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Atmospheric Chemistry and Physics Discussions

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

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Responses to anonymous Referees #1 and #2

The authors extend many sincere thanks to the referees for their useful and thoughtful comments on the manuscript. We have addressed every reviewer comment below and in some cases have revised the manuscript in accordance with both reviewers' suggestions. If the manuscript is revised in a particular instance, the specific changes are made clear and are quoted in addition to any response to a given comment.

Response to comments by Reviewer #1:

Reviewer: Primary Weaknesses: [snip]

The authors agree that caution is prudent with the use of new remote sensing observations, especially those that are derived from backscatter, reflectivity, and radiance like those made by CALIPSO, CloudSat, and AIRS. The lead author diligently sought the advice and assistance of several CALIPSO and CloudSat team members and product developers, some of whom appear as co-authors and are also primarily responsible for some of the released products used in this work. The lead author has been fully apprised of data limitations by team members and co-authors, and in the case of CloudSat, has been involved in using the data through the first four releases (1-4). With regard to AIRS, the lead author has been an integral member of the AIRS product validation team for years, has published extensively using AIRS observations, and works closely with the developers of the AIRS retrieval algorithm, where one (C.D. Barnet) is included as a co-author.

Similar comparisons among CloudSat, CALIPSO, and AIRS have been performed using different data versions (e.g., releases 1-4 for CloudSat, and versions 3-5 for AIRS). This paper is a culmination of these efforts with the most recent (and highest quality) versions publicly available at the time of writing. The level of maturity of a given remote data set is a judgment call and depends on the scientific application of the data. However, all of these products are publicly released data sets available for use (and are being used extensively in our field) by the entire scientific community, and have been judged to be of sufficient quality for scientific studies. There is no rule of thumb for "using these resources too soon" (quote from Reviewer #1). Given that the publicly released products have passed many stringent quality checks, initial validation efforts, have met specific targets for accuracy and precision before public release, and the enormous level of scientific interest in using joint A-train data sets, we judge that the use of these data in this study as appropriate.

Furthermore, a comforting result is that the comparisons in this work are consistent with numerous physical insights in sensitivity differences between active radar and lidar, and passive IR observations of clouds. Also, the strengths and limitations of AIRS cloud retrievals are consistent with expectations and algorithm and sensitivity limitations to particular cloud types, cloud amount, and cloud altitude. In essence, the results of these comparisons give further confidence to the quality and precision of the derived products from CloudSat, CALIPSO, and AIRS, which further justifies its use in research.

Reviewer: Specific Comments

1. The size of the field of view (FOV) will not change significantly based on the altitude of the cloud for a satellite orbiting at ~ 700 km. All three platforms observe the same cloud from nearly the same altitude at roughly nadir view within about ~ 1 minute of each other. If the authors understood the reviewer's point correctly, this viewing perspective is a concern for surface- and aircraft-based observations, but not for satellite instruments orbiting at ~ 700 km. The "shared footprint" is limited to the size of CloudSat and CALIPSO measurements because they are so much smaller than the AIRS FOV. The location of the CloudSat and CALIPSO FOVs are rarely aligned down the middle of the AIRS FOV as depicted in Fig. 3; they are located off-center more frequently. This is described in the caption of Fig. 3: "The number and relative placement ... vary substantially between FOVs."

2. The radar-only cloud classification scheme has undergone independent validation and evaluation using field campaign data during its development over the past few years. A combined radar-lidar classification algorithm is being developed at present. In regards to its reliability for different cloud types, here are some general statistics (quoted from Zhien Wang via personal communication):

* Ns and Cb clouds are very well detected at a rate of 100% and classified accurately 95% of the time

* High clouds (Ci) are very well classified because the height is accurately known. On one hand, it is well known that CloudSat under-detects high cloud occurrence that will be improved with a combined lidar-radar algorithm (CALIOP + CloudSat). On the other hand, the addition of lidar will not improve cloud classification accuracy.

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* As are very well detected ($>$ 99% accuracy) in the midlatitudes and tropics and are classified with a good deal of accuracy ($>$ 90%)

* Ac are not well detected by CloudSat, especially in the absence of ice virga. They are classified accurately around 70% of the time. Lidar measurements will improve Ac detection and classification.

* St and Sc are under-detected by CloudSat because they can be composed of small droplets. Also, because of ground clutter issues, these clouds are difficult to detect below 1 km, although some improvements were made in Release 4. Lidar measurements will definitely help improve detection and classification of St and Sc, and the separation between the two.

* Cu clouds include both Cu congestus and fair weather Cu. Cu congestus is well detected and classified more than 80% of the time. The radar misses most of the fair weather Cu. The lidar will improve fair weather Cu detection and classification.

To summarize the cloud classification characteristics in the paper, we have added the following text to Sect. 2.2, p. 13922, line 29:

"The radar-only cloud classification scheme has some differences when compared to a combined radar-lidar scheme. The cloud types As, Ns, Cb, and Cu (congestus) are well detected and classified with a radar-only algorithm. Ci is well classified but under-detected because of the existence of small ice particles in thin Ci that a lidar is able to detect. Ac, St, Sc, and fair weather Cu (in the absence of virga or drizzle) are under-detected using a radar-only algorithm and will be greatly improved with a combined radar-lidar algorithm. The classification of these cloud types is sufficient except that a combined radar-lidar approach is needed to partition St from Sc clouds. The relative merits between a radar-only and combined radar-lidar classification algorithm will be summarized and published elsewhere."

3. The authors have added two sentences in Sect. 2.4 on p. 13924 to address the

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reviewer's point to clarify the behavior of f_A in Fig. 2, the first starting at line 11:

"Effective cloud fraction (f_A) tends to be much higher in the presence of geometrically thick cloud (observed by the radar), or large backscatter (observed by the lidar), and vice-versa, implying qualitative agreement of f_A with radar and lidar observations."

The following text is inserted on the same page on line 13:

"The radar occasionally misses clouds below f_A $<$ 0.2 - 0.3 that the lidar easily observes."

4. We have emphasized the difference between CloudSat and CALIPSO cloud frequencies more directly in Sect 3.1, p. 13925, by inserting the following text at line 11:

"Most notable is the large difference in cloud frequency between CloudSat and CALIPSO. Although the CloudSat and CALIPSO data products used have 1 and 5 km ground resolution, respectively, the majority of the difference is due to the relative sensitivity of each instrument to hydrometeors that was discussed in Sect. 2."

We have applied the reviewer's suggestion and removed the following text in the caption and inserted it into line 29 on p. 13925:

"For the five days in table 1, averages of 19.3 and 10.6 CloudSat profiles containing cloud (6.0 and 4.3 CALIPSO 5 km profiles) are located within a typical AIRS FOV for scenarios (B) and (E), respectively."

5. Each percentage listed in each of the scenarios defined in Fig. 3 indicates the percent frequency of occurrence for each scenario using CloudSat or CALIPSO (in parentheses) as a baseline. To clarify further, we have modified the sentence in the Fig. 3 caption:

"The relative frequency (in percent) for the five days listed in Table 1 is shown for each scenario separately for CloudSat and CALIPSO (in parentheses)"

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which is now the following:

"The relative frequency of occurrence (in percent) for each scenario is shown separately for CloudSat and CALIPSO (in parentheses) for the five days listed in Table 1."

We have added additional text to Sect. 3 per the reviewer's suggestion that emphasizes the essential information regarding cloud heterogeneity (e.g., scenarios B and E in Fig. 3). The following text has been added to Sect. 3.1, p. 13926, on line 6 at the beginning of the paragraph:

"According to Scenarios B and E, the AIRS FOV is heterogeneous 49.8% of the time using coincident radar-derived cloud profiles, but is reduced to 26.5% using lidar profiles. The higher sensitivity of lidar in detecting small hydrometeors suggests a lower frequency of clear sky/cloud heterogeneity on the scale of the AIRS FOV than implied by the radar. Regardless of the instrument sensitivity, a significant percentage of AIRS observations contain heterogeneous mixtures of clear sky and cloud."

6. The authors thank the diligence of the reviewer in reviewing the percentages. It turns out that the value for CloudSat in Scenario C was miscalculated. It should be "10.9%" instead of "9.5%". All other percentages for CloudSat and CALIPSO Scenario frequencies are correct, and individually CloudSat and CALIPSO percentages now sum to ˜100%.

Now the difference is 2.1%, which is more in line with the reviewer's point regarding the CloudSat/CALIPSO difference in Scenario C.

7. To address the reviewer's concern that the sensitivity of AIRS to particular cloud types must emphasize that the cloud classification scheme is derived from radar and not lidar, we have added the following statement of clarification on p. 13936, line 12:

"Given that the cloud classification scheme used in this work is developed from radar observations, the sensitivity of AIRS to particular cloud types is based strictly on clouds observed by CloudSat."

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With regard to the validity of the cloud classification scheme, see the response to point (2).

With regard to "clearly stating in the conclusions the cloud types that excel, and those where AIRS does poorly", we have modified the text somewhat to make this clearer to the reader. First, the sentence on lines 20-22 on p. 13936 is changed to:

"The results presented herein show that AIRS has skill in detecting and assigning cloud top heights to these difficult cloud types."

This makes clearer the connection of difficult retrievals in the presence of Cumulus, Stratocumulus, and Cirrus, and the ability of AIRS to accurately determine a cloud top in many of these cloud types. Second, the sentences on lines 9-12 attempt to point out that as f_A increases, the accuracy of AIRS cloud top increases irrespective of cloud type. To clarify, we have added the following sentence on line 12:

"Therefore, AIRS cloud top height is shown to excel for most cloud types with relatively high values of f_A."

With regard to additional specifics about particular cloud types, these are discussed at length in Sect. 4.1, are shown in Figs. 8 and 9, and Tables 3 and 4. We feel that the conclusions will be too detailed and long by re-iterating specifics for all cloud types that are already discussed at length in Sect 4.1.

8. With regard to "tip-toeing around the issue of CloudSat sensitivity", we are not sure of the reviewer's particular concern. On lines 1-4 on p. 13937 we specifically discuss that the added sensitivity of the lidar to small hydrometeors increases the "bias" between AIRS and the lidar when compared to the radar. To clarify this further, we added the following sentence at line 4:

"This demonstrates that CloudSat and AIRS is not as sensitive to thin Ci and boundary layer clouds compared to CALIPSO."

With regard to underestimating thin Ci cloud tops by "X%" (we believe this could be

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a typo and the reviewer meant "height"), we refer to lines 27-29 on p. 13936. A joint radar-lidar classification scheme is currently under development but is not available for the present work. Therefore, we are unable to partition "thin Ci" from "thick Ci", "Cb", and other cloud types. When this data set is available we will be able to do this.

With regard to missing "thin Ci X% of the time", the same problem arises as discussed above.

With regard to "layered clouds" we are not validating multi-layered retrievals per se. Rather, we are assessing the relative sensitivity of the upper and lower layers to particular cloud types. Multi-layer detection/validation in itself is a difficult subject because there is rarely, if ever, two uniform/plane-parallel clouds that the AIRS retrieval may excel at. An imager with higher spatial resolution (e.g., AIRS VIS channels, MODIS, etc.) is probably necessary for multi-layer validation. In the case of three or more cloud layers, the lower AIRS layer may not represent any of the lower layers detected by the radar and lidar. Furthermore, this subject is probably more appropriately addressed with the joint radar-lidar cloud type algorithm in development for future release, especially for thin Ci clouds over thick, low clouds (e.g., St, Sc, Ac, As, etc.). We intend on pursuing further analysis, especially with regard to multi-layer clouds oce the combined radar-lidar products are released.

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