Quantifying impacts of climate change and variability on future US $PM_{2.5}$ by dynamically downscaling a global chemistry-climate model in WRF and CMAQ

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1. Introduction

i. Climate, Air Quality and Health Connection

Meteorology can influence air quality in many ways as **Figure I** illustrates.[1,2,3]

For example, sources of natural emissions of air pollutants or their precursors, like biogenic VOCs, dust, wildfires, sea-salt and lightning, are meteorology sensitive.

Air quality, in turn, impacts human health and visibility.

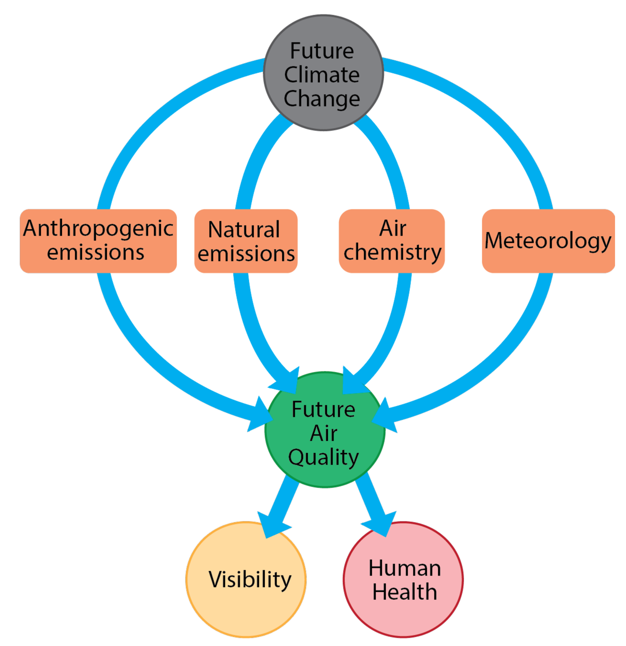
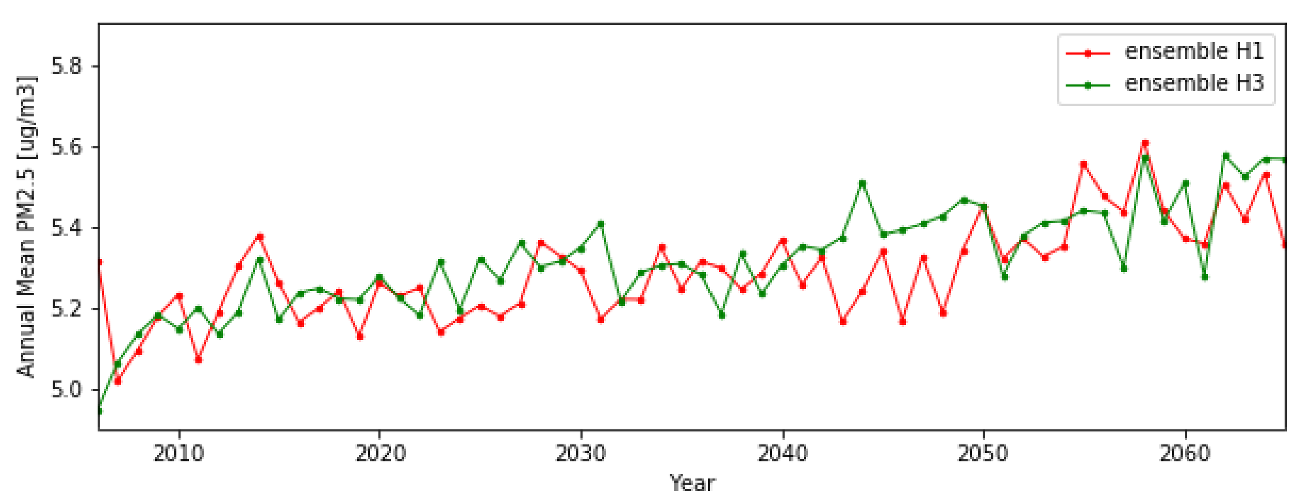


Figure I: Influences of future climate change on future air quality

ii. Climate Change and Climate Variability

Noise from climate variability can confound the signal of climate change:



The two ensemble members H1 and H3 of the global model GFDL-CM3, which vary only in initial conditions, show similar overall upward trend of US mean annual $PM_{2.5}$ from 2006 to 2065. However, the mean annual values for each year differ between the two ensembles.

iii. Past Research Findings

Past studies have noted that:

i. synoptic meteorology is a key driver of $PM_{2.5}$ and O_3
ii. there is potential for climate change to influence $PM_{2.5}$ distributions over the US, although studies disagree in the sign and magnitude of impact.[3]
iii. different $PM_{2.5}$ components have different climate responses.

However, some studies also had limitations as they simulated:

i. limited number of years without considering full distribution of $PM_{2.5}$.
ii. single realization from a single chemistry-climate model.

2. Objectives and Methods

i. Study Objectives

In this study, we address the limitations of past studies to understand the signal of future climate change on $PM_{2.5}$ in the presence of climate variability until mid-21st century, by

i. combining the statistical power of a global model with spatial refinement of regional meteorology and air quality models,
ii. making probabilistic estimates of changes in $PM_{2.5}$ air quality attributable to climate change only, under constant present day emissions, and
iii. estimating probability distributions of changes in visibility and $PM_{2.5}$-related human mortality.

ii. Approach

Our novel approach involves these steps:

1. 3-ensemble, coarse Global Chemistry-Climate Model simulations for 2006-2100
2. Select 8 GCM years representing high/median $PM_{2.5}$
3. Dynamical downscaling of meteorology (WRF 12km)
4. Air quality downscaling (CMAQ 12km) with inline biogenic, lightning, dust emissions
5. Construct fine scale probability distribution of mean annual $PM_{2.5}$
6. Study associated probabilistic impacts on visibility & human health

We have planned these WRF/CMAQ simulations:

Scenario	Time	Meteorology	GFDL IC/BCs	Anthrop. Emissions	# Realizations
PRES	2006-2020	2005 RCP8.5_WMGG	RCP8.5_ WMGG	2016 NEI	4
FUT	2050-2065	2050 RCP8.5_WMGG	RCP8.5_ WMGG	2016 NEI	4

In these simulations:

- FUT - PRES = effect of only climate change on future $PM_{2.5}$
- Land Use/Cover is set to be constant for all WRF/CMAQ simulations
- GFDL RCP8.5_WMGG fixes aerosol, ozone precursor emissions at 2005 level
- CMAQ simulations use 2016NEI emissions to reflect current emissions

3. Expected Results

We will fit a probability distribution of present day mean annual $PM_{2.5}$ in individual 12km CMAQ grid cells:

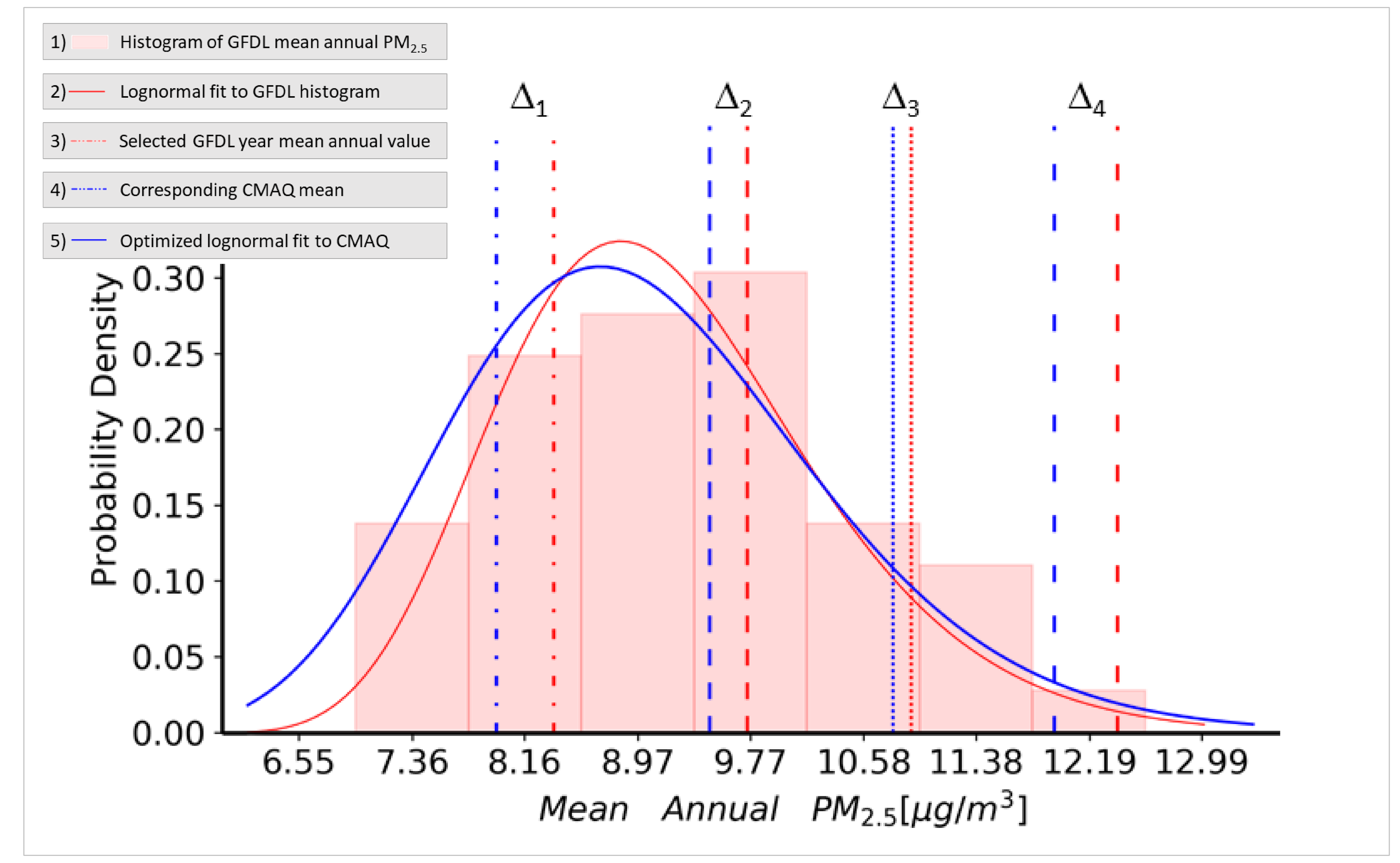


Figure II hypothetically illustrates

1) histogram of mean annual $PM_{2.5}$ in the decade 2006-2020 from 45 years of 3 GFDL-CM3 ensemble members in peach-colored bars
2) lognormal fit to GFDL ensemble histogram in 1) as a solid red curve
3) mean annual $PM_{2.5}$ values from the four selected years of median and high $PM_{2.5}$ GFDL years from 2006-2020 in dotted vertical red lines
4) WRF/CMAQ downscaled result of the selected GFDL years in 3) as vertical blue dotted lines
5) refined probability distribution of mean annual $PM_{2.5}$ for 2006-2020 reconstructed from the WRF/CMAQ downscaling results as solid blue curve (optimum distribution parameters minimize $(\Delta_1^2 + \Delta_2^2 + \Delta_3^2 + \Delta_4^2)$, which is the least sum of squares of distribution percentile differences).

Climate change impacts will be estimated by Monte Carlo sampling from present and future $PM_{2.5}$ distributions.

4. Current Progress

i. Meteorological Downscaling: Completed

We have downscaled GFDL-CM3 meteorology of all 8 selected GFDL years in WRF. WRF monthly T2 (max, min, mean) and precipitation totals compare well with corresponding GFDL values in all of selected years. As an example, **Figure III** compares mean July (CONUS 12km domain) 2m temperature between GFDL and WRF for year 2058 (H3 ensemble):

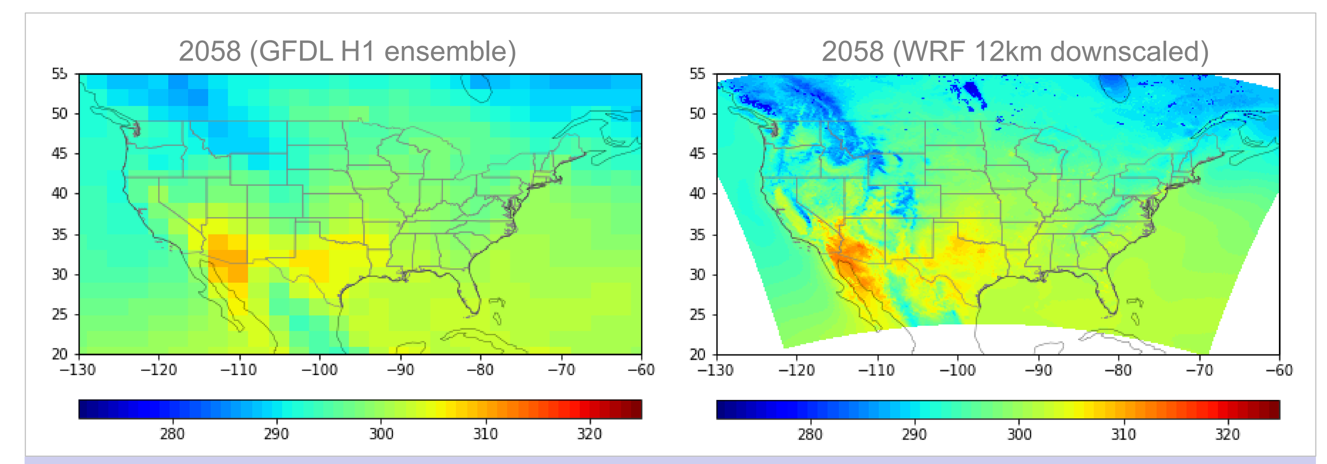


Figure III: July mean 2m temperature from GFDL and WRF (12km)

ii. Air Quality Downscaling: Ongoing

We are testing air quality downscaling of GFDL-CM3 chemistry of year 2014 (ensemble H1) in CMAQ. While mean annual and monthly (example in **Figure IV**) $PM_{2.5}$ levels are reasonable, winter O_3 from CMAQ is unexpectedly high and is being further investigated before production run.

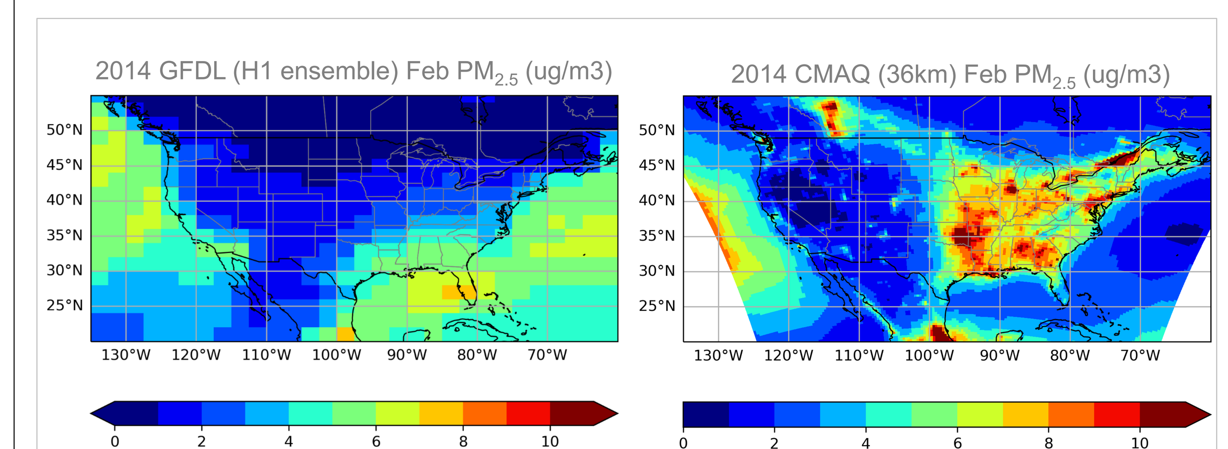


Figure IV: February mean surface $PM_{2.5}$ in GFDL and CMAQ (36km)

5. Conclusion

We will quantify climate change impacts on US $PM_{2.5}$ in the 2050s, in the presence of climate variability, by:

i. using large ensemble global model simulation to characterize variability
ii. downscaling meteorology and air quality in selected years to fine resolution (12km)
iii. setting anthropogenic emissions to present levels
iv. allowing sea spray, lightning and biogenic emissions to evolve with meteorology
v. mapping fine scale probability distributions of $PM_{2.5}$ in individual grid cells

Our study will yield an improved air quality projection method for individual US subregions, in context of future climate change and variability.

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