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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Sensitivity of aerosol optical thickness and aerosol direct radiative effect to relative humidity" *by* H. Bian et al.

H. Bian et al.

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We would like to thank Christiana Textor for her positive remarks, constructive comments, and valuable suggestions, which are highly appreciated and will be taken into account upon revision of our manuscript. In particular we added some statements as recommended and listed below. Page and line numbers refer to the paper published in Atmos. Chem. Phys. Discuss. 8, 13233-13263, 2008 unless they are specified otherwise.

General Comments

The paper shows the effects of better resolving the variations in RH on the AOT and the DRE. The subject is very timely and highly interesting, the manuscript is suitable for publication. However, I would suggest to extend the analysis somewhat and to improve

the explanations. For example, the effects of aerosol composition should be explored. Please find more specific comments below.

Reply: The effects of aerosol composition on the relationship between the variation of RH horizontal resolution and the variation of AOT and DRE have been explored over various regions dominated by aerosols with different hygroscopic properties. For example, we found that the highest AOT/DRE difference generally occurs over regions with high industrial pollutants (P13240 L16-17, P13245 L18-21, P13246 L24-25). The oceans, where were dominated by sea salt particles, also have high AOT/DRE differences (P13241 P6-8, P13245 L1-6, P13246 L24-25), but less than that due to industrial pollutants (P13245 L18-21). The dust dominated regions showed the smallest AOT/DRE change (P13241 L25-26, P13242 L21-26, P13246 L15-17). To further explain the effects of aerosol composition, we changed the figure 9 which now shows the RH distributions, the aerosol masses and compositions over 2 oceanic sites. The discussions of how the aerosol compositions over the two sites impact on the AOT calculations at various RH distributions were given in the section 3.4.

Specific Comments

(1). Abstract: The comment on the AeroCom should be rephrased as this model intercomparison highlights the differences between models including their very different resolutions and the effects of such differences. One of the major outcomes of the AeroCom initiative is exactly that model results should be taken with caution. The present study is a very valuable addition to AeroCom as it emphasizes again how uncertain the results from aerosol simulations still are.

Reply: The relevant sentence in the abstract has been modified: Our study is a specific example of the uncertainty in model results highlighted by multi-model comparisons such as AeroCom, and points out one of the many inter-model differences that can contribute to the overall spread among models.

(2). Introduction: The sentence on the relevance of this work to AeroCom confirms

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what I said above.

(3). P 13235, l 8: AeroCom showed differences of MEE among models of a factor of 2, see aerocom web site.

Reply: Differences of MEE among models may be due to many reasons. Our paper only addresses the influence of change of RH resolution on MEE.

(4). P 13235 , l 20: *This study helps us to estimate the extent to which the AOT diversities in the AeroCom models may be caused just by different model resolutions*. How do you want to seperate this effect that you investigate from others you do not consider (e.g. composition, transport in the different models), and how can you know that other models react in the same way to the modifications?

Reply: We agree that our statement is too strong. We deleted it in our revised version.

(5). P 13236, l 24: Another model environment would react differently to the same meteorological fields. Please add a remark that the host model in which a specific aerosol module is embedded also effects the RH fields and thus the aerosol properties.

Reply: True. We added the remark in the conclusion (revised version paragraph 2 last 3 lines).

(6). P 13238, l 1: *The size distribution and the hygroscopic growth factors for internally mixed fossil fuel and biomass burning particles, as well as for natural sulfate and organic matter, are described in Liu et al. (2007)*. This parameterization will determine the sensitivity of your model to RH and should briefly be summarized here.

Reply: Thanks. The aerosol size distributions and the hygroscopic growth factors have been described in the section 2.1.

(7). P 13238, radiative transfer model: Please explain briefly the relation between MEE, AOT, DRE and the link to RH.

Reply: Mie theory is used to provide MEE based on the aerosol properties such as

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the size distributions, complex refractive indices, and hygroscopic growths [P13237 L21-26]. RH, through altering aerosol hygroscopic growths, influence on aerosol MEE [Figure 1]. MEE multiplied with aerosol dry mass determines AOT (P13235, L9-14, also see Figure 1). Aerosol DRE was defined in P13244 L5-9. Three aerosol optical properties (AOT, single scattering albedo, and asymmetry factor) calculated from aerosol model were used in our radiative transfer model to obtain aerosol DRE [P 13237 L17-19].

(8). Table 1: Please exchange *spatial* with *horizontal* resolution, since you do not modify the vertical resolution.

Reply: Done.

(9). Table 1: I I would suggest to add a run with fine horizontal resolution and 6 hours RH update, and also run with maybe 1.5 hours temporal resolution and a factor of 2 coarser horizontal resolution. This way one would better understand if the observed effects are of systematic nature.

Reply: We do not think that it is necessary to have an extra run in order to get the conclusion that the observed effects (i.e. the AOT is always enhanced when the RH horizontal/temperal resolution is increased) are of systematic nature. This conclusion is solid and is backed up by the fact that there exists a non-liner relationship between AOT and RH. Let us look at a general case from the numerical approach. Choose two points on the x-y domain with the y-axis as AOT and the x-axis as RH. Draw a straight line and an exponential (in y-axis) curve respectively between the two points. The straight line has a linear relationship between y-value change (dy) and x-value change (dx). In other words, for a given dx, dy is always the same. However, for the exponential curve, dy will grow larger at any given dx as x-value increases. This feature results in a distribution where the exponential curve must be positioned under the straight line. As a consequence, for any give x, the corresponding y-value on the straight line is inevitably higher than the y-value on the exponential curve. Above

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Interactive Comment

explanation is briefly summarized in section 3.2 second paragraph.

(10). P 13239, l 17 *Overall, the GMI captures the main features of the observed AOT*. Very optimistic statement. Please add at least *apart from the Americas*.

Reply: Done.

(11). Figure 2: Have the model results been filtered for the presence of satellite data? You could give the correlation and biais for MODIS and MISR at each grid point vs the model (this might require interpolation to the same grid resolution), as you did for AERONET.

Reply: We did not post such a filter for the model data shown in Figure 2 (We added this statement in the caption of the Figure 2). We agree that such a filter makes the comparison more reasonable. Since such a filter requires tremendous work in reprocessing model data constrained by satellite data at every time step and since the purpose of this paper is not a model evaluation, we simply compared the non-filtered monthly mean model data with the monthly mean satellite data. According to the reviewer’s suggestion, we explored the correlation, bias, and root mean square between model simulation and MODIS and MISR at each grid point when satellite monthly mean value existed. The statistical analyses were conducted over various scales (global, land, and ocean) [Table 2 in the revised version].

(12). Figure 3: Is the correlation line forced to go through 0, i.e. model=B*Aeronet + A with A=0 ? Please add in the figure caption the temporal resolution of the data (monthly average at XX AEERONET stations?)

Reply: The line shown in Figure 3 upper panel describes the best case that model and measured AOTs could be matched. The line was drawn to help readers to identify the bias between model and AERONET AOTs easier. The figure caption has been modified as suggested by reviewer.

(13). Figure 4: Please show also the maps of RH in the different resolutions, are they

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very different? This would show the locations with strong RH gradients and changes, and also the higher values in the higher resolutions. It would also be interesting to have a map indicating spatial distribution of hygroscopic aerosol, for example a map of the growth factors at a given RH. Please add such a map and discussion on the composition effects.

Reply: We showed RH at 930 mb for the base run (Figure 8) to give general information of how RH was distributed. However, the RHs at the other resolutions were not shown out because the difference in RHs is hard to be discerned. This is because all RHs stemmed from the same underlying GCM, i.e. their averaged RHs are the same at each grid box (or time period) at the lower resolution. We had shown the effect of growth factors of hygroscopic aerosols (sea salt and fossil fuel) on MEE (and AOT) in Figure 1. We changed the figure 9 in assisting a discussion of the aerosol composition effects over two ocean sites in section 3.4 (also see reply for the general comment). We feel our current discussion is sufficient to address the issue of composition effects.

(14). P 13240 l 22: *A feature revealed in the figure is that the AOT is always enhanced when the RH horizontal resolution is increased*. I assume that you mean that larger values of RH occur in the runs with high resolution because the sub-grid behaviour is captured? Please improve clarity of explanation.

Reply: As we pointed out in the above answer, the averaged RH at the higher resolution is the same as that in the low resolution at each of its grid boxes. It is the non-linear relationship between AOT and RH which makes the AOT change when RH resolution changes (see reply to specific comment 9 above). Please also see the explanation of the non-linear AOT-RH relationship in section 3.2 second paragraph.

(15). Figure 5: Caption: vertical bars: standard deviation, range? *seasonal variations*: what is the temporal resolution of the data on which these bars are based?

Reply: The vertical bars represent the seasonal variations, i.e. the range of maximum to minimum monthly AOT change during the year 2001 (also refer to P13241 L1-3). The

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temporal resolution of the data based on was 3 hours (please see the figure’s title).

(16). Figure 6: Please use the same color scale as in figure 4. It would be interesting to see where the RH changes are larges. This would explain for example the change in AOT over the SH storm tracks in response to the change in the temporal resolution but not to that in the spatial resolution is a direct consequence of the spatial distribution of RH changes. Please show 3 additional figures with the RH in the different runs (the fine resolution run on the coarse grid).

Reply: It would be nice to show Figure 6 with the same color scale as used in Figure 4. However, such plotting makes the change of AOT in Figure 6, particularly for the AOT relative change, hard to identify. As we explained above (specific comment 9), the additional runs may not add much new information to the issue addressed in the paper.

(17). Figure 7, p 13242, I do not understand where you discoverd the seasonal pattern, please explain.

Reply: Similar to Figure 5, the vertical bars in Figure 7 represent the seasonal variations, i.e. the range of maximum to minimum monthly AOT change during the year 2001. We further pointed out the seasonal pattern in the paper based on our calculation (P13242, L7-11].

(18). Figure 8: for the BASE run?

Reply: Yes.

(19). Figure 9: I do not think that these figures are best suitable to show the effect of different RH*AOT regimes that are linked to figure 1. (But I cannot suggest a better one ad hoc.)

Reply: We made a substantial change for Figure 9 and for the section 3.4 by focusing on the two oceanic sites to give a detailed analysis of how RH magnitude and variation, constrained by the aerosol components, play in the AOT change with the RH resolution

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change.

(20). P 13243, l 9: *comparable absolute AOT differences* differences in which of your runs BASE*CTRT?

Reply: *comparable absolute AOT differences* (P13242 L9) was consistent to what was shown on the run BASE*CTRT (i.e. Figure 4 upper panel).

(21). P 13243, l 15: *These opposite effects compensate each other; ultimately their overall impact on the simulated AOT at the two sites is very similar*. I do not agree with the wording. This is not a compensation effect, you are in different RH-regimes with different AOT sensitivity. In A, small variations in RH have a large effect on AOT as RH is already high. In B, RH is lower, but Delta-RH is larger, this leads to a similar impact on AOT.

Reply: Thanks. This section (section 3.4) has been changed substantially. Please also refer to question 19.

(22). P 13245, l 15 *Nevertheless, the change is systematic: the higher the resolution, the higher the TOA DRE*. This sentence does not correspond to table 2, the unit of the change is different: The DRE for the CTRT runs is always less negative than in the BASE case, where as the CTRH runs show increased negative DRE. Units should be added to the percentage changes. How do you explain this behavior?

Reply: The sentence was at P13245 L 25. Aerosol TOA DREs, calculated with downward irradiance minus upward irradiance, are negative in Table 2. This means that aerosol has an atmospheric cooling effect. In table 2, we observed that the higher the resolution, the more negative the TOA DRE (i.e. the larger the aerosol cooling effect). The unit of the table 2 is right. The sentence has been rephrased.

(23). P 13245, l 18 *These changes are larger than those contributed from all aerosols even over oceans*. Do not understand what is meant here.

Reply: *These changes* were contributed only from anthropogenic aerosols. What

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we want to point out here is that the effect of anthropogenic aerosols on atmospheric cooling is even larger than that of sea salt. We clarified the sentence.

(24). Conclusions: DRE is less negative for increase of temporal resolution, it is by 9% more negative for + spatial res. but by 3% less negative for + temporal res. Or do I miss something substantial here?

Reply: The sentence has been modified as: Correspondingly, the aerosol cooling effect (i.e. the magnitude of the negative value of TOA DRE) increases by 9% and 3% for a use of the higher spatial and temporal resolution respectively.

(25). P 13246, l 10 Comment on AeroCom model diversity: our analysis did not show a systematic model behavior*performance dependent on the resolution.

Reply: We did not state that the 24% diversity among the AOT annual global means shown in AeroCom inter-model comparison has a systematic relationship to the model resolution, nor the diversity is caused by the resolution issue only. What we pointed out here is that, based on our study, simply changing RH resolution used in AeroCom analysis could result in a large AOT change if other compounding factors are isolated.

(26). P 13246, l 19 *In other words, a high resolution model should have a l arger, yet close to reality, AOT simulation than a low resolution model, and vise versa*. Such an analysis was made in AeroCom, but AOT did not increase with model resolution, nor did we find any other clear and systematic indication of model resolution on model performance. This does of course not mean that such effects do not exist, it just shows again the complexity of the system, as the authors state in their conclusions.

Reply: Once again we agree that caution should be taken to make a conclusion in a multi-model comparison due to the complexity of the system. However, it is highly desirable to understand the possible influence of each individual process to uncover the final puzzle.

(27). P 13248, end of conclusions: You may want to find a more finalizing last sentence

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of your paper?

Reply: Thanks. The last paragraph of the conclusion has been moved to section 3.4. The current last paragraph (and last sentence) is more appropriate.

(28). Suggestions for additional analyses: Standard deviation of RH fields for different resolutions Diffenrence between RH fields for different resolutions Correlation between RH and AOT differences? Correlation between RH variations and AOT differences?

Reply: The correlation between RH and AOT and between RH variation and AOT variation are discussed in Figure 9 in the revised version.

Technical corrections

Please check if all the abbreviations are explained, e.g. TOA DER, omega, etc.

Reply: Done.

Figure 2: Remove country-lines in the satellite plots.

Reply: We added country-lines in the model plot to maintain consistency among the plots.

Figure 4: Lower panel: give values in %, use a more linear scale like 5-50 % in steps of 5.

Reply: The value was given consistently in fractions in the Figures 4-7. We gave a linear scale except the first and last steps for a better demonstration.

P 13243, l 3 *In addition to the RH magnitude and the atmospheric aerosol composition, the variation of RH in spatial and temporal distributions is also a key factor in determining where and when a large AOT change occurs*. ARE a key factor

Reply: Section 3.4, including this sentence, has been changed based on the reviewer’s suggestions. Please refer to specific questions 19 and 21 above.

P 13243, l 5 *An overall explanation of how these two 5 factors in determining the AOT

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changes is given in Fig. 9*. Please correct sentence.

Reply: Again, section 3.4, including this sentence, has been modified.

P 13245, l 5 nature aerosols -> natural aerosols

Reply: Done.

P 13246, l 5 * is likely depends on* -> depending on

Reply: Deleted *is*; (P 13247, L5).

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