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Commentary on Wang and Zender—MODIS snow albedo bias at high solar zenith angles relative to theory and to in situ observations in Greenland

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ABSTRACT

The recent paper by Wang and Zender [Wang, X., & Zender, C. S. (2010). MODIS snow albedo bias at high solar zenith angles relative to theory and to in situ observations in Greenland. Remote Sensing of Environment.] draws erroneous conclusions about solar zenith angle biases at high latitudes by not making appropriate use of the extensive quality flags available with the MODIS BRDF/Albedo. Coarse resolution MODIS white-sky albedo data are compared with actual blue-sky field albedometer measurements from the Greenland GC-Net. By utilizing large area averages of the MODIS data product that combine both high quality and poor quality data indiscriminately, the authors erroneously conclude that the accuracy deteriorates for solar zenith angle (SZA)>55° and often becomes physically unrealistic for SZA>65°. Once the quality flags are considered, however, the comparisons demonstrate that the MODIS product performs quite well out to the recommended limit for product use of 70° SZA. This verifies the conclusions of an earlier more rigorous evaluation performed by Stroeve et al. [Stroeve, J., Box, J. E., Gao, F., Liang, S., Nolin, A., & Schaaf, C. B. (2005). Accuracy assessment of the MODIS 16-day albedo product for snow: comparisons with Greenland in situ measurements. Remote Sensing of Environment.]. With over a decade of observations and products now available from the MODIS instrument, these data are increasingly being used to evaluate and tune climate and biogeochemical models. However, such use should take into account the documented quality and limitations of the satellite-derived product.

The wealth of high quality biophysical products that have been produced from MODerate resolution Imaging Spectroradiometer (MODIS) observations over the past decade has been eagerly embraced by the climate and biogeochemical modeling communities (Justice et al., 1998; Oleson et al., 2003; Myhre et al., 2005; Tian et al., 2004; Roesch et al., 2004; Lawrence & Chase, 2007; Zhou et al., 2003; Wei et al., 2001; Morcrette et al., 2008). These global quantities have undergone several reprocessing efforts and the Collection V005 products represent the highest quality values produced by the MODIS Science Team to date. The MODIS products are particularly distinguished by the extensive quality fields that accompany the data values and which are considered an integral component of each product. Unfortunately, the modeling community has not always utilized these quality fields with as much enthusiasm as they have the data values—sometimes leading to misuse of the MODIS data.

The recent paper by Wang and Zender (2010) represents an example of conclusions drawn without full consideration of the MODIS BRDF/Albedo product quality information. We feel it is important to draw attention to misinterpretations of this sort so that they are not promulgated in to subsequent work and that they may be avoided in future.

The paper compares MODIS intrinsic surface albedo values from MCD43C3 (Gao et al., 2005) with GC-Net station data from automatic weather stations on the Greenland Ice Sheet. Unlike the earlier work of Stroeve et al. (2005), which also compared the MODIS values with the surface GC-Net values, this Wang and Zender study suffers from four major shortcomings. First, the authors chose not to correct the station data to adjust for limited sensing of the full shortwave spectrum. As noted by Stroeve et al. (2005), the GC-Net ground sensors only sense in the range 0.4–1.1 μm, resulting in a positive bias of 0.04 to 0.09 as compared to full spectrum calibration sensors. Secondly, they chose to only present the results for bihemispherical reflectance under isotropic illumination (white-sky albedo) rather than both white-sky albedo and the solar zenith angle dependent directional hemispherical albedo (black-sky albedo). Thirdly, they chose to compare small footprint albedometer readings with averaged values of MODIS data, encompassing areas as large as 17 km by 17 km around the ground point measurements. Fourthly, and most importantly, they did not properly consider the quality information associated with the MODIS data.

The MODIS BRDF/Albedo product (MCD43) (Schaaf et al., 2002; Lucht et al., 2000; Liang et al., 2002; Jin et al., 2003a,b; Salomon et al., 2006; Liu et al., 2009; Román et al., 2009, 2010; Disney et al., 2004;

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Wang et al., 2004; Shuai et al., 2008) is produced from high quality, cloud-free, multi-date, multi-angle surface reflectance data over a 16 day period. If sufficient observations exist to adequately sample the surface reflectance anisotropy, a best-fit anisotropic model describing the surface bidirectional reflectance distribution function (BRDF) is attempted. The availability of sufficient samples over the viewing/illumination geometry is fully as important as the fit of the model to the data. This full inversion retrieval is attempted every 8 days with data from both Terra and Aqua and, if successful, the final result is reported at a 500 m gridded resolution in a sinusoidal projection. Snow-free observations are considered separately from snow-covered observations.

Once a high quality full inversion BRDF retrieval has been accomplished, intrinsic measures of spectral directional-hemispherical reflectance (black-sky albedo) for local solar noon and wholly diffuse spectral bihemispherical reflectance under isotropic illumination (white-sky albedo) are computed through integration of the retrieved BRDF in each MODIS spectral band. Lastly, the spectral albedos are combined in a weighted sum to provide intrinsic shortwave albedo values that include the full shortwave spectrum (Liang et al., 1999; Stroeve et al., 2005).

The intrinsic shortwave black-sky at a specific solar zenith angle and the isotropically illuminated white-sky albedo values must be further combined as a function of the atmospheric optical depth and even some consideration of the multiple scattering (Lucht et al., 2000; Román et al., 2010) to produce actual blue-sky albedo values (bihemispherical reflectance) which are directly comparable with those measured by ground based albedometers. The MODIS high quality full inversion products are only recommended for use up to a 70° solar zenith angle as the anisotropic model often has difficulties at solar zenith angles higher than this (Lucht et al., 2000; Schaaf et al., 2002; Stroeve et al., 2005; Liu et al., 2009).

If sufficient high quality, cloud-free observations are not available, the algorithm resorts to lower-quality back-up magnitude inversions from the noisy or insufficient data (Strugnell et al., 2001; Schaaf et al., 2002). Here an *a priori* estimation of the surface BRDF shape is assumed and coupled with whatever few observations are available to provide black-sky and white-sky albedos. In the case of pure snow, the *a priori* BRDF shape is based on field measurements and modeling (Stroeve et al., 2005). While the back-up magnitude inversions often produces acceptable values, the albedo values obtained are more likely to be affected by residual cloud contamination and atmospheric turbidity and are thus less consistent. This is particularly true of magnitude inversions at high latitudes, where the few input surface reflectance values available may not be properly corrected for aerosols under high solar zenith angles, or in the case of pure snow-covered pixels are not corrected for aerosols at all. Therefore, magnitude inversions are considered poor quality results and labeled as such in the product.

The MODIS BRDF/Albedo product is also provided at a 0.05° resolution in a geographic latitude/longitude projection (Gao et al., 2005). This reduced resolution product provides the average of all pixels of all qualities in the 0.05° grid box. The quality flag only presents the most frequently occurring flag value of the underlying 500 m pixels and thus should be considered carefully. Gap-filled, 1 arc minute products that utilize only the highest quality values have been prepared explicitly for the modeling community from earlier collections (Moody et al., 2005, 2007, 2008) and are presently under production at 30 arc second for the current reprocessing data collection.

The Wang and Zender (2010) paper however only utilized three by three windows of the coarse averaged 0.05° MODIS MCD43C pixels for comparison with dry snow conditions at the GC-Net stations. The five GC-Net sites used include South Dome, Saddle, Summit, NGRIP, and Humboldt, and range from the south to the far north of Greenland, respectively. At these stations, albedo is measured using paired upward- and downward-looking pyranometers at a 2 m height, leading to footprint diameters of less than 25 m. As stated earlier, these instruments only sense in the 0.4–1.1 μm range rather than the full shortwave spectrum which can lead to overestimations of 0.04–0.09 as compared to the shortwave albedo values provided both from broadband albedometers and from the broadband computations of the MODIS product. Moreover, it should be noted that these pyranometer field observations are also not recommended for use at solar zenith angles above 70° (Stroeve et al., 2005) due to increased variability (a variability of approximately 0.1 in the 10 year mean noon albedo for the Summit site is demonstrated in Fig. 4 of Wang and Zender (2010)).

As mentioned above, the satellite-derived white-sky albedo under isotropic illumination should actually be combined as a function of aerosol optical depth with the solar-zenith angle-specific black-sky albedo to produced albedo values that are directly comparable to field albedometer measurements. In the Wang and Zender (2010) paper, however, only the wholly diffuse white-sky albedo values, rather than both the white-sky and the solely direct black-sky albedos, were considered. While these intrinsic quantities are similar, the black-sky albedos are relatively higher at larger solar zenith angles (Lucht et al., 2000). As there were no aerosol optical depth data available for the Wang and Zender (2010) study, this computation was not accomplished, yet both the solar-zenith-angle dependent black-sky albedo and white-sky albedo should have been presented (as in Stroeve et al., 2005).

The mismatch in scale between tower measurements and MODIS satellite observations has been noted before; typically, the gap in scale is bridged using higher-resolution imagery, such as Landsat data, to determine if the footprint is representative of the larger MODIS grid cell and to adjust the comparison if it is not (Román et al., 2009, 2010). Even at the finest gridded scale of MODIS albedo retrievals—500 m by 500 m—there will be inconsistencies in a completely snow-covered surface that can affect the observation with respect to a small footprint tower measurement. Surface undulations, sastrugi, and the buildings and roads associated with the sites are all known to be of sufficient height to cast shadows in the 500 m footprint, particularly at larger solar zenith angles and thus such shadowing is realistic of albedos at these resolutions. The Wang and Zender (2010) study utilized the even coarser scale 0.05° averaged values, as well as latitudinal averages that were even coarser still, without fully acknowledging that such large areal averaging only further exacerbates the scaling and shadowing problems in comparisons between satellite acquisitions and field measurements.

Most important, however, Wang and Zender (2010) did not utilize the quality flags associated with the product. We show that their results are primarily indicators of the reduction in the numbers of high-quality retrievals that are associated with the MODIS product at these coarse resolutions during the shoulder seasons. When the high quality 500 m pixels for each location are investigated within the limits of 70° solar zenith angle, it is clear that the high quality values do not support their primary conclusion that the MODIS albedos consistently decrease with increasing solar zenith angle above 55°.

Fig. 1 plots full and magnitude inversions for each of the five GC-Net sites using 500-m data; both white-sky and black-sky albedos are presented. These graphs may be directly compared with those in Fig. 6 in Wang and Zender (2010). In their graphs, sharp reductions in white-sky albedo values appear at solar zenith angles in the 55°–70° range for many of the sites and years, notably South Dome (2005–2006), Saddle (2003–2004), Summit (all years), NGRIP (2003, 2005) and Humboldt (2004–2005). As shown in Fig. 1, when quality flags are taken into account, the 500-m high quality, full-inversion data are quite stable and consistent and do not display sharp reductions in the 55°–70° range. Moreover, even the lower-quality magnitude inversions, while certainly displaying more scatter, do not consistently