AVHRR BASED BLUE, BLACK AND WHITE SKY ALBEDO VALUES FOR CLARA-A3 SAL

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Abstract

The next polar radiation parameter data record of CM SAF, CLARA-A3, will contain besides the black-sky albedo also the white-sky and blue-sky albedo values. This study presents the methods to be used in calculating them. A new snow-covered terrain white-sky albedo retrieval method is developed based on *in situ*, mainly BSRN, radiation data. The mean absolute deviation of the estimated snow-covered terrain white-sky albedo from the empirical one was 0.027 with a standard deviation of 0.023. Example maps of white-sky and black-sky albedo difference are shown for the Antarctic and the Arctic.

INTRODUCTION

The black-sky surface albedo (α_{black}) data record CLARA-A2 SAL covers the years 1982-2015 and is based on homogenized AVHRR data. It has been developed in CM SAF project, which is financially supported by EUMETSAT. The retrieved albedo is defined to wavelength range 0.25 -2.5 µm and the observations are averaged to 0.25° grid. In the next version of the SAL product, CLARA-A3 SAL, also the blue (α_{blue}) and white-sky albedo (α_{white}) values will be provided for the same time range and grid as α_{black}.

Only clear sky pixels are used for α_{black} retrieval. The top of atmosphere reflectance values of AVHRR are corrected for the aerosol optical depth (AOD), water vapour and ozone in order to get the surface reflectance values using the SMAC code (Rahman and Dedieu, 1994; Proud et al., 2010). The atmospheric paths are corrected both in the direction to the sun and the satellite, so that the effect of the atmosphere is completely removed from the albedo retrieval. The calculation of the atmospheric correction produces also an estimate of the diffuse radiation component (Tanré et al., 1990; Rahman et al., 1993). In order to get α_{blue}, one has to remove only the atmospheric effect of the path to the direction of the satellite. Theoretically α_{blue} is defined as the weighted average of α_{black} and α_{white} values (Pinty et al., 2005; Schaepman-Strub et al., 2006):

$$\alpha_{blue} = (1 - f_{diff})\alpha_{black} + f_{diff}\alpha_{white} \tag{1}$$

where f_{diff} denotes the fraction of the diffuse incoming radiation. In principle, one could derive α_{white} using Eq. 1 on the basis of the α_{black} and α_{blue} values and f_{diff}, which may be calculated during the atmospheric correction. However, the theoretical f_{diff} of Eq. 1 is assumed to be completely isotropic, which may not be the case in realistic clear sky conditions. Then α_{blue} value obtained from such data would not be the theoretical one of Eq. 1. In fact, deviations of several percent are possible, when the solar zenith angle value θ_z is large, even for optically thin atmosphere (Pinty et al., 2005). In addition, f_{diff} is always small in clear sky cases, which would lead into high uncertainty values of α_{white} values derived using Eq. 1. If the bidirectional reflectance distribution function (BRDF) could be modelled reliably, α_{white} could be derived as an integral of α_{black} over the hemisphere (Schaepman-Strub et al., 2006). Unfortunately, the BRDF of snow is varies in a wide range from dominantly forward scattering to essentially backward scattering and almost isotropic

(Peltoniemi et al., 2010). In addition, mostly snow cover tends to be located in areas, where the sun elevation is low. Hence, the values of α_{black} available for the integral do not cover the whole θ_z range 0 … π/2 needed for the integral, but only a subsection of relatively large zenith angle values. Extrapolation of the numerical integral might cause large uncertainty to the obtained value of α_{white}. For the above mentioned reasons, α_{blue} and α_{white} values are not derived from the satellite data only, but statistical methods based on large amounts of in situ measurements are applied.

MATERIAL AND METHODS

For snow-free land cover classes the relationship between the direct (i.e. α_{black}) and diffuse (i.e. α_{white}) albedo values has been presented by Yang et al. (2008). Their relationship is parametrised with the solar zenith angle value:

$$\alpha_{white} = \frac{1+1.48\cos\theta_z}{2.14}\alpha_{black} \tag{2}$$

For sea ice the following relationship between α_{blue} and α_{black} is utilized (Key et al., 2001):

$$\alpha_{blue} = -0.0491243 + 1.06756\alpha_{black} + 0.0217075\ln(\tau+1) + 0.0179505\ \cos\theta_z \tag{3}$$

where τ is the cloud visible optical depth (unitless). The formula is applicable in the range 1 < τ < 50. Since the satellite based surface albedo retrieval is reasonable only when τ < 1, the above formula is used only for α_{white} retrieval, taking then $\tau = 45$. The ocean α_{white} presented by Jin et al. (2011) will be used for CLARA-A3-SAL and is not discussed here in detail.

For snow-covered terrain the relationship between α_{black} and α_{white} values was analyzed similarly using *in situ* measurements available via the BSRN network (König-Langlo et al., 2013; Table 1). In addition, FMI measurements at Sodankylä were included to have more seasonal snow cases in the analysis. A subset of the whole amount of data was used by requiring that 1) all needed fluxes are measured simultaneously, 2) the solar zenith angle is at least 70°, 3) the empirical α_{blue} exceeds 0.4 (except in Sodankylä 0.25) and 4) at least 50 cases per month meet the preceding three conditions.

First the upward flux $F^{\uparrow}_{dir}$ associated with the downward direct-beam flux was calculated (Yang et al., 2008)

$$F^{\uparrow}_{dir} = F^{\uparrow}_{total} - \alpha_{white} f_{diff} F^{\downarrow}_{total} \tag{4}$$

where $F^{\downarrow}_{total}$ is the global downward shortwave (SW) flux and $F^{\uparrow}_{total}$ is the reflected upward SW flux available in the *in situ* measurements. When the diffuse downward SW flux $F^{\downarrow}_{diff}$ is provided, f_{diff} is calculated as the ratio $f_{diff} = F^{\downarrow}_{diff}/F^{\downarrow}_{total}$ otherwise it is calculated as $f_{diff} = F^{\uparrow}_{total} - \cos\theta_z F^{\downarrow}_{dir}$, where $F^{\downarrow}_{dir}$ is the measured direct downward SW flux. The threshold for white-sky case was f_{diff} = 0.98 (Yang et al., 2008). For larger values of f_{diff} than that the reflected upward flux was considered to equal the diffuse upwards flux so that α_{white} was then the ratio of $F^{\uparrow}_{total}$ and $F^{\downarrow}_{total}$. In order to take into account the seasonal variation of α_{white}, a periodical relationship $\alpha_{white} = \alpha_{white0} - c_0\cos(t - t_0)$ was fitted to the empirical cloudy condition fluxes. Here α_{white0} is a reference value of α_{white} (the mean value of the brightest month), t is time and c_0 and t_0 are nonlinear regression parameters. The inverse of the number of data points per month was used as regression weights. Finally, using Eq. 4 α_{black} is derived as the ratio of $F^{\uparrow}_{dir}$ and $F^{\downarrow}_{dir}$. Finally, α_{blue} is derived both in snow-covered, sea ice and snow-free cases applying Eq. 1. The pentad α_{white} is then taken to depend similarly as α_{black} on the corresponding monthly value. Individual CLARA-A2-SAL products of December and June 2015 were used for demonstrating the areal α_{white} in the Antarctic and the Arctic, respectively.

In situ site	Distribution	Latitude	Longitude	Time range	Maximum θ_z
ALE	BSRN	82.4900°	-62.4200°	2004-2014	59.1°
DOM	BSRN	-75.1000°	123.3830°	2006-2015	51.7°
FPE	BSRN	48.3167°	-105.1000°	1995-2017	30.9°
NYA	BSRN	78.9250°	11.9300°	1992-2016	55.5°
Sodankylä	FMI	67.3666°	26.6290°	2013-2017, April-May	47.8°
SPO	BSRN	-89.9830°	-24.7990°	1992-2016	66.5°
SYO	BSRN	-69.0050°	39.5890°	1994-2015	45.7°

Table 1. In situ **data used for deriving a statistical relationship between the α_{black} and α_{white} for snow covered areas (König-Langlo et al., 2013; ALE: Cox 2012-2014, Halliwell 2004-2011; DOM: Lanconelli 2006-2014, Lupi 2011-2015, Vitale 2006-2014; FPE: Augustine 2002-2017, Deluisi 1995-2002; NYA: Herber 1992-2006, Maturilli 206-2016; SPO: Dutton 1992-2009, Long 2015-2016, Michalsky 2010 2014; SYO: Doi 2010, Fukuda 2013-2015, Kawashima 2011-2013, Yamanouchi 1994-2010; Sodankylä: FMI operational observations).**

RESULTS

Distributions of α_{black} and α_{white} are shown for the Sodankylä *in situ* site in Figure 1, for the Arctic BSRN *in situ* sites in Figure 2 and for the Antarctic BSRN *in situ* sites in Figure 3 and. The mean values of the distribution descriptors are given in Table 2.The distribution bin width is adapted to the data in questions so that direct comparison of peak heights and widths is not reasonable. The width of the distribution is revealed by the mean and standard deviation lines. In SPO they practically coincide for α_{white}, whereas in NYA α_{white} varies about 10%. Naturally, the α_{black} distributions are broader. The difference between the mean and median value can also be large for α_{black}, although sometimes they coincide, like in DOM and SYO. The mean values of α_{black} and α_{white} tend to deviate from each other more than the corresponding median values.

In situ site	$\overline{\alpha_{white}}$	$\widetilde{\alpha_{white}}$	σ_{white}	γ_{1white}	β_{2white}	$\overline{\alpha_{black}}$	$\widetilde{\alpha_{black}}$	σ_{black}	γ_{1black}	β_{2black}	$\overline{\theta_z}$
ALE	0.81	0.81	0.006	-0.20	3.83	0.78	0.79	0.08	-1.66	21.6	65.8°
DOM	0.84	0.84	0.001	0.48	2.27	0.78	0.78	0.04	-0.22	9.06	63.6°
FPE	0.74	0.74	0.003	0.17	5.36	0.69	0.69	0.09	-0.14	3.98	62.0°
NYA	0.74	0.74	0.008	0.09	2.38	0.67	0.66	0.09	0.73	4.41	64.4°
Sodankylä	0.69	0.69	0.005	0.43	2.03	0.61	0.63	0.13	-0.27	3.15	60.3°
SPO	0.87	0.87	0.0001	0.13	1.91	0.81	0.82	0.04	-2.72	18.0	68.1°
SYO	0.77	0.77	0.003	0.18	2.19	0.76	0.77	0.09	-0.91	6.56	59.3°

Table 2. **Mean values of the *in situ* data distribution descriptors of α_{white} and α_{black} (*Table 1*). The mean of θ_z is given as well.**

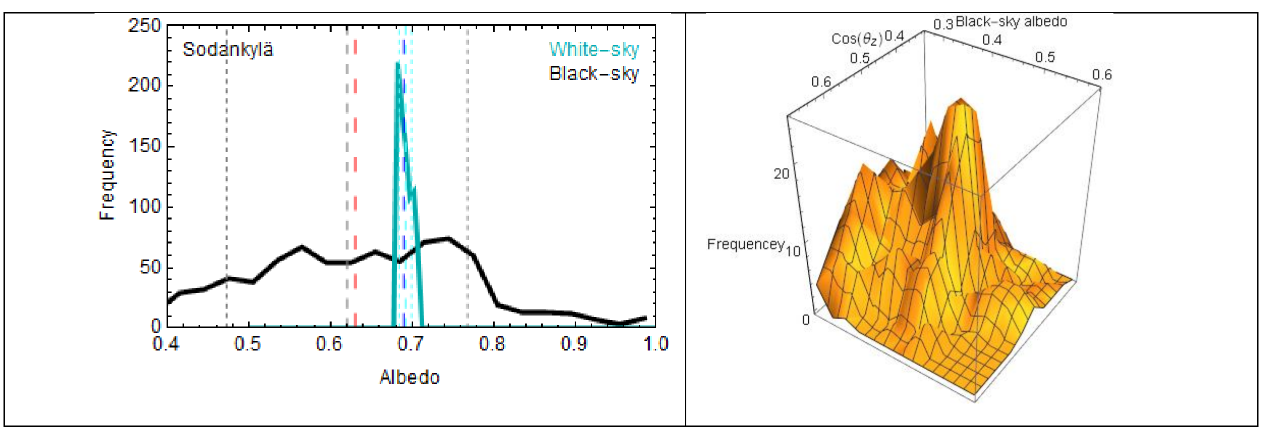

Figure 1. **α_{white} and α_{black} distributions (left) and combined α_{black} and $\cos(\theta_z)$ distribution (right) at the Sodankylä *in situ* site.The mean values of α_{white} and α_{black} distributions are shown (dashed) and the corresponding standard deviations from the mean (dotted) are shown as well. In addition, the median values are in blue and red dashing, respectively (Table 1).**

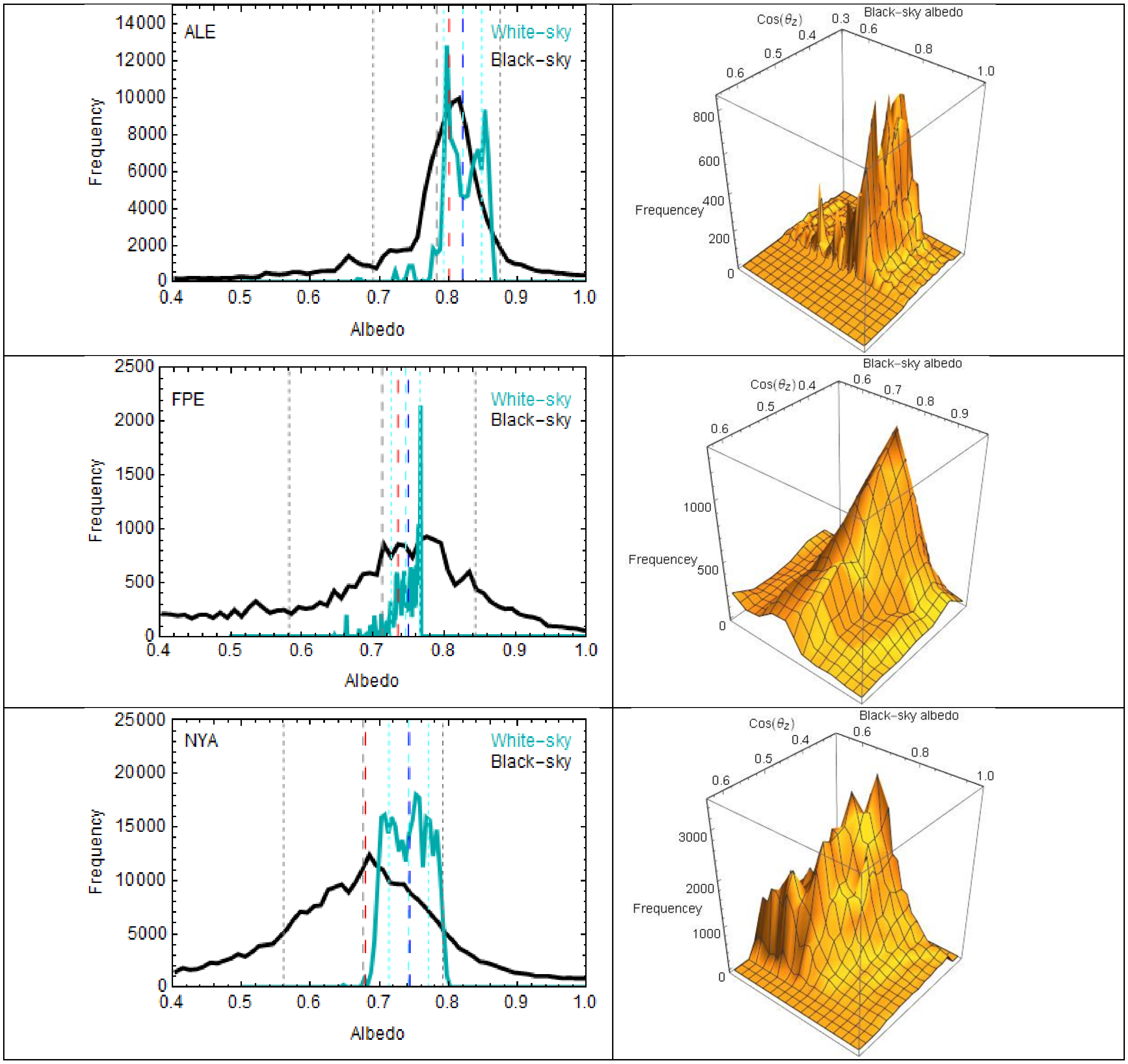

Figure 2. **α_{white} and α_{black} distributions (left) and combined α_{black} and cos(θ_z) distribution (right) at the Arctic *in situ* sites.The mean values of α_{white} and α_{black} distributions are shown (dashed) and the corresponding standard deviations from the mean (dotted) are shown as well. In addition, the median values are shown in blue and red dashing, respectively (Table 1).**

Obviously the variation in the α_{black} value is smallest in the coldest Antarctic sites (SPO, DOM) and largest in late melting season (Sodankylä), as expected. The skewness of α_{black} and α_{white} distributions is mostly opposite. α_{white} distributions are more flat than the normal distributions (i.e. β_{2white} < 3), except for ALE and FPE. On the contrary α_{black} distributions are all more peaked than the normal distributions (i.e. β_{2black} > 3).

It turned out that for individual sites it was possible to derive a relatively good relationship between α_{black} and α_{white} like in Eq. 2. However, generalization of the individual relationships was not successful, because the properties of snow vary in such a wide range and the relationship between α_{black} and α_{white} is not similar everywhere. In fact, in the coldest sites (DOM, SPO) α_{white} is practically independent of α_{black} and its value

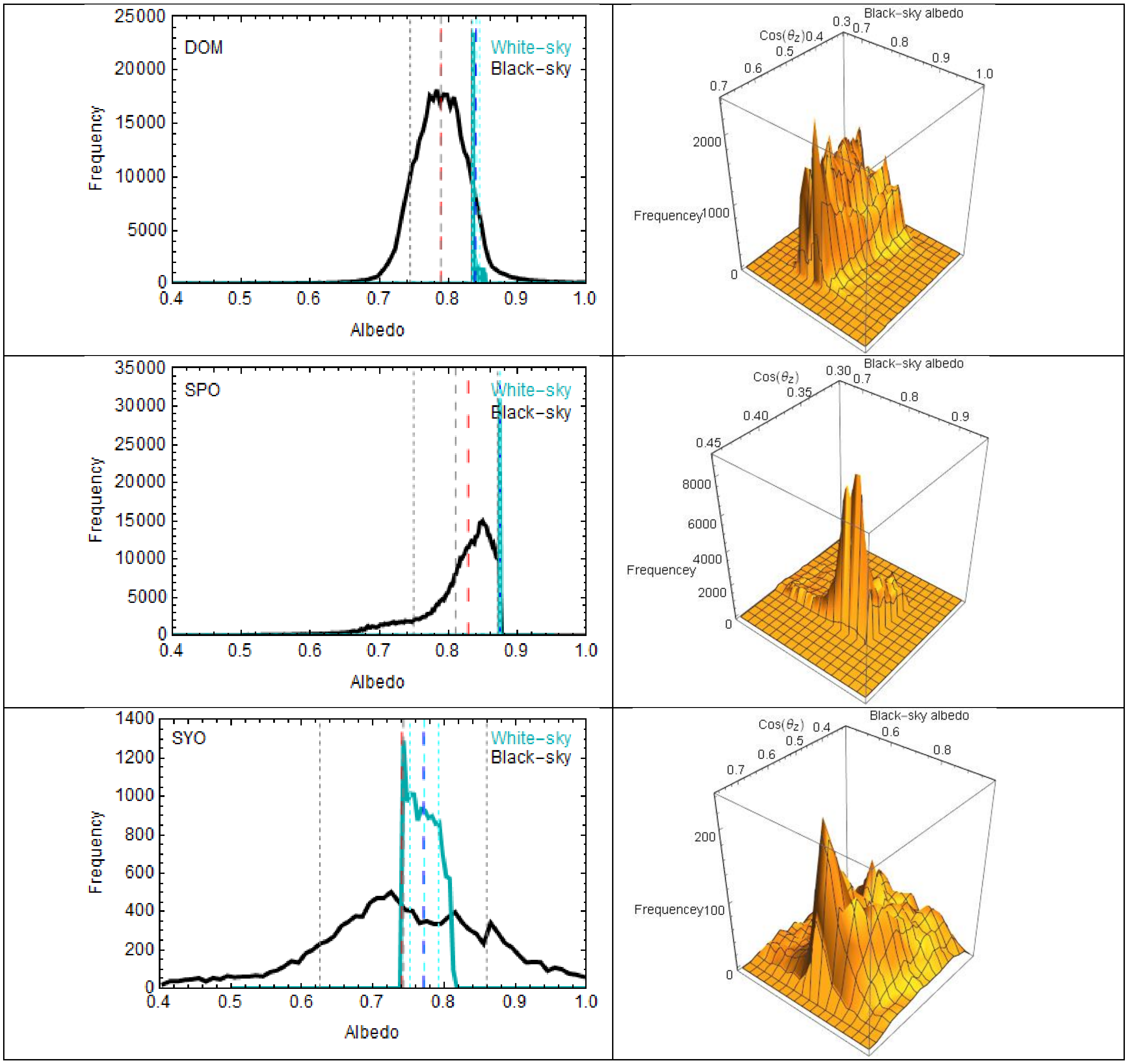

Figure 3. **α_{white} and α_{black} distributions (left) and combined α_{black} and cos(θ_z) distribution (right) at the Antarctic *in situ* sites. The mean values of α_{white} and α_{black} distributions are shown (dashed) and the corresponding standard deviations from the mean (dotted) are shown as well. In addition, the median values are shown in blue and red dashing, respectively (Table 1).**

is clearly higher than in the other sites, except a few cases in ALE (Figure 4). Hence, a distribution based approach between α_{black} and α_{white} was sought for using θ_z value as an additional parameter. Descriptors of the distribution used were the mean, median, standard deviation, skewness and kurtosis.

The data set contains only relatively to large values of θ_z, (> 44°), but the formula to be derived will be applied also to smaller values of θ_z. Using cos(θ_z) as a parameter would be more risky than θ_z, because the large θ_z values correspond to the dynamic part of the cosine curve and smaller cosine values. Hence, extrapolation of the relationship between α_{black} and α_{white} to smaller values of θ_z might lead to overly large differences. For this reason the relationship is sought using directly the θ_z value. In addition, α_{white} is presented by introducing a correction factor to α_{black}, and the correction factor has the form θ_z(…) so that it decreases from the poles to the equators, where α_{white} coincides with α_{black}, which is a reasonable estimate for α_{white}, if a better one is not known. Thus, the risk of the extrapolating the use of the correction factor from the latitudes it was derived for automatically decreases. The following statistical relationship between monthly mean white-sky albedo $\overline{\alpha_{white}}$ and the monthly mean black-sky albedo $\overline{\alpha_{black}}$ was obtained:

$$\overline{\alpha_{white}} = \overline{\alpha_{black}}[1 + \overline{\theta_z}(1.003 + 0.128\,\overline{\theta_z} - 1.390\,\overline{\alpha_{black}} + 0.0341\widetilde{\alpha_{black}} - 0.998\,\sigma_{black} - 0.0155\,\gamma_{1black} - 0.000625\,\beta_{2black})] \quad (5)$$

where $\widetilde{\alpha_{black}}$ refers to the median, σ_{black} to the standard deviation, γ_{1black} to the skewness and β_{2black} to the kurtosis of the black-sky albedo monthly distribution and $\overline{\theta_z}$ is the monthly mean of the solar zenith angle values in radians.

The mean difference between empirical α_{white} and α_{white} estimated using Eq. 5 was 0.027. The corresponding standard deviation and median value were 0.023 and 0.022, respectively. Comparison of the estimated and empirical α_{white} values is shown in Figure 4. Taking into account that the relationship between α_{black} and α_{white} is very weak, this estimation uncertainty can be considered reasonable. Examples of the α_{white} values were calculated using Eqs. 2, 3 and 5 and existing satellite based α_{black} data of CLARA-A2-SAL for the Antarctic in December 2015 and for the Arctic in June 2015. As expected, the monthly mean α_{white} mostly exceeds the monthly mean α_{black}. The methods of Eqs. 2, 3 and 5 will also be applied in calculating the CLARA-A3-SAL α_{white} values.

CONCLUSIONS

Estimating white-sky albedo values is divided in four classes: snow-free terrain, snow-covered terrain, sea ice and open water. Methods for the first three classes were presented in this study and the fourth is available by Jin et al., (2011). The relationship between the white-sky and black-sky albedo values is weak for snow covered-terrain, but a method for estimating the monthly mean white-sky albedo on the basis of various black-sky albedo monthly distribution parameters and the solar zenith angle monthly mean is presented. The deviation of the white-sky albedo estimate from empirical values of six BSRN *in situ* sites and the Sodankylä *in situ* site of FMI was on the average 0.027, the standard deviation being 0.023.

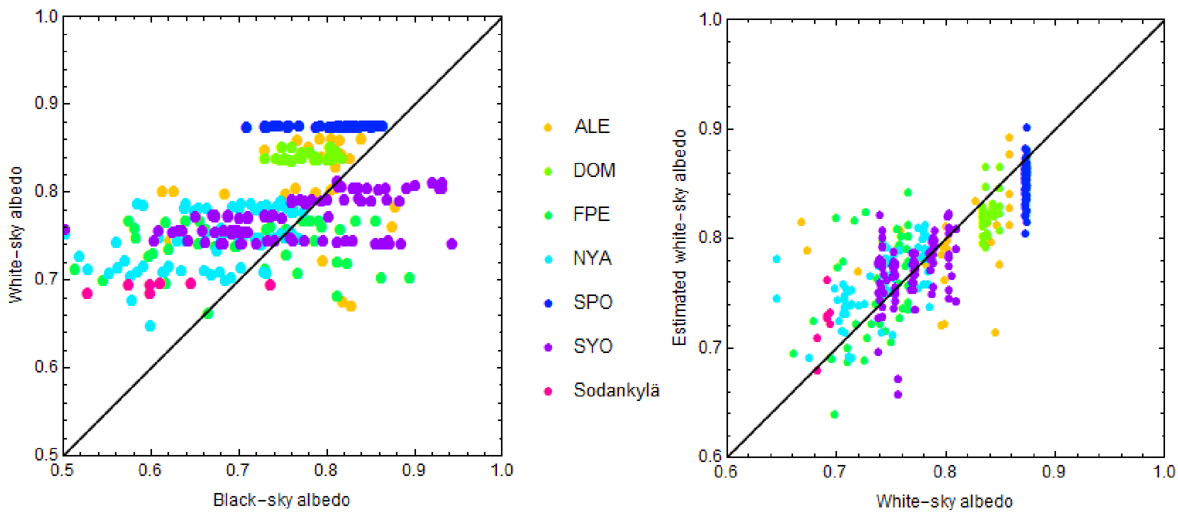

Figure 4. **Monthly mean empirical value of α_{white} vs. monthly mean empirical value of α_{white} at the test sites (left) and Estimated monthly mean α_{white} based on Eq. 5 vs. monthly mean empirical value of α_{white} (right).**

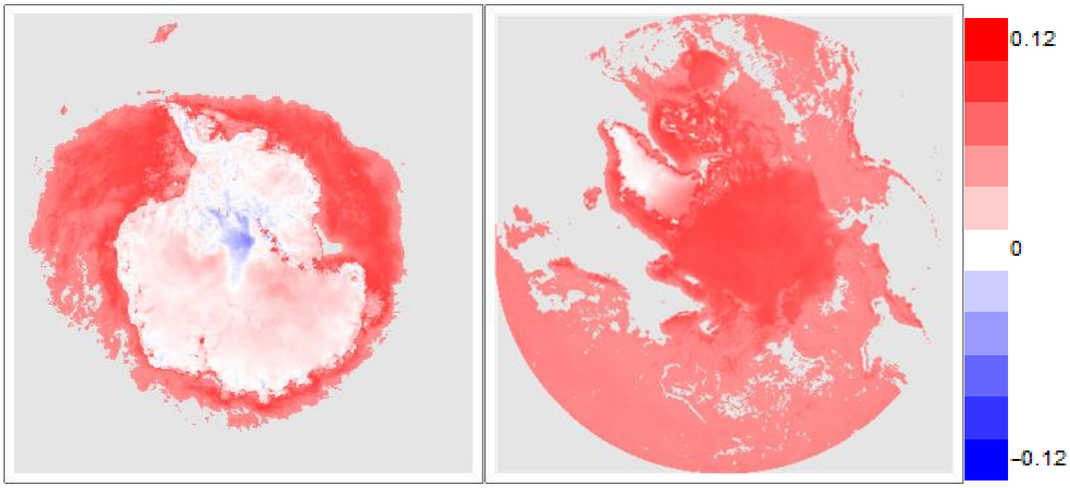

Figure 5. Difference of the monthly mean α_{white} - α_{black} estimates based on Eqs. 2, 3 and 5 for December 2015 in the Antarctic (left) and June 2015 in the Arctic (right).

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