Point-by-point response to the reviews

Anonymous Referee #3

General

The authors present a methodology to estimate the outgoing longwave radiation (OLR) at the global scale from cloud products derived with the help of long-term space-borne measurements with the lidar CALIOP onboard CALIPSO. The major information comes from the opacity altitude of the atmosphere, i.e. the altitude at which the laser beam is fully attenuated due to clouds, and the geometrical cloud top height, which together allow the estimation of the radiative temperature of the cloud. It is shown that the latter one is linearly related to the OLR. Non-opaque (thin) clouds are treated in terms of top and base heights together with their emissivity, which is estimated from the lidar attenuated scattering ratio below the cloud under consideration of a constant multiple-scattering factor. For opaque clouds, a very good correlation between the derived OLR and the one measured by CERES is found, whereas a systematic deviation is seen for thin clouds. Despite some possible explanations the reason for the deviation in the case of thin clouds does not finally become clear.

In general, the paper presents an interesting approach to study longwave radiation effects of clouds at the global scale. The paper deserves publication, but has the potential to be improved both in terms of scientific contents as well as style of presentation. I recommend publication after consideration of the comments below.

Major

My major concerns are related to the rather simplified approach of using only two cloud scenarios, namely single-layer thin and opaque clouds. I would at least expect an extended sensitivity study regarding more realistic scenes in the very beginning. Justifying the approach before the presentation and discussion of results would be much more satisfying for the reader than the currently provided discussion of limitations in Sec. 6 (where several questions are tackled which the reader has already in mind when reading the major part of the paper). In particular, the following cases need to be considered in the evaluation and discussion of obtained results throughout the paper, starting already in Sec. 2.1 and Fig. 1.

- **Response:**
  - We agree with the reviewer that the proposed cases need to be discussed. We have dedicated a subsection in Sect. 6 for this. Specifications are given below.
  - We first tried to discuss all these aspects throughout the paper. However, this approach drowns the main message of the paper in digression. This is why we have decided to summarize them in Sect. 6.
- **Change made:**
  - In Sect. 6: Sect. 6.2 Multi-layer cloud and broken cloud situations has been added.

1) Multi-layer clouds: The discussion related to multi-layer clouds is not sufficient. The authors have added a very short paragraph in Sec. 2.1 (lines 176-179) during the technical revision of the paper. However, this explanation deals with thin clouds only. The more common feature is the appearance of thin, high cirrus clouds over mid-level or low-level opaque clouds. It is well known that retrievals from passive sensors locate the radiative cloud top height (or radiative temperature) in between the cloud layers in such cases, and that the location will depend on the optical thickness of the upper "thin" cloud. This fact is obviously not covered by the presented approach, since it considers only the geometrical properties of cloud top height and opacity altitude for the calculation of the radiative temperature. Although some discussion is provided in Sec. 6.2, no substantial investigation of the related consequences for the approach is given.

- **Response:** Thank you for this comment. An extensive investigation of multi-layer clouds is now given in Sect. 6.2.
- **Change made:**
  - 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 (1st §).
    - Fig. A5 has been added. It shows improvement on OLR_{Opaque} when considering multi-layer cloud in the computation of T_{Opaque}. The main text refers to Fig. A5 in Sect. 6.2 (1st §).

2) Broken clouds: The authors find a high amount of "thin clouds" in the lower troposphere at temperatures above 0 ◦C, i.e. liquid clouds (Fig. 4). Usually, liquid clouds are not penetrated by lidar, even if they are geometrically thin (thickness of a few hundred meters). Those occasions of "thin clouds" might often be related to broken opaque

clouds partly hit and partly missed by the lidar beam, thus leading to signals from the cloud and from the atmosphere and surface below the cloud in the same profile, so that the cloud appears to be transparent. The effect may be due to broken clouds within a single laser footprint, but can also result from averaging of laser shots over cloudy and clear atmospheric volumes before further retrievals are applied. From the description in Sec. 2.1, it does not become clear how averaging of lidar profiles is done, what exactly is meant with "each atmospheric single column" (line 127), which basic products (single shot, 1-km averages, 5-km averages) are used, and how the averaging to the 2∘x2∘ grid is performed. It should be studied which differences in the results are expected when sub-scale broken opaque clouds instead of thin clouds appear. It would be interesting to see whether the worse correlation between calculated and measured OLR found for thin clouds could be explained in this way. In this context, also the discussion in Sec. 6.2 is insufficient.

- **Response:** We agree with the reviewer that broken opaque clouds can be classified as thin clouds. However, in the GOCCP product, we do not average lidar profiles horizontally, so we only use single shot (90 m diameter footprint), which minimize this misclassification. Moreover, we plotted same as Fig. 6b only for Thin clouds with $T_{Thin} > 0\,°C$ (see Fig. A6): it shows excellent agreement between observed and lidar-derived OLR, and so does not explain the worse correlation between calculated and measured OLR as these clouds show excellent agreement.
- **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".
  - In Appendix:
    - Fig. A6 has been added. It shows Fig. 6b but only with $T_{Thin}^{\varnothing} > 0\,°C$. The main text refers to Fig. A6 in Sect. 6.2 (2nd §).

Minor

Abstract: The abstract doesn't say anything about the retrievals for thin clouds.

- **Change made:**
  - In Abstract: "Similarly, the longwave cloud radiative effect of optically thin clouds can be derived from their top and base altitudes and an estimate of their emissivity." has been added.

Line 185, should be: "Flux observations collocated with lidar cloud observations"

- **Change made:**
  - In Sect. 2.2 (title): "Fluxes observations collocated with lidar clouds observations" has been replaced by "Flux observations collocated with lidar cloud observations".

Line 290, regarding the "second mode": What does "more diffuse" mean? What about altocumulus, altostratus clouds?

- **Response:** We agree the reviewer it could also be due to altocumulus or altostratus clouds.
- **Change made:**
  - In Sect. 3.2 (3rd §): "The second mode could be due to more diffuse or developing convective clouds." has been replaced by "The middle mode, near 5 km, might be due to developing convective clouds or middle altitude clouds.".

Line 300, "cloud emissivity of the cloud": correct to either "cloud emissivity" or "emissivity of the cloud".

- **Response:** Thank you.
- **Change made:**
  - In Sect. 3.2 (last §): "cloud emissivity of the cloud" has been replaced by "cloud emissivity".

Lines 331-332, "in spite of significant differences in the atmospheric temperature and humidity profiles": What does "significant" mean? How are these differences considered/validated in the calculations?

- **Response:** The sentence was indeed not very clear, it has been modified.
- **Change made:**

- In Sect. 4.1 (2nd §): "Linear regressions done on other regions with different atmospheric conditions give a similar coefficient. This means that, in spite of the significant differences in the atmospheric temperature and humidity profiles, $OLR^{|}_{Opaque}$ depends essentially only on $T^{|}_{Opaque}$." has been replaced by "Conducting the same linear regression on very different atmospheric conditions (from tropical to polar) gives similar coefficients. This means that $OLR^{|}_{Opaque}$ depends mainly on $T^{|}_{Opaque}$.".

Line 372, "The evaluation . . . is only using observation from January 2008": This explanation should be given in the beginning of the discussion of Fig. 6.

- **Response:** .
- **Change made:**
  - In Sect. 4.2 (2nd §): "Figure 6 compares lidar-derived and observed OLR during January 2008." has been added.
  - In Sect. 4.2 (last §): "The evaluation showed in Fig. 6 is only using observation from January 2008." has been removed.

Lines 405-415: Explain the units to be applied in the equations.

- **Change made:**
  - In Sect. 5.1: "[…] where $CRE^{\boxplus\,(LID)}_{Opaque}$ and $OLR^{\boxplus}_{Clear}$ are expressed in W·m-2 and $T^{\boxplus}_{Opaque}$ in K." and "[…] where $CRE^{\boxplus\,(LID)}_{Thin}$ and $OLR^{\boxplus}_{Clear}$ are expressed in W·m-2 and $T^{\boxplus}_{Thin}$ in K." have been added after Eqs. (7) and (8).

Lines 556 and 561, "decreases...from...", "reduces...from...": The meaning of the sentences with the word "from" is unclear.

- **Change made:**
  - In Sect. 6.4: "from" has been replaced by "by".

There a many language/grammar/punctuation errors, which cannot be listed in detail here. The manuscript needs careful copy editing.

- **Response:** A native English speaker copy-edited the paper.