

1. Introduction

Studies examining the impact of climate change on future air quality disagree on the sign of the changes in many northern mid-latitude regions. Previous studies have typically used 3-10 year simulations from climate models [e.g., Chen et al., 2009; Dawson et al., 2009; Hogrefe et al., 2004; Huang et al., 2008; Mickley et al., 2004; Murazaki and Hess, 2006; Nolte et al., 2008; Racherla and Adams, 2008; Wu et al., 2008], making it difficult to distinguish whether the meteorological changes driving the air quality changes arise from a true climate change signal or internal (inter-annual or decadal) variability. In a review of how a warmer climate will influence air pollution at northern mid-latitudes, Jacob and Winner [2009] conclude:

- **Ozone (O₃) pollution** in urban areas **will worsen** as temperature and stagnation increase, which climate models consistently project for the **northeastern U.S. and southern and central Europe** [Christenson et al., 2007]
- **Aerosol** (particulate matter; hereafter **PM_{2.5}**) changes in a warmer climate are highly uncertain reflecting discrepancies in model projections for changes in precipitation frequency and ventilation in polluted regions [Christenson et al., 2007]

We design simulations to **maximize the detection of a climate signal** from internal model variability and focus on four regions at northern mid-latitudes: East Asia, Northeastern U.S., Southeastern U.S., and Central Europe.

Our ultimate goal is to **assess which meteorological changes are most important for future air quality** in these regions, and whether those changes reflect a robust climate signal. Here, we present a first look at the changes in air quality and driving meteorology in a warmer climate as projected by the new GFDL AM3 chemistry-climate model.

2. Simulations in the GFDL AM3 Chemistry-Climate Model

PRESENT Simulation (20 years completed)

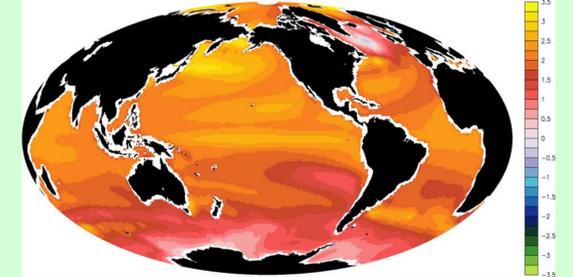
- Greenhouse gases at 1990 values
- Climatology of observed SSTs and sea ice (HadISST): annually repeating monthly mean values averaged over 1981-2000

FUTURE Simulation (20 years completed)

- Greenhouse gases at 2090 values
- Climatology of observed SSTs and sea ice from PRESENT simulation + mean changes under the A1B scenario from 19 IPCC AR-4 models, averaged over 2081-2100

All simulations use annually-invariant emissions of ozone and aerosol precursors (except for lightning NO_x) representative of the 1990s as in Horowitz [2006]. We will also test the sensitivity of our conclusions after updating to the IPCC AR-5 emissions for the year 2000.

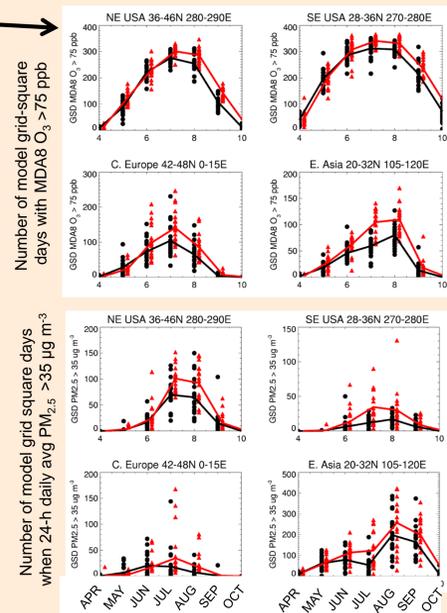
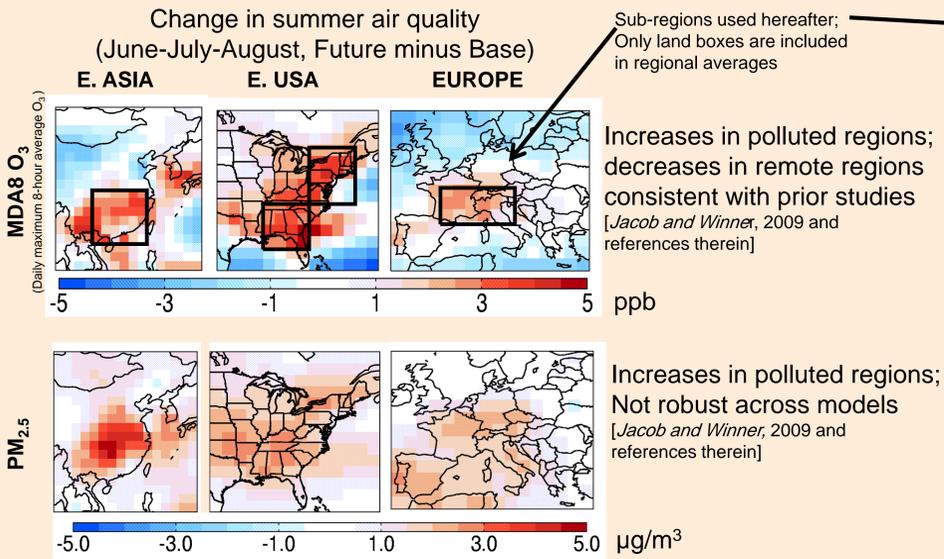
This pair of **idealized simulations** removes confounding influences of interannual and decadal variability, enabling earlier detection of a climate change signal. Model internal variability still produces year-to-year variations.



Annual mean SST change (in K) from 1981-2000 to 2081-2100, averaged for 19 IPCC AR4 climate models

3. Changes in Air Quality at Northern Mid-latitudes

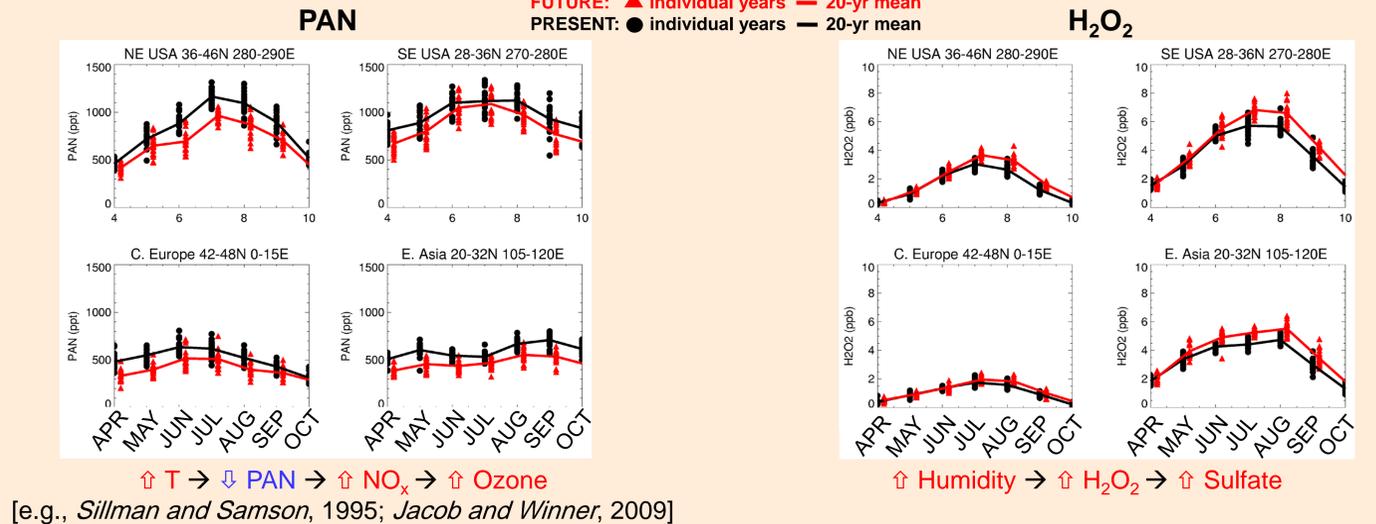
FUTURE: ▲ individual years — 20-yr mean
PRESENT: ● individual years — 20-yr mean



Over source regions, a warmer climate leads to degraded air quality

4. Mechanisms by which Meteorological Changes Affect Air Quality

FUTURE: ▲ individual years — 20-yr mean
PRESENT: ● individual years — 20-yr mean



Evidence for photochemical shifts (NO_x-PAN partitioning, sulfur oxidation) influencing air quality
Uncertain effects from meteorological changes (e.g., stagnation events, boundary layer height, precipitation)

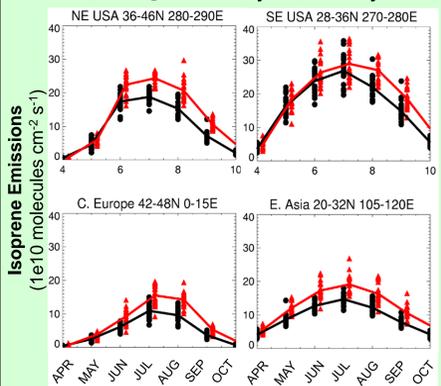
5. Next Steps

(1) Include climate feedback on isoprene emissions

(2) Evaluate air quality – meteorology relationships

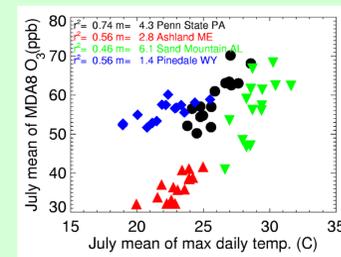
6. References

FUTURE: ▲ individual years — 20-yr mean
PRESENT: ● individual years — 20-yr mean



Isoprene emissions calculated with MEGAN [Guenther et al., 2006] as diagnosed from our simulations (new simulations in progress allow them to feed back on chemistry)

Impact on O₃ depends on uncertain isoprene oxidation chemistry [e.g., Fiore et al., 2005; Horowitz et al., 2007; Wu et al., 2008]; we use recommendations of Horowitz et al. [2007].



Regional variability in the ozone-temperature relationship, plotted here as July mean daily maximum 8-hour average (MDA8) O₃ (ppb) vs. July mean daily max temperature (°C) from 1989 to 2004 at selected U.S. CASTNet sites in the northeast (Penn State, PA), far northeast (Ashland, ME), southeast (Sand Mountain, AL), and western (Pinedale, WY) U.S.

How well are observed relationships (such as ozone-temperature, left) represented in global chemistry-transport models?

What other observed relationships should we use for model evaluation? e.g., increase in high-O₃ events with decreasing frequency of migratory cyclones as determined from a recent observational analysis for the northeastern U.S. [Leibensperger et al., 2008]

(3) Determine whether modeled meteorological changes are forced by climate change (versus internal variability)

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