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 scenarios 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 predictions due to natural variability and climate response may be as significant as the uncertainty associated with emissions scenario.

Policy and climate scenarios

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 projections: Climate change impact on US air quality

<table>
<thead>
<tr>
<th>ΔO₃ (ppb)</th>
<th>ΔPM₂.₅ (µg m⁻³)</th>
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| Policies for reduced climate penalty and policy impacts
- Increase in O₃ over polluted regions of the U.S. and a decrease in background concentrations.
- Larger climate penalty on O₃ for summer and 8-hour daily maximum concentrations.
- Significant change in PM (SO₂, EC, OA, NH₄NO₃) 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 model response

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

- 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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MIT IGSM - Policy scenarios and climate projections

Community Earth System Models (CESM)

Global atmospheric chemistry and air quality

Em. 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 characteristic climate (1981-2010, 2036-2065, 2081-2113)

Natural Variability

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

Climate penalty on annual-average O₃ (µ g m⁻³) under Reference scenario can be estimated from different single-year means:

- 1-year mean
- 10-year mean

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

Analyzes 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
   - Natural variability
     - Multidecadal simulations
     - Multiple model initializations

Modeling Framework

MIT IGSM → CESM → BenMAP

Change in annual-average daily-maximum O₃ and annual-average PM₂.₅ from 2000 to 2100 under Reference greenhouse gas emissions scenario

Climate response significantly captured the anthropogenic contribution to climate change impacts.

Change in average population over the 21st century climate simulations and policy scenarios:

- Policy analysis model
- Interpreted as a warming or cooling penalty relative to a baseline climate
- Determined by the difference in climate mean temperature between the baseline and scenario simulations
- Captured by the strength of climate change impacts on air quality:

ΔO₃ (ppb) for Reference and Policy scenarios

Annual avg.
PM₂.₅
Summer avg.
daily max. 8-hr O₃
Summer avg.
daily max. 8-hr O₃

- Ensembles for different greenhouse gas emissions scenarios: 30
- Change generated driven by meteorological fields derived from an ensemble simulation of climate uncertainty on projections of U.S. air quality beyond emissions scenario by evaluating the
- 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 scenarios 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 predictions due to natural variability and climate response may be as significant as the uncertainty associated with emissions scenario.

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