Answers to the comments of reviewer #2 are in blue.

General Comments

This paper presents a statistical method of calculating temporally averaged black-sky surface albedo from measurements made by a satellite imaging radiometer - in this case AVHRR. The unique aspect of the method presented is that it includes measurements effected by partial cloud-cover, using a cloud-probability (CP) product (essentially the Bayesian probability that a given observed pixel is, or is not, cloudy) to correct the albedo derived from top-of-atmosphere observations with a given CP threshold. The method is presented as an improvement on previous albedo retrieval schemes which rely on binary cloudy-clear masks. The authors provide a derivation of the equations used to make this correction, with a description of the assumptions and limitations of the method, before presenting results of the algorithm applied over a small range of stations which provide in-situ surface albedo observations.

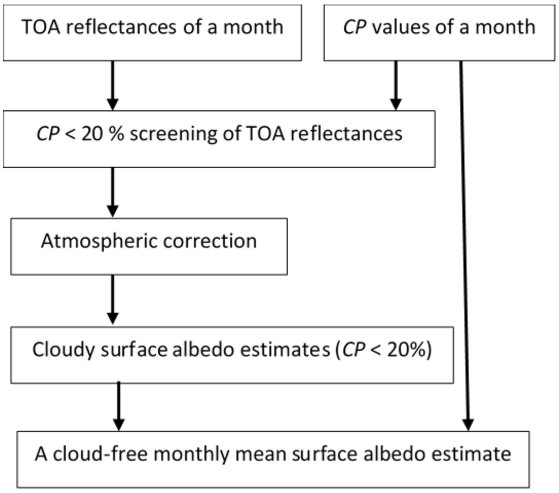
The work presented is interesting, especially as the method is being operationally applied to calculate surface albedo in the new CLARA-A3 AVHRR products produced by the CM-SAF, and the derivation and analysis seem sound. The paper draws heavily on work done previously by the lead author (Manninen et al. 2004) and represents the (long-awaited, one imagines) practical realisation of that more theoretical analysis. Thus, as an improvement and application of an existing approach, which is being applied to a large data record, I feel it is worthy of publication. However, the paper itself could do with some improvement. My biggest complaint is the paper lacks a clear description of its structure - there is a brief (3 sentence) overview of what the paper covers, but without an existing knowledge of the analysis undertaken by the authors, I felt lost for much of the paper. The authors have a tendency to provide a series of related, but not directly connected statements, which makes following the thread challenging. Thus, I would recommend that the introduction is extended, or an introductory section is added to the methods (section 3), to include a overview of the algorithm which clearly lays-out the steps involved and the final product - maybe a flow diagram would help.

Thank you for encouragement. The manuscript will be revised by adding to the end of the introduction the following paragraph:
The in situ albedo data used for validation of the satellite based albedo estimates are presented in Section 2.1. The satellite data used is described in Section 2.2 with emphasis on the atmospheric correction (Section 2.2.2) and the cloud probabilities (Section 2.2.3). The method how to take cloudiness into account when estimating the surface albedo is described in Section 3. The essential points of a previous theoretical study (Manninen et al., 2004) of deriving cloudy albedo distributions are summarized in Section 3.1.1. Then the approach is further developed to adapt it to cloudy surface albedo simulations based on the cloud probability data (Section 3.1.2) and finally a new method how to derive the cloud-free surface albedo using cloud probabilities is presented (Section 3.2).

The method section will be provided the following introduction:
The cloud-free surface albedo estimates of CLARA-A3 will be estimated using the TOA reflectance and CP values available in pixel basis (Figure 1). First the TOA reflectance values with CP > 20% are discarded, as well as values flagged as low quality by the PPS software, for example because of sun glints. Then the atmospheric correction is carried out the same way for all remaining TOA reflectances independently of the cloud probability. Finally, the

monthly mean cloud-free surface albedo is estimated using the atmospherically corrected reflectances and corresponding CP values. The main points of the theoretical background for the cloudy surface albedo distributions (Manninen et al., 2004) are summarized in Section 3.1.1. The adaptation of the theoretical approach to using cloud probability data is described in Section 3.1.2 and finally the formulas for deriving the cloud-free monthly mean surface albedo estimates are provided in Section 3.2.

The flow diagram describing how the cloudiness is taken into account when estimating monthly mean surface albedo values will be a new Figure 1:



One specific omission in the paper is that no indication of which wavelength(s) the albedo is being derived for. I presume it is one or more of the AVHRR visible/near-IR bands. Please include this information in the paper.

Yes, the visible and near infrared bands are used. This will be made clear in the revised manuscript.

Specific corrections and suggestions

Abstract: The abstract doesn't scan well and should be revised. For example the basic purpose of the paper should be stated in the very first sentence, so the abstract should start will something like (as an example): "This paper describes a new method for cloud-correcting observations of black-sky surface albedo derived using the Advanced Very High Resolution Radiometer (AVHRR)."

The abstract will be revised as suggested:
”This paper describes a new method for cloud-correcting observations of black-sky surface albedo derived using the Advanced Very High Resolution Radiometer (AVHRR). Cloud cover constitutes a major challenge for the surface albedo estimation using AVHRR data for all possible conditions of cloud fraction and cloud type on any land cover type and solar zenith angle. This study shows how the new cloud probability (CP) data to be provided as part of the edition A3 of the CLARA (CM SAF cLoud, Albedo and surface Radiation dataset from AVHRR data) record by the project Satellite Application Facility on Climate Monitoring (CM SAF) of EUMETSAT can be used instead of traditional binary cloud masking to derive cloud-free monthly mean surface albedo estimates. Cloudy broadband albedo distributions were simulated first for theoretical cloud distributions and then using global cloud probability (CP) data of one month. A weighted mean approach based on the CP

values was shown to produce very high accuracy black-sky surface albedo estimates for simulated data. The 90% quantile for the error was 1.1% (in absolute albedo percentage) and for the relative error it was 2.2%. AVHRR based and in situ albedo distributions were in line with each other and also the monthly mean values were consistent. Comparison with binary cloud masking indicated that the developed method improves cloud contamination removal."

Pg.1, Ln.20: Again, these introductory sentences don't scan well and come across as a series of dis-connected sentences. For example, I would suggest re-structuring the first few sentences like so: "The surface albedo is a key indicator of climate change (GCOS, 2016) and is continuously and accurately measured across contrasting climatic zones by the Baseline Surface Radiation Network (BSRN), operated by the World Climate Research Programme (WCRP). However, satellite remotes sensing is required to augment these regional measurements with global estimates of surface albedo".

The beginning of the introduction will be revised as suggested.

Pg.2, Ln.11: I'm not sure what is meant by the sentence "However, for the really large deviations also other cloudy vs clear non-separability issues become important"

This sentence and the previous ones in the text discuss the cases when cloud detection fails and falsely labels a pixel as being cloud-free. This concerns mainly very thin clouds and is problematic for the surface albedo retrieval if radiances in the two visible and near-infrared channels are then still higher than what the surface would produce in the true cloud-free case. However, there are situations for high solar zenith angles when low-level clouds are missed even if they are optically thick (e.g. fog or stratus). These clouds may give near-zero reflectances despite being optically thick, typically if these clouds are shadowed by other clouds or mountains. The reason for not being detected in these cases is typically that cloud top temperatures are close to surface temperatures meaning that not even in the infrared AVHRR channels there is a typical cloud signature (clouds are normally colder than the surface). The impact on surface albedo retrievals for such a case, which might be quite serious over snow-covered surfaces, depends on the maximum allowed solar zenith angle that is used for the surface albedo retrieval. If this threshold is too close to 90 degrees, the risk to encounter shadowed mis-classified clouds might be high. As a consequence, surface albedo retrievals might give unrealistic visible and NIR reflectances coming from clouds rather than from the underlying surface. For a snow-covered surface this might lead to an underestimated surface albedo. Hence, the CLARA surface albedo product is limited to cases, when the solar zenith angle is ≤ 70°.

The following revised text is proposed:

" However, for the really large deviations also other cloudy vs clear non-separability issues become important. For example, low-level clouds being in shadow at high solar zenith angles (e.g., caused by higher level clouds or mountain peaks) might be missed as a consequence of having non-typical visible and NIR reflectances as well as a lacking temperature difference between the cloud top and the surface. If such missed clouds occur over snow-covered surfaces they might lead to a seriously underestimated surface albedo. Using such data would introduce errors on the order of 100% on derived surface albedo, with potentially much higher errors occurring in cases with the combination of snow, complex terrain and low sun elevation, which are common in Northern Europe for example. For this reason, the surface albedo of the CLARA surface albedo product is restricted to limited to cases, for which the solar zenith angle ≤ 70°.”

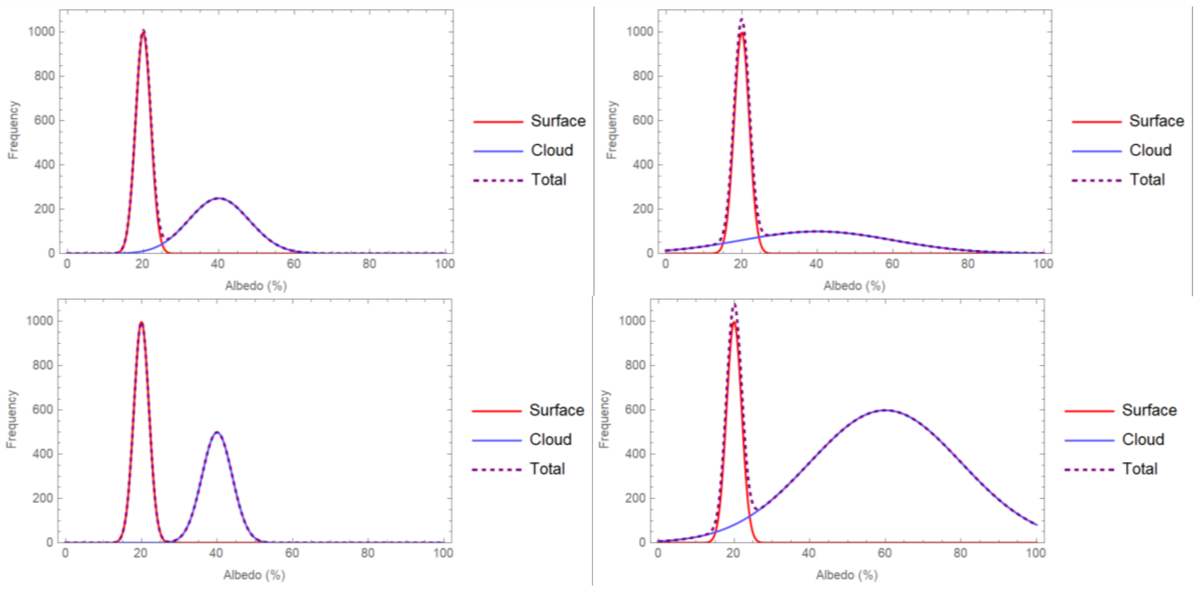
Pg.2, Ln.13-15: I would suggest replacing the last two sentences of this paragraph is something more succinct. For example: "Using such data would introduce errors on the order of 100% on derived surface albedo, with potentially much higher errors occurring in cases with the combination of snow, complex terrain and low sun elevation, which are common in Northern Europe for example."

The text will be edited as suggested.

Pg.2, Ln.19-21: A couple of points here. Firstly, the sentence needs restructuring, I would suggest something like: "Thus, across a 0.25 x 0.25 degree grid-box over one month, the slowly varying surface albedo would be expected to dominate the broadband albedo distribution observed by non-cloud masked AVHRR data". The second question is, why would you expect the albedo distribution to be dominated by the surface contribution, even though the cloud albedo is more variable? Surely this would be rather dependent on how much, and just how variable, the cloud cover was for the region and period in question?

The text will be edited as suggested.

The total distribution of a cloudy region albedo can be thought to be a combination of the cloud albedo distribution and the cloud-free surface albedo distribution. When there are equal number of both cases the distribution of the less varying target has the higher peak, i.e. it dominates the total distribution from the point of view of the highest peak. Below are three fictive case demonstrations for that (top left, top right and bottom left). It is true that the variability of the cloud cover affects also the total distribution. However, the highest peak comes from the least varying target, typically the surface. But even if the number of cases is larger for the broader distribution (below lower right figure), the narrower distribution peak is usually still higher.



Pg.2, Ln.32: Replace "surrounding area, an important" with "surrounding area, which is an important".

The text will be edited as suggested.

Section 3.1.1 I feel this section would benefit from restructuring. As it stands, it reads like a series of seemly unconnected statements. For example, Pg.5 starts with a description of the distribution of cloud fraction and then suddenly switches to the diurnal variation of surface black-sky albedo, before switching again to seasonal and monthly variation of surface albedo. A simple introductory statement laying out what albedo components are to be discussed and why at the start of the section is required - something along the lines of what appears starting at Pg.6, Ln.5, for example.

This section will be revised as suggested.

Pg.5, Ln.9: Replace "like ceilometer observations show" with "as is shown by ceilometer observations, for example"

The text will be edited as suggested.

Pg.5, Ln.12: I'm not sure how Figure 1 could be described as resembling a U-curve. If this is not an error, more explanation is needed.

Figure 1 shows the left part of the U-curve. As almost 100% cloudy pixels will not be suitable for albedo estimation, it is not considered of interest, what the right part of the U-curve looks like, as it will never be used for albedo retrieval. The question is what is the reasonable CP threshold: 50% or smaller. Obviously the text was written unclearly and will be revised to clarify the issue.

Pg.5, Ln.17/18: Remove "also".

The text will be edited as requested.

Pg.11, Ln.7: Remove comma after "shown".

The text will be edited as requested.

Pg.11, Ln.27: "high" rather than "highest".

The text will be edited as requested.

Pg.12, Ln.1: Replace "zenith angle so that" with "zenith angle such that".

The text will be edited as requested.

Pg.12, Ln.7: Remove "per pass".

The text will be edited as requested.

Pg.12, Ln.10: "also provides" rather than "provides also".

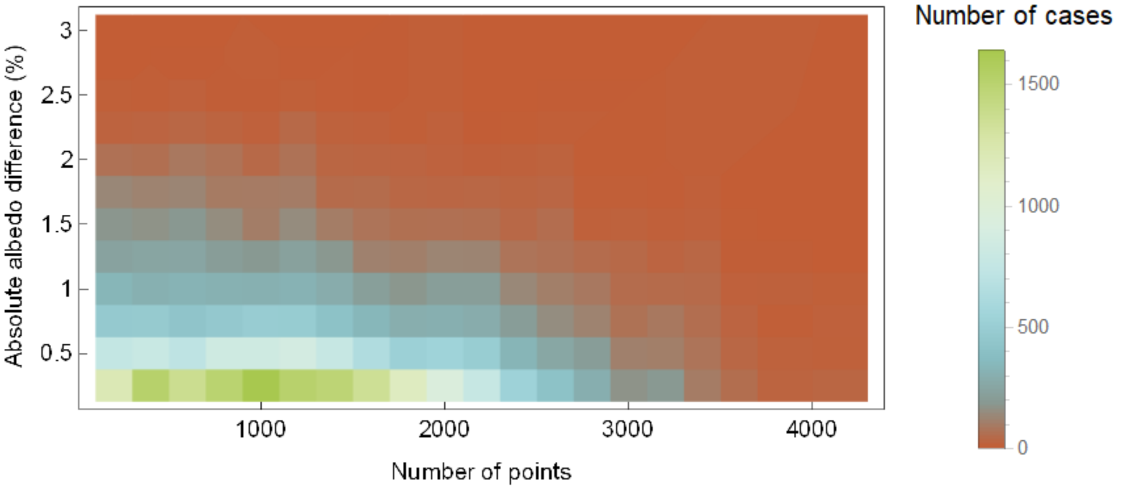
The text will be edited as requested.

Pg.13, Ln.9: Remove comma after "show".

The text will be edited as requested.

Figure.3: These plots do not effectively convey the distribution of the points plotted, beyond showing they are concentrated in the bottom left corner. I would suggest a density plot (where the data-space is divided into a regular grid and the number of points in each bin is shown by a colour gradient).

The figures are edited as suggested.



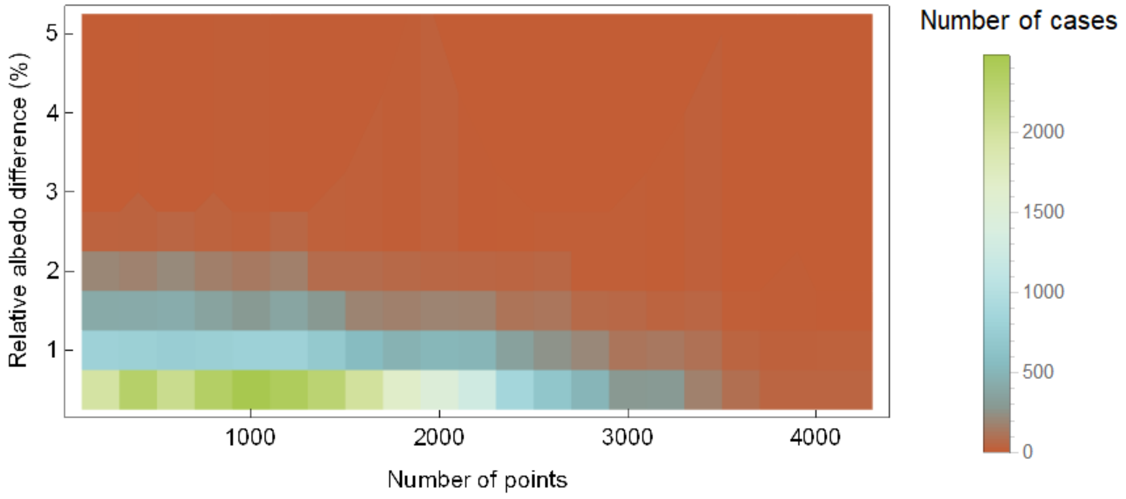
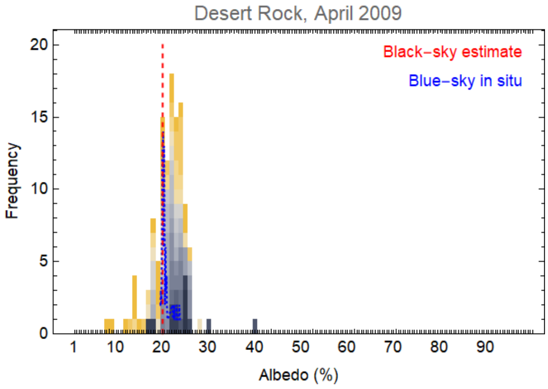


Figure.4: I assume the top-left panel should be labelled "Desert Rock", rather than "Payerne"? Also, I don't think it is necessary to show the full range of albedo for each panel - the distributions would be clearer if the x-axis was limited to the range of albedo observed at each station.

It seems the Payerne figure was erroneusly provided twice and the Desert Rock Figure was missing. It should have been this one:



This will be corrected and the scales will be adjusted as suggested.

Figure.5: See figure.4.

The scales will be adjusted as suggested.

Figure.6: I would suggest that this plot be regenerated to show the distributions of CP values flagged as cloudy or clear relative to the total number of observations of at each CP value (so that the sum of the red and blue lines is always 1). This would convey the the distributions in a more intuitive way and remove the need to include the dotted "cloud-fraction" line.

The Figure will be revised as suggested: