GEODETIC OPERATIONS IN FINLAND

2004 - 2007

Edited by

Markku Poutanen and Hannu Koivula

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I Reference Frames

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1. Permanent GPS network

The Finnish permanent GPS network FinnRef® consists of 13 permanent GPS stations. The network is the backbone of the Finnish realisation of the EUREF frame, referred as to EUREF-FIN.

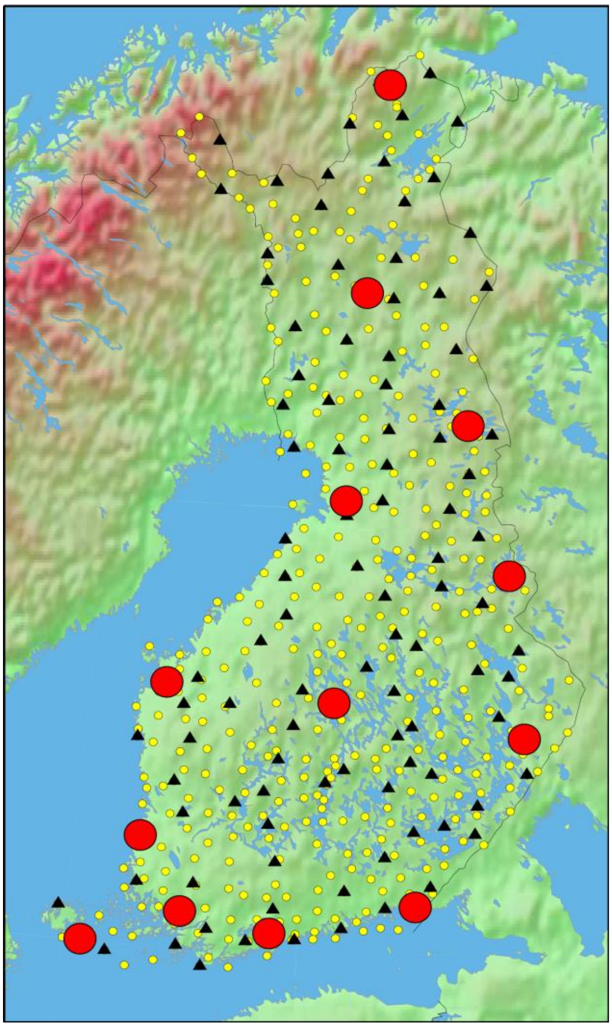

Fig 1. The permanent GPS network FinnRef (red dots), 100 points defining the ETRS89 realisation in Finland (black triangles) and GPS densification points (small yellow dots).

Four stations in the FinnRef network (Metsähovi, Vaasa, Joensuu, Sodankylä) belong to the *EUREF permanent GNSS network* (EPN), and one station (Metsähovi) belongs to the network of the *International GNSS Service* (IGS) of the IAG. Through these stations FinnRef creates a connection to the global reference frames and the stations are used for maintaining global reference frames and geodetic studies.

During the 2004-2006 to all except one (Kivetty) GPS stations were installed a wideband Internet or wireless connection. This allows an automatic hourly download. The data recorded in the EPN stations are transferred automatically hourly to the EPN regional data centres in Austria and Germany. The data are also transferred to the Onsala Space Observatory in Sweden for the BIFROST project. Both Sodankylä and Metsähovi provide also real-time RTCM 2.2. stream for EUREF-IP service.

All FinnRef® stations are used in the computation of the joint Nordic GPS network. FinnRef® forms the backbone for Finnish GPS point densifications and enables the study of the crustal motions of the Earth.

The absolute gravity observations have been made at six GPS stations in 2004-2007, viz. in Metsähovi, Vaasa, Joensuu, Kevo, Kuusamo and Sodankylä. The measurements were made with FG5 gravimeter owned by the FGI. The absolute gravity has been observed in Metsähovi more than 80 times since 1988, and nowadays annually at other stations.

Related to the IAGs project GGOS (Global Geodetic Observing System), the Nordic plan, NGOS (Nordic Geodetic Observing System) was continued as a task force of the Nordic Geodetic Commission. Markku Poutanen was the chairman of the task force, and a member of the GGOS steering committee. GGOS will be the most important geodetic effort in the coming years, and in NGOS the development of GGOS will be followed. Via GGOS geodetic data will be made available to the great public and researchers in a well controlled and uniform way.

FinnRef data are also used for example in the research carried out in a co-operation project with the Finnish Meteorological Institute on the tropospheric effect on GNSS positioning. The Sodankylä weather station was renewed, and data are now used in a EUMETSAT-related international project. FinnRef data are also used in studies on crustal loading, together with other observing methods. More than ten-year time series allow us to detect minor crustal motions, like postglacial rebound.

Fig. 2. The permanent GPS station of Vaasa. Photo Markku Poutanen

Fig. 3. The EUVN-DA observations near the border of Finland-Sweden-Norway in Lapland. Photo Pasi Häkli.

2. National realization of the ETRF89 reference frame

Work on promoting the new EUREF-FIN reference frame continued in collaboration with the National Land Survey (NLS). The FGI and NLS co-operate via a working group that was established already in 2000.

The working group prepared two recommendations for the public administration (JHS 153, JHS 154). The recommendations contain the definition of the EUREF-FIN, transformation parameters between the EUREF-FIN and the National Grid Coordinates system (Kartastokoordinaattijärjestelmä, kkj), the new map projection, coordinate transformation methods and formulas between plane coordinates.

The use of the new reference frame was promoted by giving lectures and presentations. Guidance and information were given to municipalities and various surveying companies, especially concerning coordinate transformations.

The Finnish Geodetic Institute has participated in national committees and working groups in order to advance the usage and help in practical questions of the reference frame, EUREF-FIN, in Finland.

3. EUVN-DA

The original EUVN (European Vertical Network) campaign was performed in 1997. The initial practical objective of the EUVN project was to unify different European height datums. The network of 12 permanent GPS stations, FinnRef®, was already working, but only 5 of the stations were accepted in the campaign.

In 2002 the EUREF commission initiated the EUVN_DA campaign (Densification Action). A large number of the GPS/levelling points, which were measured in Finland 1995-1999 did not fulfill the requirements stated for the EUVN_DA stations. The number of the accepted station was only 20, which was regarded too low.

The GPS observations for the densification of the EUVN-network were made in July-August 2005. The observation sites were precise levelling benchmarks or new bench-marks, which were levelled before GPS observations. During the campaign 30 new GPS/levelling sites were observed. The nominal GPS observation time was 24 hours.

The GPS observations were processed using the Bernese 5.0 software. The Finnish permanent GPS network FinnRef® (12 stations) served as backbone for the GPS solution of the coordinates. Besides, the GPS observations from the new private GPS network, GPSNet (84 stations), were used in the solution. The computations were made in the ITRF2000 frame using the 4 Finnish EPN stations and Kiruna and Tromsø as fiducial stations in the solution. The estimation of the accuracy of the coordinates of the new sites was made according to the discrepancies between consecutive half day solutions. The RMS values of the deviations were ± 3 mm, ± 3 mm and ± 6 mm for N, E and U components, respectively.

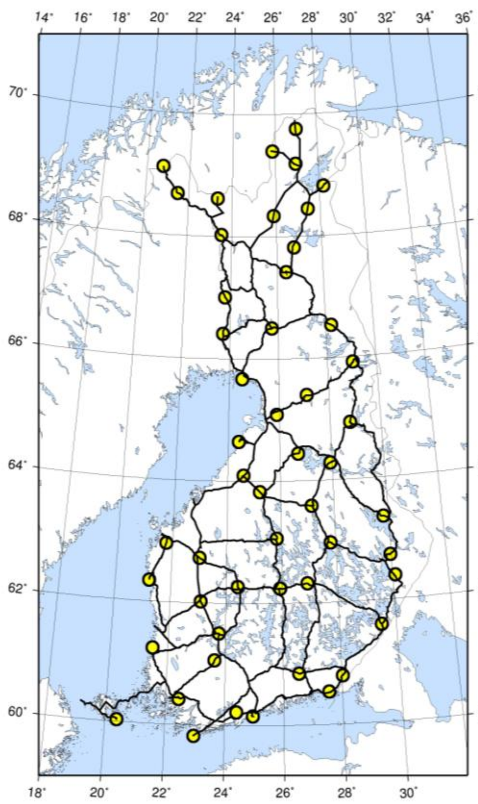

Fig. 4. The precise levelling network and the EUVN_DA stations after the densification in 2005.

4 Third Precise Levelling and the new national height system N2000

To create and maintain the height system in Finland, three national precise levellings have been carried out during the last 100 years. The National Board of Public Roads and Waterways executed the First Levelling of Finland during 1892–1910. This levelling extended to the line Joensuu–Kajaani–Oulu–Tornio. The FGI made the Second Levelling of Finland during 1935–1975 and it covered the whole country. As a result of the Second Levelling, the N60 height system was created. Its zero point is adjusted to the mean sea level in Helsinki in 1960.0 and also the land uplift is computed according to the year 1960.

The Third Levelling of Finland was started in 1978 and the field measurements were completed in 2006. The precise levelling network of Finland has been connected to Sweden in 8 places, to Norway in 5 places and to Russia in 8 places.

A total of more than 9000 km of double-run lines were measured, comprising more than 6000 benchmarks. A common Nordic adjust-ment was made on the network around the Baltic Sea to tie the national networks firmly into the European network. This enables also a unified vertical datum around the Baltic Sea

Fig 5. Field work of the Third precise levelling of Finland. Photo Markku Poutanen.

Based on the results of the joint Nordic adjustment, the new national height system N2000 was created following the guidelines of the European EVRS2000, and those agreed in the Nordic Geodetic Commission. N2000 coincides with the new Swedish height system better than 2 mm at the border of Finland and Sweden in the valley of Tornio River.

N2000 system is solely based on the Third Levelling of Finland. Geopotential differences were reduced to the epoch 2000.0 using the Nordic uplift model NKG2005LU. The datum is Normaal Amsterdams Peil (NAP), the same as for the European Vertical Reference Frame 2000 (EVRF2000).

The initial level for the fundamental bench mark of the national N2000 adjustment (PP2000 at the FGI Metsähovi research station) was obtained by the common adjustment of the levelling networks around the Baltic Sea (Baltic Levelling Ring, BLR) from NAP. The zero system for the permanent tide is used and the geopotential numbers are converted to normal heights.

Since 1960, land uplift has resulted in heights at the coast of the Gulf of Bothnia increasing by more than 40 cm. In South-East Finland the uplift is less pronounced; the change in height is less than 20 cm. These changes have practical implications e.g. in the planning of waterways.

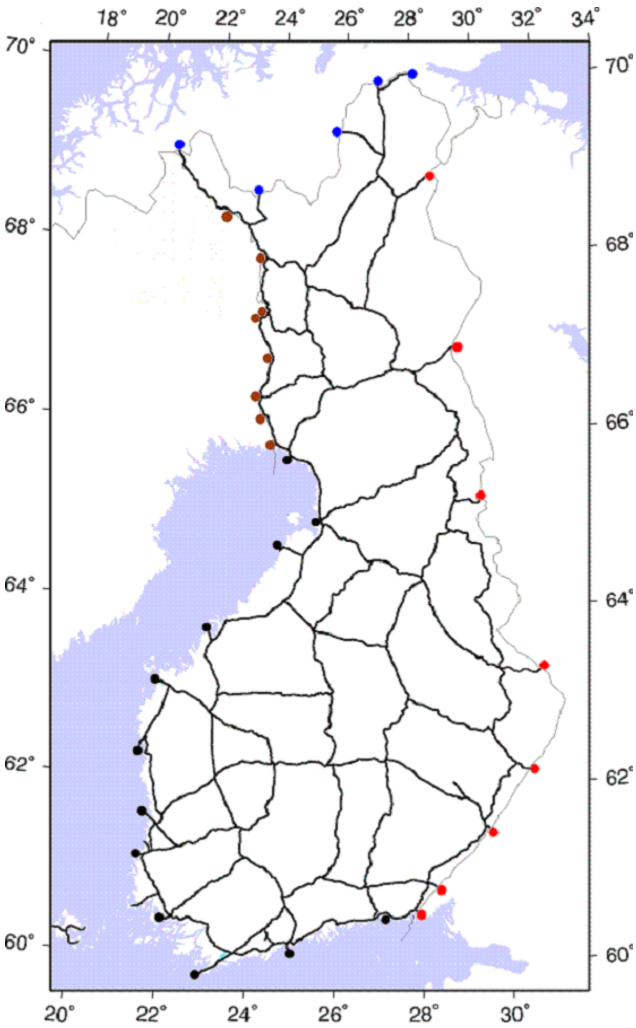

Fig 6. Levelling lines of the Third Precise levelling of Finland (1978-2006). Drawing Veikko Saaranen and Pekka Lehmuskoski.

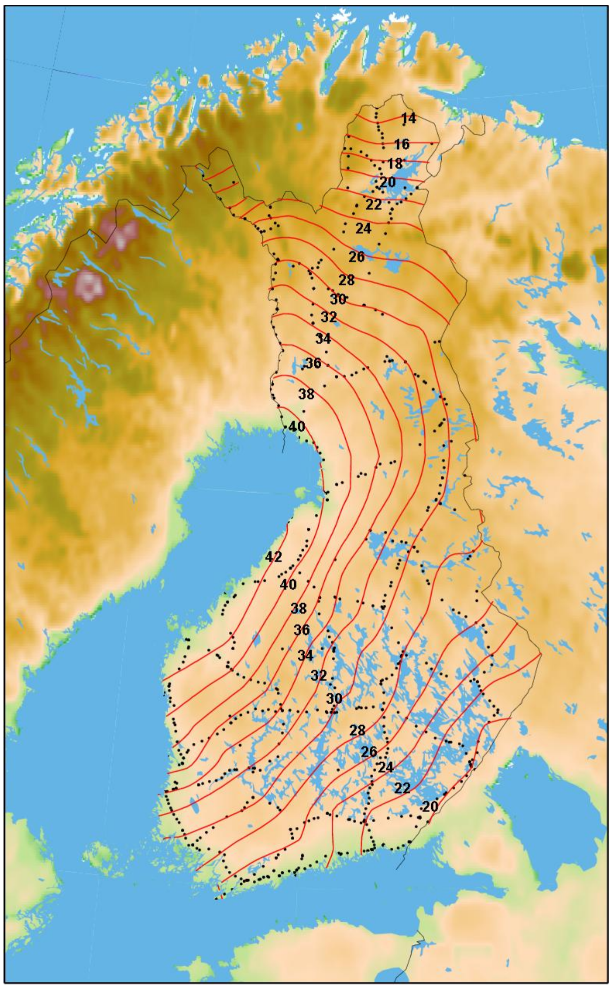

Fig. 7. Height difference (in cm) between the N60 and N2000 height systems in Finland. Drawing Veikko Saaranen.

The ever increasing use of GPS in height determination will also set new demands for the new height systems. The epoch 2000 was chosen as a common Nordic epoch in the Height determination Working Group of the Nordic Geodetic Commission.

As a joint work of the FGI and the National Land Survey, the new Recommendation for the Public Administration (JHS 163) was prepared. The recommendation was accepted in 2007. JHS163 defines the N2000, and recommends its use to local authorities in height related work.

In 2002-2006 the Finnish and Russian precise levelling networks were connected crossing the border at eight places by Finnish and Russian levelling teams. Results were published in the series of the FGI.

Fig 8. Signing the co-operation agreement between the FGI and the Russian Mapping Authorities. Photo Markku Poutanen.

5 Metsähovi Research Station

The Metsähovi research station ($\varphi = 60^{o}13'$N, $\lambda = 24^{o}24'$E) was founded in 1978 and it has through the years become an essential part of the activities of the FGI. The measurements made at the station serve both the Institute's own research and the international scientific community.

The instrumentation at Metsähovi covers the satellite laser ranging (SLR), geodetic VLBI, GPS and GLONASS receivers, DORIS beacon, superconducting gravimeter and a seismometer. There is also the fundamental absolute gravity point.

The Metsähovi Satellite Laser Ranging (SLR) was discontinued during the year 2005. Renewal the laser system was started, and a new laser was ordered in 2006. Installation of the laser was in 2007, and the renovation of the telescope was initiated.

As a co-operation project with the Metsähovi Radio Research Station of the Helsinki University of Technology, geodetic VLBI observations were continued.

The astronomical VLBI system of Metsähovi Radio Observatory of the Helsinki University of Technology was upgraded in 2003 for geodetic work by adding five baseband converters, a cooled S/X receiver, a removable subreflector and the cable delay and phase calibration units.

Fig 9. The Metsähovi SLR is to be renewed in 2007. Photo Markku Poutanen.

The Cassegrain telescope with a radome has a primary paraboloid dish with a diameter of 13.7 m and a focal length of 5.08 m. The cooled, axially positioned and removable, S/X converter (15 K) and feed was constructed by a Spanish company TTINorte. A Mark 5A system was purchased for data acquisition. Six to eight campaigns are made annually, as a part of the IVS (International VLBI Service) network and the European geodynamics project.

The Metsähovi GPS station continued as a part of the Finnish permanent GPS network, FinnRef. Since 1992 the permanent GPS receiver has been operational. The data have been submitted to the *International GPS Service* (IGS) and to the computation centre of the *EUREF Permanent GPS Network* (EPN). Metsähovi is also included in the computation of the *International Terrestrial Reference Frame* (ITRF).

Based on an agreement with NASA, a GPS receiver of JPL was installed in 2006, submitting real-time 1 s data in the NASA network.

A Javad Legacy GPS/GLONASS receiver was purchased in 1998. The GLONASS data have been used since then in the *International GLONASS Experiment* (IGLOS).

The DORIS beacon has worked since 1991 in the vicinity, in Sjökulla, at the Kylmälä village. The station has been used for the determination of the orbits of the SPOT and the TOPEX/POSEIDON satellites in co-operation with the French Space Agency (CNES).

Currently, the data collected by various observation instruments in the Metsähovi station are stored in several international data banks and used in the following international scientific projects and IAG services:

- IGS: *International GPS Service,*
- EPN: *EUREF permanent GPS-network,*
- IGLOS: *International GLONASS experiment,*
- DORIS: *Doppler Orbitography by Radiopositioning Integrated on Satellite,*
- ILRS: *International Laser Ranging Service,*
- GGP: *Global Geodynamics Project,*
- ICET: *International Center for Earth Tides.*

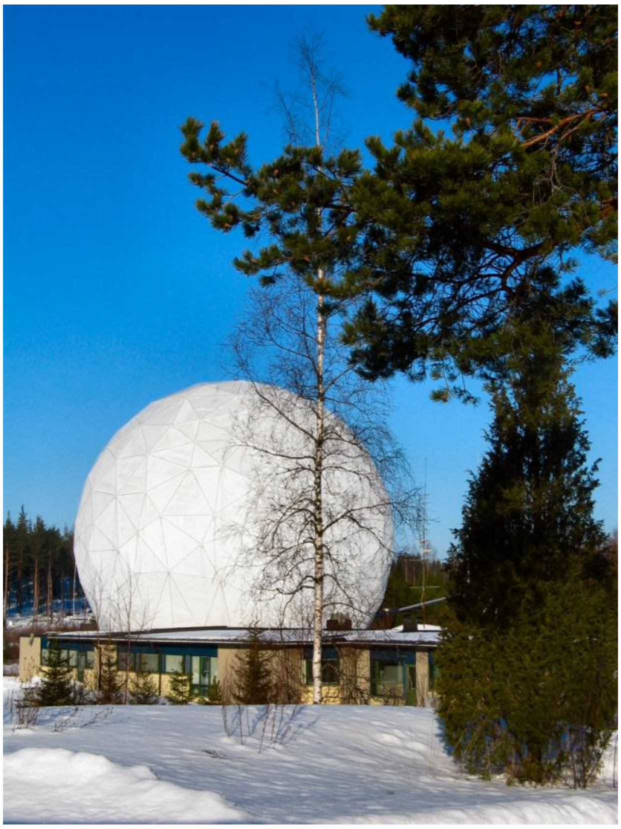

Fig. 10. Operating of the Doris receiver at Metsähovi (above). Photo Markku Poutanen.

Fig. 11. Metsähovi radio telescope. The telescope is owned by the Helsinki University of Technology (left). Photo Markku Poutanen.

II Gravity Field

by
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1. Absolute gravity measurements

The FGI absolute gravimeter FG5 no. 221 has been operational since 2003. Regular absolute gravity measurements in Metsähovi research station with the FG5 have been continued, typically once or twice per month. A number of FinnRef®-stations were occupied annually based on the NGOS absolute gravity plan of the Nordic Geodetic Commission. A number of stations abroad were also visited.

The absolute gravity site at the Finnish Antarctic base Aboa in the Western Dronning Maud Land (φ = 73º03’ S, λ = 13º24’ W), first measured in 1994 was reoccupied in 2003/2004 and 2005/2006. Gravity is also affected by snow and ice coverage in the vicinity of the site. Therefore, a terrain model, consisting of about 2000 points was measured with real-time GPS in the vicinity of the point.

Table 1. Absolute gravity stations observed by FGI in 2004–2007.

Station	Country	Year
Metsähovi	Finland	2004-2007
FinnRef stations (Joensuu, Vaasa AB, Kevo, Sodankylä, Kuusamo)	Finland	2004-2007
Vaasa AA	Finland	2004-2007
Aboa	Antarctica	2003/2004 2005/2006
Sanae IV	Antarctica	2004, 2006
Novolazarevskaya	Antarctica	2004, 2006
Paarl	South Africa	2004, 2006
Sutherland	South Africa	2004, 2006
Władysławowo	Poland	2004, 2005
Zakopane	Poland	2004
Accra	Ghana	2004
Bolgatanga	Ghana	2004
Kukurantumi	Ghana	2004
Onsala	Sweden	2004
Sevres	France	2005
Zvenigorod, Moscow	Russia	2005
Pulkovo	Russia	2007
Lovozero	Russia	2007

Additionally, 21 profiles (100 m to 2 km) were measured with RTK-GPS down the slope. The permanent GPS station, which was established at Aboa in 2003, was used as the reference station. The continuous GPS data can be used for crustal movement studies

Based on the law, the Finnish Geodetic Institute acts as the National Standards Laboratory of acceleration of free fall and geodetic length. Metrological research and measurements include maintenance and development of the national gravity network, absolute and relative gravity measurements, gravimeter calibration lines, and continuous recording of temporal gravity variations with a superconducting gravimeter.

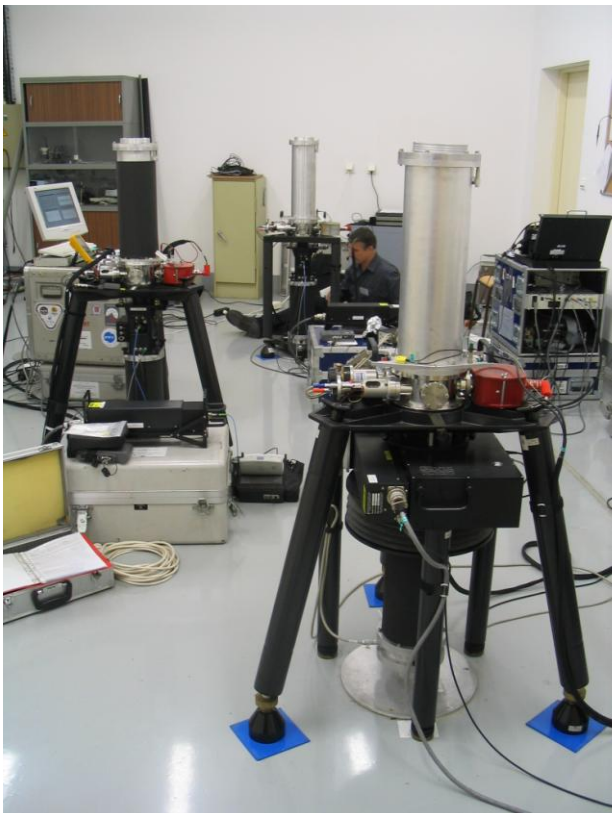

Fig. 12. Intercomparison of absolute gravimeters in Sevres, France. Photo Mirjam Bilker-Koivula.

The FG5 (Nr. 221) absolute gravimeter is the National standard of the acceleration of free fall. It is maintained by regular international intercomparisons with other absolute gravimeters. During this period, FG5 (221) participated intercomparisons in Sevres, Metsähovi and Moscow.

2. Relative gravimetry

The FGI has three relative gravimeters, LCR-G600A, Scintrex CG5 and Worden. In relative gravity measurements LCR and Scintrex have been used.

The gravimetrer calibration control line Masala-Vihti was used for calibrating the relative gravimeters in Finland. Gravimeters of the Estonian Land Survey were also calibrated on the line. Relative gravity ties between gravimetric pillars and their gravity gradients were taken at the Metsähovi gravimetric laboratory.

A study on Keurusselkä meteorite impact, discovered by amateur geologists in 2003, was made using the Bouguer anomalies of the FGI gravity database. A total of 149 new gravity points were measured in 2005 in the area to study details of the structure in co-operation with the Department of Geophysics of the University of Helsinki.

A local densification of the gravity network was measured in the vicinity of the Metsähovi observatory. A total of 122 new gravity points in a 100 m grid were measured with the Scintrex CG5 gravimeter. Positioning of the measurements was carried out with a Leica RTK-GPS instrument. A Master's Thesis was prepared on the topic.

Gravity change/PGR (Postglacial rebound) studies have been performed in Nordic cooperation since 1966, using relative gravity measurements on the Fennoscandian Land Uplift Gravity Lines. Measurements yield the relationship -1.7 ± 0.5 nm s^{-2}/mm between the gravity change and vertical motion relative to the Earth's centre of mass.

Fig. 13. Absolute gravity measurements at Vaasa GPS station. Photo Markku Poutanen.

Fig. 14. Gravity measurements at the Keurusselkä meteorite impact. Photo Hannu Ruotsalainen.

3. Superconducting gravimetry

The superconducting gravimeter GWR T020 in Metsähovi measures temporal variations in gravity, as small as 10^{-12} g. The gravimeter has been recording continuously since August 1994. After removing the influence of e.g. tidal variations and polar motion from the record, other geodynamical phenomena can be studied.

The variable loading and attraction by the Baltic Sea was computed using realistic water-level models, based on tide gauge data around the Baltic Sea. The influence of atmosphere on gravity was studied using the HIRLAM air-pressure grid provided by the Finnish Meteorological Institute.

Using the HIRLAM grid and the local barometric measurements a correction to the gravity observed with the superconducting gravimeter is computed. Combining the air-pressure grid and sea level data (without need to make assumptions on barometric response) was especially successful. Load models verified by the gravity record have then been applied to GPS observations.

Gravity variations associated with the local hydrology have been studied in cooperation with the Laboratory of Rock Engineering of the Helsinki University of Technology, with the Geological Survey of Finland and with the Finnish Environment Institute. Groundwater level (in bedrock), precipitation, and soil moisture are measured, and bedrock fractures mapped. The work is in part financed by the Academy of Finland.

Metsähovi is an excellent site for SG studies because of its low background noise level. In the frequencies of tens of minutes, SG is a superior instrument relative to the traditional seismometers. Free oscillations of the Earth can be observed, and all low order frequencies have been observed at Metsähovi. For example, the Sumatra-Andaman earthquake in 2004 induced a radial mode ${}_0S_0$ (frequency 20 minutes) which was observable at Metsähovi for as long as four months. Very weak continuous background oscillation has also been observed. Microseismic events have been observed and spectral analyses have been made. There is a correlation between the microseismic events and storms in the Northern Atlantic.

In 2006 a doctoral thesis was defended about the Metsähovi superconducting gravimeter: Studies of Earth Dynamics with the Superconducting Gravimeter.

The superconducting gravimeter in Metsähovi is one of 22 similar instruments participating in the Global Geodynamics Project (GGP). The data are sent to the GGP data center (http://ggp.gfz-potsdam.de).

Fig. 15. Filling the Metsähovi superconducting gravimeter with liquid helium. Photo Markku Poutanen.

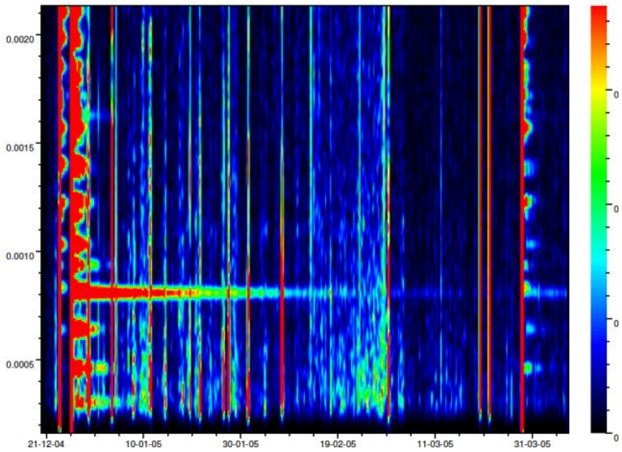

Fig. 16. Free Earth oscillations after the Sumatra-Andaman earthquake in 2004. The Y-axis is frequency (mHz) and X-axis is time (20.12.2004 – 5.4.2005). The earthquake 23.12.2004 at Macquarie Island did not cause particular excitation of the Earth. After Sumatra earthquake 26.12.2005 continuous excitation of 0S0 (0.814 mHz) and 0s2 (0.309 mHz) are clearly seen (horizontal bar). Drawing Heikki Virtanen.

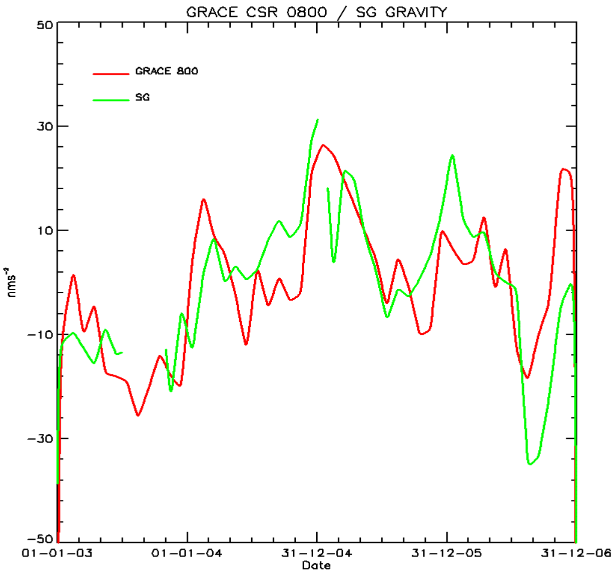

Fig. 17. Gravity variations in Metsähovi from the superconducting gravimeter (green) and GRACE monthly models (red) using an 800 km smoothing radius. Drawing Mirjam Bilker-Koivula and Heikki Virtanen.

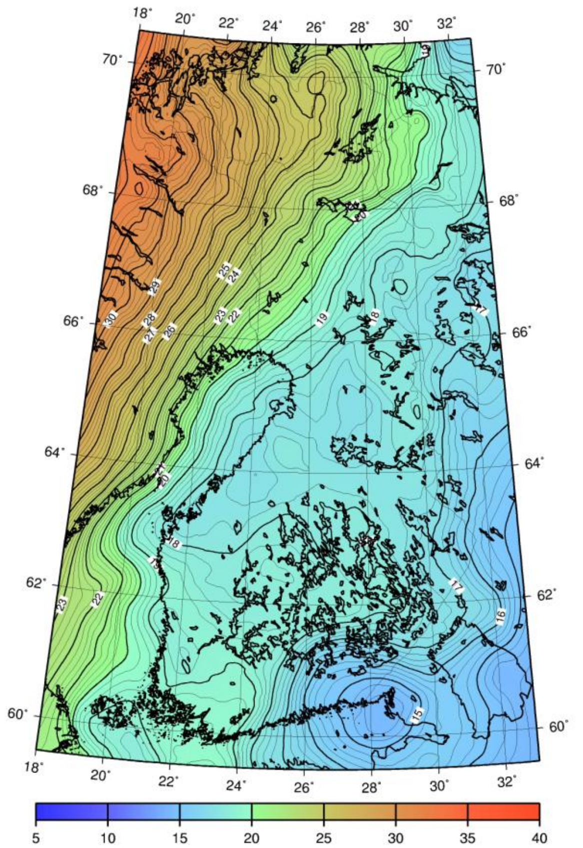

Fig. 18. Geoid model FIN2005. Drawing Mirjam Bilker-Koivula and Matti Ollikainen.

4. Satellite gravimetry

The CHAMP, GOCE and GRACE satellites probe the gravity field of the Earth. Studies in the FGI are related to the use of satellite data in geodetic research and to improve local and regional geoid models.

GRACE time series were analysed and compared with time series from the superconducting gravimeter in Metsähovi. Loading of atmosphere, sea, groundwater and snow were included in the model. Furthermore, surface mass variations were estimated from the GRACE time series and they were compared with variations in global watershed models and the Finnish Watershed Simulation and Forecasting System of the Finnish Environment Institute. Good correlations were found. Projects are funded by the Academy of Finland.

A co-operation with the Institute of Geodesy of Stuttgart University on satellite gravimetry was performed. The project was partly funded by the Academy of Finland.

5. Geoid models

The Nordic NKG2004 geoid model and the EUVN-DA GPS/levelling observations were used to determine a new National geoid model, which can be used to transform the heights from the ETRS89 to the national N2000 and N60 height systems. The model, referred as to FIN2005, was obtained fitting a surface to the height differences between GPS/levelling and spirit levelling.

Methods for geoid determination were studied. Geoid models computed for Finland and Sweden were compared, augmented with geopotential models derived from CHAMP and GRACE data.

A co-operation project was started with Prof. A. Ardalan of the University of Tehran. A local geoid model was computed using the method developed by Prof Ardalan. Data included gravity observations, levelling and deflection of vertical observations derived from astronomical positioning. The project is partly funded by the Academy of Finland.

III Geodynamics

by
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1. Studies on the deformation of Earth's crust

BIFROST (Baseline Inferences for Fennoscandian Rebound Observations, Sea Level and Tectonics) project continued. The research area of the project covers whole Fennoscandia. The aim of the project is to develop models for the mechanism of the post glacial rebound. Researchers in United States, Canada, Great Britain, Sweden and the FGI take part in the BIFROST project. Data from the FinnRef GPS stations is transferred daily to the Onsala Space Research Station in Sweden.

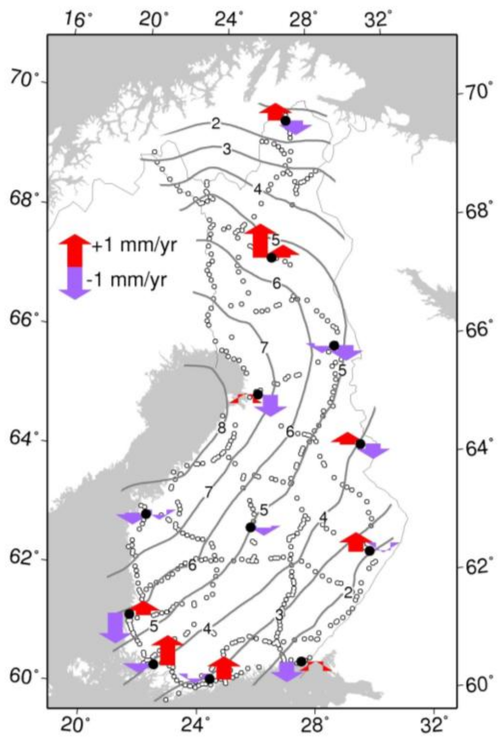

Fig. 19. Uplift rates in Finland from three different determinations. Contour lines are based on repeated precise levelling (open dots), arrows show determination on GPS stations, left hand side = BIFROST solution, right hand side = national solution. Drawing Jaakko Mäkinen and Hannu Koivula.

The study of the land uplift was continued by computing the land uplift values between Metsähovi and other FinnRef stations from the GPS observations. The GPS determinations were used together with the observations obtained by the superconducting gravimeter to study the atmospheric loading effect (see chapter on superconducting gravimeter). The periodical change of the GPS time series was studied in order to detect an explanation for the behaviour of the GPS results.

In 2007 a multidisciplinary project proposal was submitted to the International Lithosphere Program (ILP) for studying the relationship between the Glacial Isostatic Adjustment (GIA), upper mantle structure, dynamics and Quaternary climate. The DynaQlim (Upper Mantle Dynamics and Quaternary Climate in Cratonic Areas) project is aimed to be an ILP-driven task force which integrates existing data and models from a variety of disciplines that consider processes over a range of spatial and temporal scales.

The idea is to bring together researchers world-wide with complementary expertise and knowledge to identify key scientific problems relating to the Quaternary evolution of cratonic regions that can be addressed through innovative and multidisciplinary collaboration. Decision of the task force will be made in the IUGG General Assembly in Perugia 2007.

2. Local deformation studies

In co-operation with the Finnish POSIVA company, the Finnish Geodetic Institute established three highly precise GPS monitoring networks in 1994–1995. The networks are *Olkiluoto Kivetty* and *Romuvaara*, located around permanent GPS stations carrying the same name. The networks have a diameter of 2…3 km.

Fig. 20. EDM measurements at the Olkiluoto network. Photo Terhi Ahola.

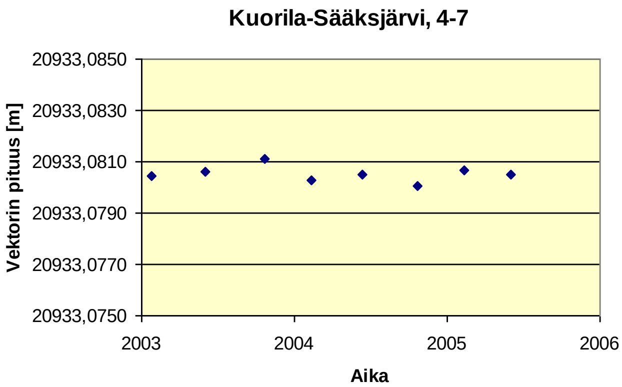

Fig. 21. Distance variation between two pillars of the GeoSatakunta network. No movement is visible in this time series. Drawing Joel Ahola.

Deformation studies are based on repeated GPS observations on the concrete pillars, which are located on solid bedrock. We have carried out two annual GPS measurement campaigns at Olkiluoto and annual reference observations at Kivetty and Romuvaara.

The FGI has established a calibration baseline at Olkiluoto for GPS scale. The baseline is measured with a precise electronic distance measuring instrument (EDM) in connection to the GPS measurements.

We can determine annual crustal deformations to a ± 0.1 mm accuracy based on 12-years time series. However, the largest movements have been only 0.3 mm/a.

Precise levelling for land uplift and local vertical motions has been carried out bi-annually to control the vertical motions. The network is connected to the national precise levelling network.

The Finnish Geodetic Institute, the Geological Survey of Finland, Posiva Ltd and the Cities of Pori and Rauma started GeoSatakunta project in 2002.

The goal of the project is to increase understanding of the unique bedrock of the area, and to make good use of geo-scientific results. One objective of the project is to get more information on recent crustal movements in the area. Seven GPS pillars were established around Pori in 2002. The number of pillars has been increased now to 13, and the network covers the southern part of the Satakunta district.

The pillars have been observed with GPS three times per year since 2003. The measurement campaigns have been carried out in January, June and October. A four-year time series is still too short to carry out reliable deformation analysis, because possible movements are only on the millimetre level.

Auxiliary markers were established for 11 pillars in 2006. The distances and angles between markers and pillars have been observed accurately. Repeated observations of auxiliary markers can reveal any possible instability of the pillars.

3. The Nordic Geodetic Observing System NGOS

The Nordic Geodetic Commission (NKG) established in 2002 a Task Force NGOS (Nordic Geodetic Observing System) with the mission to prepare the plan and the practical implementation of the NGOS. NGOS is planned to be a regional implementation and densification of the Global Geodetic Observing System, GGOS.

Table 2. Summary of techniques considered in NGOS.

Technique	Objective	Accuracy	Component(s)
VLBI	Point positioning relative to the network of quasars	0.001 ppb 0.1 mas	Surface displacement; Earth rotation; Reference frame orientation
SLR	Point positioning relative to satellites	< 1 cm (range) 1-2 cm	Surface displacement; Earth rotation; Reference frame origin
GNSS	Point positioning relative to a satellite system	E: 1-2 cm *) C: 1-2 mm	Surface displacement; Reference frames, densification
DORIS	Point positioning relative to satellites	1-5 cm	Surface displacement; Reference frame
Levelling	Height differences of points relative to the geoid	< 1 mm/km½	Surface displacement; Height differences
Tide gauges	Height of points relative to sea level	E: 10 cm C: 1 cm	Surface displacement; Sea level variation
Absolute gravimeters	Absolute gravimetric accelerations	2-3 μGal	Surface displacement; Earth rotation; Gravity; Reference frame
Superconducting gravimeters	Relative gravimetric accelerations	0.1 μGal (< 1 nGal periods)	Surface displacement; Earth rotation; Gravity; Reference frame
Spring gravimeters	Relative gravimetric accelerations	2-3 μGal	Gravity; Reference frame

*) *E means episodical and C continuous measurements*

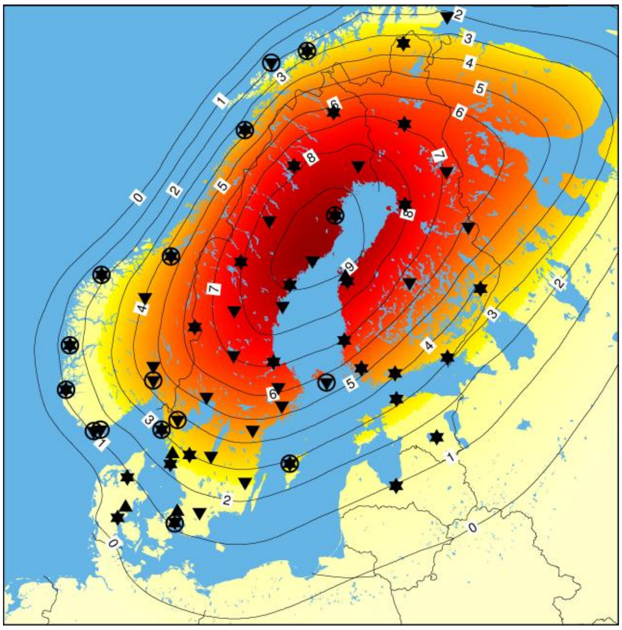

Fig. 22. The netwok of the NGOS in the Fennoscandian area. Upside-down triangles are permanent GPS stations, triangles stations with repeated absolute gravity measurements, and circles denote tide gauges. Drawing Markku Poutanen.

NGOS will contribute to the GGOS and other IAG Services; European activities such as EUREF, ECGN, EUVN, and ESEAS; provide the reference frames for the Nordic countries, as well as contribute to the global ones; support scientific projects related to the geodynamics of the Nordic area and provide ground-truth for satellite missions.

The geographic extent of NGOS is currently defined as the Nordic region, including Iceland, Greenland and Svalbard. This includes the area of the ice-covered part of the Northern Europe during the last ice age, and therefore of the common geophysical interest.

NGOS aims to provide geodetic observations for the Nordic area that are of sufficient quantity and quality to serve most of the needs of global Earth observation as well as practical and scientific applications in the region. For the Nordic countries, a main focus will be on crustal motion, dynamics of glaciated areas and sea level. In particular, NGOS

- will contribute to the GGOS and other IAG Services
- will contribute to global Earth observation systems,
- will contribute to European activities such as EUREF, ECGN, EUVN, and ESEAS,
- will coordinate the work on the reference frames for the Nordic countries, and the region as well as contribute to the global ones,
- will support scientific projects related to the geodynamics of the Nordic area,
- will provide ground-truth for satellite missions.

4. EUREF-RE

The major objective of the EUREF-RE campaign is to use the Global Positioning System (GPS) in studying deformations of the Earth's crust in Finland. The major element deforming the crust in Finland is the Glacial Isostatic Adjustment (GIA). There has been a rebound in the Fennoscandian area ever since the last Ice Age. GIA, and the associated land uplift in particular, have been known for centuries.

Land uplift has traditionally been studied using tide gauges or repeated levellings. There has been no method for carrying out accurate direct observations of the horizontal part of GIA. Plate tectonics moves the Fennoscandian shield in the north-east direction together with the rigid Eurasian plate that moves away from the North-American plate. Earthquakes in Finland, far inside the rigid Eurasian plate, indicate intra-plate deformations.

By repeating the GPS measurements it is possible to determine 3-D deformations. The GPS measurements may be carried out as episodic campaigns or as continuous time series from permanently installed GPS-stations. The FinnRef permanent GPS network offers time series that are over 10 years long. The distances between the stations are 100-200 km.

A more dense set of measurements was carried out over the period of 1996-1997 when the FGI created a EUREF-FIN coordinate reference in Finland by measuring 100 old 1st order triangulation points with GPS. This measurement was repeated in 2006 (EUREF-RE campaign, black triangles in Fig. 1.) and it will offer us a possibility to study the intra-plate deformations in a more detailed way.

We will reprocess all the existing GPS data with Bernese 5.0. Reprocessing the daily GPS data of all FinnRef stations gives us an accurate 3-D velocity field, which will show regional horizontal and vertical motions resulting from GIA. It is hard to see any intra-plate deformations on this regional scale since the stations are located far from each other. By including the campaign-based GPS data from the EUREF-FIN and EUREF-RE campaigns we are given a denser network with two epochs with a 10-year time span.

Fig. 23. EUREF-RE GPS measurements on top of the mountain Korvatunturi, the home of the Santa Claus. Photo Pasi Häkli.

As a result, an accurate regional 3-D picture of contemporary crustal motion and an observation-based present day stress and strain field will be created for Finland. All the new information obtained here supports the maintenance of Finland's co-ordinate system.

5. Antarctic project

Since 1989 FGI has participated on research in Antarctica. The field expeditions have measured the geodetic reference net for the mapping of the surroundings of the Finnish Antarctic base Aboa, and measured a regional gravity network.

Currently the FGI maintains a program of repeated absolute gravity and continuous GPS (CGPS) in Dronning Maud Land. The purpose is to detect the gravity change and deformation of the solid Earth due to past changes in the ice mass (postglacial rebound, PGR) and to the present ice balance of the Antarctic. The work is a part of the Finnish Antarctic Research Program FINNARP.

In January 2003 the FGI installed a CGPS station at the Finnish Antarctic Research Station Aboa (lat = 73° 03' S, long = 13° 24' W) on the nunatak Basen in Western Dronning Maud Land. Aboa is a summer station only, and during the winter the receiver relies on a battery pack, wind generators and solar panels for electricity. It collected over three years of uninterrupted data before the software failure in

March 2006. The receiver was replaced in early 2007 as a part of Finnarp 2007 expedition. We have processed the GPS data together with the IGS station VESL at the South African base Sanae IV.

FGI performed the first measurements at Aboa with the JILAg-5 gravimeter (January 1994 and January 2001). During the austral summer 2003/4 we made measurements at Aboa, at the South African base Sanae IV and at the Russian base Novolazarevskaya using the FG5-221. These three stations were repeated during the season 2005/6.

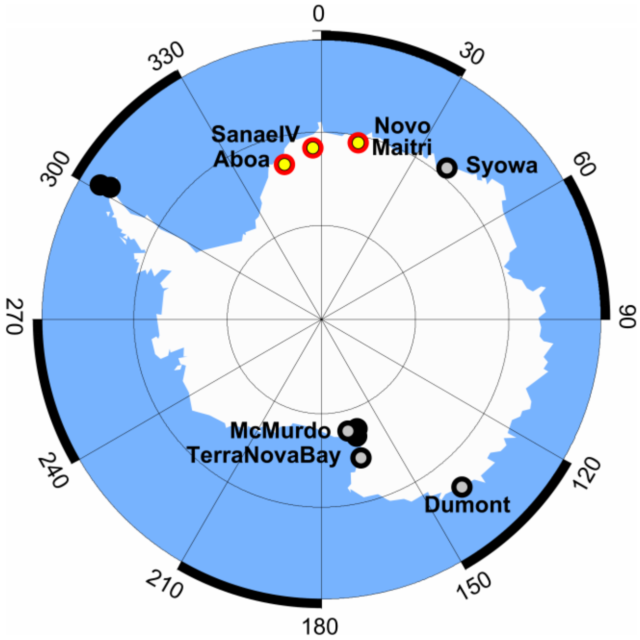

Fig. 24. Absolute gravity stations in the Antarctic, status March 2006. (right) Sites with repeated observations are named (Maitri is overlapping with Novolazarevskaya at this scale). Our gravity stations are Aboa, Sanae IV and Novolazarevskaya (Novo).

Fig. 25. Absolute gravity laboratory and permanent GPS station at the Finnish Antarctic base Aboa. Photo Joel Ahola.

Variation in local ice and snow mass causes a change in gravity through the direct attraction. It could easily overshadow the postglacial rebound signal, and the loading by the regional ice mass. Therefore it must be estimated separately. At Aboa we monitor the near-field snow surface heights using RTK-GPS techniques. The RTK-GPS rover is towed on a sledge along the profiles.

From GRACE the current total mass balance of the Antarctic (sum of ice mass and mantle inflow due to PGR) can now be estimated. Combining GRACE with estimates of ice sheet elevation change from ICESAT and soon from CryoSat-2 will help to separate the two contributions, but uncertainties due to e.g. firn density variations remain. Point wise observations of vertical motion and of surface gravity change provide powerful checks, and the possibility to estimate/eliminate unwanted signals and modelling errors.

6. Long interferometrically recording water tube tilt meter

The development work of the old interferometrically recording water tube tilt meter continued. The Michelson-Gale type tilt meters were developed in the Finnish Geodetic Institute 1965–1998. A prototype tilt meter with a new fiber-optic Fizeau-type fluid level interferometer and recording CCD camera system was constructed in 2002–2007.

Phenomena to be measured cause fluid level tilt oscillations between a few nanometers and a few tens of micrometers in one end pot. The mechanical parts of water tube tilt meter were built at the Helsinki University of Technology.

The interferometer is powered by a JDF Uniphase HeNe laser with a single mode fibre coupler (ORC, Tampere University of Technology), single mode fibers and telescope type collimators. Interferometric fluid level sensing is carried out by a plain-convex lens immersed slightly below the surface of water in each end pot and the interference fringes are recorded with Basler 601f-cmos cameras.

Phases of the recorded fringes (typically 15 fringes/sec) are interpreted on-the-fly by computers using 2D least squares adjustment under a Linux operating system. The recording systems can be controlled via the intranet/ internet.

Analyses of the old water tube system data from the EW- and NS-water tube tilt meter recordings were continued.First full-size water tube tiltmeter will be installed in the Lohja mine in 2007.

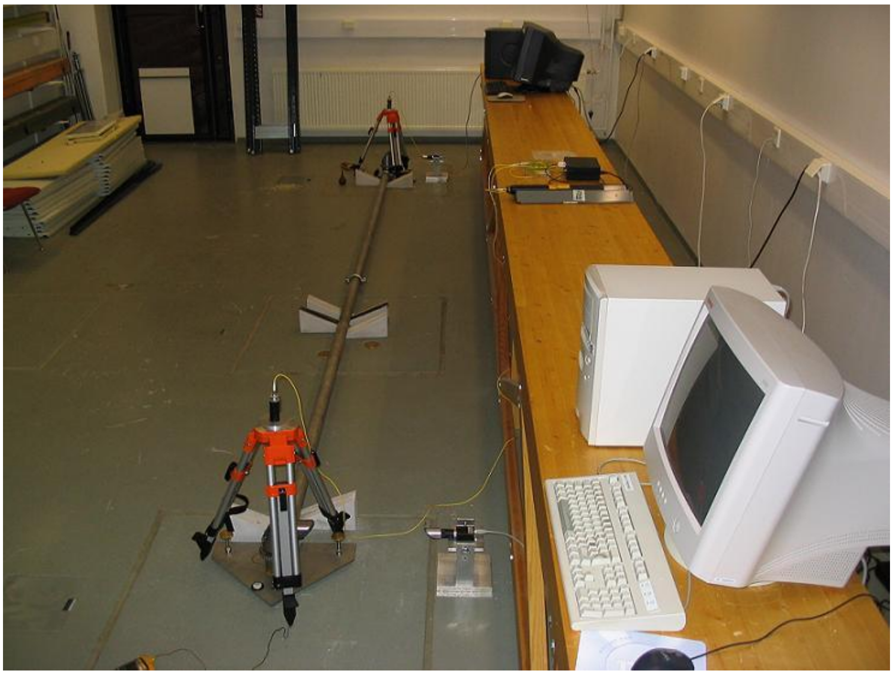

Fig. 26. Testing of the long water tube tiltmeter in the FGI laboratory. Photo Hannu Ruotsalainen.

IV Positioning and other applications

by
Ruizhi Chen, Antti Hyttinen, Pasi Häkli, Hannu Koivula, Markku Poutanen, Maaria Tervo
Finnish Geodetic Institute

1. Navigation and Positioning

In 2001 a new department, Navigation and Positioning started at the FGI. Its research topics are the new Global Navigation Satellite System (GNSS) technologies, intelligent navigation, multi-sensor positioning and real time mapping systems.

Cooperation with the European Space Agency (ESA) was established to build a Ranging and Integrity Monitoring Station (RIMS) of the European Geostationary Navigation Overlay Service (EGNOS) in Finland. The RIMS will ensure the quality of the EGNOS service in Finland. The station passed the Infrastructure Acceptance Reviewer (IAR) carried out in January 2003 by ESA. It is now in operation.

A contract with the ESSP (European Satellite Service Provider) was negotiated and signed at the end of 2005. According to the contract, the ESSP will replace the ESA in taking care of the operational activities of the station and the FGI will carry out activities to support the ESSP

The development of a system to receive the EGNOS SIS (Signal In Space) using a Pocket PC has been done under an ESA contract. The development work is important for the EGNOS users in Nordic countries because it will make it possible to access the EGNOS services on the fly over the wireless network and the Internet, without the limitation of the low elevation angles to the geostationary satellites

The department of navigation and positioning updated the data communication system of the Finnish permanent GPS network (FinnRef) and developed a system for disseminating GNSS signals over the wireless Internet. Merging these two components will form an ideal nationwide GNSS application test bed.

Some applications, such as virtual Differential GPS based on EGNOS signal and internet-based RTK, have been implemented and are available for the purpose of demonstration and scientific research. The data communication system of the FinnRef network will make it possible to access the data streams in real-time, and enable to the application scope of the test bed in the future.

Fig. 27. The RIMS station at Virolahti. Photo Ruizhi Chen.

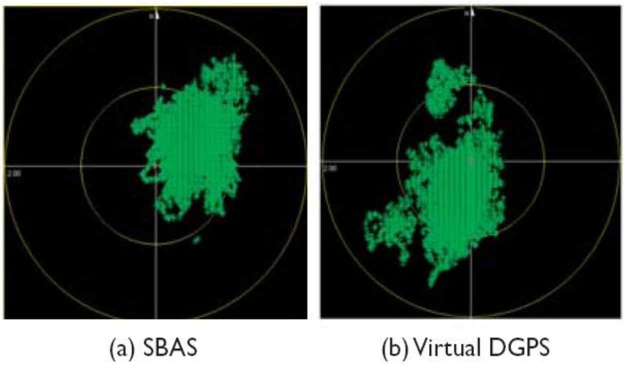

Fig. 28. Accuracy comparison of virtual DGPS solution and the direct SBAS (Satellite Based Augumentation System) solution. Drawing Ruizhi Chen.

A field test carried out in 2003 in Finland indicated that the EGNOS positioning accuracy (with the EGNOS System Test Bed Signal) are about 2 meters for the horizontal components and 4 meters for the vertical component at the level of 95%.

However, according to a driving test of 6100 kilometres around Finland, the EGNOS GEO satellites can be accessed directly only for 51% of the main roads and highways because of the low elevation angles. Therefore, the availability of the EGNOS service has been rather low in Finland for land application.

Under a contract offered by the Galileo Joint Undertaking, the Finnish Geodetic Institute, Institute of Engineering Surveying and Space Geodesy of the University of Nottingham, and the Chinese Academy of Surveying and Mapping are prototyping a multi-constellation augmentation service based on the EGNOS signal in space and Galileo simulation.

The project on wide area RTK based on EGNOS and Galileo aims to assess the potential of EGNOS RIMS network to support real-time sub-decimeter navigation based on the Wide Area RTK technique. The project consortium includes Technical University of Catalonia (Coordinator), Pildo Consulting S.L., Finnish Geodetic Institute, IfEN GmbH, Institut Cartografic de Catalunya.

2. Tropospheric delay in GPS observations

Troposphere is one of the most significant sources of error in precise GPS solutions nowadays. Especially the height component is sensitive to tropospheric delay. The tropospheric effect has been studied using slant delays derived from a numerical weather model (HIRLAM). The project was partly funded by Tekes, and it has been a joint project with the Finnish Meteorological Institute.

Two main results were achieved. A methodology to compute loading was developed and data manipulation on the observational level was successful. Atmosphere has a two-fold effect on errors in GPS solutions. Variation in air mass causes changes in tropospheric delay and changes in the loading on the Earth's crust causes additional vertical motion. These two components cannot be separated in GPS observations, and auxiliary information is therefore needed.

The superconducting gravimeter at Metsähovi was used in this work, together with the Watershed Simulation and Forecasting System of Finland, tide gauge data of the Marine Research Institute, HIRLAM data from the Finnish Meteorological Institute, and data from the GRACE satellite.

The slant delays were produced from the HIRLAM model and interpolated for every observation epoch in the direction of each satellite. The observed code and carrier pseudoranges of each satellite and each epoch were corrected for slant delay thus removing the effect of the troposphere on the observational level. Corrections were made directly on the RINEX files before processing. After this it is possible to process the data with any program that allows the troposphere modelling to be switched off.

Removing the tropospheric slant delay on the observational level remarkably improves the repeatability of the vertical component in GPS solutions. This is essential in precise height determination as well as in studies on crustal deformation.

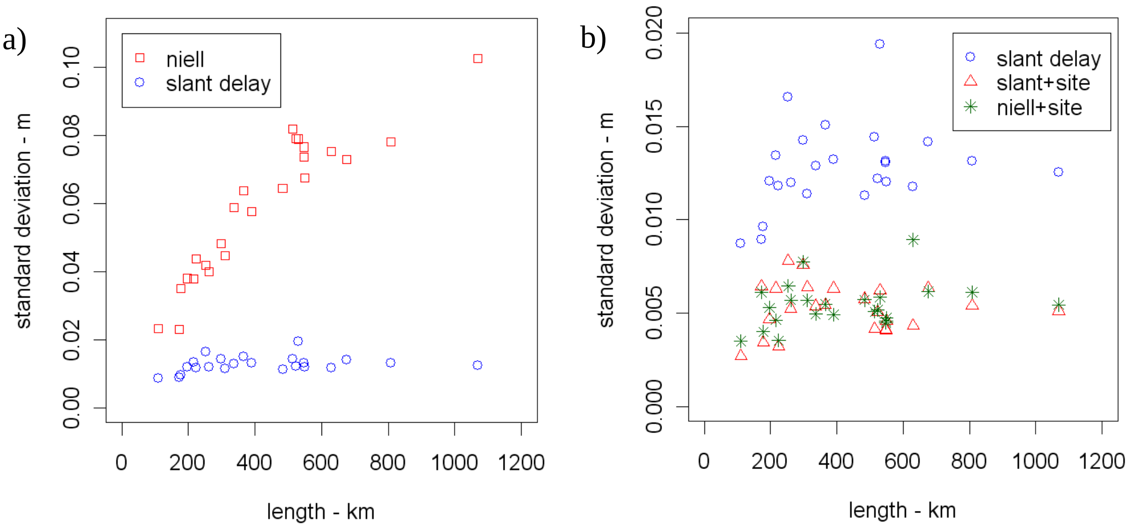

Fig. 29. The standard deviations of the up component time series respect to the length of the vector. Time series were produced using four different processing schemes. Slant delay denotes the method developed in this study. Drawing Maaria Tervo.

3. GPS quality

Finnish Geodetic Institute has an ongoing project that studies the quality of geodetic GPS. The goal of the project is to investigate both real-time and post-processing geodetic GPS in practice. Real-time applications, namely real-time kinematic (RTK) and Virtual Reference Station (VRS™) concept, were studied in 2003-2005 and static GPS in 2005-2007.

For the RTK test an adequate test field of 10 points was created. RTK test field covers distances between 0.4 and 25 km from the base station. The points are appropriate for GPS observations and they are mounted on bedrock or other stable foundations. The reference coordinates of test field were determined with minimum of three hours of static observations in order to ensure the precision of the network.

VRS measurements were carried out in two different and detached VRS networks. Half of the measurements were done in GPSNet.fi network and other half in the network of Tampere region. The test points belong to different networks and are therefore not as homogeneous as the points in the RTK test field. The VRS test points are evenly distributed with respect to baseline length in order to study distance-dependency.

Test methods were planned to minimize all non-GPS related error sources. Test points were to cover the whole operational area of the GPS mode and without unnecessary negative GPS site effects. Observations were planned to give a reliable picture about the quality of the method and therefore e.g. each RTK and VRS observation has an independent ambiguity resolution. For statistical analysis 20 observations were taken at each point and time. Every test point was measured 3-4 times under different satellite geometry resulting in over 2,100 VRS and 1,400 RTK observations.

VRS and RTK give relatively similar accuracies. Typically the accuracy of GPS is given with constant part and additional distance-dependent part. The accuracy of RTK in horizontal direction is ±(9 mm + 0,6 ppm) and ±(5 mm + 1,7 ppm) for the height. Equivalent values for VRS are ±(19 mm + 0,1 ppm) for horizontal and ±(14 mm+ 0,5 ppm) for vertical accuracies.

This study indicates that RTK gives better accuracy over short distances. This result originates from the class hierarchy of the test points. RTK test points were from one hierarchy class only when VRS test points were from several classes by FGI and Tampere. This leads to an erroneous conclusion if only theoretical accuracy is studied, but since in reality the surveyors need to measure within different coordinate classes this gives a realistic result on expectable results. Such systematic error may be diminished with local transformation that takes into account local coordinate distortions.

The aim of the static test was to find dependency between session duration, baseline length and accuracy. Therefore static data of the test was to cover wide range of baseline lengths and session durations. Baseline lengths were between 0.6 and 1,069 km with session lengths varying between 10 min and 24 hours.

The data were collected from the Finnish permanent GPS network, FinnRef, and from regular GPS campaigns, where antennas were mounted either on steel masts or concrete pillars. Therefore data is expected to be free from centring and height reading errors. The set of baseline data is a random sample from all the data from several GPS campaigns in 2003-2004. This enables us to get a realistic picture about the variations e.g. in annual and daily periods of GPS.

Reference coordinates for the stations were computed for the mean epoch (2004.5) of the test data in ITRF2000. This ensures homogeneity of the reference coordinates. The data was processed with commercial GPS software (Trimble Total Control) using standard processing parameters. These were mainly default options of the software.

Results are presented for individual baselines i.e. adjustments were not applied. A total of 10,000 baselines were processed for the study, 5,000 with broadcast and 5,000 with precise ephemerides. The final results are not published yet and they will be available in 2007.

Fig. 30. Accuracy of the real time GPS was studied with field measurements in summer 2004. Photo Hannu Koivula.

V Metrology and standardization

by
Jorma Jokela, Jaakko Mäkinen, Paavo Rouhiainen, Joel Ahola, Mirjam Bilker-Koivula, Pasi Häkli
Finnish Geodetic Institute

The Finnish Geodetic Institute is the National Standards Laboratory of acceleration of free fall and length. Metrological research and measurements include measurements at the Nummela Standard baseline, maintenance and development of Väisälä interference comparator and associated quartz gauge system, levelling rod and levelling system calibration, national gravity network, absolute and relative gravity measurements, and continuous recording of temporal gravity variations with a superconducting gravimeter. Calibration and research subjects include instruments and systems used in height determination, geodetic baselines and electronic distance measurement instruments.

The Finnish Geodetic Institute is a member in the Mutual Recognition Arrangement (MRA) of national measurement standards and of calibration and measurement certificates issued by national metrology institutes. Requirements of the ISO/IEC 17025 ja ISO 9001 standards are implemented in the quality management system of the National Standards Laboratories, described in the quality manual. Participation in the EUROMET Quality System Forum was arranged by the Centre for Metrology and Accreditation (MIKES).

1. Acceleration of free fall

The activities in the acceleration of the free fall are reported in more detailed together with the gravity work in this volume.

The Finnish Geodetic Institute has a FG5 (Nr. 221) absolute gravimeter as a National standard of the acceleration of free fall. The gravity is measured observing the acceleration of a prism falling in a vacuum. Length is measured with a laser interferometer, and time is based on a rubidium frequency standard.

During the period, the FG5 gravimeter has participated in international intercomparisons of absolute gravimeters in Sevres, Onsala, Metsähovi and Moscow. Five absolute gravimeters from four institutes participated in the intercomparison of gravimeters at Metsähovi in 2004. The participating institutes were the Federal Agency for Cartography and Geodesy (BKG, Frankfurt), the Central Research Institute of Geodesy, Aerial Surveying and Cartography (TsNIIGAiK, Moscow), Institut für Erdmessung (IfE, Hannover) and the FGI.

The Nordic gravity measurement programme continued together with the IfE of Hannover University. In addition to Metsähovi, intercomparison of FGI and IfE gravimeters was carried out in Vaasa. Additionally, in 2004 an intercomparison of gravimeters from the IfE, FGI and IMT (Agricultural Unversity of Norway, Aas) was concluted at Onsala Sweden.

Fig. 31. Intercomparison of absolute gravimeters in Zvenigorod, Moscow 2005. Photo Mirjam Bilker-Koivula.

2. Levelling calibrations

Instruments and systems used in height determination are calibrated and researched using a horizontal and automated vertical laser rod comparator, and as system calibration of digital levelling. New observation pillars were rebuilt in 2004 in the comparator laboratory for system calibration.

In addition to domestic calibrations, levels and rods were calibrated for Estonia, Latvia, Lithuania, Sweden, Denmark and Iceland. Co-operation with the Swedish Land Survey and Graz University of Technology continued.

Table 3. Number of calibrations made with the FGI rod and system calibration comparator.

Year	Invar rods	Digital levels
2003	49	62
2004	40	47
2005	55	47
2006	40	62

3. Standard baselines and calibration baselines

Calibrations for scale transfer measurements have been performed at the Nummela Standard Baseline. The Nummela Calibration Baseline is a freely available self-service baseline. The baselines are maintained with regular control and projection measurements.

Leica TC2003 and Wild T2002+DI2002 tacheometers with high precision reflectors of the FGI are regularly calibrated at Nummela. Projection measurements are taken simultaneously. The Mekometer 5000 belonging to Helsinki University of Technology are calibrated in connection of the POSIVA baseline measurements.

Interference measurements using the Väisälä comparator was done 14th time in Nummela standard baseline in 2005. The measurement was done previous time in 1996. The length of the baseline, 864 m, is the best known baseline in the world. The length uncertainty is about 0.08 mm. Due to unfavourite weather, the measurement was done only up to 432 m. According to the preliminary results, no significant changes has happened in the length of the baseline.

Remeasurement is planned for the year 2007 after renovation of the observing pillars. A new building containing facilities for observers and a small storage area was completed in 2004. The baseline was partly surrounded by a fence and a light roof construction was built on pillars.

Fig. 32. Comparison of Quartz gauges. Photo Pasi Häkli.

Fig. 33. Väisälä interference measurements at the Nummela Standard baseline. Photo Pasi Häkli.

In 2006 the FGI participated in the Asia-Pacific Metrology Programme (APMP) comparison for the pilot study on the calibration of EDM. The comparison was arranged by the Korea Research Institute of Standards and Science (KRISS) at a 280-metre 7-pillar Heerbrugg-type baseline in Daejeon.

The purpose of the comparison was to determine the lengths at the baseline with the best possible accuracy from different traceability chains and to study the field procedures for testing high precision surveying instruments according to the ISO 17123-4 standard. The FGI and ITRI, Taiwan, participated with Kern ME5000 precise distancers and the KRISS and AIST, Japan, with Leica precision tacheometers.

The FGI transferred the traceable scale from the Nummela Standard Baseline of the FGI with the Kern ME5000 of the Department of Surveying of the Helsinki University of Technology. The scale of the instrument was also checked at KRISS with a brief comparison with laser interferometers at an indoors baseline and with a rubidium frequency standard. In the second part of the comparison the Japanese team also tested a new apparatus utilizing femtosecond frequency comb technology. The frequency comb technique is one of the most promising for future precise length determination. A comparison of the frequency comb at the Nummela Standard Baseline is planned.

Fig. 34. EDM comparison in Daejon, South Korea. Photo Souichi Telada.

VI Publications, Finnish Geodetic Institute

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VII Geodetic Activities of the National Land Survey of Finland

by
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The NLS consists of 13 District Survey Offices, five national operational units and the central administration. The NLS has staff about 1800, of whom over 80% are employed in the District Survey Offices. The NLS is a governmental agency subordinate to the Ministry of Agriculture and Forestry.

District Survey Offices provide expert assistance in matters pertaining to land, real estate and maps. They carry out land surveys and help to prepare deeds of sale and provide assistance in applications for registration of title of property. They also supply cadastral information. The Offices gather and update data on the maps covering their areas for the topographic database.

NLS's national operational units are responsible for development and research in their own areas, coordination of activities and nationwide services. The units are located in Helsinki as well as the central administration.

The NLS benchmark register contains information about control points and bench-marks. Most of these horizontal control points and levelling benchmarks are measured by the NLS. Some benchmarks measured by other agencies are also included.

Within the NLS, control surveys are carried out by Uusimaa District Survey Office. They are also responsible for maintaining the system of horizontal control points and benchmarks. The unit also provides expert and measurement services related to geodetic measurements and coordinate and height systems.

The densification of the National networks was continued. The densification of the EUREF-FIN network, originally measured by the Finnish Geodetic Institute (FGI), was continued by measuring lower order points. Some measurements were still done in the kkj grid coordinate system, which is the previous coordinate reference system in Finland. Promotion of the new reference frame was continued, and map production in the new system was started.

The densification of the levelling network and re-levellings of some old levelling lines were continued.

Preparations for using the new height system of Finland (N2000) were initiated. Adjustments of National Land Survey's levelling lines into the new height system have been done and preparations for converting lower order point into N2000 have been studied. The recommendations for public administration concerning the new height system and its utilization have been prepared in co-operation with FGI. Project to promote the new height system has been started.

In 2005, the World Heritage Committee approved inclusion of the Struve Geodetic Arc in the World Heritage List. The Struve Geo-detic Arc is Finland's sixth World Heritage Site. A total of 34 station points have been selected for protection, six of these being located in Finland.

VIII Gravity Operations of the Geological Survey of Finland

by
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Geological Survey of Finland (GTK) continued applying gravity measurements to bedrock research, to exploration of metallic ores and industrial mineral deposits, and to environmental studies. In regional gravity surveys, the average station interval was 445 m. Local gravity profiles were measured with a station spacing of 20 m. Local gravity surveys were conducted on regular grids of 20 m x 100 m.

In addition, to our own measurements, the data of the Finnish Geodetic Institute and those compiled in international projects were utilized. GTK contributed to and benefited from a substantial demand in Finland for commercial gravity work.

In the four-year period 2003-2006, the number of gravity stations measured by GTK was as follows:

1. Regional gravity measurements: 25 999 stations
2. Local measurements: 113 874 stations

At the end of 2006, the regional gravity database of the Geological Survey of Finland contained 257 878 gravity stations, which cover an area of 73 217 sq. km.

GTK had in its disposal one Scintrex CG-5, one Scintrex CG-3M, two Scintrex CG-3, and four Worden gravimeters. A quality system for gravity measurements taken into use in 2002 was followed. Among other things, the calibration and behavior of the gravimeters are regularly checked on the Masala-Vihti calibration line of the Finnish Geodetic Institute.

In bedrock research, targets include major fault and shear zones, strati¬graphic cross-sections, greenstone belts, metamorphic zoning, mafic and granitic intrusions, sedimentary basins and meteorite impact craters. It also is very important to provide additional information to deep seismic soundings such as Finnish Reflection Experiment. Important targets in exploration included ore-bearing mafic intrusions and bedrock structures in gold-prospecting areas.

The gravity method maintained its position in estimating overburden thickness mostly in conjunction of assessing and protecting groundwater resources and mapping contaminated soils. Results of the GPS-gravity measurements at a waste treatment center to obtain estimates for the subsidence rate and density changes of landfills and the density of bio-waste in composting tunnels were presented at the EAGE 66th Conference & Exhibition in Paris, 2004. Tests were made on two dimension stone deposits in southeastern Finland to demonstrate to what a degree weathering can be mapped using gravity measurements.

Problems and advances of near surface gravity applications were presented in Near Surface 2006: 12th European Meeting of Environmental and Engineering Geophysics, 4-6 September 2006, Helsinki, Finland. The contribution of anomalous masses to the state of stress in the uppermost crust was modeled in southwestern Finland.

The Geological Surveys of Finland (GTK), Norway (NGU), Sweden (SGU), and the Ministry of Natural Resources of Russia made public three new digital compilations of geological and geophysical data within the Fennoscandian Shield of northern Europe. The cartographic presentation is in the form of three maps at the scale 1:2 million. These compilations include a geological, a Bouguer anomaly and a magnetic anomaly map.

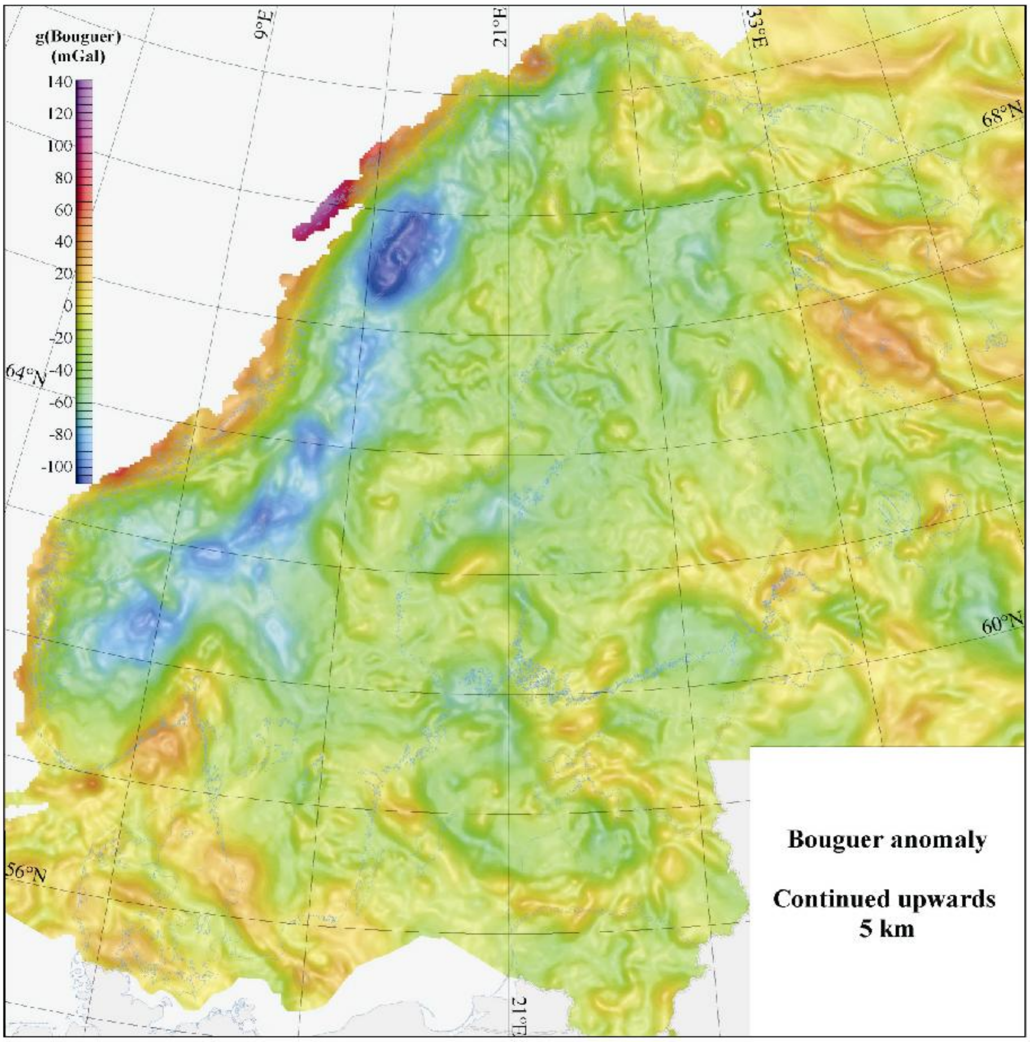

Fig. 1. Fennoscandian Bouguer anomaly map continued upwards 5 km. Compiled from Korhonen, J. V. (comp.); Aaro, S. (comp.); All, T. (comp.); Elo, S. (comp.); Haller, L. Å. (comp.); Kääriäinen, J. (comp.); Kulinich, A. (comp.); Skilbrei, J. R. (comp.); Solheim, D. (comp.); Säävuori, H. (comp.); Vaher, R. (comp.); Zhdanova, L. (comp.); Koistinen, T. (comp.) 2002. Bouguer anomaly map of the Fennoscandian Shield: IGSN 71 gravity system, GRS80 normal gravity formula. Bouguer density 2670 kg/m3, terrain correction applied. Anomaly continued upwards to 500 m above ground: scale 1:2 000 000. Espoo: Trondheim: Uppsala: Moscow: Geological Survey of Finland: Geological Survey of Norway: Geological Survey of Sweden: Ministry of Natural Resources of Russia.

The Bouguer anomaly map was compiled in cooperation with the Finnish Geodetic Institute (GL), the National Land Survey of Sweden (Lantmäteriet) and the Norwegian Mapping Authority (SK). The magnetic and Bouguer anomaly maps were complemented by data from Denmark, Estonia, Latvia and Lithuania. Information on the maps originates from 40 scientific and mapping organisations, national governmental offices and commercial companies, with which agreements concerning use of the data were obtained.

Each of the printed maps (scale 1:2 million) is available as two sheets that cover the western and eastern parts of the shield area, respectively. The collected digital set of geological and geophysical data establishes an exceptionally useful source of information to study raw material resources and environmental questions, and to increase our general geoscientific understanding of this important segment of the Earth´s crust. Printed maps and digital data sets are available from each of the four governmental organisations upon request.

The magnetic and Bouguer anomaly maps are useful standard geophysical tools that provide information on unexposed parts of the bedrock. The anomalies are correlated with geological observations using petrophysical properties obtained from measurements on rock samples. Summaries of these correlations in time and space are given on both the anomaly maps.

The main results of the Geomex geophysics sub-project were published in 2006. The Geomex project was a joint venture between the Geological Survey of Finland (GTK) and Outokumpu Mining Oy (OKU). The purpose of the project was to collect, reprocess and archive existing geological and geophysical data and material and locate new target areas for exploration.

GTK cooperated with the University of Oulu in a project the aim of which was to construct an integrated 3-D geophysical model of the crust below the southern and central Finland by joint interpretation of seismic tomographic, gravity, aeromagnetic, petrophysical and geological data. The principal scientist of the project, Dr. M. Pirttijärvi, developed software for three-dimensional modelling and interpretation of gravity field data (GRABLOX), visualization and maintenance of the three-dimensional models (BLOXER program), and lithologically weighted interpolation of petrophysical data (PETROCK program). Results were presented in the EGU General Assembly 2004, Nice, France. The project ended in 2004.

In applying gravity methods to the study of meteorite impact structures GTK cooperated with the Universities of Helsinki and Oulu, Finland.

Altogether, during the four-year period 2003-2006, the geological applications of gravity measurements were fully alive and the prospects for future application were "as good as they get".

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Öhman, T.; Pesonen, L.J.; Elo, S.; Uutela, A.; Tuisku, P.; Raitala, J. 2003. The origin and evolution of the Saarijärvi impact structure. In: 66th Annual Meteoritical Society Meeting, July 28 - August 1, 2003, Münster, Germany : abstracts. Meteoritics & Planetary Science supplement 38 (7), A52.

IX Geodetic activities at the Department of Surveying, Laboratory of Geoinformation and Positioning Technology, Helsinki University of Technology (TKK)

Martin Vermeer

Helsinki University of Technology, Laboratory of Geoinformation and Positioning Technology

During the reporting period Prof. Martin Vermeer chaired the IAG Sub-commission 2.2: Spatial and Temporal Gravity Field and Geoid Modelling.

The IAG International Symposium "Gravity, Geoid and Space Missions - GGSM2004" was held in Porto, Portugal in 2004. Prof. Vermeer acted as co-convener of the Session 8: Temporal gravity variations: modeling and measurements. A peer-reviewed proceeding was published by Springer.

The First Symposium of the International Gravity Field Service (IGFS2006) took place in Istanbul, Turkey, Aug 28 - Sept 1, 2006. Prof. Martin Vermeer acted as convener of Session 10: Geodynamics and gravity change.

In 2004 Prof. Vermeer acted as opponent of Artu Ellman's doctoral dissertation "The geoid for the Baltic countries determined by the least squares modification of Stokes' formula", and in 2006 Ramin Kiamehr's doctoral dissertation "Precise Gravimetric Geoid Model of Iran Based on GRACE and SRTM Data and the Least-Squares Modification of Stokes' Formula with Some Geodynamic Interpretations". Royal Institute of Technology, Stockholm, Sweden.

A study on a number of rough theoretical estimates for the precision of a geoid model computed from a local gravimetric survey combined with global reference model information was derived. Example calculations for Finland and Estonia were presented in a peer-reviewed journal.

In 2005 the Institute of Geodesy modernized the base network of the city of Joensuu. This included the determination of transformation parameters from the local system to kkj (National Map Grid Co-ordinate System) and to the geocentric EUREF-FIN. Staff and students participated in the work, which counts as a course. In 2007 the similar measurement was made in the city of Uusikaupunki.

Five diploma theses and one licentiate thesis appeared on geodetic subjects.

The Nordic Journal of Surveying and Real Estate Research (NJSR), editor-in-chief Martin Vermeer, has been published annually, with a number of geodetic articles.

Starting fall 2006, two divisions of Surveying Department, namely Cartography and Geoinformatics and Geodesy were merged into one. The new unit is called Laboratory of Geoinformation and Positioning Technology.

Publications:

Milne, G.A., J.X. Mitrovica, H.-G. Scherneck, J.L. Davis, J. M. Johansson, H. Koivula and M. Vermeer, 2004. Continuous GPS measurements of postglacial adjustment in Fennoscandia: 2. Modeling results, Journal of Geophysical Research, volume 109, DOI: 10.1029/2003JB002619

Vermeer, M., K. Kollo, 2007. Geoid precision from limited-area gravimetric surveys. *Geodesy and Cartography*. Vilnius: Technika, Vol. **33**, No. **1** , p. 3-8.

Vermeer M., M. Vaisanen, 2006 "Geodetic Baseline GPS Processing by a Simple Sequential Technique." Presented at the 19th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS 2006). Fort Worth, Texas. September 2006.

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