Response to interactive comment of anonymous referee 2 — High-resolution satellite-based cloud detection for the analysis of land surface effects on boundary layer clouds

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We would like to thank the reviewer for the valuable and very constructive comments and the effort that was put into reviewing the manuscript. We think the points raised by the reviewer helped improving the main message of the manuscript, substantially. Please find the point-to-point reply below.

This paper examines two-slightly different regional cloud mask algorithms using the high-resolution broadband visible channel from MSG SEVIRI instrument for a region in Paris and its vicinity. Both algorithms started with pixel-level and solar zenith angle binned histogram of reflectance. The localized algorithm (LECDA) uses a localized (down to pixel-level) threshold based on a gaussian fitted reflectance histogram, while the regional algorithm (RECDA) uses the maximum of LECDA thresholds for the entire domain. The RECDA algorithm is considered as independent of surface albedo.

The paper claims slightly better performance of RECDA method compared with measurements of a ground Cloudnet station. In addition, the cloud fraction from RECDA algorithm is shown to be able to demonstrate the impact of urban heat effect on fog formation from the city of Paris.

The study is interesting as high-resolution cloud detection algorithm will enable the study of impact on cloud formation due to various natural and anthropogenic factors in very small scales. However, I am not convinced that RECDA is a better algorithm than the LECDA algorithm due to the following reasons:

1. Both algorithms have pros and cons as demonstrated by better POD, larger FAR in LECDA and poor POD, lower FAR in RECDA since the threshold in RECDA is mostly higher than those used in LECDA. The large contrast in POD and FAR of the two algorithms and relatively insignificant difference in overall scores (PC, CSI, HSS) indicate the more fundamental difference of the two algorithm lies in the choice of more clear-conservative or cloud-conservative rather than whether fine tuning of local threshold is better or worse. Therefore what is more important in this case depends on the application. Does the application require to have high POD or low FAR or an overall better score?
   We agree with the reviewer that the performance measures calculated in this study should not be used to show that one approach is better than the other. As pointed out by the reviewer for this approach we do not require to perform better in

terms of POD or FAR than LECDA. Indeed, we would expect LECDA to perform better in a local validation (it is locally tuned after all). The higher suitability of RECDA compared to LECDA for this application is shown in Figure 4 of the manuscript where the difference of both approaches shows a clear signal over forest areas. We think that the dependence of LECDA on the surface signal is better conveyed in Figure 1 (Figure 5a in the manuscript) where the difference of LECDA and RECDA is plotted as a function of clear sky surface reflectance. 75 % of the variability of the difference between RECDA and LECDA can be explained by the surface reflectance. It is assumed that the dependence on the surface reflectance is mostly attributed to LECDA, while a small dependence of RECDA on the surface reflectance may occur in conditions of thin liquid clouds. Thus, RECDA being more robust than LECDA is better suited for this kind of application.

The validation of both approaches with ground truth using the traditional measures and scores is intended to provide an additional context where the developed regional approach can be compared to the local one. The manuscript was modified as follows:

"The general dependence of LECDA on the surface reflectance is shown in Figure 5a) where the difference of LECDA and RECDA is a function of clear sky surface reflectance. 75 % of the variability of the difference between RECDA and LECDA can be explained by the surface reflectance. It is assumed that the dependence on the surface reflectance is mostly attributed to LECDA, while a small portion may be attributed to RECDA in conditions of thin liquid clouds. Thus, RECDA being more robust than LECDA is better suited for this kind of application assuming the presence of thick clouds."

"The validation of the two cloud masks CM_{loc} and CM_{reg} with respect to the Cloudnet data seeks to compare both approaches with ground-truth data using conventional statistics. However, it is not intended to prove the better applicability of one over another for the analysis of land surface effects on boundary layer clouds as this was shown in Section 4, e.g. Figure 4 and 5."

"It is notable that a main difference in validating both approaches originates from the definition of a more cloud-conservative threshold vs. a more clear-conservative threshold."

2. The LECDA tries to follow the distribution of clear sky pixels, as the algorithm is derived from clear sky portion of the GMM, while RECDA tries to preserve the cloud distribution as it assumes the cloudy portion of Gaussian distribution is fixed. This assumption will be more appropriate for thick clouds but not thin clouds as surface reflectance could also impact cloudy sky reflectance.

The calculation of LECDA and RECDA is effectively based on the clear sky distribution while the cloud distribution is rather an assumption. We agree with the reviewer that thin liquid clouds - ice clouds are mostly excluded in the preprocessing - can introduce a small bias depending on the surface signal that should be minor compared to the influence of the surface signal in LECDA. As we cannot exclude an effect due to thin liquid clouds, subpixel clouds or cloud edges

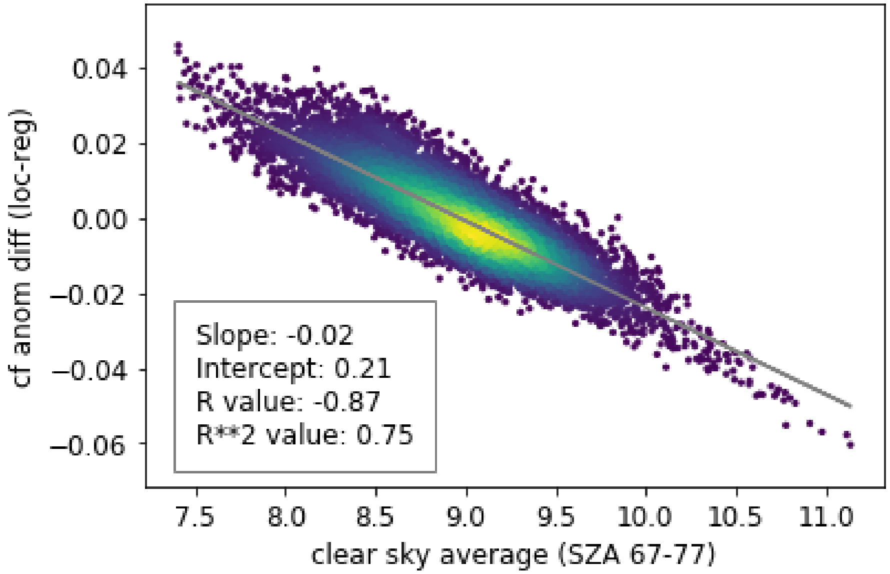

Figure 1. a) Linear regression: Difference of cloud fraction anomalies (LECDA-RECDA) vs. clear sky reflectance (average of SZA bins 67-77). Bright colors represent a higher probability density of the data points using Gaussian kernels.

we have added this limitation now in Section 4.3. of the manuscript.

3. The evaluation is only conducted over one location even though the reflectance of the selected location is close to the domain mean. As mentioned by the author, the comparison over bright surface would be similar but over dark surface, LECDA is expected to have higher POD and little influence on FAR. Therefore, over the entire domain, it is yet to be seen which algorithm performs better. It may help to compare the cloud mask with other multiple-channel satellite cloud mask products such as MODIS with 1km resolution with full spatial coverage.

With this study we do not intend stating that the performance of RECDA is better than LECDA in terms of POD. We want to show the improved applicability of LECDA compared to RECDA for the analysis of land surface effects on boundary layer clouds. We think that validating both approaches at one location is sufficient to assess and compare both approaches to the ground truth (as done e.g. Roebeling et al. 2008). A validation with an additional satellite-based product would not support the message of the manuscript. The manuscript was modified to clarify this aspect.

"The validation of the two cloud masks CM_{loc} and CM_{reg} with respect to the Cloudnet data seeks to compare both approaches with ground-truth data using conventional statistics. However, it is not intended to prove the better applicability of one over another for the analysis of land surface effects on boundary layer clouds as this was shown in Section 4, e.g. Figure 4 and 5."

4. The Cloudnet cloud sample selection requires 90% of cloud fraction which is very cloud conservative while SEVIRI cloud masks only require 1/9 fraction to be cloud. This mismatch in spatial/temporal cloud fraction could contribute to slightly better performance in relatively underestimated RECDA algorithm as cloud detection rate would be even lower if more partial Cloudnet pixels are selected as cloudy.

   This is an important point that we have discussed internally performing multiple threshold tests. Decreasing the cloud net cloud fraction or increasing the SEVIRI cloud fraction required to be classified as cloud will decrease POD together with FAR for both algorithms, RECDA and LECDA. Less clouds will be detected in the cloud mask and less false alarms will occur. Finding the optimum aggregation scale is complicated as we are comparing a vertically and temporally highly resolved point measurements of Cloudnet with a 15 minute SEVIRI snapshot of the cloud top over a larger spatial area. Following the recommendations of reviewer 2 and 1 we now decided using more moderate and objective thresholds. We recalculated the validation measures for both algorithms using a Cloudnet cloud fraction of 50% over a time window of 1 hour (Deneke et al. 2009) and a SEVIRI cloud fraction of 4/9. The results show a degradation of the performances of both RECDA and LECDA with respect to POD, while FAR is reduced. We have modified the manuscript accordingly.

5. The relative performance of RECDA and LECDA might change with the domain size and dominant cloud types in the region. It is well known that a globally fixed threshold does work well. What is the domain size and surface uniformity requirement for the RECDA to perform better than LECDA?

   Thanks for raising this point. We expect that the performance of RECDA could be affected by the availability of data (more data per SZA bin), the distribution of dark vs. bright pixel and the variability of the satellite viewing geometry. A profound analysis would be required that is dedicated to test the different domain sizes, regions as well as cloud types. Based on this study we can recommend RECDA for the proposed application and suggested domain size with a clear sky reflectance between 8 and 10 % (see Figure 2.). RECDA will not provide reliable results over regions with clear sky reflectances varying between 8 and 50% as e.g. over agricultural and desert regions. This is now added to Section 4.3.

Minor comments:

What is the bandwidth of the HRV of SERVIRI? I saw some website mentions 0.4-09.um instead of 0.4-1.1μm.

The bandwith of HRV is 0.4 to 1.1μm according to Schmetz et al. 2002

What is x in Equation 2)?

This was meant to be a multiplication sign. We deleted it according to the equation guidelines.

P7L185-190. I don't see how RECDA would not create surface albedo dependent bias unless the algorithm only focused on thick clouds (in that case surface albedo doesn't matter). It is a cloud-conservative approach and assumes that reflectance distribution of cloudy pixels does not change. However, due to overlap of clear sky and cloud sky histogram, fixing threshold for cloud distribution (even assuming it does not change) inevitably affect cutoff of clear sky distribution.

We agree with the reviewer that the RECDA approach may suffer from a surface dependent bias in cases where thin liquid clouds are present. We expect that this could introduce a small bias that should be minor compared to the influence of the surface signal in LECDA. We have added this limitation now in Section 4.3. of the manuscript.

Figure 6. How is the anomaly computed? Anomaly with respect to domain averaged mean for all samples or anomaly of individual pixels in fog-prone conditions versus all conditions? Could you plot the same anomaly figure (Fig.6a) from the LECDA method?

We computed the anomaly of individual pixels with respect to domain averaged means constrained by fog conditions. A description was added to the caption of Fig. 6 in the manuscript. The cloud fraction anomaly from the LECDA method shows a comparable pattern to the cloud fraction anomaly from the RECDA method (Fig. 2). The difference of both (Fig. 3) shows a similar pattern as in Fig. 4a of the manuscript.

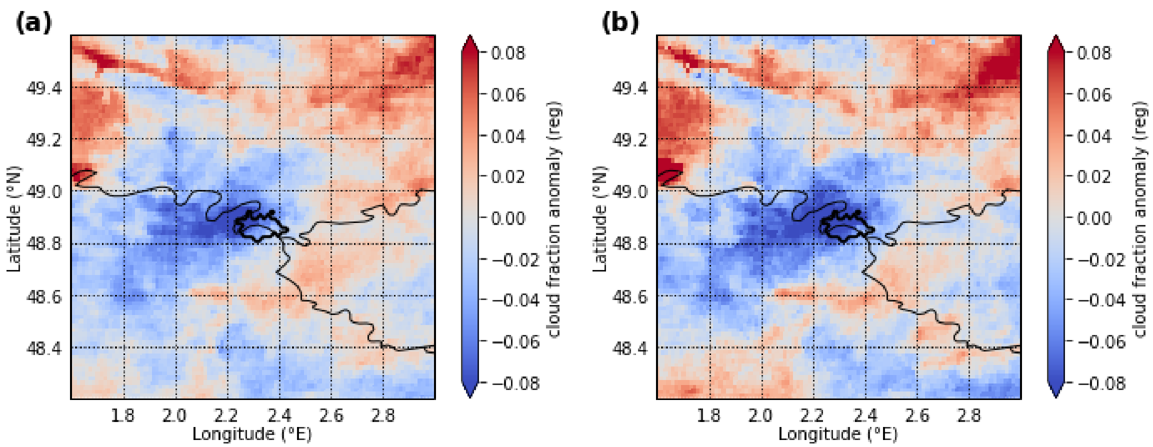

Figure 2. Cloud fraction anomaly from RECDA (a) and LECDA (b) constrained by the following meteorological conditions: low wind speed (<3 ms^{-1}), low blh (<300 m), high msl (>1020 hPa).

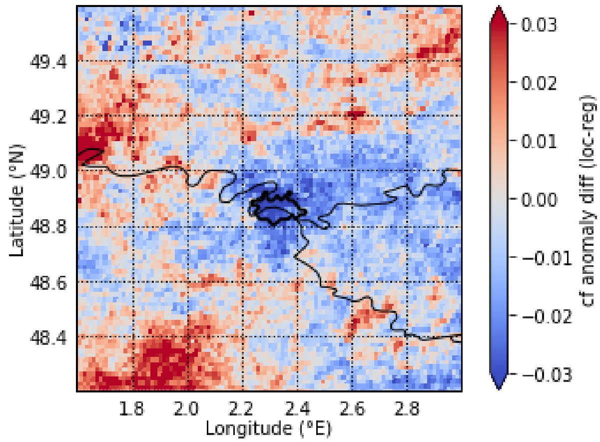

Figure 3. Difference of cloud fraction anomalies (CFloc anomaly-CFreg anomaly) constrained by meteorological conditions as in Fig. 2.

References

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