34 Comparison of digital elevation models of alpine glaciers

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Motivation

Glaciers are indicators of the global climate change. The change in the extent and volume of a glacier can be estimated from digital elevation models (DEMs) produced from remotely sensed spaceborne or airborne data using photogrammetric, interferometric, or laser scanning techniques. For this study, the most promising data sources available were selected and tested. The selected sites were two alpine glaciers, Hintereisferner valley glacier in the Central Eastern Alps in Austria and Svartisen ice gaps in Northern Norway. The data included very high resolution optical images of the Ikonos and Eros satellites, aerial photographs and airborne digital camera images, spaceborne and airborne radar images, airborne laser scanner data, terrestrial photographs and ground control points and profiles measured with GPS equipment. The objective was to find out which data and method would yield the most accurate result by comparing the different DEMs generated from data acquired as simultaneously as possible. Methods were also developed for estimation of accuracy of change in the volume of a glacier between two time instants.

Results

Five test cases at Hintereisferner and five test cases at Svartisen, including a total of 34 DEMs or other data sets, were carried out. The differences between the DEMs were analyzed within the whole images, along profiles, or at single points. The surface shapes were also studied. It appeared that the DEMs had been georeferenced quite differently and the elevations of most of the DEMs were biased by several meters when compared to the ground control points.

A surface matching algorithm [1] was then applied for accurate registration of the DEMs into the same coordinate system and thus for the correction of differences in georeferencing. This matching algorithm has been shown to provide high accuracy, a large pull-in range and short computing time, when the data can be represented as single valued parametric surfaces such as DEMs [1]. The difference images between the elevations of the DEMs after surface matching revealed shape distortions and other errors in the DEMs which would have been difficult to detect from a single DEM or from two inaccurately georeferenced DEMs. This is illustrated in Figures 34.1 and 34.2 which show the differences in elevation between the DEMs produced from aerial and Ikonos images captured on the same day at Hintereisferner.

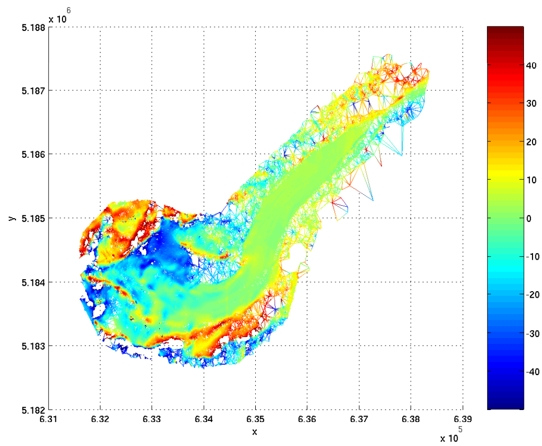

Figure 34.1: *Aerial DEM minus Ikonos DEM according to the initial georeferencing. Large differences exist due to differences in georeferencing.*

Figure 34.1 is according to the original georeferencing and there exist differences of several tens of meters although the DEMs should represent the same surface. After registering the DEMs, a couple of distortions in the original Ikonos images and in the aerial DEM appear as orange and yellow stripes in the difference image in Figure 34.2. The broader stripes result from imperfections in the original Ikonos images while one narrower stripe and the edge between the light green and light blue areas in the middle of the figure are near the borderlines of image blocks which were combined when the aerial DEM for the whole area was produced. The differences in elevation larger than 50 m and 5 m have been left out for clarity in Figures 34.1 and 34.2, respectively. More illustrative examples have been presented in [2] and differences in the georeferencing of DEMs have been studied further in [3]. The comparison results after surface matching showed that the laser DEMs were the most reliable ones at Svartisen and the Ikonos DEMs at Hintereisferner. The lowest RMS differences in elevation were obtained in comparisons involving terrestrial, laser, aerial, or Ikonos DEMs.

As a second task, estimates for the accuracy of the volume that remains

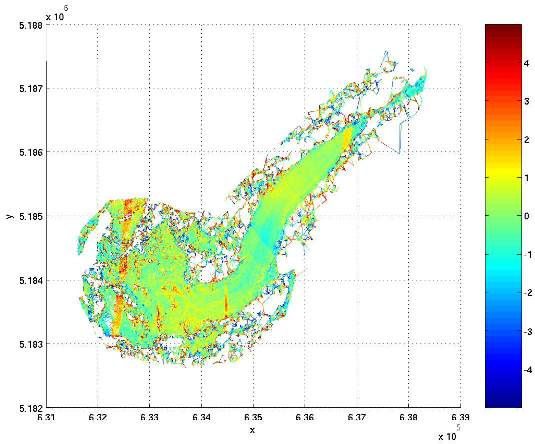

Figure 34.2: *Aerial DEM minus Ikonos DEM after surface matching. Distortions in the DEMs appear as stripes.*

in between two surfaces representable as functions of two variables were derived. The volume integral was approximated by a finite sum and the truncation error was estimated for two cases where the integration area was given either as a set of irregular triangles or regular rectangles the vertices of which represented the domain of one of the surfaces discretized and considered as a DEM. Errors resulting from measurement noise, interpolation of the other DEM, and registration of the DEMs were also estimated after differences in the georeferencing of the DEMs had been corrected. Error propagation techniques were applied to estimate the overall effect of these factors on the accuracy of the change in the volume of a glacier under assumptions that the bottom of the glacier stayed stable and no cavities existed below the surface. The error estimates were tested at Svartisheibreen outlet glacier of Svartisen with an aerial DEM and a laser DEM having a time difference of one month. The decrease in the volume of the glacier could be verified using the error bounds derived [2].

Practical benefits

The comparisons between the DEMs showed the advantages and disadvantages of different methods and data for the production of DEMs in difficult mountainous areas. The surface matching algorithm applied to the correction of differences in the georeferencing of the DEMs and the subsequent detection of distortions in the DEMs can be used to improve current techniques for the production of DEMs. The error bounds derived for the accuracy of the change in the volume can be applied to the estimation of the long-term evolution of glaciers from a series of DEMs and hopefully to reduce the uncertainty of predictions made on the global climate change.

Use of CSC resources

The computations were performed using MATLAB software in the SGI Origin 2000 and Sun Fire 25K servers of CSC. The surface matching algorithm was coded using the array operations in MATLAB, and due to this, the computation time remained very moderate. MATLAB is suitable for processing data in the image format but handling the large amount of data of the high resolution DEMs requires a lot of memory.

Future direction of the research

For the present, the research will concentrate on detecting distortions in the DEMs and finding explanations for them. The next step would be to transfer this knowledge to the Finnish companies producing DEMs.

Acknowledgements

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