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

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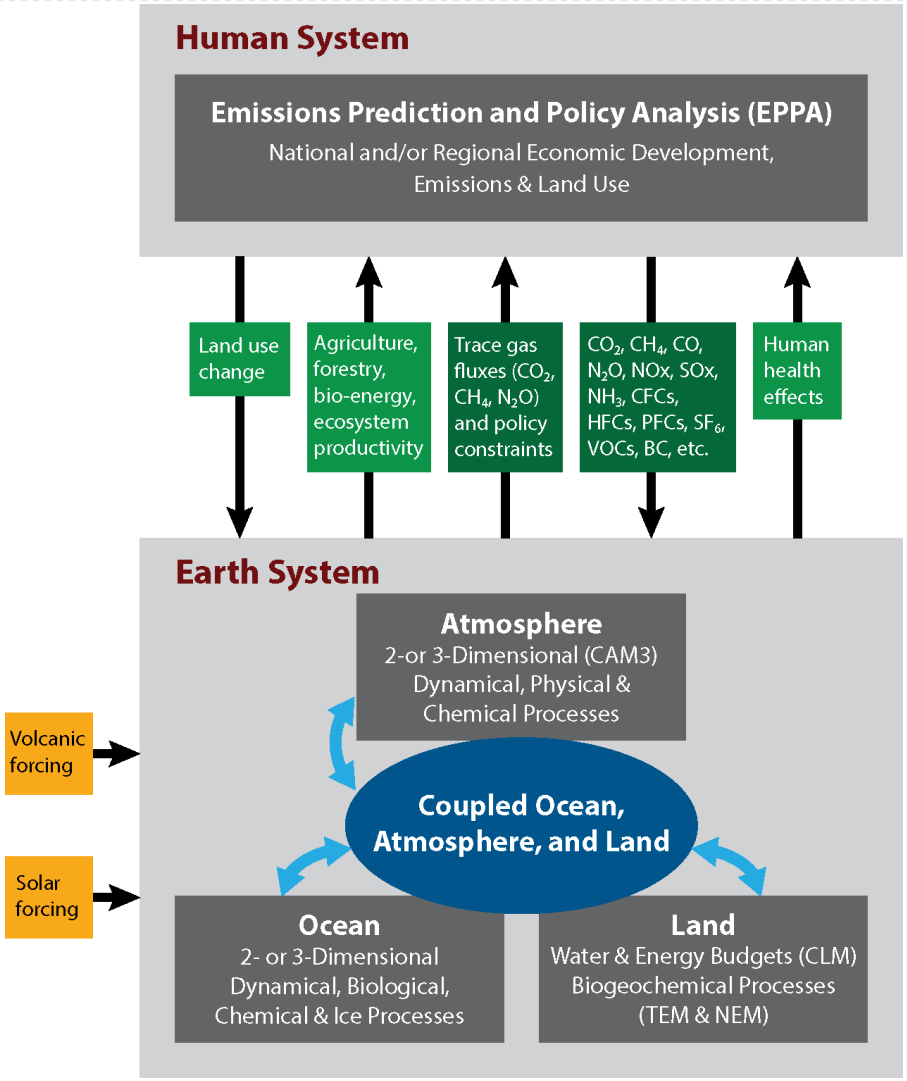
Uncertainty in projections of climate change and air quality

- Climate change may significantly perturb meteorology and impact future air quality.
- Large uncertainties 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 and guide environmental decision-making

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

Climate and policy scenarios



MIT Integrated Global System Model:

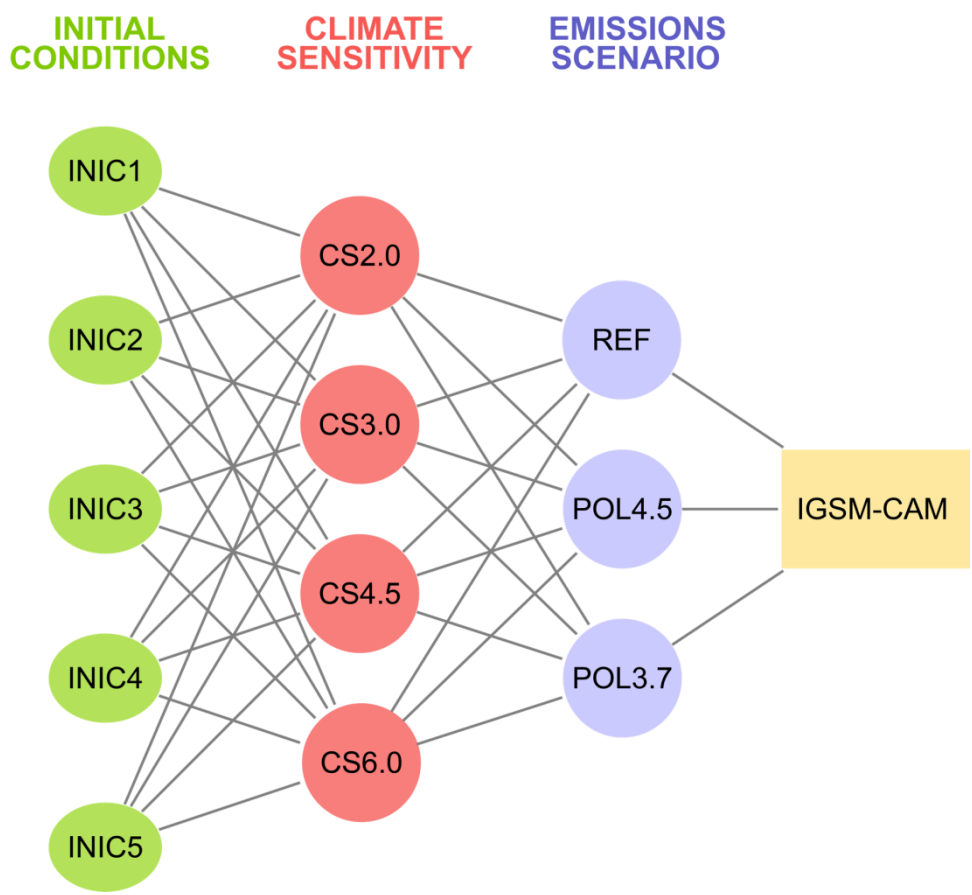
Two major coupled components:

- 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

Ensemble simulation of 21st century climate change

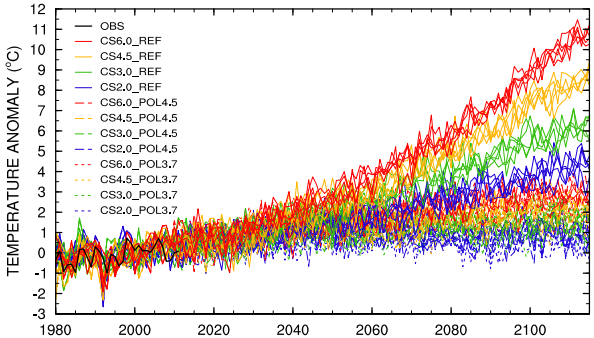


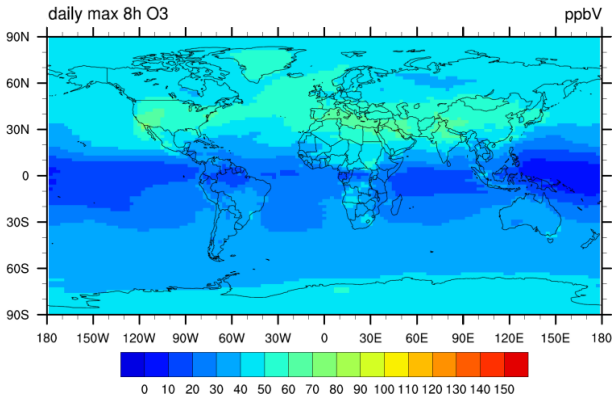
We focus on the 3 main sources of uncertainty in climate projections:

1. Emissions-scenario uncertainty:
   - 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
   - Climate sensitivity = 2.0°C, 3.0°C, 4.5°C or 6.0°C
3. Natural variability
   - Multidecadal simulations
   - 5 different initializations

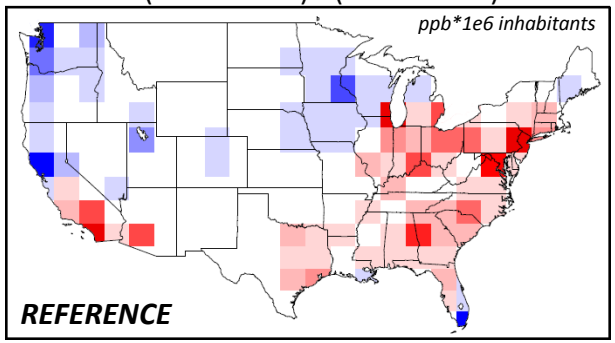
Air Quality Modeling Framework

MIT IGSM → **CESM** → **BenMAP**

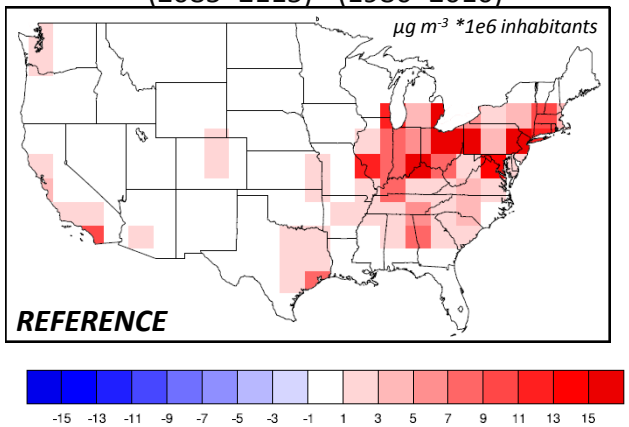




Δ Annual-avg. pop.-weighted O_3
(2085–2115) - (1980–2010)



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



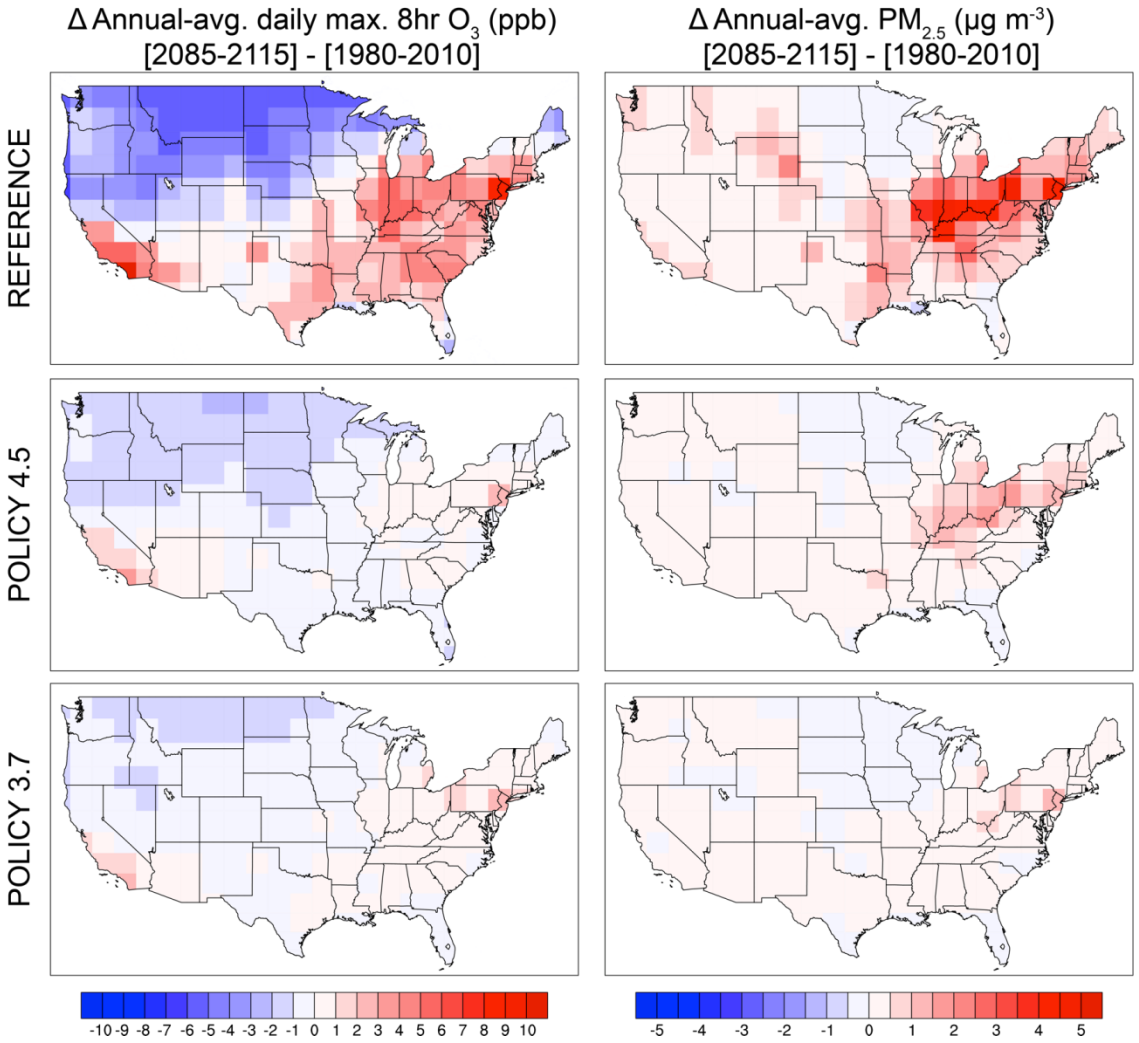
MIT IGSM: Policy scenarios and climate projections

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

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

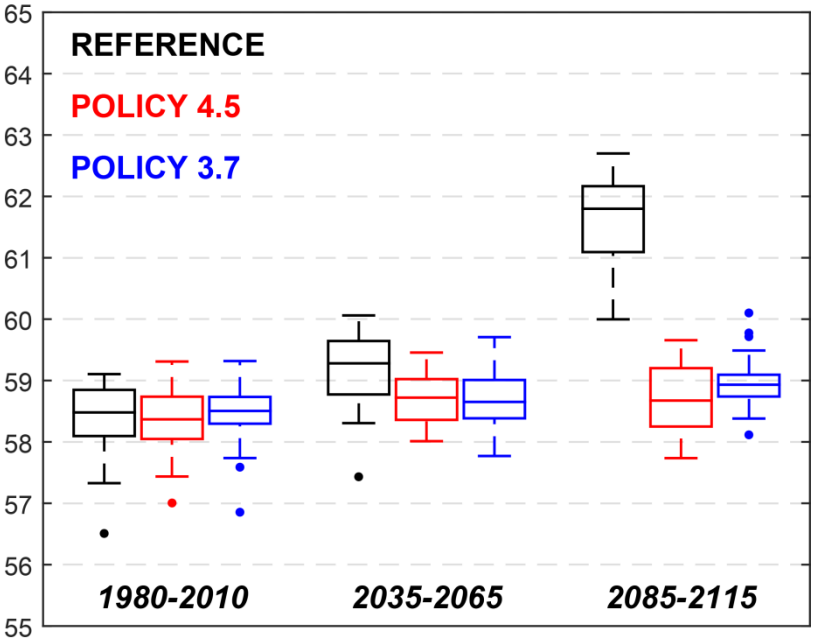
- *Atmospheric emissions fixed at yr-2000 levels to estimate climate penalty on air quality*
- *30-yr simulations used to characterize climate (1981→2010, 2036→2065, 2085→2115)*

Climate penalty on U.S. air quality



Climate penalty and policy benefits for U.S. O_3

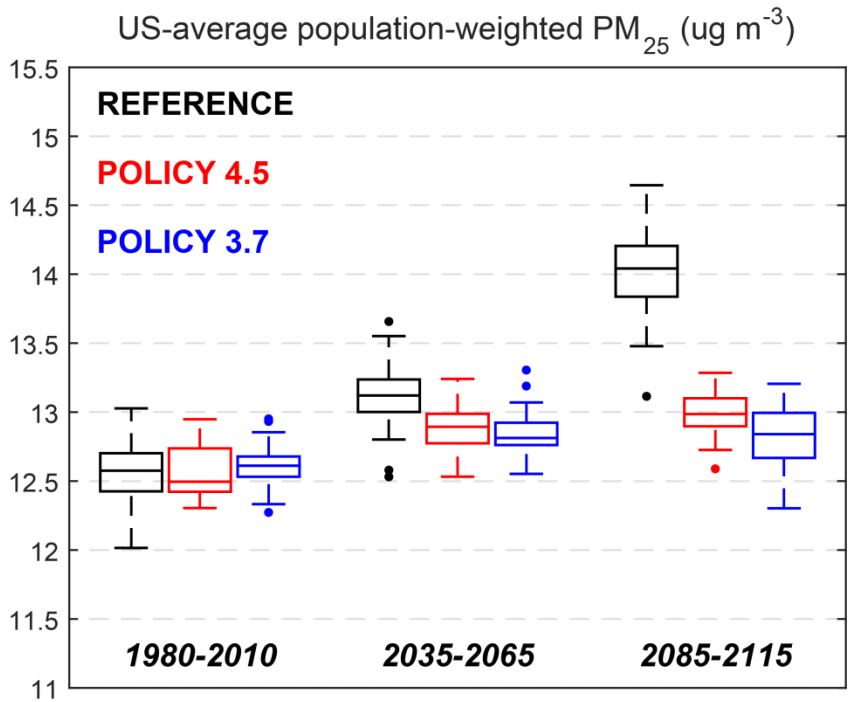
US-average population-weighted daily max. 8hr O_3 (ppb)



Climate Penalty (Δ US-avg pop-wtd O3)		Annual O3 (ppb)	Summer O3 (ppb)	Daily max 8hr O3 (ppb)
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 Impacts (Δ climate penalty)		Annual O3 (ppb)	Summer O3 (ppb)	Daily max 8hr O3 (ppb)
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 and policy benefits for U.S. $PM_{2.5}$

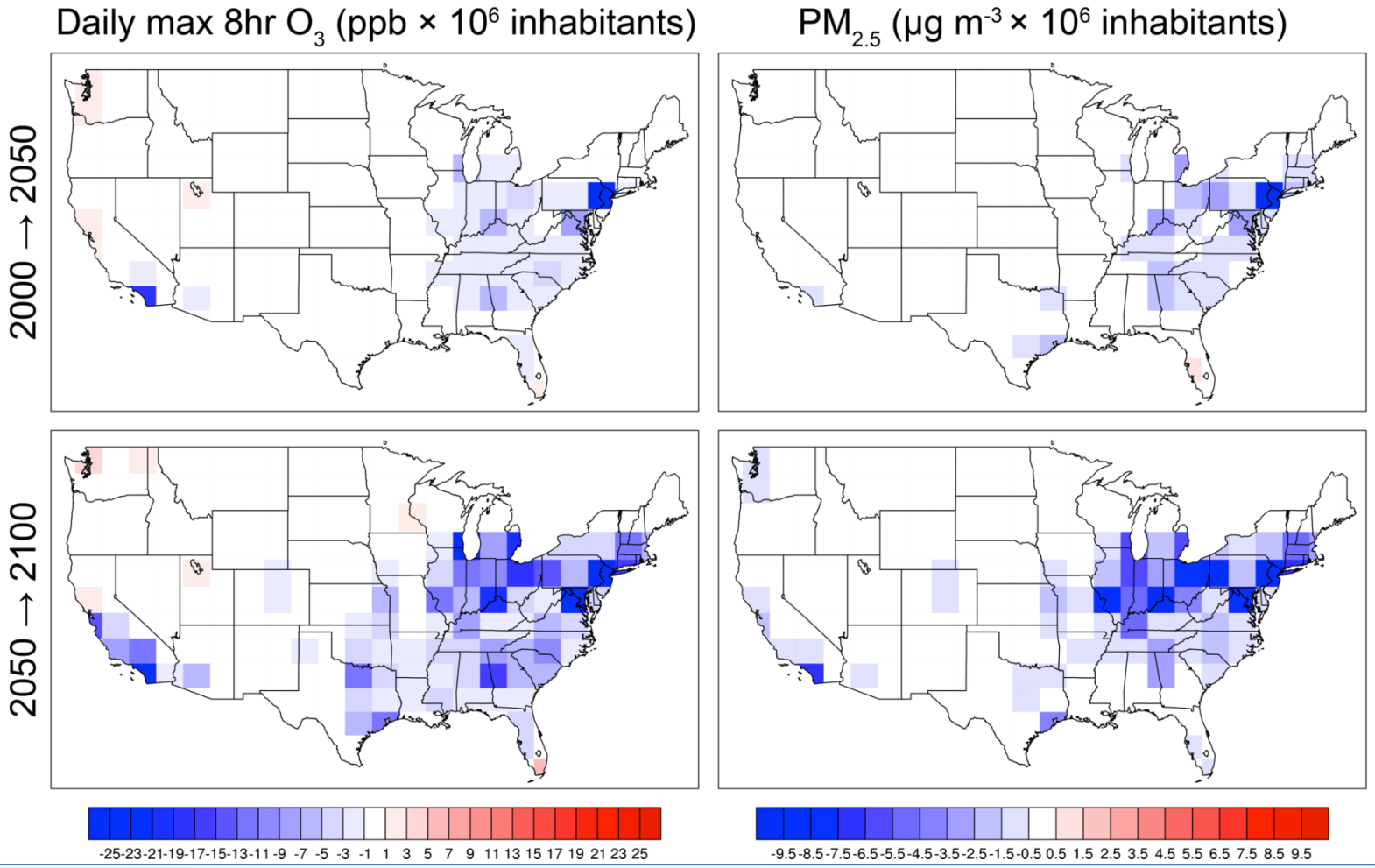


Climate Penalty (Δ US-avg pop.-wtd $PM_{2.5}$)		Annual $PM_{2.5}$ ($\mu g\ m^{-3}$)
REF	*2000 → 2050*	0.5 ± 0.05
	2000 → 2100	1.5 ± 0.06
POL45	*2000 → 2050*	0.3 ± 0.05
	2000 → 2100	0.4 ± 0.05
POL37	*2000 → 2050*	0.2 ± 0.04
	2000 → 2100	0.2 ± 0.05

Policy Impacts (Δ climate penalty)		Annual $PM_{2.5}$ ($\mu g\ m^{-3}$)
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

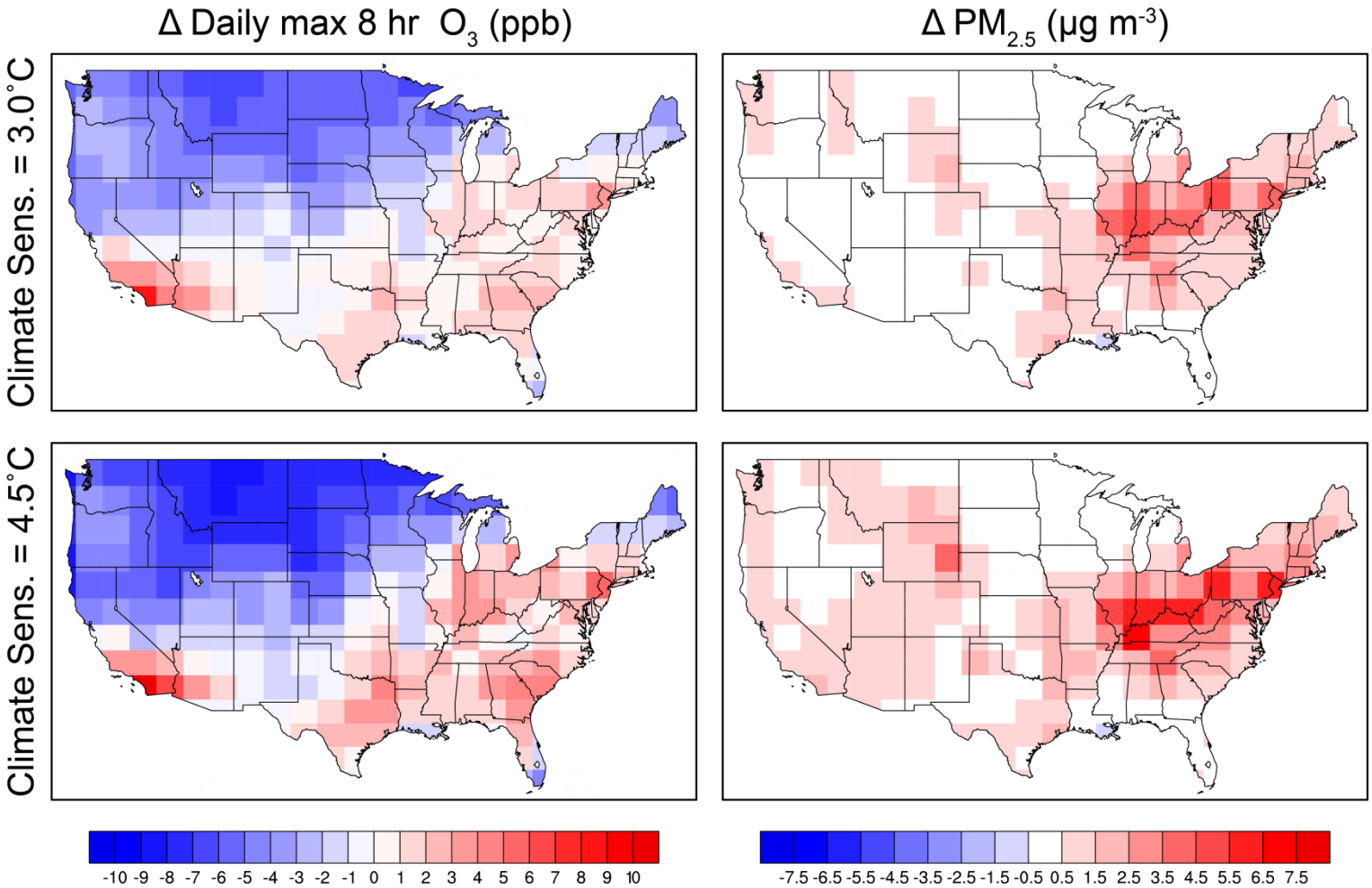
Emissions scenario

Avoided climate penalty under stabilization scenario P45 relative to Reference:



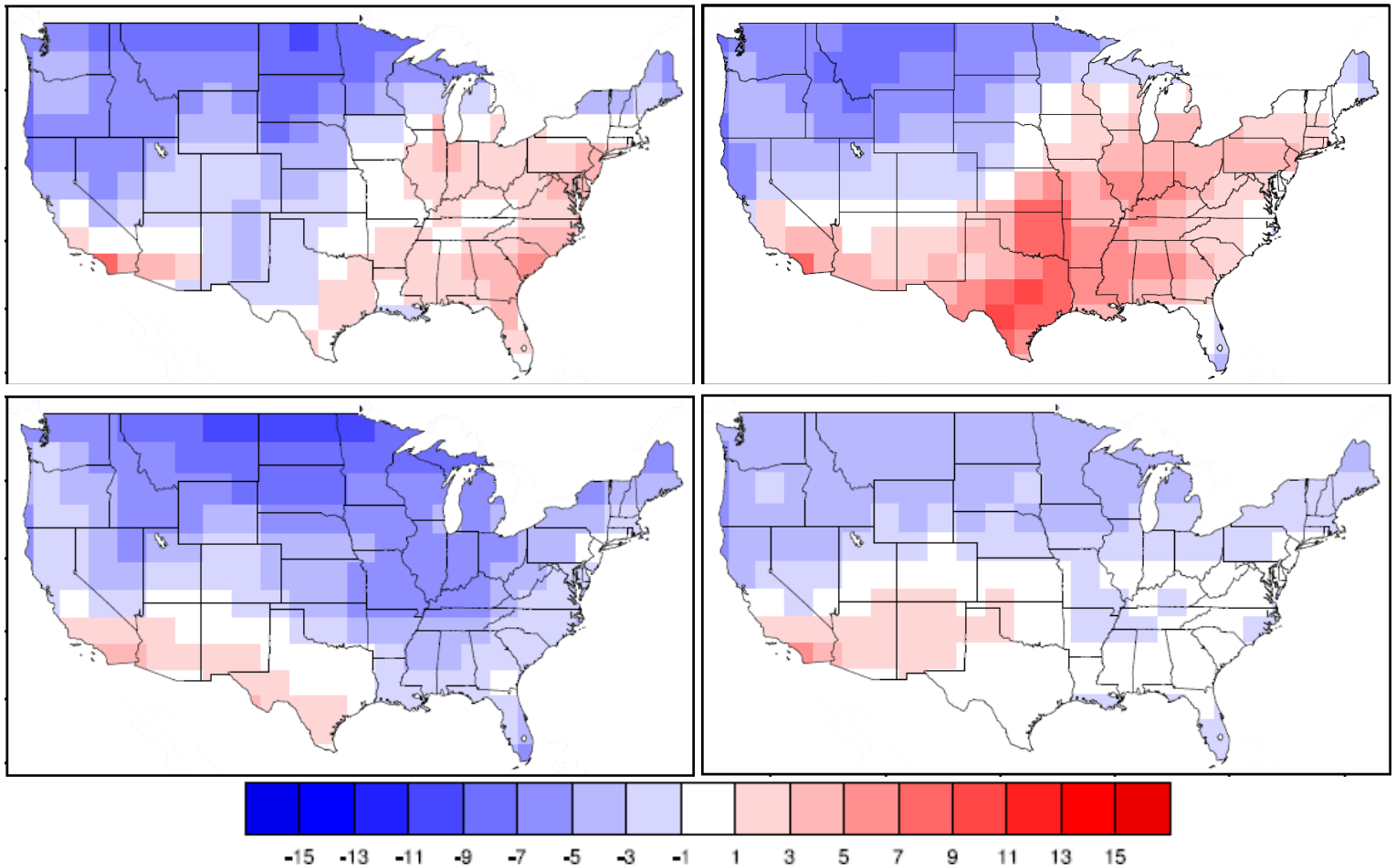
Climate model response

Climate penalty from 2000 to 2100 under Reference scenario:



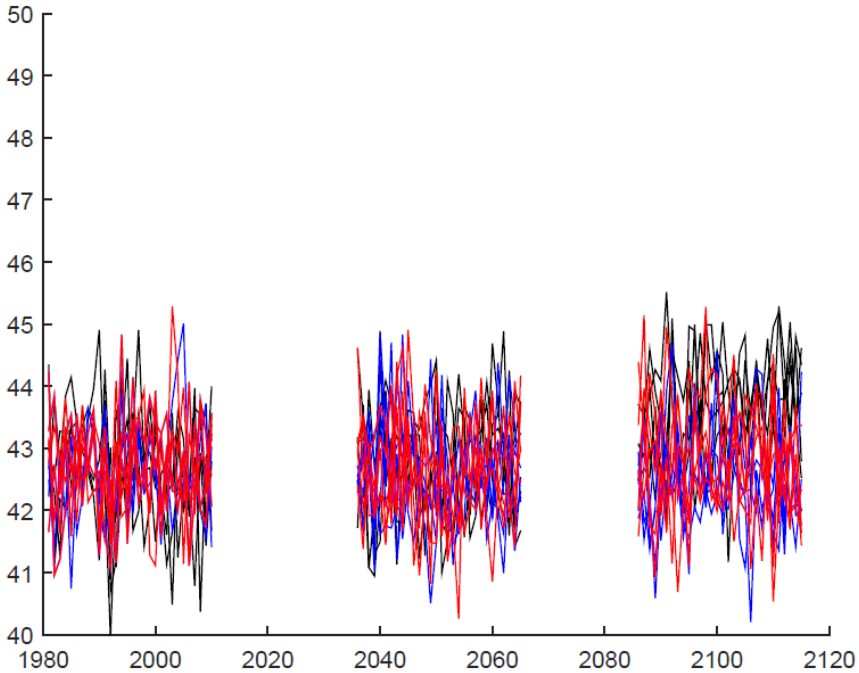
Influence of Natural Variability

Climate penalty on annual-average O_3 (Δ ppb) from 2000 to 2100 under Reference scenario estimated from <u>different single-year means</u>:

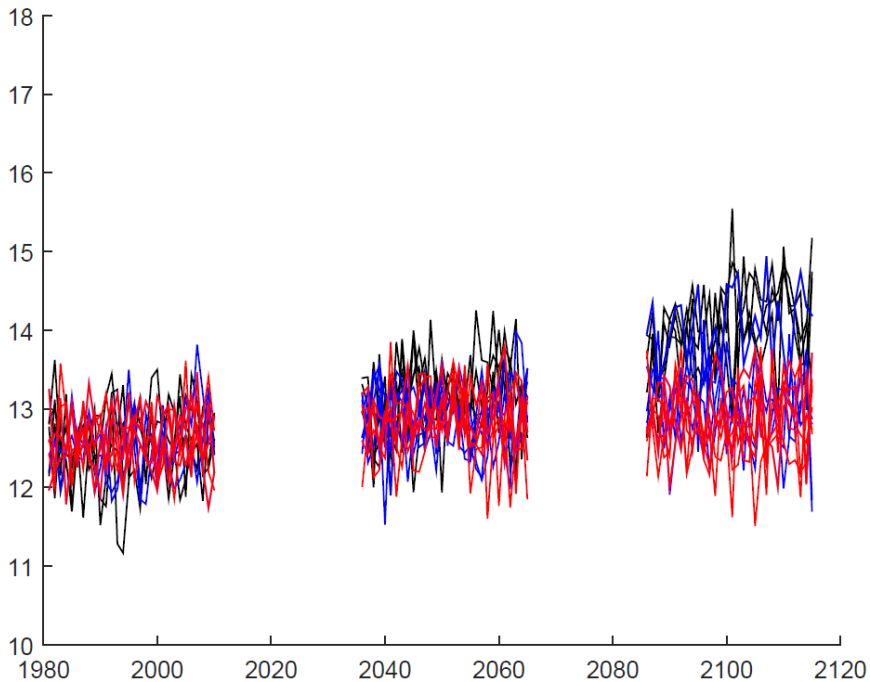


Internal variability in U.S. air quality projections

U.S. pop.-weighted annual O_3 (ppb)



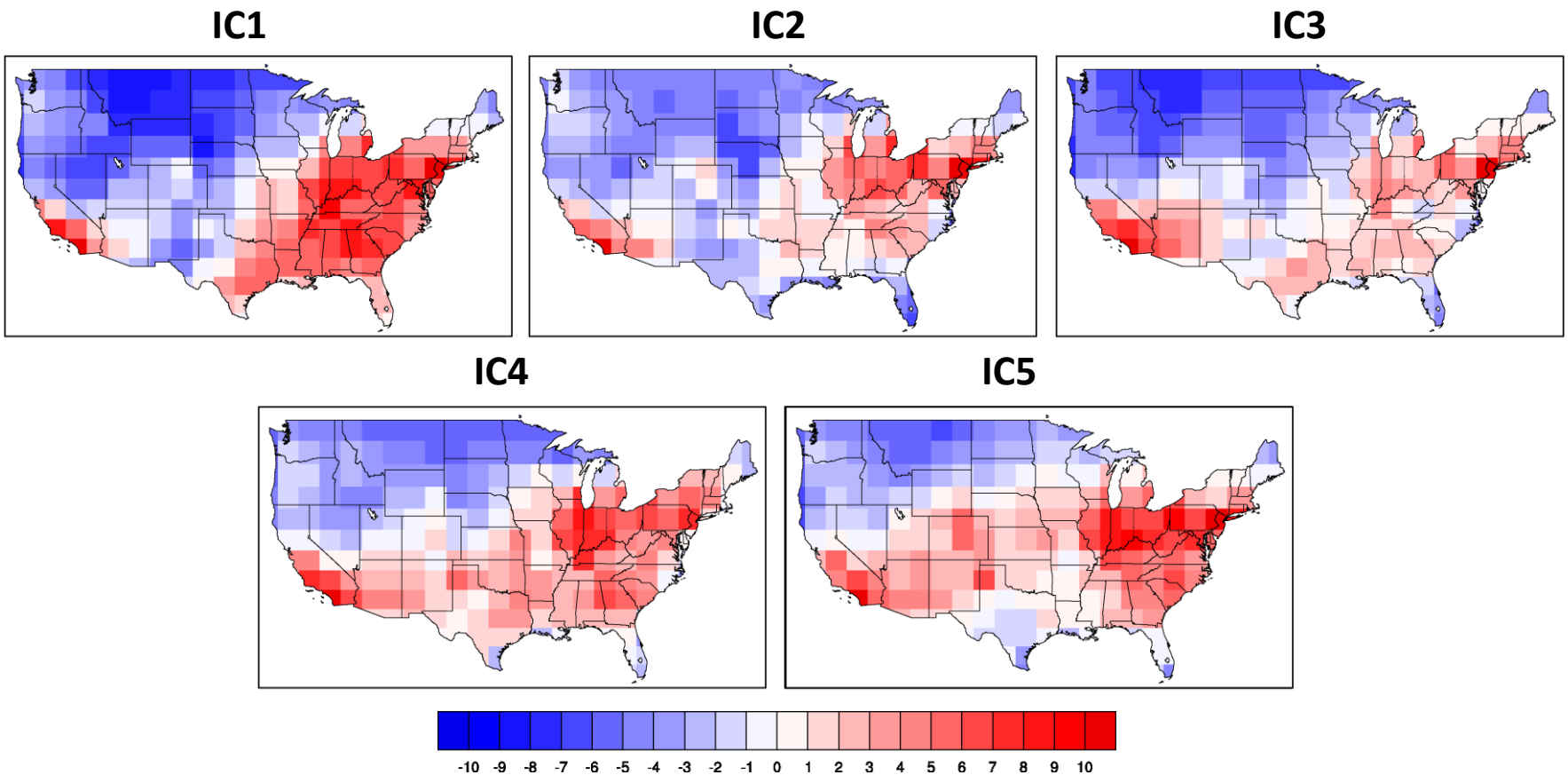
U.S. pop.-weighted annual $PM_{2.5}$ ($\mu g\ m^{-3}$)



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

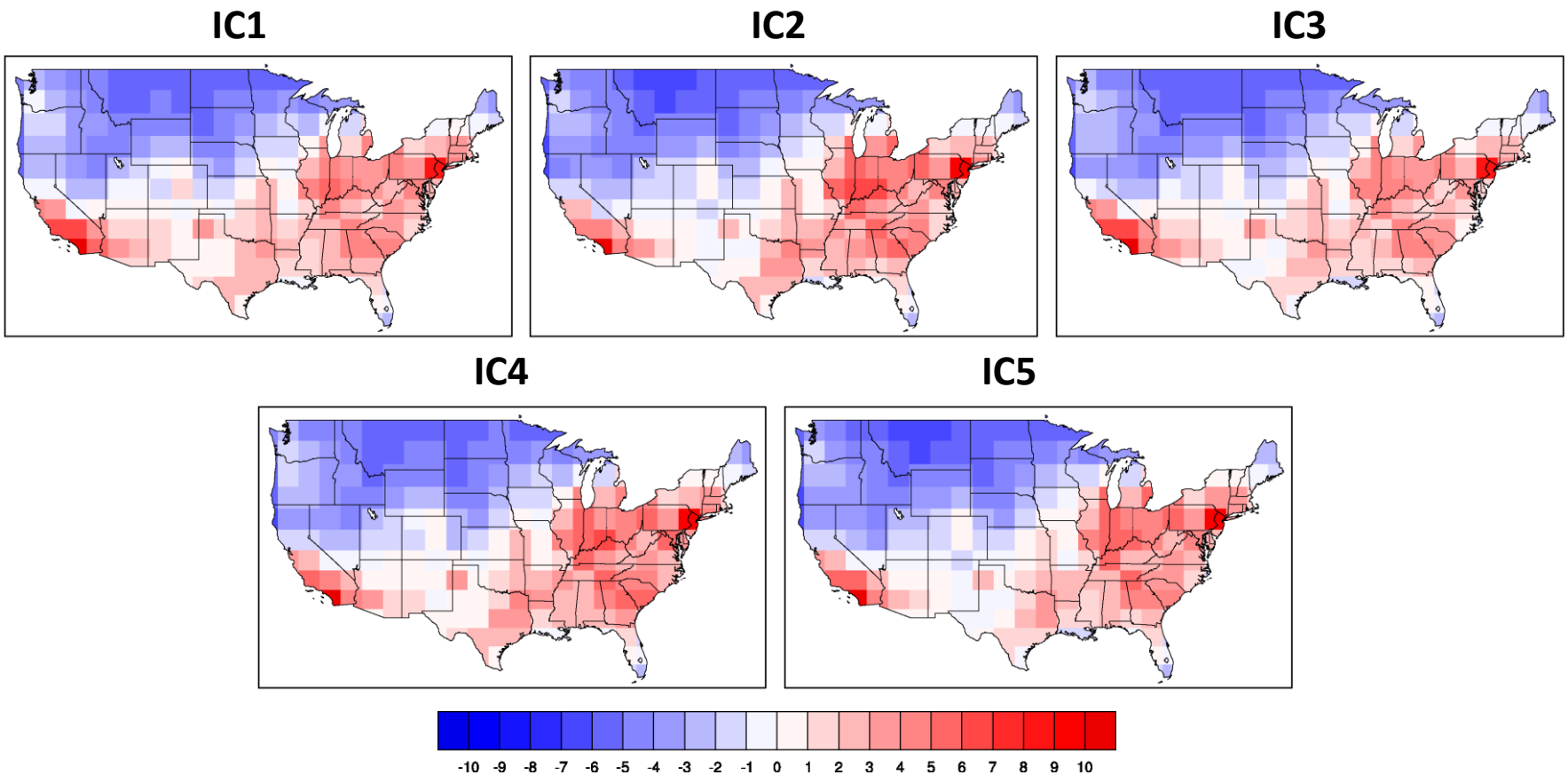
Climate model initialization

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

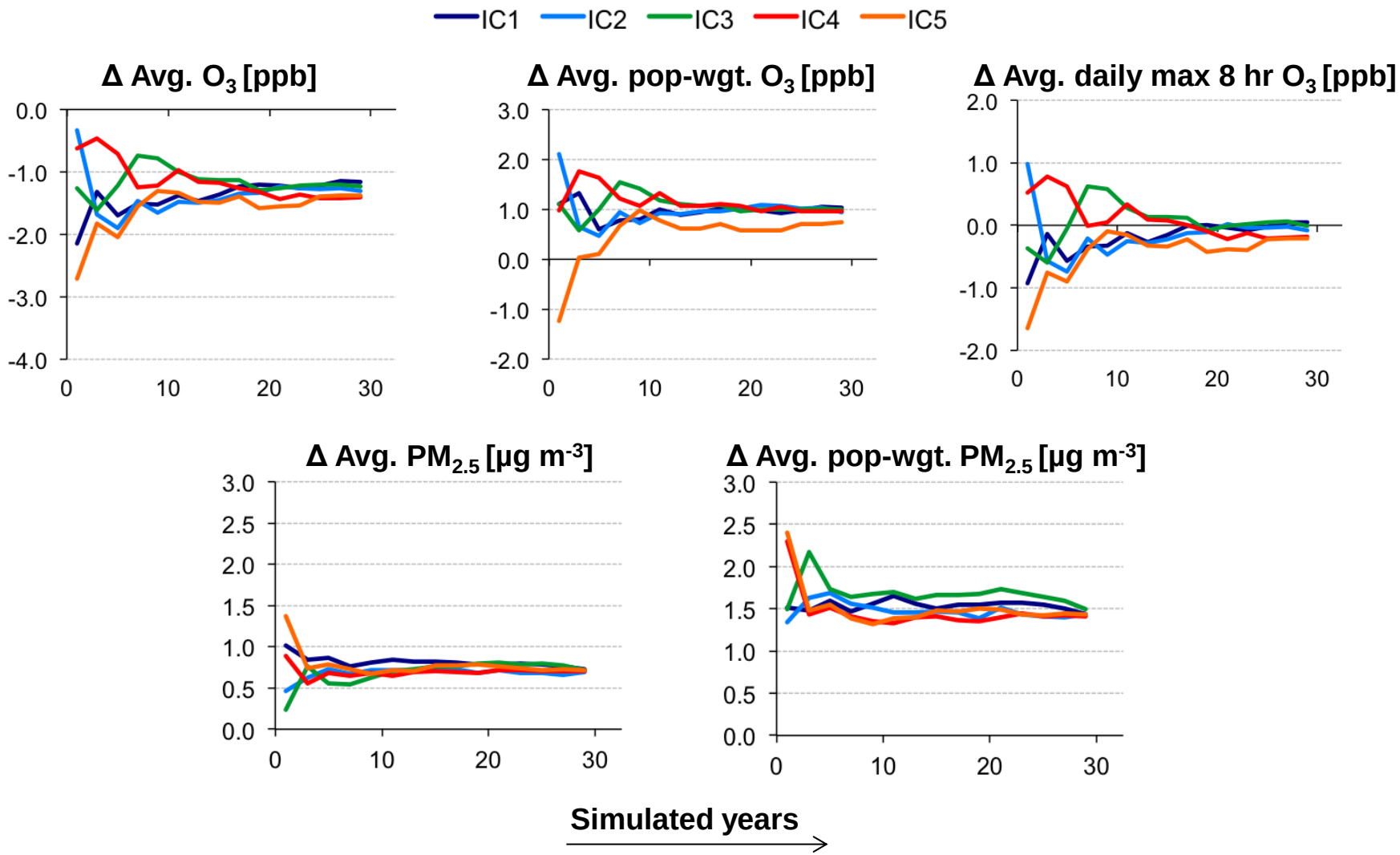


Considering variability in air quality projections

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



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.

THANK YOU!

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