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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "Impacts of cirrus clouds heterogeneities on TOA thermal infrared radiation" *by* T. Fauchez et al.

T. Fauchez et al.

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First of all, we would like to thank the reviewer for his helpful comments and suggestions.
The paper has been modified following these recommendations. In particular, we add to the revised paper:

- a paragraph concerning the problem of cloud edges in the Field et al., 2007 parameterization.

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Interactive Discussion

Discussion Paper

- a paragraph concerning the impact of the optical property parametrization on the TOA brightness temperatures.

- a new figure and section concerning the heterogeneity effects as a function of the spatial resolution. In this answer, we also show in figure 1, that heterogeneity effects in radiance space and in brightness temperature space are equivalent. However, because of the already important number of figures in the paper, we chose to add only few sentences in the paper.

The more specific comments of the reviewer are discussed below:

1. The typographical errors noted in the pre-published version still persist to some degree, the authors are again asked to give the manuscript to a native English speaker and writer. The most persistent error occurs when describing some variable as a function of another variable. Often "... in function of" please re-write this as "...as a function of ...." This error occurs throughout the manuscript, please correct throughout. Other errors are noted in the minor corrections below, but not all.
We corrected typographical errors in the paper.

2. Fig. 4. The authors do not show how well the 3D model represents the observed distribution of IWC in both the vertical and horizontal directions. The IWC values can be quite large. From the model fields, the authors should simulate the CloudSat radar reflectivity at 94 GHz, and compare the radar reflectivities directly. This will then give an indication of how well the 3D model represents the distribution of IWC.

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The objective of the CIRCLE-2 cirrus generation was the simulation of a realistic cirrus field as the one observed on the 25 May, 2007. We used ECMWF meteorological profile with some adaptations of the humidity profile to generate the cirrus with the top and base altitudes corresponding to those observed by CALIOP. The mean value as well as the standard deviation of IWC are constrained by CPI+FSSP measurements and the optical thickness by the IIR retrieval. We do not use Cloudsat measurements, therefore the IWC distribution would not be really comparable. Furthermore, we do not have a radar simulator to test the IWC distribution.

3. Small ice crystals are as the authors show, very important to the transfer of radiation at thermal infrared wavelengths. However, to study the impact of 3D cloud optical properties, they use the PSD parameterized by Field et al. (2007), which is based on the bulk measurements of cirrus and are not directly related to the cloud edges, where small particles will be important. How confident can the authors be that the Field 2007 parameterization is representative of the PSD at the edges of cloud? The authors need to state how important the omission of cloud-edges is to their work, if not, then why not?
Right, aircraft measurements of Field et al., 2007 were made inside the cloud not in the edges. This can be a limitation but we show that, the influence of the optical property parametrization does not impact significantly the TOA brightness temperatures at least under the IIR instrumental accuracy. We add this sentence:

"Note that the Field et al., 2007 parametrization is based on bulk measurements inside the cirrus and are not directly related to the cloud edges where they can be different. However, as we showed, the microphysical properties have a slight influence on TOA brightness temperatures with regard to the IIR instrumental accuracy"

4. The equations are written in radiance space, but the results are given in

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terms of brightness temperatures. Moreover, satellite instruments measure radiances and NWP centers assimilate radiances and not brightness temperatures. Figures 8 and 9 give results in brightness temperature, which are significant, but this may not necessarily be true in radiance. Can the authors state that they have shown that differences in radiance are significant, and the absolute radiance differences are greater than the radiometric noise of the instrument? The authors should also include in Figures 8 and 9 the radiometric noise of IIR.

We plot Figures 2 and 4 corresponding to Figures 8 and 9 (10 in the revised paper)in the brightness temperature space and Figures 1 and 3 in the radiance space. We can check that the behaviour observed for radiances is close to that of brightness temperatures with the same order of magnitude comparing to the instrument accuracy. The article contains already a significant number of figures, we chose thus not to include them but we add the following sentence in the comments of Figure 8 and 9: *"We present Figure 8 and 10 for brightness temperatures but results are similar in the radiance space."*

The IIR accuracy is included in Fig. 10 but not in Fig. 8 as Fig. 8 represents brightness temperatures at 100 m $\times$ 100 m, which does not corresponds to the IIR spatial resolution.

5. Concerning the general conclusion that assumption of ice optical properties is not as important as the PPA. This may be true, although, there are cases, which are above the radiometric noise of IIR in Figures 13 and 14. However, SEVERI, for instance, has a radiometric noise of only 0.2 K and as such the results presented in both figures are significant for that instrument. With improved instrumentation the results presented can still be significant and should not be written as if correct 3D representation of the ice optical properties

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is not important. Please re-write accordingly.

For IIR, 1K represents the absolute accuracy for the BT measurement but the radiometric performance (precision) is about 0.2 K, close to SEVIRI one. It is however right, that with a better instrumental accuracy, the bias due to the ice vertical heterogeneity of the optical properties could become non negligible. We add thus this sentence at the end of the paragraph 3.3:

"However, it could become significant for radiometer with a higher instrumental accuracy."

6. As alluded to previously, some NWP centers now assimilate cloudy radiances at lower horizontal resolutions than considered in this paper. Can the authors say how important the 3D effect is at lower resolutions, and the implications that this may have for NWP centers? Can the authors suggest a correction that NWP centers might apply to correct the solution obtained assuming the PPA?

That is a very interesting comment and we add a new figure (Figure 5, called Figure 18 in the revised paper) and subsection (3.6) concerning heterogeneity effects in function of the spatial resolution, at the nadir:

3.6 Influence of the observation scale on cloud heterogeneity effects

The previous results have been presented for the IIR spatial resolution of 1 km $\times$ 1 km. In this section, heterogeneity effects are presented for different spatial resolutions. Figure 5 shows the average brightness temperature difference $\overline{\Delta BT}$ as a function of

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the increasing in the spatial resolution: 1 km 1 km, 2.5 km (only for the cirrus 5 for time calculation reason), 5 km, 10 km and 20 km (only for CII-1, CII-2 and CII-3 cirrus). For each spatial resolution, differences are computed between 3D brightness temperatures, first calculated at 100 m and then averaged at the indicated spatial resolutions, and brightness temperatures computed from the average of the optical properties at the scale of 1 km, 2.5 km, 5 km, 10 km or 20 km. The difference of brightness temperatures at each scale are then averaged to the whole cirrus to obtained $\overline{\Delta BT}$*. We observe that the* $\overline{\Delta BT}$ *is maximal for cirrus 5, the most heterogeneous, with a value about 1.5 K at* $12.05\ \mu m$*. We also notice that,* $\overline{\Delta BT}$ *quickly increases between 1 km, 2.5 km and 5 km and reaches an asymptote after. This increase is all the more important as the cirrus mean optical thickness and mean heterogeneity parameters are large.*

We also add this sentence in the summary section:

"We also show that heterogeneity effects increase with the decrease of the spatial resolution strongly until 10 km. Numerical Weather Prediction models assimilate cloudy radiances at 10 km resolution, it would be interesting to study the possibility to correct the heterogeneity bias using for example IIR, MODIS or SEVIRI information at 1km."

Minor comments.

1. Abstract. Line 1. "... study on..." to ". . .study of..."

Done.

2. Line 8. "...resulting of..." to "...resulting from..."

Done.

3. Throughout the paper "plan-parallel" to "plane-parallel"

Done.

4. Line 9. "...view zenith..." to "...zenith view..." should this be nadir?
Done.

5. Introduction. Line 21. Infrared radiation is emiited by the earth's surface and atmosphere. Please correct.
Done.

6. Line 21 "...to the..."to ". . .to. . ."
Done.

7. Line 23 cloud radiative effect is now generally preferred to radiative forcing. Please change.
Done.

8. Page 27461. Line 3, satellite instrumentation also presently measure microwave radiation. Please correct.
Done.

9. Line 10. "...bias on..." to "...biases in..."
Done.

10. Line 11. Again "in function..." to "...as a function..."
Done.

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11. Section 2.1 line 25. "...for that an important sedimentation..." this sentence does not make sense please re-write.
Done (I deleted the sentence).

12. Page 27464. Line 12 Please define MODIS and supply a reference.
Done.
"(Moderate-Resolution Imaging Spectroradiometer, Platnick et al. 2003)"
13. Line 17. "On Fig 4a..." to "In Fig 4a..."
Done.

14. Line 19 "on 25 May" to "on the 25 May"
Done.

15. Line 26 "...same with the IWC increase twofold."to "...same but with the IWC increased by two-fold."
Done.

16. Line 28 replace "resumed" with "summarised"
Done.

17. Section 2.2. In this section some clarifications on the cited references is required. The 3D ice optical property parameterization is fundamentally based on the singles scattering properties described by Baran et al. (2013) [Q. J. R. Meteorol. Soc. (2013) $DOI : 10.1002/qj.2193$] and the parameterization used is the same as that developed by Baran (2012) [Atmospheric Research 112 (2012) 45–69]. The Baran et al. (2009) citation should remain as that was the first to show a direct couple between (IWC, cloud temperature) and the optical

properties of atmospheric ice. You might also like to sate in this section that previous parameterizations based on De alone to not fully describe the 3D effects as De varies vertically only, with littler variation in other dimensions. The authors do state something along these lines but the statement could be stronger.

The citations are changed and updated in the whole document as explained section 2.2:

"To study the impact of the optical property variabilities on the TOA BT, we use the parametrization developed by Baran et al., 2012, 2013 for the CII-1 and CII-2 cirrus. Baran et al., 2009 show that the extinction coefficient σ_e*, the single scattering albedo* ϖ_0 *and the asymmetry factor g could be related to the couple (IWC, Temperature)."*

18. Page 27465 lines 13-15. I would re-write this sentence as follows. "Furthermore, ...are smooth enough to be approximated by the Henyey-Greenstein phase function (reference), and these are assumed in the. . .model."
Done:
"Furthermore, in the thermal infrared, the forward peak is weak and the particle phase functions are smooth enough to be approximated by by the Henyey-Greenstein phase function (Henyey and Greenstein (1940)) and this is assumed in the Yang et al. (2001, 2005) model."

19. Section 2.3. page 27467 line 1 "neglectful" to "negligible"
Done.

20. line 24 "source flux" to "the source flux"

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Done.

21. The comparisons against SHDOM was achieved assuming a specific geometry, were a number of other geometries assumed? If so please state this.
Yes, we tested different case of cirrus with different geometry and thermal channel. We add this sentence:
"Comparisons were also been made for several cases of cirrus, with different geometry of observation (θ_v =30° , 60° and ϕ_v =45° , 90° , 180°) and spectral bands (at $8.65\ \mu m$ and $12.05\ \mu m$) and give similar results."

22. Line 24 units of radiance is incoorect please correct. The radiance unit used for radiative transfer computation is $W/m^2/sr$.

23. Section 3. Sub-section 3.1. Line 15 The layers are also assumed to be infinite in horizontal extent? If so please state.
We wrote:
"the cloud layers are assumed to be vertically and horizontally homogeneous, independent of each other with an infinite horizontal extent."

24. Please re-write sentence beginning on page 27472 as it is difficult to read.
We rewritted this sentence:

" We notice that, the larger $\sigma_{\tau_{1km}}$ is, the greater ΔBT_{1km} is."

25. Line 16 the linear relationship between sigma(tau) and the differences are linear if tau <2? Rather than for all tau. Please be more precise.

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It is true regarding Figure 11 of the revised paper, that our optical thickness remains below 2 . We complete the sentence:
"We see that the relation between ΔBT_{1km} *and* $\sigma_{\tau_{1km}}$ *is almost linear for pixels presented in this study, that are for optical thicknesses below 2."*

26. Line 15 page 27473 "in a cirrus" to "in cirrus"
Done.

27. line 28 "it is maximum" to "it is a maximum"
Done.

28. Section 3.4 page 27475 line 21 "in the order" to "on the order"
Done.

29. Page 27476 line 1. You mean infinite horizontal layers?
Yes, we change this in the line 1, page 27476.

30. Section in the summary you missed out SEVERI, this is an geostationary satellite that should be mentioned.
We included SEVIRI in the summary:
"We also show that heterogeneity effects increase with the decrease of the spatial resolution strongly until 10 km. Numerical Weather Prediction models assimilate cloudy radiances at 10 km resolution, it would be interesting to study the possibility to correct the heterogeneity bias using for example IIR, MODIS or SEVIRI information at 1km."

31. Page 27477 line 4 "simulated to the nadir" to "simulated at nadir"
Done.

32. Page 27477. In this section you might also like to state that the SEVERI radiometric noise is about 0.2 K, in this case 3D effects become important for tau (1 km) < < 0.4!
As we explained in question 5, for IIR, 1K represents the absolute accuracy for the BT measurement but the radiometric performance (precision) is about 0.2K, close to SEVIRI one. It is however right, that with a better instrumental accuracy, the bias due to the ice vertical heterogeneity of the optical properties could become non negligible. We add thus this sentence at the end of the paragraph 3.3:

"However, it could become significant for radiometer with a higher instrumental accuracy."

FIGURES
1. Fig. 1 (b) Please place units over the color bar.
Done.

2. Fig. 4 (b) There is no scale for the CALIOP observations. Is it the measured backscatter coefficient or volume extinction coefficient? Please state and insert a color bar of whatever the measurement is.
Done

3. Fig. 5. A plot of the IWC and cloud-temperature would be useful here as this

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would help the reader interpret the results more easily.
The temperature profile is plot in Figure 2 and the IWC in Figure 4. We add a sentence to indicate it in the paragraph concerning Figure 5.:
"The corresponding vertical temperature profile is shown in Fig. 2 and the IWC vertical profile in Fig. 4d."

Caption CII-12 to CII-2?
Done

4. Figs. 8 and 9 please also insert the absolute accuracy of the IIR radiometer and not just the model noise.
We include the absolute accuracy of IIR for Fig. 9 (10 in the revised paper) only, because Fig. 8 is at the spatial resolution of 100 m $\times$ 100 m, which do not corresponds to IIR measurements.

5. Fig. 17. Please insert the noise of SEVERI and state at which optical depth 3D effects become important.
As the paper is principally based on IIR measurement, we prefer only to show the accuracy of this sensor to not overload the figure.

FIGURE CAPTIONS
CAPTION FIGURE 1
Absolute radiances differences at 100 m ΔR_{100m} (in blue) due to the horizontal transport (in red), the extinction vertical variability (in green) and the statistical error of the code (black line) for cirrus 5 for bands at 8.65 μm (a), 10.60 μm (b) and 12.05 μm (c).

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CAPTION FIGURE 2

Absolute brightness temperature differences at 100 m ΔBT_{100m} *(in blue) due to the horizontal transport (in red), the extinction vertical variability (in green) and the statistical error of the code (black line) for cirrus 5 and for bands at 8.65* μm *(a), 10.60* μm *(b) and 12.05* μm *(c).*

CAPTION FIGURE 3

(a), (b), (c): Absolute radiances differences at 1 km $\times$ *1 km* ΔR_{1km} *(in blue) due to the horizontal transport (in red), the extinction vertical variability (in green) and the statistical error of the code (black line) for cirrus 5. Results are presented for the bands at 8.65* μm*, 10.60* μm *and 12.05* μm *respectively.*

CAPTION FIGURE 4

(d), (e), (f): Absolute brightness temperature differences at 1 km $\times$ *1 km* ΔBT_{1km} *due to the horizontal transport (in red), the extinction vertical variability (in green) and the statistical error of the code (black line) for cirrus 5. Results are presented for the bands at 8.65* μm*, 10.60* μm *and 12.05* μm *respectively.*

CAPTION FIGURE 5

Brightness temperature differences $\overline{\Delta BT}$ *at* 12.05 μm *as a function of the spatial resolution for different cirrus.*

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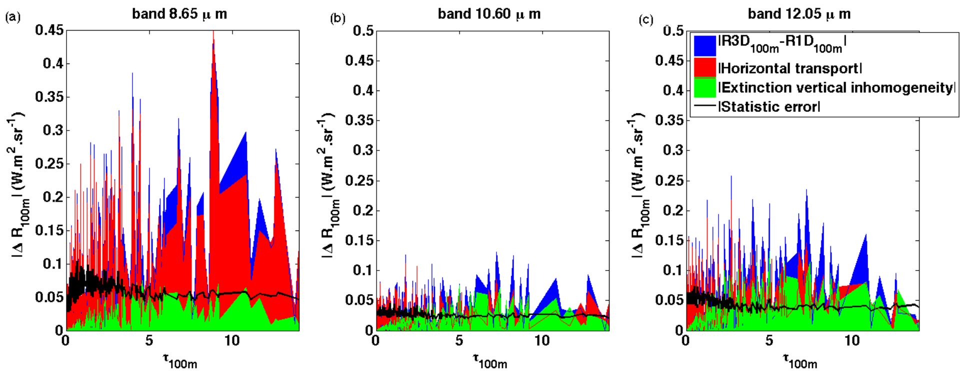

Fig. 1.

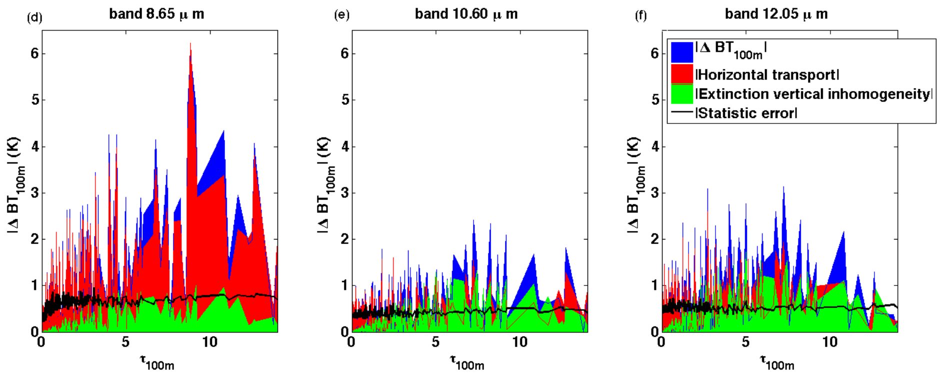

Fig. 2.

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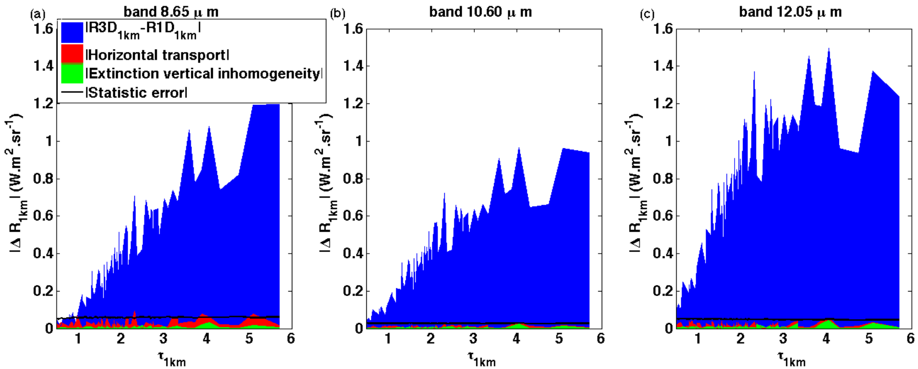

Fig. 3.

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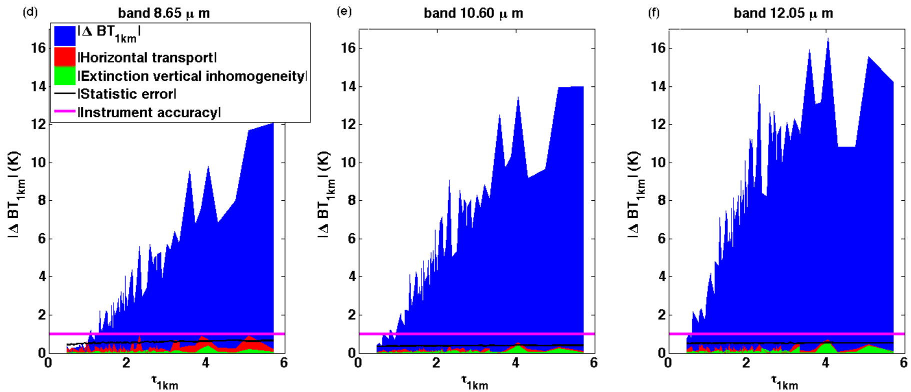

Fig. 4.

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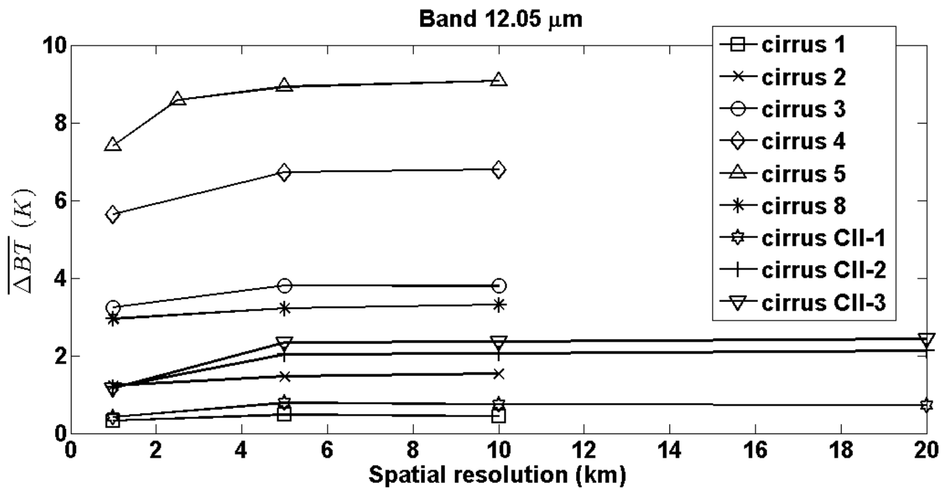

Fig. 5.