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Interactive comment on "Differences in cloud microphysical properties between MODIS Collections 5.1 and 6" *by* John Rausch et al.

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The authors thank both reviewers for their very thorough review of the manuscript and insightful comments and suggestions that improve the manuscript.

Response to the comments of reviewer 1:

The manuscript presents a needed comparison of the impact of algorithm updates for a widely used cloud remote sensing data set. It definitely deserves publication. In my opinion, a few important points can be improved nonetheless.

General comments: I see three major points, I would like to see improved before publication. 1) The title raises expectations that differences in all cloud microphysical properties of the standard MODIS products would be discussed. However, the paper fo-

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Discussion paper

cuses on the CDNC/ cloud number droplet concentration which is not a part of the MODIS standard product itself. Optical thickness, water path ... and ice microphysical parameters are not mentioned at all. Please either extend the discussion/comparison towards a more general comparison (preferred) or choose a more specific title.

The reviewer is correct that the broad title would suggest that more microphysical parameters would be included in the discussion and we have retitled it as "Differences in droplet effective radius and cloud droplet number concentration estimates between MODIS Collections 5.1 and 6 over global oceans" This research originated as a study of the differences in calculated CDNC between both collections for liquid clouds. As such, we were interested as to see changes to the MODIS product were driving the aggregated intercollection CDNC differences. We investigated the retrieved input variables needed to calculate CDNC (droplet effective radius, cloud-top temperature and cloud optical thickness). From this we determined that of the three parameters, effective radius differences were primarily driving the CDNC changes (naturally because of greater relative sensitivity, but also due to larger relative intercollection differences). COT and CTT differences on average increase CDNC only by about 1-2%. Consequently, the discussion focused on effective radius. In the modified manuscript, we have added to the discussion that COT differences are relatively small and have minimal influence on CDNC. With the title change, we hope that the readers do not feel mislead as to the content of the manuscript.

2) Throughout large parts of the manuscript, the explanation of presented details and reasons for the seen differences is too short to be understood without extensive reading of further literature. This should be extended wherever needed (see specific comments).

This is a good point. We have addressed the concerns listed in the specific comments below. Also, we have removed the independent pixel comparison section and the related figure (5), per the suggestion in the specific comments. The globally averaged CDNC retrievals with the two disparate screening techniques do not offer significant

insight into the differences between the collections compared to the 1-to-1 screening method used in the rest of the study.

3) Language is sometimes sloppy. Sentences are sometimes contructed in a complicated way. Technical slang is used. Should be improved.

Also a good observation. In the revised manuscript we have addressed rather clumsily constructed sentences and eliminated the technical slang noted by both reviewers so that the manuscript is easier to read. Much of which is addressed in the specific comments.

Specific comments: Page 1, lines 16+17: sloppy unprecise language in several places, technical slang:

“Channel pairs” cannot be “retrieved” and are hardly “successful”. Should be a “retrieval based on channel pairs” and a “retrieval which is successful”. Other places P5, l14: “retrievals exist for all three effective radii retrievals” or P5, l15: “primary advantage of this ... is a comparison”

P1,L16-17 now reads: Comparisons between both collections are performed for cases in which all three effective radii retrievals are classified by the MODIS Cloud Product as valid for each pixel.

P5,L14 reads: Common pixel scenes are those in which all three effective radius retrievals are valid for both collections with otherwise consistent selection criteria.

P5,L15 reads: A common pixel selection allows for an objective comparison of effective radius and CDNC estimates between both collections, free of . . .

P1, l19: Maybe mention other MYD06 differences before talking about derived quantities? What about COT? LWP? Cloud mask? As mentioned in the general comments, we note in the abstract and body that COT differences were small compared to effective radius and found not to significantly impact CDNC estimates. We feel that a discussion of parameters not used/investigated (vertically homogenous LWP and cloud mask

classification differences) would be beyond the scope of the study.

P1, l25: I'm missing a short outline of reasons for the differences in the abstract. We now mention that we explore the contributions of reflectance differences, CTP and pixel registration in the abstract.

P2, l19: What means "nearly identical"? Can you say that in a few words, that readers don't have to look into the literature mentioned. That sentence wasn't clear. There are no algorithmic differences in essence between MODIS on Aqua and Terra. The sentence has been revised to read: "note the MOD06 and MYD06 products are produced by the same algorithm"

P3, l 20: Menzel and Baum papers certainly do not contain C6 change description. The sentence sounds like they would. Pleaser reword. Yes, that was poorly cited. Platnick et al., 2015 is cited instead.

P4, l1: Is this chapter completely taken from literature? Please make that clear and tell the reader whether this is a standard MODIS cloud product from the official data sets or a matter of post- processing. We felt that a summary of the basic material relevant to how CDNC is calculated from COT and Reff would be beneficial to the reader. The reviewer is correct about it being an adaptation of existing literature and needs to be noted as such. We now state in the section that this is adapted from Bennartz, 2007 and also make clear that CDNC is not part of the MODIS cloud product.

P5, l14: Sentence is hardly readable as it is split by the >"independent of vertical stratification" ... By the way, did you talk about this stratification before? Otherwise it only confuses the reader. If it's important here, you have to spend another sentence on it. That was a very difficult to read sentence. We've revised to be clearer. It now states: Common pixel scenes are those in which all three effective radius retrievals are valid for both collections with otherwise consistent selection criteria

P5, L19: That means, you only compare all pixels for which retrieval exist in both

collections for the same phase and for all three combinations. The way you say it is slightly confusing. Please say this in a simpler way. That was also a rather difficult sentence to read. This revised sentence is: . . . free of the influence of pixel population differences due to, e.g., reclassification of cloud phase due to changes to the cloud thermodynamic phase algorithm (Marchant et al., 2016) or where one or more effective radius retrievals have failed between collections (Cho et al., 2015)

P5, l20 Tell us the specific difference you show: C6-C5.1 or C5.1-C6? You could insert "for the common pixels" after "droplet effective radius". C6-C5.1 is now stated in the sentence as well as the for common pixels suggestion.

P6, l10: Tell the reader why re3.7 is considered the most appropriate retrieval? The last sentence of the paragraph now reads . . .re,3.7 is therefore considered to be the most appropriate effective radius for estimating CDNC based upon the assumption of the adiabatic model that the effective radius is the cloud top value.

P6, l25: What is "tau"? Did you introduce the symbol before? Yes. It was introduced in the original manuscript at P3,L6.

P7: Please clarify the whole first paragraph. It is not clear where changes and numbers for them should come from in several places:

1. P7, l1: It is not clear why reff is lowered? Does the surface get darker on average? Then the lookup table would get darker. Bright measurements would be related to more reflective smaller particles. The sun glint, on the other hand, would cause a brighter surface and reverse effect. Am I wrong? Where does the value "1 mu" come from? Literature? Tests? Guessing? Please clarify.

The lookup tables over ocean scenes in C6 now take into account variations in surface reflectance, rather than the fixed 5% Lambertian reflector assumed in prior collections. This better accounts for surface reflectance. With the new lookup tables, this results decrease in retrieved re for optically thin clouds and in sun-glinted scenes, with 1.6

microns being most strongly affected due to greater non-orthogonality of the solution space. As requested below, a case study was included and figure 6 for the case study helps illustrate where the 1 micron value arises in the glint region.

2. P7, l4: Does the re-registration cause any systematic effects? How? Please clarify.

The case presented shows that re-registration results in no significant systematic bias, but the 1.6 and 2.1 micron retrievals are naturally affected more strongly in broken cloud scenes, due more sensitivity to shadowing/illumination differences due to non-orthogonality of the solution spaces.

3. P7, l6: Of what nature where the updates to the CTP algorithm? A 100 hPa change for stratocumulus decks would mean more than 1000 m change in height. Are you sure? Is this for the same pixel population? That must strongly affect the CDNC values towards smaller values, but this emphasis on stratocumulus regions is not striking. Please explain in more detail.

We cite, Baum 2012 as a source of information on CTP changes in C6. For stratocumulus regions with strong inversions, the cloud top height was deemed to be too high (above the inversion). In C6 in those regions the CTP is now about 75-100 hPa higher for the same pixel population. For C6, the above cloud gaseous absorption corrections are stronger, leading to brighter scenes and smaller effective radii, which translates to a higher CDNC.

4. I guess a lower cloud means more absorption. That means cloud of otherwise unchanged properties will appear darker in NIR in the LUT. Looking up a measurement of given reflectivity in such a table would indeed lead to lower Reff, but for other reasons as you formulated.

With a cloud being placed lower, there is a greater absorption correction, which would result in a brighter input to the lookup table, which would result in a lower reff.

P7, l17: Why don‘t you show such a case study? A small 4 panel display of effects

of CTP change, F0 change, emission and total result could illustrate everything. This way the explanation is once more a bit too short and the reader has to accept your explanation without any supporting data.

As mentioned above, we have added a case study which shows how the lookup tables, pixel re-registration, CTP affect all three radii and the influence of F0 and above cloud emission for re,3.7. We feel this case study effectively illustrates what is changing in the retrievals.

P7, l20: The way you aggregate the individual data points I cannot see any additional source of difference. Please explain.

We feel the granule-level results presented in the revised manuscript will help address this. The effects of the 3.7μm changes are often potentially offsetting, and because there are numerous smaller algorithm changes how those effects scale up to the aggregated statistics is really difficult to determine. In other words, for the 1.6 and 2.1μm CER retrievals, the C6 changes impacted the retrievals in a systematic way (generally smaller retrievals), but for 3.7μm the impacts of the C6 changes were often in different directions so it's not clear which change dominates globally (if any one change actually dominates).

P8, l10: "However, in the subtropical subsidence regions, the decrease is near 4%." Why do you use "however"? I do not see a contradiction here? Please clarify.

"However" was ill-chosen. The sentence has been changed to: "The largest observed difference is in the subtropical subsidence regions, where the decrease is near 4%."

P9, l7: Why is it better to exclude the more problematic or different cases, if 1.6 or 2.1 fails and 3.7 worked than the other way round? Please explain.

Since there are roughly $\frac{1}{2}$ as many observations from 1.6 microns, it will be more sensitive to variations in sample size. This is part of the independent pixel comparison, which has been removed from the discussion.

P9, l18: “Biomass season”. Do you mean the “biomass burning season”?

We do, and it has been changed to “biomass burning season”.

P10, l14: There are no statements about optical thickness differences in this manuscript? I’m missing something about it. And about ice properties.

The reviewer is quite correct, optical thickness differences were missing. As discussed in the general comments section, we found that optical thickness had a very minor impact on CDNC. In the manuscript, we now note that C6-C5.1 optical thickness differences are around 0.5 or less, with little geographic variation in the latitudes focused on in this study. Since the study focuses on warm cloud retrieval, we feel that ice microphysics is beyond the scope of the study.

P10, l22: Sentence “N3.7 differences ... uniform.” Two points: 1) Can you say in which N3.7 differences are more subtle in simple words? 2) The sentence does not seem to be a sentence. Please check.

We feel the following is an easier to read sentence: “N3.7 differences are generally smaller and unlike N1.6 and N2.1, the signs of the differences are rarely uniform throughout the annual cycle.”

P11, l3 and last paragraph: You have to draw some conclusions for yourself? It could be something like: further analysis is needed. Please tell the reader. The last sentences are very vague. Can you be a little more specific about new dangers and new posibillities?

The intent was to caution the reader about issues with re3.7 from collection 5.1 which makes comparisons quite difficult. We have revised P11, L3 to read: Additional research is necessary in order to quantify the contribution of these dependencies to the observed intercollection differences of re,3.7 and N3.7. Furthermore, it is recommended that quantitative uses of the C5.1 re,3.7 retrieval be avoided given its known shortcomings. The last sentences have been modified to note that with C6, pixels that

are likely more problematic can potentially be included. While this provides new research oppurtunities, it also, complicates comparisons to aggregated studies such as this because of how retrieval artifacts may compound.

Figure 1: Total of what? Is this for liquid phase clouds only? Is this valid Re3.7? Is this valid CTP retrievals? Pleases tell us.

The revised caption should clarify that. It now states: Annual total of Aqua MODIS liquid phase cloud observations where all three effective radii retrievals are valid per 1 x 1 degree grid box

Figure 2: Does that means that the vertical Reff profile as probed by the three retrievals steepened by 5 mu? Can you comment in the text?

In the discussion of figure 2 we have added a paragraph noting the re differences do not necessarily imply a 5 micron steepening due to the our screening criteria not selecting only adiabatically stratified clouds (r3.7>r2.1>r1.6) and that retrieval artifacts and cloud field inhomogeneities in aggregated scenes complicate the determination of the liquid water content profile.

Figure 4: What happens in regions with increasing CTP and decreasing CTT? How can that happen at the same time. Please comment in the main text.

We now note the increase in CTP in C6 due to altered lowered inversion heights in stratocumulus regions when discussing fig 4a. For the discussion of fig 4b, we note that the changes in CTP placement are largely independent of the CTT changes, allowing for seemingly contradictory differences.

Figure 5: You could maybe skip this figure and discussion in the text. It does not contribute any additional understanding as the independent comparison is, as you correctly state, highly depending on the selected population of pixels. In addition these are mostly problematic pixels, as you also mention, because retrievals failed for one or more channel combinations.

You are correct. We have chosen to remove this section and figure since independent sampling of pixels does not significantly contribute to the understanding of the intercollection differences.

Technical corrections: P.2, l. 3: Typo “though” –>through Fixed

P2, l23: The sentence starting “As there is a considerable ...” does not make sense. Please correct. Fixed

P5, l14: “radii retrievals” –> “radius retrievals” Fixed

Figure 2 caption: Technical slang ... Please replace “products for a) 1.6 mu” by “products using a) 1.6 mu”. This is fixed in the revised plots.

Figure 2-5: Plot titles should be integrated in the caption text and removed. Per the suggestion, plot titles have been moved to the captions.

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