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

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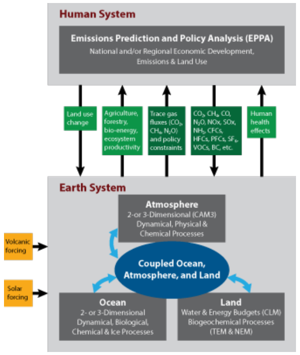
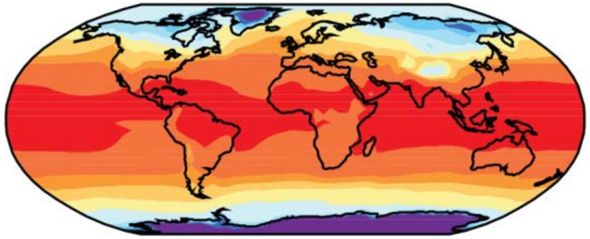
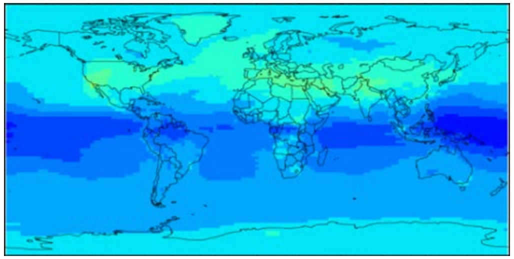
Modeling climate change impacts on air quality

Socioeconomic emissions scenario → **General circulation models** → **Global and regional atmospheric chemistry- transport models**



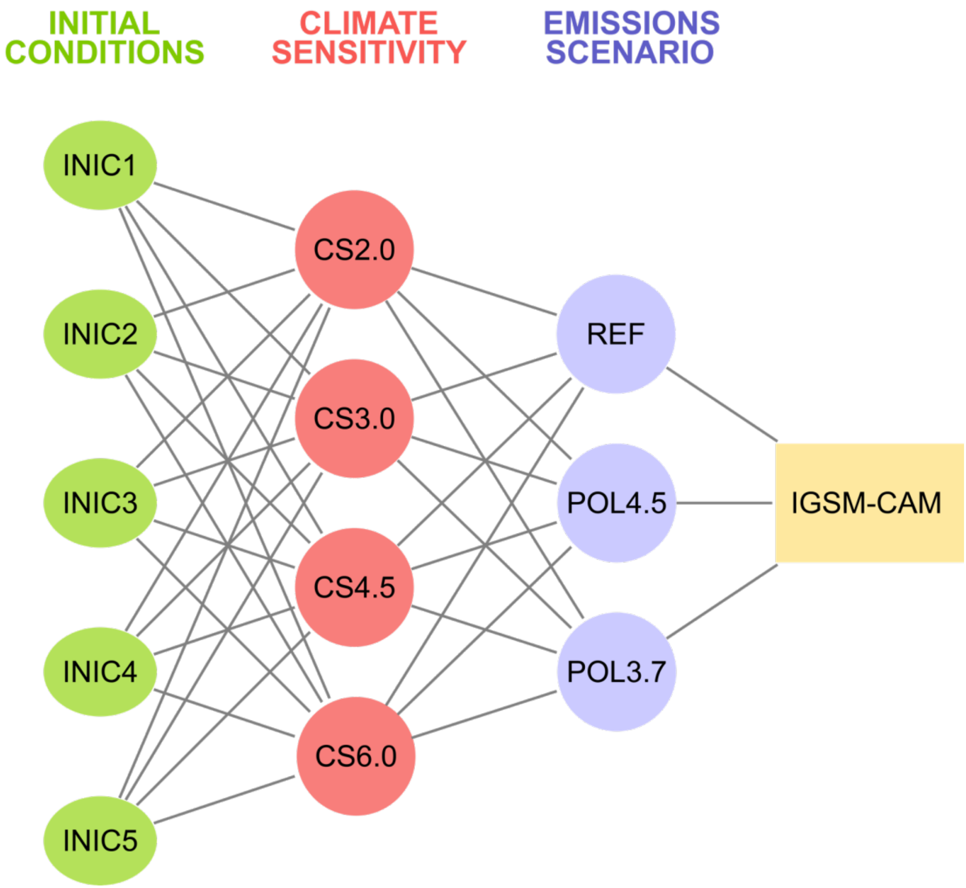




- ***Uncertainty and variability*** are associated with climate simulations and propagate to projections of air quality

- Characterizing uncertainty across the complete human-climate system is essential to generate policy-relevant insights

Ensemble simulation of 21st century climate change



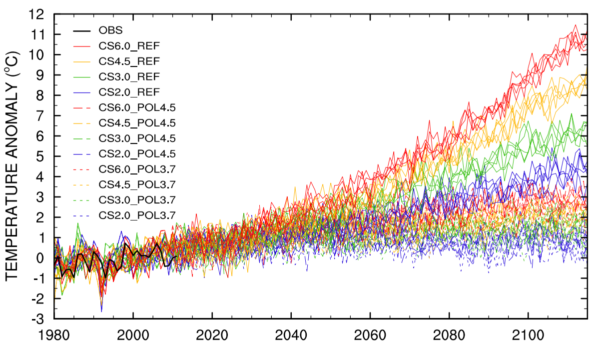
We focus on the 3 main sources of uncertainty in climate projections:

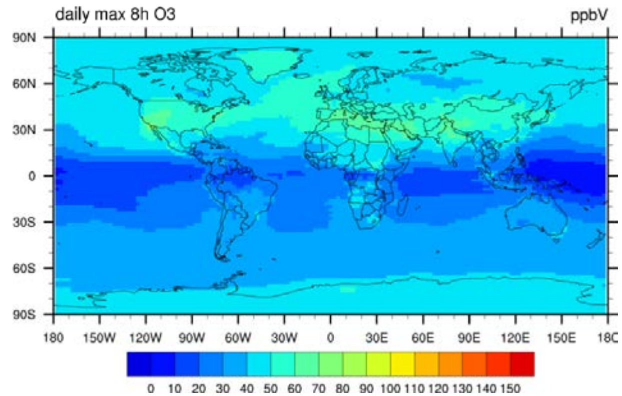
1. Emissions scenario:
   - Reference: No policy
     2100 radiative forcing = 9.7 W/m^2
   - Policy 4.5: Stabilization
     2100 radiative forcing = 4.5 W/m^2
   - Policy 3.7: Stringent stabilization
     2100 radiative forcing = 3.7 W/m^2
2. Climate model response [1]
   - Climate sensitivity =
     2.0°C, 3.0°C, 4.5°C or 6.0°C
3. Natural variability
   - Multidecadal simulations
   - 5 different initializations

[1] Monier et al., *Climatic Change*

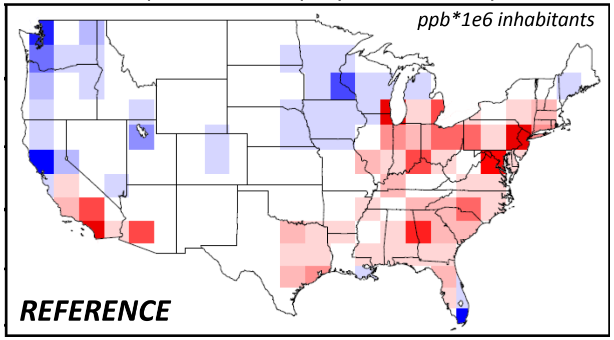
Air quality modeling framework

MIT IGSM → CESM → BenMAP

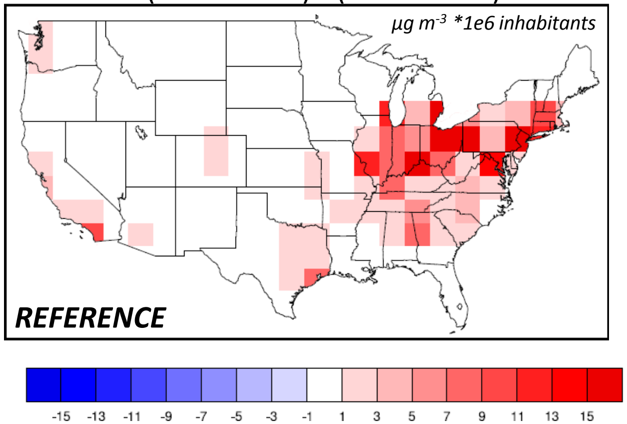




Δ Annual-avg. pop.-weighted O_3
(2085–2115) - (1980–2010)



Δ Annual-avg. pop.-weighted $PM_{2.5}$
(2085–2115) - (1980–2010)



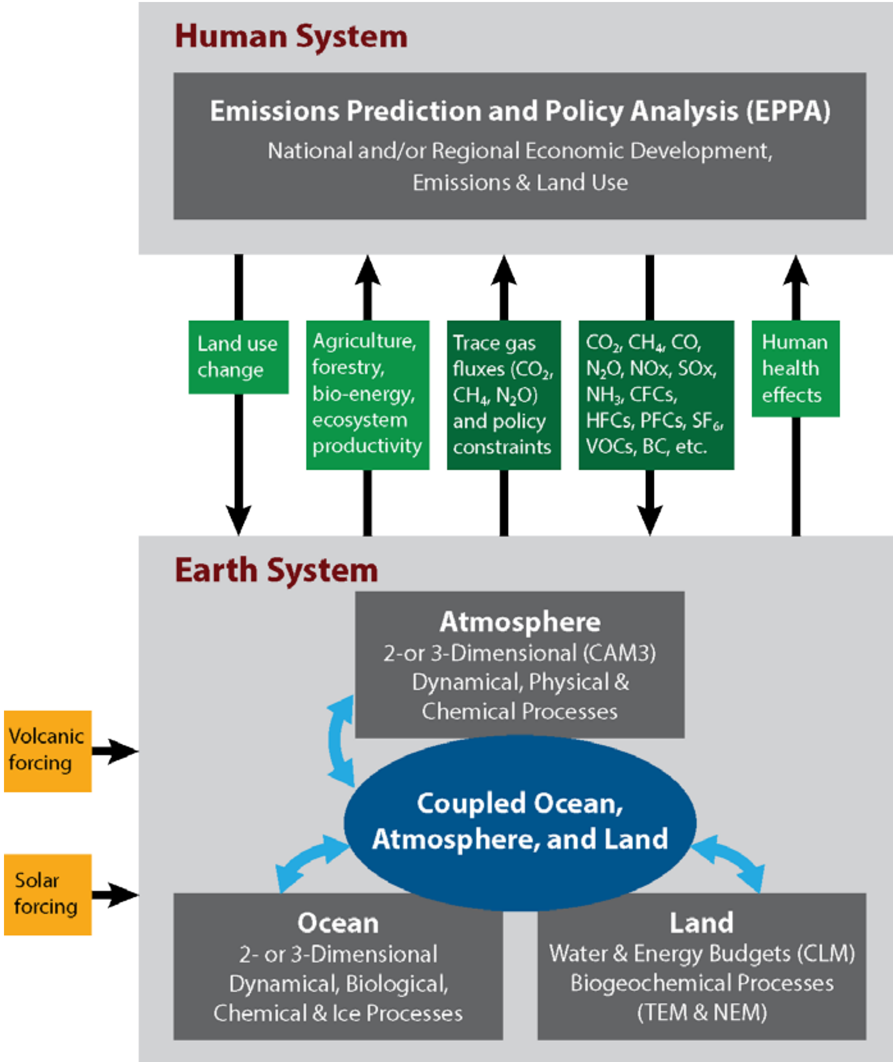
MIT IGSM: Policy scenarios and climate projections

Community Earth Systems Model (CESM):
Global atmospheric chemistry and air quality

Env. Benefits Mapping & Analysis Program (BenMAP):
Health and economic impacts

- *Atmospheric emissions fixed at yr-2000 levels to estimate climate penalty on air quality*
- *30-yr simulations used to characterize climate (1981→2010, 2036→2065, 2085→2115)*

Climate and policy scenarios



<u>MIT Integrated Global System Model:</u>

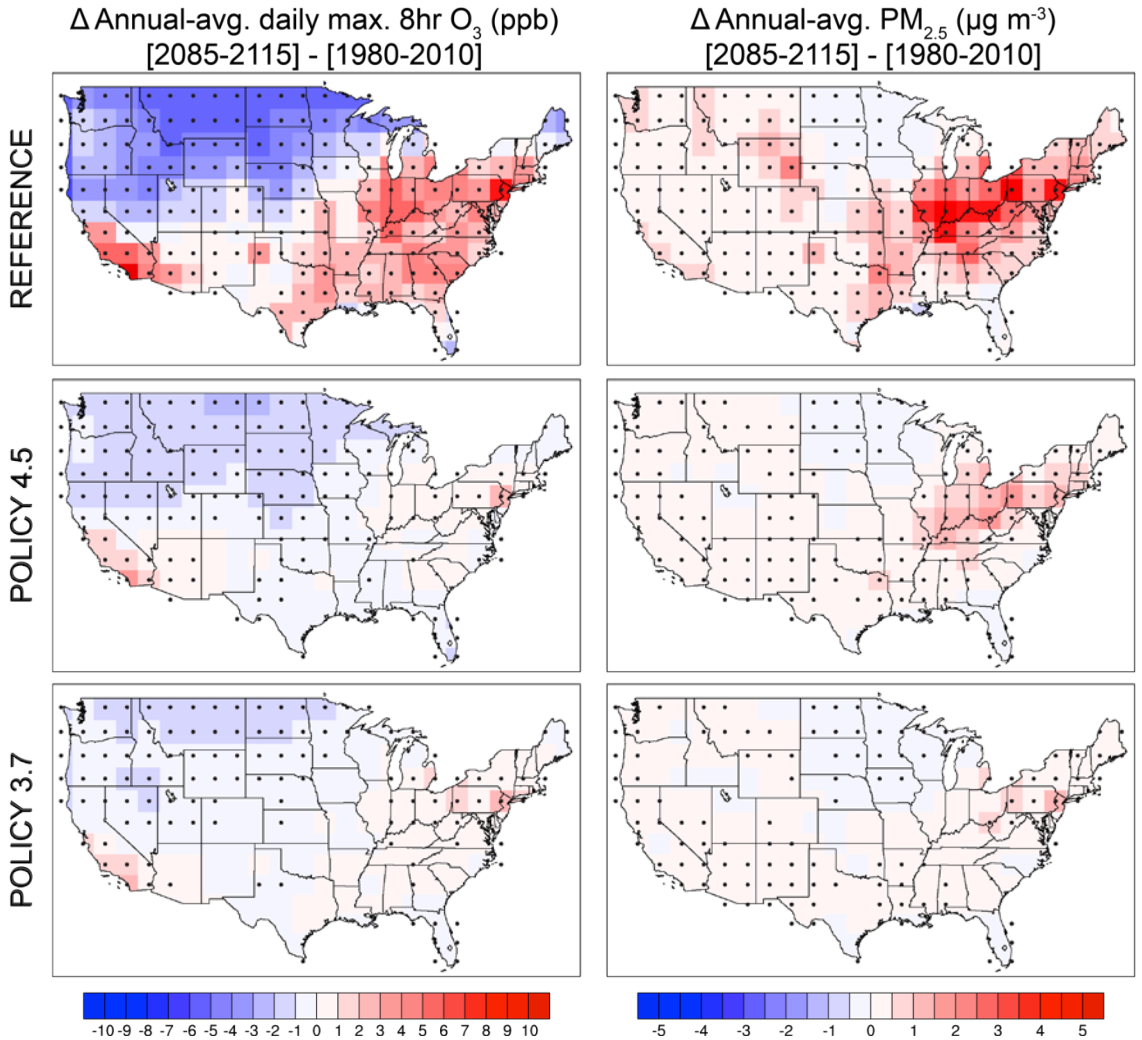
Two major coupled components:

- Earth system model
- Economic projection and policy analysis model

Important features:

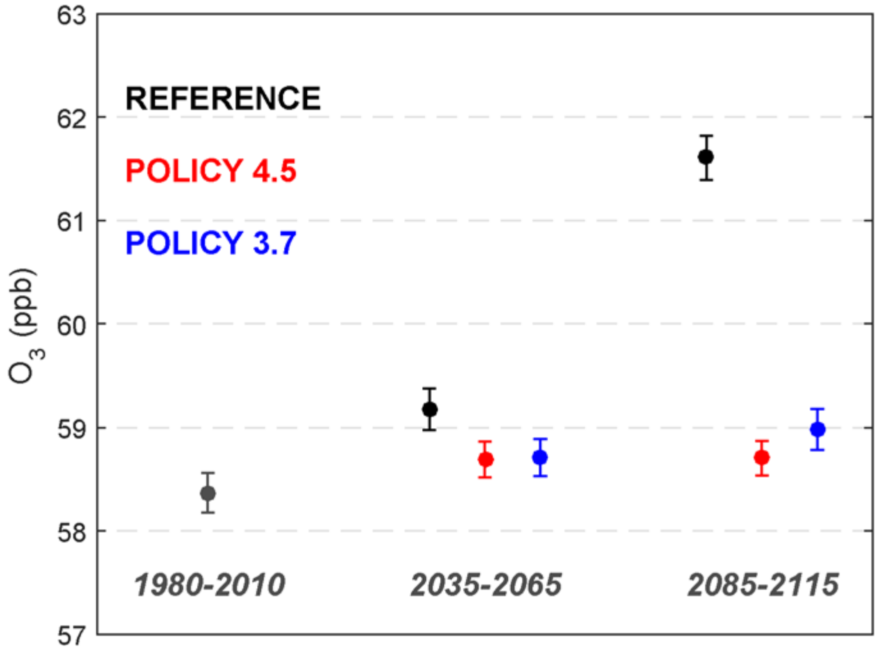
- Single consistent framework for greenhouse gas emissions policy and climate change scenarios
- Ability to alter climate system response
- Computationally efficient

Climate penalty on U.S. air quality



Climate penalty and policy benefits for U.S. O_3

US-average population-weighted daily max. 8hr O_3:

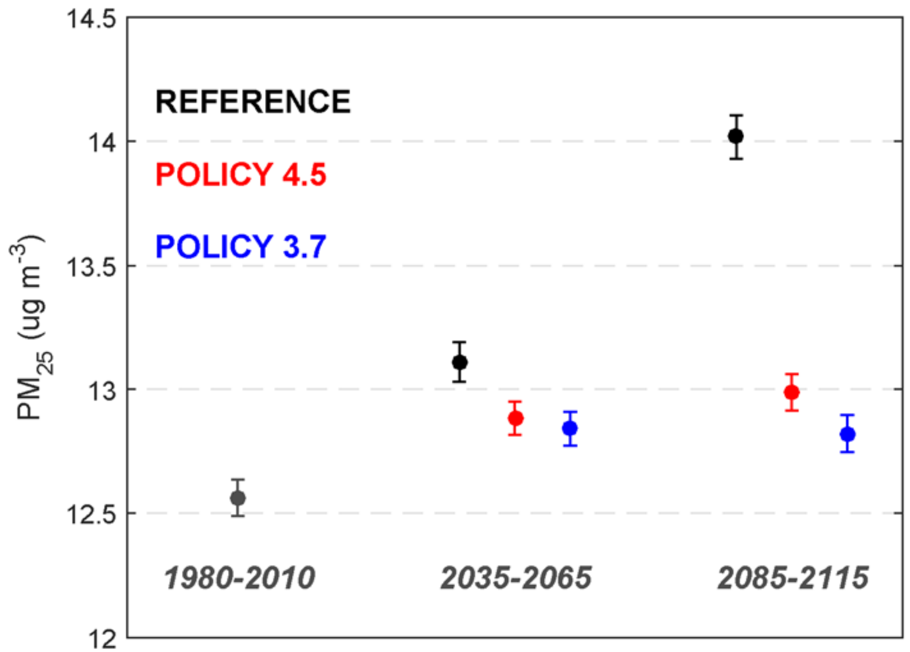


Climate Penalty (ppb)		Annual avg. daily max. 8-hr O_3	Summer avg. daily max. 8-hr O_3
REF	*2000 → 2050*	0.8 ± 0.3	3.4 ± 0.7
	2000 → 2100	3.2 ± 0.3	10.4 ± 0.7
POL45	*2000 → 2050*	0.4 ± 0.2	2.0 ± 0.6
	2000 → 2100	0.4 ± 0.2	2.3 ± 0.6
POL37	*2000 → 2050*	0.3 ± 0.3	1.6 ± 0.7
	2000 → 2100	0.6 ± 0.3	2.3 ± 0.6

Policy Impacts (ppb)		Annual avg. daily max. 8-hr O_3	Summer avg. daily max. 8-hr O_3
REF → P45	*2050*	-0.5 ± 0.3	-2.0 ± 0.7
	2100	-2.9 ± 0.3	-8.7 ± 0.7
REF → P37	*2050*	-0.5 ± 0.3	-2.1 ± 0.7
	2100	-2.6 ± 0.3	-8.3 ± 0.7

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

US-average population-weighted $PM_{2.5}$ ($\mu g\ m^{-3}$):

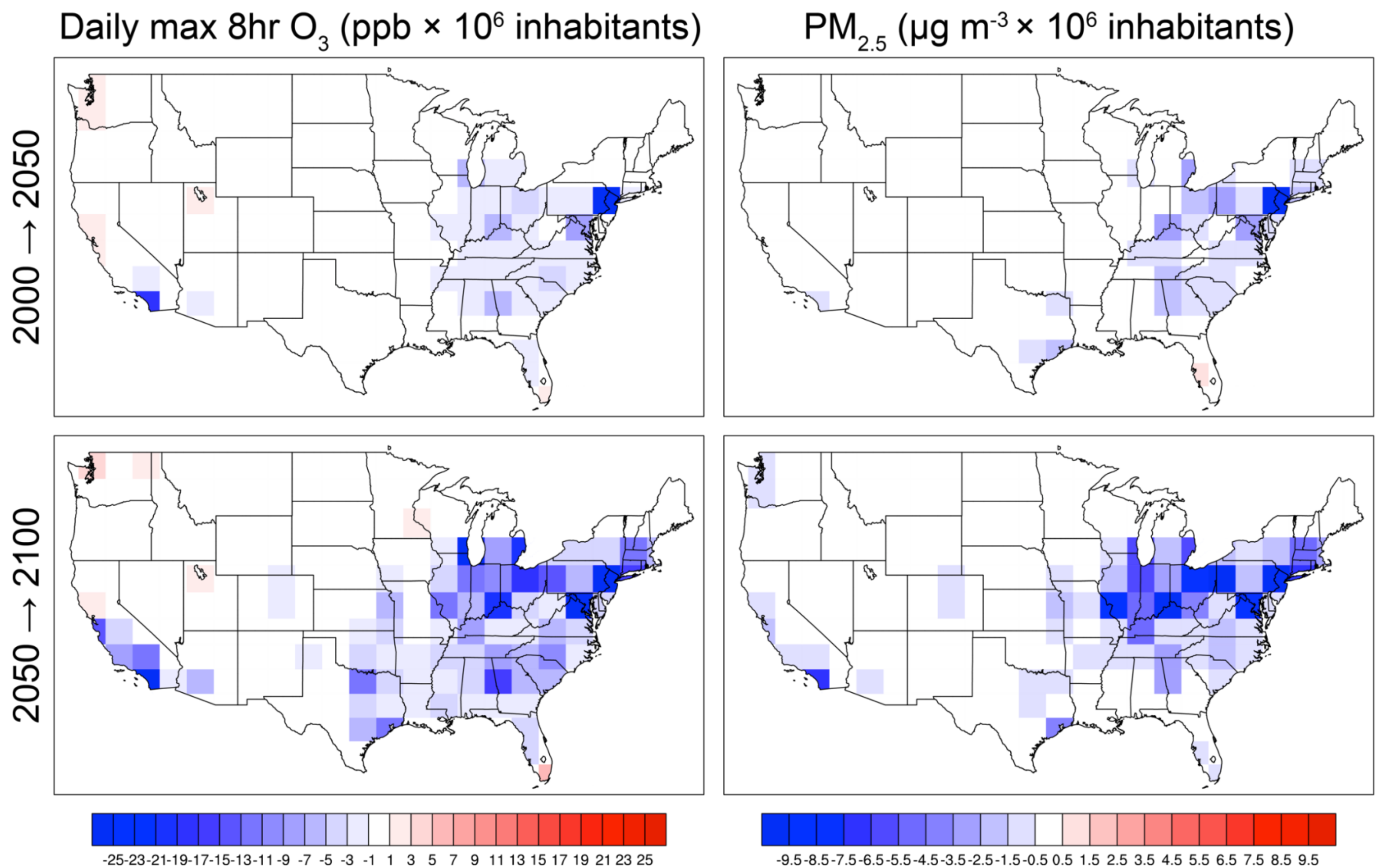


Climate Penalty ($\mu g\ m^{-3}$)		Annual avg. $PM_{2.5}$
REF	*2000 → 2050*	0.5 ± 0.1
	2000 → 2100	1.5 ± 0.1
POL45	*2000 → 2050*	0.3 ± 0.1
	2000 → 2100	0.4 ± 0.1
POL37	*2000 → 2050*	0.2 ± 0.1
	2000 → 2100	0.2 ± 0.1

Policy Impacts ($\mu g\ m^{-3}$)		Annual avg. $PM_{2.5}$
REF → P45	*2050*	-0.2 ± 0.1
	2100	-1.0 ± 0.1
REF → P37	*2050*	-0.3 ± 0.1
	2100	-1.2 ± 0.1

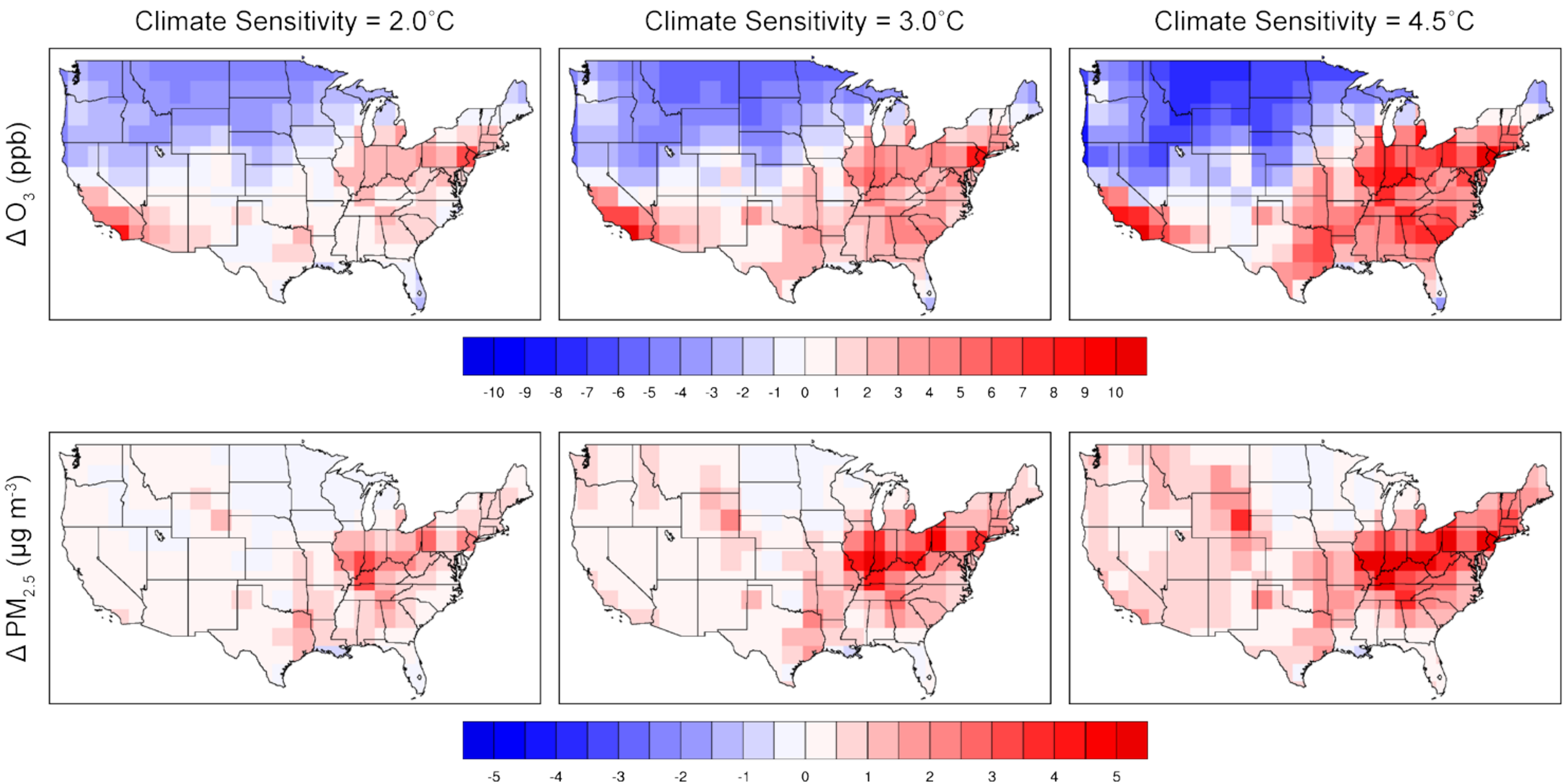
Emissions scenario

Avoided annual climate penalty under stabilization scenario P45 relative to Reference:

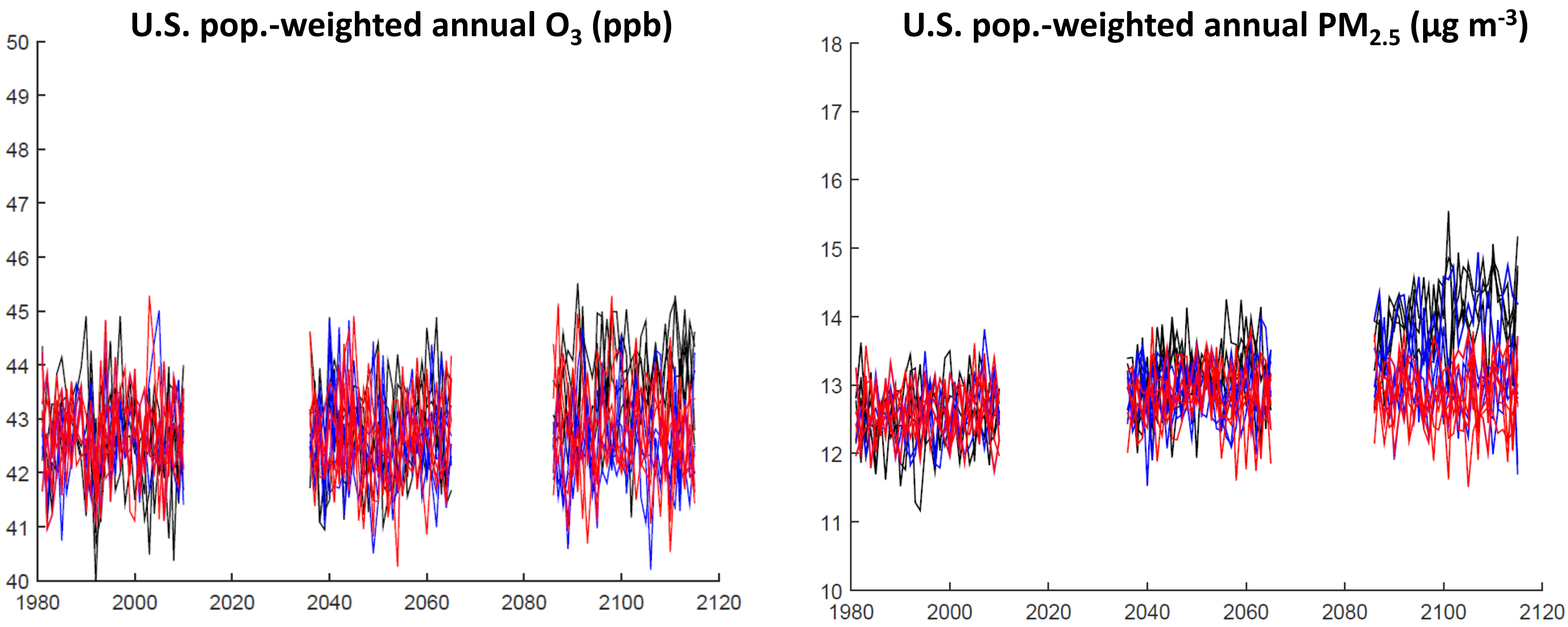


Climate model response

Climate penalty on annual daily max. 8hr O_3 and average $PM_{2.5}$ from 2000 to 2100 under Reference scenario:



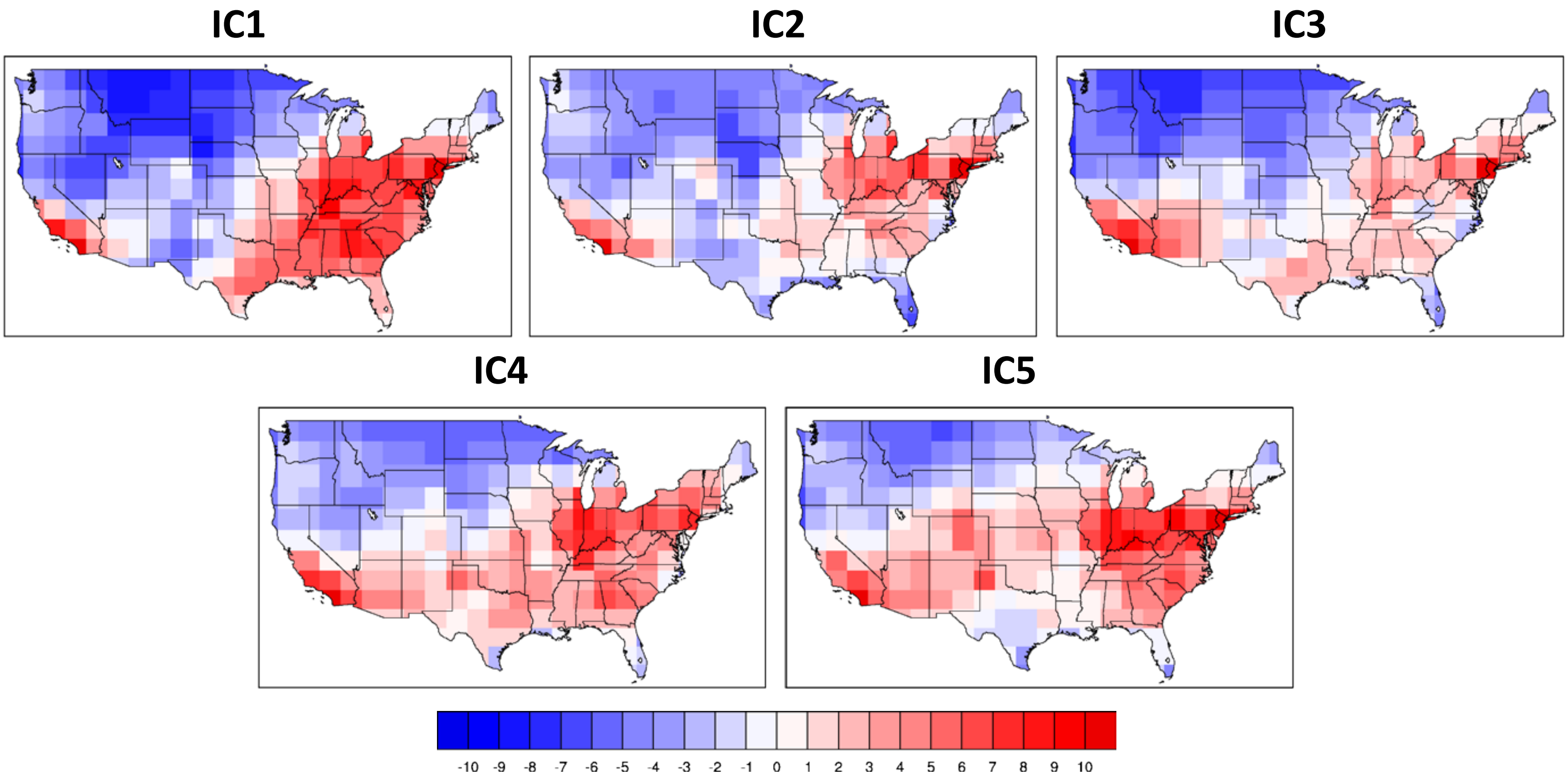
Internal variability in U.S. air quality projections



Reference **Policy 4.5** **Policy 3.7**

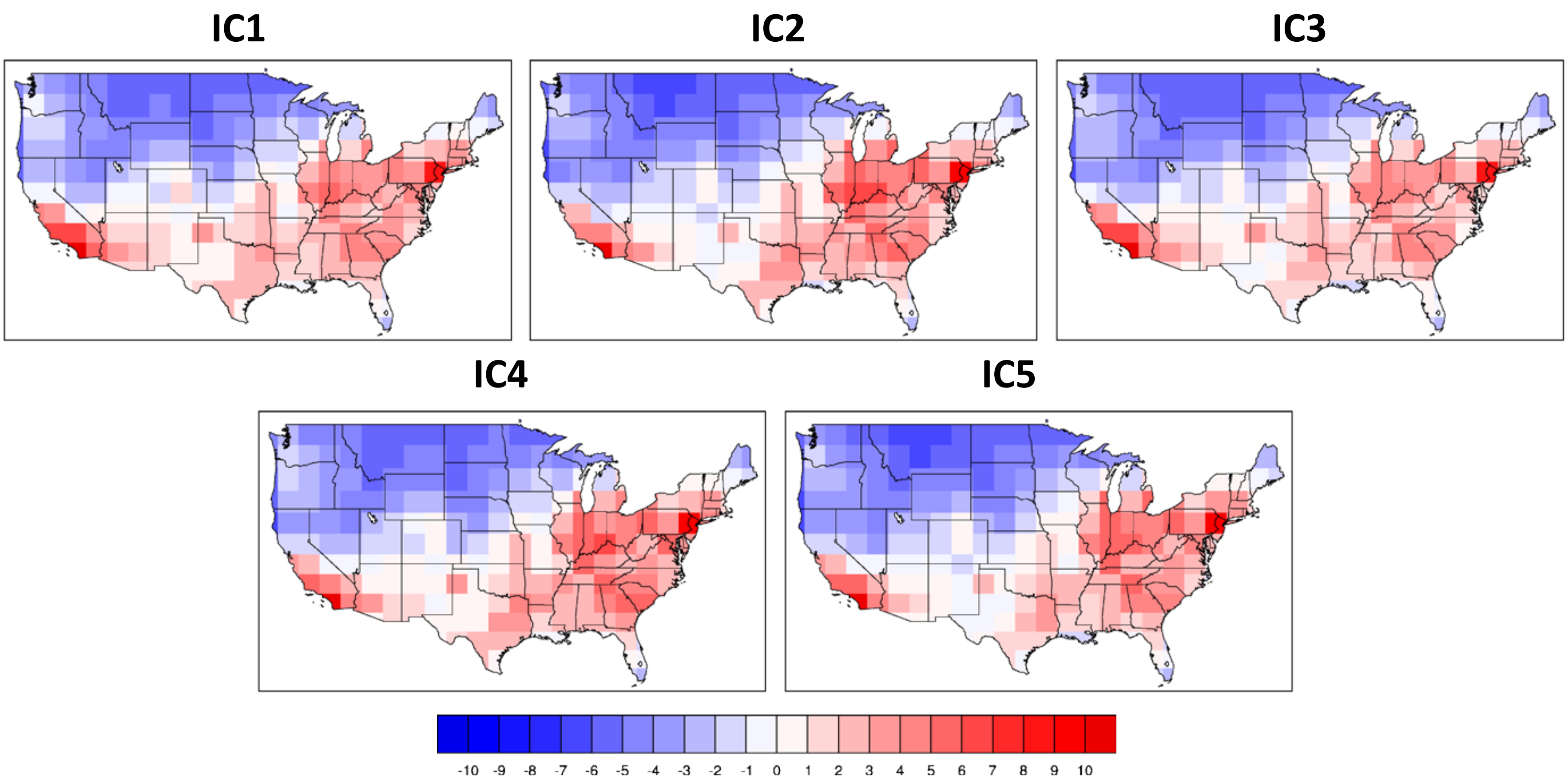
Influence of natural variability

Climate penalty on annual-average daily max. 8hr (Δ ppb) from 2000 to 2100 under Reference scenario estimated from <u>1-year simulations</u>:

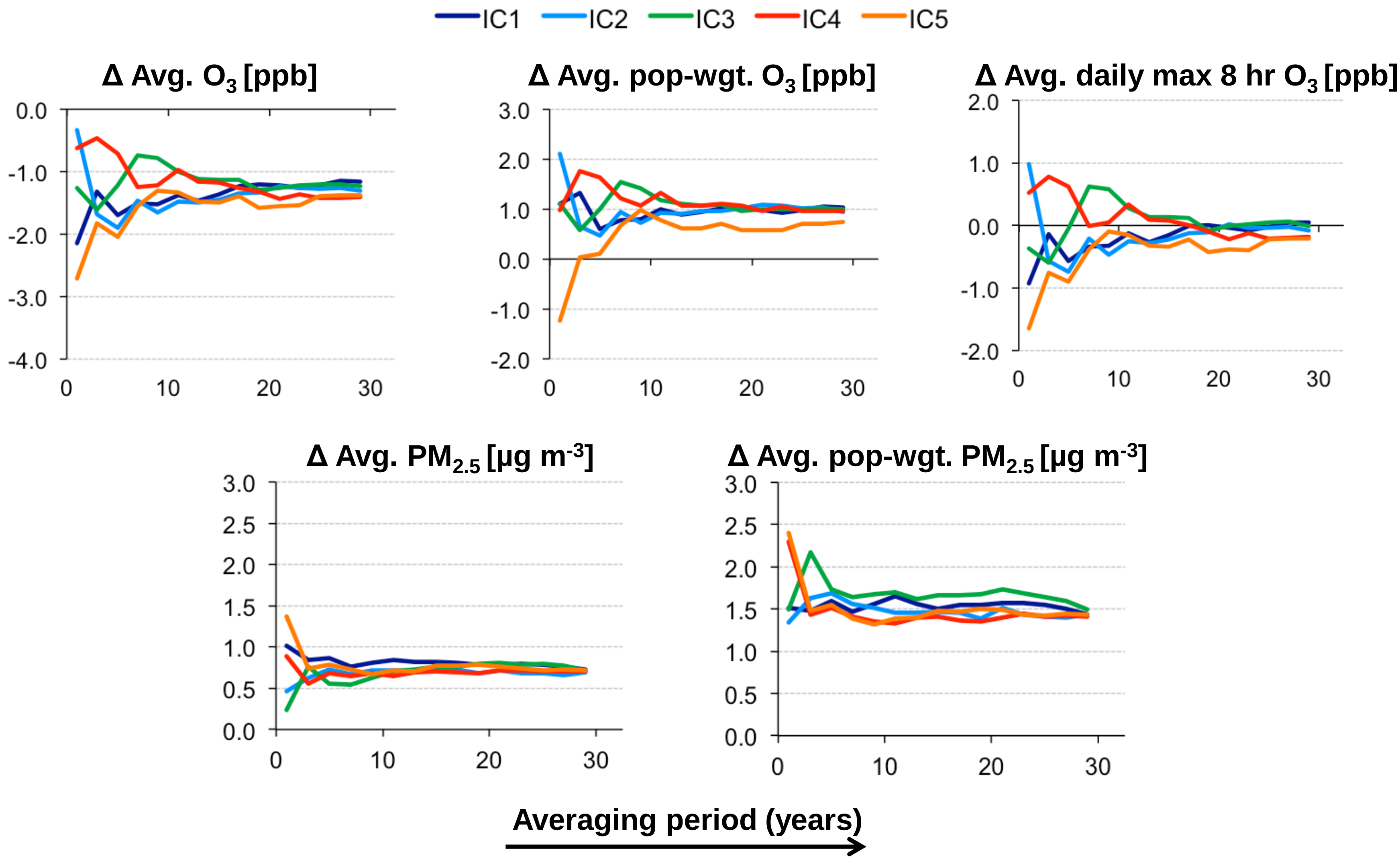


Considering variability in air quality projections

Climate penalty on annual-average daily max. 8hr (Δ ppb) from 2000 to 2100 under Reference scenario estimated from 30-year simulations:



Considering variability in air quality projections



Climate uncertainty in air quality impacts assessments

- Substantial uncertainties associated with climate projections significantly influence simulations of future air quality.

- Beyond anthropogenic emissions scenarios, large uncertainty associated with natural variability and climate model response.

- Simulations > 15 years may be needed to capture anthropogenic-forced climate signal.

- Projections of climate change impacts before 2050 remain considerably uncertain.

- Propagation of uncertainty is stronger for regional-scale impacts and extremes.

Acknowledgments

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