General comment #1:
Dear Authors,
I would like to note that the application of Goudriaan's simple parameterisation of the G-function of vegetation media may lead to uncertainties. A discussion of its accuracy is given in the paper:
Otto S, Trautmann T, A note on G-functions within the scope of radiative transfer in turbid vegetation media, J. Quant. Spectrosc. Radiat. Transfer, 109, 2813-2819, 2008.

Unfortunately, Fig. 1 in that paper is incomplete and can be found in Otto S, Trautmann T, Fast analytical two-stream radiative transfer methods for horizontally homogeneous vegetation media, Scientific Communications of the Institute for Meteorology of the University of Leipzig, Meteorologische Arbeiten (XIII) und Jahresbericht 2007 des Instituts für Meteorologie der Universität Leipzig, self-published, ISBN 978-3-9811114-2-2, 42, 17-32, 2008 http://www.unileipzig.de/_meteo/de/orga/LIM_Bd_42.pdf on page 21.

Wouldn't it be reasonable to use more accurate parameterisations or exact G-functions for certain leaf normal distributions? Did you already perform tests like this with regard to their influence on the canopy reflectivity and hence the soil albedo under nonvegetation- free conditions?

Reply:
We thank S.Otto for the comment. This paper deals explicitly with the parameterization of bare-soil (vegetation-free and snow-free) albedo. Whilst we agree that exploring alternative parameterizations for the G-function would be a useful exercise to further explore uncertainties in the vegetation albedo parameterization, it does not fit within the scope of this paper. The largest errors are related to the soil albedo in desert areas, as pointed out by reviewers 1, 3, and 4. Hence we have focused the revised manuscript on addressing this issue, rather than exploring alternative G-functions.

Reviewer #1:
In this study, a simple parameterisation for snow-free and vegetation-free (background) land surface albedo is implemented into the land surface model (LSM) Community Atmosphere Biosphere Land Exchange CABLEv1.4b. The simulated land surface albedo is evaluated with MODIS MCD43GF albedo product. Simulated surface parameters of CABLE with parameterised and prescribed soil albedo are compared to investigate the models sensitivity to the parameterisation. With this content, the paper is within the scope of GMD. But it becomes not clear, if the presented soil albedo parameterisation is useful; and the evaluation against only MODIS seems not sufficient. With regard to science, there is no innovative approach in it. There are more advanced methods for background albedo parameterisations available, which are also cited in the paper, but not applied here.

Reply: We thank the reviewer for their constructive comments which we have taken on board thoroughly we hope. We now use an additional remotely sensed albedo data-set (SPOT albedo) for evaluation. We have also re-calibrated the soil color maps used, such that the errors in albedo are now acceptable and the new scheme can be used. Whilst this paper certainly does not fix the issue of parameterizing soil albedo in land surface models perfectly, it does show added capacity to an existing LSM, CABLE, which can now be used to investigate soil-moisture albedo feedbacks. Recognizing the need to make our results as broadly relevant as possible we have also added some text to the conclusions that we hope is broadly useful. We have not adopted more advanced methods for background albedo parameterizations, but instead focused re-calibrating the soil color map, such that parameterization is usable. Given that this is the very first attempt to introduce a soil albedo parameterization in CABLE, we think it is appropriate to have introduced one of the simpler and currently used soil albedo parameterizations in other LSMs (e.g CLM).

Major Comments:
On the one hand, the authors state that incorrect parameterisation of surface albedo can result in large model biases. On the other hand, the CABLE LSM with the new albedo parameterisation simulates larger differences compared to MODIS albedo than the LSM with prescribed albedo. Assuming that MODIS product represents realistic surface albedo values, the new parameterisation would potentially lead to larger model bias. As demonstrated in figure 8, net radiation is up to 50 Wm-2 higher

than in the control run, also sensible heat and temperature show high sensitivity. The high sensitivity of the simulated surface parameters demonstrate the large importance of an accurate representation of land surface albedo. Accordingly, you state on p. 1682, l. 26, that the new parameterisation should be used with caution. But for which purpose can it be used then? It is correct that with the new parameterisation dynamic soil moisture - albedo feedbacks are enabled, but how realistic will those feedbacks be represented?

Reply:
These were legitimate criticisms. We have re-calibrated the soil color map, and the differences in albedo between CABLE and two remotely sensed estimates, MODIS and SPOT is now acceptable. This new parameterization can now be used when running CABLE coupled to an atmospheric model. The majority of the required changes are reflected in the revised results and discussion section.

2. The prescribed soil albedo in the CABLE control run is derived from MODIS data. The evaluation of the simulated total surface albedo is also done with MODIS data. Thus, it is no surprise that CABLE results with prescribed soil albedo shows high agreement with MODIS data, as you also state in line 24, p.1683. The new soil parameterisation leads to larger differences compared to MODIS, but this does not automatically mean, to larger errors. Only, if we assume that MODIS perfectly represents the real values. First, I suggest to avoid the absolute word "error" and use the relative word "difference" or "deviation". Second, I recommend to compare the simulated albedo with another data source, e.g. land surface albedo from MERIS data.

Reply: We agree, and do not use the term “error”, but “difference” instead. We also use an alternative remotely sensed albedo data-set, the SPOT albedo product. The majority of the required changes to accommodate this advice are in the revised results and discussion section.

3. With respect to the soil albedo parameterisation: soil moisture in LSMs are model specific quantities, and in most cases more an index of moisture state for a 3D soil layer, than a reliable absolute quantity (Koster et al. 2009). You also discuss this issue on p. 1685, but does it make sense then, to use this model quantity for your parameterisation? For the relation between soil moisture and soil colour, an absolute quantity is necessary which represents realistic near surface soil moisture. Is this

the case? How is soil moisture parameterised in CABLE? For which soil depth is it representative? And is it comparable to AMSR-E soil moisture?

Reply: The parameterization is based on an absolute surface soil moisture quantity. Our discussion was pointing to the issue that this quantity differs from model to model, and hence a limitation of this approach. This limitation can be overcome in part by re-calibrating the parameterization to account for differences in soil moisture which has been included in the revised manuscript. We have added some more details on soil moisture and CABLE and the rational for comparing against AMSR-E estimates:

"CABLE's surface soil moisture is representative of the first 2.2 cm of the soil, and details of the numerical scheme used to solve the 1-Dimensional Richard's equation can be found in Kowalczyk et al. (2006). While comparing an LSM soil moisture to a satellite derived product is not strictly comparing like-to-like, our goal here is to identify whether there are any spatial similarities in the differences between CABLE albedo and soil moisture from satellite derived alternatives, rather than examine the absolute soil moisture values. CABLE's soil moisture is generally higher compared to AMSR-E for most of the continent (Fig. 8), especially during DJF and SON. Higher soil moisture should result in lower simulated soil albedo and hence larger differences as compared to MODIS. Hence this could partly explain the large deviations in the NIR albedo.

To further quantify the contribution of the uncertainties in CABLE simulated soil moisture on albedo, we computed the correlation between the monthly mean differences in CABLE surface soil moisture and AMSR_E soil moisture, and CABLE Black-Sky NIR albedo and MODIS and SPOT estimates. This is shown in Figs. 9 (a) and (b) respectively. The correlations were computed over the period 2003-2008 (we did not compute correlations at the yearly and seasonal time-scales as the time-series was too short) and results shown are at the 95% level. A negative correlation shows that an over-estimation of soil moisture (i.e., +ve difference between CABLE and AMSR_E) is correlated with an under-estimation in albedo (i.e., -ve difference between CABLE and remotely sensed (MODIS and SPOT) Black-Sky NIR albedo). Large parts of the centre of the continent showed a negative correlation, with SPOT

albedo showing larger and more statistically significant correlations as compared to MODIS. Hence, at least part of the large differences in the Black-Sky NIR albedo over the centre of the continent can be attributed to CABLE over-estimating soil moisture."

4. At several places, the authors state that there are more advanced methods for background soil albedo available, e.g. Jiang et al. 2005, and others. The strong dependence of desert albedo on solar zenith angle is pointed out. Why is this not represented in your background albedo parameterisation? Can you give an estimation on the relevance and magnitude of potential effects on the LSM simulations by factors that are not directly represented in your parameterisation?

Reply: We have added some details on this in the discussion including the following text:

"The use of re-calibrated maps, whilst reducing the difference between CABLE and MODIS and SPOT estimates, did not completely fix the issue of underestimation of the local-noon black-sky NIR albedo as there were still small areas in central Australia whereby differences in the local noon NIR black-sky albedo were up to approximately -0.2. There may be several reasons for this. Firstly, as was shown in Fig. 9, at least part of the large differences in the NIR albedo can be attributed to CABLE over-estimating surface soil moisture, and hence simulating lower albedo. Secondly, the parameterisation and coefficients in Eq. 1 were originally developed for the BATS LSM (Dickinson et al., 1993), subsequently adopted in CLM, and now in CABLE. Eq. 1 is based on an absolute soil moisture value and this presents issues with regards to the universal application of the scheme irrespective of LSM, as the latter vary considerably in their treatment of soil moisture (Koster et al., 2009), as well as the processes which influence soil moisture (Koster and Milly, 1997). Whilst we re-calibrated the soil colour maps, we have not re-calibrated the coefficients used in Eq. 1 as this formulation was designed such that the soil albedos range in a nonlinear manner between their saturated and dry values (Dickinson et al., 1993). Rather than altering the formulation, we choose to re-calibrate the soil colour maps. Additionally, it is assumed that the ratio of the NIR to VIS albedo is exactly a factor of 2. However, Wang et al. (2005) have shown that this ratio from MODIS data over the arid part of central Australia is 2.69. We could make use of a higher factor and

this would help over Australia, but it would also lead to larger differences elsewhere in global simulations."

Minor Comments

p-1672, l-10: with differences "compared to" MODIS, instead of "with"

Reply: Change implemented.

p-1676, l-1: "Land albedo", instead of "Albedo"; I assume, that you also consider albedo of fractional water surfaces in the LSM

Reply: Change implemented. The albedo of fractional water surface is not considered when running CABLE offline. We have made this clearer in the manuscript:

> *"Land albedo in CABLE is a function of the vegetation albedo, snow albedo, and the background snow-free and vegetation-free soil albedo (the fractional albedo of inland water surfaces was not considered in the simulations)."*

p. 1686, l-24: the expression "soil wetness" stands not necessarily for a certain soil moisture concept in LSMs, in many cases, "soil wetness" and "soil moisture" are even used as synonyms;

Reply: We have removed this part of the discussion.

p. 1699, fig. 1: in the first box with red line, some text is missing in the end

Reply: This has been fixed.

p. 1702, fig. 4 and p. 1703 fig. 5: the colour bar is not well chosen, it is not possible to distinguish between the first 2 yellow and green colours

Reply: We have decided not to change the color bar for the soil color maps. Being able to distinguish successive color is not the point here, rather, the point is to show that lower soil colors have higher VIS and NIR saturated albedos and higher soil colors have lower values. This is an important pattern to discern from the maps. If we use a different "contour color" for each successive soil number, it becomes difficult to see this pattern, which is what we want to illustrate.

p. 1707, fig. 9: the relevance of this comparison to FLUXNET observations is not clear

Reply: We have removed the comparison with FLUXNET observations. On reflection, we accept that this was not adding much value to the manuscript, as noted the other reviewers.

Reviewer #2:

The improvement and evaluation of the albedo scheme in the land surface model and the earth system model are very important in terms of the significant impact of albedo on the energy, water and even carbon fluxes within the atmosphere-vegetation-soil system. The topic of this paper is interesting and important not just to the CABLE community but also to other land surface modelers. It is generally well organized and clearly demonstrated. So, the reviewer suggests the acceptance of this paper after addressing the following minor questions:

1. For the albedo related study, I don't see the necessity for the authors to evaluate CABLE's capability in reproducing the energy fluxes at the two FLUXNET sites. This topic would be worth writing another paper that systematically evaluates CABLE's performance against more towers and observation-based large-scale estimations of energy budget and partitioning over the Australia.

Reply: We thought about this criticism at length. On reflection we agree with the reviewer and have removed the comparison against FLUXNET sites.

2. For the Figures 4, 5, 7 and 8, it would be useful to know whether those differences are significant or not.

Reply: We carried out statistical significance testing of the differences in albedo between CABLE and MODIS and SPOT, and most of the differences were found to be statistically significant at 95%. Hence, we simply show all the differences. Additionally, in this context, the absolute differences in albedo provide all the necessary information, as deviations in albedo of more than 0.1-0.2 have a large enough influence on the surface energy balance, to warrant further improvements. We have clarified this in the text:

"An initial analysis of the differences between CABLE and MODIS and SPOT albedo showed that most of the differences greater than +/- 0.05 were statistically significant at 95%. Hence, we simply show the absolute differences. In this context, deviations of more than 0.1-0.2 from remotely sensed estimates are considered to be large enough to warrant further improvements to the model.

Reviewer #3:

General comments:
This paper describes and evaluates the CABLE land-surface scheme with respect to predicting albedo. The authors also propose a soil albedo parameterisation and evaluate its performance in CABLE with respect to MODIS data. However, the parameterised albedo performs somewhat more poorly compared to the prescribed albedo. Although I think the paper has definite merit and should eventually be published, it is not clear why the authors did not trial a statistical parameterization as well, or possibly tuned the soil colour dataset to achieve better agreement with the MODIS dataset. If this issue could be addressed, then I recommend the paper for publication in GMD.

Reply: We considered this comment at length and concluded that this would be a really valuable addition to our manuscript. We have now tuned the soil color to CABLE soil moisture, and extended the soil colors from 8 to 20, which has improved the comparisons against MODIS and SPOT albedo estimates.

Specific comments:

1) Although the analysis of the new parameterization is valid, the proposed soil albedo parameterization seems to fail in a similar way as for BATS. Can the authors suggest a context where the parameterize scheme would have an advantage compared to the prescribed soil albedo? Alternatively, could the authors trial a 'statistical' approach which may achieve their goal of improving the model parameterization.

Reply: We have not trialed a statistical approach, but re-calibrated the soil color map to CABLE soil moisture, which has reduced the large differences in the NIR albedo. Please see the revised results and discussion section.

2) Is it possible to estimate errors for the observed soil albedo (i.e., using alternate datasets), or some measure as to what accuracy would be sufficient for the new soil albedo parameterization.

Reply: We accept this criticism and we now employ an alternate Albedo dataset, the SPOT product.

3) Is it possible to derive a soil colour dataset which would be more consistent with the MODIS data? Possibly this parameter could be adjusted to improve the consistency with MODIS?

Reply: Yes – thanks for this suggestion. We have carried this out. See the revised results and discussion section.

Technical corrections: Appendix A: Equation (A1) – Authors should mention than A1assumes equal partitioning between shortwave and longwave radiation.

Reply: We make it clearer that alpha_s in A1 is the surface albedo for shortwave radiation, as described in Kowalczyk et al. (2006).

Fig 1: Text for "Fraction of direct-beam shortwave radiation" seems incomplete.

Reply: The text has been fixed in Fig 1.

Reviewer #4:

General Comments
This paper raises the problem of implementing soil-moisture-albedo feedbacks in the CABLE land surface model (LSM). However, despite finding that importing a simple (two-line) parameterisation from another LSM significantly degrades model performance and "should be used with caution", no improvements are trialled. The paper in its current form does not represent a significant advance in land surface modelling, but could be made suitable for publication in GMD if an improvement on the parameterisation presented here could be proposed, implemented and tested.

We thank the reviewer for their comments. We have worked hard to improve the parameterization and the differences between CABLE and MODIS and an alternative remotely sensed albedo dataset, SPOT, is now acceptable. Our original goal was substantially around documentation of model developments, it is clearly preferable to document model improvements and the reviewer's comments have helped us considerably in this direction.

Specific Comments

p.1677, l 11-17: What is the origin of the coefficients in Eq 1, and are they specific to the soil moisture parameterisation in BATS. If so, is it reasonable to transfer the scheme directly to CABLE without re-calibration?

Reply:
Based on the BATS model documentation, these coefficients were chosen to represent the soil albedos range in a nonlinear manner between their saturated and dry values. Based on how this scheme was implemented within CLM, we adopted the same approach of calibrating the soil color maps, rather than the coefficients. We make this clearer in the discussion:

"Whilst we re-calibrated the soil colour maps, we have not re-calibrated the coefficients used in Eq. 1 as this formulation was designed such that the soil albedos range in a nonlinear manner between their saturated and dry values (Dickinson et al., 1993). Rather than altering the formulation, we choose to re-calibrate the

soil colour maps"

p. 1683, l10. I notice the above issue is touched on here, and a suggestion made to use relative soil moisture instead of absolute soil moisture. A physical or empirical justification for this suggestion would be helpful.

Reply: We have removed this section from the manuscript.

Do results improve if the parameters in Eq 1 are re-calibrated using model-(CABLE)-specific relative or absolute soil moisture?

Reply: Yes, we have carried out a re-calibration of the soil color map and this has improved comparisons with MODIS and SPOT albedo. Please see the revised results and discussion.

p.1681, l6-10: "The CNTL experiment (with prescribed soil albedo), shows that CABLE simulates albedo well": there is no mention of the significant overestimate of Blue-Sky NIR albedo (by~0.1) over regions of high vegetation cover (eg Tasmania). This is a known problem for "two-stream" type radiation transfer models (of which the CABLE schme is a simplification). For example, Widlowski et al. (2011) found that both ACTS (Ni-Meister et al., 2010) and JRC2S (Pinty et al., 2006) (which both use a clumped two-stream approach) tend to underestimate canopy absorption and overestimate canopy reflectance when compared with a 3-D Monte Carlo reference model. This finding is consistent with Pinty et al. (2011) who state that, in order to correctly account for absorption due to multiple scattering in a structurally heterogeneous canopy, the near infrared (NIR) leaf scattering coefficient in JRC2S had to be lowered relative to its true value.

Reply: We have added this to the results section:

> *"We also note that that there is a consistent difference of 0.05 to 0.1 for the blue-sky NIR albedo in densely vegetated areas of Tasmania and the northern tropics. This has been documented elsewhere for other LSMs which use a similar two-stream radiation transfer scheme, as is used in CABLE. For example, Pinty et al (2011) report that the lowering of the NIR leaf scattering coefficient below it's true value was required to correct the absorption due to multiple scattering a structurally heterogeneous canopy."*

p. 1680, l12-119: What is the relevance of energy partitioning to the accuracy of albedo simulation? If data from flux sites are to be used, it would be more helpful to look at the radiometric observations, rather than the observations of turbulent fluxes.

Reply: We have removed the comparison with flux site observations on the grounds that on reflection we agree with the reviewer's implied criticism.