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SHORT NOTE

Giacomo TRAVERSA [1,2*] & Davide FUGAZZA [2]

EVALUATION OF ANISOTROPIC CORRECTION FACTORS FOR THE CALCULATION OF LANDSAT 8 OLI ALBEDO ON THE ICE SHEETS

Abstract: Traversa G. & Fugazza D., *Evaluation of anisotropic correction factors for the calculation of Landsat 8 OLI albedo on the ice sheets.* (IT ISSN 0391-9838, 2021).

The calculation of ice and snow albedo on the ice sheets from remote sensing has always been an important objective in climate research, especially at a high spatial resolution. In this study, a model of albedo retrieval based on Landsat 8 OLI satellite data is validated by comparing ground observations from Antarctica and Greenland, with a particular focus on the anisotropic correction of satellite data. Different correction factors for the anisotropy of snow and ice were considered, as well as two different conversion formulas from narrowband to broadband albedo. Our findings point out that existing anisotropic-correction models are unable to adequately account for albedo variations at high solar zenith angles, which is a relevant factor in Greenland and especially in Antarctica. Thus, the present study suggests that the anisotropic correction may be omitted when calculating ice and snow albedo on the ice sheets, as on average worse statistics were found when using the correction.

Key words: Albedo, Landsat, Antarctica, Greenland, Anisotropy.

Riassunto: Traversa G. & Fugazza D., *Valutazione dei Fattori di Correzione Anisotropa per il calcolo dell'albedo da Landsat 8 OLI sulle Calotte di Ghiaccio.* (IT ISSN 0391-9838, 2021).

Il calcolo dell'albedo di ghiaccio e neve sulle calotte glaciali tramite telerilevamento è sempre stato un obiettivo importante nella ricerca sulle variazioni climatiche, soprattutto ad alta risoluzione spaziale. In questo studio, un modello di albedo basato sui dati del satellite Landsat 8 OLI viene convalidato confrontando le misurazioni al suolo in Antartide e Groenlandia, con un focus particolare sulla correzione anisotropa dei dati satellitari. Sono stati considerati diversi fattori di correzione per l'anisotropia di neve e ghiaccio, nonché due diverse formule di conversione da albedo *narrowband* a *broadband*. I nostri risultati sottolineano che i modelli di correzione anisotropa esistenti non sono in grado di spiegare adeguatamente le variazioni dell'albedo ad alti angoli dello zenit solare, che risulta essere un fattore importante in Groenlandia e, soprattutto, in Antartide. Pertanto, questo studio suggerisce che la correzione anisotropa può essere omessa quando si calcola l'albedo di ghiaccio e neve sulle calotte glaciali, poiché mediamente si ottengono risultati peggiori quando tale correzione viene applicata

Termini chiave: Albedo, Landsat, Antartide, Groenlandia, Anisotropia.

INTRODUCTION

On the Antarctic Ice Sheet (AIS) and Greenland Ice Sheet (GrIS), where snow is the main type of surface, the albedo (or bi-hemispherical reflectance, Schaepman-Strub & *alii,* 2006) has an important impact on the surface energy balance. Specifically, in the polar regions, the albedo depends on various factors, i.e., snow metamorphism (Grenfell & Warren, 1994; Gay & *alii*, 2002; Warren & *alii*, 2006; Gallet & *alii*, 2011), snow density and stratigraphy and snow roughness, owed to the presence of different peculiar morphologies and surfaces (e.g., sastrugi, glazed snow, blue ice) (Bintanja, 1999; Frezzotti & *alii*, 2002; Scambos & *alii*, 2012; Traversa & *alii*, 2021a, 2022). Additionally, the rate of snow metamorphism is affected by temperature, relative humidity, wind and the overburden pressure (Pirazzini, 2004; Picard & *alii*, 2012; van Kampenhout & *alii*, 2017). While field campaigns for albedo acquisition using e.g., Automatic Weather Stations (AWSs) require a relevant logistic economical effort for Antarctica and Greenland, the calculation of this variable from remote sensing allows covering large areas and can exploit free imagery. Thus, this work aims at contributing to the knowledge of albedo variations of ice and snow covered surfaces from remote sensing and it complements a recent paper by Traversa & *alii* (2021b), which provided a model (based on previous

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studies, Klok & *alii*, 2003; Fugazza & *alii*, 2016) to retrieve the albedo on the ice sheets based on Landsat imagery. The model by Traversa & *alii* (2021b) included 1) conversion from raw satellite data to radiance and reflectance; 2) atmospheric correction; 3) topographic correction; 4) conversion from narrowband to broadband albedo. An anisotropic correction step was lacking in this model, compared e.g. to the study of Naegeli & *alii* (2017) or Fugazza & *alii* (2019) which used a similar approach to calculate the albedo and its variations on Alpine glaciers. The anisotropic correction can be important because satellites can only measure radiance in a specific direction, but ice and snow do not reflect isotropically but rather show a higher amount of forward scattering compared to the other directions (Reijmer & *alii*, 2001). Based on such premises, this study evaluates different albedo retrievals from Landsat 8 OLI calculated by implementing anisotropic correction factors, and then converting anisotropically corrected narrowband albedo to broadband albedo using algorithms developed by (Knap & *alii*, 1999) and (Liang, 2001). The comparison between the different approaches has recently become possible as new correction factors for snow and ice at high Solar Zenith Angle (SZA) have been developed for Liang algorithm (Ren & *alii*, 2021), in addition to the existing ones based on Knap algorithm (Lucht & *alii*, 2000; Reijmer & *alii*, 2001). We then compare the two final albedo products against the values obtained in the previous study, lacking anisotropic correction (Traversa & *alii*, 2021b) and validate both methods through comparison with field observations from a network of weather stations.

DATA AND METHODS

With respect to the satellite database used in this work, we included Landsat 8 OLI imagery acquired between 2013 and 2020 from Collection 2 products downloaded from the USGS Earth Explorer website (https://earthexplorer.usgs.gov/) (spatial resolution 30 m). We used bands 2-3-4-5-6 and 7, respectively: Blue, Green, Red, near-infrared (NIR) and the two shortwave-infrared (SWIR) bands which are required in spectral to broadband albedo conversion (Knap & *alii*, 1999; Liang, 2001). The Knap algorithm uses bands 3 and 5, while Liang algorithm uses bands 2 and 4-7. Each satellite band was processed through four corrections steps: radiometric, atmospheric, topographic and anisotropic correction. For the first three steps, see Traversa & *alii* (2021b) for further information, considering that a pixel-specific solar zenith angle was used for the radiometric correction, a sub-arctic winter model for the atmospheric correction and the cosine method for the topographic correction. Regarding the anisotropic correction, two different approaches were used to comply with Knap and Liang algorithms for narrowband to broadband albedo conversion. For Knap algorithm, bands 3 and 5 were corrected using the coefficients developed by Greuell & de Ruyter de Wildt (1999) for ice and Reijmer & *alii* (2001) for snow. For the Liang algorithm, the coefficients developed by Ren & *alii* (2021) were used for bands 2 and 4-7. To discriminate between ice and snow, we followed the approach by Ren & *alii* (2021), i.e. by setting a threshold of 0.45 on the Normalized Difference Snow Index (NDSI). Additionally, we set pixels with a NDSI < 0 to non-icy areas. Here, the reflectance was assumed isotropic, and no anisotropic correction was applied. After calculating the anisotropic correction, the spectral albedo values for each scene were converted into broadband albedo using the two algorithms. We define $\alpha_{Knap,anis}$ as the final albedo calculated using anisotropic correction coefficients from Greuell and de Wildt (1999) and Reijmer & *alii* (2001) and Knap algorithm for broadband conversion. We describe as $\alpha_{Liang,anis}$ the final albedo calculated using anisotropic correction coefficients from Ren & *alii* (2021) and Liang algorithm for broadband conversion, while $\alpha_{Liang,na}$ is the albedo calculated without anisotropic correction. We compared all three albedo products to albedo observations from weather stations using three different datasets (Greenland: PROMICE AWSs, Van As & *alii*, 2011; Antarctica: IMAU AWSs, Jakobs & *alii*, 2020, and BSRN Stations, Driemel & *alii*, 2018). 64 scenes (21 in Greenland and 43 in Antarctica) were compared between 2013 and 2020 (for a detailed description of stations and scenes, see the final dataset of Traversa & *alii*, 2021b) and the statistics used to estimate the performance of the three models were : correlation coefficients (Cc or R), bias estimate (BE), mean absolute error (MAE), root-mean-square error (RMSE) and bias-removed-root-mean-square error (BRRMSE) (as defined in Traversa & *alii*, 2021b).

RESULTS

In the comparison of the three models against ground observations, $\alpha_{Liang,na}$ presents the best statistics, showing a MAE of 0.022 (lower in Antarctica, with 0.020, against 0.026 for Greenland), an STD of 0.016, a BE of -0.007, a coefficient of correlation of 0.99 and RMSE and BRRMSE respectively of 0.027 and 0.026. Applying the anisotropic correction (Ren & *alii*, 2021), the statistics were worse and most of the times the errors increased two- to threefold compared to the previous case. The MAE of $\alpha_{Liang,anis}$ increases to 0.065 (in this case, Greenland has a lower MAE of 0.047, compared to 0.074 in Antarctica), an STD of 0.045, BE of -0.065 (more than 9 times higher than without the correction), a coefficient of correlation of 0.976, a RMSE of 0.080 and a BRRMSE of 0.047. In comparison, the albedo values from $\alpha_{Knap,anis}$ showed better statistics than $\alpha_{Liang,anis}$. However, these statistics were all worse than , showing values of MAE, STD, BE, R, RMSE and BRRMSE respectively of: 0.040 (0.047 in Antarctica and 0.027 in Greenland), 0.034, 0.016, 0.962, 0.053 and 0.051. All the statistics are summarized in table 1.

DISCUSSION

Compared to the findings of Traversa & *alii* (2021b), Knap algorithm performs better than Liang algorithm when the anisotropic correction is applied, as all the calculated statistics, except for BRRMSE, are significantly

TABLE 1 - Statistics of the validation of satellite-albedo with in-situ observations (64 scenes), with the three proposed models. Correlation is always significant at the 99% confidence level.

Dataset	MAE tot	AIS MAE	GrIS MAE	STD	BE	R	RMSE	BRRMSE
$\alpha_{Liang,na}$	0.022	0.020	0.026	0.016	-0.007	0.990	0.027	0.026
$\alpha_{Liang,anis}$	0.065	0.074	0.047	0.045	-0.065	0.976	0.080	0.047
$\alpha_{Knap,anis}$	0.040	0.047	0.027	0.034	0.016	0.962	0.053	0.051

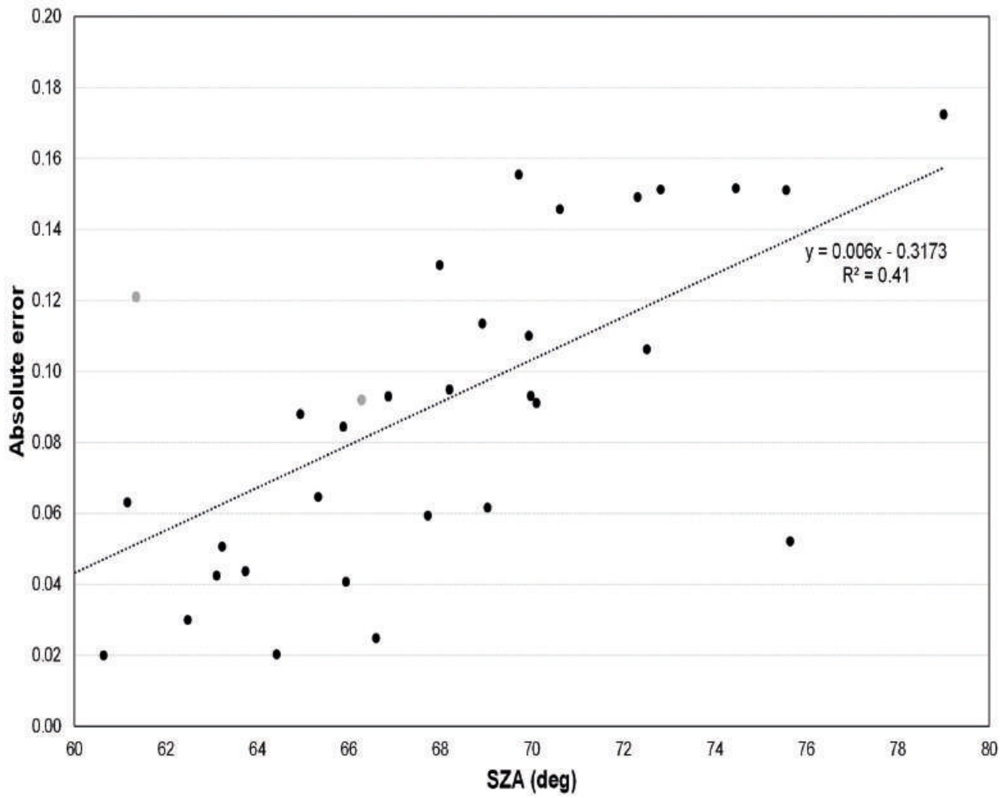

FIG. 1 - Plot showing SZA (x) and absolute error (y) of scenes having SZA > 60° ($\alpha_{Liang,anis}$), demonstrating the correlation between the two parameters (grey dots for GrIS and black dots for AIS).

better. Nevertheless, worse results were obtained in comparison to the model proposed by Traversa & *alii* (2021b), which used Liang conversion to broadband albedo without any correction for anisotropy. In detail, looking at the MAE for the AIS and GrIS, it is evident how the statistics were worse especially for Antarctica, while in Greenland only slight differences were found between $\alpha_{Liang,na}$ and $\alpha_{Knap,anis}$ (0.026 vs 0.027). What mostly diverges between the scenes used for satellite albedo validation in Antarctica and Greenland is the SZA, which tends to be generally higher on the AIS than on the GrIS (on average 65° and 50° respectively), due to the different latitude range (between 59° and 84° N for Greenland and between 63° and 90° S for Antarctica). In fact, anisotropy is strongly related to SZA and tends to increase with higher angles (Warren & *alii*, 1998). Anisotropic correction factors developed for Knap algorithm were not tested with such high SZA values (maximum SZA was given as 60° in Reijmer & *alii*, 2001), while the factors developed by Ren & *alii* (2021). In detail, in this study, 70% of Landsat scenes in Antarctica had a SZA > 60° compared to just 10% in Greenland. Calculating the correlation between the difference between ground and satellite albedo of each scene and the corresponding SZA, we found no correlation when using the albedo obtained in the previous model without anisotropic correction (Traversa & *alii*, 2021b), i.e. a correlation coefficient of -0.04, a much higher value for $\alpha_{Knap,anis}$, i.e. 0.25 and a significant (at 99% confidence level) correlation for $\alpha_{Liang,anis}$: 0.67 (fig. 1).

The effect of the SZA could therefore explain the larger differences found for the Antarctic continent and the lower ones in Greenland, as in the second case the average latitude of ground observations is lower, as is the corresponding SZA. In fact, out of 32 scenes having SZA ≥ 60°, only 2 are located on the GrIS and 30 on AIS. These findings highlight how the present anisotropic-correction models do not adequately compensate for the SZA, which is particularly relevant in polar regions (Traversa & *alii*, 2019). Nevertheless, it is also evident that the anisotropic-correction factors for snow and ice proposed for Knap algorithm by Reijmer & *alii* (2001) provide reliable results when SZA is lower than 60°, in accordance with the findings of Fugazza & *alii* (2016).

CONCLUSIONS

The present study intends to evaluate the use of anisotropic correction for calculating broadband albedo on the ice-sheets (AIS and GrIS), through a comparison between Landsat 8 OLI imagery, corrected following the model of Traversa & *alii* (2021b), and three different datasets of ground observations from AWSs and manned weather stations (Van As & *alii*, 2011; Driemel & *alii*, 2018; Jakobs & *alii*, 2020). Three models were taken into account: one using Liang algorithm for narrowband to broadband conversion, without anisotropic correction (Traversa & *alii*, 2021b) and two models with anisotropic correction (Reijmer & *alii*, 2001; Ren & *alii*, 2021) using Knap and Liang algorithm for conversion to broadband albedo. The statistics were all better in the first case, and a significant correlation was found between the difference between ground and satellite albedo and the SZA when using anisotropic correction factors developed for Liang algorithm, particularly at high SZA (> 60°). Thus, considering that on Greenland and particularly the AIS the SZA can be higher than 60°, our findings suggest that the anisotropic correction may be omitted for these polar areas. and a model that does not include this correction, e.g., Traversa model (Traversa & *alii*, 2021b), would be more efficient at present to calculate broadband albedo on the ice-sheets from satellite data from Landsat 8 OLI. More research is needed to develop anisotropic correction factors which can adequately represent ice sheet albedo at high SZA.

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