Evaluating the role of climate uncertainty in assessments of climate change impacts on air quality

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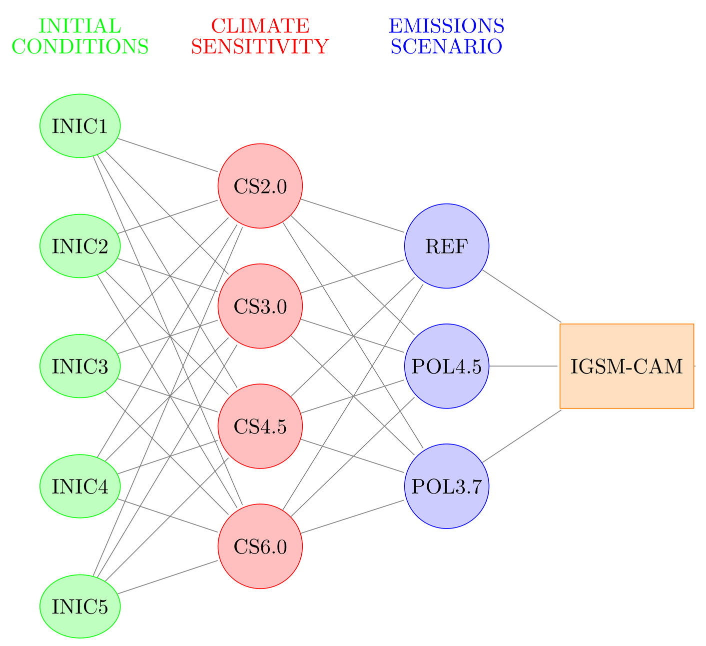
Motivation

Large uncertainties associated with climate projections propagate to simulations of future air quality driven by general circulation models. In this study we investigate the effects of uncertainty in climate simulations on projections of air quality using a global atmospheric chemistry model driven by meteorological fields derived from an ensemble simulation of 21st century climate change generated through the MIT Integrated Global System Model. The ensemble considers uncertainties in emissions of climate forcers, natural variability, and climate model response. Here, ozone and particulate matter are simulated across the climate ensemble to assess uncertainty in the climate penalty on air quality in the U.S.

Ensemble simulation of 21st century climate change



We focus on the 3 main sources of uncertainty in climate projections:

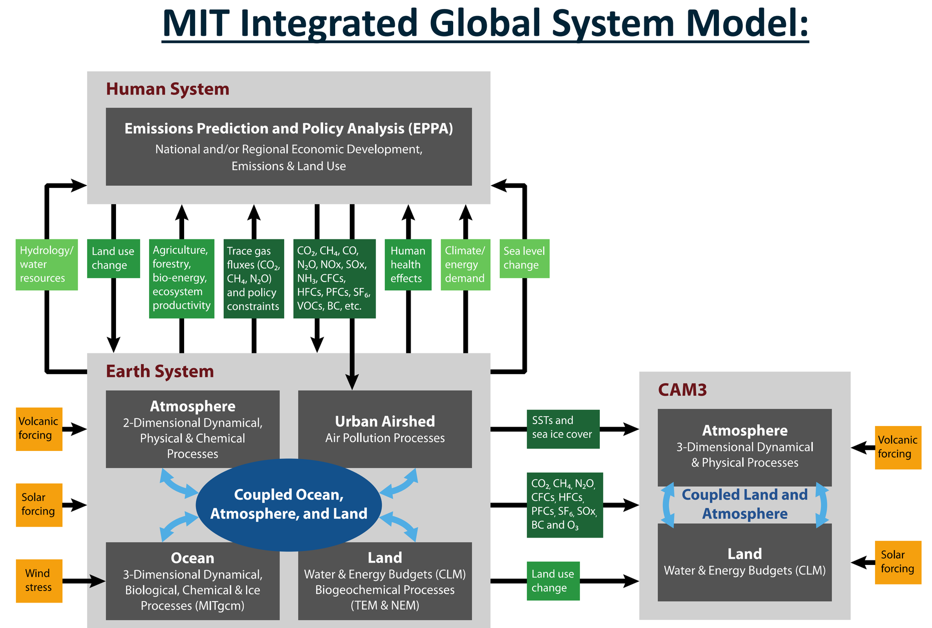
1. **GHG emissions**
   - 3 policy scenarios: reference, stabilization, and stringent stabilization
2. **Climate model response**
   - 4 climate sensitivities: 2.0°C, 3.0°C, 4.5°C, and 6.0°C
3. **Natural variability**
   - Multidecadal simulations under 5 different initializations

MIT IGSM climate policy scenarios

Climate policy scenarios:

1. **Reference scenario**
   - Unconstrained emissions; 2100 rad. forcing = 9.7 W/m^2
2. **Policy scenario I (P45)**
   - Stabilization scenario; 2100 rad. forcing = 4.5 W/m^2
3. **Policy scenario II (P37)**
   - Stringent stabilization; 2100 rad. forcing = 3.7 W/m^2

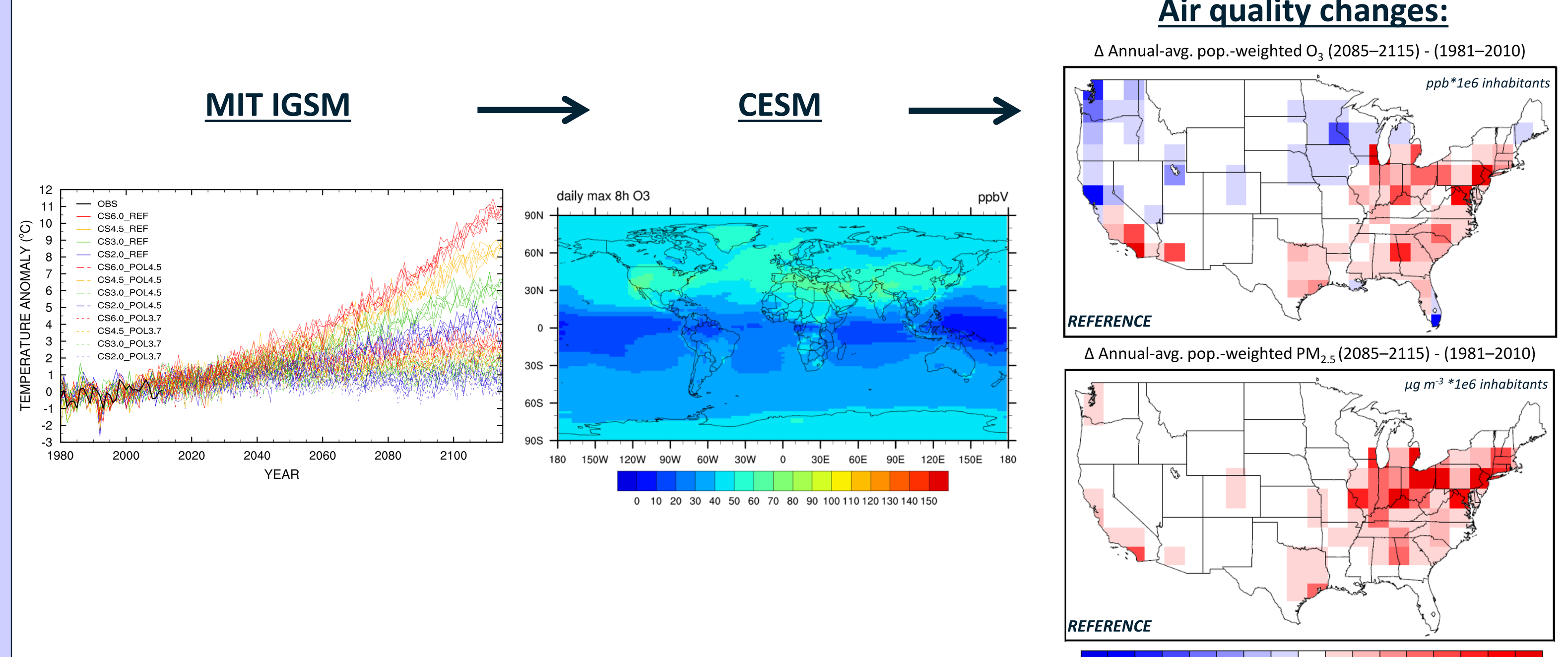
MIT Integrated Global System Model:



Modeling Framework

- The **MIT IGSM** is used to generate policy scenarios and project climate.
- The Community Atmosphere Model with chemistry (**CAM-Chem**) is used to simulate O_3 and PM within the Community Earth Systems Model (**CESM**).
- Atmospheric emissions are fixed at yr-2000 levels to estimate climate penalty on air quality.
- 30-yr simulations (1981→2010, 2036→2065, 2085→2115) are used to characterize climate.
- O_3 and PM are weighted by U.S. population.

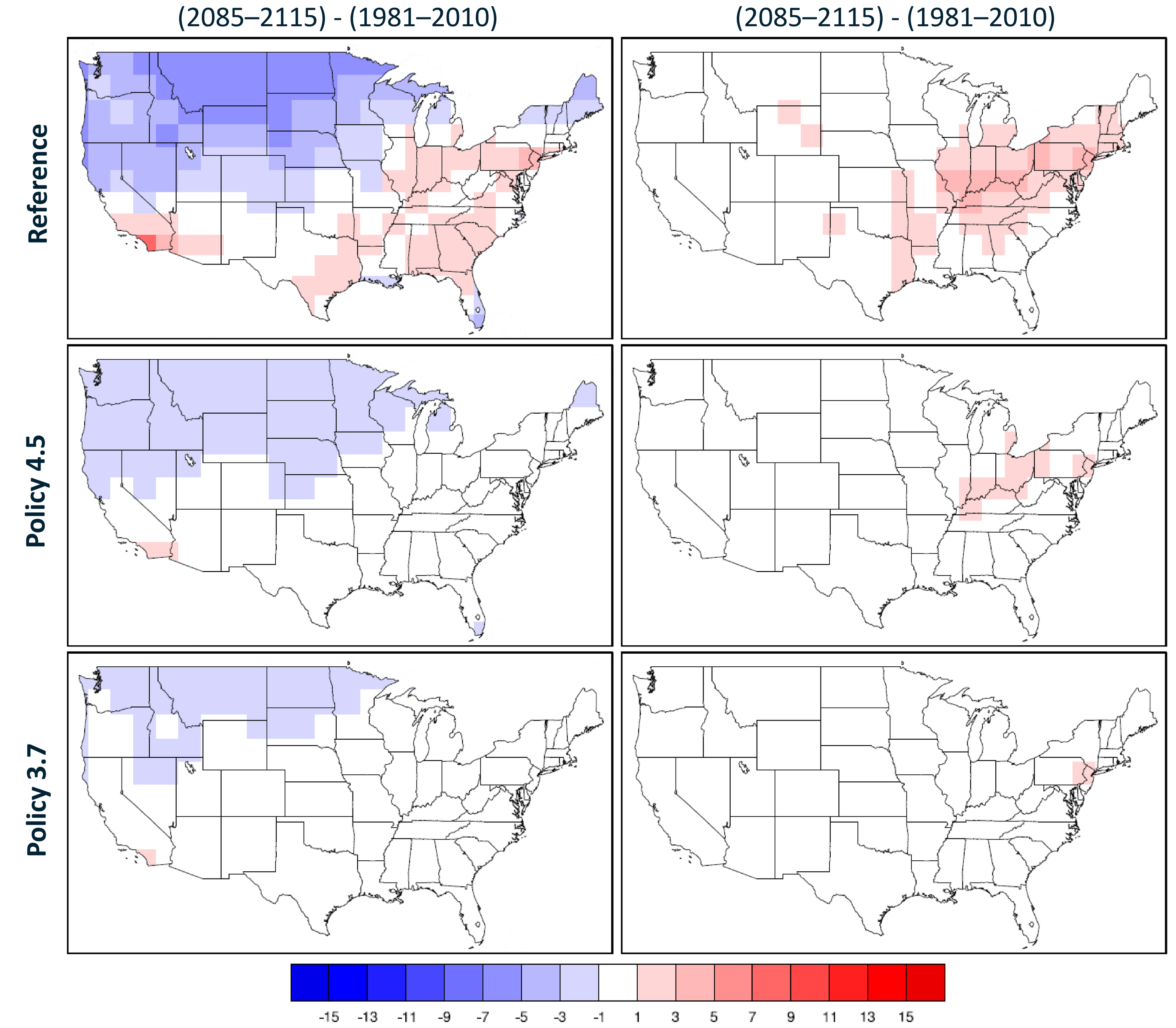
Air quality changes:



Climate impact on O_3 and $PM_{2.5}$ concentrations

Δ Annual-avg. O_3 (ppb) (2085–2115) - (1981–2010)

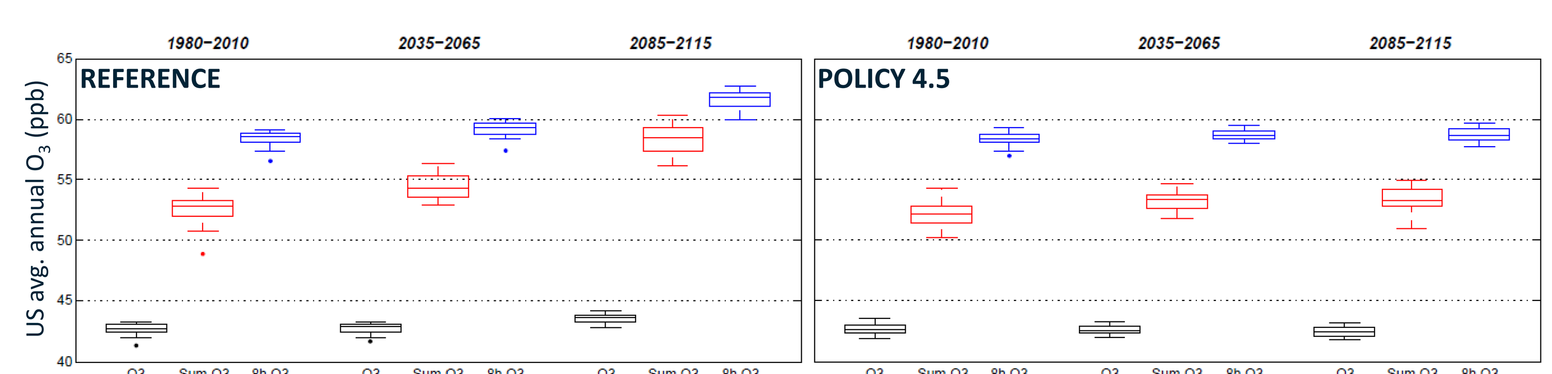
Δ Annual-avg. $PM_{2.5}$ (μg m^{-3}) (2085–2115) - (1981–2010)



Ensemble-mean projections:

- Increase in O_3 over polluted regions of the U.S. and a decrease in background concentrations.
- Larger climate penalty on O_3 for summer and 8-hour daily maximum concentrations.
- Significant increase in PM (SO_4, EC, OA, NH_4NO_3) concentrations over the eastern U.S.
- Important regional differences in climate impacts on air quality.
- Climate change mitigation policies significantly reduce impacts; most of the reduction is achieved by implementing the 4.5 W/m^2 stabilization policy.

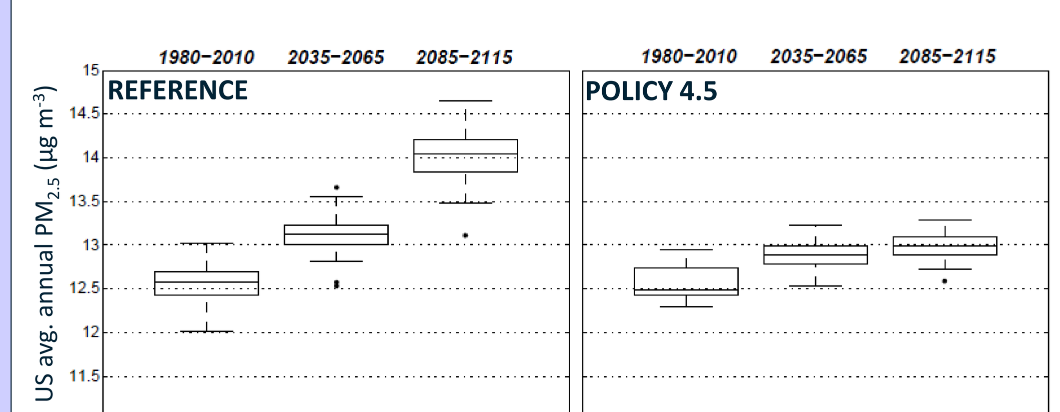
Climate penalty & policy benefits for U.S. O_3



Climate Penalty (Δ ppb O_3)		Annual O_3 (pop-wgt)	Summer O_3 (pop-wgt)	Daily max 8h O_3 (pop-wgt)
REF	*2000 → 2050*	0.1 ± 0.1	2.0 ± 0.2	0.8 ± 0.1
	2000 → 2100	0.9 ± 0.1	5.8 ± 0.3	3.2 ± 0.2
POL45	*2000 → 2050*	-0.1 ± 0.1	1.1 ± 0.2	0.4 ± 0.1
	2000 → 2100	-0.2 ± 0.1	1.2 ± 0.2	0.4 ± 0.1
POL37	*2000 → 2050*	-0.1 ± 0.1	0.8 ± 0.3	0.3 ± 0.1
	2000 → 2100	0.1 ± 0.1	1.3 ± 0.2	0.6 ± 0.1

Policy Benefit (Δ climate penalty)		Annual O_3 (pop-wgt)	Summer O_3 (pop-wgt)	Daily max 8h O_3 (pop-wgt)
REF → P45	*2000 → 2050*	-0.1 ± 0.1	-0.9 ± 0.3	-0.4 ± 0.2
	2000 → 2100	-1.1 ± 0.1	-4.6 ± 0.4	-2.8 ± 0.2
REF → P37	*2000 → 2050*	-0.2 ± 0.1	-1.1 ± 0.3	-0.5 ± 0.2
	2000 → 2100	-0.8 ± 0.1	-4.5 ± 0.4	-2.7 ± 0.2

Climate penalty & policy benefits for U.S. $PM_{2.5}$



Climate Penalty (Δ μg m^{-3})		Annual PM (pop-wgt)
REF	*2000 → 2050*	0.5 ± 0.1
	2000 → 2100	1.5 ± 0.1
POL45	*2000 → 2050*	0.3 ± 0.05
	2000 → 2100	0.4 ± 0.05
POL37	*2000 → 2050*	0.2 ± 0.0
	2000 → 2100	0.2 ± 0.1

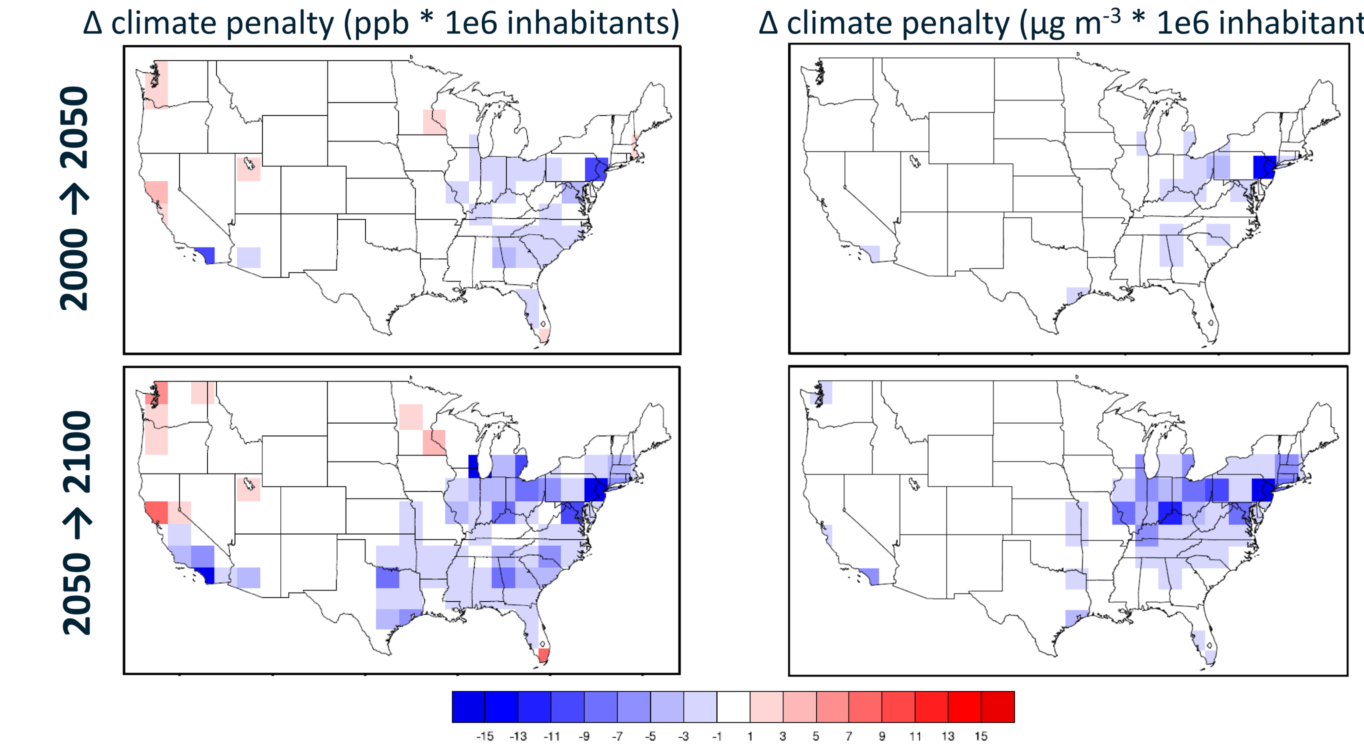
Policy Benefit (Δ climate penalty)		Annual PM (pop-wgt)
REF → P45	*2000 → 2050*	-0.2 ± 0.1
	2000 → 2100	-1.0 ± 0.1
REF → P37	*2000 → 2050*	-0.3 ± 0.1
	2000 → 2100	-1.2 ± 0.1

Benefits of climate policy in 2050 vs 2100

Largest fraction of policy benefits projected to occur during the 2nd half of 21st century:

Benefits of policy 4.5 on O_3
Δ climate penalty (ppb * 1e6 inhabitants)

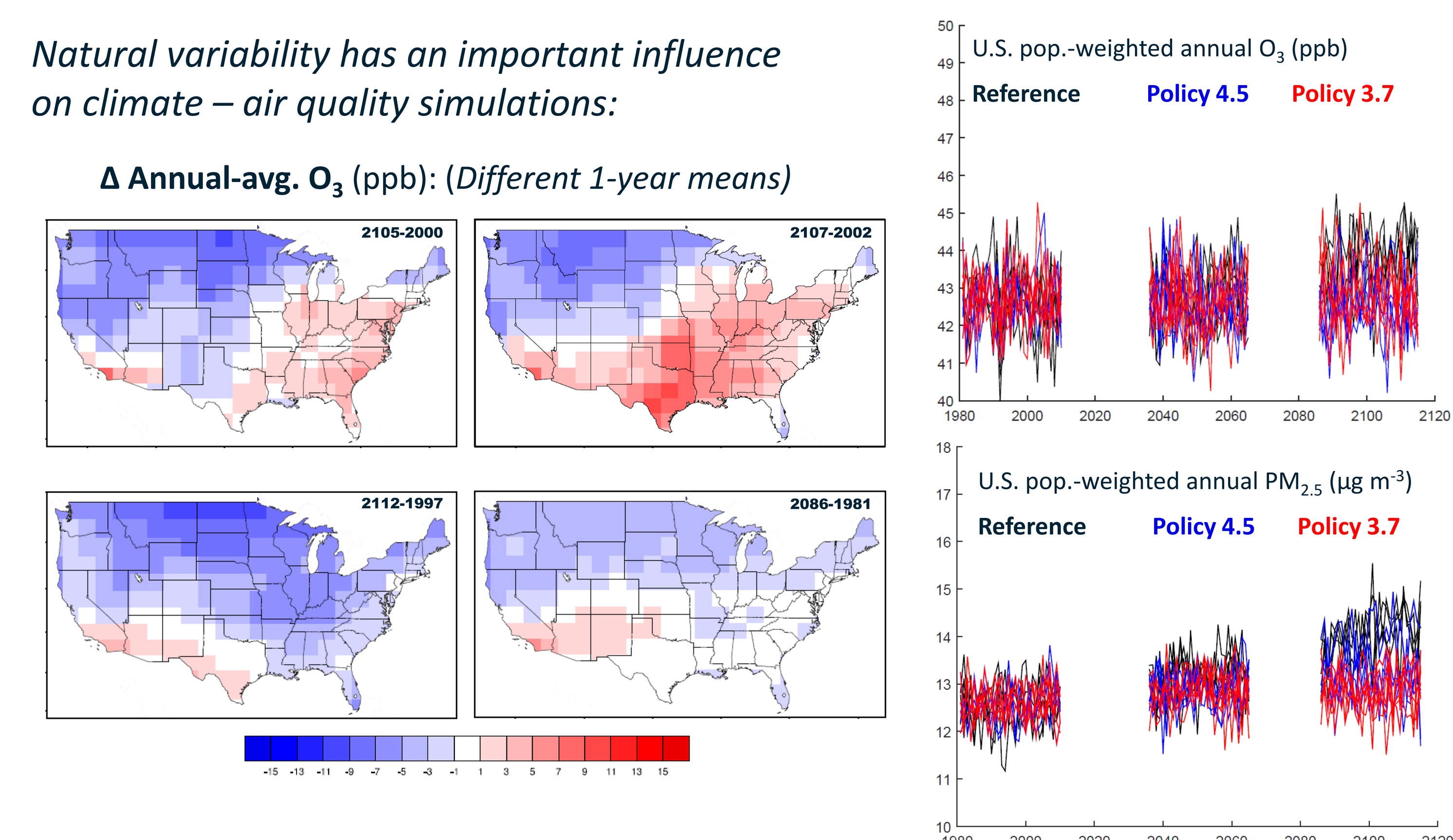
Benefits of policy 4.5 on $PM_{2.5}$
Δ climate penalty (μg m^{-3} * 1e6 inhabitants)



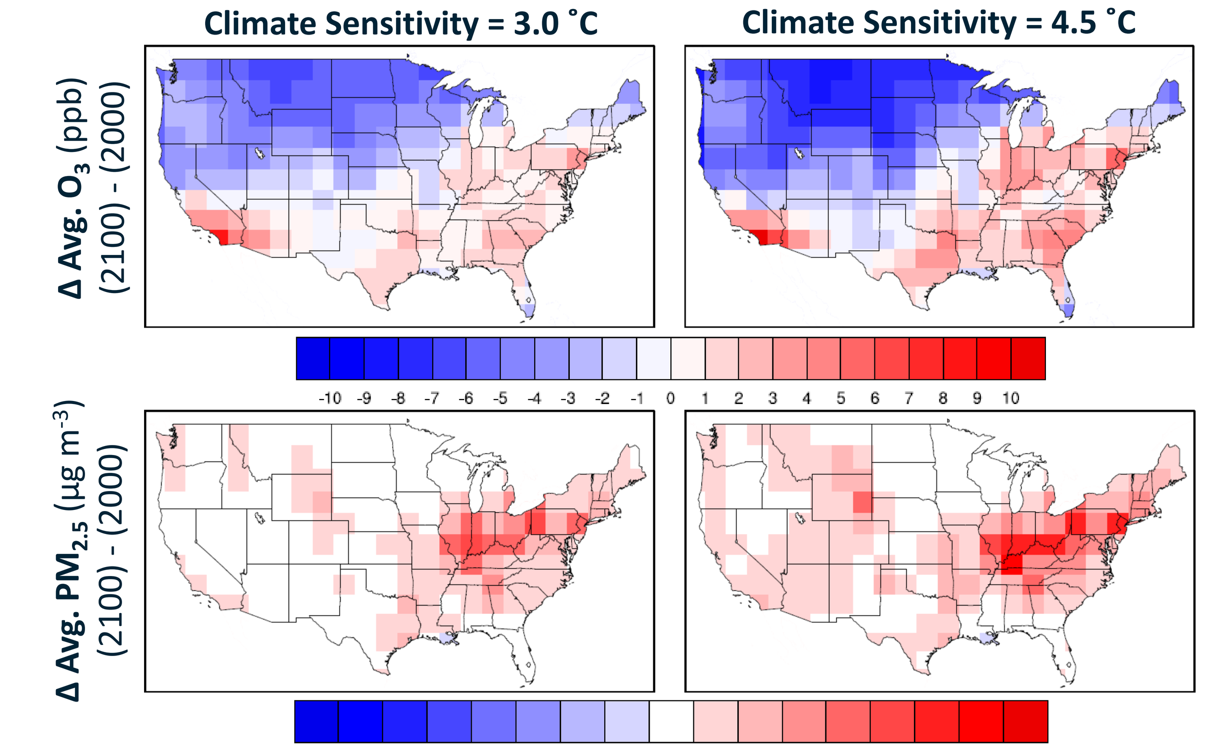
Internal variability and climate model response

Natural variability has an important influence on climate – air quality simulations:

Δ Annual-avg. O_3 (ppb): *(Different 1-year means)*



Climate model response affects the strength of climate change impacts on air quality:



Implications for regional-scale simulations of climate impacts on air quality :

- Substantial uncertainties associated with natural variability and climate model response.
- Simulations > 15 years may be needed to capture anthropogenic-forced climate signal.
- Large uncertainty in projections of climate change impacts on air quality before 2050.
- Propagation of uncertainty is stronger for regional-scale impacts and extremes.

Contact Information and Acknowledgements

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