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Atmospheric Measurement Techniques Discussions

Interactive comment on "Simultaneous retrieval of water vapour and temperature profiles and cirrus clouds properties from measurements of far infrared spectral radiance over the Antarctic Plateau" *by* Gianluca Di Natale et al.

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Author response to Referee #1

Reply. We thank the Reviewer for the appropriated suggestions. Below we reply the questions with reference to page (P) and line (L) of the updated manuscript (AC1-supplement file).

Comment. Introduction: At first I was surprised, because I didn't consider the far IR a good area for such a retrieval approach. But I got almost convinced otherwise. The authors try it, and point out the sensitivity of the radiance with respect to the effective radius below 667 cm-1. However, they are just showing the scaled optical parameters (Figure 1). Such a sensitivity gets often “buried” in changes of other parameters, like optical thickness, water vapor or temperature can mask the impact of the effective radius. So, instead of a plot like Fig 1, I would like to see a short sensitivity study: for example, how does the radiance spectrum change if you increase the diameter from 20 to 50 micron, compared to a change of 10% in water vapor, temperature, optical thickness, ... I think this would help to convince the reader.

Reply. We have added the new Fig. 2 in the text to show the sensitivity for the different parameters. The sentence at P5 L9-12 has been rephrased and the following text has been added at the end of P5 L16-22: “A sensitivity study has been performed to compare the different responses of radiance to atmospheric state and cirrus cloud parameter variations. We considered a typical case simulated using climatological water vapour and temperature profiles (see Sect. 4 for more details about the climatological profiles used) and a cirrus cloud of 1 km with the bottom at 1800 m above ground and τ = 1. Figure 2 shows that a variation of 10 % in water vapour has the same effect of a 10 μm variation in D_e in the FIR, but above 500 cm^{-1} the behaviour is the opposite. Therefore the effect of these two parameters can be discriminated in spectral measurements including both spectral regions. Moreover Figure 2 also shows that the effect of a variation in the cloud τ and D_e can be discriminated by using the FIR spectral range.”

Comment. I like the detailed description of the RTA approach and the retrieval algorithm in the chapters 2 and 3. However, some sentences are pretty long and sometimes difficult to read. If possible, try to split and shorten sentences, it would make everything easier to read. One thing that caught my eye in chapter 3: you speak about your “high resolution of the first layers”. However, neither eigenvalue decomposition nor results show a reason to do this. Actually, your results (Figure 8) show a very coarse resolution. Perhaps I misunderstood this, so please try to explain the reasoning for choosing these many layers in the lower atmosphere.

Reply. We have rephrased the longer sentences to improve the clarity in Sect. 2 and 3. In the particular the sentence at P6 L2-10 has been modified to make clearer the concept of the forward model and retrieval vertical resolutions: "The simulation of the downwelling spectral radiance at the instrument level is performed by dividing the atmosphere into 52 levels with irregular vertical resolution. The vertical resolution varies from 2 m in the first layer above the instrument, where the values and variations of the main atmospheric variables are very large, up to 1 km in the upper part of the profile, around 11 km and close to the tropopause, where the atmosphere is almost transparent. The cloud temperature is calculated from the atmospheric profile as the average between the values at the top and the bottom of the cloud, the latter two levels as supplied by the lidar measurements. The retrieved variables are D_{ge} and the IWP for the cloud and the volume mixing ratio (VMR) of water vapour (**Q**) and the temperature (**T**) at selected levels of the vertical profiles. Selection of the fitting levels will be described later on in Sect. 4. The remaining levels of the vertical profiles are interpolated."

Comment. Chapter 3.1 is a little bit confusing to me. First you speak about a measurement every 12 minutes. That's a lot of measurements. But then you use only 15 selected spectra near to 12 UTC sonde time. Then you speak about 4 selected days. Why only 15 spectra and why these 4 days? Is the spectra selection based on a quality control? Please explain this in more detail. Why are these days so special? They look like selected to show different seasons, but why not equal time distance? I guess there is a reason for this selection, but you have to explain it.

Reply. In this paper we would like to show the simultaneous retrieval of the atmospheric and cirrus cloud variables and compare the results with the available independent measurements i.e. the vertical radiosoundings of the atmosphere. Therefore we have chosen to analyse only the measurements around 12 UTC and in presence of cirrus clouds. These case studies were 15 in the year 2014, in each case we analyzed the 2-3 spectra in better temporal coincidence with the radiosounding. Finally, to show some typical fitting results for the vertical profiles, we presented in the paper 4 representative cases, one per season, whereas for the cloud parameters all the 15 cases are shown.

The text has been modified at P10 L2-12 to: "The measurements of the downwelling spectral radiance used in this work were performed from the Antarctic station Concordia by the REFIR-PAD spectroradiometer (Palchetti et al., 2015), and covered the 100–1400 cm^{-1} spectral range with a 0.4 cm^{-1} resolution. Each spectrum is the average of 5 min of atmospheric observations. The measurement is repeated every 12 min due to the instrument calibration cycle. The instrument operates with a duty cycle of about 5 hours out of 7 to allow for pre-analysis and data transfer to Italy.

To evaluate the performances of the developed retrieval algorithm, we have selected exclusively measurements performed in presence of ice clouds and in a coincidence as close as possible with the radiosoundings routinely performed from Concordia at 12 UTC using Vaisala RS92 radiosondes. The cloud phase was identified by analysing the logarithmic range corrected signal (RCS) and the depolarisation component provided by the lidar every 10 min. We identified 15 cases in which the above mentioned requirement were fulfilled in 2014. For each case we selected the three atmospheric spectra measured in presence of cirrus that were in better temporal coincidence with the radiosounding."

Comment. Chapter 3.2: I don't think it does not belong here, at least not the first part. You just explained the selection of data, so you should go to the results and not back to the theory of the optimization. Honestly, the entire chapter numbering is a little bit confusing. I would more do it this way: 1. Introduction 2. Theory : 2.1 Modelling . .

., 2.2. Retrieval algorithm, 2.3 (your 3.2) Optimization 3. Data selection and Results : 3.1. Selected data, 3.2 Eigenvector decomposition (where you describe Fig 5), 3.3 Results 4. Conclusion

Reply. We have simplified the chapter structure by removing the subsections and rearranged the new sections following the Referee suggestions as: 1. Introduction 2. Modelling of the thermal radiance emitted by cirrus clouds 3. Retrieval algorithm 4. Climatology and optimisation of the retrieved state vector 5. Data selection and results 6. Conclusions

Comment. Another thing about Chapter 3.2 : It has a lot of errors with respect to grammar ("These corresponds . . ."), punctuation or citation brackets. For example: "As shown by (Rodgers, 2000) . . ." should be “As shown by Rodgers (2000) . . .". A few lines later you do it exactly the other way around. Please read this part again and eliminate these errors.

Reply. The corrections have been done.

Comment. Chapter 4: Again your 15 spectra are reduced to 4 days without much explanation. Figure 8: why do you show the water vapor on a log scale? I realize, that your "allowed range" is between 1 and 1000 ppmv, but in reality changes or errors in water vapor should be easily shown on a linear scale. Using a log scale is a little bit suspicious. Be honest and give quantitative numbers, like "compared to radio sondes, differences of 100 ppmv - or 50% - are seen at 200 m . . .". You start from a climatological profile, so errors of 50-100% in water vapor are very common and understandable, so nothing to worry about. But it has to be visible and understandable. I cannot decipher anything in these plots. You could also mention things like "it works better for water vapor in summer than winter" or "better for thin optical clouds (tau < 1) than thick clouds." I don’t want to judge or condemn your retrieval approach, I want to understand the performance for the different cases and see where it performs best. As I mentioned before, the resolution of these results does not overlap with the promised high resolution of your model. Perhaps I misunderstood the reasoning, so please reiterate here or, why the high resolution in layers is not visible. Figure 9: Ok, I am guessing, that's the 15 selected spectra suddenly. So you have one per day and the 4 special days are just one spectra per day? Would be nice if you could clarify this earlier, when I asked my question about it. But you write almost nothing about this plot. Just 3 lines about the way it looks. Why should diameter and temperature be correlated? Why are clouds usually thin? OR does your retrieval only work on thin cirrus? You don't mention z or delta-z here. As a rule: if you show something, you have to talk about it. Ok, you mention is shortly suddenly in connection with Fig.10, but that's all. Talk more about it, if you show something.

Reply. The question about the selected cases has been addressed in the previous reply and a clearer description has been added at the beginning of Sect, 5 at L10 L2-12. The high vertical resolution is required in the forward model calculations to describe the large variability in the atmospheric profiles. For operating the retrieval in all the cases, including low altitude cirrus clouds as frequently occurs over the Antarctic Plateau, we have chosen to use only a very coarse vertical resolution.

Figure 8 (now Fig. 9) is in log scale because of the wide range of variation of the water VMR. However, this choice can mask the differences with the radiosoundings, as noted by the Referee. Actually the comparison between vertical profiles at very high and very low resolution connot be more than qualitative, so to allow for a more quantitative comparison between retrieved quantities and radiosoundings (and to reply also to the Major Comment 4 by Referee #3), we have added a new figure, Fig. 10, In which we plot the total precipitable vapor (PWV) as obtained by the fitting and by the radiosonde profiles, and the temperature at the 13 m level, compared with the average of the radiosounding temperature profile over an altitude range of 50 m roughly corresponding to the sensitivity range of the fitted point.

The figure also shows the retrieval error bars for each parameter and the time delay between measurement and radiosounding (bottom panel). We see that the largest differences in temperature happen in wintertime when the inversion near ground is very large, while for humidity the largest difference is in January, in a case in which we have one of the highest time delays between radiosounding and measurement, together with a high atmospheric variability (as shown by the three corresponding measurements giving different results).

Figure 9 has been better described by addressing all the questions raised by the Referee.

The text has been modified at P11 L17-27 to: "The fitting results for the cirrus cloud optical and micro-physical properties are plotted as a function of time in Fig. 11 together with the cloud geometrical parameters inferred from the lidar measurements. The retrieved effective particle diameters D_e vary between 20 and 90 μm with an error lower than 20 %, with the higher uncertainties corresponding to shallow clouds with a thickness of about 300-500 m. The optical depths τ, calculated from the retrieved IWP by means of Eq. (3), are between 0.05 and 1.1. The errors, obtained through propagation from the retrieval error of the IWP, are less than 20 %. The cloud temperature T_c, corresponding to the mean temperature between cloud top and bottom, is between -30 and -60 °C. T_c is obtained from the retrieved atmospheric profile using the cloud bottom height z_b and the thickness Δz provided by the lidar, parameters that are also shown in the bottom panel of Fig. 11. We can see as the largest particle diameters occur in summer when temperature is higher, as expected from the ice particle formation process, and the optical depths are generally lower than 1, hence the analysed cirrus clouds are optically thin (Mahesh et al. 2001b, Kahn et al. 2004). The retrieved cloud temperature is, in most cases, lower than -40 °C, that is consistent with the single phase of particles as detected by the lidar."

The developed algorithm is able to work with optically thin clouds with τ < 1.2 because the single homogeneous layer approximation as now explicitly stated in the text at P3

L7-13.

Comment. Overall: talk more in this chapter in a quantitative way. Validation is all about numbers. You are mainly defending the deviation (points 1-3 at page9, lines 20-25), without actually giving quantitative numbers of the deviation. Again, use something like "100 ppmv – or 50 percent - deviation at layer 100 m, in summer, when thick ice clouds present . . ." and THEN give reasons for the deviation. Or point out things like "the retrieval is not able to capture the fine structure at 1000 m on day XY, which is visible in the radiosondes."

Reply. The plot of the difference between the retrieved values and the radiosondes has been added (see discussion in the reply to the previous question) that shows the deviation for all the cases. A discussion about the largest differences has been added and the sentence has been modified at P10 L26-29 to: "The comparison between the retrieved water vapour and temperature profiles with the radiosounding, in the 4 cases considered in Fig. 6, are presented in Fig. 9. As we can see the retrieved profiles generally agree with the radiosoundings measurements. Due to the low vertical resolution of the retrieval procedure, shown by the SVD analysis, it is not possible to capture the fine vertical structures visible in the radiosounding, e.g. the sharp variations occurring around 1000 m on October 1st, 2014."

Comment. - Conclusions: I just say the same again: quantitative numbers. You can give the residuals as a Chi-squared number to show the small residuals. And then you shoot out a few numbers compared to the radio sondes. Also: point out some things that do not work, try to give a reason and how you are planning to solve it. Some outlook is always a nice thing, instead if pretending you made already the perfect retrieval. Summary of the review: retrievals are hard to build and they do not perform well all the time. They have caveats, but also advantages – and they are usually never really finished. You are introducing a new retrieval algorithm here, so you are allowed to have a non-perfect retrieval. I know that people are often aiming on the bad cases and take them apart. And I know that's not helping. But you have to risk showing bad performance so that people can evaluate improvements in the future. As I final guideline, I would propose you follow a certain path with respect to this article: A) describe the retrieval, which is actually done very well in this article B) quantify the current performance – with numbers C) evaluate good cases and bad cases, if possible try to find reason for the good or bad cases D) give an outlook, how the certain bad cases could be improved or of you think you reached the limit of your possibilities. If you do this, I don't see a problem to get through the final review.

Reply. We thank very much the Referee for the appropriate suggestions. We think to have improved the manuscript by replying to all the questions raised in the review.

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