DIGITAL ELEVATION MODELS FROM GROUND-BASED GPS AS VALIDATION FOR SATELLITE ALTIMETRY ON THE GREENLAND INLAND ICE

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ABSTRACT

A long-term geodetic project on the Greenland inland ice is performed in order to determine elevations, elevation change, flow velocity, and deformation of the ice surface in the western part of the Greenland ice sheet. There are two main research areas: Swiss Camp (ETH/CU-Camp) which was started in 1991, and ST2, started in 2004. Until 2008 a total of 10 measuring campaigns were carried out at Swiss Camp. The 3D-coordinates of the snow and ice surfaces were measured by ground-based static and kinematical GPS survey. As a result very precise digital elevation models of the research areas are available.
The digital terrain models can be used as ground control areas for satellite altimetry. As an example, they were used for validation of ICESat satellite elevation data. Height comparisons along one track show in average a discrepancy of 0.13 m ± 0.06 m.
Due to their very high accuracy, the measured areas can also be used as control areas for CryoSat. The next field measurements are planned in summer 2011. The location of the ground measurements will be coordinated with predicted tracks for CryoSat.

1. INTRODUCTION

Since 1991 a geodetic long-term project is performed on the western part of the Greenland icecap in order to determine elevation change, flow velocity, deformation and strain of the ice surface. The main research area is situated at the Swiss Camp in an elevation of 1170 m, at a distance of 80 km from the coastal town of Ilulissat *(fig. 1a, 1b).* Until 2008, here a total of 10 measuring campaigns were carried out. A second research area, called ST2, was established in 2004 and here we have until now four campaigns in 2004, 2005, 2006 and 2008. In both of the measuring areas a stake network was established consisting of a triangle and a stake in its centre.

An overview about the project was published in [1].

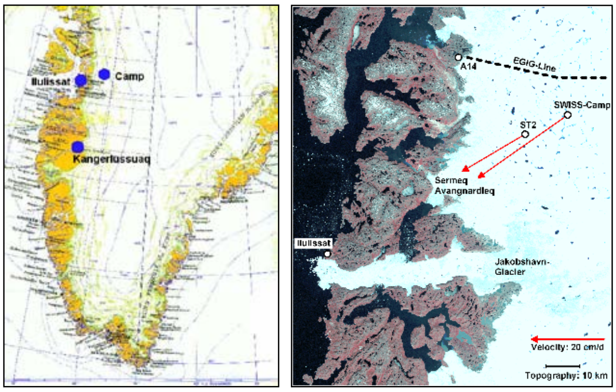

Figure 1a, 1b: Geographical location of the research areas and the ice flow vectors

2. MEASURING METHODS

All GPS measurements on the ice were connected to a stable control point on rock at the coast by an 80 km long baseline *(fig. 2).* This baseline was measured for at least 6 hours resulting in a 3D-accuracy of about 0.02 m.

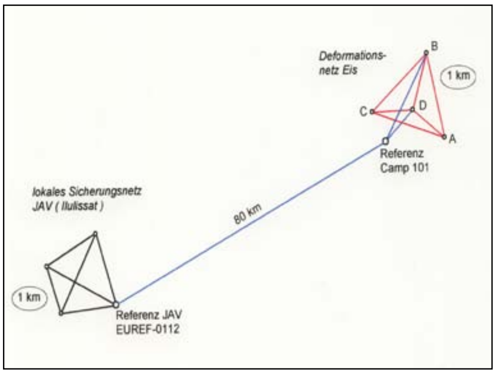

Figure 2: Principal sketch of the GPS network (not on scale)

The current and former positions of the stakes were measured by differential two-frequencies-GPS in the static and the stop-and-go method.

The snow surface was measured by two methods:

a) Stop-and-go GPS: Measurements of grid points in a regular grid with step width of 100 or 200 meters.

b) Kinematic GPS: Profiling of all the terrain.

Examples for the measuring procedure are shown in *figures 3* and *4.*

Figure 3: Kinematic GPS profiling

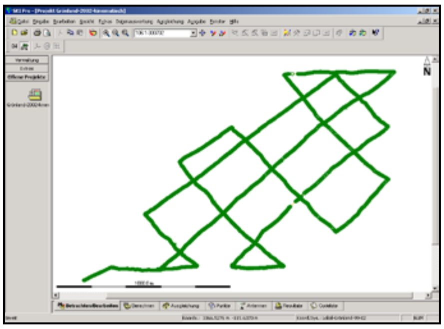

Figure 4: Profiling with cross sections

The cross sections according to *figure 4* are valuable for an accuracy study. From the double measurements of the 12 cross over points we get height discrepancies with a standard deviation of 0.03 m.

3. RESULTS

From all the surveys, digital elevation models (DEM) of the whole measuring area were created. An example for the research area Swiss Camp is shown in *figure 5*.
The research areas can be specified by the following features:

- Area about 2 x 2 km^2
- Terrain inclination 2%
- Smooth topography
- Ablation area, snow layer melted end of summer
- High accuracy of digital elevation models, ca. 4 cm in height
- Elevation change and ice flow vector well known

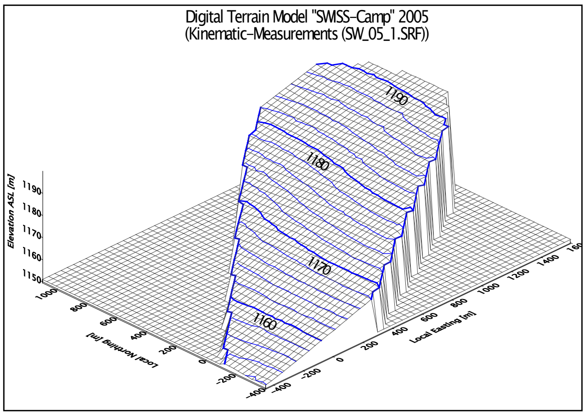

Figure 5: Digital elevation model, Swiss-Camp, as basis for elevation changes and for height comparison with satellite altimetry results.

Elevation changes can be derived from the comparison of the digital elevation models in consecutive campaigns. In every campaign the current snow layer was measured and subtracted from snow elevation in order to get ice elevations and ice elevation changes, respectively. Elevation changes are also determined by height comparison at previous stake positions. The results for all campaigns 1991-2008 are shown in *figure 6*. The ice elevation is decreasing significantly, and even accelerated in the last years, when the elevation change is three times bigger than in the long-term trend of the first years.

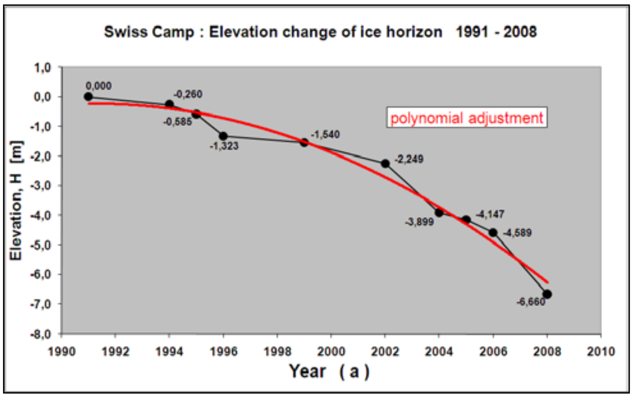

Figure 6: The latest results between 2006 and 2008 show an extremely huge and accelerated elevation decrease of -1,04 resp. -1,40 m/a. The actual ice thickness degression is more than three times bigger than in the long-term trend of the previous years.

Another application of the digital elevation models with a height accuracy of a few centimetres is the validation of satellite altimetry results. We compare surface heights along a track from ICESat in the year 2005. Our ground-based GPS profiles and 5 footprints of ICESat are shown in *figure 7***.**

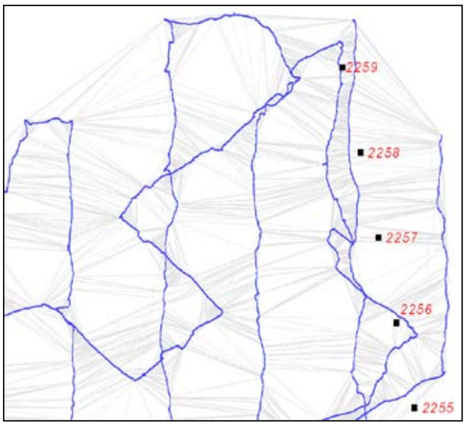

Figure 7: Profiles of kinematic GPS-measurements and location of the ICESat-footprints

The discrepancies between the GPS-DEM heights and the ICESat heights are in average (+0.13 ± 0.06) m *(table 1)*. Reasons for differing results are: The laser (GLAS) of ICESat generates footprints at an interval of 170 meters and the height result is averaged within an area diameter of 70 meters. By contrast our measurements refer to the centre of this diameter. In 2005 the surface was covered with some remaining snow, so the surface definition due to roughness was not better than about one decimetre. Systematic differences due to other ellipsoid dimensions (ICESat = Topex/Poseidon ellipsoid, GPS = WGS84 ellipsoid in ITRF) were eliminated before the comparison.

Height differences GPS-ICESat:	
2255:	-0.20m
2256:	+0.08m
2257:	-0.24m
2258:	-0.06m
2259:	-0.23m
Average:	0.13 ± 0.06 m

Table 1: Height differences GPS – ICESat from a track in 2005

4. OUTLOOK

The Digital Elevation Models with their very high quality in both of our measuring areas are suitable for validation of satellite products, especially the heights, but also the influences of signal quality (backscatter). According to [2], CryoSat-2 requires on Ice Sheets an accuracy of 3.3 cm/year, which can be achieved with our ground-based GPS methods. The long-term measurements will be updated in the next campaign which will be carried out in summer 2011. We will use the predicted tracks of CryoSat for measuring particularly along that area in order to be able to validate the CryoSat heights as well.

5. REFERENCES

1. Stober, M. & Hepperle, J. (2006):
Changes in Ice Elevation and Ice Flow-Velocity in the Swiss Camp Area (West Greenland) between 1991 and 2006.
Polarforschung 76 (3), pp. 109 – 118, 2006, (printed 2007).

2. ESA (2003) : *CryoSat Science Report, SP 1272*, European Space Agency, March 2003.