Evaluating the Contribution of Natural Variability and Climate Model Response to Uncertainty in Projections of Climate Change Impacts on U.S. Air Quality

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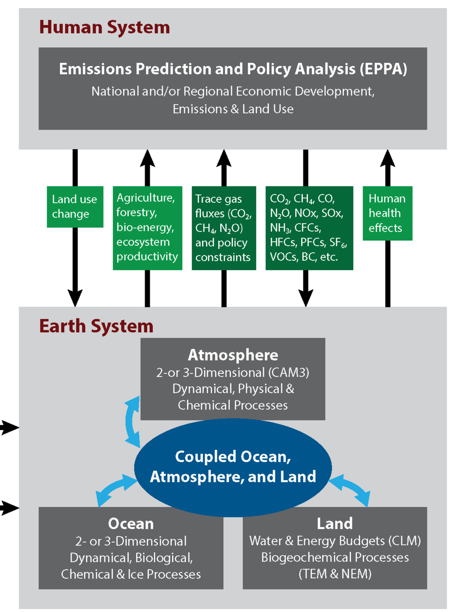
Motivation

Large uncertainties associated with climate projections propagate to simulations of future air pollution, as well as related health and economic impacts. Here, we investigate the influence of climate uncertainty on projections of U.S. air quality beyond emissions scenario by evaluating the roles of natural variability and climate sensitivity. We use a global atmospheric chemistry model driven by meteorological fields derived from an ensemble simulation of 21st century climate change generated with the MIT Integrated Global System Model. Under different greenhouse gas emissions scenarios, 30-year simulations centered around the years 2000, 2050 and 2100 are carried out using multiple initializations to assess the influence of internal variability in the projected climate penalty on U.S. air quality. The effect of climate model response is evaluated by perturbing the climate sensitivity within the MIT IGSM. We find that uncertainties in air pollution projections due to natural variability and climate response may be as significant as the uncertainty associated with emissions scenario.

Policy and climate scenarios



Monier, E., et al. (2013) Geoscientific Model Development

MIT Integrated Global System Model:

Two major coupled components:

- Earth system model
- Economic projection and policy analysis model

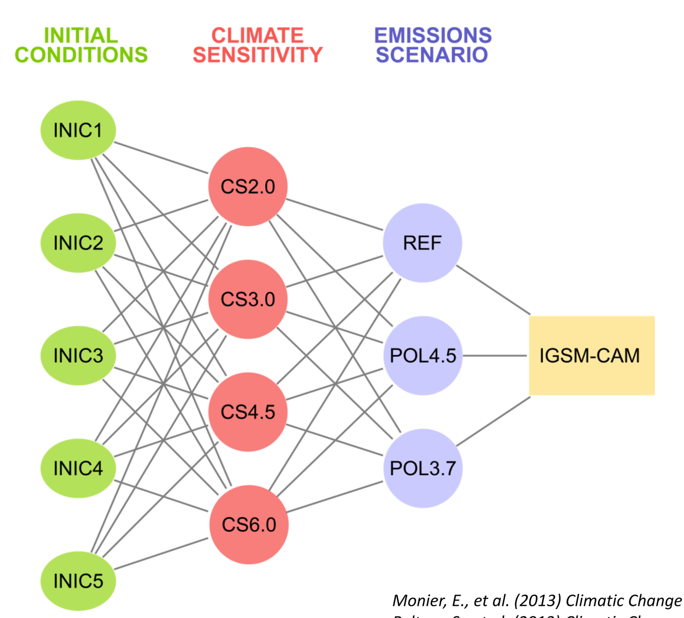
Internally consistent and policy prescriptive climate scenarios:

- *Reference*: Unconstrained growth
  2100 radiative forcing = 9.7 W/m²
- *Stabilization*:
  2100 radiative forcing = 4.5 W/m²
- *Stringent stabilization*:
  2100 radiative forcing = 3.7 W/m²

Ensemble simulation of 21st century climate change

Analyses explore the three main sources of uncertainty in climate projections:

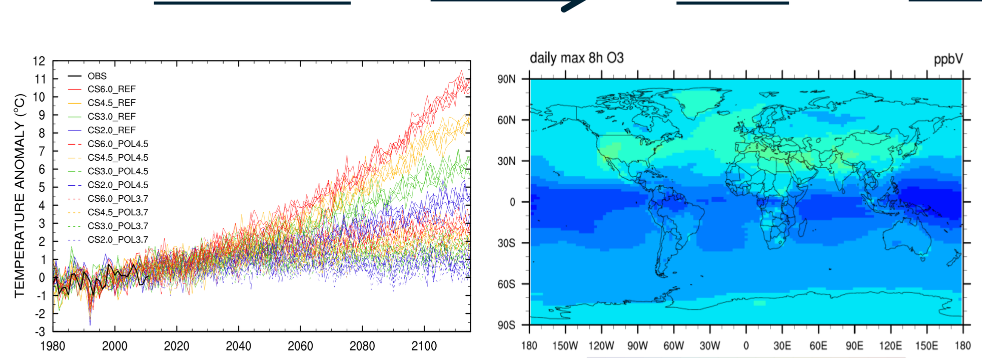
1. Greenhouse Gas Emissions
   Economic projection and emissions scenarios: Unconstrained (**REF**), Mitigation (**P45** and **P37**)
2. Climate model response
   Varying climate sensitivity:
   2.0°C, 3.0°C, 4.5°C, and 6.0°C
3. Natural variability
   Multidecadal simulations
   Multiple model initializations

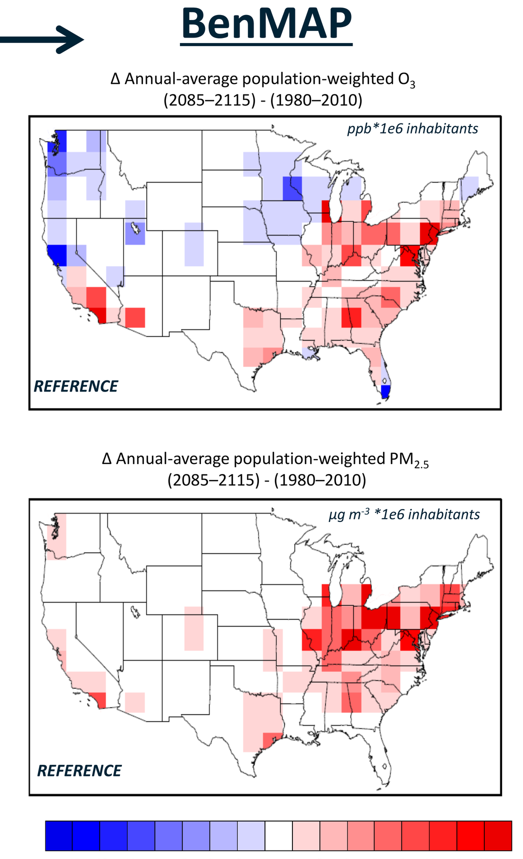


Monier, E., et al. (2013) Climatic Change
Paltsev, S., et al. (2013) Climatic Change

Modeling Framework

MIT IGSM → **CESM** → **BenMAP**





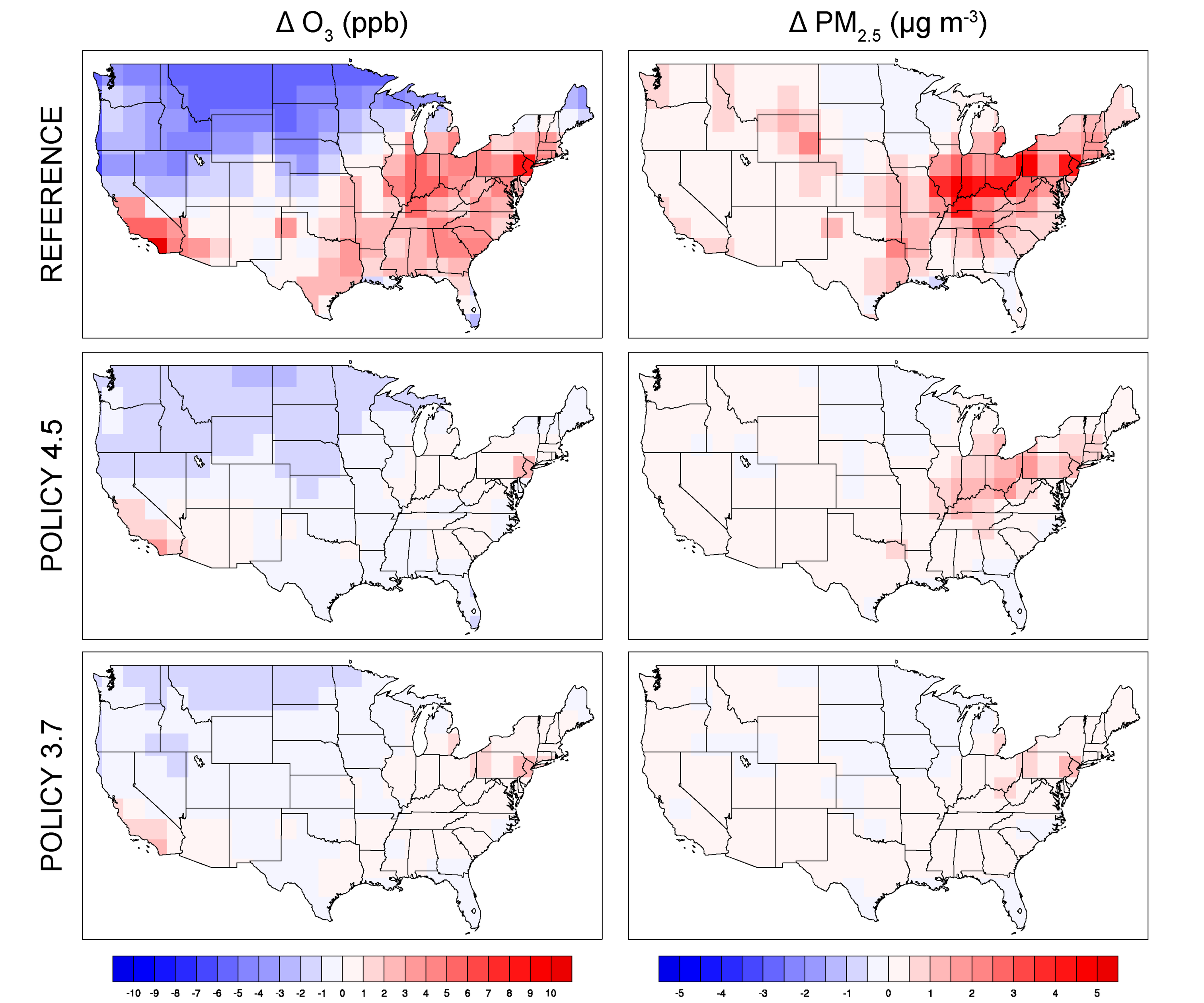
MIT IGSM: Policy scenarios and climate projections

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)*

Ensemble projections: Climate change impact on US air quality



Change in annual-average daily-maximum 8-hour O_3 and annual-average $PM_{2.5}$ from 2000 to 2100 under Reference greenhouse gas emission scenario

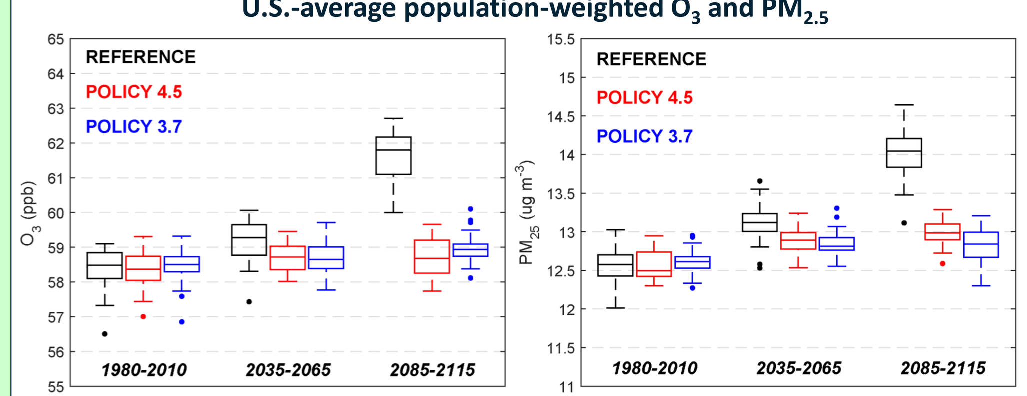
Ensemble-mean projections:

- 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/m² stabilization policy.

Climate penalty and policy impacts

Stabilization policies are projected to reduce the climate penalty on air quality:

U.S.-average population-weighted O_3 and $PM_{2.5}$

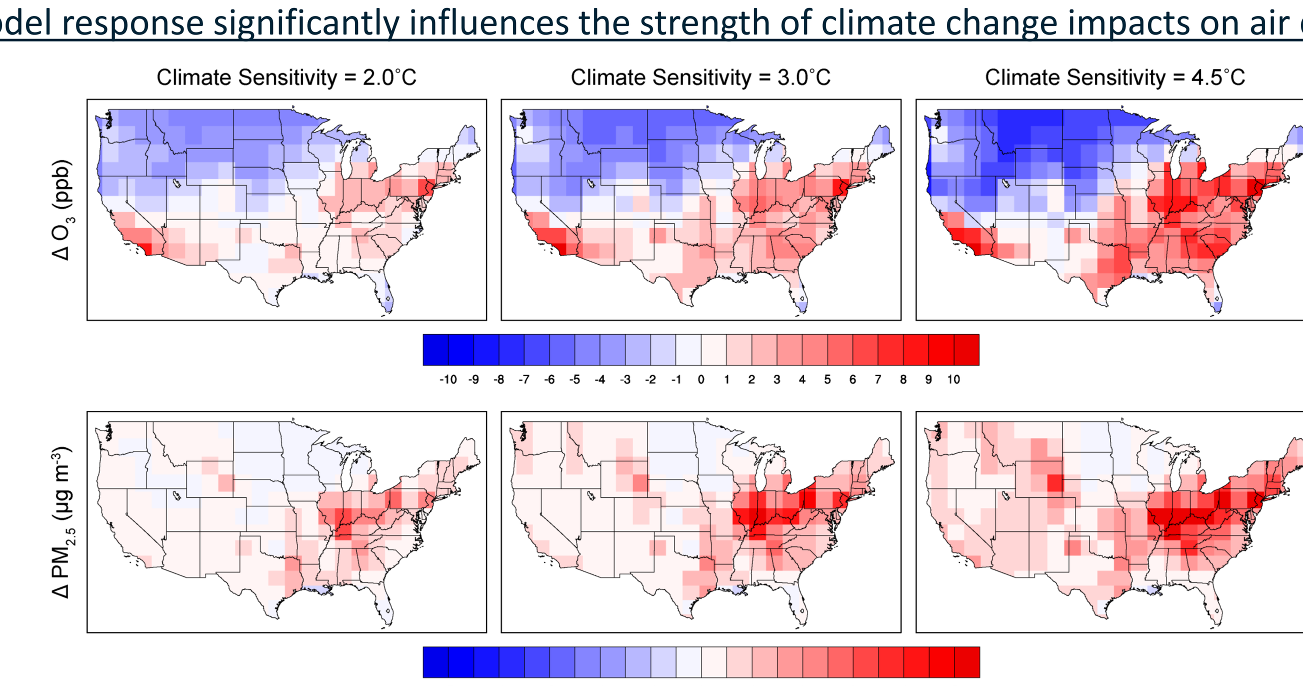


Climate Penalty (Δ ppb / μg m⁻³)		Annual avg. daily max. 8-hr O_3	Summer avg. daily max. 8-hr O_3	Annual avg. $PM_{2.5}$
REF	2000 → 2050	0.8 ± 0.1	3.4 ± 0.4	0.5 ± 0.1
	2000 → 2100	3.2 ± 0.2	10.4 ± 0.5	1.5 ± 0.1
POL45	2000 → 2050	0.4 ± 0.1	2.0 ± 0.3	0.3 ± 0.05
	2000 → 2100	0.4 ± 0.1	2.3 ± 0.3	0.4 ± 0.05
POL37	2000 → 2050	0.3 ± 0.1	1.6 ± 0.4	0.2 ± 0.04
	2000 → 2100	0.6 ± 0.1	2.3 ± 0.3	0.2 ± 0.1

Policy Impacts (Δ climate penalty)		Annual avg. daily max. 8-hr O_3	Summer avg. daily max. 8-hr O_3	Annual avg. $PM_{2.5}$
REF → P45	2000 → 2050	-0.4 ± 0.2	-1.4 ± 0.4	-0.2 ± 0.1
	2000 → 2100	-2.8 ± 0.2	-8.1 ± 0.5	-1.0 ± 0.1
REF → P37	2000 → 2050	-0.5 ± 0.2	-1.9 ± 0.5	-0.3 ± 0.1
	2000 → 2100	-2.7 ± 0.2	-8.1 ± 0.6	-1.2 ± 0.1

Climate model response

Model response significantly influences the strength of climate change impacts on air quality:

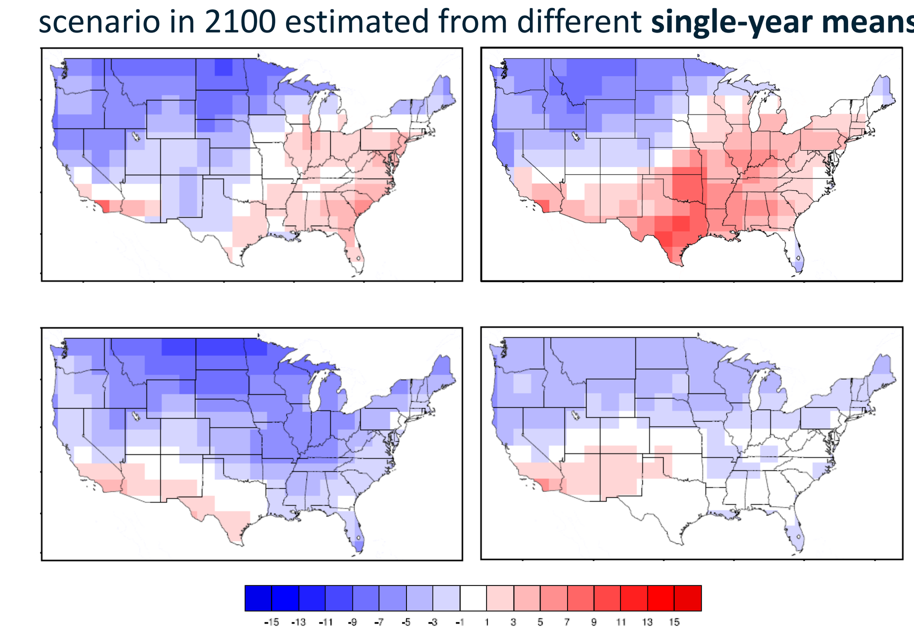


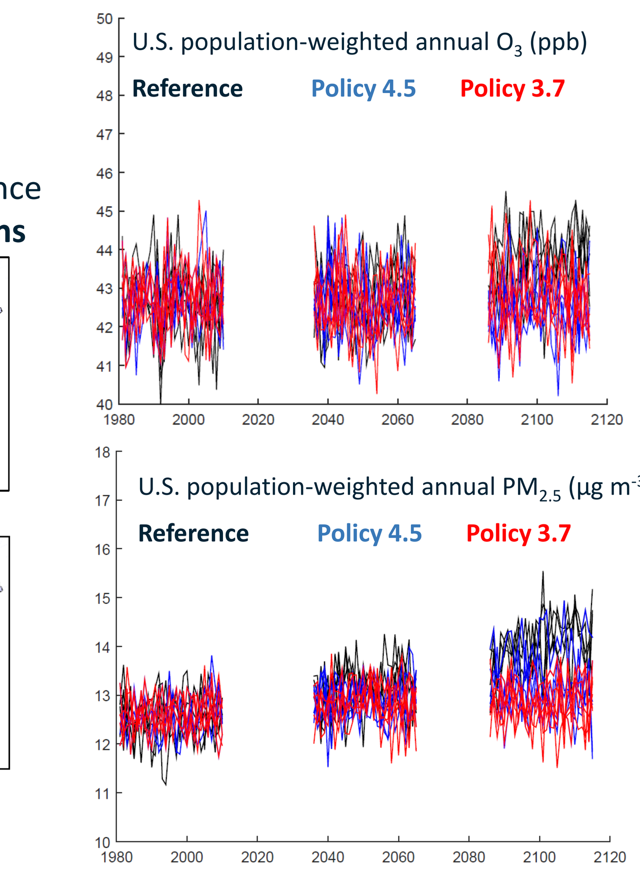
Climate penalty on annual daily max. 8hr O_3 and average $PM_{2.5}$ from 2000 to 2100 under Reference scenario

Natural Variability

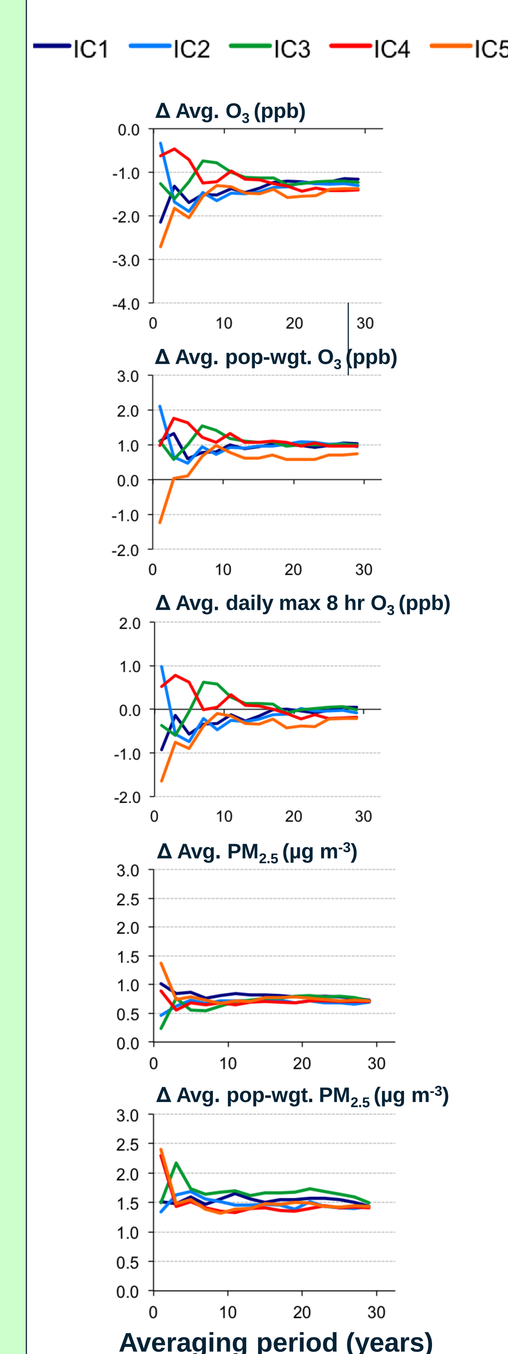
Natural variability has a major influence on climate – air quality simulations:

Climate penalty on annual-average O_3 (Δ ppb) under Reference scenario in 2100 estimated from different **single-year means**

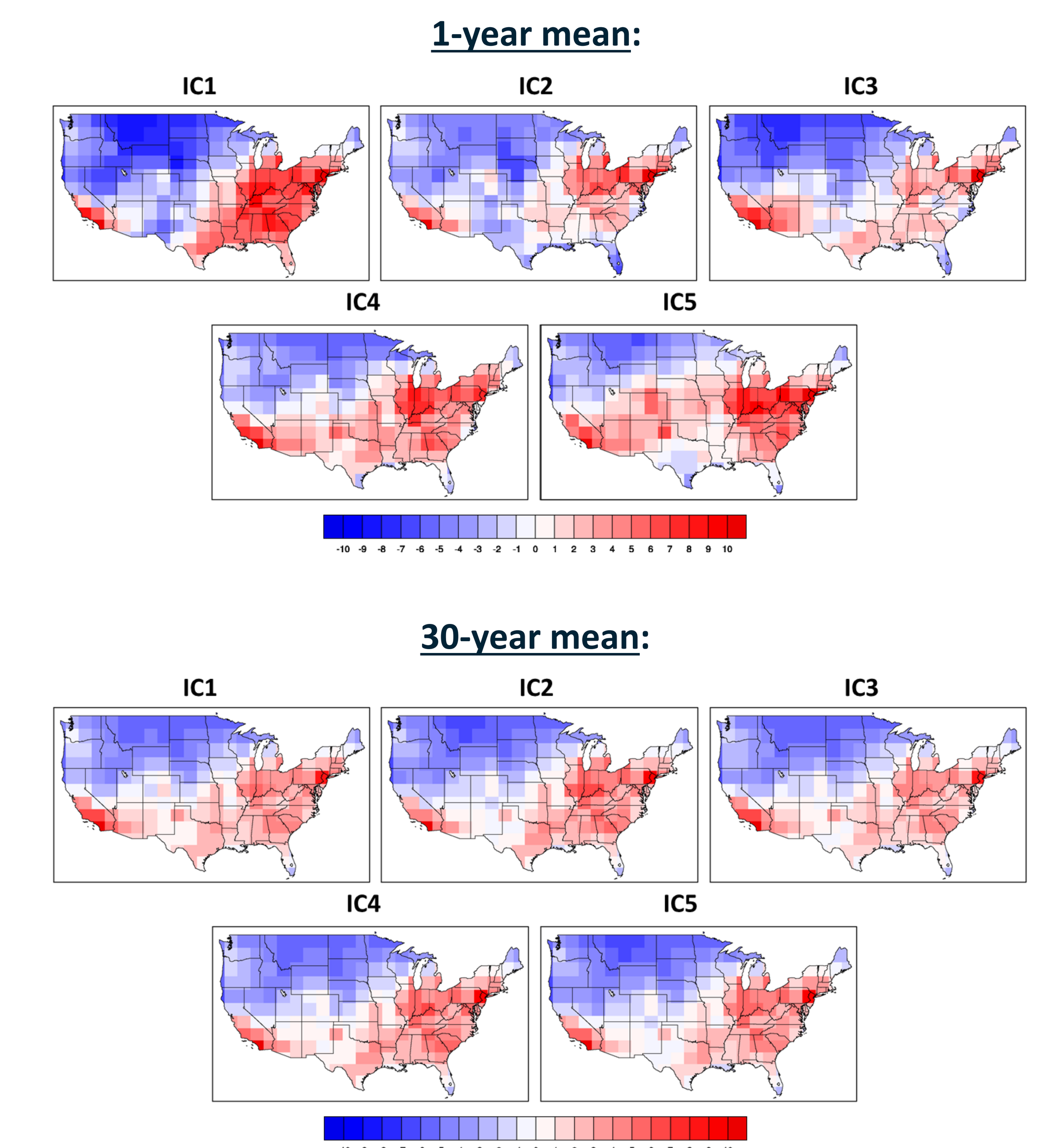




Internal variability in air quality projections can be better captured with mutidecadal simulations and multiple model initializations:



Climate penalty on annual-average daily max. 8hr O_3 (Δ ppb) from 2000 to 2100 under Reference scenario



Insights

- Uncertainties associated with climate projections can significantly influence simulations of future air quality and climate change impacts.
- Beyond anthropogenic emissions scenarios, large uncertainties are associated with natural variability and climate model response.
- Simulations > 15 years may be needed to capture the 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.

Contact Information and Acknowledgements

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