Exploiting airborne far-infrared measurements to optimise an ice cloud retrieval by Panditharatne et al.

This is an interesting and valuable work. It describes the first retrieval of the cloud parameters, including optical depth, effective radius and top height, along with the atmospheric profiles of temperature and water vapour from upwelling far-infrared spectral radiances. In this work the RAL retrieval scheme, introduced in previous works, has been applied to the spectral radiance measurements performed with two spectrometers: the Tropospheric Airborne Fourier Tranform Spectrometer (TAFTS), operating in the far infrared (FIR) portion of the spectrum between 80-600 cm-1, and the Airborne Research Interferometer Evaluation System (ARIES) operating in the mid infrared (MIR) between 550-3000 cm-1. These measuremenets were performed on board of the aircraft B895 which flew in 2015 as part of CIRCCREX campaign. Carrying on board several instruments for cloud and atmosphere characterization, such as a series of three probes or CPIs and a backscattering/depolarization lidar to assess the cloud particle habit/size distributions and the extinction coefficient along with Vaisala probes providing information about humidity and temperature. The availability of such in situ measurements allowed the comaparison with the retrieval products. The results show in generally a good accordance but also point out on the necessity of a refinenement of the currrent ice optical properties in models particularly in the FIR. Furthermore, it is shown the improvement in the retrieval performance by using the FIR portion with respect to neglect it, in particular in distinguishing the different crystal habits.

The manuscript is well written and structured even though some minor revisions need to be addressed before publication. I also suggest few corrections to enhance the clarity:

We thank the reviewer for their comments and have made the following changes to improve the clarity.

Abstract:

line 5 ":with and without the far infrared.." → "including and neglecting the far infrared portion of the spectrum.."

Changed

line 17: "..cover.." → "..cover permanently.."

The reference I have used for this does not explicitly say permanently.

Line 54: "This work" → "The present work.."

Not changed

Section 2.2

Please, can you structure the initial part of the section by listing the in situ instruments present on board for cloud characterization, describing briefly what they provide? I think it is more simple for a reader to follow the text having the scheme in mind.

The following addition has been made to the start of Section 2.2:

There were a number of instruments onboard the FAAM aircraft used to characterise the cirrus cloud that will be used to assess the retrievals performed here. These include an elastic backscatter lidar (used to derive a reference for the COT and CTH), a 2-DS probe (used to derive a reference for the CER), a 3-View Cloud Particle Imager (3V-CPI) (used to derive the ice crystal habits in O'Shea et al. (2016)), and a CIP 100 and a holographic cloud probe (HALOHolo) (used to measure the particle sizes).Further details about each of the instruments and their measurements are provided below.

You say that the extinction coefficient profile obtained from lidar signal in Fig. 2a is not reliable for deriving optical depth due to calibration issues; if you don't use it to calculate the COT, maybe, this is a little bit misleading, wouldn't be better to show the raw signal?

In Section 2.3.2, the extinction coefficient profile is used to perform the LBLDIS simulation following the work in Bantges et al 2020 (where the extinction coefficient profile is scaled to match a best-fit COT that has been determined using a minimization process). In this way, it is useful to have the extinction profile in Figure 2. However, we agree it would be useful to show the range-corrected signal that is used for the COT derivation, and so an additional subplot has been added to Figure 2 showing the range-corrected signal.

Regarding this, the COT calculated in Eq. (1) with the new method, is it obtained using the raw signal? I mean, are the Patt and Pref raw signals? Maybe it is better to report this in the text. If so, this is a reason to show the raw signal. in Fig. 2.

The range-corrected signal is used not the raw signal. The following is added:

This approach considers the power of the attenuated Rayleigh backscatter range-corrected signals below 6 km

However, how much the COT differ from that one calculated from the extinction profile? By eye, it does not look too far from the value you found, if we multiply the thickness for the mean extinction, but maybe I'm wrong. How the extinction coefficient has been derived from the backscattering signal?

The COT calculated from the extinction profile was 0.584. While not significantly different, this is a distinct underestimation that was shown in Bantges et al 2020 to limit our ability to simulate a spectrum within the TAFTS and ARIES uncertainty.

Vertical profiles of the particle extinction coefficient were determined using the Fernald-L=Klett method as described in Fox et al.,2019. The following statement has been added to the manuscript:

…and a vertical profile of the particle extinction coefficient using the method described in Fox et al. (2019).

The extinction due to the molecular contribution is already considered in the new method?

Yes, in this method the molecular extinction is considered but assumed to be constant along the short flight path, with signal variation attributed to particle (cirrus clouds) extinction. For clarity, the following sentence has been added:

It is assumed that the molecular extinction is constant along the short flight path, and so the signal variation can be attributed to the ice crystals in the cirrus cloud.

Caption Fig. 2: please indicate that are dashed lines.

Changed

Fig. 2 : the blue lines shouldn't be dashed?

Changed

I would suggest , if possible, to show some pictures of the habit and size distributions provided by the CPIs. It is just a suggestion because it would be very interesting to see the in situ measuremenets of the ice crystals inside cirrus. And of course, I think, it would be an added value.

Images from the CPI and the size distributions have been provided in O'Shea et al (2016) and so are not provided here.

<u>Section 2.2.1</u>

Line 145: can you indicate the size range of the dominant smaller crystal?

Added: *Due to the dominance of smaller crystals (<30 μm),*

Can you show which parameters are fitted of the PSDs and report some results of the fit? Or briefly explain the procedure?

Information has been added about the procedure here:

Following the findings of O'Shea et al. (2016), we find n(D) by fitting the PSDs measured by the Cloud 2-DS probe with bimodal Gaussian distributions using the non-linear least squares method. The fitted PSDs and parameters are shown in Figure S1 and Table S1 in the Supplement… The uncertainty presented here for the CER is calculated using the relative standard deviation of the fitting parameters, and so represents one standard deviation in the fitting of the bimodal Gaussian distribution to the PSD.

The parameters fitted to the PSDs and results of the fit can be seen in the Figure S1 and Table S1 in the Supplementary information.

Line 148: "..the habit and.." → "..the habit type and.."

Changed

Line 148: "..CPI measurements habit recongnition.." → "..CPI measurements by applying habit recongnition.."

Changed to: CPI measurements using the habit recognition algorithm

Can you report, if possible, a numerical example of the habit fractions derived from CPIs by applying the recognitional algorithm?

The exact numbers are shown in Figure 6b in O'Shea et al (2016) but the following has been added:

Particles were found to be a mix of predominantly aggregates (~30 %) and droxtals (~25 %), with some rosettes (~15 %) and columns (~10 %).

Section 2.3.1

Line 186: with "remove" you mean deconvolved?

Changed

Line 191 and 193: Just remember that are available more recent version of LBLRTM and, in particular, of continuum MT_CKDv3.8

Thank you for your comment. We note that we use MT_CKDv3.5 which has a significant update to the water vapour spectroscopy in the far-infrared, but of course is still an older version.

Line 199: "..using the Masuda model above 769cm-1" → "..using the Masuda model above 769cm-1 since the radiometric measurements were performed over the Ocean" (Is it correct? If so I would clarify why the Masuda model has been used)

'as the radiance observation was taken over the ocean' has been added

Line 203: "and the GHM model" → "assuming the GHM model"

Changed

Fig. 4: The differences of TAFTS in blue are not visible, would be possible to expand the scale just for this plot of TAFTS for example in logarithmic scale to make it more readable?

The difference with TAFTS is significantly smaller than it's ARIES counterpart, and when a log scale is used (or a logscale is used only for TAFTS), the plot implies that the two are both noteworthy while only the differences for ARIES are significant. To avoid misinterpretation, a version of Figure 4 has been included in the supplementary information (Figure S2) with a smaller scale used for the TAFTS residuals shown in Figure 4a, and the following has been added to the caption in Figure 4:

(a) The brightness temperature (BT) residual between the LBLDIS simulation of the TAFTS and ARIES observations during the B895 flight that has had the FORUM apodisation directly applied and been made to look like TAFTS or ARIES first (FORUM-aircraft simulation) as outlined in Section 2.3.2. The TAFTS residuals remain less than 0.05 K and can be seen in an additional plot in the Supplement for clarity.

Section 3

Could you indicate what is the initial guesses or if they are equal to a-priori?

Added: *'In all the retrievals performed in this work, the initial guess is equivalent to the a-priori'*

Which are the correlation lengths used for a-priori atmospheric profiles?

The correlation lengths are not explicitly defined in this retrieval scheme. Instead, the a-priori covariance matrix is used to define correlations between atmospheric layers with its off-diagonals. This is described in the Siddans, et al 2019. which is referenced when the retrieval scheme is introduced.

Eq. (7) the differential dz is missing inside the integral.

Changed

If you fit the CTH how much did you fix the geometrical thickness?

Clarified: Within IMS, the ice cloud is modelled as a Gaussian with a standard deviation of 1 km.

Line 431: maybe you mean "..increase from 0.9 to 1.0"? not from 0.9 to 0.1

Changed