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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Aerosol indirect effect on the grid-scale clouds in the two-way coupled WRF-CMAQ: model description, development, evaluation and regional analysis" *by* S. Yu et al.

Anonymous Referee #3

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General Comments

This paper describes a new, coupled meteorology and chemistry model system that is based on WRF and CMAQ and its initial application over the continental US at a 12-km grid resolution and eastern Texas at a 4-km resolution during August and September of 2006. Different from some online-coupled models that integrate meteorology and chemistry into one model system such as WRF/Chem, WRF and CMAQ are coupled via a coupler with 2-way meteorological and chemical data exchange but one single executable program. The two-way coupled WRF-CMAQ accounts for both direct and indirect aerosol effects, in particular, the first, second and glaciation aerosol indirect

effects. It treats both cloud droplet and ice number concentrations as prognostic variables that depend on aerosol predictions of CMAQ and meteorological predictions of WRF. Developed and supported by the U.S. EPA, CMAQ has been widely applied and extensively evaluated for both scientific and regulatory applications worldwide since its first release in late 1990s'. Inclusion of indirect aerosol effect treatments in CMAQ represents a significant advancement and milestone in air quality modeling in terms of scientific understanding of the complex relationship between air pollutants and climate change and the development of integrated win-win emission control strategies for air quality management and climate change mitigation. The paper represents the first documentation of the two-way coupled WRF-CMAQ with aerosol indirect effect and the first comprehensive evaluation of its capability in reproducing shortwave cloud forcing and other cloud properties. The model development and evaluation involve substantial efforts that should be recognized in both air quality and climate communities. The results demonstrated the scientific merits to treat aerosol indirect effects in air quality models. I therefore strongly support its publication on ACP. The paper is overall well written and organized. The literature review section is quite comprehensive. The method for model development and evaluation is technically sounds. It can be accepted with minor revisions. The paper would be strengthened by incorporating the following points:

1) The significance and policy implications of the two-way coupled WRF-CMAQ should be pointed out in the abstract and conclusion sections.

2) Scientific objectives should be stated clearly and explicitly in the Introduction section.

3) In the simulation design section (Section 2), the reasons and purposes for the four simulations, WRF/CAM, WRF/RRTMG, WRF-Chem/CAM, and WRF-Chem/RRTMG should be provided.

4) In Section 3, the evaluation protocol for model performance (e.g., variables selected for model evaluation, criteria/threshold values to judge model performance, time period for simulated cloud data processing against satellite data) should be described.

5) In Section 4, the coupled model underpredicts some aerosol species (e.g., NH4+, SO42-) but overpredicts the other species (e.g., OC and EC). Please discuss the impacts of such biases on the accuracy in the aerosol indirect effect predictions. In section 4.3, some discussions should be added regarding how will the inclusion of aerosol indirect effects improve precipitation.

6) The paper is a bit too long, and can be shortened. Some tables (e.g., Tables 2, 3, 4, 7, and 8, Figures 4, 8, 12, 16, 18, 21, 23) can be moved to supplementary material. The conclusion section can also be shortened a bit to avoid repetition of results that are already discussed in previous sections.

Specific Comments

(1) Page 25651, line 8, change "CASTNet" to "CASTNET", please make the same change throughout the paper text, tables and figures.

(2) Page 25651, lines 16-17, change "Both models" to "Both simulations", as you are using one model system with two different configurations, so you refer to two simulations, not two models.

(3) Page 25654, lines 25-29, the resulting coupled met and AQ models using the first and second approaches should be the same, as they are integrated model systems, which is different from the coupled model using the 3rd approach. This should be indicated clearly.

(4) Page 25656, lines 1-2, to avoid using two "used" in one sentence, please change "The RRTMG and CAM radiation schemes are used because these two schemes are used in many studies." to "The RRTMG and CAM radiation schemes are selected because these two schemes are used in many studies."

(5) Page 25656, line 8, change "observation" to "observational"

(6) Page 25656, please describe the scientific objectives of your work before section 2. Also, in section 2.1, please describe why Aug-Oct 2006 was selected.

(7) Page 26659, line 12, change "Note that "OTHR" specie" to "Note that "OTHR" species"

(8) Page 25660, line 4, change "using a aerosol activation scheme for multiple externally mixed lognormal modes" to "using an aerosol activation scheme for multiple externally-mixed lognormal modes"

(9) Page 25659, line 18, change "Yu et al., 2007a, b, 2004, 2005, 2008" to "Yu et al., 2004, 2005, 2007a, b, 2008"

(10) Page 25660, lines 6, 7, 13, 16, change "Abdul-Razzak and Ghan (2002, 2000)" to "Abdul-Razzak and Ghan (2000, 2002), as the citation order should be chronologically. Lines 16-17, change "(Abdul-Razzak and Ghan, 2002, 2000; Abdul-Razzak et al., 1998)" to "(Abdul-Razzak et al., 1998; Abdul-Razzak and Ghan, 2000, 2002)"

(11) Page 25661, line 2, change "Where" to "where"

(12) Page 25661, line 8, change "Here" to "here"

(13) Page 25662, line 2, change "Hanel" to "Hänel"

(14) Page 25662, line 9, change "from the different investigators." To "from different investigators."

(15) Page 25663, lines 3, 14, 20, change "Abdul-Razzak and Ghan, 2002, 2000" to "Abdul-Razzak and Ghan, 2000, 2002"

(16) Page 25663, change "scheme for treatment of cloud droplet nucleation and vertical diffusion of cloud droplets simultaneously" to "scheme for simultaneous treatment of cloud droplet nucleation and vertical diffusion of cloud droplets"

(17) Page 25664, line 1, change "Morrison et al.," to "Morrison et al."

(18) Page 25664, line 15, change "study to avoid to double accounting" to "study to avoid double-accounting"

(19) Page 25664, line 16, change “the effective radius; Slingo (1990)” to “the effective radius. Slingo (1990)”. (note that this sentence should be split into two sentences).

(20) Page 25666, line 16, change “Where” to “where”

(21) Page 25667, line 12, change “cloud microphysics scheme which is based on the approach of Meyers et al. (1992) is” to “cloud microphysics scheme, which is based on the approach of Meyers et al. (1992), is” to increase readability.

(22) Page 25667, line 14, change “allow estimation” to “allow an estimation”.

(23) Page 25667, line 23, change “Where” to “where”

(24) Page 25668, section 3, change the subtitle from “Observational data sets” to “Observational data sets and evaluation protocol”

In addition to the description of obs data, please describe your evaluation protocol, e.g., what statistics matrix did you use to evaluate the results, and what criteria/threshold values did you use to determine good vs. poor model performance.

(25) Page 25669, line 9, change “clouds and the aerosols” to “clouds and aerosols”

(26) Page 25669, section 3.2, what is the time resolution/overpassing time of the CERES data? Is it once per day? If so, is a consistent time period (i.e., during the satellite overpassing time) used to compare model predictions with the CERES data?

(27) Page 25670, section 4.1.1, since the focus of this paper is aerosol and its indirect effect, suggest to move Table 4 and most discussions on O3 to supplementary material.

(28) Page 25670, move lines 4-11, “To evaluation. . .. PM2.5 observations.” To section 3 after description of surface and satellite data.

(29) Page 25670, lines 11-12, why August and September 2006 were chosen? Some justifications for this selection should be provided in section 2.

(30) Page 25670, lines 14 and 21, change “both models” to “both simulations”

(31) Page 25670, line 20, change “indicating the overestimation” to “indicating that the overestimation”

(32) Page 25671, line 8, change “both models” to “both simulations”

(33) Page 25672, lines 6, 8, and 18, change “both models” to “both simulations”

(34) Page 25672, line 9, change “with the NMB $< \pm 6$ %” to “with NMBs within ± 6 %.”

(35) Page 25672, line 18, change “with the NMB $< \pm 7$ %” to “with NMBs within ± 7 %.”

(36) Page 25673, lines 3, 12, 24, 25, change “both models” to “both simulations”

(37) Page 25673, line 5, change “As pointed by” to “As pointed out by”

(38) Page 25673, line 25, change “with the NMB < 15%” to “with NMBs < 15%”

(39) Page 25674, line 1, change “with NMB< 6 %.” to “with NMBs < 6 %”.

(40) Page 25674, lines 2-3, “gaseous SO2 concentrations were not oxidized enough to produce aerosol SO42- in the models over the WUS.” Is this due to uncertainties in gas-phase chemistry or the aqueous-phase chemistry? Please elaborate likely causes for the insufficient oxidation.

(41) Page 25674, lines 6-7, “This indicates too low NOx emissions in the emission inventory over the WUS.” Is this statement supported by references or analyses in this work? Please provide relevant references or justifications.

(42) Page 25674, lines 13, 23, 25, 26-27, 29, change “both models” to “both simulations”

(43) Page 25674, line 14, change “the NMB < 20%” to “NMBs < 20%”

(44) Page 25674, line 15, change “NMB $< -11\%$” to “absolute NMBs within 11%”

Note that since NMB is negative, only an absolute value of NMB that is < 11% can be considered a good performance, for larger absolute values such as 30%, even through

it satisfies “-30% < −11%, it actually means poorer performance, instead of better performance.

(45) Page 25675, lines 1, change “both models” to “both simulations”

(46) Page 25676, the two simulations with met only, WRF/CAM and WRF/RRTMG should be mentioned in the simulation design section. The reasons and purposes for those met only runs should be provided.

(47) Page 25676, lines 9, 13, change “wattsm−2” to “W m−2”

(48) Page 25676, lines 19-22, please explain why the WRF-CMAQ/CAM produced more cloud than the WRFCMAQ/RRTMG over the CONUS.

(49) Page 25677, line 20, change “CMAQ/CAM, WRF-CMAQ/RRTMG” to “CMAQ/CAM and WRF-CMAQ/RRTMG”

(50) Page 25678, line 4, change “the slightly overestimations” to “the slight overestimations”

(51) Page 25678, line 8, change “WRF-CMAQ/CAM, WRF-CMAQ/RRTMG” to ‘WRF-CMAQ/CAM and WRF-CMAQ/RRTMG”

(52) Pagte 25678, line 19, change “shows that” to “show that”

(53) Page 25678, lines 22, 26, change “both models” to “both simulations”

(54) Page 25679, line 24, change “generally underestimations” to “general underestimations”

(55) Page 25680, line 20, change “All models” to “All simulations”

(56) Page 25681, line 8, change “Figure 24 and Table 12 indicates” to “Figure 24 and Table 12 indicate”

(57) Page 25681, line 23, change “these cells” to “these grid cells”

(58) Page 25682, line 12, change “a uniform internal mixtures” to “ uniform internal mixtures”

(59) Page 25682, line 13, change “Abdul-Razzak and Ghan (2002, 2000)” to “Abdul-Razzak and Ghan (2000, 2002)”

(60) Page 25682, lines 7-11, what are the likely reasons for those overestimations?

(61) Page 25683, line 29, Page 25684, lines 6, 11, change “both models” to “both simulations”

(62) Page 25684, line 15, change “have significant” to “show significant”

(63) Page 25688, line 28, change “Hanel” to “Hänel” , line 29, “ityat” should be “ity at”

(64) Page 25700, please add a column (column 2) to explain the full name of each species

(65) Page 25704, for a fair comparison, the statistics from 12-km and 4-km simulation should be calculated using observations in the 4-km domain. Was this done for Table 6? If so, please add this in the evaluation protocol section.

(66) Page 25714, figure 2. Please use the same color for the parentheses for “Interaction and feedback”

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