We’d like to thank the editor for handling our manuscript, as well as reviewer #1 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 #1 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.

Point-to-point Response to Anonymous Referee #1

Received and published: 29 August 2016
'Marine boundary layer cloud property retrievals from high-resolution ASTER observations: case studies and comparison with Terra-MODIS', F. Werner, G. Wind, Z. Zhang, S. Platnick, L. Di Girolamo, G. Zhao, N. Amarasinghe, and K. Meyer, submitted to AMT

This manuscript describes a long overdue attempt at cloud optical thickness (COT) and effective radius (CER) retrievals from the ASTER instrument using a MODIS-like look-up table approach. Some adjustments have to be made because of spectral response function differences but overall the approach is very similar. As ASTER and MODIS are located onboard EOS-Terra that makes pixel-level comparisons (as done in this paper) straightforward with new insights gleaned on resolution-dependent issues between the two instruments.

This is an excellent paper that is very straightforward in its presentation and messaging with two primary purposes: to describe the retrieval, and compare the ASTER results to MODIS Collection 6 retrievals. A couple of case studies are presented in detail with images shown and details of the scene described at length, then 48 scenes are shown for statistical comparisons between ASTER and MODIS. In my opinion, there is little to improve upon in this paper and I only have a few minor revisions to suggest and comments to make below.

What about the land challenge? Can this approach be extended to land retrievals without much development? Are there plans to do so, and if not, why not?

As mentioned in lines 323-324, one of the inputs for the retrieval algorithm is the gap–filled MODIS surface albedo product (Moody et al., 2005, 2007, 2008). ASTER even samples observations around $\lambda=0.66$ μm, a channel MODIS usually employs for retrievals over land surfaces. This means that there are no technical limitations preventing a cloud property retrieval over land. ASTER also has a channel centered around $\lambda=1.6$ μm, which (in combination with the usual 2.1 μm band) is suggested in Platnick et al. (2001) and Moody et al. (2007) for retrievals over sea ice.

However, retrievals over land require a more thorough testing of the cloud mask, together with possible adjustments to individual cloud mask tests. As for MODIS, cloud property retrievals over land induce larger uncertainties in retrieved cloud products due to the larger uncertainties in the highly variable surface albedo. This is the reason for just choosing scenes over the ocean for this comparison study.

The MODIS cloud mask algorithm MOD35 can not be applied directly to

ASTER because the MODIS cloud mask algorithm uses many more channels than are available on ASTER, notably the 1.38µm channel and many IR channels as described in Ackerman et al (2006), many more than ASTER carries.

We mention the possible adjustments to the cloud masking scheme for scenes with different characteristics (such as cloud scenes over land) in Section 3.1:
"As demonstrated below, the quality of the cloud mask tests meet the purpose of this study and are believed to be more broadly appropriate for deep ocean scenes, in atmospheres with low aerosol turbidity, and outside of strong sun–glint and large θ_0. However, it should be noted that further refinements of these thresholds are likely for investigations outside the scope of this study."

Extending our cloud masking and cloud property retrievals to land is certainly on our to-do list for future research.

p. 3 around lines 65-75: there is at least one other attempt at an ASTER cloud mask that could be considered for citation (if deemed relevant): Hulley, G. C., and S. J. Hook (2008), A new methodology for cloud detection and classification with ASTER data, Geophys. Res. Lett., 35, L16812, doi:10.1029/2008GL034644.

Thanks for this relevant reference, we included this study in the introduction:
"Hulley and Hook (2008) describe a number of spectral tests to distinguish cloudy observations from those over different surfaces and cloud shadows."

Lines 101-102: do the authors think that the backward-viewing direction has some potential to improve upon the ASTER COT and CER retrievals? If so, what geophysical field(s) would this benefit the most?

The backward-viewing 0.86 band is indeed interesting. However, three factors complicate the application of this band in the cloud property retrieval:

(i) The viewing geometry for the backward-viewing 0.86 band is different from all other channels. For a perfectly plane-parallel cloud this can be handled by an adjustment to the LUT. For clouds with a complex 3D structure and varying cloud top heights, however, 3D radiative effects can impact the two channels used in the retrieval in different ways. The two bands might even sample different parts of the cloud.
(ii) There is a time lag between the samples in forward and backward direction.
(iii) The backward-viewing image is offset with respect to the nadir image,

which requires complicated cross-registering of all pixels. Because ASTER pixels are so small (15m and 30m for the VNIR and SWIR band, respectively), pixel co-location needs to be extremely precise and small differences would induce additional uncertainty in the retrieval.

As mentioned in the introduction, Seiz et al. (2006) and Genkova et al. (2007) uses the stereoscopic capabilities of ASTER for cloud top height analysis. There The retrieval here is similar to the cloud top height retrieval approach by the Multi-angle Imaging SpectroRadiometer (MISR) described in Moroney et al. (2002). The retrieval of cloud top heights from ASTER might benefit from the backward-viewing channel.

Section 3.2.1 cloud top properties: First, it wasn't fully clear how the ASTER pixel level data was averaged up to the MODIS resolution. Second, are all ASTER retrievals done at the ASTER resolution then averaged to the MODIS resolution for comparison, or are the reflectances/radiances averaged then the retrieval is performed? It appears that the former was the case for most, if not all, of the paper but it should be made clearer or in a few places if made already. Third, are retrievals compared if ASTER is partly cloudy within a cloud-identified MODIS pixel?

The retrieval of cloud top properties, as well as optical and microphysical parameters, is independent from the MODIS resolution and the ASTER cloud top property retrieval does not require averaging to the MODIS resolution. Therefore, everything stated before Section 5 (i.e., the cloud masking scheme, retrieval algorithm, …), is completely independent from the MODIS resolution. Only later in Section 5, do we aggregate the ASTER observations within the MODIS geometry to show the viability of the retrieval algorithm.

We looked at the introduction of Section 3.2 again and believe that the confusion possibly stems from this part:
"… eliminates uncertainties when comparing retrieval products between the different sensors. This allows for a comprehensive comparison between the MODIS and ASTER results without biases due to the applied set of equations."

Again, Section 3 only documents the retrieval setup and differences to the operational MODIS code. Everything is completely independent from the MODIS resolution and, as shown in Figures 7a-c and 8a-c, yields retrievals at the native ASTER resolution of 15m. As a result, we shortened the introduction to Section 3.2:
"The research-level ASTER retrieval setup uses the same algorithms as the operational MODIS C6 retrieval, which has been extensively tested and documented."

Moreover, the introduction to Section 5 (i.e., the comparison between the ASTER and MODIS retrievals) now includes the following sentences:

"By employing the operational MODIS C6 retrieval algorithms, uncertainties in the comparison of retrieved cloud products from both sensors are mitigated. This allows for a comprehensive comparison between the MODIS and ASTER results without biases due to the applied set of equations."

We believe that these steps help in clearing things up, especially since information about aggregation immediately follow in the first sentence in Section 5.1, "… the high–resolution ASTER digital counts $d_A(\Delta\lambda)$ are aggregated within each (1000·1000) m MODIS pixel."

Regarding the retrieval for partially cloudy pixels: A retrieval is always attempted (if the pixel is considered cloudy), and in the comparison we differentiate between overcast and partially cloudy pixels. This fact is stated at the beginning of each individual subsection in the Section 5 (e.g., in lines 514, 548, 619 and 657).

Line 413: constrained

We fixed the spelling error.

Lines 580-587: how do the ASTER uncertainties fall within the MODIS uncertainties? Does this work yield further insight on the character of MODIS COT and CER pixel-level uncertainty estimates?

We now provide information on the derivation of pixel-level ASTER uncertainty estimates in Section 3.2:
"The current MODIS retrieval products provide pixel-level uncertainty estimates for τ and r_{eff}. Because the ASTER retrieval algorithm deploys the same retrieval code, ASTER pixel-level retrieval uncertainties are derived in a similar way. They are comprised of uncertainties in the applied surface albedo (15%), calibration and model uncertainties (5%) and uncertainties in the amount of above-cloud precipitable water, which are an input variable in the atmospheric correction (20%)."

This means that ASTER retrieval uncertainties are almost identical to the MODIS results, with two exceptions:
(i) The gap-filled albedo values, employed for retrievals over land, are provided for the MODIS SRF. (This is not important for this study, as we only compare maritime cloud scenes.)
(ii) MODIS C6 pixel-level uncertainty estimates include scene-dependent L1B uncertainties, while ASTER uses a constant value.

Both differences to the operational MODIS C6 product are now mentioned in Section 5.4:
"Since the land surface albedo product is created for MODIS bands 1-7 and there is no specific surface albedo product for ASTER, the SRF differences

between ASTER and MODIS bands induce uncertainties in the derived spectral surface albedo values. This is acknowledged by an increase in surface albedo uncertainty from 15% to 30% in the pixel-level uncertainty calculations. However, since the focus of this study is on MBL clouds sampled over ocean, this effect is mitigated by the use of ocean surface reflectances derived from the Cox-Munk model generated using the precise ASTER SRF."

And:
"The pixel-level uncertainty estimates for retrieved cloud products based on ASTER observations are comprised of uncertainties in surface albedo, radiometric calibration, the applied models and the amount of above-cloud precipitable water. This closely follows the MODIS Collection 6 approach and yields similar retrieval uncertainties for both the ASTER and MODIS results. However, while for ASTER the calibration and model uncertainties are assumed to be a constant value of 5%, uncertainties in the operational MODIS C6 cloud products include spectral, scene-dependent Level-1B uncertainty indices (Sun et al., 2012)."

New insights into the MODIS pixel-level retrieval uncertainty estimates can be gathered by the high-resolution sub-pixel reflectance distribution. Following the discussion in Platnick et al. (2004) and Zhang et al. (2016), high-resolution reflectance samples can be used to explain, and possibly correct for, biases in retrieved τ and r_{eff}.

We added these outlooks in the Summary:
"ASTER observations at native resolution can help in determining the subpixel cloud structure of heterogeneous cloud pixels, which result in significant uncertainties in the cloud property retrieval (Marshak et al., 2006). Studies by Platnick et al. (2004) and Zhang et al. (2016) show that information about the subpixel reflectance distribution can be used to explain, and possibly correct for, biases in retrieved cloud optical thickness and effective droplet radius. Similar analysis on the distributions of subpixel $\gamma_{0.86,\mathrm{A}}$, $\gamma_{2.1,\mathrm{A}}$, τ_{A} and $r_{\mathrm{eff,A}}$ can improve the understanding of MODIS PCL retrievals and their uncertainties."

Lines 753-756: it is somewhat unclear in the way currently described how the ASTER uncertainties are obtained. Maybe a graphic, table, or improved discussion will help clarify.

We agree with the reviewer and added the following information in Section 3.2:
"The current MODIS retrieval products provide pixel-level uncertainty estimates for τ and r_{eff}. Because the ASTER retrieval algorithm deploys the same retrieval code, ASTER pixel-level retrieval uncertainties are derived in a similar way. They are comprised of uncertainties in the applied surface albedo (15%), calibration and model uncertainties (5%) and uncertainties in

the amount of above-cloud precipitable water, which are an input variable in the atmospheric correction (20%).”

Additional information about the MODIS and therefore ASTER pixel-level uncertainly calculations can be found in Platnick et al. (2016).

Figure 3: the authors may want to consider labeling flag=0,1,2,3 also as the four categories of clear/cloudy and how they map to the MODIS cloud mask. Labeling as flag=0,1,2,3 makes the figure less useful because you have to page to the discussion to figure it out.

We agree with the reviewer and added the four categories to flags 0-3 in Figure 3. We also added a sentence in the Figure caption:
“The results of tests (i)-(iv) yield a designation of cloudiness flag '0' (confidently cloudy), '1' (probably cloudy), '2' (probably clear) or '3' (confidently clear) for each pixel”.

The naming convention follows the MODIS designation, which is made clearer in Section 3.1, where a new sentence states:
“Following the MODIS cloud mask designation presented in Platnick (2003), ASTER pixels can be flagged as confidently cloudy, probably cloudy, probably clear, or confidently clear.“

Figure 9: are MODIS pixels really perfect squares? How does the spatial weighting of the reflectance as seen by the instrument look like within the pixel? Same point about ASTER. Any references of previous work discussing current state of knowledge of pixel-level characteristics would benefit the methodology of the paper.

The reviewer’s concerns about the shape of a MODIS pixel are valid, as MODIS pixels are not always perfect squares. We added the following information in Section 5.1:
*“*It must be noted that while MODIS pixels from scene C19 can almost be considered squares, this is not universally true for all MODIS pixels. Scenes closer to the edge of a MODIS swath are characterized by an increase in pixel size along the scan direction.”

The reviewer is also correct that MODIS samples are characterized by a point spread function (PSF), where the largest contribution of a MODIS signal comes from the center of the pixel and slightly extents past the pixel borders. We mention this issue in Section 5.4, where we say:
“Moreover, uncertainties arise due to the MODIS point spread function (PSF), which characterizes the signal distribution within and outside a MODIS pixel (Huang et al., 2002). While $d_A(\Delta\lambda)$ from all ASTER samples contribute equally to the aggregated signal, the MODIS PSF implies that the largest

contribution in a MODIS signal comes from the center of the pixel, while there is also a noticeable influence from surrounding pixels."

If we were interested in a thorough instrument characterization, or even cross-calibration, this would be an issue. Ideally, a similar PSF could be assumed for each 15m and 30m ASTER pixel. Subsequently, for each MODIS pixel, some sort of aggregated signal from each of these ASTER pixels (including their PSF) could be constructed, following the overall MODIS PSF. We have not done such an analysis. However, the goal of this paper is to show the feasibility of reliable, high-resolution ASTER retrievals. Because of the very good agreement, we feel comfortable in showing the retrieval comparison as presented in the manuscript, with the acknowledgment that the PSF induces uncertainties in the comparison.

Figure 11: Impossible to see 'partial' in the upper row. May consider shrinking y-axis scale or presenting data in a different manner if seeing gray points is a key take-away from this figure.

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 2, 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.

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