Validation Studies and Sensitivity Analyses for Retrievals of Snow Albedo from EOS AM-1 Instruments

Annual Report for the Period 1 January 2002 to 31 December 2003

Background and Objectives

Snow albedo is a critical parameter affecting climate at global, regional, and local scales. Albedo controls the radiation balance at the snow surface and is an indicator of physical aspects of the snowpack such as snow thickness, grain size, and liquid water content. On glaciers and icesheets, there are strong feedbacks albedo and patterns of snow accumulation/ablation making albedo the controlling parameter in the surface energy balance. Because snow is so bright, even differences of 0.05 (in absolute albedo terms) can have a large effect on surface energy balance and snowmelt calculations.
Albedo is defined as the integral of reflected radiation over all angles:

$$a_s(\theta_0,\lambda) = \int \mu' \, d\mu' \int R(\theta_0, \mu', \phi', \lambda) \, d\phi'$$

where, $a_s(\theta_0,\lambda)$ is the spectral albedo, $R(\theta_0, \mu', \phi', \lambda)$ is the spectral bidirectional reflectance, λ is the wavelength, θ_0 is the solar zenith angle, μ' is the viewing zenith angle, and ϕ' is the viewing azimuth angle. Over snow, differences between reflectance and albedo can be as great as a factor of 3 or higher.

The specific objectives of this investigation are to:

1. Quantify sensitivity of snow albedo estimates to atmospheric variables
2. Validate angular model used to convert snow reflectance to snow albedo
3. Test different approaches for converting narrowband snow albedo to broadband snow albedo

This investigation focuses on snow albedo measurements from MODIS and MISR.

2002-2003 Accomplishments:

We have completed objective 1 and our efforts over the past year have focused on completing objectives 2 and 3. Specifically, our 2002-2003 activities were to:

a. Develop a community-wide narrowband-to-broadband albedo model for snow
b. Assess the angular model for conversion of hemispherical-directional reflectance factor to albedo and identify improvements

Over the past year, we have worked with others in the albedo field to agree upon a community-wide model for narrowband-to-broadband snow albedo. This is important to the snow albedo validation effort because the various schemes that are being used to estimate snow albedo, particularly those for MODIS, are in substantial disagreement. We have joined with other scientists in the albedo community (Dr. Andrew Klein, Texas A&M; Dr. Shunlin Liang, Univ. of Maryland; and Dr. Crystal Schaaf, Boston Univ.) to develop a consensus model for estimating broadband albedo. We compiled snow reflectance data from several sources and compared results using the different methods. Specifically, we tested two new narrowband-to-broadband conversion models; both are regression models. The first model (from S. Liang) takes spectral albedo data, from spectral libraries, and computes a broadband albedo by numerical integration. Multivariate regression is performed to obtain the regression coefficients. The second model uses in situ Greenland snow spectral albedo measurements and concurrent broadband albedo measurements to develop the regression coefficients. When the Liang coefficients are used to compute broadband albedo for the MODIS and MISR channels, we notice that the estimates are 8-10% lower than in situ broadband measurements. This is true regardless of which combination of channels we use. Figure 1 shows these results for the MODIS channels.

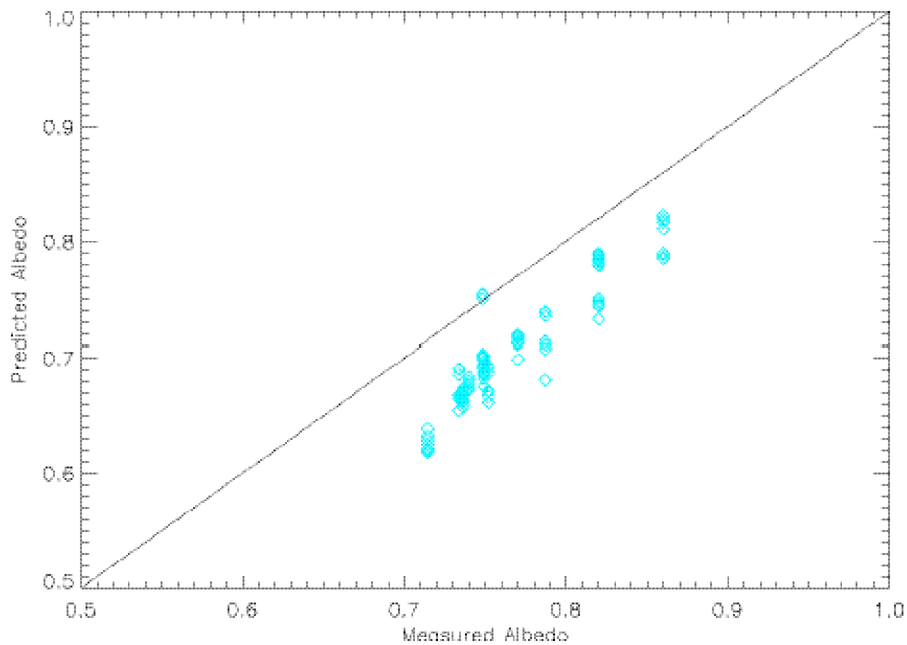

Figure 1. In situ measurements of broadband albedo over Greenland snow vs. predicted albedo using the Liang coefficients with MODIS data. Predicted values are consistently 8-10% lower than measured values.

In another test, we have taken the in situ Greenland snow spectral albedo measurements and have numerically integrated them and convolved them with solar irradiance (from the 6S RT model) to obtain broadband albedo. As with the Liang broadband estimates, we find that these numerically integrated values are also about 8-10% lower than the in situ broadband albedo measurements. The broadband measurements are made using well-calibrated Eppley pyranometers and there is no indication of bias in these measurements. However, it is clear that when we model the broadband measurements using spectral albedo data, we have a low bias. When we derive the regression coefficients by convolving the spectral albedo measurements to the particular MODIS and MISR channels and regressing them against the broadband in situ data, we see good agreement with independent data.

We have also compared in situ broadband albedo measurements with data from the MOD43 16-day albedo product (both “black sky” and “white sky”). The in situ measurements are averaged over the same 16-day period as the MOD43 product, using only the data from local solar noon. We find that the MODIS albedo product consistently underestimates snow albedo over our Greenland sites, except in the case of extensive melt and possible ponding of surface water. Figures 2 and 3 show comparisons with in situ broadband albedo measurements made at automated weather stations in the Jakobshavn ablation region (69.29ºN/49.41ºW, 967 m.a.s.l.) and Summit (72.58ºN/38.50ºW, 3200 m.a.s.l.).

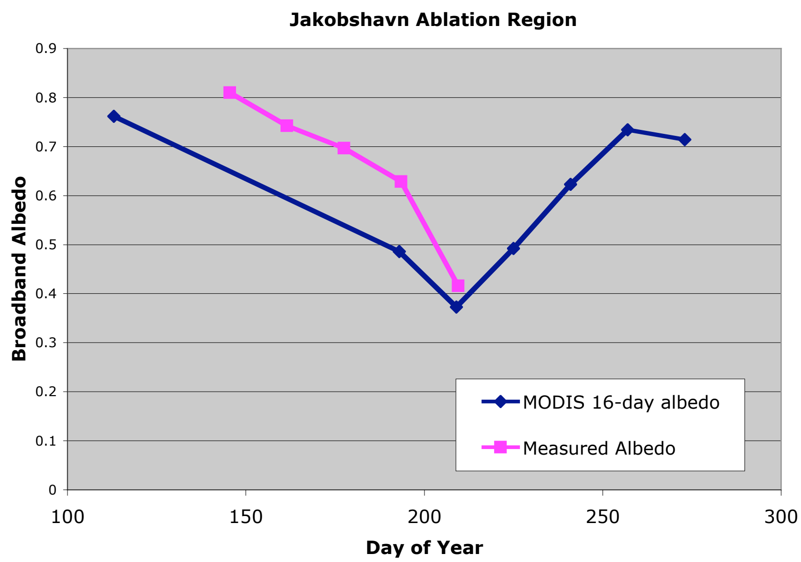

Figure 2. Comparison of the MOD43 "black sky" albedo (16-day composite) with in situ measurements of broadband albedo for the Jakobshavn ablation region site.

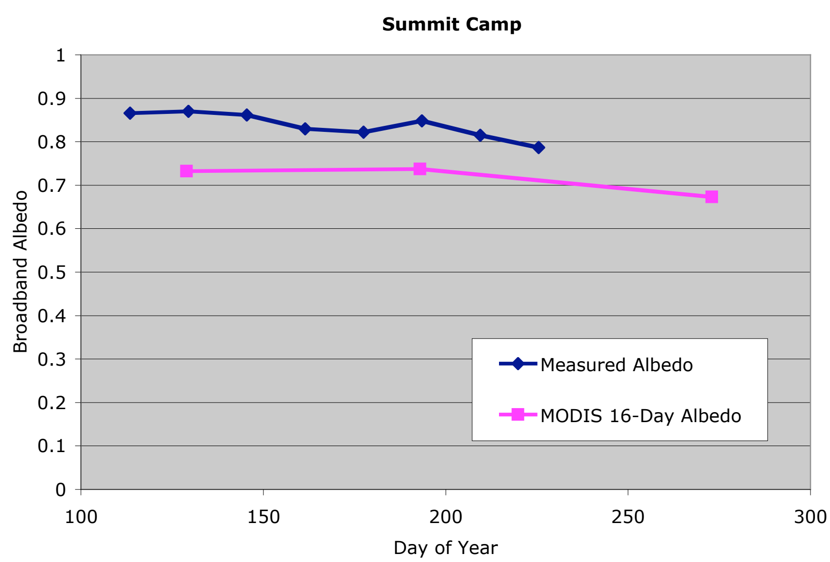

Figure 3. Comparison of the MOD43 "black sky" albedo (16-day composite) with in situ broadband albedo measurements for the Summit camp site.

It was hoped that these MODIS comparisons would allow us to select the most accurate and robust narrowband-to-broadband conversion model and bring consensus to this community and, to some extent this has happened. However, a number of important questions remain and will require further examination.

Albedo retrievals from MISR have seen significant progress in the past year. We have performed a comparison between a multispectral and a multiangular approach to estimating snow albedo. Again, we use the Greenland in situ broadband albedo measurements for validation of the MISR-estimated broadband albedo. The spectral method uses the 4 MISR channels at nadir (440nm, 550nm, 650nm, 866nm) in a multivariate regression to compute broadband albedo. The angular method uses data from all 9 camera angles, but only the 650nm channel. Results show that the angular approach gives a more accurate estimate of broadband albedo when compared with the in situ measurements (see Figure 4). These results are described more fully in Stroeve and Nolin (2002).

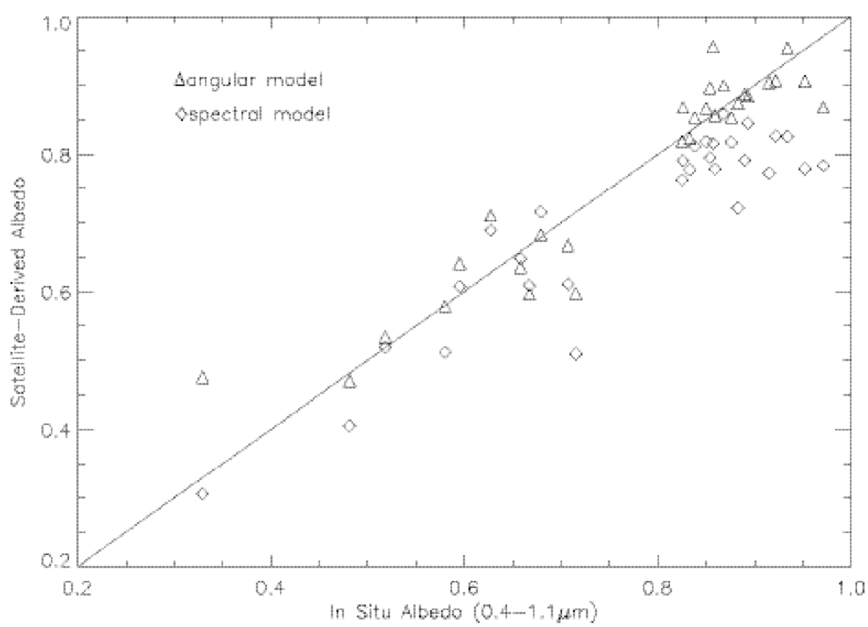

Figure 4. Comparison of multispectral and multiangular derived albedo with in situ measurements of broadband albedo from AWS sites on the Greenland ice sheet.

In the second focus area of our 2002-2003 validation effort, we have assessed the errors associated with the angular model for converting hemispherical-directional reflectance factor (HDRF) to albedo and we have identified an approach for improving this model. For this assessment, we used data collected with the PARABOLA instrument at our field experiment in Steamboat Springs, CO in 2001. Using snow and atmospheric properties derived from concurrent measurements, we modeled the snow HDRF at the same angular resolution (5° in azimuth and zenith) as the PARABOLA HDRF measurements. Figure 5 shows the HDRF differences when the solar zenith angle is large (75°).

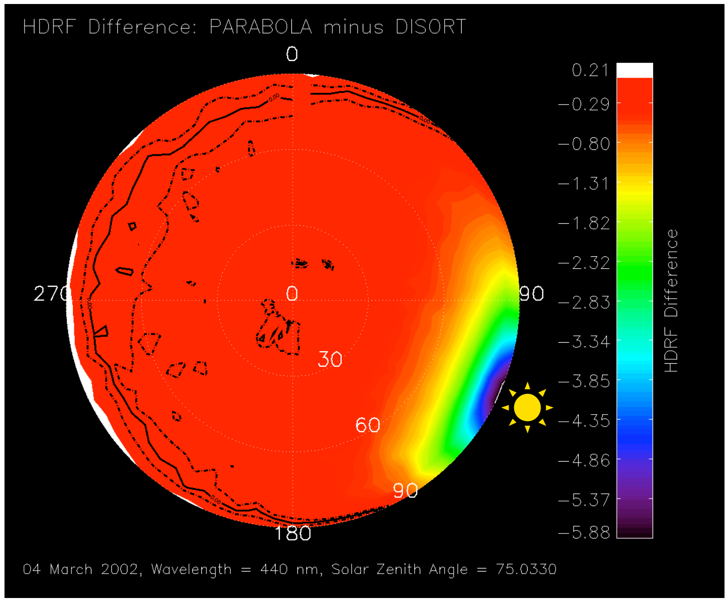

Figure 5. HDRF difference between PARABOLA measurements and DISORT model output for a solar illumination angle of 75 degrees. The model greatly overestimates the forward scattering peak and underestimates HDRF outside of the forward peak. The PARABOLA instrument and tripod are located at the center of the plot.

When the solar zenith angle is 50° or less, the HDRF differences are significantly less. The forward scattering peak is still overestimated by the model (by about 22%) but the range of viewing angles for which the differences are less than 10% is much greater. Translating these HDRF errors into albedo errors (narrowband) we see that Figure 6. shows the HDRF differences when the sun is highest in the sky for that day. Overall, we see that for solar illumination angles less than 50°, the albedo is within 5% of its measured value for viewing zeniths less than 70°, except in the forward scattering direction where this is limited to a viewing zenith of less than 30° in order to achieve the needed accuracy.

It is clear that the current model for converting reflectance to albedo is not sufficiently accurate for the range of solar illumination angles that are typically encountered when measuring snow at middle and high latitudes. Overestimation of the forward scattering peak is likely due to two sources 1) the model does not account for surface roughness, which has the effect of decreasing the anisotropy of the HDRF and 2) the phase function in the model is not appropriate for characterizing scattering from snow surfaces. Discussions with colleagues at the Third International Workshop on Multiangular Measurements and Models (IWMMM-3) point to another model approach that can potentially resolve both the surface roughness and phase function questions. Mishchenko et al. (1999) have compared several approaches and have shown that their method of representing the phase function for a snowpack (incorporating ice crystal shape) offers accurate and robust results for a wider range of viewing and illumination geometries. Testing of this new angular model will start in June 2003.

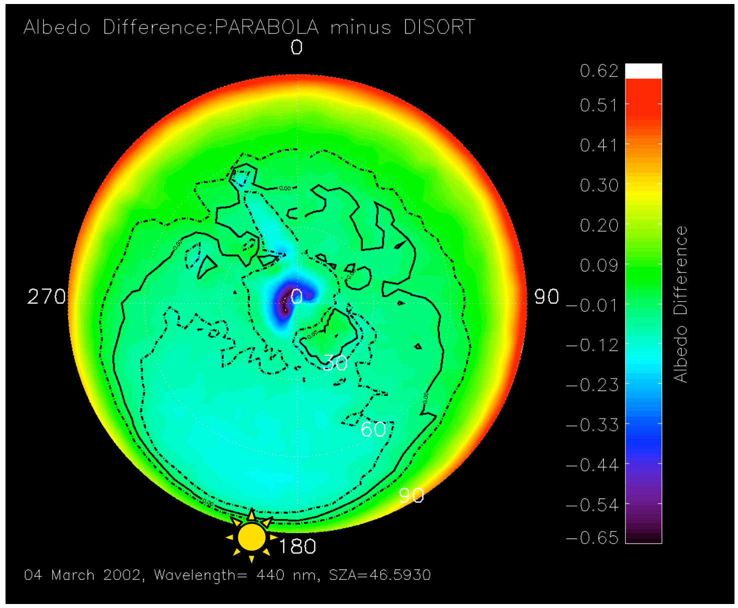

Figure 6. Measured and modeled narrowband albedo differences (blue channel) for a solar zenith angle of 46°. The dark area in the center of the plot is the location of the PARABOLA instrument and tripod.

Work Plan for 2003

1. Continue to process MODIS and MISR imagery over Greenland AWS sites to create time series of albedo and to better understand differences between in situ measurements and predicted broadband albedo. Comparisons with the MOD43 product (v.4) will also continue. The latest version of the MOD43 product uses the newest set of narrowband-to-broadband regression coefficients from Liang which seem to slightly increase the MODIS albedo retrievals over homogeneous snow. Stroeve will be responsible for these activities.
2. Test angular model of Mishchenko and compare with PARABOLA measurements. Nolin will be responsible for these activities.
3. Write up results in journal articles. Both Nolin and Stroeve will be responsible for these publications.

References

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