Anonymous referee #1

In my opinion, this paper presents an interesting analysis and provides new insights that can help us better understand cloud-related enhancements in surface irradiance. The proposed theoretical classification makes sense, the methodology is suitable for the task, and the analysis is thorough. (I believe this even though, as mentioned near the end of the manuscript, the study does not use the most powerful analysis approach of examining photon paths and scattering directions.) The presentation is of a generally high quality, but important improvements are still needed, most critically in the introduction section. My specific comments are listed below.

Thank you for your constructive and helpful comments. We have made several larger changes as stated in our general reply and smaller ones as described here below, which hopefully properly addresses your concerns.

Major issue:

The introduction section needs a thorough revamping, for several reasons.

First, the introduction should provide context and historical perspective to the presented study. For example, it should address the following questions. Did other researchers previously examine (using observations and/or theoretical calculations) cloud-related surface irradiance enhancements, and what were their main findings about the frequency, magnitude, sources, and consequences of these enhancements? What is the underlying motivation for us to care about these enhancements: Is it perhaps something about solar energy production or the health risks of UV radiation, etc.? Did the earlier results leave major gaps that we still need to fill, perhaps in observing, understanding, simulating, or predicting the enhancements? Which of these gaps does the current paper help us fill?

These are all valid questions, some of which were not answered adequately in the initial submission while some others were not logically placed and were therefore easily missed (scattered through original Subsection 1.2 and Section 2). For clarity:

- The introduction section now covers the context of this research including our motivation for doing this study and (some of) the impacts of radiation variability
- We now more clearly state that we discuss the previous work (observations, modelling, theory) on 3D radiative transfer and mechanisms of variability in Section 2 (definition and examples of variability) and Section 3 (our proposed mechanisms).

- We discuss previous work more clearly and include a few more studies that were originally missing

Second, Section 1.2 does not seem introductory, as it proposes a new theoretical framework that is a key element of this study. Therefore, I recommend moving Section 1.2 into a new section of its own.

We have revised the structure of the introduction after rewriting most of it and moved original subsection 1.2 to a separate section as suggested.

Third, the introduction (just before the start of Section 1.1) presents a brief preview of what we can expect in each section of the paper, but this preview stops at Section 3 and does not include sections 4 and 5 (which present the results and conclusions, respectively).

This mistake has been fixed, thanks for noticing.

Finally, the very first sentence starts the paper off by telling about the introduction section rather than about the paper as a whole, and by referring to a “chapter” and a “thesis” (which suggests that the text was simply copied from an academic thesis).

Regarding ‘chapter’ and ‘thesis’: this manuscript was written as a final content chapter of my thesis, in parallel to my thesis introduction and discussion chapters. Evidently, I haven’t managed to keep the references in this ACP version separate from the thesis. I’m not sure how we missed the mistake in the first sentence… In revising the introduction, I have taken care of the incorrect references.

Minor issues:

Line 3: The wording should make it clear that the paper covers only extreme highs and does not discuss extreme lows.

This is now changed to “variations” rather than “extremes”. While extreme highs is a large part of our focus, “variations” more completely covers our analyses.

Lines 8-9: The wording should be changed because as is, it discusses an albedo effect but not discussed a mechanism. Perhaps trapping or multiple reflection between surface and clouds could help in phrasing the albedo-related process as a mechanism.

True. Upon re-reading the abstract, we found some other conclusions that were not summarized sharply either. We have rephrased most of the abstract while not changing the conclusions we draw therein.

Figure 1: The caption or a newly added legend should explain what the lines of various colors represent.

Indeed, there should have been a legend. This is now fixed.

Line 88: Just a typo: The correct start to the sentence should be “In all cases…”

Fixed.

Line 139: It would help to clarify the main between between Monte Carlo ray tracers and radiative transfer models.

I have dedicated a sentence to briefly clarify the main difference (Section 2).

Line 147: It should be clarified what RTE-RRTMGP stands for (I imagine RTE is for Radiative Transfer Equation) and, if possible, a reference should be given.

I have added a reference to where this model is originally described, but would rather not give the meaning of the long acronym. It is a name of a model and otherwise adds little information to the reader that is relevant to this study: “Radiative Transfer of Energetics – Rapid Radiative Transfer Model for General circulation models – Parallel”. There are now two references to cover the origin of the model: Veerman et al. for the Monte Carlo implementation and Pincus et al. for the RTE+RRTMGP reference, and I describe the model as “radiative transfer solver”.

Line 150: Are longwave simulations used in this study? If yes, it should be mentioned what they are used for; if not, they should not be mentioned.

They are used in the online 1D radiative transfer calculations for the simulated altocumulus case, but not used in any analyses. I have removed the mention of longwave here.

Line 158: What are the wavelength limits of the used visible spectral band?

625 to 768 nm. I could use other bands in more energetic parts of the spectrum (more green and blue wavelengths), but the difference in tau is small (< 5%) and much of the energy is in longer wavelengths too. The text was ambiguous, but ‘most energetic’ was

meant to refer to the visible spectrum as a whole, not the specific band chosen. The text is now clarified, and it also includes the wavelength limits and a bit of context for how much optical thickness varies.

Figure 8: In the caption, it would help to clarify what exactly is meant by “relative to clear-sky values”; I guess it’s clear-sky values of diffuse irradiance rather than clear-sky total irradiance. Also, it could help to explain why, in the right-side plot, the area under the cloud is white. (Alternatively, could the location of the cloud be marked by a circle and allow us to see the enhancement inside the circle?) Finally, it might help to clarify in the caption or around Line 245 that the yellow dashed line is not visible in the left side plot simply because it coincides with the solid line.

These are all good suggestions, thank you. ‘Diffuse’ added to ‘clear-sky’, changed the white circle to a line, described what the line means in the caption, and added that albedo has no effect at low tau in the text. I also added (a) and (b) subplot labels.

Line 270: The word “under” could be changed to something like “in cases of”, as most values under clouds (i.e., shaded areas) are blocked out by grey in the key, lowest row in Figure 9.

I disagree. Figure 9d,e,f show clearly how irradiance is strongly enhanced specifically only under optically thin clouds.

Figure 11: It should be explained what the “diffuse peak probability” (shown in dashed lines in the right-side column) is.

It is the most probable value of diffuse irradiance. This was awkwardly phrased. I now say “most probable diffuse irradiance”. Adding the PDF to these plots would make it much harder to read, unfortunately.

Figure 12b: It should be clarified whether optical depth increases when cloud depth increases, or the optical depth remains unchanged, and the cloud gets less dense as it gets deeper. This could be clarified either around here or around Line 170.

This is now clarified in the case description in section 3.1.2. We don’t rescale the liquid water over each deepened cloud, but rather copy the liquid water values upward. Optical depth and liquid water path therefore increase linearly with height, because all else is kept constant.

Line 354: The wording “scattered direct irradiance” seem self-contradicting, as direct irradiance is, by definition, non-scattered.

It refers to all the direct irradiance that is scattered rather than transmitted or absorbed. I do not find it contradicting, in the same way that ‘condensed water vapour’ is not self-contradicting: it

Figures 12 and 13 (and perhaps others) should be placed after they are described in the text.

Figures are now placed after they are referenced in text. One exception is Figure 5 which is referenced immediately after placement, hopefully it will fit better during eventual typesetting.

Line 370: It might be worth adding “and its immediate surroundings” after “itself”, given the finding that, for 16.5 km cloud depth, some very high values occur outside the updraft.

I am not quite sure I follow. High peak IE values disappear once the anvil grows large enough to shade the updraft. At 16.5 km cloud depth in initial Figure 13a, this simply did not yet happen. After our ice-related bug fixes the difference in SSI between shaded and unshaded updraft is now less dramatic, however.

Lines 396-397: It seems worth mentioning that parts of the scene are shown in the right-side plot of Figure 7.

Indeed. I have changed the caption of Figure 16 to add the time step and therefore the cloud scene matches what is seen in the last time step of Figure 7.

Lines 420-421: I suggest either deleting the word “zone” or replacing the word “between” by “around”.

I used ‘zone’ because it is not a hard threshold, but I agree this reads a bit strange. I have rephrased the sentence to “transition from dominantly forward escape to downward escape is estimated to occur between”