

We'd like to thank the editor for handling our manuscript, as well as reviewer #2 for reading our manuscript and providing numerous, helpful comments. We have carefully read through all the comments and questions and revised the manuscript accordingly. Please find our point-to-point response to reviewer #2 below. Here, the reviewer's general remarks are formatted to be left-aligned text in italic font, the specific questions/comments are shown in left-aligned text in bold and italic font, while our responses are indented and formatted in regular font.

Interactive comment on “Marine boundary layer cloud property retrievals from high-resolution ASTER observations: Case studies and comparison with Terra-MODIS” by Frank Werner et al.

Anonymous Referee #2

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* Overall comment This paper is a technical report that discusses retrievals of cloud properties obtained from ASTER (new generating) and MODIS C6 (existing). The significance of this paper is that this paper reveals bias and differences between ASTER and MODIS products. However, discussion is too long comparing with the volume of contents and a little bit dull. I recommend to authors to refine this manuscript e.g. shorten the paragraphs and focus on a few topics that authors like to emphasis the most.

Questions and minor correction

Line 74: The sentence “there remains no cloud property retrieval algorithm for ASTER” contradicts to the sentence “(Line 66) Zhao and Di and Dey et al. use the high-resolution ASTER reflectance measurements at the $\lambda=0.86\mu\text{m}$ band to derive a statistical description of the macrophysical properties of trade wind clouds”. Please clarify this point.

The referenced paper describes macrophysical properties, i.e., cloud extent and scene cloud cover.

We rephrased this part as follows:

“Despite all these studies, there remains no retrieval algorithm that provides cloud top, optical and microphysical properties for the high-resolution ASTER observations.”

Line 106 and Line 485, Line 723 etc.: I don’t understand the meaning of symbol “delta” in $dA(\Delta\lambda)$.

The symbol $\Delta\lambda$ indicates that the radiance/reflectance is sampled within a specific wavelength range (i.e., a spectral band) and is not a monochromatic (or even close to monochromatic) variable.

We explain this symbol in the following way:

“... the respective wavelength ranges $\Delta\lambda$...” in Line 100 (in the original submission)

and:

“... wavelength range ($\Delta\lambda$)...” in the caption of Table 1.

Line 180: Is it reasonable to use the thresholds of 0.03 and 0.065 that obtained from MODIS algorithm to ASTER analysis?

The reviewer is correct, in that it is not reasonable to just adopt threshold derived for another instrument. However, as stated in the manuscript the cloud masking scheme is independent from the MODIS algorithm and is performed with an ASTER-specific algorithm. The respective thresholds have been derived from extensive analysis of over 210 MBL cloud scenes and just happen to be similar to the MODIS thresholds, which is not so surprising because similar spectral bands are used for cloud masking.

To make sure that we do not just adopt these thresholds we state in the manuscript:

“Similar tests to identify clear-sky pixels have been reported by...”

and

“These thresholds, which comprise the first step in the new cloud masking scheme, were set through inspection of 210 ASTER MBL scenes sampled...”

As shown in Section 3.3, this similarity is understandable, since the VNIR bands of both sensors are very similar.

In Fig 3 : $0.80 > r1 < 1.75$ seems an error. Please correct it.

We fixed this error.

Line 204: Is it reasonable to use the thresholds of 0.065, 0.02, 0.80, 1.75 that obtained from MODIS algorithm to ASTER analysis?

Again, this is just a coincidence. Following our reply to the similar question earlier, we agree that simply adopting these thresholds from MODIS for ASTER is not reasonable. However, for ASTER observations we apply an ASTER-specific cloud masking scheme and thresholds have been developed independently for over 210 MBL scenes. These thresholds happen to agree with the MODIS thresholds, which is not surprising given the overall agreement of both VNIR bands.

Line 215: How to obtain the values of 33.4egs, 63.2degs, and aerosol optical thickness of (0.04-1.49) ? Please clarify this point.

They are the observed ranges of the 210 MBL scenes that were inspected to derive the cloud masking thresholds.

We added this information to the manuscript:

“(observed $\theta_0 = 33.4^\circ - 63.2^\circ$ for the 210 MBL scenes)” and “(observed 0.04-1.49 for the 210 MBL scenes)”

Lin 230: How to scale up the TB11? Please clarify this point.

We removed the reference to “scale up” and this part now just reads:
“In order to match the spatial resolution of the VNIR observations, each $T_{B,11}$ sample at 90m resolution is replicated onto 36 subpixels with a horizontal resolution of 15m.”

This replication is also illustrated in the Figure below:

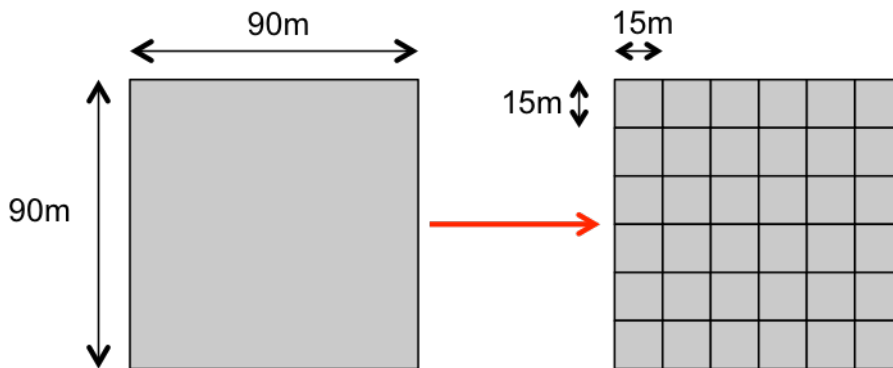


Figure 1: Sketch of replicating a single 90m $T_{B,11}$ sample at 90m resolution to match the ASTER VNIR resolution of 15m.

Line 244: What does “a single case-by-case threshold for $\gamma_{0.86,A}$ ” mean?

The cloud masking scheme introduced in Zhao and Di Girolamo (2006), Uses a single threshold for the sampled digital counts in the ASTER VNIR band (instead of multiple tests), which is determined individually on a case-by-case basis.

As an example, this threshold might be 120 (digital counts out of 255) for one scene, but 90 for another, and 101 for a third scene.

Please note that in the originally submitted paper we mistakenly wrote that Zhao and Di Girolamo (2006) apply a threshold for VNIR reflectances $\gamma_{0.86,A}$. This has been corrected in the revised manuscript.

Line 255: $-0.04 > \Delta CA < 0.04$ seems an error. Please correct it.

We fixed this error.

Line 296: Why do you use such a complex method such as “If the calculated cloud top pressure is larger than 650mb the operational MODIS C6 IR window retrieval algorithm is used to calculate the final value of cloud top pressure”? Please clarify this point.

As mentioned throughout the manuscript, we adopt the operational MODIS C6 retrieval algorithm for ASTER. MODIS applies the IR window technique when the CO₂-slicing algorithm, if the latter is unable to retrieve a valid cloud-top pressure. This can happen if the cloud signal signal in the thermal bands between 13.3 and 14.2 μ m is too low. More information on the applied IR window technique in C6 is provided by Baum (2012), which is also referenced in the manuscript.

Line 337 and Line 326: There are two similar sentences to explain the Cox and Munk (1954a, b). Could you unify these two sentences into one?

We changed the first mention of the Cox-Munk parameterization as follows: “This wind speed is used as input in the parameterization following Cox and Munk (1954a, b), which yields the wind speed-dependent bidirectional ocean surface reflectance.”

We changed the second mention as follows:

“Similar to the correction of surface contributions, the ocean surface reflectance is obtained from the Cox-Munk parameterization, as implemented in the radiative transfer library libRadtran (Mayer and Kylling, 2005; Mayer, 2009).”

This changes help in avoiding the multiple explanations of the wind dependence and the double citation.

Line 348: How to scale up SWIR (30m) in to 15m spatial resolution?

We removed the confusing mention of “scale up” and the revised sentence reads:

“It must be noted that for the cloud property retrieval at 15m horizontal resolution each SWIR reflectance sample at 30m resolution is replicated onto 4 subpixels to match the band 3N resolution.”

See also Figure 1.

Line 370- and Eq (4): I cannot understand significance of examining the scale factor $f_{0.86m}$ LUT, because you have set up ASTER LUT and MODIS LUT, individually. There are no mean to examine ratio (scale factor) of LUT values. Please clarify this point.

The reviewer is correct in that the difference between the respective ASTER and MODIS bands is accounted for in the respective LUTs. However, the scale factor is introduced to better compare sampled reflectances in Section 5.2.1 and 5.3.2.

We clarified this fact in the revised manuscript, by stating at the end of Section 3.3:

“The calculation of the ratios $f_{0.86, L}$ and $f_{2.1, L}$ allows for a direct comparison of measured ASTER and MODIS reflectances, as illustrated in Section 5.2.1. and Section 5.3.2.”

Line 406: It is difficult to understand “124 ASTER scenes” and “48 MBL cloud case”.

We thank the reviewer for noticing this artifact of an old version of the manuscript. In this older version we put more emphasis on distinguishing the different regions where the ASTER scenes were sampled. Overall, we currently have 210 ASTER MBL scenes, most of them sampled either off the Coast of California or during in the tropical Atlantic. These latter cases are trade wind cumulus scenes with a very low cloud cover. As a result, we limited the data set to scenes sampled off the Coast of California.

We rewrote this part as follows:

“For this reason, not all of the 210 ASTER MBL scenes, that were used in evaluating the 15m cloud mask in Section 3.1, are sufficient. The scenes sampled in the tropical western Atlantic (Zhao and DiGirolamo, 2006) were populated entirely by trade wind cumuli with a peak in the cloud fraction distribution at 400-500m in cloud equivalent diameters (see Zhao and Di Girolamo, 2007). The data set used in the following comparison consists of 48 MBL scenes sampled over the Pacific Ocean off the Coast of California between 05/2003 and 07/2007. Granules were manually chosen to include MBL clouds that resemble altocumulus or broken cumulus scenes and thus are characterized by extensive MBL cloud cover and cloud sizes.”

We also changed “cloud cases” to “scenes”

Line 412: 48 MBL cloud cases were sampled between 05/2003 and 07/2007. However, in line 123, it is mentioned that “the SWIR signal started to suffer from anomalous striping and saturation of values due to an increase in the SWIR detector starting in May 2007”. Is it unreasonable to use 05/2007 to 07/2007 data for the cloud retrieval?

The ASTER SWIR data issue is connected to the detector temperature. As noted by the ASTER team: “As long as the detector temperature remains at 83°K, little or no degradation of ASTER SWIR data is expected.” Information and graphs on this issue can be found on the ASTER science team website: <https://asterweb.jpl.nasa.gov/swir-alert.asp>

For a brief period in June and July 2007 attempts to reduce the detector temperature were successful and the SWIR data quality was fine. As mentioned in the manuscript, we made sure that the scenes from 2007 were not impacted by the temperature problems of the SWIR detector.

Line 416: How to eliminate overlying cirrus scenes and complex multi-layered cloud system?

From the whole data set we selected possibly suitable scenes based on the inspection of the RGB image of each scene. Subsequently, the MODIS cloud phase and cloud top height retrievals were used to eliminate scenes with thin cirrus clouds that were not visible in the RGB maps.

Line 457: Why there appeared cloud holes in MODIS than ASTER?

The MODIS retrieval is performed at 1km, while the ASTER retrieval is performed at 15m. The lower resolution of MODIS means that the pixel values are aggregated over low cloud reflectances and even lower ocean surface reflectances. This means, that the 1km pixel values is too low and the retrieval fails, where ASTER yields successful retrievals for the low cloud reflectances.

We added this additional information to the manuscript:
“...there are visibly more MODIS pixels throughout the granule where the retrieval fails. These pixels are characterized by $R_{0.86,M}$ and $R_{2.1,M}$ (sampled at 1000 m) that are too low for a successful cloud property retrieval (i.e., measurements fall outside the LUT).”

Line 468: It is difficult to identify “visible striping in the reff, M results in this figure.

The striping is definitely not as pronounced for the presented scenes, but it can be much worse for granules. However, people familiar with MODIS measurements noticed the striping in these scenes. For that reason we decided to include this sentence in order to avoid confusion with some readers.

In the Figure below (a close-up of Figure 8d) slight striping becomes apparent.

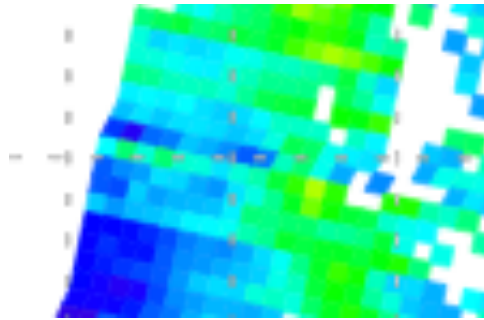


Figure 2: Slight striping visible in a close-up of Figure 8d.

Line 497: what does 4400 and 1100 pixels mean in this sentence.

A MODIS pixel has a horizontal resolution of 1000x1000m. VNIR and SWIR ASTER pixels are characterized by 15x15m and 30x30m resolutions, respectively. This means that a MODIS pixel contains $(1000/15 * 1000/15) > 4400$ ASTER VNIR pixels.

We added the following information in the revised manuscript:
 “Taking into account the different spatial resolutions of both instruments (1000m for MODIS, 15m for the ASTER VNIR band, 30m for the ASTER SWIR band)...”

Line 549: It is difficult to identify black circles and gray circles in the Fig.11 because the figure size is too small. It may be a technical problem but significant to audiences. Please improve Fig. 11.

The upper row shows retrieval results for the very homogeneous scene C14. This case includes no partially cloudy pixels. As noted in the reply to reviewer 1, Figures 10 and 11 in the old manuscript were actually older versions of the correct Figures. We tested the effects of different cloud masking algorithms and LUT resolutions on the retrieval comparison and just implemented the wrong version of these Figures. We updated both Figure 10 and 11 to the final versions, using the correct cloud mask. We also removed the “Overcast” and “Partial” for the homogeneous case C14 to remove any possibility of confusion (as there are no partially cloudy pixels for this case).

Not affected were the statistical analysis plots Figure 12-14, which used the correct LUTs, as well as the correct version of the cloud masking algorithm.

We decided against shrinking the y-axis to put emphasis on the significant differences that are obvious for the inhomogeneous cloud scene shown in c) and d). We think that this also illustrates why the large differences between MODIS and ASTER retrievals, shown in Figures 11c-d for the inhomogeneous scene C19, are not observed for C14.

We apologize for the confusion and thank both reviewers for noticing that there was something wrong with the Figures.

Line 573: I cannot find “-12.36um” of r_{eff} , AaM - $r_{eff,M}$ in the figure 11.

We thank the reviewer for noticing this error. As noted in the previous reply, this was an older version of the Figure, where we tested the effects of different cloud mask algorithms on the retrieval comparison. We updated the Figure to the final version, using the correct cloud mask. This error also affected Figure 10, which has likewise been corrected. Not affected were the statistical analysis plots Figure 12-14, which used the correct version of the cloud masking algorithm.

Line 663: What does “ τ_M , $\tau_{AaM}=0.17-24.92$.” mean? I cannot find that range of values of τ between 0.17 to 24.92 in Fig. 14(b).

The lowest retrieved optical thickness from the 48 MBL scenes is 0.17. These numbers are mentioned to give the reader the observed ranges (similar to the mention of the observed ranges in the reflectance comparison). The (0-1)-bin in Figure 14b shows such low optical thickness observations for both ASTER and MODIS. For the very large optical thicknesses there are only very few observations for PCL pixels, which makes the PDF value very low. We feel that logarithmic axis would not help the visibility of Figures 14a-14d.

Line 668: What does “ $r_{eff,M}$, r_{eff} , $AaM = 4.76\mu m$ ”? I cannot find that 4.76um will have a specific values in Fig. 14 (c).

The lowest retrieved effective droplet radius from the 48 MBL scenes is 4.76 μm . As before, we wanted to mention the observed value range of retrieval results for the comparison (similar to the mention of the observed ranges in the reflectance comparison). As seen in Figure 14c there are some observations in the bin 4-5 μm , which includes this specific value.

Line 672: $10.00\mu m > r_{eff,M}$, $r_{eff,AaM} < 20.00\mu m$ will be an error.

We fixed this error.

Line 679: $0 > \tau_{AaM}$, $\tau_M < 5$ will be an error.

We fixed this error.

Line 710: Where does “15% to 30%” come from. Can you add some references?

The MODIS MCD43D product yields daily 16-day (averaged) BRDF/Albedo data. Information about this product and its uncertainties can be found online at:

https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mcd43d61_v006

or in, e.g., Mira (2015).

The 15% albedo bias can be attributed to measurement uncertainties and the fact that the 16 day average is not the actual value at the time of the cloud retrieval. Information about the albedo uncertainty is reported in the Summary of the Changes in the MODIS Collection 5 Cloud Optical Property Retrieval Algorithm. It can be accessed online at: http://modis-atmos.gsfc.nasa.gov/_docs/C005CloudOpticalPropertiesver3.3.pdf

In the ASTER retrieval algorithm we use the MODIS BRDF/Albedo CMG Gap-Filled Snow-Free Product MCD43GF V005, which is reported for the MODIS spectral bands. There is no albedo product for ASTER, so we have to make due with the MODIS results.

The 30% value is our estimation of the uncertainty for ASTER, due to the fact that we use the MODIS surface albedo product. It is very conservative and for measurements over the ocean probably too high. As mentioned throughout the manuscript, the algorithm is a research-level retrieval algorithm and for now this value is our best guess for the surface uncertainty contribution.

Line 749: I cannot identify visible striping in Fig 8(b) and 8(d).

Please see our answers to the similar question: "***Line 468: It is difficult to identify "visible striping in the reff, M results in this figure. "***

References:

Baum, B. A., Menzel, W. P., Frey, R. A., Tobin, D., Holz, R. E., Ackerman, S. A., Heidinger, A. K., and Yang, P.: MODIS Cloud-Top Property Refinements for Collection 6, *J. Appl. Meteor. Climatol.*, 51, 1145–1163, doi:10.1175/JAMC-D-11-0203.1, 2012.

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Zhao, G. and Di Girolamo, L.: Cloud fraction errors for trade wind cumuli from EOS-Terra instruments., *Geophys. Res. Lett.*, 33, L20 802, doi:10.1029/2006GL027088, 2006.

Zhao, G. and Di Girolamo, L.: Statistics on the macrophysical properties of trade wind cumuli over the tropical western Atlantic, *J. Geophys. Res.*, 112, 2007.