Inverse Modeling and Attainment Analysis for Improved Decision Support of $PM_{2.5}$ Air Quality Regulations

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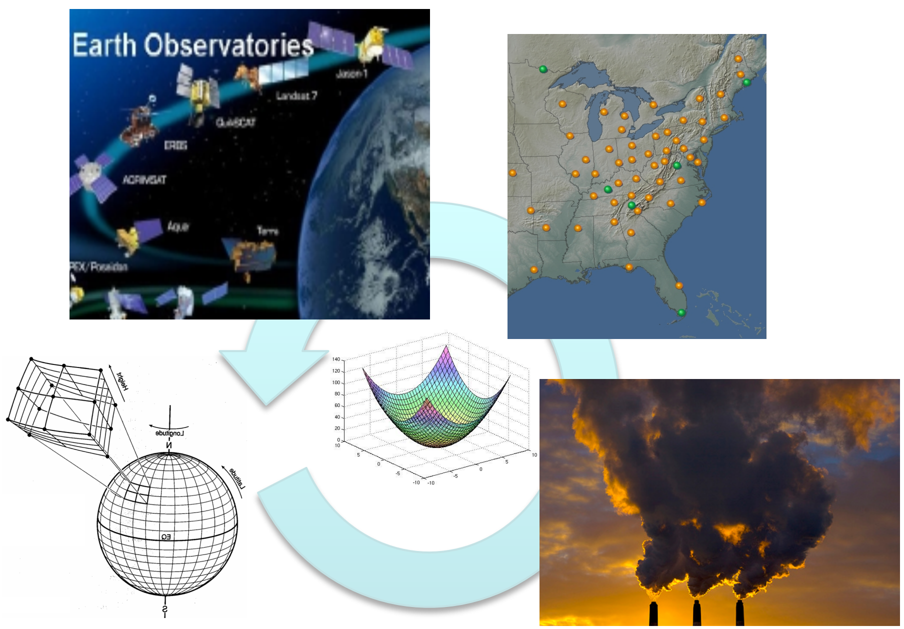

Partners at US EPA:

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Emissions Group
- Doug Solomon
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OAQPS
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Project overview

Earth System Models

drivers:

- GISS Model E

- GEOS-Chem

- WRF

air quality predictions:

- CMAQ

- GEOS-Chem

Earth Observations

remote sensing:

- SCIAMACHY / OMI NO_2

- TES NH_3

in situ:

- IMPROVE, STN, CASTNet, AMoN, CAMNet, NADP, CalNex

Data Assimilation

- CMAQ adjoint

- GEOS-Chem adjoint

Predictions / Products

- Emissions

- Control Strategies

Development of effective $PM_{2.5}$ control strategies hindered by:

- uncertainty in knowledge of sources

- lack of information relating emissions from specific sectors, locations and species, to health endpoints.

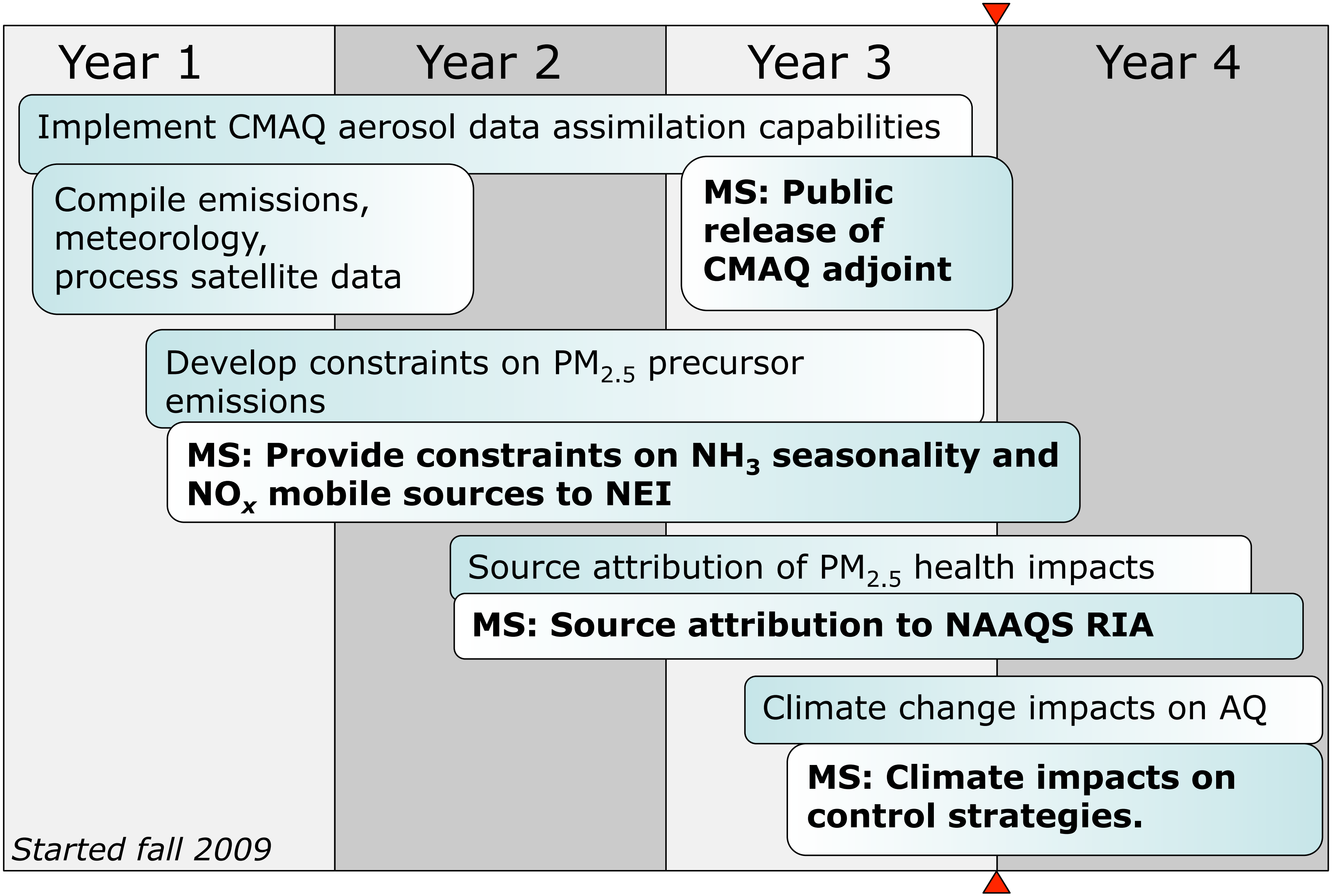
Here we are using the tools outlined on the left to:

- constrain estimates of $PM_{2.5}$ sources

- develop improved emissions mitigation strategies with detailed source – receptor analysis

- provide new tools to the EPA for long term adoption of these techniques.

Schedule and Milestones (MS)



Milestone #2: Constraining emissions of NH_3

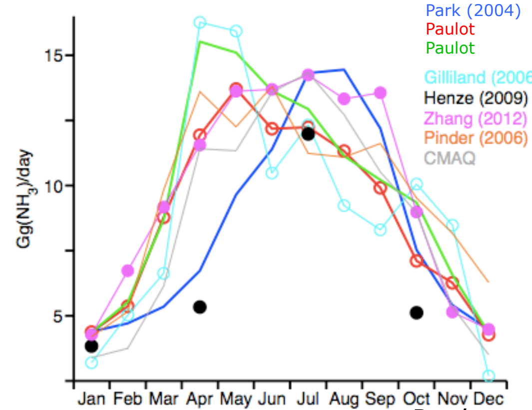
Impacts of NH_3
- governs 10-30% of $PM_{2.5}$ mass
- aerosol water and phase
  --> clouds & climate
- deposition of reactive nitrogen

Large uncertainties
- seasonality
- fertilizer vs animals
- primary sources vs redistribution

EPA's national emission inventory (NEI) uses inverse modeling to constrain seasonality *(Gilliland et al., 2006)*

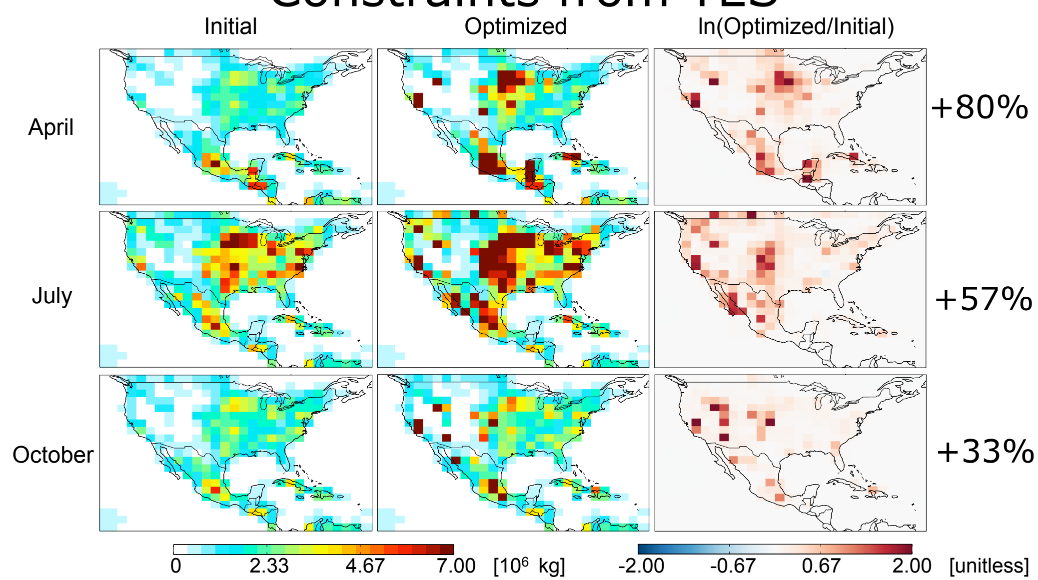
Room to improve upon this using new data (TES, AMoN) and new inverse models
(Shephard et al., 2011; Pinder et al., 2011; Zhu et al., submitted, Paulot et al., in prep)

Range of total US NH_3 emissions



Paulot et al., in prep

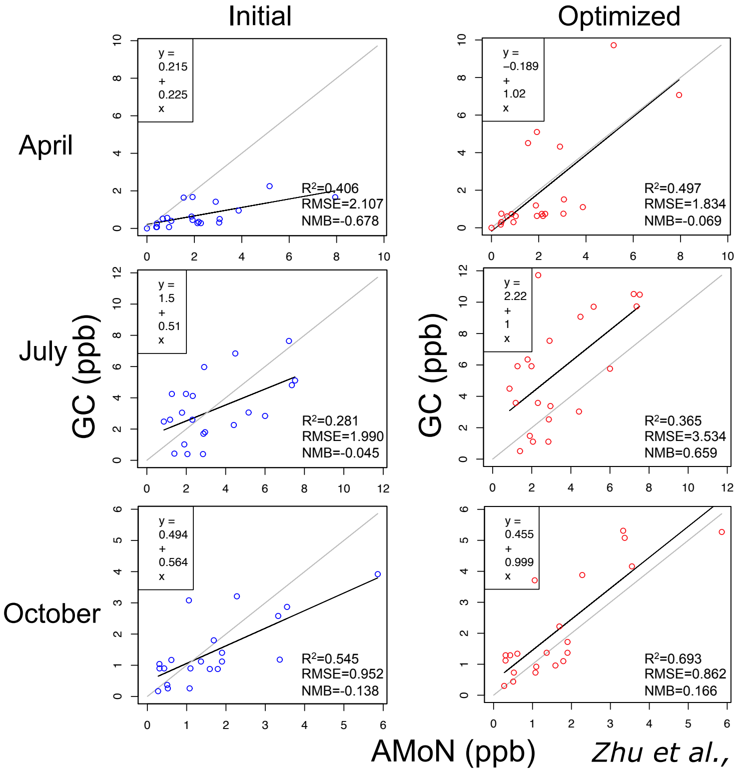
Constraints from TES



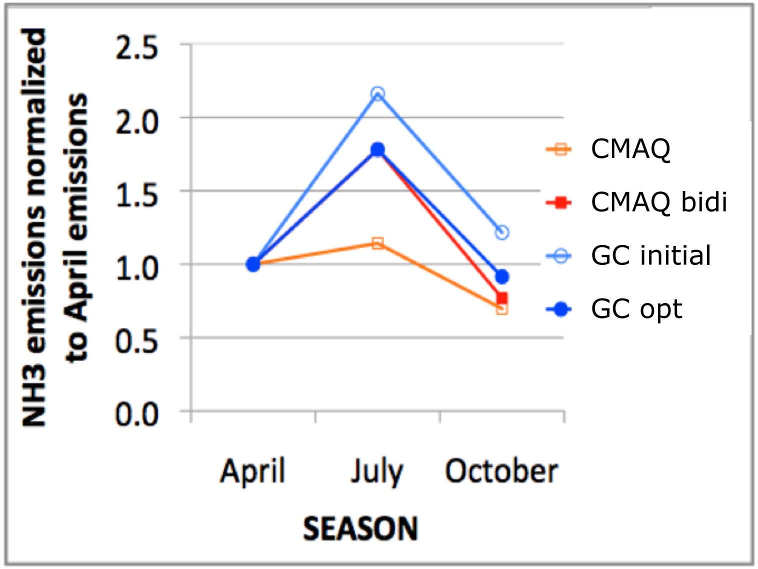
Zhu et al., submitted

Milestone #2: Constraining emissions of NH_3

Constraints provided by TES lead to improved estimates of NH_3 measured at AMoN sites in April and October (right)



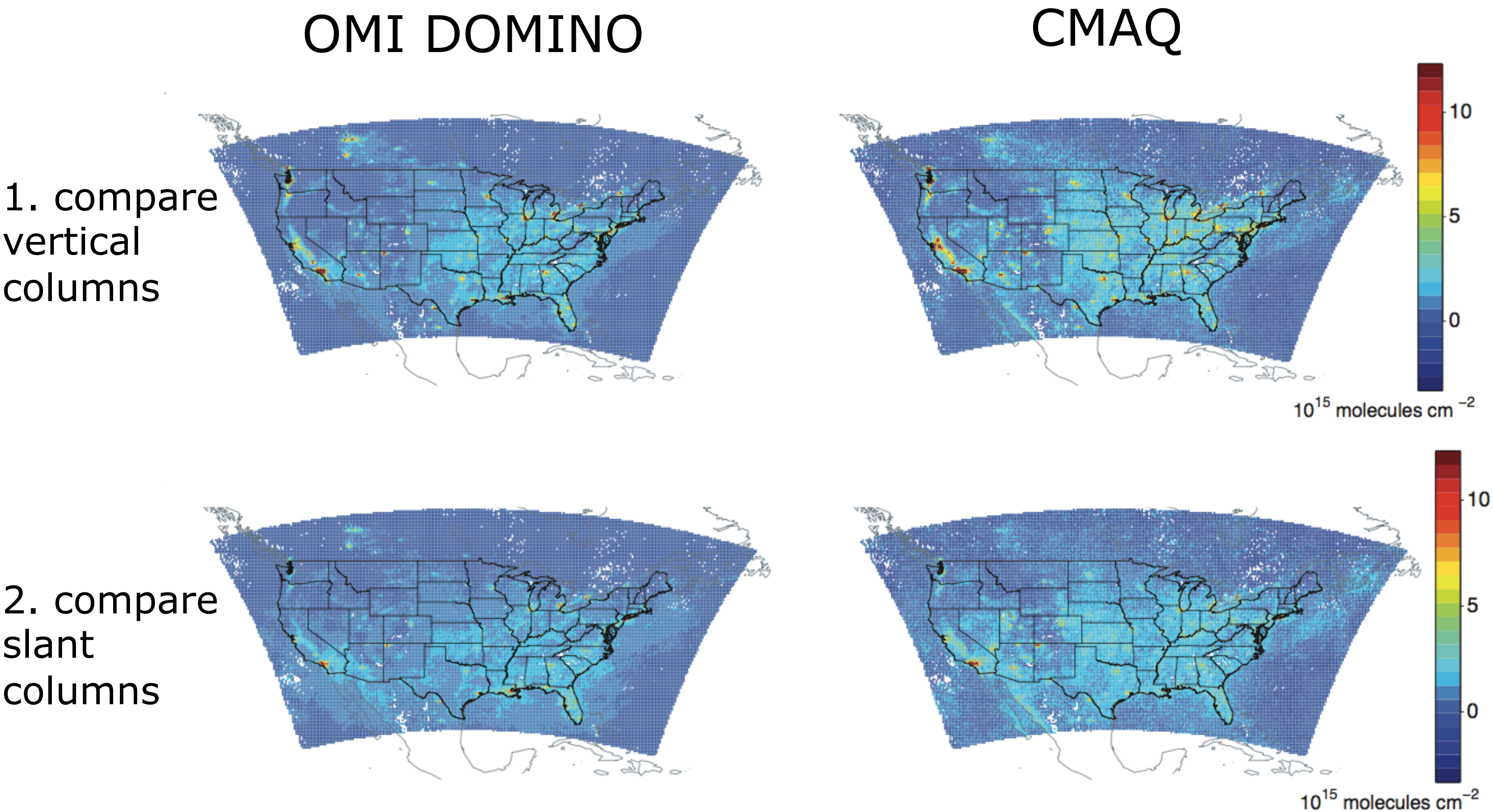
Zhu et al., submitted



Jeong et al., 2011 AGU

Constraints provided by TES shift the seasonality towards higher emissions in April, consistent with updates to CMAQ NH_3 bidirectional flux model (left)

Milestone #1: Online observation operator for assimilating NO_2 into CMAQ



1. Leads to more rigorous slant vertical column comparison
2. Emphasizes altitudes where OMI is most sensitive

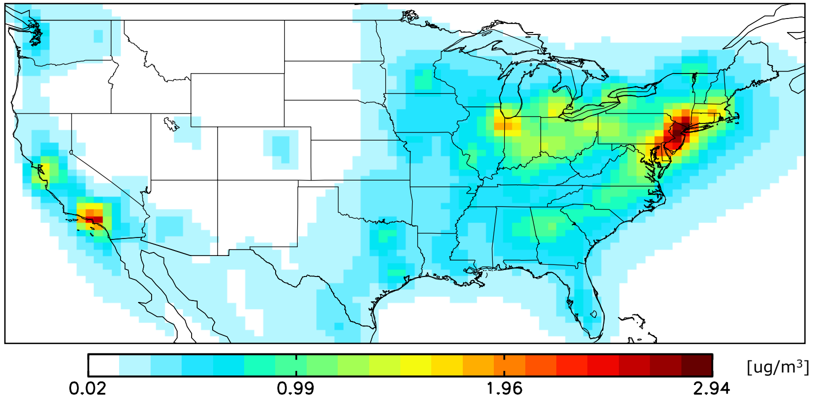
Pye et al., 2010

Milestone #3:
Source attribution of BC aerosol related mortality

Question: How much do emissions from each location / species / sector contribute to mortality?

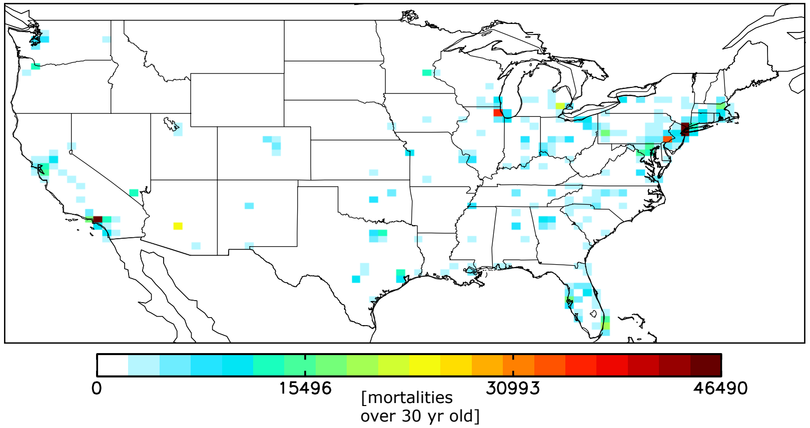
Approach:

GEOS-Chem / CMAQ annual BC



+

baseline mortalities (BenMAP*)



**EPA's health impact model*

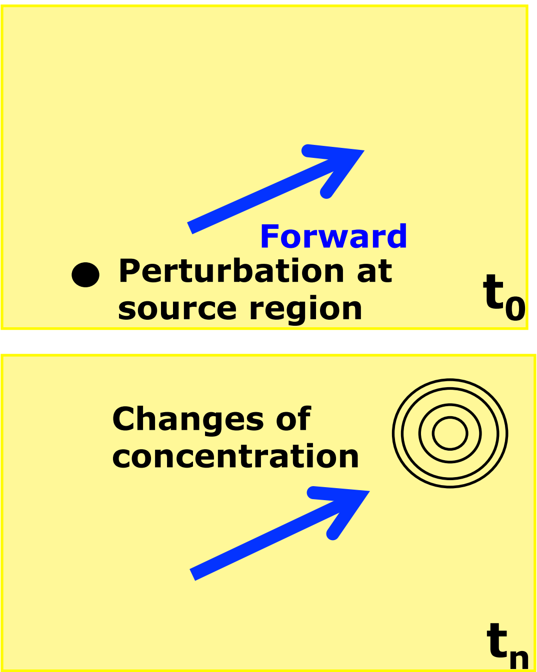
+ response factor (0.005827) = 14,000 deaths

Apportion sources contributing to these mortalities using adjoints, and use tool for EPA's Regulatory Impact Analysis (RIA)

Adjoint modeling for source-receptor analysis:

Forward Model (source-oriented)

Sensitivity of all model concentrations to one model source



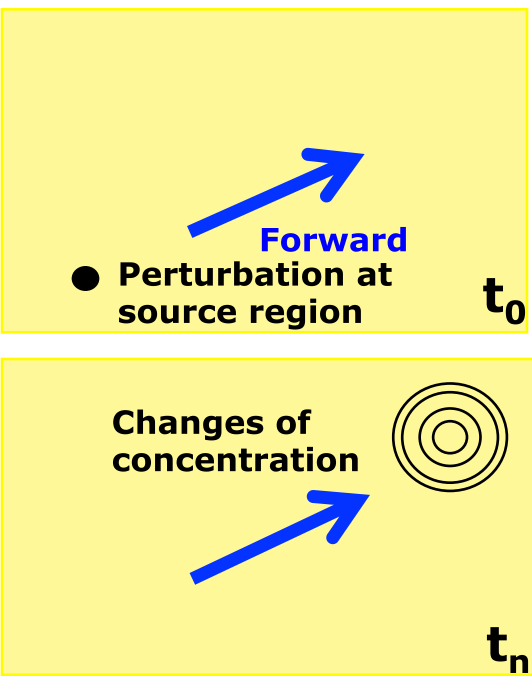
Adjoint modeling for source-receptor analysis:

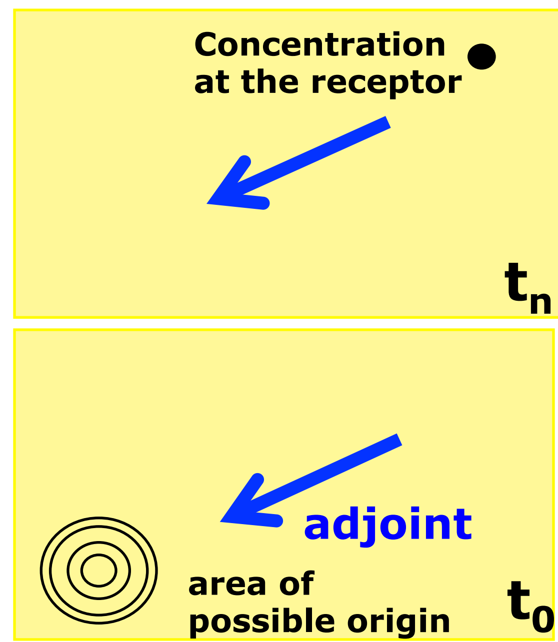
Forward Model (source-oriented)

Sensitivity of all model concentrations to one model source

Adjoint Model (receptor-oriented)

Sensitivity of model concentration in specific location to many model sources





Adjoint modeling for source-receptor analysis:

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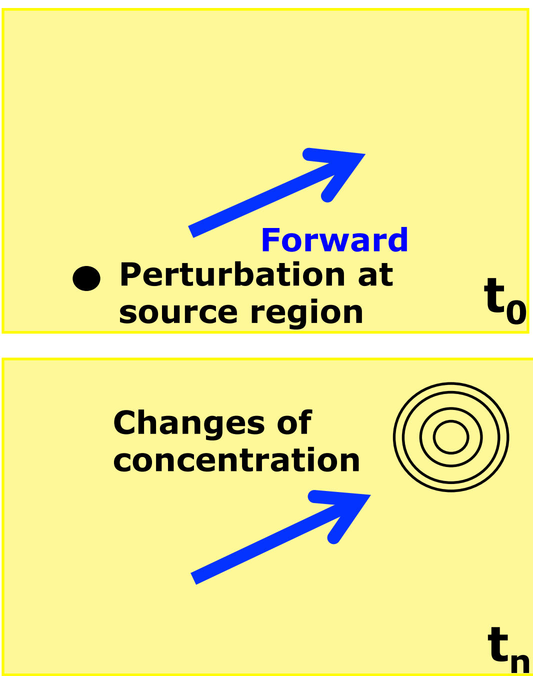
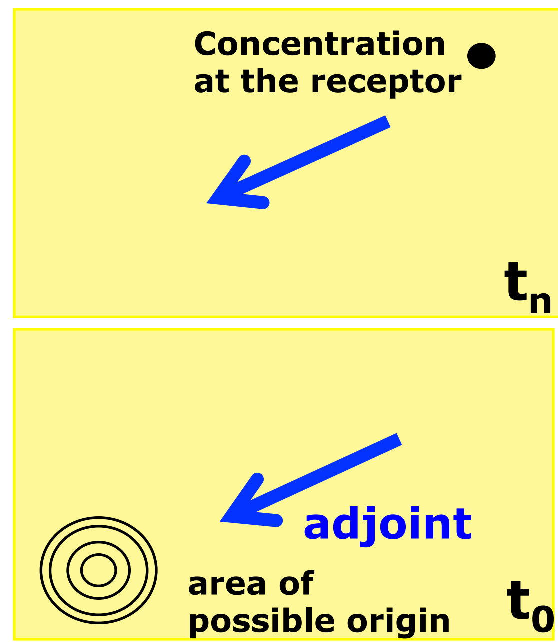


Adjoint Model (receptor-oriented)

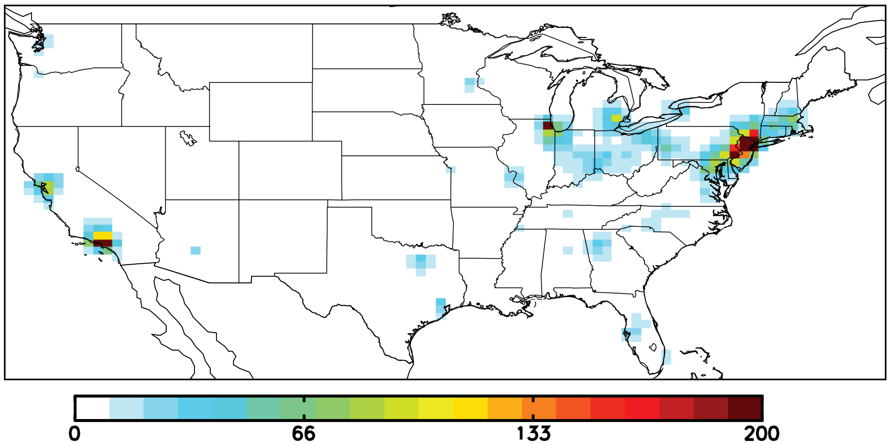
Sensitivity of model *response over any region* to many model sources

example responses: national exceedence, statewide mortality,...

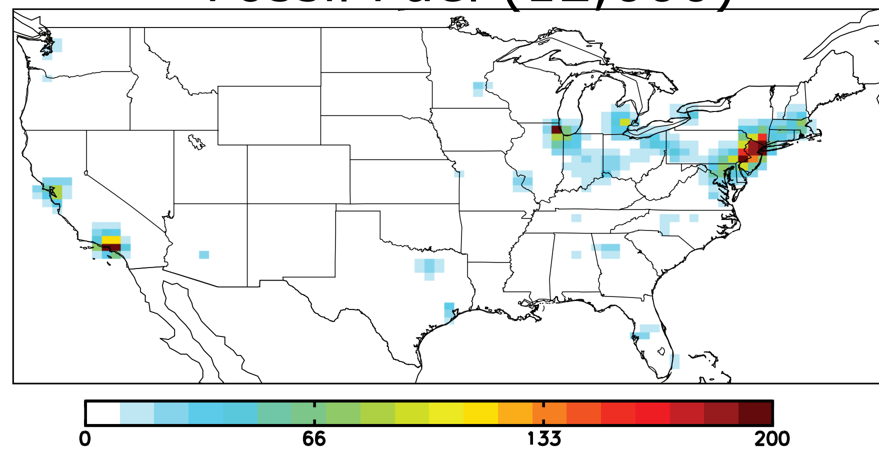


Milestone #3:
Source attribution of BC aerosol related mortality

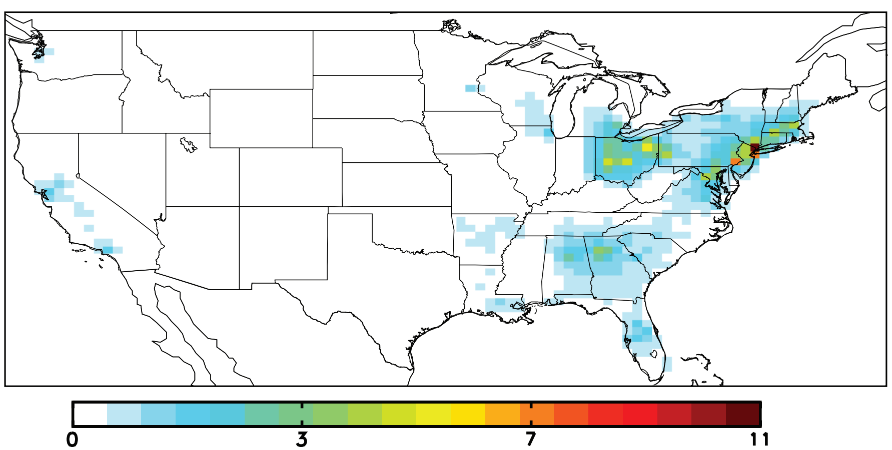
All sectors



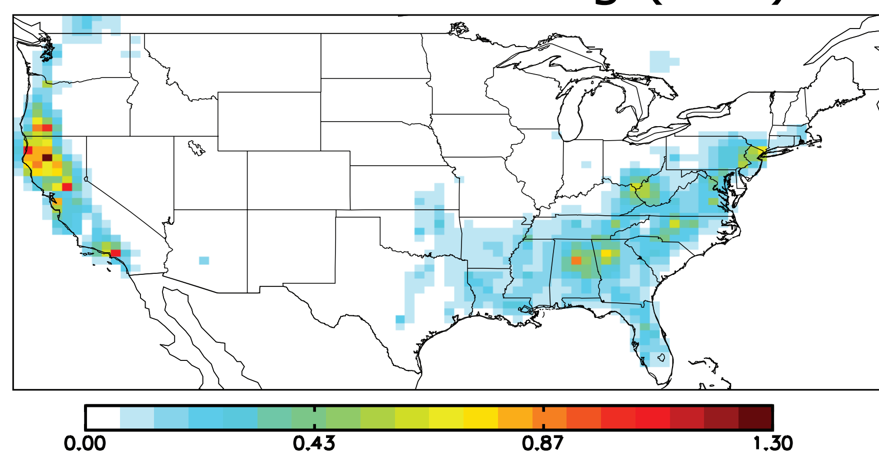
Fossil Fuel (12,600)



Biofuel (900)



Biomass Burning (200)

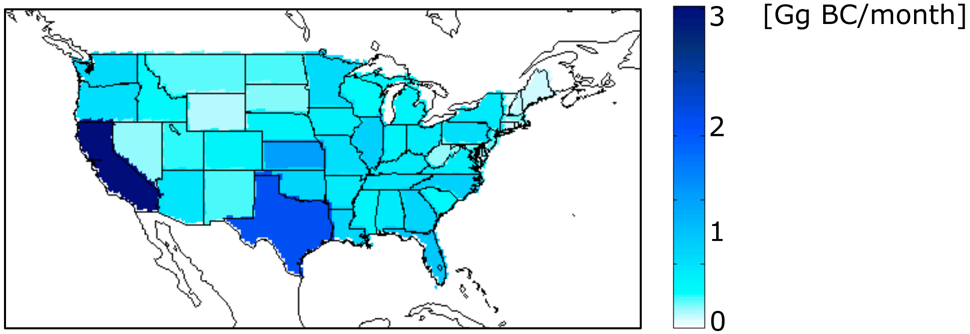


Annual mortalities from BC emissions in each grid cell

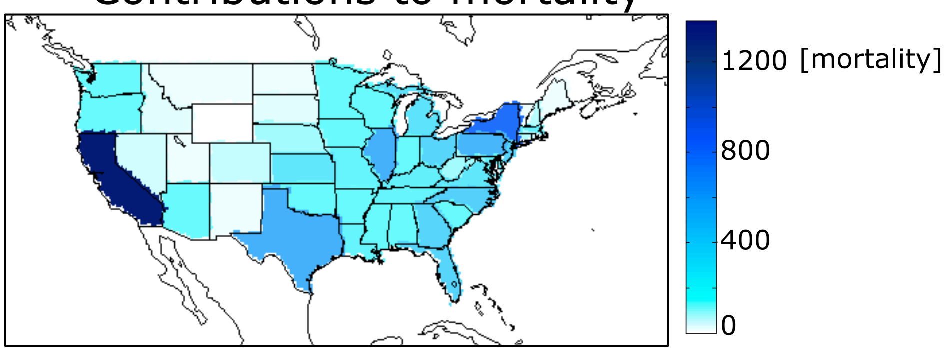
Milestone #3: Source attribution of BC aerosol related mortality

Disparities between state contributions to national emissions vs contributions to national health impacts

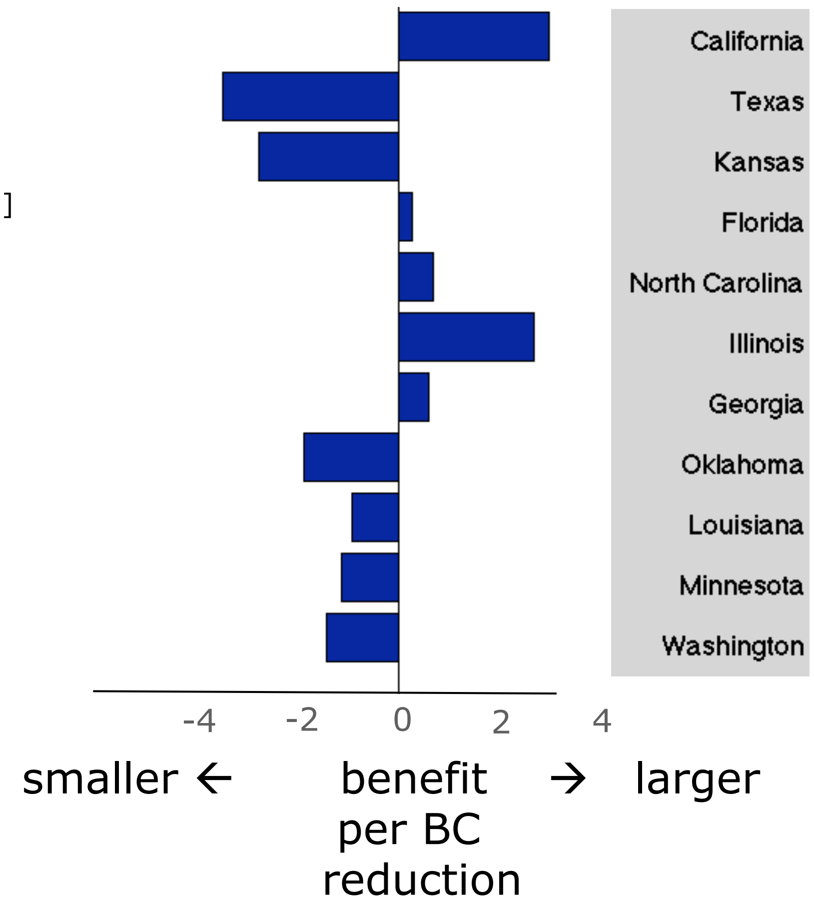
Emissions



Contributions to mortality



% contrib. to US mort. - % US emissions

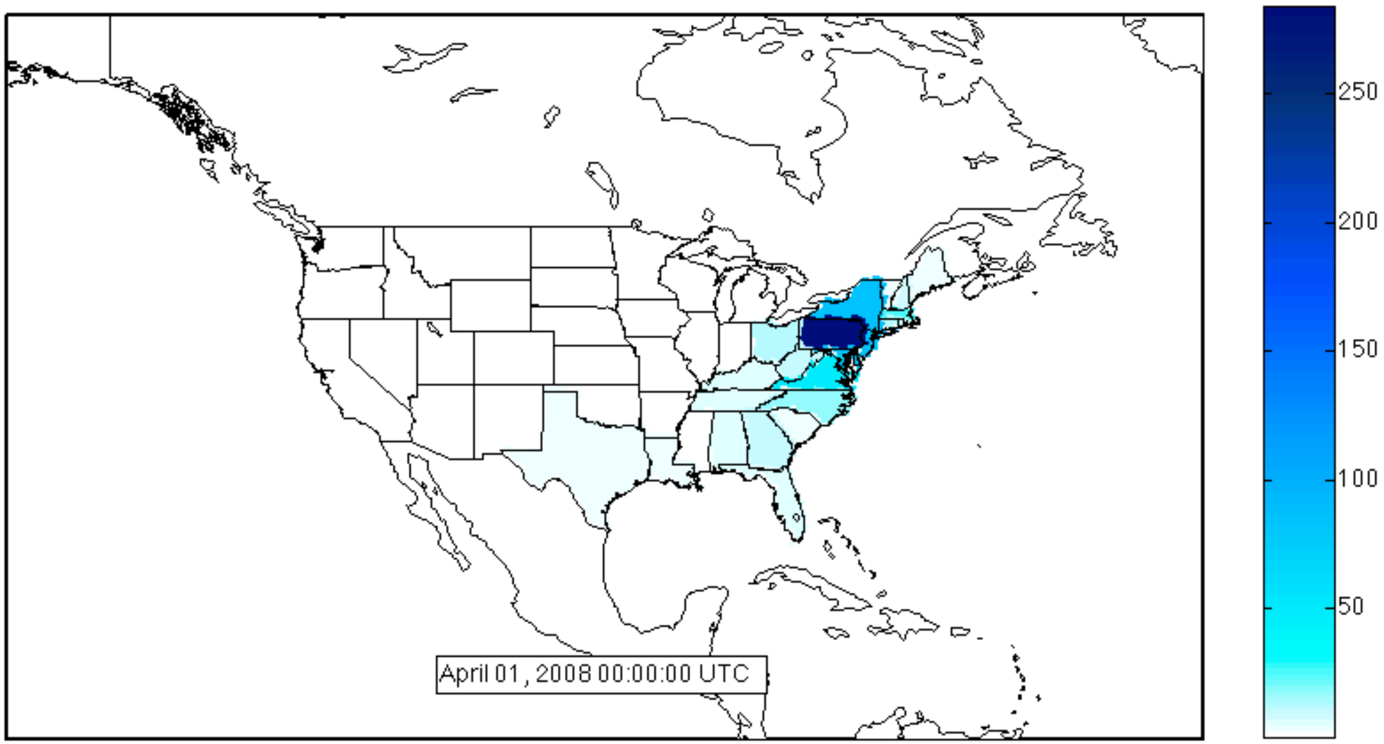


Receptor modeling allows us to identify states where emissions reductions would have the greatest benefit

preliminary results (April)

Milestone #3: Source attribution of BC aerosol related mortality

Contributions of emissions to mortality in Pennsylvania:



- A significant fraction of mortality in PA is owing to emissions outside PA
- Important in light of recent court ruling against interstate controls

preliminary results (April)

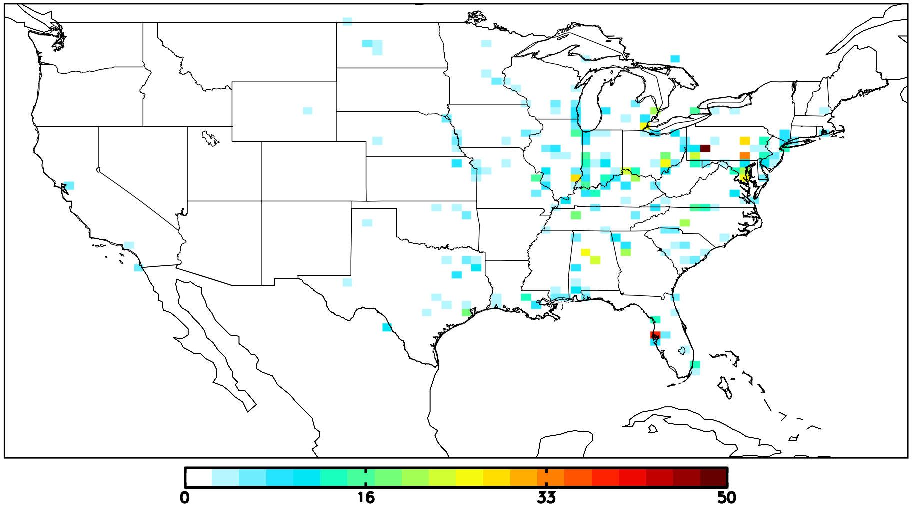
Milestone #3: source attribution of $PM_{2.5}$ related mortality

Source contributions to national mortality from $PM_{2.5}$
- total estimated to be 103,000 / yr

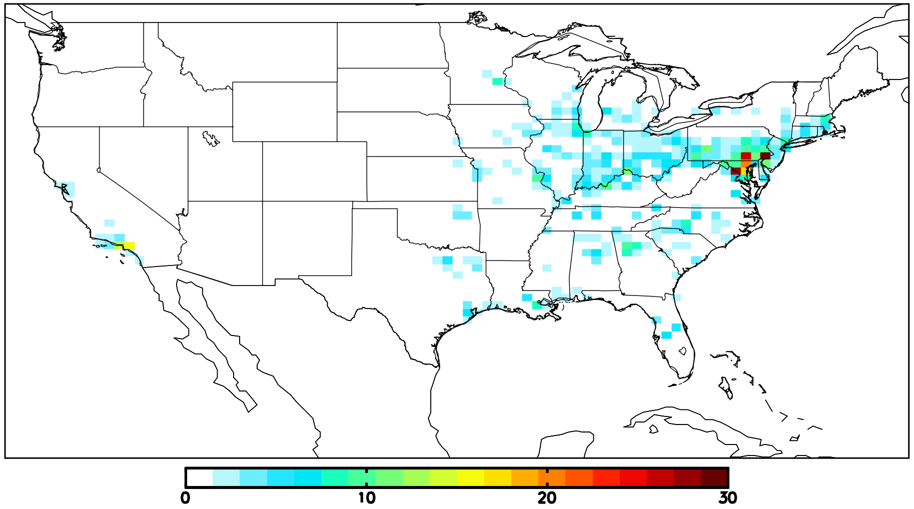
    compare to 130,000 / yr from EPA study (Fan et al., 2012))

- contributions by location / sector / species:

From fossil fuel SO_2 (26,300)



From fossil fuel NO_x (20,300)



note: preliminary analysis, complete annual average results in progress

Analysis valuable for determining health impacts of future emissions control strategies, particularly jointly addressing $PM_{2.5}$ and O_3

Summary of Progress

MS #1: New inverse modeling and source apportionment tools:
 - aerosol microphysical adjoint (*Turner et al., 2011a, 2011b, posters*)
 - ANISORROPIA thermodynamic adjoint (*Capps et al., ACP, 2012*)
 - online OMI NO_2 observation operator (*Pye et al., 2010, poster*)
 - GEOS-Chem nested adjoint model

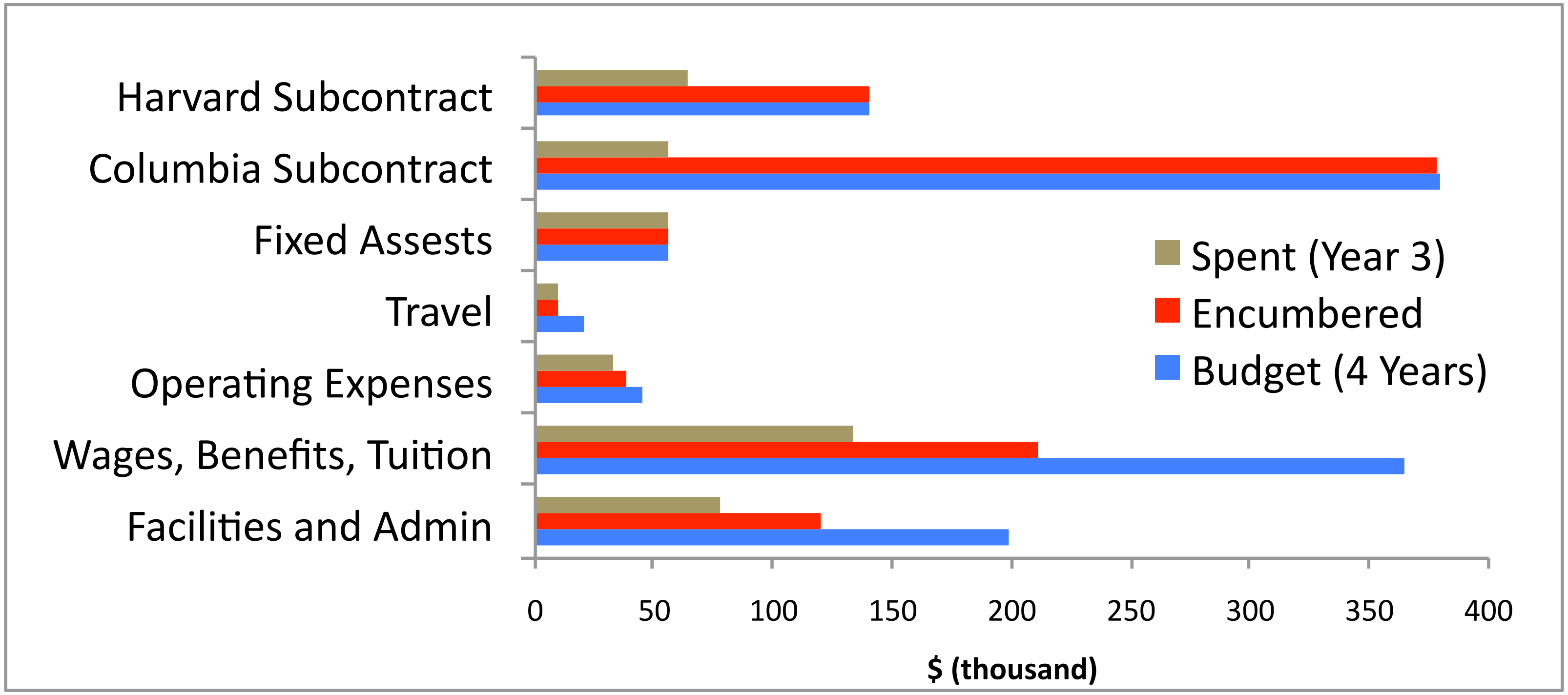
MS #2: Remote sensing constraints on emissions:
 - NEI underestimates NH_3 sources (*Zhu et al., submitted to JGR*)
 - TES imparts a different seasonality than wet deposition for NH_3 sources
 - Transport & chemistry important for constraining even very short-lived species (*Turner et al., GRL, 2012*)

MS #3: Source attribution of health impacts:
 - with GEOS-Chem and CMAQ for BC aerosol
 - for inorganic $PM_{2.5}$ with GEOS-Chem

MS #4: Accounting for interactions between AQ regulations and climate
 - source attribution of aerosol indirect effects from specific precursors (*Karydis, submitted to GRL*)
 - drive GEOS-Chem simulations with higher resolution AR5 climatology

$ Budget $
1,200,000 over four years

Budget update from year 3 report (08/01/2009 – 07/31/2012):



- Includes funding from year 4, expenses up through year 3

- Uncosted funds largely owing to
  - slow processing of subcontract to Harvard, Columbia
  - challenges hiring / maintaining postdocs jointly at CU Boulder / EPA

Risks and Challenges

Management:

- challenge to hire / maintain postdocs at EPA RTP through CU
  - initial plan was joint CU Boulder / EPA postdoc
  - significant bureaucratic barriers for internationals at EPA
  - US postdocs soon hired away to permanent positions
- Henze's group just getting started in 2009
  - building group from scratch took time
  - building computer lab postponed 1 year owing to campus delays

Technical:

- CMAQ adjoint model still being finalized
- TES NH_3 data challenging to utilize
- TES / OMI lifetime (consider CrIS, TROPOMI, GEO-CAPE for future)
- Driving GEOS-Chem with high resolution GISS climatology difficult

Scheduling:

- NAAQS review process at EPA a constantly moving target
- challenge to make our applications relevant to their needs

Applications Readiness Level

Present

ARL 4: Components technically integrated

- CMAQ aerosol aerosol verified on a component-by-component basis
- GEOS-Chem aerosol adjoint on North American nested grid
- EPA data sets (BenMAPs) used to calculate mortality owing to $PM_{2.5}$ exposure integrated into both, agree with BenMAPs to within >99%.

ARL 4: Organizational challenges identified and managed:

- Farhan Akhtar, Shannon Capps trained with these tools, currently or soon to be at EPA offices to facilitate long-term adoption

Goal: ARL 6 by end of 2012, ARL 8 by end of 2013

ARL 5: Prototype system: to be released this fall

ARL 5: Potential determined and articulated:

- presentation at CMAS 2012, build on 2011 workshop & town hall event

ARL 6: Prototype system beta-tested in a simulated operational environment: - already ongoing

References

Turner, M., D. K. Henze, A. Hakami, S. Zhao, J. Resler, G. Carmichael, C. Stanier, J. Baek, P. Saide, A. Sandu, A. Russell, G. Jeong, A. Nenes, S. Capps, P. Percell, R. W. Pinder, S. Napelenok, H. Pye, J. O. Bash, T. Chai, D. Byun, Aerosols Processes in the CMAQ Adjoint, International Aerosol Modeling Algorithms Conference, Davis, CA, Nov 30 - Dec 2, 2011a.

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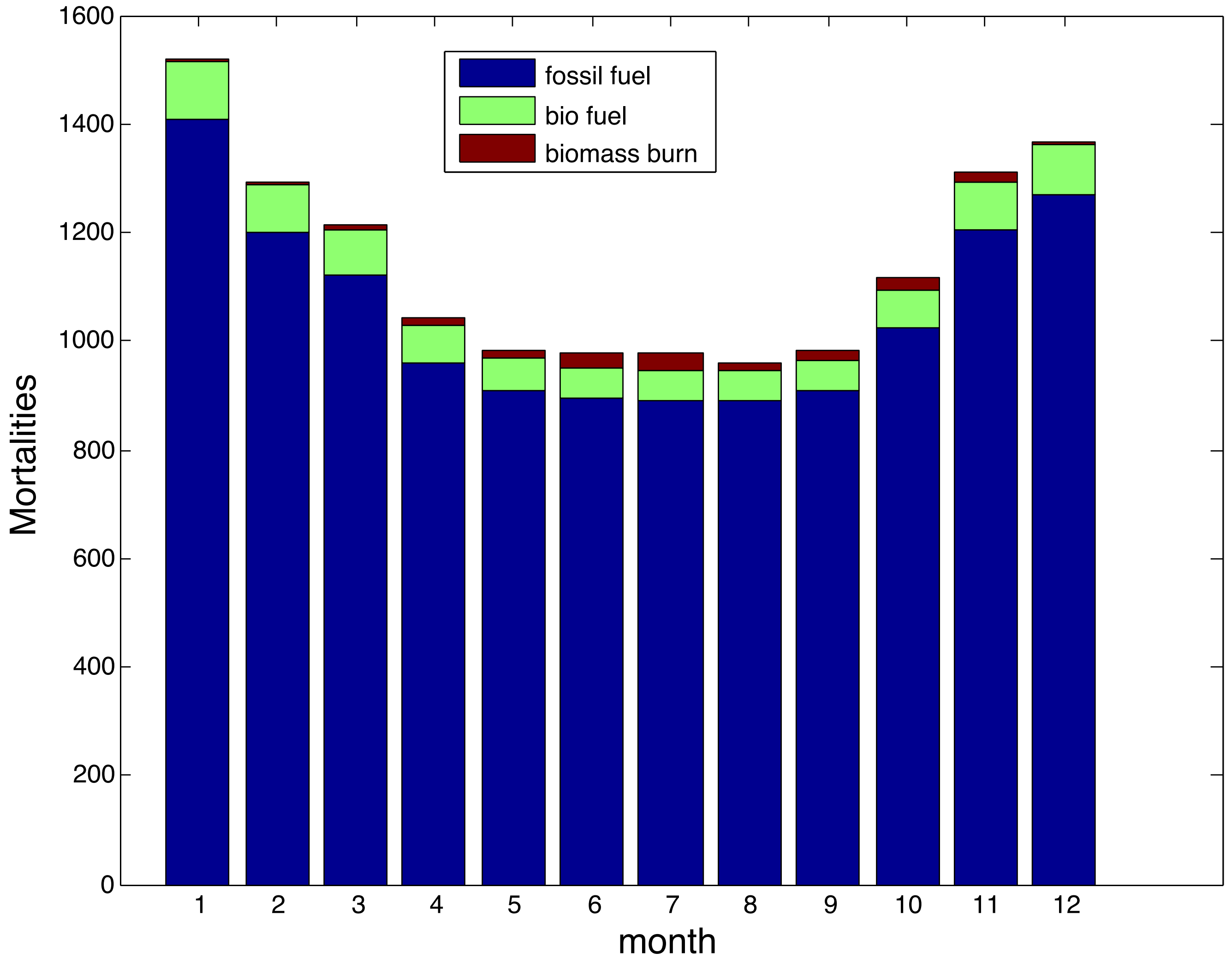
L. Zhu, D. K. Henze, K. E. Cady-Pereira, M. W. Shephard, M. Luo, R. W. Pinder, J. O. Bash, G. Jeong, Constraining U.S. ammonia emissions using TES remote sensing observations and the GEOS-Chem adjoint model, *submitted to JGR*, 2012.

bonus slides!

Technical results: source attribution of carbonaceous aerosol related mortality



Monthly mortalities owing to BC emissions from entire domain

Milestone #3:
Source attribution of BC aerosol related mortality

Interpretation of adjoint model results

Example:

- Value of 35 in grid box over your county means?

  --> emissions in your county contributed to 35 premature mortalities

- where were those 35 mortalities?

  --> Adjoint only tells us they were somewhere in the entire US.

Milestone #3:
Source attribution of BC aerosol related mortality