Potential Impacts of Climate Change on U.S. Ozone Concentrations

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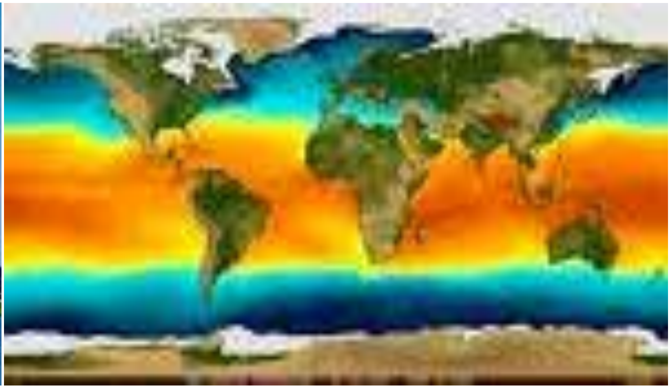


Outline

- Why?
- How?
- What can we say (so far)?
- What can we say about what we can say?

Background – Why is this important?

- Climate change expected to impact air pollution in ways that have not been explicitly considered very much in AQ program planning
  - *Changes in chemical reaction rates*
  - *Changes in atmospheric transport processes*
  - *Changes in biogenic (and anthropogenic) emissions rates*

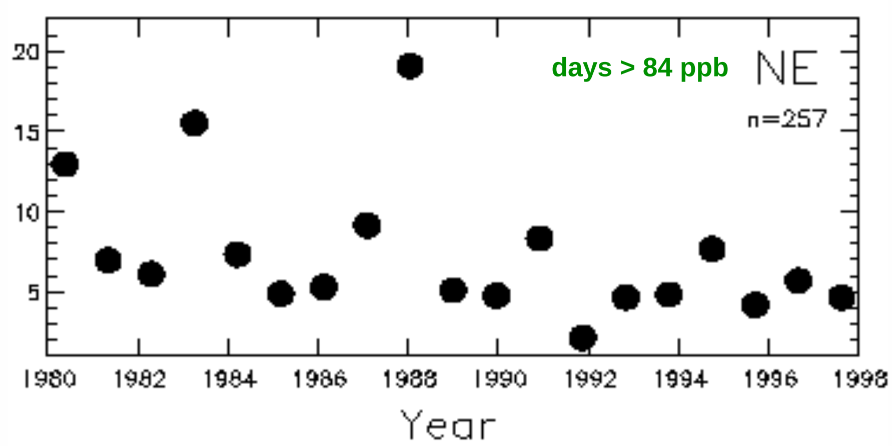
- Recent National Academies committee (NRC, 2004: Air Quality Management in the U.S.) identified *"adapting the air quality management system to a changing (and most likely warmer) climate"* as key challenge in coming decades

- Potential to confound attainment of Clean Air objectives?

- Critical assessment of emerging science needed as a first step in assisting long-term decision-making

Background – Why is this important?

- Extensive empirical evidence suggests climate change could strongly affect ground-level O_3 concentrations
- Already a lot of variability in O_3 under current climate



- O_3 episodes – right combination of meteorological conditions
  - high temperatures
  - clear skies
  - stagnant air
  - blend of precursor pollutants, e.g., NO_x, VOCs
- Global climate change has the potential to affect all of it

We need to systematically study this …

EPA Global Change-Air Quality Assessment

2001 – EPA GCRP and OAR initiate effort to increase understanding of the multiple complex interactions between climate, atmospheric chemistry, emissions, and AQ

Ultimate goal: Enhance ability of AQ managers to consider global change in their decisions

Collaborative:
- EPA labs and centers (NCEA, NCER, NERL, NRMRL)
- Academic community (> $25 million in STAR grants)
- AQ policy and management community (OAR)

Communication of findings in 2 directions:
- Policy and management community
- Climate science research community

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Multi-Phase Assessment Effort

Take a marginal approach …

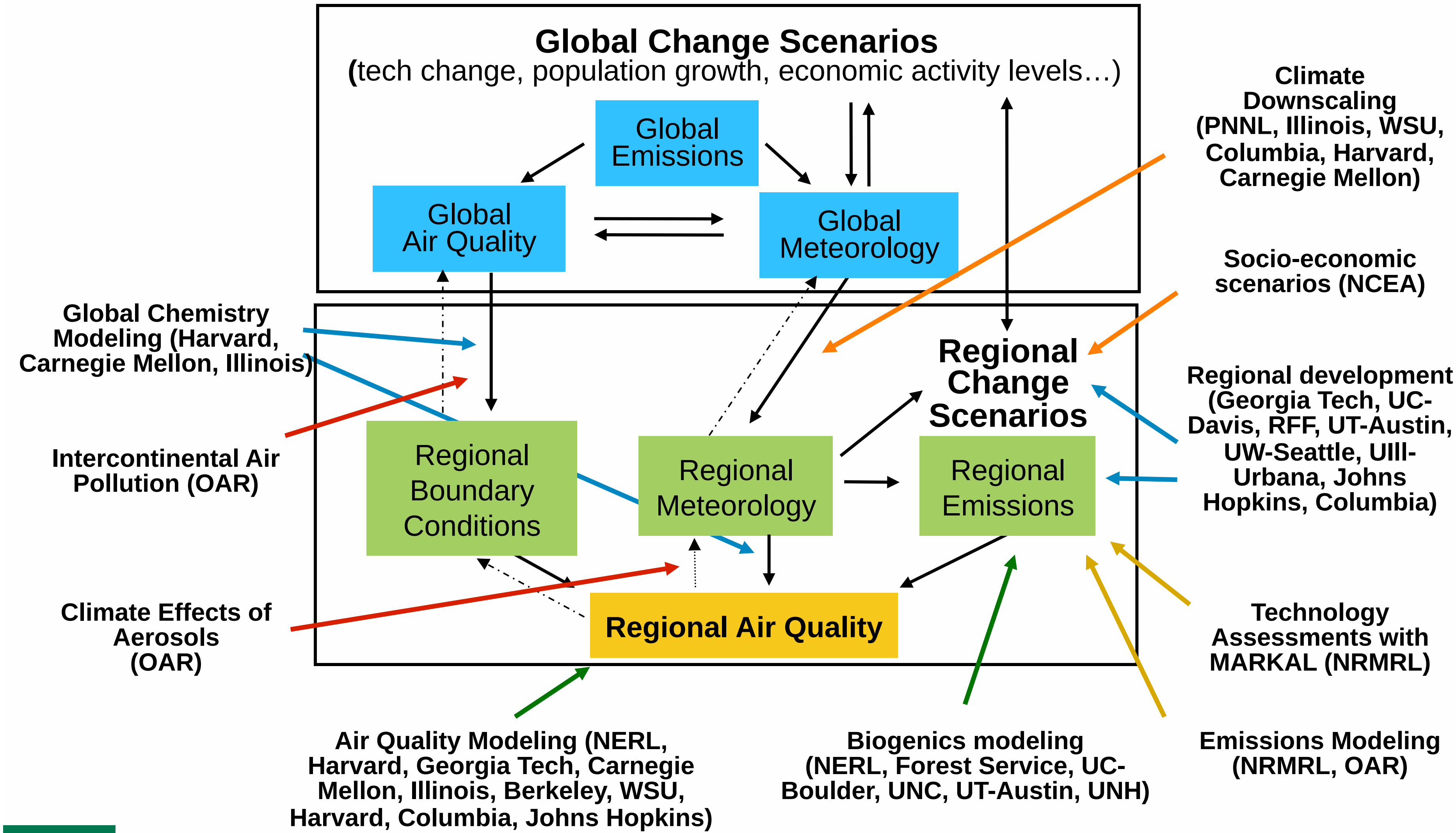
Phase I

- First look at impacts of climate change alone on regional U.S. AQ (initial focus on O_3)
- Explore range of climate scenarios and alternative climate and AQ models
- Begin to get a handle on uncertainty space
- Interim synthesis (2009 report)

Phase II

- Then look at the integrated effects of changing emissions and changing climate
- Investigate additional pollutants (PM, Hg)
- Develop scenarios of land use, technology, demographic, and transportation changes to feed into air pollutant emissions modeling

Participants and Linkages



Findings discussed here drawn from the following 2 products:

Weaver, C.P., X.-Z. Liang, J. Zhu, P.J. Adams, P. Amar, J. Avise, M. Caughey, J. Chen, R.C. Cohen, E. Cooter, J.P. Dawson, R. Gilliam, A. Gilliland, A.H. Goldstein, A. Grambsch, D. Grano, A. Guenther, W.I. Gustafson, R.A. Harley, S. He, B. Hemming, C. Hogrefe, H.-C. Huang, S.W. Hunt, D.J. Jacob, P.L. Kinney, K. Kunkel, J.-F. Lamarque, B. Lamb, N.K. Larkin, L.R. Leung, K.-J. Liao, J.-T. Lin, B.H. Lynn, K. Manomaiphiboon, C. Mass, D. McKenzie, L.J. Mickley, S.M. O'Neill, C. Nolte, S.N. Pandis, P.N. Racherla, C. Rosenzweig, A.G. Russell, E. Salathe, A.L. Steiner, E. Tagaris, Z. Tao, S. Tonse, C. Wiedinmyer, A. Williams, D.A. Winner, J.-H. Woo, S. Wu, and D.J. Wuebbles, 2009: A preliminary synthesis of modeled climate change impacts on U.S. regional ozone concentrations. *Bulletin of the American Meteorological Society,* in press.

U.S. Environmental Protection Agency (EPA), 2009: *Assessment of the impacts of global change on regional U.S. air quality: a synthesis of climate change impacts on ground-level ozone.* An Interim Report of the U.S. EPA Global Change Research Program [Grambsch, A., Hemming, B.L., and Weaver, C.P. (Lead Authors)]. National Center for Environmental Assessment, Washington, DC; EPA/600/R-07/094F. Available from the National Technical Information Service, Springfield, VA, and online at http://www.epa.gov/ncea.

See also …

Jacob, D. J., and D. A. Winner, 2009: Effect of climate change on air quality. *Atmospheric Environment,* **42**, 51-63.

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Modeling Teams and Simulations

"Ensemble of Opportunity"

Regional	Berkeley	Columbia	EPA (NERL)	GNM	Illinois 1	Illinois 2	WSU
Domain	Central CA	Eastern U.S.	**CONUS**	**CONUS**	**CONUS**	**CONUS**	**CONUS**
Simulation Period	1 August	5 JJAs	**5 JJAs**	**3 JJAs**	**1 JJA**	**1 JJA**	**5 Julys**
GCM	CCM3	GISS AO	**GISS II′**	**GISS II′**	**PCM**	**PCM**	**PCM**
Global Grid	2.8º × 2.8º	4º × 5º	**4º × 5º**	**4º × 5º**	**2.8º × 2.8º**	**2.8º × 2.8º**	**2.8º × 2.8º**
GHG Scenario	2 x CO_2	A2	**A1b**	**A1b**	**A1Fi**	**B1**	**A2**
RCM	MM5	MM5	**MM5**	**MM5**	**CMM5**	**CMM5**	**MM5**
Regional Grid	4 km	36 km	**36 km**	**36 km**	**90/30 km**	**90/30 km**	**36 km**
RAQM	$CMAQ^3$	CMAQ	**CMAQ**	**CMAQ**	**AQM**	**AQM**	**CMAQ**
Chemical Mechanism	SAPRC99	CB-IV	**SAPRC99**	**SAPRC99**	**RADM2**	**RADM2**	**SAPRC99**

Global	Harvard 1	Harvard 2	CMU	Illinois 1	Illinois 2
Simulation Period	**5 summers/falls**	5 summers	**10 summers/falls**	5 summers	5 summers
GCM	**GISS III**	GISS II′	**GISS II′**	PCM	PCM
Grid	**4º × 5º**	4º × 5º	**4º × 5º**	2.8º × 2.8º	2.8º × 2.8º
GHG Scenario	**A1b**	A1b	**A2**	A1Fi	B1
GCTM	**GEOS-Chem**	GISS II′	**GISS II′**	MOZART v.4	MOZART v.4

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National-Scale Insights

Consistent messages:

For every region of the country, at least one (usually multiple) of the set of model results found that climate change caused increases in summertime O_3 concentrations.

These climate-induced increases, averaged over the summer season, were in the range of approximately 2-8 parts ppb for MDA8 O_3.

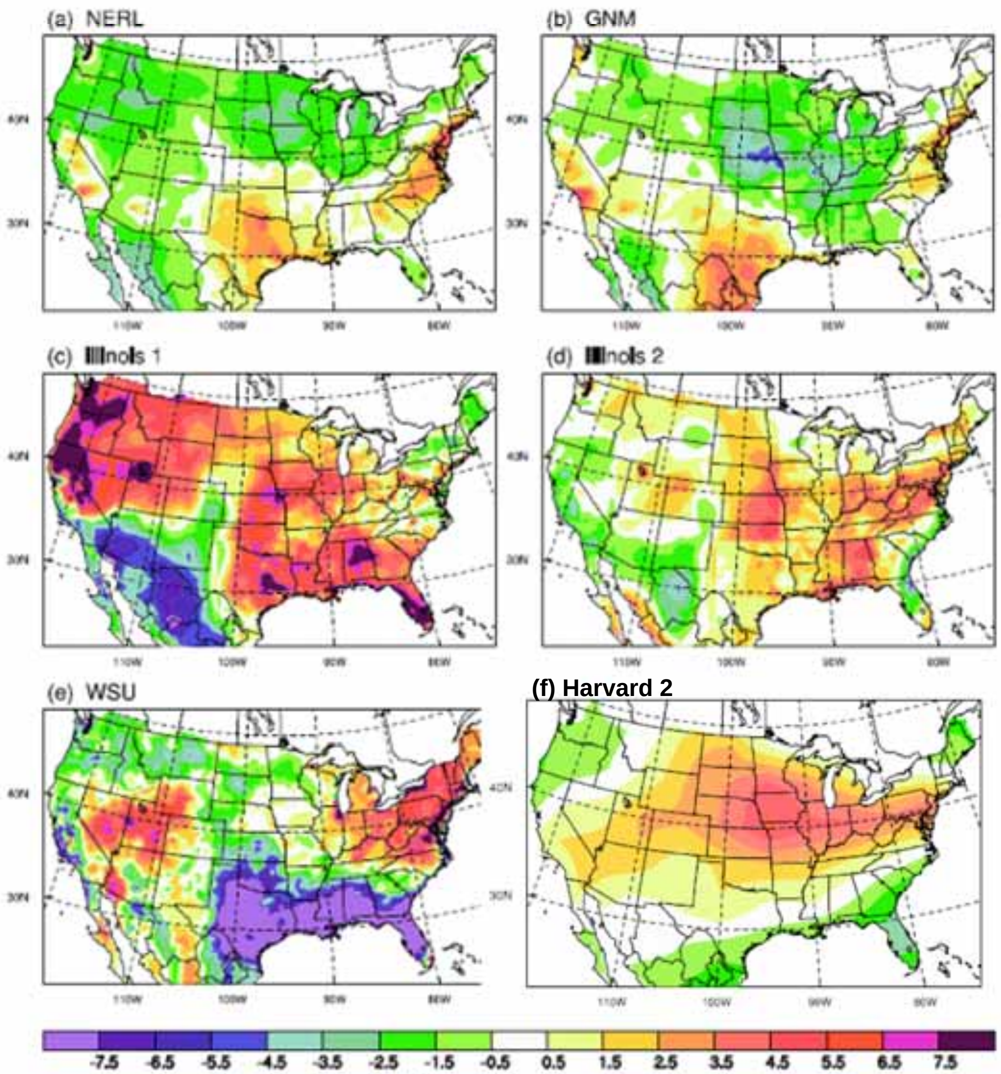
The sensitivity of O_3 to climate change is substantially larger during the highest-O_3 periods of the summer.

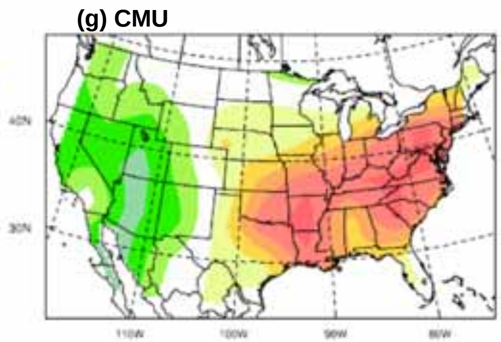
The regional distribution of climate-induced O_3 changes can largely be explained by the competing/reinforcing effects of changes in certain key drivers, e.g., T, sunlight, and natural VOC emissions.

However:

There are large disagreements among the different simulations about the spatial (regional) distribution of the climate-induced O_3 changes.

Changes in summer-average MDA8 O_3 in 2050s compared to present (in ppb)





Sensitivity to climate change is a few/several ppb, but with strong inter-regional and inter-model variation

Different modeling groups agree on some things and disagree on others (more on this in a minute)

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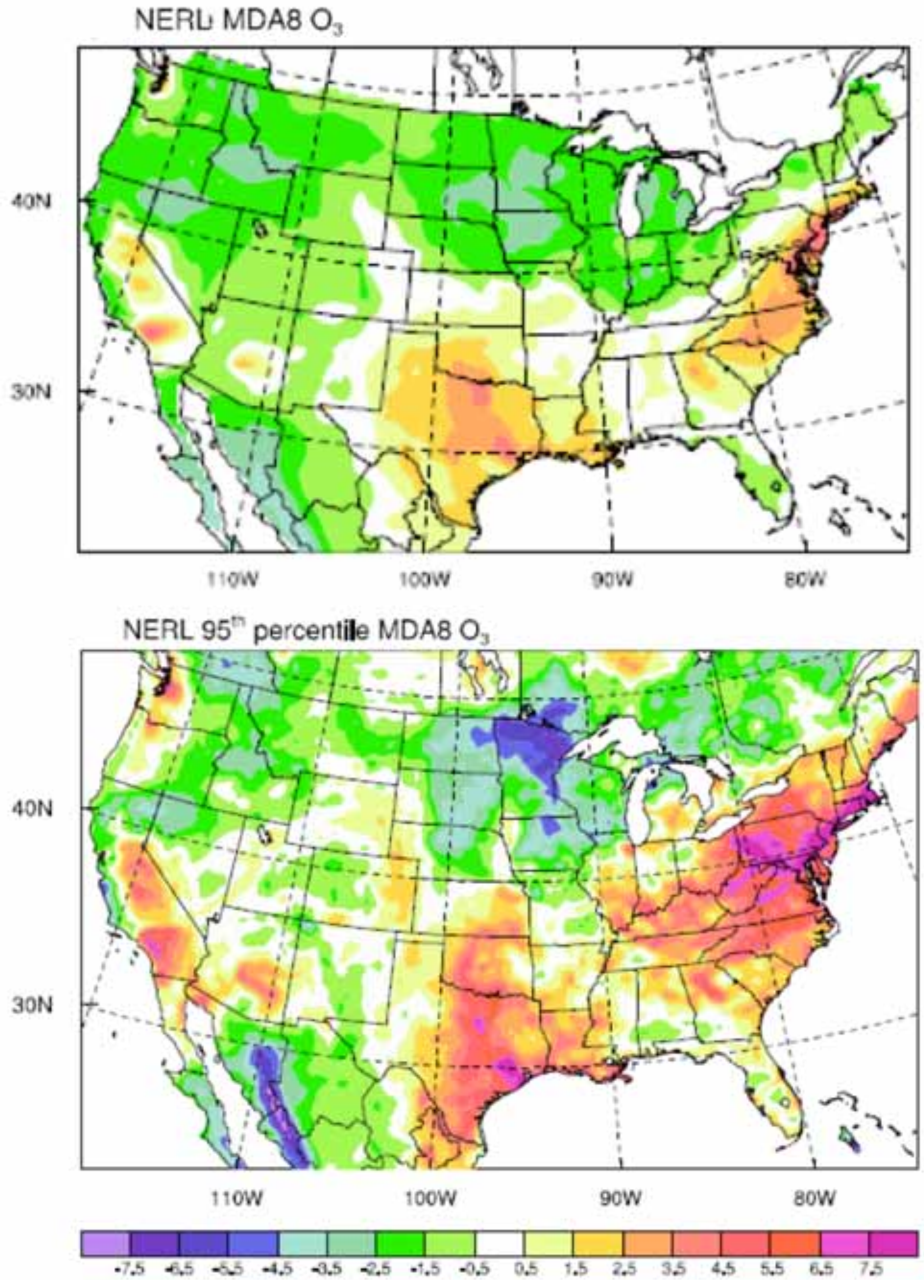
Climate change shifts the O_3 distribution – more at the high end and less at the low end

Critical in terms of effects on people and ecosystems

This basic result is consistent across all the modeling groups

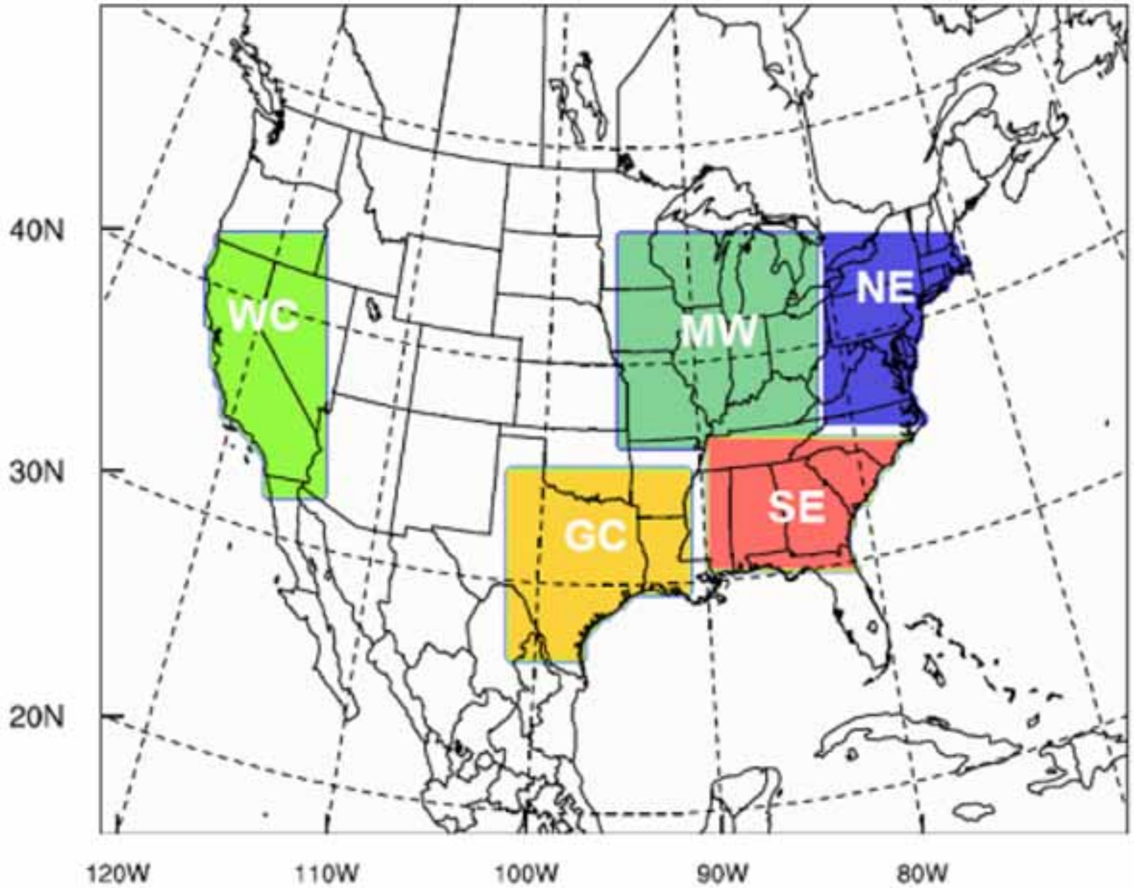
It is also consistent across many different metrics – e.g., the duration (days) of periods in which O_3 exceeds a certain value



The Regional Picture

Averages over O_3 and key drivers

Improve our understanding of competing interactions



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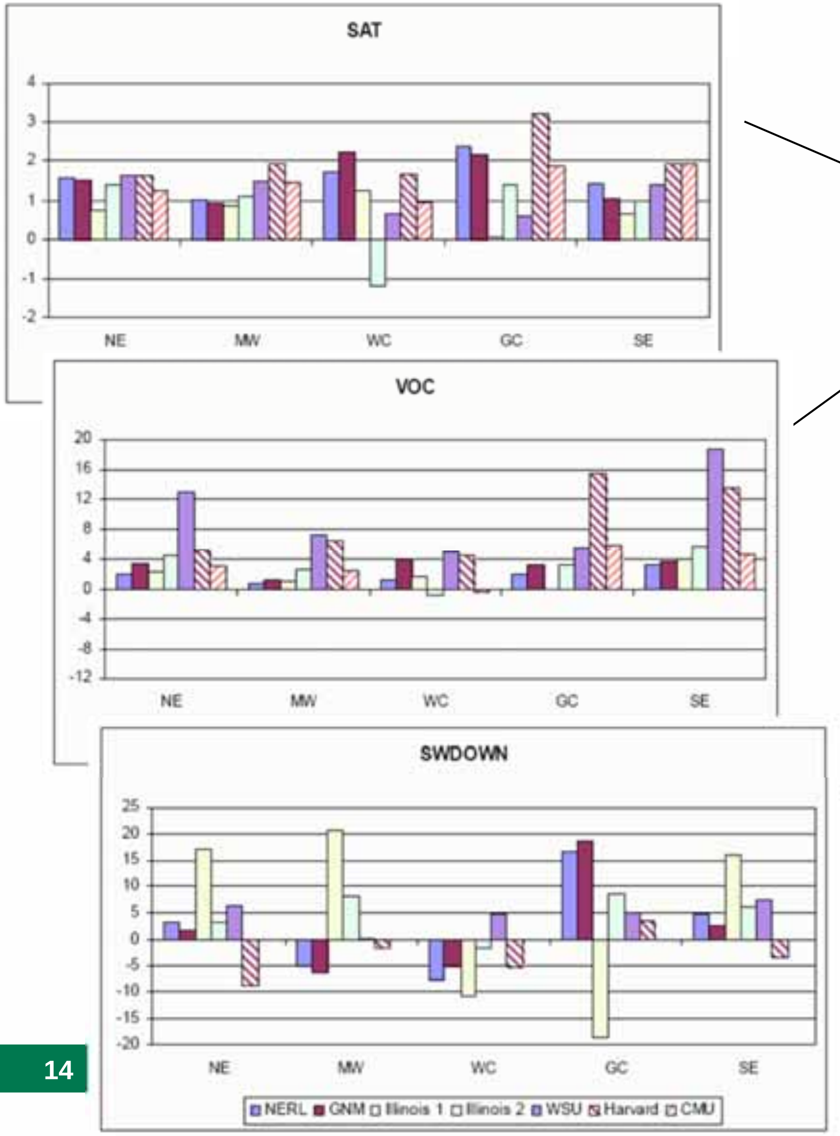
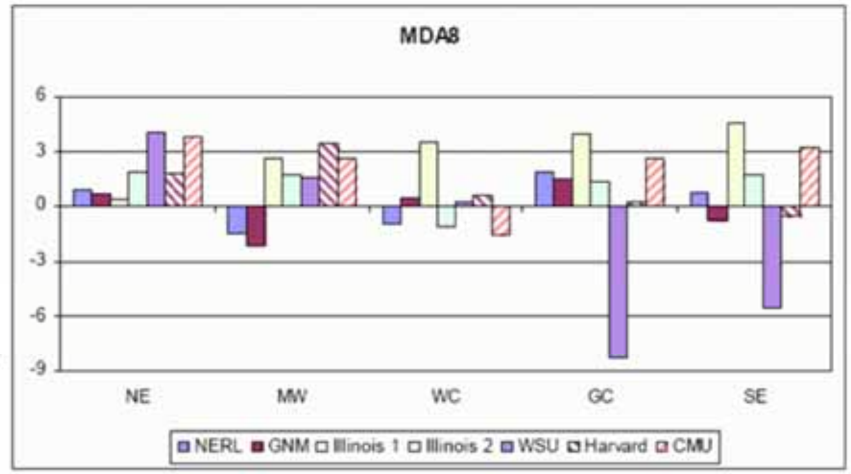
The Regional Picture – Drivers of O_3 Changes





O_3 – regional & model variations
T – uniform increases
VOCs – also relatively uniform

SW (cloud cover) – a major factor

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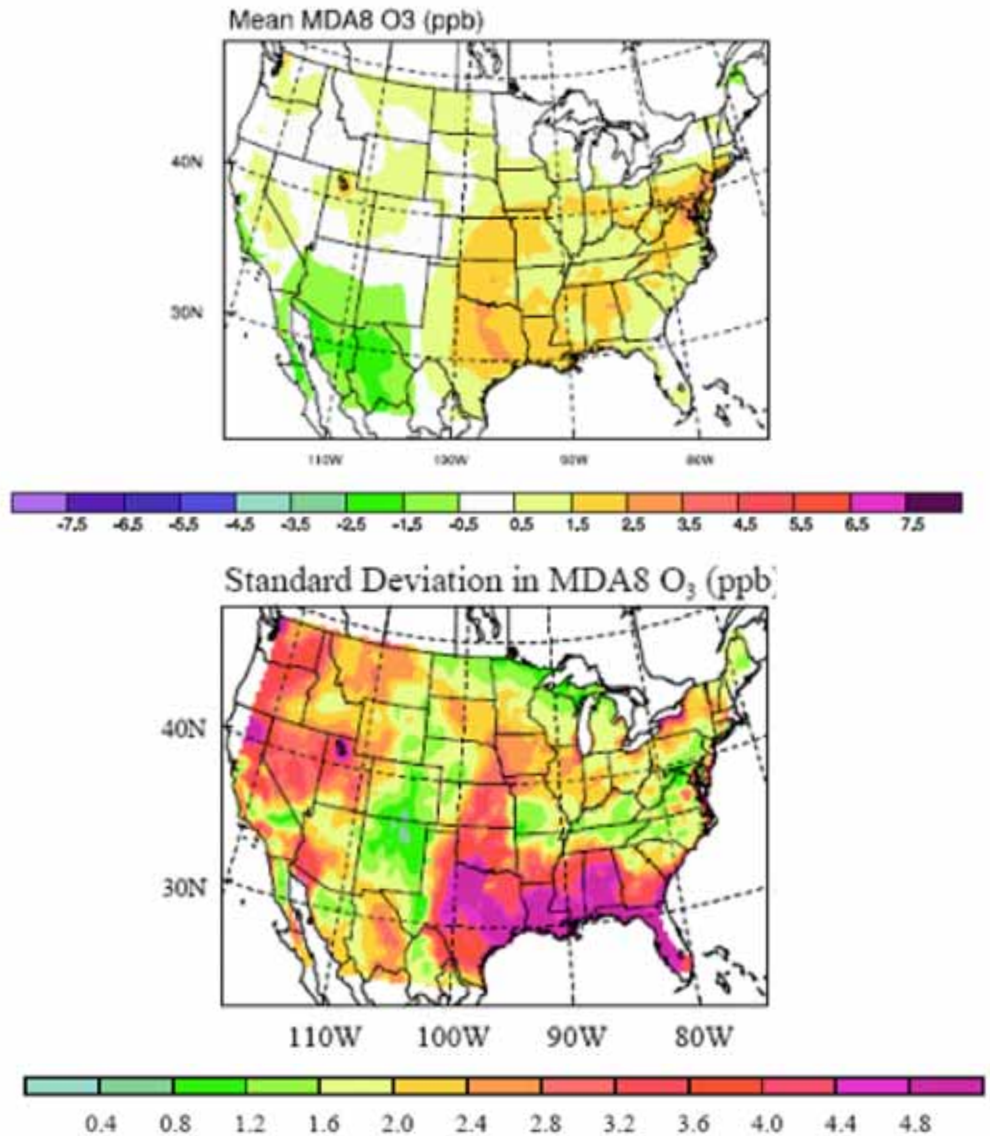
Inter-Model Disagreement

The different modeling systems clearly do not always simulate the same regional patterns of climate-induced O_3 changes

<u>4 major factors</u>:

- large-scale circulation patterns that strongly affect regional meteorology (storm tracks, subtropical highs)
- parameterized processes, e.g., clouds
- chemical response to VOC changes
- interannual variability

Regional impacts of global CC: *very hard problem*.



Overarching conclusions (from 2009 EPA assessment report):

"First, while these modeling studies cannot tell us what the future will hold, they demonstrate the potential for global climate change to make U.S. air quality management more difficult, and therefore future air quality management decisions should begin to account for the impacts of climate change."

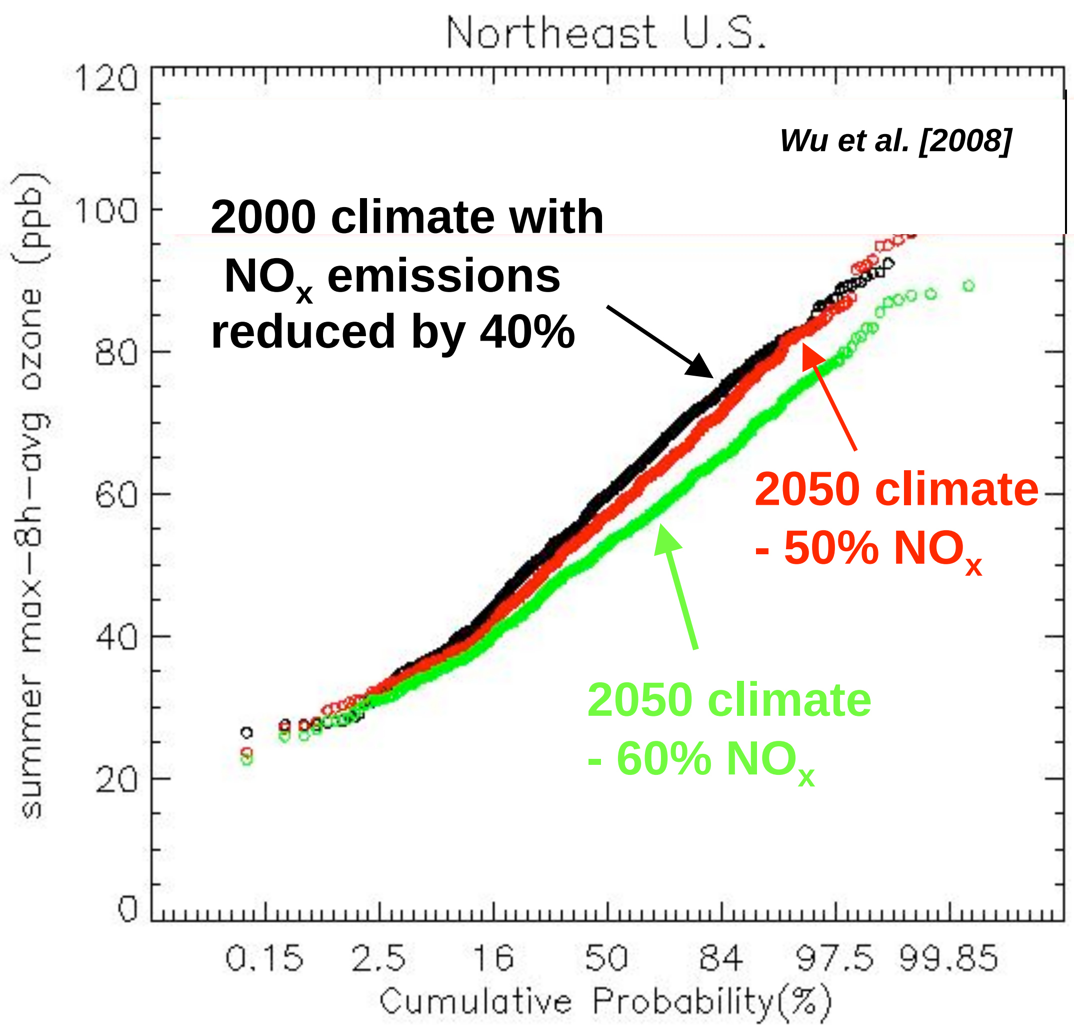
"Second, the science of modeling climate and atmospheric chemistry for the purposes of understanding the sensitivity of regional air quality to climate change is in its early stages. This effort highlights a number of uncertainties that limit the information that can be provided to support decision-making, as well as what work is needed (some currently underway) to begin addressing these uncertainties."

Implications

All else being equal, what kind of additional pressure might climate change put on our existing concerns and strategies? Is this something we need to begin folding in to our planning?

Extension of "O_3 season" in many parts of the country

"Climate Penalty" on control strategies – extra emissions reductions required in the future?



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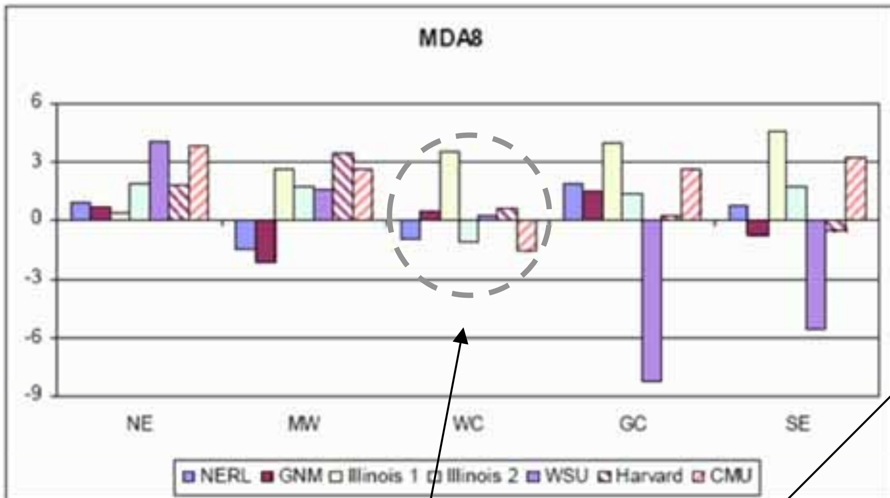
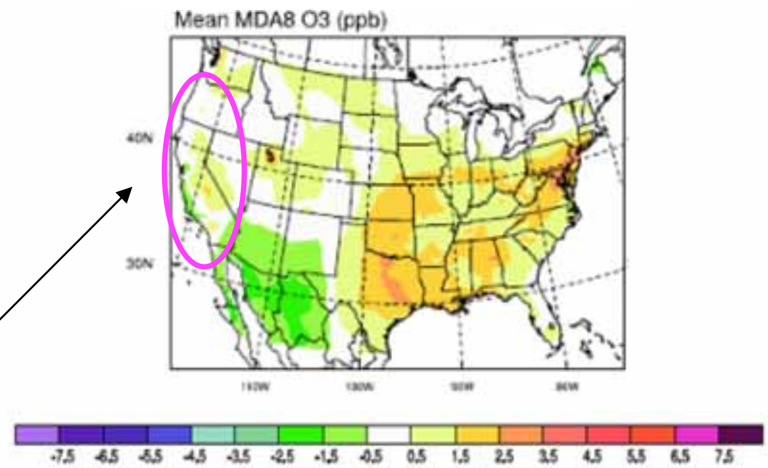
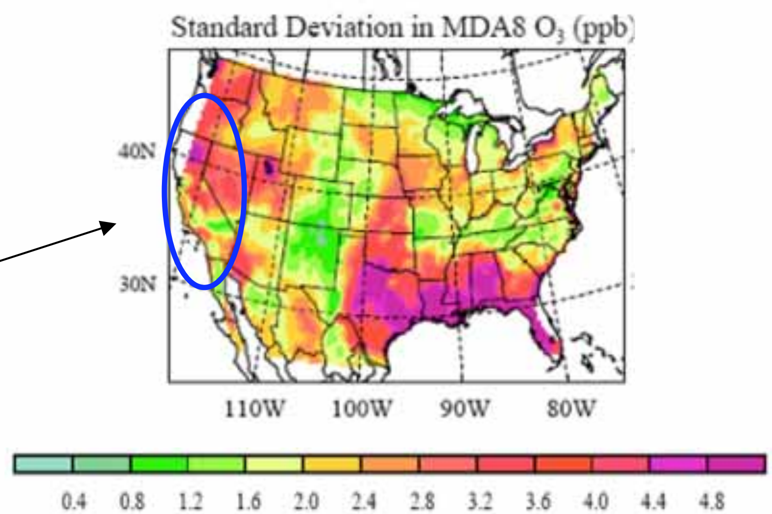
Regional Uncertainty

Focus on West Coast







A lot of variability across models

More complicated w/ emissions and transport

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Uncertainty and the Usefulness of Models

Why bother if all the models give different results? What are we trying to do here anyway?

Skillful, multi-decadal predictions of regional-scale climate change impacts are not on the horizon – are we out of luck?

- Science-based alternatives to prediction – risk assessment
- Decision context determines what scientific uncertainty "means"
- Scenario-based approaches can reveal where our vulnerabilities lie
- "Robustness" vs. "optimality"
- Avoiding unintended consequences
- Not "What will happen?" but "How does the system work?"

Best practices …

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Supplemental Slides

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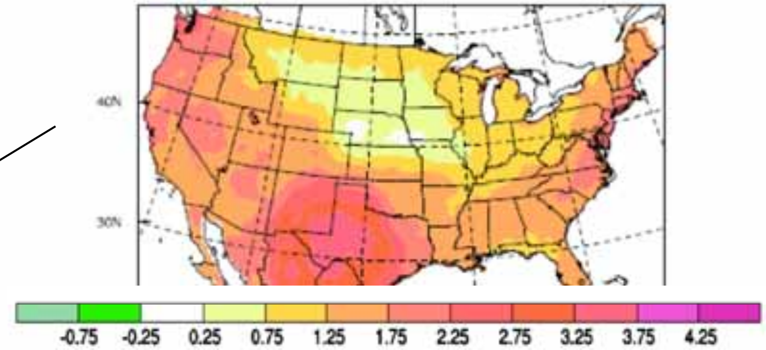
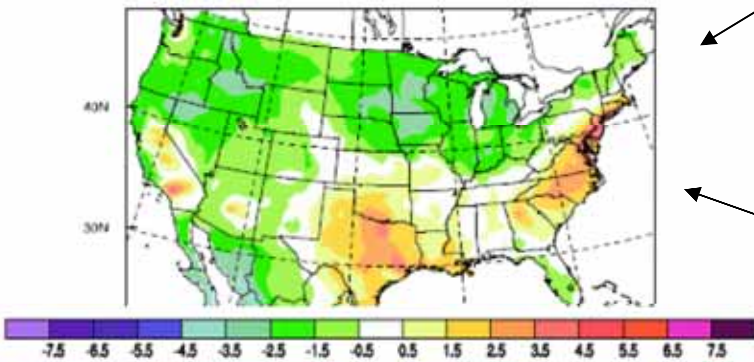
Key Drivers of O_3 Changes

EPA NERL Simulations

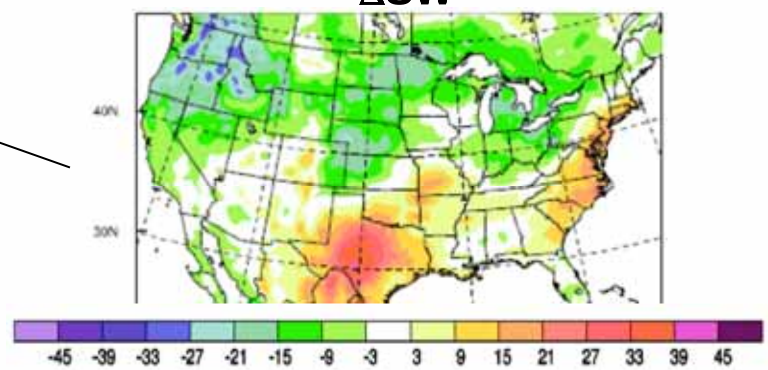
ΔT



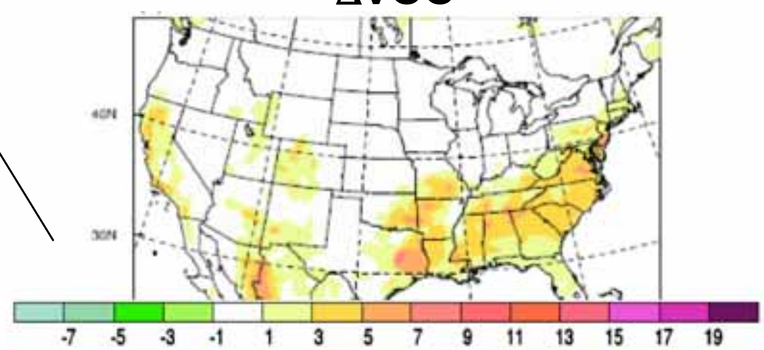
ΔO_3



ΔSW

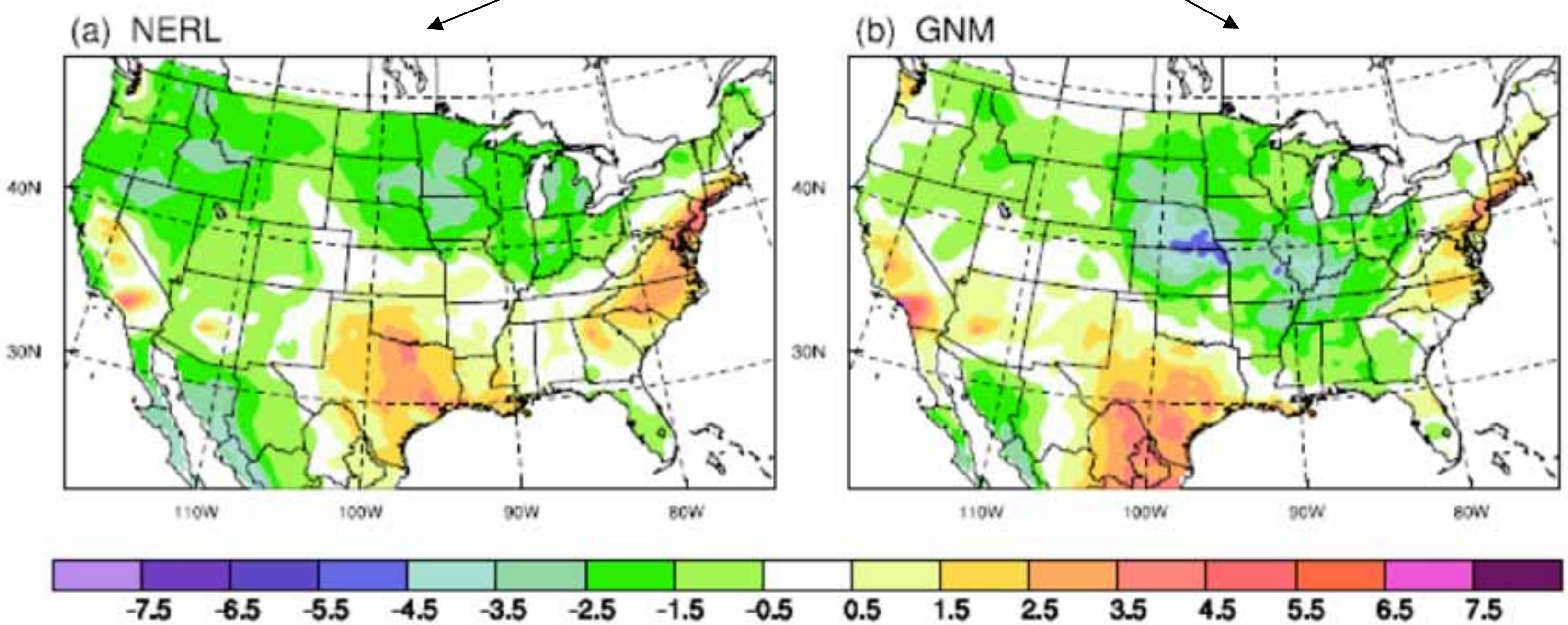


ΔVOC

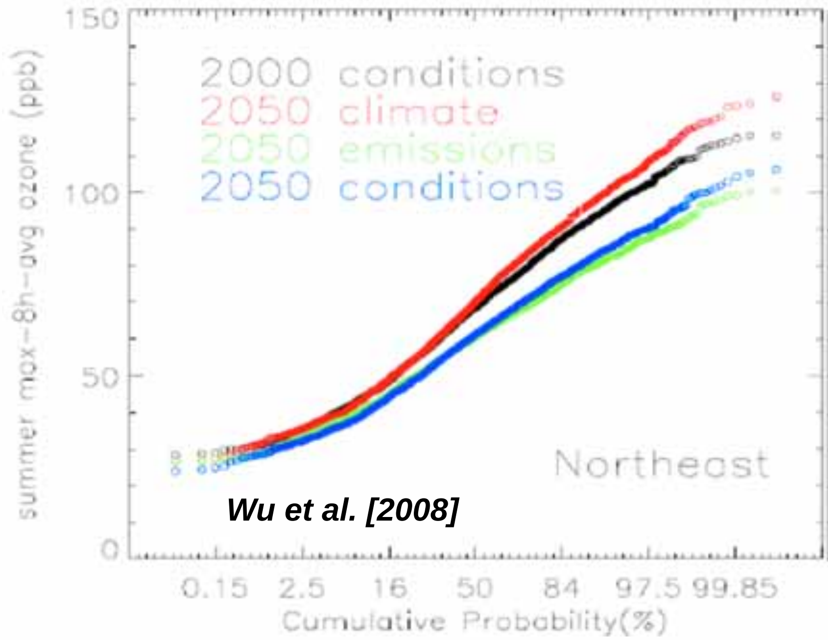


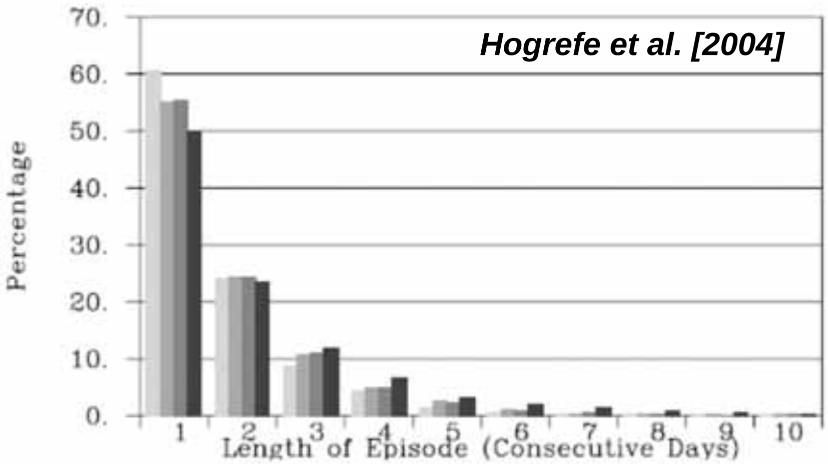
Interannual variability is important … highlights need for multi-year simulations …

5 year 3 year



Shift in the O_3 Distribution





Shift in Typical Duration of > 84 ppb O_3 Episodes