Relative gravity measurements on the ice of Lake Vänern

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Abstract. One of the key activities in Geodesy 2010, Lantmäteriet's strategic plan for geodetic activities during the coming ten years, is the restoration of the national gravity network.

This year two major circumstances made it possible to cover the Lake Vänern with gravity measurements. First, the cold winter resulted in favourable ice conditions with at least 0.3 m ice all over the lake. Second, there was a good opportunity to hire a hovercraft for transportation.

With a minimum of experiences and only one month of preliminaries this three weeks campaign in March resulted in more than one hundred gravity points on the ice observed with the Scintrex CG-5 Autograv™ Gravity Meter

Keywords. Relative gravimetry, gravimeter. geoid

1 Introduction

One of the key activities in Geodesy 2010, Lantmäteriet's strategic plan for geodetic activities during the coming ten years, is the restoration of the national gravity network. The goal is to get gravity data that will make it possible to determine a national geoid model in 2020 with an uncertainty of 5 mm (RMS). It is questionable whether the geoid determination method will ever allow this high accuracy, but the quality of the gravity data should not be the limitation. Test computations and error propagations show that 5 km data density is enough for the main part of Sweden (assuming a high quality DEM is utilised in the geoid determination). One area without good gravity observations was the lake Vänern (5 490 km²)

2 Background

2.1 Error propagation

The goal to have gravity data that will make it possible to determine a national geoid model in 2020 with an uncertainty of 5 mm (RMS) make great demands on data density. Presently Lantmäteriet investigates what is required of the national gravity system and the gravity data to be able to compute a more accurate geoid model in the future (with standard uncertainty of the order 5 mm). Two preliminary conclusions from this ongoing project (not yet published) are that a new gravity system is needed and that 5 km resolution is sufficient for the detail gravity in case a dense, high quality Digital Elevation Model (DEM) is used for the topographic corrections.

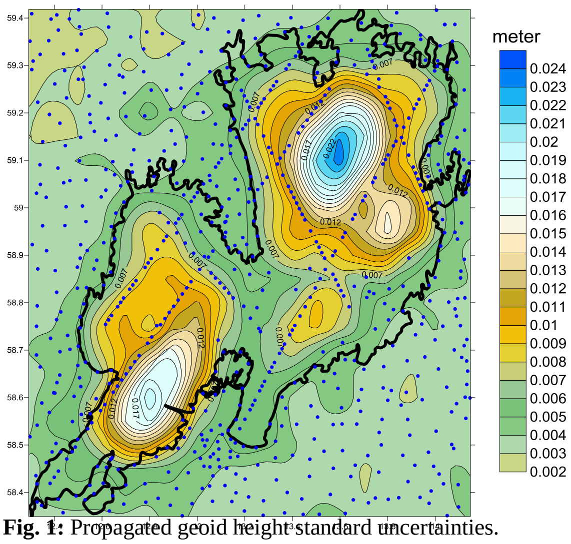

Fig. 1: Propagated geoid height standard uncertainties.

Figure 1 shows Geoid height standard uncertainties computed using Least Squares Collocation, assuming:

- a realistic, empirically computed covariance function,
- a GOCE Global Geopotential Model (GGM),
- the previously available gravity observations with standard uncertainties and
- that these gravity observations are uncorrelated (very questionable!).

2.2 Gravity observations

Most of the old gravity observations in the Vänern area have been carried out on islands mostly along the shores, see Figure 2.

There are also a few lines of airborne gravity measured in connection with the NKG Baltic 99 airborne gravity project. Those lines are shown in Figure 1.

To cover the Lake Vänern with gravity observations, points were planned in a grid with latitude difference 0.05° and longitude difference 0.10° (approx. 5.5 km × 5.5 km). After some modifications due to islands etc. the final plan consisted of 114 points on the ice.

3 Observations

3.1 Gravity

Gravity observations were carried out with the Scintrex CG-5 Autograv™ Gravity Meter. A minimum of five sessions was collected, each consisting of 60 one-second observations. If the estimated standard deviations were too high, or if the tilt deteriorated too much, five more 60 second sessions were observed.

The instrument height above the ice was registered at every observation point.

When measuring on bare ice, a special wooden tripod, see Figure 3, was used to prevent movements due to ice melting caused by the weight of the instrument. If the ice was covered with snow a "LCR-plate" was used instead.

A small wind shelter, se Figure 3, was used to minimize influence from the wind even though the instrument always was in a position to the leeward of the hovercraft.

3.2 Position

The positions of the planned observation points were stored in the navigation equipment (GPS) in the hovercraft. Normally, depending upon the ice, the actual measured point was within a few hundred meters from the planned position. Current position, in three dimensions, was measured at every observation point with the Leica 1200 receiver and SWEPOS network-RTK service, see Figure 4. The sampling time was 30 seconds. The geoid model SWEN08_RH2000 (Ågren 2009, Ågren et al 2009) was utilised to get normal heights in the Swedish height system RH 2000.

Fig. 2: Old gravity observations around the Lake Vänern (dots) and planned observation spots on the ice (circles).

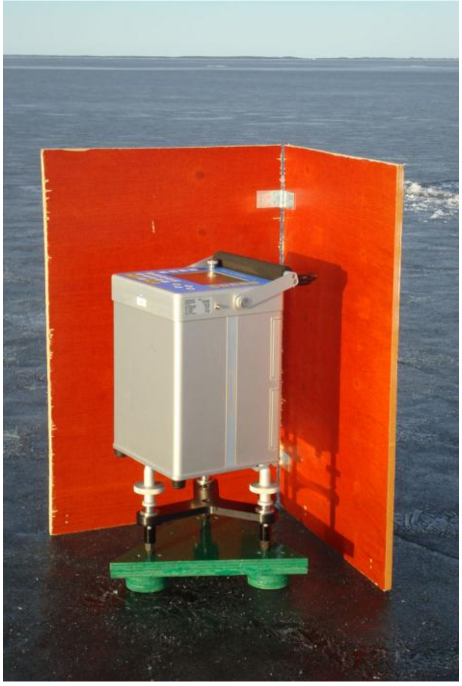

Fig. 3: CG-5 on the ice.

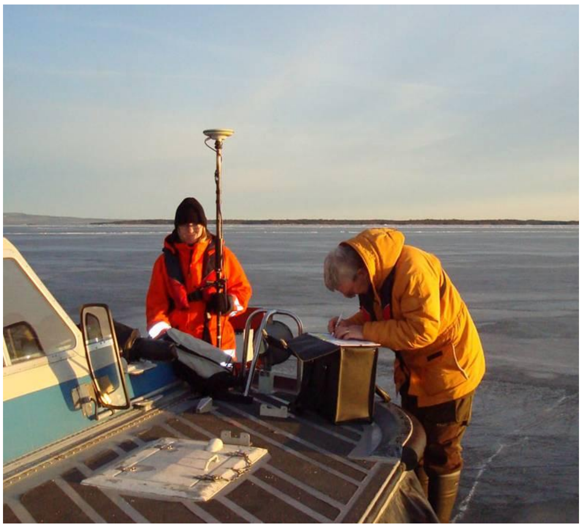

Fig. 4: Positioning with Leica 1200.

Fig. 5: Measuring depth and ice thickness.

3.3 Meteorology

At each point the atmospheric pressure and temperature was observed and registered. For measuring the atmospheric pressure, a Baromec 1975 was used.

3.4 Water depth and ice thickness

The water depth was measured with echo sounding. The instrument used was Humminbird Piranha-MAX 150x. It has a single beam transmitter and the opening angle is 20° and the maximum depth is 180 m. The transmitter/receiver was fixed to a graded rod with hook that was used for measuring the ice thickness in a drilled hole, see Figure 5.

3.5 Observation procedure

The observation procedure on the ice was as follows:

- Place the gravimeter on the ice and level it.
- Measure and record the following:
- horizontal and vertical positions,
- ice thickness,
- water depth,
- atmospheric pressure,
- air temperature.
- Level the gravimeter again, if needed.
- Start the Scintrex CG-5 observations.

3.6 Base points

Four base points, used for connection to gravity system and for control of the instrument drift, were established on stable ground close to the ice. These

Fig. 6: Base point at Hästviken, Hammarö

Fig. 7: Base point at Trellevarvet, Kållandsö

points were later connected to the Swedish national gravity network and determined in the gravity system RG 82 (≈IGSN 71). Points indoors as well as outdoors were used, see Figures 6 and 7.

Griffon 2000 TDX, hovercraft
Length: 11.7 metre.
Beam: 5.9 metre in operation.
Approx. obstacle clearance: 0.5 metre.
Height: 3.2 metre, 3.7 metre hovering
Light displacement: 3.1 ton
Full displacement: 5.6 ton
Engine type: 1×Deutz
Fuel consumption: 30-50 litre/hour
Cruising speed: 15 knots
Top speed: 35 (50) knots
Radius of action: 450 nautical miles
Operated by Vänertjänst, Hammarö

4 Transport

All transports on the ice were done with a hovercraft, Griffon 2000 TDX leased from Vänertjänst, Hammarö, with driver and mechanic. Accessibility to the hovercraft was a prerequisite of the whole expedition. The hovercrafts home port, Hästviken, in Hammarö was used as starting point during the first week. Later on, we used a small shipyard, Trellevarvet, at Kållandsö in the southern part of the lake.

During transport the gravimeter was placed in the instrument case that had been mounted on the deck of the hovercraft. All the rest of the equipment was transported in a ski-box also mounted on the deck, see Figur 8.

Fig. 8: Ski-box and instrument case mounted on the deck.

4.1 Travel routes

The travel route for the day was planned in view of ice conditions and wind-force.

The number of points measured during one day strongly depended upon how fast the hovercraft could travel between adjacent points as well as if we had to run the measuring process more than once. Nine points were observed per day on average.

Table 1: Number of points (NoP) visited each day

Date	Base point	Base point	NoP
20110303	Hästviken	Hästviken	10
20110304	Hästviken	Hästviken	8
20110305	Hästviken	Hästviken	8
20110306	Hästviken	Hästviken	9
20110307	Hästviken	Trellevarvet	5
20110308	Hästviken	Trellevarvet	2
20110309	Hästviken	Trellevarvet	9
20110311	Trellevarvet	Trellevarvet	9
20110312	Trellevarvet	Trellevarvet	10
20110313	Trellevarvet	Trellevarvet	11
20110315	Trellevarvet	Trellevarvet	16
20110316	Trellevarvet	Hästviken	5
20110317	Hästviken	Hästviken	13

In Figure 9 the travel routes are schematized on a map. Normally it was impossible to travel along the straight line between the planned points. The travel time varied from 10 to 60 minutes.

5 Experiences from the ice

Even though gravity measurements on the ice have been done earlier in the Gulf of Bothnia by our old colleagues thirty years ago we have to meet this challenge with our own experiences.

5.1 Wind problems

The main problem during the campaign was vibrations caused by the wind, which have an effect both directly and indirectly on the instrument. To prevent the direct effect from the wind we put up the gravimeter leewards of the hovercraft. After some time we found out that parking the hovercraft with the stern against the wind and placing the instrument ahead of the hovercraft, we got as much shelter from the wind as possible and reduced the tilt effect to a minimum, see below.

The indirect effect from the wind revealed oneself as a movement of the ice up and down like

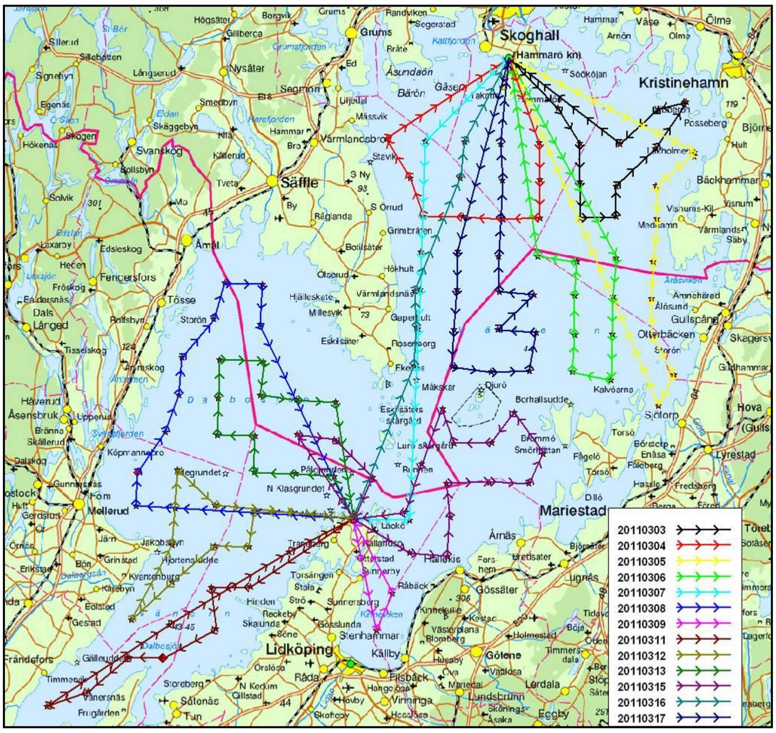

Fig. 9: Map showing schematized travel routes.

Fig. 10: The gravimeter in front of the hovercraft.

Fig. 11: A small "lake" around the hovercraft.

waves, caused by the press from the wind onto the ice. This was mainly a problem when the ice thickness was less than 30 cm.

5.2 Tilt problems

When the ice was thin, less than 25 cm, the weight of the hovercraft slowly pressed the ice down. Figure 11 shows "the lake" around the hovercraft formed by water coming through cracks in the ice. The inward bend made the instrument tilt even if it was placed in front of the hovercraft, approximately 10 m from the heavy engine. The inclination of the ice could increase more than 100 arcsecs during the five minutes of observation time.

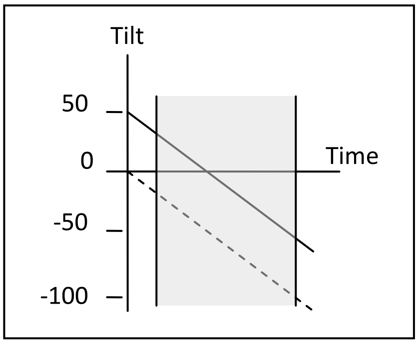

Fig.12: Principle for compensation of tilting ice.

To manage this problem we did not level (tilt ≈ 0) the tripod but started the observations with the gravimeter tilted ≈ 50 in the direction off the engine, se Figure 12. In this manner the average tilt was kept down and the outer ends of the compensation function in the gravimeter software were avoided.

5.3 Difficulties due to ridges

The hovercraft Griffon 2000 TDX has an obstacle clearance of about 0.5 m and sometimes there were problems with ridges and hummocked ice, which made it impossible to travel the shortest route. A long way round was the only way to pass those ridges and hummocks, see Figure 13. Instead of 5.5 km we had to travel almost the double distance now and then. The occurrence of ridges also led to a lower velocity because there are no brakes on a hovercraft. The only possibility to stop was to skidding and thus rotates the hovercraft a half turn. When we travelled with the wind the stopping distance could run up to several hundred metres.

6 Results

The field campaign went on during seventeen days including the travel to and from the Lake Vänern. Two days we had to stay on land, one day it was too

Fig.13: Examples of ridges and hummocked ice.

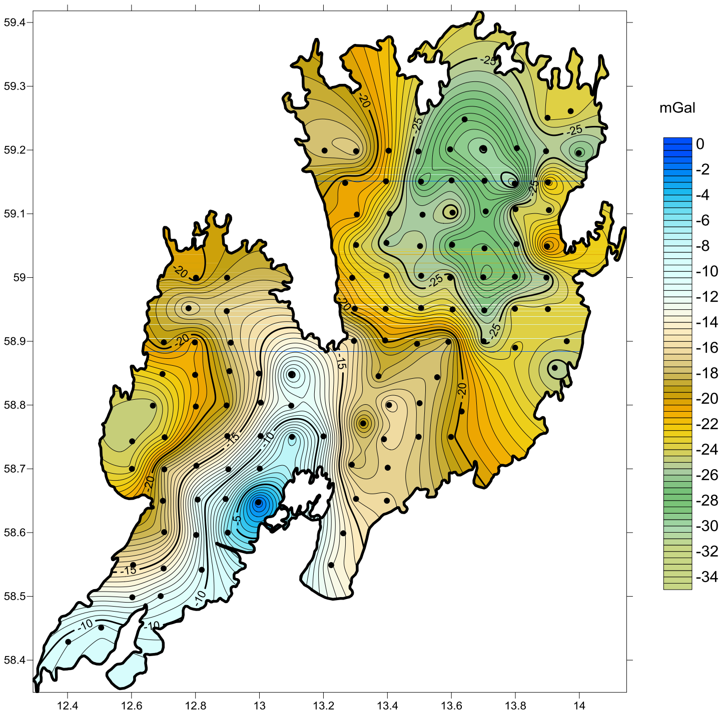

Fig.14: Free air gravity anomaly.

windy and the other we had to repair the hovercraft. That gave us thirteen days on the ice for observations and we manage to measure 114 points as planned.

6.1 Preliminary analysis

When the work on the ice of Lake Vänern was finished and the base points were connected to the gravity system RG 82, we made a first preliminary calculation.

The calculation was made in two steps. In the first step, the “relation” between the known points and the base points was calculated in the second step, the “relation” between the base points and the ice points were determined.

Input data to the software are three files of different types:

- One file ccontaining gravity values for the known points. In our case three points in the gravity system RG 82 (step one) and the base points (step two).
- One file containing network-RTK-observations (latitude and longitude) for the known and unknown points.
- One file containing the new observations exported from the gravimeter.

Initially the internal correction for earth tide was changed to a better one (ETGTAB) and corrections for atmospheric pressure and eccentricity was added. The observations were adjusted separately for each day. These preliminary calculations give an estimated standard uncertainty of ≈ 0.2 mGal.

From these preliminary results free air gravity anomalies were calculated, see Figure 14.

7 Concluding remarks

Notwithstanding the short time for preparations this campaign has given us useful results and experience of measuring relative gravity on the ice of a lake. Two main factors, having the hovercraft at hand and fairly good weather, have been contributed to this successful accomplishment.

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