Cross-Comparison of Snow Albedo Products Derived from Satellite (Sentinel-2 and Landsat 8) Optical Data

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Abstract. Snow albedo is an important factor affecting global climate change. Due to the limitation of atmospheric conditions and cloud cover, remote sensing products of snow albedo have data missing and error uncertainty. In this study, based on the method of directly inverting the reflectance of the top of the atmosphere, the difference and accuracy of the snow albedo derived from the Sentinel-2 and Landsat 8 data were compared. We used two narrowband-to-broadband conversion algorithms to obtain a total of four snow albedo products. Then we use scatterplots and three indicators (the mean absolute value error, root mean square error, and pearson correlation coefficient) to compare the correlation and accuracy of the four products. The research results show that four snow albedo products derived from satellite (Sentinel-2 and Landsat 8) optical data have a strong correlation. Finally, we use IDL to check each field for regression analysis to obtain a linear regression equation. The fitting coefficient of the equation is between 0.85-0.90. The snow albedo is inverted by a variety of remote sensing data, which provides a solution to the problem of missing data.

1. Introduction

Snow albedo is an important basis for monitoring changes in snow information. Snow albedo is usually defined as the ratio of the solar radiation reflected by the snow surface to the total solar radiation received, that is, the ratio of the total radiant energy emitted from all directions per unit time and unit area to the total incident radiant energy, reflecting the surface to the sun shortwave [1]. The physical parameters of radiation reflection characteristics can intuitively reflect snow information. When the snow albedo increases, the radiant energy on the earth’s surface will suffer severe losses. At the same time, the sensible heat flux and latent heat flux on the earth’s surface will decrease, resulting in a weakened rise in atmospheric convergence. Eventually, it will lead to a decrease in precipitation. Snow albedo is also an important factor affecting seasonal snow cover changes. Therefore, obtaining accurate surface snow albedo data plays an important role in the study of local or global climate change [2].

In recent years, with the development of satellite technology, more and more snow albedo products have been produced. The method of inverting snow albedo by satellite remote sensing meets the needs of large-scale snow monitoring in time and space. These snow albedo products are based on the theoretical basis of the spectral reflectance characteristics of the snow surface. At home and abroad,
many experts and scholars have established many snow albedo remote sensing retrieval algorithms, mainly including the albedo retrieval algorithm based on the bidirectional reflectance distribution function model (BRDF) [3,4], the albedo retrieval algorithm based on Lambert's assumption [4-6]and the GLASS albedo algorithm [7]. According to the Atmospheric Radiation Transfer Theory (ART), Liang [8] proposed a direct albedo algorithm based on the reflectance of the top of the atmosphere. Knap et al. [9] directly regressed the broadband albedo to the corresponding band of the sensor to obtain the empirical relationship. This relationship can accurately estimate broadband albedo directly in accordance with narrow-band reflectance, without the need to classify snow.

In the inversion process of surface albedo, many algorithms have achieved ideal results. Now its main problems are: (1) The limitation of atmospheric conditions and the occlusion of clouds have caused serious data lack of snow albedo products [2]. (2) Different types of data products require different inversion algorithms. The difference in the spatial resolution of data products causes great uncertainty in the accuracy of various albedo products.

Through thinking about these issues, this paper compares the difference and accuracy of the snow albedo products. These snow albedo products are derived from Sentinel-2 and Landsat 8 data based on the method of directly inverting the reflectance of the top of the atmosphere. Our work includes: (1) Using Sentinel-2 satellite data to retrieve snow albedo, after radiometric calibration, atmospheric correction, anisotropy correction and narrowband to broadband conversions, the snow albedo of the study area is obtained. (2) Similar to (1), perform algorithmic processing on Landsat 8 satellite data to obtain the snow albedo of the study area. (3) Validate and analyze of the snow albedo products derived from satellite (Sentinel-2 and Landsat 8) optical data. (4) Discuss the influence of the number of bands and spatial resolution on the snow albedo products. (5) These snow albedo products are derived from Sentinel-2 and Landsat 8 data are used for regression analysis.

2. Study Site and Data
The study area is part of Henan Province. From January 8th to 10th, 2018, the weather in these areas was snowing. The experimental data of this paper is the optical data of two kinds of satellites (Sentinel-2 and Landsat 8).

2.1. Sentinel-2 (S2)
The Sentinel-2 satellite is an optical satellite that carries a multi-spectral imager (MSI) to produce optical data and has an altitude of 786km. The data produced by the Sentinel-2 satellite has a width of 290km and covers a total of 13 bands (443m-2190m). The two satellites of Sentinel-2 are Sentinel-2A and Sentinel-2B. The revisit period of one satellite is 10 days, and the revisit period of two satellites is 5 days.

The experimental data for this article is the Level-1C data of Sentinel-2. The image acquisition time is January 8, 2018, and the spatial resolution is 20m×20m. Level-1C data has been geometrically accurate correction. We use Sen2cor software to perform atmospheric correction on Level-1C data. Data source: https://earthexplorer.usgs.gov/. The download address of Sen2cor is: http://step.esa.int/main/third-party-plugins-2/sen2cor/. In the following, we use S2 as the abbreviation of Sentinel-2 to improve readability.

2.2. Landsat 8 (L8)
Landsat 8 is an optical satellite, which mainly carries two payloads: OLI (Operational Land Imager) and TIRS (Thermal Infrared Imager). The terrestrial imager has a spatial resolution of 30m and contains a total of nine bands. The thermal infrared imager has a spatial resolution of 100m and contains two separate thermal infrared bands. This paper uses L1T data products. The image acquisition time is January 10, 2018. The L1T data product has undergone a precise calibration process, so the follow-up work is to carry out radiation calibration and atmospheric correction. From here on, we use L8 as the abbreviation for Landsat 8. The data comes from http://glovis.usgs.gov/.
Table 1 The data in this study. Number of bands refers to available surface reflectance spectral bands.

| Band     | Wavelength (\(\mu m\)) | Resolution (m) | Band     | Wavelength (\(\mu m\)) | Resolution (m) |
|----------|-------------------------|----------------|----------|-------------------------|----------------|
| Landsat 8 |                         |                | Sentinel-2 |                         |                |
| 1(Coastal)| 0.433-0.453             | 30             | 1(Coastal)| 0.433-0.453             | 60             |
| 2(Blue)  | 0.450-0.515             | 30             | 2(Blue)  | 0.458-0.523             | 10             |
| 3(Green) | 0.525-0.600             | 30             | 3(Green) | 0.543-0.578             | 10             |
| 4(Red)   | 0.630-0.680             | 30             | 4(Red)   | 0.650-0.680             | 10             |
|          |                         |                | 5(Red Edge)| 0.689-0.713             | 20             |
|          |                         |                | 6(Red Edge)| 0.733-0.748             | 20             |
|          |                         |                | 7(Red Edge)| 0.773-0.793             | 20             |
| 5(NIR)   | 0.845-0.885             | 30             | 8(NIR)   | 0.785-0.900             | 10             |
|          |                         |                | 8A (Red Edge)| 0.798-0.932             | 20             |
| 6(SWIR-1)| 1.560-1.660             | 30             | 9(Water vapor)| 0.935-0.955             | 60             |
| 7(SWIR-2)| 2.100-2.300             | 30             | 10(SWIR-Cirrus)| 1.360-1.390             | 60             |
| 8(PAN)   | 0.500-0.680             | 15             | 11(SWIR) | 1.565-1.655             | 20             |
| 9(Cirrus)| 1.360-1.390             | 30             |          |                         |                |

3. Methodology
The main technical route includes three parts (Figure 1): (1) The extraction of snow albedo products from Sentinel-2 optical data. (2) The extraction of snow albedo products from Landsat 8 optical data. (3) Cross-Comparison of the snow albedo derived from satellite (Sentinel-2 and Landsat 8) optical data.

Figure 1 Technology flow chart.
3.1. Extraction of snow albedo products from S2
Firstly, the Level-1C data is atmospherically corrected through Sen2cor software. Sen2cor is a processor for Sentinel-2 Level 2A product generation and formatting. Secondly, the snow albedo is obtained by an algorithm that directly inverts the albedo through the reflectance at the top of the atmosphere. We need to convert the narrow-band reflectance into the broadband. The direct conversion relationship has different differences for different sensors. The conversion principle from the narrow-band reflectance to the broadband [8,10] is:

\[ R = a + b_1 CH_1 + b_2 CH_2 + \ldots + b_n CH_n + \epsilon \]  

(1)

\( b_n \), the reflectance of the n bands of the satellite; \( CH_n \), the polynomial regression coefficient;

Knap et al. [9] performed an empirical regression of the albedo between the corresponding band and the broadband of the sensor to obtain the empirical relationship. Hence, the formulae adopted for S2 is as follows:

\[ \alpha_{S2}^{Knap} = 0.726b_3 - 0.322b_7^2 - 0.015b_8 + 0.581b_5^2 \]  

(2)

\( \alpha_{S2}^{Knap} \), S2 snow albedo obtained by the formula of Knap;

Liang [8] obtained the conversion coefficient from the narrow-band reflectance to the broadband through many experiments and models. Hence, the formulae adopted for S2 is as follows:

\[ \alpha_{S2}^{Liang} = 0.356b_1 + 0.130b_4 + 0.373b_5 + 0.085b_11 + 0.072b_{12} - 0.0018 \]  

(3)

\( \alpha_{S2}^{Liang} \), S2 snow albedo obtained by the formula of Liang;

Finally, we use ENVI5.3 software to perform band calculations to obtain snow albedo. Carry out correlation analysis on snow albedo products obtained by different formulas.

3.2. Extraction of snow albedo products from L8
Firstly, L1T data products are pre-processed by ENVI5.3. The main steps include radiation calibration and atmospheric correction. Then, based on the direct inversion albedo algorithm of the atmospheric top albedo, the L8 snow albedo is obtained. For Knap et al. [9], the formula of L8 snow albedo is as follows:

\[ \alpha_{L8}^{Knap} = 0.726b_3 - 0.322b_7^2 - 0.015b_8 + 0.581b_5^2 \]  

(4)

\( \alpha_{L8}^{Knap} \), L8 snow albedo obtained by the formula of Knap;

For Liang [8], the formula of L8 snow albedo is as follows:

\[ \alpha_{L8}^{Liang} = 0.356b_1 + 0.130b_4 + 0.373b_5 + 0.085b_11 + 0.072b_{12} - 0.0018 \]  

(5)

\( \alpha_{L8}^{Liang} \), L8 snow albedo obtained by the formula of Liang;

3.3. Cross-Comparison of tow snow albedo
Firstly, the four snow albedo images are registered. Then crop out the image without clouds. 836 sample points were randomly selected. Import these points into Excel to make scatter plots. Then, we calculate the mean absolute value error (MAE), root mean square error (RMSE), and Pearson correlation coefficient (R) of S2 and L8 snow albedo products. These parameters evaluate the accuracy of the albedo product. Finally, the snow albedo of S2 and the albedo of L8 are used for regression analysis. For the significance test of the regression equation, this paper uses the r test method.

4. Results
4.1. Impact of spectral resolution
For S2, two snow albedo products that are obtained by two formulas make a scatter plot by Excel. For L8, repeat the same steps as S2.
For $\alpha_{S2}^{Liang}$ and $\alpha_{S2}^{Knapp}$, their mean absolute value error (MAE) is 0.02. The root mean square error (RMSE) is 0.03, and Pearson correlation coefficient (R) is 0.95 (Figure 2). Therefore, there is a strong correlation for $\alpha_{S2}^{Liang}$ and $\alpha_{S2}^{Knapp}$. Although the two formulas are different in types and numbers of bands, the snow albedo products ($\alpha_{S2}^{Liang}$ and $\alpha_{S2}^{Knapp}$) are highly correlated. Therefore, the number and type of bands involved in the calculation have little influence on the S2 snow albedo products. For $\alpha_{L8}^{Liang}$ and $\alpha_{L8}^{Knapp}$, their mean absolute value error (MAE) is 0.03. The root mean square error (RMSE) is 0.04, and Pearson correlation coefficient (R) is 0.93 (Figure 3). Therefore, there is a strong correlation for $\alpha_{L8}^{Liang}$ and $\alpha_{L8}^{Knapp}$. For L8, we get the same conclusion as S2. The number and type of bands involved in the calculation have little influence on the L8 snow albedo products. We can conclude that these two methods are very suitable for calculating albedo.

4.2. Impact of satellite sensor
We randomly select 836 sample points. Then we import these points into Excel to make scatterplots.
Figure 4 The scatterplot of between $\alpha_{Knap}^{S2}$ and $\alpha_{Knap}^{L8}$.

For $\alpha_{Knap}^{S2}$ and $\alpha_{Knap}^{L8}$, their mean absolute value error (MAE) is 0.11. The root mean square error (RMSE) is 0.12, and Pearson correlation coefficient (R) is 0.81 (Figure 4). Therefore, there is a strong correlation for $\alpha_{Knap}^{S2}$ and $\alpha_{Knap}^{L8}$. For $\alpha_{Liang}^{S2}$ and $\alpha_{Liang}^{L8}$, their mean absolute value error (MAE) is 0.10. The root mean square error (RMSE) is 0.11, and Pearson correlation coefficient (R) is 0.89 (Figure 5). Therefore, there is a strong correlation of $\alpha_{Liang}^{S2}$ and $\alpha_{Liang}^{L8}$. Their correlation is more than the correlation of $\alpha_{Knap}^{S2}$ and $\alpha_{Knap}^{L8}$.

Figure 5 The scatterplot of between $\alpha_{Liang}^{S2}$ and $\alpha_{Liang}^{L8}$.

For S2 and L8, the formula of Liang et al. [8] is more suitable for calculating the snow albedo. And by comparing with the result of 4.1, it can be concluded that the type of sensor will have some influence on the calculation of snow albedo.

4.3. The result of regression analysis

We use IDL software to check each field of the four snow albedo products and perform regression analysis on them. The results are shown in the table 2 and table 3.

Table 2 Regression parameters of between $\alpha_{Knap}^{L8}$ and S2 snow albedo.

|       | a   | b   | r   |
|-------|-----|-----|-----|
| $\alpha_{Knap}^{S2}$ | 0.759 | 0.019 | 0.850 |
| $\alpha_{Liang}^{S2}$ | 0.865 | -0.029 | 0.850 |

Table 3 Regression parameters of between $\alpha_{Liang}^{L8}$ and S2 snow albedo.

|       | a   | b   | r   |
|-------|-----|-----|-----|
| $\alpha_{Knap}^{S2}$ | 0.706 | 0.046 | 0.897 |
| $\alpha_{Liang}^{S2}$ | 0.812 | -0.003 | 0.905 |

x Snow albedo of S2.
y Snow albedo of L8.
' fitting coefficient.

According to the conclusions of 4.1 and 4.2, it can be concluded that the snow albedo products of S2 and L8 have a strong correlation. Therefore, regression analysis can be performed on them. Our analysis shows that the snow albedo products of S2 and L8 conform to the unary linear regression model. From
the overall results, the fitting coefficient of the model is between 0.85 and 0.90 (table 2 and table 3). This shows that the fit of the equation is very high. We can get the regression equation of the snow albedo products of S2 and L8. This conclusion can help us solve the problem of missing data. When the S2 snow albedo product is missing due to cloud occlusion, we can use the linear regression equation to fill the missing S2 data with the L8 snow albedo product.

5. Conclusions
In this paper, four snow albedo products are obtained by using an algorithm based on the reflectance of the top of the atmosphere to directly invert the snow albedo. We verify the accuracy by cross-comparing the correlation between S2 and L8 snow albedo products. After systematic analysis, we have three conclusions: (1) By drawing scatterplots of four snow albedo products, we conclude that they have a strong correlation. Moreover, the average absolute value error (MAE), root mean square error (RMSE) and Pearson correlation coefficient (R) all indicate the high accuracy of the four snow albedo products. (2) We perform regression analysis on S2 and L8 snow albedo products, and the fitting coefficient is between 0.85 and 0.90. (3) The type and number of bands have little effect on snow albedo products (S2 and L8), while different satellite sensors have some influence on snow albedo products. For S2 and L8, Liang et al.’s algorithm has a better inversion consequence.

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