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Development & Application of Advanced Plume-in-Grid PM Models

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AER

San Ramon, CA

CMAS Workshop 2005

Chapel Hill, NC

Why Use Plume-in-Grid Approach?

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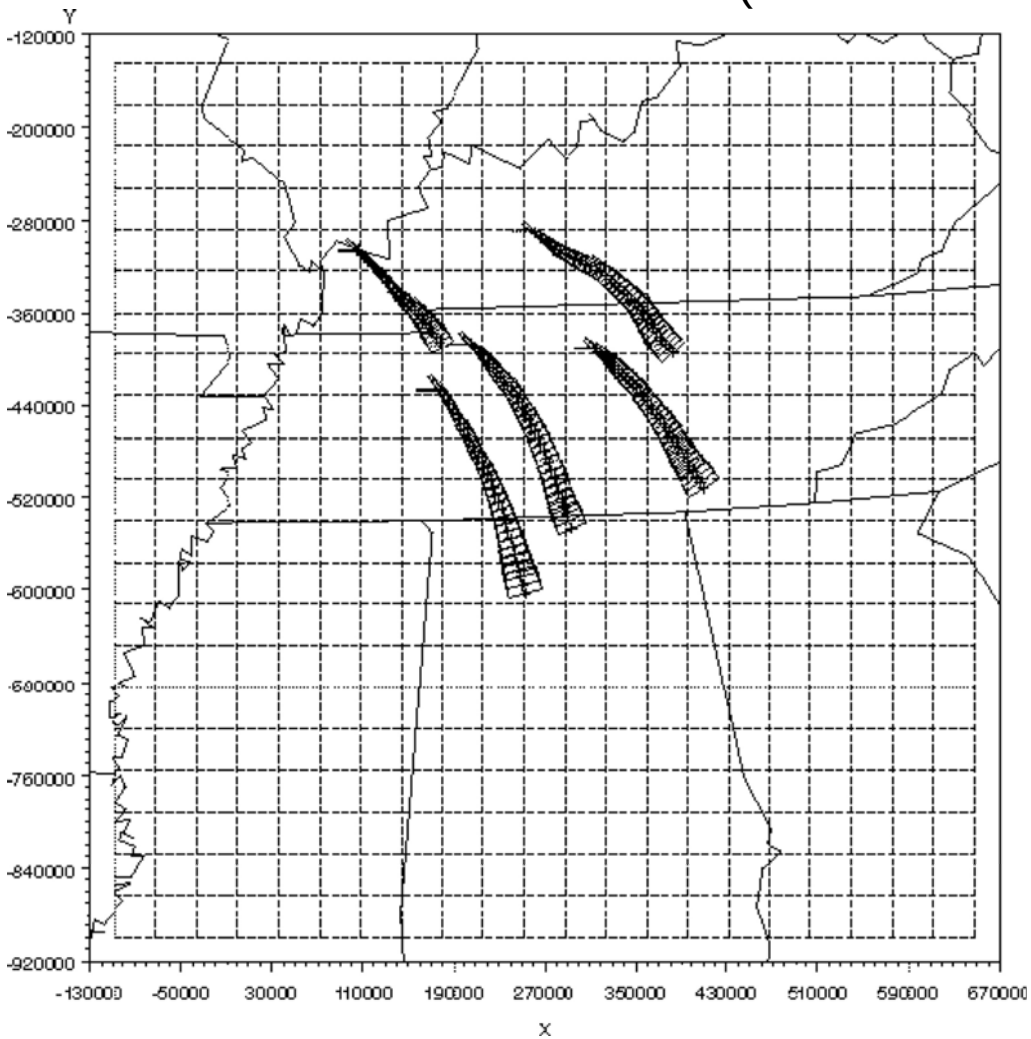
Plume Size vs Grid Size (from Godowitch, 2004)



Limitations of Purely Grid-Based Approach

- **Artificial dilution of stack emissions**
- **Unrealistic near-stack plume concentrations**
- **Incorrect representation of plume chemistry**
- **Incorrect representation of plume transport**

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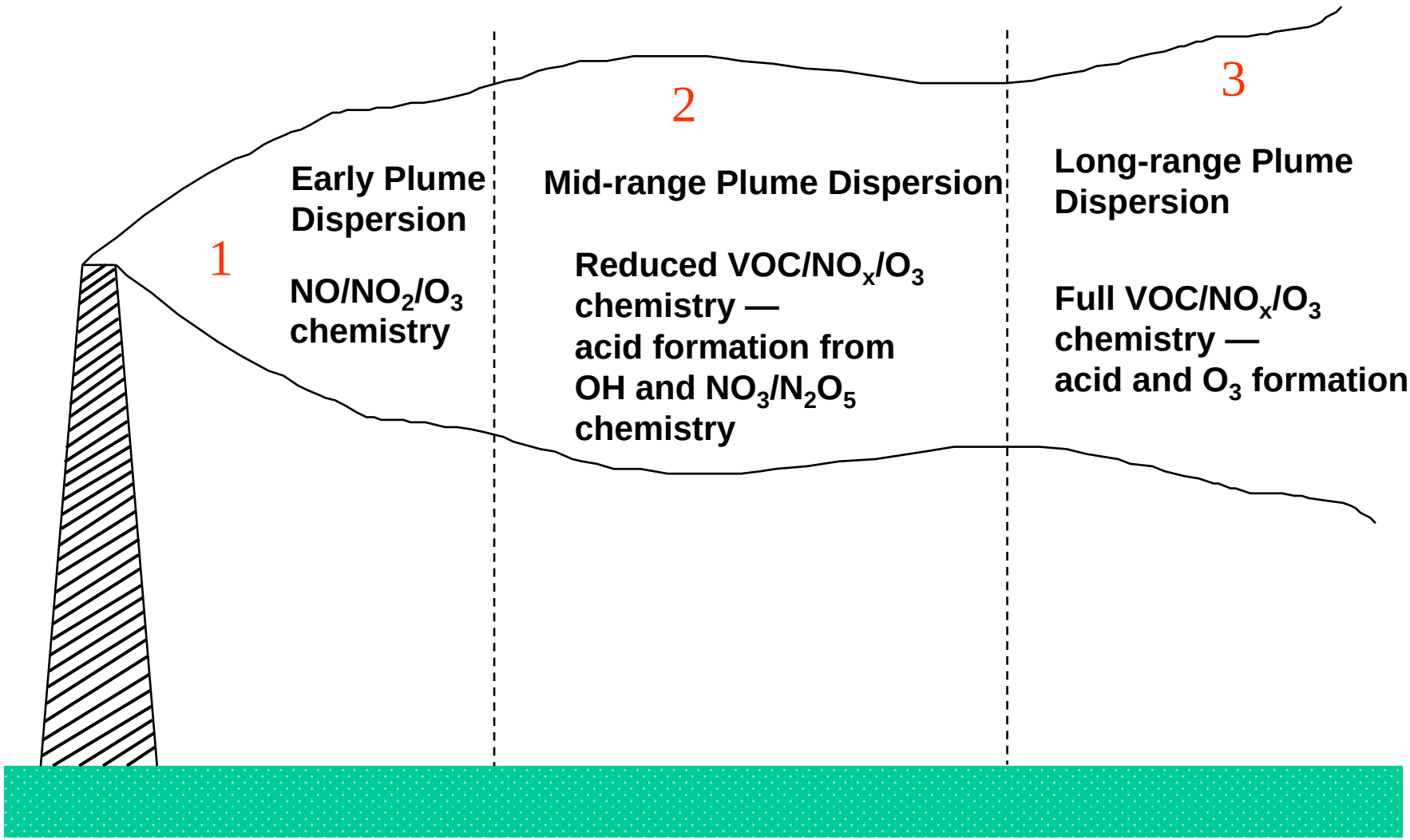
Plume Chemistry & Relevance to PM Modeling



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CMAQ-APT-PM & CMAQ-MADRID-APT

- **Based on CMAQ v 4.4, October 2004 release**
- **APT: Advanced Plume Treatment**
- **MADRID: Model of Aerosol Dynamics, Reaction, Ionization and Dissolution**
- **Host Models:**
  - **CMAQ for CMAQ-APT-PM**
  - **CMAQ-MADRID for CMAQ-MADRID-APT**
- **Embedded Plume Model: SCICHEM (state-of-the science treatment of stack plumes at the sub-grid scale)**

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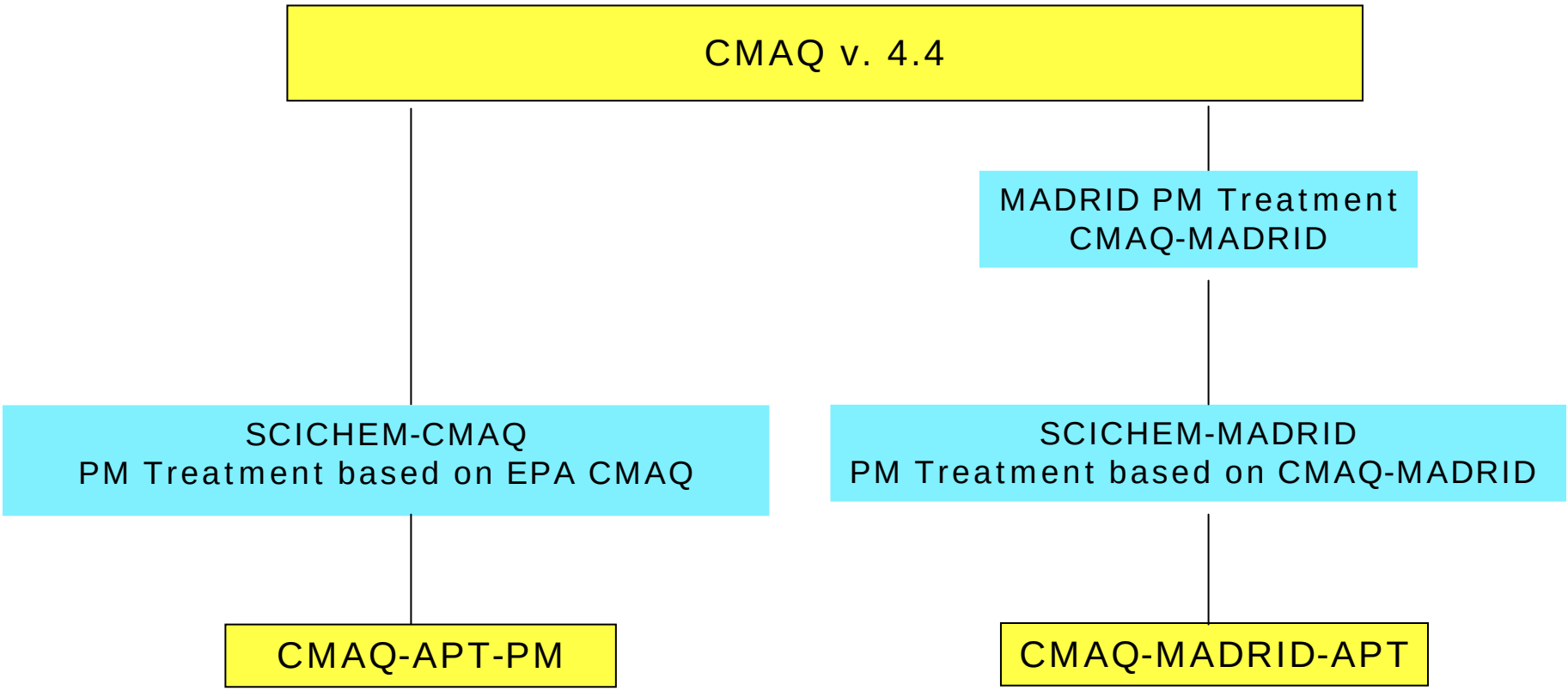
Model Components



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SCICHEM

- **Three-dimensional puff-based model**
- **Second-order closure approach for plume dispersion**
- **Puff splitting and merging**
- **Optional treatment of building downwash**
- **Non-linear chemical kinetics based on commonly used gas-phase chemistry mechanisms (e.g., CBM-IV)**
- **Optional treatment of turbulent chemistry**
- **PM and aqueous-phase chemistry treatments consistent with host model**

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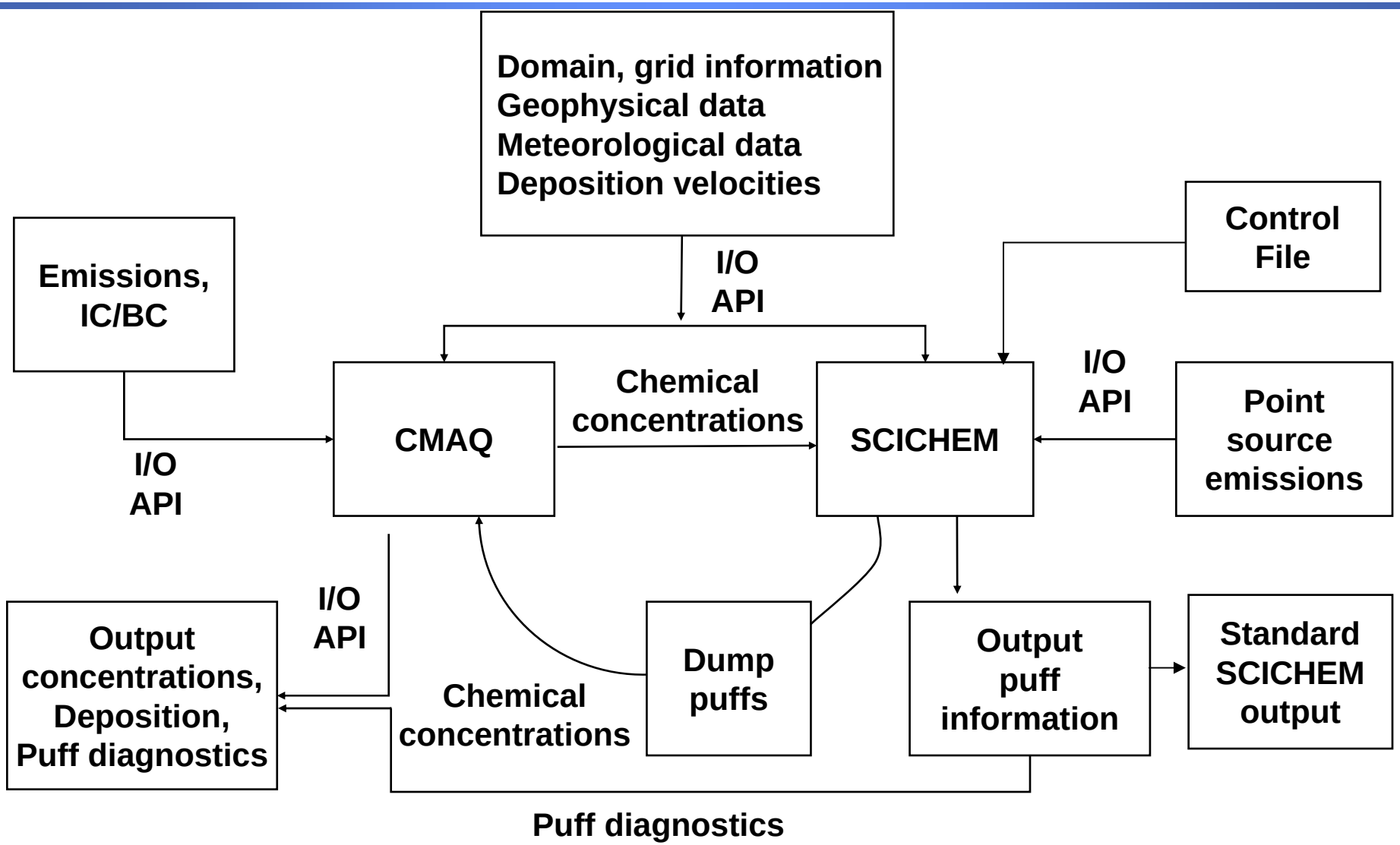
Model Interaction Diagram



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Application to Southeastern U.S.

- **Study designed to supplement RPO modeling being conducted by the Visibility Improvement State and Tribal Association of the Southeast (VISTAS)**
- **2 months simulated (January and July 2002) with Base CMAQ v 4.4 and CMAQ-APT-PM**
- **14 Southern Company (SoCo) power plant plumes explicitly simulated with plume-in-grid approach**
- **Model performance: Base CMAQ vs. CMAQ-APT-PM**
- **Power plant contributions to $PM_{2.5}$ components calculated and compared for Base CMAQ and CMAQ-APT-PM**

Modeling Domain and Locations of SoCo PinG sources

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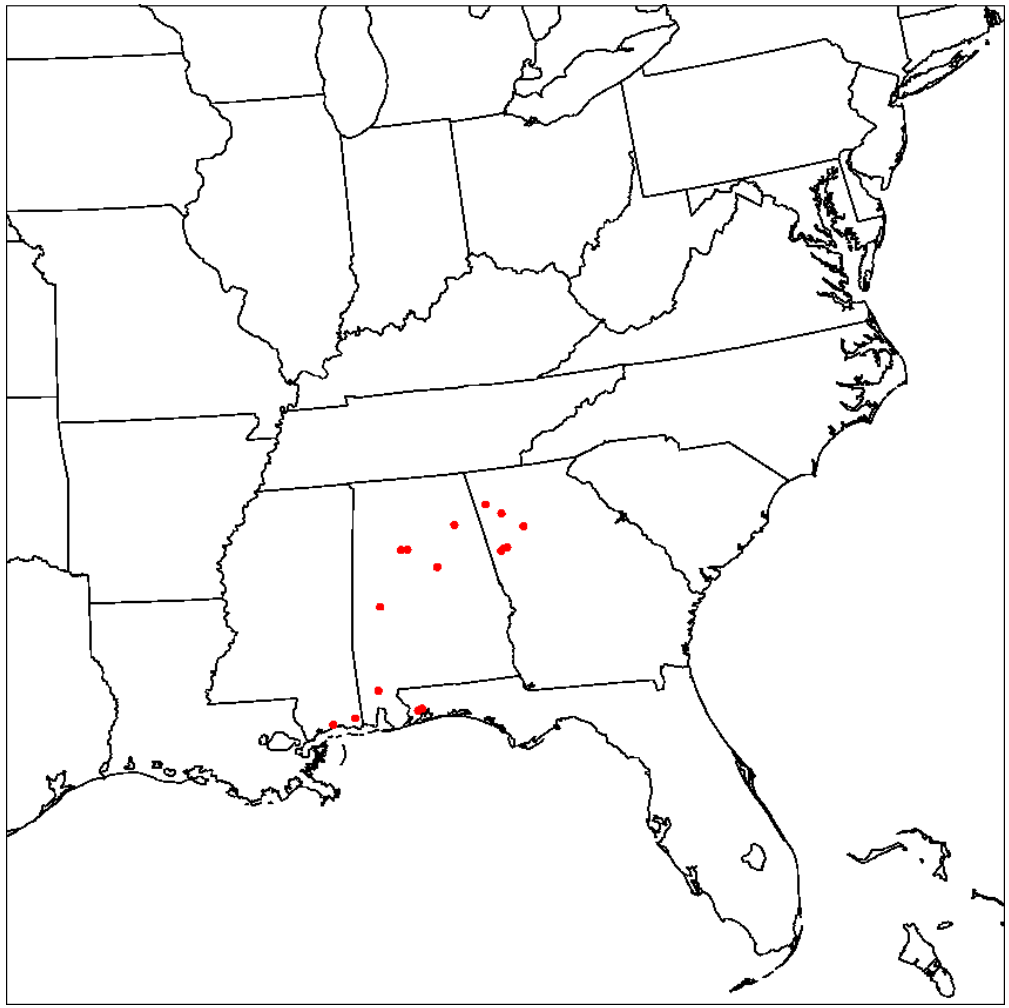

Alabama
Barry
Gadsden
Gaston
Gorgas
Greene County
Miller

Florida
Crist

Georgia
Bowen
Hammond
McDonough
Wansley
Yates

Mississippi
Daniel
Watson

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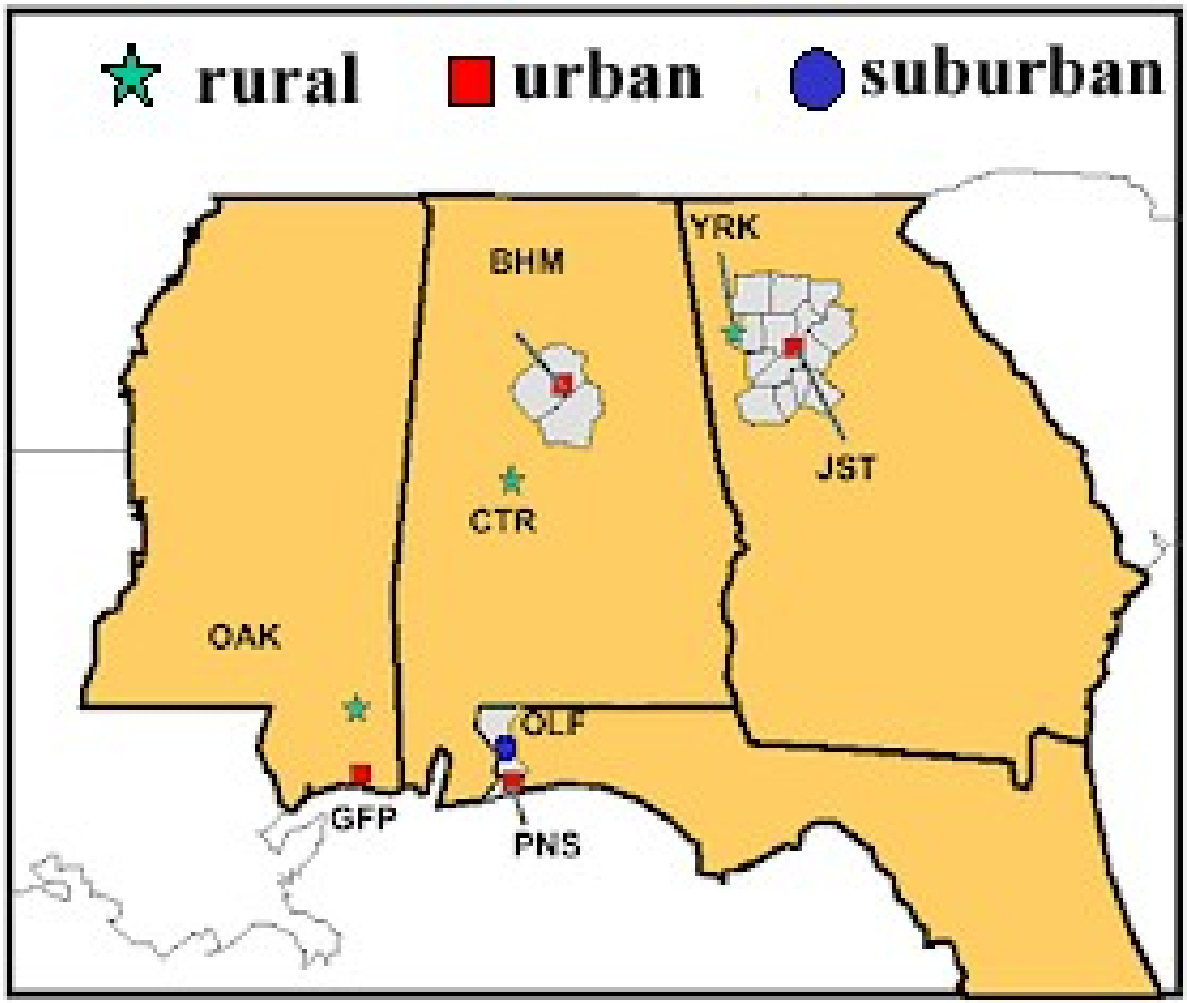
Model Performance Comparison

- **SEARCH (8 sites)**
- **AQS (~25 sites for PM components)**
- **CASTNet (~45 sites)**
- **IMPROVE (~35 sites)**
- **Comparisons for AQS, CASTNet and IMPROVE networks show very small differences in model performance between Base CMAQ and CMAQ-APT-PM**
- **Larger differences noted for the SEARCH network where monitoring sites are located in the region of interest**

Monitoring Stations in SEARCH network (from ARA web site)

operated by Atmospheric Research & Analysis, Inc. (ARA)



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Performance Statistics for SEARCH Network, July 2002

	Sulfate		Nitrate		Total $PM_{2.5}$	
	BASE	APT	BASE	APT	BASE	APT
Mean Observed Value ($\mu g/m^3$)	4.9		0.4		16.1	
Mean Modeled Value ($\mu g/m^3$)	6.3	5.8	0.1	0.1	11.7	11.2
Mean Normalized Bias (%)	30	19	-90	-90	-31	-34
Mean Normalized Error (%)	60	53	90	90	42	43
Coefficient of Determination (r^2)	0.46	0.49	0.24	0.24	0.52	0.54

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Performance Statistics for SEARCH Network, January 2002

	Sulfate		Nitrate		Total $PM_{2.5}$	
	BASE	APT	BASE	APT	BASE	APT
Mean Observed Value ($\mu g/m^3$)	2.2		1.1		11.2	
Mean Modeled Value ($\mu g/m^3$)	2.3	2.2	1.3	1.3	11.8	11.7
Mean Normalized Bias (%)	12	7	13	15	7	6
Mean Normalized Error (%)	43	42	76	77	34	34
Coefficient of Determination (r^2)	0.09	0.08	0.54	0.54	0.51	0.51

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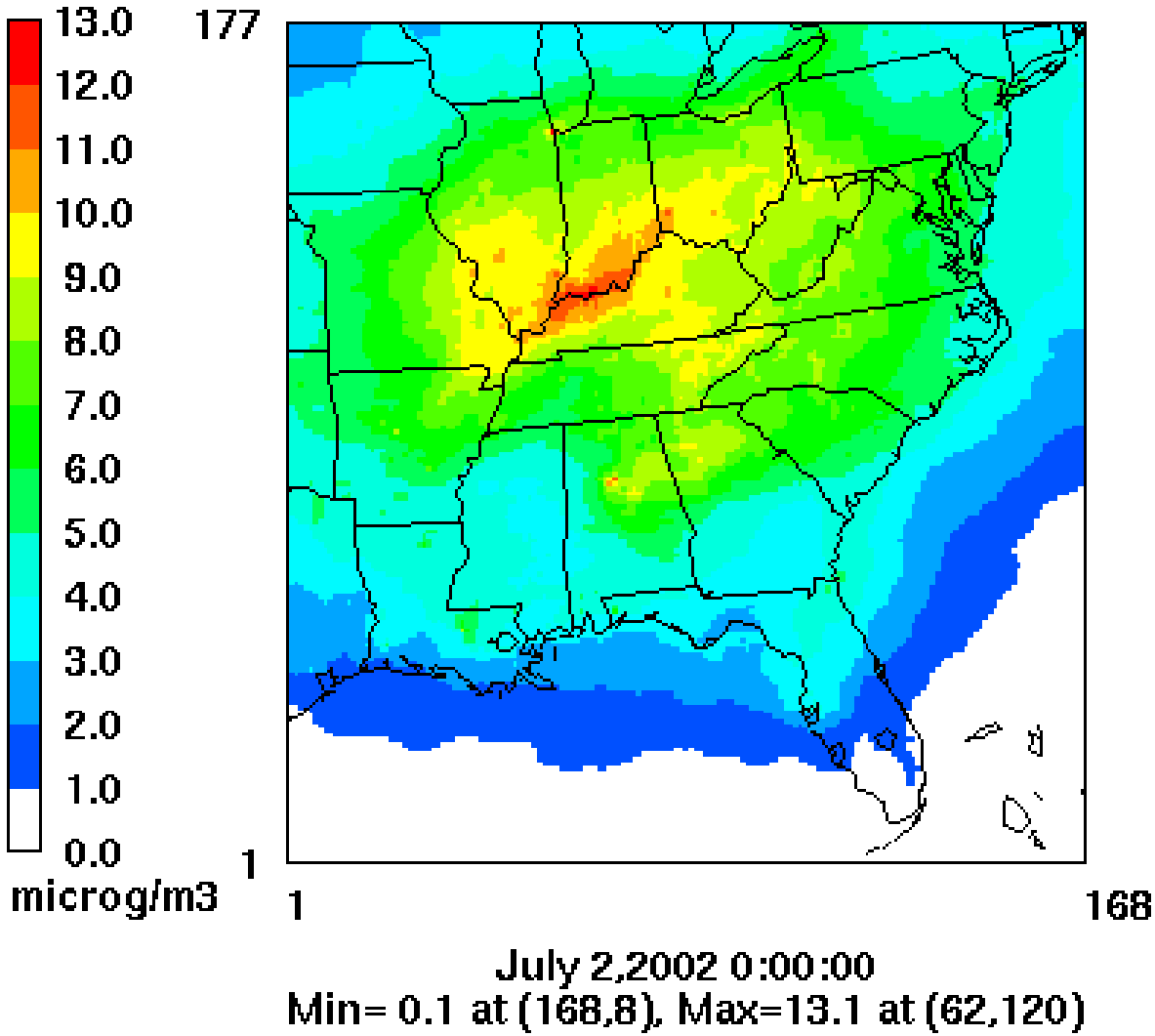
Average $PM_{2.5}$ Sulfate Concentrations During July 2-31, 2002 (Base CMAQ)



SoCo Power-Plant Contributions to Average July $PM_{2.5}$ Sulfate Concentrations

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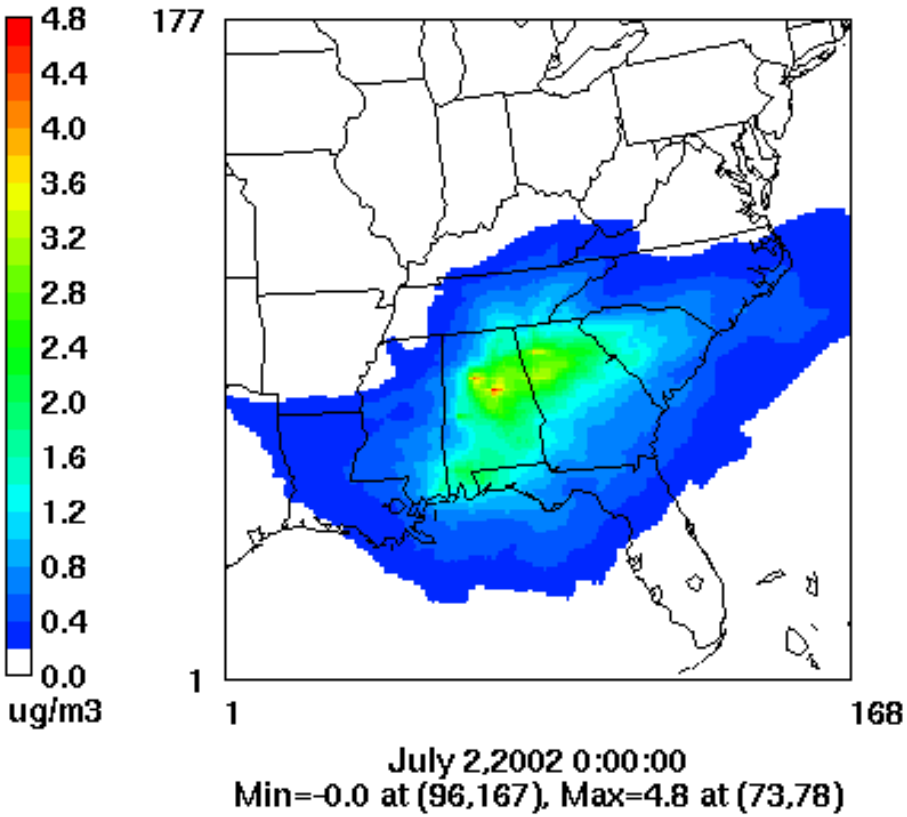
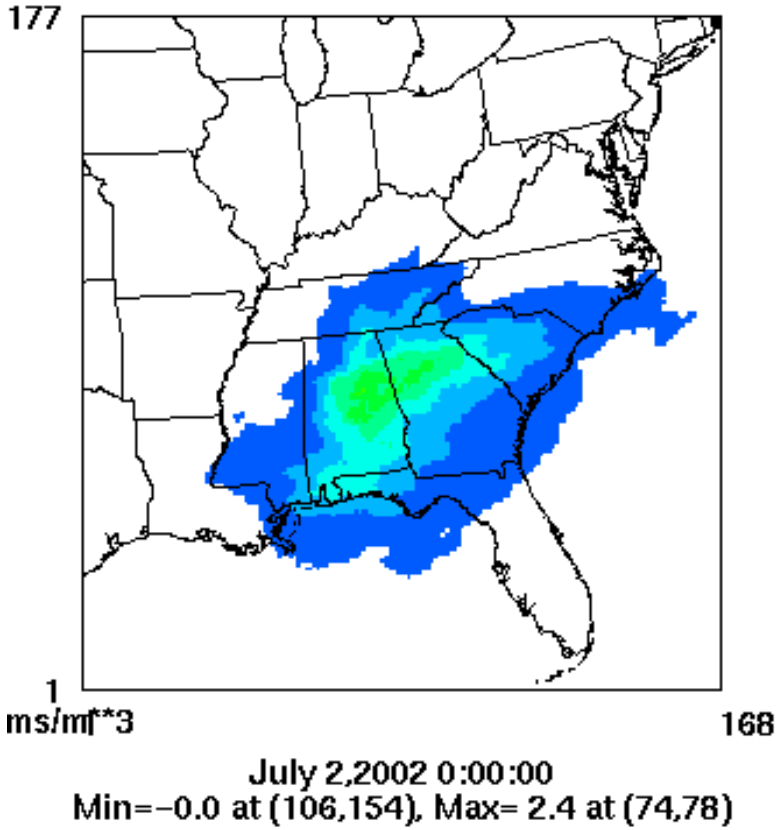


Base CMAQ



CMAQ-APT-PM

Change in SoCo Power-Plant Contributions to $PM_{2.5}$ Sulfate Concentrations When a Plume-in-Grid Approach is Used

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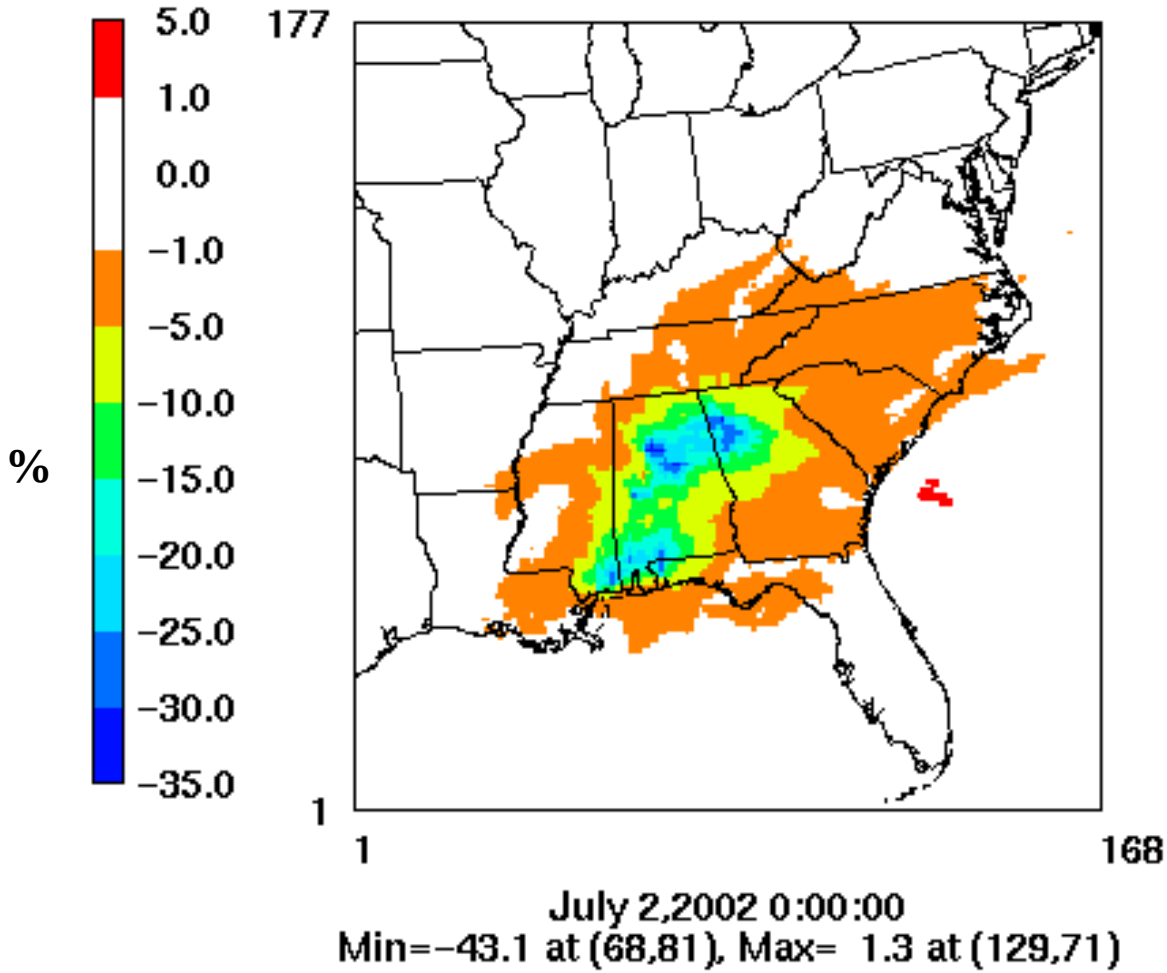

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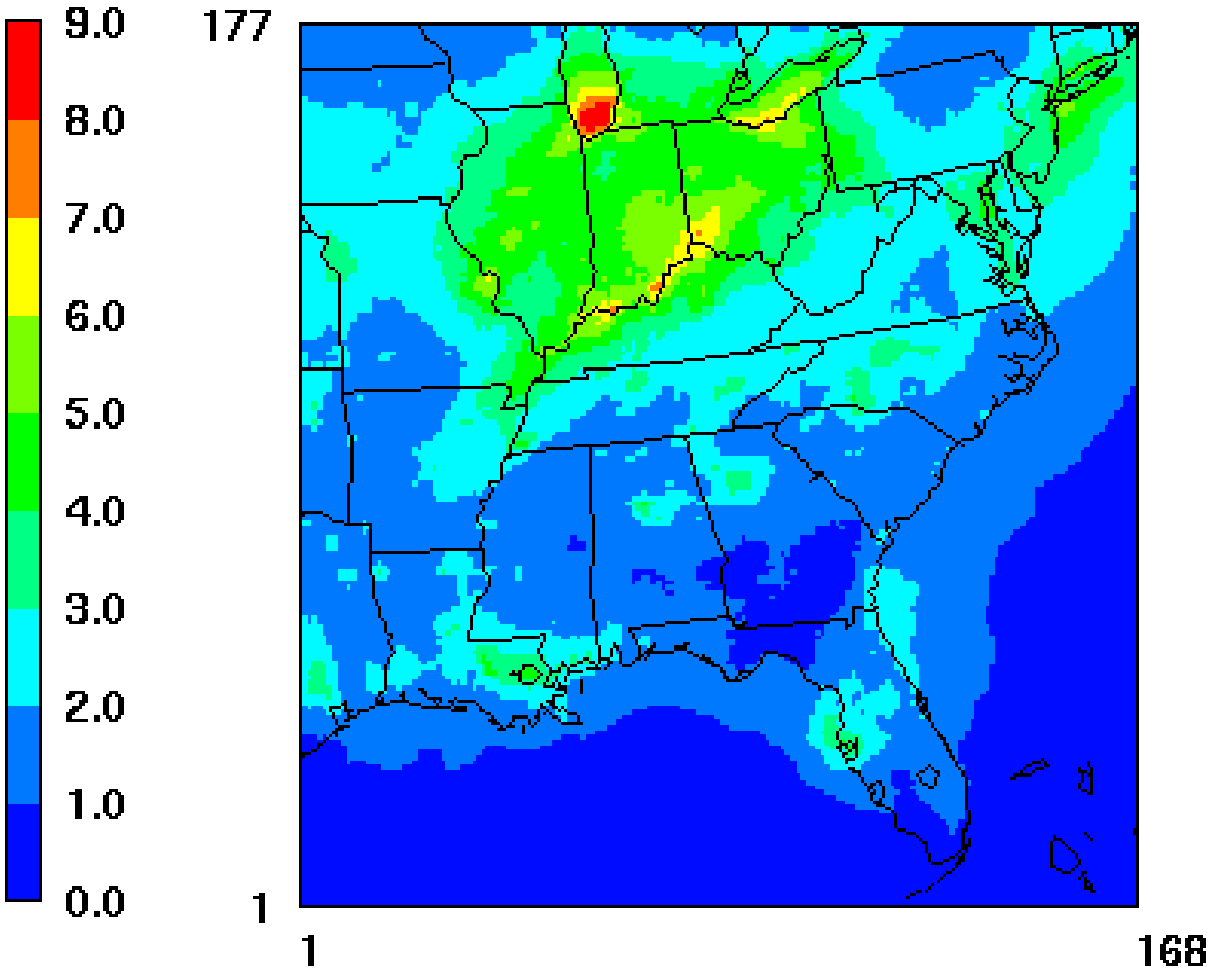
Average Total Nitrate Concentrations During July 2-31, 2002 (Base CMAQ)



SoCo Power-Plant Contributions to Average July Total Nitrate Concentrations

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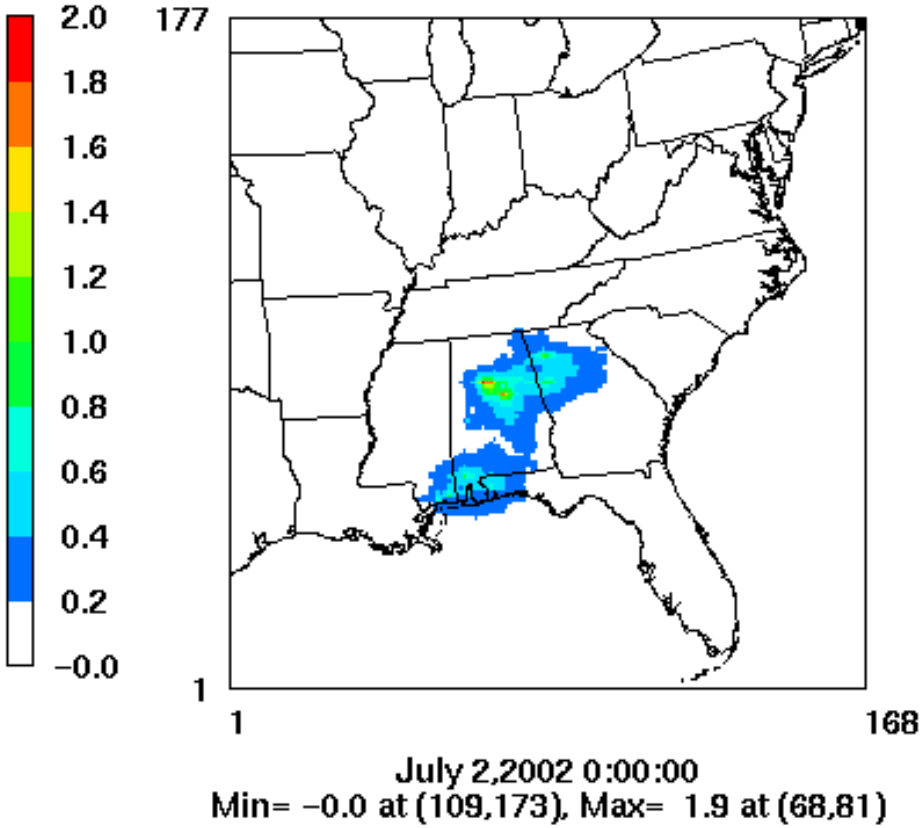
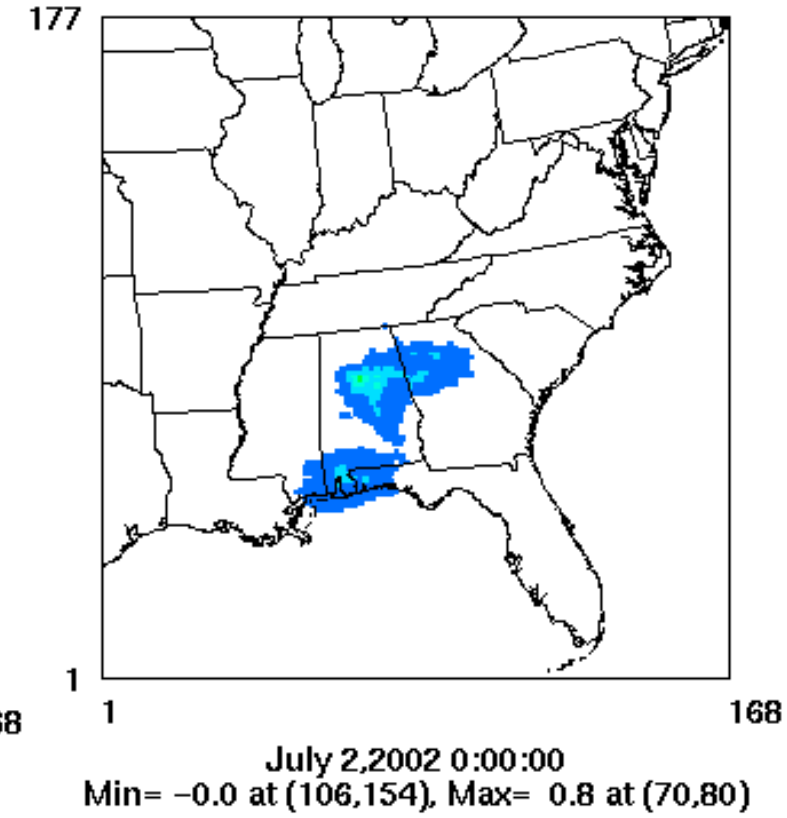


Base CMAQ



CMAQ-APT-PM

Change in SoCo Power-Plant Contributions to Total Nitrate Concentrations When a Plume-in-Grid Approach is Used

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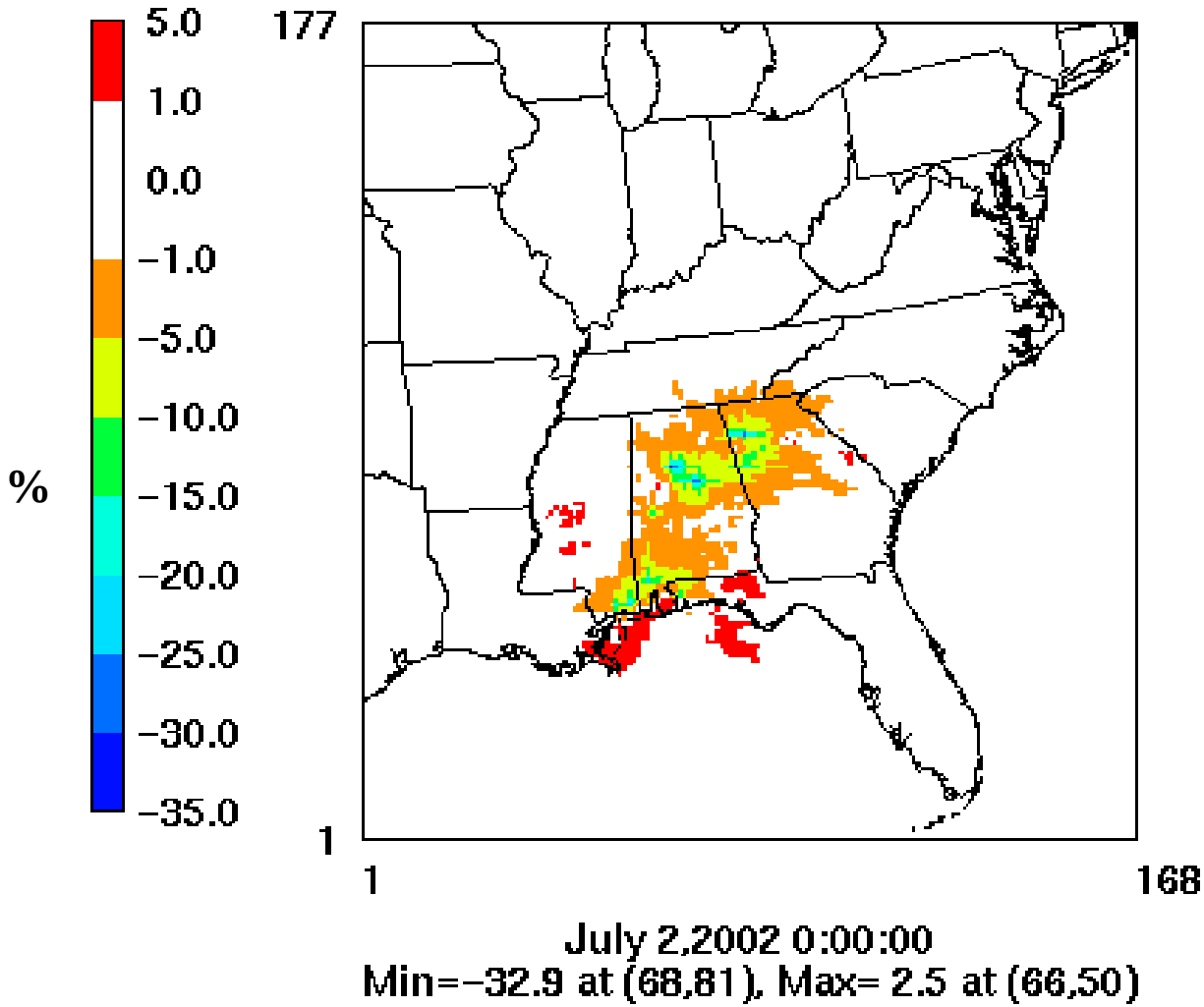

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Conversion of SoCo Power Plant SO_2 Emissions

Domain-wide mass-budget analysis performed for SO_2 and sulfate attributable to SoCo power plant emissions

Sulfate to Total Sulfur Ratios (%)

	Emissions	Base CMAQ	CMAQ-APT
January	2.25	17.8	15.6
July	2.35	75.5	67.4

Approximate SO_2 Conversion (%)

	Base CMAQ	CMAQ-APT	Change
January	15.9	13.7	-14%
July	74.9	66.6	-11%

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Conclusions

- **Using a purely gridded approach will typically overestimate power plant contributions to PM because SO_2 to sulfate and NO_x to nitrate conversion rates are overestimated**
- **Plume-in-grid PM modeling provides a better representation of the near-source transport and chemistry of point source emissions and their contributions to $PM_{2.5}$ concentrations**
- **Base CMAQ predicts larger power plant contributions than CMAQ-APT-PM to sulfate and total nitrate, particularly in summer**

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Ongoing Work & Next Steps

- **Development of CMAQ-MADRID-APT (completed)**
- **Application of CMAQ-MADRID and CMAQ-MADRID-APT for July and January 2002 VISTAS episodes (ongoing)**
- **Implementation of mercury modules in CMAQ-MADRID-APT (ongoing, see Knipping and Vijayaraghavan presentations in this session)**

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Acknowledgements

- **EPRI**
- **Southern Company**
- **VISTAS**