Comparison between atmospheric chemistry model and observations utilizing the RAQMS–CMAQ linkage

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HIGHLIGHTS

\begin{itemize}
  \item Updated RAQMS–CMAQ linking tool by adding the CMAQ aerosol modules (AERO3 & AERO4).
  \item Included additional gas phase species from RAQMS to RAQMS–CMAQ.
  \item Investigated the impacts of the lateral boundary condition on CMAQ simulations.
  \item Characterized the model results by comparing with in-situ measurements at Moody Tower.
  \item Used the improved dynamic boundary conditions to discuss the improvement of ozone simulation.
\end{itemize}

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ABSTRACT

EPA’s Community Multiscale Air Quality (CMAQ) model was used to investigate the influence of lateral boundary conditions (LBCs) on ozone simulation. Meteorological fields used to drive the model were from the fifth generation Mesoscale Model (MMS). Emission files were prepared from the Sparse Matrix Operating Kernel for Emissions (SMOKE) model. Realtime Air Quality Modeling System (RAQMS) model with assimilated satellite observations were used as the LBCs for the CMAQ. CMAQ simulations with RAQMS LBCs and predefined LBCs were compared with INTEX Ozone Network Study (IONS) ozonesonde data and Ozone Monitoring Instrument (OMI) satellite measurements. CMAQ forced with RAQMS LBCs could reasonably reproduce the vertical profiles of ozone mixing ratio. It was revealed that the influence of LBCs on ozone simulations is significant in the upper troposphere, moderate in the middle troposphere, and small in the lower troposphere. CMAQ model outputs provided a unique opportunity to evaluate the quality of the current air quality model and would help mission designers to better design future mission.

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1. Introduction

The Community Multiscale Air Quality (CMAQ) model (Byun and Ching, 1999; Byun and Schere, 2006) is a state-of-the-art science atmospheric chemistry model, which has been widely used to study and simulate multi-scale air quality issues. The CMAQ model provides high quality atmospheric chemistry profiles through the utilization of high-resolution meteorology and emissions files. However, it can not simulate air quality accurately if input data are not appropriate and reliable. One of the most important inputs required by CMAQ are lateral boundary conditions (LBCs), which continue to affect model predictions throughout the simulations. Although a nesting technique may be used to reduce uncertainties of boundary conditions in the urban-scale domain, this technique is not applicable for the regional-scale domain or when the in-flux mass of pollutants is not negligible. The current CMAQ model uses a set of constant lateral background condition profiles of the pollutant species, which doesn’t reflect temporal and spatial variations at the boundaries. Therefore it is critical to generate proper model-ready boundary data for model inputs.

The key hypothesis of this study is that such limitations can be improved by the utilization of the NASA’s substantial archives of earth science remote sensing and modeling data products. The Realtime Air Quality Modeling System (RAQMS) (Pierce et al., 2003, 2007, 2009) model with satellite observations assimilated can provide such dynamic lateral boundary conditions for CMAQ. A similar attempt to improve the model by...
linking CMAQ with a different global chemistry transport model (for example, GEOS-Chem) has successfully been demonstrated in studying the impact of trans-boundary transport of carbonaceous aerosols on regional air quality in the United States for a case study of South American wild fires (In et al., 2007). Driving the regional model by time-varied lateral and top boundary conditions from the global models, Tang et al. (2007, 2008) found that the regional model simulations were sensitive to the boundary conditions.

This study aims to improve predictability of CMAQ modeling by means of the lateral boundary conditions generated from RAQMS results. Based on the previous research (Song et al., 2008), we updated the RAQMS—CMAQ linking tool by adding the CMAQ aerosol modules (AERO3 and AERO4) as well as additional gas phase species from RAQMS. We investigated the impacts of the lateral boundary condition on CMAQ simulations, and characterized the model results by comparing with various measurement data. We discussed the improvement of ozone simulation by using the improved dynamic boundary conditions from RAQMS outputs. Three-dimensional features of ozone from the lower troposphere to the upper troposphere/lower stratosphere were demonstrated by comparing CMAQ results with ozonesonde network data. We also compared CMAQ results with Ozone Monitoring Instrument (OMI) satellite measurements to demonstrate the overall CMAQ performance on the horizontal gradient of ozone distributions. Three-dimensional atmospheric chemistry model data generated in this study will be used to support NASA’s intention to produce a high spatial resolution air quality data set, which will help determine or optimize sampling strategies in the Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission’s design.

2. Data and model

2.1. Data

INTEX Ozonesonde Network Study (IONS) 2006 data were used (Thompson et al., 2007, 2008) for the comparison with CMAQ simulations. IONS 2006 data are available at http://croc.gsfc.nasa.gov/intexb/ions06.html. Details for the IONS ozonesonde sites are summarized in the Appendix. IONS balloon-borne ozonesonde data were sampled by electrochemical concentration cell sensors. The accuracy of IONS ozonesonde data is about 10% in the troposphere, and can be degraded to 15% when ozone is lower than 10 ppb (Tang et al., 2008). We also used Level-2 OMI ozone data in this paper. The OMI on the NASA/EOS-Aura satellite provides the capability for the global monitoring of atmospheric ozone columns via nadir-viewing backscattered radiances in the ultraviolet and visible range from 270 to 500 nm (Levett et al., 2006). The spatial resolution for Level-2 OMI ozone is 13 km × 24 km (latitude × longitude). OMI data are available at http://mirador.gsfc.nasa.gov.

2.2. Model

EPA’s Community Multiscale Air Quality (CMAQ) model was used to investigate simulation of ozone in the boundary layer and troposphere. Meteorological fields used to drive the model were from the fifth generation Mesoscale Model (MM5). MM5 was set up as that in Cheng and Byun (2008). The first guess and boundary conditions for the MM5 were taken from the National Center for Environmental Prediction (NCEP)Eta model. MM5 was run at three different domain sizes, 36, 12, and 4 km. Since coarse resolutions could not resolve the cumulus well, a cumulus scheme (Grell) was applied to the coarse spatial resolutions, 36 and 12 km. Medium-range forecast (MRF) planetary boundary Layer (PBL) schemes (Hong and Pan, 1996), Dudhia simple ice microphysical scheme, cloud-radiation scheme, and the Noah land surface model (LSM) were incorporated in the MM5 model (Cheng and Byun, 2008). Three-dimensional wind, temperature, cloud/precipitation, pressure, and hydrological fields from the MM5 were used to drive the CMAQ. A retrospective MM5 meteorological simulation with multi-stage four-dimensional data assimilation approach has already been established for the 2006 TeXaQS-II intensive period. The assimilated meteorological inputs have significantly improved air quality simulations for locations of ozone peak and magnitudes of maximum ozone of the TeXaQS-II period compared to those with the air quality forecasting results (Byun et al., 2008; Ngan et al., 2012).

Emission files were prepared from the Sparse Matrix Operating Kernel for Emissions (SMOKE) model. We used a set of emission input components that were projected for 2006 from the 2000 Texas Commission for Environment Quality (TCEQ) with ethylene imputation. Updated 2006 Texas point-source special inventories were used to generate the “best-effort model ready” (BEMR) emissions. New biogenic emissions for the Houston-Galveston-Brazoria (HGB) 4-km domain were included for the BEMR emission data (Byun et al., 2008). The CMAQ simulation with BEMR emissions reproduced important features of TeXaQS-II air quality measurements (Byun et al., 2008).

Two different lateral boundary conditions (LBCs) were used to force the CMAQ model, which are predefined constant LBCs and RAQMS LBCs. Predefined constant LBCs profiles (Byun and Ching, 1999) were intended to represent relatively clean air conditions in the eastern half of the United States and were formulated from measurements and results obtained from modeling studies. The limitations of predefined constant LBSs mean that they have no horizontal variations across the four boundaries and only range from 30 to 75 ppb through all the layers. Thus, they do not represent any specific time period and any specific location for each lateral boundary. RAQMS model with assimilated satellite observations was also used to provide the dynamic lateral boundary conditions for the CMAQ. RAQMS assimilated trace gas measurements from the OMI and Tropospheric Emission Spectrometer (TES) (Pierce et al., 2009). Meteorological analyses from the NCEP Global Data Assimilation System (GDAS) were used to initialize the RAQMS model (Pierce et al., 2009). RAQMS 6-h outputs were used as the dynamic lateral boundary conditions for the CMAQ model. Chemical and aerosol species in the RAQMS model were mapped for the CB4-AE4 mechanism species and corresponding concentrations were extracted temporally and spatially through interpolations to generate lateral boundary conditions for CMAQ simulations. RAQMS—CMAQ aerosol species mapping table is listed in the Appendix.

MM5, SMOKE, and CMAQ were run from August 30 to September 9 in 2006 with three different spatial resolutions (36, 12, and 4 km). The Conterminous US (CONUS) was applied with 36 km resolution. Texas and its adjacent states were applied with 12 km resolution. The East Texas was applied with 4 km resolution grids. The dynamical boundary conditions were provided by the 36 km resolution CONUS domain CMAQ simulations with background concentrations from RAQMS model in the spatial resolution of 2° × 2.5°. CMAQ was set up with 23 vertical layers. The bottom 12 layers are exactly the same as those in MM5. The lowest level has a thickness of ~34 m. Above 1 km, two or three MM5 layers are collapsed to the MM5 model top at 50 ha using the MM5-CMAQ Interface Processor (Byun and Ching, 1999; Byun et al., 2007).
3. Results

3.1. Comparisons between CMAQ with IONS ozonesonde

Simulations from CMAQ with predefined and RAQMS LBCs were compared with IONS ozonesonde data at 20:00 UTC on August 30, 2006. IONS ozonesonde data were averaged within 17:00–23:00 UTC. Three different vertical layers (22nd, 18th and 14th model layers) were compared between CMAQ and IONS ozonesonde measurements in Fig. 1. At the 22nd model layer (13–17 km; upper troposphere and lower stratosphere), ozone simulations from CMAQ with predefined LBCs are distinctively different from IONS ozonesonides, while ozone simulations from CMAQ from RAQMS LBCs are more close to the IONS ozonesonde. It indicates that the upper troposphere and lower stratosphere are highly influenced by lateral boundary conditions. Maximum value from CMAQ ozone with predefined LBCs is 76 ppb, which is much lower than observations, suggesting the predefined LBCs are not capable of providing sufficient ozone in the upper troposphere and lower stratosphere. CMAQ with RAQMS LBCs well simulates high ozone concentrations at this layer, except under-prediction of ozone over some areas (for example, Trinidad, Narragansett sites).

At the 18th model layer (4.5–6 km; middle troposphere), two CMAQ results are different, indicating that middle troposphere is moderately influenced by lateral boundary conditions. CMAQ ozone with predefined LBCs has widespread areas of elevated ozone in the domain, and CMAQ with RAQMS LBCs shows some well defined areas with maximum ozone values in the northwestern, central, and northeastern part of domain. At the 14th model layer (1.4–1.9 km; lower troposphere), two CMAQ results are very similar, indicating that lower troposphere is slightly influenced by lateral boundary conditions. Both CMAQ simulated ozone concentration ranges are 20–70 ppb with slightly different spatial distributions, while the observation range is 26–66 ppb. These results show that CMAQ ozone predictions are influenced by LBCs, significantly at upper troposphere and lower stratosphere, moderately at middle troposphere, and slightly at lower troposphere. This is because the stratosphere–troposphere exchange is hard to simulate in the model, correct LBCs will help the ozone
prediction in the upper troposphere and lower stratosphere. Stronger influences are found in the regions with high latitude and high surface elevations. It should also be noted that general vertical ozone structures are simulated by CMAQ with RAQMS LBCs reasonably well.

To better investigate ozone vertical profiles simulated by the CMAQ, six IONS sites were selected by their locations: Kelowna and Trinidad for the western part; Brattslake and Houston for the central part; and Yarmouth and Wallops for the eastern part of model domain. CMAQ simulated ozone profiles on August 30 were compared with IONS 2006 ozonesonde measurements in Fig. 2. Comparisons between MM5 simulated and ozonesonde observed temperature profiles were also presented in Fig. 2. Model predicted temperatures are in good agreement with observations at all sites, with the exception of the slight under-prediction of model temperature below 8 km at the Kelowna site.

Fig. 2. Comparisons between CMAQ simulated ozone profiles with IONS ozonesonde measurements at Kelowna, Trinidad, Brattslake, Houston, Yarmouth and Wallops on August 30. Black solid line is the ozonesonde data. Purple and blue lines are the ozone concentration from CMAQ with predefined and RAQMS LBCs, respectively. Black dashed and red lines are the observed and simulated temperature profiles, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
It is clearly shown that the vertical variation of observed ozone concentrations from the surface to top layer (~20 km) is over 400 ppb. The vertical variations in the predefined LBC are less than 50 ppb with almost no variations above the middle troposphere (5 km). Because CMAQ assumes zero-flux top (upper) boundary conditions, the predefined constant LBCs with 75 ppb ozone concentration at the top can not sufficiently provide ozone at this altitude. Compared to the predefined constant LBCs, CMAQ simulated ozone with RAQMS LBCs successfully represents observed ozone concentrations, especially in the upper troposphere and lower stratosphere as shown in Fig. 2. It is also shown that the coarse vertical resolution of CMAQ in the upper troposphere limits the CMAQ ozone predictability as seen in Yarmouth and Wallops sites. Large differences between the CMAQ simulation with the observed ozone in the model top layers are present, when the CMAQ predicted ozone, influenced by RAQMS LBCs in the top layers, is not able to resolve ozone gradient between upper troposphere and lower stratosphere. These results show that RAQMS LBC, with satellite ozone assimilation, can capture the general ozone profiles measured by ozonesondes.

3.2. Comparisons between CMAQ with OMI satellite measurements

Since satellite observations provide vertically integrated data of air pollutants and have large spatial coverage with reliable repeated measurement, they are suited for studying the horizontal gradients of the pollutants. In order to verify and characterize the model results, we compared CMAQ simulated ozone with OMI Level-2 Total Column Ozone (TCO) data from Aura satellite.

The 13 × 24 km tessellation OMI Level-2 data in latitude/longitude coordinates are mapped to the CMAQ grid on a Lambert Conformal projection by the ‘drop-in-grid’ method. The OMI pixels are assigned to the CMAQ grid if the central point fell within the CMAQ grid cell, and if multiple OMI pixels are present in a single CMAQ grid, they are averaged. We calculated column density (molecules cm⁻²) of ozone from CMAQ outputs for the comparison.

The column density can be obtained as:

\[
\text{Column density} = \frac{\sum_{i=1}^{N} \left( C_i \times Z_i \times \text{DENS}_A \times \text{AVGR} \right)}{\text{MWAIR} \times 10^7}
\]

where \(N\) is the CMAQ layer number, \(C_i\) is the concentration of each grid cells in layer \(i\) (ppm), \(Z_i\) is the layer thickness of each grid cells (m), \(\text{DENS}_A\) is air density of each grid cells (kg m⁻³), \(\text{AVGR}\) is the Avogadro’s number \((6.02214 \times 10^{23}\) molecules mol⁻¹), \(\text{MWAIR}\) is the molecular weight of air \((28.97\) g mol⁻¹), and \(10^7\) is the unit conversion factor. For the TCO in Dobson units, ozone column density values are divided by \(1\) DU \((= 2.68676 \times 10^{16}\) ozone molecules cm⁻²). All model layers (CMAQ top layer height is about 20 km AGL) are used for the TCO calculation. The model output of full-layer height above ground \((ZF)\) is used to calculate the layer thickness of each grid cell.

Spatial distribution of TCO from OMI and the two CMAQ results are presented in Fig. 3. The OMI TCO including stratospheric ozone shows higher values in the northern region (higher latitude) and lower values in the southern region (lower latitude) with a range of 280–320 DU due to Brewer-Dobson circulation (Seinfeld and Pandis, 2006). Because the amounts of stratospheric ozone are higher than those of tropospheric ozone, spatial characteristics of ozone related to surface or near-surface air pollutants are not shown in OMI TCO. The two CMAQ TCO integrated from surface to model top layer are substantially different from the OMI TCO. Although CMAQ with RAQMS could capture general patterns of spatial distribution of TCO similar to OMI TCO (high at higher latitudes, low at lower latitudes), both TCO distributions from CMAQ with predefined and RAQMS LBCs are much lower than those from OMI TCO, as expected, because

\[\text{Fig. 3. Spatial distribution of total column ozone (TCO) from OMI (top) and CMAQ results simulated with Predefined (bottom-left) and RAQMS (bottom-right) LBCs. CMAQ grid-mapped OMI TCO are averaged for whole modeling period (August 23–September 9, 2006) and corresponding CMAQ results of 15–23 h are averaged for the same period. Note that the color code scales for OMI and CMAQ are different (OMI = 0–500 DU, CMAQ = 0–170 DU). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)}\]
the amounts of stratospheric ozone are not taken into account in the CMAQ TCO.

There is no doubt that the amounts of stratospheric ozone have dominant impacts on TCO, thus we further compared the Tropospheric Column Ozone (TropCO) estimated from the OMI and CMAQ to characterize the spatial distributions of ozone in the troposphere. Similar to the tropospheric ozone residual method (Fishman and Larsen, 1987), the OMI TropCO is derived by subtracting concurrent RAQMS Stratospheric Column Ozone (SCO) from TCO measured by the OMI instrument (OMI TropCO = OMI TCO – RAQMS SCO). The RAQMS ozone data in latitude/longitude coordinates with 2° × 2° horizontal resolutions are mapped to the CMAQ grid using the ‘nearest neighbor’ method and RAQMS SCO is estimated by integrating ozone from the tropopause to the model top layer. The CMAQ TropCO is estimated by integrating ozone from the surface to the tropopause for the comparison. Both RAQMS SCO and CMAQ TropCO are vertically interpolated utilizing the pressure gradients. Because determining tropopause is of utmost importance in estimating SCO from RAQMS as well as TropCO from CMAQ, we utilized the tropopause pressure data provided by NCEP. NCEP daily global tropopause pressure data in latitude/longitude coordinates with 2.5° × 2.5° horizontal resolutions are mapped to the CMAQ grid using the ‘nearest neighbor’ method and averaged for August 23–September 9, 2006 as presented in Fig. 4(a). Since the tropopause is highly dependent on latitudes, tropopause pressure shows a strong latitudinal gradient increasing from 110 to 240 hPa toward high latitudes. Due to topographical differences, higher tropopause pressure (lower tropopause) over the mountainous regions (for example, Rocky Mountain in the western USA) at the same latitude is shown as well since the lower the surface temperature, the lower the tropopause is.

The TropCO is contributed by the combination of ozone concentration in the lower and upper troposphere. The ozone concentration is highly dependent on precursor concentrations such as NOx and VOCs because ozone is a secondary pollutant. The lower tropospheric ozone production is attributed mostly to surface emissions (for example, power plants, vehicles, and petrochemical industries) and upper tropospheric ozone production is related to lightning NOx, transport from upwind regions, and intrusion from the stratosphere. Spatial distribution of TropCO from OMI and two CMAQ results are depicted in Fig. 4. The OMI TropCO shows high ozone values of 60–70 DU in the eastern USA where large emission sources of industries (power plants) and urban areas (automobiles) are located. The low ozone values of 44–54 DU are seen by the OMI TropCO in the western USA, except for the west coastal area in California where the vehicles are the primary sources for the ozone formation. Although the spatial patterns in the two CMAQ-derived TropCO are somewhat similar (high in eastern, low in

![Fig. 4](image-url)
western USA), the two CMAQ TropCO are significantly different. The CMAQ with predefined LBCs cannot reproduce ozone over 45 DU, resulting in a low regression slope (0.33) and low correlation coefficient (0.55) as presented in Fig. 5. However, CMAQ with RAQMS LBCs can capture most of the observed characteristics of TropCO derived from the OMI. Some of these characteristics include high TropCO in the eastern USA, high TropCO in the west coast in California, and low TropCO in the western USA including over the mountain area. However, the high OMI TropCO near the northeastern boundary is not captured by CMAQ with RAQMS LBCs. This is possibly due to the emission uncertainties in Canada, especially in the Ottawa, Montreal and Quebec areas.

Although CMAQ with RAQMS LBCs can capture most of the observed features of OMI TropCO qualitatively, the CMAQ TropCO values are consistently lower than the observed values by 15 to 20 DU over the entire model domain. This is possibly due to the coarse vertical resolutions of CMAQ in the upper layers (for example, the thickness of 22nd model layer is about 4 km (13–17 km)), which can not resolve the ozone gradient between the upper troposphere and lower stratosphere. This might also be related to the RAQMS ozone biases. As revealed in Pierce et al. (2007), the mean high biases in the RAQMS ozone is up to 20% in the lower stratosphere. This can contribute to the difference between the OMI and model TropCO. In the meanwhile, the biases in the OMI O3 data can also contribute to the difference between the OMI and model TropCO. The scatter diagram in Fig. 5 supports the fact that the characteristics seen in OMI TropCO are well simulated in the CMAQ with RAQMS LBCs with consistent bias of −15 DU. Note that the correlation coefficient from the CMAQ with RAQMS LBCs is improved from 0.55 to 0.81.

**4. Conclusions**

Utilizing the updated RAQMS–CMAQ linking tool for the regional scale air quality simulations, lateral boundary conditions were generated from the results of global model RAQMS with satellite data assimilations. CMAQ simulations were conducted with RAQMS LBCs and predefined LBCs. Ozone simulations from CMAQ were compared with IONS ozonesonde and OMI tropospheric column ozone data. It was found that the impacts of LBCs on CMAQ ozone simulations are significant in the upper troposphere, moderate in the middle troposphere, and small in the lower troposphere. The overall performance of CMAQ ozone at surface and upper troposphere are improved with the LBCs from RAQMS model. This study demonstrates the need to use proper LBCs, such as those provided by satellite-data assimilations RAQMS output, to reproduce the general vertical ozone structure measured by ozonesondes.

CMAQ simulated ozone was compared with CMAQ grid-mapped OMI TropCO data. The OMI TropCO shows high ozone values of 60–70 DU in the eastern USA and low ozone values of 44–54 DU in the western USA, except for the west coastal area in California. The CMAQ with predefined LBCs cannot reproduce ozone over 45 DU, resulting in a low correlation coefficient (0.55), while CMAQ with RAQMS LBCs can capture most of the observed characteristics of TropCO derived from the OMI including high TropCO in the eastern USA, high TropCO on the west coast in California, and low TropCO in the western USA, resulting in an improvement of the correlation coefficient from 0.55 to 0.81.

We verified and characterized the CMAQ results by comparing with various measurements data, and showed the benefits of using fully assimilated RAQMS LBCs to improve regional air quality simulations of ozone and aerosols. These CMAQ 36 km domain results can be nested down to 12–4 km domain simulations to generate high spatial resolution atmospheric chemistry model data. This analysis will be useful to evaluate capability of the current meteorological and air quality models to represent the fast-changing phenomena observed during the experiments. It is also helpful for mission designers to better design the mission.

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Appendix

Appendix 2. List of IONS 2006 ozonesonde sites used for the comparison.

<table>
<thead>
<tr>
<th>Site name</th>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m)</th>
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Appendix 3. RAQMS—CMAQ aerosol species mapping table.

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<th>CMAQ aerosol species</th>
<th>RAQMS—CMAQ species map</th>
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<td>ANH4J</td>
<td>ACCM ammonium mass</td>
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<td>ANO3J</td>
<td>ACCM nitrate mass</td>
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<td>AORGAJ</td>
<td>ACCM anthropogenic</td>
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<td>AORGPAJ</td>
<td>secondary organic mass</td>
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<td>AORPC</td>
<td>organic mass</td>
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<tr>
<td>AECJ</td>
<td>ACCM elemental carbon</td>
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<tr>
<td>A25J</td>
<td>unspecified anthropogenic mass</td>
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<tr>
<td>ACORS</td>
<td>COSM unspecified</td>
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<tr>
<td></td>
<td>anthropogenic mass</td>
</tr>
</tbody>
</table>

ACCM: Accumulation mode.
COSM: Coarse mode.

Gas-phase species map addition

<table>
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<th>CMAQ</th>
<th>RAQMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO2</td>
<td>iso2</td>
</tr>
<tr>
<td>NH3</td>
<td>inh3</td>
</tr>
</tbody>
</table>

Species mapping table for the CB4-AE3 and CB4-AE4 mechanisms is used to convert RAQMS species into CMAQ species. Some species with the same chemical definitions in RAQMS and CMAQ are converted directly, but others are mapped by partitioning and/or regrouping species. The RAQMS—CMAQ aerosol species mapping table for AERO3 and AERO4 is summarized in the above table. Dusts in the RAQMS are separated by their size distribution and are redistributed by the CMAQ size definition. Sea salts in RAQMS are also separated by their size distribution and speciated into Na and Cl with a typical ratio of sea salt composition (Seinfeld and Pandis, 2006).

References


