

# A METHOD OF GLACIER IDENTIFICATION WITH INTERFEROMETRIC AND POLARIMETRIC SAR

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***Abstract:** The glacier is important factor in climatologic and hydrological investigations. The remote sensing plays an important role on glacier inventorying and monitoring work. SAR systems have an important ability to observe the earth's surface, independent of cloud conditions. Particularly, the SAR interferometry and polarization provide a useful tool for glacier investigation, such as extraction of glacial border. In this paper, the methods for glacier identification are introduced, using different SAR data, including C-band ENVISAT/ASAR, Radarsat-2 and L-band ALOS/PALSAR in the Dongkemadi glacier. The interferometric SAR provides the coherence information, and polarimetric SAR give rich information about density and phase; we build a new method for estimation of the glacial border. Finally, the characteristics and accuracy are analyzed. The results showed that the multi-temporal repeat-pass interferometric techniques and polarimetry techniques are efficient for glacier identification.*

***Keyword:** InSAR, PolSAR, Glacier and snow cover, Qinghai-Tibetan Plateau*

## 1. INTRODUCTION

Glacier changes are among the clearest signals of on-going warming trends existing in nature. In view of environmental changes, combined with the high thermal sensitivity of earth's mountain glaciers, especially in the Qinghai-Tibetan Plateau, is of growing interest. Satellite remote sensing play an important role on glacier inventorying and monitoring work, such as Global Land Ice Measurements from Space (GLIMS) is an international consortium established to acquire satellite images of the world's glaciers and analyze them for glacier extent and changes [1]. Most remote sensing data used to mountain glaciers study is mainly optical data, which is hard to achieve in more cloud region. SAR systems have an important ability to observe the earth's surface, independent of cloud conditions. This property is particularly useful in the plateau, where harsh weather conditions restrict the use of optical sensors. Utilization of SAR backscatter coefficients only, limits the number of glacier classes that can be distinguished, and decreases the accuracy of classification because snow cover and moisture change [2]. The characteristics of SAR polarimetry are particularly useful in classification. In this paper, the coherence characteristics and polarization of SAR are used to analyze the glacial border extraction and the classification of the glacier, because SAR coherence coefficients of interferometric pair and polarimetric information show the different value for different objects caused of the change of backscattering characteristic at the separate time [3].

## 2. STUDY AREA AND DATASETS

The Qinghai-Tibetan Plateau is located between the Karakorum and Himalayan. It has a mean elevation between 4,500 and 5,000 m with many isolated mountain massifs of more than 6,000 to 7,000 m. The high mountain ranges and especially the Qinghai-Tibetan Plateau play a major role in the climatic system of Asia and the monsoon systems that in turn affect even the global climate. The plateau is the most concentrated glacier center in the middle and low latitudes of

the Earth and has an important influence on the regional and atmospheric circulation; it splits the upper westerly winds in winter into northern and southern branches. The total area of glaciers is 104,850 km<sup>2</sup>, including 40,000 km<sup>2</sup> in India and Pakistan and 49,873 km<sup>2</sup> in China. The largest glacier covers are on the Himalayas, amounting to 34,660 km<sup>2</sup> [4], and the largest distribution of glaciers is in the plateau margins of the Himalayas, Karakorum and West Kunlun mountains, which have both more and larger glacier cover; inland plateaus have less glacier cover. The Tanggula Mountain is an east-west trending mountain range in the central Qinghai-Tibetan Plateau, China. It has an average elevation of 6,000 meters. The Yangtze River rises from its highest peak, Geladaindong, which is 6,621 meters above sea level. Our test site, Dongkemadi glaciers area (33.08N, 92.09E) in the central part of the Qinghai-Tibetan Plateau, which is located in the head region of the Buq river, on the northern slope of the Tanggula Mountain. A sanatake (nunatak) separates the glacier into two branches, Dadongkemadi Glacier and Xiaodongkemadi glacier. The Dadongkemadi glacier is 5.4 km in length, and the area is about 14.63 km<sup>2</sup>. The summit and terminal of the glacier is 5926 m and 5275 m, respectively. The Xiaodongkemadi Glacier is 1.8 km in length, and is a small valley glacier with an area of 1.76 km<sup>2</sup>. The Dongkemadi Glacier (Figure 1) is characterized by small relative height, gentle glacial surface, no avalanche in the back of the glacier, no surface moraine on the glacier [5].

We use the two kinds of SAR data (C-band and L-band) to extract the glacial border information. The ASAR data pair with C-band acquired from descending orbits at Jul. 10, 2007 and Aug. 14, 2007. The PAISAR data pair with L-band in ascending mode is selected at Jun. 11, 2006, Sep.11, 2006, Dec.10, 2007, and Jan.25, 2008 in the Dongkemadi glaciers area. The orbits parameters of two InSAR data are given in Table 1. The full polarimetric PAISAR data used in the Dongkemadi glacier is acquired with Radarsat-2 in Aug. 30, 2009.

Table 1. The orbit parameters of the test data for InSAR

Satellites	InSAR pairs	Temporal baseline (d)	Perpendicular baseline(m)
ALOS/PALSAR	20060611/20060911	92 D	1111
ENVISAT/ASAR	20070710/20070814	35 D	362

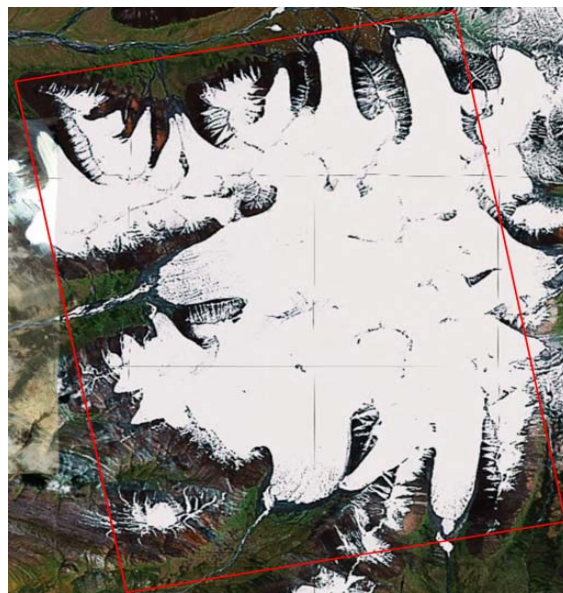


Figure 1. Dongkemadi Glacier test site optical image from Google Earth.

The other site area (30.19N, 94.51E) is located in south-east of the Tibetan plateau for full polarimetric SAR experiment. At high altitude regions, there are many alpine valleys of the landscape which form the large undulating terrain. For the intersection of the west wind and monsoon in this region, the precipitation is rich. The moist climate leads to the glaciers in the region have a huge accumulation of snow. The main features are: high-altitude region of glaciers and snow cover, vegetation in the high altitude and low-elevation valleys, rivers and lakes. The full polarimetric PAISAR data used in the second test-site is acquired with ALOS in Mar.11, 2007.

### 3. METHODS AND RESULTS

#### 3.1. Repeat-pass Interferometric Technique of the Classification methods

Measurements of interferometer correlation describe processes occurring on the time scales of the orbit repeat time and size scales on the order of a radar wavelength, such as vegetation growth, glacier motion, permafrost freezing and thawing, and soil moisture induced effects. The low coherence observed over wet snow cover is mainly caused by the rapid change in scattering properties and geometry as the result of wet snow metamorphism due to the movement of free liquid water content, ice grain growth, displacements of adjacent scatters, and formation of density heterogeneities (layering, ice-lenses, etc.), which all result in significant decorrelation. On the other hand, the high coherence is regularly observed over no-forested snow free areas.

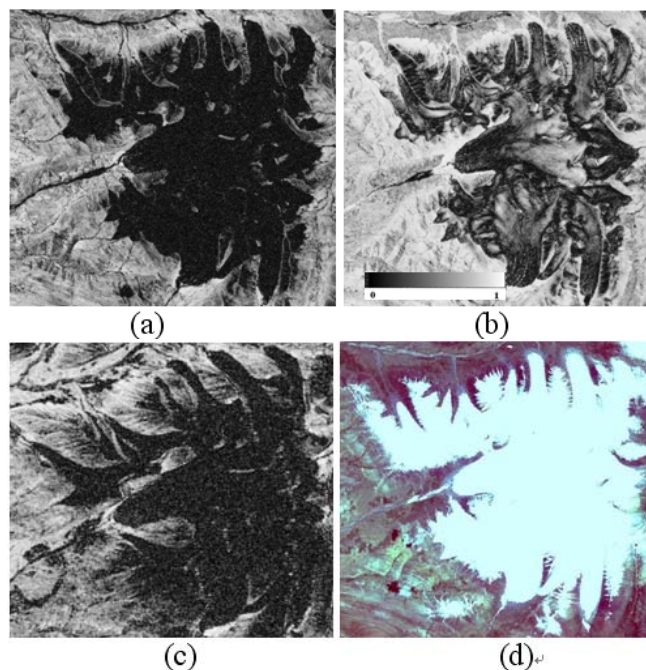


Figure 2. (a)The coherence coefficients image at the Dongkemadi glaciers area for PalSAR pair between Jun. 11, 2006 and Sep.11, 2006, (b)PalSAR pair between Dec. 10, 2007 and Jan.25, 2008, (c) ASAR pair between Jul. 10, 2007 and Aug. 14, 2007, (d) TM image in the same area.

We evaluated the coherence measurements between three pair repeat-pass ALOS/PALSAR and ENVISAT/ASAR image data from June of 2006 to January of 2008. The coherence coefficients of interferometric pair were calculated at different time interval and frequency. This measurement indicates that the coherence coefficients of glaciers are lower than other objects in Figure 2(a), which may be caused by the glacier motion, snow freezing and thawing, especially, in summer and autumn. Correspondingly, the coherence coefficients of glaciers in Figure 2(b) are higher due to short time interval which SAR pairs were obtained between Dec.10, 2007 and Jan.25, 2008. With this characteristic of low

coherence for glaciers, the area of glaciers can be extracted from other object. In Figure 2(c), though the time interval is shorter than Figure 2(a), the coherence coefficients of glaciers are lower for the ASAR's shorter wavelength. In a word, the L-band is suitable for the glaciers identification by a long period of change detection and the C-band is more sensitive to small changes on the glacier.

### 3.2. Polarimetry Techniques of the Classification methods

The full polarimetric SAR provides more information about object scattering characteristics. Figure 3(a) and Figure 4(a) respectively give the composite image from ALOS/PalSAR (Mar. 11,2007) and Radarsat-2 SAR(Aug. 30, 2009) full polarimetric SAR data with the Pauli decomposition. It has been shown that  $0.5*|S_{hh}+S_{vv}|$ (Red) determines the power scattered by targets characterized by single- or odd-bounce;  $2*|S_{hv}+S_{vh}|$ (Green) represents the scattered power by the targets of which scattering mechanism characterized by double- or even-bounce and  $0.5*|S_{hh}-S_{vv}|$ (Blue) relates to volume scattering. According to the color in Figure 3(a) and Figure 4(a), we can identify the glacier directly which indicates that the scattering mechanism of glacier is distinct, though the radar shadow has a great impact.

Because there is undulating terrain in southeast Tibet, the feature type changes dramatically along with it too. In order to better identify the scope of glaciers and snow cover, the various features of the classifications parameters need to be calculated. We classify firstly the basic scattering mechanism by the polarization decomposition, and then choose some valid parameters to solve the difficult to distinguish glaciers from the background.

The polarimetric backscattering behavior may be expressed in term of polarimetric coherency matrix  $T$ . It is a complex representation, widely used to characterize incoherent polarimetric scattering properties of natural media.

$$\mathbf{T}_3 = \mathbf{k}_{3p} \cdot \mathbf{k}_{3p}^H \quad (1)$$

where 
$$\mathbf{k}_{3p} = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{hh} + S_{vv} & S_{hh} - S_{vv} & 2S_{hv} \end{bmatrix}^T$$

Through the Cloud-Pottier polarimetric decomposition,  $H$ ,  $A$  and  $\alpha$  can be extracted from to characterize physical scattering characteristics [6, 8].

$$\mathbf{T}_3 = \mathbf{U}_3 \mathbf{\Lambda} \mathbf{U}_3^{-1} = \sum_{k=1}^3 \lambda_k \mathbf{u}_k \mathbf{u}_k^{*T} \quad (2)$$

where  $\mathbf{u}_k = \begin{bmatrix} \cos \alpha_k & \sin \alpha_k \cos \beta_k e^{j\delta_k} & \sin \alpha_k \cos \beta_k e^{j\gamma_k} \end{bmatrix}^T$ . To apply this method to our test-site, we get the

result that the range of alpha angle in the region of glacier is low than  $50^\circ$  from the sample statistics of H-Alpha (see from Figure 3 (b)) and at L band, a cluster is assigned to the surface class if  $\alpha < 45^\circ$  in the case of a single dominant scattering mechanism. According to this rule, we mask out the region of alpha in  $10^\circ \sim 35^\circ$ , and then the rest work is to subtract the volume scattering produced by the forest canopy.

In the microwave part of the electromagnetic spectrum, ice is almost transparent, and the radar penetration depth, depending on the frequency, can reach tens of meters for dry snow. The major scattering source is the snow-ground interface, and it is difficult to discriminate dry snow cover from bare surfaces or short vegetation with backscattering

measurements from a single-polarization radar measurements. In order to extract the glacier from the short forest, first, we sample of (3x3) complex coherence variance [T3] matrices from an image using the defined pixel coordinates; then apply the OPCE procedure [7] on the glacier and short Forest centers.  $(\psi_t, \chi_t)$  and  $(\psi_r, \chi_r)$  denote the transmit and receive polarization.

$$CR(\psi_t, \chi_t, \psi_r, \chi_r) = \frac{P_{target}(\psi_t, \chi_t, \psi_r, \chi_r)}{P_{clutter}(\psi_t, \chi_t, \psi_r, \chi_r)} \quad (3)$$

The optimal transmit polarization are as:  $g_0 = 1.00$ ,  $g_1 = 0.1914394$ ,  $g_2 = 0.1715749$ ,  $g_3 = -0.9663917$ , and optimal receive polarization is 3.072752.

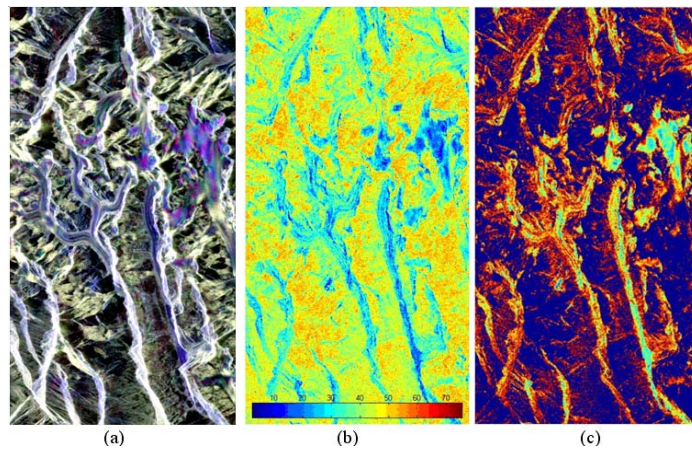


Figure 3. (a) The glacier at southeast of Tibetan plateau is codified by means of the Pauli decomposition with  $0.5*(Shh+Svv)/2:(Red)$ ,  $2*(Shv+Svh)/2:(Green)$ ,  $0.5*(Shh-Svv)/2 (Blue)$ . (b) The image of  $\alpha$  in test-site. (c) The glaciers distribution map.

The RadarSat-2 C band data in Dongkemadi area is taken as example for polarization classification. With combination parameters from Pauli decomposition (Fig4(a)) and Cloude decomposition, Decision Tree Classification algorithm and SVM(Support Vector Method) are used to classify in this area (Fig4(b, c)).

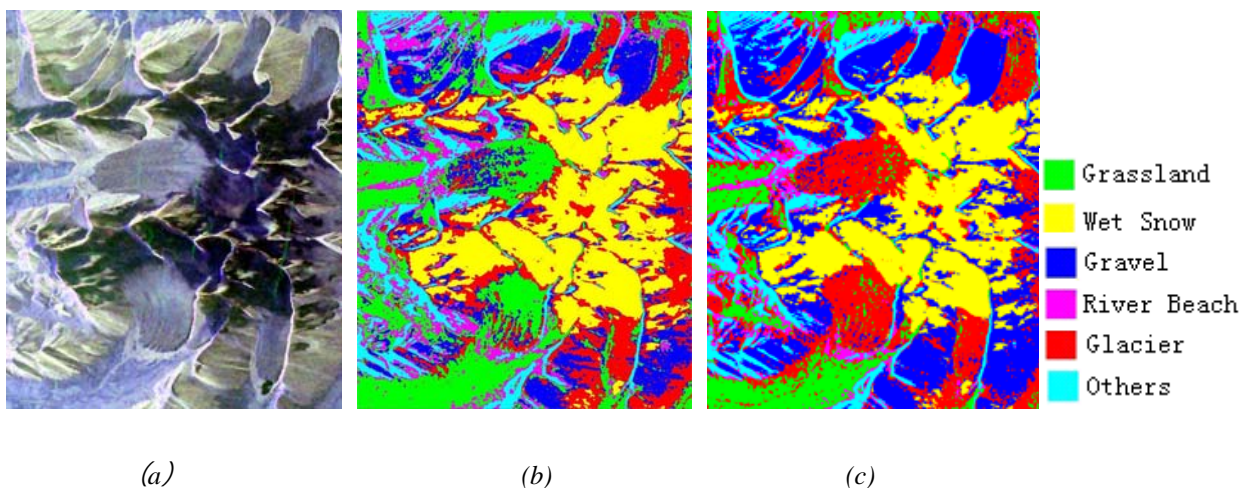


Figure 4. (a) The Dongkemadi glacier is codified by means of the Pauli decomposition; (b) The Dongkemadi glacier's classified image based on Decision Tree; (c) The Dongkemadi glacier's classified image based on SVM.

The classification results of two different methods are showed as followed (Tab. 2, 3). It can be observed that accuracy of glacier identification is only 34.51% with Decision Tree method, which is mainly because the hypothesis threshold value only uses the single scattering information of Pauli decomposed to separate this kind of target. Moreover, single scattering cannot contain all the object scattering information using single supervised classification parameter, which caused to confuse with grassland and gravel. Thus, more parameters can be added to solve this problem, such as parameters of Cloude decomposition, and the accuracy of glacier identification reach up to 86.74%.

*Table 2 Confusion Matrix of Decision Tree Classification for polarization data*

Classes	Grassland	Wet snow	Gravel	River beach	Glacier	Others	Total
Grassland	98.62	0	1.12	40.78	41.65	0	31.01
Wet snow	0	95.65	0	0	0.07	0	16.41
Gravel	0	0	85.75	1.36	23.76	0	29.48
River beach	1.3	0	0.59	45.57	0	0	2.65
Glacier	0.07	4.35	12.54	0.16	34.51	0	18.73
Other	0.02	0	0	12.13	0	100	1.72
Total	100	100	100	100	100	100	100

*Table 3 Confusion Matrix of SVM Classification for polarization data*

Classes	Grassland	Wet snow	Gravel	River beach	Glacier	Others	Total
Grassland	96.36	0.53	0	1.22	4.26	0	11.9
Wet snow	0	95.36	0.01	0	0.09	0	15.97
Gravel	0	0.01	98.91	6.33	8.86	0.08	25.66
River beach	0.41	0	0	48.54	0.04	0	2.53
Glacier	3.24	4.11	1.08	35.23	86.74	0	42.44
Others	0	0	0	8.69	0	99.92	1.5
Total	100	100	100	100	100	100	100

#### 4. DISCUSSION AND CONCLUSION

Integrating the backscattering intensity, we can make classification using the different of coherence degree for different surface type. Because of the complex terrain and movement for glaciers in the mountain regions, the fast changes of backscattering characteristic and the coherence of glacier surface will be completely decorrelation for the long temporal baseline (such as 35 days and 92 days) SAR image data. So the glacier can be separated from the other ground objects with different coherence coefficients in the Qinghai-Tibetan Plateau. The polarimetric response of glacier are distinguished in the Qinghai-Tibetan Plateau, thus glacier classification can be completed through the polarimetric decomposition and its related parameters. It has been proved that the multi-temporal repeat-pass interferometric technique and polarimetry techniques are efficient in glacier identification in Qinghai-Tibetan plateau. In the future, we will give the further researches on it, including the multi-temporal, multi-frequency and multi-polarization method.

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