We thank the reviewer for the careful and thoughtful review. Our responses are outlined in bold and italics below.

General Comments :
The methodology described in this paper is based on several independent measurements which can limit the applicability of the method to other arctic datasets. This should be clearly mentioned in the abstract / conclusion. Additionally, independent measurements should also be used to validate/estimate the retrieval especially for the ice retrievals (in the case study only a LWP comparison is presented). Section 2 could also be modified in order to clarify the different steps used in the retrieval methodology. The authors seem to make the assumption that ice crystals are spherical which impacts the retrieval of ice crystal effective radius. I think this needs to be justified and compared to "conventional" ice crystal habits used in infrared remote sensing (hexagonal columns or plates...). Finally, mixed phase clouds in Arctic play a dominant role in the surface radiation balance. The authors should clarify the way their retrieval algorithm treats these types of clouds (phase determination, microphysical and optical properties).

The retrievals described in this paper take use of measurements from four sources, the ozone profiles from ERS-GOME, temperature and water vapor profiles from NWS, surface ozone measurements from GMD, and surface spectral radiation, radar and lidar measurements from ARM. This could limit the use of this retrieval algorithm for sites which do not contain spectral radiation measurements, profiles of temperature and water vapor, or ozone information.

The last sentence of the abstract has been changed to read
The primary limitation is the inapplicability to thicker clouds that radiate as blackbodies and that it relies on a comprehensive suite of ground based measurements

The original definition of the effective radius from Hansen and Travis (1974) was introduced in order to enable climate models to convert from the prognostic cloud quantity of liquid water path to the diagnostic quantity of optical depth, which was required for local radiative absorption and scattering computations. As currently outlined in our text:
"The definition applies equally to all shapes, independent of whether they are hexagonal ice crystals or spherical droplets…. r_e here, as it is applied to ice crystals,is more a radiative length scale than a spherical radius"

While many authors have calculated the effective measurements from in situ aircraft measurements of ice crystal shape, due to concerns about shattering of crystals on probes, they have proved hard to interpret even when available. So what we are doing is using ground based infrared data to measure a radiatively relevant length scale rather than one that is tied to boundaries in molecular density.

That said, suspended cloud ice crystals tend to have size parameter values that are small at infrared wavelengths. Being in the Mie rather than the Geometrics optics

regime, shape details have a small effect on the single-scattering properties of ice crystals. To clarify this point, we have amended the text to read

"The retrieval algorithm described here is based on retrievals of a cloud particle ``effective radius'' r_e and optical depth in the geometric-optics limit at visible wavelengths (τ). Here, r_e is proportional to the ratio of the bulk ice or liquid volume to the scattering cross-section of the particle, as introduced by Hansen and Travis (1974). The original definition r_e can be applied equally to all shapes, independent of whether they are spherical droplets or hexagonal ice crystals (Foot, 1988). However, because ice crystals are not spherical, the concept of effective radius does not relate directly to the ice crystal geometric size. Rather, it is a length scale used to calculate how efficiently ice crystal mass corresponds to radiative extinction. That said, at the infrared wavelengths considered here, the size parameter $2\pi r/\lambda$ of cloud ice crystals is sufficiently small to lie below the geometric optics regime where the details of shape become important. "

A comparison between in-situ measurements and retrievals would be great. However, there are many issues for this kind of intercomparison, including co-location problems and as mentioned above, concerns about how ice crystals in clouds are most appropriately measured from a fast moving airborne platform. Instead, we added one intercomparison between retrievals from our method and retrievals from a method developed by Dong and Mace (2003).

With regards to mixed-phased clouds, we have modified the text to read
Clouds that are more spectrally flat, or in between ice and liquid, are not amenable to phase discrimination and are labeled ``uncertain''. In reality, many of these cases may be clouds that are in fact ``mixed-phased'', however the ambiguity in the retrieval prohibits us from identifying such clouds with certainty. Nonetheless, as will be shown, retrievals of cloud properties are relatively insensitive to an a priori *assessment of cloud phase, so retrievals of cloud properties are still performed where possible.*

Specific Comments :
Abstract :
- P8654 ; Line 4 : specify the wavelengths or wavenumbers values of the three "micro-windows".

Done

- Line 13 : Please mention that the LWP intercomparison was perform during one single case study.

We have added text to clarify that that the comparison was *evaluated for all cases where comparisons were possible*

Introduction :
P8655 ; Lines 12-17 : Could be rephrased/shortened to clarify the text.
The text now reads
However, large ice crystal precipitation particles are often co-located with small liquid droplets in Arctic clouds (Hobbs et al., 2001), and this makes interpreting a radar signal more difficult.

Section 2.1:
This section is crucial for understanding the physics behind the micro-window selection. Unfortunately it is not always clear mainly because figure 3 and 9 are swapped. Additionally, Lorentz-Mie theory is used regardless of the cloud phase. This should be justified considering the wavelength domain used; are the authors assuming that the ice crystal shapes are spherical?

As described above, for the wavelengths considered in this study, the size parameter is small, so we can use Loretz-Mie theory regardless of the cloud phase.

P8658 ; Lines 8-9: I don't agree with the authors when they state that the choice of their split window technique gives broad sensitivity to "a wide range of values of Re". It looks sensitive to small ice crystals with size smaller than 25 µm (Figures 4 and 9). Ice crystals are expected to be larger than that. Could you comment on that?

Compared to the selection of other pairs of wavenumbers, our selection gives broad sensitivity to a wide range of re values. Of course, as the figures show, the sensitivity generally decreases with increasing re and tau, something that is currently reflected in the error analysis shown in Figure 10. To accommodate the reviewer concern, the sentence has the following clause added:
, although sensitivity diminishes for values of r_e larger than about 25 µm.

Figure 4: please check for typos in the figure caption : "emssivity" "labeld"
Done

P8658 ; Lines 13 to 20 and Figure 5 : I have trouble to clearly understand this paragraph mainly because figure 5 is hard to read. Could you clarify your figure and its description?

The caption and text have been rewritten to read:
Caption:
Range of re (dashed: 5 and 10 µm) and τ (solid: 0.5, 1, 2, 4, 8, 16) associated with the split-window difference ε_b - ε_e, depending on whether a cloud is assumed to be liquid or ice. The dotted line represents 1:1 perfect correspondence.
For example, a re = 5 µm liquid droplet in a cloud with an optical depth of 1 has a split-window difference that is lower than an equivalent cloud composed of ice crystals. Right: The difference in transmissivity within the ozone band associated with cloud phase assumption as a function of ozone band transmissivity t_{ozone} and cloud r_e.

Text:

The second strength is that the relationship of either r_e or τ to any particular value ε_b - ε_e is comparatively insensitive to whether the cloud is assumed to be liquid or ice (Fig.5). The mapping does not lie along a perfect 1:1 line. However, the sensitivity of the mapping to phase is small compared to other possible combinations of micro-windows. Further, errors are constrained by the incorporation of ozone band transmissivity at 1040 cm^{-1} (t_{ozone}) in the retrieval algorithm. Cloud transmissivity in the ozone band is only weakly dependent on cloud phase.
Errors only exceed 10 % for optically thick clouds with very small particles. In any case, normally such clouds can safely be assumed to be liquid. The reason for the weak dependence of transmissivity on cloud phase is that the imaginary component of the refractive index at 1040 cm^{-1} is close to 0.045 for both ice and water (Warrant and Brandt, 2008).

Section 2.2
The authors point out the difference between “radiatively” mixed phase cloud and “microphysically” mixed phase cloud. This is an important point but I’m not sure they make that kind of differences in their retrievals (their method is sensitive to radiatively mixed phase clouds). Moreover, it is not clear if the clouds labelled “uncertain” are “mixed phase” cloud. The authors need to clarify this as it makes the phase determination algorithm quite confusing.

This point was addressed as described above.

Section 2.3 :
Don’t you think this section could be modified and part of it moved in an appendix as the contribution of the precipitation water vapour to the total cloud emission does not seem that significant given the measurements uncertainties presented in section 3?

It is true that the general contribution of the precipitation and water vapor to the cloud emission is small, but there are times that their contributions are sufficiently large to affect retrievals, which is why we keep it in the main body of the text. The section on water vapor has been moved to an appendix.

Additionally, I don’t understand how equation 3 is evaluated (how do you estimate the number concentration for instance). Do you have an idea of the errors made considering crystals as spheres rather than non spherical particles (using r instead of a projected surface of ice crystals).

The details of the retrieval method for precipitation, along with an error analysis, are described in Zhao and Garrett (2008), as currently referenced in the text. The retrieval method incorporates a temperature dependent estimation of ice crystal shape for fall speed, but not for relating radar return and Doppler velocity to number concentration. The reason is the same as described previously: the size

parameter of precipitation particles is too small for the details of shape to have a large impact on the retrievals.

Section 2.4 :
In this section, it is not clear why it is necessary to make an interpolation to obtain the cloud brightness temperature within the P and R branches (needs more scientific arguments) could you clarify?

The text has been rewritten to clarify the method. It now reads
In order to constrain estimates of cloud emissivity, it helps to have an estimate of cloud transmissivity t since, to first order, $\varepsilon = 1 - t$. *Cloud transmissivity is often estimated using the sun as a direct source. The drawback is that the sun can be absent for long stretches of time in the Arctic.*

Here we estimate cloud transmissivity from the degree to which a cloud attenuates strato-spheric ozone emission within a 1038 cm^{-1} *to 1042* cm^{-1} *microwindow. Because ground based measurements of downwelling radiation include both cloudy emission and ozone transmission, cloudy emission must first be subtracted to obtain the ozone signal. Transmissivity can then be obtained if atmospheric ozone, temperature and moisture profiles are known.*

The procedure for estimating cloud transmissivity within the 1038 cm^{-1} *to 1042* cm^{-1} *microwindow follows a series of steps illustrated in Fig. 8. In the first step, surface radiance measurements Imeas(ν) are corrected for precipitation emission to give*

$I_{sky}(\nu)=I_{meas}(\nu)-\varepsilon P(\nu)B(T_P,\nu)$ (7)

In the second step, a wavelength dependent brightness temperature T_{cb} *representative of cloud base is estimated from the relation* $I_{sky}(\nu) = B(T_{cb},\nu)$. *Intensity measurements are evaluated in two ranges, between 960* cm^{-1} *and 975* cm^{-1} *and between 1070* cm^{-1} *and 1085* cm^{-1}. *These spectral bands lie within the atmospheric window, but just outside the P and R branches of ozone emission.*

In the third step, the prior estimates of brightness temperature from outside the ozone band are used to evaluate values of T_{cb} *within the P and R branches associated with ozone emission. This is done using simple linear interpolation. The calculated value of* T_{cb} *within the ozone band is used to estimate the background radiance from all sources other than ozone and precipitation,* $I_{bkg}(\nu)$.

Fourth, cloud transmissivity t is calculated within the P and R branches of ozone emission. The calculated background emission I_{bkg} *is subtracted from measurements of downwelling emission Isky withing the P and R branches. The difference is divided by calculated values of the clear sky downwelling radiance* I_{clear} *in the P and R branches that would be associated with an atmosphere without precipitation or clouds*

$t(\nu)=I_{cloudy}(\nu)/I_{clear}(\nu)=(I_{sky}(\nu)-I_{bkg}(\nu))/I_{clear}(\nu)$ (8)

Values of I_{clear} are estimated using the LBLRTM radiative transfer model and measured profiles of atmospheric ozone, temperature and moisture.

Fifth, values of t that are calculated in two narrower spectral bands – 1020 cm^{-1} to 1040 cm^{-1} in the P branch and 1048 cm^{-1} to 1065 cm^{-1} in the R branch – are then used to interpolate values of t in the Q branch between 1040 cm^{-1} and 1048 cm^{-1}, thereby completing estimates of t within the ozone band. Interpolation is used because ozone emission is weak within the Q branch.

Finally, the desired values of t_{ozone} are obtained from a subset of these ozone transmissivity values, evaluated within a microwindow between 1038 cm^{-1} and 1042 cm^{-1}. This microwindow is chosen because water vapor absorption is particularly small in this band.

Figure 8 : the authors should separated the two top panels
Done.

P8662 ; Lines 4-6 : the sentence is incomplete :" Finally, to calculate cloud transmittance t....."

Corrected.

Section 2.5 :
P8663 ; Lines 7-9 : The mixed phase cloud identification is not clear, please state explicitly when does your retrieval algorithm identifies a mixed phase cloud. I'm surprised that a simple average of the effective radius is used to determine the effective radius of the mixed phase clouds. I may be making a mistake but the sum should be weighted by concentration (microphysically) or extinction coefficient (radiatively).

Thank you for catching this. This is an unfortunate error in the text that occurred because the text reflects a prior approach we tried. The text is now rewritten to state
For clouds with an uncertain phase, retrievals of cloud properties are made assuming that the clouds are liquid. The assumption is that many ``uncertain'' clouds are in fact mixed-phased, in which case most of the cloud water path (and thermal emission) comes from high concentrations of small liquid droplets (Hobbs and Rangno, 1998). In any case, as will be shown, retrievals tend not to be highly sensitive to this choice.

P8663 ; Lines 19-20: . What instrument did you use to assess the droplet size distribution? Is there any contamination of small ice crystals in your measurements ?

The text now clarifies that the measurements were with an FSSP-100. Ice crystals tend to be in much smaller concentrations than droplets.

P8664 ; Lines 5-9 : Please clarify this, I don't get your point here.

The text has been rewritten to read:
Sensitivity to liquid water path can even extend beyond 60 g m^{-2} *if cloud particle radii are larger than about 10 µm. The reason is that the skin depth for droplet absorption is smaller than the droplet radius itself. Any incident radiation is absorbed almost completely by the droplet exterior such that the interior is effectively invisible to the incident infrared radiation. The consequence is that the water path of a cloud can be higher before the cloud approximates a black body.*

Section 3 :
I have the feeling that this section could be more appropriate if it was positioned before section 2. This might contribute to a better understanding of the retrieval algorithm.

We see the reviewer's point but there may be disadvantages from both sides. The retrieval algorithm should be independent of the precise measurements that are used, so that it is not wedded to the exact combination of instrumentation that we used.

Section 3.1 :
P8665 ; Line 9 : What is the impact of precipitation on the uncertainty of the Ceilometer measurement ?

The ceilometer works by identifying very sharp gradients in the extinction coefficient that show up at the base of clouds but not in precipitation
A Vaisala Laser Ceilometer is used to determine cloud base, separate from precipitation, from sharp gradients in backscatter, and with an uncertainty of 7.6 m

P8665 ; Lines 13-17 : MMCR profiles of radar reflectivity are used to exclude cases with multiple cloud layers. The problem is that most of the clouds in arctic have multiple layers (for example with liquid layers at the top and ice crystals near the cloud base). Doesn't this limit the significance of the study?

As currently stated in the text
More complicated scenes with multi-layered liquid clouds and ice crystal precipitation filling the vertical space between layers are interpreted as single layer clouds.

Section 4 :
Figure 10 : please clarify the caption of this figure. It is difficult to understand without looking for additional information in the text

The caption has been rewritten to read
"Calculated uncertainties in retrievals of liquid cloud re, LWP and N that are associated only with the look-up table method outlined in Section 4, separate from any errors associated with uncertainties in measurements. Errors (contours) are expressed in percent within a space of re and τ for a cloud with fixed boundaries and a specified atmospheric profile."

P8668 ; Lines 1-2 : it is said that clouds are assumed to be vertically homogeneous. Did you make any simulations with vertically inhomogeneous clouds? It would be nice to say something about that as most of the arctic clouds are clearly not homogeneous.

The text has been elaborated to read
That we have assumed clouds that are microphysically homogeneous in the vertical may mean that additional errors are associated with true clouds. Retrievals based on cloud transmissivity of downwelling atmospheric radiation will tend to be biased by the microphysics at cloud top since this is near where radiative attenuation is a maximum; retrievals based on cloud thermal emission will be biased by properties at cloud base. Because the retrievals here are based on both emission and transmission, derived properties are expected to represent some radiative average of the vertical profile.

P8668 ; Line 4 : Section 4 should be Section 3.
Corrected

Equation 12 : Could you justify why the covariance between the quantities is assumed to be zero (Temperature and water vapour...).

Here the text is amended to read
Here, the covariance between the different quantities is assumed to be zero because the measurements are independent.

P8668 ; Line 28 : I'm surprised that the uncertainty of the ice crystal concentration is only 38% (better than in situ probes and liquid phase), could you comment on that please ?
Here is an error we made. It should be "For *N*, they are and 38% and 55% for liquid and ice, respectively." Perhaps one perspective on why the retrieval errors are comparatively low is that they don't attempt to go the extra effort of measuring size distributions, and also that they are more highly constrained than individual in situ probes. The errors in the retrievals would be higher if they were based on emission unconstrained by transmission.

Section 5.1 :
p8669 Line 18 : The authors state that there is a fairly high correlation between measured and retrieved LWP. In my opinion 0.46 cannot be considered as "fairly high correlation". Could you moderate this statement, please?

Considering that the stated uncertainties in the MWR retrievals are of similar magnitude to the range of values of LWP considered, it is fairly high we think, with the word "fairly" being the moderating adjective. The main point is that the correlation with retrieved IWP is much worse. The text now emphasizes this point through addition of the words *"By comparison…"*

Figure 11 and 12 : please specify the meaning of the different contours.
Both figure captions now specify that these are linear probability density distributions (contours)

Additionally, I'm surprised that the effective radius of ice clouds is so low. I would expect typical values higher than 35-40 μm, especially at the cloud base. Could you specify that your infrared measurements are not sensitive to large particles? In your conclusions it is said that the retrieval technique is limited to particle smaller than 50μm.

Figure 12 deals only with those clouds that are "uncertain" phase. As described previously, such clouds are most likely dominated by liquid water droplets, in which case it is not surprising that the retrievals tend to be for small effective radii. The point of Figure 12 is that the retrieved size is not highly sensitive to whether the composition of the particles is assumed to be liquid or ice.

Section 5.2 :
P8670; lines 6-10 : In section 2.3, the impact of water vapour and precipitation on the cloud retrievals is considered in details. In section 5.2, it is said that the contribution of water vapour is negligible. Therefore, I don't understand the purpose of section 2.3. Could you consider moving part of section 2.3 in an appendix?

The section on water vapour has been moved to an appendix following the suggestion.

Section 5.3 :
I would suggest that the case study includes some independent measurements in order to validate your technique.

Section 5.1 has compared our retrieved LWP with independent measurements from MWR. In this revised version, we also include a comparison with another independent retrieval product from Dong and Mace (2003).

Figure 15 : Could you use colours to separate liquid, ice and uncertain in your phase retrieval?

Done

In the conclusions it is said that the limit of effective radius retrievals is 50μm.
You find a median effective radius of 48μm for the ice phase. Is this a real 48 μm or can it be regarded as the maximum size that you can retrieve using your technique?

The text has now includes the following statement.
Given that the ice crystal effective radius retrieval is near the upper limit for retrieval sensitivity of 50 μm, it is possible that the true sizes are larger and the concentrations lower.

Section 5.4 :
Could you give a statistics on the relative fraction of graybody clouds compared to blackbody clouds.

The text now includes the following statement
where gray bodies clouds encompass 42% of the total.

Figure 16: I'm surprised by the fairly high concentration of ice crystals (reaching more than 1000 particles /liter). Could you compare this to previously published data (aircraft or ground based measurements over Barrow). I'm wondering if this high concentration retrieval is not a compensation of the limited effective size range authorized by your technique.

We have added a paragraph that reads
When ice clouds are present, they have crystal concentrations that are about two orders of magnitude lower than liquid droplet concentrations, and effective radii that are about four times 25 as large. While we lack any direct point for intercomparison, in-situ aircraft observations of ice crystal concentrations from the Arctic tend to be lower than those we observe (e.g. Jouan et al., 2012). One reason for the discrepancy could be that post-analysis of in-situ ice crystal concentration measurements used an algorithm that removed particles with unusually short inter-arrival times at airborne probes. Assuming this algorithm was appropriately applied, another possibility is that the retrieval method discussed here is in error because it is limited to clouds (not below- cloud precipitation) with effective radii smaller than 50 μm: if ice crystal effective radii are in fact larger than 50 μm, then retrieved ice crystal number concentrations would be erroneously high.