General comments:

Thank you for your comprehensive review of the manuscript.

Major Comments:

1. In fact, the use of the weighted standard deviation as quantity describing the uncertainty of cirrus retrieval has to be linked to the specific surface conditions of the investigated scene. Other statistic parameters would have to deal with the same issue of course. Nevertheless the weighting reduces the variability and improves the feasibility in consequence. It is another approach to reduce the variation of the surface albedo and therefore the variation of the retrieval. The choice of the desired statistic parameter illustrating the variation depends on the desired probability. An implementation of an extended theoretical study including a larger surface albedo range may illustrate the potential of the retrieval approach using weighted frequency distributions as well as prevents readers from false impressions of the presented retrieval. Here the replacements of the "statistical"description with "approaches" as uniform declaration is considered.
2. The motivation is extended in this regard. Dealing with mostly single scattering due to the thin cirrus investigated here, this error source is implemented supported by references.
3. Presented results are case studies only dealing with the spectral surface albedo characteristics during the measurements. They do not act as systematical result, as mentioned in the conclusion. However, the systematical (though homogeneous) study presented in section 4 illustrates a non negligible influence of the surface albedo being consistent with other published work mentioned in the comment.

Title:

The crystal shape does not act as controlling topic. However, it has to be discussed in regard to the optical thickness comparison with the HSRL measurements. Although the retrieved values vary in dependence to the ice crystal shape, the uncertainty of the retrieval parameters show no significant influences as illustrated in Fig. 16.

Abstract:

Line 7: Will be rephrased. "The applied retrieval of cirrus optical properties is based on a standard two wavelength approach utilizing measured and simulated reflected radiance in the visible and near infrared spectral region."

Line 9: "For each albedo cirrus optical thickness and effective crystal radius are retrieved as function of the assumed surface albedo"

Introduction:

One aspect is missing in your comparison to water clouds. What separates the cirrus next to the fact of the ice crystal parameterization problem is the general smaller optical thickness compared to water clouds in most cases. Especially the two investigated here offer cirrus optical thicknesses below two, concluding in a proportionally large portion of surface reflected radiance compared to

the one reflected from the cirrus. This does not devaluate the influence on water cloud retrievals. However, as shown in section 4 the influence on thin cirrus is higher by the way of comparison.

Page 3785, line 2:

Edited based on your suggestion.

Page 3785, line 7:

An atmospheric correction of the measurements was not performed. Flying in about 14 km altitude measuring reflected radiances from cirrus still being above 9 to 10 km reduces atmospheric influences to a minimum compared to the measurement uncertainty of 5 %. The surface albedo product on the other hand already includes the atmospheric correction based on the common correction procedure.

Page 3785, line 8:

This sentence refers to surface albedo measurements simultaneously performed to the passive remote sensing. This would allow a surface albedo allocation in the radiative transfer calculation and therefore no necessity for a approach using frequency distributions and/or the use of other albedo introducing additional error sources like the different footprints.

Page 3785, line 10:

Although the variation reduces for optical thick clouds, the surface reflected radiation is in fact not fully absorbed. Although only displayed to optical thickness up to 4, Fig. 6b contains an uncertainty even for thicker clouds, as it reduces asymptotic. In consequence a variation remains, so the statement is correct.

Page 3785, Line 13:

Edited as suggested.

Page 3785, Line 22:

Parameters are now summarized as optical properties despite that.

Page 3785, Line 29:

Edited as suggested.

Measurements and surface albedo:

Page 3786, line 17:

The calibration, which is performed utilizing an Ulbricht sphere, mostly contributes to the measurement uncertainty introducing an error up to five percent.

Page 3786, line 22:

HSRL backscatter ratio is given at 532 nm. The possibility of water and/or mixed phase clouds is excluded as only cirrus was present above 8km during the investigated timeframe (Fig.2a) of 4 November. The timeframe of 3 November excludes the signal below 8km, so once more only cirrus

above 8 km altitude is considered in the backscatter ratio. In both cased temperature measurements show values below 235K.

Page 3786, line 26:

Unfortunately no flight patterns with larger surface albedo variability exist beside the presented timeframes. For a more general interpretation an extended theory study may act.

Page 3787, line 3:

Will be rephrased: “Cloudy and cloudless situations were alternating. During the cloudy timeframes two separate cloud layers were present.”

Page 3787, line 7:

Water surface conditions do not exist as the presented flight legs cover heterogeneous surface conditions in Southwest Germany. During the campaign no flights over open water were performed. In consequence no transitions are available. Nevertheless, I agree that especially a transition from homogeneous (water) to heterogeneous surface conditions would be more representative. Unfortunately an exact identification of the surface type beyond that is not possible, as the spatial resolution combined with small scale surface conditions leads to a mixture of different surface types. The considered wavelengths will be mentioned explicitly. Regarding the plot of spectral cloud radiation, a full spectrum plot is not included. Instead of that Fig. 4 is replaced by a more comprehensive timeframe clearly showing cloudy and cloud free cases. By this, the influence of the surface and the cirrus on the measured radiances of both wavelengths used for the retrieval is presented. Regarding the HSRL measurements references are added explaining the method including possible errors in detail.

As the surface albedo occurs on a small scale (as mentioned), the work deals with numeric values instead of types. For the majority of cases the footprint consists of a mixture instead a single surface type making a type declaration difficult. However, the 2-D distribution of the 3600 km² area gives a good impression of the value range and in consequence possible surface types.

The sentence regarding the spectral difference is obviously misleading and therefore excluded. In general the value range of surface albedo offers changes due to the season, affecting the distribution of the surface albedo.

Statistics of surface albedo from MODIS

The investigated flight scenes were performed in comparable timeframes leading to nearly identical solar zenith angles. These solar zenith angles are also within the range of the used MODIS product the investigation is based on.

A spectral plot of the surface albedo types based on the used MODIS product can be provided. The imaginary picture is not suitable to detect the urban areas. The area covered by the flight legs lies in south-west Germany featuring numerous small scale village structures, which indeed are hard to see in the imaginary picture. The fall season adds to the heterogeneity of the surface conditions. A

parallel increase of the variability is case dependent. Nevertheless this seasonal effect should be mentioned in general.

The frequency distribution is extracted from each flight leg. As each timestamp of measurement is considered, the appropriate (GPS based) location is included in the frequency distribution. This will be expanded.

Retrieval of Cirrus properties from HALO-SR:

Page 3788, line 14:

Yes, you're right. Excluding it here.

Page 3788, line 14:

Both parameters are considered and declarared as optical properties now.

Page 3789, line 6-14 + Equations 1) and 2)

Due to the current structure of the paper, the equations fit best here in my humble opinion. So the position isn't changed. The manuscript doesn't include a too detailed theoretical discussion up to this point, as some aspects may be trivial to readers that are familiar with the general topic. However, the physical basis of the ice crystal parametrization is extended including references based on your suggestion. Furthermore, the parametrized optical properties are displayed in a plot spectrally to illustrate differences between the individual parametrized shapes. The DISORT II solver uses 16 terms in the scattering phase function. The atmospheric discussion regarding the reflected measurements is discussed above. The vertical aerosol distribution, that is used as input for the radiative transfer calculations, is retrieved based on lidar measurements during clear sky. Due to the comparable small area covered, it is considered as constant for the timeframe of the two days investigated.

Homogeneous surface albedo sensitivity:

Rephrasing of title is considered. Furthermore, homogeneous refers to the wavelength independency in this part/study. To illustrate the influence of radiation reflected by the surface on the retrieval the influencing parameters are reduced. Here, especially the "spectral heterogeneity" is not considered to allow a better comparison of the bispectral retrieval results. So maybe the "homogeneous" is indeed misleading in this case and will be replaced by the rephrasing.

Page 3789, line 16: Edited as suggested

Page 3789, line 17: Absorption is not directly affecting the measured radiances, so I think the sentence is valid this way.

Page 3789, line 22: Upwelling may sound misleading, as it somehow connects to "waves". Maybe upward directed should be implemented: "The received upward directed radiance above cirrus"

Page 3789, line 25: It has to be 650nm, sorry for the mistake.

Page 3790, line 2: You are right. The investigated value range of simulated surface albedo will be extended covering most of the surface types (excluding the ones based on ice).

Cirrus properties from statistical retrieval:

The suggestion of changing the statistical retrieval to approach using frequency distributions of surface albedo is adopted. The justification for these approach is furthermore given in the implementation of two additional retrieval approaches not using PDFs illustrating the sensitivity and differences between the single approaches regarding to the surface albedo.

Page 3792, line 5: As the bispectral retrieval is based on two wavelengths, a corresponding 2-D display is the best choice of illustration in my opinion. Keeping the caption in mind misinterpretations are avoidable. The retrieval works mostly the way you have summarized. The reflected radiation (LUT) is created as a function of B1/B6 surface albedo (bin size of 0.05), cirrus optical thickness (resolution of 0.1) and effective radius (resolution of 5 µm). Then, tau and reff are interpolated based on the measured radiances. The weighting is not performed separately as a measurement always consists of a B1/B6 surface albedo pair. So it is weighted based on the 2-D distribution.
Regarding your example, the "distance impact" is more a less a contribution of (maybe homogeneous) surface types to the whole dataset the statistical retrieval is based on. So in the pseudo case of the homogeneous surface type, a reduced uncertainty illustrates the reduced probability of measuring above surface types different from the "dominating" one. Nevertheless, it is true that the uncertainty depends clearly on the distribution (value range) of the surface. It is now mentioned/discussed in the conclusion/interpretation part more detailed. Thank you for this point.

Systematic and microphysical uncertainties: *Shape Effects*:

Looking at the differences between the statistically retrieved and the lidar derived optical thicknesses, the crystal shape may be one error source. Extended by references introducing errors up to 60% for tau and 20% for the motivation is strengthened.

Page 3793, line 13: Uncertainty bars are implemented. Maybe I don't got the question right, but as the uncertainty variation between the individual parametrizations is minimal, the influence of the shape is visible despite the measurement error of HALO-SR and HSRL-lidar.

Page 3793, line 20: The statement got corrected.

Page 3793, line 26: The explanations in the manuscript refer to the investigated range of values (up to tau = 2). You are right however – so as this advice is an important add-on, the statement got extended therefore.

Grid Density:

You are right again. However, although an orthogonal relationship does not exist in general for cloud optical thicknesses below 40, there is an increase in nonlinearity for small optical thicknesses especially thin cirrus is affected of. So the explanation is extended to illustrate the physical reason more detailed.

Page 3794, line 17: Missing bin size will be implemented. For both B1/B6 the bin size is 0.005, so a relationship to the illustrated numbers can be created. But also for different bin sizes this exponential decrease would occur in a comparable value range of tau.

Page 3794, line 14: The different look-up tables always defined by both wavelengths. They are not investigated separately.

Bidirectional Reflectance distribution function:

Page 3795, line 4: Basically the dimension of the surface albedo (for each wavelength) within the lookup tables is replaced by the three BRDF parameters. As a result two additional dimensions (four as a sum for both wavelengths) have to be considered. The retrieval approach itself does not change. Regarding the simplifications: both albedo products are not corrected for the zenith angle. Though, both got measured with close to nadir zenithal angles, reducing errors driven by the angle to a minimum. Concerning aerosol, both products got measured in comparable timeframes, leading to similar aerosol situations. An error may remain here, but it is playing a minor role compared to the measurement uncertainty especially.

Conclusions:

The mentioned modifications are included trying to prevent readers from misinterpretations.

Page 3796, line 19: "The smaller the cirrus optical thickness the larger the uncertainty of the effective radius…"

Line 20: With respect to the investigated range of values (up to optical thickness 2) this range is added.

Line 23: Sentence will be replaced. The systematic retrieval issue will be rephrased.

Line 24: Good point – a reference will be included.

The ice crystal shape influence discussion is extended based on the extended motivation given in section 5.1.

Figures:

Not all Figures are available in higher resolutions, but improvements are tried to implement whereever possible. Furthermore the consistency for the axis labeling is improved.

Figure 2b) caption: Edited as mentioned.

Figure 4: As explained before, a direct allocation of surface albedo based on the radiance measurements is not possible due to the footprint size and shape. Instead, the plot is changed by a more illustrating timeframe. Additionally, cloudy and cloud-free regions are indicated here.

Figure 6: You are right, sorry for this mistake. The line styles are now consistent.

Figure 7: The method deriving the mean is not of that importance here. Having a fixed value as reference showing the potential of differences to the statistical approaches is the motivation. Even if the distributions are not Gaussian, both approaches do the job of illustrating this.

Figure 8: Corrected, thank you.

Figure 11: For the calculations a parametrization simulating a mixture of ice crystal shapes is used.

Figure 12: Corrected, thank you.

Grammatical and spelling errors:

All points are edited based on the suggestions.

Figure 13: The plot refers to the optical thickness. Even if the particle size decreases, the optical thickness assignment is correct. Trying to implement colors somehow “overloaded” the plot, so keeping the dashed lines gives the best impression in regard to the desired message of the plot. In general, this is a plot illustrating the retrieval feature without a direct connection to the measurements shown throughout the manuscript. Indeed, the plot shows a constant VIS surface albedo to reduce the influencing dimensions.

Figure 14: Both wavelengths are affected corresponding to the homogeneous surface albedo influence investigation in section 3.2.