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Methods of glacier mapping using remote sensing techniques: review

Glacier mapping using remote sensing techniques has become popular in the past decade. This paper presents a review of glacier mapping methods using remote sensing. It also highlights the advantages and problems of remote-sensing-based glacier mapping. In addition, our previous experience on glacier mapping method are provided.It is concluded that semi-automated mapping of clean glacier ice is faster, not generalized and generating reproducible results, i.e. the same threshold values always generate the same outlines. This method can be the best method for glacier mapping comparatively large area.

Key words: methods of glacier mapping, manual delineation, automated mapping, remote sensing.

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Арақашықтықтан зондылау арқылы мұздықты картографиялау әдістері: шолу

Соңғы онжылдықта арақашықтықтан зондылау арқылы мұздықты картографиялау әдісі кең таралды. Бұл мақалада мұздықты картографиялаудың әдістеріне шолу жасалды. Сонымен қатар арақашықтықтан зондылауға негізделген картографиялаудың артықшылықтары мен кемшіліктері де қарастырылған. Мұздықты картографиялау бойынша алдыңғы тәжірибеміздің әдістері де көрсетілген. Ашық мұздықты жартылай автоматты картографиялау әдісі ең жылдам, генерализацияланбаған және қайта тексергенде сәйкес нәтижеге алып келетін әдіс болып қорытыланды. Бұл әдіс үлкен аймақтың мұздықтарын картографиялауда ең тиімді әдіс екені анықталды.

Түйін сөздер: мұздықты картографиялау әдістері, қолмен сызу, автоматты картографиялау, арақашықтықтан зондылау.

Калдыбаев А.А.

Методы картографирования ледников с использованием дистанционного зондирования: обзор

Методы картографирования ледников с использованием дистанционного зондирования стали популярными в последнее десятилетие. Эта статья представляет обзор методов картографирования ледников с использованием дистанционного зондирования. Также приведены преимущества и недостатки методов ДЗЗ. Кроме того, предоставлен наш предыдущий опыт по методу картографирования ледника. Установлено, что полуавтоматический методкартографирования чистого ледника быстрее, не генерализует результата и генерируют повторимые результаты, т.е. те же пороговые значения всегда генерируют те же контуры. Этот метод является лучшим способом для картографирования ледников сравнительно большой площади.

Ключевые слова: методы картографирования ледников, ручная оцифровка, автоматическое картографирование, дистанционное зондирование.

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METHODS OF GLACIER MAPPING USING REMOTE SENSING TECHNIQUES: REVIEW

Introduction

The principal goal of glacier mapping is to represent the spatial morphology of glacier terrain features on maps [1]. Glaciologists can use maps to obtain information about glacier variability, estimate mass balance, infer the morphometric status of glaciated regions, calculate changes in ice volume, and estimate the position of the equilibrium line.

Compared with the traditional methods which are always time-consuming, laborsome and sometimes unpractical spatially in isolated areas, remote sensing has been an excellent choice for analyzing glaciers in remote mountains and to monitor numbers of glaciers at the same time [2]. It cansave much money, time, manpower, material resources and also acquire information in isolated areas [3]. Automatic classification of glaciers and GIS-based extraction of glaciers from Landsat TM data have been widely recognized as highly valuable methods for glacier mapping. Much of work has been done to analyze glacier changes using remote sensing techniques [4, 5]. However, few studies have focused on comparison of different glacier mapping methods and selection of an appropriate mapping method.

This paper presents a review of glacier mapping using remote sensing. It also highlights the advantages and problems of remote sensing based glacier mapping. In addition, previous our experience on glacier mapping method are provided.

Manual delineation

Initial glacier inventory studies using remote sensing, such as by Williams [6]and Hall [7], started in Iceland and Austria, respectively, with the manual digitization of glacier boundaries on standard false colour composites of Landsat MSS and TM images. This method is time-consuming for larger areas, and its accuracy depends on the efficiency of identification and recognition of glacier terrain features on satellite imageries.Manually digitized glacier outlines differ in each digitization(even when performed by the same person), as the degree ofgeneralization (e.g. spatial averaging over several pixels,number of vertices used for the line, interpretation of subtledifferences in colour) varies each time. Hence, manualdigitizing gives inconsistent and generalized results that aredifficult to reproduce. This is also a point to consider forchange assessment.In Kazakhstan, almost all the glacier mapping techniques based on satellite imageries have been carried out by manual delineation [8, 9].

Automated glacier mapping

Automated mapping of glaciers involves image processing techniques on multispectral data such as simple band mathematics andclassification. Automated mapping of snow and ice is based on the fact that snow exhibits high reflectance in the visible and near-infrared region (VIS and NIR) as compared to short-wave infrared (SWIR) region of the solar spectrum.

The methods for automated glacier delineation can be divided these distinct group:

a) Image rationing based mapping of various snow and ice types [10-12];

b) Normalized Difference Snow Index (NDSI) based techniques [13-16];

c) Multispectral image classification based techniques [11, 17-19];

d) Fractional snow-cover or sub-pixel classification based techniques[20,21].

Study by Bayr et al. [22] proposed thresholds of a ratio image of TM-4 to TM-5 (NIR/SWIR) and TM-3 to TM-5 (RED/SWIR) ratio bands to delineate glacier ice area. Paul [12] evaluated both ratio image techniques and concluded that the TM-4 to TM-5 ratio technique is the more appropriate for clean-ice glacier mapping. The ratio RED/SWIR performs better in areas with dark shadow and thin debris cover [23,24]. A number of inventories used simple and robust ratio methods[12, 24, 25]. Research by Hall et al. [26] proposed the Normalized Difference Snow Index (NDSI, [VIS – SWIR] / [VIS + SWIR]) technique for identification of snow. Racoviteanu et al. [27] successfully used the NDSI for glacier mapping of Cordillera Blanca,Sidjak and Wheate [18]obtained best results using a combination of principal components two, three and four of the masked glacier area, the ratio TM-4/TM-5, and the NDSI. However, many valley glaciers throughout the world are coveredwith varying amounts of supraglacial debris cover, which having asimilar spectral response as that of the adjacent terrain cannot beclearly differentiated. Thus, delineation of debris-covered glaciersposes a major problem for rapid, automated inventorying of glaciersfrom satellite data.

Mapping of debris-covered glaciers

The general spectral similarity betweensupraglacial debris and adjacent unglaciated terrain (periglacial debrisand valley rock) renders them indistinguishable from remote sensingdata, which makes delineation of the actual glacier boundary difficult [28].

In previous studies, a variety of techniques have been reported formapping of debris-covered glaciers. Stokes et al. [29] carried outmanual digitization of debris cover on Landsat TM and ETM+imagesover the Caucasus Mountains, Russia and reported that retreat ofglaciers was accompanied by an increase in the overall areal extent ofthe debris cover. Bishop et al. [4] applied artificial neuralnetwork (ANN) classifier for estimation of debris cover over Himalayanglaciers. However,these studies concluded that sufficiently lower temperatures apt fordelineation of debris-covered glacier ice from surrounding terrain werefound only when thickness of debris cover did not exceed 40–50 cm.Kieffer et al.[30] analysed the DEM and observed that a distinctchange in curvature occurs at the contact of the glacier ice with thelateral moraine. Bolch and Kamp [31]applied morphometry-based glacier mapping (MGM) for some debris-covered glaciers in Alps, using clustering of curvature features (i.e., plancurvature and profile curvature). However, the DEM-based methodsrequire intense user interaction by specialists, encounter severelimitation in areas where the transitions between glaciated andunglaciated regions are smooth and not represented in the DEM and the availability of accurate DEMs over mountain regions is scarce.

Comparison of methods

According to comparative analysis of several glacier identification techniques by Paul et al. [32], the most efficient and accurate results for identification of glaciers were got with thresholding of ratio images (TM4/TM5), particularly for the glaciers located in shadow. The accuracy is better than 3% for debris-free glacier areas. Compared to other investigated methods, this method is easy and fast to perform, needs no special image-processing software, and interactive selection of the threshold value is quite robust. According to Paul et al. [32], the use of a median filter improves the results of the classification by removing misclassification (small snowfields, shadow pixels) and adding pixels where needed (small debris cover, glacier parts in shadow).

Paul et al.[33] concluded that automated delineation of debris-free glacier is better than hand delineation and recommended to use manual method only for required corrections of wrong identified glaciers (lakes, debris, shadows).According to published results [33], automated mapping of clean glacierice is at least as accurate as manual digitization, but glaciersizes tend to be a few per cent smaller than the referencedatasets. Automated mapping has the clear advantages ofbeing much faster, not generalized and generating reproducible results, i.e. the same threshold values always generatethe same outlines. Manual digitization should thus focus onthe correction of automatically derived outlines to cope withthe typically problematic issues such as debris cover or ice inshadow.

Our experience

In our previous study [34] we have used a well-established semi-automated method utilizing the TM3/TM5 bands to glacier area delineation. We visually examined delineated glaciers for gross errors, and edited them by hand where needed. Glaciers with debris-cover, glacial lakes, snow patches and the data gaps only in SLC-off scenes results main reasons of errors. Additionally, the ETM+ pansharpened images were also used to mapping the most likely margin. Moreover, a 3 by 3 median filter was applied which only marginally alters the glacier size but eliminates isolated pixels. These are often wrong pixels because of debris or boulders on the ice cover. Supraglacial debris cover is a cause resulting to the bigger error of the glacier outline. However, in our study area, the glaciers were almost free of debris cover. We have used the glacier area from the 1989 image as a mask to minimize misclassification due to certain factors, such as seasonal snow cover. When using this mask, we assumed that glaciers did not advance between 1989 and 2012. This consistency is important in the case of seasonal snow that hampers correct identification of the upper glacier boundary [35]. Only the glaciers that were bigger than 0.01 km^2 were delineated in our study, small ice bodies are quite difficult for identification if they are snow or ice. Where an ice bodies had divided into the parts, the net area change in a research time was based on the total area of the parts.

In our study, the error was calculated by the buffering technique advised by Bolch et al. [35] and Granshaw &Fountain [36]. The buffer size was chosen to be half of the estimated RMSE, i.e. 7.5 m to each side. The resulting accuracy was within ±5%.

Summary

This review provides a comprehensive overview of the constraints and challenges relating to mapping of clean-ice and debris-covered glaciers, the comparison of methodsbased on remote sensing techniques. According to results of comparison, the most efficient and accurate results for identification of glaciers were got with thresholding of ratio images. This semi-automated method was successfully used in our previous investigation with the accuracy within ±5%.

Semi-automated mapping of clean glacier ice is faster, not generalized and generating reproducible results, i.e. the same threshold values always generatethe same outlines. This method can be the best method for glacier mapping comparatively large area.

References

1 Bhambri R, Bolch T (2009) Glacier mapping: a review with special reference to the Indian Himalayas. Progr. Phys. Geog. 33 (5):672-704.

2 Paul F, Huggel C and Kääb A (2004) Combining satellite multispectral image data and a digital elevation model for mapping debris-covered glaciers. Remote Sens. Environ. 89:10-518.

3 Hall DK, Benson CS, Field WO (1995) Changes of glaciers in Glacier Bay Alaska, using ground and satellite measurements Phys. Geog. 16:27-41.

4 Bishop MP, Kargel JS, Kieffer HH (2000) Remote-sensing science and technology for studying glacier processes in high Asia. Ann. Glaciol. 31(1):164-170.

5 Ventura AD, Rampini A, Rabagliati R (1987) Development of a satellite remote sensing technique for the study of alpine glaciers Int. J. Remote Sens. 8(2):203-215.

6 Williams MW (1986) Glacier inventories of Iceland: evaluation and use of sources of data. Ann. Glaciol. 8:184–91

7 Hall DK, Williams RSJr, Bayr KJ (1992) Glacier recession in Iceland and Austria. EOS, Transactions of the American Geophysical Union 73:135-41.

8 Severskiy IV, Vilesov EN, Kokarev AL, Shesterova IN, Morozova VI, Kogutenko LV, Usmanova ZS. (2012) Lednikovye sistemy Balkash-Alakol'skogo bassejna: sostojanie, sovremennye izmenenija. Probl. Geogr. Geoecol. 2: 31-40 (in Russian).

9 Vilesov EN, Morozova VI and Severskiy IV (2013) Oledenenie Dzhungarskogo (Zhetysu) Alatau: proshloe, nastojashhee, budushhee. Volkova, Almaty (in Russian).

10 Hall DK, Chang ATC, Siddalingaiah H (1988) Reflectances of Glaciers as calculated from the Landsat 5 Thematic Mapper data. Rem.Sens. Environ. 25:311-321.

11 Bronge L, Bronge C (1999) Ice and snow type classification in Vestfold Hills, East Antarctica, using LANDSAT TM data and ground radiometer measurements. Intern. J. Rem. Sens. 20(2):225-240.

12 Paul F (2000) Evaluation of different methods for glacier mapping using LANDSAT TM. EARSEL eProceedings No.1:239-244

13 Dozier J (1989). Spectral signature of alpine snow-cover from the Landsat Thematic Mapper. Rem. Sens. Envir, 28:9-22.

14 Winther JG, Hall DK (1999) Satellite derived- snow coverage related to hydropower production in Norway: Present and future. Intern. J. Rem. Sens. 20(15–16):2991-3008.

15 Silverio W, Jaquet JM (2005) Glacial cover mapping (1987–1996) of the Cordillera Blanca (Peru) using satellite imagery. Rem. Sens. Envir. 95(3):342-350.

16 Gupta RP, Haritashya UK, Singh P (2005) Mapping dry/wet snow cover in the Indian Himalayas using IRS multispectral imagery. Rem. Sens. Envir,97(4):458-469.

17 Aniya M, Sato H, Naruse R, Skvarca P, Casassa G (1996). The use of satellite and airborne imagery to inventory outlet glacier of Southern Patagonian Icefield, South America. Photogr. Engineering Rem. Sens, 62:1361-1369.

18 Sidjak RW, Wheate R D (1999) Glacier mapping of the Illecillewaet icefield, British Columbia, Canada, using Landsat TM and digital elevation data. Intern. J. Rem.Sens. 20(2):273-284.

19 Shukla A, Gupta RP, Arora MK (2009) Estimation of debris-cover and its temporal variation using optical satellite sensor data – a case study in Chenab basin, Himalayas. J. Glaciol, 55(191):444−451.

20 Rosenthal W, Dozier J (1996) Automated mapping of montane snow-cover at sub-pixel resolution from the Landsat Thematic Mapper. Water Res Research 100:115−130.

21 Salomonson VV, Appel I. (2004) Estimating fractional snow-cover from MODIS using the normalised difference snow index. Rem.Sens. Envir. 89: 351−360.

22 Bayr IJ, Hall DK, Kovalick WM (1994) Observations on glaciers in the eastern Austrian Alps using satellite data. Int. J.Rem. Sens. 15:1733–42.

23 Paul F, Kääb A (2005) Perspectives on the production of a glacier inventory from multispectral satellite data in Arctic Canada: Cumberland Peninsula, Baffin Island. Ann. Glaciol. 42:59–66.

24 Andreassen LM, Paul F, Kääb A, Hausberg JE (2008) Landsat-derived glacier inventory for Jotunheimen, Norway, and deduced glacier changes since the 1930s. Cryosphere 2:131–45.

25 Bolch T (2007) Climate change and glacier retreat in northern Tien Shan (Kazakhstan/Kyrgyzstan) using remote sensing data. Glob. Planet. Change 56:1-12.

26 Hall D., Riggs GA, Salomonson VV (1995) Development of methods for mapping global snow cover using Moderate Resolution Imaging Spectroradiometer (MODIS) data. Rem. Sens. Environ. 54:127-40.

27 Racoviteanu AE, Arnaud ., Williams MW and Ordonez J (2008) Decadal changes in glacier parameters in the Cordillera Blanca, Peru, derived from remote sensing. J. Glaciol. 54:499-510.

28 Kargel J, Abrams M, Bishop M, Bush A, Hamilton G, Jiskoot H (2005) Multispectral imaging contributions to global land ice measurements from space. Rem.Sens. Environ 99:187-219.

29 Stokes CR, Popovnin V, Aleynikov Gurney SD, Shahgedanova M (2007) Recent glacier retreat in the Caucasus Mts, Russia, and associated increase in supraglacial debris cover and supra/proglacial lake development. Ann. Glaciol. 46:195-203.

30 Kieffer HH, Kargel JS, Barry R, Bindschadler R, Bishop M, Mackinnon D (2000). New eyes in the sky measure glaciers and ice sheets. Eos, Transactions of the American Geophysical Union, 81:270-271.

31 Bolch T, Kamp U (2006) Glacier mapping in high mountains using DEMs, Landsat and ASTER Data. Grazer Schriften der Geographie und Raumforschung (Proceedings of the 8th International Symposium on High Mountain Remote Sensing Cartography, 20–27 March 2005, La Paz, Bolivia) 41:13-24.

32 Paul F, Kaab, Maisch M, Kellenberger T, Haeberli W (2002) The new remote-sensing-derived Swiss glacier inventory: I. Methods. Ann.Glaciol. 34:355-361.

33 Paul F and 19 others (2013) On the accuracy of glacier outlines derived from remote-sensing data. Ann. Glaciol., 54(63 Pt 1):171-182 (doi: 10.3189/2013AoG63A296).

34 Kaldybayev A, Yaning Chen Y, Vilesov E (2016) Glacier change in the Karatal river basin, Zhetysu (Dzhungar) Alatau, Kazakhstan. Annals of Glaciology, 57(71). doi:10.3189/2016AoG71A005.

35 Bolch T, Yao T, Kang S, Buchroithner MF, Scherer D, Maussion F, Huintjes E, Schneider C (2010) A glacier inventory for the western Nyainqentanglha Range and Nam Co Basin, Tibet, and glacier changes 1976–2009. Cryosphere 4:419-433.

36 Granshaw FD, Fountain AG (2006) Glacier change (1958-1998) in the North Cascades National Park Complex, Washington, USA. J. Glaciol. 52(177):251-256.