Airborne Laser Scanning Technology
Quantification of Glacier Volume Changes
Results from Engabreen, Svartisen (Northern Norway)

Th. Geist (1), E. Lutz (1), J. Stötter (1), M. Jackson (2), H. Elvehøy (2)

(1) Institute of Geography, University of Innsbruck,
(2) Norwegian Water Resources and Energy Directorate (NVE), Oslo

Further information: Thomas.Geist@uibk.ac.at,
(Phone +43-512-5075428, Fax +43-512-5072895)

1 Background

The OMEGA project

The investigations presented are part of the EC-funded OMEGA project (EVK2-CT-2000-00069). The main objective of OMEGA is to develop an operational monitoring system for European glacial areas by

1) evaluating and utilising the full potential of airborne and satellite remote sensing techniques for operational glacier monitoring,
2) designing a monitoring system which can utilise different types of earth observation data,
3) constructing a regional glaciological database.

An important aspect of OMEGA is the generation and evaluation of digital elevation models (DEMs) derived from different data sources.

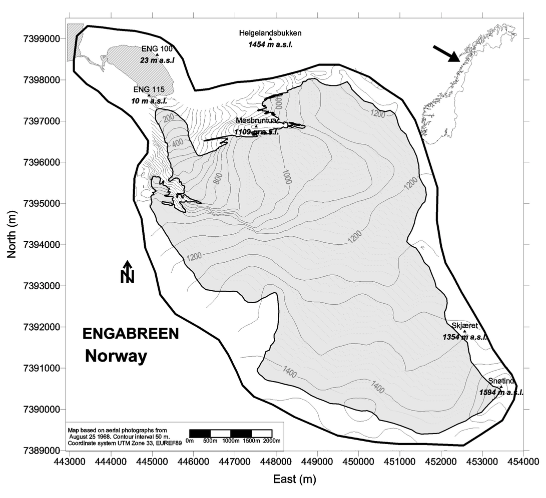
References:

Pellikka, P., K. Kajuutti, R. Koskinen, M. Jackson, H. Stötter, H. Haggren, K.-M. Luukkonen, T. Guneriussen & A. Sharov, 2001. Development of an operational monitoring system for glaciers - synthesis of earth observation data of the past, present and future. Proceedings, International workshop on geo-spatial knowledge processing on natural resource management, 28 - 29 June 2001, Varese, Italy, pp. 283 - 288.

http://omega.utu.fi

The study site

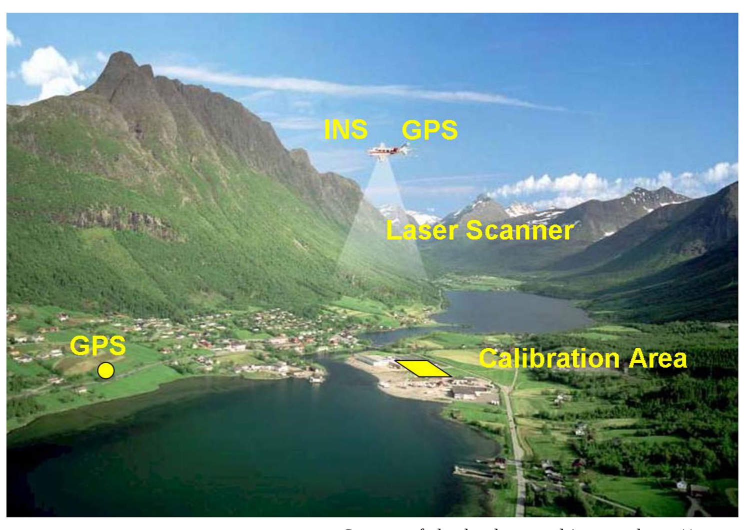
Engabreen (38 km2) is an outlet of the West Svartisen ice cap, situated in a maritime climate close to the Atlantic Coast in Nordland, Northern Norway. The altitudinal range is from close to sea level to almost 1600 m a.s.l. Annual precipitation in the area can exceed 2000 mm. There is a relative abundance of glaciological data from Engabreen, including data of the change in front position since 1903, aerial photo documentation since 1945, continuous mass balance measurements since 1970, and more recently bottom topographic mapping.



2 Airborne Laser Scanning

The airborne laser scanning system consists of a laser scanning device, a Global Positioning System (GPS) receiver, and an Inertial Navigation System (INS), all of which are time-synchronized. While the airborne laser scanner measures the distance between the sensor and the surface (the range), the absolute position and the attitude of the sensor is calculated from GPS and INS measurements. During post-processing, the z-coordinate of a point on the earth´s surface can easily be calculated from the collected information. Both the laser point density (e.g. 500'000 points per km²) and distribution depend on the scan angle, the scan frequency, the height above ground, the aircraft speed and the swath overlap. This method enables high-quality coordinates to be derived with a vertical accuracy of up to +/- 0,15 m.

The main application of airborne laser scanning technology is topographic surveying, especially in wooded areas. To date, only a few attempts have been made to utilise airborne laser scanning for glaciological purposes.



Source of the background image: http://www.optech.on.ca

References:

Ackermann, F. 1999. Airborne laser scanning – present status and future expectations. ISPRS Journal of Photogrammetry & Remote Sensing. 54: 64-67.

Favey, E. 2001. Investigation and improvement of airborne laser scanning technique for monitoring surface elevation changes of glaciers. IGP Mitteilungen 72. Institut für Geodäsie und Photogrammetrie, ETH Zürich.

Kennett, M. and Eiken, T. 1997. Airborne measurement of glacier surface elevation by scanning laser altimeter. Annals of Glaciology. 24: 293-296.

3 Data Acquisition and DEM Generation

The data acquisition was conducted by TopScan GmbH, Steinfurt, Germany with an Optech ALTM 1225 laser scanner. Three data acquisition flights were completed over Engabreen within the glaciological year 2001/2002. During each campaign the entire area of Engabreen was scanned within 2 - 3 hours. The data presented here are from the first two flights, covering the accumulation period of the glaciological year 2001/2002.

Technical Parameters of the ALTM 1225

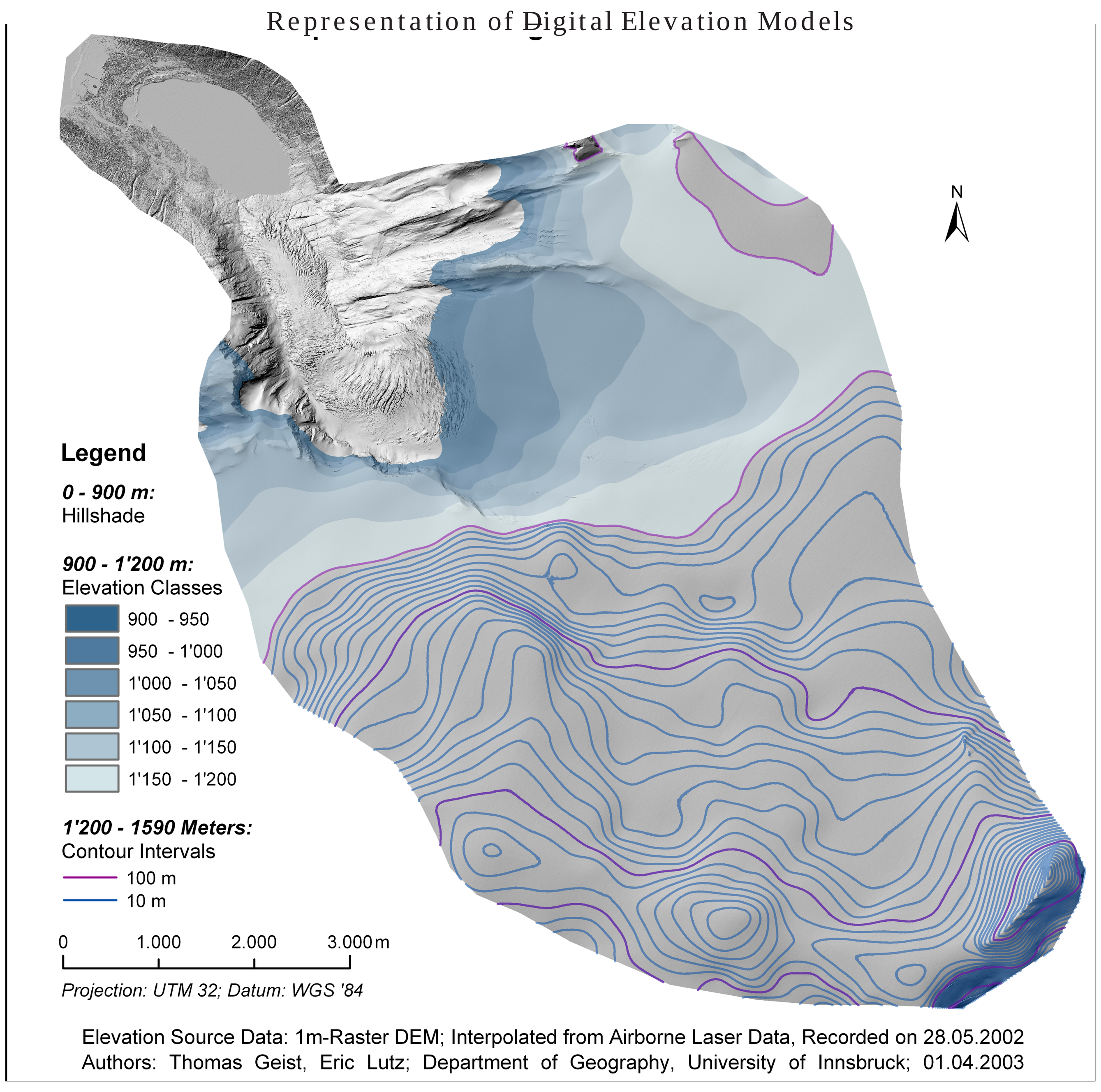
Measuring frequency	25.000 Hz
Scanning angle	+/- 20°
Scanning frequency	25 Hz
Max. operating altitude above ground	2000 m

Data Characteristics from 24 September 2001 (28 May 2002)

Area	ca 62 km²
Number of flight paths	28
Swath width	ca 650 m
Average altitude above ground	ca 900 m
Number of data points (X, Y, Z)	29.572.046 (33.360.203)
Density of data points	476.968 points/km² (538.068)
Average distance between data points	1.5 m (1.4)

The primary product of data acquisition are points (x-, y-, z-coordinates) of single reflections from which the shape of the earth´s surface can be derived. The high density of these points allows for the generation of highly accurate DEMs. GRID-format DEMs with 1m resolution were interpolated from all data points within each of the data sets in enable the multitemporal comparison. From these DEMs standard products such as shaded reliefs or contour lines were derived for visualisation.

Representation of Digital Elevation Models

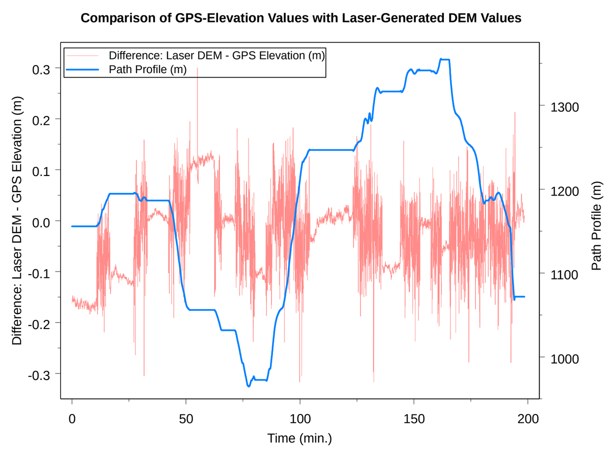


4 DEM Accuracy

A football field nearby the test site was surveyed with a tachymeter, providing a reference surface for the calibration of the laser scanner data. This surface was scanned during both flights. The following table shows statistical values of the comparison between the data sets (DiffH = HLaserPoints-HReferenceDEM):

Date	Calibration Area	Number of points	Max ΔH [cm]	Min ΔH [cm]	Arithmetic mean ΔH [cm]	Standard deviation ΣΔH [cm]
24.09.2001	Halsa	3231	30,0	-31,0	0,3	8,8
28.05.2001	Halsa	3361	35,0	-25,0	0,2	8,3

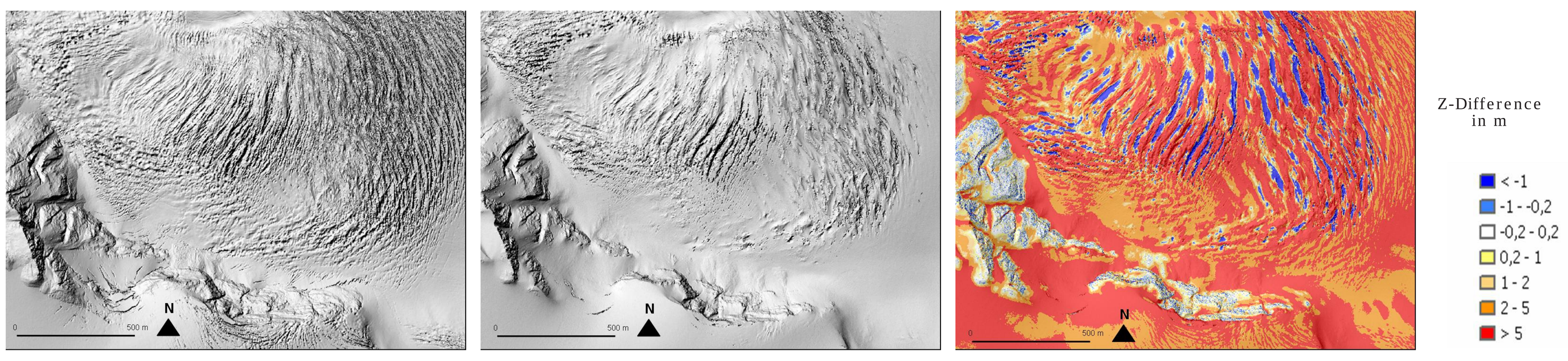
During the laser scanner flight on 28 May 2002 GPS reference profiles were measured simultaneously on the glacier surface. Nearly 6000 point measurements were recorded using a Ashtech Z-Surveyor with antennas mounted on a tripod on a snow mobil. The comparison (see below) between the z-values of the GPS measurements and the corresponding z-values of the laser scanner DEM show minimal deviations (mean = 2.7 cm +/- 7.5 cm).



5 Change Detection

In the figure below, a section of Engabreen is visualised for both flights. The potential of the data for morphological interpretation is made clearly visible; features such as small crevasses can be identified and mapped using the Laser Scanner DEM.

In the initial multitemporal evaluation, it was made apparent that snow had accumulated at the end of the winter period in May 2002 (middle), covering a substantial part of the crevassed area which was nearly snowfree in September 2001 (left).



The difference image (right) confirms and quantifies this observation.The red and orange coloured areas indicate higher surface elevations in May than September, easily explained by winter snow accumulation.The blue colours indicate lower surface elevations in May than September, most likely caused by crevasses which had opened or moved between the data acquisition dates. The mainly white areas indicate surfaces with insignificant changes in elevation; these areas correlate closely with exposed bedrock surface.

6 Summary and Outlook

Airborne laser scanning provides highly accurate and precise DEMs of glacier surfaces. Multitemporal analysis and evaluation of the derived DEMs allow the detection of elevation changes at the glacier surface. Hence, airborne laser scanning can be used for calculating changes in glacier volume in time. The project is still in progress with much of the data analysis at a preliminary stage. Forthcoming analysis will include:

Comparison with DEMs from other data sources

Especially intersting are DEMs derived from terrestrial photography, which provide a good comparison for the quality of the laser scanning DEMs (see Kajuutti, K., Pitkänen, T., Geist, Th., Heiskanen, J., Pellikka, P., Comparison of terrestrial photography and laser scanning as a data source for digital elevation models of glaciers in the same poster session).

Mass balance estimates

Estimates of changes in glacier mass volume can be made and compared with those derived from standard glaciological methods.

Glacier movement

Comparison with snow depth soundings made during the data acquisition flight in May 2002 on Engabreen give information about the vertical component of glacier motion between September 2001 and May 2002. With feature tracking methods, both horizontal glacier motion and velocity can be reconstructed. Data from the other OMEGA test site Hintereisferner, Ötztal, Austria will be especially interesting as there were 7 laser scanning flights covering the glaciological year 2001/2002.

Accumulation and Ablation patterns

The fine temporal resolution of the Hintereisferner data can be used to infer patterns in accumulation/ablation.