Examples of Using WRF-Chem for Aerosol-Climate Applications

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WRF-Chem & Aerosol-Climate Investigations

- The released WRF-Chem v2.2 now has built in capabilities for aerosol-climate investigations
- Two recent projects are presented here as examples
  - Impact of sub-grid scale CCN heterogeneity for GCMs
  - Impact of black carbon (BC) on snowpack
Aerosol-Climate Processes in WRF-Chem

• Direct effect for shortwave
  – Scattering and absorption by aerosols

• 1\textsuperscript{st} indirect effect
  – Cloud albedo due to altered CCN counts

• 2\textsuperscript{nd} indirect effect
  – Cloud life cycle changes due to altered CCN counts

• Common tie is the sectional aerosol module, MOSAIC

• More details Friday at the WRF-Chem tutorial
Application 1: CCN Heterogeneity

- GCMs represent CCN characteristics at a coarse scale
- Regions with complex aerosol distributions get smoothed out when diagnosing CCN
- What is the impact of this smoothing on cloud characteristics?
Approach for the Investigation

Simulation 1: IA
- Interactive Aerosols
- Control run
- Used to generate a realistic spatially and time varying aerosol field
  - Hygroscopicity
  - Size
  - Number

Simulation 2: PA_{XY}
- Prescribed aerosols based on horizontal (XY) average
- Aerosol distribution varies in height and time

Simulation 3: PA_{XYZT}
- Prescribed aerosols based on horizontal, time and height (XYZT) average
- Aerosol distribution is constant
Comparison to MFRSR, Indiana, PA

Symbols = Observations

Orange = Modeled range of values in 9 points surrounding observation location

Gustafson et al. 2007, GRL, in review
Cloud Optical Depth Percentiles

- Averaging leads to an increased occurrence of thick clouds
- Little change in thin clouds

Gustafson et al. 2007, GRL, in review
## Domain Average Time Series

<table>
<thead>
<tr>
<th></th>
<th>Change PA_{XYZ} vs. IA</th>
<th>Change PA_{XY} vs. IA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cloud Optical Depth</strong></td>
<td>27%</td>
<td>6%</td>
</tr>
<tr>
<td>(1&lt;COD&lt;20)</td>
<td>-6%</td>
<td>-2%</td>
</tr>
<tr>
<td>(20&lt;COD&lt;200)</td>
<td>13%</td>
<td>4%</td>
</tr>
<tr>
<td><strong>Cloud Fraction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1&lt;COD&lt;20)</td>
<td>-3%</td>
<td>-1%</td>
</tr>
<tr>
<td>(20&lt;COD&lt;200)</td>
<td>-11 W m^{-2}</td>
<td>-3 W m^{-2}</td>
</tr>
<tr>
<td><strong>Downwelling Shortwave</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cloud Water</strong></td>
<td>5%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Gustafson et al. 2007, GRL, in review
Impact Summary

• The error from CCN in cloud characteristics is presumably smaller than from other aspects of the cloud parameterizations
• Neglecting time and height dependence of CCN leads to the largest systematic bias
• Including time and height variability of CCN reduces bias for downwelling shortwave to 1%
  – If GCMs can account for the CCN variability, then they will improve their ability to reproduce cloud characteristics
  – More extensive spatial and temporal simulations need to confirm this
Application 2: BC Impact on Snow

- Black carbon (BC) deposition on snow reduces the albedo
- Cascades have lost up to 60% of their snowpack since 1950, Northern Rockies have lost 15%
- How much of this can be attributed to BC influences?

Stohl et al., 2007, ACP

Observed Snowpack Reduction
Approach to the Investigation

WRF-Chem
- 1-yr simulation, dx=12 km
- 4-bin MOSAIC
- Maps of BC deposition and snow

Offline BC-snow model
- BC-snow mixing ratio for radiative layer of snowpack
- Bounds for snow albedo

WRF Regional Downscaling
- Decade simulations
- Sensitivity runs for snow albedo guided by offline model results
WRF vs. IMPROVE, Black Carbon (0-2.5 μm)

- Large BC gradients near mountains
- WRF simulation tends to over predict surface concentrations of BC
- Partially due to “non-seasonal” emissions?
• Patterns of BC-snow mixing ratio shift by month
• Lower elevations affected more in important regions, e.g. Sierra Nevada
• East-west asymmetry around Washington Cascades
• Next step… relate these monthly mixing ratios to albedo
Parting Comments

• WRF-Chem has the potential to study many types of aerosol-cloud interactions
  – Resolution studies
  – Process studies
  – Sensitivity of climate to aerosols
• Currently, interactions are limited to the liquid phase; ice phase linkages are in development
• We are looking to partner with others to link the aerosol mechanism to biogeochemical and toxics models