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Comment on acp-2021-453

Anonymous Referee #2

Referee comment on "Optically thin clouds in the trades" by Theresa Mieslinger et al.,
Atmos. Chem. Phys. Discuss., <https://doi.org/10.5194/acp-2021-453-RC3>, 2021

General Comments:

This paper highlights the challenges in quantifying cloud cover in trade wind cumulus cloud regimes from passive satellite measurements. It focuses on the toughest conditions: optically thin low clouds. It uses ASTER measurements during the during EUREC4A field campaign. Employing a conservative approach to identify confidently cloud-free areas, it quantifies the percentage of optically thin cloudy pixels classified as clear by the ASTER cloud mask algorithm, which is a threshold-based method of classifying pixels as clear or cloudy. The authors also use WALES HSRL lidar measurements to identify the fraction of optically thin low clouds over a smaller spatial domain and on fewer days than what is used for the ASTER analysis. It then attempts to quantify the impact of misclassifying optically thin clouds as clear on cloud radiative effect and discusses the implications of cloud masking errors on satellite-based studies of aerosol-cloud interactions.

Trade cumulus clouds have a significant influence on Earth's radiation budget yet are difficult to characterize both in observations and models. This topic is therefore of scientific importance and merits publication after major revisions (described below) are addressed.

- The ASTER cloud mask identifies pixels in four categories: confidently clear, probably clear, probably cloudy, and confidently cloudy pixels. In this study, a simulated clear-sky reflectance distribution constrained by ASTER cloud mask "confidently clear" pixels is used to identify optically thin clouds. By design, it seems that this approach assumes pixels identified as "probably clear" are optically thin clouds, which may not necessarily be true, especially in the vicinity of pixels that are probably or confidently cloudy. As a result, the authors may be overestimating the impact of what they are calling "optically

thin clouds" since an unknown fraction of these may in fact be clear (e.g., humidified aerosols). There is no attempt to quantify the fraction of "optically thin clouds" that are clear (humidified aerosols). While this is likely not possible using the ASTER measurements, I believe the WALES lidar measurement can provide some relevant information, at least in the region and on the days WALES measurements are available.

- The clear-sky methodology introduced in Section 3 and the ASTER cloud mask of Werner et al. (2016) are not independent since the ASTER cloud mask's "confidently clear" population is used as input to the "clear-sky" method. It seems like the "probably clear" population from the ASTER cloud mask likely makes up the bulk of what is classified as "optically thin clouds" from the "clear-sky" method. If the "confidently clear" population from the ASTER cloud mask were too conservative or not conservative enough, how would this impact the results? That is, what is the sensitivity of the final results (fraction of undetected optically thin clouds) to the thresholds used in the ASTER cloud mask?
- What fraction of the pixels identified as "optically thin cloud" by the methodology in Section 3 are classified as confidently clear, probably clear, probably cloudy, and confidently cloudy pixels by the ASTER cloud mask? I suspect close to 100% fall into the "probably clear" category, but it would be interesting to know.
- The WALES comparisons to ASTER would be more meaningful if the same days and region were considered in both cases. Table 3 compares 395 ASTER regions over 60x60 km² with WALES from 13 research flights (days) and over a limited spatial domain. Given the spatial and temporal variability of trade cumulus, this does not seem like an apples-to-apples comparison. Is there any reason why the authors can't make a more direct comparison (e.g., compare the same days and location)?
- There is a danger that readers might be led to believe that all cloud masking algorithms share the same biases as the ASTER cloud masking algorithm of Werner et al. (2016). This may very well be the case, but it has not been shown in this paper. As a result, the paper needs to clearly state that the results shown here only apply to the ASTER cloud masking algorithm.

Specific Comments:

Title of paper: Consider adding "low" or "shallow" before "clouds" in the title.

Line 6: "In this study we develop a method to quantify the cloud cover from a clear-sky perspective."

At this point in the paper (abstract), it is not at all obvious what this means. Consider revising or removing this sentence.

Line 9: "common cloud masking algorithms".

Only the ASTER cloud masking algorithm of Werner et al. (2016) is considered in this paper. "Common cloud masking algorithms" is therefore misleading and should be replaced with "the ASTER cloud masking algorithm".

Lines 9-10: "We find that the cloud-mask cloud cover underestimates the total cloud cover by a factor of 2."

This should be replaced with: "We find that the **ASTER** cloud-mask cloud cover underestimates the total cloud cover by a factor of 2."

Line 11: "a high abundance of optically thin clouds"

Please specify whether these are optically thin low clouds or high clouds (or both).

Lines 17-18: Earth's trade wind regions combine a dry atmosphere and a high abundance of shallow clouds"

What about thin cirrus above the shallow clouds? Is this not a common feature? How is thin cirrus screened from the ASTER analysis?

Line 20: "Changes in the cloud radiative effect with warming pace cloud feedbacks"

This phrase is unclear. Please reword.

Lines 30-31: "Estimating the cloud cover is a well-known issue in the sense that it decisively depends on the instrument used and the purpose of respective datasets."

The paper below could be cited here (in fact, I'm surprised that it was not cited at all):

- J. Stubenrauch et al., "Assessment of global cloud datasets from satellites: Project and database initiated by the GEWEX radiation panel," Bull. Amer. Meteorolog. Soc., vol. 94, no. 7, pp. 1031–1049, 2013. doi: 10.1175/BAMS-D-12-00117.1.

Lines 44-47: The method used here ("clear-sky approach") depends upon the ASTER cloud mask clear-sky distribution as a starting point. As a result, It is not independent of existing cloud thresholding approaches.

Lines 52-53: "With the clear-sky approach we can detect enhanced reflectances from anomalously humidified aerosols and optically thin cloud areas that are undetected by traditional cloud-masking algorithms."

How do you distinguish between these two? Are humidified aerosols classified as optically thin clouds instead of clear? The humidified aerosol cases are likely classified as "probably clear" by the ASTER cloud mask and (presumably) optically thin cloud using the methodology described in Section 3.

Line 53: "With the clear-sky approach we can detect enhanced reflectances from

anomalously humidified aerosols and optically thin cloud areas that are undetected by traditional cloud-masking algorithms”.

Some groups use both approaches (e.g., Trepte et al., 2019).

Lines 68-69: “a Sun-synchronous orbit with an equator crossing time of 10:30 local solar time”

“a **descending** sun-synchronous orbit with an equator crossing time of 10:30 local solar time”

Line 75: Cite Werner et al. (2016) reference after “ASTER cloud mask”.

Lines 76-77: “We further draw comparisons to the ASTER cloud mask which is based on several bands in the VNIR.”

The two methods are not independent since the ASTER cloud mask’s “confidently clear” population is used as input to the “clear-sky” method described in Section 3. It seems like the “probably clear” population from the ASTER cloud mask likely makes up the bulk of what is classified as “optically thin clouds” from the “clear-sky” method. The “optically thin clouds” are likely a mixture of humidified aerosols, optically thin low clouds and (possibly) optically thin high clouds.

If that is the case, the authors should point this out. As written, it sounds as if the two methods are independent.

Lines 89-92: Did WALES detect any thin cirrus above the trade cumulus in any of the scenes? This should be noted.

Line 117: "lowest pressure level 1000 hPa".

Should this be lowest ALTITUDE pressure level?

Lines 133-135: "Knowing the theoretical clear-sky contribution to an all-sky ASTER image we can then investigate the cloud-related contributions that are undetected by the cloud mask and which we attribute to optically thin clouds."

In broken cloud conditions, part of the observed clear-sky radiance is contaminated by scattering from cloud layers adjacent to cloud-free areas, which then redirect some of the scattered light into the sensor field-of-view. This results in a positive "clear-sky" radiance bias. This effect likely is not accounted for in the theoretical clear-sky calculation, so that some clear areas might be erroneously flagged as cloudy. Is there a sense of what the magnitude of this bias is? This should at least be mentioned here and maybe discussed in more detail later in the paper.

Also, how does one distinguish between thin low clouds, thin high clouds and humidified aerosols? It seems these are all grouped together as "optically thin low clouds", which may not be true in reality.

Section 3.1: Has the simplified clear-sky model (SCSM) been compared with a more sophisticated model to assess the uncertainty in the clear-sky radiance calculations? From Appendix A, it appears not.

Lines 149-150: "Although the aerosol load does not vary much within a 60 x 60 km² ASTER image"

This is only really true for completely cloud-free conditions, free of dust and smoke plumes. In broken cloud regions, the AOD certainly vary appreciably due to humidification of the aerosols. Please clarify.

Line 151: "We assume that the pixels labeled confidently clear in the ASTER cloud mask are a good first guess for clear-sky and shall serve as a reference for finding a suitable effective AOD such that the simulated clear-sky values are in close agreement with the selected ASTER pixel values."

So, the simulated clear-sky reflectance distribution is really constrained by the ASTER cloud mask's "confidently clear" pixels? By doing so, do the authors implicitly assume that pixels identified as "probably clear" are optically thin clouds? How do you know this for sure? How would the results change if the ASTER cloud mask were less conservative and labled some of the "probably clear" pixels as "confidently clear"?

Lines 158-159: "We further optimize this image AOD value iteratively by minimizing the summed squared difference between simulated and observed reflectances."

AOD for each pixel or for the entire distribution of pixels?

Line 162: "From comparing simulated clear-sky reflectance distributions to the observed ones for fully clear-sky ASTER observations".

This sentence is unclear. What does "fully clear-sky ASTER observations" mean. Does this refer to "confidently clear" and "probably clear" pixels? Please clarify.

Lines 171-172: "However, the ASTER dataset is confined to a narrow set of sensor-sun geometries and outside of possible sun glint observations."

Is a glint angle threshold used to define areas influenced by glint? If so, please specify the value.

Lines 174-176: "The output from our SCSM model provides us with a distribution of clear-sky reflectances $p(R|FCLEAR,B)$, which is the probability distribution of reflectance values R given that they originate from clear-sky area with the flag $F = FCLEAR$ and additional background conditions B ".

Strictly speaking, isn't this just the same as the distribution you would get if only "confidently clear" pixels from the ASTER cloud mask were considered?

Lines 183-185: "The darkest observed pixels originate from clear-sky ocean observations. Small cloud fragments and humidified aerosols slightly enhance the reflectance, though they are often undetected by cloud masking scheme."

This sentence is likely only partly true. The population identified by the ASTER cloud mask as "probably clear" likely is a mix of clear pixels in humidified aerosol conditions, unresolved low cloud fragments and thin cirrus. This paper appears to assume that anything identified as "probably clear" is optically thin low cloud, without justification. As a result, it is likely that the bias attributed to the ASTER cloud mask is overestimated, but it is unclear by how much.

Lines 203-204: "Thinking visually, we scale the simulated clear-sky distribution up until it touches the allsky distribution $p(R)$."

What precisely does this mean?

Figure 4: How does one interpret the light blue area to the left of the orange line? These are flagged as optically thin clouds whose reflectance is smaller than the clear-sky reflectance. How can this be?

Also, it would be helpful if the authors used a different color for the "ASTER cloudy pixel" distribution. The two blue colors are hard to differentiate.

Line 251: "and thus lead to strong over- or underestimation of $p(\text{OTC})$ as high as $\pm 10\%$."

Please indicate if this is a relative bias or an absolute bias. I suspect it's the former.

Table 3: Why not compare the same days and the same location? Table 3 shows results of a comparison between 395 ASTER scenes over a large area and WALES for 13 research flights over a much smaller area (Fig. 1). It's not clear what conclusions can be drawn from this comparison since cloud variability is likely too large for these to be directly compared.

Lines 330-338: Are the comparisons with the Leahy et al. (2012) study relevant at all. That study looked at two years for 60S-60N whereas the current study only considers the EUREC4A region for 17 days in January and February 2020.