

Reply to: Anonymous Referee #1

General Comments to the Author

The author gives a very detailed critique of the operational MODIS cloud mask (MOD35) aggregation strategy using the CALIOP lidar cloud detection product as “ground truth”. Collocated 1-km CALIOP and Aqua MODIS data is used to assign mean cloud amounts to the four output cloud mask categories (confident clear, probably clear, probably cloudy, confident cloudy) for various illumination and surface types.

The manuscript is very well written and organized with tables and figures that add detail and understanding to the text. The main object of the paper is to ascertain the suitability of the operational aggregation method from pixel level (Level 2) to temporal and spatial averages (Level 3). The current method simply compares numbers of cloudy pixels to the total number when calculating cloud amounts, where “cloudy” includes confident cloudy and probably cloudy categories and “clear” is confident clear and probably clear categories. This makes the implicit assumption that the two cloudy categories indicate 100% cloudiness while the two clear categories imply 0% cloudiness. The author concludes that this method leads to significant errors in regional level 3 cloud amounts and reassigns cloudiness values to each mask output category based on the collocated CALIOP cloud detection data.

My only objection is that the author makes the assumption that variability in the confidence of clear sky depends only on cloud fractions within 1-km pixels. However, there are other possibilities. Some of them are: 1) optically thin clouds that cover an entire pixel (thin cirrus) 2) surface brightness approaches that of clouds 3) orientation of clouds relative to the sun (scattering angle, 3-D effects) 4) variability in surface characteristics (brightness, topography, shadows, land/water boundaries).

The stated philosophy of the MODIS cloud mask is to be clear sky conservative (see cloud mask ATBD), i.e., if there is any hint of cloudiness in a given pixel, it should be considered “not clear”. In this sense then, the practice of considering both confident and probably cloudy pixels to be “cloudy” during aggregation seems reasonable to me, given that no information about cloud morphology is available. However, this is not to say that the present study is not useful as an error analysis or otherwise beneficial to users.

I am recommending the manuscript be accepted for publication with minor revisions as outlined in the specific comments below.

I am aware that the confidence in detecting clear sky is not only a function of cloud fraction within the IFOV. Thermal and reflectance contrast between a cloud and a background is controlled by many factors, including those listed by the Reviewer. The role of the cloud masking algorithm is to account for all of these factors as closely as possible, and maximize cloud detection success. In this study, only the resulting product of cloud detection (the Level 2 cloud mask) is evaluated. There is no attempt to investigate which factor – and to what degree – impacts the performance of the L2 algorithm. It is assumed that the algorithm, and the resulting L2 product, come “as they are”, and are not 100% perfect.

The goal is to use the MODIS L2 product with independent data (namely CALIOP) to evaluate how the further processing of Level 2 observations impacts the uncertainty level of the L3 product (gridded monthly cloud amount). The study does not focus on generating the Level 2 product itself, but on calculating the Level 3 data, which is why cloud detection conditions are not explored in detail. We only consider day-time and night-time differences, latitudinal variability, and individual algorithm paths – assuming the latter reflect variation in the background’s brightness temperature, reflectance, topography, etc. Differences in MODIS and CALIOP sensitivity to cirrus are discussed.

Specific Comments to the Author

Many high, very optically thin clouds detected by CALIOP have no chance to be categorized as cloudy by observations from a passive radiometer such as MODIS. Please mention this as a partial reason for the 21.5% cloud amount associated with confident clear.

Explanation added (in the Discussion section), as suggested.

Abstract: What is the meaning of “uncertainties were related to the efficiency of the cloud masking algorithm”? Please clarify or delete.

This has been deleted in order to keep the abstract concise (clarification at this point would make the Abstract too discursive).

Please delete “Until the algorithm can be significantly modified”. After 20 years, algorithm issues notwithstanding, large and potentially disruptive modifications to the cloud mask are unlikely and probably unwise.

Deleted, as suggested.

Line 133: “IFOV” should be “scan lines”.

In my opinion, ‘IFOV’ is the correct term. The CALIOP-MODIS matching procedure is IFOV-based, not scan line-based. MODIS is a whiskbroom-type scanner, meaning one rotation of the instrument’s mirror results in a scan of 10 lines (considering 1 km detections only). Each line is then divided into 1354 instantaneous fields of view. Only a few, those located close to the MODIS ground track (~10 IFOVs per scan event, ~2030 per data granule) can be matched with CALIOP detections. The use of ‘scan lines’ would be misleading in this context.

Line 183: “probably cloudy” should be “probably clear”.

Corrected.

Line 140: The first two sentences beginning at line 140 are probably better placed at the beginning of Section 3.2. I would eliminate the last sentence of this section as it seems superfluous.

Changed, as suggested.

Lines 152-154: This would be a good place to insert a few words about the difficulty of cloud detection from passive instruments during polar night. Thermal contrast is almost nil in these situations and what does exist is often due to temperature inversions, many times multiple ones, that exist with or without clouds being present. Please explain that in polar night, CALIOP has an even bigger advantage in detecting clouds than in warmer climes.

The discussion has been added – as suggested – however, not in the Results, but in the Discussion section.

Line 258: What is “the most modest version” of the MODIS cloud mask? Please explain or eliminate the phrase.

Clarified, as suggested (changed to Collection 061).

Lines 265-268: Given the errors inherent in remote sensing of cloud properties in general, and in the difficulty of accurate cloud detection in particular, I am surprised that the author would ever expect 100% accuracy from any type of cloud amount calculation. All algorithms are inadequate in some way

and to some extent. I strongly advise the author to eliminate the section beginning with “We found the approach to be inadequate” and ending with “environmental conditions”. The statistics given here are just a restatement of previously reported results. Of course there are limitations to the cloud masking procedure and undoubtedly “certain cloud regimes and/or environmental conditions” are more difficult than others. On the other hand, it is quite fair to report the results of the 100% clear/cloud assumptions in the MODIS cloud amount calculations, as is done immediately following.

The MODIS cloud detection algorithm is only one of many methods, and no method is completely free of limitations. 100% and 0% are only points of reference – the theoretical cloud fraction that an ideal, perfect algorithm would give (if it existed). However, because the Reviewer found this paragraph to be a restatement of previously-reported results, I have followed the recommendation and deleted the suggested part.

Line 275: I think you mean Table 3. Please add a sentence or two justifying the use of collocated near-nadir CALIOP data on entire swaths of MODIS data or a description of a corrective measure.

Corrected and additional information added.

Line 310: The sentence beginning with “Therefore, the standard” is unnecessary.

Deleted, as suggested.

Line 327: Variability is to be expected within algorithm paths as they are necessarily very general categories. The statement that the same thresholds are applied in widely varying locations is not completely true. The important 0.65 μm daytime land cloud test is a function of background NDVI and scattering angle. Please include this information.

Information included, as suggested.

Line 329: Again, the text “Until significant modifications are made to the MODIS cloud masking algorithm,” is unnecessary and a bit high-handed. I would simply begin with “CALIOP-based : : :”.

Changed, as suggested.

References Line 63: Fontana et al., 2013 is missing from the reference list.

Reference added.

Figures and Tables Table 3: Caption should indicate that the cloud fractions listed are CALIOP-based.

Information added, as suggested.