Reply to G. Van Harten

The authors would like to thank G. Van Harten for its valuable comments and suggestions that improve greatly the paper. We also acknowledge him deeply for his carefully reading and time spent to list all the point concerning grammatical and vocabulary errors. That increases a lot the readability of the paper.

Please, find below the point-by-point answers to the specific comments.

Specific comments

To draw the right conclusions on the effects of heterogeneity, it is important that the clouds are as similar as possible, except for their heterogeneity. Listed below are comments related to the choice of simulation parameters:

Page 4, line 23-24: Why are the rho's for the fractional cloud not closer to 0.6 for better comparison to the flat and bumpy cloud?

The aim of the paper is to study cloud heterogeneity effects for typical clouds. We thus generated clouds according to typical values of heterogeneity parameters. However, the choice of these values is not easy as the estimation of the heterogeneity parameter is not straightforward and depends on different parameters such as the type of measurement (radiometric data, radar/lidar data, airborne in-situ data), on the measured quantity (optical depth, liquid water content) and on the spatial resolution and scale used to compute it. Shonk et al.(2010) made a review of the different definitions and values that can be found in the scientific literature. We chose to follow the values obtained by Barker et al.(1996) from Landsat as the spatial resolution of the instrument (50m) is close to the spatial resolution of our simulations. Barker et al..(1996) found values between 0.2 and 0.8 for overcast stratocumulus clouds and 0.6 to 2.3 for small cumulus or broken clouds.

To explain our choice, we modified the paragraph page 7 as:
We created two stratocumulus clouds and one cumulus cloud. The latter is the result of instabilities of the boundary layer and lead to fractional cloud cover and larger heterogeneity parameter (Kawai and Teixeira, 2011). The flat and bumpy clouds representing overcast stratocumulus clouds have the same heterogeneity parameter across the 140x140 pixels with $\rho = 0.6$. The cumulus cloud has a fractional cloud cover equal to 0.76 and a heterogeneity parameter equal to 1.12 setting clear sky pixels to null values (0.95 if computed only with the cloudy pixels). These values are typical values obtained from Landsat data (Barker et al., 1996) for stratocumulus and cumulus clouds.

Page 4, line 28: How are the flat and bumpy clouds parameterized? What are the settings for cloud top height, etc?

The users do not prescribe explicitly the cloud top height nor the bumps structures. Indeed, they are the result of the numerical simulation using basic cloudy atmospheric numerical equations (first step of the 3DCLOUD algorithm). This numerical simulation is driven by the assimilation of the meteorological vertical profiles prescribed by the user.
To explain better how the clouds are generated, we add Figure 1 in the paper and this paragraph:

Figure 1 shows the vertical profiles of potential temperature and of vapor mixing ratio prescribed in this study to generate the three cloud fields. Globally, the vertical profiles of potential temperature and vapor mixing ratio give the cloud position. The mean cloud top height is mainly determined by the height where the potential temperature increases and the vapor mixing ratio decreases. Cloud top height fluctuations (shapes of top bumps) are mainly the result of the intensity of the vertical gradient of the potential temperature and vapor mixing ratio.

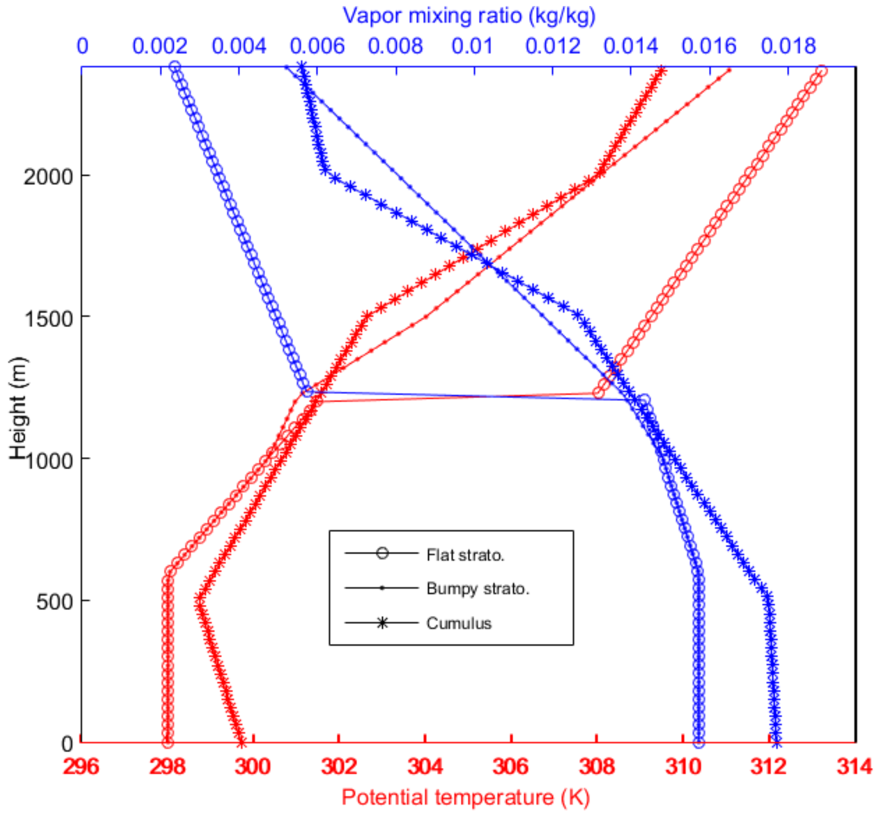

Figure 1:Vertical profiles of potential temperature and of vapor mixing ratio prescribed in this study to generate the flat stratocumulus (circle), the bumpy stratocumulus(point) and the cumulus (star) cloud fields.

Page 5, line 6: Why a black surface for polarized reflectances? The surface seems important in particular for the fractional cloud. At certain angles it can be very bright in polarization (sun glint).

The operational algorithm using polarized reflectances assumes a black surface because the multi-angularity of POLDER allow to not use the directions close to the sun glint where polarized reflectances can be high. In the other directions the polarized ocean surface reflection is almost null (black).

We add page 7 :
Indeed, for retrieval using polarized reflectances, the multi-angular ability of POLDER provides the advantage of not using the directions close to the sun-glint where polarized reflectances can be high.

Page 5, line 15; Page 18, CTOP: Max(z) / min(z) for cloud top height / bottom of the 3D clouds does not seem like a representative value to me. See Fig. 1: realistic values are closer to 1.2 (Fig. 1 only shows y=3.5 whereas the realistic value should be computed from all y). Better values should be used, or at least the retrieval results should be compared to more than just max(z).

You're right that max(z) was not a representative value for cloud top height. Following your comment, we computed the mean cloud top height. The table 2 was changed accordingly as well as comments page 9 :
In table 2, we report the mean cloud top height for each heterogeneous cloud and the retrieved value. The 1D homogeneous values used for control was set the intermediate mean cloud top altitude. We note slight difference about -4 hPa (+ 37m) between input and 1D retrieval, which reveals small differences between the radiative transfer codes used for the simulation and for the retrieval. Differences between

3D and 1D are however much larger, especially for the bumpy and fractional cloud with values of +62hPa (-550m) and +45hPa (-390m).

Page 11, line 3-5: This belongs in Section 2 to put the synthetic clouds into perspective. Apparently, the fractional cloud with stdev(COT)=7 exceeds POLDER's homogeneity limit of 5. The fractional cloud also gives the worst results compared to the flat and bumpy clouds. I think it would be good if the choice for stdev(COT)=7 would be justified in Section 2, and if at least rough numbers are given for how the results compare to a similar fractional cloud with stdev(COT)=5.

As explained before, we chose typical value of heterogeneity parameter corresponding to the cumulus cloud. We apply the aerosol above cloud algorithm to the worst case, which can be seen as the upper limit of the possible error on retrieved AOT. Afterwards, when we computed the stdev(COT) from the 1km pixels real COT (different to the retrieved one), we found a value slightly above the limit fixed arbitrary in the algorithm. For computational time reason, that is not possible to modify the cloud case in order to have stddev(COT)=5 and we do not think that the results would be a lot different. We modified the paragraph page 15-16.
For the fractional cloud of this study, we checked the standard deviation value computed from the input cloud optical thickness (different from the retrieved one) and found 7. It is slightly above the homogeneity limit fixed in the aerosol above cloud algorithm developed for POLDER (Waquet et al., 2013). The results presented here for aerosol above cloud retrieval can thus be seen as an upper limit for the operational algorithm.

Detailed comments:
Text has been modified according to all the detailed comments addressed in the review. See the joined file with tracking changes. Note that some corrections were already made in the preview phase.
The authors acknowledge deeply G. Van Harten for his careful attention and the time spent to do it.

Please find below answers to comments, which require more precise answers and were not reported in the specific comment section.

26: "which is supposed, in real cloud, to be more important than" Reference? How much more important? Which retrieval parameters are affected?

We add as the reference (Magaritz-Ronen L. et al., 2016) which explores the mechanisms leading to low horizontal variability of effective radius at the top of the cloud and gives many others references in the introduction. The maximum variability is estimated to be of order of 10%.

18: "algorithm retrieves" Does it really retrieve cloud cover, or should it say "algorithm assumes"?

Right, the cloud cover is an output of the algorithm for the super pixel POLDER but here the term "retrieve" is not adequate. We removed the sentence

P7 :
I found the paragraph about albedo hard to read. If I understand correctly, the train of reasoning is: - In order to retrieve cloud albedo, the POLDER retrieval algorithm first retrieves COT from multi-angle reflectances, then does a forward computation from COT to albedo. - A heterogeneous cloud has lower reflectance than a homogenous cloud with the same (mean) cloud optical depth, due to plane-parallel bias. - The POLDER algorithm will thus retrieve a COT that is too low. - From that too-low COT, the POLDER forward computation will produce an albedo that is also too low if the cloud were really a homogeneous cloud, but since it is really a heterogeneous cloud with a

lower albedo due to plane-parallel bias, the POLDER-retrieved albedo is actually very close.

You understand well.

- To compare this retrieval result to the "truth", the actual albedos are directly calculated from the 3DMCPOL radiances. It would be helpful if this could be explained in a more direct way, e.g. by preparing the reader by summarizing this at the beginning of the paragraph, before going into the details.

Other suggestions for textual changes:
- Page 6, line 26: "3D reflectances and from 1D reflectances are not comparable" -> "a heterogeneous cloud are not the same as the ones retrieved from an equivalent homogenous cloud"
- Page 6, line 27: "simulated 3D reflectances are lower than the 1D ones, the retrieved optical thickness is an effective optical thickness, lower than the averaged one (Figure 2)" -> "reflectances off of a heterogenous cloud are lower than the reflectances off of an equivalent homogenous cloud with the same (mean) COT, leading to an effective optical thickness, which is lower than the mean optical thickness."

Following the above advices of the reviewer and hoping to be clearer, we rephrase the paragraph about albedo as:
The assessment of cloud heterogeneity effects on cloud albedo is realized by comparing the retrieved POLDER algorithm albedos with the ones directly computed with the 3DMCPOL radiative transfer model identified as the true one. Direct comparison of retrieved albedos values from homogeneous or from the heterogenous clouds as done for other parameters are not suitable for cloud albedo. Indeed, the plane-parallel bias leads to reflectances off of a heterogenous cloud lower than the reflectances off of an equivalent homogenous cloud with the same (mean) COT. The retrieved optical thickness is lower than the mean optical thickness of 10 (Figure 4). Using it to recompute the albedo in the POLDER algorithm leads to a too low value comparing to the albedo of the equivalent homogeneous cloud. Contrarily, using 1D cloud radiative model in the inversion and in the direct computation as it is done in the operational algorithm, is consistent and leads to a sound cloud albedo. The plane-parallel bias is indeed almost cancelled.

P7 : 27-29: If 41%, 52%, and 38% of the pixels are considered "a large part", aren't the remaining 59%, 48%, 62% even larger parts? I don't understand.

We wanted to highlight that 41%, 52% and 38% of reflectances pixels cannot be reproduced and explained with 1D radiative transfer but only with 3D radiative transfer. We add "and thus cannot be obtained with 1D radiative transfer simulation"

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