# Studying the influence of climate change and variability on mid-21$^{st}$ century US $PM_{2.5}$ by dynamical downscaling


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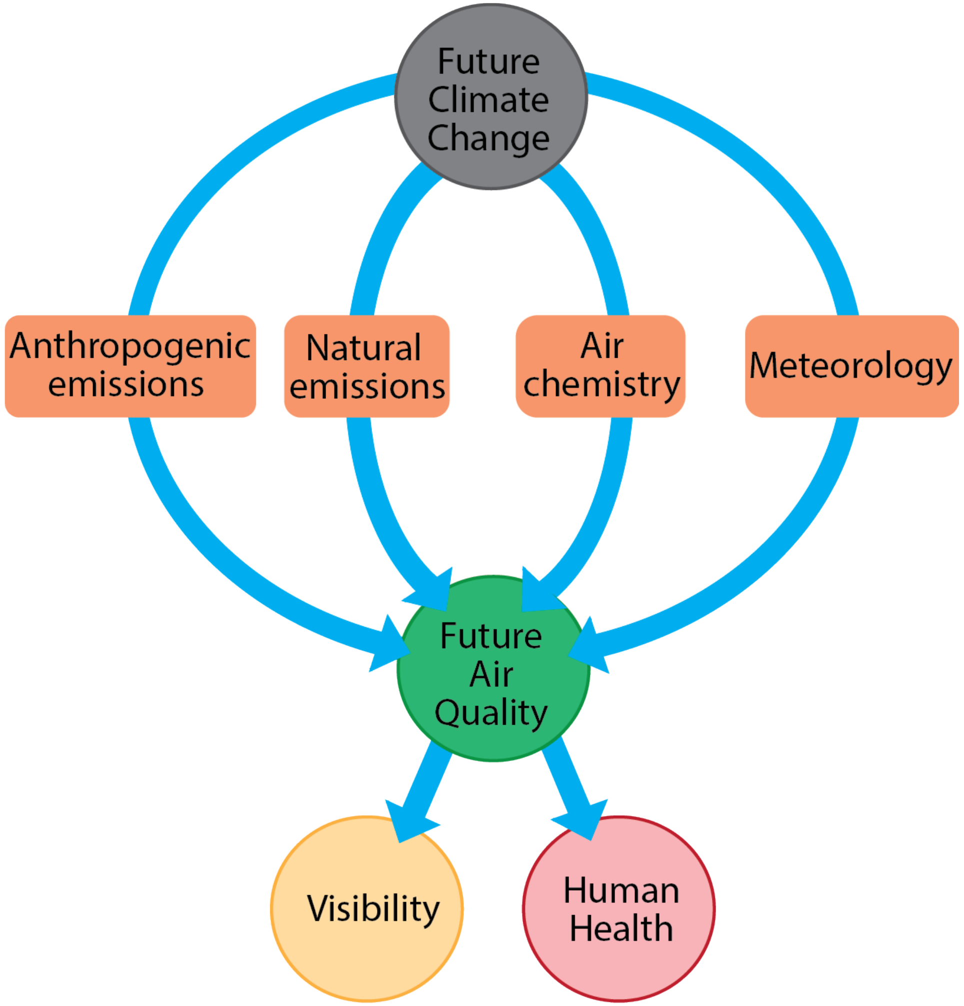
# Climate Change Impacts on Air Quality: Pathways

- Meteorology influences $PM_{2.5}$ air quality in many ways:

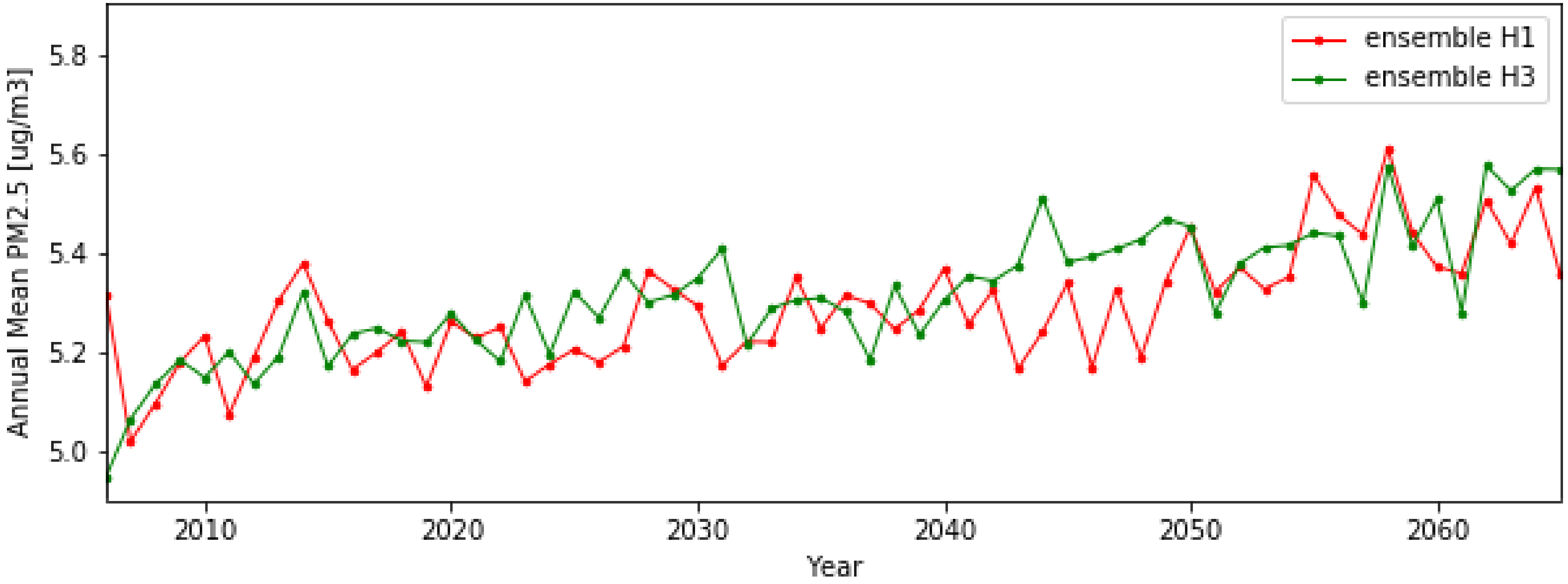



- $PM_{2.5}$, in turn, affects visibility and human health

Figure adapted from Jacob & Winner, 2009

# Climate Variability vs Climate Change for $PM_{2.5}$

- $PM_{2.5}$ variability+change illustrated by two GFDL ensemble members H1 and H3:




Area used in averaging $PM_{2.5}$ for the timeseries

**NATURAL CLIMATE VARIABILITY = fluctuation around a steady mean**

≠

**CLIMATE CHANGE (SIGNAL) = long term change of mean**

**NATURAL FORCING =** caused by solar activity, volcanoes

+

**INTERNAL VARIABILITY (NOISE) =** internally arising due to chaotic nature of climate system

- Internal Variability (noise) can confound Climate Change (signal)

# Past Studies of Climate Change on US $PM_{2.5}$

Notable findings of past studies:

- synoptic meteorology key driver of $PM_{2.5}$ and $O_3$
- inconsistency in climate impact on air quality:

| | $[O_3]$ results | $[PM_{2.5}]$ results |
|---|---|---|
| **Δ Direction** | Consistently +ve | Inconsistent sign |
| **Δ Magnitude** | 1-10 ppb (polluted regions) | Between -1 and +1 $\mu gm^{-3}$ |

Fiore et al, 2015

- Complex $PM_{2.5}$ components with different climate response

| Crustal Elements | | | Bulk Organic Carbon | | Secondary Inorganic Ions | | | Anthropogenic (Industrial) Tracers | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Si | Ca | Al | OC | EC | $NH_4^+$ | $SO_4^{2-}$ | $NO_3^-$ | Fe | Zn | Pb |

from Kundu & Stone, 2015 study

But some studies have:

- Averaged limited number of future years
- Used single realization of one climate model

# Study Objectives and Method

**Objective** - Characterize the role of climate variability and change on US $PM_{2.5}$ distribution in fine scale, using a novel approach:

3-ensemble, coarse Global Chemistry-Climate Model simulations for 2006-2100

↓

Select 8 GCM years representing high/median $PM_{2.5}$

↓

Dynamical downscaling of meteorology (WRF 12km)

↓

Air quality downscaling (CMAQ 12km) with inline biogenic, lightning, dust emissions

↓

Construct fine scale probability distribution of mean annual $PM_{2.5}$

↓

Study associated probabilistic impacts on visibility & human health

# Year Selection for Downscaling based on GFDL Output EOF Analysis

We select years from GFDL chemistry-climate global model that represent upper quartile and median $PM_{2.5}$ levels in each US region

## Method of Year Selection

Daily mean $PM_{2.5}$ from GFDL-CM3

↓

### EOF analysis of GFDL

Identify US regions that vary $PM_{2.5}$ coherently

↓

### Year Selection for Downscaling

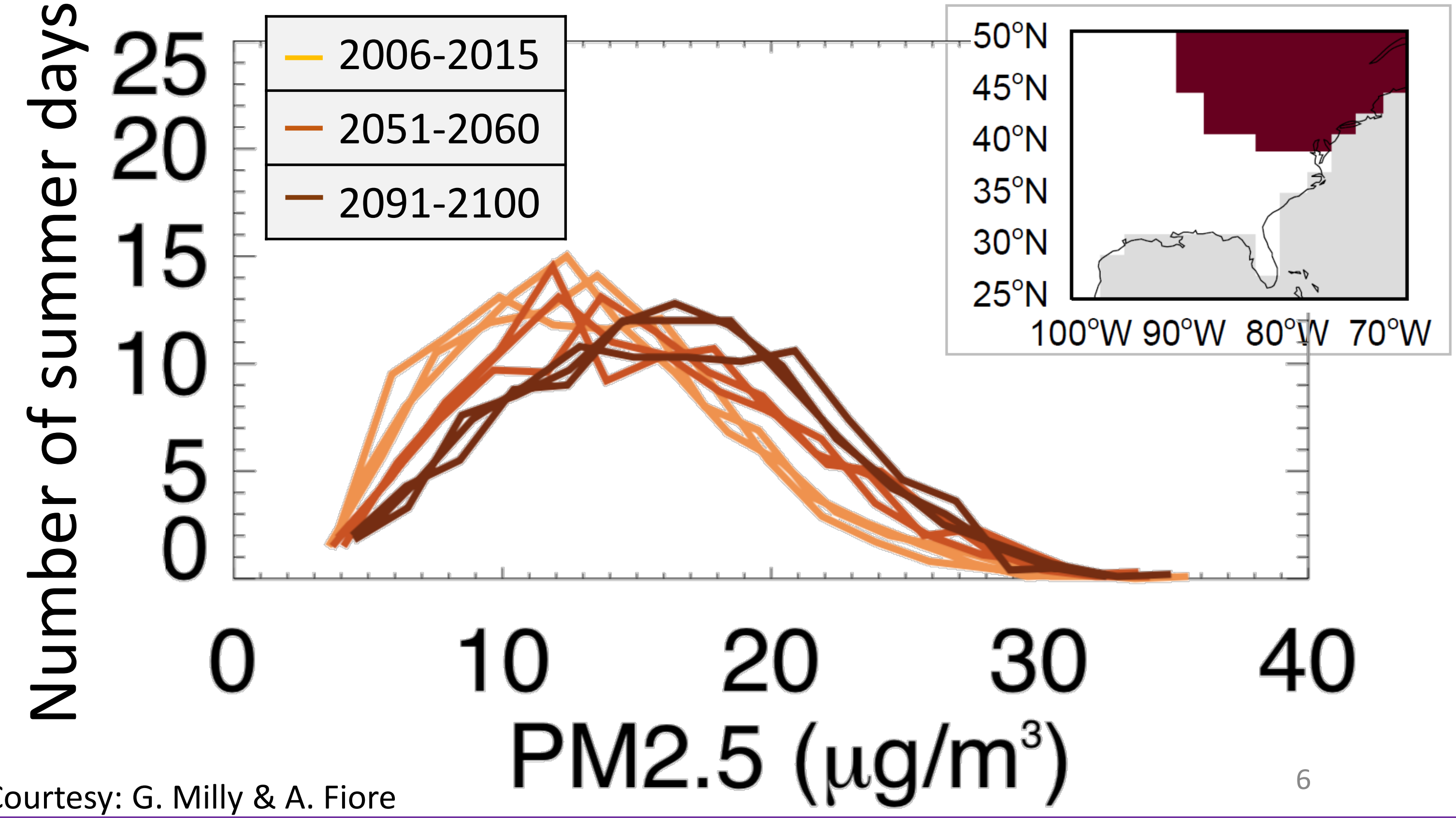
Identify upper-quartile and median annual $PM_{2.5}$ years in different CONUS regions

↓

Present years: 2006/07 H1, 2010/11 H5, 2014/15 H1, 2018/19 H3

Future years: 2054/55 H3, 2054/55 H5, 2058/59 H1, 2058/59 H5

**Histograms of summer daily mean $PM_{2.5}$ of 3 ensemble members of GFDL CM3 to (i) better characterize internal variability, and (ii) show the shift in $PM_{2.5}$ distribution due to climate change**




Courtesy: G. Milly & A. Fiore

# WRF/CMAQ Simulations

| Scenario | Time | Meteorology | GFDL IC/BCs | Anthrop. Emissions | # Realizations |
|---|---|---|---|---|---|
| RCP8.5m_2005e_PRES | 2006-2020 | 2005 RCP8.5_WMGG | RCP8.5_WMGG | 2016 NEI | 4 |
| RCP8.5m_2005e_FUT | 2050-2065 | 2050 RCP8.5_WMGG | RCP8.5_WMGG | 2016 NEI | 4 |

RCP8.5m_2005e_FUT - RCP8.5m_2005e_PRES = effect of only climate change on future $PM_{2.5}$

- Land Use/Cover remains 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

# WRF Physics Options

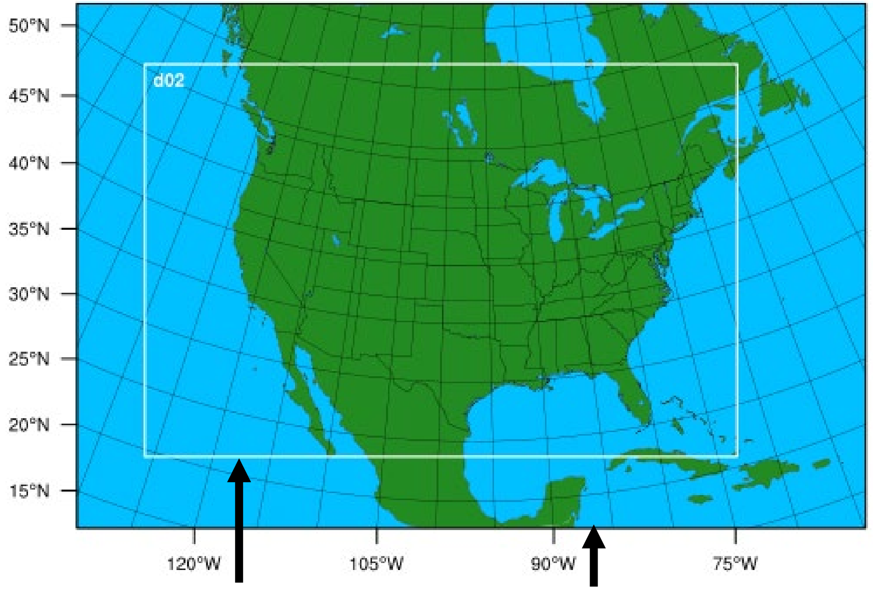
- 8 selected GFDL years (RCP8.5 met. and 2005 emissions) downscaled in WRF:

**Physics Options used in WRFv3.9.1.1 simulations**

| Parameter | Physics options used in WRF simulation |
|---|---|
| mp_physics = 6 | WSM 6-class graupel scheme microphysics |
| ra_lw_physics = 4 | RRTMG radiative transfer scheme for longwave radiation |
| ra_sw_physics = 4 | RRTMG radiative transfer scheme for shortwave radiation |
| sf_surface_physics = 2 | Unified Noah land-surface model |
| cu_physics = 1 | Kain-Fritsch (new Eta) scheme for cumulus parameterization |
| num_land_cat = 40 | 40 land categories of NLCD2011 used |
| num_soil_cat = 16 | 16 categories of soil data |

* Spectral nudging is applied to moisture for better precipitation results (Spero et al, 2018)

**Domains used in Simulations**

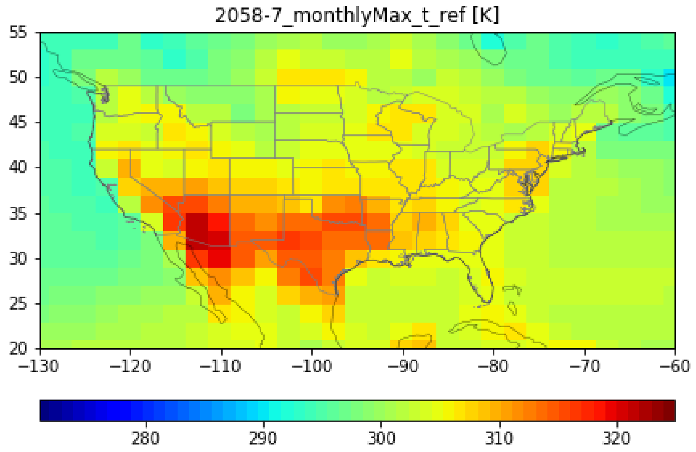
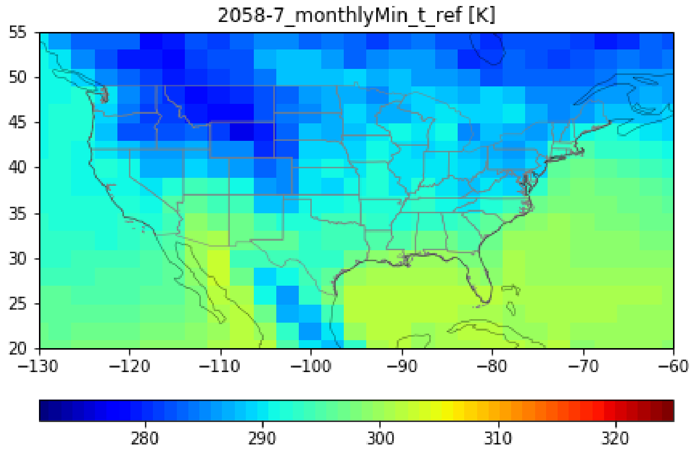
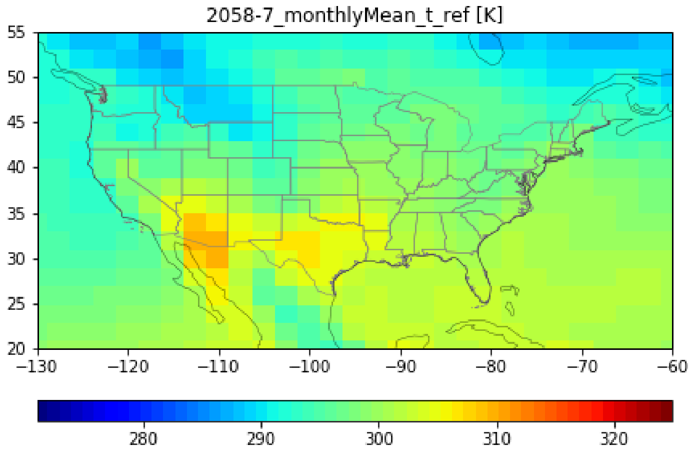
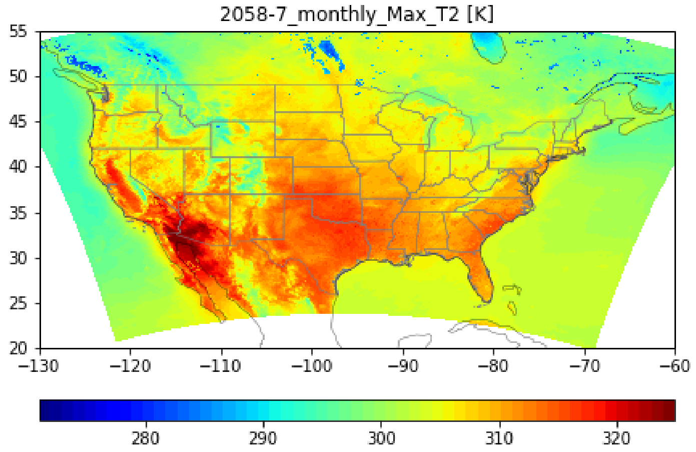
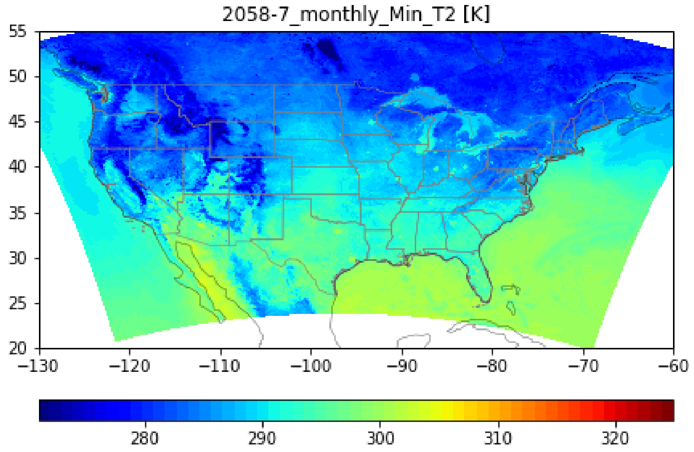
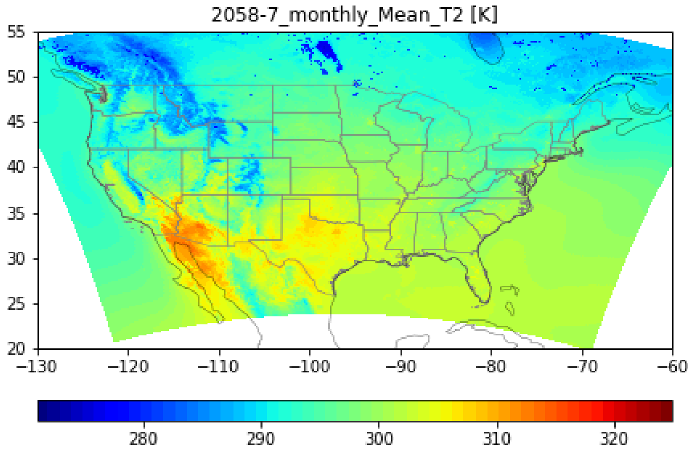



12km domain

36km domain

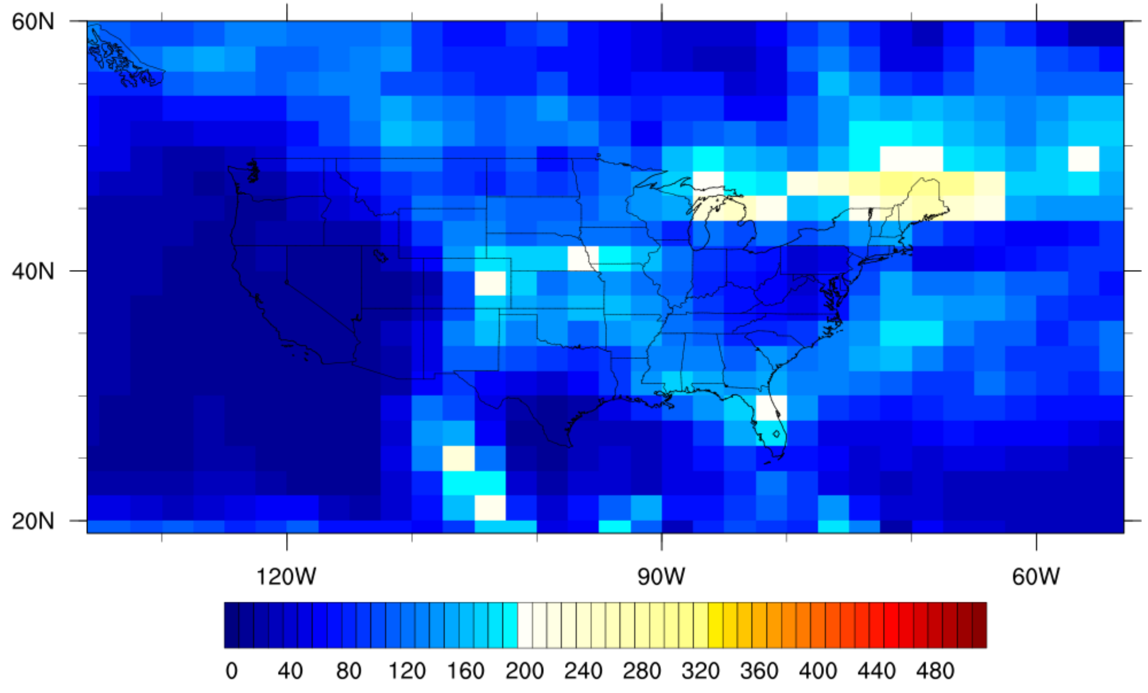
# Comparing GFDL & WRF T2 [K] Statistics: July 2058 (ens. H1) Example

- General temperature patterns of GFDL simulations are represented in WRF
- WRF simulation adds fine scale details

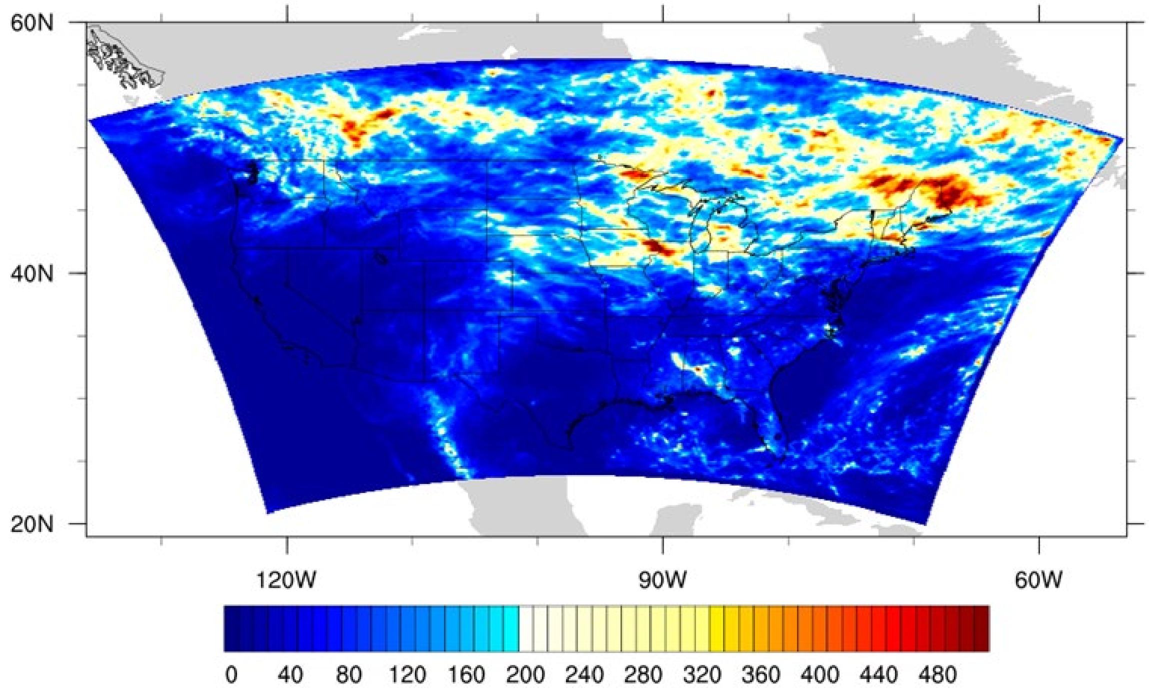
| | T2 July 2058(H1) Maximum | T2 July 2058(H1) Minimum | T2 July 2058(H1) Mean |
|---|---|---|---|
| **GFDL 2058 H1** |  |  |  |
| **WRF 12km** |  |  |  |

# Comparing GFDL & WRF Monthly Total Precipitation [mm]: July 2058 (ens. H1) Example

- General precipitation pattern of GFDL are represented well in WRF*
- WRF simulation adds finer scale details in precipitation




**GFDL 2058 H1**




**WRF 12km**

* Spectral nudging applied to moisture in WRF simulations for better precipitation results (Spero et al, 2018)

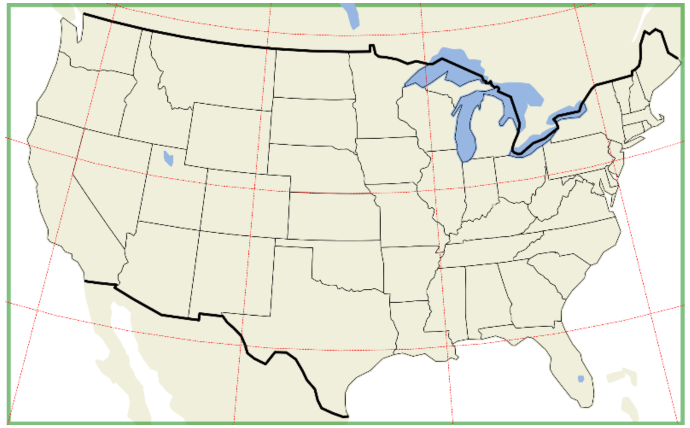
* July-December 6-month spinup used for surface temperature IC for better Inland lake model results

# Current Progress: CMAQ test-run configuration

- CMAQ test-run of Jan-Feb of a selected GFDL year 2014/15 H1 conducted

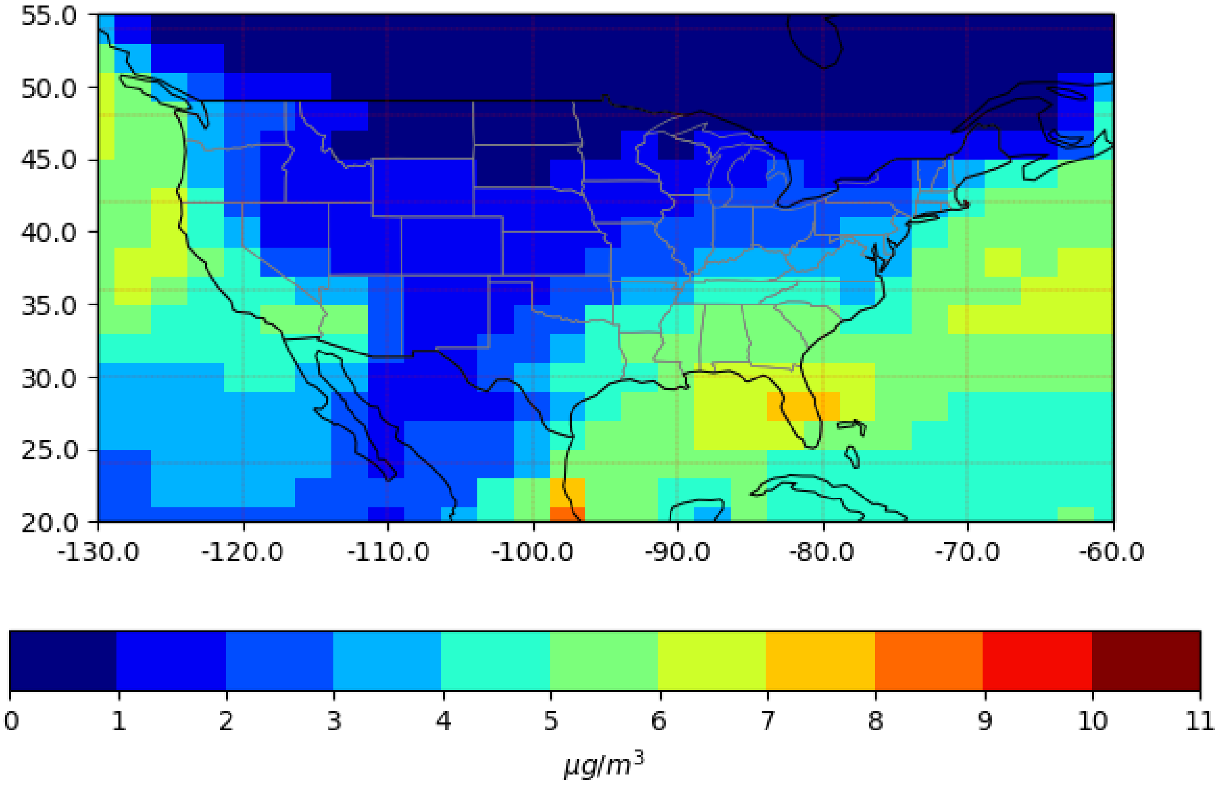
- Meteorology-sensitive emissions used inline in CMAQ:
  - sea spray aerosol emission
  - windblown dust emissions
  - lightning $NO_x$ emissions
  - biogenic emissions

- 12US2 domain (12km) used in CMAQ test-run:

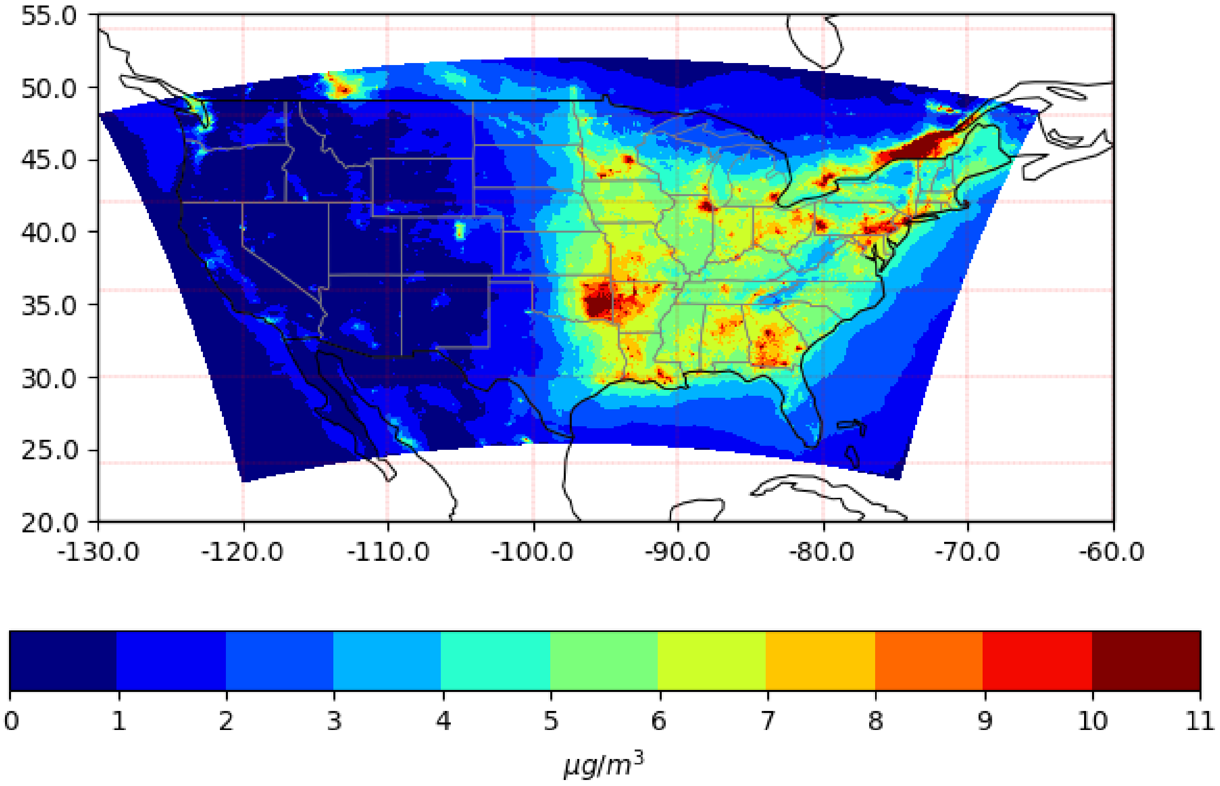


# Comparing GFDL & CMAQ Feb 2014 (H1) Monthly Mean of Total $PM_{2.5}$

- CMAQ test-run looks different from GFDL-CM3:
  - they are different in horizontal grid size
  - they use different emissions
  - other technical issues also being investigated for the difference



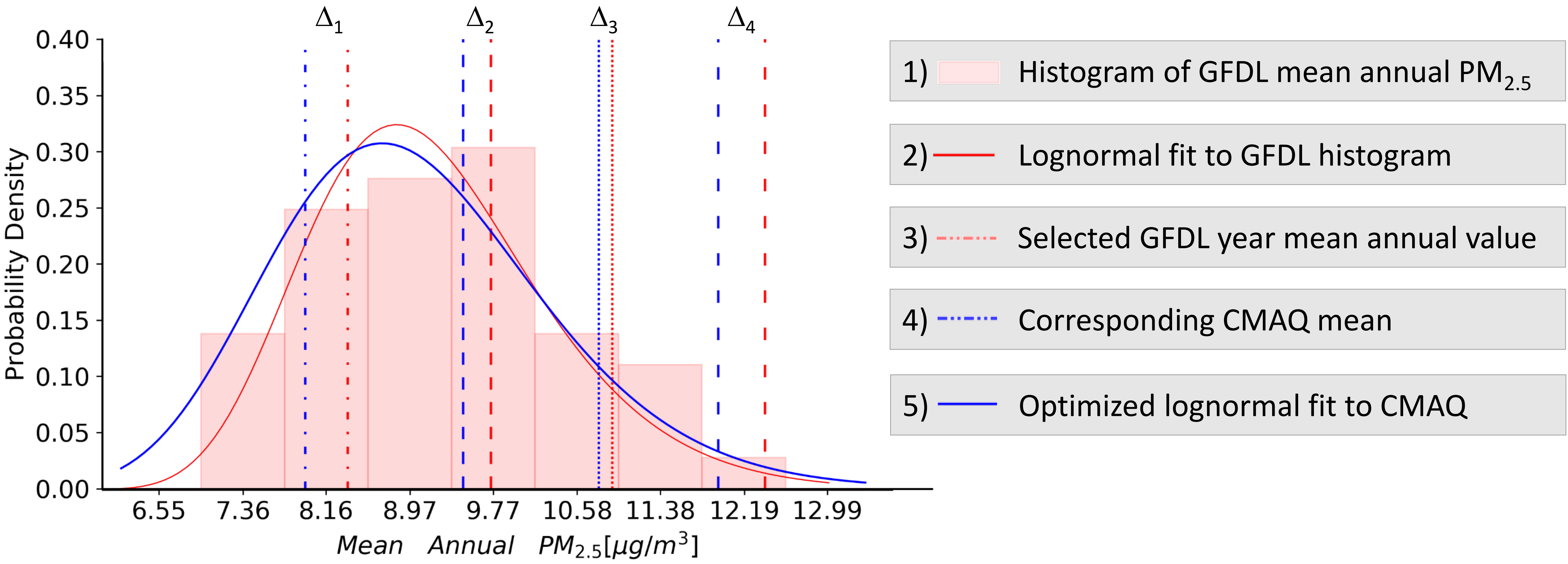

**GFDL 2014 H1**




**CMAQ 12km**

# Constructing Fine Scale $PM_{2.5}$ Probability Distribution based on Global Model Ensembles

- Illustration of a single grid cell mean annual $PM_{2.5}$ for a specific period (e.g. present decade)




- 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
- Impact of climate change estimated by Monte Carlo sampling from present and future distributions

# Expected Outcomes & Summary

- To quantify climate change impacts on US $PM_{2.5}$ in the 2050s, considering variability, we:
    - use large ensemble global model simulation to characterize variability
    - downscale meteorology and air quality in selected years to fine resolution (12km)
    - set anthropogenic emissions to present day levels
    - allow dust, sea spray, lightning and biogenic emissions to evolve with meteorology
    - map 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.
- We will also map the associated impacts of climate change and variability on human health and visibility.

# References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# Thank You for listening!

Thanks to my

| | | | |
|---|---|---|---|
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Also, thanks to

| | | | |
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# Questions?