Effects of Climate, Emissions and Land Cover Changes on Air Quality in the U.S. National Parks

Maria Val Martin (CSU) and Colette L. Heald (MIT)
J-F Lamarque, S. Tilmes and L. Emmons (NCAR)

Thanks to the National Park Service for funding
Effects of Climate, Emissions and Land Cover Changes on Air Quality in the U.S. National Parks

Maria Val Martin (CSU) and Colette L. Heald (MIT)

J-F Lamarque, S. Tilmes
and L. Emmons (NCAR)

About 50% of forests will be exposed to damaging O$_3$ by 2100; and 20% will exceed critical loads from S and N deposition by 2050 [FAO, 2007]
NCAR Community Earth System Model (CESM 1.1_alpha12b)

CAM-Chem
1.9x2.5 spatial resolution
26 vertical levels to ~3 hPa

Coupler

Land Model (CLM 4)

IPCC scenarios and derived emissions (RCP 4.5 and 8.5)
2000 and 2050

GHGs

O₃ and PM Precursors

Prescribed sea-ice and ocean data (e.g., SST and sea-ice fraction)

Land cover/use data (e.g., LAI, PFTs, etc)
Projections of global AQ-relevant emissions

- Similar GHGs projections, except CH$_4$
- The RCP scenarios project large decreases for all emissions, except NH$_3$ and CH$_4$ in RCP 8.5
Projections of land cover/land use changes

- **RCP 4.5**
  - % Trees
    - Scale: -25 to 25
  - % Crops
    - Scale: -40 to 40
  - LAI
    - Scale: -0.40 to 0.40

- **RCP 8.5**
  - % Trees
  - % Crops
  - LAI
Fine Dust and Seasalt were adjusted to match IMPROVE observations. Emissions reduced by a factor of 2 and used an improved soil erodibility map. Emissions reduced by a factor of 10.
Effects on changes in climate alone

Annual Average in 2000

Temperature

2050 RCP 4.5 - 2000

↑3 °C

2050 RCP 8.5 - 2000

Precipitation

Annual Average in 2000

[mm/day]

0.0 2.3 4.7 7.0

Temperature [°C]

-4.0 -1.3 1.3 4.0

Precipitation [mm/day]

-3.0 -1.0 1.0 3.0
Effects of overall change on ozone

Summer Daily Max 8-hr Avg Surface O₃

<table>
<thead>
<tr>
<th>Year</th>
<th>RCP 4.5</th>
<th>RCP 8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2050 RCP 4.5</td>
<td><img src="image1" alt="Map" /></td>
<td><img src="image2" alt="Map" /></td>
</tr>
<tr>
<td>2050 RCP 8.5</td>
<td><img src="image3" alt="Map" /></td>
<td><img src="image4" alt="Map" /></td>
</tr>
</tbody>
</table>

ΔTotal = 2050-2000

- RCP 4.5: ~↓10 ppb
- RCP 8.5: ↑2 ppb, ↓4 ppb
RCP4.5 projects an important $O_3$ reduction from decreased anthropogenic emissions.

**Important decrease in NO$_x$ emissions**

- **ΔAnthro Emissions**
- **ΔClimate**
- **ΔLand Cover/Use**
In RCP8.5, climate and land cover changes offset benefits from emission reductions.
Both RCPs project a decrease in PM2.5

Annual Average PM 2.5

2000

2050 RCP 4.5

2050 RCP 8.5

RCP 4.5

RCP 8.5

0.0 5.7 11.3 17.0 [ug/m^3]

-12.0 -4.0 4.0 12.0 [ug/m^3]
Change in PM2.5 due mainly to SO$_4^-$ and NH$_4$NO$_3$ emission reduction

Changes in Chemical Speciation

**East US**

- 2000: 10.1
- 2050 RCP4.5: 5.0
- 2050 RCP8.5: 5.5

**West US**

- 2000: 4.6
- 2050 RCP4.5: 2.8
- 2050 RCP8.5: 3.2
What is next...

Rocky Mountain NP affected by Haze

- Study the effect of nitrogen deposition.
- Perform high resolution (0.5x0.5) simulations, and analyze the effect of spatial resolution on the results.
- Focus on the air quality over the US National Parks

http://www.nature.nps.gov/
EXTRA
Future simulations for RCP4.5 and RCP 8.5 scenarios
We will repeat the runs for 10 different meteorological scenarios to estimate the effect of interannual climate variability.
Model Evaluation: PM2.5

\((=\text{SO}_4+\text{NH}_4\text{NO}_3+\text{BC}+2\times\text{OC}+\text{SOA}+\text{Fine DST}+\text{SSLT})\)

Model 2000 with IMPROVE observations (1998-2010)

Annual average

Chemical Speciation

Overall, model captures the magnitude and spatial gradient of much of the IMPROVE PM2.5 observations
Further Model Evaluation: Ozone


- $O_3$ is simulated well over western US, and overestimated over eastern US (~20 ppb).
- This strong positive bias in CESM and other models is well known [e.g., Fiore et al, 2008, Brown-Steiner and Hess, 2011].
Temperature does not explain the O$_3$ bias over the eastern US

- On an average, model captures the magnitude and spatial gradient of much of the temperature
- Summer afternoon temperature is slightly overestimated
Model Evaluation: Sulfate and Ammonium Nitrate

Model 2000 with IMPROVE observations (1998-2010)

SO$_4$

NH$_4$NO$_3$

The model captures the spatial gradients of much of the observations. NH$_4$NO$_3$ is overestimated in the Midwest.
The model captures the spatial gradients, but low bias of OC compared to the IMPROVE observations.

Dust and Seasalt not shown. Fine sea salt and dust emissions were adjusted in the model to match surface observations.