# High Resolution Source Attribution of PM Health Impacts with the CMAQ Adjoint Model

*CMAS 2011*

**Turner, M.**[1]; Henze, D.[1]; Hakami, A.[2]; Zhao, S.[2]; Resler, J.[3]; Carmichael, G.[4]; Stanier, C.[4]; Baek, J.[4]; Saide, P.[4]; Sandu, A.[5]; Russel, A.[6]; Jeong, G.[6]; Nenes, A.[6]; Capps, S.[6]; Percell, P.[7]; Pinder, R.[8];Napelenok, S.[8]; Pye, H.[8]; Bash, J.[8]; Chai, T.[9]; Byun, D.[9]

[1]University of Colorado at Boulder; [2]Carleton University; [3]ICS Prague; [4]University of Iowa; [5]Virginia Tech; [6]Georgia Tech; [7]University of Houston; [8]USEPA; [9]NOAA

October 26, 2011

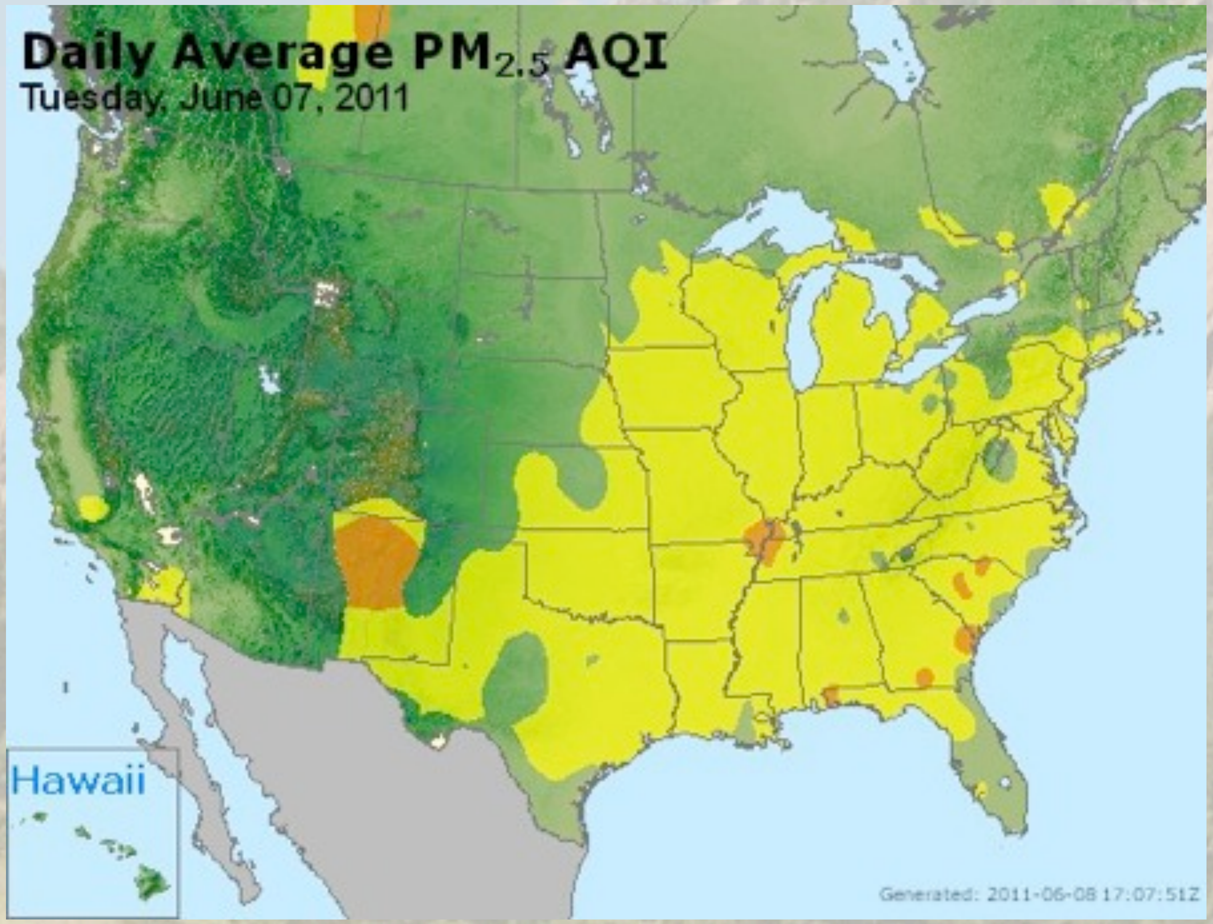
This research is supported through NASA Applied Sciences Program grant NNX09AN77G.

# What is Black Carbon?

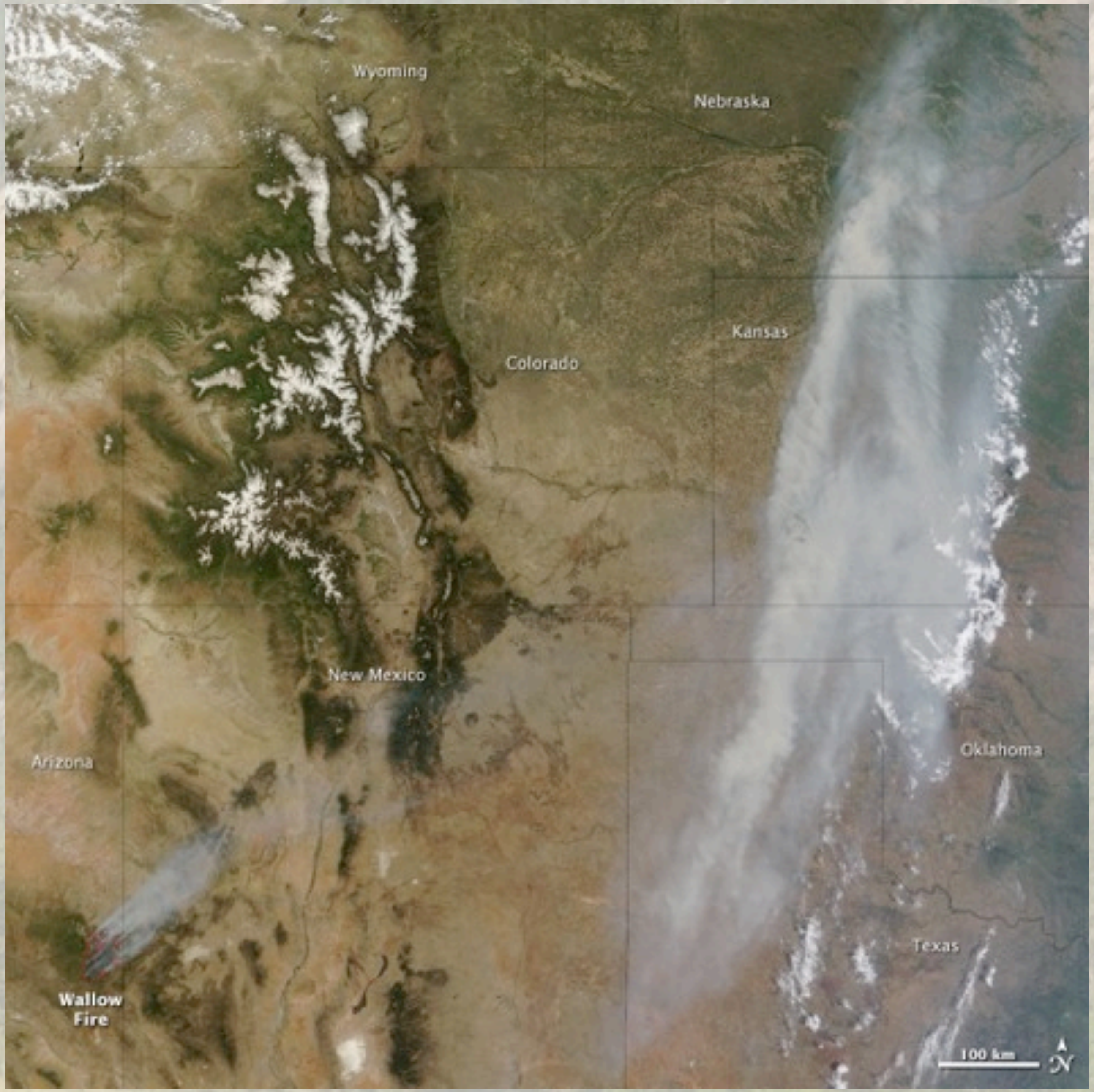
- Component of $PM_{2.5}$ produced by incomplete combustion of fossil-fuel, bio-fuel, and open biomass burning.
- Light-absorbing particles
- Commonly called “soot”
- $PM_{2.5}$ mixtures with higher BC percentage may have greater effects on mortality (Cooke et al., 2007)

Smoke billowing from a plant in Copsa Mica, Romania. Photograph: Andrew Holbrooke/Corbis. Source: The Guardian

# Where is it Coming From?



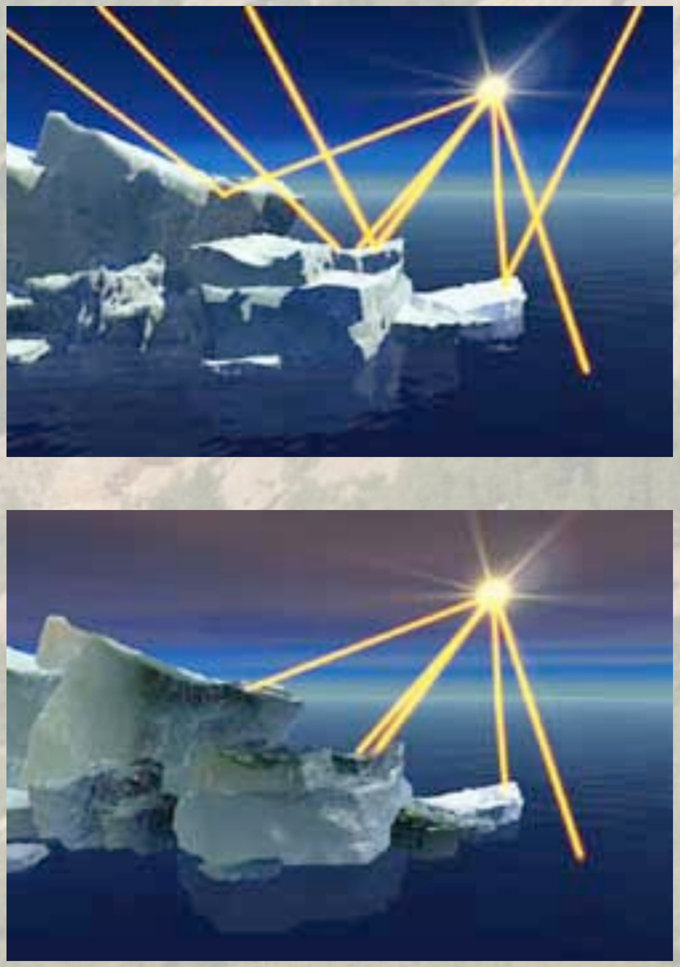

EPA AIRNow
June 07, 2011




MODIS
June 07, 2011

# Co-benefits of Reducing BC

- Health effects of BC
- Effects on climate change.
- BC is short-lived climate forcer
  - “Reducing black carbon...now will slow the rate of climate change within the first half of this century” (UNEP, 2011).
  - “A small number of emission reduction measures targeting black carbon...could immediately begin to protect climate, [and] public health” (UNEP, 2011).

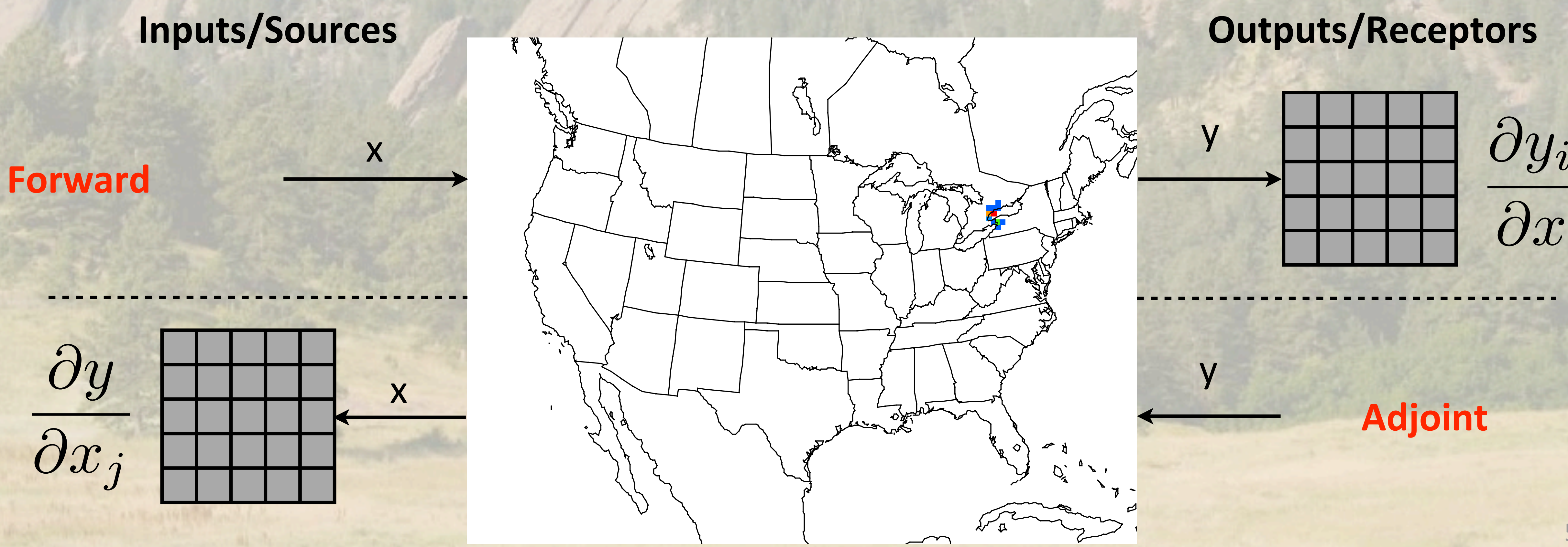


Schematic representation of BC effect on Arctic melting

**Integrated Assessment of Black Carbon and Tropospheric Ozone: Summary for Decision Makers (UNEP, 2011)**

# Adjoint Models

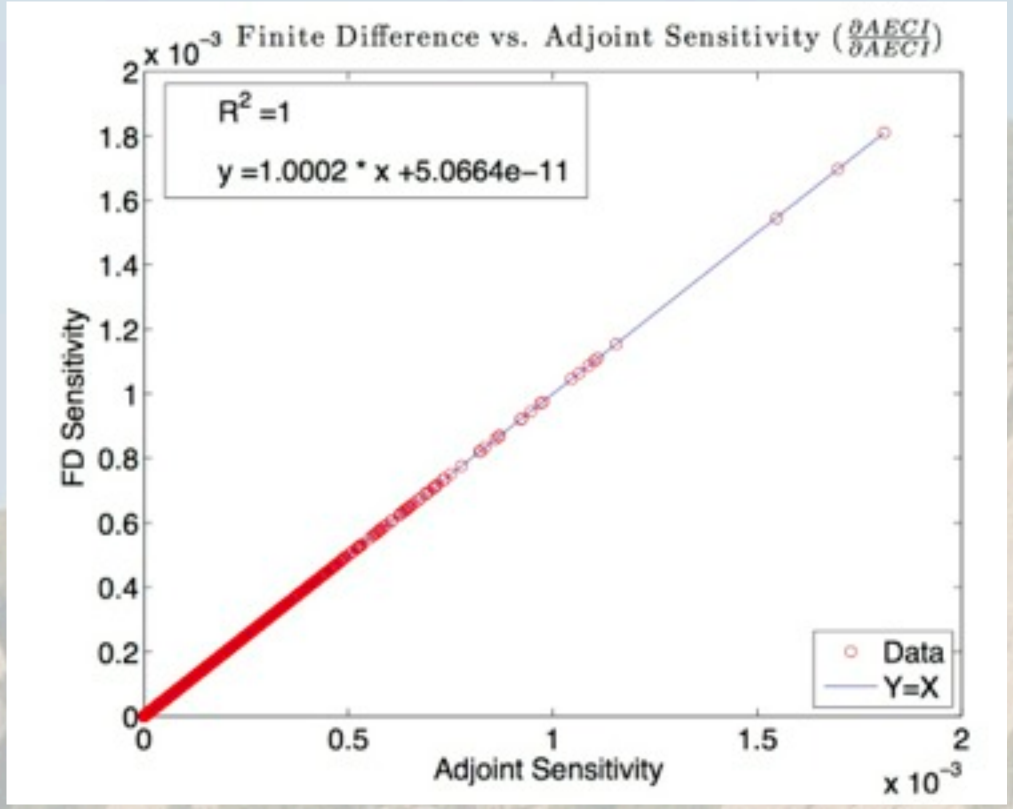
- Forward sensitivity analysis are source-based
- Adjoint method provides receptor-based sensitivities
- Adjoint method has 2 main advantages over FD:
  - Quickly calculate sensitivities with respect to all model parameters (sources) at the same time.
  - Don't need multiple forward runs

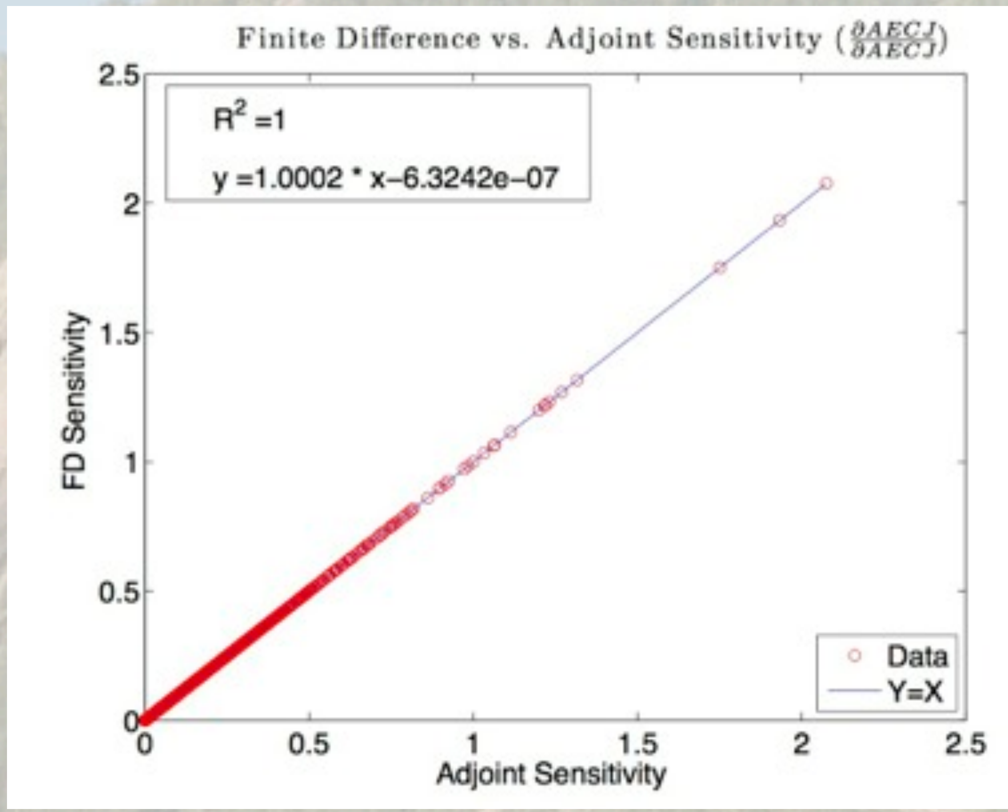


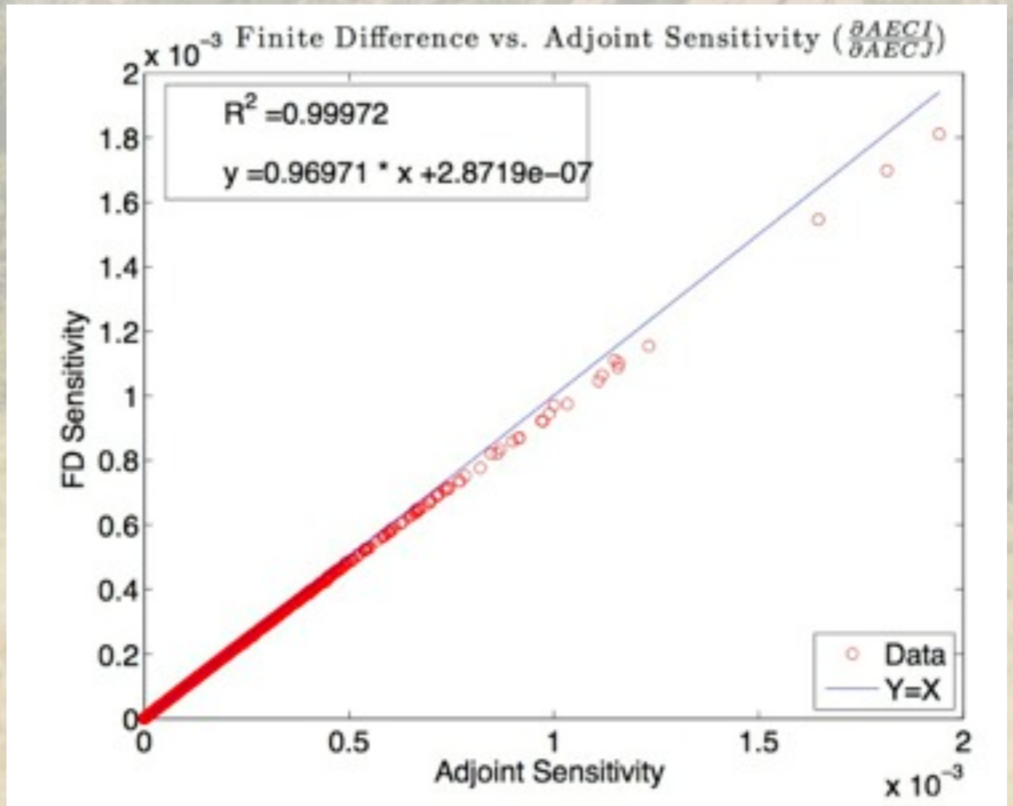
# Adjoint Validation

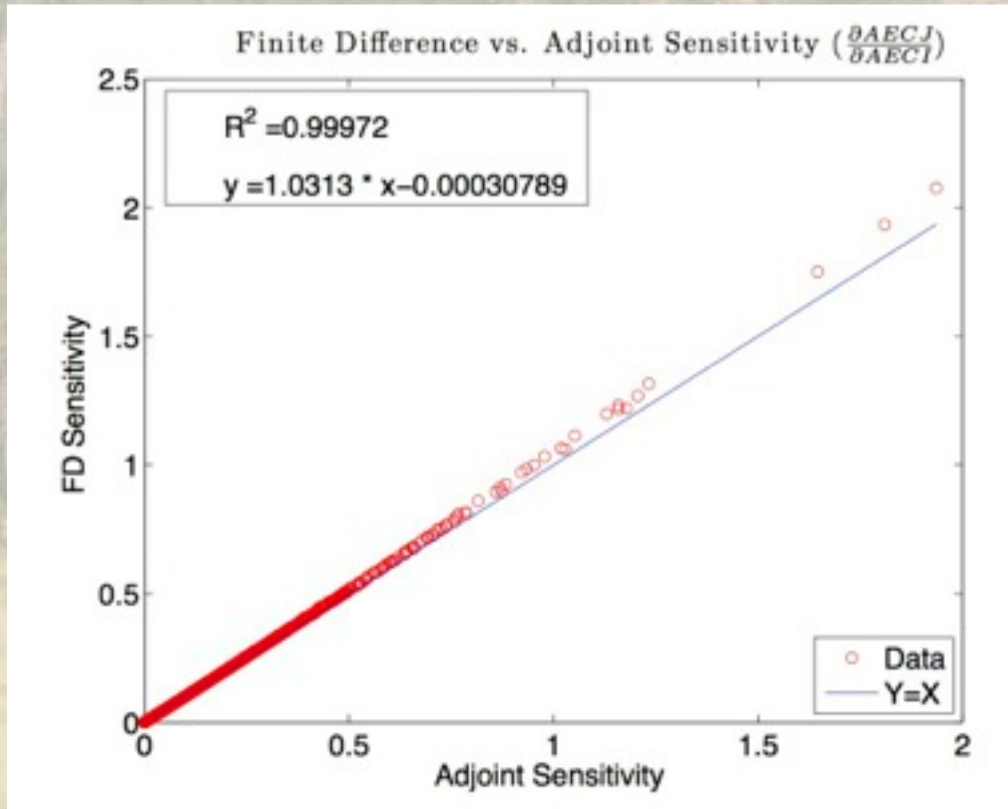
- Validate adjoint by comparing Finite Difference sensitivities to Adjoint sensitivities.
- Finite Difference:
  – Run simulation --> store output values
  – Run simulation after perturbing parameter --> store output values
  – FD = (Perturbed output - base output ) / perturbation
- Adjoint:
  – Specify adjoint forcing (what drives adjoint model)
  – Run simulation

# Aerosol Dynamics - Full Model

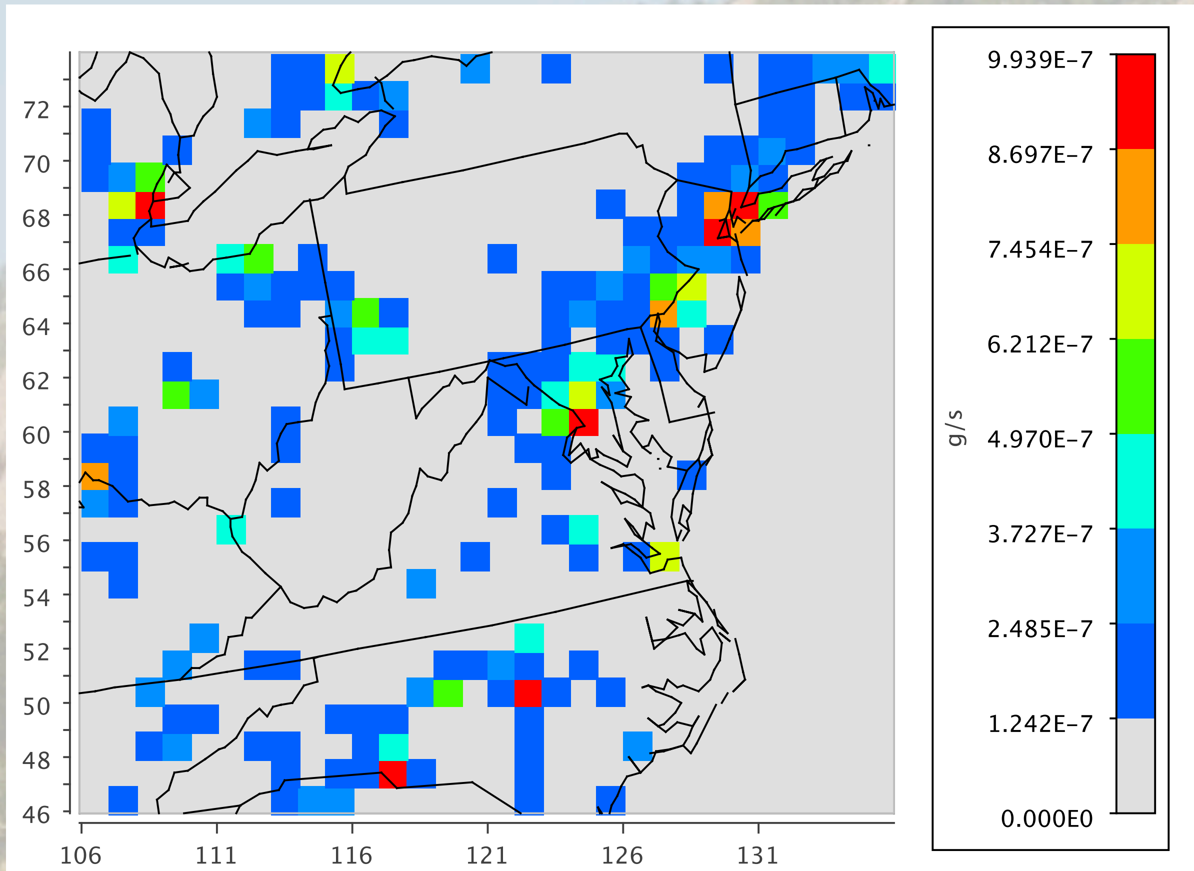


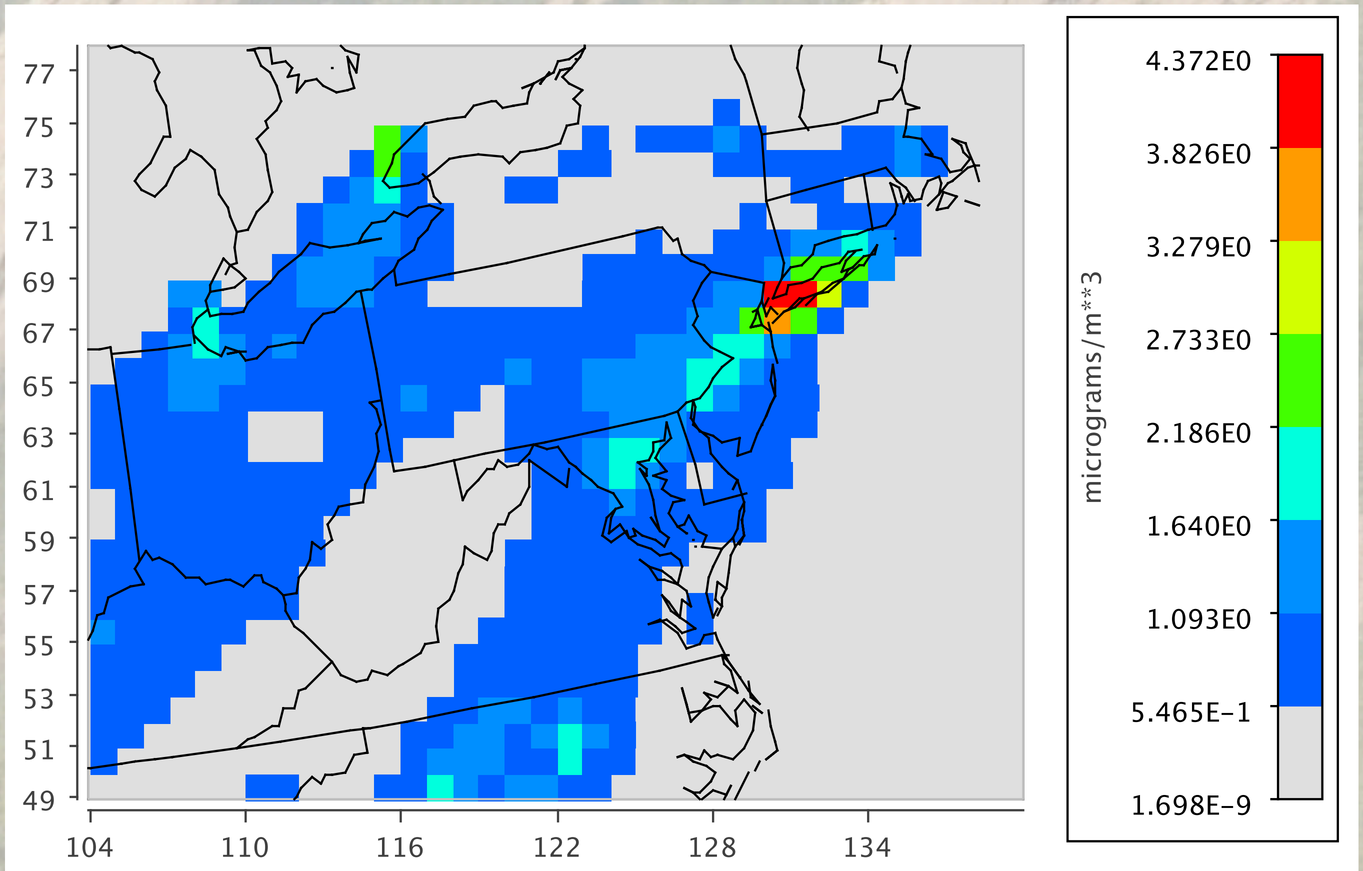



# Black Carbon Analysis




AECJ Emissions




AECJ Concentrations

# Black Carbon Analysis - Balt.

Health Impact Function: $\Delta Mort = y_0(1 - exp^{-\beta \Delta X})Pop$

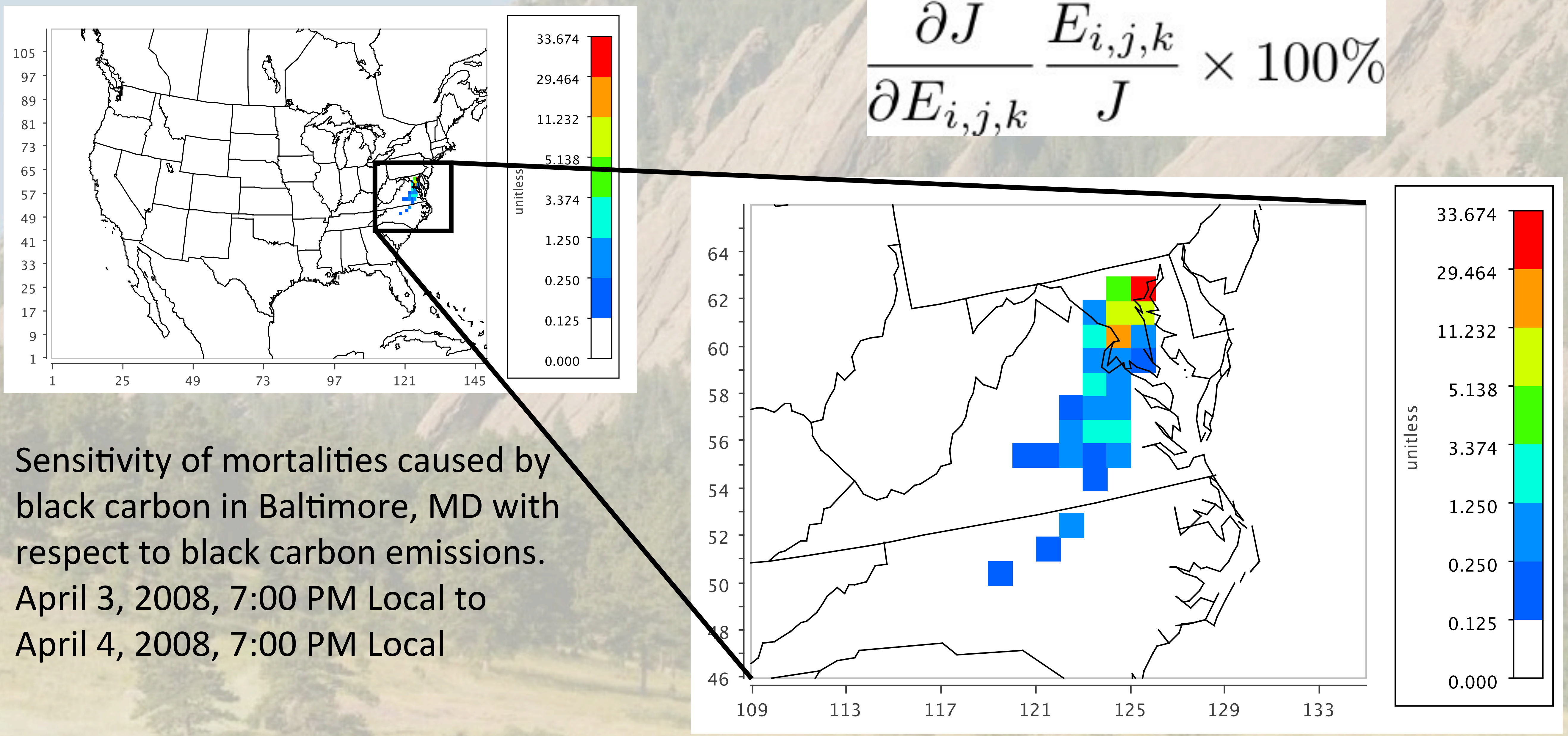
- $y_0$ = baseline mortality rate, 1.02 (Calculated from Maryland Vital Statistics)
- ß = Concentration Response Factor, 0.005827 (calculated from Relative Risk from Annenberg et al. 2011. $PM_{2.5}$ only)
- X = concentration (microgram per cubic meter for BC)
- Pop = population, 636,919 (Baltimore, MD. 2008 Maryland Vital Statistics)

J = Health Impact Function = 2.05

Adjoint model driven by: $\frac{\partial Mort}{\partial X} = \beta * y_0 * Pop * exp^{-\beta X}$

# Black Carbon Analysis - Balt.

$$\frac{\partial J}{\partial E_{i,j,k}} \frac{E_{i,j,k}}{J} \times 100\%$$




Sensitivity of mortalities caused by black carbon in Baltimore, MD with respect to black carbon emissions. April 3, 2008, 7:00 PM Local to April 4, 2008, 7:00 PM Local

# Black Carbon Analysis - NY

Health Impact Function: $\Delta Mort = y_0(1 - exp^{-\beta \Delta X})Pop$

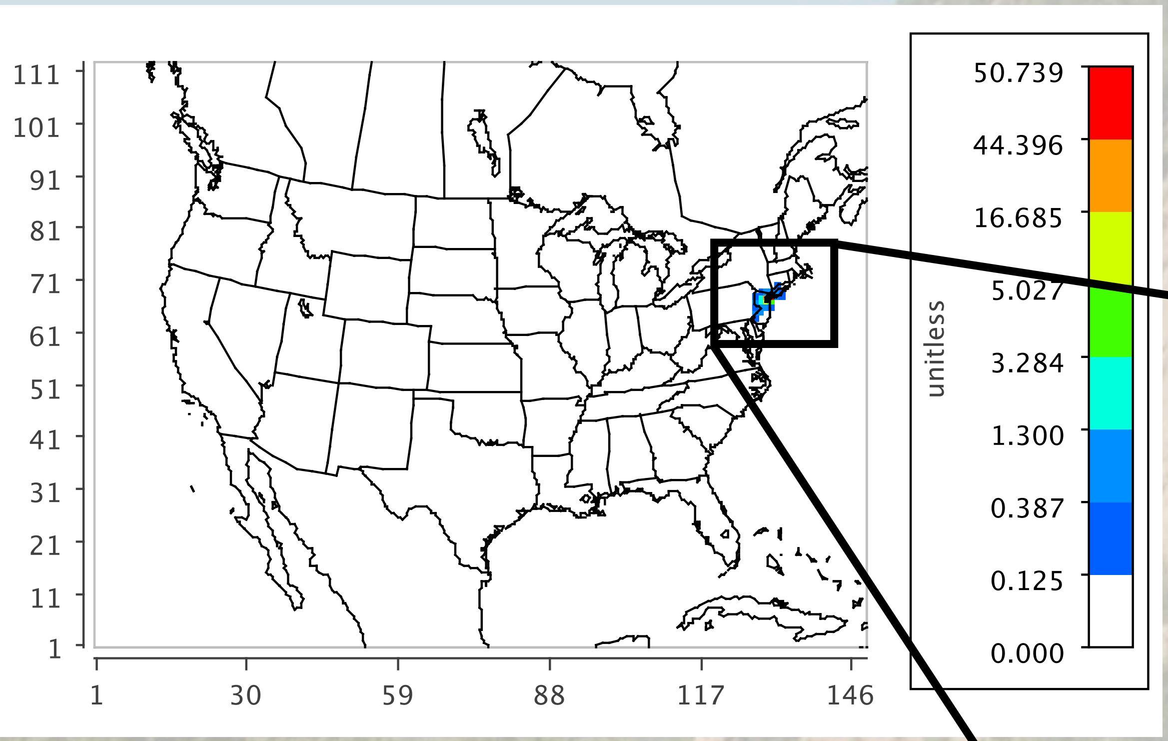
- $y_0$ = baseline mortality rate, 0.634 (Calculated from NY Vital Statistics)
- ß = Concentration Response Factor, 0.005827 (calculated from Relative Risk from Annenberg et al. 2011. $PM_{2.5}$ only)
- X = concentration (microgram per cubic meter for BC)
- Pop = population, 8,363,710 (NY, NY. 2008 New York Vital Statistics)

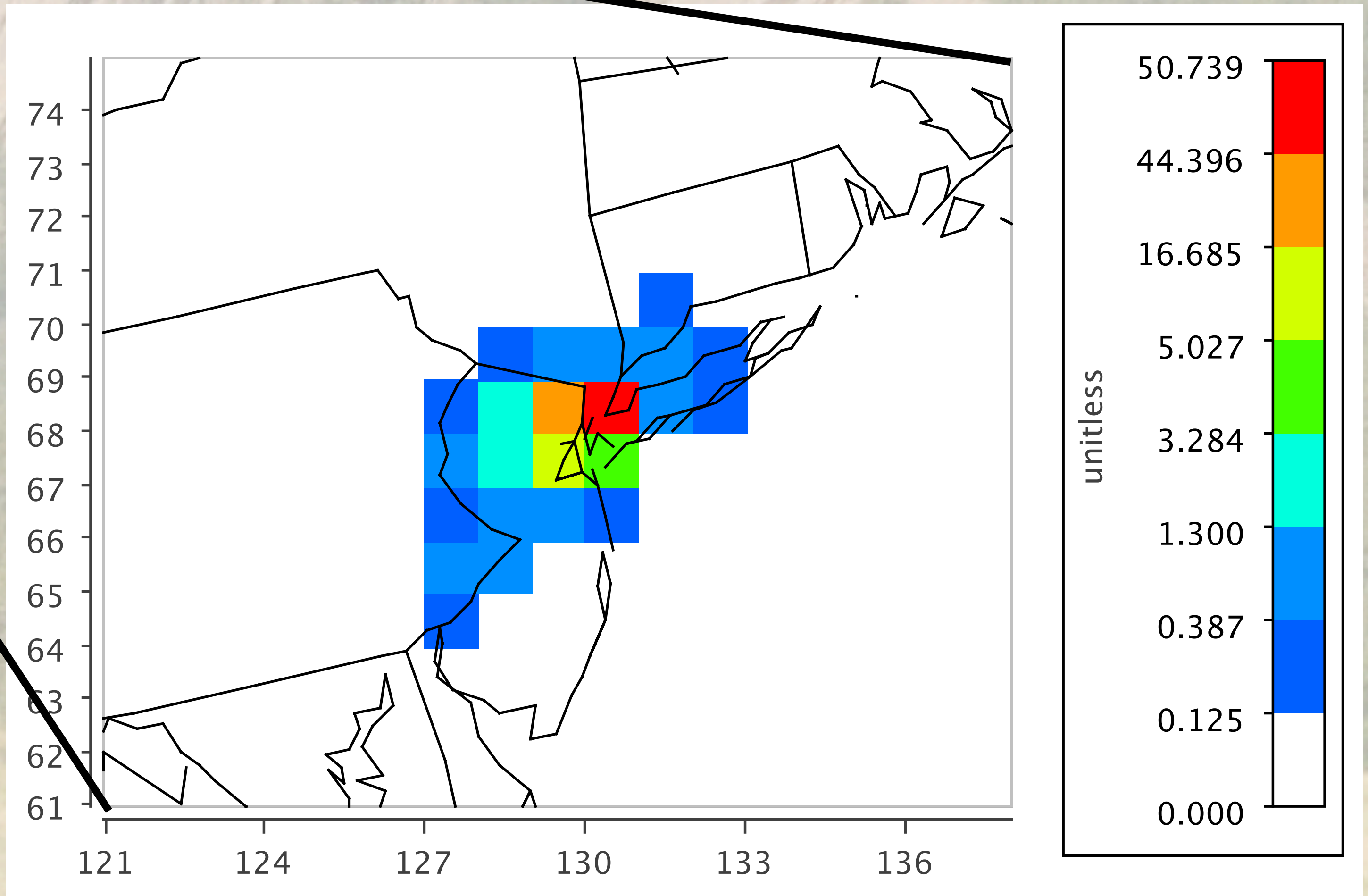
J = Health Impact Function = 36.96

Adjoint model driven by: $\dfrac{\partial Mort}{\partial X} = \beta * y_0 * Pop * exp^{-\beta X}$

# Black Carbon Analysis - NY

$$\frac{\partial J}{\partial E_{i,j,k}} \frac{E_{i,j,k}}{J} \times 100\%$$




Sensitivity of mortalities caused by black carbon in New York, NY with respect to black carbon emissions. April 3, 2008, 7:00 PM Local to April 4, 2008, 7:00 PM Local

# Summary

- Adjoint of CMAQ aerosol module has been developed and validated for black carbon.
- Sensitivities with respect to emissions have been obtained for single day simulations for Baltimore, MD and New York city.
  - Mortalities in Baltimore caused by exposure to black carbon most sensitive to emissions in Baltimore down through DC.
  - Mortalities in New York city caused by exposure to black carbon most sensitive to emissions in New York City and and into Newark and New Brunswick, NJ.

# Future Work

- Expand Black Carbon simulation time period to 4 months.
  - Average over 4 day periods (atmospheric lifetime of BC).
- Run simulations for various regions and cities.
  - Requires gridded baseline mortality rates and gridded populations for cost functions consisting of a range of cells.