Response to Anonymous Referee #3

The reviewer's comments are in black and our answers are in blue. Snippets of text from the submitted are in italics while modifications of the manuscript are shown in bold italics. The pages and lines reported here correspond to the submitted manuscript.

This paper reports on the development and testing of new LIRAD method that utilizes thermal infrared bands available on the CIMEL CE-312 radiometer, which is considerably cheaper than the AERI. The latter has been used in the recent past to provide the thermal components to retrieve COD and Deff from the surface. The implicit motivation for this study seems to be that the LIRAD method can be used more often if the CIMEL-312 could be used instead of the AERI, since it is attempting to do the same things that AERI already provides. The explicit motivation is that the ability to discriminate between small and large Deff values would help the study of aerosol/cloud interactions in polar regions, especially regarding aerosol influence on precipitative cooling and (as inferred from the DLCRF computations) on radiative heating of the surface. The writing is of average quality, but has some grammatical issues. The paper is scientifically sound in its approach, but the results and method do not appear to be particularly new.

We are grateful to this reviewer for the helpful comments. We provide below a point-by-point reply to his comments.

The algorithm is new in that it uses specific bands not previously employed in the AERI-LIRAD approach. However, they are not all that different from the AERI microwindows. Except for lacking the wavelengths longer than 14 μm, this is essentially the same algorithm. If not, then it needs more contrasting with the MIXCRA. It relies on the phase being known already, whereas, I believe, the longer wavelengths used in the MIXCRA were primarily for phase discrimination. It is not surprising then that the results are quite close to those from the MIXCRA. The botton line that I believe the authors should address is "how many wavelengths are actually needed to replace the 19 microwindows of MIXCRA having lambda < 13 μm to perform the retrieval?" Could you do it with 2 or 3 channels? There appears to be a lot of information redundancy in the bands that were used.

The question about information redundancy is pertinent. We believe the information in section 4 (the discussions centered on Figures 2, 3 and 4) shows the sensitivity of each band to the key radiative transfer parameters and therefore helps to demonstrate the importance of those bands. The T_b separation of the spectral curves in Figures 3a and 3b is a progressively damped out sensitivity to the cold-space temperature that is essentially controlled by water vapour absorption at COD = 0.The variation of the brightness temperature with D_{eff} in Figure 3b is reflective of essentially two dominant optical mechanisms juxtaposed on the progressive warming of the cold background : (i) the classical increase in the extinction efficiency with increasing D_{eff} (and, optically speaking, with decreasing wavelength) in what we call the small-particle Angstrom-exponent regionand (ii) the filtering / masking of this robust monoticity (linearity on a log-plot) caused by significant variations in the real and complex parts of the refractive index in the last 3 bands (notably the last 2 bands). This translates, in a 1st order sense, to an Angstrom type of slope requirement for at least 2 short wavelength bands (3 for better redundancy).The monotonic dependence of brightness temperature as a function of COD in Figure 3a is also dependant on the interplay of the 2 extinction efficiency influences and the progressive warming of the cold-space temperature. It is clear that any single band would fare quite well in a T_b inversion to extract COD but that the most transparent bands to water vapour would be more sensitive (the 11.3 μm band in Figure 3a). As the brightness temperature of all bands is also sensitive to a variety of parameters (Figure 4), it is important, we believe, to maintain a certain redundancy in order to ensure a robust retrieval.

To further support this answer to the reviewer's question, we performed retrievals with different band configurations and compared retrieval statistics for the COD and D_{eff} retrievals (tables below). The order of the elimination of these bands was based on a progressive increase in per-band information content (roughly from minimum to maximum dX / dTb_i where X = COD or D_{eff} and where Tb_i is the brightness temperature for band i in the region of greatest sensitivity to X)

Table 1: Retrieval statistics for different band configurations.

Bands used (µm)	COD retrieval (R^2– RMS Errors)	Deff retrieval (overall accuracy)
8.4, 8.7, 9.2, 10.7, 11.3, 12.7	**0.95 – 0.09**	**83%**
8.7, 9.2, 10.7, 11.3, 12.7	0.95 – 0.09	75%
9.2, 10.7, 11.3, 12.7	0.95 – 0.09	72%
10.7, 11.3, 12.7	0.95 – 0.09	71%
10.7, 11.3	0.95 – 0.09	74%
11.3	0.95 – 0.09	69%

Bands used (µm)	COD retrieval (R^2 – RMS Errors)	Deff retrieval (overall accuracy)
8.4, 8.7, 9.2, 10.7, 11.3, 12.7	**0.95 – 0.09**	**83%**
8.4, 8.7, 9.2, 10.7, 11.3	0.95 – 0.09	81%
8.4, 8.7, 9.2, 10.7	0.95 – 0.09	77%
8.7, 9.2, 10.7	0.95 – 0.10	73%
8.7, 9.2	0.94 – 0.11	67%
9.2	0.94 – 0.11	67%

The COD retrieval statistics are similar even if only one band is used in the retrieval algorithm (where that one band is the most T_b sensitive, 11.3 µm band). In the case of the D_{eff} retrieval, the overall accuracy decreases slowly until the Angstrom slope information is eliminated by reducing the band number from 2 to 1.

The validation effort includes the comparisons with MIXCRA (noted above) and with lidar for COD. This begs the question: If the lidar is required for the LIRAD method and it produces a reliable COD (it is used as a reference), why then is the IR method used to estimate COD? Why not simply estimate D_{eff} using the IR data and the lidar COD as input? Lidar retrievals of COD are quite common for most lidars deployed for surface observations. What am I missing? How will phase be determined if this approach is implemented elsewhere?

The radiometer is designed to be a portable instrument and can be easily deployed to a remote station. We could certainly use the lidar COD as input but the requirementforapplying our retrieval method is only cloud base altitude information (and ideally also cloud thickness). This could be obtained from a ceilometer or a portable, low-power lidar (CE370 LiDAR from CIMEL, for example). Put another way, the advanced capabilities of a lidar such as the AHSRL were needed for the validation but only a ceilometer was required to estimate the required input parameters to our passive retrieval algorithm (the

AHSRL is overkill in the latter case).

We inserted to following sentences in the conclusion of the paper: P.20 L.12 ***One of the perspectives could be to deploy this technique as part of a network of low-cost and robust instruments to monitor arctic clouds. Because their occurrence, type and altitude are spatially inhomogeneous (according to Eastman and Warren (2010) and Shupe et al. (2011)), we believe that additional ground-based stations would be helpful to broaden our knowledge of arctic ice clouds.***

Some authors have proposed to use the absorption coefficient differences between 10 and 13µm for phase discrimination (ice being absorbing than water;see, for example, Baum et al., 2000). However,inasmuchas absorption is also a function of particle size (see Fig. 2), it could be difficult, to separate ice and water in the case of small particles (Turner, 2003). This is why the bands between 16 and 20 µm are used in the case of MIXCRA.
Moreover, as shown by Shupe (2011), the frequency of liquid clouds (either liquid-only ormixed-phase clouds) is low at Eureka (annual average of 30%, mainly occurring in the summer and autumn and below 20% during the wintertime, when the cases in this study were chosen).

I think this paper can be published, but it needs some major revisions to provide better justification as to why it is necessary and to flesh out the analysis by addressing the questions above.

Minor comments
P1, L24: “temperatures” does not belong here

It has been removed.

P3, L4: “ aerosols acting as ice and water cloud nuclei, cloud microphysics, precipitation and radiation” does not make any sense. Please reorder this so that aerosols do not appear to act as cloud microphysics.

This sentence was rewritten: P3 L4 : *Much of the recent research has been focused on aerosol-cloud interactive processes involving aerosols acting as ice and water cloud nuclei* ***and their subsequent affect on*** *cloud microphysics, precipitation and radiation.*

P3, L14: You may want to modify the sentence with "could possibly lead to" or something similar, since the “dehydration greenhouse feedback” is only a proposed mechanism.

This sentence was rewritten as suggested: P3 L14 : *In terms of the purpose and motivation for this paper, we note that the presence of sulphuric-acid bearing aerosols (viz., Arctic haze) can significantly increase the size of ice particles (relative to the size of ice particles formed from more pristine, low acid aerosols or supercooled droplets). This process can* ***cause*** *~~leading~~ enhanced precipitation and important cooling effects during the polar winter* ***and could lead to a dehydration greenhouse feedback (DGF) effect, as proposed by Blanchet and Girard (1994).***

P4, L3: Please “COD” for singular and “CODs” or “COD values” for plural here and throughout the paper

The consistency of the use of the singular and plural forms was corrected in the paper.

P4, L9: “northern most” should be one word

Corrected.

P4, L14: if the same summary is given by both references, then leave one out. If two different summaries are provided, then change everything to the plural form.

We chose to keep the reference of Bourdages et al. (2009) as the technical specifications were more detailed.

P4, L17: “in the order of” should be “on the order of”

Corrected.

P5, L24-25: The <2% refers only to downwelling radiation viewed at the zenith. It can be up to10% for other viewing conditions, particularly for upwelling radiation (e.g., Minnis et al., JAS 93). The viewing limitation should be highlighted again when referring to the 2%.

We have added this correction: P5 L24: *Platt (1973) (and later authors such as* ***Turner and Lohnert, 2014, for wavelengths higher than 10 µm and shorter than 16 µm****) indicated that less than 2% of the* ***zenith-looking, downwelling*** *radiation emitted by a cloud was due to scattering.*

P7,L16: COD can only have an amplitude if you are referring to its oscillation with time or space. Otherwise, please refer to it as magnitude or value.

That is true, we were talking about its magnitude. P7, L16: *At COD* ***magnitudes*** *~~amplitudes~~ greater than 2-3, ...*

P8, L3-6: Sentence should be broken up for clarity.

The rewritten sentences are: P8 L3-L6: *The simulation results in Figure 4 detail the band dependent effects of six different parameters by comparing changes in Tb induced by each parameter individually.* ***These were obtained*** *using a random number generator with a normal probability distribution whose mean and standard deviation was controlled by the six parameter values of Table 2 (COD,* D_{eff}*, cloud base height, cloud thickness, column integrated water vapor of the atmosphere (WVC) and particle shape).*

P8, L16: cloud altitude and thickness uncertainties do not have amplitudes in this context. See comment above.

It was corrected. P8 L16: *If the altitude and the thickness of the clouds are known from vertical lidar (and radar) profiles then the* ***magnitude*** *~~amplitude~~ of the altitude and cloud thickness uncertainties of Figure ...*

P10, L1: Here and elsewhere, the form of the modifier does not need to match that of the noun. Should be “ice cloud retrievals”.

Corrected.

P11, L10: “mean’t” appears to be a typo.

Corrected.

P12, L12: “produces gives”, please use one or the other

We removed “produces”.

P12, L18: should be “hydrometeor diameter”

Corrected.

P16, L4-5: “ommission” has only one “m”

Corrected.

References:

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Eastman, Ryan, Stephen G. Warren, 2010: Arctic cloud changes from surface and satellite observations. J. Climate, 23, 4233–4242.doi: 10.1175/2010JCLI3544.1

Shupe, M.D., 2011: Clouds at Arctic Atmospheric Observatories, Part II: Thermodynamic phase characteristics. J. Appl. Meteor. Clim., 50, 645-661.

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Turner, D. D. and U. Löhnert, 2014: Information Content and Uncertainties in Thermodynamic Profiles and Liquid Cloud Properties Retrieved from the Ground-Based Atmospheric Emitted Radiance Interferometer (AERI). J. Appl. Meteor. Climatol., 53, 752–771, doi: 10.1175/JAMC-D-13-0126.1