Atmos. Chem. Phys. Discuss., 7, S944–S952, 2007
www.atmos-chem-phys-discuss.net/7/S944/2007/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "The direct effect of aerosols on solar radiation based on satellite observations, reanalysis datasets, and spectral aerosol optical propertiesfrom Global Aerosol Data Set (GADS)" *by* N. Hatzianastassiou et al.

N. Hatzianastassiou et al.

Received and published: 3 April 2007

I. General Comments

1. The sign convention adopted in the revised version has been changed according to the suggestion of the Referee. The fluxes in Eq. (1) refer now to the net incoming SW fluxes at all levels, i.e. at TOA, in the atmosphere, and at the Earth's surface. Hence, the increase/decrease of the outgoing SW radiation at TOA due to aerosols is counted as negative/positive, in line with the IPCC reports and other studies. The changes are explained in sub-section 2.1, page 6, lines 1-11, whereas a new Eq. (2) referring to DFTOA has been introduced in the revised version. Note also that Fig. 1

has been changed according to the new adopted convention so that planetary cooling (blue colors) has negative values, and planetary warming (reddish colors) has positive values.

2. Additional information on GADS is given in sub-section 2.2 (page 6, line 25 through to page 7, line 4). Information is given on how GADS treats the different aerosol components, and determines the optical properties of aerosols. For further information the reader is referred to the GADS references (Koepke et al., 1997; Hess et al., 1998). Following the suggestion of the Referee, we provide a new Table (Table 1, the previous Tables were re-numbered), in which we report the computed mean global and hemispherical long-term (1984-1995) extinction aerosol optical thickness (AOT), aerosol single scattering albedo and aerosol asymmetry parameter at the visible wavelength of 0.5 microns. Note that the values given in this Table are slightly different to those given by Hatzianastassiou et al. (2004a). For example, the AOT at 0.5 microns is found to be equal to 0.097, which is larger than 0.08 given by Hatzianastassiou et al. (2004a). These differences are due to the use of different model input data in the present study (see section 2.3), as well as to its higher spatial and temporal resolution, i.e. 1deg x 1deg latitude-longitude against 2.5deg x 2.5deg in Hatzianastassiou et al. (2004a), and daily against monthly. In addition, the AOT value in Table 1 is discussed and compared with other model- and satellite-based estimates (see sub-section 2.2, from page 7 line 17 to page 8, line 12). Reference is made to the model estimates of the AeroCom project (Kinne et al., 2006), as well as to the global mean AOT estimate from AERONET data. Further, our AOT estimate is compared with satellite retrievals and to the value that we have computed from TOMS data for the period 1984-1993, which almost overlaps our study period (1984-1995). Although it is larger than the value given by Hatzianastassiou et al. (2004), our present AOT value based on GADS (0.097) is still slightly underestimated compared to other estimates, and this is now reported in the text (sub-section 2.2, page 7, line 22 through to page 8, line 3), while it is further discussed in context of the annual global mean aerosol DREs given in Table 2 (sub-section 3.5, page 15, line 15 through to page 16 line 19). Also, we make reference to

ACPD
7, S944–S952, 2007

EGU

some missing regional features (sub-section 2.2, page 8, lines 3-12), such as biomass burning in the Congo basin. For a detailed discussion of the GADS aerosol optical properties the reader is referred to Hatzianastassiou et al. (2004a, 2006).

We recognize that there are limitations in the GADS aerosol properties. Their specification requires comparison against satellite- or surface-based measurements of corresponding aerosol optical properties, i.e. aerosol optical thickness, single scattering albedo and asymmetry parameter. Nevertheless, such a comparison is not an easy task because of the different nature of the data. The GADS dataset was created to represent a comprehensive aerosol climatology by compiling aerosol data, on a global basis, that existed from different measurements and models. In addition, such a comparison is difficult because there are not many available globally distributed surface-based aerosol optical properties overlapping with the time period covered by our study (i.e. 1984-1995). For example, such surface data (e.g. AERONET) are mainly available from 2000 onwards. However, we have attempted a comparison between our GADS-derived aerosol optical depth data and available AERONET measurements at the visible wavelength of 0.5 microns. Although at present the number of AERONET stations exceeds 300, only 17 stations with data in the period 1993-1995 were found, which resulted in a limited number of matched data pairs for comparison. The scatterplot of these data reveals a rather satisfactory comparison, with a correlation coefficient equal to 0.5, a standard deviation of differences between AERONET and GADS equal to 0.04 and a bias of 0.12 (underestimation by GADS). These results indicate some agreement, given all the difficulties already mentioned and the uncertainties and errors involved in surface-based measurements themselves. We have attempted a comparison between our GADS-derived (re-computed for actual relative humidity values, as explained in section 2.2.) aerosol optical depth data with available TOMS measurements at the visible wavelength of 0.5 microns. The comparison was performed on a pixel-level (1deg x 1deg latitude-longitude) and monthly mean basis, for the years 1984-1995. The results of our comparison show that apart from rare cases, the absolute differences between GADS and TOMS aerosol optical thickness (AOT) are mostly

ACPD
7, S944–S952, 2007

EGU

within +/-0.25, whereas the relative percentage differences are mostly smaller than 50% and even 25% over extended areas. It was found that GADS generally underestimates AOT, but there are also some areas (e.g. parts of Sahara desert and India in January, European continent and Australian desert in July) where GADS overestimates AOT. Overall, the scatterplot comparison between TOMS and GADS, with a total of 81609 matched pairs, indicates a bias equal to 0.04 (GADS underestimation), and a standard deviation of differences equal to 0.06. These results are not too bad if one takes into account the very different philosophy and nature of the two datasets, and also the errors associated with the TOMS data and the discrepancies between satellite and climate model products themselves (see e.g. Zhao et al., 2005; Schulz et al., 2006). In conclusion, we believe that GADS is not really adequate for a month to month and year by year assessment of aerosol radiative effects, but is useful for climatological assessments. Reference to the GADS-related uncertainties is made at the end (last paragraph) of the conclusions section (4).

The aerosol single scattering albedo values over Sahara and Arabia are equal to about 0.85. These values are slightly different than those given by Hatzianastassiou et al. (2004a, Fig. 2ii), for the same reasons as for AOT, as already explained in the previous paragraphs. In the third paragraph of sub-section 3.1 (page 10, lines 12-20) in the revised manuscript, the sensitivity analysis is described more clearly. We provide values for both single scattering albedo and DFTOA for the reference case and the sensitivity study, to explain more clearly the change of sign of DFTOA over Sahara and Arabia.

3. We would like to clarify that only interpolation is applied (Introduction, page 3, line 26). We use as high as possible spectral resolution in aerosol optical properties to match the high spectral variation in the solar radiation, which drives the aerosol solar radiative effects. It is also useful to match the spectral information for other atmospheric constituents (e.g. gases and water vapour), also needed by the spectral radiative transfer model.

In the present study the aerosol asymmetry parameter is used to describe the angular

ACPD
7, S944–S952, 2007

distribution of scattered radiation by aerosols. As stated by the Referee, although the use of the Henyey-Greenstein (HG) phase function, which is defined in terms of the aerosol asymmetry parameter, is common in most radiative transfer models (see e.g. Yu et al., 2006) it has been shown (Marshall et al., 1995; Boucher et al., 1998) to introduce significant errors (up to 20%) in the computation of aerosol radiative effects, depending on solar zenith angle, aerosol size and refractive index. These have been discussed in the sub-section 2.2, page 6, lines 15-22, where cautioned is made about the introduced uncertainties in the computations of DREs shown in this study. Further reference to these uncertainties is also made in the conclusions, page 19, lines 10-12.

We would like to note that our model takes into account the dependence of solar radiative fluxes, and hence of the aerosol DREs, on the solar zenith angle. Further information can be found in the work by Hatzianastassiou et al. (2004c). The model was run for all days of each year of the study period (1984-1995) to account accurately for the variations in the solar zenith angle, declination and eccentricity of the orbit of the Earth around the sun. This has been mentioned in sub-section 2.1, page 5, lines 26-28. Our model does not use the two-stream method to solve the radiative transfer equation. As stated in sub-section 2.1 (radiative transfer model) the model uses the Delta-Eddington method of Joseph et al. (1976) which is an extension of the Eddington method described in Shettle and Weinman (1970). Note that the model radiative fluxes have been successfully validated at both TOA and the Earth's surface against quality satellite and surface station measurements, respectively (see e.g. Hatzianastassiou et al., 2004c; 2005).

A brief description of the treatment of surface reflectance in the model is given in sub-section 2.1, page 5, lines 11-26, as suggested by the Referee. For more details, the reader is referred to other relevant studies (Hatzianastassiou et al., 2005). As is briefly stated on page 5, line 16-20, and explained in detail by Hatzianastassiou et al. (2005), the ocean reflectivity depends on solar zenith angle.

In our opinion, in Fig. 4 (surface aerosol DRE) the discontinuity between land and

ACPD
7, S944–S952, 2007

EGU

ocean is no stronger than for the atmospheric aerosol DRE (Fig. 3). Probably, this view was produced by the color scheme used in the previous version. The color scheme has been changed in the revised manuscript, and Figs 4a and 4b are re-drawn. Any remaining discontinuity can be attributed to the GADS aerosol optical properties (not shown in this study). We agree with the Referee in that any remaining discontinuity of DFsurfnet between land and ocean should be attributed to the rapidly changing optical properties of the aged (transported) aerosols in GADS, and we have noted this in sub-section 3.3, from last line of page 12 to line 2of page 13.

4. The estimates given in Table 3 (previously Table 2) are not homogeneous, as stated by the Referee. However, they are given just for inter-comparison with our computations. Given the different approaches, model- or satellite-based estimates, the different aerosol properties, the different properties of the rest of the atmospheric and surface parameters, the different time periods, the different spatial and temporal resolutions etc, perfect agreement is not expected. This is noted in sub-section 3.5, page 15, lines 17-24.

In view of this, differences like those reported by the Referee are not surprising. Note that large discrepancies have been reported between computations of aerosol optical properties and DREs obtained from satellite-based products (Zhao et al., 2005) and models (e.g. Schulz et al., 2006). Although our DFTOA estimate is found to be larger than that of Reddy et al. (2005), it is however in rather good agreement with the estimates given by Yu et al. (2004a; 2006) and Jacobson (2001). Note that model simulations give a wide range of aerosol DRE and DRF (direct radiative forcing) estimates that on average are smaller than the measurement-based DRE (Bellouin et al., 2005; Yu et al., 2006). Despite this, the difference between our estimate and that of Reddy et al. (2005) can be explained by considering all the physical parameters that determine aerosol DREs. Among these parameters, the aerosol optical properties play an important role. Nevertheless, it is well known (e.g. Hatzianastassiou et al., 2004b) that the aerosol DREs also strongly dependent on other physical parameters, for example

ACPD
7, S944–S952, 2007

atmospheric humidity, clouds and surface albedo, amongst others. Therefore, all these parameters have to be taken into account to assess the differences. It is true that based on the AOT values of the present study and those of Reddy et al. (2005), our DFTOA estimate should be larger than the value reported in Table 2. However, the aerosol absorptivity (in terms of single scattering albedo) and the asymmetry parameter should be considered as well. Furthermore, note that our estimate refers to the 12-year period 1984-1995, against that of Reddy et al. (2005) for simulation years 2000-2001, not to mention other differences, such as radiative transfer models, spectral resolutions etc.

We would like to note that the aerosol DRE values reported by Yu et al. (2004) and Yu et al. (2006) are given for clear-sky conditions. The corresponding values reported in Table 3, have been adjusted for all-sky conditions, using a mean (spatial and temporal terms) cloudiness equal to 0.65 (based on satellite ISCCP data) and considering the DRE negligible under cloudy skies. This is noted in the Table caption.

5. An advantage of this study, and of other modeling studies, is that the aerosol DRE can be estimated separately for clear- and cloudy-sky conditions. To match the realistic conditions in the Earth-atmosphere system, but also for brevity, only the all-sky estimates were given in the study. Nevertheless, separating the effects is important for assessing the validity of the zero cloudy-sky effect, assumed by measurement-based techniques. Thus, ratios of cloudy- over clear-sky aerosol DREs, at TOA, within the atmosphere, and at the Earth's surface, are given at the end of sub-section 3.5 (page 16, lines 20-29) for both hemispheres and the globe. However, we would like to clarify that aerosols are not considered within or above clouds in this study, which introduces some degree of uncertainty, for example in the case of absorbing aerosols within and above clouds. This is explained in sub-section 2.1, page 5, lines 3-11.

II. Other Comments

1. It is now clearly stated in the Abstract (page 1, lines 1-2) that the spectral aerosol optical properties (optical thickness, single scattering albedo and asymmetry parame-

ACPD
7, S944–S952, 2007

EGU

ter) are taken neither from satellite measurements nor from reanalysis data, but from the Global Aerosol Data Set.

2. It is now stated (page 1, lines 27-29) that: “The effect of anthropogenic aerosols only, on a global average, is likely to be comparable in magnitude to the radiative forcing of about 2.4 W/m2 by anthropogenic greenhouse gases (IPCC, 2001).”

3. We now refer (page 2, lines 17-18) to the correct reference of Chin et al. (2001), which also assesses the aerosol forcing.

4. The reference of Remer and Kaufman (2006) was replaced by the more appropriate Schulz et al. (2006), as suggested by the Referee (page 2, line 24).

5. The relevant text in the Introduction (last sentence of the 3d paragraph of Introduction) was removed, while the text in sub-section 3.4 (page 13, lines 23-24) was corrected, according to the Referee’s suggestion.

6. The text in sub-section 2.2, page 6, lines 22-25, has been corrected accordingly.

7. In sub-section 3.1, page 11, line 1, the wording “especially in January” has been removed.

8. We agree with the comment of the Referee and the text has been modified accordingly (page 11, lines 12-13).

9. We prefer to keep the second decimal point, though not significant, for consistency in case of averaging (e.g. between north and south hemispheres in deriving mean global values).

10. An effort has been made to reduce the list of references.

References

Hatzianastassiou, N. and Vardavas, I.: Shortwave radiation budget of the Northern Hemisphere using International Satellite Cloud Climatology Project and NCEP/NCAR

ACPD

7, S944–S952, 2007

climatological data, J. Geophys. Res., 104, 24 401-24 421, 1999.

Hatzianastassiou, N. and Vardavas, I.: Shortwave radiation budget of the Southern Hemisphere using ISCCP C2 and NCEP/NCAR climatological data, J. Climate, 14, 4319-4329, 2001.

Hatzianastassiou, N., Fotiadi, A., Matsoukas, C., Pavlakis, K. G., Drakakis, E., Hatzidimitriou, D. and Vardavas, I.: Long-term global distribution of Earth's shortwave radiation budget at the top of atmosphere, Atmos. Chem. Phys., 4, 1217-1235, 2004c.

Hatzianastassiou, N., Fotiadi, A., Matsoukas, C., Drakakis, E., Pavlakis, K. G., Hatzidimitriou and Vardavas, I.: A 17-year global distribution of Earth's surface shortwave radiation budget, Atmos. Chem. Phys., 5, 2847-2867, 2005.

Hess, M., Koepke, P. and Schult, I.: Optical properties of aerosols and clouds: The software package OPAC, Bull. Am. Meteorol. Soc., 79, 831-844, 1998.

Interactive comment on Atmos. Chem. Phys. Discuss., 7, 753, 2007.