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Atmospheric Measurement Techniques Discussions

Interactive comment on “Evolution of DARDAR-CLOUD ice cloud cloud retrieval: new parameters and impacts on the retrieved microphysical properties” *by* Quitterie Cazenave et al.

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We would like to express our thanks to the reviewer for his/her help in improving the paper. We are grateful for the time spent on this review. In what follows, we respond point-by-point to the comments made.

Major issues

1. In the abstract, the impacts of changes are presented in an inconsistent way. The impact for IWC is provided with the upper range while the range for size is given. Up

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to 50% for IWC is a huge difference. It will be better that the impacts are accessed in term of mean changes and ranges.

Response: Below is the new abstract.

Change in manuscript: Abstract: In this paper we present the latest refinements brought to the DARDAR-CLOUD product, which contains ice cloud microphysical properties retrieved from the cloud radar and lidar measurements from the A-Train mission. Based on a large dataset of in-situ ice cloud measurements collected during several campaigns performed between 2000 and 2007 in different regions of the globe, the parameterizations used in the microphysical model of the algorithm – i.e. the normalized particle size distribution, the mass-size relationship, and the parameterization of the a priori of the normalized number concentration as a function of temperature – were assessed and refined to better fit the measurements, keeping the same formalism as proposed in DARDAR basis papers. Additionally, in regions where lidar measurements are available, the lidar ratio retrieved for ice clouds is shown to be well constrained by lidar-radar combination or molecular signal detected below thin semi-transparent cirrus. Using this information, the parameterization of the lidar ratio was also refined, and the new retrieval equals on average 35 sr +/- 10 sr in the temperature range between -60°C and -20°C. The impact of those changes on the retrieved ice cloud properties is presented in terms of IWC and effective radius. Overall, IWC values from the new DARDAR-CLOUD product are in average 20% smaller than the previous version. In parallel, the retrieved effective radii increase between 5% and 40%, depending on temperature and the availability of the instruments, with an average difference of +20%. Modifications of the microphysical model strongly affect the ice water content retrievals with differences that were found to range from -50% to +40%, depending on temperature and the availability of the instruments. Larger IWC values are found with the new version in the cold regions detected by the lidar. On the contrary, in warmer regions, where only the radar measurement is available, a reduction of the retrieved IWC is found. The largest differences are found for the warmest temperatures (between

-20°C and 0°C) in regions where the cloud microphysical processes are more complex and where the retrieval is almost exclusively based on radar-only measurements. The new lidar ratio values lead to a reduction of IWC at cold temperatures, the difference between the two versions increasing from 0% at -30°C to 70% below -80°C. Effective radii are not impacted. At cold temperatures, the impact of the new lidar ratio on the retrieved IWC is larger than that of the new microphysical model, hence a reduction of IWC values for the new DARDAR-CLOUD product, for all temperatures.

2. The quality of the figures is poor. The x-axis and y-axis titles are too small, and units also need to be correctly displayed.

Response: This has been modified, an example is presented in Fig. 1.

3. It is not clear why short periods of data were selected for comparison. It will be great that results on seasonal and global scales are presented to document the impacts due to algorithm changes.

Response: This short period of data was used to reduce calculation time. Since CloudSat and CALIPSO have a polar orbit, we considered this subset was enough to test the new version of the algorithm and statistically represent the entire range of the retrieved properties and the impact of a modification of the algorithm, globally.

4. The algorithm outputs lidar ratio, which has limited information from observations directly. The V1 lidar ratio a prior was clearly wrong. The V2 results are more reasonable. However, the results of lidar ratio should be compared with CALIPSO results. Also, it is important to discuss on how multiple scattering is treated in the algorithm because it is directly tied to effective lidar ratio selection.

Response 1: A comparison with CALIPSO can be made, based on the work by Garnier et al. 2015. To do so, only pixels corresponding to single layer semi-transparent cirrus clouds were selected from the dataset, and the statistic of the corresponding retrieved lidar ratios are compared to the parameterization of S as a function of temperature determined by Garnier et al, 2015. This is presented in Fig.2, with the parameterization by Garnier et al in red triangles and the parameterization for the Varcloud algorithm in black solid line with circles. As can be seen, the slope of the parameterization differs from one algorithm to the other, and the difference between the two algorithm increases when the temperature decreases. This is already discussed in the manuscript in section 3.1. Since the retrieved lidar ratio strongly depends on the a priori in the case of DARDAR-CLOUD, it also moves away from the CALIPSO retrieval when the temperature gets colder. However, it is visible that the new version of DARDAR-CLOUD is more in agreement with CALIPSO results. This result is hinted at in the current manuscript by combining the results described by Figure 1 with those presented in Figure 6. Therefore, since the paper is already rather long, we propose not to make any change regarding this matter.

Response 2: Multiple scattering is accounted for in the lidar backscatter forward model. This forward model was developed by Hogan (2008). It uses a fast, approximate analytical method based on the representation of the photon distributions by their variance and covariance to infer multiple scattering effect at each gate of the measured profile.

Hogan, R. J., 2008: Fast Lidar and Radar Multiple–Scattering Models. Part I: Small–Angle Scattering Using the Photon Variance–Covariance Method. J. Atmos. Sci., 65 (12), 3621–3635, doi:10.1175/2008JAS2642.1.

Eloranta, E. W., 1998: A practical model for the calculation of multiply scattered lidar returns. Appl. Opt., 37, 2464–2472.

Change in manuscript (Page 7, line 6): Additionally, multiple scattering is not accounted for the same way. Based on the work from Platt (1973, 2002), Garnier et al (2015) define a multiple scattering factor to correct the two-way transmittance from the contribution of multiple scattering. This correction factor equals 1 in the single-scattering limit and varies from 0.5 to 0.8 as a function of temperature for the CALIOP instrument. In the Varcloud algorithm, multiple scattering is accounted for in the lidar backscatter forward model that was developed by Hogan (2008). This forward model uses a fast, approximate analytical method based on the representation of the photon distributions by their variance and covariance to infer multiple scattering effect at each gate of the measured profile.

Minor issues

1. Page 3, line 23: change “restate” to “summarize”.

Response: This has been changed accordingly.

Change in manuscript (Page 3, line 23): We summarize here the main characteristics of the inverse method. . .

2. Page 4, line 3: change “apparent” to “attenuated”.

Response: This has been changed accordingly.

Change in manuscript (Page 4, line 3): Then, the lidar attenuated backscatter at range r from the instrument can be expressed in the single-scattering limit as a function of αv and S

3. Page 4, line 11-14: the equivalent diameter discussion here is confusion.

Response: OK, the discussion has been modified, getting more into details.

Change in manuscript (Page 4, line 11-13): D_eq is the equivalent diameter of the ice crystal (in meters). It corresponds to the diameter the particle would have if it was a spherical liquid particle of the same mass. It is obtained from the mass of the particle M and the density of water rho_w=1000 kg/m3 as follows: D_eq=[6M/(π rho_w)]ˆ(1/3) In the normalized framework, this equivalent diameter is scaled by the mean volume diameter, D_m, defined as the ratio of the 4th and the 3th moments of the PSD, in terms of D_eq.

4. Page 4, line 24: “the LUT” refers which LUT. Is there only one LUT for the algorithm?

Response: Yes, there is only one LUT. This LUT is defined for bins of D_m. Each value of D_m corresponds to a value of α/N_0*, Z/N_0*, IWC/N_0*, r_e etc. . . It is then possible to find an unambiguous relationship between α/N_0* and Z/N_0* (for the forward model of radar reflectivity) or between α/N_0* and IWC/N_0* (for the retrieval of IWC).

Change in manuscript (Page 4, line 24): Once the optimized cloud profile has been determined, this same LUT is also needed to retrieve additional features of the profile such as the IWC and effective radius.

5. “Page 5, line 4-5: The logic does not make sense. Maintaining continuity does not mean accurate results.

Response: Mass-size relationships are difficult to parameterize since they depend on many factors, and not only temperature. Ideally, each cloud type (and associated cloud processes) should be given its specific parameterization. There have been many studies, some of them are referred to in this paper (and work still ongoing), trying to refine those relationships that are crucial to retrieve cloud properties from remote sensing measurements. However, in the case of the DARDAR-CLOUD product, since we lack information to be able to accurately fit to each and every cloud situation, we decided to focus on the statistical side of the problem. Hence the choice to use a single relationship, that was determined using a selection of cloud in-situ measurements performed on different kinds of ice clouds in different parts of the globe.

Change in manuscript (Page 5, line 4-6): However, temperature is not the only parameter that matters for the determination of M(D). In order to accurately fit this relationship to each and every cloud situation, we would need more information on cloud type, particle size, that are not straightforward to derive from the CloudSat-CALIPSO synergy. In addition, it is difficult to change M(D) in the retrieval scheme upon the cloud type and the meteorological conditions without risking to bring discontinuity on the retrievals. As a result, in the case of the DARDAR-CLOUD product, we decided to focus on statistical results and assume a single M(D) relationship which can work for most of the situations.

6. Page 13, lines 9-10: The two extremes of radar-only results seem indicating that the algorithm for the radar-only region is not very stable

Response: Yes, unfortunately, it is more or less the case. The reason is also that in such regions, the complexity of microphysical processes increases with different impacts of the changes in the algorithm depending on the processes at stake.

7. Table 1: use the formal way to represent the constant coefficients.

Response: Sorry, but we do not understand what you mean by “the formal way”.

8. Figure 5a and 5b: It is hard to separate the two line styles. How about using color lines for them?

Response: This has been modified, the new figure is presented Fig. 3.

9. Figure 9, figure caption: What does “33.2” mean here?

Response: It is a mistake. It refers to the paragraph 3.2 “The microphysical model”.

Change in manuscript (caption Figure 9): Comparison of the retrieved IWC for the 2 microphysical parameterizations presented in section 3.2 (but with the same lidar ratio a priori).

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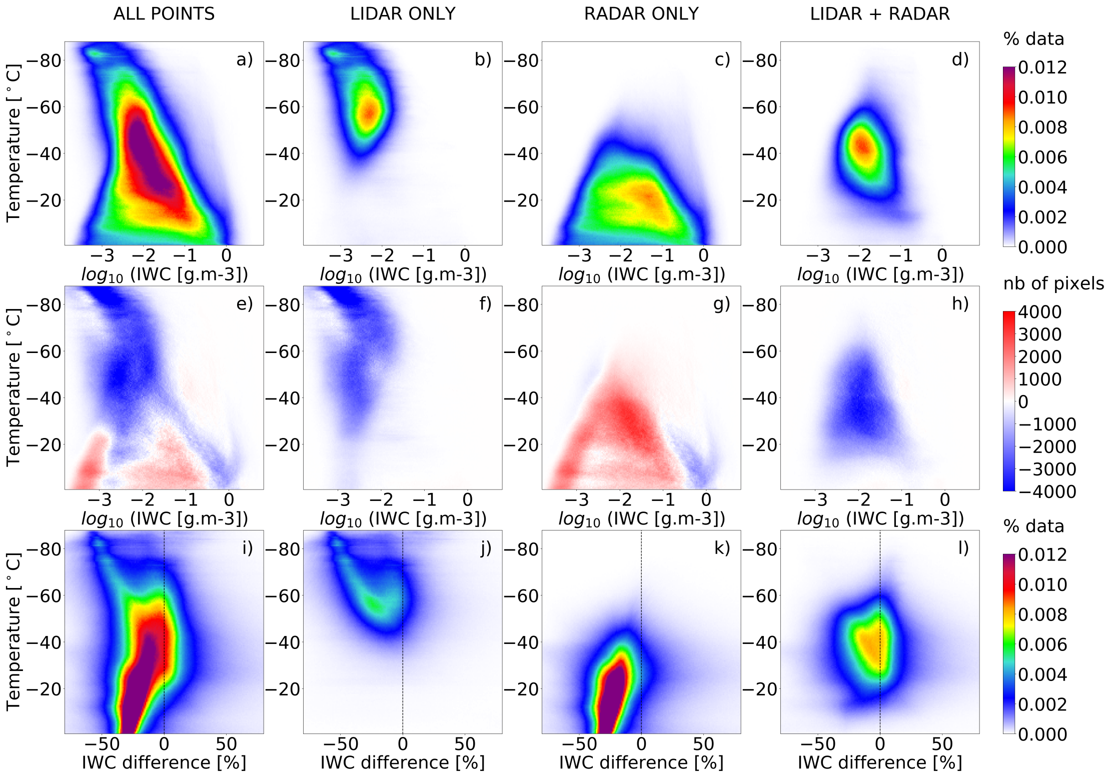
ALL POINTS
LIDAR ONLY
RADAR ONLY
LIDAR + RADAR
a)
b)
c)
d)
e)
f)
g)
h)
i)
j)
k)
l)
Temperature [° C]
−80
−60
−40
−20
−3 −2 −1 0
log_{10} (IWC [g.m-3])
−50 0 50
IWC difference [%]
% data
0.012
0.010
0.008
0.006
0.004
0.002
0.000
nb of pixels
4000
3000
2000
1000
0
−1000
−2000
−3000
−4000

Fig. 1.

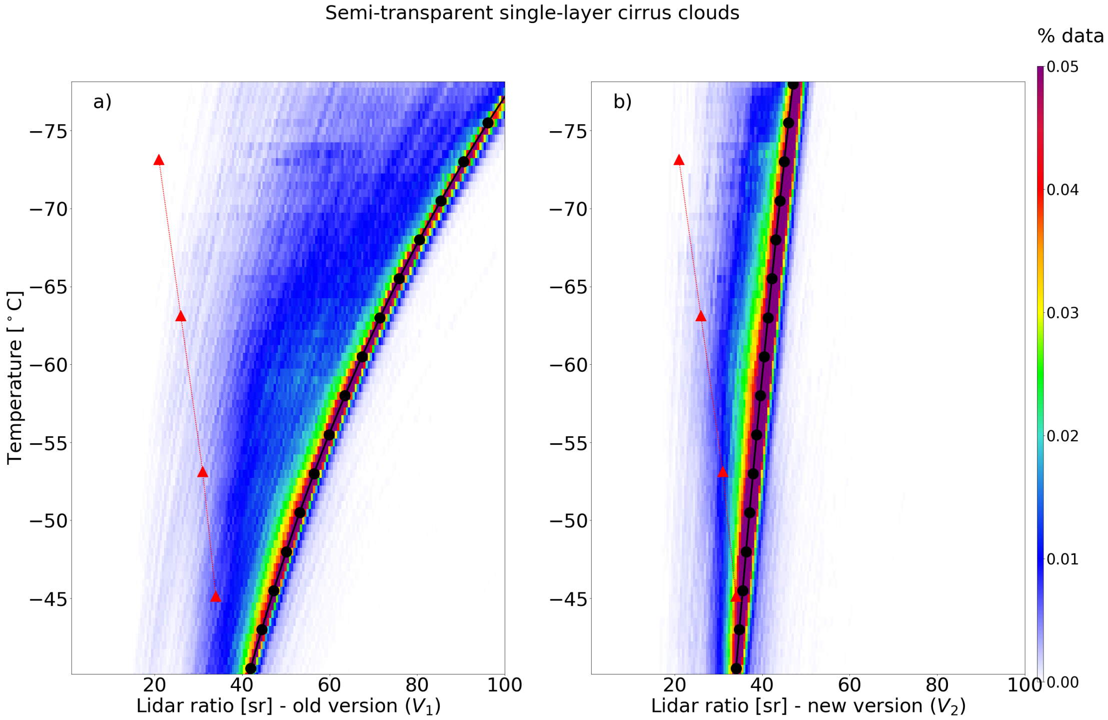

Fig. 2.

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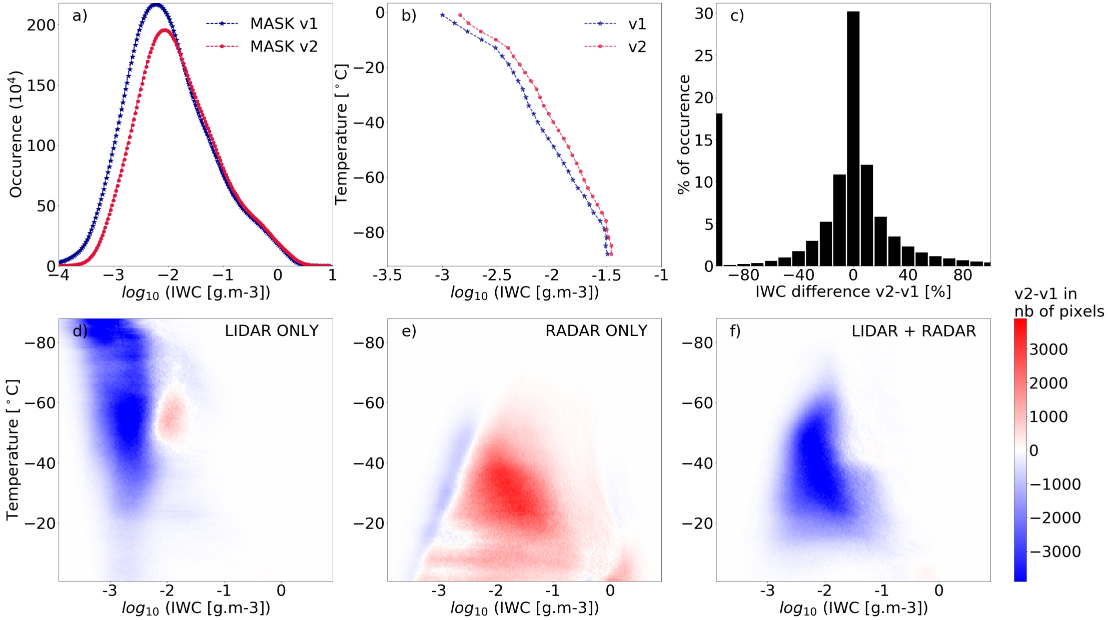

Fig. 3.

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