Multi-scale and Ensemble Modeling of the Effects of Global Change on Air Quality in the US

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Research Questions

1) How will global change affect regional air quality in the future?
2) How will changes in U.S. anthropogenic emissions impact regional air quality
3) How are biogenic emissions affected by global climate change and land management practices and thus affect air quality?
4) How will changes in emissions in Asia impact U.S. air quality?
5) How will the role of fire change be with respect to regional air quality in the future?
6) How will global change affect atmospheric deposition in sensitive ecosystems and visibility?

Research Collaborators

- **WSU**: Rodrigo Gonzalez Abraham, Serena Chung and Brian Lamb
- **UW**: Cliff Mass, Eric Salathé and Yongxin Zhang (now at NCAR)
- **NCAR**: Tiffany Duhl, Alex Guenther and Christine Wiedinmyer
- **USDA Forest Service**: Sim Larkin, Don McKenzie, Natasha Stavros and Tara Strand
- **CARB**: Jeremy Avise
- **EPA:** Dan Loughlin and Chris Nolte
- **Argonne National Lab**: David Streets

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Modeling Approach

Modeling Approach

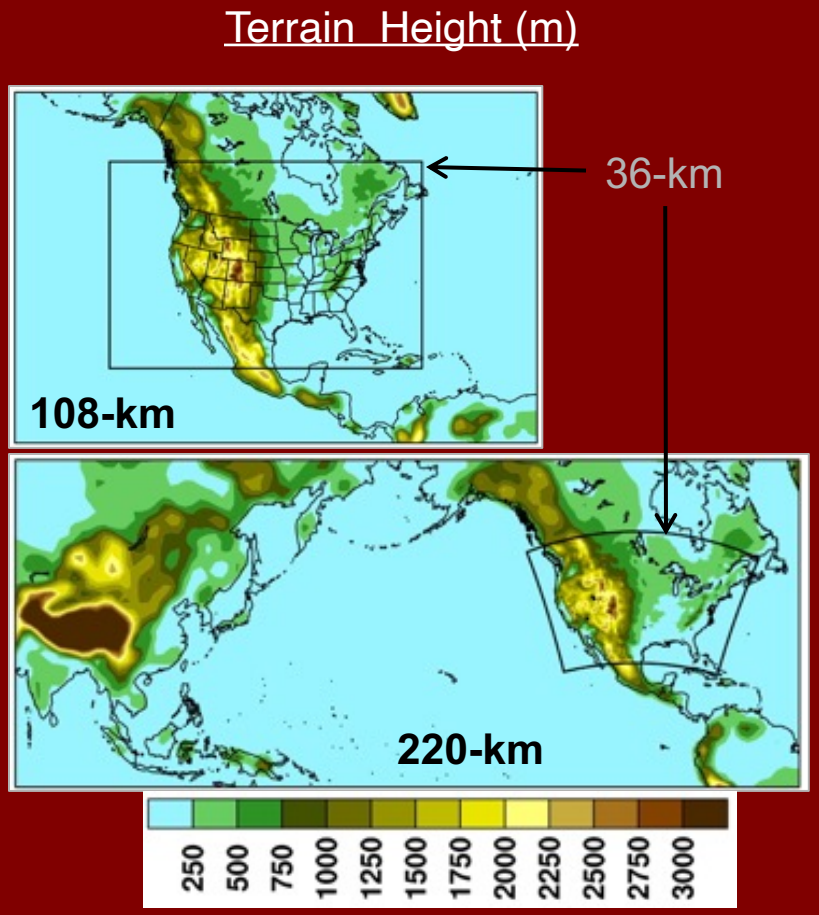
Employ an ensemble of simulations to address the research questions AND to assess the uncertainty in the modeling framework and in future projections.

Meteorological Downscaling

- WRF simulations:
  - ➢220-km grids for partial hemispheric domain
  - ➢nested domains with 108-km & 36-km grids for the US

Chemical Downscaling

- CMAQ v4.7 with 220-km grids for partial hemispheric domain
- CMAQ v4.7 with 36-km grids for the US domain

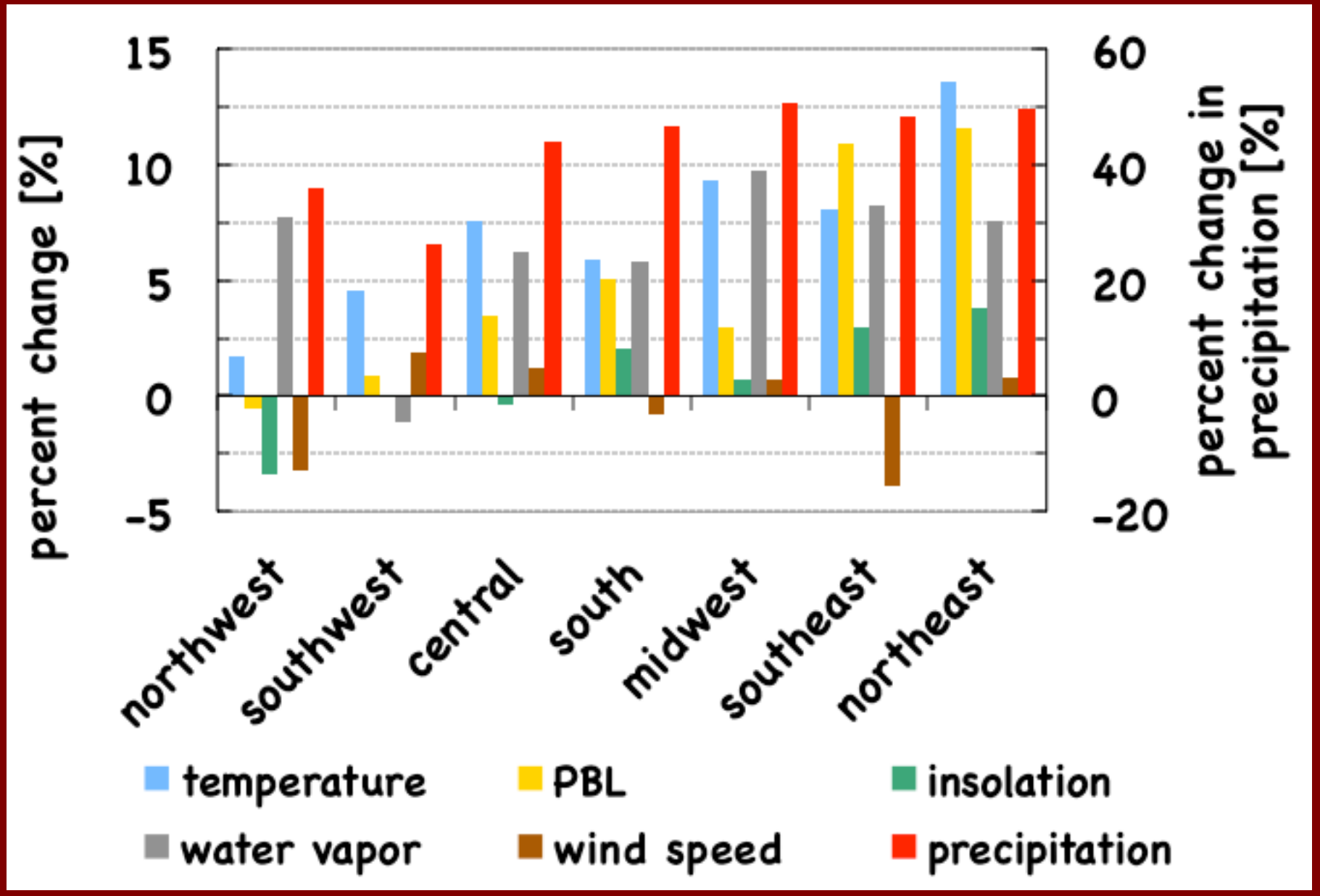


Modeling Approach

- Climate
  - ECHAM5 and CCSM3 global climate models
  - IPCC SRES A1B and B1 scenarios
  - 1995-2004 & 2045-2054 using distribution of five summers in each decade
- Anthropogenic Emissions:
  - Partial hemispheric domain CMAQ simulations
    - POET inventory and Bond et al (2004) for current decade
    - 2050 projection factors from David Streets.
  - US-domain CMAQ simulations
    - NEI 2002 for current decade
    - MARKAL (MARKet Allocation) business-as-usual scenario with regulatory curtailment for future decade.
- MEGAN biogenic emissions model
  - Future land-use data based on IMAGE 2100 global cropland extent data, the SAGE maximum cultivable land data, and the MODIS cropland data
- Fire Scenario Builder
  - Current and future meteorology to determine the effect of forest fires in US-air quality

Attribution Simulations

	Climate	Biogenic Emissions		Anthropogenic Emissions	
		Climate	Land Use	US	Global
1	Current	Current	Current	Current	Current
2	Future	Current	Current	Current	Current
3	Future	Future	Current	Current	Current
4	Future	Future	Future	Current	Current
5	Current	Current	Current	Future	Current
6	Current	Current	Current	Current	Future
7	Future	Future	Future	Future	Future

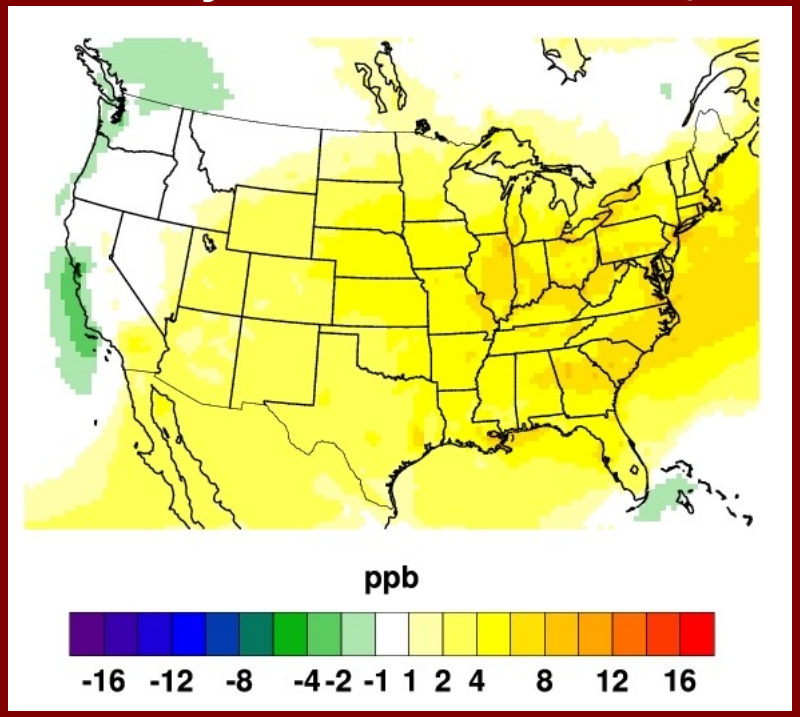


Temperature and PBL are change in the average daily maximum value, while other parameters are change in the average value

Preliminary Results

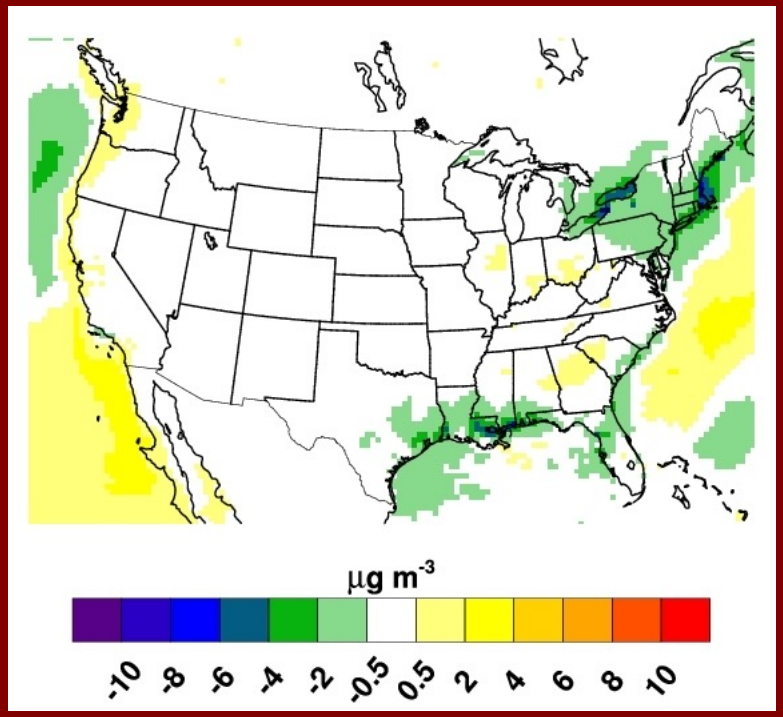
Future Climate vs Current

Δ Daily Maximum 8-Hour O_3



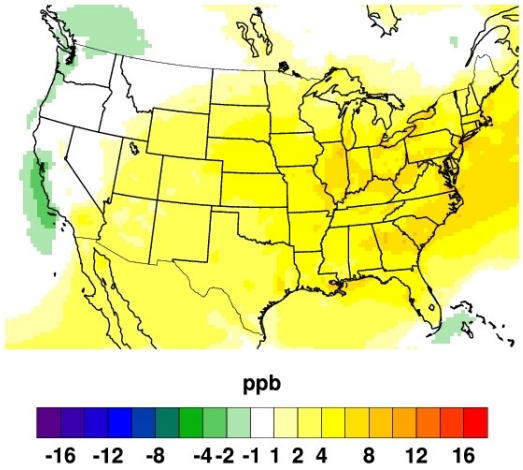
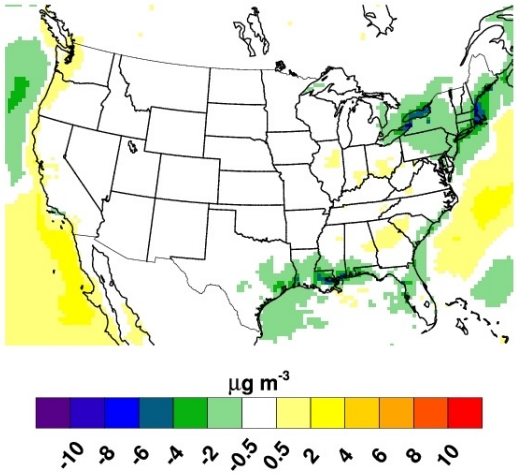
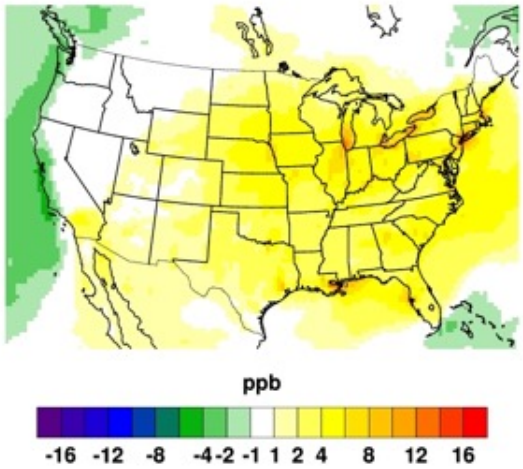
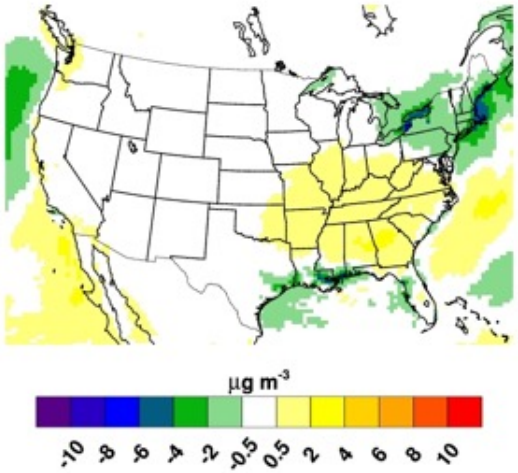
- Increase in O_3 in the eastern 2/3s of the US
- Decrease in O_3 in the Northwest and western California
- Correlate with temperature changes

Δ Hourly $PM_{2.5}$



- Increase in SOA in the Southeast due to increased photochemistry
- Decrease in the Northeast due to increased precipitation

Future Climate & Biogenic Emissions vs Current

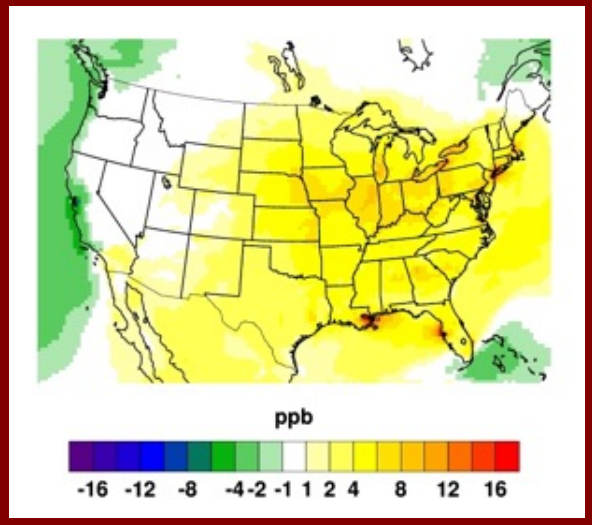
	Δ Daily Maximum 8-Hour O_3	Δ Hourly $PM_{2.5}$
No Biogenic Emission Change		
with Biogenic Emission Change but no Land-Use Change		

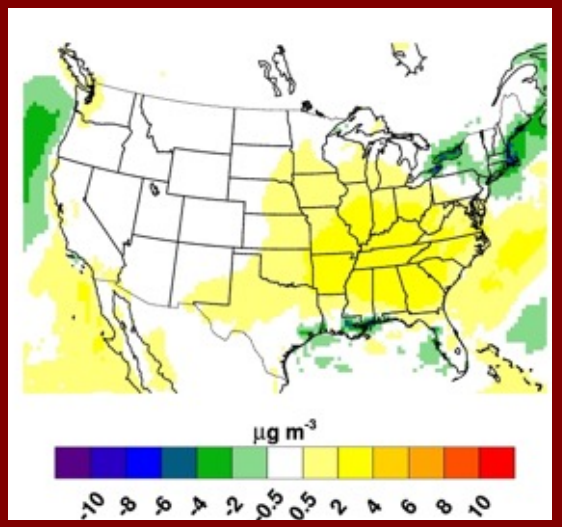
Future Climate & Biogenic Emissions vs Current

Δ Daily Maximum 8-Hour O_3

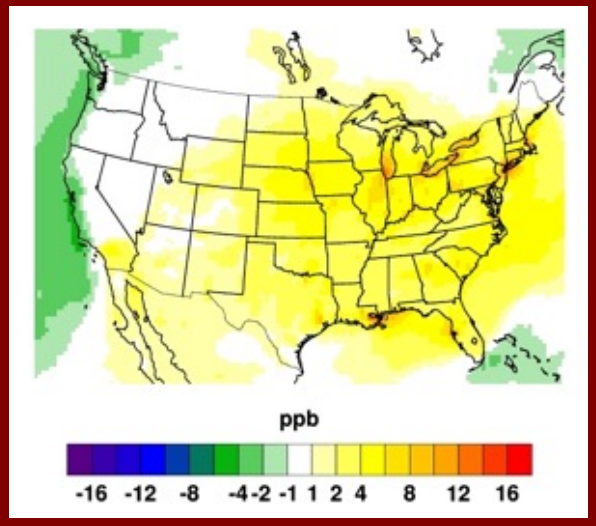
Δ Hourly $PM_{2.5}$

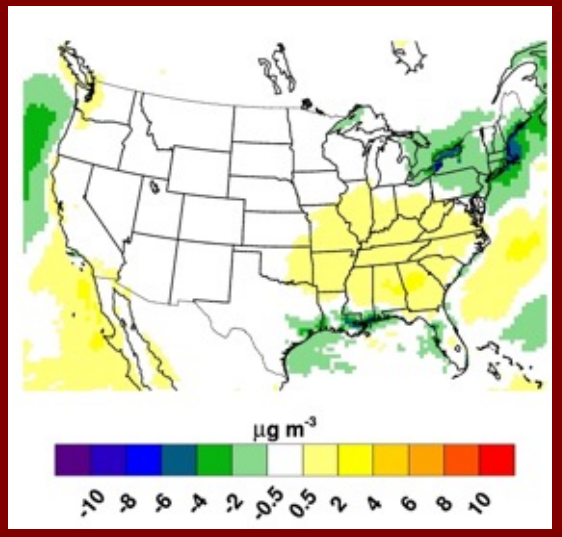
with Biogenic Emission & Land-Use Change





with Biogenic Emission Change but no Land-Use Change



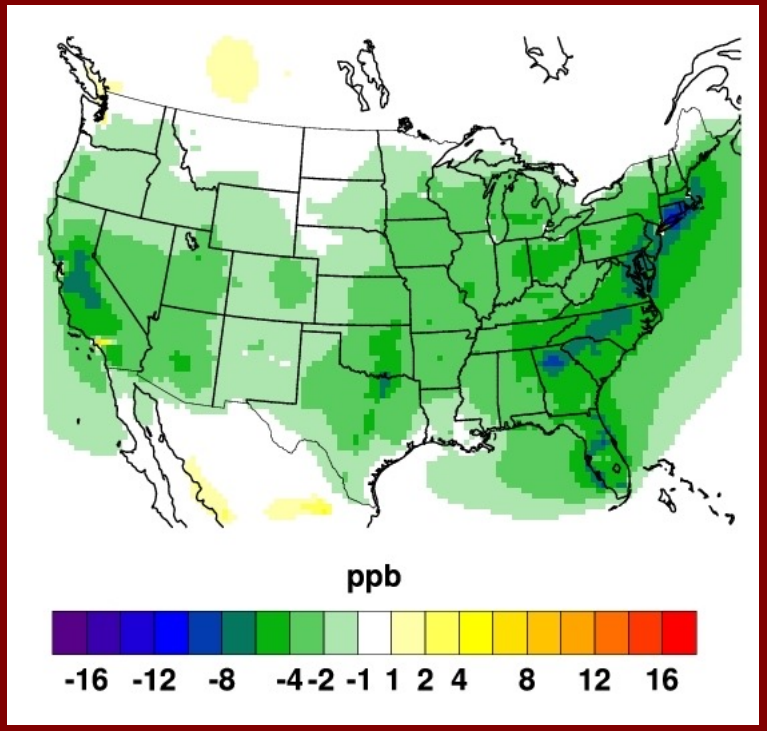


- Changes in land use slightly increases O_3.

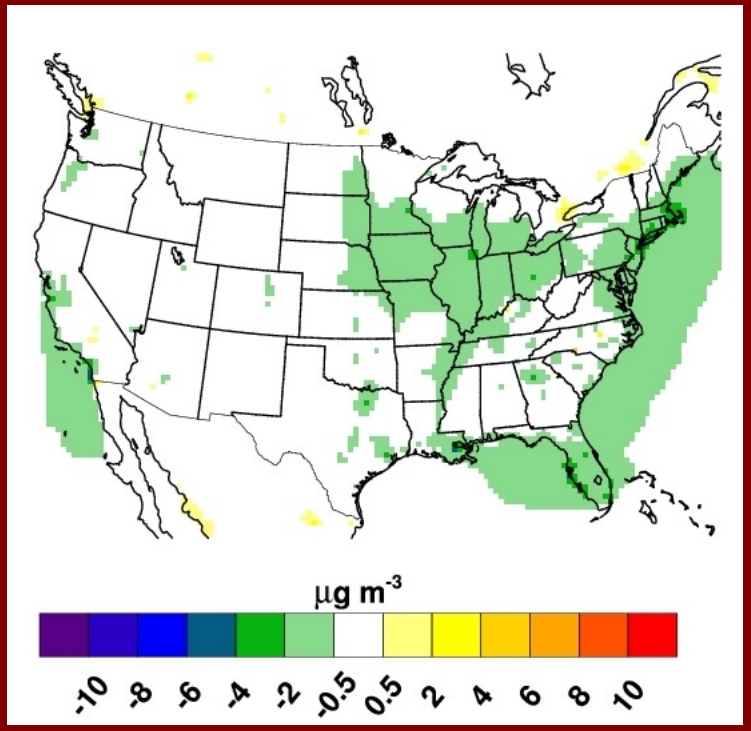
- Land use changes increase SOA because of increased terpene-emitting species.

Future US Anthropogenic Emissions vs Current

Δ Daily Maximum 8-Hour O_3



Δ Hourly $PM_{2.5}$

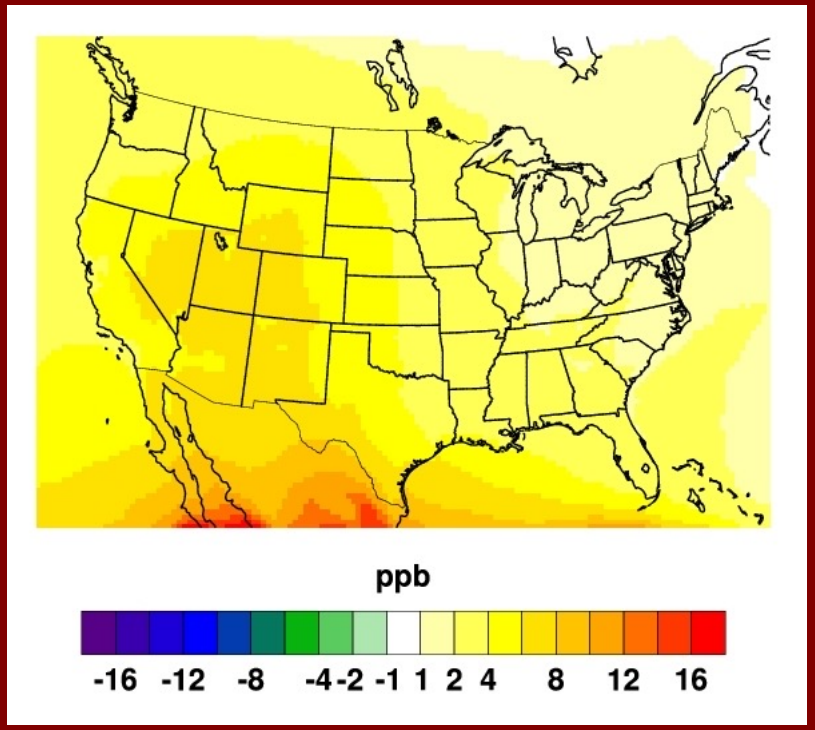


Emission Mass Ratios

Pollutant	Future/Current
CO	1.33
NH_3	1.35
NO_x	0.79
PM	1.13
SO_2	0.18
VOC	1.01

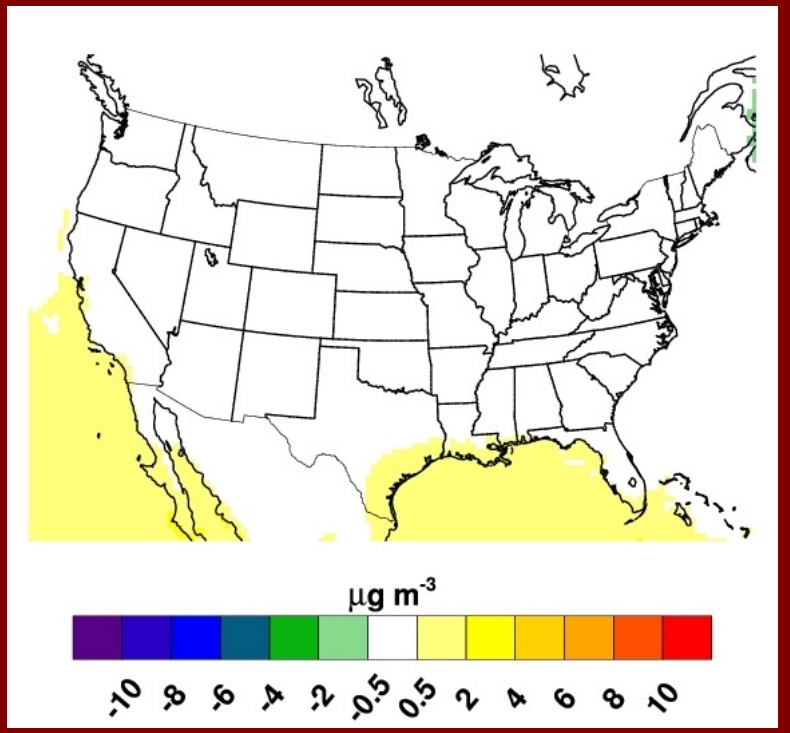
Future Global Anthropogenic Emissions vs Current

Δ Daily Maximum 8-Hour O_3



- Relatively uniform increase of 2 to 6 ppb across the West to the Midwest
- Gradient is consistent with west to east transport

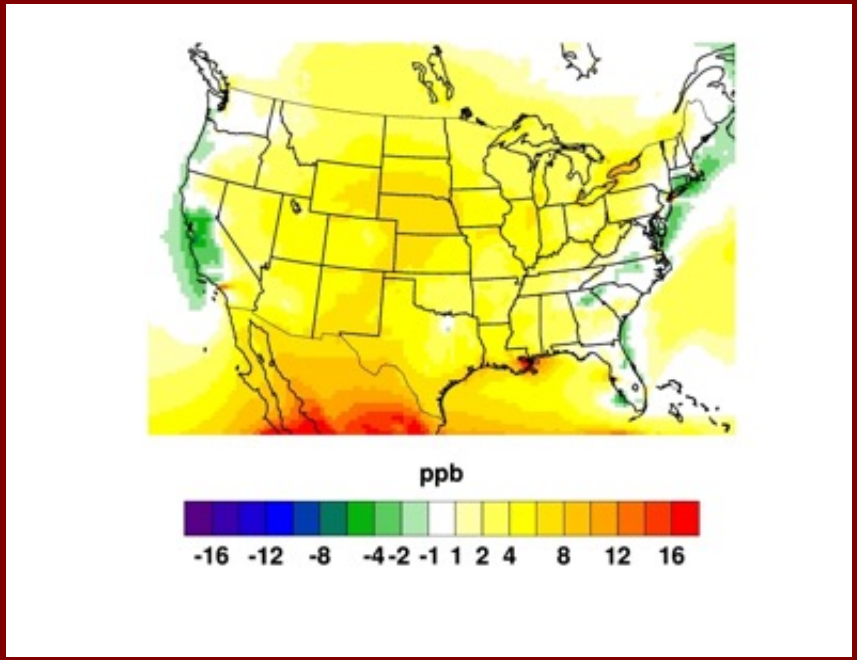
Δ Hourly $PM_{2.5}$



- Insignificant impact on $PM_{2.5}$ because PM precursors have relatively short atmospheric lifetimes.

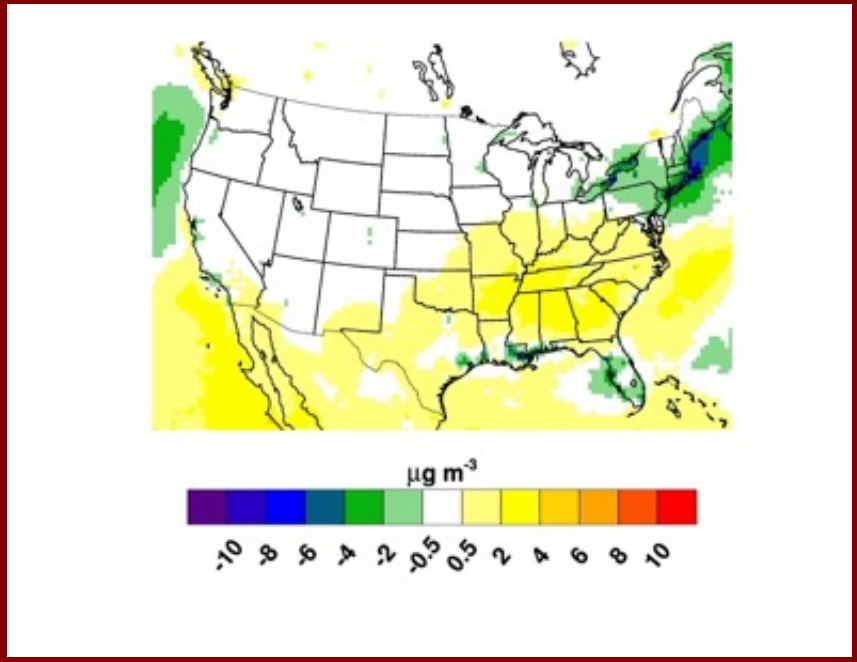
Combined Effects: Future vs Current

Δ Daily Maximum 8-Hour Ozone



- Climate, biogenic, land-use & Asian emission effects generally increase O_3, while US emission reduction somewhat offset these increases.

Δ Hourly $PM_{2.5}$

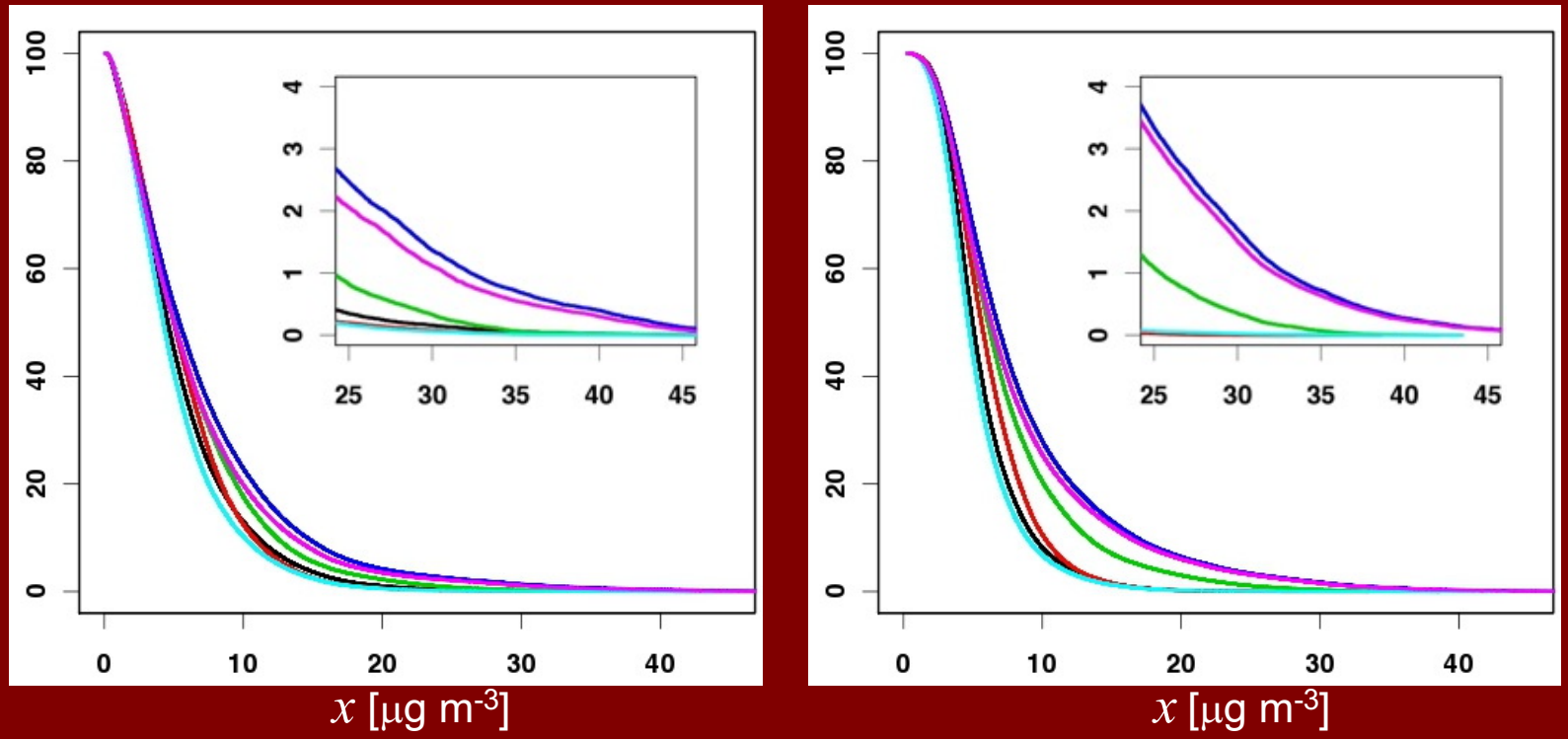


- Dominant effect is increased SOA in the Southeast due to increased biogenic emissions, especially mono- & sesqui-terpene emissions
- Decrease in the Northeast due to increased precipitation

Impact on NAAQS for $PM_{2.5}$

Northeast

Southeast



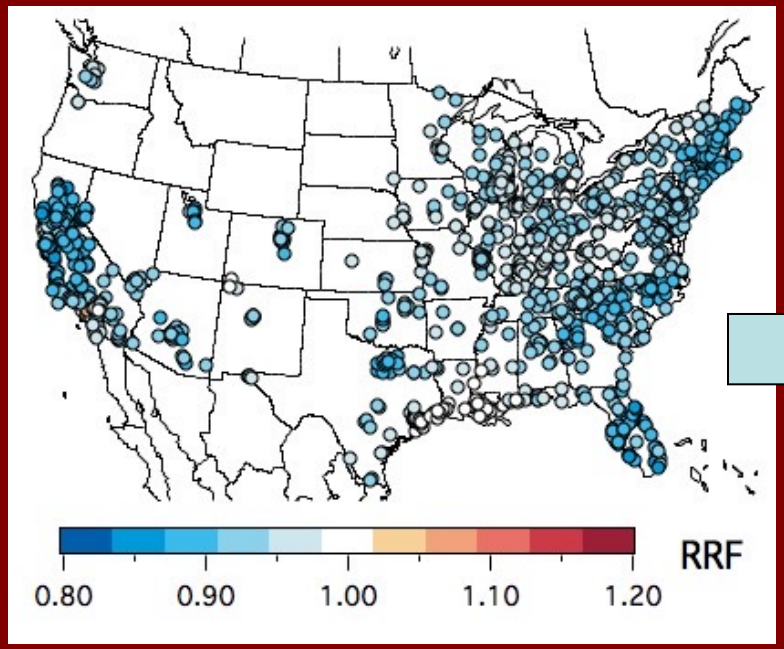
Climate change and land-use impacts on biogenic emissions substantially increase the percentage of grid-days going above the $PM_{2.5}$ NAAQS.

Relative Response Factor for O_3

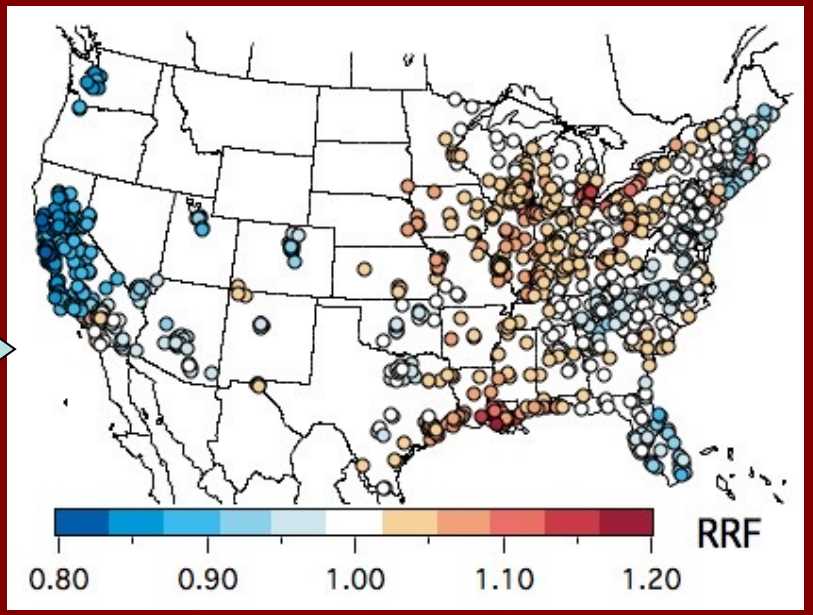
Relative Response Factor (RRF)

for Anthropogenic Emissions Changes

(EPA AQS sites)



Climate-Adjusted RRF



$$RRF = \frac{1}{N_{all}} \sum_{t=1}^{N_{all}} \frac{[O_3]_{t,\ \text{future emission}}}{[O_3]_{t,\ \text{current emission}}}$$

$$RRF_{\text{climate adjusted}} = RRF \times \frac{1}{N_{all}} \sum_{t=1}^{N_{all}} \frac{[O_3]_{t,\ \text{future climate}}}{[O_3]_{t,\ \text{current climate}}}$$

O_3 Attribution Results:

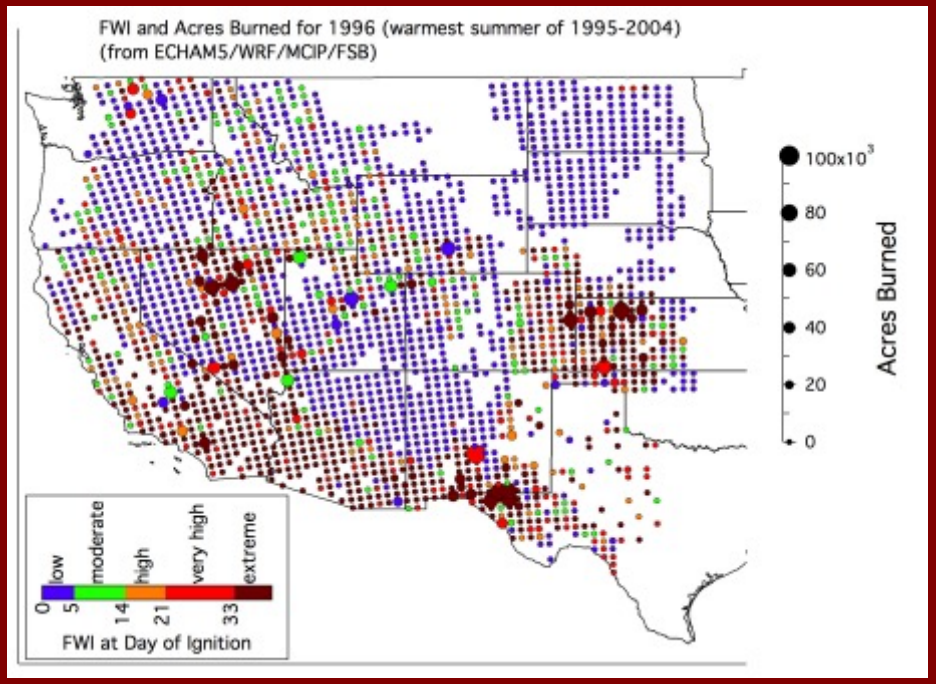
	Boundary Conditions	US emissions	Climate	BVOC	Combined Effects
Northwest	+	-	-	+/-	+
Southwest	+	-	+/-	+/-	+/-
Central	+	-	+	+/-	+
South	+	-	+	+/-	+
Midwest	+	-	+	+/-	+
Northeast	+	-	+	+/-	+
Southeast	+	-	+	-	+/-

$PM_{2.5}$ Attribution Results:

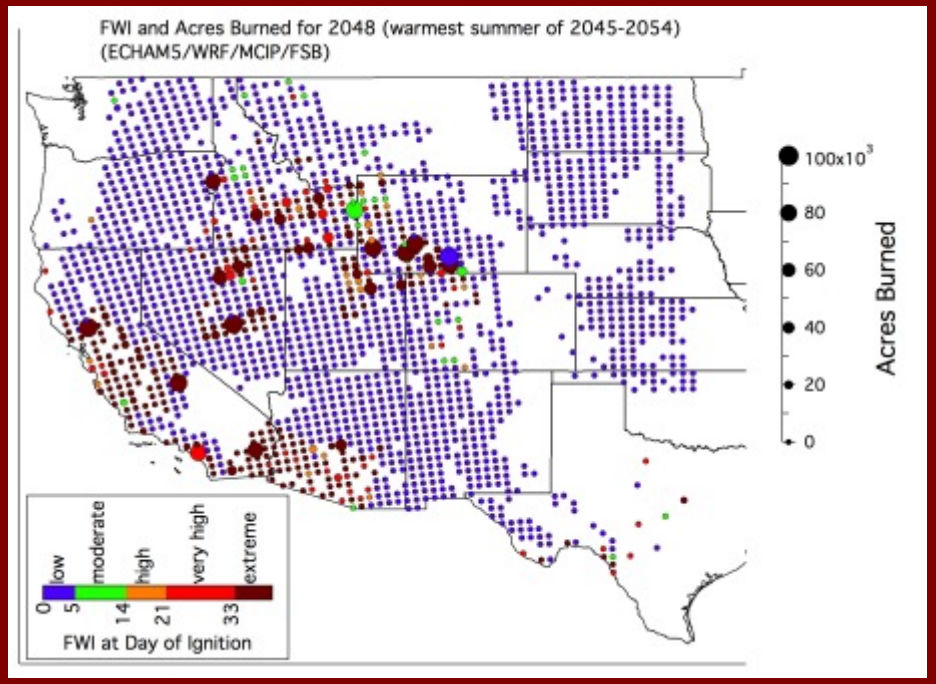
	Boundary Conditions	US emissions	Climate	BVOC	Combined Effects
Northwest	+	-	+	-	+
Southwest	+	-	+	~	+/-
Central	~	-	~	+	+/-
South	+	-	-	+	+/-
Midwest	~	-	+	+	+
Northeast	~	-	-	+	-
Southeast	+	-	+/-	+	+

The Role of Fire in US Air Quality

1996
(for the whole year)



2048
(for the whole year)



Summary

- A1B-ECHAM5 global configuration with MARKAL US emission projection, & future land use distributions:
  - Overall O_3 increases by a few ppb across most of the US
  - Climate, biogenic, land-use & global emission increase effects generally increase O_3
  - By increasing biogenic emissions, climate warming leads to increase in SOA and the percentage of area in the Northeast and the Southeast going above the NAAQS for $PM_{2.5}$.

Next Steps

- Complete distribution of summer simulations for both ECHAM5 and CCSM3
- Repeat the simulations for IPCC B1 scenario
- Complete ensemble meteorology analysis using Bayesian theory for propagated uncertainty estimates
- Complete simulations using current vs future climate FSB data and incorporate into the ensemble analysis

Thank You!