Responses to Anonymous Reviewer #1

General Comments

This study evaluates changes in Nov-May surface albedo and radiative forcings from land cover change in Norway using six land surface models and a radiative transfer model. The authors identify biases in modeled snow-covered and snowfree albedo for open and forested land cover types relative to MODIS albedo, with consistent positive bias of modeled open area albedo. Overestimation of the change in albedo from to conversion of forest to open led to overestimation of radiative forcing from land use/land cover change relative to MODIS. The authors suggest some model-specific improvements that could reduce modeled αs biases and reduce RF bias relative to MODIS, a strong contribution to the field.

In general, there are a lot of references to the 61-page Supplement in the Discussion section. With only two figures and one table in the main body of the manuscript, there is plenty of room to bring important Supplement findings into the main manuscript.

We thank Anonymous Reviewer #1 for his/her comments. We agree that important supplementary material -- notably information pertaining to key methodological assumptions and detail -- could be incorporated into the main manuscript. We have now shifted text from the supporting material file into the manuscript including a figure and table.

Specific Comments

(1) Three of the six models used in this study calculate direct-beam and diffuse albedo separately, yet only MODIS direct-beam (black sky) albedo is used as the observational benchmark. It would be helpful to see some discussion on why this choice was made. Why not use the full expression of MODIS blue-sky albedo from diffuse (white-sky) and direct-beam (black-sky) to compare all six models on equal ground? It doesn't seem fair to compare MODIS direct-beam to models that do not provide direct-beam.

We elected to go with the intrinsic black-sky albedo rather than calculate the total/blue-sky albedo, since the black-sky albedo under clear sky conditions for most SZAs (below 80 deg) typically dominates the total-sky albedo (Ni and Woodcock, 2000; Wang, 2005; Wang and Zeng, 2009). We checked this by employing a MODIS subset tool (ORNL DAAC, 2014) providing the calculated blue/total-sky albedo for one of our open and forested sites for our study time period. Mean shortwave total/blue-sky albedos at the forested and open site were 2.5% and 2.2% lower than the black-sky albedos, respectively. This does not alter our conclusions regarding the systematic biases identified for the three schemes in question (GISS, JULES All-band, and JSBACH).

We have better explained our assumptions and their implications in section 2.3.

(2) In mid-winter, the solar zenith angle at local solar noon in this region would be quite high. Noted that December values were omitted from the analysis, but isn't SZA greater than 70o at local solar noon for these sites during much of January and early February? Previous versions of MCD43A are considered high quality up to SZA of 70o, but beyond that the anisotropic model becomes unrealistic (Lucht et al., 2000, Schaaf et al., 2002, Stroeve et al., 2005 and Liu et al., 2009; Schaaf et al., 2011). Is this guideline

for appropriate use of MCD43A also true for V006? It would be helpful to see some discussion on the accuracy of MCD43A V006 at high solar zenith angles.

MODIS BRDF/Albedo V005 product is indeed less accurate with SZAa >70-75. To our knowledge this is also applicable to the V006 product. Although we elected to use the January and early February retrievals (i.e., SZA > 70 deg.), we do not believe this decision affects our results and main conclusions as they pertain to the systematic biases connected to the albedo parameterizations evaluated in our study. In any case we add a sentence in the Discussion section that highlights this known MODIS issue in light of our use of Jan. and Feb. retrievals.

 (3) The land surface and radiative transfer modeling workflow needs more detail. From what I could gather, the six land surface models were run offline to calculate αs of open and forested lands. Top-of atmosphere radiative forcing was calculated for each of the three study regions at 1o x1o horizontal resolution using the 3D four spectral band, eight stream radiation transfer model using observed MODIS and modeled forest αs, and open αs. Is this correct? I thought I would find more detail in the 61-page supplement but I couldn't find any information on how the radiative transfer model was used with the land surface models. This type of information deserves more space in the methods section of the manuscript. The study regions shown in Figure S1 are much smaller than 1o (maybe 0.2o x0.4o at best?). How was this difference in domain size and resolution of the radiative transfer model reconciled? Is the radiative transfer modeling performed as single 1o x1o column centered over each of the three domains in Figure S1? Or are the domains rounded to the nearest whole degree? Was the entire grid cell assigned forest αs and open αs or were you able to use subgrid parameterization of albedo? A map of the radiative transfer modeling domain for each study region would be helpful for understanding how much existing cropland exists in each grid cell (p. 17344, line 20-21).

We agree that more attention is needed in the Methods section (section 2) surrounding both the albedo and RT modeling workflow. An important point of clarification to which we give more attention in our revision is that we do not run the entire land models offline, but rather, we extract only the equations required to calculate the surface albedos. We have now made this explicitly clear in section 2.1 to absolve any doubt.

Additionally, we add new information to section 2.4 describing more explicitly the steps taken when estimating RFs from both MODIS and predicted albedos.

(4) The TOA modeling has four spectral bands (undefined) but results are presented for two spectral bands, VIS and NIR. How was this addressed? Is the RF reported only for VIS and NIR? Or does the RF reported also include SWIR? If so, how might this affect the relationship between albedo and RF biases?

To clarify how the radiative transfer has been performed in terms of spectral resolution we have added the following description to the manuscript:

The four spectral bands are divided into the spectral regions 300-500 nm, 501-850 nm, 851-1500 nm, and 1501-4000 nm where MODIS VIS albedos are included in the two first bands and MODIS NIR albedos are included into the latter two bands. The reported RF is the integrated over the four spectral bands.

The radiative transfer code has been compared to detailed line-by-line calculations for various applications with agreement of the order of 10% (Myhre et al., 2009; Randles et al., 2013).

(5) In the discussion, I'd like to see a comment on how landscape heterogeneity and surface roughness within the MODIS footprint might also be contributing factors to lower than expected snow-covered albedo over open lands. While gridded at 500 m resolution, the actual observational footprint at high latitudes may include up to 1 km (Wang et al., 2012). Roads, buildings, clusters of trees, uneven snow surfaces and landscape features that cast shadows could all be contributing to lower than expected albedo over open lands in MODIS.

This is another good point, and we have therefore expanded the Discussion to include a discussion of the uncertainties stemming from landscape heterogeneities within the MODIS signal footprint, with relevant references to the work of Cescatti et al. (2012) and Wang et al. (2012).

Technical Corrections

p. 17340, line 6-7

"Unexpectedly, however, biases of equal magnitude were evident in predictions at open area sites." I am not sure why the authors find this to be unexpected, and do not believe that the data presented in Figure 1e and 1f support the claim for "equal magnitude".

What we mean is that we find it "unexpected" relative to the large range of biases for forests and given the lower diversity across parameterizations for completely snow-covered vegetation. Data in Figure 1a-d for some months and cases do in fact support the claim that some of the open-area biases were found to be of "equal magnitude" to those seen for forests. We re-write the confusing sentences in question so as to clarify our semantics.

p. 17342, lines 10-19.

Resolution of MCD43A3 used in this study should be stated somewhere in this paragraph. I assumed 500 m.

Added, thanks.

p. 17342, line 12

Define "winter-spring". I assumed that winter included December through February and spring included March through May. Later in the manuscript winter is defined as January through March (p. 17345, line 18) and November is also included in the analysis. Be clearer in defining "winter" and "spring".

We elected to list the actual dates rather than define "winter-spring" (or seasons) in the revised manuscript.

p. 17343, line 8

Change "12 open area sites…" to "Twelve open area sites…"

Corrected.

p. 17345, line 5

This is the first mention of using spectral bands. Please describe bands and

wavelengths used for VIS and NIR in the MODIS data section.

OK, we defined the spectral bands used in the analysis at the beginning of section 3.1.

p. 17346, line 4

Change "sits" to "sites"

Corrected.

p. 17347, line 18

The authors state, "For JSBACH, the result of having both positive and negative Δαs biases…" could you point to a table or figure that supports this?

OK, we have added references to the relevant tables and figures in the Supporting Information that support this.

p. 17347, line 24

There is no Table 3 in the manuscript. Did the authors intend Table S3? If so, there are two Table S3's in the Supplement. Please correct.

Thanks for pointing this out. Indeed, "Table 3" here should have been Table S3 and there are indeed two Table S3s in Supporting Information. The correct reference here should have been to "Table S7", which we have corrected here and at all other places in the manuscript that were incorrectly referenced.

p. 17349, line 6-7

Is there any empirical basis for lowering extinction coefficients from 0.3 and 0.4 for NIR and VIS, respectively, to 0.25 and 0.3 in this region? If so, please cite.

What we actually lowered is the "correction factor" used to estimate the extinction coefficient. This implies a slightly higher distribution of vertical leaf area which is more in line with an ellipsoidal leaf angle distribution (Campbell and Norman, 1998; Flerchinger and Yu, 2007; Wang et al., 2007). This serves to lower the extinction coefficient (increase canopy transmittance) to values more in line with those observed in boreal evergreen forests (Aubin et al., 2000; Balster and Marshall, 2000; Pierce and Running, 1988). We have now added the relevant supporting references.

p. 17350, line 28-29

Change "high CC%" to "high canopy cover fraction (CC%)"

Corrected.

p. 17359, Figure 1

The caption references a,b,c…f however the figures lack such labels. Please include labels on the figures and reference Fig 1a, 1b, etc correctly in the main body of the manuscript. No need to state left column, right column if these are labeled correctly. Recommend equation be moved to the text.

Corrected figure. We elect to leave the equations in the captions, however, as they are only needed to interpret the figure.

Supplement

Several tables span page breaks without the table headings repeating on the second page. Either keep the tables on a single page or repeat the headings on the second page.

Corrected. Tables have been fit to single pages.

Supplement, Figure S1

This figure and associated text ought to be in the methods section of the manuscript, not the Supplement

We agree and have moved it to the main manuscript.

Supplement, Table S1

What is H80?

We have added a definition of "H80" in Table S1's (now Table 1) caption.

References:

Liu et al., 2009. Validation of Moderate Resolution Imaging Spectroradiometer (MODIS) albedo retrieval algorithm: dependence of albedo on solar zenith angle. Journal of Geophysical Research – Atmospheres, 114 (2009), p. D01106.

Lucht, et al. 2000. An algorithm for the retrieval of albedo from space using semiempirical BRDF models. IEEE Transactions on Geoscience and Remote Sensing, 38 (2000), pp. 977–998.

Schaaf, et al. 2002. First operational BRDF, albedo, nadir reflectance products from MODIS. Remote Sensing of Environment, 83 (2002), pp. 135–148.

Schaaf et al. 2011. Commentary on Wang and Zender – MODIS snow albedo bias at high solar zenith angles relative to theory and to in situ observations in Greenland. Remote Sensing of Environment, 115(5), pp. 1296-1300.

Stroeve et al., 2005. Accuracy assessment of the MODIS 16-day albedo product for snow: comparisons with Greenland in situ measurements Remote Sensing of Environment, 94 (2005), pp. 46–60.

Wang et al., 2012. Evaluation of Moderate-resolution Imaging Spectroradiometer (MODIS) snow albedo product (MCD43A) over tundra. Remote Sensing of Environment, 117, pp. 264-280.

References used in our responses:

Aubin, I., Beaudet, M., and Messier, C.: Light extinction coefficients specific to the understory vegetation of the southern boreal forest, Quebec, Canadian Journal of Forest Research, 30, 168-177, 2000.
Balster, N. J. and Marshall, J. D.: Eight-year responses of light interception, effective leaf area index, and stemwood production in fertilized stands of interior Douglas-fir (Pseudotsuga menziesii var. glauca), Canadian Journal of Forest Research, 30, 733-743, 2000.
Campbell, G. S. and Norman, J. M.: An introduction to environmental physics (2nd Ed.), Springer-Verlag, New York, NY, USA, 1998.
Flerchinger, G. N. and Yu, Q.: Simplified expressions for radiation scattering in canopies with ellipsoidal leaf angle distributions, Agricultural and Forest Meteorology, 144, 230-235, 2007.
Myhre, G., Kvalevåg, M., Rädel, G., Cook, J., Shine, K. P., Clark, H., Karcher, F., Markowicz, K., Kardas, A., Wolkenberg, P., Balkanski, Y., Ponater, M., Forster, P., Rap, A., and de Leon, R. R.: Intercomparison of radiative forcing calculations of stratospheric water vapour and contrails, Meteorologische Zeitschrift, 18, 585-596, 2009.
Ni, W. and Woodcock, C. E.: Effect of canopy structure and the presence of snow on the albedo of boreal conifer forests, Journal of Geophysical Research, 105, 1879-11888, 2000.
ORNL DAAC: MODIS subsetted land products, Collection 5. Available online [http://daac.ornl.gov/MODIS/modis.html] from ORNL DAAC, Oak Ridge, Tennessee, USA. Accessed Nov. 28, 2014., Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC), 2014.
Pierce, L. L. and Running, S. W.: Rapid Estimation of Coniferous Forest Leaf Area Index Using a Portable Integrating Radiometer, Ecology, 69, 1762-1767, 1988.
Randles, C. A., Kinne, S., Myhre, G., Schulz, M., Stier, P., Fischer, J., Doppler, L., Highwood, E., Ryder, C., Harris, B., Huttunen, J., Ma, Y., Pinker, R. T., Mayer, B., Neubauer, D., Hitzenberger, R., Oreopoulos, L., Lee, D., Pitari, G., Di Genova, G., Quaas, J., Rose, F. G., Kato, S., Rumbold, S. T., Vardavas, I., Hatzianastassiou, N., Matsoukas, C., Yu, H., Zhang, F., Zhang, H., and Lu, P.: Intercomparison of shortwave radiative transfer schemes in global aerosol modeling: results from the AeroCom Radiative Transfer Experiment, ATMOSPHERIC CHEMISTRY AND PHYSICS, 13, 2347-2379, 2013.
Wang, S.: Dynamics of surface albedo of a boreal forest and its simulation, Ecological Modelling, 183, 477-494, 2005.
Wang, W. M., Li, Z. L., and Su, H. B.: Comparison of leaf angle distribution functions: Effects on extinction coefficient and fraction of sunlit foliage, Agricultural and Forest Meteorology, 143, 106-122, 2007.
Wang, Z. and Zeng, X.: Evaluation of Snow Albedo in Land Models for Weather and Climate Studies, Journal of Applied Meteorology and Climatology, 49, 363-380, 2009.