Enhancement and Testing of Hemispheric CAMx

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HEMISPHERIC CAMx (PHASE I)

- Improve the characterization of “background” ozone within regional (continental) air quality simulations
- Apportion ozone in hemispheric scale simulations
- Transfer hemispheric ozone source apportionment to regional domains via boundary concentrations (BCs)
HEMISPHERIC CAMx (PHASE II)

- Evaluate and develop use of satellite data to derive lateral and top boundary conditions

- Test effects of improved vertical resolution and use of CAMx “cloud-in-grid” (CiG) convective sub-model

- Comprehensive model performance for entire 2016 year vs. GEOS-Chem and H-CMAQ
SATELLITE O$_3$ FOR CAMx TOP BC

- NASA-AIRS V6 product includes ozone, CO and methane
  - Good for stratospheric concentrations
  - Poor in the lower and mid troposphere

- Use to characterize spatial and temporal variations of ozone at the top of the model

- AIRS2CAMxTC: new tool generates top BC from daily global AIRS ozone data
  - Easily adaptable to AIRS-OMI when available
MULTI-YEAR INITIAL/BOUNDARY CLIMATOLOGY

- Initializing from simple profile assumptions require excessive model spin-up to achieve chemically equilibrated atmosphere

- AIRS has little tropospheric temporal and zonal variability (monthly climatological a-priori dominates), limited chemical species

- Developed a library of monthly-averaged, spatially-varying IC/BC for all CAMx species from 2016 GEOS-Chem

- Can be used to represent a recent global climatology within a reasonable interval (arguably $\pm 5$ years) from 2016

- Shortens model spin-up times from IC ($\sim 1$ month to 1 season)
HEMISPHERIC WRF SIMULATIONS

- Key WRF sensitivity tests:

  1) Vertical resolution:
     - Increase in mid-troposphere through lower stratosphere
     - Improve winds for long-range transport and stratospheric intrusion?
     - 9 additional layers (from 44 to 53)

  2) Convective submodel:
     - Use Multi-scale Kain-Fritsch (MSKF) cumulus option that supports CAMx cloud-in-grid (CiG) convective submodel

<table>
<thead>
<tr>
<th>WRF runs</th>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run0</td>
<td>EPA’s WRF output</td>
<td></td>
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<tr>
<td>Run1</td>
<td>Replicate EPA’s setup but parallelize over 5.5-day sections (speed up WRF)</td>
<td></td>
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<tr>
<td>Run2</td>
<td>53 layers</td>
<td></td>
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<tr>
<td>Run3</td>
<td>MSKF cumulus</td>
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<thead>
<tr>
<th>WRF physics options used in Run0 through Run3</th>
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<tbody>
<tr>
<td><strong>WRF Physics</strong></td>
</tr>
<tr>
<td>Surface Layer Physics</td>
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<tr>
<td>PBL</td>
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<tr>
<td>Sub-Grid Convection</td>
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</tbody>
</table>
Near-surface fields are cooler and drier, whereas high latitude areas are warmer.

Near-surface winds are slightly stronger in equatorial and mid-latitude regions.

Better resolution of the jet stream’s vertical structure and hence higher speeds.

Improved resolution of temperature profile near the tropopause, leading to lower temperatures.
CUMULUS SENSITIVITY (RUN 3)

- Slightly stronger winds in equatorial convergence zone in both seasons, slightly weaker mid-latitude winds in winter

- Cooler winter temperatures over the subtropical oceans and warmer over Saharan Africa

- Cooler summer subtropical temperatures globally (especially Africa and India)
  - Higher humidity in same areas and in both seasons

- Little impact in mid/high latitudes and at tropopause
  - Low-altitude/low-latitude sensitivity to PBL and cumulus mixing
# H-CAMx SIMULATIONS

## Meteorology, Emissions, IC/BC/TC

<table>
<thead>
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<th>Scenario</th>
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<tbody>
<tr>
<td>Run0</td>
<td>EPA WRF and most emissions (Mathur et al., 2017) &lt;br&gt; Oceanic &amp; wind blown dust, day specific GEOS-Chem IC/BC/TC &lt;br&gt; V1 H-CAMx stratospheric ozone parameterization</td>
</tr>
<tr>
<td>Run1</td>
<td>WRF replication, monthly IC/BC, daily satellite TC, updated natural emissions &lt;br&gt; V2 H-CAMx stratospheric ozone parameterization to reduce ozone bias above 10km</td>
</tr>
<tr>
<td>Run2</td>
<td>WRF with 53 layers, re-extracted monthly IC/BCs</td>
</tr>
<tr>
<td>Run3</td>
<td>WRF with MKSF/YSU/MM5 schemes &lt;br&gt; CAMx cloud-in-grid convective mixing scheme</td>
</tr>
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<table>
<thead>
<tr>
<th>H-CAMx Run</th>
<th>Run Duration</th>
<th>Run Dates (Total # Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run0</td>
<td>4 days, 11 hr, 46 mins</td>
<td>12/22/2015 - 12/30/2016 (375 days)</td>
</tr>
<tr>
<td>Run1</td>
<td>5 days, 3 hr, 46 mins</td>
<td>10/01/2015 - 12/31/2016 (458 days)</td>
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<tr>
<td>Run2</td>
<td>5 days, 23 hrs 21 mins</td>
<td>10/01/2015 - 12/31/2016 (458 days)</td>
</tr>
<tr>
<td>Run3</td>
<td>6 days, 9 hr, 15 mins</td>
<td>10/01/2015 - 12/31/2016 (458 days)</td>
</tr>
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Parallelization: 9 MPI x 6 OMP
GLOBAL SURFACE MEASUREMENT DATA

World data center for reactive gases (WDCRG) ozone monitor locations for 2016

All surface monitors for 2016:
- Europe (26 sites)
- US (24 sites)
- Asia (4 sites)
- Northern Latitudes (7 sites)
- Oceanic (6 sites)

(Source: https://www3.epa.gov/castnet/docs/CASTNET2016/AR2016-main.htm#chapter1-3)
OZONESONDE MEASUREMENTS

Global ozonesonde launch sites in 2016

Source: https://woudc.org/data/explore.php

Ozonesonde locations selected for H-CAMx Evaluation
INTER-MODEL PERFORMANCE COMPARISON

- GEOS-Chem qualitatively best replicates stratospheric ozone, negative bias in the troposphere
- H-CMAQ is similar to GEOS-Chem but consistently more negatively biased
  - Occasional ozone gaps around the tropopause at low-latitudes
- H-CAMx has negative stratospheric bias and positive tropospheric bias
- All models exhibit narrower minimum-to-maximum ranges than the observations
• **US/CASTNET:**
  - Models exhibit little NMB and a range of 10-20% NME
  - GEOS-Chem and H-CMAQ exhibit the lowest bias
  - H-CAMx has consistent positive bias, large deviations from the other models at few sites

• **Europe:**
  - Performance trends similar to US
  - GEOS-Chem negatively biased
  - H-CMAQ and H-CAMx bias is rather good
  - H-CAMx has consistent positive bias while H-CMAQ has a slight negative bias
INTER-MODEL PERFORMANCE COMPARISON

Site-averaged annual bias (NMB, %), gross error (NME, %) and correlation coefficient (R) over five global monitoring groups for each model.

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</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>2%</td>
<td>15%</td>
<td>4%</td>
<td>16%</td>
<td>20%</td>
<td>18%</td>
<td>0.65</td>
<td>0.67</td>
<td>0.59</td>
</tr>
<tr>
<td>Europe</td>
<td>-14%</td>
<td>6%</td>
<td>-5%</td>
<td>20%</td>
<td>17%</td>
<td>17%</td>
<td>0.76</td>
<td>0.74</td>
<td>0.73</td>
</tr>
<tr>
<td>Asia</td>
<td>-8%</td>
<td>16%</td>
<td>13%</td>
<td>21%</td>
<td>25%</td>
<td>27%</td>
<td>0.78</td>
<td>0.74</td>
<td>0.76</td>
</tr>
<tr>
<td>Oceanic</td>
<td>-19%</td>
<td>9%</td>
<td>19%</td>
<td>21%</td>
<td>18%</td>
<td>23%</td>
<td>0.71</td>
<td>0.72</td>
<td>0.62</td>
</tr>
<tr>
<td>Polar</td>
<td>-20%</td>
<td>-3%</td>
<td>-25%</td>
<td>24%</td>
<td>15%</td>
<td>30%</td>
<td>0.68</td>
<td>0.43</td>
<td>0.22</td>
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Color coded according to whether they meet (green) or exceed (orange) ozone statistical performance criteria recommended by Emery et al. (2016) for regional photochemical modeling (NMB ≤ ±15%; NME ≤ 25%, R > 0.50).

- 15 metrics listed for each model (3 statistics over 5 monitoring regions)
- Performance is generally good among most models/regions (esp. US and Europe)
  - GEOS-Chem tends toward negative bias
  - H-CAMx Run0 tends toward positive bias
  - H-CMAQ statistics are mixed
**H-CAMx SENSITIVITY RESULTS**

Site-averaged annual bias (NMB, %), gross error (NME, %) and correlation coefficient (R) over five global monitoring groups for each H-CAMx run.

<table>
<thead>
<tr>
<th>Monitor Group</th>
<th>Run1 NMB</th>
<th>Run2 NMB</th>
<th>Run3 NMB</th>
<th>Run1 NME</th>
<th>Run2 NME</th>
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<th>Run1 R</th>
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- Higher ozone in all sensitivity cases relative to Run0: upward shifts in NMB and NME over all regions
- Poor Run0 correlation in the Polar group is improved substantially in all sensitivity cases
- Bias and error performance over US and Asia degrade to outside benchmark criteria
- High bias among the Asia group is driven by higher ozone at Hanoi, Vietnam (an apparent emission issue discussed with EPA)
CONCLUDING REMARKS

- Developed daily H-CAMx ozone TCs from AIRS satellite data at 50 mb
- Monthly spatially-varying IC/BCs provide best balance between flexibility and representativeness, allow for a shortened spin-up period
- Modified layer structure influenced resolution of the boundary layer, and temperature and wind profiles at jet stream altitudes, minor effect on tropospheric ozone
- Implementing cumulus convection had little impact meteorologically and increased tropospheric ozone
- Comparison to GEOS-Chem and H-CMAQ indicates:
  - H-CAMx tends to under predict stratospheric ozone profiles, over predict tropospheric profiles
    - Stratospheric scheme adjustment improves stratospheric ozone, slightly exacerbates tropospheric ozone
  - GEOS-Chem is best overall performer globally
  - H-CMAQ tends to slightly under predict tropospheric profiles, has most performance variability of the three models