Determining of the Equilibrium Line on an Alpine Glacier Using Remote Sensing Data Fusion Techniques

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Abstract - High-resolution remote sensing satellite data serve as a source for equilibrium line (EL) analysis on top of glaciers. Data fusion techniques are used in order to take advantage from both the multispectral and panchromatic information available from simultaneously acquired IRS-LISS and -PAN recordings. As a result of segmentation between snow and ice the EL is derived based on multispectral classification of the fused data.

INTRODUCTION

The Equilibrium Line (EL) on top of glaciers indicates the boundary between accumulation and ablation areas and shows changes in the net mass balance at the end of a given year which is important for long time glacier monitoring. The EL of temperate glaciers coincides with the snow line — which is the line between snow and ice — at the end of the melt season [4]. From the yearly change of the EL evaluations of the glacier net mass balance can be derived [5]. However, especially on flat glaciers the EL is not a straight line but is typically irregularly shaped due to the snow distribution on top of the glacier and it is not easily assessable from in situ measurements.

Since snow and ice differ in their spectral reflection it is possible to detect the EL from multispectral remote sensing images, but data with high spectral and geometrical resolution is needed [3]. In our approach we use data from the IRS-1C satellite which acquires simultaneously both multispectral images with coarse spatial resolution and panchromatic images with high spatial resolution. We use data fusion techniques to combine both data types in one image. The fused image permits a precise segmentation of snow and ice for a reliable detection of the EL.

METHOD

Geometrical co-registration

The used IRS-1C images cover the region of Valais in the Western Alps (4900 km², 400 m – 4634 m a.s.l.) and were acquired on 20 September 1997, shortly before the first winter snowfall event. Both the panchromatic image (PAN, 5.8 m resolution) and the multispectral image (LISS, 23.5 m resolution) have been orthorectified using a DEM of 25 m grid resolution. Further the LISS imagee was geometrically co-registered to the PAN image as reference [1]. The analysis has been carried out for a detail of the Findelen Glacier, 4 km east of Zermatt, Switzerland, a small subframe of the above mentioned image dataset.

Data Fusion

For the data fusion of PAN and LISS conventional methods at pixel level have been used. The result should support the mentioned segmentation process between snow and ice. The methods used extract details from the high resolution image and insert them into the low resolution multispectral images.

First, we investigate the IHS technique [9]. After performing the inverse transformation the radiometry of the spectral channels is modified which is taken as a disadvantage especially for visual inspection. This is due to the fact that the PAN image usually has a different spectral characteristic as the intensity channel of the LISS image. For reducing this problem histogram matching has been applied.

Second, we investigated the wavelet approach to data fusion: In the Eighties the wavelet transform [10], [2], has been established as a mathematical tool to transform a signal into an approximation and a detail (for an overview see [7] [8]). The approximation carries only the low frequency information so that it can be interpreted as a low resolution version of the signal. Recursive application of the transform to the approximation leads to a pyramid of approximations at successively lower resolutions.

The steps in our scheme for the application of the wavelet transform to data fusion are:

1. Transform the high resolution PAN image in an approximation of the same resolution as the LISS image and the complementary detail.
2. Replace the approximation in the transformed image by one channel of the LISS image.
3. Modify the detail to match the spectral characteristics of the corresponding LISS channel.
4. Perform an inverse transform.

These steps have to be repeated for each channel of the LISS image. The difficult point is the modification of the
detail in order to preserve the spectral characteristics of the LISS image. It has been shown that the ARSIS algorithm [6] yields a very good preservation of the spectral features. In our work, we obtain a satisfactory result by matching the variance of the PAN detail to the detail-variance estimated from the LISS image.

Segmentation of snow and ice

Investigations using common line detection algorithms and filters showed dissatisfying results for the EL, because many line features like crevasses and moraines respond with stronger edges than the interesting line between snow and ice which is more distinguished by spectral differences. It is more advantageous to use multispectral classification, but a simple threshold method reaches its limits at the differentiation of old snow and ice. For detecting the EL we classify the transformed images with Maximum Likelihood into the feature classes snow, ice and rocks. The boundary between snow and ice indicates the EL. For a more significant and pronounced EL small snow-patches on ice (up to 100 m²) have been eliminated. Fig. 1 shows the ELs resulting from the images. Depending on the data the EL exhibits a varying amount of detail.

RESULTS

The classification results were finally compared with a high-resolution aerial orthophoto of Findelen Glacier at the scale 1 : 18 700, acquired at 10 September 1997 which has been digitized to a pixel size of 0.5 m. The airphoto has been carefully interpreted into snow, ice and rocks and is taken as reference. With visual criteria the EL from IHS fusion gives the impression of the best fit, against which the EL from wavelet fusion shows an unrealistic geometrical pattern. Tab. 1 presents quantitative results for the comparison of snow, ice and rocks from the data fusion images with reference to the aerial image. The table shows nearly equal results of both methods with slightly better values for the IHS fusion. The feature class ice is not properly recognized in the wavelet image, it is more often assigned to the classes snow and rocks. The results show that it is important to fuse the images, but the method of the fusion does not affect strongly the segmentation.

SUMMARY

The presented method shows an approach to determine the boundary between snow and ice on top of glaciers. We merged multispectral and high-resolution IRS-1C data — both couldfree— of the end of the melt season using IHS and wavelet methods. It is not possible to determine the line with edge detection or filtering due to the manyfold line features like crevasses and moraines. For the segmentation of snow, ice and rocks we used supervised classification followed by a delineation of the snow—ice transition. In a next step we will calculate the equilibrium line altitude (ELA) by combining the extracted EL with a DEM. The investigation demonstrates a high potential for mass balance evaluations as they are needed e.g. as climate change indicators.

ACKNOWLEDGMENTS

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REFERENCES


Table 1: Error matrix for classification results from IHS fusioned and Daubechies wavelet fusioned IRS-1C data referring to airphoto evaluation.

<table>
<thead>
<tr>
<th></th>
<th>IHS</th>
<th>Daubechies Wavelet</th>
</tr>
</thead>
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<td></td>
<td>Snow</td>
<td>Ice</td>
</tr>
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<tr>
<td>Rocks</td>
<td>0.00</td>
<td>0.25</td>
</tr>
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</table>

Figure 1: Comparison of different processing stages, the black line between snow and ice indicates the EL of a detail of Findelen Glacier, Switzerland. Upper left the PAN image with high spatial resolution (5.8 m), upper right the LISS image with high spectral but lower spatial information (23.5 m) and a very simplified EL. Lower left the IHS image which fits best to the airphoto evaluation, lower right the Daubechies wavelet image.