Atmos. Chem. Phys. Discuss., 9, C10587–C10598, 2010
www.atmos-chem-phys-discuss.net/9/C10587/2010/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Evaluation of aerosol distributions in the GISS-TOMAS global aerosol microphysics model with remote sensing observations" *by* Y. H. Lee and P. J. Adams

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Received and published: 6 February 2010

General Comments

The manuscript evaluated simulated AOD as well as Angstrom coefficient in the GISSTOMAS global aerosol microphysics model, using satellite (MODIS and MISR) and ground-based (AERONET) data. An offline module is used to calculate AOD, using the monthly-averaged aerosol fields from the GISS-TOMAS model. Possible causes for the over- and underestimation compared with observations are discussed. The manuscript is well organized, and the methodology is described in detail. This manuscript services as a good document about their model performance. A fair amount of efforts are put to

understand the discrepancy between the model and observations. This kind of exercise is important for their model development, and can produce valu- able information for their future model improvement. But unfortunately, the manuscript did not produce significant new sights that are useful to a more general audience.

Comments

Satellite and ground-based aerosol optical property data have been used in many previous studies. The authors fail to distinguish this study with previous studies. A similar study by Liu et al (2006) is missed in the references. Liu et al. (2006) used more satellite data (MODIS, MISR, AVHRR, POLDER, and TOM) and did a better job to explain and to explore the difference between different satellite data. Liu et al. (2006) also evaluated more aerosol optical property parameters (AOD, single scattering albedo, and Angstrom coefficient). As pointed out by Reviewer 1, the aerosol microphysics model used in this study has some advanced features, but the authors did not go deep enough to evaluate these features, such as mixing state, and size distribution. Angstrom coefficient is meant to evaluate simulated aerosol sizes, but the authors only have one paragraph for the evaluation of the parameter. More discussion regarding this parameter will be helpful. It will be also desirable to compare simulated single scattering albedo with observations. This may provide insights about simulated mixing states.

Response: The primary goal of our global aerosol microphysics model is to obtain accurate CCN predictions with its advanced features for predicting aerosol number and size. Unfortunately, remote sensing data is generally not the best choice for evaluation of CCN and aerosol microphysics. Remote sensing data provides essentially no detailed information about size distributions and mixing states. The Angstrom coefficient gives limited size information (it essentially lets one compare the relative magnitudes of the fine and coarse modes). The detailed shape of the fine mode number distribution, which is essential for CCN, is not well characterized by the Angstrom coefficient (Gobbi et al., 2007). So, the scope for evaluating the novel aspects of our model with remote

sensing data is quite limited. In other papers (Lee et al., 2009; Pierce and Adams, 2006, 2009), we make these evaluations using in-situ measurements of aerosol size and number.

Of course, the strengths of the remote sensing data are the global coverage of AOD data, which is a good measure of total column aerosol loadings. Like any other aerosol model, it is important for us to do this reasonably well. Therefore, this evaluation is the primary focus of our paper. We agree that a lot of the value of the paper is on the basic model evaluation and as a guide for our future model improvement. Certainly, if we neglected this basic model evaluation, others would rightly question our model's ability to predict global aerosol spatial distributions. While the resulting insights may be modest, we think they are significant and important to have documented in the open literature. Even though perhaps somewhat "routine" in nature, a published evaluation is useful to us and the wider community in several ways: others can clearly see/evaluate for themselves over where significant biases in our model occur and this provides useful context for other results we publish, it helps to explain/justify future model improvements and changes we make, other modeling groups can see by comparison where or why they might have similar problems, we can cite a quantitative evaluation of our model skill in different regions, etc.

Nevertheless, the following paragraph on AC evaluation is updated in Section 3.3 in the revised manuscript.

"Figure 8 displays seasonal cycles of monthly averaged model AC and AERONET AC. Higher AC (>1) indicate an aerosol dominated by fine mode particles, while lower AC (<1) indicate a substantial fraction of coarse mode particles (e.g. Holben et al., 2001). AERONET AC in biomass burning regions (1-4) is mostly above 1 throughout the year and is the highest during the dry season, the maximum biomass burning season. Model AC in Alta Floresta and Mongu is within the interannual variability of AERONET AC except the spring in Alta Floresta. Ilorin and Banizoumbou shows low AC during the spring and high AC during summer, which reflects the seasonal influ-

ences of mineral dust and biomass burning in those regions. Generally dusty sites have AC below 1 in the presence of mineral dust but the model underpredicts AC compared to AERONET for Capo Verde, Sede Boker, Bohrain, and Solar Village. Polluted continental sites show generally good agreement to AERONET, although the model AC tends to be slightly higher than observed. Oceanic sites, except Bermuda, tend to underpredict AERONET AC."

Moreover, the following discussion on AC is added in Section 4 in the revised manuscript.

"In general, model AC reflects the dominate aerosol type in a region and tends to agree with AERONET AC. Despite poor AOD predictions in biomass burning regions, AC is well predicted. Dusty sites (7, 10, 11, 12) underpredict AC compared to AERONET. The dust model in the GISS-TOMAS model produces few sub-micron dust particles compared to limited available observations (Lee et al., 2009), which may explain the lower AC. Model AC in Barbados and Bidi Bahn is overpredicted from June to October, which can be explained by an underprediction of mineral dust mass concentration (Lee et al., 2009). "

Aerosol single-scattering albedo is also retrieved by AERONET and measures the contribution of absorbing particles, mostly black carbon and dust particles, to AOD. Unlike AOD data, the uncertainty in the single-scattering albedo retrieved by AERONET is relatively high (i.e. within 0.03 for high aerosol loading with an optical thickness at 440 nm higher than 0.5, while it increases to 0.05–0.07 for lower aerosol optical thicknesses (Dubovik et al., 2000)). These mass of these strongly absorbing components generally makes a weak contribution to CCN. Therefore, the SSA evaluation is not considered in this study. The paragraph above is included in Section 1 in the revised manuscript.

Comments

The GISS global atmospheric circulation model runs at very coarse resolution (4x5 horizontal resolution, and with 9 vertical sigma layers), and only one year integration is

used (I am not aware of any other global aerosol model studies that used a similar resolution in recent years). This coarse resolution may affect simulated winds, cloud and precipitation fields, which are critical to their simulated aerosol fields as the authors suggested in their manuscript. Please comment on the use of this old global atmospheric circulation model, and how the coarse resolution will affect the model results, and please also comment why the model does on run at finer resolutions (more vertical levels, and more horizontal grids).

Response: The coarse, 4x5 resolution is a necessary tradeoff for the higher sophistication that we have with aerosol size. Although, in principle, higher resolution is theoretically better, we are unaware of any data that show that global aerosol models with higher (slightly higher, typically 2x2.5) resolution are systematically better at predicting observations. One good example is in Textor et al (2006), which shows no linkage between the model dispersivity and model horizontal resolution. Unfortunately, the length scales of interest for clouds and precipitation are much shorter than even a "high" resolution aerosol model. Do we really expect a precipitation parameterization for a 2x2.5 model to be systematically better than a 4x5 parameterization of the same process?

Table 2 in Kinne et al (2006) presents several global aerosol models with its grid resolution information. 4 out of 20 global models in Kinne et al (2006) use 4 by 5 resolutions or even larger. GEOS-CHEM, one of global aerosol model, also use the same grid resolution (Trivitayanurak et al., 2008). We agree that a model with finer resolution would be better in term of predicting some regional pollution than coarse grid, but it depends on the scale of pollution, of course. Figure 17 in Kinne et al (2003) present how well AOD at AERONET site (local measurement) represent regional event and shows clear evidence of local pollution in Mexico City. Most global models in Kinne et al. (2003) even those has finer resolution than our model fail to capture AOD in Mexico City.

Comments

p. 19476, section 2.2: Need more details about the module. How is your approach different with those used in Stier et al. (2005) and Ghan and Zaveri (2007)? Can your approach be computationally fast enough to be included online? It is still a challenge to calculate aerosol optical properties online in global climate models, using size-resolved aerosol composition from detailed aerosol microphysics models. Also, do the TOMAS's aerosols affect the radiation in GISS? If they do, how are their effects calculated, e.g., is this consistent with the offline calculation described here?

Response: The AOD module does not add much computational time to the TOMAS model. Therefore, it could be included online without any significant problem. The reason we used offline calculation is the computational burden of the TOMAS model itself. A one year simulation require 3 months on a single SGI processor. Therefore, it is convenient to do the AOD calculations offline where we can test different assumptions about refractive index, etc. For this paper, we use an existing simulation to get model AOD. Since it is offline calculated, there is no feedback to the radiation in GCM by aerosols. Our AOD calculation approach is different to Stier et al. and Ghan and Zaveri (2007) whose approach is suitable for a modal approach.

The following paragraph explains how AOD is calculated in our module.

"Based on Mie theory, AODs at 550 nm (or 500 nm) wavelength are calculated. Refractive indices and aerosol density used are selected from various references as shown in Table 1. Water uptake by sulfate, sea-salt, and organic aerosols is accounted for and is based on ISORROPIA results for sulfate and sea-salt and is based on observations of Dick et al. (2000) for organic carbon. In the global model, aerosol species are assumed to be internally mixed expect hydrophobic EC. The volume averaging method is applied to calculate the complex refractive index for the internally mixed aerosol particle including water. Optical properties are compiled into a lookup table, which is pre-calculated based on Mie theory. For each grid cell and size bin, particle composition is used to determine the volume-averaged refractive index, and optical properties are determined from the lookup table based on particle size and (mixed) refractive index. Based upon

its concentration, the optical properties are used to calculate the contribution of that size bin and grid cell to column AOD. The column AOD is the sum of these contributions over all size bins in a grid cell and all cells in the column."

Comments

p. 19476, line 27, p. 19484, line 17-29: Why does the model not distinguish the clearsky with the cloudy sky? The difference between clear-sky and cloudy-sky mainly comes from aerosol water. So how does the model calculate aerosol water in the clear-sky and cloudy-sky? Schmidt et al. (2006) suggested that clear sky value is the most appropriate comparison to the satellite observations. So why is the aerosol water in clear sky not used in this study? Your model should be able to track aerosol water in the clear-sky. A large part of the discussion in section 4 is related to this clear-sky vs. cloudy-sky issue.

Response: Our model accounts the water uptake in relative humidity up to 99% in a grid cell regardless of clear-sky or cloudy sky. The clear-sky AOD can be obtained only in online simulation. Since our model estimate AOD offline (based on monthly average aerosol field), we can not distinguish the clear-sky from the cloudy-sky. Therefore, it is for all-sky.

Comments

p. 19486, line 17-29; p. 19487, line 1-6: I agree with Reviewer 1 that more is needed about wet deposition. In your aerosol microphysics model, are all aerosol species assumed to be internally mixed in each aerosol bin? How does the assumption about the mixing state in the aerosol model affect the wet removable rate of biomass burning aerosols?

Response: Aerosol species are assumed to be internally mixed expect hydrophobic EC. Related to wet deposition for biomass burning regions, please see our response to Review 1.

Comments

p. 19496, Table 2: need references for refractive index (references for density are also missed). Please also comments about the large imaginary part used for dust and OM. 0.0055 is probably too large for dust. Myhre et al. (2003) suggested that 0.0014 is better. A table of global aerosol optical depth will be helpful.

Response: References for density and refractive indices are included in Table 2. Refractive index for dust varies from 0.006 to 0.0014 (e.g. Patterson et al., 1977; Sato et al., 2003; Torres et al., 2002). In fact, our choice is a relatively high imaginary refractive index for dust among previous studies. Most models assume zero absorption for OM. However, there is some evidence on OM to be absorbing. In a sensitivity study (not included in paper), we compute the AOD with lower imaginary refractive indices for mineral dust (0.0014) and for OM (0). AOD is very insensitive to this change in refractive index. Since our model is focused on CCN and absorbing aerosol components do not contribute much to CCN, we choose not to make this a focus of our evaluation.

Technical corrections

p. 19475, line 20: Pierce and Adams (2009a) is not in the references.

p. 19476, line 6: Correct the sentence "Dry deposition is used the series resistance";

p. 19477, line 20: miss "," after "However";

Response: All corrected.

Comments

p. 19480, line 15: the model did not do a good job during SON too.

Response: AOD prediction is poor during SON, which is due to low surface wind speed in the model during the autumn, mentioned in p. 19483 line 24-25. To be consistent, the following sentences are corrected.

"the model AOD plume from North Africa is quite well predicted throughout the year except JJA." ⇒ "the model AOD plume from North Africa is quite well predicted throughout the year except June to October."

Comments

p. 19483, line 16: I do not think agreeing within a factor of 2 for AOD is a good agreement.

Response: We don't find it entirely satisfactory either. However, it is often found that the model AOD prediction do not agree within a factor of two against AERONET (e.g. Figure 5 in Reddy et al. (2005), Figure 14 in Chin et al. (2002)). "Good" here was used in this relative sense (compared to the current state-of-the-art). To clarify this, the first sentence of the Discussion section now reads:

"Generally, the GISS-TOMAS evaluation of AOD against MODIS, MISR, and AERONET shows a level of agreement (within a factor of 2) similar to other global aerosol models with the best agreement occurring in polluted continental regions (high sulfate regions), dusty regions, and moderate sea-salt regions."

(Elsewhere in the paper, we continue to use "good" however; it gets tedious to say "similar to other global models" each time)

Technical corrections

p. 19485, line 17: "party" ! "partly"?? Also, you may want to add "caused" after "partly";

Response: Corrected.

Comments

p. 19487, line 8: The calculation of aerosol optical depth is an offline calculation. So it may not be accurate to say that the module "is implemented in the GISS-TOMAS global aerosol microphysics model";

Response: The sentence is rewritten as the following.

"A module for calculating AOD is implemented in the GISS-TOMAS global aerosol microphysics model," ⇒ "A module for calculating AOD is developed for the evaluation of the GISS-TOMAS global aerosol microphysics model,"

Comments

p. 19495, Table 1: Should the burden and the model column mass be the same thing? With the units used in Table 1, the amount of column mass is about 2 times of the burden. That is the case for dust, total EC, and total OM in your table. But why is that not the case for sulfate.

Response: For sulfate, the burden is presented as Tg of S, and the column mass is presented as mg of sulfate per year.

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