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Interactive comment on "A review of measurement-based assessment of aerosol direct radiative effect and forcing" *by* H. Yu et al.

H. Yu et al.

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We appreciate the reviewer's detail and insightful comments on the work. We fully agree that enhanced uncertainty analysis and attribution of differences observed between methods are important to advancing the knowledge of aerosol direct effect and forcing. In the revision, we now discuss uncertainties associated with individual methods more quantitatively and in more detail, focusing on measurement-based estimates (section 3.1). We briefly discuss model diversities that have been documented and discussed in recent Global Aerosol Model Intercomparison (AEROCOM) papers (Kinne et al., 2005; Textor et al., 2005; Schulz et al., 2005), in which recent intercomparison results from 16 different global models are presented and some explanations of the model diversities and uncertainties are offered. We add in the revision (section 3.2.3) some new sensitivity analyses (using GOCART aerosol simulations as an example) to discuss if potential factors (such as surface albedo parameterizations and clear-cloudy differences in aerosol properties) would have contributed to the systematic satellite-model differences.

Details of our revision plan are laid out in the response to specific comments as follows:

1) We add specific goals to the abstract and define the focus of this assessment more clearly.

2) The goal in the first stage of CCSP assessment is to assess current observational capabilities and identify uncertainties in the aerosol direct effect through differences among measurements and among measurements and models. Identifying uncertainties in the models is being conducted in the framework of AEROCOM and we will not discuss them in detail. The advantage of the present paper is the use of independent approaches with independent sources of errors - models and measurements. The examined difference is therefore indicative of the uncertainty. Prioritizing the uncertainties and their remedies will be our focus in the second stage of the CCSP assessment.

3) The accuracy for estimating the anthropogenic aerosol optical depth is $\pm$7% (Kaufman et al., 2005) - added to the abstract.

4) We refer "these achievements" to good accuracy of AOD retrievals and TOA DRE estimates over ocean. We now reword the sentence.

5) Yes, we refer to globally averaged forcing due to direct and indirect effects.

6) The stated uncertainty of DCF is based on the IPCC report.

7) Yes, it shall be more appropriate to use the suggested title.

8) Absorption efficiency is defined as absorption cross section per unit aerosol mass (unit: m2/g).

9) changed.

10) It is true that only AERONET data is used in our comparisons. Other measurements are not used because they are limited in space and time. On the other hand, in such a review paper, it is necessary to give an overview of other ground-based networks that are complementary to AERONET measurements. An integration of these measurements is essential to a better understanding of aerosol direct effect/forcing and should be a focus in the future. We will keep but simplify these descriptions.

11) We refer "quantitative aerosol size parameters" to aerosol effective radius, fine-mode fraction in terms of aerosol optical depth. In comparison to AERONET retrievals, for moderate AOT, the standard deviation of MODIS effective radius is $\pm 0.11\mu$m. On monthly basis, the MODIS fine-mode fraction agrees to AERONET retrievals over ocean to within 20%. At low AOT the uncertainties associated with MODIS size parameters are greater (Remer et al., 2005; Kleidman et al., 2005).

12) According to Kahn et al. (2005), an implementation of the calibration on a trial basis removes about 40% of a 0.05 bias in retrieved midvisible AOT (before version 16) over dark water scenes.

13) We refer to AOT measurements. We now clarify it in the revised paper.

14) We discussed in section 3.1 (p.7675-7676) two approaches employed by Loeb and Manalo Smith (2005) and Zhang et al. (2005b). We will reword the sentence.

15) We now give brief details of the results that have already been published. Initial results demonstrate the capability of GLAS in detecting and discriminating multiple layer clouds, ABL aerosols, and elevated aerosol layers.

16) ABC stands for "Atmospheric Brown Cloud".

17) We mean that it is necessary to account for the anisotropy of ocean reflection and its dependences on the solar zenith angle, wavelength, wind speed, and chlorophyll concentration. We now discuss the uncertainties by citing results from previous papers (e.g., Remer and Kaufman, 2005; Yu et al., 2004; Bellouin et al., 2004; Jin et al., 2004;

and others). Our new sensitivity tests also show that 20% of low bias in DRE could be resulted from a use of a broadband albedo that is independent of solar zenith angle.

18) We have rephrased this sub-section and will not use “global albedo” in the revision.

19) We agree and now incorporate this excellent suggestion in the revision. For example, in discussing satellite remote sensing of aerosols, we add discussion on AOT uncertainties associated with spherical and bi-modal assumption employed in current retrieval algorisms. In albedo section, inclusion of comment 17 should enhance the discussion. It is a mistake that we overlooked a discussion of uncertainties and limitations of satellite retrievals of clouds. We now discuss some issues associated with cloud retrievals (e.g., overestimate of cloud effective radius resulting from a plane-parallel approximation, uncertainties/biases in cloud optical depth and effective radius due to a presence of aerosol above cloud layer, current lack of cloud-base observations) and their influences on DRE estimates (Abel et al., 2005; Brennan et al., 2005; Breon and Doutriaux-Boucher, 2005; Haywood et al., 2004; Mahesh et al., 2004; Reid et al., 1999; Platnick and Valero, 1995; Kaufman and Nakajima, 1993; and others).

20) Yes, it should be “almost always”.

21) We will discuss briefly the recent results from AEROCOM activities (Kinne et al., 2005; Textor et al., 2005).

22) We should clarify that this example taken from Zhou et al. (2005) is used to demonstrate how various factors discussed in section 2 determine DRE. We will describe in more detail on how these calculations are performed and analyzed.

23-24) Yes, the vertical bars in Figure 4b also represent one standard deviation. We will add discussion on uncertainties associated with AERONET measurements, i.e., ± 0.01 for AOD, ± 0.03 for SSA, and ± 0.02 for g (Holben et al., 1998; Dubovik et al., 2000), and their influences on the DRE estimate. Following the suggestion, aerosol parameters are now plot in separate panels with expanded y-axes to more clearly demonstrate regional differences.

25) Yes, for the models considered in this study, only the dust and sea salt components are size resolved.

26) We will describe the integration in more detail.

27) Based on 4-year MODIS retrievals by Remer and Kaufman (2005), interannual variations of AOD and DRE are fairly small on a global scale. However, variations could be significant on a regional basis.

28) We clarify that MOD04 is level-2 daily aerosol retrieval at a resolution of 10 km.

29) Figure 6 is used to illustrate similarities and differences in the patterns of AOD and DRE. Here we use year 2001 for all AODs and for DREs of CERES_A, MO_MI_GO, and GOCART. For MODIS DRE, we use data for 2002 because the algorithm has been run starting from September 2001 (Remer and Kaufman, 2005). We now clarify these in text and figure caption. Because all DRE calculations were done on a monthly basis, it is difficult to present standard deviations.

30) Yes, the filling process for MODIS should introduce biases toward GOCART AOD over bright deserts and snow-melting regions. Our new calculations indicate that MODIS over-land AOD is 61% and 42% larger than the GOCART simulation without and with the filling gaps, respectively. For MISR, the bias should be very small on global average because the filling occurs mainly over persistently cloudy regions (such as Amazon basin during the wet season). We now clarify these in the paper.

31) The reduction is 40% for MISR (Kahn et al., 2005; see also response to comment 12) and about 30% for MODIS (according to ongoing work by Robert Levy of MODIS aerosol group).

32) ADM stands for “Angular Dependence Model” that converts radiance to flux.

33) When calculating standard errors, n is the number of methods used. We now add

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standard deviations to the tables.

34) It is impossible to estimate the model errors from fundamental calculations only through comparison among models and to measurements - the goal of this paper. AEROCOM activities have resulted in three papers that document model diversity (Textor et al., 2005; Kinne et al., 2005; Schulz et al., 2005). We will cite their major results, as our paper focuses on measurement-based estimates. It has been formidable for modelers to estimate the uncertainties in their emission rates, washout rates, and cloud oxidation, among others. We do not attempt to do it either. Explaining model-measurement differences is challenging. Our MODI_G and MISR_G experiments (using satellite AOD to replace GOCART AOD, with other parameters same as the GOCART) suggest that the low bias of model AOD should be one of major reasons for the systematic model-satellite difference (in addition to satellite cloud contamination). In the revision (section 3.2), we use GOCART aerosols to do some new sensitivity exercises by (1) replacing model surface albedo with MODIS retrievals over land and a more detailed description of ocean albedo; and (2) using low-humidity single-scattering albedo and asymmetry factor (intuitively, more representative for clear-sky aerosol than using those at the ambient humidity). Preliminary results suggest that these two modifications would raise the TOA DRE efficiency by about 20% over ocean and hence reduce the model-satellite discrepancy. Because of large model diversity, however, a decisive conclusion can only be drawn after examining a number of factors (e.g., aerosol properties, surface albedos, and radiative transfer schemes) for all models. Such comprehensive intercomparisons and assessments are beyond the scope of this paper and demand significant endeavor in the future.

35) We meant the measurement-based SFC DRE is 60% larger (in magnitude) than the TOA DRE. We have clarified this and removed “slightly”.

36) We really do not know if the systematic differences between models and measurements over ocean are going to persist the same way over land. We hope that the models are more realistic over land, closer to their sources, and we do know that satel-

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lite measurements are worse. Given that satellite flux measurements have not been used to derive DRE over land and satellites can only measure the optical depth, we use model simulations to supplement satellite measurements and derive DREs over land. The model-satellite integration of AOD does improve the agreement with AERONET measurements (e.g., Yu et al., 2003). Surface albedo has also been more observationally constrained. Such efforts would have constrained the satellite-model integrated DRE to some degree. However, other DRE controlling factors, such as aerosol single scattering albedo and asymmetry factor, rely completely on GOCART simulations in this paper. And uncertainties associated with them should be major sources of uncertainties in the satellite-model integrated DRE values.

37) To avoid too crowded plots, we here present only a portion of methods that are representative for measurement, satellite-model integration, and model simulations. Our purpose is to show more detail comparisons of DRE in these regions in addition to regional averages. We will rephrase the discussion and hopefully eliminate any confusion.

38) We have discussed the major factors that are likely to contribute to the differences in estimated DREs in section 3.1, and 3.2. These factors include, as we mentioned before, the model uncertainties in aerosol composition, mixing state, optical properties, and surface albedo and meteorological conditions such as RH and cloudiness; the satellite retrieval uncertainties in aerosol type, particle shape, surface properties, and cloud interference. p.2686 (line 20): We feel that it is not appropriate to make such a general statement as “model-satellite integration-based assessments in the region are generally higher than both the measurement-based and model-based estimates”, because only GOCART simulations have been used in the model-satellite integration. We now remove this sentence.

39) We have made new plots by using smaller and more unique symbols.

40) We have incorporated the reviewer’s suggestions and made a clearer demonstra-

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tion. We have also modified the statement accordingly.

41) Yes, corrected.

42) We understand the reviewer's frustration with our laundry list of possible reasons for the discrepancies. We would also like to find out exactly what is going on, but that is an overwhelming job when confronted with the number of data sets involved in this study and the complexity of the Earth's aerosol system. The inadequacies of specific satellite retrievals and specific model results are well-documented in several other papers that pinpoint regions and situations most likely to suffer from a particular problem. The main point of this study is to put all of these results on the same page for the first time. It will take a different type of paper, one with more depth and less breadth, to uncover specific factors causing specific differences. In such a study of depth, we may very well find that factors differ from data set to data set. The bottom line is that due to inability to specify and quantify fundamental uncertainties in models or uncertainty in AERONET representation we are comparing different methods with independent though not well defined uncertainties.

43) We have conducted additional analysis for MODIS, MODIS_A, and GOCART covering January-March in east (65-90E, 0-30N) and west (30-65E, 0-30N) part of the region separately. Following Kaufman et al. (2005), a combination of MODIS/Terra AOT and fine-mode fraction gives an anthropogenic fraction of 0.81 in the east part and 0.45 in the west part (for 2001). GOCART simulations in the same period also give the respective anthropogenic fraction of 0.72 and 0.42. Similarly, MODIS_A algorithm gives the respective anthropogenic fraction of 0.76 and 0.30 in the east and west part of the region (for January-March, 2002). Note that these numbers of the anthropogenic fraction in the east part of region agree quite well with chemical measurements during INDOEX experiment (Satheesh et al., 2002). These consistent east-west contrasts clearly suggest geographical differences in aerosol composition and hence in the forcing efficiency. MODIS_A algorithm also derives that the DRE efficiency for anthropogenic aerosols is about 30% less negative than that for natural aerosols in the region.

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We give this as an example. Such detailed analysis is generally beyond the scope of the type of paper we intend to write. Lack of good documentation of all relevant parameters in previous publications also makes it formidable to attribute differences in all regions presented.

44) Yes, we have assumed the sources of error are independent. We clarify this in the revision.

45) We clarify that estimates of DRE over land and at the ocean surface are less constrained than the estimate of TOA DRE over ocean.

46) It is a excellent suggestion and we will try to make such connections when applicable.

47) We now keep two significant figures only.

48) We shall briefly discuss limitations with different methods of measuring/retrieving aerosol single-scattering albedo. More details can be found in comprehensive review papers (e.g., Heintzenberg et al., 1996; Reid et al., 2005).

References:

Abel, S.J., Highwood, E.J., Haywood, J.M., and Stringer, M.A.: The direct radiative effect of biomass burning aerosols over southern Africa, Atmos. Chem. Phys., 5, 1999-2018, 2005. SRef-ID: 1680-7324/acp/2005-5-1999.

Bellouin, B., Boucher, O., Vesperini, M., and Tanre' , D.: Estimating the direct aerosol radiative perturbation: Impact of ocean surface representation and aerosol non-sphericity, Q. J. Roy. Met. Soc., 130(601), 2217-2232, 2004.

Brennan, J. I., Kaufman, Y.J., Koren, I., and Li, R.-R.: Aerosol-cloud interaction – misclassification of MODIS clouds in heavy aerosol. IEEE Trans. Geos. Rem. Sens., 43 (4), 911-915, 2005.

Breon, F., and Doutriaux-Boucher, M.: A comparison of cloud droplet radii measured from space, IEEE Trans. Geoscience and Remote Sensing, 43(8), 1796-1805, 2005.

Dubovik, O., Smirnov, A., Holben, B. N., King, M. D., Kaufman, Y. J., and Slutsker, I.: 5 Accuracy assessments of aerosol optical properties retrieved from AERONET sun and sky radiance measurements, J. Geophys. Res., 105, 9791-9806, 2000.

Haywood, J.M., Osborne, S.R., and Abel, S.J.: The effect of overlying absorbing aerosol layers on remote sensing retrievals of cloud effective radius and cloud optical depth, Quart. J. Roy. Met. Soc., 130, 779-800, 2004

Heintzenberg, J., Charlson, R. J., Clarke, A. D., et al.: Measurements and modeling of aerosol single-scattering albedo: progress, problems and prospects, Beitr. Phys. Atmosph., 5 70, 249-263, 1997.

Holben, B. N., Eck, T. F., Slutsker, I., et al.: AERONET - A federated instrument network and data archive for aerosol characterization, Remote Sens. Environ., 66, 1-16, 1998.

Kahn, R., Li, W.-H., Martonchik, J. V., Bruegge, C., Diner, D. J., Gaitley, B., Abdou, W., Dubovik, O., Holben, B., Smirnov, A., Jin, Z., and Clark, D.: MISR low-light-level calibration, and implications for aerosol retrieval over dark water, J. Atmos. Sci., 62(4), 1032-1052, 2005.

Kaufman, Y., and T. Nakajima, Effect of Amazon smoke on cloud microphysics and albedo - Analysis from satellite imagery, J. Appl. Meteorol., 32, 729-744, 1993.

Kaufman, Y. J., Boucher, O., Tanr’e, D., Chin, M., Remer, L. A., and Takemura, T.: Aerosol anthropogenic component estimated from satellite data, Geophys. Res. Lett., 32, L17804, doi:10.1029/2005GL023125, 2005.

Kinne, S., Schulz, M., Textor, C., et al.: An AeroCom initial assessment - optical properties in aerosol component modules of global models, Atmos. Chem. Phys. Discuss., accepted, 2005.

Kleidman, R.G., O’Neill, N.T., Remer, L.A., Kaufman, Y.J., Eck, T.F., Tanre, D., Dubovik, O., and Holben, B.N., Comparison of MODIS and AERONET remote sensing retrievals of aerosol fine mode fraction over ocean, submitted to J. Geophys. Res., 2005.

Loeb, N. G. and Manalo-Smith, N.: Top-of-Atmosphere direct radiative effect of aerosols over global oceans from merged CERES and MODIS observations, J. Clim., in press, 2005.

Mahesh, A., Gray, M.A., Palm, S.P., Hart, W.D., and Spinhirne, J.D.: Passive and active detection of clouds: Comparisons between MODIS and GLAS observations, Geophy. Res. Lett., 31, L04108, doi:10.1029/2003GL018859, 2004.

Platnick, S., and Valero, F.: A validation of a satellite cloud retrieval during ASTEX, J. Atmos. Sci., 52, 2985-3001, 1995.

Reid, J.S., Hobbs, P.V., Rangno, A.L., and Hegg, D.A.: Relationships between cloud droplet effective radius, liquid water content, and droplet concentration for warm clouds in Brazil embedded in biomass smoke, J. Geophys. Res., 104, 6145-6153, 1999.

Reid, J.S., Eck, T.F., Christopher, S.A., Koppmann, R., Dubovik, O., Eleuterio, D.P., Holben, B.N., Reid, E.A., and Zhang, J.: A review of biomass burning emissions part III: intensive optical properties of biomass bunring particles, Atmos. Chem. Phys., 5, 827-849, 2005. SRef-ID : 1680-7324/acdp/2005-5-827.

Remer, L. A., Kaufman, Y. J., Tanre, D., Mattoo, S., Chu, D. A., Martins, J. V., Li, R.-R., Ichoku, C., Levy, R. C., Kleidman, R. G., Eck, T. F., Vermote, E., and Holben, B. N.: The MODIS aerosol algorithm, products and validation, J. Atmos. Sci., 62(4), 947-973, 2005.

Remer, L. A. and Kaufman, Y. J.: Aerosol effect on the distribution of solar radiation over the global oceans derived from five years of MODIS retrievals, Atmos. Chem. Phys. Discuss., 5, 5007-5038, 2005, SRef-ID: 1680-7375/acpd/2005-5-5007.

Satheesh, S. K., Ramanathan, V., Holben, B. N., Moorthy, K., Loeb, N. G., Maring, H., Prospero, J. M., and Savoie, D.: Chemical, microphysical, and radiative effects of Indian Ocean aerosols, J. Geophys. Res., 107, 4725, doi:10.1029/2002JD002463, 2002.

Schulz, M., Textor, C., Kinne, S., et al., Radiative forcing by aerosols as derived from the AeroCom present-day and pre-industrial simulations, submitted to Atmos. Chem. Phys. Discuss., 2005.

Textor, C., Schulz, M., Guibert, S., et al.: Analysis and quantification of the diversities of aerosol life cycles within AEROCOM, Atmos. Chem. Phys. Discuss., accepted, 2005.

Yu, H., Dickinson, R. E., Chin, M., Kaufman, Y. J., Zhou, M., Zhou, L., Tian, Y., Dubovik, O., and Holben, B. N.: The direct radiative effect of aerosols as determined from a combination of MODIS retrievals and GOCART simulations, J. Geophys. Res., 109, D03206, doi:10.1029/2003JD003914, 2004.

Zhang, J., Christopher, S. A., Remer, L. A., and Kaufman, Y. J.: Shortwave aerosol radiative forcing over cloud-free oceans from Terra. II: Seasonal and global distributions, J. Geophys. Res., 110, D10S24, doi:10.1029/2004JD005009, 2005b.

Zhou, M., Yu, H., Dickinson, R. E., Dubovik, O., and Holben, B.N.: A normalized description of the direct effect of key aerosol types on solar radiation as estimated from Aerosol Robotic Network aerosols and Moderate Resolution Imaging Spectroradiometer albedos, J. Geophys. Res., 110, D19202, doi:10.1029/2005JD005909, 2005.

Interactive comment on Atmos. Chem. Phys. Discuss., 5, 7647, 2005.