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Using satellite and in situ data to evaluate snow albedo schemes in weather and climate models

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1. Introduction

Albedo plays an important role in land surface energy balance, and it is strongly affected by snow cover. Although some previous studies have evaluated the snow albedo as part of an overall land model study (Oleson et al. 2003; Zhou et al., 2003; Wang et al. 2004; and Tian et al. 2004), it is difficult to conclude whether the snow albedo treatment itself in land models is appropriate. For instance, a land model could have an earlier snowmelt due to a variety of reasons, and the subsequent albedo in the model would be very different from the observed snow albedo. This difference, however, does not necessarily imply that the snow albedo formulation itself is incorrect.

Complementary to the previous studies, we have addressed this issue in this study by directly testing the snow albedo formulations used at some of the major weather forecasting and climate research centers, including Noah land model used at the NCEP regional and global forecasting models and at the NCAR WRF model, the Hou et al. (2002) scheme for albedo computation used for NCEP global forecasting models (denoted as NG), the NCAR Community Land Model (CLM3), and the ECMWF land model.

2. Evaluation of snow albedo treatments in Noah, NG, CLM3, and ECMWF

2.1 Four idealized cases

First four idealized cases were designed better understand the different albedo formulations in these models. The model formulations were run for 20 days, starting from 00LST on 1 February.

Case1: Grass is assumed to be covered by snow of 1 m in depth with 100 kg/m^3 as the initial snow density at the BOREAS grass site (52.16 °N, 106.6 °W).

Case 2: Same as Case 1 except for the BOREAS forest site (53.92 °N, 104.69°W) with 2 m of snow on the ground (under trees).

In ECMWF, the snow density varies only with time. In contrast, snow density in Noah varies with time and temperature. Comparison of the diffuse albedo over the grass versus forest sites indicates that NG treats snow above grass and snow under trees in the same way in computing snow fraction and hence significantly overestimates snow albedo over the forest site in comparison with observations. Noah shows different albedos over the two sites, because of the use of different maximum snow albedos over these sites. With the explicit treatment of snow on the ground, snow burial fraction, and snow intercepted by canopy, CLM3 is able to handle the two cases well.

The snow cover fraction plays an important role in the computation of albedo and energy balance of the land surface. Therefore, Cases 3 and 4 are designed to examine the snow cover fraction used in different models and its effect on snow albedo.

Case 3: Same as Case 1 (i.e., over the grass site) except running the model formulations for one day with different initial snow depths from 0−1 m.

Case 4: Same as Case 2 (i.e., over the forest site) except running the model formulations for one day with different initial snow depths from 0−2 m.

Figure 1 shows comparison of snow cover fraction and diffuse albedo as a function of snow depth for four land surface models over the grass site at local noon on 1 February for the idealized Case 3. The snow fraction in NG initially increases fastest with snow depth, but ECMWF snow fraction reaches unity first at snow depth of 15 cm. In contrast, even with 1 m snow, the ground is still not fully covered in CLM3 or NG. These differences in snow fraction directly contribute to the diffuse albedo differences in Fig. 1b.

2.2 Comparison of model results with in situ data

The above four cases consider the idealized conditions but do not compare with the observational data. Here the BOREAS in situ data over the same sites as in idealized case were used.

We have evaluated the multi-year BOREAS data (from 1994 to 1996) over the grass and forest sites to choose days with snow on the ground but without snowfall and snowmelt, and results are summarized in Fig. 2. Over the grass site, CLM3, Noah, and to a lesser degree ECMWF, underestimate the albedo (Fig. 2a). While NG albedo is slightly higher than observed values for one day, it is overall smaller than the observed values when the whole BOREAS data are analyzed (Fig. 2a), indicating the importance of using long$-$term observations. Over the forest site, CLM3 and ECMWF albedos are relatively close to measurement, but Noah and NG overestimate albedo (Fig. 2b).

2.3 Sensitivity tests

While model formulations or parameters can be tuned to substantially reduce the albedo bias, excessive tuning usually reduces the transferrability of revised formulations or parameters to other regions over global land. Furthermore, there is an inherent difference between point measurements and grid cell average albedos from models. Therefore, our goal here is to make only minor changes to each model to significantly improve each model's performance.

For NG, there is a significant overestimate of albedo over forest (Fig. 2b), while the albedo bias is much smaller in magnitude over grass (Fig. 2a). Because NG does not explicitly consider the snow–shading effect of trees, our suggestion is to replace the global constant diffuse snow albedo by the vegetation-type-dependent MODIS maximum snow albedo in Barlage et al. (2005). Because the MODIS maximum snow albedo differs most from 0.825 as used in NG over forests, the effect is most significant over forests (rather than over short vegetation), as demonstrated in Fig. 3.

For the Noah land model, W_{cr} is a critical parameter controlling the computation of snow fraction. Because Noah significantly underestimates albedo over grass (Fig. 2a) but overestimates albedo over forest (Fig. 2b), it is necessary to reduce W_{cr} for short vegetation but increase it for tall vegetation. Therefore our suggestion is to use 0.01 m for short vegetation and 0.20 m for tall vegetation (in contrast to 0.04 *m* and 0.08 *m* used in Noah, respectively). Furthermore, while satellite-based maximum snow albedo is used over each grid cell in Noah as implemented at NCEP, a specified value for each vegetation type is used for Noah as implemented in the WRF model at NCAR. In our Noah tests so far, the MODIS maximum snow albedos (Barlage et al. 2005) are used. Therefore, we have also done sensitivity tests using the vegetation-type-dependent maximum snow albedo as used in WRF at NCAR. Figure 4 summarizes the sensitivity of Noah to W_{cr} and maximum snow albedo. Over the grass site, the MODIS albedo is similar to the default value used in WRF at NCAR, while the decrease of W_{cr} from 0.04 m to 0.01 m reduces the albedo bias by more than 50% (Fig. 4a). Over the forest site, using the revised W_{cr} value significantly reduces the Noah albedo bias, while the use of the maximum snow albedo from WRF at NCAR significantly increase the Noah albedo bias (Fig. 4b). Note that while the aging effect of snow density is considered, the direct effect of aging on snow albedo is not considered in Noah. For instance, the fresh snow albedo is generally higher than the MODIS value of 0.7 as used in Fig. 4a, and the explicit inclusion of aging effect on snow albedo (with a higher fresh snow albedo than the MODIS maximum snow albedo) would further reduce the Noah albedo bias in Fig. 4a.

For ECMWF, there is an underestimate of albedo over grass (Fig. 2a), and our suggestion is to simply revise the snow fraction formulation as

$$c_{sn} = \min\left[1, \left(\frac{S}{S_{cr}}\right)^{0.5}\right] \qquad (1)$$

Figure 5 shows that this revision reduces the albedo bias by more than 50% over grass without affecting the already good results over forest.

For CLM3, there is a substantial underestimate of albedo over grass (Fig. 2a), and this is related to the computation of ground snow fraction [i.e., Eq. (2)]:

$$f_{sno} = \frac{z_{sn}}{10\, z_{0m,g} + z_{sn}} \qquad (2)$$

Previous studies (e.g., Niu and Yang 2007) and our snow fraction comparisons have demonstrated the underestimate of snow fraction using Eq. (2). This can be easily understood: because $10\, z_{0m,g}$ in Eq. (2) roughly represents the height of ground elements, snow as deep as these elements only covers 50% of the ground based on Eq. (2) rather than fully covers the ground. It needs to be emphasized that the use of Eq. (2) in the original BATS land model (Dickinson et al. 1993) is not necessarily as bad, because of compensating effects of other BATS components for the computation of snow albedo. For CLM3 in which snow burial fraction and radiative transfer through canopy are computed, Eq. (2) needs to be revised, and our suggestion is to simply drop the factor '10' from the term $10\, z_{0m,g}$:

$$f_{sno} = \frac{z_{sn}}{z_{0m,g} + z_{sn}} \qquad (3)$$

This revision substantially reduces the albedo underestimate over grass (Fig. 6a) without much effect over forest (Fig. 6b).

3. Conclusions

We have made some progress by identifying and understanding model deficiencies and making suggested minor revisions to significantly improve the performance of each of the four land models. These revisions are easy to implement in these models. This can also be further refined by using more comprehensive observational data in different regions.

Even though we have focused on four specific land models, some conclusions are relevant to all land models. For instance, snow fraction cannot be evaluated independently. In other words, the same snow fraction could yield very different snow albedos in different models. Therefore, we are not attempting to give a single snow fraction formulation for all land models here.

While the use of satellite maximum snow albedo (e.g., from MODIS) is overall beneficial, additional factors (e.g., the snow aging effect and the possibly higher albedo of fresh snow intercepted by canopy than the MODIS albedo) need to be considered, particularly over forest regions. While verification using additional data is needed, our data analyses indicate that the snow albedo decrease with time is most significant when albedo itself is high.

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References:

Barlage, M., X. Zeng, H. Wei, and K. E. Mitchell 2005: A global 0.05° maximum albedo dataset of snow-covered land based on MODIS observations. *Geophys. Res. Lett.*, *32*, L17405, doi:10.1029/2005GL022881.

Bonan, G. B., D. Pollard, D., and S. L. Thompson 1992: Effects of boreal forest vegetation on global climate. *Nature*, *359*, 716 – 718.

Dickinson, R. E., A. Henderson-Sellers, P. J. Kennedy, and M. F. Wilson 1986: Biosphere–Atmosphere Transfer Scheme (BATS) for the NCAR Community Climate Model. *NCAR Tech. Note, NCAR/TN-275+STR,* Natl. Cent. for Atmos. Res., Boulder, Colo..

Dickinson, R. E., A. Henderson-Sellers, and P. J. Kennedy 1993: B iosphere–Atmosphere Transfer Scheme (BATS) version 1e as coupled to the NCAR Community Climate Model. *NCAR Tech. Note, NCAR/TN-387+STR*, 20 pp., Natl. Cent. for Atmos. Res., Boulder, Colo.

Hou, Y. –T., S. Moorthi, and K. Campana 2002: Parameterization of solar radiation transfer in the NCEP models. *NCEP Office Note 441,* 46 pp.

Koren, V., J. Schaake, K. Mitchell, Q. Y. Duan, F. Chen, and J. M. Baker 1999: A parameterization of snowpack and frozen ground intend for NCEP weather and climate models. *J. Geophys. Res.*, *108*(D16), 19569 – 19585.

Mitchell, K. E., and Coauthors 2004: The multi-institution North American Land Data Assimilation System (NLDAS): Utilizing multiple GCIP products and partners in a continental distributed hydrological modeling system. *J. Geophys. Res.*, *109*, doi:10.1029/2003JD003823.

Niu, G., Y., and Z. L. Yang 2007: An observation-based formulation of snow cover fraction and its evaluation over large North American river basins. *J. Geophys. Res.*, **112**, doi:10.1029/2007JD008674.

Oleson, K. W., G. B. Bonan, C. Schaaf, F. Gao, Y. Jin, and A. Strahler 2003: Assessment of global climate model land surface albedo using MODIS data. Geophys. Res. Lett., 30, 1443, doi:10.1029/2002GL016749.

Oleson, K. W., and Coauthors 2004: Technical description of the community land model (CLM), *NCAR/TN-461+STR*, Natl. Cent. for Atmos. Res., Boulder, Colo. 173 pp.

change. *J. Climate*, **19**, 2617 – 2630.

Tian, Y., R. E., Dickinson, L. Zhou, R. B. Myneni, M. Friedl, C. B. Schaaf, M. Carroll, and F. Gao 2004: Land boundary conditions from MODIS data and consequences for the albedo of a climate model. *Geophys. Res. Lett.*, **31**, L05504, doi:10.1029/2003GL019104.

Wang, Z., X. Zeng, M. Barlage, R. E. Dickinson, F. Gao, and C. B. Schaaf 2004: Using MODIS BRDF and albedo data to evaluate global model land surface albedo. *J. Hydrometeorol.*, **5**, 3–14.

Wang, Z. and X. Zeng 2008: Snow albedo's dependence on solar zenith angle from in situ and MODIS data. *Atmos. and Oceanic Sci. Lett.*, in press.

Yang, Z. L., R. E. Dickinson, A. Robock, and K. Y. Vinnikov 1997: Validation of the snow submodel of the biosphere – atmosphere transfer scheme with Russian snow cover and meteorological observational data. *J. Clim.*, *10*, 353 – 373.

Zhou, L., R. E. Dickinson, Y. Tian, X. Zeng, and Coauthors 2003: Comparison of seasonal and spatial variations of albedo from MODIS and Common Land Model. *J. Geophys. Res.*, **108**, 4488, doi:10.1029/2002JD003326.

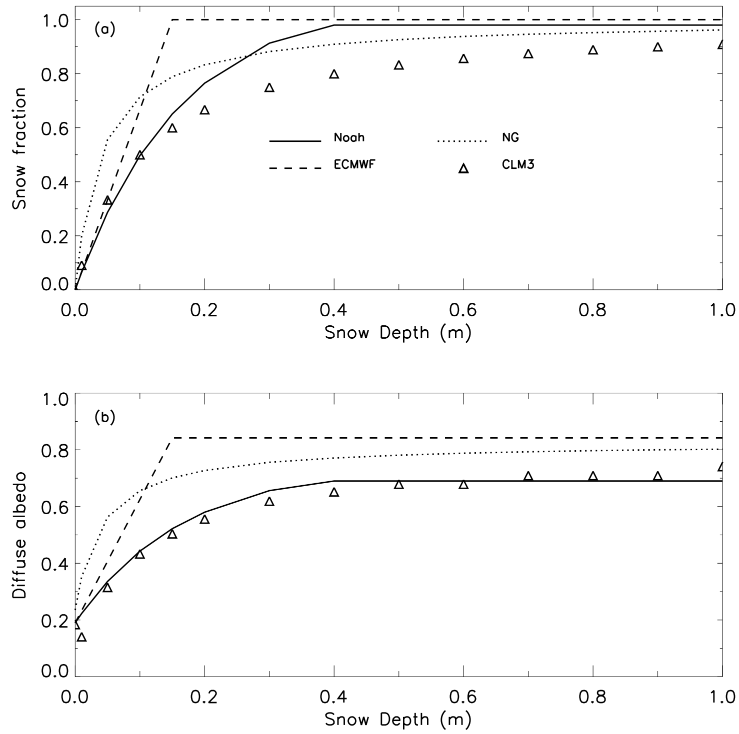

FIG. 1. Comparison of snow cover fraction and diffuse albedo as a function of snow depth for four land surface models over the grass site at local noon on 1 February for the idealized Case 3.

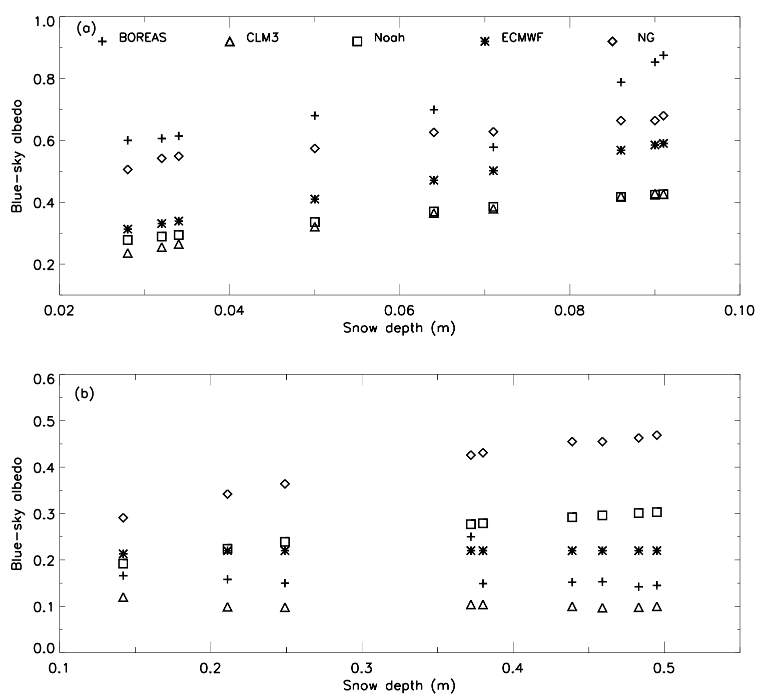

FIG. 2. Comparison of blue-sky albedos from CLM3, Noah, NG, and ECMWF with the multi-year BOREAS data (from 1994 to 1996) on the days with snow on the ground but without snowfall and snowmelt (a) over the grass site and (b) over the forest site.

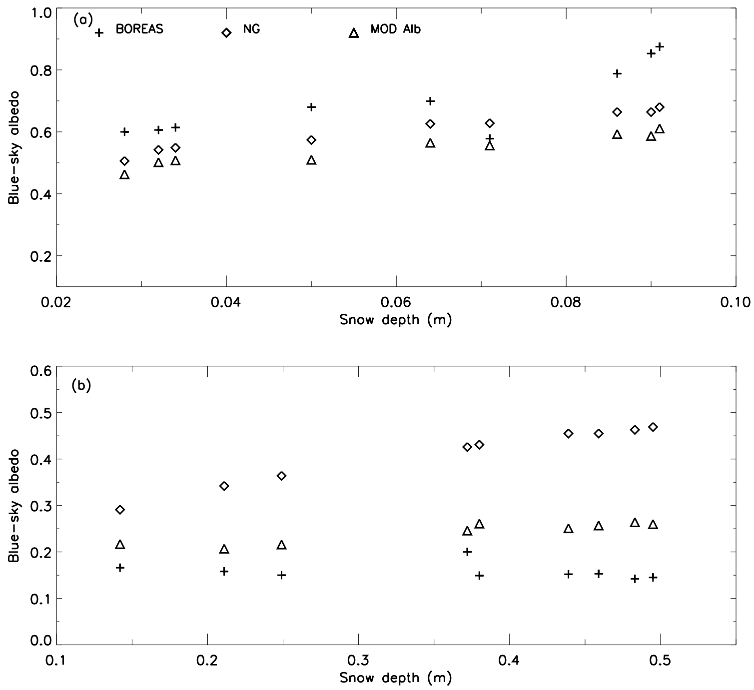

FIG. 3. The sensitivity of NG snow-covered surface albedo to maximum snow albedo over the grass site in (a) and the forest site in (b) using the data in Fig. 2. The MODIS averaged maximum snow albedo values that are dependent on vegetation type (0.70 and 0.34 for grass and evergreen needleleaf forest, respectively) are used in the sensitivity test.

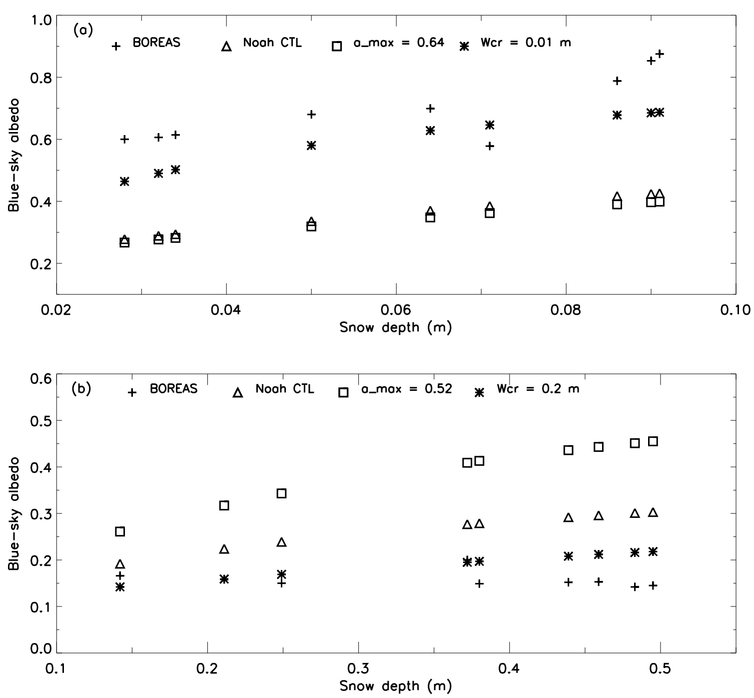

FIG. 4. Sensitivity of Noah snow albedo to the use of maximum snow albedo as used in WRF (at NCAR) and revised W_{cr} values over the grass site in (a) and the forest site in (b) using the data in Fig. 2

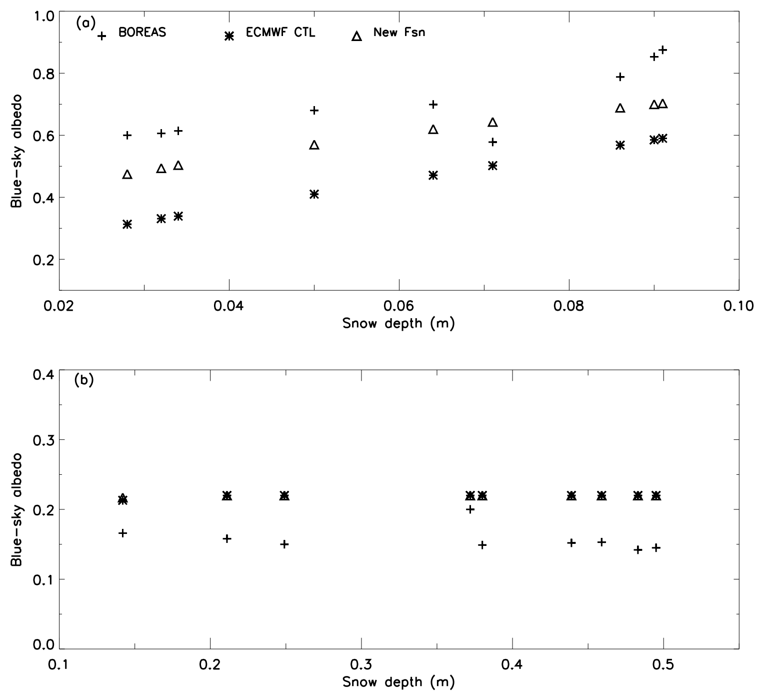

FIG. 5. The sensitivity of ECMWF snow-covered surface albedo to the control and new [i.e., Eq. (1)] snow fraction formulations over the grass site in (a) and forest site in (b) using the data in Fig. 2.

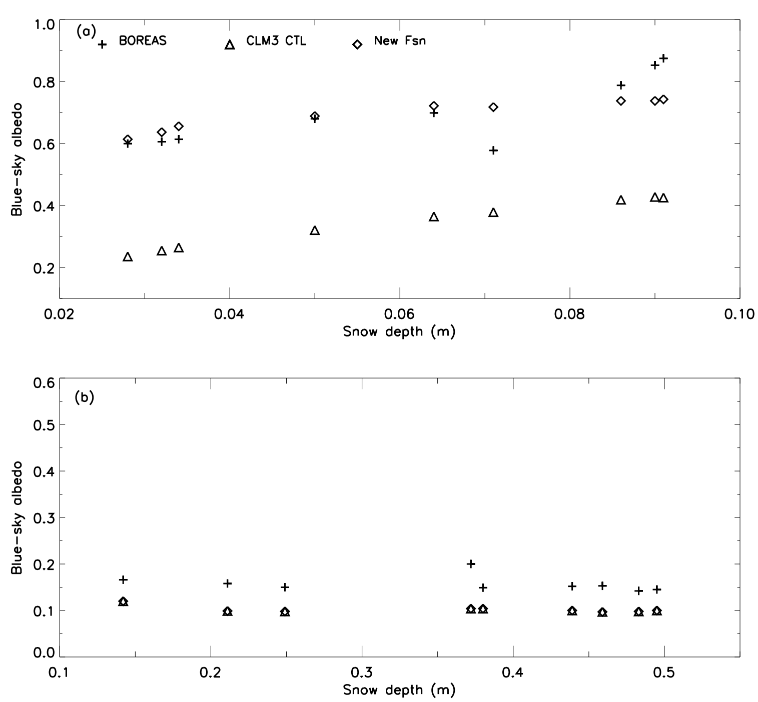

FIG. 6. The sensitivity of CLM3 snow-covered surface albedo to the control [i.e., Eq. (2)] and new [i.e, Eq. (3)] ground snow fraction formulations over the grass site in (a) and forest site in (b) using the data in Fig. 2.