SOURCE ATTRIBUTION OF AIR POLLUTION ABATEMENT HEALTH BENEFITS

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OPTIMAL CONTROL STRATEGY DESIGN

What are the impacts of *specific* emission sources on:

- Climate change (GHGs)?
- Air quality and human health (criteria pollutants)?
  - Sensitivity questions by nature

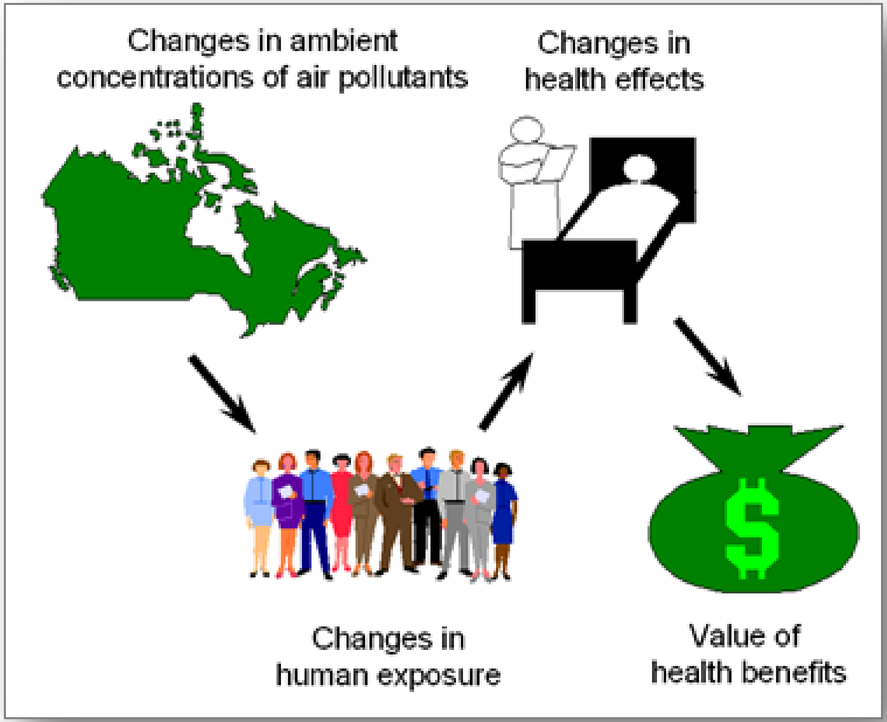
- Backward (adjoint) sensitivity modeling can provide an answer if health benefit assessment tools are integrated with air quality modeling

PRESENTATION OVERVIEW

- Background
  - Estimating health benefits
  - Adjoint sensitivity analysis
- Results
  - Health benefit sensitivities
- Potential policy applications

BACKGROUND

HEALTH BENEFITS IN CANADA



(Modified from Health Canada, 2008)

Air Quality Benefits Assessment Tool (AQBAT)

- Criteria Air Contaminants:

  $PM_{2.5}$, O_3, NO_2, SO_2, CO

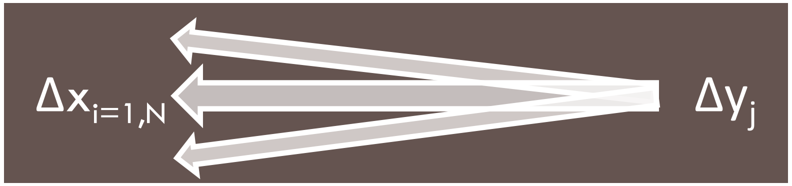
- Monetary valuation of health endpoints to allow for benefit-cost analysis

  → dollar benefits

ADJOINT SENSITIVITY ANALYSIS

Estimating the impacts of individual sources on human health

Backward (Adjoint) Analysis



Sensitivity: $\frac{\delta y_j}{\delta x_{1,N}}$

- Sensitivity of a small number of outputs with respect to a large number of inputs
- Receptor-based but differentiates between source impacts

MAKING USE OF ADJOINT SENSITIVITIES

Sensitivity of what?

- Mortality in Canada (integrated across receptors)

Sensitivity to what?

- Anthropogenic NO_X emissions at each location

AQBAT Sensitivity: $\frac{\Delta\$}{\Delta C}$

CMAQ-Adjoint Sensitivity: $\frac{\Delta C}{\Delta E}$

→ **Combined Sensitivity:** $\frac{\boldsymbol{\Delta\$}}{\boldsymbol{\Delta E}}$

ADJOINT TERMS

Adjoint cost function:

$$J = Mortality = M$$

$$J = \sum_{i,j=1}^{N} \left(M_{0_{i,j}} \cdot POP_{i,j} \cdot \left(\beta_{O_3} \Delta C_{O_3\,i,j} + \beta_{NO_2} \Delta C_{NO_2\,i,j} \right) \right)$$

Adjoint forcing term:

$$\frac{\Delta M}{\Delta C} \approx \frac{\delta J}{\delta C} = M_0 \cdot POP \cdot \beta$$

VSL = \$5.5M (2007 CAD)

$\beta_{O_3} = 8.39 \cdot 10^{-4}\, ppb^{-1}$ 1-hr maximum

$\beta_{NO_2} = 7.48 \cdot 10^{-4}\, ppb^{-1}$ 24-hr average

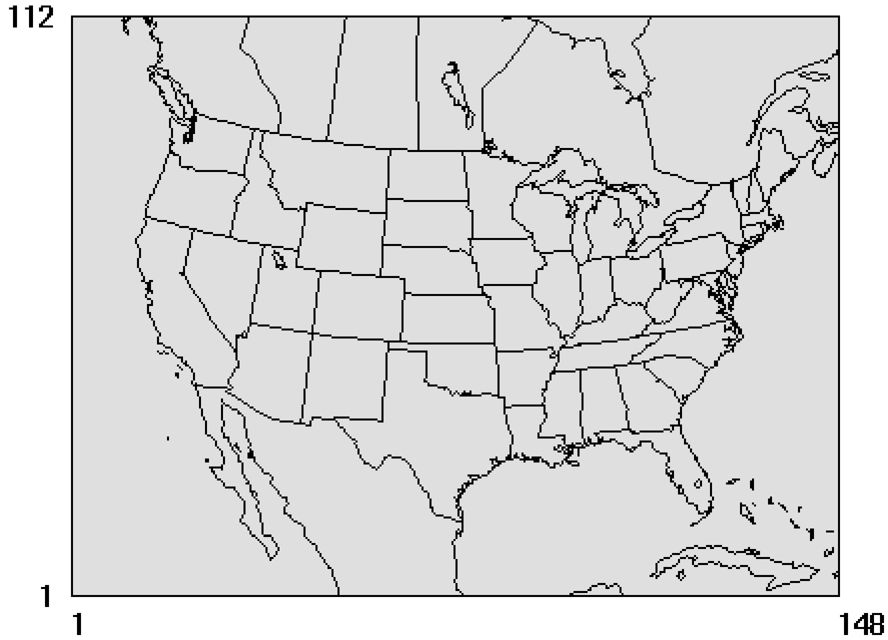
MODELING CASE

Continental domain

- 36 km resolution
- 13 vertical layers

- Gas-phase CMAQ-Adjoint

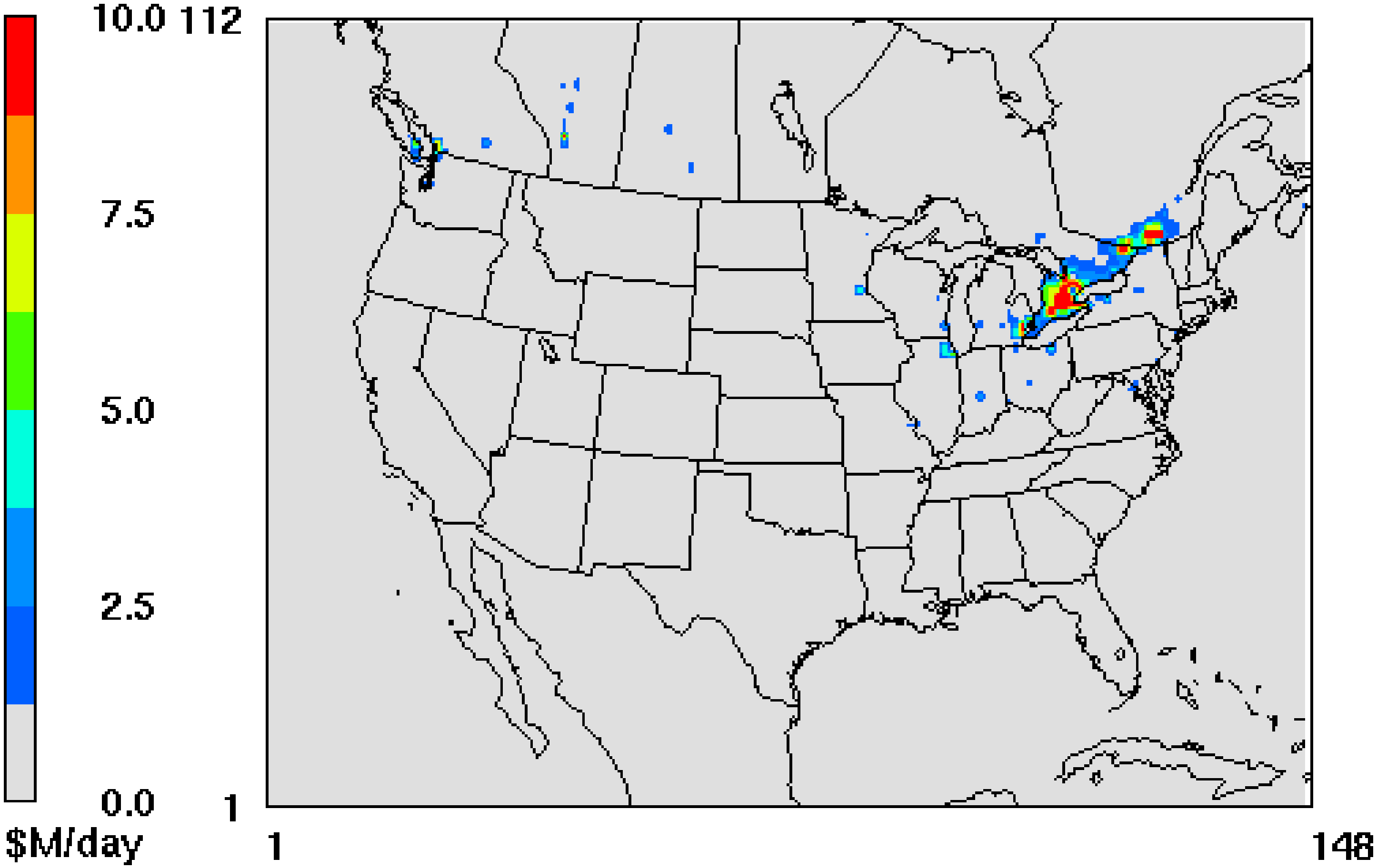
- July-September 2007 modeling period (90 days)



SENSITIVITY RESULTS

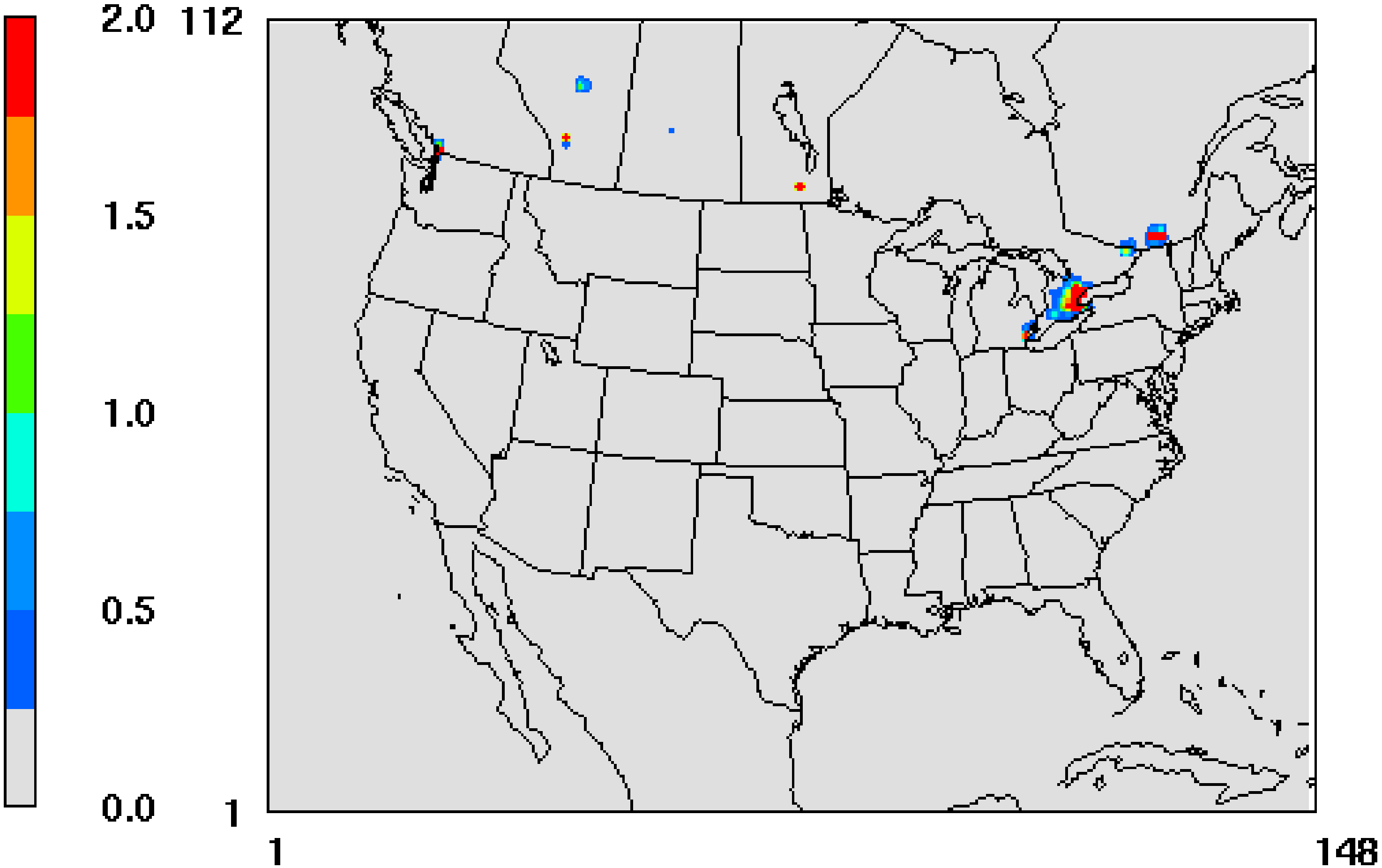
DAILY HEALTH BENEFITS: O_3

MAX = $33.8 M/DAY, MONTREAL



DAILY HEALTH BENEFITS: NO_2

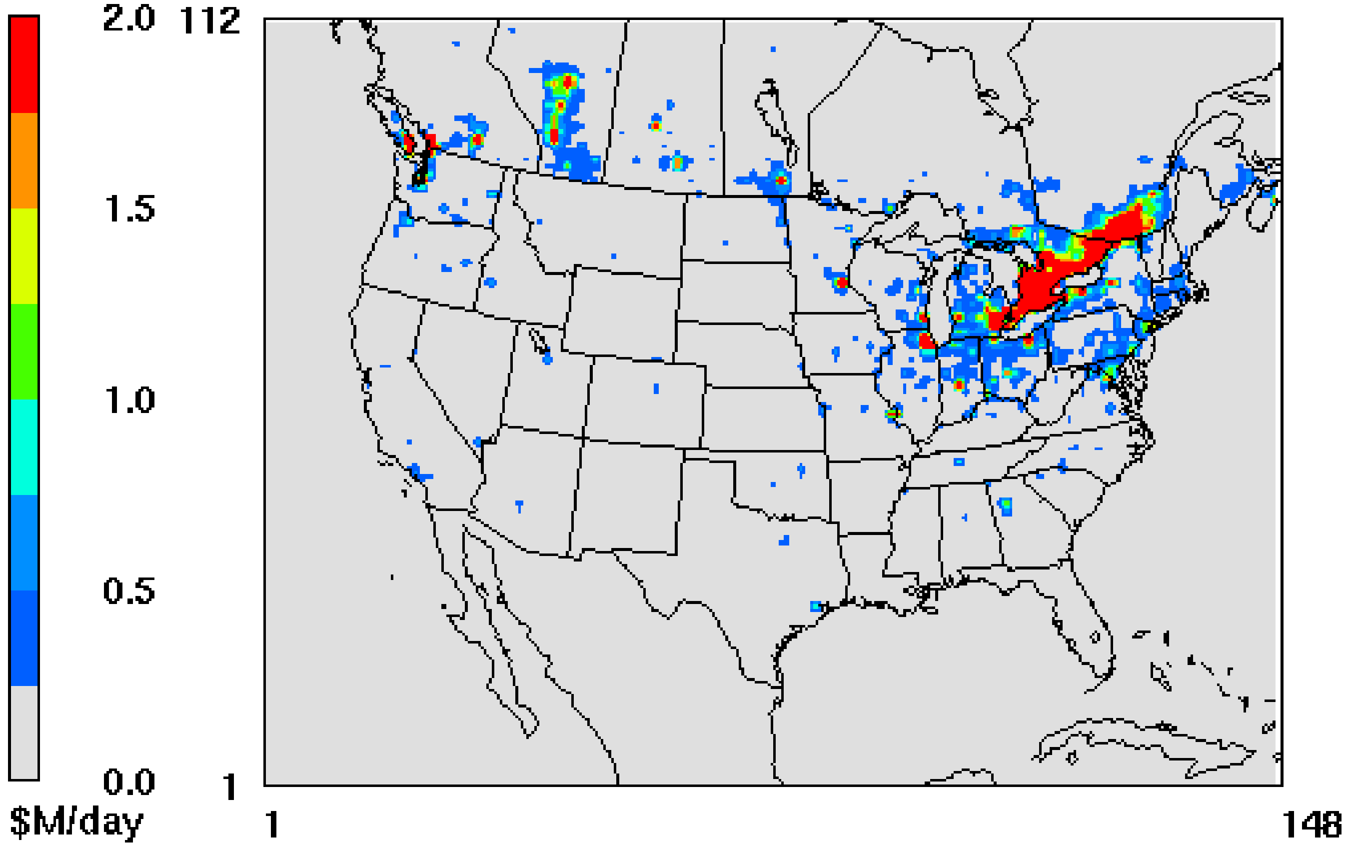
MAX = $32.5 M/DAY, TORONTO



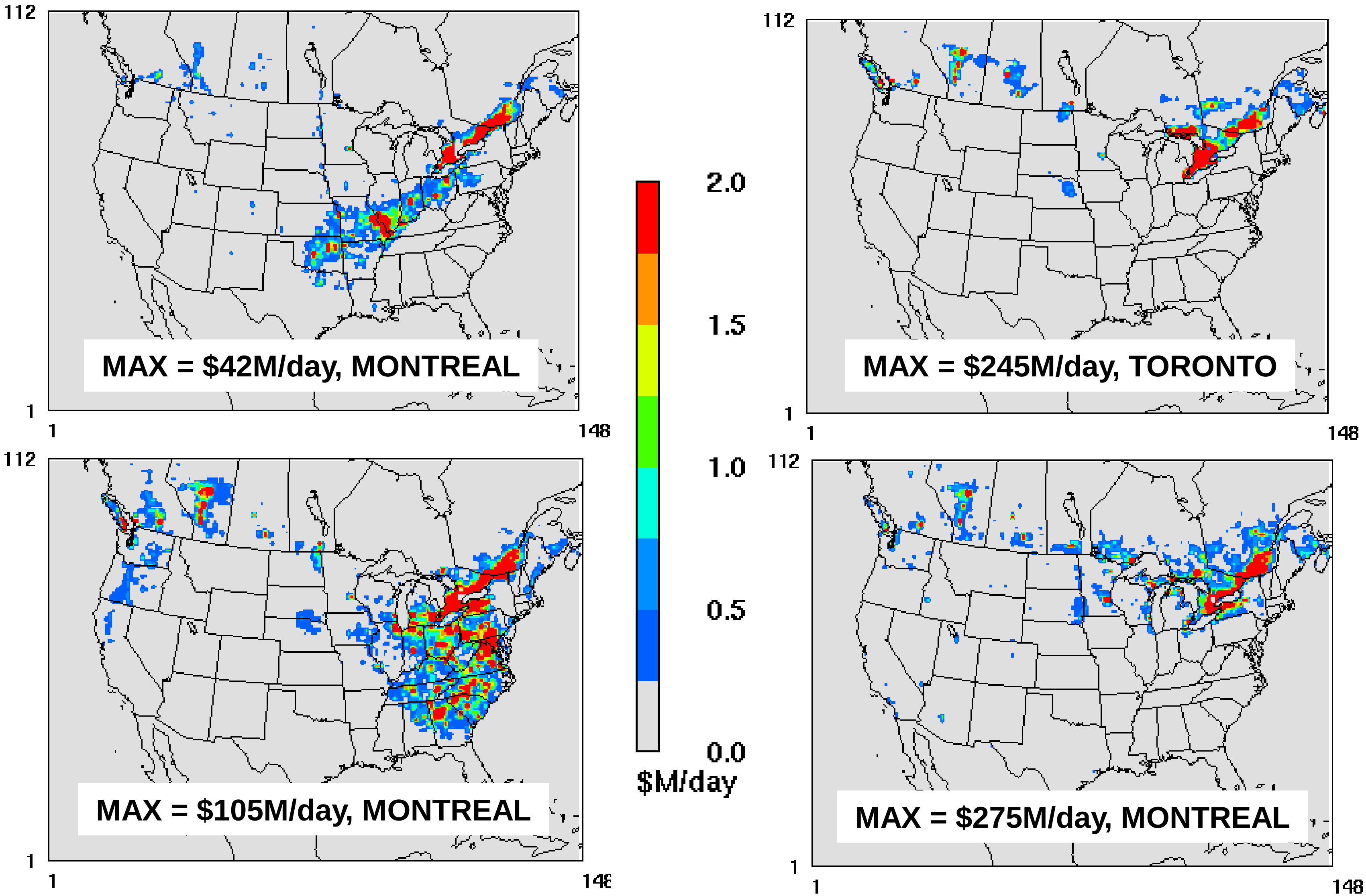
TOTAL DAILY HEALTH BENEFITS

MAX: $41.7M/DAY, MONTREAL

ATLANTA & HOUSTON = $1.1M/DAY, LOS ANGELES = $0.6M/DAY



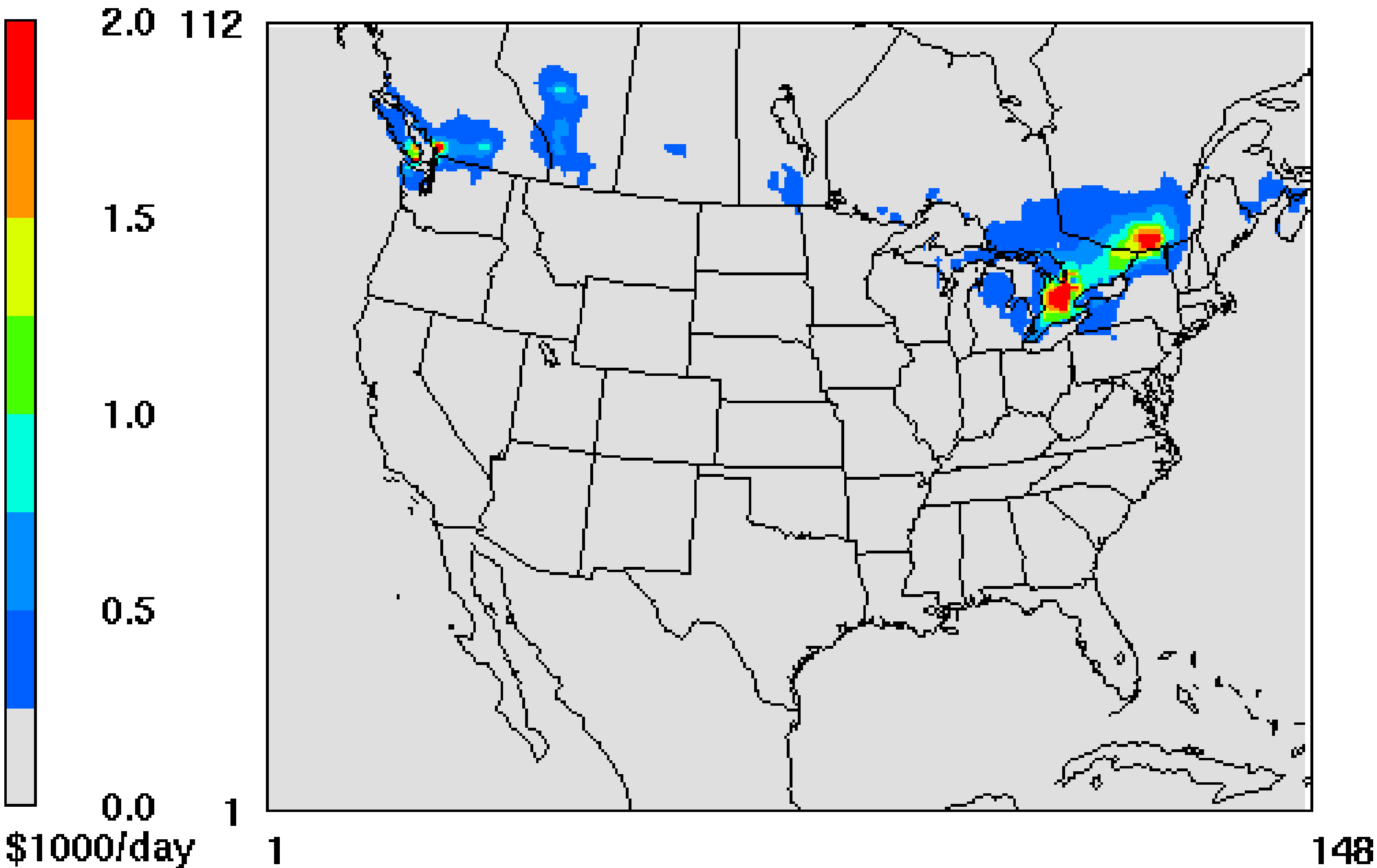
VARIABILITY IN HEALTH BENEFITS



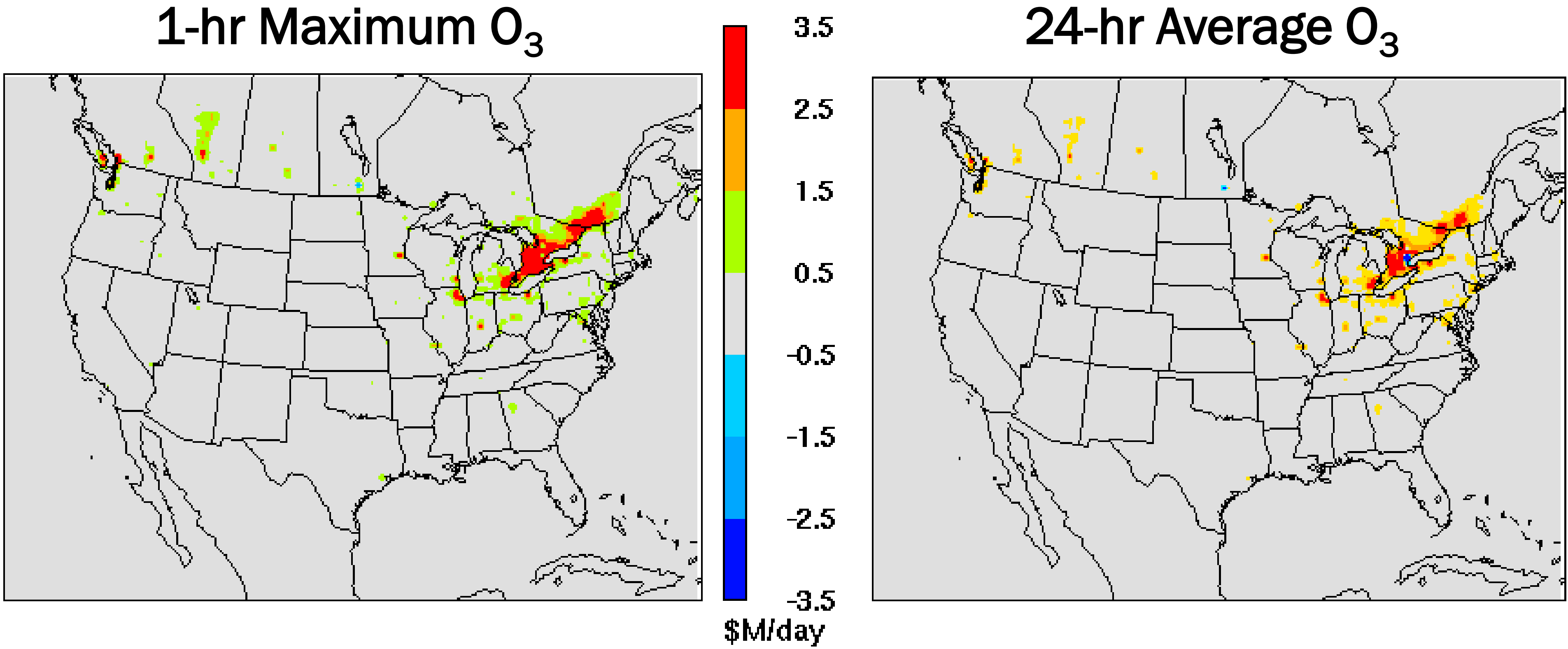
DAILY UNIT REDUCTION HEALTH BENEFITS

MAX: $3,400/DAY, MONTREAL

TORONTO = $1,100/DAY, OTTAWA = $1,500/DAY



EFFECT OF AVERAGING PERIOD



POLICY APPLICATIONS

1. PUBLIC TRANSPORTATION SYSTEMS

What are the health benefits of the Toronto subway system?

- Annual vehicle reduction (@ 11,000 miles/vehicle-yr):
  → 302,000
- NO_X emissions reduction
  → 2,000 tonnes/yr (2007)
- $1,100 benefit/day per 1 tonne NO_X reduction in Toronto

$800M benefit/yr compared to without the subway system

2. PERSONAL VEHICLES

What is the health cost associated with personal vehicles in major Canadian cities?

- 1 tonne NO_X/yr ≈ 110 vehicles (2007)
- **Toronto: $3,800/yr per vehicle**
- **Ottawa: $5,000/yr per vehicle**
- **Montreal: $11,000/yr per vehicle**

3. CAP-AND-TRADE

What is the Benefit-to-Permit Cost ratio for a Canadian power plant operating under NO_X cap-and-trade?

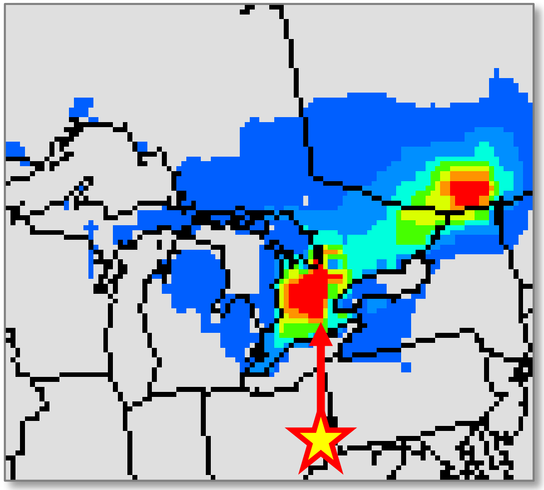
NO_X permit price in the U.S. (2009) ≈ \$2,000/tonne NO_X/yr

Nanticoke Generating Station, Ontario

→ 2,760 MW coal-fired power plant

→ 38,000 tonnes NO_X/yr emitted

→ \$1,100 benefit/day per tonne NO_X



Health benefits are 200 times the cost of emissions permits!

CONCLUDING REMARKS

- Health benefits are vastly undervalued in current regulatory frameworks

- Intercontinental transport does not tell the whole story
- There is benefit to be seen from Canadian pollution control

- The source-specificity of adjoint modeling makes it very relevant to policy decision-making

FUTURE RESEARCH

- Sectoral analysis of health benefits
- Taking advantage of temporal variability in health benefit sensitivities

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