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Interactive Comment

Interactive comment on "Cloud type comparisons of AIRS, CloudSat, and CALIPSO cloud height and amount" *by* B. H. Kahn et al.

B. H. Kahn et al.

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Response to comments by Reviewer #2:

Reviewer: General Comments: [snip]

The authors agree with the statements/summary of the reviewer.

Reviewer: Comments regarding the use of CloudSat and CALIPSO data as reference [snip]

The authors generally agree with the reviewer's views on radar and lidar sensitivity.

Reviewer: This will affect cloud base height detection.

This is entirely true. However, we are not trying to derive cloud base from AIRS radiances, rather a "radiative" cloud top height that tends to be located within a transparent

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cloud layer. But this is an important point to consider when locating an IR-derived cloud top with respect to its physical top and base.

Reviewer: So this reviewer suggests that the authors develop a thorough discussion in Section 2 to address the following issues

The issues are detailed below, numbered from (1) to (4). The authors think that much of this subject material is already sufficiently addressed in the manuscript. However, the authors have added some new material in response to the reviewer's concerns, and in a few instances referred to some submitted/published reports and publications for further detail on CloudSat and CALIPSO data products that are beyond the scope of this work. Also, Reviewer #2 brought up several similar/identical points as Reviewer #1, and in those cases is directed to the responses to Reviewer #1 that include new text revisions to the manuscript.

1. Reviewer: What are the known limitations of CloudSat cloud occurrence and cloud height detections in the current 2B-GEOPROF product?

Some details of this subject are discussed in Sect. 2.2 (with regard to the lower range bins contaminated by ground clutter, and the sensitivity limitations of radar to small hydrometeors) and in the cloudy snapshot illustration in Sect. 2.4 when radar, lidar, and passive IR derived cloud fields are overlaid. Furthermore, in Sect. 2.2, we cite the publication of Marchand et al. (2007) (in press) that discusses the algorithm and procedure of constructing the 2B-GEOPROF data product. The application of the radar-only 2B-GEOPROF product was first used by Mace et al. (2007) and is cited, and the reader is referred to this work for further detail.

Reviewer: What are the known limitations of CloudSat cloud type detections in the current 2B-CLDCLASS product?

We refer the reviewer to the answer we gave Reviewer #1 in point (2) under specific comments. That answer covers the extent of the reviewer's question, and also includes

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some additional text added to the manuscript.

2. Reviewer: What are the known limitations of CALIPSO cloud occurrence and height in the current Level 2A?

As the reviewer pointed out, one of the more important limitations is with regard to clouds being misidentified as aerosol. We did not include this limitation in the original manuscript and have added the following sentence to p. 13923, line 18:

"Cloud identification is considerably accurate in Version 1.10, although some thick aerosol can be misidentified as cloud (see the data quality statement at http://eosweb.larc.nasa.gov/PRODOCS/calipso/table_calipso.html)."

Feature detection is limited in tenuous aerosols and clouds and must undergo some horizontal averaging to "tease" out the signal. This is addressed on lines 18-22 on p. 13923.

Further limitations are addressed in the online quality statements and in Vaughan et al. (2005), which is cited in Sect. 2.3.

3. Reviewer: What are the justifications for using unvalidated satellite products, or satellites that are currently going through a validation process to validate other satellite products?

The authors disagree with the reviewer that these products are unvalidated. In the case of AIRS there are many publications on AIRS validation including clouds (see reference list at end of manuscript). With regard to using CloudSat and CALIPSO products, they are publicly released and have undergone cursory testing, quality control, and some limited validation that includes coincident in situ measurement campaigns. For a fuller answer to this concern we refer Reviewer #2 to the response of "Primary Weaknesses" by Reviewer #1.

4. Reviewer: How will these issues affect the outcome of this study?

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With regard to point (1), the authors think that the negative impacts will be largely negligible with regard to the radar-only products but there will be added value with a future combined lidar-radar GEOPROF and CLDCLASS products. Improvements to radar-only GEOPROF and CLDCLASS are very likely to be quite minor after Release 4. Specifically, slightly better low cloud detection will be achieved with further improvements to the surface clutter problem with the radar. More importantly, a combined CLDCLASS product will be helpful to partition the bias and variability statistics of the radar+lidar by cloud type, and will also be useful to study multi-layer scenes, especially thin Ci over other cloud types. But these additional capabilities can be thought as added value to the present analysis and won't affect the general outcomes of this work that are inherently limited to radar-only and lidar-only products.

With regard to point (2), some aerosol misidentified as cloud may appear in some of the lidar observed cloud layers below 7 km. This problem exists in the passive IR as well: some recent ongoing work (by the lead author, and others such as L.L. Strow) has shown that AIRS often detects very thick aerosol layers and retrieves them as clouds. These regions are highly limited in coverage and are mainly associated with dust near African sources, and probably do not have any measurable impact on the statistics presented in this work.

With regard to point (3), we refer back to the answer given to Reviewer #1 under "Primary Weaknesses". Both CloudSat and CALIPSO are of sufficient accuracy and precision to be extremely useful to evaluate passive IR derived cloud retrievals.

Reviewer: Comments regarding the analysis of AIRS cloud occurrence and cloud height products

Reviewer: This reviewer suggests that CloudSat should be used as reference only for those cloud types for which CloudSat has the best skills. Similarly CALIPSO should be used as a reference for the cloud types for which CALIPSO has the best skills. This is at issue in Section 3.1 and throughout Section 4.

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The authors appreciate the reviewer's insights with regard to emphasizing the lidar or radar depending on its ability to assess different cloud types. However, the problem with applying this suggestion is that a lidar classification product is unavailable as of writing to even attempt this, let alone incorporate revisions in the manuscript. Ideally a combined lidar+radar product will be used in such a comparison, and will be in the future when a combined product is publicly released.

Reviewer: Section 3.1 [snip] This reviewer finds that an average number for all cloud types leaves a false impression on the detection skills of AIRS. The reviewer suggests that the author discuss false detection for each cloud type in order to establish a more accurate evaluation of AIRS skills.

This is a very good suggestion and the authors have performed some additional analysis with regard to CloudSat cloud type. Since there is no operational cloud type algorithm released for CALIPSO, this necessarily must be limited to the radar only. Also, since this necessarily requires CloudSat detected clouds to assess cloud type (AIRS does not have a cloud type assessment), this must be applied only to Scenarios D and E in Figure 3. This will not work with Scenario C because CloudSat is reported as clear for these situations. The authors feel that this additional analysis has yielded significant useful insights.

Based on the results of this additional work, we have shown that the missed detections in Scenarios D and E are dominated by St, and less so by Ac, As, and Ns, which holds true in both Scenarios. We have added an additional paragraph to the manuscript to describe these results, added to p. 13926, starting after line 5:

"For Scenarios D and E (instances when the radar senses clouds and AIRS does not), the cloud types that dominate the missed cloud detections are assessed. For Scenario D (E), the percentage of missed St is 55% (70.1%) of all cloud types, respectively. This is not a surprise given that St dominates the overall frequency statistics (Wang and Sassen 2007). Furthermore, the AIRS channel list was modified for V5 in such a

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way to be less sensitive to low clouds, hence increasing missed St detections over V4 that is to be discussed in Sect. 4.3. For Scenario D (E), As explains 23.7% (22.7%) missed cloud detections, while Ac composes 5.9% (3.6%) of all cases. Approximately 14.5% (1.6%) of Ns clouds explain missed detections; the difference in percentages between Scenarios D and E are largely explained by the frequency of homogeneous Ns clouds within the AIRS FOV (see Table 3). Missed detections of Ns are consistent with limitations of the AIRS algorithm in the presence of precipitating clouds (Kahn et al. 2007a). All other cloud types explain about 1.5% or less of the missed cloud detections by AIRS. For instance, it is very rare that CloudSat detects Ci cloud when AIRS does not."

Section 3.2 Reviewer: The evaluation of retrievals of Za and fa and their discrepancies are more problematic in Polar latitudes? Please explain why or provide reference.

The authors assume the reviewer is referring to lines 17-18 on p. 13926. This statement needs some clarification. Analyses of AIRS-derived cloud fields in the polar latitudes appear to be of much poorer quality than at lower latitudes. In particular, the combined false and missed detection rates (e.g., AIRS reporting clear when CSat/CAL reports cloud, and vice-versa) is much higher than in the 70S-70N latitude band. The reasons for this could be many, but the frequent occurrence of lack of thermal contrast between the cloud and surface (due to a weak lapse rate/deep isothermal layer) causes significant problems for AIRS cloud retrievals (even at low latitudes). Algorithm improvements and ongoing validation by the AIRS team is now emphasizing the high latitudes and results will be presented elsewhere. To clarify this statement, we have modified the text on lines 17-18 to the following:

"Although the biases of Z_A relative to the radar are not appreciably different in the Polar latitudes, the rate of false or failed cloud detections is greatly increased (31%) compared to all latitudes (22%). The reasons for poorer cloud retrievals in high latitudes are being explored and will be presented elsewhere."

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Reviewer: The peak frequency in the tropical upper troposphere is zonally offset between AIRS and CloudSat by 5 deg lat. This is not evident from Fig. 6. Analysis of differences between the various panels of Fig. 6 would be made easier if the figures included a grid.

We tried the figures with grids, but their modified appearance seemed overwhelming and distracting to the patterns and central messages of the figures, thus we decided not to modify with grids. With regard to the zonal offset, it is most apparent between Figs. 6a and 6e. However, the emphasis is on the differences between Figs. 6c-e. Thus, we have modified lines 12-13 on p. 13928 to the following:

"This feature is more expansive from 15S-15N, whereas the peak frequency is shifted 5N (10N) relative to AIRS in Figs. 6a-b. Using a more appropriate cloud top boundary-based cloud climatology in Figs 6c-e, the tropical cloud features compare much more favorably."

Reviewer: Are CloudSat and CALIPSO cloud height products validated enough to know which retrieval is biased and which one is not?

Please see many of the previous points addressed to both reviewers. Both the radar and lidar are essentially correct, but they sample different hydrometeors that can cause height differences.

Reviewer: The lower frequency of lidar-detected clouds from 5S-5N? Narrow vertical range resulting in fewer detected clouds? The opacity of clouds should not affect the detection of cloud tops and hence their frequency of occurrence.

The authors agree with this insight. However, the point that was being made on lines 17-20 on p. 13928 was in reference to cloud profiles, not cloud tops. The profiles are very much affected by cloud opacity, especially for the lidar, because it cannot sample clouds it does not see. The attenuation of the lidar compared to the radar causes severe sampling biases, the effects of which are clearly seen in Fig. 6. This is

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discussed explicitly on lines 17-20 on p. 13928.

Reviewer: The main results and sources of discrepancies for each cloud type that emerge from the comparison should be summarized in a paragraph or in Table 4. E.g., Explain what specific skills are missing for detection of Ci, Cu. Discussion should be limited to cloud types where the reference (CloudSat or CALIPSO) is known to have the necessary skill OR estimate what part of the difference (e.g., Table 4) is due to CloudSat and/or CALIPSO uncertainty.

CALIPSO is able to detect Ci, Cu, and Sc as long as an upper layer does not obstruct the cloud, but we cannot assign cloud types (as of now) to CALIPSO-observed clouds. This is the primary weakness in this work, and a future lidar cloud type product will supplement the limitations of the radar-only CLDCLASS product. So the authors cannot compare lidar and radar results for every cloud type as the reviewer suggests.

Reviewer: Discussion of v4 and v5 results is split between this Section (Fig. 10) and Section 4.3. The reviewer suggests to combine the discussion of Fig. 10 and Section 4.3. Section 4.3 This section could be significantly shorter. The technical details of the difference between v4 and v5 can be described thoroughly in a technical report.

The authors organized Section 4 as follows: 4.1 addresses CloudSat-AIRS differences (and briefly shows differences between v4 and v5 AIRS retrievals), 4.2 addresses CALIPSO-AIRS differences, and 4.3 addresses some algorithm details that have changed between v4 and v5. Both Sects. 4.1 and 4.2 are organized such that they focus on the comparisons themselves and the scientific implications. Sect. 4.3 was written to give the reader some sense that there are a myriad of reasons why v4 and v5 may differ, and some of the reasons have been identified during the course of this study. The authors believe that it will be too confusing and counter-productive to the reader to combine technical details on AIRS version differences with scientific outcomes of the paper in the same section, and each subject is better served by having its own section.

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With regard to the length of Sect. 4.3, it could have been much, much longer. There are internal (to NASA) and a few externally released reports regarding validation, but the detailed version 4/5 testing report was not publicly released (to the lead authors' knowledge). The authors summarized a fairly short but comprehensive list of reasons for differences in the first paragraph from experienced AIRS algorithm scientists, and the most important items were elaborated on in the following short paragraphs. We believe this information is important to the reader concerned about AIRS retrievals. We also believe that the scientific community is better served if some information on AIRS algorithm details is published in the refereed literature since this project has history of not publishing much of its work in the open refereed literature, making it very difficult for others to repeat work and use AIRS data to its fullest potential.

Reviewer: The discussion on CO2 and its effect on Ci detection is interesting and feeds back to discussion of Fig. 10. The effect on Ci should be compared to CALIPSO retrievals rather than to CloudSat retrievals.

The authors appreciate the compliments of the reviewer and fully agree that CO2 seems to be a key, yet underappreciated issue for thin Ci detection using passive IR radiances. To make a more direct link between the CO2 issues and Fig. 11 (the CALIPSO-AIRS comparisons), we have added the following text to line 4 on p. 13935:

"Erroneous values of CO2 are likely to have some impact on the misplaced cloud height for very low values of f_A seen in Fig. 11."

Reviewer: Conclusions: substantial conclusions are reached, but an objective conclusion on the skill of both reference datasets (CloudSat and CALIPSO) for each cloud type would be welcome.

With regard to CALIPSO cloud type comparisons, as discussed before there is no publicly released cloud type product for the lidar, hence the authors cannot revise the manuscript accordingly. This will be done in future analyses as these products are released in future data product versions. With regard to the CloudSat cloud type ac-

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curacy, this was discussed in some detail earlier in the manuscript, and additional discussion was added based on the concerns of both reviewers. See the replies to reviewer comments on the sensitivity of CloudSat to different cloud types.

Interactive comment on Atmos. Chem. Phys. Discuss., 7, 13915, 2007.

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