Modeling the Air Quality Impacts of Specific Sources

Talat Odman

Principal Research Engineer

School of Civil & Environmental Engineering

Georgia Institute of Technology

Georgia Air Policy Symposium

December 19, 2005

Background

- Two methods for analyzing the impacts of specific sources:
  - Indirect Emission Reduction (a.k.a. "brute-force" method)
    - Two model simulations are conducted with different levels of emissions. Difference between the results yields the impact of the source.
    - Reliable for large sources such as power plants
  - Direct Decoupled Method (DDM)
    - Direct calculation of impact; more efficient
    - Impact of small sources
    - First-order accurate DDM for linear response; higher-order for non-linear response
    - Incorporated in CMAQ for ozone and $PM_{2.5}$

Overview

- Summary of 2 recent projects (both based on FAQS):
  - Unal, Hu, Chang, Odman, Russell, "Impacts of aircraft and airport-related emissions on air quality and the importance of comprehensively prescribing the timing, location, mode and type of emissions with application to the **Hartsfield-Jackson** Atlanta International Airport," *Atmospheric Environment*, vol. **39**, no. 32, pp. 5787–5798, October 2005.
  - Unal, Hakami, Odman, "Adaptive grid modeling for predicting the air quality impacts of biomass burning" (application to prescribed burning at **Fort Benning**)
- Synopsis of ongoing/future work

Hypothesis 1

- There are uncertainties in emission inventories for various sources.
  - Aircrafts /airports
  - Biomass burning
  - …
- These uncertainties can be reduced by:
  - Incorporating new information
  - Using more accurate data
  - Finding and correcting errors

Hypothesis 2

- There are uncertainties in model results due to inadequate resolution. These can be reduced by:
  - Increasing the models' grid resolution
    - Adaptive Grid Model
  - Using better resolved data (e.g., terrain, land-use)
  - Improving physical parameterizations (e.g., urban canopy)

Impacts of Aircraft/Airport Emissions

Objectives

- Determine the impact of aircraft emissions on regional air quality for $PM_{2.5}$ and O_3
  - Hartsfield-Jackson International Airport
  - Annual LTO > 420,000
- Improve emissions estimation and processing for aircrafts
  - $PM_{2.5}$ estimation
  - Temporal and spatial distribution

$PM_{2.5}$ Emissions from Aircraft

- A "First Order Approximation" was introduced by FAA (Wayson and Fleming, 2001)

$$E(PM_{2.5}) = 0.6 \times (SN)^{1.8} \times (FF)$$

  - E: Mass of $PM_{2.5}$ emissions
  - SN: Smoke Number
  - FF: Fuel Flow rate

- NASA is conducting a more detailed study

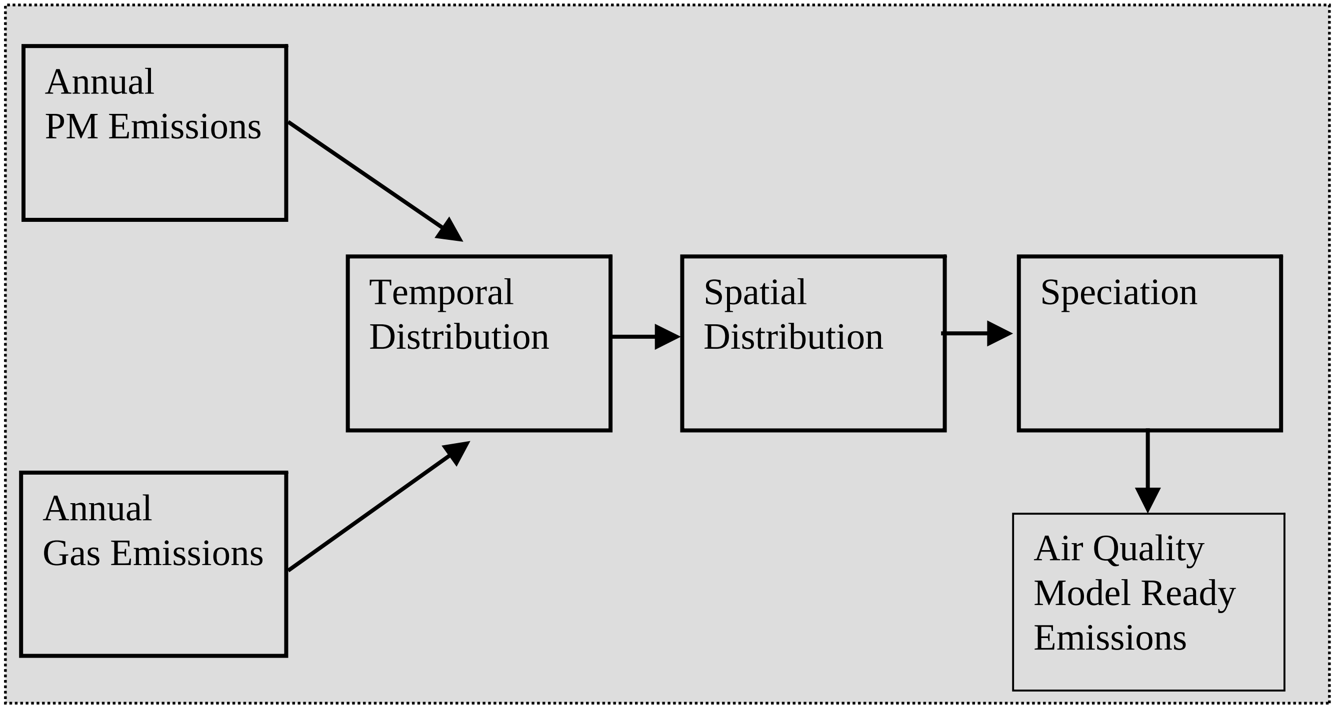
$PM_{2.5}$ Emission Estimates at Hartsfield-Jackson

- Characteristic Value:
  - Based on International Civil Aviation Organization (ICAO) database
  - 70 tons/year
- Mode Specific:
  - We used statistical relations b/w take-off and other modes

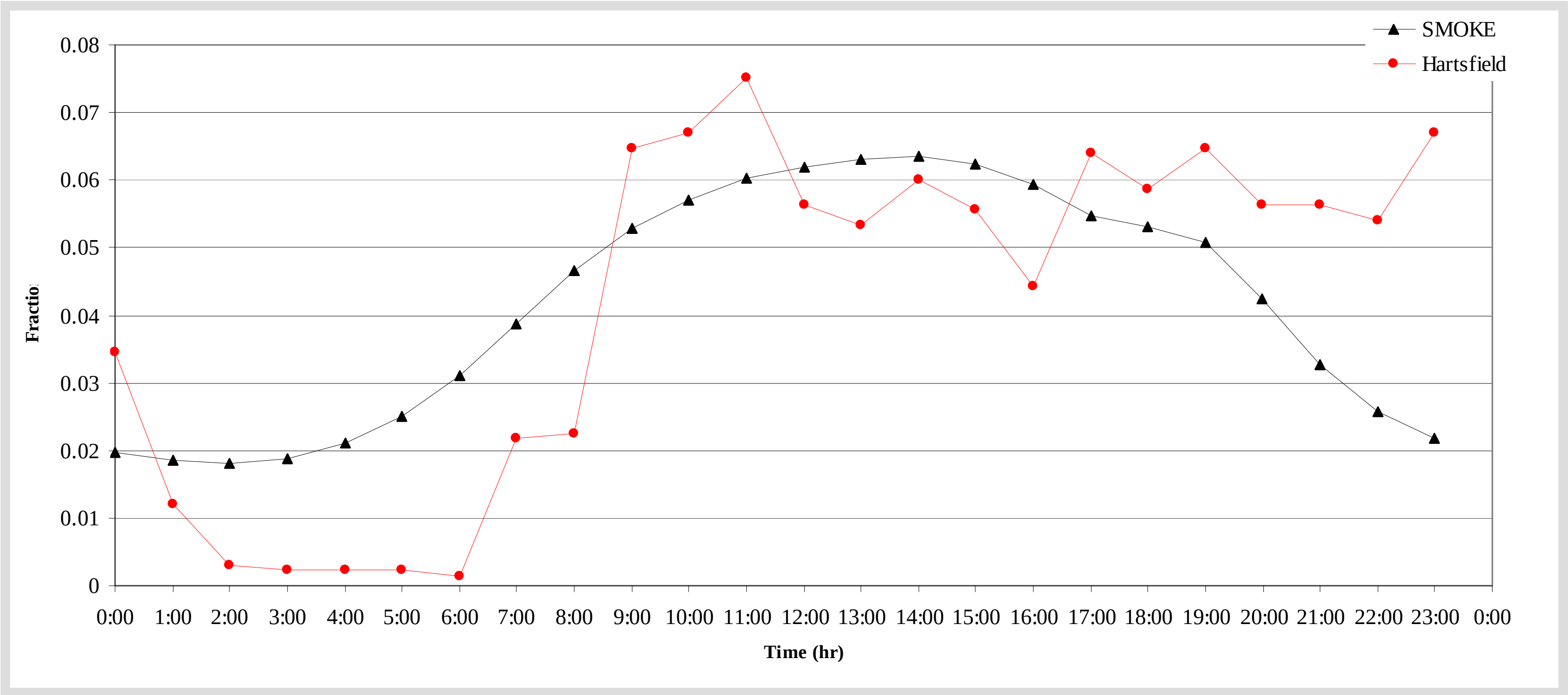
$$SN_{climb-out} = 0.86 \times SN_{take-off}$$

  - 27 tons/year

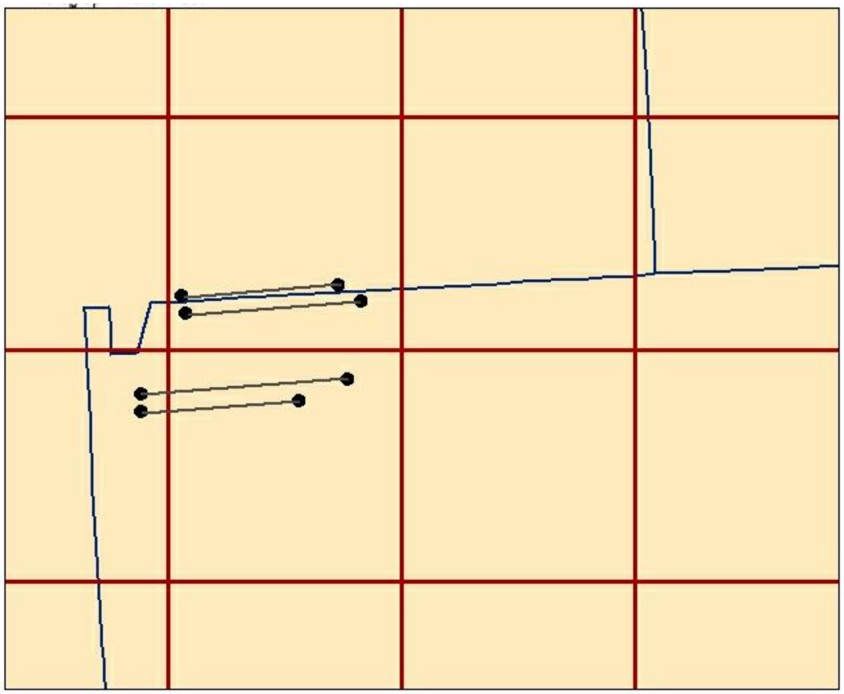
Emissions Processing

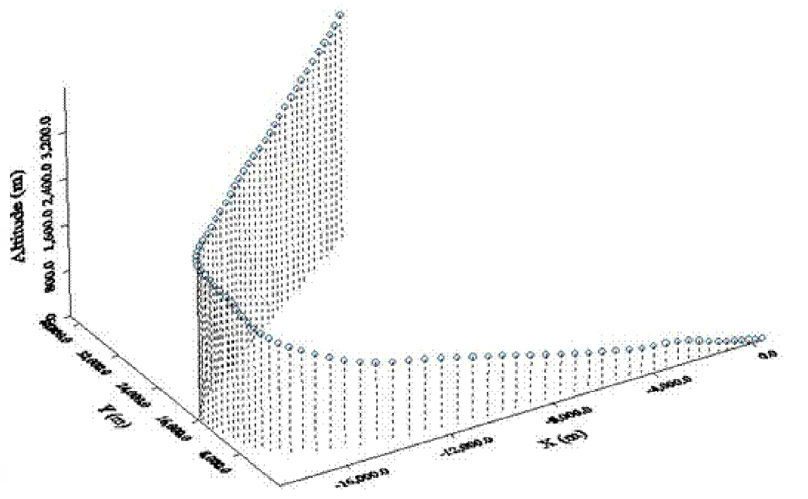


Temporal Considerations



Spatial Considerations

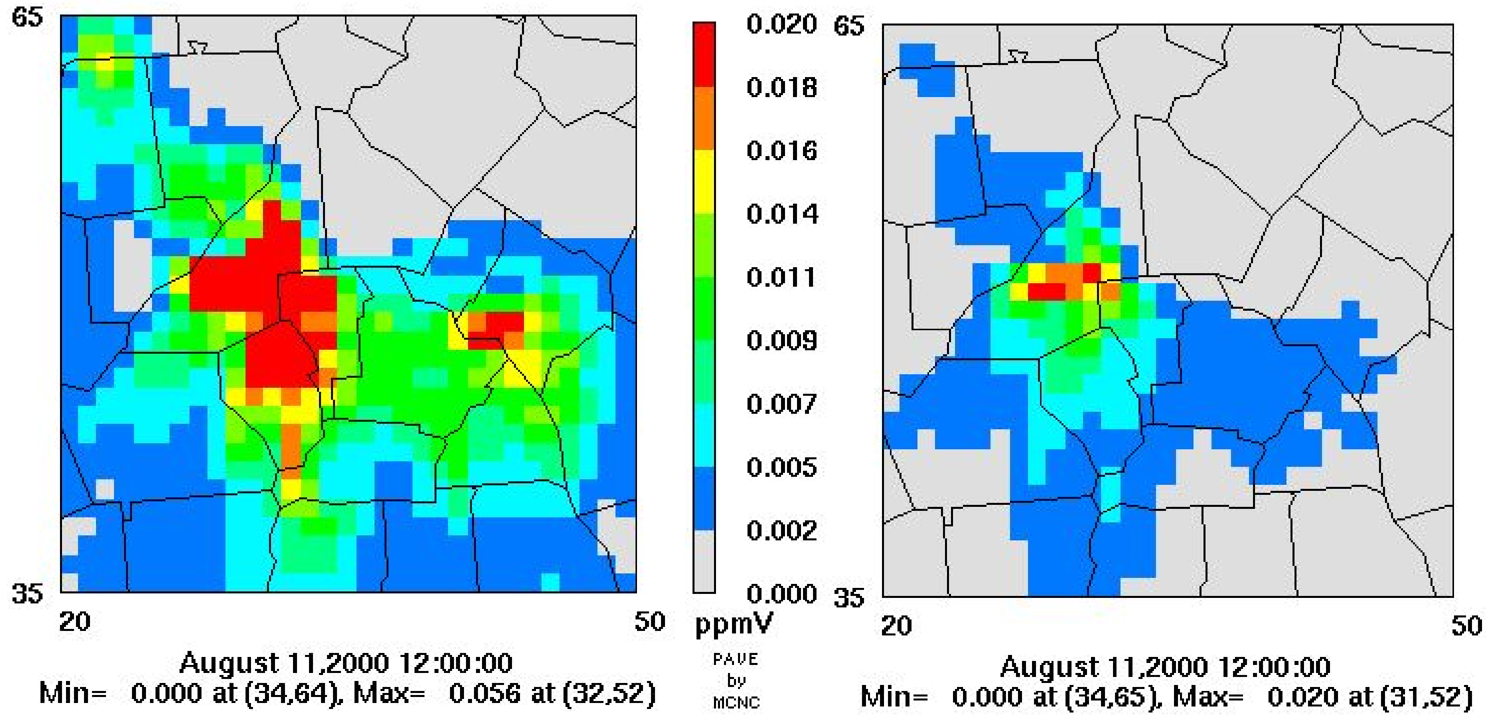




Chemical Considerations

Composition of $PM_{2.5}$ emissions (%)			
EC	OC	SO_4	NO_3
65.87	29.21	4.60	0.32

Aircraft Impact - Ozone

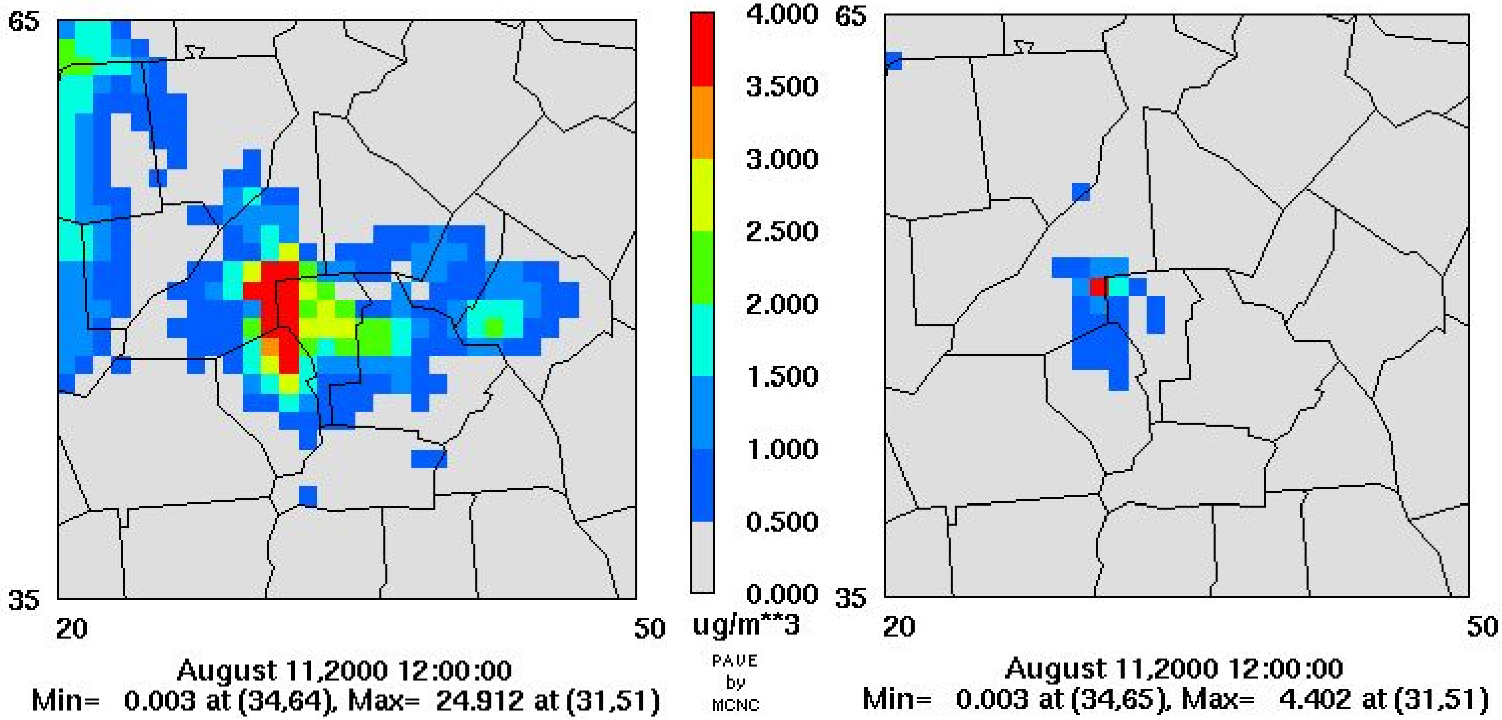


Characteristic Value
& 1st layer

Mode Specific
& 3-D

Maximum sensitivity of regional concentrations to aircraft emissions

Aircraft Impact - $PM_{2.5}$

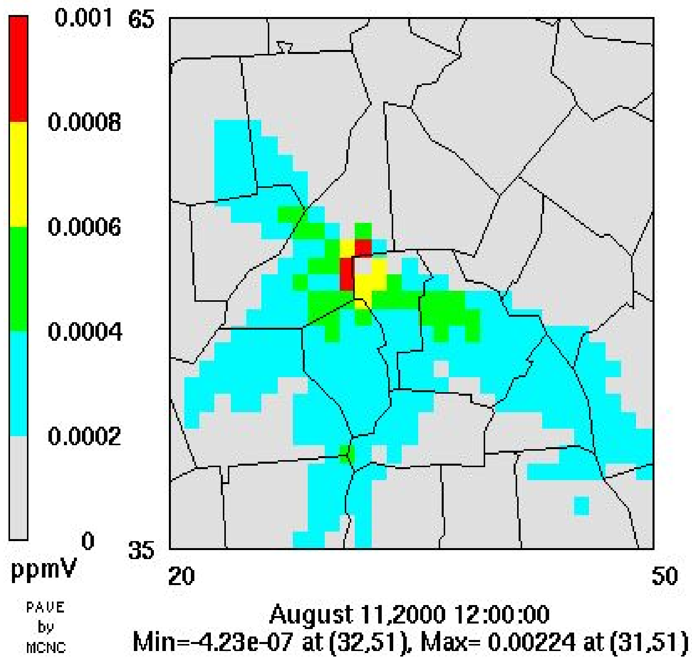


Characteristic Value & 1^{st} layer

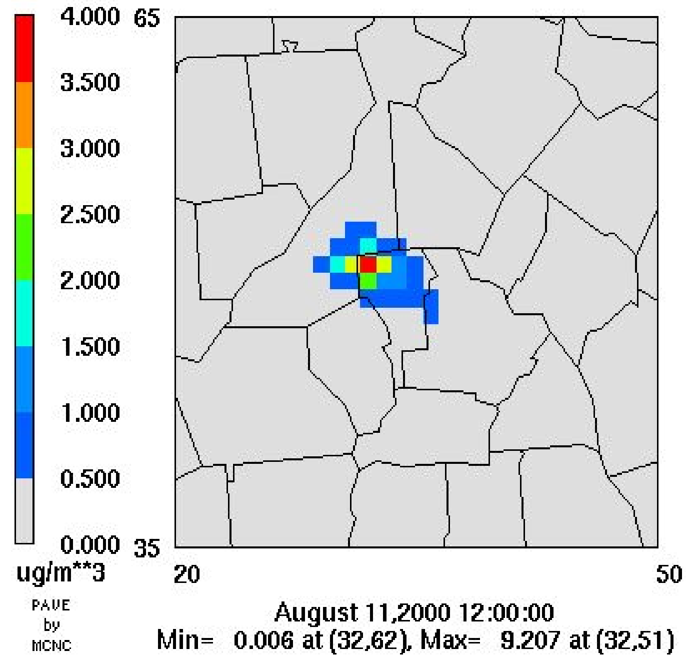
Mode Specific & 3-D

Maximum sensitivity of regional concentrations to aircraft emissions

Ground Support Equipment Impact



Ozone



$PM_{2.5}$

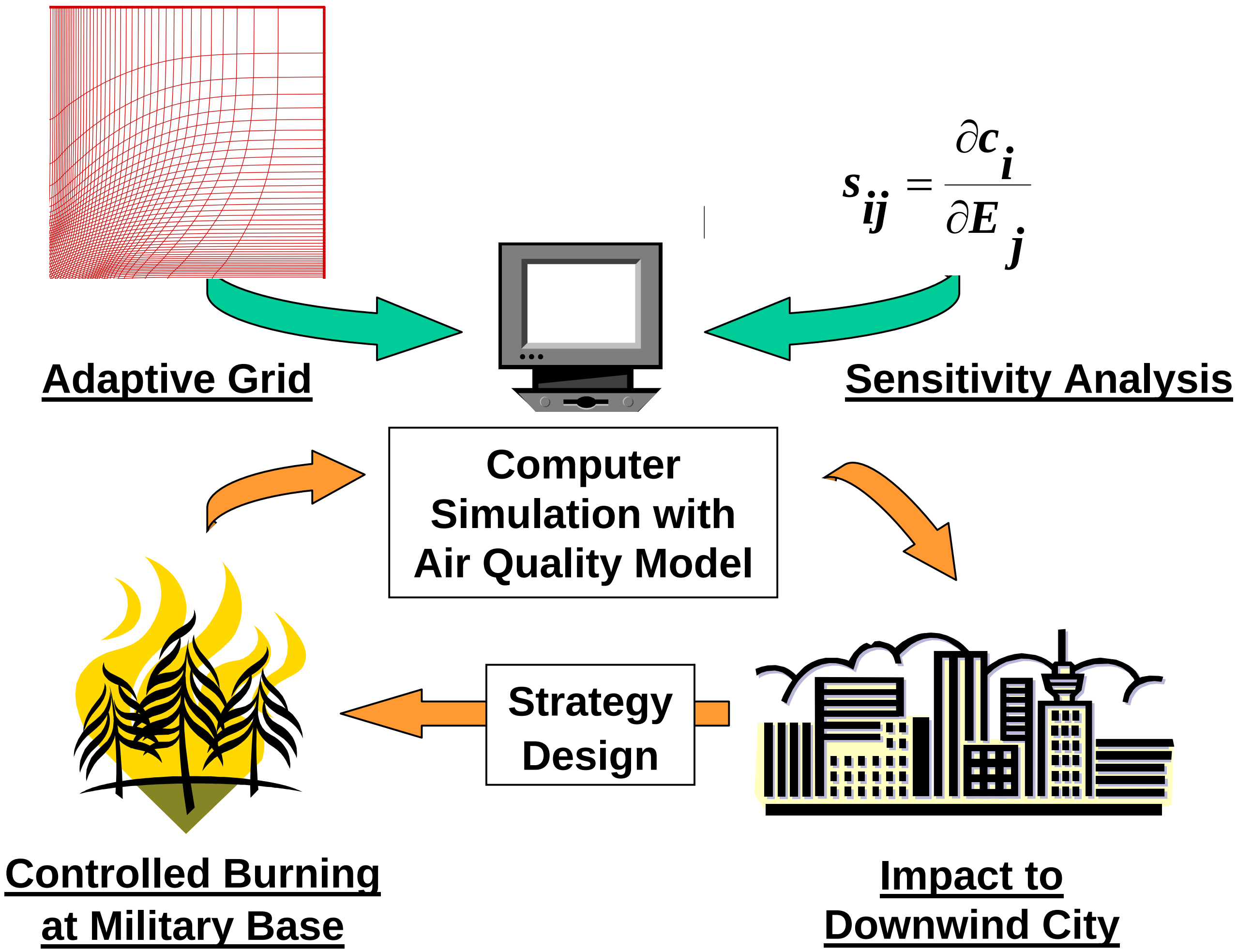
Maximum sensitivity of regional concentrations to Ground Support Equipment emissions

Findings

- Large uncertainties in aircraft $PM_{2.5}$ emission estimates
- Maximum aircraft impacts for the August 11-20, 2000 period are estimated as:
  - Ozone:
    - 56 ppb (Characteristic Value)
    - 20 ppb (Mode Specific and Spatial Distribution)
  - $PM_{2.5}$:
    - 25 $\mu g/m^3$ (Characteristic Value)
    - 4 $\mu g/m^3$ (Mode Specific and Spatial Distribution)
- Ground support equipment impacts are smaller and more local

Impacts of Biomass Burning

Objectives


$s_{ij} = \frac{\partial c_i}{\partial E_j}$
Adaptive Grid
Sensitivity Analysis
Computer Simulation with Air Quality Model
Strategy Design
Controlled Burning at Military Base
Impact to Downwind City

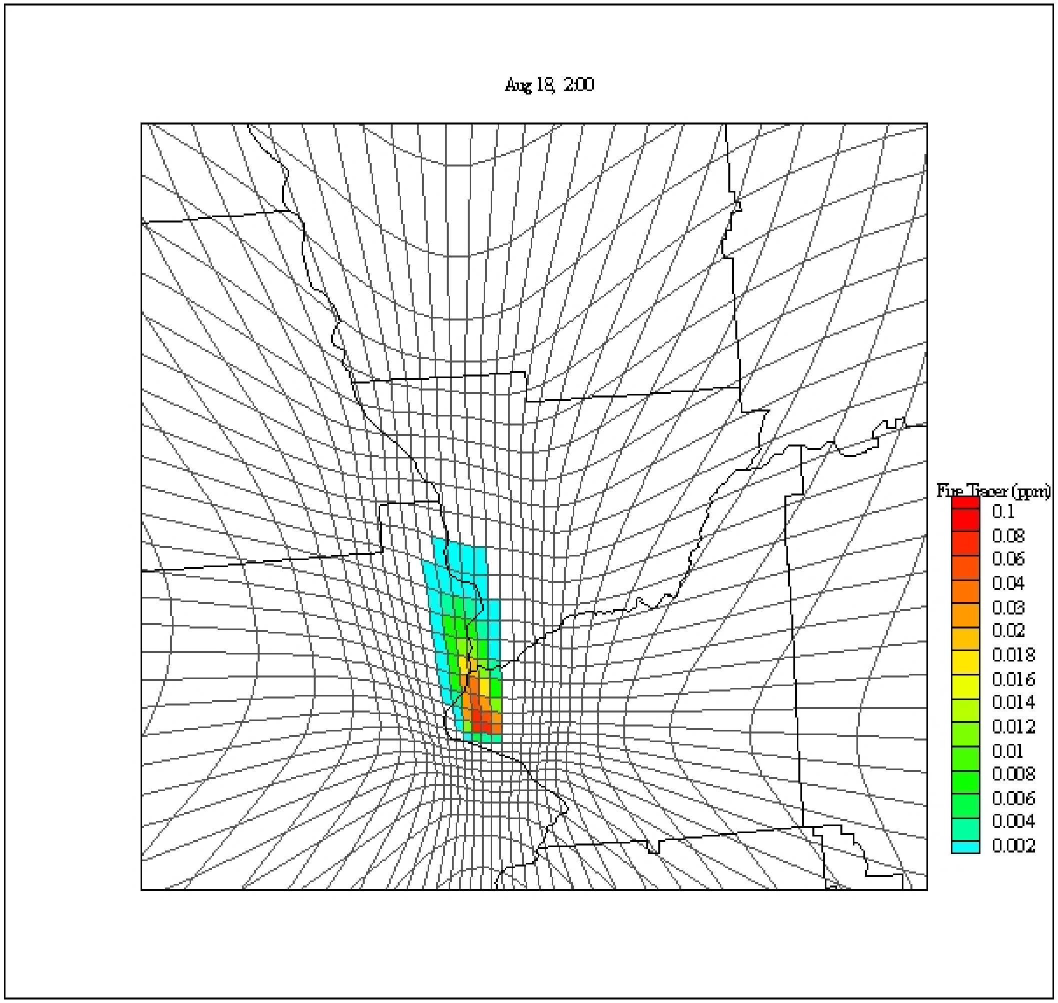
Biomass Burning Emissions

- First Order Fire Effects Model (FOFEM) Version 5, was utilized.
  - Fuel type was assumed as natural fuel with long leaf pine
- For speciated VOCs and NO_x, emission factors provided by Battye and Battye (2002) were used.

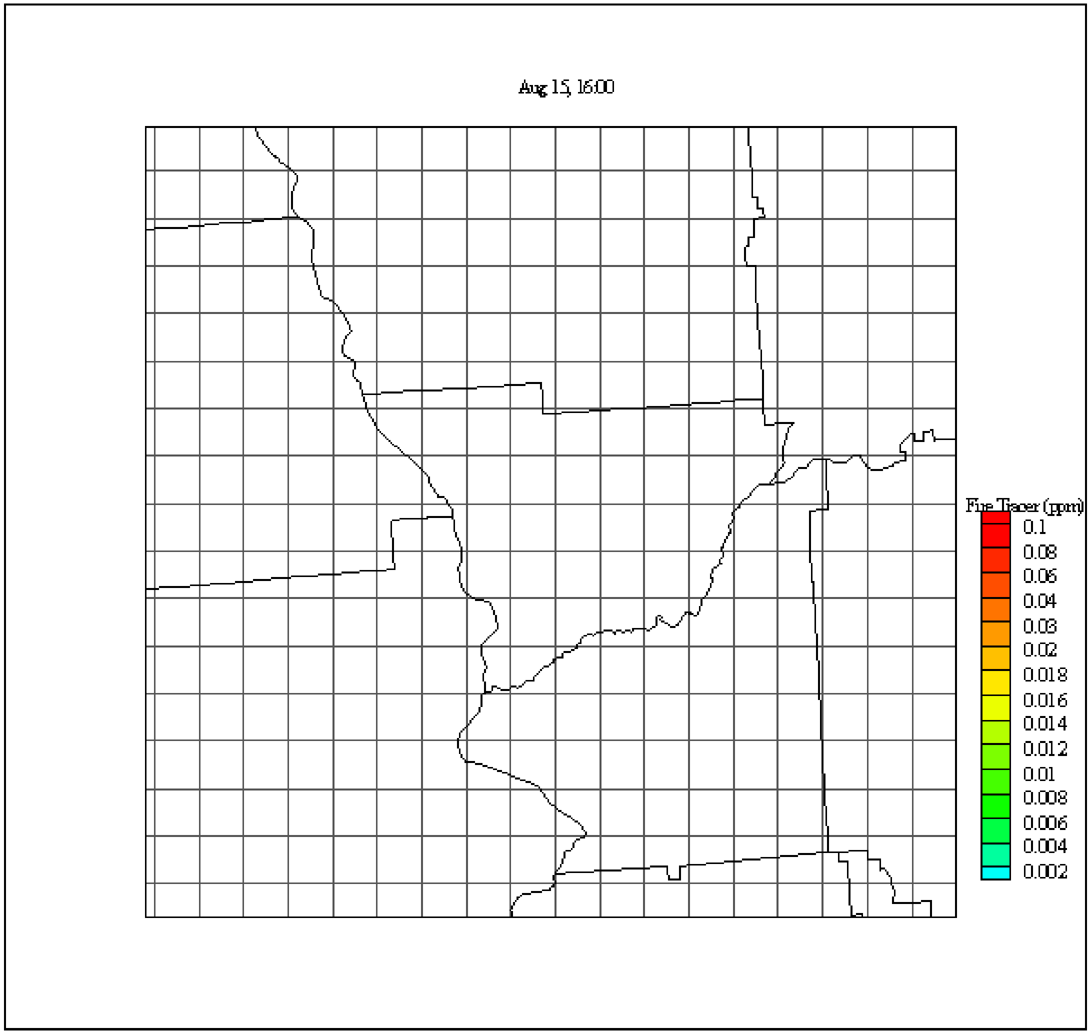
Adaptive Grid Model

- Our adaptive grid technique is a *mesh refinement* algorithm where the number of grid cells remains constant and the structure (topology) of the grid is preserved.
- Grid nodes move continuously during the simulation. Grid cells are automatically refined/coarsened for a more accurate solution.
- A weight function controls the movement of the grid nodes according to user-defined criteria (change in NO_x gradients here).

Adaptive Grid Model

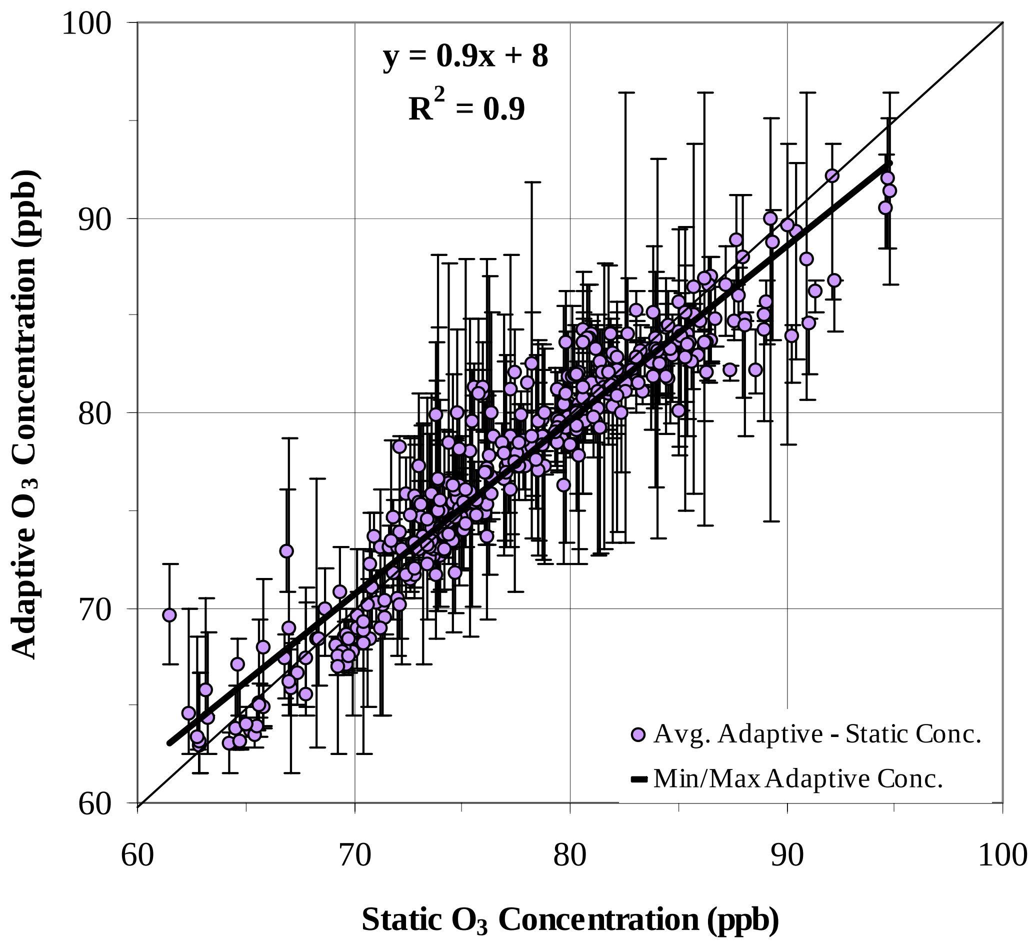


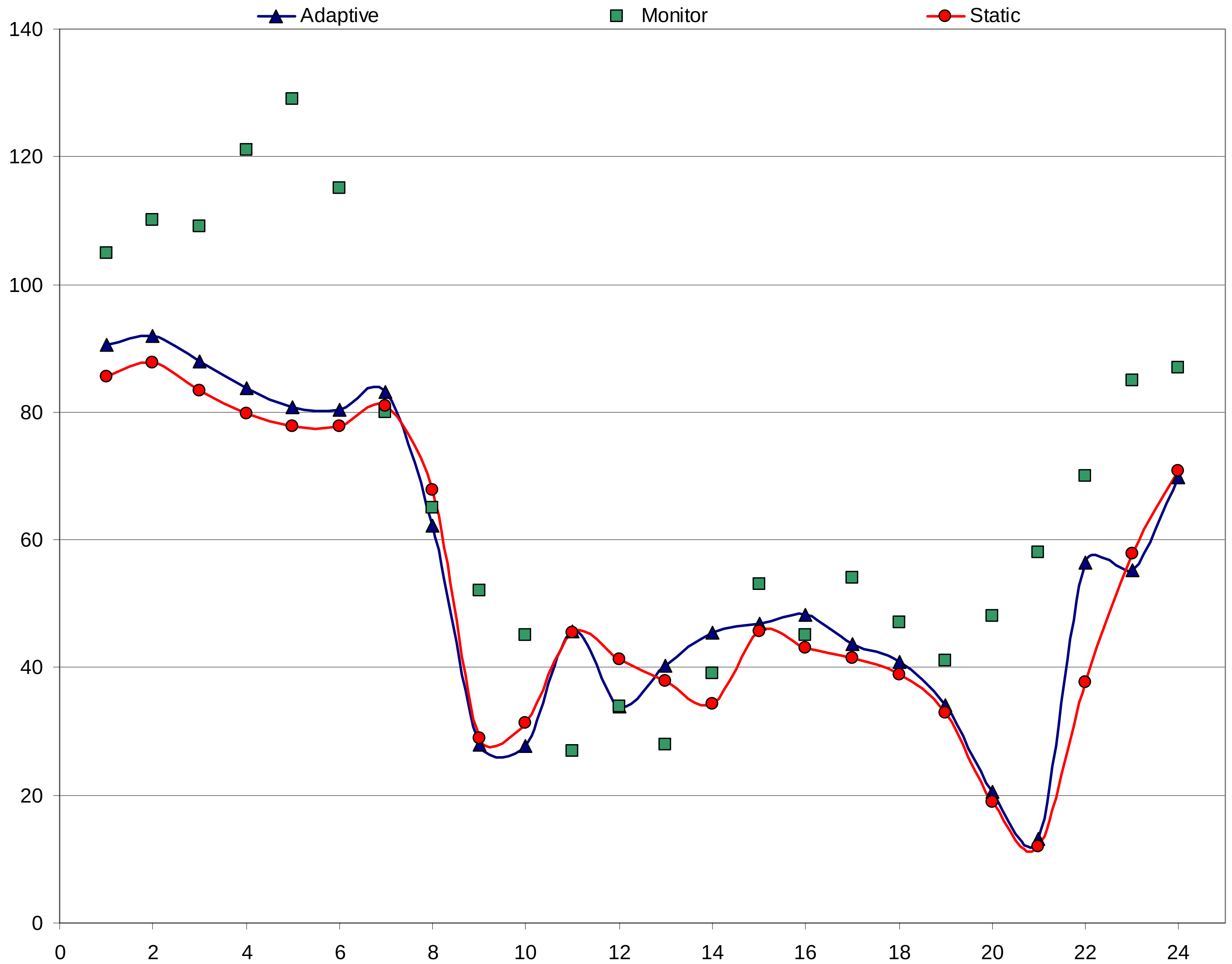
Adaptive Grid Model



O_3 Concentration: Adaptive vs. Static Grid

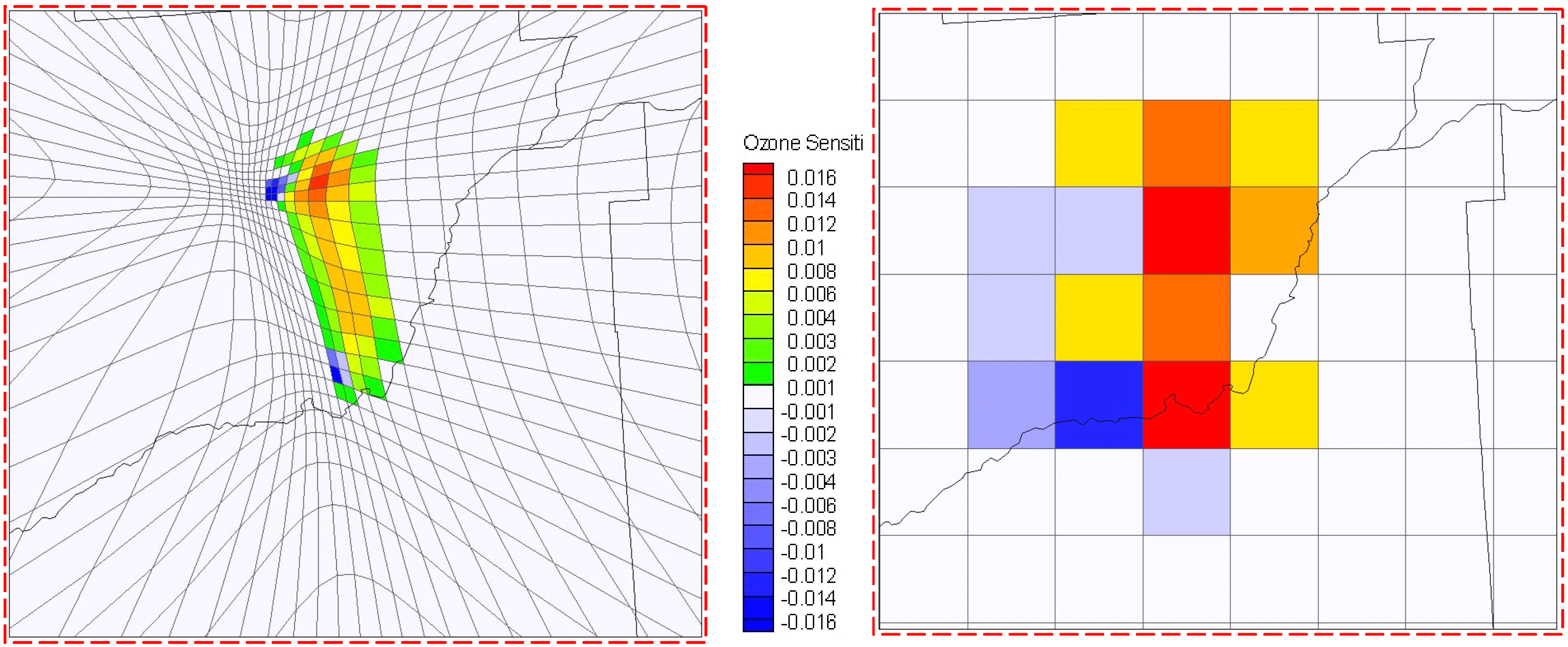
August 15, 21:00 (GMT)




Adaptive
Monitor
Static
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
18
20
22
24

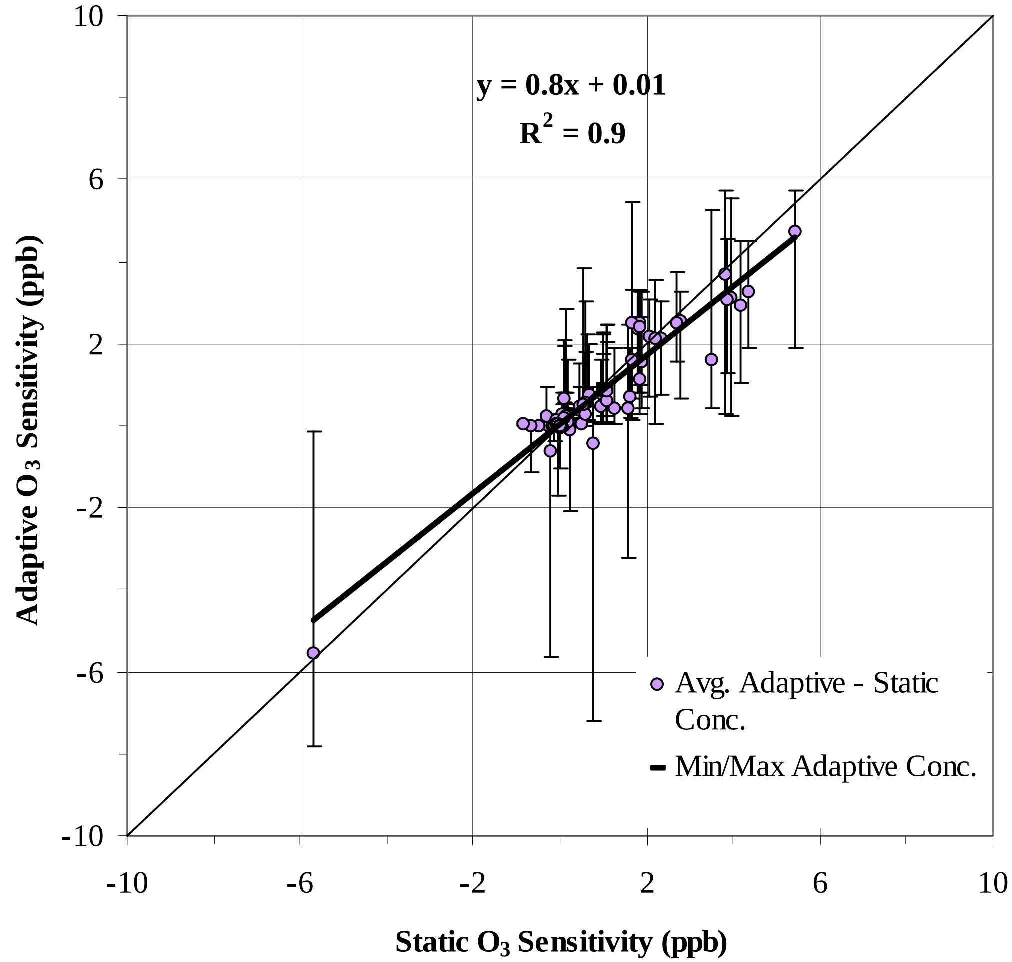
O_3 Sensitivity: Adaptive + DDM vs. Static + BF

August 15, 20:00 GMT



O_3 Sensitivity: Adaptive + DDM vs. Static + BF

August 15, 20:00 GMT



Findings

- Two techniques, Adaptive Grid Modeling and Direct Sensitivity Analysis (DDM), were merged to determine the impact of biomass burning.

- The impact of fires at Fort Benning during the modeled episode (August 15-18, 2000) ranged from 16 ppb reduction to 7 ppb increase in O_3 concentrations.
  - Impacts on Columbus were minimal due to wind directions

- Compared to static grid, concentration gradients were better resolved by Adaptive Grid.

- DDM with adaptive grid and Brute Force with static grid showed different ozone impacts.

Next Steps: Fine-Scale Forecasting

- 2006:
  - $PM_{2.5}$ forecast using “state-of-science” models
    - WRF (meteorology) and CMAQ (air quality)
- 2007 and beyond:
  - Fine-scale air quality forecasts (archived for health effects)
    - More accurate emissions
    - High resolution for sources and receptors
    - Sensitivity forecasts
    - Individualized forecasting products

Acknowledgements

- NASA Glenn for financial support
- Tom Nissalke at Hartsfield-Jackson Atlanta International Airport for providing airport data

- Strategic Environmental Research & Development Program (SERDP) for financial support (CP-1249)
- Hugh Westburry at Fort Benning for providing fire data