Validation of the Climate-SAF Inner Arctic broadband surface albedo product: Greenland and the polar ice cap

Aku Riihelä, Vesa Laine and Terhikki Manninen
Finnish Meteorological Institute, P.O. Box 503, 00101 Helsinki, Finland
Tel. +358 9 1929 4152, Fax +358 1929 3146, E-mail: aku.riihela@fmi.fi

Abstract

Recent studies and observations have shown that the Polar Arctic is changing: the sea ice extents are below their long-term averages, and the thickness of Greenland's snow and ice cover is decreasing. The Earth's radiation budget may thus be changing in the Arctic, requiring routine monitoring to aid modellers in understanding the cause of the changes. One of the key factors of the radiation budget is the surface albedo, which determines the amount of absorbed solar radiation at the Earth's surface. Continuous routine monitoring of the surface albedo in the remote Arctic areas requires operational satellite observations to be practical.

The Climate-SAF project of EUMETSAT answers this need by introducing a new shortwave broadband surface albedo (SAL) product for the Arctic region. Extending from the North Pole to 70 degrees North latitude and over, the product offers operational coverage over the entire Arctic. Augmented with sea ice extent data from OSI-SAF, the product incorporates albedo retrievals over all cloud-free sea ice regions as well as the whole of Greenland.

As the product is to be released into operational use in 2009, a thorough validation is required. We compare the SAL product with in situ albedo observations over Greenland and the polar sea ice for the period of summer 2007. The reference data over Greenland comes from the Greenland Climate Network (GCN) stations, and the sea ice albedo observations are from the Tara schooner expedition. The results show that the SAL product meets the requirement of 25% relative accuracy for the majority of retrievals. While product development is still ongoing, SAL shows a good potential to help in the observation of the climate change effects in the Arctic.

Introduction

The Polar region is predicted to play a major role in the coming climate change (Holland and Bitz, 2003). Understanding the energy budget of the Polar region and its trends is crucial for the mitigation of climate change effects for the societies of the Northern Hemisphere. Surface albedo is one of the key drivers of the Earth's energy budget, as it determines the amount of solar radiation that is absorbed and reflected by the Earth's surface. In the Arctic, surface albedo influences the energy feedback between Polar and mid-latitude regions, as well as the thickness and coverage of sea ice and Greenland's snow cover (Stroeve et al., 1997, Hall and Qu, 2006). Over the remote and sparsely populated areas of the Arctic, remote sensing from satellites is the most practical and cost-effective means of continuous observation of surface albedo.

Surface albedo of the Arctic has previously been observed using the AVHRR (Lindsay and Rothrock, 1994, Knap and Oerlemans., 1996, Stroeve et al., 1997, Stroeve et al., 2001, Xiong et al., 2002, Laine 2004) and MODIS instruments (Liang et al., 2005, Stroeve et al., 2006). However, the present coverage of Arctic albedo datasets has some gaps. The MODIS snow albedo products may not be extended to a climatological dataset because there is no heritage. Also, the current MODIS albedo products do not cover the Arctic sea ice. The AVHRR Polar Pathfinder dataset does cover the sea ice, but the dataset extends only to 2005. One of the most critical phenomena concerning the Arctic albedo is the recent quick decrease in the sea ice extent. Hence, there is a need for a timely albedo product covering both land and sea ice in the Arctic, with the capacity for extension to a climate data record. The Climate-SAF Inner Arctic SAL (IA-SAL) product aims to answer this need.

To provide value to the scientific community, the product must first be rigorously validated against reliable reference datasets. The *in-situ* datasets used for the IA-SAL validation are the Greenland Climate Network (GCN) weather station albedo measurements (Steffen et al., 1992) and the Tara schooner expedition albedo measurements from the polar ice cap (Vihma et al., 2008). The validation period is the polar summer 2007.

This paper provides first an overview of the methods and algorithms used to generate the IA-SAL product, then discusses both the satellite dataset and the reference observations, describes the results obtained during the validation exercise thus far and finishes with conclusions drawn from the study.

Algorithm

The IA-SAL product is a surface broadband albedo at the waveband of 0.25 – 2.5 micrometers. The product is derived from the NOAA-17, NOAA-18 and Metop-A satellites. The product features an atmospheric correction, therefore it may be described as a black-sky albedo product (i.e. diffuse radiation component is removed). The flow of product processing is shown in Figure 1.

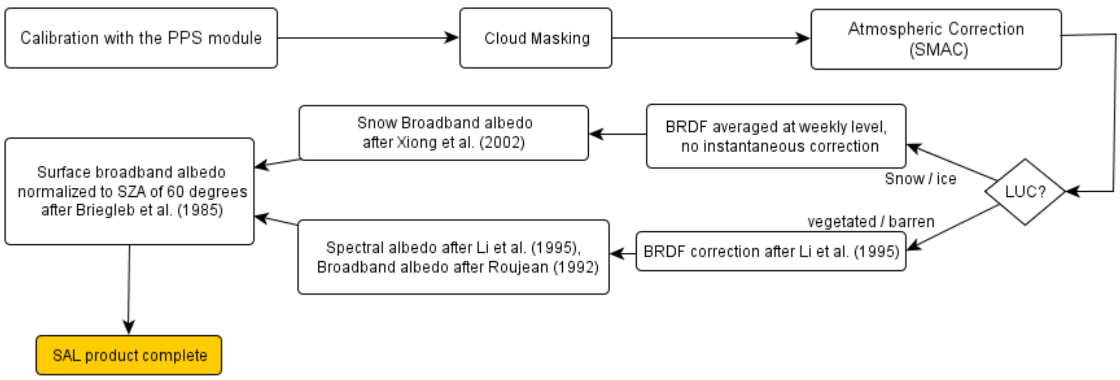

Figure 1: The product flow for instantaneous SAL product generation.

The preprocessing of the data is done by the Polar Platform System software (Dybbroe et al., 2005). PPS creates a cloud mask which is then used to remove all cloud-contamined pixels from the SAL processing. The cloud mask is updated with current Arctic sea ice extent information provided by OSI-SAF (Breivik, 2001). The atmospheric contribution to the reflectances is removed using the SMAC algorithm (Rahman and Dedieu, 1994). The correction uses atmospheric composition inputs partly from Deutscher Wetterdienst meteorological model data and partly uses constant values. The surface pressure and water vapour column data are model-based, while the atmospheric ozone content is set to 0.35 atm/cm^2 and the aerosol optical depth is set to 0.1.

A notable distinction between IA-SAL and other snow/ice albedo algorithms is that IA-SAL does not incorporate a BRDF correction at the instantaneous level. This is a calculated choice caused by two factors: Firstly, there are currently no snow BRDF models to the authors' knowledge that could robustly predict the reflective behaviour of all the diverse types of snow. Secondly, the user-distributable IA-SAL products are the weekly and monthly means, which are averaged from a high number of instantaneous observations during the timeperiod due to the high AVHRR observation frequency at Polar latitudes. Thus, we expect that the time-averaging of the products will also result in a sufficient sampling in the viewing and illumination angle domain to ensure that a representative mean value is formed. A detailed analysis of the angular sampling achievable is to be completed in the near future.

The narrow-to-broadband (NTB) conversion is performed following the algorithm by Xiong et al. (2002). The algorithm is as follows:

$$\alpha = 0.28(1 + 8.26\Gamma)\alpha_{RED} + 0.63(1 - 3.96\Gamma)\alpha_{NIR} + 0.22\Gamma - 0.009 \qquad (1)$$

Where

$$\Gamma = \frac{\alpha_{RED} - \alpha_{NIR}}{\alpha_{RED} + \alpha_{NIR}} \quad (2)$$

The term Γ accounts for ponding encountered on top of snow during melting season. Ponding is a significant source of albedo variation especially on the Arctic sea ice (Xiong et al., 2002).

Because the end user products of IA-SAL are the weekly and monthly means of surface albedo, it is necessary to normalize the instantaneous albedo images to a common solar illumination geometry (i.e. we need to account for the SZA dependence of surface albedo). The algorithm that performs the normalization is after the works of Dickinson (1983) and Briegleb et al. (1986). It may be written as

$$\alpha(\cos\theta_s) = \alpha_0 \frac{(1+d)}{(1+2d\cos\theta_s)} \quad (3)$$

Where α_0 is the albedo at 60 degrees SZA, θ_s is the SZA of the instantaneous albedo scene, and d is an empirically derived land cover type-specific coefficient. The values of d are derived from the work of NASA CERES/SARB group. For snow, d equals 0.1. It should be noted that there are references in the literature (Pirazzini, 2004) which suggest that this form of SZA dependence is not appropriate for snow. The issue will be discussed further in the results-section.

Datasets

The IA-SAL validation dataset consists of 1083 AVHRR images from NOAA-17, -18, and MetOp-A satellites. The time period covered is 12.6. – 15.7.2007. The full dataset under construction will cover the entire polar summer 2007 between June and August. The satellite data is validated in this data only on the instantaneous level; validation of the weekly and monthly data products will be performed as a routine part of the Climate-SAF annual validation exercises. The geographical locations of the reference datasets used in this study are shown in Figure 2.

The GCN validation reference dataset comes from the Summit research station located at 72.58 N, 38.50 W (3208 a.s.l). Summit station is a permanently manned research outpost, providing quality-controlled and continuous observations of local environmental conditions. Surface albedo observations are made at 1-hour intervals. The data are matched spatially by selecting the IA-SAL pixel containing the station; due to the relatively homogeneous nature of snow fields on the Greenland high plateau and negligible topography differences, the representativeness of a point measurement of surface albedo at station is assumed to be high. Temporal matching is performed by selecting the closest hourly *in situ* observation to each overpass, thus the maximum discrepancy is 30 minutes. Spectral matching is straightforward as the station albedo measurement matches IA-SAL waveband directly.

The Tara schooner expedition dataset serves as the albedo reference for Arctic sea ice. Tara sailed into the polar ice cap in 2006 and was allowed to drift with the ice. During polar summer 2007 it passed close to the North Pole, with the crew making continuous observations of the environment. The surface albedo measurements were made with an Eppley PSP precision pyranometer at 1 minute intervals. The temporal matching to AVHRR overpasses is therefore near-perfect. However, on the sea ice the spatial representativeness of a point-like albedo observation can be challenged. Sea ice topography changes often, exposing pure ice and causing large local shadowing effects with low SZAs. It may be expected, though, that the multi-year sea ice encountered by Tara during its close passing of the North Pole during summer 2007 should be more stable than the first-year ice found at lower latitudes. Spectral matching of the data is straightforward as the in situ pyranometer covers the same waveband as IA-SAL.

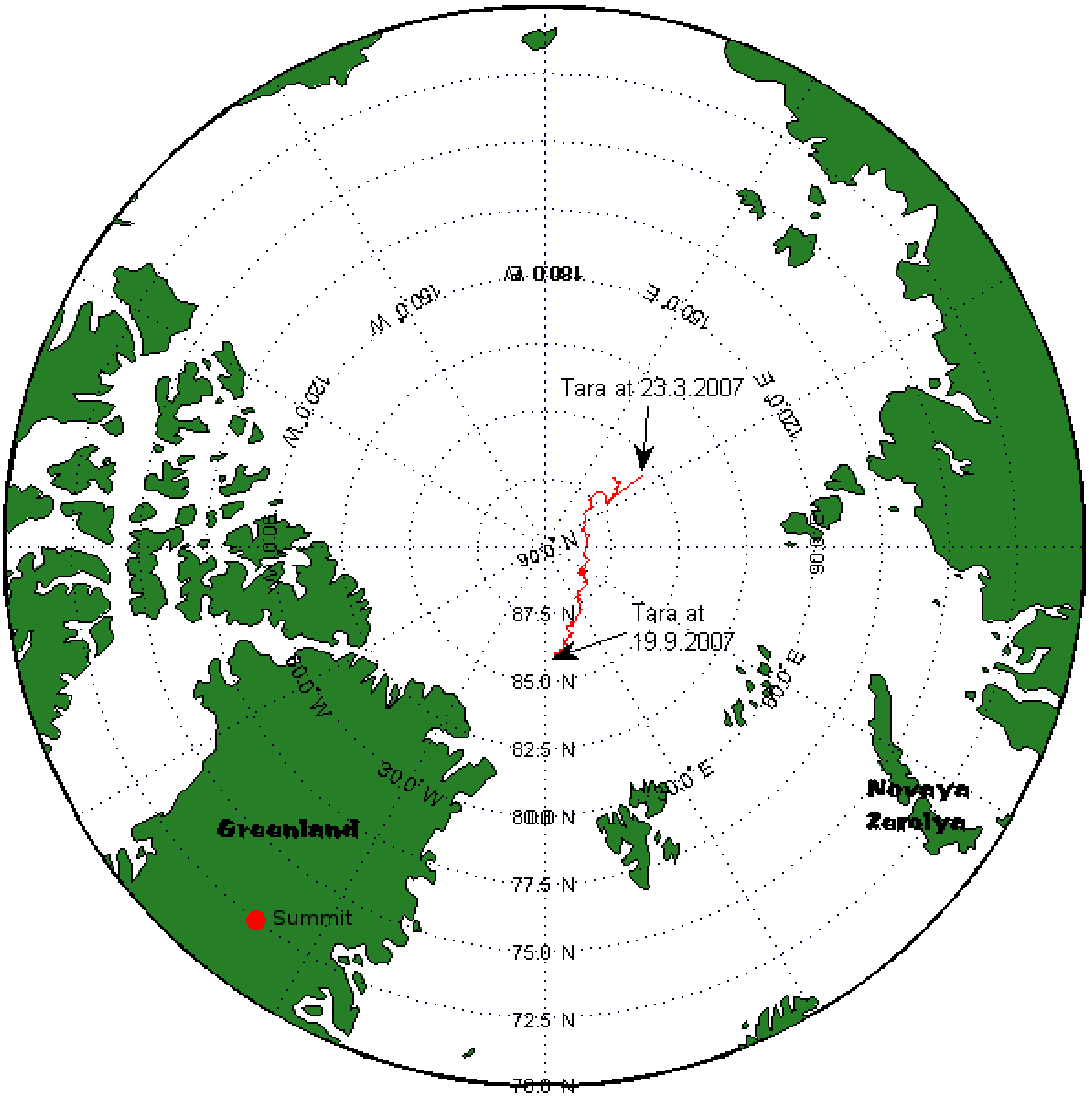

Figure 2: The locations of the reference datasets

All AVHRR overpass pixels are screened for cloud contamination using the PPS cloud mask. The cloud mask is further augmented with OSI-SAF sea ice extent data to correct any misclassifications over the ice cap. Any pixels suspected of cloud contamination are removed from the surface albedo processing. Thus, even though the IA-SAL is a “black sky” albedo product from which all diffuse radiation components are removed, we may still compare it to the “blue sky” in situ observations assuming that the diffuse radiation contribution is small enough to be ignored during fully clear sky conditions. The assumption will be tested more thoroughly in the full dataset analysis that is to follow in the near future.

Results & Discussion

The validation results for Summit station are shown in Figure 3. The overall match is quite good with RMSE of 0.056. As expected, the omitted BRDF correction leads to large variability in the individual albedo retrievals as the viewing and illumination geometry varies. However, there appears to be a balance between over- and underestimations so that the weekly mean would estimate the in situ observations closely.

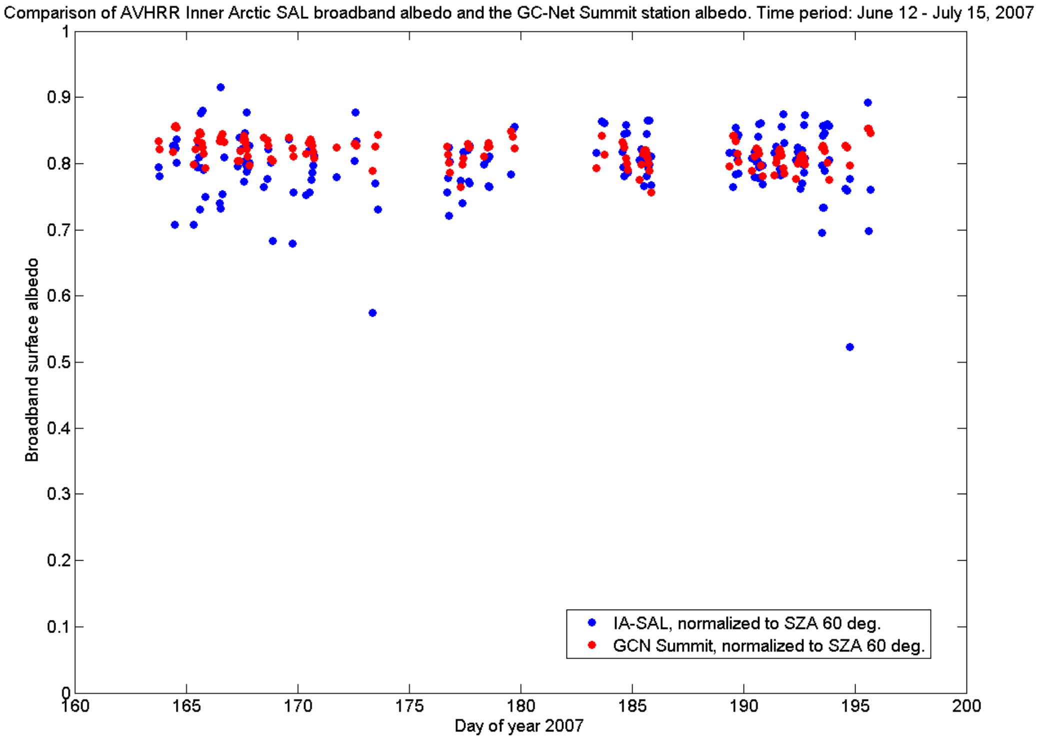

Figure 3: Validation results from the GCN Summit station. Red circles indicate GCN measurements, blue circles indicate IA-SAL retrievals. All data is normalized to SZA 60 degrees using the algorithm (3).

The surface albedo at Summit station is remarkably stable during this time period. Due to its height and location, Summit experiences no significant snow melt during the early and middle summer, keeping the surface albedo nearly static. The diurnal cycle of snow albedo is present; the snow albedo falls linearly as the day progresses due to snow metamorphism. This supports earlier findings of Pirazzini et al. (2008) for Antarctic snow.

The validation results for Tara are shown in Figure 4. The match remains acceptable with RMSE of 0.053. However, here we see that the dynamic range of surface albedo in the IA-SAL data appears smaller than in *in situ* observations. The reason may be the limited spatial representativeness of a point-like in situ observation when compared to a kilometer-scale area observed by AVHRR. For example, winds may affect the immediate snow cover around the in situ pyranometer, changing the in situ observation while the coarse resolution AVHRR remains insensitive to such small-scale changes. Nevertheless, IA-SAL is clearly able to follow the general trend of the snow-covered sea ice albedo to diminish as the summer progresses and snow ages.

All datasets have been normalized using (3) for clarity. However, study of the unnormalized in-situ and satellite albedo data shows that the method is not advisable for snow-covered surfaces, because the correction factor depends only on cos(SZA). For snow, as shown by Pirazzini (2004) in Antarctica as well as Pirazzini et al. (2006) over Baltic sea ice, there is a temporal dependency in clear-sky snow albedo resulting from increasing snow metamorphism from the morning towards afternoon. Symmetrical SZA dependency corrections such as (3) do not account for this effect. The authors of this study are aware of the effect on IA-SAL and are currently researching improved means of SZA normalization for snow.

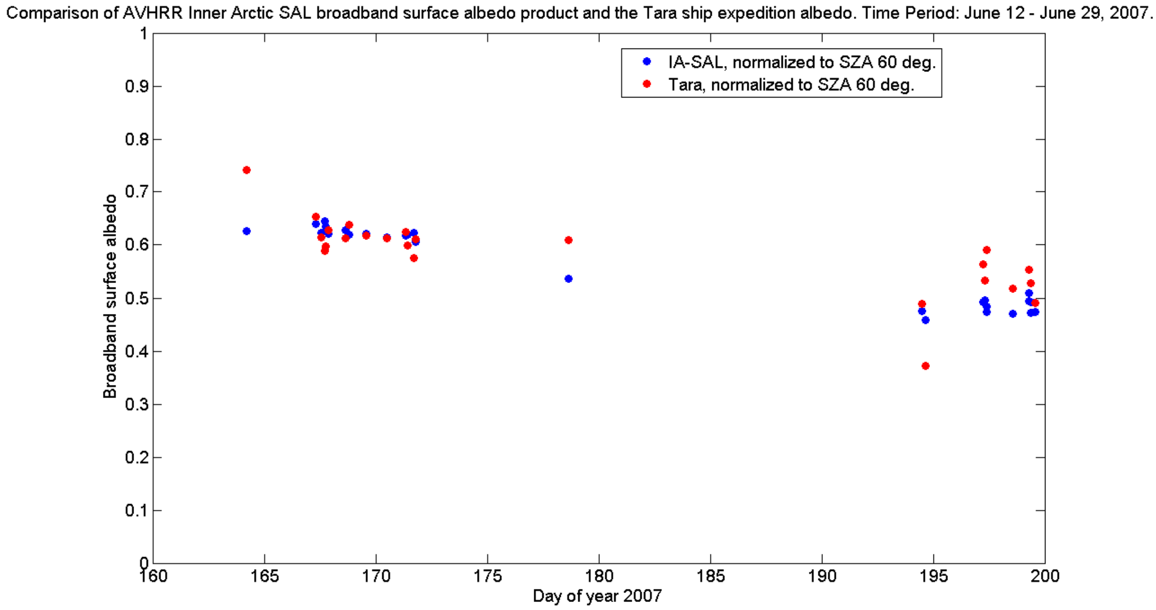

Figure 4: Validation results from the Tara drifting ice station. Red circles indicate Tara measurements, blue circles indicate IA-SAL retrievals. All data is normalized to SZA 60 degrees using the algorithm (3).

Uncertainty analysis

The GCN user guide states that the expected retrieval error for solar radiation measurements is 5-15% relative (GCN, 2001). The Tara observations were made with a precision pyranometer, thus the expected retrieval error is 3% relative (T. Vihma, personal communication). The uncertainty of retrieval for SAL is a sum of uncertainties in various stages of processing. The atmospheric correction uncertainty is estimated to be 5% relative, mainly due to the static AOD value of 0.1. The reader should note, however, that in situ observations of AOD over Greenland place the obtained values between 0.05 and 0.1. Therefore the actual retrieval error is likely smaller than 5%. The uncertainty of the NTB conversion is reported to be no more than 10% relative. Omitted BRDF correction introduces an estimated uncertainty of 10% relative (Xiong et al., 2002). All told, the total uncertainty of IA-SAL albedo retrieval is 25% relative. But as we plot the relative accuracy of retrieval in Figure 5, we find that the retrieval error is much less on average. Here the retrieval error is defined as

$$\delta = \frac{|\alpha_{INSITU} - \alpha_{IA-SAL}|}{|\alpha_{INSITU}|} * 100\% \qquad (4)$$

As figure 5 shows, the average retrieval error of IA-SAL is 4.98% at Summit and 7.16% at Tara. The outliers in the Summit dataset at days 173 and 194 are misclassified clouds.

Conclusions

We have introduced the new Inner Arctic Surface Albedo (IA-SAL) product of EUMETSAT's Climate-SAF project and some early validation results. The validation was carried out against the Greenland Climate Network's Summit station albedo observations as well as albedo observations gathered during the Tara schooner expedition during Polar summer 2007. The satellite dataset is culled to eliminate all detectable cloud contamination conditions as well as conditions where the illumination or viewing geometry is unfavorable.

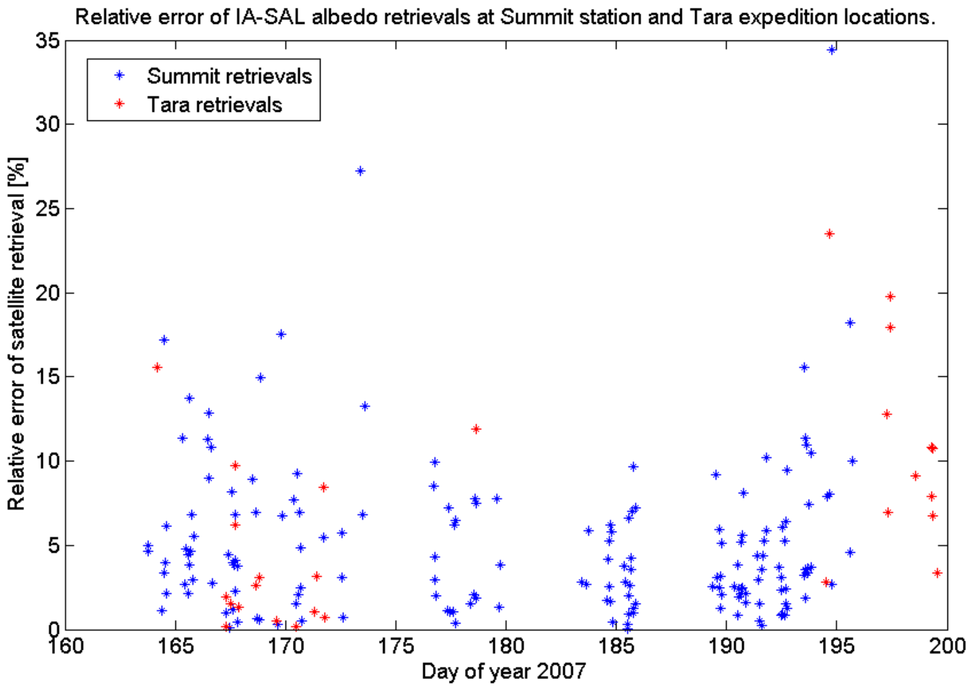

Figure 5: Relative error of IA-SAL retrieval versus in-situ observation. Blue stars indicate retrievals at Summit station, red stars indicate retrievals at Tara.

The validation exercise here using the partial AVHRR dataset yielded 170 temporally and spatially matched data points at Summit station and 28 at Tara. The lower data amount at Tara is simply due to the predominantly overcast conditions over the high latitudes of the Arctic ocean. The results showed that IA-SAL generally achieves a relative retrieval accuracy better than 10%. This study was limited to only studying the instantaneous albedo retrievals, referring the weekly and monthly mean analysis to the future. It is expected that the weekly and monthly means would yield higher accuracies than the instantaneous retrievals, since the under- and overestimations resulting from the omitted BRDF correction would begin to cancel each other out in a temporal means product.

Future work on the algorithm and its validation will focus on a) performing the validation with the full AVHRR dataset and a wider array of GCN in-situ locations, b) studying the possibilities for the generation of a robust snow BRDF model and c) studying alternatives to the current SZA normalization scheme, which has been found insufficient during this exercise.

Acknowledgments

This work was financially supported by the CM-SAF project of EUMETSAT. The authors are grateful to Jaak Jaagus, Erko Jakobson and Timo Palo of Tartu University and Timo Vihma of FMI for the Tara reference dataset, and prof. Konrad Steffen of CIRES and his research group for the GCN dataset. Thanks also to CM-SAF operations team for IA-SAL preprocessing.

References

Box, J., Steffen, K. (2000) Greenland Climate Network (GC-NET) Data reference. Available from cires.colorado.edu/science/groups/steffen/gcnet/ [Accessed 6.11.2009].

Breivik, L.-A., Eastwood, S., Godøy, Ø., Schyberg, H., Andersen, S., Tonboe, R. (2001). Sea ice products for EUMETSAT satellite application facility. Canadian Journal of Remote Sensing, **27** (5), 403-410.

Briegleb, B., Minnis, P., Ramanathan, V., Harrison, E. (1986) Comparison of regional clear-sky albedos inferred from satellite observations and model computations. Journal of Climate and Applied Meteorology, **25**, 214-226.

Dickinson, R. E. (1983) Land surfaces processes and climate - surface albedos and energy balance. Advances in Geophysics, **25**, 305-353.

Dybbroe, A., Thoss, A., Karlsson, K.-G. (2005) SAFNWC AVHRR cloud detection and analysis using dynamic thresholds and radiative transfer modelling part I: Algorithm description. Journal of Applied Meteorology, **44**, 39-54.

Hall, A., Qu, X. (2006) Using the current seasonal cycle to constrain snow albedo feedback in future climate change. Geophysical Research Letters, **33**, doi:10.1029/2005GL025127

Holland, M. M., Bitz, C. (2003) Polar amplification of climate change in coupled models. Climate Dynamics, **21**, 221-232.

Knap, W. H., Oerlemans, J. (1996) The surface albedo of the greenland ice sheet: satellite-derived and in situ measurements in the søndre strømfjord area during the 1991 melt season. Journal of Glaciology, **42** (141), 364-374.

Laine, V. (2004). Arctic sea ice regional albedo variability and trends, 1982-1998. Journal of Geophysical Research, **109**, C06027, doi:10.1029/2003JC001818.

Liang, S., Stroeve, J., Box, J. E. (2005) Mapping daily snow/ice shortwave broadband albedo from moderate resolution imaging spectroradiometer (MODIS): The improved direct retrieval algorithm and validation with greenland in situ measurement. Journal of Geophysical Research, **100** (D10109), doi:10.1029/2004JD005493.

Lindsay, R. W., Rothrock, D. (1994) Arctic sea ice albedo from AVHRR. Journal of Climate, **7**, 1737-1749.

Pirazzini, R. (2004) Surface albedo measurements over Antarctic sites in summer. Journal of Geophysical Research, **109**, D20118.

Pirazzini, R., Vihma, T., Granskog, M.A., Cheng, B. (2006) Surface albedo measurements over sea ice in the Baltic Sea during the spring snowmelt period. Annals of Glaciology, **44**, 7-14.

Rahman, H., Dedieu, G. (1994) SMAC: a simplified method for the atmospheric correction of satellite measurements in the solar spectrum. International Journal of Remote Sensing, **15**.

Steffen, K., Box, J., Abdalati, W. (1996) Greenland Climate Network: GC-Net. CRREL 96-27 Special Report on Glaciers, Ice Sheets and Volcanoes, tribute to M. Meier, **1996**, 98-103.

Stroeve, J. (2001) Assessment of greenland albedo variability from the advanced very high resolution radiometer polar pathfinder data set. Journal of Geophysical Research, **106** (D24), 33989-34006.

Stroeve, J., Nolin, A., Steffen, K. (1997) Comparison of AVHRR-derived and in situ surface albedo over the greenland ice sheet. Remote Sensing of Environment, **62**, 262-276.

Stroeve, J. C., Box, J. E., Haran, T. (2006) Evaluation of the MODIS (MOD10A1) daily snow product over the greenland ice sheet. Remote Sensing of Environment, **105**, 155-171.

Vihma, T., Jaagus, J., Jakobson, E., Palo, T. (2008) Metorological conditions in the Arctic Ocean in spring and summer 2007 as recorded on the drifting ice station Tara. Geophysical Research Letters, **35**, L18706

Xiong, X., Stamnes, K., Lubin, D. (2002) Surface albedo over the arctic ocean derived from AVHRR and its validation with SHEBA data. Journal of Applied Meteorology, **41**, 413-425.