Using Airborne Laser Scanner data and Open Source software for a glacier inventory

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Abstract

Monitoring glaciers can give valuable insights on glacier changes affecting the local economy, natural hazards and water supply. The spatial extent of glaciers can be half - automatically monitored with the help of raster data calculated from Airborne Laser Scanning (ALS) point data.

Glacier outlines can be derived from ALS data by setting up a classification of the elevation model into the classes "glacier" and "non - glacier" area. The topographical smoothness as calculated from the Airborne Laser Scanner data is used as one classification criterion. The necessary data were acquired for the whole territory of South Tyrol, Italy, in 2005 by the Autonomous Province of Bozen/Bolzano – South Tyrol. The area of the Southern Stubai Alps in the north of South Tyrol was chosen for testing the algorithm because several different glacier types such as valley glaciers and mountain glaciers or glacierets can be found in that region. After identifying these glacier outlines the next step is to calculate the parameters of the glacier inventory based on the guidelines of the World Glacier Monitoring Service (WGMS). The result is a highly accurate inventory of glaciers based on ALS raster data, which is methodically transferable to all glacierized regions in the world where such datasets are accessible.

Introduction

The observation of glaciers and their changes in the past, present and future has given valuable insights on the climate and its changes affecting a wide variety of research fields. In this paper glacier outlines are calculated half-automatically with the help of ALS raster data and digital orthophotos.

The recent outlines of glaciers are derived from ALS raster data using the GRASS GIS software package, version 6.3.0 (GRASS development team, 2006). Several other classification criteria such as "topographical smoothness" (Kodde et al., 2007) can also be calculated from the Airborne Laser Scanner data.

The area of the Southern Stubai Alps in the north of South Tyrol was chosen for testing the original delineation algorithm of Kodde et al. (2007) for the calculation of the glacier outlines because several different glacier types can be found in this mountain range. After checking the results of the delineation procedure some improvements of this calculation rule needed to be done as the original method was developed for a completely different dataset based on other raster

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resolutions. It was necessary to sort out glaciers with an area of less than 1 hectare and to calculate all possible glaciers on each raster tile and not just the largest one. The original algorithm was tested on Hintereisferner in the Ötz Valley, Austria, on a 1 m raster dataset with good results (Kodde et al., 2007), while the improved calculation rule works on the 2.5 m raster dataset of South Tyrol with comparable results.

In a second step, the algorithm was used to calculate all possible glaciers within South Tyrolean borders. The main difference between the results of the two different methods is that the accuracy for the new algorithm is limited by the raster size and resolution of the DEM but this loss of accuracy was corrected by using digital orthophotos for the correction of the glacier outlines applying the QGIS software, version 0.9.0.

After identifying the glacier outlines, the parameters of the glacier inventory based on the guidelines of the World Glacier Inventory (WGI) were calculated. The result is a highly accurate glacier inventory based on ALS raster data, which is methodically transferable to all regions in the world where such ALS and orthophoto datasets are available.

Data acquisition and data processing

All glaciers in the research area of South Tyrol (see Figure 1) are located in high mountain regions which entails certain problems for the application of ALS. The rugged topography of these areas with large differences in the relief can cause serious troubles on ALS systems with a limited laser range, point density and spectral resolution for the data acquisition (e.g. Albertz, 2001, Geist and Stötter, 2003, Lutz et al., 2003).

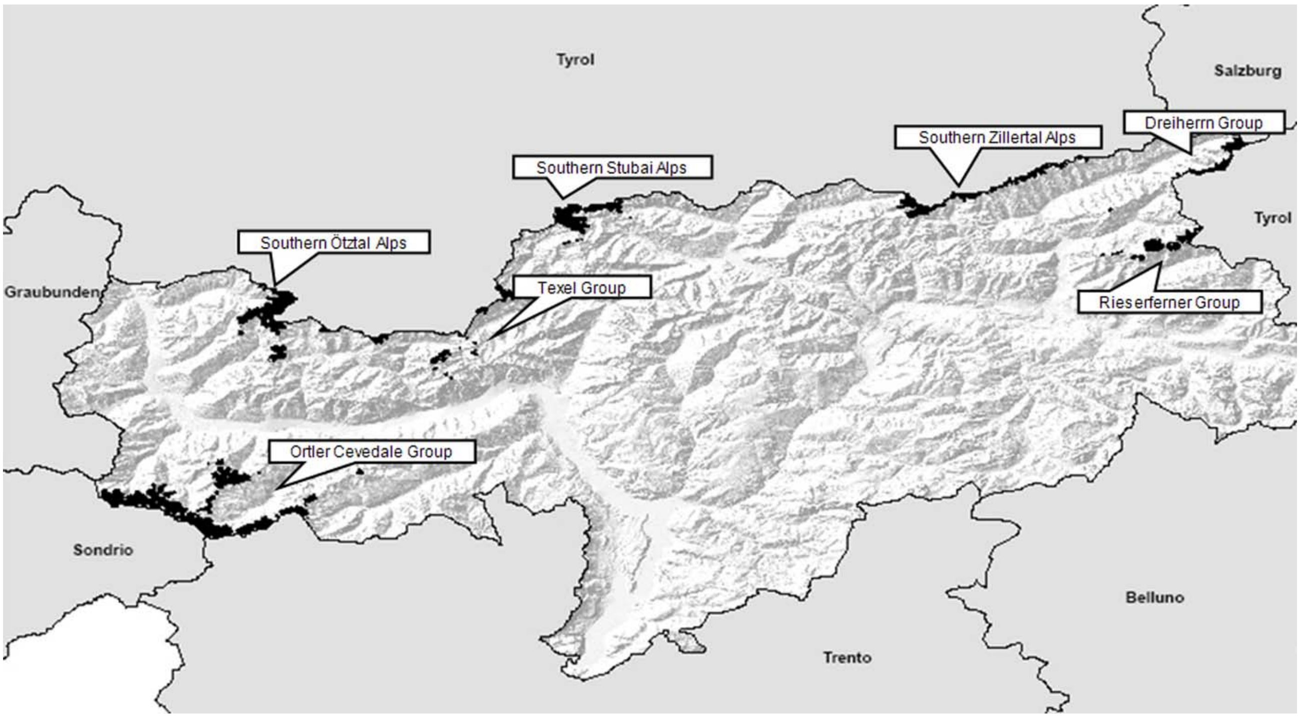

Figure 1: Glaciated mountain ranges in South Tyrol.

The area of interest for this research comprises the entire glacier and remote firn areas. As this study is a derivative of an already existing algorithm of Kodde et al. (2007) it was necessary to adapt this so called “l.delineation algorithm” so that it works not just for a single glacier but for all possible glaciers in a raster data file.

Despite the lack of detailed information about scanner types and their respective scanning areas, mean flight altitude, minimum or maximum slant range, an average point density of 8 points per 25 m² for areas below 2000 m a.s.l. and 3 points per 25 m² for areas above 2000 m a.s.l. was achieved. The average vertical accuracy over a control area was 0.095 m.

The digital elevation model (DEM) used is a 2.5 m raster dataset of South Tyrol which is calculated out of the ALS point data using a nearest neighbor interpolation method on the last pulse returns. The resulting raster data are used as input for the algorithms presented in the following sections (Kodde et al., 2007). The scanning flight took place in the end of summer of the year 2005 with an elevation accuracy of 0.4 m below 2000 m a.s.l. and 0.55 m above 2000 m a.s.l. This gives a sufficient accuracy for further calculations.

The glacier algorithm

As the term “glacier” is ambiguous it was necessary to choose a clear definition. UNESCO (1970) defined a glacier as “a mass of ice with a minimum size of 1 hectare”. For the identification of the debris covered parts of the glaciers, the surface shape and roughness of the DEM, as well as a hillshade of the DEM and existing orthophotos of the year 2006 were used. The final identification and correction of the glacier boundaries was done manually using the QGIS Software.

In Figure 2 the workflow of the used algorithm is pictured. First the raster datasets of the DEM had to be imported into the GRASS database and the regions for each raster data file had to be set to a minimum of each raster file to improve speed. In a second step the glacier delineation algorithm of Kodde et al. (2007) was improved in a way that it was possible to set the minimum size of a glacier to 1 hectare and to calculate all possible glaciers on a raster file and not just the largest one. The original algorithm was tested on Hintereisferner in the Ötz Valley, Austria, on a 1 m raster dataset with good results but the improved algorithm worked on the 2.5 m raster dataset of South Tyrol as well. The main difference is that the accuracy for the algorithm is limited by the raster size of the DEM but this loss of accuracy was corrected in the use of the orthophotos for the correction of the glacier outlines.

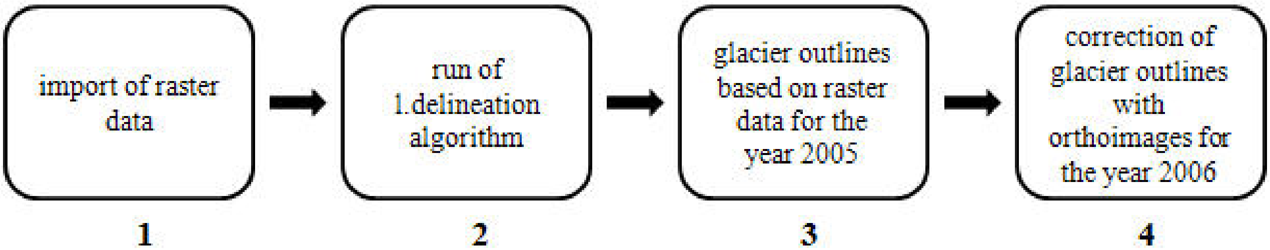

Figure 2: Workflow for the glacier outline algorithm and boundary correction.

The results of the improved algorithm (red in Figure 3) are good but not accurate enough especially in the ablation areas of the glaciers and so the results of the derivation needed to be corrected with the orthophotos of 2006 (green in Figure 3).

For the recording year of the DEM no orthophotos were available. So the glacier outlines have been checked against the hillshade which was calculated from the DEM and the corresponding orthophotos of the survey flight of 2006.

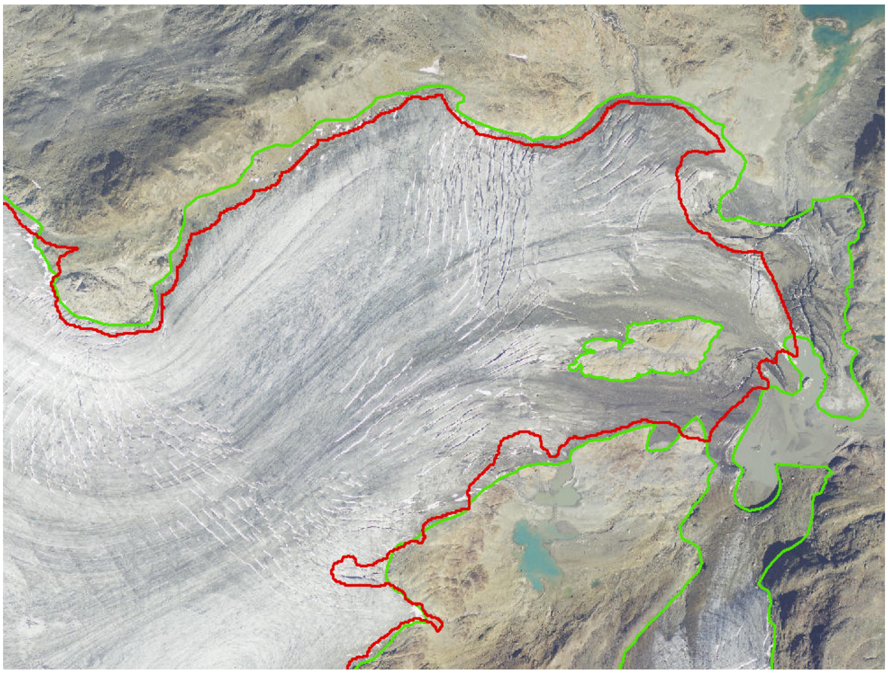

Figure 3: Calculated (red) and corrected (green) glacier boundaries.

To the corrected glacier boundaries additional information like drainage area, identification numbers, glacier name, glacier area, aspect of the ablation area etc. was added. Once the glacier boundaries had been determined, information like area–elevation distributions, minimum, maximum, mean elevation,… of the glaciers could be derived. Finally, the glacier boundaries have been converted into the ESRI shapefile format.

Problems with the used algorithm

As this study is an advancement of the work of Kodde et al. (2007) certain problems still remain unsolved. As the glacier delineation is based on criteria like the smoothness of the surrounding area, the connectivity and hydrological constraints (Kodde et al., 2007) it is still not possible to detect glaciers without human supervision and error handling. This algorithm was tested for the first time for more than a single glacier and for more glacier types than just a valley glacier. Good results were achieved for all three glacier types (valley glacier, mountain glacier and glacierete) that occur in the South Tyrolean Alps.

However Figure 4 (Uebeltal Ferner in the Ridnaun valley) shows the main problem which need further improvement. The results of the algorithm (red in Figure 4) are good but two extensive parts (see **1** and **2** in Figure 4) which are connected to the main glacier through parts considerably covered with debris or which have a different hydrological constraint are not taken into account by the algorithm. The corrected glacier extent (green in Figure 4) shows the result for the glacier that is just limited in its accuracy by the resolution of the raster dataset and the orthophotos.

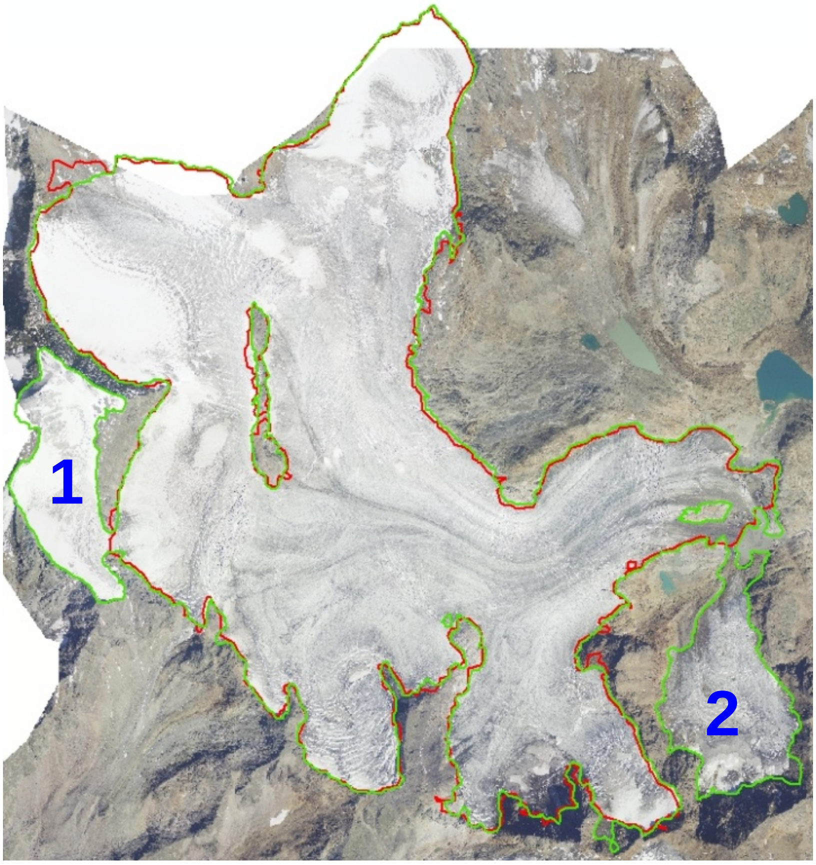

Figure 4: Results of the delineation algorithm (red) and the correction via orthophotos and hillshades (green).

Results of the glacier inventory

Comparison of different datasets

The glacier inventory data for the year 1983 is not available digitally so a direct comparison and quantification of the glacier changes for that year is not possible. There are also no information available which glacier definition was used and whether the firn boundaries are included.

For the inventory of the year 1996 shapefiles and tables are available. These shapefiles have been calculated by the Technical University of Munich with a Plancomp P1 system using aerial photographs of the year 1996.

For 2006 the whole dataset of the research area was calculated by the Institute of Geography at the University of Innsbruck and is described above. The results of the inventory are shapefiles and tables.

Glacier changes between 1983, 1997 and 2006

In line with a global trend glacier recession in the investigation area is partly rather drastic and shows problems in compiling glacier inventories. A comparison of the three inventories (1983, 1996 and 2006) is difficult because of the disintegration of previously continuous glaciers. The biggest glacier in South Tyrol, the Uebeltal Ferner, split up into four parts of different sizes. In order to compare the three inventories it is necessary to consider all parts of the former glacier as one big ice mass. In the World Glacier Monitoring Service (WGMS) each glacier is assigned a worldwide unique inventory number and with this number the glacier parts are summarized to one big single glacier. A count of these numbers a total of 205 glaciers in the research area for the year 1983. A count for 2006 gives a sum of 188 glaciers so in the last 23 years 17 glaciers collapsed and melted away completely.

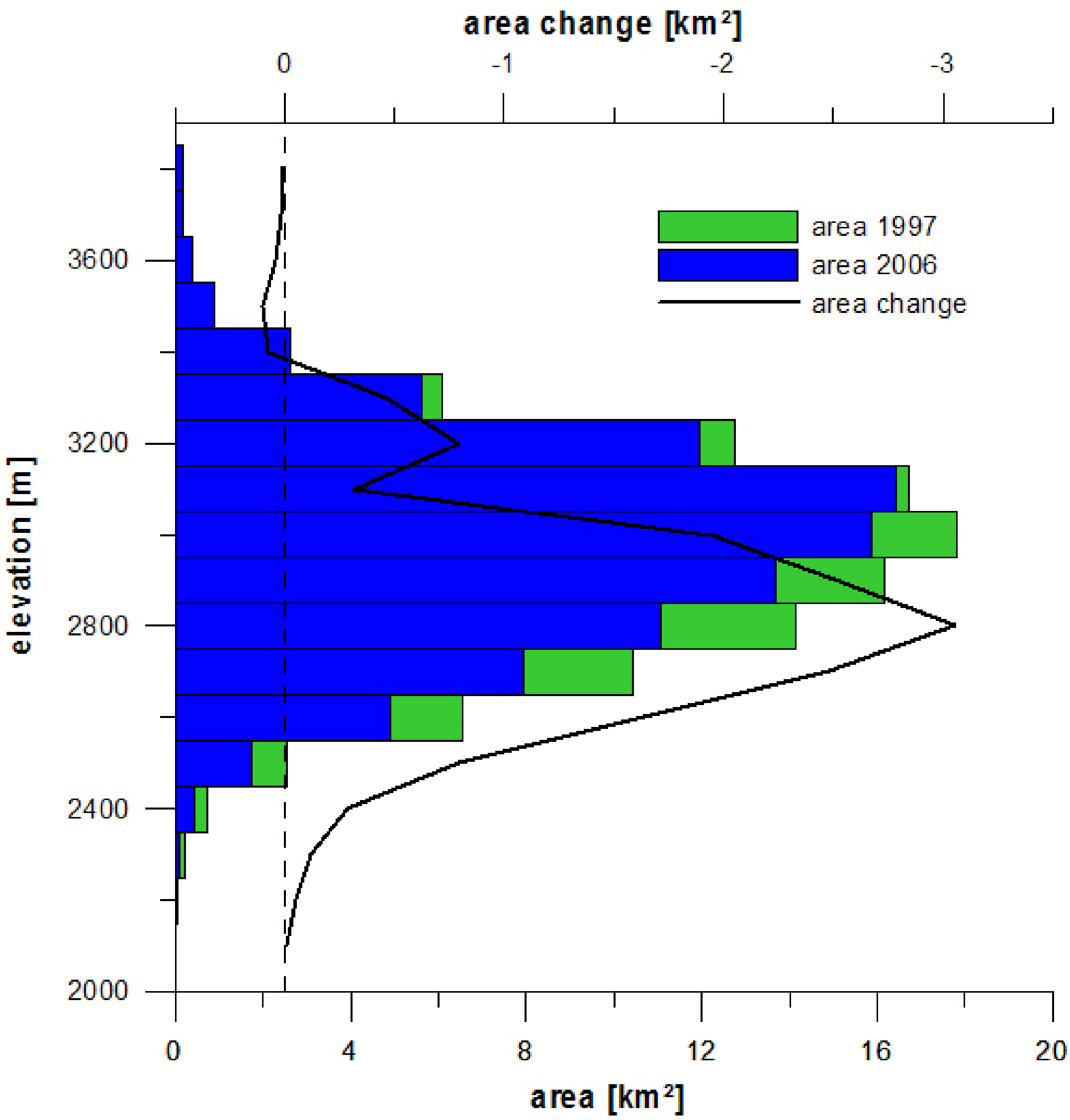

Figure 5: Area-elevations distribution for 1997 (green) and 2006 (blue) and the absolute area change between the two inventories in 100 m elevation bands.

The analysis for the three different datasets shows an overall glacier area reduction of 37.7 %, from 136.8 km² to 94.1 km², for the period from 1983 to 2006. In the first 13 years from the first glacier inventory 1983 to the second inventory 1996, the loss was higher (24.7 % from 136,8 km² to 109.7 km²) than in the last ten years from the inventory of 1996 to new third glacier inventory of 2006 for the research area (16.6 % from 109.7 km² to 94.1 km²). Our results show large variations for the extent of small glaciers (< 0.12 km²). These glaciers lost more than 75 % of their area in average. For the larger glaciers (> 0.12 km²) the mean area loss was 31 %. Similar observations for small glaciers have been made by Lambrecht and Kuhn (2007) for the new Austrian glacier inventory and Paul et al. (2004) for the new Swiss glacier inventory.

A comparison of the area-elevation distribution is only possible for the glacier inventory 1996 and the inventory of the research area 2006 (Figure 5) as area-elevation distribution data for the year 1983 is missing. The results show the maximum glacierized area at elevations of 3000-3100 m in 1997 and 3100 – 3200 m in 2006. The largest loss of area is between 2700 m and 3100 m where glacier area decreased by 11.6k m². The mean glacier elevation in 1996 has been at an altitude of 2978 m, in the year 2006 it was at 3017 m.

Conclusions and perspectives

The calculation method presented in this work shows that ALS based raster data technology is a highly accurate tool for monitoring glaciers but needs human supervision. The glacier boundaries are delineated from ALS data of the raster resolution (2.5 m) but they need to be corrected on corresponding orthophotos. The algorithm used smoothness as well as other classification criteria to calculate the glacier boundaries.

One important conclusion can already be drawn for the South Tyrolean glaciers. The glaciers in the research area of the South Tyrolean Alps are threatened by the worldwide processes of global warming. These glaciers have only a small height extension of three elevation bands or 300 m in average. During the last 23 years glaciers have shown a strong reduction of area and number. 12 of them have melted away completely, some of them have shrunken to an extension that is per definition not a glacier anymore and some are endangered of degeneration. Almost all elevations are affected by the melting process but elevations between 2600 m and 2900 m are especially affected. If the climatic conditions stay as they are only the highest glaciers, as in the Ortler Cevedale group will survive.

Acknowledgements

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