Using Linked Global and Regional Models to Simulate U.S. Air Quality in the Year 2050

Chris Nolte
NOAA/ARL/ASMD and EPA/ORD/AMD
Research Triangle Park, North Carolina

EPA Region 9 Workshop

Impacts of Climate Change on Air Quality in the Pacific Southwest

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Coauthors

Alice Gilliland	NOAA/EPA
Christian Hogrefe	SUNY Albany
Loretta Mickley	Harvard University

Climate Impacts on Regional Air Quality (CIRAQ)

Research Problem:

Air quality is known to be sensitive to meteorological conditions. How might future climate conditions affect air quality (ozone, particulate matter) under current and future emission scenarios?

Why examine this issue?

- Air quality management decisions are presently made assuming current climate conditions (*yet controls can be implemented over several decades*).
- If future climate differs substantially, there is an additional layer of uncertainty when looking at future controls scenarios.
- Modeling potential influences of future climate on air quality is a first step towards introducing climate as a consideration in air quality management.

CIRAQ Modeling Approach: Regional-scale meteorology and air quality predictions via ‘downscaling’

- Global scale climate and chemistry modeling
  - GISS II’ GCM
  - IPCC A1B scenario
  - Mickley et al. (2004)
- Downscaling via MM5 regional climate model
  - Boundary conditions every 6 h from GCM
  - No assimilation of observations
  - Criteria: consistency with global model
  - “1999-2003” and “2048-2052” i.e., climatological runs, intended to capture interannual variability.
  - Leung and Gustafson (2005)

Chemical Transport Modeling (CTM)

Air Quality modeling with CMAQ v4.5

- 5 year simulations for current and future climate
- SAPRC chemical mechanism, 36km×36km, Cont. U.S. domain
- No feedbacks from aerosols and ozone on meteorology!
- Current simulation: 2001 EPA National Emission Inventory
- Future simulation #1: 2001 emissions, except isoprene and mobile source emissions vary with meteorology (isolate climate)
- Future simulation #2: Anthropogenic emissions of VOCs, NO_x, and SO_2 scaled according to A1B scenario for developed nations

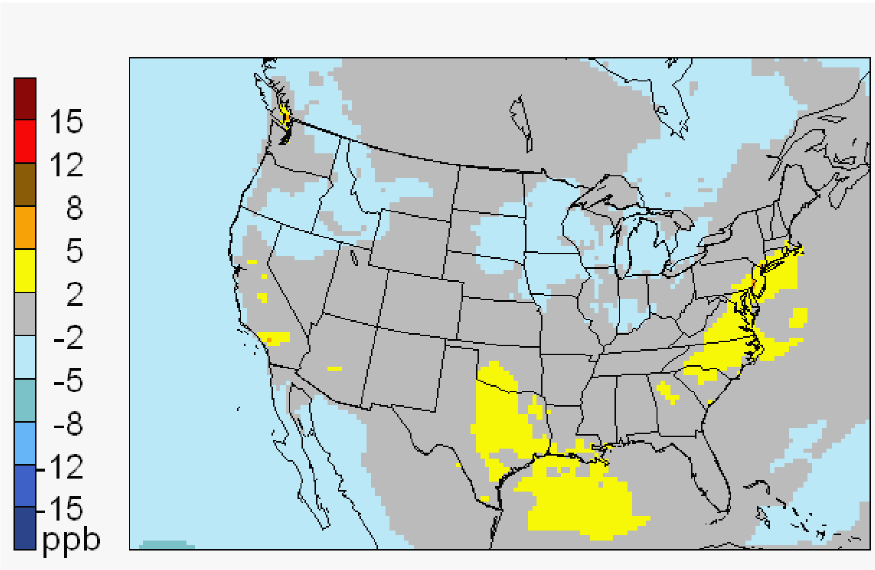
Chemical boundary conditions (BCs)

- Harvard tropospheric ozone chemistry module (coupled to GISS II' A1B): *Loretta Mickley, Daniel Jacob*
- Aerosol BCs provided by Carnegie Mellon University model (same GISS II' GCM)*: Peter Adams, Pavan Racherla*
- Monthly averaged BCs capture long-term changes, not intercontinental transport of episodic pollution

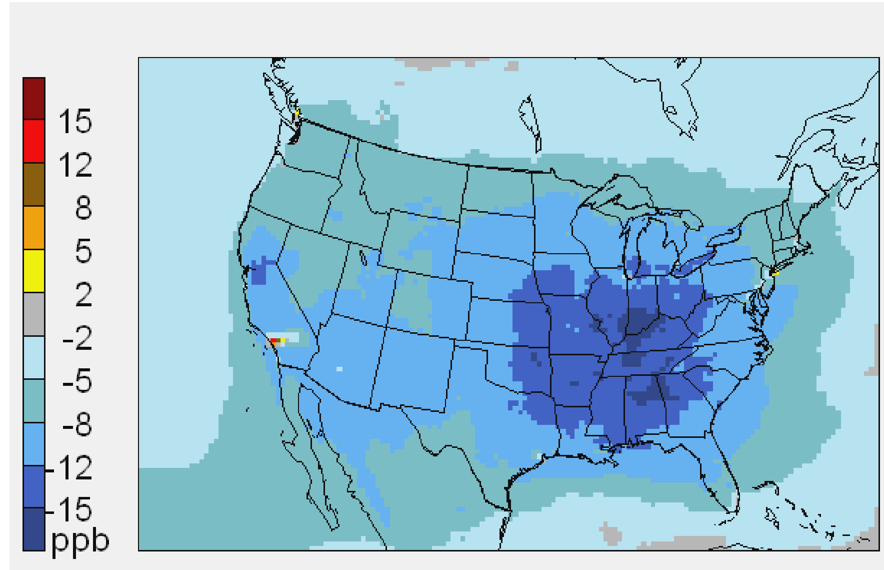
Emission Scaling Factors for Future Simulation #2

Species	Factor
NO_x	0.52
SO_2	0.37
VOCs	0.79
CO	1.5
Primary PM	1 (unchanged)
NH_3	1 (unchanged)

Change in mean summer 8-h max O3

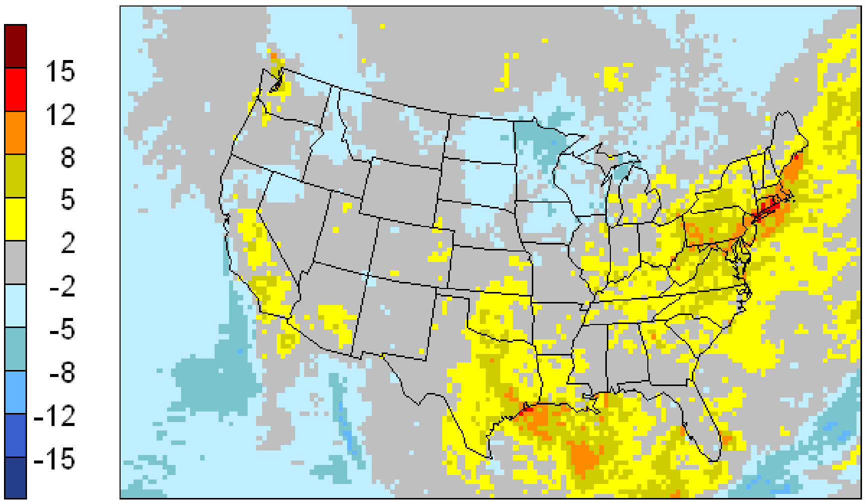


Climate change only

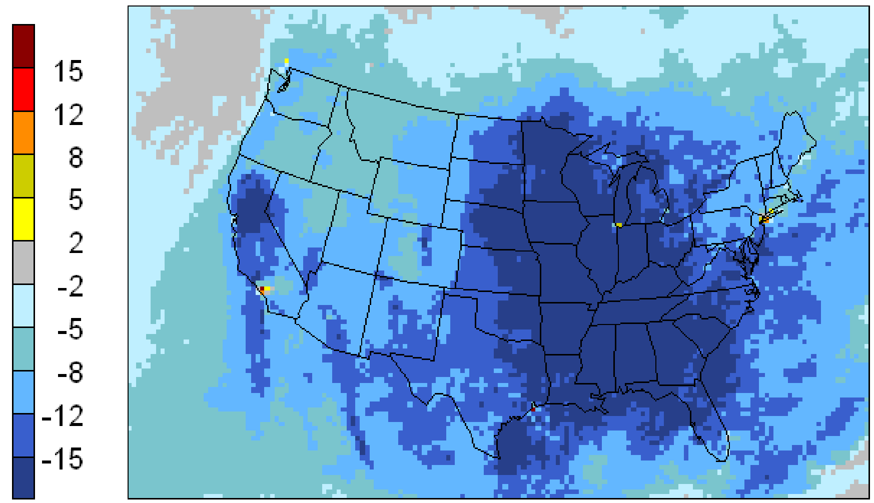


Changed climate and emissions

Change in 95th percentile summer 8-h max O3

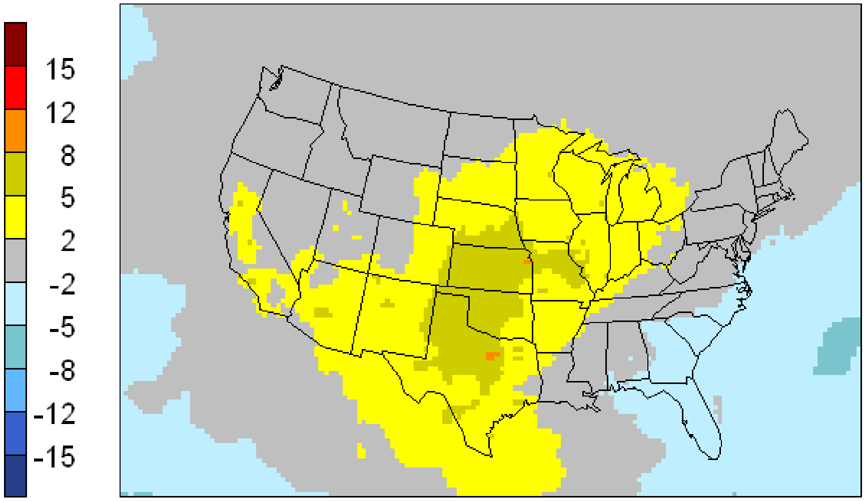


Climate change only

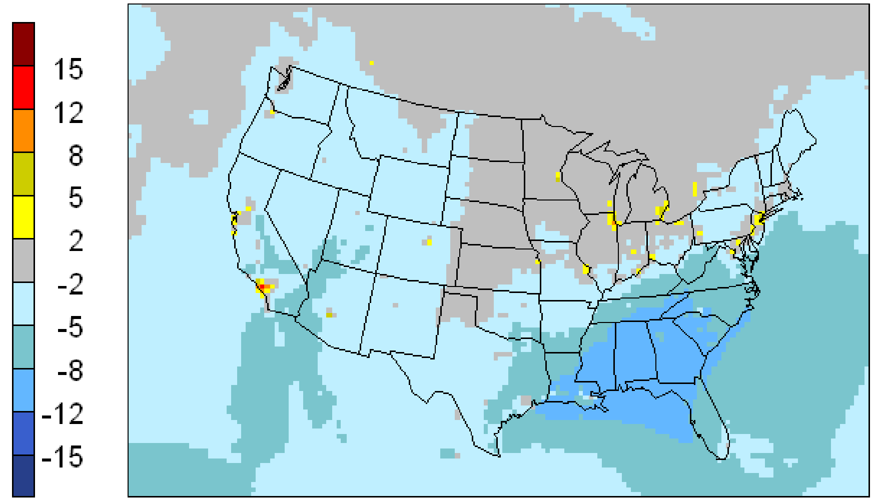


Changed climate and emissions

Change in mean Sept-Oct 8-h max O3



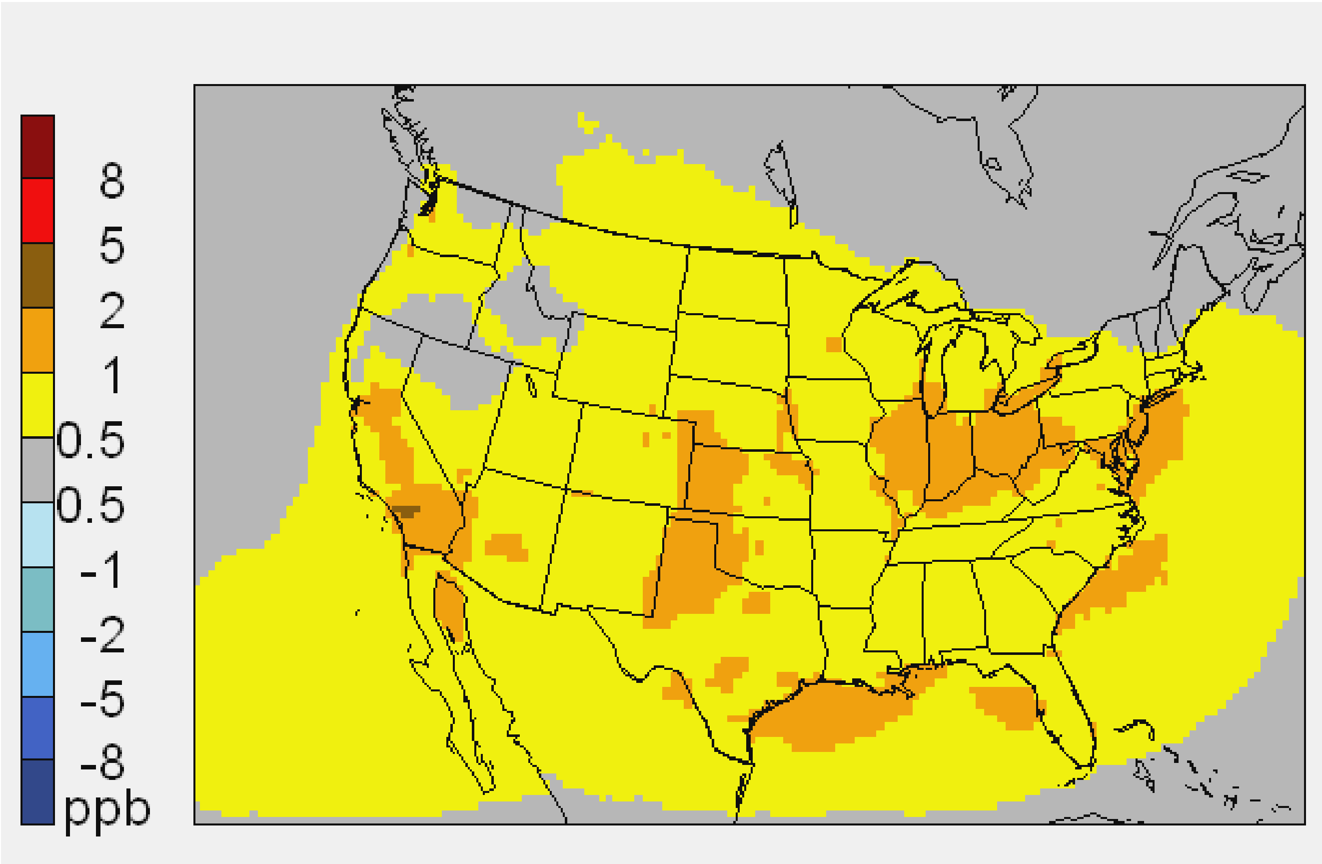
Climate change only



Changed climate and emissions

Change in summer 8-h max O3

CH4 increased from 1.85 to 2.40 ppm



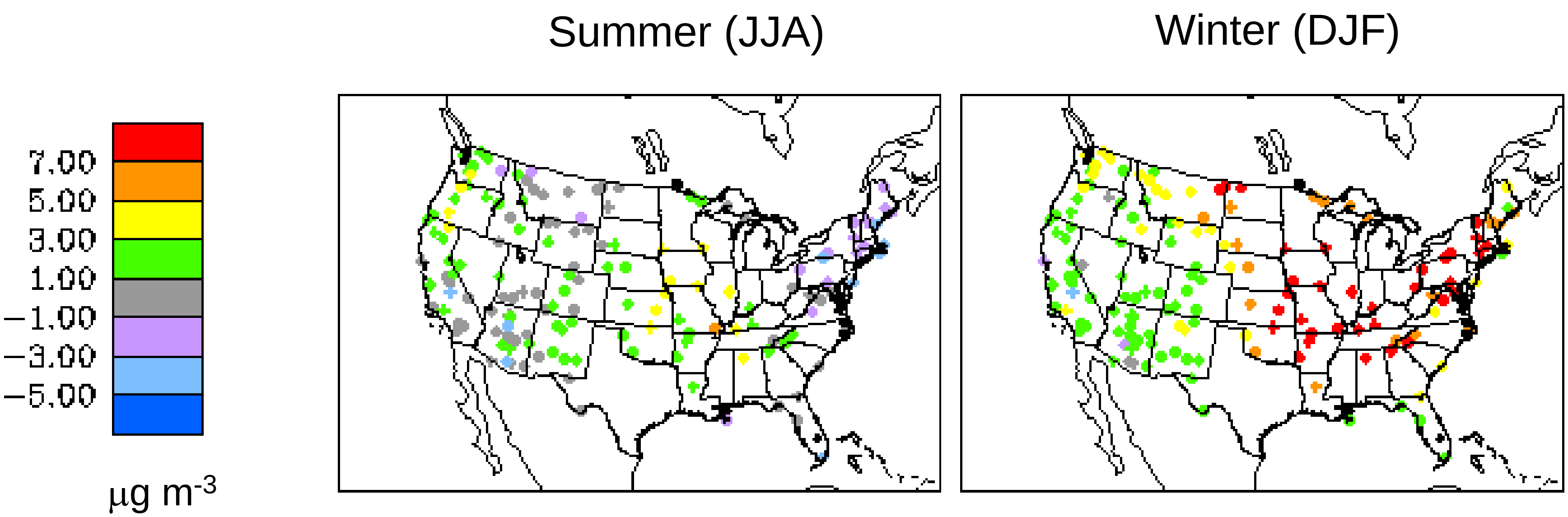
Conclusions from CIRAQ ozone simulations

- Effect of climate change on ozone concentrations is smaller than the effect of planned emission changes, which are highly uncertain.
- Predictions suggest future climate could cause ozone increases between 2-5 ppb in Eastern U.S. and Texas
- Need to consider increasing global methane concentrations alongside climate change
- Interannual variations require multi-year assessment
- Substantial positive bias in model predicted ozone under current climate, influenced by
  - Meteorological uncertainties from RCM approach
  - Chemical mechanism uncertainties

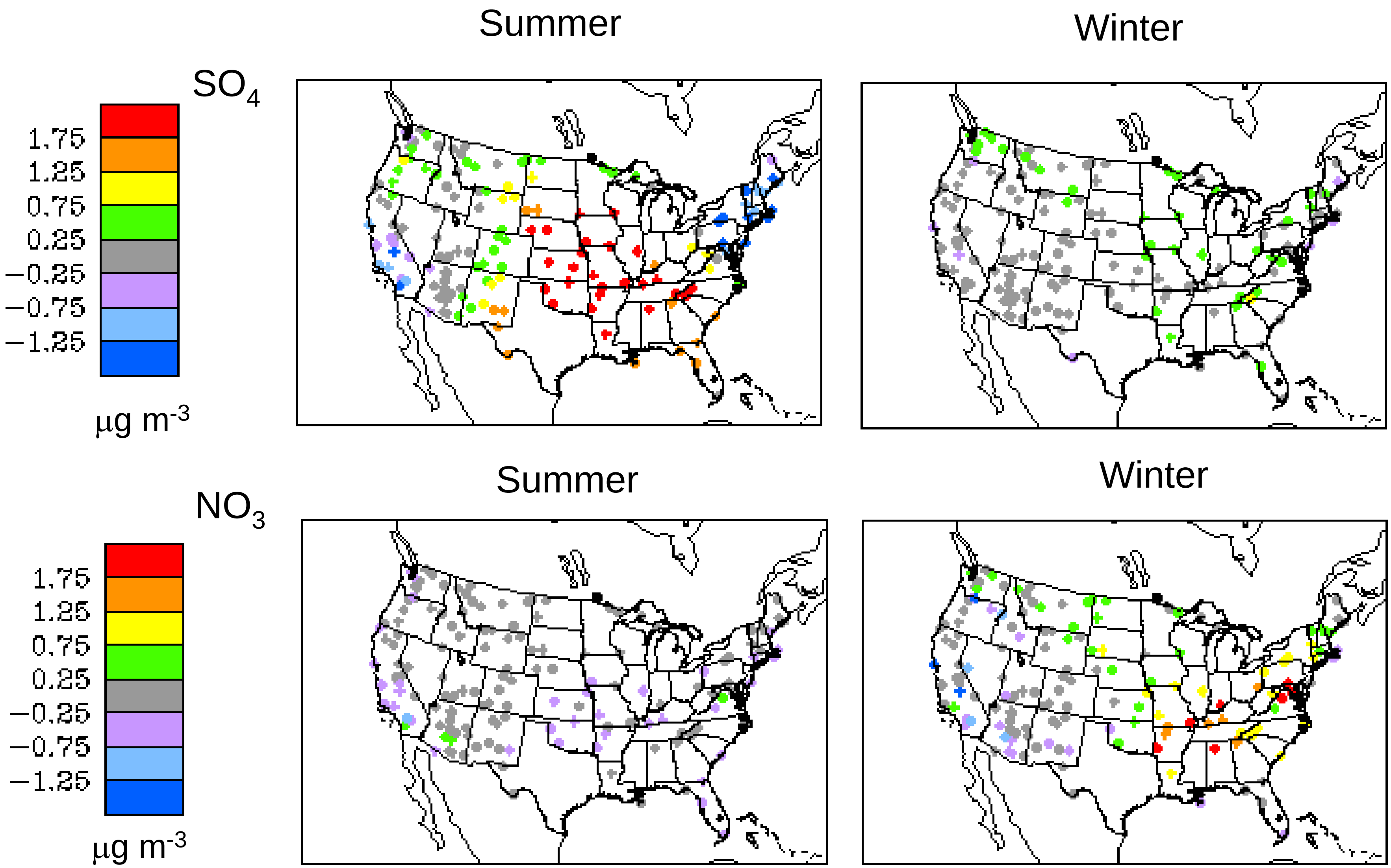
Evaluations of CIRAQ PM Predictions for Current Climate

- IMPROVE monitoring network
  - 24-h samples collected every third day
  - 2000-2004 observations compared with "1999-2003" predictions for matching grid cell.
- Subsequent maps show 5-year seasonally averaged model bias (CMAQ – observations) in $\mu g\ m^{-3}$.

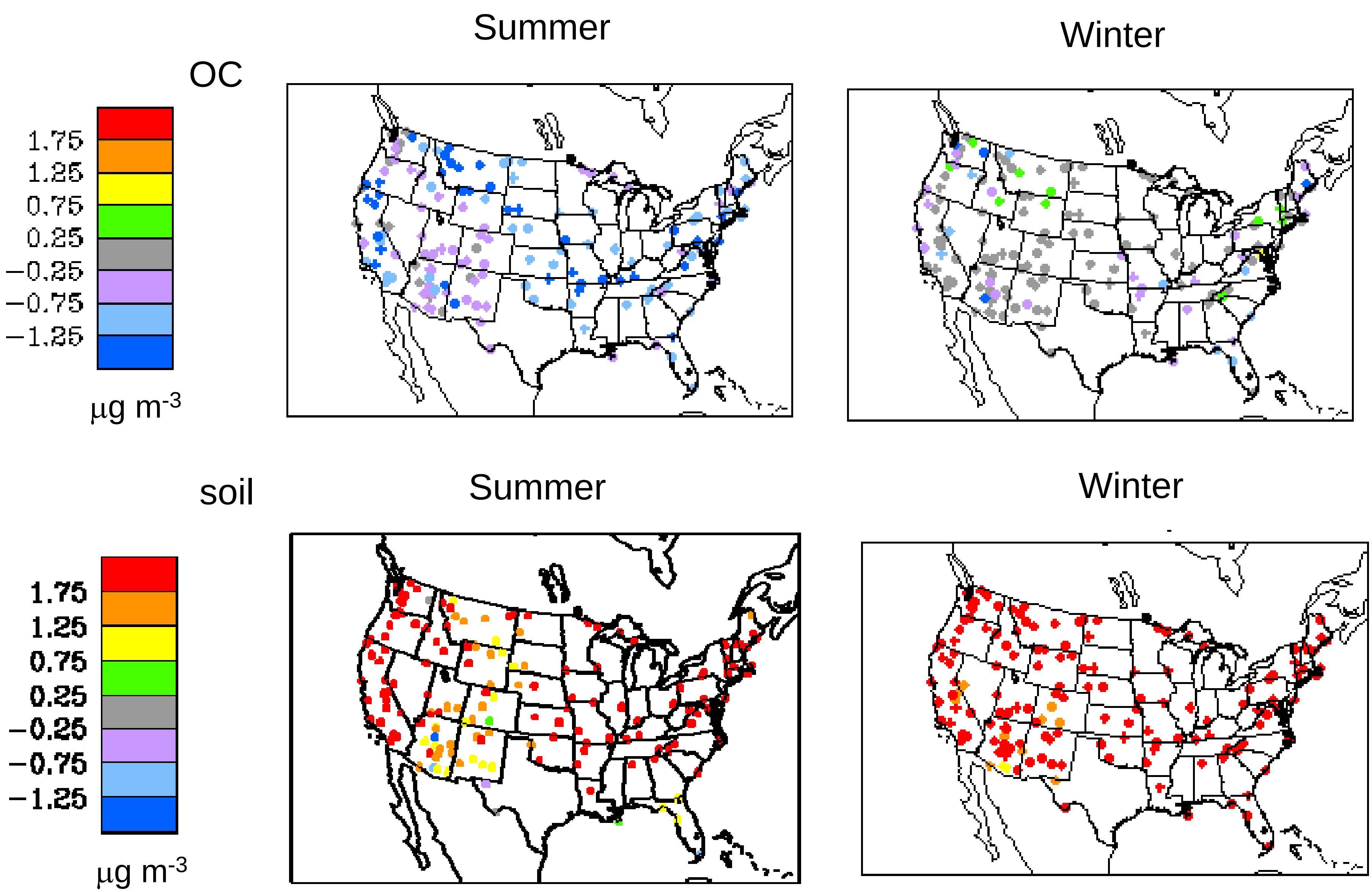
Model Bias—$PM_{2.5}$



Model Bias—SO_4 and NO_3



Model Bias—OC and soil dust



Current/Future Comparison

- Plots show 5-year seasonally averaged differences between future and current simulations
  - FUT1 – 2001 NEI
  - FUT2 – emissions scaled according to A1B scenario for OECD.

Species	Factor
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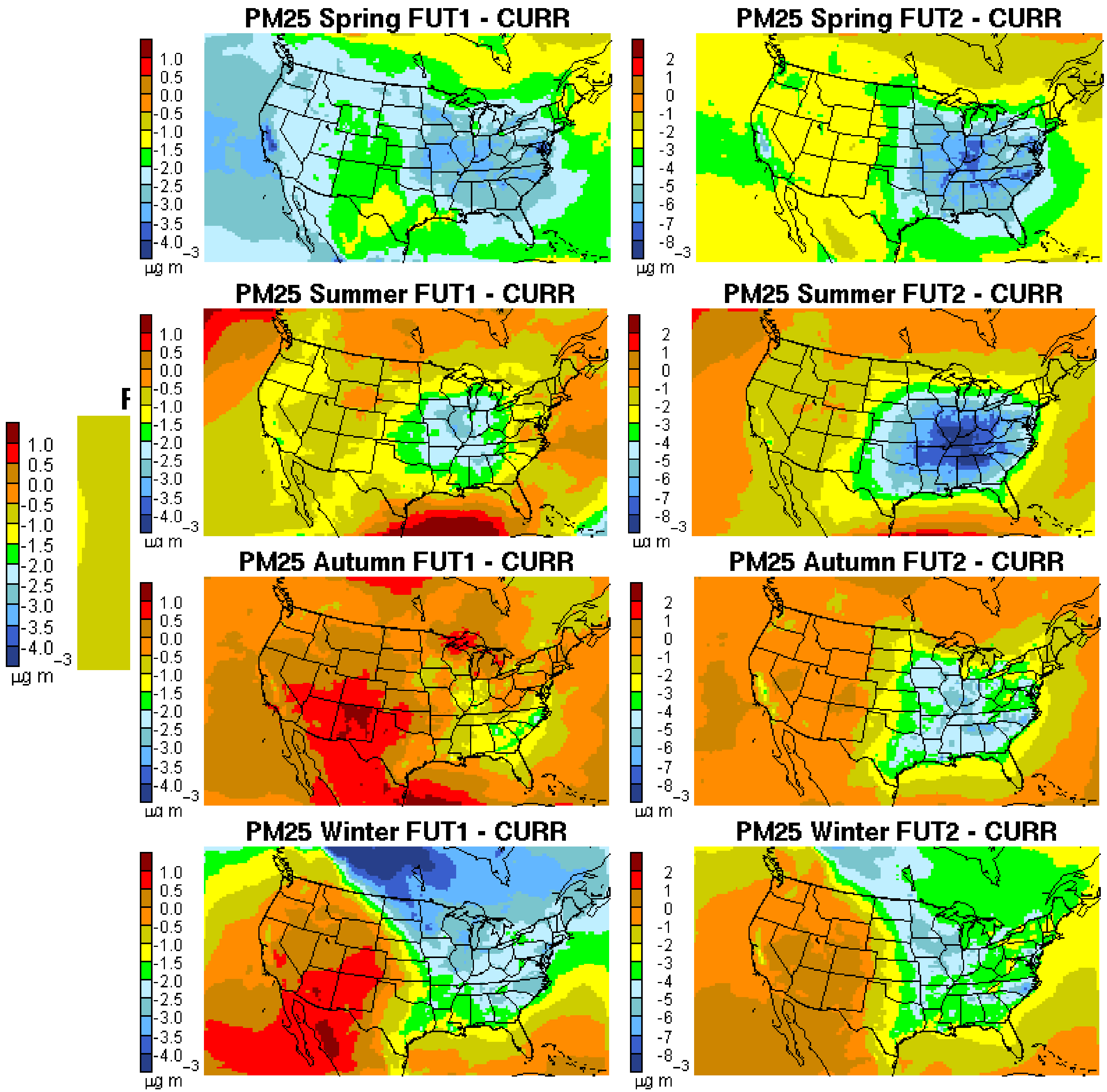
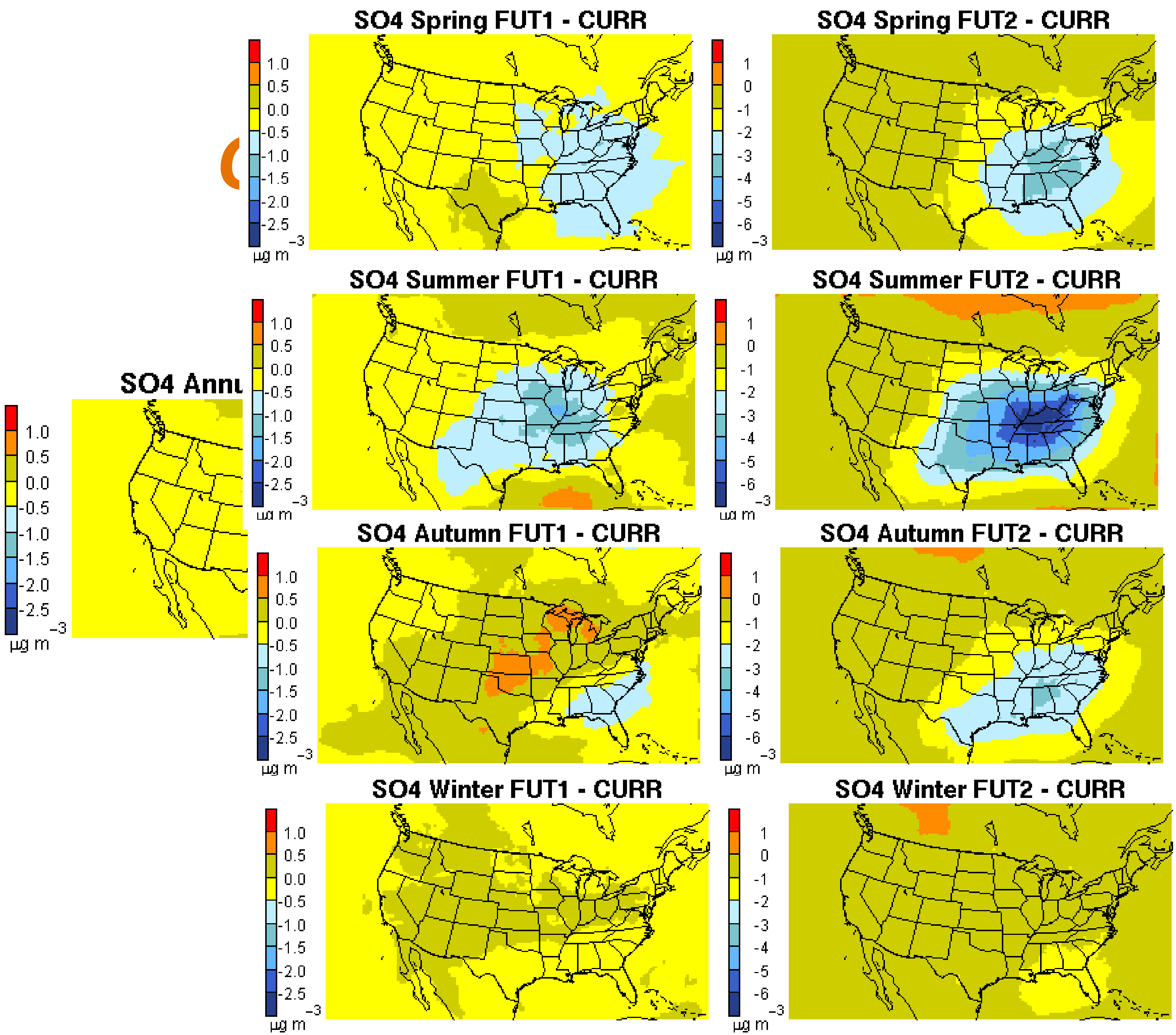
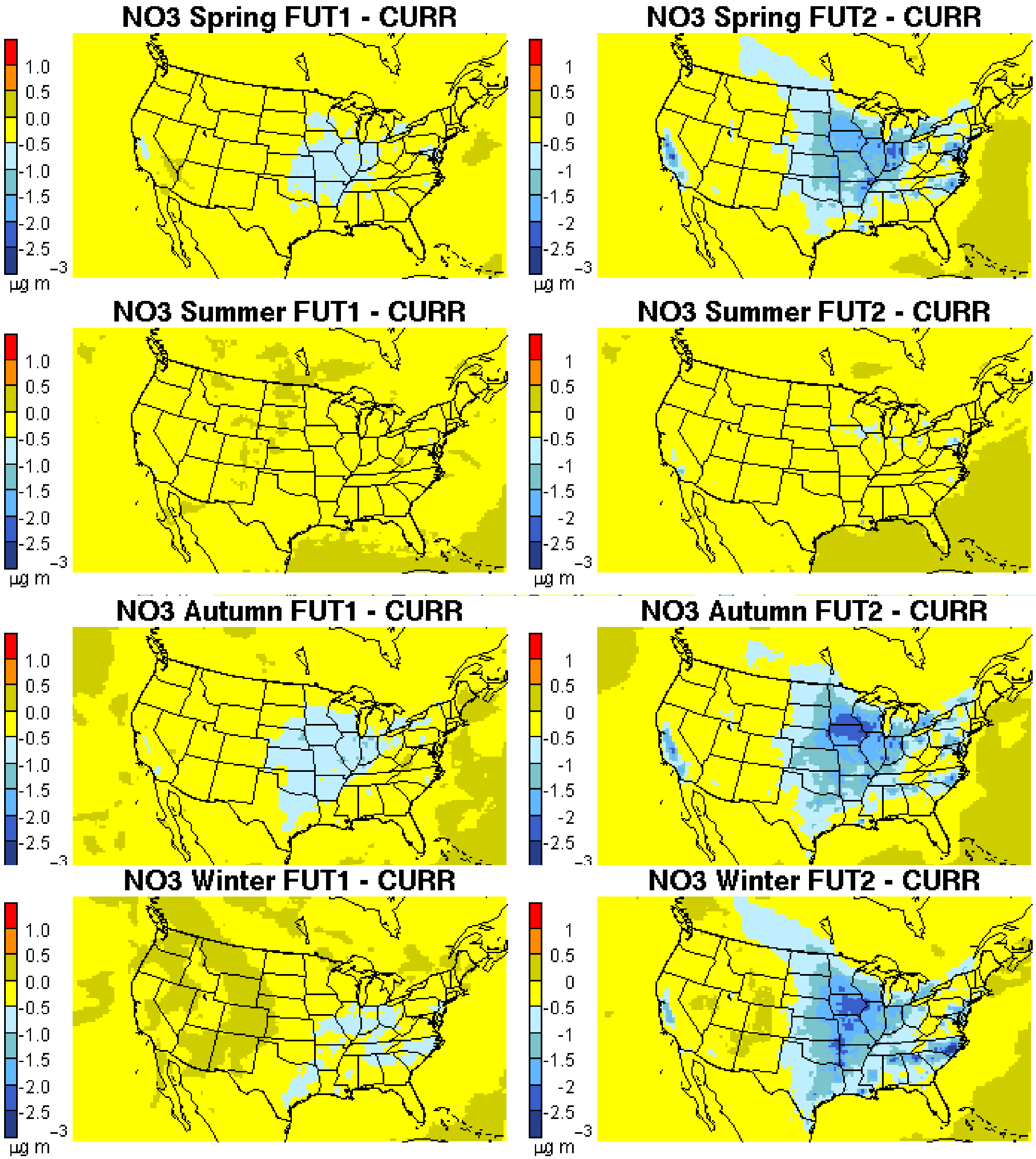
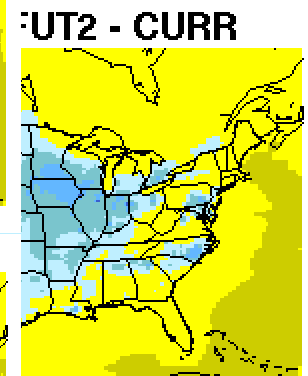
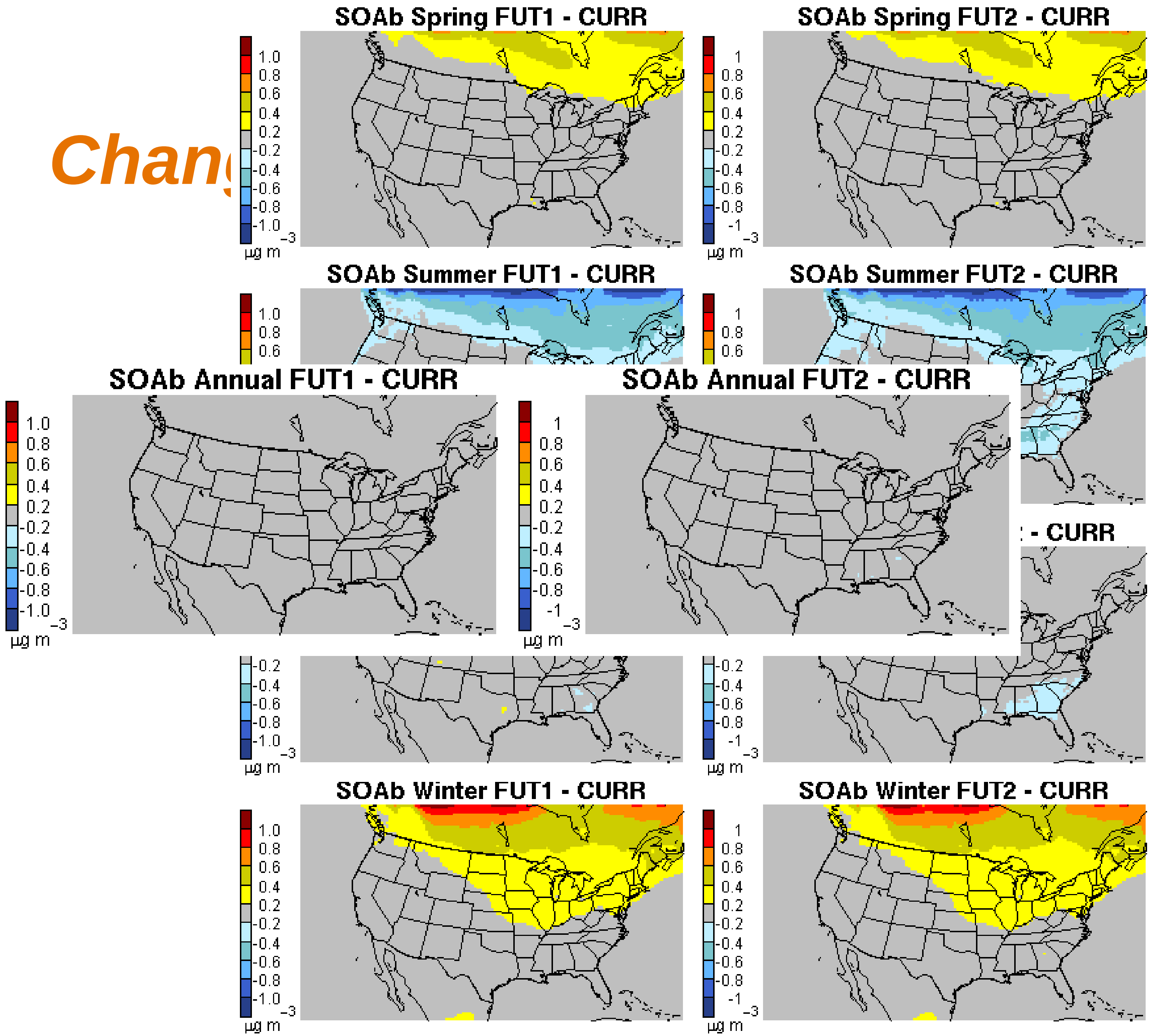

PM25 Spring FUT1 - CURR
PM25 Spring FUT2 - CURR
PM25 Summer FUT1 - CURR
PM25 Summer FUT2 - CURR
PM25 Autumn FUT1 - CURR
PM25 Autumn FUT2 - CURR
PM25 Winter FUT1 - CURR
PM25 Winter FUT2 - CURR
1.0 0.5 0.0 -0.5 -1.0 -1.5 -2.0 -2.5 -3.0 -3.5 -4.0
2 1 0 -1 -2 -3 -4 -5 -6 -7 -8
μg m-3


SO4 Annu
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
µg m^{-3}
SO4 Spring FUT1 - CURR
SO4 Spring FUT2 - CURR
SO4 Summer FUT1 - CURR
SO4 Summer FUT2 - CURR
SO4 Autumn FUT1 - CURR
SO4 Autumn FUT2 - CURR
SO4 Winter FUT1 - CURR
SO4 Winter FUT2 - CURR
1
0
-1
-2
-3
-4
-5
-6


NO3 Spring FUT1 - CURR
NO3 Spring FUT2 - CURR
NO3 Summer FUT1 - CURR
NO3 Summer FUT2 - CURR
NO3 Autumn FUT1 - CURR
NO3 Autumn FUT2 - CURR
NO3 Winter FUT1 - CURR
NO3 Winter FUT2 - CURR
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
µg m


UT2 - CURR

Chan


SOAb Spring FUT1 - CURR
SOAb Spring FUT2 - CURR
SOAb Summer FUT1 - CURR
SOAb Summer FUT2 - CURR
SOAb Annual FUT1 - CURR
SOAb Annual FUT2 - CURR
- CURR
SOAb Winter FUT1 - CURR
SOAb Winter FUT2 - CURR
1.0
0.8
0.6
0.4
0.2
-0.2
-0.4
-0.6
-0.8
-1.0
µg m-3

Summary

- Over prediction of current $PM_{2.5}$ driven by too much dust (unspeciated PM) in the emission inventory.
- Organic carbon is under predicted, especially during the summer.
- SO_4 and NO_3 predictions are generally better, though biases exist for certain regions and seasons.
- PM concentrations in the eastern U.S. are predicted to decrease by 1-3 $\mu g\ m^{-3}$ if emissions are unchanged, and by 2-8 $\mu g\ m^{-3}$ under the A1B emissions scenario.

Future Work

- Explore meteorological factors driving FUT1 – CURR differences
  - Changes to deposition due to differing precipitation and wind speeds
  - Changes in chemical boundary conditions from global model
  - Ventilation: changes in wind speeds and/or PBL heights
  - Increased cloudiness causing enhanced SO_2 oxidation?

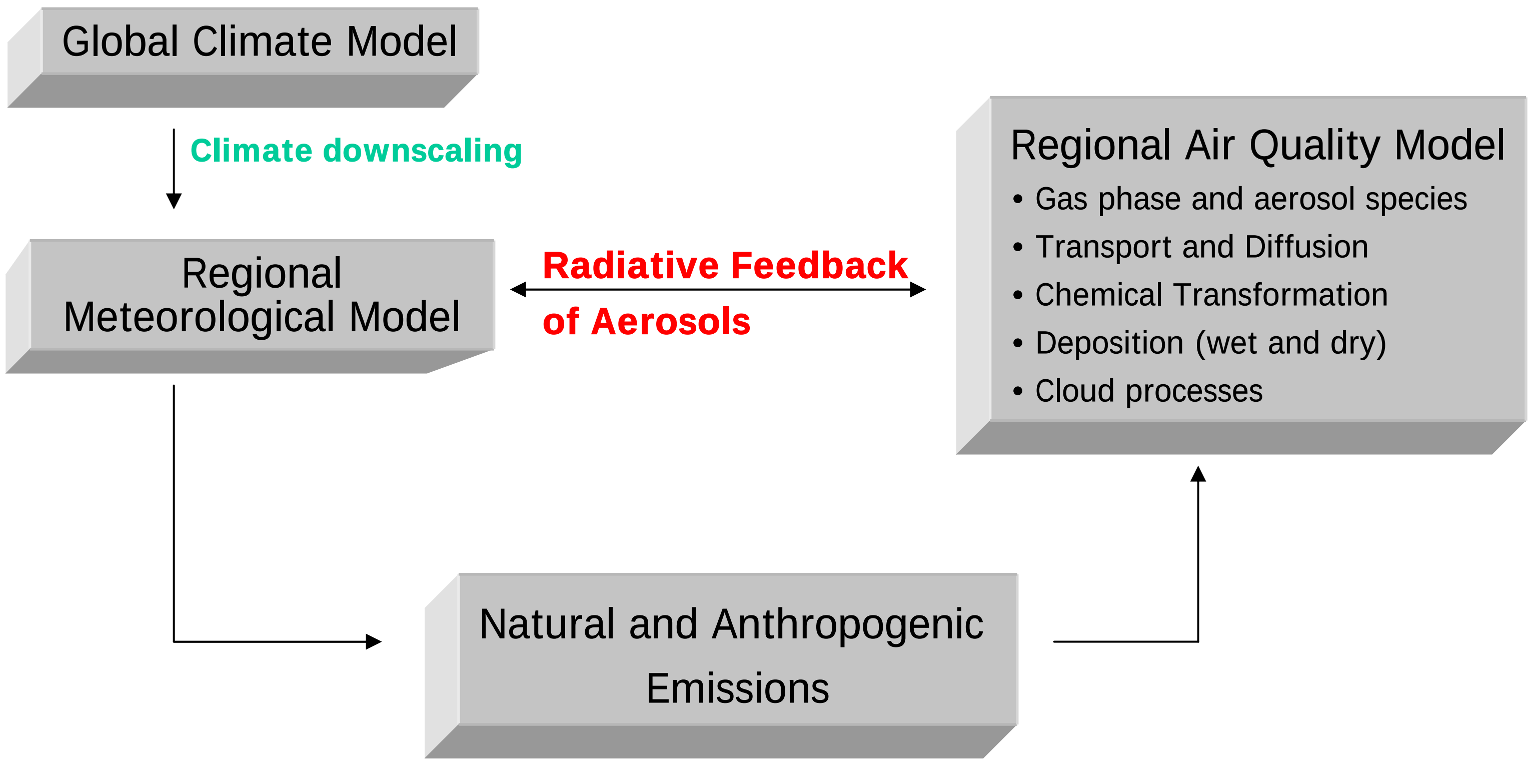
- Assess extent of interannual variability in PM predictions

Future Work
NOAA FY10 Gap Analysis for Climate and AQ

NOAA GFDL-ARL
Global to Regional Modeling Strategy

- GFDL's AM3 global climate & chemistry model
- ARL's integrated WRF-CMAQ
- Linking the above global and regional models
  - Provides capability to downscale variety of climate scenarios for air quality sensitivity
  - Provides consistent treatment of future scenarios for chemistry and climate from global model
  - Radiative feedbacks from emission scenarios and future air quality
  - Offers tools to study interactions between climate and air quality more comprehensively

Developing Integrated Model for Climate - Air Quality Interactions



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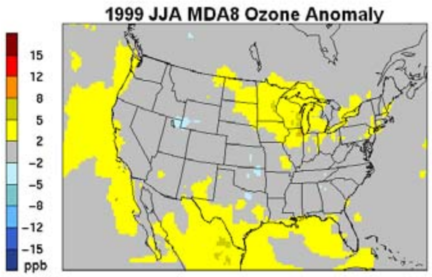
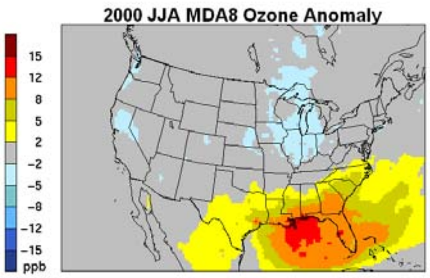
Pavan Racherla, Peter Adams

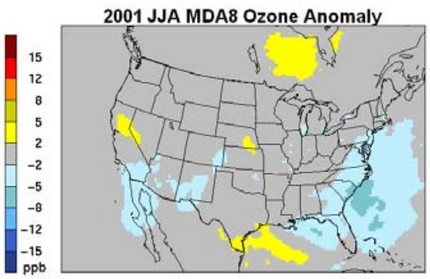
Harvard University

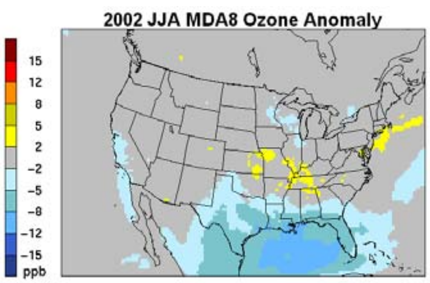
Daniel Jacob

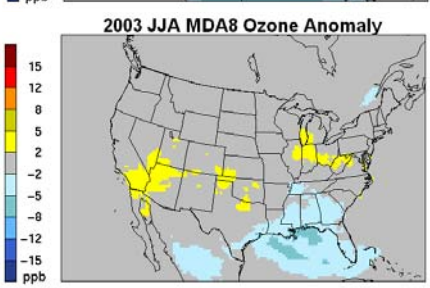
Email: nolte.chris@epa.gov











How significant is the change in 5-yr averages relative to year-to-year variability?