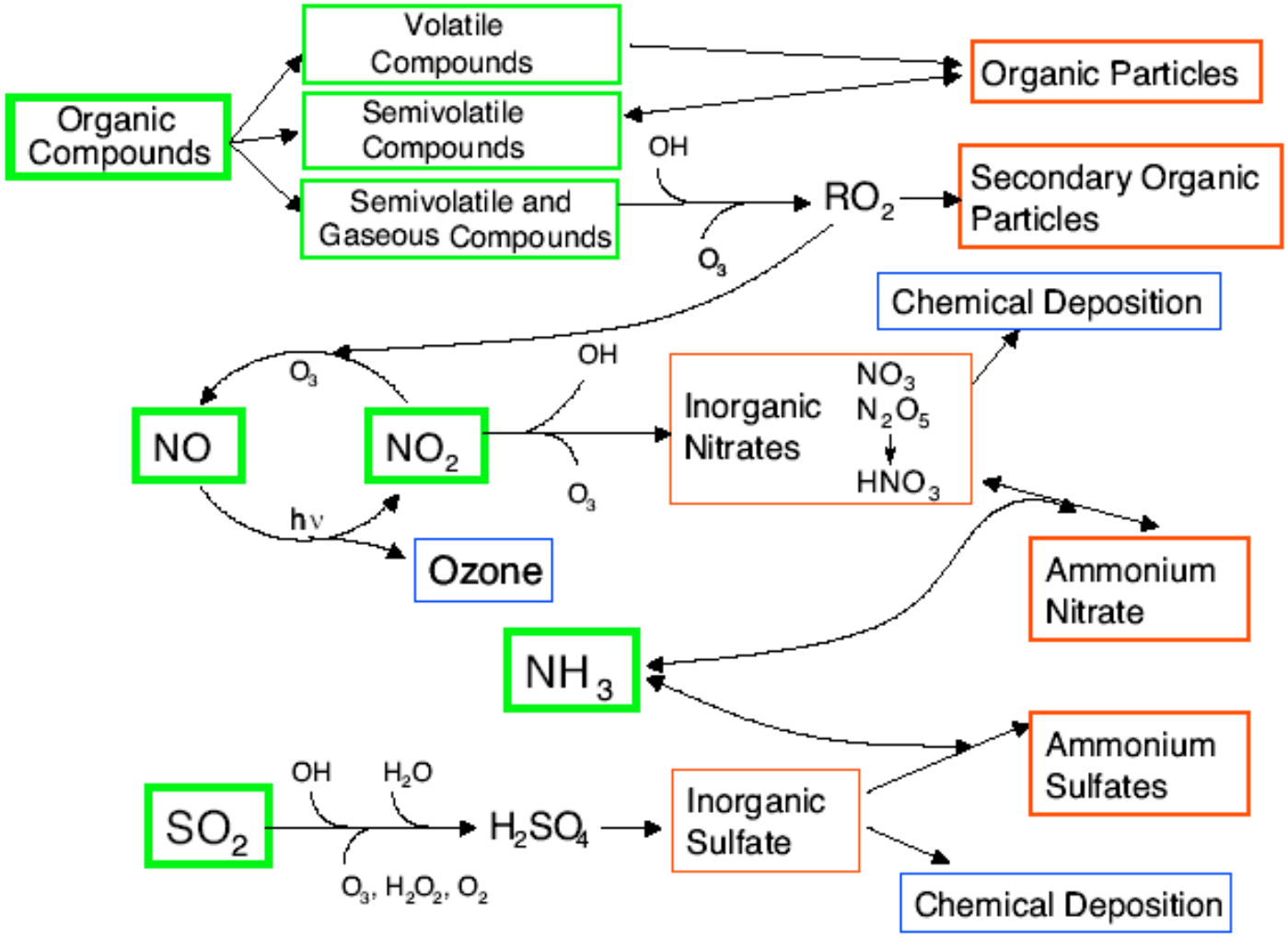



Figure 3.16. Chemical links between the ozone and PM formation processes. The major precursors a shown in green squares. The VOC can be gaseous (always in the gas phase), non-volatile (always in tl condensed phase), and semivolatile (partitioned between the gas and condensed phases (adapted from MS( 2001).

Table S.4 (3.2). Typical pollutant / atmospheric issue relationships.[a]

| Reduction in pollutant emissions | Change in associated pollutant or atmospheric issue | | | | | |
|---|---|---|---|---|---|---|
| | | PM Composition | | | | |
| | Ozone | Sulfate | Nitrate | Organic compounds | $PM_{2.5}$ | Acid Deposition |
| $SO_2$ | | ↓ | ↑[f] | | ↓ | ↓ |
| $NO_x$ | ↓↑[b] | ↑↓[d] | ↓[g] | ↓↑[i] | ↓↑ | ↓↑ |
| VOC | ↓ | ↑↓ | ↓↑[h] | ↓[j] | ↓↑ | ↓↑ |
| $NH_3$ | | ↓[e] | ↓ | | ↓ | ↑[l] |
| Black Carbon | ↑[c] | | | ↓[k] | ↓ | |
| Primary Organic Compounds | ↑[c] | | | ↓ | ↓ | |
| Other primary PM (crustal, metals, etc.) | ↑[c] | | | | ↓ | ↑[l] |

[a] Arrow direction denotes increase (↑) or decrease (↓); arrow color denotes undesirable (red) or desirable (blue) response; arrow size signifies magnitude of change. Small arrows signify possible small increase or decrease. Blank entry indicates negligible response.
[b] In and downwind of some urban areas that are VOC limited.
[c] Effect on daytime $O_3$ due to increase in solar flux and decrease in radical scavenging; effect on nighttime $O_3$ unknown.
[d] Due to effect of $NO_x$ on oxidant levels (OH, $H_2O_2$ and $O_3$); e.g., see SAMI modeling results.
[e] Due to effect of $NH_3$ on cloud/fog pH.
[f] Decrease in sulfate may make more $NH_3$ available for reaction with $HNO_3$ to form $NH_4NO_3$, more important when $NH_4NO_3$ is $NH_3$ limited.
[g] Decrease except special cases (e.g., SJV); decrease in $NO_x$ may lead to increase in $O_3$ with associated increase in $HNO_3$ formation.
[h] Increase due to less organic nitrate formation and more OH available for reaction with $NO_2$; decrease due to decrease in oxidant levels.
[i] Related to effect of $NO_x$ on oxidant levels (OH, $O_3$ and $NO_3$).
[j] Decrease of secondary component; magnitude depends on OC fraction that is secondary anthropogenic.
[k] Reduction of OC adsorbed or emitted with black carbon.
[l] Refers to net acidity atmospheric deposition, not to acidification potential to ecosystem.

Table S.5 (9.2). Responses of regional haze and climate to reductions in the emissions of secondary PM precursors and primary PM.

| Pollutant Emitted | Change In Associated Issue | |
|---|---|---|
| | Regional Haze [a] | Climate Impact [c] |
| $SO_2$ | ↓ | ↑ |
| $NO_x$ | ↑↓ [b] | ↑↓ |
| VOC | ↑↓ [b] | ↑↓ |
| $NH_3$ | ↓ | ↑ [d] |
| Black Carbon | ↓ | ↓ |
| Primary Organic Compounds | ↓ | ↑ |
| Other primary PM (crustal, metals, etc.) | ↓ | ↑ |

[a] Direction of arrow indicates increase (↑) or decrease (↓) and color signifies undesirable (red) or desirable (blue) impact; size of arrow signifies magnitude of change. Small arrows signify possible or small change.

[b] No change if little $NH_3$ available in atmosphere.

[c] Direct effects only; indirect effects through clouds and precipitation are highly uncertain. Note that the extent and possibly the scale of climate impacts for listed pollutants is quite different from $CO_2$ and $CH_4$. Direction of arrow indicates warming ↑ or cooling ↓.

[d] More accurately, decreased aerosol-induced cooling.

# Conclusions - 5

- There is a need for collaboration across disciplines
  - Atmospheric Sciences
    - ✓ Measurement & Modeling
    - ✓ Climate Change
  - Exposure
  - Heath Effects

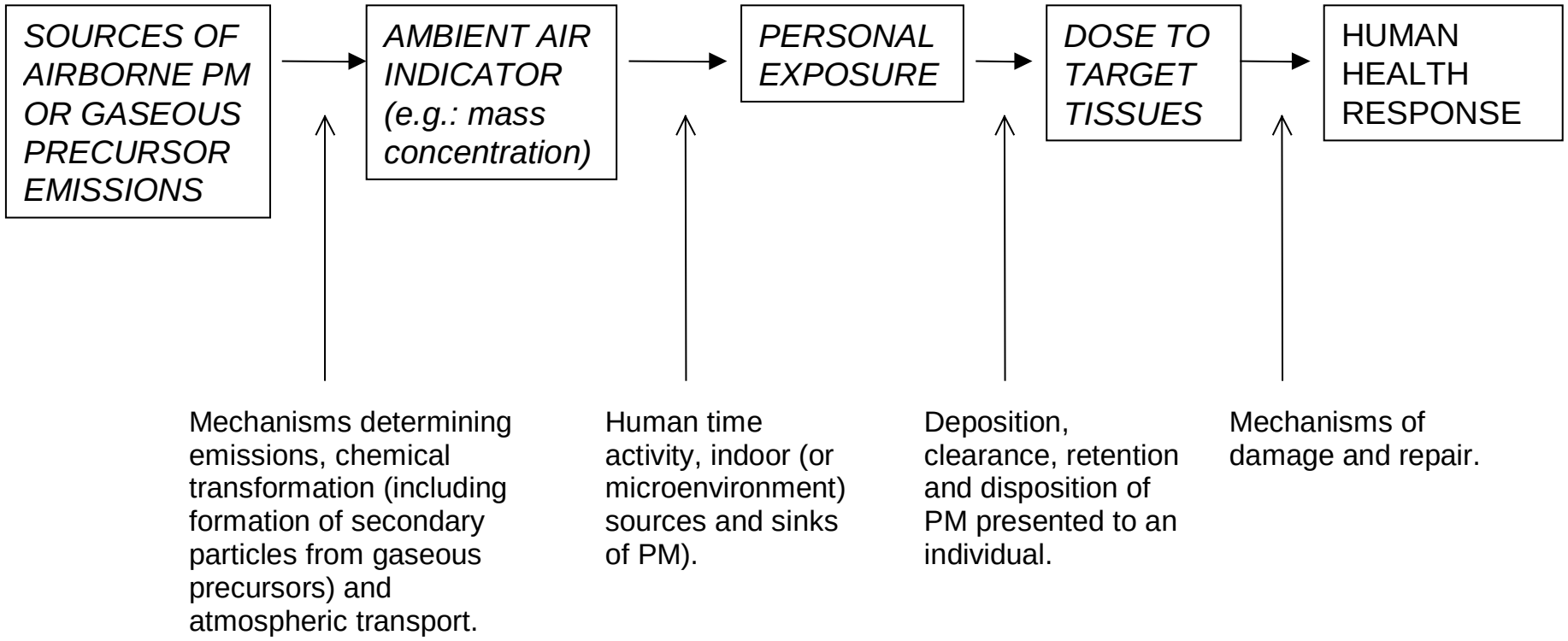



Figure 1.4. Pollutant source to receptor response paradigm (NRC, 1998).

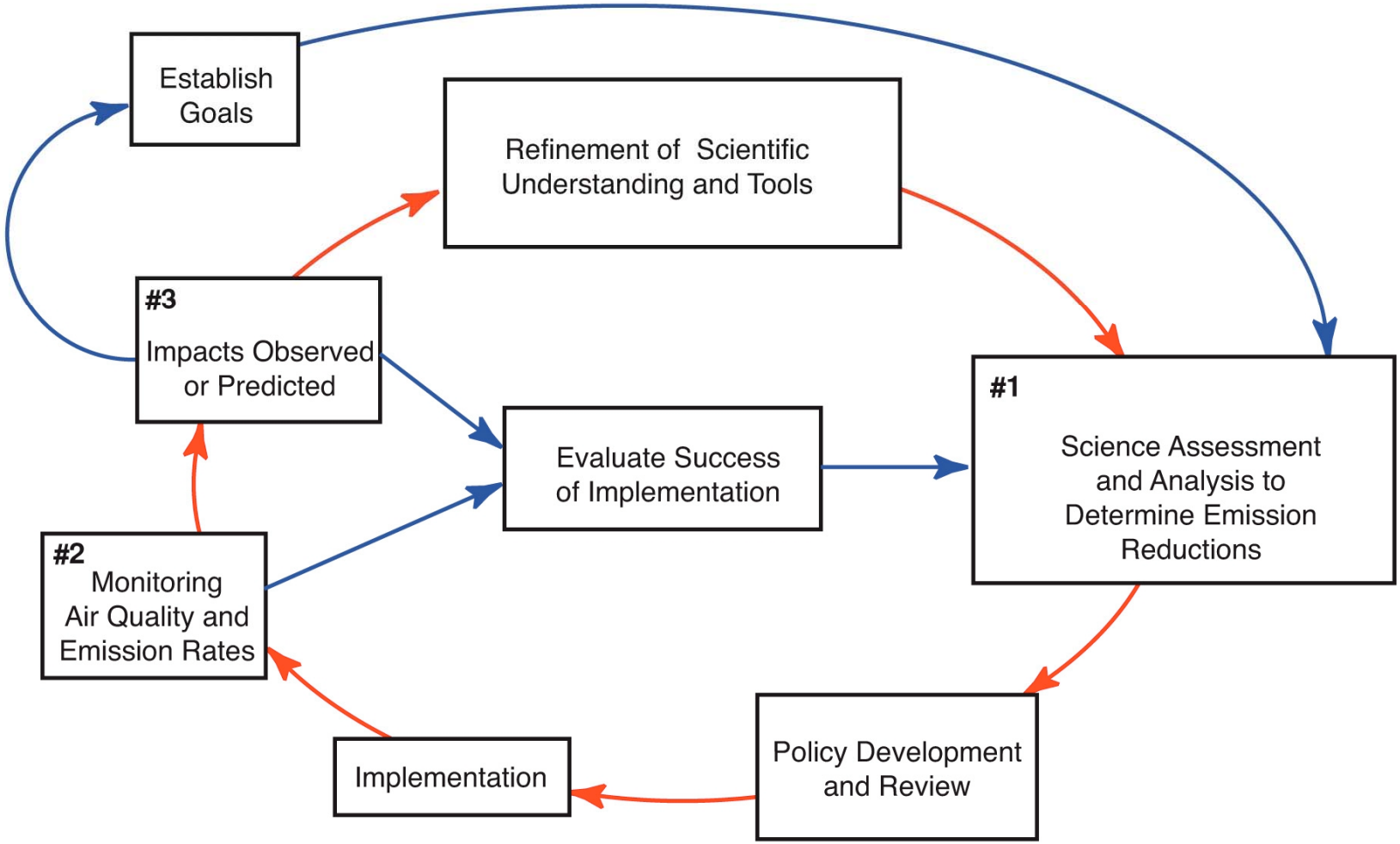
Table S.8 (adapted from Textbox 2.5). Availability of ambient measurement methods for hypothesized causal elements of PM-induced health effects.

| Hypothesized Element(s) - Rationale | Ambient Air Measurement Capability |
|---|---|
| 1. **Particle Mass Concentration -** Non-chemically specific mass cardio-pulmonary loading response associated with a complex chemical mixture of wide range of particle size. | Routine |
| 2. **Particle Size/Surface Area -** Response to fine particles with major surface area for adsorption of chemical species and subsequent desorption in lower lungs. | Research |
| 3. **Ultrafine PM -** Animal experiments suggest particles less than 0.1 μm diameter may have a strong physiological effect on the respiratory system. | Research |
| 4. **Metals or Metal Compounds -** Certain metals like V, Cu, Fe, Zn, and Ni have cytotoxic or inflammatory properties. These may catalyze an adverse respiratory response. | Research |
| 5. **Acids -** Acidic particles have been shown to have toxic properties in some animal studies based on hydrogen ion delivered to respiratory surfaces. | Research |
| 6. **Organic Compounds - T**here are a large number of organic compounds found in PM, some of which are known to be carcinogenic. | Research |
| 7. **Biogenic Particles -** There are a variety of particles that are found from biogenic sources, including spores, fungi, bacteria and viruses. | Research |
| 8. **Sulfate and Nitrate Salts -** These compounds are believed to be mainly ammonium salts in PM. | Routine |
| 9. **Peroxides -** The presence of peroxides in particles and their toxic properties provide a hypothetical pathway to health effects. | Unavailable |
| 10. **Soot -** Soot particles (or black carbon) potentially can stimulate a toxic response in themselves or carry adsorbed material that can initiate a response. | Research |
| 11. **Co-pollutant Interactions - S**ome epidemiological and/or laboratory exposure studies have suggested that a synergistic response may take place when PM and gases such as $SO_2$, $NO_2$, $O_3$ or CO are present. | Routine |

# Conclusions - 6

- More systematic approaches are needed for integrating diverse types of knowledge on origins, properties, and effects of atmospheric PM to assist with the development of management strategies and the measurement of the progress towards protecting health.

# Iterative communication for managing air quality to reduce health and environmental impacts



# Recommendations

- 1. Better understanding of carbonaceous aerosols
- 2. Long term (multi-decade) monitoring of PM mass, composition, and gas/particle distributions, and gas phase precursors and co-pollutants in parallel with health impacts studies.
- 3. Evaluating and further developing the performance of chemical transport models.
- 4. Improve emissions inventories and emission models
- 5. Commitment to the analysis, synthesis and archiving of ambient data and fostering interactions between atmospheric, climate, and health science communities
- 6. More systematic approaches for integrating diverse types of knowledge on sources, properties, and effects of PM to assist with the development of management practices and tracking their progress towards protecting health.

Table S.9. Policy benefits of the specific research directions: major benefits, modest benefits.

| Recommendation | Policy Question | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | ● | ● | ● | ● | ● | | | ● |
| 2 | ● | ● | | | ● | ● | | ● |
| 3 | | | ● | ● | ● | ● | | ● |
| 4 | | | ● | ● | ● | | | ● |
| 5 | ● | ● | ● | ● | ● | ● | ● | ● |
| 6 | ● | ● | ● | ● | | ● | ● | ● |