Climate Change Impacts on Air Quality: An Uncertainty Analysis

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http://globalchange.mit.edu/
Climate Change Impacts and Risk Analysis (CIRA) Project:

- Project led by USEPA - Climate Change Division
- Analyze climate change impacts and risks in the U.S. under different global mitigation scenarios
- Includes multiple integrated assessment and sectoral impact models
- Investigate key sources of uncertainty

→ Infrastructure and Coastal Resources
→ Forestry and Agriculture
→ Water resources
→ Ecosystems
→ Energy
→ Health
Climate - Air Quality Objectives:

- Investigate the effects of uncertainty in climate projections on future U.S. air quality estimates.
- Weight uncertainty in climate penalty on U.S. air quality.
The MIT Integrated Global System Model


http://globalchange.mit.edu/
Ensemble simulation of 21st century climate change

Focus on 3 sources of uncertainty in climate projections

12 core IGSM simulations:
- 3 policy scenarios (reference, stabilization at 4.5 and 3.7 W/m²)
- 4 climate sensitivities (2.0, 3.0, 4.5 and 6.0°C)

60 IGSM-CAM simulations:
- 5 different representations of natural variability for each set of policy/climate parameters
Climate policy scenarios

1. **Reference scenario**:  - Unconstrained emissions after 2012  
   - Total radiative forcing of 9.7 W/m² by 2100

2. **Policy scenario I**:  - Stabilization scenario  
   - Total radiative forcing of 4.5 W/m² by 2100

2. **Policy scenario II**:  - Stringent stabilization scenario  
   - Total radiative forcing of 3.7 W/m² by 2100

Climate system parameters

- Climate sensitivity changed through cloud radiative adjustment method

- 4 choices of climate sensitivity:
  - $2.0 \, ^\circ C$
  - $3.0 \, ^\circ C$
  - $4.5 \, ^\circ C$
  - $6.0 \, ^\circ C$

Sokolov, A.P. and E. Monier (2012) J. Climate
Change in U.S. mean temperature

Anomalies from present day (1991–2010 mean)
Change in U.S. mean precipitation

Anomalies from present day (1991–2010 mean)
Impact of policy scenario and climate sensitivity

Change in future surface air temperature (2091–2110 mean) relative to present (1991–2010 mean)

ENSEMBLE MEAN FOR REF WITH DIFFERENT CLIMATE SENSITIVITIES

ENSEMBLE MEAN FOR CS3.0 WITH DIFFERENT POLICIES

http://globalchange.mit.edu/
Impact of policy scenario and climate sensitivity

Change in future precipitation (2091–2110 mean) relative to present (1991–2010 mean)

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Air Quality Modeling

**Meteorology**

T (K)

- 2° x 2.5° resolution
- 26 vertical levels

**Air Quality**

Surf. O₃ (ppb)

- Multiyear simulations present & future climate
- Specified dynamics
- 1.9° x 2.5° resolution
- Mozart trop. chem. & bulk aerosol

**MERRA-Meteorology**

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Air Quality Modeling

- Objective function => Air-quality related health impacts
- Systematically assess uncertainty in future health impacts

**Air quality:**
- 8-hr max. $O_3$
- 24-hr avg. $PM_{2.5}$

**Exposure:**
- Population-weighted concentrations

$$M_{pop} = \frac{\sum_g (p_g \times \{c_g\})}{\sum_g p_g}$$

**Health Impacts:**
- Mortality & Morbidity


[Image: Map of USA showing air quality and population distribution, bar chart showing avoided mortalities for different distances.]
Ongoing work

I. 30-year reference simulation - present climate:
   - Pollutant emissions at fixed level
II. Reference simulation - future climate
    - Reference policy scenario; best estimate climate sensitivity
III. Systematic test simulations
    - Climate policies, climate parameters, initial conditions
...
IV. Integrate uncertainty for pollutant emissions

Some initial questions we hope to address:
   - How long must simulation periods be to characterize climate?
   - How sensitive are air quality/health impacts to meteorology?
   - How significant is the climate change signal in projected changes to air quality?
Thank you

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GDP

REFERENCE

POLICY 4.5

POLICY 3.7

http://globalchange.mit.edu/
The MIT Integrated Global System Model

The IGSM is an integrated assessment model that couples an earth system model of intermediate complexity to a human activity model.

Major advantages of the IGSM:

• Flexibility to change the climate system response
  - climate sensitivity
  - strength of aerosol forcing
  - ocean heat uptake rate

• Flexibility to test different climate policies

• High computational efficiency, allowing large ensemble simulations to estimate PDFs of climate parameters
Impact of choice of policy and climate response

2041-2060 mean minus 1991-2010 mean

a) IGSM-CAM ENSEMBLE MEAN FOR POL4.5 WITH DIFFERENT CLIMATE SENSITIVITIES

b) IGSM-CAM ENSEMBLE MEAN FOR CS3.0 WITH DIFFERENT POLICIES
Impact of natural variability and choice of model

2041-2060 mean minus 1991-2010 mean

a) IGSM-CAM FOR CS3.0_POL4.5 WITH DIFFERENT INITIAL CONDITIONS

INITIAL CONDITION 1

INITIAL CONDITION 3

INITIAL CONDITION 5

b) IGSM-PATTERN SCALING FOR C3.0_POL4.5 WITH DIFFERENT MODELS

NCAR_CCSM3.0

BCCR_BCM2.0

MIROC3.2_MEDRES

0 0.4 0.8 1.2 1.6 2 2.4 °C