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Atmospheric Measurement Techniques Discussions
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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 #2

We thank the Reviewer for the useful suggestions and comments. In the following response we will address each specific comment with reference to page (P) and line (L) of the revised manuscript (AC1-supplement file).

Comment. Title: This should be the most carefully worded part of the paper and it isn't grammatically correct. How about the following: Simultaneous retrieval of water vapor,

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Discussion paper

temperature, and cirrus cloud properties from measurements of far-infrared spectral radiance over the Antarctic plateau Comments on the subject of the title: technically, this paper isn't about retrievals only from the far-infrared. The mid-infrared channels were used too since they are shown in Figure 7 with modeled and observed spectral fits shown for the entire 250-1000 cm^{-1} region. Which matters more? The mid-infrared or the far-infrared? The authors may want to consider showing what might happen if one spectral region was used without the other, and vice-versa, if that is not a significant level of effort. This way the authors can really show without a doubt that the far-infrared is really valuable for the ice cloud properties, especially the effective diameter, as argued in the Introduction section.

Reply. We have corrected the Title to: "Simultaneous retrieval of water vapour, temperature, and cirrus cloud properties from measurements of far infrared spectral radiance over the Antarctic plateau"

Concerning the far infrared, we prefer to leave the reference in the title because it is the most unique aspect of the measurement and because it allows to improve the capability to discriminate the effect of the particle size variation. This issue has been addressed in the revised text (see also the reply to the other Referees) and the new Fig. 2 showing the far infrared sensitivity has been added at the end of Sect. 2.

Comment. Abstract: poorly written although the content appears appropriate. However, lines 16-17 are not clear. What does 'disturbed' mean? That the atmospheric state as retrieved has a bias in the presence of clouds, or that temperature and water vapor geophysical variability aren't correlated to cloud presence? Certainly the latter can't be right.

Reply. The abstract has been rephrased and the text has been modified at P1 L17-19 to: "In most of the cases, the retrieved humidity and temperature profiles show good agreement with the radiosoundings, demonstrating that the simultaneous retrieval of the atmospheric state is not biased by the presence of cirrus clouds."

Comment. Introduction: Some additional papers of relevance should be included: Bromwich, D. H., et al. (2012), Tropospheric clouds in Antarctica, Rev. Geophys., 50, RG1004, doi:10.1029/2011RG000363. This paper contains many relevant papers to infrared remote sensing of clouds in Antarctica that are not cited.

For global ice cloud climatology: Wylie, D. P. and Menzel, W. P.: Eight years of high cloud statistics using HIRS, J. Climate, 12, 170–184, 1999.

Reply. These and more references have been added in the Introduction as described in the reply to Major Comment 5 by Referee #3 (see Author Comment AC1).

Comment. Line 2: cirrus clouds do not permanently cover 30% of the same part of Earth. They cover 30-ish percent of the Earth at any given time. But there are big differences depending on the platform (ISCCP, HIRS, AIRS, IASI, MODIS, AVHRR, etc.). The Baran references aren't the right ones for cloud climatology percentages.

Reply. The statement at P2 L5-7 has been modified to: "Furthermore their coverage is still not well characterised, and spans from about 30% of the planet surface at any given time to 70% in tropical areas (Wylie and Menzel, 1999), so their climate effect could be very important."

Comment. Line 9: I believe this is "Lynch"

Reply. Corrected.

Comment. Lines 14-15: what are the different components of which system?

Reply. The sentence has been modified at P2 L18-19 to: "Wide-band spectral measurements are essential to try to separate the atmospheric state and cloud components of the climate system (Huang et al. 2010)."

Comment. Line 16: these are high spectral resolution measurements, not broadband

Reply. Yes, the measurements have high spectral resolution and cover wide spectral range. The sentence has been clarified by removing the reference to "broad band".

Comment. Lines 31-32: they aren't so much 'unpredictable' as 'highly variable' for a given temperature range

Reply. Corrected.

Comment. Lines 33-35: need to connect better that you are using the delta-Eddington approach because it is appropriate for single layer clouds

Reply. The sentence has been modified at P3 L21-23 to: "The δ-Eddington two-stream approximation has been applied to simulate the radiative transfer through the cloud layer, as considered appropriate for single layer clouds (Turner 2005).

Comment. Lines 4-5: more description of the radiosondes is needed. How many times per day? At the same times or different times? What types of sondes?

Reply. More information has been added here and in Sect. 5

Comment. line 9: choose, not choice

Reply. Corrected.

Comment. Section 2: line 24: parameterise

Reply. Corrected.

Comment. Section 3: Lines 2-3: how can these two parameters completely describe clouds? What about cloud temperature (single layer), habit distribution, temperature and water vapor profiles, etc.?

Line 19: why use "U" for water vapor? Its pretty standard to use ‘q’ or ‘Q’

Reply. The beginning of Sect. 3 has been modified to: “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.”

"U" has been changed to "Q".

Comment. Section 3.1: Line 8: why 3-sigma? Should also make clear that the climatology was constructed from actual radiosondes - this is not entirely clear. Also, is it a climatology for only those cases simulated, e.g., for the radiosondes launched closest to the times of the attempted retrievals?

Reply. The climatology has been constructed using the whole radiosonde measurements performed in 2014 from the Station. The 3-sigma values have been used to limit the retrieval domain. The text in Sect. 3.1 (now Sect. 4) has been rephrased and clarified at P8 L17-25 "A study of the climatology of water vapour and temperature profiles has been performed using the whole radiosoundings dataset available for the year 2014 to calculate seasonal averages, shown in Fig. 3, and standard errors. In the right panel of Fig. 3 we can note the strong temperature inversion which occurs at about 500 m above ground in Winter and Autumn, a peculiar characteristic of the Antarctic atmosphere: in these conditions the ground mean temperature can reach values below -60 °C. The water vapour VMR profiles also manifests a strong inversion in Winter and Autumn as shown in the left panel.

The standard deviation σ of the climatological profiles is used to calculate the a priori VCM. The limits of the retrieval domain are set to $\pm$ 3-σ in order to take into account the profile variability. Only for the ground level larger limits of (-200,+300) K and (1,3000) ppmv have been chosen for temperature and VMR, respectively. This is due to the much larger variability of the very first layer, that corresponds to the internal environment of the Physics Shelter. These limits represent the real physical domain in which the atmospheric variables can be varied by the retrieval routine."

Comment. Section 4: Lines 19-20: with regard to why T and U are retrieved, it isn't necessarily for getting an accurate set of T and U profiles, but rather so that the retrieval can obtain better estimates of cloud properties. Is this a correct supposition to make? Next, given that there are only two or three levels (U and T respectively) based on the singular value approach in the previous section, how can one conclude that the profiles are in 'very good' agreement with the sondes? They are off by large amounts at some levels. Also, if one looks at Figure 8, you can see that the T and U retrievals (red curves) are more than simply two or three levels. Each level has some "curvature" or "shape" to them. That is not consistent with a two or three level retrieval, which should have (presumably) linear segments within each level unless there is some other assumption made or something is not explained well in the paper.

Reply. Yes, the supposition is correct. Because the possibility to have very low cirrus clouds and with very high variability of the atmospheric conditions near ground present on the Plateau, the usage of a limited set of fitting levels allow to use the same retrieval approach for all the conditions and to obtain cloud parameter estimates. Concerning the fitted profiles, the grid levels have been interpolated (linearly for the temperature and logarithmically for the water vapour) between the fitted points and the portion of the profile above the last fitted level was simply scaled. This is way the water vapour profiles have a "curvature" in loglog scale. This concept has been better explained at P9 L22-29: "The retrieval levels have been set by selecting a first point at ground in order to correctly keep into account the effect of the very first atmospheric layers that are affected by the presence of the shelter and the instrument itself. Two other fitted temperature levels are set at about 10 and about 300 meters and above the ground to take into account the strong gradient in the first layers. For water vapour, other than the ground level point, another fitting point at 200 meters above ground has been chosen to correctly rescale the humidity profile in the atmosphere above the layers that are influenced by the shelter. The grid levels of water vapour and temperature profiles are interpolated between the fitted levels (linearly for temperature and logarithmically for water vapor), while the portion of the profile above the upmost fitted level is scaled according to the upmost fitted value."

Fig. 8, now Fig. 9, is only indicative of the performance of the retrieval. It is true that we are comparing "in situ" measurements with remote sensing values and as a consequence a quantitative comparison is not straightforward. However the plots in Fig. 9 are effective in showing how well the retrieval procedure finds a profile compatible with the radiosondes. In order to have an indication of the results for all the analysed cases, a new figure (Fig. 10) has been added. The text has been clarified where appropriated to take into account this comment and the description of the new figures has been added at P11 L5-16.

Comments.

- Line 24: ambient air

- Line 26: varies

- Lines 27 and 28: the fact that larger Des are obtained in summer is consistent with downlooking Atmospheric Infrared Sounder retrievals. See the following papers:

Lubin, D., et al. (2015), Variability in AIRS-retrieved cloud amount and thermodynamic phase over west versus east Antarctica influenced by the SAM, Geophys. Res. Lett., 42, doi:10.1002/2014GL062285.

Kahn, B. H., et al. (2014), The Atmospheric Infrared Sounder Version 6 cloud products, Atmos. Chem. Phys., 14, 399–426. Specifically, Figure 13 shows the big seasonal variations.

- p.10, lines 11-12: a strong correlation is suggested but no correlations coefficient is shown (unless I missed it somewhere)

Reply.

- Line 24: corrected to: "outside environment".

- Line 26: corrected.

- Lines 27 and 28: a comment and the suggested references have been added to the paper.

- p.10, lines 11-12: in Fig. 10 (now Fig. 12), we compared the retrieved values with the correlation laws given by Del Guasta et al., (1993) and Liou, 2008 (black and green lines, respectively). The figure also shows the red curves resulting from the fitting of the correlation coefficients of the corresponding relationships of Eq. 23 and 24. Their values were reported in the text at P12 L12.

Comments.

- Figure 2: the seasons should be labeled on the individual panels

- Figure 7: label seasons on the individual panels so that they match better with Figure

2. There is little obvious difference between the four panels. What about taking the four observed spectra and making an additional plot (or panel) in which they are overlaid with the radiance on a log scale so that the spectral shapes and differences become more apparent? All Figure 7 does is to show that the simulations fit the observations quite well, which is nice to know. However, it would be also nice to see what the spectral variations due to cloud properties look like and perhaps if they are shown against each other in some stretched scale that could be seen.

- Figure 9: the y-axes are too constrained. Stretch it out so that the variability can be better seen. Also, is each dot an error bar for an individual single cloud layer case? Or is it from a set of spectra over some extended single layered ice cloud that lasted for some time? Or do these include more complicated ice clouds? Is the error estimate from a single retrieval or is it from several single layer ice clouds combined together ? Additional detail on what data was used to make this figure is warranted.

- Figure 10: Same problem as figure 9 except that the range could be narrowed for both optical thickness and De.

Reply.

- Figure 2 (now Fig. 3): Seasonal labels have been added on the panels.

- Figure 7 (now Fig. 8): Date labels have been added to the panels. They are four examples, one per season, to show the residual differences which is low, so they appear quite similar. A plot with all these cases with overlaid curves is very confusing and the log scale does not help in this case. We prefer to use only these four figures.

- Figure 9 (now Fig. 11) has been updated to show better the parameter variability. The dot size has been reduced and the error bars are now visible for the retrieved parameters De and OPD. The other parameters, shown in the figure, are recovered from the lidar measurements, so no error estimate was performed. The error bars are the retrieval error for a single measurement performed close to radiosounding and are relative to a single cloud layer. The clarification about this comment has been added to the text at P11 L17-27: "The fitting results for the cirrus cloud optical and microphysical 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., 2014). 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."

- Axis scales in Figure 10 (now Fig. 12) have been narrowed and made linear.

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