FRACTIONAL SNOW COVER MAPPING WITH HIGH SPATIOTEMPORAL RESOLUTION BASED ON LANDSAT, SENTINEL-2 AND MODIS OBSERVATION

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ABSTRACT

Fractional snow cover (FSC) mapping with high spatiotemporal resolution is of great significance to the study of surface hydrological processes, agricultural irrigation, and disaster monitoring. In this study, we use the spectral mixture analysis based on automatic endmember extraction (MESMA-AGE) algorithm to retrieve FSC from Landsat-5/7/8, Sentinel-2, and MODIS data using the Google Earth Engine (GEE) platform. The algorithm can produce FSC product with 30m spatial resolution and 4-day temporal resolution at regional scale, even globally with GEE. The result shows that the accuracy of the FSC product is high with the root mean square error (RMSE) being 0.18 with the comparison of Gaofen-2 imageries.

Index Terms—*Data fusion, Fractional snow cover, GEE*

1. INTRODUCTION

Fractional snow cover mapping with high spatio-temporal resolution is of great significance to the study of surface hydrological processes, agricultural irrigation, and disaster monitoring[1]. Optical sensors are the main sources for snow fraction estimation due to large-scale observation and accurate data acquisition[2]. Several remote sensing approaches have been developed during recent decades to retrieve FSC from Moderate-resolution Imaging Spectroradiometer (MODIS) images at 500m[3]. Normalized snow cover index (NDSI), combined with a series of parameters and bands, is often used to establish the linear regression relationship between it and the real snow cover, which is simple and effective to retrieve FSC[4]. Some scholars use multiple endmember linear spectral mixture analysis method, which can retrieve the fraction of snow by determining the best linear combination of the components of pixel-averaged surface reflectance[5].

However, due to the limitation of the moderate spatial resolution, MODIS pixels often contain mixtures of different surface types[6]. To overcome the subpixel heterogeneity of MODIS, remote sensing images with higher spatial resolution, such as Landsat images (30-m,16-day resolution) and Sentinel-2 images(20-m,5-day resolution), need to be used [7]. Of course, the availability of single high-resolution satellite data is much lower than that of MODIS data, which may not provide the necessary temporal resolution to identify rapidly changing snow cover, so we need to fuse Landsat data with Sentinel-2 data.

In this study, we efficiently combine Landsat-5/7/8, Sentinel-2, and MODIS to map high temporal-spatial FSC in the Tibetan Plateau (TP). The algorithm can produce FSC product with 30m spatial resolution and 4-day temporal resolution.

2. STUDY AREA AND DATA

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2.1 Study region

The study area is located in Tibetan Plateau, with latitude and longitude of approximately 26°–40° and 70°–105°E. Fig. 1 shows the location and land-cover types of the study area. Forest, grass, snow, and barren, which were determined by the GlobeLand30 dataset, were considered as the main land-surface types in TP[8].

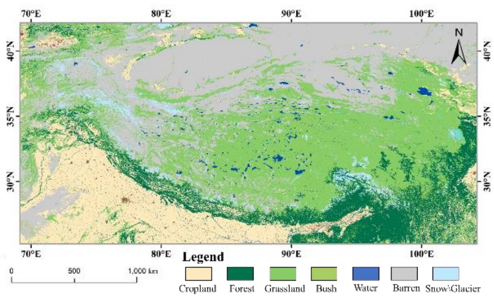

Fig. 1. Location and land-cover types of the Tibetan Plateau.

2.2 Data

2.2.1 Landsat, Sentinel-2, and MODIS data

The GEE platform hosts Sentinel-2 images (MSI), Terra/Aqua images (MODIS), and Landsat images including TM, ETM+, OLI images. The Sentinel-2A/B images we use were surface reflectance (SR) data computed by running sen2cor, with a spatial resolution of 20m and temporal resolution of 5-day. The Landsat-5/7/8 data were atmospherically corrected surface reflectance data in GEE, with a spatial resolution of 30m and temporal resolution of 16-day. We also use MODIS data as MOD09GA and MYD09GA, which are the surface reflectance products that provide an estimate of the surface spectral reflectance, with a spatial resolution of 500m.

2.2.2 Gaofen-2 data

Gaofen-2 is the satellite of China's high-resolution Earth observation system. The panchromatic and Multispectral cameras (PMS) on Gaofen-2 can provide remote sensing data with 3.2 m spatial resolution. Gaofen-2 data was used here as truth value to evaluate 30-m snow fraction from Landsat, and Sentinel-2.

3. METHODS

3.1 Image pre-processing

The bad-quality observations, including cloud, cloud shadow and ETM+ SLC-off gaps, need to be masked out. For Landsat-5/7/8 and MODIS images, we use the QA band to identify bad pixels. For Sentinel-2 A/B images, Sentinel Hub's cloud product was used to remove cloud from MSI images. All images were resampled to 30m, and MODIS FSC downscaled by random forest algorithm based on the high-resolution FSC images of the same period[9].

We also harmonized the ETM+, MSI and MODIS data to the standard of the OLI data using the method of ordinary least squares regression coefficient[10],[11], which improved the multi-sensor consistency of remote sensing data.

3.2 MESMA-AGE

Multiple endmember spectral mixture analysis can retrieve the snow cover fraction by determining the best linear combination of the components of pixel-averaged surface reflectance. The algorithm is as follow:

$$R_\lambda = \sum_{i=1}^{N} F_i R_{i,\lambda} + \varepsilon_\lambda \qquad (1)$$

where R_λ is the pixel-averaged surface reflectance at wavelength λ, N is the number of spectral endmembers, F_i is the fraction of endmember i at wavelength λ, $R_{i,\lambda}$ is the surface reflectance for endmember i at wavelength λ, and ε_λ is the residual error for the endmembers.

The endmember selection method we use is automatic endmember extraction[12], which can automatically select the endmembers (including snow, vegetation, water, and soil/rock) directly from each image. This method ensures this model can partially reduce the effects of spatial heterogeneity[8].

3.3 Validation

The Gaofen-2 sensor provides multispectral data at a high spatial resolution of 3.2 m. we mapped the snow cover from Gaofen-2 by using supervised classification after atmospheric and radiance correction, and the results are used as the truth value to verify the accuracy of other results.

4. RESULTS

As Fig.2 shows, high spatial resolution remote sensing images of Landsat-5/7/8 and sentinel-2 images can cover almost the entire Tibetan Plateau during four days. However, according to statistics from December 2018 to December 2021, due to the influence of bad-quality observations, the average effective observation ratios under the synthetic days of 2 to 4 fusion days are 53.2%, 67.7%, 79.9%, and 85.3%, respectively.

As Fig.3 shows, for higher temporal resolution, we set the fusion day as 4-day and used MODIS data to fill the data gap areas. Almost the entire study area can be observed after the fusion. The red area in Fig.3 is the bad-quality observation, which accounts for 2.82% of the study area in TP from December 1, 2020 to December 4, 2020.

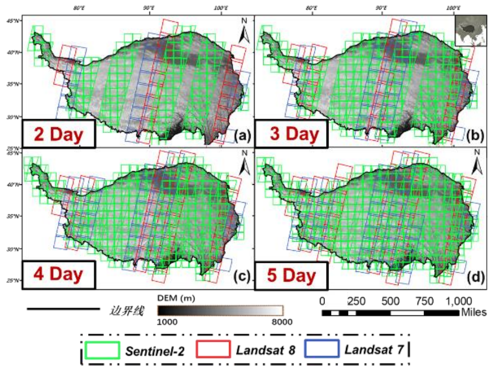

Fig. 2. Average satellite sensor observation coverage of Landsat -7/8 and Sentinel-2A/B in TP under 2 to 4 fusion days.

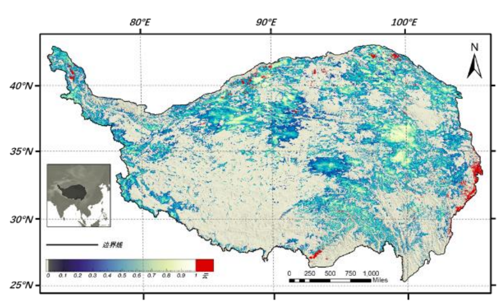

Fig. 3. The 4-day 30m fractional snow cover result in TP from December 1, 2020 to December 4, 2020. The red area is the bad-quality observation.

We use 62 Gaofen-2 images to evaluate the retrieval results, classifying the surface types of the study area into mountain forest, grass, and barren. Its average accuracy and RMSE are shown in the table below. The validation accuracy of mountain forest area is poor compared to other regions. Due to the shadow of the mountain, the surface reflectance of the shadow area will be low, and the algorithm cannot accurately determine whether it is snow, which will reduce the value of FSC during the retrieval process. Barren and grass areas are mostly distributed in the middle of TP. In this area, the snow cover has a short duration, the snow layer is shallow and the degree of fragmentation is high (Fig.3). The low-value FSC mixed pixel problem will lead to certain errors.

Table 1. The validation for fusion images

Land cover（#of images）	Accuracy	RMSE
Mountain Forest(21)	0.88	0.19
Grass(20)	0.89	0.16
Barren(21)	0.9	0.17
All(62)	0.89	0.18

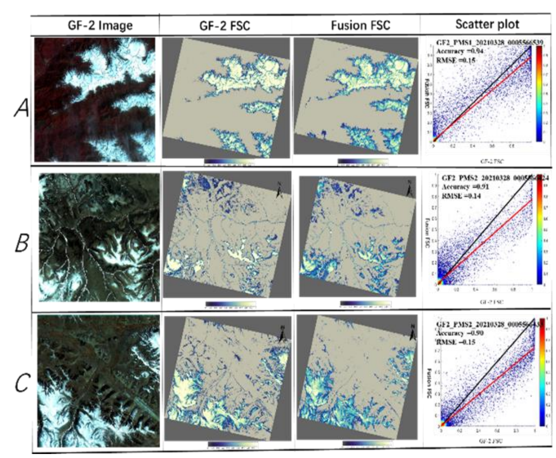

Fig. 4. Fractional snow cover comparison of fusion FSC and Gaofen-2 in different landcover types of (A) mountain forest (B) grass (C) barren area on March 28, 2021.

5. CONCLUSIONS

The fusion of multiple high spatial resolution sensors can make the temporal resolution of the results higher. We use the MESMA-AGE algorithm to retrieve FSC efficiently from Landsat-5/7/8, Sentinel-2, and MODIS data using the Google Earth Engine (GEE) platform. The algorithm can produce FSC product with 30m spatial resolution and 4-day temporal resolution at regional scale, even globally with GEE. The accuracy of the FSC product is high with the RMSE being 0.18. The accuracy of this algorithm in plain areas is better than that in mountainous areas. In the following research, the downscaling work of MODIS and endmember extraction in complex terrain areas such as mountainous areas should be focused on.

6. ACKNOWLEDGEMENTS

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