GLACIER INFORMATION EXTRACTION BASED ON MULTI-FEATURE COMBINATION MODEL

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ABSTRACT:

As a typical landform class of Qinghai-Tibetan Plateau, glacier is widely distributed in alpine terrain. However, field measurement is impossible in those areas because of complex terrain and adverse weather. At first, on the basis of analyzing the features of glacier image spectrum, object shape, spatial relations and environment distribution including terrain and climate, this paper combines and develops the existing feature description algorithm of object-oriented method. Secondly, we build a series of combined extraction models for glacier landform by using high resolution remote sensing images and DEM data. At last, based on object-oriented method and combined extraction models, this paper tests glacier landform extraction in Qinghai-Tibetan Plateau study area of Western Mapping Project. Results demonstrate that the multi-feature combination model is feasible. The researches introduce a new approach to remote sensing auto-extraction of glacier information which is difficult to measure in the field. Moreover, the paper explores some new ideas in the researches of monitoring glacier ablation and climatic change.

1. INTRODUCTION

In recent years, the fact that the world's glacier is accelerating ablation has caused great concerns of native and international scholars (Aizen, 2007; Noferini, 2009; Scherler, 2008; Wolken, 2006; Yao, 2006). With an area of more than 2.5 million km^2, an average elevation of 4500m above, Qinghai-Tibet Plateau is located in Eurasia, which has unique alpine climatic characteristics of Qinghai-Tibet Plateau. As a typical landform landscape of the plateau, glacier is widely distributed in the alpine region. According to statistics of glacier catalogue in 2004, the glaciers area of Qinghai-Tibet Plateau covers about 47000 km^2, accounting for more than 80% total glacier area of China. Permafrost area is about 1.5 million km^2, accounting for more than 60% total area of Qinghai-Tibet Plateau (Pu, 2004). Glacier ablation of Qinghai-Tibet Plateau has great research value to the worldwide climate change. Therefore, the monitoring of glacier change is an important topic of current global change research. In the process of glacier ablation, retreat and thinning of glacier result in various types of glacial landforms. Based on remote sensing techniques, this paper explores to find a quick automatic extraction method of glacier information, which has great research significance to monitoring glacier ablation and global climate change.

Solely based on a single gray level or spectral information, traditional remote sensing image analysis methods often focus on gray-level statistical characteristics of image and calculate its variance, mean and other statistical parameters to achieve the purpose of image analysis. However, because the interrelated information of spatial characteristics contained in image is ignored, those image analysis methods often limit the accuracy of information extraction, even make wrong judgments since the rich information of shape, texture and context is treated as noise, resulting in the phenomenon of misjudgment and misclassification in image interpretation process (Chen, 2006; Tan, 2007). Compared to the traditional methods of image analysis, object-oriented approach, which primarily produces a certain criterion of polygon objects composed of homogeneous pixel cluster by image segmentation, is used in glacier information extraction of multi-feature combination. Further, we can extract varieties of landform classes based on the analysis of object features, including spectrum, shape, texture and spatial relations. This paper attempts to find a suitable combination model to describe glacier features and achieve the purpose of glacier information automatic extraction, which mainly includes the following steps: image segmentation, feature description and glacier information extraction of multi-feature combination model.

2. GLACIER IMAGE SEGMENTATION ALGORITHM

Image segmentation is a critical step of information extraction based on object-oriented method, in which its segmentation quality has a direct impact on image analysis accuracy. Image segmentation is a process that image is expressed as a number of region set , which fulfils the homogeneity standard including spectrum, shape and other features description while meeting the heterogeneity standards among the adjacent regions (Definiens, 2007). Starting from the pixel, the smaller homogeneous objects gradually merged into a large homogeneous image object by using region merging approach of bottom-up. Usually, in accordance with the different research purpose, image segmentation approaches are generally classified as three categories based on edge, region, and the mixture of the previous two.

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Since differences of target size and spatial structure still exist in high resolution remote sensing images, it is difficult to reflect the rich object and spatial semantic information only in a single spatial scale. Therefore, we need different scales to express and describe different size target. The structure of image object obtained in different segmentation scales represents different scales image object information, in which a smaller object is a child object of a larger object (Tan, 2007). Since each object has interrelated spatial feature information with adjacent objects, child object and parent object, the purpose of our experiment is to explore the spatial feature of interrelated objects and add it to the multi-feature combination model.

3. FEATURE DESCRIPTION

The purpose of information extraction is to distinguish interested regions in remote sensing image. There are different methods corresponding to different targets. Especially, some specific thematic objectives need to fully consider the characteristics of data (Datcu, 2002; Anthony, 1997; Zhou, 1999). Features description is object-oriented expression for latent knowledge in the primitive obtained from image segmentation. In addition to visual features such as spectrum, feature description also includes the object shape, spatial relationship and terrain features (Yang, 2009).

3.1 Spectrum features

In addition to traditional statistical value of image gray such as histogram, variance, mean, the normalized difference snow index is suitable for extracting glacier information since it is very sensitive to the changes of water content in snow and ice. In the following formula, ρ_{Red} is the red band reflectance and ρ_{Green} is the green band reflectance (Guo, 2003).

$$NDSI = \frac{\rho_{Red} - \rho_{Green}}{\rho_{Red} + \rho_{Green}} \quad (6)$$

3.2 Shape features

Generally, the boundary of ice cover is clear, around which there is often a large number of moraine. Meanwhile, some clear curved contours are left behind the ice tongue in the process of glacier retreat. In addition to the compactness and smoothness mentioned above, there are some shape indexes to describe glacier feature.

3.3 Spatial relation features

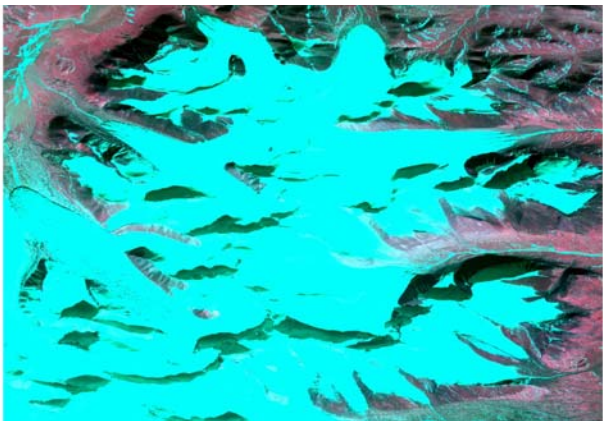
As for each object in the spatial relationship, we can calculate the mean difference among the objects, and give a weight according to border length or area size to achieve classification and clustering of object (Definiens, 2007). Some statistics can reflect the spatial distribution features of pixels enclosed by different object.

3.4 Terrain features

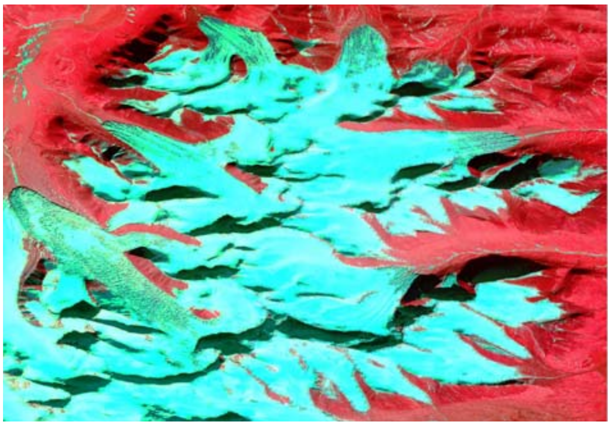
Glacier is distributed above the perennial snowline of the alpine region， in which valley glaciers are located in canyons of high mountain. Since the shapes of ice tongue, ice pillar and ice cliff are closely related to the terrain factor, the terrain features have more important role to the glacier information extraction. Digital elevation model (DEM) mainly describes spatial distribution of region landform, and can determine slope, aspect and relief degree of earth's surface (Song, 2007), so we can identify and extract glacier information by the DEM.

4. GLACIER INFORMATION EXTRACTION BASED ON MULTI-FEATURES COMBINATION MODEL

In our researches, the data we used are both of 2.5 m panchromatic and 10 m multi-spectral SPOT-5 images. After pretreatment, we select a sub scene fused image of eastern Qinghai-Tibet Plateau as trial data, with a rectangle area of 436 km^2. The original image is shown as Figure 1 (a), and the enhanced image by histogram is shown as Figure 1 (b). The glacier information extraction of multi-feature combination model mainly includes the following steps: (1) multi-scale image segmentation; (2) the bound identification of ice and snow; (3) glacier information extraction.



(a) Original image

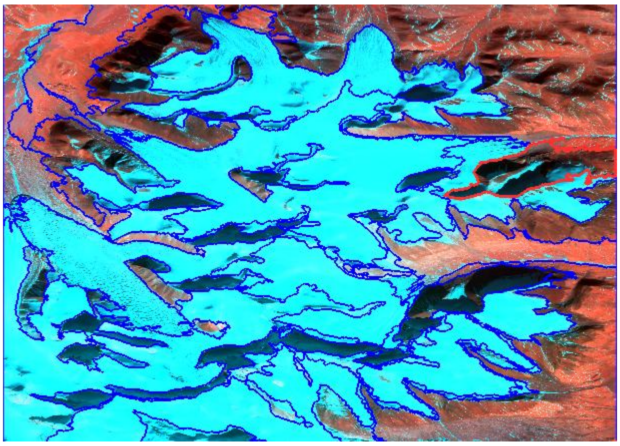


(b) Enhanced image

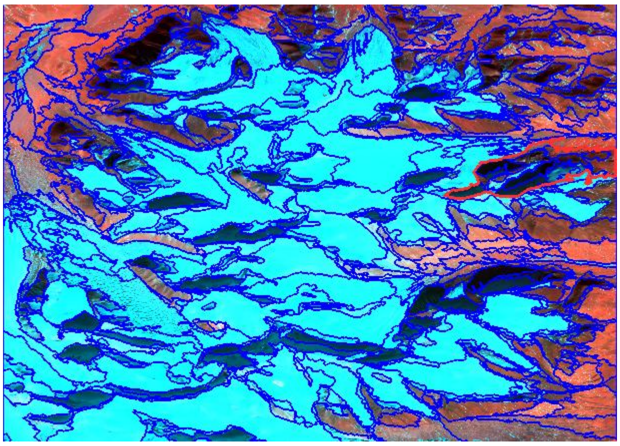
Figure.1 Image of Qinghai-Tibetan Plateau trial area

4.1 Multi-scale image segmentation

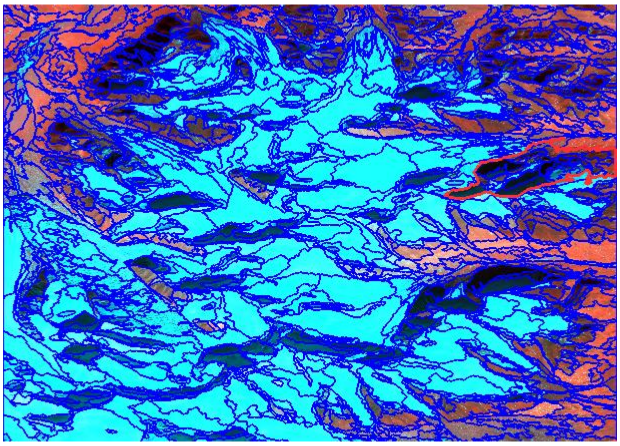
In the process of multi-scale image segmentation, we select 0.1 and 0.7 as the weight of shape and smoothness. Meanwhile, we set the segmentation scale as 500, 200,100 and 50 and get different results as Figure 2 (a) to (d), with 72, 354, 1036 and 3290 image objects, respectively. Obviously, over-segmentation phenomenon exists in the Figure 2 (c) and (d), and under-segmentation phenomenon exists in the Figure 2 (a) and (b).



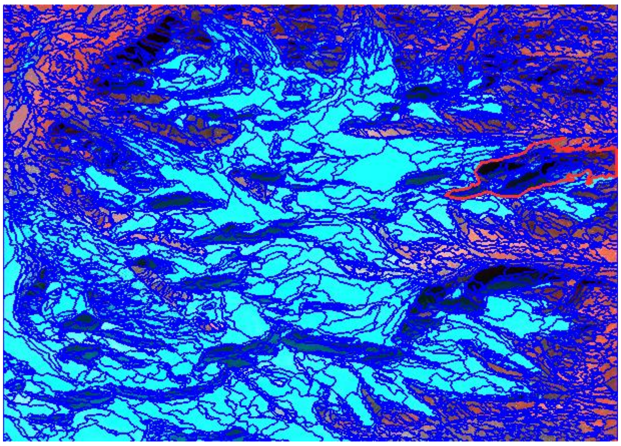
(a) segmentation scale is 500



(b) segmentation scale is 200



(c) segmentation scale is 100



(d) segmentation scale is 50

Figure.2 Image segmentation results in different scales

After repeated experiments, the image has the best segmentation results when the scale parameter is 150, the shape weight is 0.18 and the smoothness is 0.56. Under these conditions, the test image is segmented out 555 valid polygons, with medium size and even distribution.

For multiple object layer segmented in different scales, we can decide spatial membership by calculating the difference between adjacent objects and the difference between object and its supperobject or subobject. Usually, one superobject obtained in a larger segmentation scale can segment several subobjects. Because of the changes in spatial resolution, these subobjects may belong to or not belong to the class under superobject according to the subobject decision criterion. The ultimate purpose of segmentation is not segmentation, but re-clustering according to certain classification rules.

4.2 Glacier and snow boundary detection

Because glaciers and snow show a relatively strong reflectivity, it is easy to distinguish from the surrounding grassland and soil. However, it is difficult to distinguish the glaciers from snow. In our study, based on spectral analysis, we use an appropriate threshold of snow cover index to extract the common scope of glaciers and snow. In addition to snow and glaciers, the rest area is permafrost and tundra regions. Tundra is mainly distributed in the low zone of full sunlight, while most of the permafrost is distributed in the shady slope and valley areas. So we can further distinguish permafrost from tundra by using slope, aspect and spectral index analysis.

Since snows are different from glaciers and new snow gradually becomes coarse snow, the spectral reflectance of snow decreases over time and environment changes. Studies have shown that the best reflectance of new snow occurs in the wavelength range of 0.80 to 1.10μm, with reflectivity more than 80%, up to 95%, corresponding to MSS-7 band of Landsat. From the process of snow into glacier, the spectral reflectance gradually drops to around 60%. However, the best reflectance of glacier occurs in the wavelength of 3μm which is around the transition border of the mid-infrared to the thermal infrared. Basically, there is not reflection below 2.8μm. Due to the moraine and its uneven ablation, the reflectance of ice tongue gradually declines from 60% to 30% in the visible region (Song, 2007; Zeng, 1990). These features provide a new idea for extracting the boundaries of snow and glacier. Therefore, we can extract the boundary of new snow based on spectral calculation. Some regions covered by coarse snow and difficult to distinguish, can be classified as the scope of glaciers, taken into the next step to extract.

4.3 Glacier information extraction

Studies have shown that serac clusters appear in the process of glaciers retreat and thinning. Ice cliff is formed while the fracture is occurred during the glaciation. Usually, the leading edge and trailing edge of ice cliff have a certain high difference and slope. Serac clusters are mainly located in the relatively low altitude and flat areas, hence its relief degree is relatively small. On the contrary, the iceberg is mainly located in the relatively high altitude areas. Both of them have a clear change of arc-shaped contour in the image. Glacial lake is located in flat areas, while the moraine is mostly distributed in the leading edge of the ice tongue with a certain slope. In our combination extraction model, the glacial lakes and ice moraine are limited in the scope of 150 m below the snow line, mainly based on the recognized law of the temperature falls 6℃ by the altitude increase 1000 m. In theory, the temperature will rises 1℃ when the height decrease 150 m, so the possibility of emerging glacial lake and ice moraine is very small as the temperature difference. This information can be used in the combination extraction model as auxiliary decision data. Some glacier information extraction models developed in our study are described as follows:

Ice pillar: slope> 45°, 4π < roundness<15, and relief degree >0.8; Ice tongue: 0<ellipseness<100, 60° <main direction angle <120°, and relief degree<0.2; Serac clusters: 4π < roundness<15, slope> 30°, relief degree <0.2, and elevation is within 150m below the snow line; Glacier lake: slope<5°, spectral reflectance<10%, and elevation is within 150m below the snow line; Moraine: slope>15°, spectral reflectance<20%, and elevation is within 150m below the snow line.

In our researches, we design multi-feature combination model based on image spectrum, object shape, spatial relation, and terrain and climatic features of trial area. In theory, the model has a possibility that some glaciers do not belong to any of the rules. However, after the steps of border extraction of snow and glacier, and exclusion of snow scope through the mask, the remainder of the extraction area should be glacier types and very limited scope. Therefore, we can classify those objects which are attributed to glacier but not meet the combination extract model as other glacier type. Furthermore, we can add more description features to the model for further extraction research.

Based on above analysis, we extract 262 non-adjacent polygons of glacier class by using multi-feature combination model. Table 1 shows the statistical results of glacier information extraction. Figure 3 shows the glacier classification map. From the analysis of extraction results, the glacier information extraction based on multi-feature combination model is feasible.

Class	Amount	Area(km^2)	Proportion
Ice cliffs	28	26.2	6.01%
Ice pillar	37	25.6	5.87%
Glacier tongue	35	68.6	15.73%
Serac clusters	39	37.2	8.53%
Other glacier	29	56.7	13.00%
Glacial lake	3	0.8	0.18%
Moraine	32	21.6	4.95%
Permafrost	18	62.3	14.29%
Tundra	22	67.2	15.41%
Perennial snow	19	69.8	16.01%
Total	262	436.0	100.0%

Table.1 Statistical results of glacier information extraction

5. CONCLUSION

Multi-feature combination model can take full advantages of rich image spectrum, object shape, spatial relation, and terrain and climatic characteristics. But because the process from snow to glacier under the action of gravity is a long-term one, thickness and the particle size of snow bring difficulties to distinguish between snow and snow-covered glacier. Studies have shown that the model can achieve a good results as much as possible large segmentation scale in the condition of ensuring object accuracy. When we use the multi-feature combination model, the most typical features of object should first consider to be used by setting appropriate weight of shape, spectrum and spatial relation. When extracting ice tongue information, the main consideration feature is object shape; the main consideration feature is image spectral feature while extracting moraine. We need to comprehensively consider the features of the image spectrum, object shape, object spatial relation and terrain, climate auxiliary data of the region while extracting serac clusters, ice cliffs, ice pillar, and glacial lakes,. It is obvious that the accuracy of model is closely related the DEM resolution and image timeliness. Furthermore, we can add more description features and set flexibility threshold to further improve the extraction accuracy of the multi-features combination model.

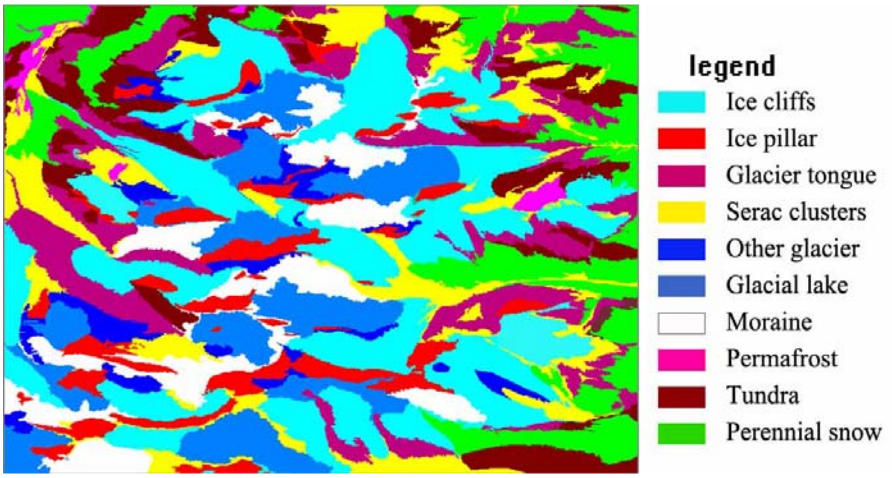


Figure.3 Results map of glacier landform class extraction

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