Point-by-point response to the reviews

Anonymous Referee #1

In this paper, which appears to be a follow-on from Guzman et al., 2017, the authors develop a simple approximation that allows them to estimate outgoing longwave radiation (OLR) using three parameters that are readily obtained from space-based lidar measurements: cloud top, cloud base (or, for opaque layers, apparent base) and cloud optical depths. Cloud altitudes are converted to temperatures using model data. The optical depths are used to compute emissivities. Since the current generation of space-based lidars cannot measure the optical depth of opaque layers, the emissivities for these clouds are assumed to be 1. For opaque clouds, OLR is approximated as a simple linear function of mid-layer temperature. The approximation for transparent clouds also uses mid-layer temperature, but is not as straightforward, as it also requires estimates of cloud emissivity and the OLR in clear sky conditions. Collocated CERES measurements are used to characterize the accuracy of both approximations.

The material presented in this paper is appropriate for AMT, and, after a few modifications are made, I believe the manuscript should eventually be published. The English language usage is, at times, somewhat (and occasionally very) awkward; however, the paper is well-organized, the figures are well-done and informative, the authors' derivation of their technique was clear and the steps taken to verify its performance were appropriate and straightforward. While the most interesting (and potentially useful) part of the manuscript was section 6, where the authors describe the limitations of their method, there are still a couple of issues that I believe deserve further investigation.

1. I had hoped to find a clear and convincing explanation for the rotation of the thin cloud data from the one-to-one line that is so evident in Figure 6b.

- **Response:**
  - The rotation of the thin cloud data from the one-to-one line does not affect the results of this study. Indeed, we did a sensitivity study to $CRE_{Thin}^{\boxplus\,(LID)}$ (Sect. 6.3): instead of computing the lidar-derived $CRE_{Thin}^{\boxplus\,(LID)}$ using the relationship used in Fig. 6b, we consider $CRE_{Thin}^{\boxplus}$ as the residual between CERES-derived total $CRE_{Total}^{\boxplus\,(CERES)}$ and lidar-derived $CRE_{Opaque}^{\boxplus\,(LID)}$: $CRE_{Thin}^{\boxplus} = CRE_{Total}^{\boxplus\,(CERES)} - CRE_{Opaque}^{\boxplus\,(LID)}$. This leads to Opaque clouds contributing to 74 % to the total CRE instead of 73 % in global mean. It is then not sensitive.
  - The rotation of the thin cloud data from the one-to-one line is the consequence of multiple effects. We examine hereafter the points raised by the reviewer. Thank you.

In particular,

(a) I'd like to know if this rotation is diminished in the "single-cloud-layer situations (not shown)", for which R increases from 0.89 to 0.92 (I suggest including the "not shown" plots in a future revision);

- **Response:** This rotation is not diminished in the "single-cloud-layer situations" (Fig. A4d).
- **Change made:**
  - In Sect. 6: Sect. 6.2 Multi-layer cloud and broken cloud situations has been added.
  - In Appendix: Fig. A4 has been added. It shows the decomposition of Fig. 6 in "single-layer cloud" and "multi-layer cloud" situations. The main text refers to Fig. A4 in Sect. 6.2.

(b) I'm intrigued by the differences in the sampling distributions for the opaque clouds vs. the thin clouds. For opaque layers, there is a noticeable skew in the distribution caused by (per line 518) "occurrences far from and over the identity line in Fig. 6a". But for the thin clouds in Fig. 6b the sampling distribution appears to be normally distributed about a single straight line). Do the authors have any thoughts or speculations about the root cause(s) for this difference in behavior?

- **Response:** The new Fig. A4e shows that the noticeable skew in the distribution is due to multi-layer cloud situations. In these situations, an optically thin cloud overlapping an optically opaque cloud will tend to significantly underestimate $T_{Opaque}^{|}$ as we do not consider the difference of emissivity between the two clouds. For thin clouds, in presence of multi-layer cloud situations (Fig. A4f), $T_{Thin}^{|}$ can be overestimated or underestimated depending on which cloud is optically thicker. The contrast between their emissivity is generally smaller than for an opaque multi-layer cloud situation. This is the reason why there is no noticeable skew in the distribution for the thin clouds.

2. How sensitive is the thin cloud OLR to emissivity errors introduced by aerosol contamination of "clear air" beneath the clouds detected by GOCCP?

- **Response:** The computation of the Thin cloud emissivity $\varepsilon^{|}_{Thin}$ used all the clear sky layers (without aerosol) located below the lowest cloud layer, in order to determine the optical thickness of the cloud layers. If, for example, an aerosol layer is present just below the cloud, $\varepsilon^{|}_{Thin}$ would be derived from the sum of the cloud layer optical thickness and the aerosol layer optical thickness. As this study is only over ocean, errors introduced by aerosol are essentially found during boreal summer over a limited area: the dust plume (Peyridieu et al., 2010 DOI:10.5194/acp-10-1953-2010). Moreover, with regards to this study, we are interested in CRE, which, over ocean, are far larger than aerosol direct radiative effect.

Minor issues:

Line 17 : how much does the "atmosphere opacity altitude" depend on the (a) capabilities of the lidar used to measure the cloud, (b) the ambient lighting conditions, and (c) the algorithms used to retrieve apparent cloud base?

- **Response:** The "atmosphere opacity altitude" $Z^{|}_{Opaque}$ indeed depends on these three aspect.
  (a) The accuracy of $Z^{|}_{Opaque}$ depends on the vertical resolution of the lidar, the telescope field of view, and the capabilities receiver sensor (noise). These uncertainty sources likely give error smaller than one 480 m bin.
  (b) $Z^{|}_{Opaque}$ retrieval is difficult during daytime because daytime conditions are much noisier than the nighttime conditions in CALIOP data. This is the reason why we only use nighttime data in this study.
  (c) $Z^{|}_{Opaque}$ depends on the algorithm used to retrieve apparent cloud base. It depends on the horizontal and vertical averaging choice (Chepfer et al., 2013; Cesana et al., 2016).
    · Chepfer et al. (2013) – DOI:10.1175/JTECH-D-12-00057.1
    · Cesana et al. (2016) – DOI:10.1002/2015JD024334
- **Change made:**
  - In Sect. 2.1 (1st §): "$Z^{|}_{Opaque}$ depends on the horizontal and vertical averaging used in the retrieval algorithm. It is also affected by sunlight noise during daytime. At 480 m vertical resolution, it poorly depends on the lidar characteristics." has been added.

Lines 126–175 : nothing in this description makes it clear that columns containing multiple layers are actually included in the analyses. The fact that all columns are partitioned into one of the three categories (i.e., clear, thin cloud, and opaque cloud) should be made clear from the very beginning, and not postponed until lines 176–179.

- **Change made:**
  - In Sect. 2.1 (1st §): "The GCM-Oriented CALIPSO Cloud Product (GOCCP)-OPAQ (GOCCP v3.0; Guzman et al., 2017) segregates each atmospheric single column sounded by the CALIOP lidar as one of the 3 following single column types" has been replaced by "The GCM-Oriented CALIPSO Cloud Product (GOCCP)-OPAQ (GOCCP v3.0; Guzman et al., 2017) has 40 vertical levels with 480 m vertical resolution. Every CALIOP single shot profile — including multi-layer profiles — is classified into one of three types".

Line 171 : in the vast majority of CALIPSO literature (including Garnier et al., 2015, which is cited here), the symbol for optical depth is τ. δ is used for depolarization ratios.

- **Response:** We agree with the reviewer.
- **Change made:**
  - Throughout the paper: "δ" has been replaced by "τ".

Lines 378–383 : here and elsewhere, I find the authors' notation to be very complex and cumbersome, which makes the text difficult to read and hard to understand.

- **Response:** We agree with the reviewer that our notation can be sometimes cumbersome. However, we choose this very explicit notation in order to avoid misleading interpretation as, throughout the paper, calculations are made at different spatial resolution (lidar single shot, CERES footprint, and gridded).

Lines 530–531 : to my eye, the midlatitude emissivities are not "mostly centered around 0.25"

- **Response:** We agree with the reviewer that this statement is not very accurate and has been removed.
- **Change made:**

- In Sect. 6.3 (3rd §): "Given that $\varepsilon^{|}_{Thin}$ is mostly centered around 0.25 (Fig. 4d) it should not bring a substantial error, and" has been replaced by "However,".

Line 554 : according to my (admittedly limited) understanding of the way the GOCCP cloud detection scheme works, a more realistic assessment would have been obtained by using on bin lower rather than one bin higher.

- **Response:** We choose to take one bin higher for the sensitivity test on $Z^{|}_{Opaque}$ in order to be able to apply this in the same way for every opaque cloud profile. Indeed, a non-negligible amount of opaque cloud profiles have their $Z^{|}_{Opaque}$ at the lowest GOCCP level (240 m above sea level), and taking the equivalent of a bin lower would have given negative opacity altitudes (–240 m). This problem is avoided taking one bin higher instead and the sensitivity test should not be sensitive to this choice since the relation between $OLR^{|}_{Opaque}$and $T^{|}_{Opaque}$ is linear.
- **Change made:**
  - In Sect. 6.5 (first §): "(as moving $Z^{|}_{Opaque}$ one bin down would have led to negative values for some $Z^{|}_{Opaque}$)" has been added.

Lines 641–642 : the suggestion that "the laser beam is not able go through the entire cloud if its vertical geometrical thickness is greater than 5 km" is demonstrably false. For example, see
https://www-calipso.larc.nasa.gov/products/lidar/browse_images/show_detail.php?s=production&v=V4-10&browse_date=2010-01-01&orbit_time=12-47-14&page=3&granule_name=CAL_LID_L1-Standard-V4-10.2010-01-01T12-47-14ZN.hdf
The region between ~1.6° S and ~5.4° S contains numerous examples of transparent cirrus that are more than 6 km thick.

- **Response:** We agree with the reviewer.
- **Change made:**
  - In Appendix B (2nd §): "[…] the laser beam is not able go through the entire cloud if its vertical geometrical thickness is greater than 5 km […]" has been removed.