EVALUATION OF DIFFERENT METHODS FOR GLACIER MAPPING USING LANDSAT TM

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ABSTRACT

Since 1985 a variety of different glacier mapping methods with Landsat Thematic Mapper (TM) have been developed. Although some valuable results have been achieved, they have not been compared to each other and have been applied only to a small number of glaciers. Starting with manual delineation of glacier margins with a cursor, going on to segmentation of ratio images and ending at supervised classification techniques the computational effort increases rapidly. The study presented here evaluates the relative accuracy of each method. For error analysis fusion with a higher resolution data set (SPOT Pan) is performed.

INTRODUCTION

Presently, the USGS-led GLIMS project (Global Land Ice Measurements from Space) is compiling a global inventory of land ice masses mainly using data from the ASTER radiometer on board the satellite Terra (Kargel 2000). Inside this project a pilot study is carried out at the University of Zurich, which will result in a new Swiss Glacier Inventory for the year 2000 (SGI 2000) derived from satellite imagery. A first step is an evaluation of different methods for glacier mapping using Landsat TM (Thematic Mapper) data, which have been developed during recent years. Although useful results have been achieved with these methods, they have not been compared with each other. The results of this comparison are presented here. Moreover, a down-scaling approach is carried out by comparing the TM derived glacier size with results from a higher resolution data set (SPOT Pan) for assessment of absolute accuracy. In addition, but not presented here, an automatic GIS based extraction of individual glaciers and the calculation of glaciological parameters by fusion with a digital elevation model (DEM) is developed.

All glacier mapping methods presented here have been previously discussed in the literature (see below) and were applied to a Landsat TM scene from 30.9.1985 within a small test region (15km × 20km in size) located in the Weissmies area, Switzerland (Figure 1). Many glaciers of the area are covered by debris. Parts of some glaciers are situated in cast shadow. Both tasks are mentioned as presenting problems in previous studies. The highest elevations reach 4000m.

METHODS

Different glacier mapping methods can be found in the literature. They can be roughly divided into 3 groups:

a) manual delineation of the glacier outline, b) segmentation of ratio images, and c) various supervised and unsupervised classification techniques.

Manual delineation

Cursor tracking of glacier outlines was applied especially to Landsat MSS data in combination with false colour composites from Landsat TM of other years. Especially length changes were derived and compared with in-situ measurements (Hall et al. 1992, Williams et al. 1997). Manual delineation was also used from Rott and Markl (1989) for individual glaciers in the Ötztaler Alps in Austria. For a larger number of glaciers this method is too laborious.

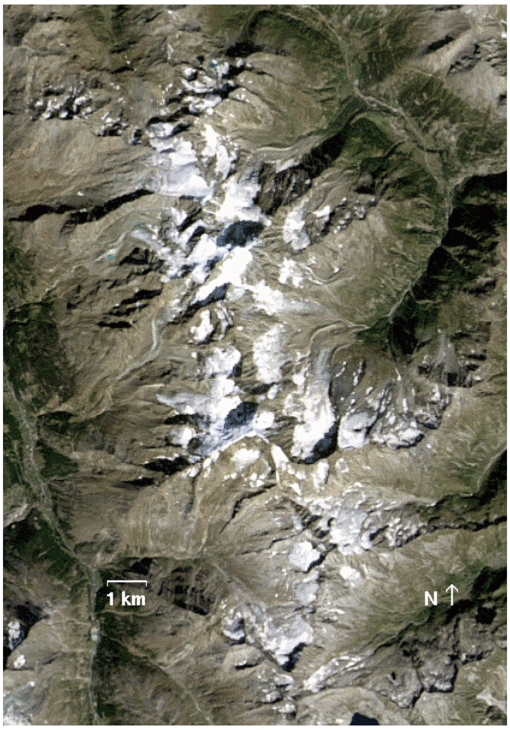

Figure 1. The test area Weissmies Group, Switzerland, as seen with Landsat TM channel 3 after contrast stretch. Size is about 15 km x 20 km, north is at top. Landsat TM data: © ESA

Segmentation of ratio images

This method was used in various combinations. Ratio images of the raw digital numbers (DN) from TM channel 4 (TM4) and TM5 were thresholded to obtain a glacier mask from Bayr et al. (1994). The planetary reflectance at the satellite sensor is treated by Hall et al. (1988) to depict different ice and snow facies within a glacier. Rott (1994) and Jacobs et al. (1997) used atmospherically corrected spectral reflectance images with TM3 / TM5 and TM4 / TM5, respectively, to obtain a glacier mask after thresholding.

Unsupervised and supervised classification

An unsupervised ISODATA clustering with TM channels 1, 4 and 5 was performed by Aniya et al. (1996) for classification of the entire South Patagonian Icefield. A supervised Maximum-Likelihood classification is applied to Landsat MSS and TM scenes with support of a GIS by Gratton et al. (1990). Although high accuracy is achieved for most classes, regions with debris cover had to be classified by visual inspection. An evaluation of different ice and snow mapping methods was carried out by Sidjak and Wheat (1999). The best results were achieved by applying a supervised Maximum- Likelihood classification to a combination of various input bands with a TM4 / TM5 ratio image, a natural difference snow index (NDSI), and the components 2-4 from a principal component analysis (PCA).

DATA HANDLING

Previous to the comparison of different glacier mapping methods the TM scene has to be georectified. Firstly, because fusion with a DEM is performed for atmospheric and terrain correction, as well as to obtain glaciological parameters from it. Secondly, because fusion with the digitized glacier outlines from the Swiss Glacier Inventory of 1973 is carried out, to obtain the divides between the individual glaciers consistent with the inventory data. Moreover, the fusion with SPOT Pan images requires georectification. This fusion is carried out between the glacier outline from SPOT Pan, which is obtained by manual delineation, and the outline from Landsat TM data, which is derived automatically. The SPOT Pan scene was acquired on 17.9.1992 and georectified with an average rms error of 5m.

In the structured terrain of the Swiss Alps with its large relief variations at a small scale a high resolution digital elevation model (DEM) is needed for georectification. Also correction of local illumination (zones with cast shadow) during the atmospheric correction process requires such a DEM. In this study a DEM product with 25m ground resolution is used (Swiss Federal Office of Topography), which is generated from digitized contour lines. Artefacts from this interpolation process are visible in the atmospherically corrected image and are notably pronounced in gradient products like slope.

All black and white glacier masks from the segmented ratio images were filtered with a 3×3 median filter before combination. In Figure 2 the influence of this filter is displayed with the best glacier mapping method: TM4 / TM5 from raw DN. Pixels in blue were added, those in red deleted with the filter. A more detailed analysis reveals, if glaciers smaller than 0.1 km^2 were excluded, the average decrease in glacier area is -0.4%. Hence, the influence of the median filter on the glacier mask can be neglected.

Only the raw DN from TM channels 1-5 revealed good results using the unsupervised ISODATA clustering. The 20 clusters were separated into snow / ice and other. Also the supervised Maximum-Likelihood classification is based on the raw DN from TM channels 1-5. Different samples of training areas were selected for classification and only the best classification result is presented here. The overall accuracy of the 10 classes reached 95%. Furthermore a NDSI was calculated and a PCA was performed. The results of both methods are not presented here, because they turned out to be not suitable for glacier mapping.

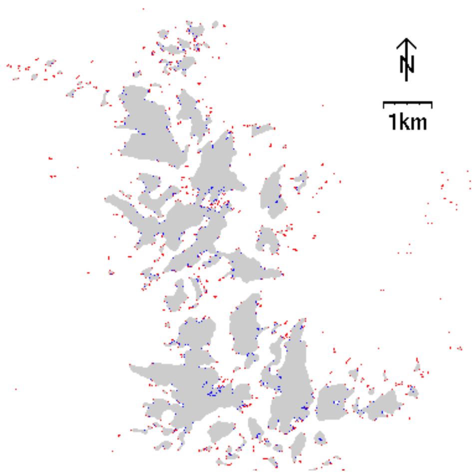

Figure 2. The influence of the 3 ´ 3 median filter on the black and white glacier mask from TM 4 / TM 5 using raw DN is shown. The blue pixels were added, the red pixels deleted with the filter.

RESULTS

Relative comparison of different glacier mapping methods

In Figure 3a-f the resulting glacier masks are shown for a subset of Figure 1 comparing two methods at a time. Glacier areas that were mapped from both methods are shown in grey. With the exception of Figure 3b, all areas in blue are mapped as snow and ice only from a thresholded ratio

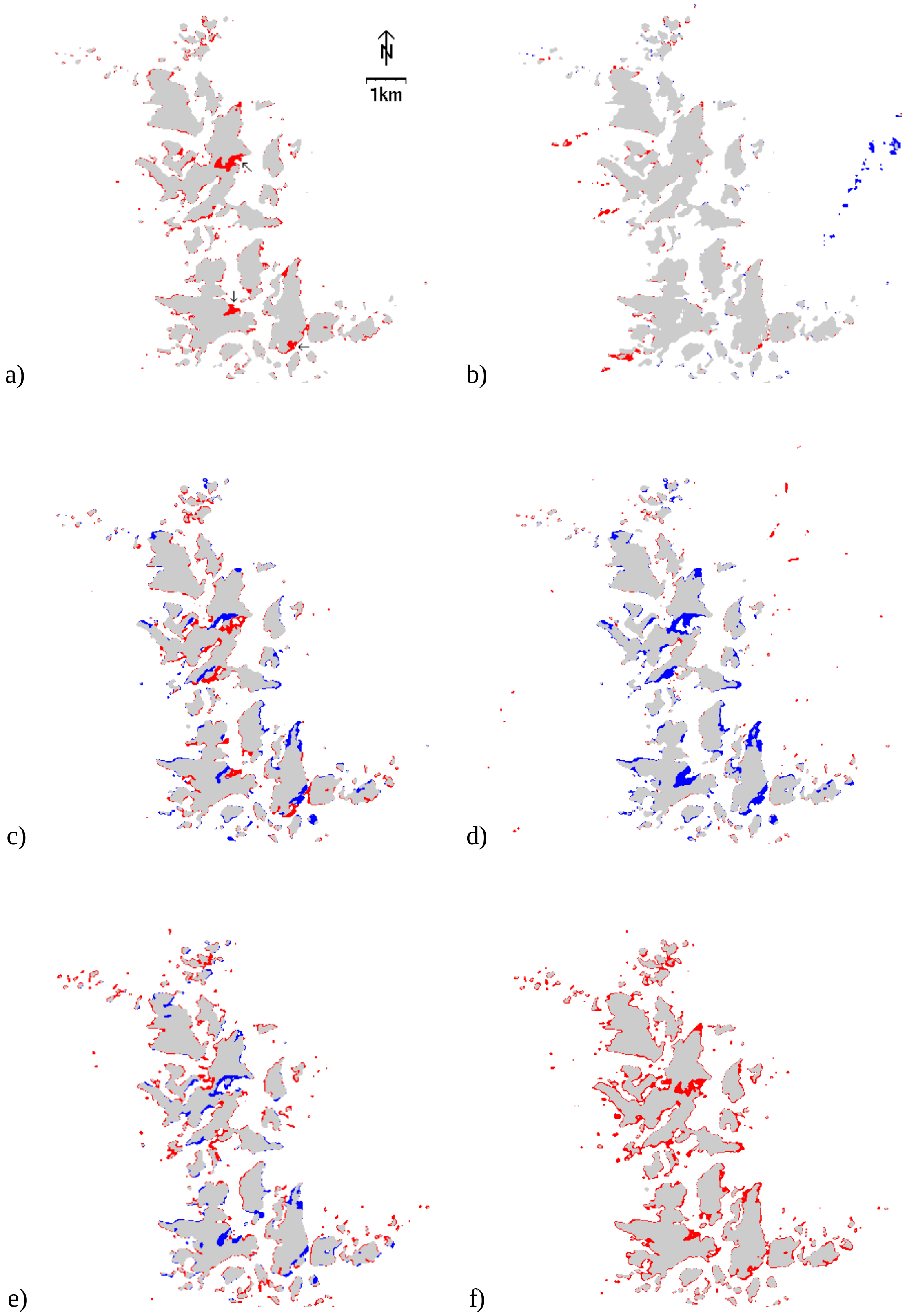

Figure 3. Glacier masks obtained from: a) TM 3 / TM 5 and TM 4 / TM 5 from DN. b) As 2a) but from satellite planetary reflectance. c) As 2a) but with TM 3 / TM 5 using atmospherically corrected reflection. d) With TM 4 / TM 5 from DN and atmospherically corrected reflection. e) With TM 4 / TM 5 from DN and ISODATA clustering with 20 clusters. f) With TM 4 / TM 5 from DN and Maximum-Likelihood classification with 10 classes. See text for discussion.

image with TM4 and TM5 using the raw DN. Additional glacier areas from the other method are depicted in red.

In Figure 3a a ratio image with TM3 / TM5 from raw DN is used for comparison. The indicated red areas (arrow) refer to regions with cast shadow (c.f. Figure 1), but without ice or snow, as can be seen by visual analysis. Thus, glacier areas would become too large with TM3 / TM5. Moving the threshold towards the grey value, where these regions were excluded, will simultaneously decrease the glacier area (not affected by cast shadow).

In Figure 3b the glacier masks from TM3 / TM5 (grey and red) and from TM4 / TM5 (grey and blue) using the satellite planetary reflectance are shown. Both masks are too large in regions with cast shadow (as shown in Figure 3a). Moreover they map snow and ice in some additional regions with cast shadow.

In Figure 3c comparison with atmospherically corrected reflectance from TM3 (R3) and TM5 (R5) as the input for a ratio image is carried out. Differences appear especially in regions with cast shadow. Here, TM4 / TM5 from DN reveals clearly the better results. In Figure 3d R4 / R5 is used for comparison. Here, the blue areas indicate regions with snow and ice in cast shadow or with thin debris cover. They were completely missed with R4 / R5.

The comparison with the ISODATA clustering is depicted in Figure 3e. Ice and snow in cast shadow is partly unmapped (blue areas) instead of the red areas, which includes mainly snow fields outside of glaciers.

In Figure 3f the comparison is carried out with the glacier mask from the Maximum-Likelihood classification. Regions in cast shadow without glacier ice and also the mixed pixels with ice / snow and terrain along the glacier outline are mapped as glacier. Thus, also this method reveals larger glacier areas than obtained with TM4 / TM5.

Comparison with SPOT Pan

To illustrate the accuracy of the TM 4 / TM 5 glacier mapping method, the outline of the Gries Glacier from TM is superimposed on a SPOT Pan scene (Figure 4). Because the TM scene was acquired in 1985 and the SPOT scene in 1992, differences occur in regions indicated with number 1 in Figure 4. Debris cover is not detected with TM in regions where the arrows with number 2 points to. The arrow with number 3 indicates a region where glacier ice is present on a steep slope in cast shadow. The latter is included with TM, if the threshold is moved towards the darker pixels in the ratio image. The arrow with number 4 point to the top of a high crest where georectification is insufficient.

The glacier area in the year 1992 (1985) derived from TM is 6.46 (6.51) km^2, if debris cover is considered. The glacier area inside the manual outline from the SPOT Pan image in 1992 is 6.41 km^2 (including debris cover). Thus, the accuracy of the TM derived glacier areas is better than 1%. Forthcoming investigations need to confirm this value.

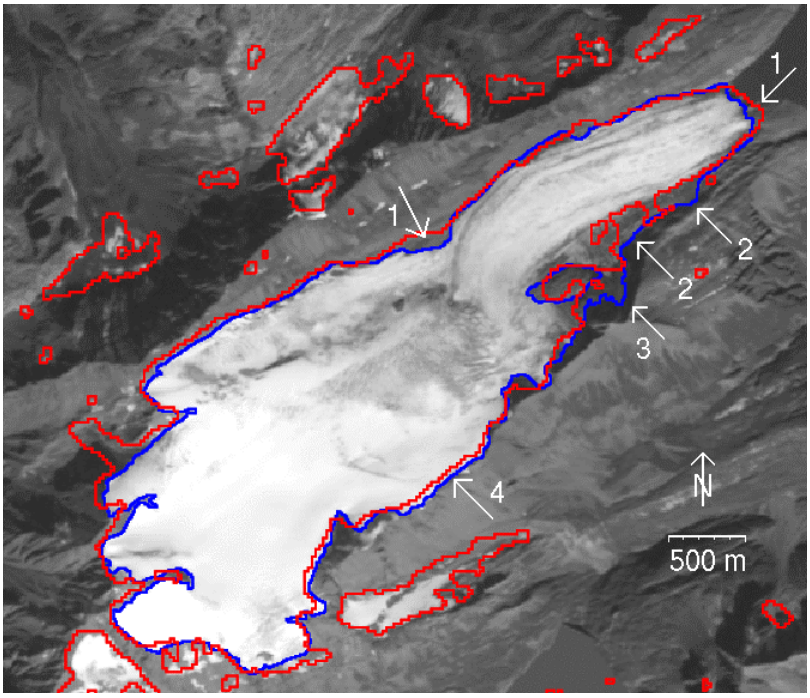

Figure 4. Gries Glacier with a manually created outline (blue) on a SPOT Pan scene from 17.9.1992. Superimposed is the TM derived glacier outline (red) from 30.9.1985. See text for numbers. SPOT Pan data: © SPOT Image.

CONCLUSIONS

It has been shown that from the investigated methods the segmentation of a ratio image from TM4 / TM5 with raw DN reveals the best results for glacier mapping in this test area, especially in regions with cast shadow. The influence of a median filter on the black and white glacier mask can be neglected. Compared with the glacier outline on a SPOT Pan image, the main differences occur in regions with debris cover. If those regions were added manually to the TM derived glacier mask, the absolute accuracy is in the order of 1%.

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