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Interactive comment on "Aerosol effect on the distribution of solar radiation over the clear-sky global oceans derived from four years of MODIS retrievals" *by* L. A. Remer and Y. J. Kaufman

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We thank the reviewers for some excellent comments and insights into the work we presented.

There is an agreement between all 3 reviewers that our discussion of uncertainty understates the true uncertainty of our final estimates. I am of firm opinion that there is no science until there are error bars. For this reason, we presented a quantitative estimate of the quantifiable uncertainty. However, we did not discuss possible errors that were not quantifiable at this time, and this was a mistake. As Reviewer 1 states, " There may not be an established way to assess the errors in derived TOA fluxes for the

approach used here, but that does not justify claiming a retrieval accuracy that seems to assume most of these errors are negligible." In our revision, we will do several things to improve the discussion of the uncertainty. (1) As Reviewer Anderson pointed out, we have made a mistake in combining the random errors. This will be corrected. (2) Rather than relying on the Ichoku et al. (2003) paper we will present a fresh sensitivity study that can quantify some of the uncertainty. In particular, we hope that this will answer some of Reviewer #2's concerns. (3) We will discuss some of the nonquantifiable uncertainty to alleviate the reviewers' concerns that our claims are misleading. (4) We will have further discussion of the differences between Terra and Aqua, using these as an opportunity to discuss retrieval precision as Reviewer Anderson suggests.

Specific Issues from Reviewer #1 (2) We will revise the paper and mention the unquantifiable sources of uncertainty.

(3) The sentence on the advantages of 500 m resolution in terms of clouds also concerned another reviewer. We are going to remove the sentence. We will mention the possibilities of cloud side light scattering when we discuss the possibilities of cloud contamination and biased error.

(4) We agree that the important aspect is "the degree of confidence with which the radiative transfer code extrapolates narrow-band MODIS spectral radiances in wavelength and angle". Again this is a difficult uncertainty to assess quantitatively, but we will definitely mention the issue in the text, and hope to address some of it quantitatively in the fresh sensitivity study.

(5) The reviewer brings up a good point. If there were relationships between aerosol properties and the distribution of scattering angle, then we are introducing additional errors into the final calculation of radiative effect. We looked into this issue and found that in some regions there is a relationship between AOD, for example, and scattering angle. Section 6, where the reviewer is concerned about Saharan dust plumes does show a significant relationship (R= 0.96 and a 0.07 change in AOD per a 70 degree

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range in scattering angle). However, it is hard to know whether this relationship is due to sampling issues, as the reviewer suggests, or due to artifacts in the retrieval. For example, in the figure in response to Reviewer Anderson's 3.3, we show how the error in the AOT retrieval for Saharan dust is dependent on scattering angle.

We will discuss the pros and cons to making the monthly mean average over a variety of scattering angles.

(6) The differences between Terra and Aqua are one of the more interesting results of the current paper. Reviewer #1 sees this as an opportunity to discuss diurnal changes in aerosol effect, while Reviewer Anderson sees this as an opportunity to quantify retrieval precision. The first assumes that there are physical changes in the aerosol between Terra and Aqua overpasses, while the second assumes that there are no changes. We do not know which assumption is correct. However, our experience working with Terra and Aqua tells us that they are entirely different instruments with their own calibration issues that can easily produce artificial differences in retrievals, much more in line with Reviewer Anderson's assumption. Based on this experience we believe that the differences between Terra and Aqua are mostly artificial and that the assumption of diurnal consistency to estimate diurnal average fluxes is valid. In the revised paper we will discuss the Terra-Aqua differences in terms of retrieval precision, as part of the overall rethinking and rewording of the discussion of uncertainties.

(7) Since we are calculating the clear sky radiative effect, don't we want to weight the grid square with 3000 pixels much more heavily than the grid square with 1 pixel? Let's say we were working with daily data at the original 10 km resolution. If we were to calculate the annual mean in one region, wouldn't we take all 3000 pixels from the one grid square and combine those with the 1 observation from the other grid square to get the mean? Yes, the mean would equal the mean of the 3000 pixels, but that is the simple average we are seeking. By pixel weighting as we have done, we are getting closer to the results of the original resolution of the data.

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(8) We intend for the revised paper to discuss the assumptions and error sources much more transparently.

Specific issues from Reviewer Anderson (1) We have discussed the reviewer's request to include a calculation of RE_regional with him off line. Multiplying the cloud free radiative effect by the cloud free area makes some sense that this is the regional or global contribution of the cloud free aerosols. However cloud free fraction is usually defined as the area with almost no clouds that allows derivation of the aerosol properties. Many regions have thin clouds where aerosol under the clouds will have almost the same effect as aerosol over the clouds. Aerosol under cloud with reflectance of 0.2 will have ˜75% of the effect as aerosol in cloud free area. So while I agree that reporting cloud free aerosol effects in an area with 90% cloudiness is an issue and multiplying by the 10% makes some sense, the product of the cloud free effect * cloud free fraction is ill defined while before the multiplication it has very clear physical definition. We feel that the quantity of RE that we present in the paper is the least ambiguous way to describe the results. However, we are curious enough to currently be calculating this new quantity, although the calculations and analysis of the results are not yet finished. If the results prove to add information to the paper without adding confusion, we may include them in the revision. At the very least we will include a discussion of the results and the differences between RE_local and RE_regional.

(2.1) See our response to Reviewer #1's comment (6) above. We do not know if the assumption that optical depth and radiative effects are the same at 10:30 and 1:30, although we expect them to be the same, at least globally. . In the revised paper we will discuss the Terra-Aqua differences in terms of retrieval precision, as part of the overall rethinking and rewording of the discussion of uncertainties.

(2.2) Making a comparison to CERES in any significant manner is beyond the scope of what we are trying to present in this paper. We can reference the final results from some of the papers that use CERES to make the same estimates.

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(2.3) Both Reviewer Anderson and Reviewer #2 expressed concerns about the sea surface albedo assumptions. We looked into the matter and realized that we had underestimated the range of sea surface albedos. In the revised sensitivity study we now calculate the uncertainty for a range of albedo of 0.07ś0.04, following Jin et al. (2002 and 2005).

(2.5) The reviewer is correct. My calculator gives me the same numbers. I don't know what happened.

(3.1) Reviewer #1 also had objections to this statement about MODIS at 500 m resolution being able to retrieve closer to clouds. (See response to comment 3, above). The original sentence did not claim to remove any bias, only to reduce it. We simply wanted to clarify one of the differences between using MODIS and relying on the 20 km CERES footprint (Christopher and Zhang, 2002) that leaves large regions of the ocean blank because of persistent cloud cover. The advantages seemed intuitive to us. Cloud effects on aerosol retrievals is an area of active research. The suggestion of using MAS data to investigate the cascade of cloud effects as a function of resolution is excellent, but not within the scope of this paper. Because the reviewer objects to this intuitive statement, we will simply remove the sentence.

(3.2) The single scattering approximation is not important. If you plot points from the MODIS look up tables, calculated with the full multiple scattering radiative transfer code, you can see how radiance is a much better predictor of flux than any individual parameter (AOT, SSA or g). Knowing AOT allows us to predict the flux, but there is scatter due to the various combinations of SSA and g at the various wavelengths. For any observation, the fit between radiance and flux is much tighter. The uncertainties of the aerosol models are reduced. Using the retrieved parameters as a consistent set is much closer to the original radiance, and thus closer to the flux. In the revised paper we will attempt to explain this better.

(3.3) Again, we felt that this was intuitively obvious. If the retrieval were perfect, it

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wouldn't matter if we used one angle or many to obtain the parameters that give us the flux. However, the retrieval is not perfect. For example, in dust regimes we know that we have systematic biases in the retrieval that are correlated to scattering angle. Above 140 degrees the AOT retrieval is biased low, while at lower scattering angles it is biased high. Because over a month we encounter observations in both ranges, a monthly mean will be less affected by error than a single observation at a single scattering angle.

The revised paper will give a better explanation of the advantages of many scattering angles in a monthly mean.

(4) We can describe the fraction of 10 km retrievals kept in each region out of the total number possible, but we can't break down the fraction of discarded retrievals to specific reasons such as clouds, sunglint etc., and we have no record at Level 3 of the fraction of 500 m pixels kept.

Specific issues from Reviewer #2

(1) We agree that SSA is very important. We are using the MODIS retrievals consistently in order to avoid the uncertainty of having to estimate the SSA from outside sources. The reviewer points out that the importance of SSA magnifies over bright surfaces, and for surface flux calculations (as opposed to TOA). All of our calculations and estimates were made over dark ocean and we do not attempt to estimate the radiative flux at the surface for precisely these reasons. We are creating a fresh sensitivity test that will include sensitivity to interpolating and extrapolating SSA from the 7 MODIS bands to the full spectrum.

MODIS does not produce a SSA product. We are backing out this information from the MODIS retrieval's choice of aerosol model that best matches the spectral radiances at TOA. MODIS will choose the models. Each model has its own SSA. These can be found in Table 3 of Remer et al. [2005, JAS, 62, 947-973]. Given the mix of models chosen for any region and season (Figure 3 in the current manuscript) and Table 3 of

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the Remer et al. (2005) paper, you can get the SSA for that region and season. Because MODIS does not produce a SSA product, we feel that reporting these numbers directly will only confuse our users, and therefore prefer not to do so.

(2) We are creating a fresh sensitivity study that will include sensitivity to changing the column water vapor and ozone. The water vapor calculation is done. A change in total precipitable water vapor from 1.25 times the original amount to 0.50 times the original amount results in a change of radiative effect of about 2.5%

(3) We did underestimate the range of surface albedo. For the range of solar zenith angles experienced, the range of ocean albedo turns out to be 0.07ś0.04. This translates into an uncertainty in the radiative effect of about 11%.

(4) We did calculate the sensitivity to aerosol height, using the difference between having an aerosol confined to the boundary layer, versus one that is located in a layer aloft. The affect on the radiative effect calculation is about 4.5%

(5) There is no information on monthly mean or seasonal values of SSA because MODIS does not produce these values and we do not want to mislead our users into thinking that these values are (a) available or (b) retrieved with any known accuracy. Only the combination of using the SSA, g and AOT in a consistent set to reconstruct the measured radiances makes any sense. Seeing the SSA alone will be misleading.

(6) In the revised paper we can make the discussion of aerosol type more clear.

Interactive comment on Atmos. Chem. Phys. Discuss., 5, 5007, 2005.