Answers to Reviewer 1 comments

Hereafter, the reviewer comments are written in Black and the Answers to reviewer comments in Blue.

The study in general is written in very good English language. It is in parts a bit lengthy and I propose some cuts to make it better readable.
I have two main remarks that could be answered by additional discussion, as well as quite a number of specific remarks.

Main remarks
- For the LW CRE at the surface, it is crucial to estimate the cloud-base height correctly. The authors do not dwell on this problem very much, they basically just use what is readily available. There are, however, several approaches to retrieve it. One such approach uses CALIPSO (Mülmenstädt et al. 2018, doi: 10.5194/essd-10-2279-2018)

We thank the reviewer for pointing us to Mülmenstädt et al. 2018.
In the new version of the paper, we have computed the CALIPSO-GOCCP Surface LW CRE using the cloud-base height (called CBASE dataset) described in Mülmenstädt et al. 2018 in replacement of Z_fully-attenuated (Z_FA). Comparing the two estimates of the Surface LW CRE allows us to estimate the impact of using a more advanced cloud base estimate than Z_fully-attenuated from lidar observations on CALIPSO-GOCCP CRE retrieval.

In the CBASE dataset, the Cloud base-height value is given at a horizontal resolution of 40km along the CALIPSO orbit track in the portion of the orbit where clouds are opaque. Along each CALIPSO orbit, we collocated the cloud-base height dataset with the GOCCP dataset whose horizontal resolution is 1/3 km along track. Over each 40 km orbit containing opaque cloud profiles, we replaced Z_fully-attenuated by the Cloud-base-height value given in the CBASE dataset, and then we computed Z_T_Opaque and the Surface LW CRE.

Figure 1 shows that CBASE values are distributed in all latitudes and are available in about one third of all the CALIPSO opaque profiles. This is because CBASE can only be retrieved when thin clouds are detected within the 40 km orbit piece that also contains opaque clouds profiles. Comparing Fig. 2a and Fig. 2b indicates that the subsample of opaque CALIPSO profiles where CBASE is documented contains both large values of CRE associated to mid and low level clouds located at mid-latitudes (upper right data in plot b) and small values of CRE (lower left), but it does not include the data where 2BFLX is much larger than CALIPSO-GOCCP which correspond to mid-latitude oceanic opaque clouds. When replacing Z_FA (Fig. 2b) by CBASE (Fig. 2c) in the CALIPSO-GOCCP algorithm, the CRE CALIPSO-GOCCP rises slightly almost everywhere because CBASE is lower in altitude than Z_FA, and CALIPSO-GOCCP CRE values lower than 18 W m^{-2} are no more present. The latter correspond to both deep convective clouds and shallow boundary layer clouds (as discussed in Sect.7.1). The correlation between 2BFLX and CALIPSO-GOCCP is similar whether we use Z_FA (0.79) or CBASE (0.78) in the CALIPSO-GOCCP algorithm.
This sensitivity study suggests that using a more advanced cloud base height (here CBASE) estimate than Z_FA in CALIPSO-GOCCP algorithm will increase the CRE value retrieved in some opaque cloud profiles slightly, but it does not fundamentally change the results.
These new results are presented in Sect. 8.1.

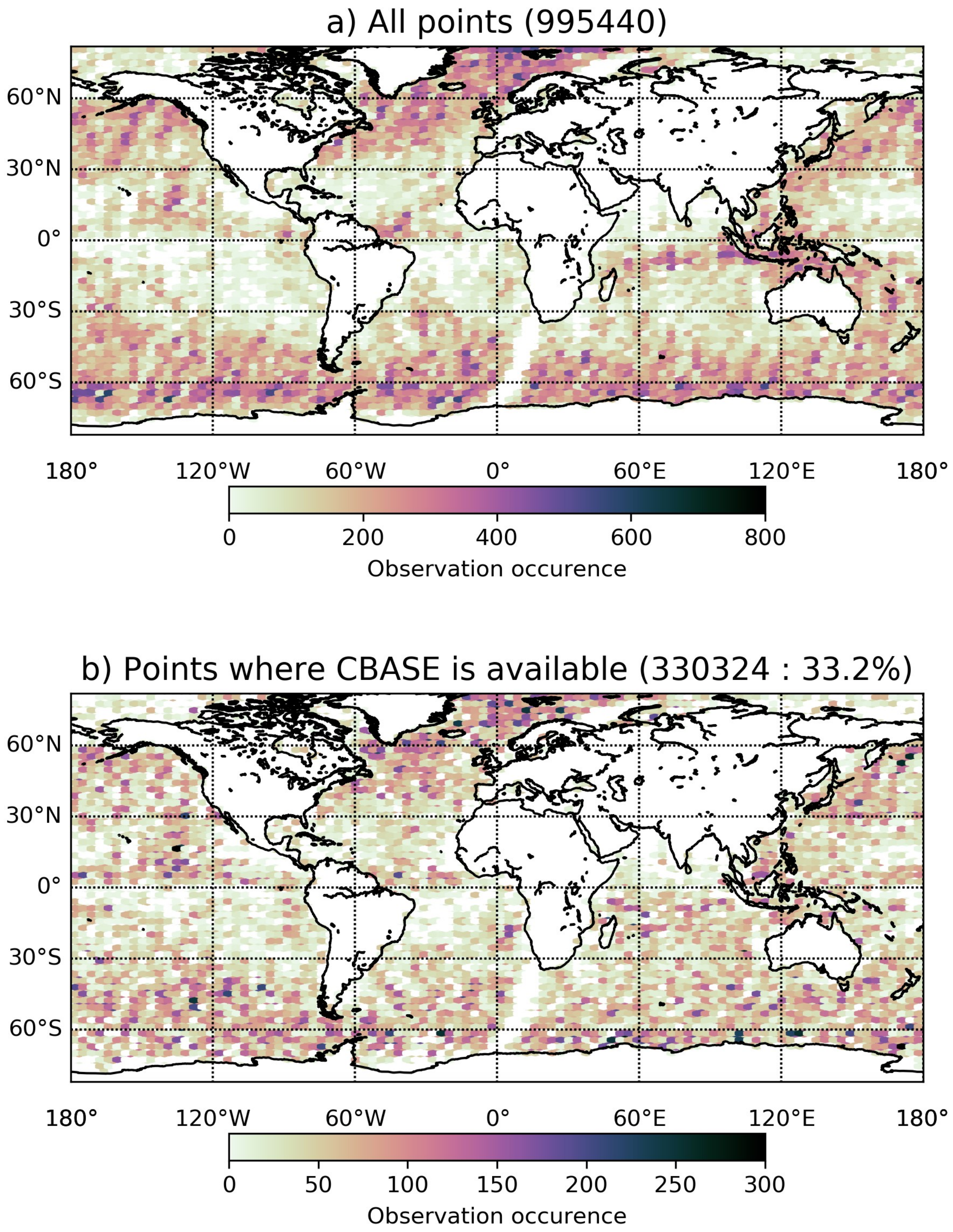

Figure 1: Maps of the number of opaque clouds collocated with 2BFLX over oceans in February 2008 a) in all the CALIPSO-GOCCP collocated dataset b) same as a) but only where CBASE data are available.

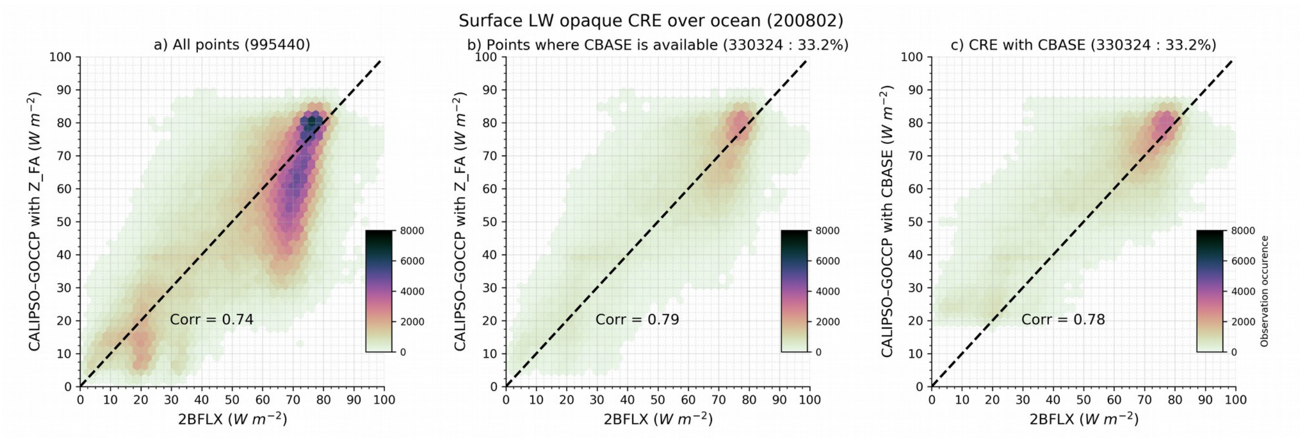

Figure 2: Surface LW CRE derived from CALIPSO-GOCCP as a function of the one derived from 2BFLX. a) CALIPSO-GOCCP surface LW CRE (y axis) computed using the altitude of full lidar attenuation b) same as (a) but containing only the sub-sample of CALIPSO profiles where cloud base-height values are available from Mülmenstädt et al. 2018 c) same as b) but the CALIPSO-GOCCP surface LW CRE is computed using the cloud base-height values from Mülmenstädt et al. 2018 instead of the altitude of lidar full attenuation. The color scale indicates the number of occurrences at 5km resolution (footprint scale of CloudSat) over ocean in February 2008.

There is no discussion of the reasons for the linear relationship between Z_T,Opaque and CRE. Can the authors produce some arguments on why this is the case, e.g. in the sense of what Corti and Peter (ACP 2009) did for TOA CRE?

This linear relationship is an empirical relation derived from radiative transfer calculations and verified in the observation at the TOA (Vaillant de Guélis et al., 2017, 2018). Corti and Peter (ACP 2009) also derived an empirical relationship (power laws) from radiative transfer computation. Our linear relationship can be considered as an approximation of the Corti and Peter power law.
We have added this information in the text of the manuscript Sect. 4.1.

Specific remarks

C0) l29 “captures”

Done

C1) l66 “ideal” and “everywhere” are a bit overdoing the statement. For the “everywhere” in particular, current lidar and radar are questionable due to the lack of swath.

“ideal way”has been replaced by a “possible way”, and the word “everywhere” has been removed.

C2) l108 the optical depth is not measured but retrieved
“measurement” has been replaced by “retrieval”

C3) l200 “does not contribute” should be revised to be more quantitative. Why would an optical thickness of 5 in the green be exactly the threshold below which also no infrared radiation escapes the cloud?
We have removed previous Fig. 3 and therefore we have removed this sentence.

C4) l210 Well, CloudSat is also not optimal to detect cloud base in particular if it is liquid-water cloud
Right, we have added this information in the sentence.

C5) l212 What could be cases in which Z_T_Opaque is a better estimator of Z_Base than Z_FA? Z_FA is below Z_T_Opaque so it should always be better, **or am I mistaken**?

It is right that Z_FA is always a better estimator of Z_Base than Z_T_Opaque, but the surface LW CRE is not always driven only by Z_Base.
The Surface LW CRE is driven only by Z_Base in specific cases where enough condensed water (corresponding to an optical depth of 1) is confined within a single geometrically very thin cloud layer located exactly at Z_Base. In all other cases, the cloud layers located above Z_Base up to the level where the cloud emissivity equal to 1 contribute to the surface LW CRE. This is why we cannot always use Z_FA and need to use Z_T_Opaque in numerous cases.
We have explained that more clearly in Section 3.1.2.

C6) l217 Why is this simpler? And what was the difference between the two choices?
It is simpler to write the equations with a single variable called “Z_T_Opaque”. In the radiative transfer computation, we found that the Surface LW CRE depends linearly on the average altitude of the opaque cloud. We could have written the equations with a variable called “Z_mean_opaque” but that would have added another variable. Since we found in the observations that “Z_T_Opaque” is a good approximation of the averaged altitude of the opaque cloud in numerous cases, we chose to write the equation directly with “Z_T_Opaque”.
We reverse the order of the sentences in the manuscript to clarify.

C7) l244 This is unclear. Is CRE computed at some aggregate scale? Because for each satellite footprint, there is either an opaque or thin cloud, and the CRE for the other type is zero. If it is aggregated in space or time, this should be stated here.
Right, this equation is only true for the gridded product.
For each satellite footprint, there is either an opaque or thin cloud, and the CRE for the other type is zero. For the gridded product, and at each grid point, the opaque surface LW CRE is weighted by the opaque cloud fraction, the thin surface LW CRE is weighted by the thin cloud fraction, and the total gridded surface LW CRE is the sum of the two.
We have re-written Section 3.4 for clarity.

C8) l269 Really theoretical or rather empirical?

We replaced “theoretical expressions” by “parameterization”

C9) l373 This point of missed multi-layer situations seems important enough to merit a broader discussion. How often may such systematic mistakes by CALIPSO-GOCCP occur?

We used the CBASE dataset by Mülmenstädt et al. (2018) to broadly discuss the impact of CALIPSO not seeing Z_Base in certain cloud situations. The details are given in the response to the main reviewers' comment here above and are reported in the manuscript in Sect. 7.
The comparison between CALIPSO-GOCCP and 2BFLX suggests that CALIPSO-GOCCP CRE is more frequently biased in the extra-tropical oceanic storm tracks than elsewhere, if 2BFLX is reliable there.

C10) l401 This idea can be tested, by comparing the humidity profiles used in the retrieval with the ones for these particular cases (e.g. from the reanalysis).

Right, we have tested this using re-analysis and added the results of the test in Sect. 7.

C11) l460 The authors provide the spatial scale, but should also note what is the temporal averaging. Or are these instantaneous values at time of satellite overpass?
Yes these are instantaneous values at the time of satellite overpass.

C12) l470 "months"
Done

C13) l476 Besides the biases, it would be useful to also report the other scalar quality indicators, RMSE and correlation coefficients, perhaps in a table.
The RMSE and correlation coefficients have been added in Table 1.

C14) l486 Is there any reference or evidence to substantiate this claim?

We have removed this sentence

C15) l498 How is this possible? The idea that it is due to humidity profiles is not plausible, since the same humidity profiles are used in both retrievals.

We have modified this section and included a new discussion based on new results in Sect. 7.

C16) l527 This section in my opinion is not very instructive, and there is room for making the paper more concise by dropping Fig. 15 and the corresponding text.

We agree with the reviewer and have removed this Fig. 15 and the corresponding text (former Sect. 7.1.2)

C17) l551 "suggest"
This section has been removed (previous comment)

C18) l570 before it was noted only for a specific location
Right, we now specify that in the text

C19) l597 It is overstated to say that CALIPSO “measures well” opacity – there are only two coarse classes distinguished.
Right, we replaced “are quite well measured” by “are documented”

C20) l830 I find the right-hand-side panel (Opaque cloud) a bit misleading, as the altitude Z_FA is just slightly above Z_Base. However, it often is quite near Z_Top, since it is at 5 optical depths (line 95).

The figure below shows the distribution of CBASE as a function of the distribution of Z_FA where CBASE data exists (about 30% of the CALIPSO-GOCCP opaque clouds profiles). It shows that 55.8% of the Z_FA values have less than 1km difference with CBASE and that the difference between Z_FA and CBASE can reach 12km.

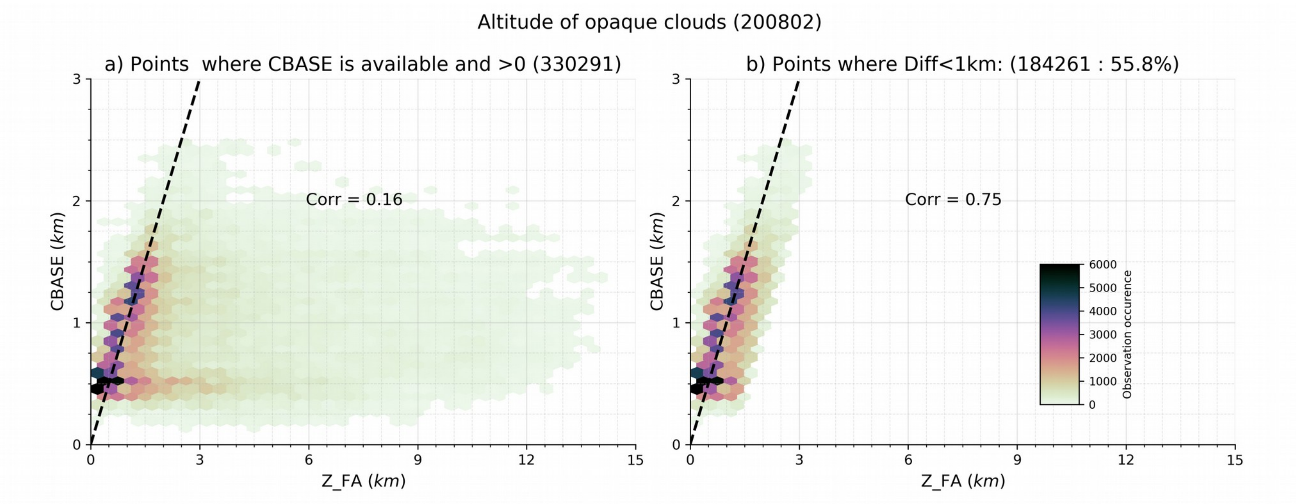

Figure 3: CBASE as a function of Z_FA sample a) where CBASE is available in the collocated data used in Fig.2 b) same as (a) but when the difference between Z_FA and CBASE is less than 1 km. The color scale indicates the number of occurrences at 5km resolution (footprint scale of CloudSat) over ocean in February 2008.

C21) l840 To me this sketch isn’t very helpful. I don’t quite get the “actual” in the rectangular clouds in (A) and (B), from the caption I would rather understand, these are the fluxes computed by the radiative transfer modelling. Also, I don’t see why the powerpoint-cloud-shaped-clouds and the rectangular carry different information with respect to the radiation arrows. Why do the arrows in (C) from the rectangular cloud end above the surface?

Right, we have removed this figure (previous Fig. 3)

C22) l898 I propose a different colour scale that does not suggest a division into two subsets.
Done

C23) l929 The mean biases lack units.
The unit is reported in the y-axis

Reference :

Corti, T. and Peter, T.: A simple model for cloud radiative forcing, 8, 2009.

Hinkelman, L. M. and Marchand, R.: Evaluation of CERES and CloudSat Surface Radiative Fluxes Over Macquarie Island, the Southern Ocean, Earth and Space Science, 7, https://doi.org/10.1029/2020EA001224, 2020.

Mülmenstädt, J., Sourdeval, O., Henderson, D. S., L'Ecuyer, T. S., Unglaub, C., Jungandreas, L., Böhm, C., Russell, L. M., and Quaas, J.: Using CALIOP to estimate cloud-field base height and its uncertainty: the Cloud Base Altitude Spatial Extrapolator (CBASE) algorithm and dataset (1), https://doi.org/10.1594/WDCC/CBASE, 2018.

Noel, V., Chepfer, H., Chiriaco, M., and Yorks, J.: The diurnal cycle of cloud profiles over land and ocean between 51° S and 51° N, seen by the CATS spaceborne lidar from the International Space Station, Atmos. Chem. Phys., 18, 9457–9473, https://doi.org/10.5194/acp-18-9457-2018, 2018.

Rutan, D. A., Kato, S., Doelling, D. R., Rose, F. G., Nguyen, L. T., Caldwell, T. E., and Loeb, N. G.: CERES Synoptic Product: Methodology and Validation of Surface Radiant Flux, 32, 1121–1143, https://doi.org/10.1175/JTECH-D-14-00165.1, 2015.