Regional Chemistry-Climate Simulations in South Asia

Mary C. Barth¹, Rajesh Kumar¹, G. G. Pfister¹, L. Delle Monache¹, J. F. Lamarque¹, S. Archer-Nicholls¹, S. Tilmes¹, S. D. Ghude², C. Wiedinmyer¹, M. Naja³ and S. Walters¹

¹National Center for Atmospheric Research, Boulder, CO, USA
²Indian Institute of Tropical Meteorology, Pune, India
³Aryabhatta Research Institute of Observational Sciences, Nainital, India

NCAR is supported by the National Science Foundation
Objectives

1. How will future air quality of South Asia respond to projected changes in climate and emissions of key trace gases and aerosols?

RCP = Representative Concentration Pathway
Projected Ozone for South Asia from Global Model
Based on CAM-Chem Simulations at 2.5° x 1.9°

CAM-Chem projects increased ozone of 2-10 ppbv
RCP8.5 Scenario

Simulations from Jean-Francois Lamarque (NCAR)
Projected PM2.5 for South Asia from Global Model
Based on CAM-Chem Simulations at 2.5° x 1.9°

CAM-Chem projects a small increase of PM2.5 by 0-8 μg/kg in India
RCP8.5 Scenario

Simulation results from Jean-Francois Lamarque (NCAR)
Objectives

1. How will future air quality of South Asia respond to projected changes in climate and emissions of key trace gases and aerosols?

2. How are these projections affected by horizontal grid resolution?
   - Evaluation with present day observations
   - Comparison of future projections at different model resolutions
Nested Regional Chemistry Climate Simulation

Two domains:
Outer: $\Delta x = 60 \text{ km}$, full year
Inner: $\Delta x = 12 \text{ km}$, Oct-May dry season

Present Day: 1995-2004
Future: 2045-2054

10-year simulation – to account for interannual variability

<table>
<thead>
<tr>
<th>Chemistry-Climate Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Present day emissions and present day climate (PRES)</td>
</tr>
<tr>
<td>2. Future emissions and future climate (RCP8.5)</td>
</tr>
<tr>
<td>3. Future emissions and future climate (RCP6.0)</td>
</tr>
</tbody>
</table>
1. Evaluation of Present Day Results

2. Importance of Model Grid Resolution
Comparison of seasonal average CO mixing ratios at 900 hPa

Spatial correlation coefficient is >0.8

Percentage difference show 0-20% differences
NRNCM-Chem Compared to CO Monitoring Stations

Outer Domain
\( \Delta x = 60 \text{ km} \)

Inner Domain
\( \Delta x = 12 \text{ km} \)

The CO seasonal cycle is well represented. Inner domain at \( \Delta x = 12 \text{ km} \) predicts magnitude better than coarse domain. The same is true for \( \text{NO}_x \).
NRCDM-Chem Compared to PM2.5 Monitoring Stations

PM2.5 seasonal cycle is fairly well represented

Inner domain at $\Delta x = 12$ km predicts magnitude better than coarse domain in October-February

AOD and Ångström Exponent seasonal variations reproduced well
Ozone seasonal cycle is represented well

Inner domain predicts magnitude similarly or somewhat better than outer domain
NRCM-Chem Compared to Ozone Monitoring Stations

100s km grid spacing

Global CTMs

Outer Domain
$\Delta x = 60 \text{ km}$

Inner Domain
$\Delta x = 12 \text{ km}$

North India
Nainital, 29.4N, 79.4E, 1958.0m, 2006-08
MB = 11.8 ppb, r = 0.70

West India
Mt. Abu, 24.6N, 72.7E, 1680.0m, 1993-200
MB = 15.5 ppb, r = 0.72

South India
Kannur, 11.9N, 75.4E, 5.0m, 2009-10
MB = 14.5 ppb, r = 0.89

From TOAR chapter 7, under review

Observations
NRCM-Chem

Regional Chemistry-Climate Model performs much better than Global CTMs
Objectives

1. How will future air quality of South Asia respond to projected changes in climate and emissions of key trace gases and aerosols?
Annual Average, Maximum Daily 8-hour Average (MDA8h) surface ozone across scenarios

- **O$_3$** increases in both RCP8.5 and RCP6.0 scenarios
- **O$_3$** remains below the National Ambient Air Quality Standard (NAAQS) of 50 ppbv over most parts of the domain

CAM-Chem has similar pattern for 24-hour average and somewhat smaller magnitude compared to NRCM-Chem
Dry season (Oct-May) average MDA8h surface ozone across scenarios

O_3 exceeds the NAAQS of 50 ppbv over most parts of the land area for all scenarios

Difference during dry season is greater than annual average
Annual Average PM2.5 across scenarios

- Increase in RCP8.5
- Decrease in RCP6.0
- PRES and RCP8.5 exceed NAAQS of 40 μg/m³

CAM-Chem has much weaker signal compared to NRCM-Chem
Frequency distributions of D01 and D02 MDA8 ozone and 24-h average PM$_{2.5}$ for the Indian states located in the Indo-Gangetic Plain during dry-season.

- Approximately same results for $\Delta x=60$km Outer domain and $\Delta x=12$km Inner Domain.

- For regions where emissions occur throughout the region, coarser grid resolution simulations represent ozone and PM2.5 well.
Number of days MDA8 ozone exceeds WHO limits increases for RCP8.5
Number of days DA24 PM$_{2.5}$ exceeds WHO limits moderately increases for RCP8.5
RCP6.0 results similar to or less than present day results
Summary

1. How will future air quality of South Asia respond to projected changes in climate and emissions of key trace gases and aerosols?

- Increase in Annual Average of Maximum Daily 8-hour Ozone Average
  - especially from present day to RCP8.5 projection (only a small increase for RCP6.0 scenario)
  - especially in dry season

- Increase in Annual Average of 24-hour PM2.5 Average for RCP8.5 projection but a decrease for RCP6.0 projection

- Exceedance days for ozone and PM2.5
  - increase significantly in RCP8.5 scenario
  - remain similar to present day in RCP6.0 scenario
Summary

2. How are these projections affected by horizontal grid resolution?

- NRCM-Chem able to capture seasonal variability of both ozone and PM2.5 at both grid resolutions

- While $\Delta x = 12$ km inner domain shows better agreement than $\Delta x = 60$ km outer domain with observations of CO and NO$_x$, their results were similar for ozone and PM2.5

- Differences between future scenarios and present day were similar for both $\Delta x = 12$ km inner domain and $\Delta x = 60$ km outer domain

- Global-scale model predicts same pattern but weaker signal compared to regional-scale model results

Air pollution is a major environmental problem in South Asia and will remain so by the mid century irrespective of the Representative Concentration Pathway
Extra slides
Same as Figure S4 but for surface PM2.5 mass concentrations

Same as Figure 11 but domain 2
Annual averaged total anthropogenic emissions of NO$_x$ and PM$_{2.5}$ over the outer model domain for present-day (ACCMIP, 2000) and future (RCP8.5 and RCP6.0, 2050) time periods.