Lantmäterirapport 2016:4

Reports in Geodesy and Geographical Information Systems

Proceedings of the NKG General Assembly

Göteborg, Sweden
1–4 September 2014

Edited by Christina Kempe

LANTMÄTERIET

LANTMÄTERIET

2016-06-20

Edited by Christina Kempe

Typography and layout Rainer Hertel

Total number of pages 144

Lantmäterirapport 2016:4 ISSN 0280-5731

Proceedings of the NKG General Assembly

Göteborg, Sweden
1–4 September 2014

Edited by Christina Kempe

LANTMÄTERIET

Preface

The Nordic Geodetic Commission – founded in 1953 – is an association of geodesists from Denmark, Finland, Iceland, Norway and Sweden. Its purpose is to give the members possibilities of fruitful gatherings and mutual exchange of professional views and experiences. The NKG is recognized and supported by a number of Nordic organizations, such as the Director Generals of the Nordic Mapping Authorities.

The Commission arranges general meetings every four years, and summer schools also every four years, with one of the Nordic countries as the host. NKG is managed by a Presidium and the actual work is done in Working groups and Working group projects. The general meeting is the occasion when a new Presidium is appointed as well as the working groups.

The 17th NKG General Assembly was held in Göteborg, Sweden on the September 1-4, 2014. This was a week with plenty of presentations and discussions with participants from Sweden, Denmark, Finland, Norway, Iceland, Belgium, Estonia, France, Germany, Latvia and Switzerland. In total, almost 120 participants enjoyed the week in Göteborg. One of the days was also arranged together with the Nordic Institute of Navigation and the Swedish Radionavigeringsnämnden, concerning high accuracy positioning and navigation. Göteborg welcomed us with nice weather and the excellent conference venue, Chalmers University Conference Centre. The program started on Monday and ended on Thursday. Several nice evening receptions were held, including an ice breaker party and a conference dinner.

In this proceedings you can find some nice national reports and geodetic papers. We are grateful to all authors who have spent time writing these important contributions.

The most important contributions come from all of you who were there. However, a NKG General Assembly need to be organised and the members of the Local Organizing Committee were Jan Johansson, Chalmers University of Technology and Mikael Lilje and Christina Kempe from Lantmäteriet. The members of the Scientific Committee were Jonas Ågren, Jan Johansson, Martin Lidberg, Oddgeir Kristiansen, Markku Poutanen, Gudmundur Valsson, Per Knudsen and Anna B.O. Jensen.

Mikael Lilje
Lantmäteriet, Sweden

Table of contents

List of participants

Last name	First name	Organization	Country
Fernández-Hernández	Ignacio	European Commission	Belgium
Andersen	Niels	DTU Space	Denmark
Hansen	Flemming	Radiolab Consulting	Denmark
Jakobsen	Jakob	DTU Space	Denmark
Jepsen	Casper	Danish Geodata Agency	Denmark
Keller	Kristian	Danish Geodata Agency	Denmark
Knudsen	Thomas	Danish Geodata Agency	Denmark
Knudsen	Per	DTU Space	Denmark
Madsen	Kurt	Danish Geodata Agency	Denmark
Meister	Aslak	Danish Geodata Agency	Denmark
Olesen	Daniel	DTU Space	Denmark
Olsen	Henrik	Danish Geodata Agency	Denmark
Strykowski	Gabriel	DTU Space, National Space Institute	Denmark
Weber	Mette	Danish Geodata Agency	Denmark
Oja	Tõnis	Estonian Land Board	Estonia
Talvik	Silja	Tallinn University of Technology	Estonia
Häkli	Pasi	Finnish Geodetic Institute	Finland
Koivula	Hannu	Finnish Geodetic Institute	Finland
Kuokkanen	Jaakko	Finnish Geodetic Institute	Finland
Marila	Simo	Finnish Geodetic Institute	Finland
Mononen	Jyrki	Finnish Transport Agency	Finland
Nordman	Maaria	Finnish Geodetic Institute	Finland
Nyberg	Sonja	Finnish Geodetic Institute	Finland
Puupponen	Jyrki	National Land Survey of Finland	Finland
Saari	Timo	Finnish Geodetic Institute	Finland
Altamimi	Zuheir	Institut National de l'Information Géographique et Forestière (IGN)	France
Graf zu Eulenburg	Botho	AXIO-NET GmbH	Germany
Etter	Felix	AXIO-NET GmbH	Germany
Sigurðsson	Þórarinn	National Land Survey of Iceland	Iceland
Valsson	Guðmundur	National Land Survey of Iceland	Iceland
Aleksejenko	Ivars	Latvian Geospatial information agency	Latvia
Abrahamsen	Trine	Kartverket	Norway
Andalsvik	Yngvild Linnea	Kartverket	Norway
Bratheim	Per Christian	Kartverket	Norway
Breili	Kristian	Kartverket	Norway
Christiansen	Stig Erik	Kongsberg Seatex	Norway
Dähnn	Michael	Kartverket	Norway
Fausk	Ingrid	Kartverket	Norway

Forssell	Börje	NNF	Norway
Gjevestad	Jon Glenn	NMBU	Norway
Hanssen	Rune	Kartverket	Norway
Hjelle	Geir Arne	Kartverket	Norway
Jacobsen	Knut Stanley	Kartverket	Norway
Kierulf	Halfdan Pascal	Kartverket	Norway
Kirkvik	Ann-Silje	Kartverket	Norway
Kittelsrud	Reidun	Kartverket	Norway
Lykkja	Ola Martin	Q-Free ASA	Norway
Løvhøiden	Laila	Kartverket	Norway
Moldeklev	Kjersti	Norwegian Space Center	Norway
Morrison	Aiden	SINTEF	Norway
Mysen	Eirik	Kartverket	Norway
Nørbech	Torbjørn	Kartverket	Norway
Omang	Ove Christian Dahl	Kartverket	Norway
Ophaug	Vegard	Norwegian University of Life Sciences	Norway
Rost	Christian	Kartverket	Norway
Simpson	Matthew	Kartverket	Norway
Sokolova	Nadezda	SINTEF ICT	Norway
Solberg	Anders Martin	Kartverket	Norway
Vestøl	Olav	Kartverket	Norway
Vigen	Erik	Fugro Satellite Positioning AS	Norway
Ørpen	Ole	Fugro Satellite Positioning AS	Norway
Alexandersson	Mikael	FOI	Sweden
Alfredsson	Anders	Lantmäteriet	Sweden
Alizadeh Khameneh	Mohammad Amin	Kungliga Tekniska Högskolan	Sweden
Aziz	Muhammad Tariq	Chalmers University of Technology	Sweden
Bagherbandi	Mohammad	Kungliga Tekniska Högskolan	Sweden
Bergstrand	Sten	SP Technical Research Institute of Sweden	Sweden
Brogren	Adam	Brogren Mätkonsult	Sweden
Bäckstedt	Jesper	Sjöfartsverket	Sweden
Chen	Deliang	University of Gothenburg	Sweden
Elgered	Gunnar	Chalmers University of Technology	Sweden
Engfeldt	Andreas	Lantmäteriet	Sweden
Eshagh	Mehdi	University West	Sweden
Frisk	Anders	Lantmäteriet	Sweden
Gabrielsson	Björn	FOI	Sweden
Haas	Rüdiger	Chalmers University of Technology	Sweden
Hammarklint	Thomas	SMHI	Sweden
Hedling	Gunnar	Lantmäteriet	Sweden
Hell	Benjamin	Sjöfartsverket	Sweden
Hobiger	Thomas	Chalmers University of Technology	Sweden
Horemuz	Milan	Kungliga Tekniska Högskolan	Sweden

Jansson	Patric	Kungliga Tekniska Högskolan	Sweden
Jarlemark	Per	SP Technical Research Institute of Sweden	Sweden
Jensen	Anna	Kungliga Tekniska Högskolan	Sweden
Jivall	Lotti	Lantmäteriet	Sweden
Johansson	Jan	Chalmers University of Technology	Sweden
Jonsson	Bo	BNB-Consulting	Sweden
Jämtnäs	Lars	Lantmäteriet	Sweden
Kareinen	Niko	Chalmers University of Technology	Sweden
Kempe	Tina	Lantmäteriet	Sweden
Kjernald	Emma	Göteborgs Stad	Sweden
Lidberg	Martin	Lantmäteriet	Sweden
Lilje	Christina	Lantmäteriet	Sweden
Lilje	Mikael	Lantmäteriet	Sweden
Lööf	Anna	Lantmäteriet	Sweden
Löfgren	Johan	Chalmers University of technology	Sweden
Norin	Dan	Lantmäteriet	Sweden
Ohlsson	Kent	Lantmäteriet	Sweden
Olsson	Per-Anders	Lantmäteriet	Sweden
Persson	Clas-Göran	Lantmäteriet	Sweden
Scherneck	Hans-Georg	Chalmers University of Technology	Sweden
Sjöberg	Lars	Kungliga Tekniska Högskolan	Sweden
Smiljanic	Ana-Marija	Göteborgs Stad	Sweden
Smith	Colby	Geological Survey of Sweden	Sweden
Steffen	Holger	Lantmäteriet	Sweden
Steinmetz	Erik	SP Technical Research Institute of Sweden	Sweden
Sunna	Johan	Lantmäteriet	Sweden
Tengbert	Henrik	Sjöfartsverket	Sweden
Uggla	Maria	Stockholm SBK	Sweden
Vium Andersson	Johan	WSP	Sweden
Wahlund	Sara	WSP Sverige AB	Sweden
Wieslander	Torbjörn	Kustbevakningen, SCG	Sweden
Wiklund	Peter	Lantmäteriet	Sweden
Wilhelmsson	Magnus	Malmö Stadsbyggnadskontor	Sweden
Winkler	Alexander	Göteborgs Stad	Sweden
Ågren	Jonas	Lantmäteriet	Sweden
Kaminskis	Janis	ETH Zürich Geodesy and Geodynamics Lab (GGL)	Switzerland
Ekman	Martin	Summer Institute for Historical Geophysics	Åland Islands

Session overview

Monday September 1

Introductory session
Chair: Mikael Lilje

13:00 Welcome – *Mats Viberg, First Vice President of Chalmers University of Technology*

13:15 Opening of the meeting – *Niels Andersen, chairman NKG Presidium*
Local organising committee – *Jan Johansson/Mikael Lilje*
Scientific committee – *Jonas Ågren*

13:30 Invited talk: Climate Change – the State of Science
Deliang Chen, Professor at Gothenburg University, one of the lead authors of IPCC Assessment Report 5.

14:45 Reports from the existing Working Groups
Reference Frames, Positioning and Navigation* – *Pasi Häkli*
Infrastructure – *Per Knudsen*
Geoid and Height Systems* – *Jonas Ågren*
Geodynamics – *Matthew Simpson (replaces Dagny Lysaker)*

15:45 NKG Presidium report – *Niels Andersen*
Includes presentation of the NKG GA 2014 resolution committee
Includes presentation of the United Nations initiative on Global Geospatial Information Management (UN-GGIM) and proposed UN resolution on Global Geodetic Reference Frame

16:35 National reports:
Denmark
Finland*
Iceland
Norway*
Sweden*

17:15 Popular Science lecture: Where on Earth are we? Using sun, stars, moons and satellites for mapping the Nordic countries 1500 – 2000 – *Martin Ekman*

18:00 Ice breaker party in the conference facilities at Chalmers, sponsored by the City of Göteborg, Lantmäteriet and Chalmers. Includes a popular presentation of Göteborg

* Included in this volume

** Published in Journal of Geodetic Science, Volume 5, issue 1 (Jan 2015), ISSN 2081-9943

*** Published in Journal of Geodetic Science, Volume 6, issue 1 (Jan 2016), ISSN 2081-9943

Tuesday September 2

Session on Geoid and Height Systems
Chair: Jonas Ågren

A Harmonized Vertical Reference System for the Baltic Sea
Jyrki Mononen

Report from the on-going project to compute the new NKG2014 geoid model
Jonas Ågren, Gabriel Strykowski, Mirjam Bilker-Koivula, Ove Omang, Silja Talvik, Tõnis Oja, Ivars Aleksejenko, Eimuntas Paršeliūnas, Lars E. Sjöberg, René Forsberg, Janis Kaminskis

Investigations towards the NKG2014 geoid model in Estonia
Silja Talvik, Tõnis Oja, Artu Ellmann

DTU Space: Marine Gravity Measurements in Denmark, Greenland and beyond
G. Strykowski, R. Forsberg, H. Skourup, J. E. Nielsen, I. Einarsson, A. V. Olesen

Fjords, lakes and marine gravity measurements
Ove Christian Dahl Omang

A comparison of methods for regional gravity field modeling: Closed-loop simulations and regularization
Vegard Ophaug

Invited: The Development of Physical Geodesy during 1984-2014- A personal view**
Lars E. Sjöberg

A mascon adjustment of the Earth's gravity field using gradiometer data
E. Mysen

A new updated empirical land uplift model*
Olav Vestøl, Jonas Ågren, Tarmo Kall, Ivars Aleksejenko, Eimuntas Paršeliūnas, Andres Rüdja

Session on Geodynamics
Chair: Matthew Simpson

Absolute gravity observations conducted under harsh conditions*
Kristian Breili & Ove Christian Dahl Omang

Five years of gravity measurement at Onsala Space Observatory: The absolute scale*
Hans-Georg Scherneck, Andreas Engfeldt, Per-Anders Olsson, Ludger Timmen

A New Fennoscandian Crustal Thickness Model
Mohammad Bagherbandi, Robert Tenzer, Lars E. Sjöberg, Majid Abrehdary

Surficial geology indicates early Holocene faulting and seismicity, central Sweden
Colby A. Smith

* Included in this volume

** Published in Journal of Geodetic Science, Volume 5, issue 1 (Jan 2015), ISSN 2081-9943

*** Published in Journal of Geodetic Science, Volume 6, issue 1 (Jan 2016), ISSN 2081-9943

Twenty one years of search for the true crustal deformation in Fennoscandia from the BIFROST project
Jan M. Johansson, Tong Ning, Hans-Georg Scherneck, Gunnar Elgered, Martin Lidberg, Gunnar Hedling, Lotti Jivall, Markku Poutanen, Hannu Koivula, Halfdan Kierulf, Oddgeir Kristiansen

NKG201xGIA – a model of glacial isostatic adjustment for Fennoscandia*
Holger Steffen, Valentina R. Barletta, Karin Kollo, Glenn A. Milne, Maaria Nordman, Per-Anders Olsson, Matthew J.R. Simpson, Lev Tarasov

Towards an improved Glacial Isostatic Adjustment model for Fennoscandia: Quantifying Earth model uncertainty using decay time estimates from Ångermanland
Maaria Nordman, Glenn A. Milne, Lev Tarasov

Investigations of the relation between gravity and vertical displacement change rates in formerly glaciated areas*
Per-Anders Olsson, Glenn Milne, Hans-Georg Scherneck, Jonas Ågren

A GNSS velocity field for Fennoscandia and a consistent comparison to glacial isostatic adjustment models*
Halfdan Pascal Kierulf, Holger Steffen, Matthew Simpson, Martin Lidberg

The Verification Of GIA In Estonia Using GNSS Data
Karin Kollo, Tõnis Oja, Priit Pihlak

Poster Session

Main poster session for all the sessions. The posters will be on display for the entire conference. See poster list below.

Wednesday September 3

"Reference frames, Positioning and Navigation" – joint seminar of Nordic Geodetic Commission, Nordic Institute of Navigation and the Swedish Radionavigeringsnämnden on high accuracy positioning and navigation
Chairs: Anna Jensen, Royal Institute of Technology (KTH), Sweden, and Jan Johansson, Chalmers University of Technology, Sweden

Keynote: Galileo Commercial Service, status and plans*
Ignacio Fernández-Hernández, European Commission, Belgium.

Keynote: The International Terrestrial Reference Frame: current status and future developments
Zuheir Altamimi, Institut Géographique National, France

The real-time ionosphere monitoring service of the NMA
Knut Stanley Jacobsen

* Included in this volume

** Published in Journal of Geodetic Science, Volume 5, issue 1 (Jan 2015), ISSN 2081-9943

*** Published in Journal of Geodetic Science, Volume 6, issue 1 (Jan 2016), ISSN 2081-9943

High latitude scintillation monitoring
Yngvild L. Andalsvik

CAT II/III GBAS Implementation Challenges*
Nadezda Sokolova & Aiden Morrison

Monitoring EGNOS performance in Norway
Anders Martin Solberg

Tests with RTK and PPP on board ships
Gunnar Hedling, Johan Sunna, Ulf Olsson

Balanced Least Absolute Value Estimator and its applications in navigation problems*
Milan Horemuz

Branch antennas improve satellite acquisition under forest canopies
Sten Bergstrand & Erik Steinmetz

How does radio-frequency interference (RFI) influence network RTK? – Results of a field test in Norway
Christian Rost, Tor-Ole Dahlø, Åsmund Skjæveland, Roger Hougen, Anders Rødningsby

Autonomous Detection of Electromagnetic Interference in the GPS band*
Björn Gabrielsson, Patrik Eliardsson, Mikael Alexandersson, Kia Wiklundh, Peter Stenumgaard, Gunnar Hedling, Anders Frisk, Peter Wiklund

ITS Applications: Precision Asset Positioning and Monitoring in Degraded GNSS Signal Environments**
Aiden Morrison, Nadezda Sokolova, Trond Arve Haakonsen

Thinning the branches of the GNSS decision tree
Sten Bergstrand, Per Jarlemark, Jan Johansson

Adapting Network RTK for Civil Engineering Purposes
Johan Vium Andersson

Panel discussion: "User needs for GNSS at high latitudes"
Moderator: *Kristian Keller, National Geodata Agency, Denmark*

Panel members:

Ignacio Fernández-Hernández, European Commission, Belgium
Peter Wiklund, Lantmäteriet, Sweden
Kjersti Moldeklev, Norwegian Space Center, Norway
Rune Hanssen, Norwegian Mapping Authority, Norway
Hannu Koivula, Finnish Geodetic Institute, Finland
Stig Erik Christiansen, Kongsberg Seatex, Norway
Jan Johansson, Chalmers Technical University, Sweden
Anna Jensen, AJ Geomatics, Denmark

* Included in this volume

** Published in Journal of Geodetic Science, Volume 5, issue 1 (Jan 2015), ISSN 2081-9943

*** Published in Journal of Geodetic Science, Volume 6, issue 1 (Jan 2016), ISSN 2081-9943

Thursday September 4

Session on Reference Frames and Geodetic Infrastructure
Chair: Pasi Häkli

Report from the project "NKG GNSS analysis centre"*
Lotti Jivall, Tina Kempe, Christina Lilje, Sonja Nyberg, Pasi Häkli, Karin Kollo, Priit Pihlak, Mette Weber, Ksenija Kosenko, Þórarinn Sigurðsson, Guðmundur Valsson, Dalia Prizginiene, Eimuntas Paršeliūnas, Oddvar Tangen

Modernization of the Finnish Permanent GNSS Network FinnRef and its open positioning service
H. Koivula, S. Nyberg, J. Kuokkanen, S. Marila, A. Laaksonen, P. Kangas, P. Häkli, U. Kallio, T. Tenhunen, M. Poutanen

SWEPOS® Status and future development
Peter Wiklund, Gunnar Hedling, Lotti Jivall, Martin Lidberg

From Passive to Active Control Point Networks – Evaluation of Accuracy in Static GPS Surveying*
Pasi Häkli, Ulla Kallio, Jyrki Puupponen

HMK – Swedish handbook in surveying and mapping*
Anders Alfredsson, Johan Sunna, Lars Jämtnäs

Sea level observations using multi-system GNSS reflectometry*
Johan S. Löfgren & Rüdiger Haas

Progress on the Norwegian Mapping Authority's GEOSAT software development project
Laila Løvhøiden

VLBI Analysis with Geosat
Ann-Silje Kirkvik

Observation of GLONASS satellites with VLBI
Rüdiger Haas, Simon Casey, Jun Yang, Ivan Marti-Vidal, Alexander Neidhardt, Christian Plötz, Jan Kodet, Sergei Progobenko, Dmitry Duev, Lucia Plank

Experience from geodetic VLBI observations at Onsala using a digital backend**
Niko Kareinen & Rüdiger Haas

Closing session
Chair: Niels Andersen

Resolutions and Elections*

Closing of the General Assembly

* Included in this volume
** Published in Journal of Geodetic Science, Volume 5, issue 1 (Jan 2015), ISSN 2081-9943
*** Published in Journal of Geodetic Science, Volume 6, issue 1 (Jan 2016), ISSN 2081-9943

Posters

Geoid and Height Systems

Review of current and near-future levelling technology
Olav Vestøl, Per-Ola Eriksson, Casper Jepsen, Kristian Keller, Jaakko Mäkinen, Veikko Saaranen, Guðmundur Valsson, Olav Hoftuft

Investigations for the requirements for a 5 mm geoid model - a project status report
Lars E. Sjöberg & Jonas Ågren

Improving the Baltic Sea geoid model by marine gravity measurements in the FAMOS project
Jonas Ågren, Günter Liebsch, Jaakko Mäkinen, Christoph Förste,Martin Lidberg, Hartmut Wziontek, Markku Poutanen, Mirjam Bilker-Koivula, Benjamin Hell, Gabriel Strykowski

Evaluation of GOCE- and GRACE-based global geoid models in Finnish territory*
Timo Saari & Mirjam Bilker-Koivula

Utilization and Quality Control of State-of-the-art Digital Elevation Data*
Thomas Knudsen

Swedish municipalities implementing the new national height system RH 2000*
Christina Kempe, Linda Alm, Fredrik Dahlström, Lars E. Engberg, Jakob Jansson

Latvian digital zenith camera in test applications*
Jānis Kaminskis, Inese Janpaule, Ansis Zariņš, Markus Rothacher

The updated Danish Elevation Model (DK-DEM) – from procurement to distribution
Gitte Rosenkranz

Geodynamics

Status report from the ongoing work with the new Swedish Gravity System RG2000
Andreas Engfeldt

Five years of gravity measurement at Onsala Space Observatory: The superconducting gravimeter*
Hans-Georg Scherneck

Regional 21st century sea-level projections for Norway based on IPCC AR5 science*
Matthew James Ross Simpson, Krisitan Breili, Halfdan Pascal, Oda Roaldsdotter Ravndal

Observed secular gravity trend at Onsala station with the FG5 gravimeters from Gävle and Hannover**
Ludger Timmen, Andreas Engfeldt, Olga Gitlein, Hans-Georg Scherneck

Evaluating the calibration of Scintrex CG-5 spring gravimeters in Estonia
T. Oja, K. Türk, H. Jürgenson

Land uplift at Kvarken archipelago and High Coast UNESCO World Heritage area
Markku Poutanen & Holger Steffen

* Included in this volume
** Published in Journal of Geodetic Science, Volume 5, issue 1 (Jan 2015), ISSN 2081-9943
*** Published in Journal of Geodetic Science, Volume 6, issue 1 (Jan 2016), ISSN 2081-9943

* Included in this volume
** Published in Journal of Geodetic Science, Volume 5, issue 1 (Jan 2015), ISSN 2081-9943
*** Published in Journal of Geodetic Science, Volume 6, issue 1 (Jan 2016), ISSN 2081-9943

The NKG2008 GPS Campaign - final results including transformation parameters***
Pasi Häkli, Lotti Jivall, Martin Lidberg, Torbjørn Nørbech, Oddvar Tangen, Karsten Engsager, Mette Weber, Priit Pihlak, Ivars Aleksejenko, Eimuntas Paršeliūnas

Recommendation for the Public Administration 184 (JHS184): Measuring control points in EUREF-FIN reference frame*
Pasi Häkli, Markku Poutanen, Hannu Koivula, Ulla Kallio, Sonja Nyberg, Marko Ollikainen, Pekka Tätilä, Reino Ruotsalainen, Jyrki Puupponen, Kimmo Junttila, Matti Holopainen

Optimization of Lilla Edet Land Slide GPS Monitoring Network**
Mohammad Amin Alizadeh-Khameneh, Mehdi Eshagh, Lars E Sjöberg

Two-epoch optimal design of displacement monitoring networks
Mehdi Eshagh & Mohammad Amin Alizadeh-Khameneh

New Developments in the SWEPOS Network
Gunnar Hedling, Peter Wiklund, Anders Frisk, Martin Håkansson, Martin Lidberg, Lotti Jivall, Mikael Lilje, Ragne Emardson, Per Jarlemark, Jan Johansson

Comparison of Vienna Mapping Function (VMF1) and Global mapping Function (GMF) for NKG GNSS AC*
Lotti Jivall

* Included in this volume

** Published in Journal of Geodetic Science, Volume 5, issue 1 (Jan 2015), ISSN 2081-9943

*** Published in Journal of Geodetic Science, Volume 6, issue 1 (Jan 2016), ISSN 2081-9943

NKG Working Group for Reference Frames, Positioning and Navigation – Report 2010-2014

Pasi Häkli
Finnish Geospatial Research Institute (FGI), National Land Survey of Finland
Geodeetinrinne 2, FI-02430 Masala, Finland
e-mail: pasi.hakli@nls.fi

1. Organisation

The NKG Working Group for Reference Frames, Positioning and Navigation (WGRFPN) was founded in the NKG General Assembly 2010 in Sundvolden, Norway. It inherited most of the tasks from the previous working group of Positioning and Reference Frames but included now also navigation related tasks.

The appointed national representatives for the WGRFPN were:

- Denmark: Mette Weber (GST)
- Finland: Pasi Häkli (Chairman, FGI), Hannu Koivula (FGI)
- Iceland: Þórarinn Sigurðsson (LMI), Guðmundur Valsson (LMI)
- Norway: Matthew Simpson (–2011, SK), Michael Dähnn (2011–, SK)
- Sweden: Lotti Jivall (LM), Peter Wiklund (LM)

In addition to the official representatives many other people, including Baltic States, were involved with the working group meetings and work.

The working group had four meetings during the period:

- Masala, Finland, 2011 March 15–16
- Hønefoss, Norway, 2012 March 27–28
- Reykjavik, Iceland, 2013 March 14
- Copenhagen, Denmark, 2014 May 26–27

In connection to NKG science week that was held in Reykjavik, Iceland, in March 12–14, 2013, the working group organized an additional full-day project meeting on the NKG GNSS analysis centre project (see next section) activities in March 13, 2013. Short working group and project meetings were arranged also during the NKG General Assembly 2014 in Gothenburg, Sweden. Minutes of the annual meetings are available at the NKG webpages.

2. Topics

The NKG General Assembly 2010 gave the following keywords as the input for the working group for the period 2010–2014:

- Reference frames
- EPN,
- ETRS 89, ITRF,
- Transformations to National realisations of ETRS89
- Positioning service

In addition to these keywords, there were some remaining, uncompleted tasks related to the NKG2008 GPS campaign that were considered important to be finalized.

The NKG structure was changed in the NKG General Assembly 2010 so that the actual work should be done in projects while the working groups were meant to be forums e.g. for scientific discussions and knowledge exchange. With the keywords and previous work, the working group identified several possible projects that were discussed in the first working group meeting. These were:

- NKG GNSS Analysis Centre
- ITRS-ETRS89 transformations
- Geodetic infrastructures
- Modernization of permanent GNSS stations
- GNSS antenna calibrations: individual vs. type calibrations
- Ionosphere and troposphere modelling in Nordic area
- Nordic Positioning Service
- Navigation related projects

From these topics WG concluded that the NKG GNSS analysis centre and the ITRS-ETRS89 transformations are the most important ones.

NKG GNSS Analysis Centre is a follow up on previously performed Nordic GNSS campaigns and the idea was to have common, densified and continuous GNSS solutions and eventually a densified velocity field for Fennoscandia. Workload would be shared by arranging analysis centre as distributed processing centres (called local analysis centers, LAC) involving all Nordic-Baltic countries and then combining solutions into a common GNSS solution.

ITRS-ETRS89 transformations project was to finalize work done with the NKG2008 GPS campaign in the previous period. The purpose was to update existing transformation approach to include the most recent ITRF reference frame and to have transformations for the Baltic states as well. Another important goal of the project was to establish a common Nordic-Baltic NKG reference frame.

Geodetic infrastructures included discussions on active definition of the national reference frames in the future. This means that active (permanent GNSS) stations would replace the traditional passive stations (benchmarks on the ground) as the defining points of the national reference frame. Consequently, and while the access to the reference frames is nowadays mostly through the active GNSS networks (e.g. network RTK), this would decrease the need to maintain passive networks of thousands of points. The topic was considered as an important issue to be discussed within the WG (for information exchange) but not needing a separate project.

Many countries were modernizing their GNSS stations and densifying their existing active GNSS networks in the beginning of the period. Related to this work some important issues to be considered are monumentation of the stations, dual sites, local ties, site dependent effects etc. This topic was considered as an important issue but to belong better to the scope of the WG of Geodetic Infrastructures. Therefore no actions for this topic were taken in the WGRFPN.

Rest of the topics were shortly introduced and discussed but considered less important at the moment. However, it was thought that they may be potential projects later.

As a conclusion from the discussions and after prioritizing, the WG decided to propose NKG GNSS Analysis Centre and ITRS-ETRS89 transformations as the first projects. The WG prepared project proposals/plans of these topics and they were later approved by the NKG Presidium.

3. Projects

Status and progress of the two approved projects are presented in separate papers in the NKG2014 General Assembly proceedings and are therefore not described here. NKG GNSS Analysis Centre project is presented in Jivall et al.: Report from the project ”NKG GNSS analysis centre” and ITRS-ETRS89 transformations in Häkli et al.: The NKG2008 GPS Campaign - final results including transformation parameters.

4. Future

The working group discussed about future work related to the field of the WG. There was a consensus that it is important to continue the work done in the period 2010–2014. Two on-going projects demand still quite a lot of work and therefore the WG considered them to be enough at the moment.

These projects are mostly related to reference frames and no positioning or navigation related topics have been covered. However, some expectations have risen to cover also these fields. The WG discussed about this and considered current topics too wide to be properly covered in one working group. Therefore the WG proposed to move positioning and navigation related work to another working group. (Note: during the NKG GA the working group on Geodetic Infrastructure was renamed to Positioning and Navigation and the working group on Reference Frame, Positioning and Navigation was renamed to Reference Frame.)

Acknowledgements

We have got very good progress and have been able to involve all Nordic and Baltic countries to both on-going projects, which to me, says that we are doing very important work. As a chairman of the working group, I would like to express my gratitude to all participants of the WG for a very fruitful co-operation. I hope that this “good tradition” will continue in the coming period!

References

Pasi Häkli, Lotti Jivall, Martin Lidberg, Torbjørn Nørbech, Oddvar Tangen, Karsten Engsager, Mette Weber, Priit Pihlak, Ivars Aleksejenko and Eimuntas Paršeliūnas: The NKG2008 GPS Campaign - final results including transformation parameters

Lotti Jivall, Tina Kempe, Christina Lilje, Sonja Nyberg, Pasi Häkli, Karin Kollo, Priit Pihlak, Mette Weber, Ksenija Kosenko, Þórarinn Sigurðsson, Guðmundur Valsson, Dalia Prizginiene, Eimuntas Paršeliūnas, Oddvar Tangen: Report from the project ”NKG GNSS analysis centre”

NKG Working Group of Geoid and Height Systems – Report 2010-2014

Jonas Ågren
Lantmäteriet, Department of Geodetic Infrastructure
Lantmäterigatan 2, SE-801 82 Gävle, Sweden
e-mail: jonas.agren@lm.se

1 Organisation

The NKG Working Group (WG) of Geoid and Height Systems (WGGHS) was constituted at the NKG General Assembly 2010 in Sundvolden, Norway. It was the result of merging the old WG of geoid determination with the WG of height determination.

At its creation, the WGGHS was given the following keywords for the period 2010-2014:

- EVRS
- Sea Level
- Height determination methods
- Maintenance of levelling networks and height systems
- Geoid modelling methods
- NKG geoid
- Data requirements
- Data management
- Ocean circulation

Many members have contributed actively to the WG, for instance:

- From Denmark: Gabriel Strykowski, René Forsberg, Casper Jepsen, Kristian Keller
- From Finland: Mirjam Bilker-Koivula, Veikko Saaranen, Jaakko Mäkinen, Hannu Ruotsalainen
- From Iceland: Guðmundur Valsson, Þórarinn Sigurðsson
- From Norway: Olav Vestøl, Ove Omang, Dagny Lysaker, Dag Solheim
- From Sweden: Jonas Ågren, Per-Ola Eriksson, Andreas Engfeldt. Lars E Sjöberg, Fredrik Dahlström, Lina Alm, Holger Steffen

Many representatives from the Baltic countries have also been very active and contributed in important ways. The key representatives here have been:

- From Estonia: Tõnis Oja, Artu Ellmann, Silja Märdla, Andres Rüdja, Tarmo Kall, Harli Jürgenssen
- From Latvia: Ivars Aleksejenko (now Liepins), Janis Kaminskis
- From Lithuania: Eimuntas Parseliunas

Many others have occasionally participated in meetings. (Please forgive me for not mentioning all of you.)

2 Meetings and activities

The WGGHS have arranged the following ordinary WG meetings (lunch to lunch),

- May 30-31, 2011, at Lantmäteriet in Gävle, Sweden
- March 8-9, 2012, at DTU Space in Lyngby, Denmark
- March 14, 2013, at the National Land Survey of Iceland, Reykjavik
- March 11-12, 2014, at Lantmäteriet, Gävle, Sweden

These meetings have typically consisted of three parts, one with scientific/technical presentations, one large part with project related business discussions and finally the national reports.

After the WG meeting in Gävle, a separate project meeting was arranged in the project "Review of current and near-future levelling technology"; see Section 5.

The meeting in Reykjavik took place during the NKG science week March 12-14, 2013. During the same week, the WG also arranged the "NKG Joint WG Workshop on Postglacial Land Uplift Modelling" together with the other WGs.

The main part of the actual work made by the WGGHS were made in the following four projects,

- Computation of the NKG2014 geoid model
- Investigations of the requirements for a future 5 mm (quasi)geoid model.
- Review of current and near-future levelling technology
- Empirical land uplift modelling

In the rest of this report we shortly summarise what has been achieved in these projects.

3 Computation of the NKG2014 geoid model

The main purpose of this project is to compute the next official NKG geoid model (with the working name NKG2014). Jonas Ågren is project leader. This has been a large project, which has involved most of the members of the WG. Up to the General Assembly 2014, the project has completed the following tasks:

- Detailed initial specifications written and agreed upon. This document describes what will be computed and how to deal with reference systems and frames as well as with the influence of postglacial rebound. The work with the specifications involved far-reaching discussions and debates.
- The NKG gravity database has been modernised, thoroughly updated and quality checked for all the Nordic and Baltic countries (except Iceland). So far only a preliminary version exists. Some minor quality checks and corrections remain before the final version can be released.
- A new NKG 3''x3'' DEM has been created, but quality checking remains. The DEM has been computed by updating the DEM constructed for EGG08 with the national DEMs from Finland, Estonia, Latvia and Lithuania.
- A preliminary GNSS/levelling dataset has been compiled with data from all the involved countries in their respective national ETRS89 and EVRS realisations. No transformation has yet been made to a common ETRS89 reference frame, which is planned.
- A first preliminary quasigeoid model has been computed by the Swedish computation centre just before the NKG General Assembly 2014. This solution shows a very good agreement to the preliminary GNSS/levelling dataset, which indicates that the new NKG model can be expected to be large step forward compared to the last NKG2004 geoid model.

Even though quite a lot of work has been made, the project is still not finished and will continue into the next 4 year period. It is clear that almost all tasks have been more time-consuming than originally planned. The project has required a lot of cooperation between the countries, which has taken much time. The following tasks remain,

- The gravity and GNSS/levelling datasets have to be finalised. The GNSS heights above the ellipsoid have to be transformed to a common ETRS89 reference frame. Here the transformations from the NKG2008 project of the NKG WG for Reference Frames, Positioning and Navigation (WGRFPN) will be utilised as soon as they are ready.
- An ice thickness model will be created for the Norwegian glaciers following the decision in the initial specifications.
- One quasigeoid model will be computed per computation centre. (There are five computation centres, in Sweden (LM), Denmark (DTU Space) Norway (NMA), Finland (NLS/FGI) and Estonia (ELB/TUT). The main computation methods that will be tested are
  - the remove-compute-restore method with Wong and Gore modification of Stokes' formula implemented using FFT.
  - the Least Squares Modification of Stokes' formula with Additive corrections (LSMSA) method.
- The computation centre solutions then have to be analysed and the differences between them understood and explained (to a reasonable extent).
- Choice of final model, then presentation, documentation and publication.

The final model is planned to be ready to the IUGG General Assembly 2015, but publication and documentation will most likely require more time.

4 Investigations of the requirements for a future 5 mm (quasi) geoid model

The main purpose of this project has been to investigate what is required in theory and in practice to reach the goal of a gravimetric (quasi) geoid model with 5 mm standard uncertainty in the future. One important aspect of this is to answer the question what data that is required in order to reach this goal. Such information is needed by the National Mapping Agencies in order to get started with the necessary measurements as soon as possible. Lars E Sjöberg was the project leader.

General questions about the project details were raised in two circular letters. In two specific studies over Sweden it was shown that (Ågren and Sjöberg 2014).

- the average 5 km resolution and quality of the gravity data in Sweden are sufficient for the task, provided that the data are updated for systematic errors and data gaps. Gravity data in the surrounding areas also have to be improved, e.g. in the Baltic Sea.
- systematic errors in DEMs are not a problem over Sweden, where a high resolution DEM with high quality is available, at least not as long as the same DEM heights are used both in the remove and restore phases of the topographic corrections.
- that additional methodological improvements are most likely needed, but this remains to be studied in deeper ways.

The project will not continue into the next four year period. The final recommendations from the project are the following (Sjöberg and Ågren 2014):

- The above and further studies should be extended to the rest of member countries to reach conclusions valid for the whole NKG region. Especially Norway is challenging in this respect, with its high mountains and deep fjords.
- The need for methodological improvements should be more thoroughly investigated. Various limitations of the error propagations should also be dealt with.

- It is very questionable whether such extended studies are suitable as a NKG project. The more theoretical and methodological questions are very difficult and time consuming. External funding would be required for academic researchers to work deeply on this.
- One alternative would be to continue as a PhD project, but this would also require funding

5 Review of current and near-future levelling technology

The main aim of this study project has been to make a literature and experience-based review that sums the current levelling methods and capacities in the Nordic countries, and also identifies promising areas for further study and modern development. One specific motivation behind the project has been to secure the knowledge of a number of key experts just about to retire. Olav Vestøl was the project leader.

The project has achieved its goal and published a 50 pages report; see Vestøl et al. (2014). Per-Ola Eriksson was the main editor of the report. It summarises the levelling experiences made in the different countries during the creation of the last generation of national height system realisations.

6 Empirical land uplift modelling

The main purpose of this project is to compute an updated version of the official **NKG2005LU** model that includes a new GNSS solution and additional levelling data from the Baltic countries plus Denmark. Also more levelling data from Norway should be included. Project leader is again Olav Vestøl.

The project has fulfilled its purpose and first computed a new purely empirical model using the above data updates. This empirical model has then been combined with the new geophysical GIA model **i82_g5102** of Holger Steffen et al., which resulted in the **NKG2014LU_test** model**.** It has been decided that this model will not be finalised at the present time, but will first be tested and evaluated by all the NKG WGs. It will then be decided whether it will be released or whether we shall continue to work towards an improved official NKG201XLU model.

Even though the project has reached its goals, it will nevertheless continue into the next four year period. Land uplift modelling is nowadays of great importance to NKG and all the NKG WGs have related studies on their agendas. The WGGHS chair would like to see this project continue forever ;-)

7 Final words and outlook

The WGGHS chairman sincerely thanks all members for very good cooperation during the last four years. International cooperation is sometimes difficult and can at times be frustrating, but it is crucial for the development of the geodetic infrastructure in our respective countries. Even though it is clear that we have not been able to finalise all the projects that we have started, we have nevertheless reach quite far, as has been summarised above. Two of the projects, NKG2014/5 geoid model and empirical land uplift, will now continue into the next four period 2014-2018. Both of them are of such a nature that they should be viewed as standing activities in the WGGHS.

Another reflection is regarding the merging of the WG for Geoid Determination with the WG for Height Determination. How did it go? The chairman believes that it went alright, but the main focus of the WG has perhaps been a little too much on geoid related issues (even though the levelling and height system parts have been reasonably well covered by the "Review of current and near-future levelling technology" project, which has been successful). However, quite a lot is happening nowadays regarding height systems, for instance the work towards a World Height System and the introduction of EVRS as common chart datum in the Baltic Sea. It is the intention of the WGGHS chairman to initiate more and deeper discussions of these and similar height system related topics. It is hoped that we - as a result - can speak with a stronger common voice regarding the development of height systems on the international level.

References

Sjöberg L. E. and Ågren J. (2014) Investigations of the requirements for a 5 mm geoid model – a project status report. Poster presentation at the NKG General Assembly 2014, Göteborg, 2014.

Vestøl O., Eriksson P-O., Jepsen C., Keller K., Mäkinen J., Saaranen V., Valsson G., Hoftuft O. (2014) Review of current and near-future levelling technology. Lantmäteriet, Reports in Geodesy and Geographic Information Systems, 2014:2, Gävle, Sweden

Ågren J., Sjöberg L. E. (2014) Investigation of gravity data requirements for a 5 mm-quasigeoid model over Sweden. In Proc. of the International Symposium on Gravity, Geoid and Height Systems (GGHS2012), U Marti (Ed.), IAG Symposium 141.

National Report of Finland 2011-2014

P. Häkli, M. Poutanen, and Department of Geodesy and Geodynamics
Finnish Geospatial Research Institute (FGI), National Land Survey of Finland
Geodeetinrinne 2, FI-02430 Masala, Finland
e-mail: pasi.hakli@nls.fi

1. Reference Frames

1.1. Finnish permanent GNSS network and positioning service

In 2012-2013 the Finnish Geodetic Institute (from the beginning of 2015 Finnish Geospatial Research Institute of the National Land Survey of Finland), FGI, updated the FinnRef permanent GPS network into a multi-satellite GNSS network in Finland. The renewal of the old GPS-only FinnRef network was funded by the Ministry of Agriculture and Forestry. The new network consists of 20 stations collecting data from GPS, Glonass, Galileo and later also from BeiDou satellites. The network stations were built on stable bedrock sites, equipped with Javad Delta-G3T receivers and individually calibrated Javad Dorne Margolin choke ring antennas covered with SCIGN radomes. Data are transferred both as hourly files and real-time streams to the FGI and distributed to the users, co-operation partners and research institutions. Old FinnRef stations are still operational next to the new ones.

Based on the FinnRef data streams the FGI opened a new positioning service that aims at a half-metre accuracy level. The GNSS data are real-time streamed to the processing centre at the FGI. In the positioning service we use GNSMART (GNssSMART) software by Geo++, where the acronym SMART comes from State Monitoring And Representation Technique. The software's primary task is the state monitoring of the FinnRef data streams. It does the ambiguity resolution within the network and determines distance dependent errors through modelling. State representation part of the software provides network information to users.

Positioning service of the FGI opened on 30th of January 2014. The service offers differential corrections for GPS and Glonass code measurements using RTCM 2.2 format. The data are delivered through IP-network using NTRIP-protocol. Users may choose the corrections from any individual FinnRef station from a mount point list or by sending their own location using NMEA-format. In that case the service automatically provides corrections from the nearest base station or corrections tailored for the user position.

In the end of 2014 a project for evaluating network-RTK capabilities of the FinnRef was initiated. An average inter-station distance between FinnRef stations is about 200 km meaning a challenging task for providing cm-level coordinates for end-users.

Fig. 1. FGI positioning service was opened in 2014. Petri Aarni (left) and Hannu Koivula are inspecting the server. Photo M. Poutanen

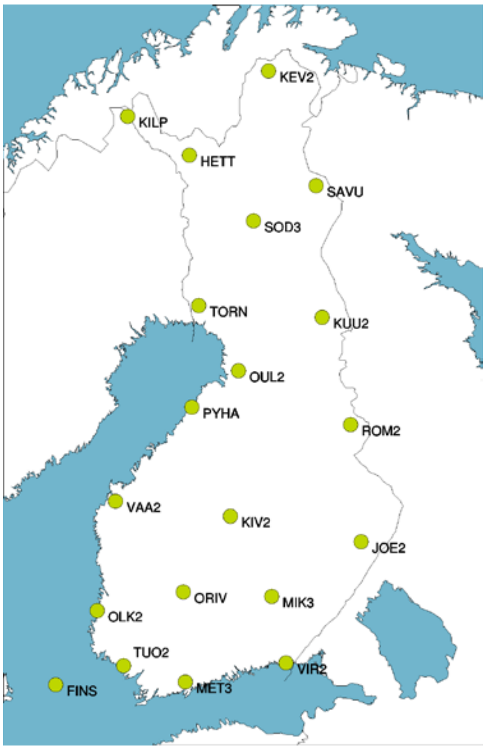

Fig. 2. Network of renewed FinnRef stations consists of 20 stations.

1.3. GNSS Analysis Centres

The FGI has been contributing to the NKG GNSS analysis centre project as one of the local analysis centre (LAC). A new environment for weekly Bernese processing was set up and routines developed for the FGI LAC. The FGI's processing centre runs on an Ubuntu Virtual machines and is powered by mainly Perl and Shell scripts. The FGI is also one combination centre of the project. For this purpose, combination routines for the CATREF software have been developed. The weekly routine processing was started in June 2014 and combination in December 2014. The developed processing environment will be utilized for other national GNSS processing needs as well.

1.4. New and updated Recommendations for the Public Administration (JHS) and E2 processing service

The Public Administration Recommendations (JHS recommendations) provide information management guidelines for public administration (both governmental and municipal). A JHS recommendation can be a uniform procedure, definition or instruction to be used in public administration. The JHS system aims to improve the interoperability of information systems and the compatibility of data in them, to facilitate cross-sector process development and to make the use of existing data more efficient.

Two new JHS recommendations related to surveying were prepared in 2012 and 2014. The recommendation 184 (JHS184) includes guidelines for measuring control points in the Finnish ETRS89 realization, EUREF-FIN. JHS184 determines the hierarchy of the EUREF-FIN control points, introduces the use of active control points (permanent GNSS stations) in control point measurements and allowed measurement methods for determining the coordinates for the control points at different hierarchy levels (coordinate classes) of the EUREF-FIN.

Together with JHS184 a related E2 processing service was established. It is a free service to compute the official EUREF-FIN coordinates and meant to those parties who need an official E2 status (2nd order coordinates in EUREF-FIN) for their active reference stations or network. The FGI published guidelines on requirements the station should fulfill, and instructions how to become an E2 station. E2 stations are continuously monitored in E2 service to confirm the quality of the coordinates.

The recommendation 185 (JHS185) gives requirements for the base map of the city plan. The recommendation includes guidelines for city plans, including measurements, composing the base maps, the methods for describing the city plan as well as guidelines for auditing the measurements and base maps.

Previously existing JHS recommendations 153 and 154 are under major update including a thorough revision of the Finnish geodetic vocabulary. These recommendations introduce the EUREF-FIN reference frame and the related projected coordinate reference systems together with the map sheet division and the transformations to the previous national grid coordinate system (KKJ). The new geodetic vocabulary introduces new geodetic (Finnish) terms to avoid previous conflicts with the GIS (ISO and Inspire) terminology.

1.5. Active control points and passive definition of the EUREF-FIN reference frame

Positioning services, such as network-RTK, have revolutionized surveying practices and challenged traditional control point networks and the ways of measuring them. In Finland, the definition of the national ETRS89 realization, EUREF-FIN, is based on traditional passive networks instead of active GNSS stations. A change from a passive to active definition of control point networks would require a comprehensive change in measuring principles. Until recently, surveyors making geodetic measurements have been obliged to do the measurements hierarchically relative to the nearest higher order (passive) control points. Since the average spacing of active stations in network-RTK services is approximately 70 km, and for passive networks much less, the use of active stations would require measurements neglecting the hierarchy of the (defining) passive networks.

Häkli et al. 2013 evaluated the accuracy of static GPS surveying through active stations with regard to the official passive control point networks in EUREF-FIN. The results conclude that the consistency of static GPS surveying using network-RTK services with respect to the official hierarchical passive control point network is in the order of 1–3 cm (rms).

However, some problems were found as well. In Finland, the reference frames (i.e. positions of control points) are influenced by postglacial rebound that challenges the determination and maintenance of accurate static coordinates, especially in wide areas and over a long time span. Therefore, determination of ETRS89 coordinates for active (or other large) GNSS networks require taking account of the effect of post-glacial rebound. These conclusions were included into the new recommendation of the public administration 184 (see section 1.3).

1.6. Height System

The national height system N2000 was published by the FGI in 2008. Border connections with the Russian levelling network were finalised in the EVRF2007 solution, in 2012 (Sacher et al. 2012). The perimeter around the Baltic Sea was 7052 km and the loop misclosure was 46 mm (Fig. 3).

The heights of the precise levelling network have been used as starting values for the lower order levellings of the National Land Survey of Finland and municipalities. Second order levellings were transformed to the new system using local network adjustments. Many municipalities are now using N2000 height system. For example, since the beginning of 2012, N2000 has been the official system of metropolitan area of Helsinki. In 2013, the levellings for the Finnish tide gauges were performed and a new tide gauge at Porvoo was established (Fig. 4).

Height determination techniques for future national height systems were studied in a master's thesis (Saari, 2013). The techniques included traditional precise levelling, GNSS-levelling using both static GNSS and VRS observations, and mobile laser scanning.

Fig. 3. In 2012 a levelling network around the Baltic Sea was finalised.

Fig. 4. Installation of a new benchmark near Porvoo tide gauge. Photo: V. Saaranen.

1.7. GNSS deformation measurement at Olkiluoto

The FGI has monitored crustal deformations at Olkiluoto, South-Western Finland, since mid-90's. Previously, a 14-pillar network was measured biannually as static GPS campaigns. The 15-year time series of static campaigns was analysed in Nyberg et al., 2013. Most of the baselines show very small motion: 75 % of change rates (velocities) are smaller than 0.10 mm/y. Roughly one third of the trends can be considered statistically significant.

During the years 2010-2014 the observation network was modernized. Almost all old pillars are now equipped for permanent tracking and a few problematic sites have been replaced by new ones. In addition, four new pillars were established to better cover the Olkiluoto Island area. So far, roughly two years of data has been collected from the first permanent stations and eventually new change rates for the baselines will be obtained from permanent station data.

1.8. Local ties at Metsähovi Fundamental station

We have developed a procedure to measure the local tie regularly at Metsähovi geodetic station between the IGS GPS station antenna and the VLBI radio telescope reference point. We have used kinematic GPS to measure the coordinates of two GPS antennas on the edge of the radio telescope dish. Using the coordinates of these two antennas collected during a 24-hour session and the radio telescope position angle readings, we can determine the reference point of the radio telescope antenna.

The repeatability of the reference point coordinates is at a few millimetre level including the whole local tie vector in the global system without further transformations. The system is semiautomatic and the latency of the product (coordinates of the reference point) is less than 24 hours if ultra-rapid orbits for GPS are utilized. With this technique it is possible to produce near real time updates to the local tie.

2. Gravity

2.1. Absolute gravimetry

The FGI has continued to measure the land uplift at dedicated absolute gravity stations with the FG5-221 (FG5X-221). New absolute gravity stations were established in Kilpisjärvi, Savukoski, Oulu and Kivetty, bringing the total number of stations to twelve.

In addition to the measurements in Finland, the FGI performed absolute gravity measurements at five stations in Russia (Pulkovo, Svetloe, Moscow/TsNIIGAiK, Zvenigorod, Lomonosov) in 2013. This was cooperation with the Central Research Institute of Geodesy, Aerial Surveying and Cartography (TsNIIGAiK) and the National Metrological Institute VNIIM. In addition to determining the gravity change at the stations, also a comparison took place with the absolute gravimeters FG5-110, GBL-2, GABL-M, GABL-PM and ABG-VNIIM-1.

Also in 2013, measurements were made at six stations in the Baltic Countries: Vilnius (Lithuania) together with the Vilnius Gediminas Technical University; Riga, Pope, Irbene and Viŝķi (Latvia) together with the Latvian Geospatial Information Agency and Riga Technical University; and Suurupi (Estonia) together with the Estonian Land Board.

The FGI started repeated gravity measurements on Antarctica in the Dronning Maud Land in 1993. The aim is to study gravity changes in the area. When combined with

GPS time series, information can be obtained on contemporary changes in ice mass. This will help to understand processes during the ice age. In the winter of 2011-2012 an expedition of the FGI performed absolute gravity measurements at several stations in Dronning Maud Land, Antarctica: Russian base Novolazarevskaya, Indian Maitri, Norwegian Troll, and the Finnish station Aboa. In the winter of 2014-2015 another measurement was made with the FG5X-221 at the Norwegian base Troll.

Fig. 5. Jyri Näränen is observing with the renewed absolute gravimeter FG5X-221. Photo M. Poutanen

2.2. Loading studies

The solid Earth is constantly being deformed due to changes in the load by atmosphere, oceans and continental water storage. In several studies, the FGI investigates the different loading effects on the geodetic measurements. For example the variable loading effect caused by the Baltic Sea between 2008 and 2012 was computed at different geodetic measurement points.

2.3. Superconducting gravimeter

The new dual sphere superconducting gravimeter (SG) OSG-073 was installed in February 2014, at Metsähovi (Fig 6). Two sensors are side by side inside the gravimeter. The first sensor is a standard iGrav™ SG, which is close to drift free (the sphere's weight is 5 grams); while the second sensor is an "ultra low noise" SG, using a 17 g sphere, with a much higher Q (Quality factor for oscillator). Studies of the noise level of the High-Q device have shown that at present it is the best SG instrument in the world (Fig 7). For comparisons we have parallel observations with the old SG T020 which has operated for twenty years. The SG T020 is located at a distance of 3 meters from the OSG-073 in the same room.

Fig. 6. New superconducting gravimeter OSG-073 of the FGI. Photo J. Näränen

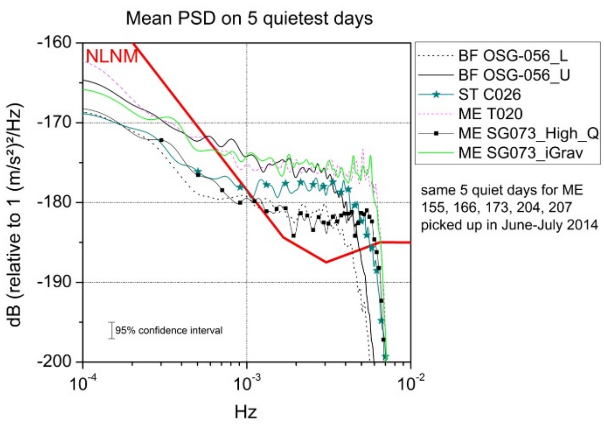

Fig. 7. Power spectral density of SG's in Metsähovi compared to the theoretical noise model (NLNM) and to Strasbourg and Black Forest Observatory SG's.

2.4. Geoid modelling

The high-resolution global gravity field models EGM2008 and EIGEN6C were analyzed using Finnish terrestrial data. Promising results were obtained when the models were used in combination with terrestrial gravity data to calculate a gravimetric geoid model. The resulting model showed a standard deviation of less than 3 centimetres when compared with GPS-levelling. It is expected that these results will improve when the latest GOCE-models are used in combination with the updated terrestrial dataset that was compiled for the NKG Geoid model project.

The impact of the GOCE mission is studied in the ESA Dragon3 project "Case study on heterogeneous geoid/quasigeoid based on space borne and terrestrial data combination with special consideration of GOCE mission data impact".

2.5. FOGN

In 2009 and 2010 the First Order Gravity Network (FOGN) of Finland was remeasured with the A10-0020 absolute gravimeter of the Institute of Geodesy and Cartography (IGiK), Warsaw, Poland. 51 sites were measured at 47 locations. The A10 visited FG5-sites regularly for control. Support measurements, such as vertical gradient measurements, relative gravity ties, levelling and coordinate determination, took place in 2010 and 2011. Support measurements were studied and documented in a master's thesis (Kuokkanen, 2012).

Fig. 8. A10 measurements at a typical FOGN station. Photo J. Mäkinen

2.6. Watertube tiltmeter

The NSWT interferometric water level tiltmeter has been operational since 2008 in Lohja, southern Finland. Geodynamic tilt data is continuously analyzed for earth tide, and obtained tidal parameters compared to several ocean tide loading models. The non-tidal residual tilt is compared to the combined tilt of a Baltic Sea loading model (FGI) and an atmospheric loading model with regression coefficient 0.86 +/- 0.02. In the beginning of 2014 the FGI designed and built a completely new Michelson-Gale type water level tilt meter (iWT). The instrument was purchased by the Geodetic and Geophysical Institute of the Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, Sopron, Hungary. According to agreement it was installed by the FGI in the Conrad observatory (Zentral Anstalt für Meteorologie and Geodynamik), Austria, in August 2014. Data is shared daily via internet to cooperating institutes in Hungary, Finland and Austria.

2.7. GIA research

As a co-operation with the University of Ottawa and Lantmäteriet the FGI has continued research on Glacial Isostatic Adjustment to use an up-to-date solution of land motion rates as well as a new generation of GIA models to extend previous studies and compute a new calibrated model of this process for the region. A secondary aim is to map out the key uncertainties in model parameters (in ice and Earth model components) and determine how these can better constrained.

3. Space Geodesy

3.1. VLBI activities

3.1.1. Geo-VLBI data analysis

There are several topics of interest in the analysis of geodetic VLBI data at the FGI. The study of two geo-VLBI networks, called EUROPE and IVS-T2, was carried out in Zubko et al. 2011. We have analyzed the difference of crustal movements obtained with these two networks and the effect of network configuration and station selection. The EPN (EUREF permanent GNSS Network) and IGS (International GNSS Service) networks were used to compare the results. Other research topics are related to the analysis of the VLBI data with different stochastic methods (Zubko et al. 2012) and to the influence of source structure variations on the estimated geodetic VLBI parameters. Zubko and Rastorgueva (2013) found that it is possible to detect the effect of source structure variations on the estimated geodetic VLBI parameters.

3.1.2. VLBI on GPS

We have been developing, in collaboration with W. Brisken (National Radioastronomy Observatory, U.S.), a method to observe GPS signals in the sidelobe of the radiotelescope simultaneously with VLBI quasar observations. This involves an expansion of the DiFX software correlator so that it will become capable of processing the GPS signals. The final goal of combining the traditional VLBI technique with the new GPS technique into a single whole is to give accurate orbital parameters of the satellites in the celestial, instead of the terrestrial, reference frame, and eventually get a direct connection between these two frames.

3.1.3. Geo-VLBI sessions

Geodetic VLBI observations are carried out at the Aalto University Metsähovi Radio Observatory. About 6-8 sessions of GeoVLBI observations take place every year. The sessions are aimed on regular observations of global reference frame (ITRF) in the global network, where stations around the world participate in observations, and also on regular observations in the European geodetic VLBI network.

3.2. Research on objects in the near-Earth space

The Earth is surrounded by two main orbital populations: space debris left behind by our over 50-year long history in space activities, and near-Earth objects (NEOs), remnants from the solar-system history. We have developed novel methods for the detection and characterization of objects in near-Earth space using various observing techniques, including optical and radar data as well as laboratory measurements.

3.2.1. Optical search for space debris.

In the ESA-funded StreakDet (Streak detection and astrometric reduction) project, we developed and evaluated an automated processing pipeline applicable to optical observations of moving objects, such as space debris or asteroids. The pipeline is capable of detecting streaks in single images (as compared to consecutive frames of the same field) obtained with any observing scenario, including space-based surveys and both low- and high-altitude populations (Virtanen et al. 2015).

3.2.2. Meteor modelling

An important step in the prediction of space-object impact threat to the Earth is the understanding and modeling of processes accompanying the object's entry into the terrestrial atmosphere (Gritsevich et al., 2012). For natural objects, i.e. meteors, we have built physically based parametrisation to describe changes in mass, height, velocity and luminosity of the object along its atmospheric path (Gritsevich and Koschny, 2011; Bouquet et al., 2014). We have demonstrated the application using a wide range of observational data from meteorite-producing fireballs appearing annually (such as Košice) to larger scale impacts (such as Chelyabinsk, Sikhote-Alin and Tunguska).

3.2.3. Meteorite spectra

On February 2013 an asteroid of about 20-m in diameter exploded over the city of Chelyabinsk in Russia. Exceptional amount of observational material exist, including videos and samples of meteorite fragments which survived from the explosion. In the project funded by the Academy of Finland, we made laboratory measurements of the meteorite reflectance spectra with a goniometer developed at the FGI and showed that the meteorite was partly formed from hard to spot dark asteroid material.

3.2.4. Detecting minimoons

Following a recent revelation that the Earth may be surrounded by temporarily captured orbiters (Granvik et al. 2012), we have studied the discoverability of these minimoons by current or forthcoming observing facilities in a joint project with the University of Hawaii. Granvik et al. (2014) showed that it is possible to detect the largest objects with optical surveys, while high-power radars could observe objects down to size of 10cm.

4. Renewal of Metsähovi Fundamental Station

The Metsähovi Fundamental Station is a key infrastructure of the FGI. It is operated under the Department of Geodesy and Geodynamics. Nationally, Metsähovi is the basic station for the national reference frame EUREF-FIN, and a part of the national permanent GNSS network FinnRef. Metsähovi is also the basic point of the national height system N2000 and the Finnish gravity system basic point is also in Metsähovi.

Internationally, Metsähovi has been participating in the IAG services IGS, IVS, ILRS, IDS, GGP and it is globally one of the few geodetic stations having all major space geodetic observing techniques at the same site. It is also one of the northernmost geodetic stations. Its long existence (operational since 1978) is important for the global reference frames.

In 2011 Ministry of Agriculture and Forestry granted a total of 8 M€ for renewal of Metsähovi instrumentation and FinnRef network in years 2012-2016. Later on, the budget was cut to cover only the years 2012-2014, leaving the purchase of a new radio telescope for geodetic VLBI for future negotiations. At Metsähovi, the following main instruments were upgraded or renewed: Satellite Laser Ranging (SLR) system, superconducting gravimeter, absolute gravimeter, and Metsähovi infrastructure.

4.1. Satellite Laser Ranging

In 2012 planning to purchase a modern kHz-capable SLR system was started. A new 0.5 m bistatic telescope was ordered early 2014 from the Cybioms Corp. with installation at Metsähovi expected in 2015. New modern observatory building was built at the end of 2014 to replace the first SLR building (Fig. 9). The automated dome was ordered from Baader GmbH. A master control software for the whole SLR system is built by SpaceTech GmBh. Already earlier, a 2kHz laser was purchased from HighQ GmbH, and this laser will be installed in the new system. During 2015-2016 all pieces will be put together, and we expect to get the first observations with the new system in 2016.

Fig. 9. The new observatory building of the Metsähovi SLR. Photo J. Näränen.

4.2. Renewal of gravimeters

The first superconducting (or cryogenic) gravimeter SG T020 of the FGI was installed in 1994 and it is the oldest SG still operational. A new superconducting gravimeter SG-073 was purchased in 2012 from GWR Instruments, Inc. It is of a new type of a dual sensor model where two separate test masses of different size are levitating in a magnetic field. The gravimeter was installed early 2014 (Fig. 10). The old instrument will be kept up and running parallel with the new one at least for one year.

The FGI absolute gravimeter FG5-221 was upgraded to FG5X-221 of Micro-g LaCoste in 2013. The upgrade included a totally new dropping chamber and drive system, reduced size of electronics and a new computer control for the instrument.

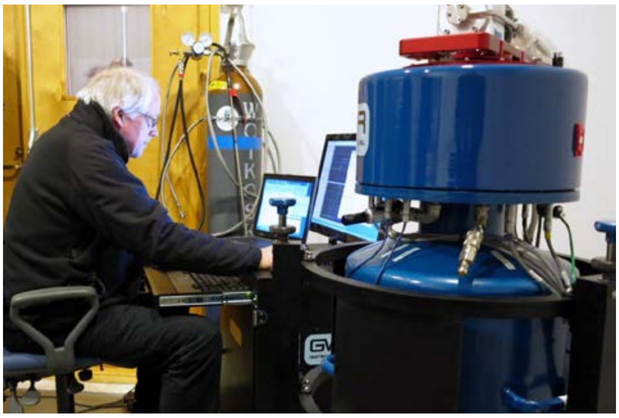

Fig. 10. Installation of the new superconducting gravimeter at Metsähovi. Photo M. Poutanen

4.3. DORIS/REGINA station

CNES/IGN maintains the Metsähovi DORIS station. A new generation receiver and a GNSS station belonging to the REGINA network were installed in 2012. The station is fully automatic requiring a minimum amount of maintenance or operation.

5. Metrology

The FGI, or actually its Department of Geodesy and Geodynamics, FGI-GG, is a National Standards Laboratory (NSL) in Finland for two metrological quantities, length (long distances) and acceleration of free fall.

5.1. Quality management according to international standards

As a Designated Institute (DI) in the specific fields of metrology, the FGI is a participant of the CIPM Mutual Recognition Arrangement (CIPM MRA), the framework through which National Metrology Institutes (NMI) demonstrate the international equivalence of their measurement standards and the calibration and measurement certificates they issue. The Technical Committee "Quality" of the European Association of European Metrology Institutes (EURAMET TC-Q) is the organization, which observes and evaluates the quality management needed to maintain and develop capable metrological services in NMIs, DIs and NSLs. In spring 2014 EURAMET TC-Q re-evaluated all Finnish metrology institutes, including the FGI-GG. The success of all participants was decent, indicating operation at a good international level. A crucial guide to obtain this is the international standard ISO/IEC 17025, "General requirements for the competence of testing and calibration laboratories". The Quality Manual of the FGI-GG NSLs, updated in 2011 and 2014, follows this standard.

5.2. Nummela Standard Baseline

The FGI-GG measured its world-renowned measurement standard for long distances, 864-m Nummela Standard Baseline, for the 16th time since 1947 using the Väisälä interference comparator in autumn 2013 (Fig. 11). Preliminary results are compatible with the previous results of 2005 and 2007 at 0.1 mm-level. Publishing the final results awaits the updated lengths of quartz gauges.

In addition to high-precision calibrations of electronic distance measurement (EDM) instruments, the baseline has recently served in several international scale transfer measurement projects and in validation and testing of new absolute distance measurement (ADM) instruments based interferometry using synthetic wavelengths.

Jorma Jokela's doctoral dissertation, "Length in Geodesy – On Metrological Traceability of a Geospatial Measurand", was approved in the Aalto University School of Engineering in autumn 2014 (Jokela, 2014). The dissertation describes the full traceability chain of the distance measurements at the Nummela standard baseline to the definition of the metre together with detailed measurement procedures of the latest Väisälä interference measurements, quartz gauge system and scale transfers to several other geodetic baselines worldwide.

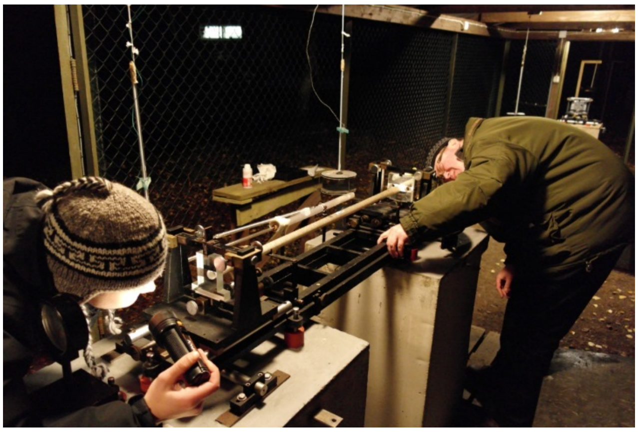

Fig. 11. Adjusting the quartz gauge in the Väisälä interference comparator at Nummela, November 2013. Photo: F. Dvořáček.

5.3. Quartz gauges

Quartz gauges transfer the traceable scale to the Väisälä interference comparator. To introduce an updated quartz gauge system, absolute calibrations of quartz gauges nos. VIII, 49, 50 and 51 are to be completed at VTT-MIKES in February 2015. Expanded uncertainties less than 100 nm are to be expected for the 1-m-long measurement standards. The FGI-GG and the Tuorla Observatory of University of Turku maintain the quartz gauge system by performing comparisons of quartz gauges at Tuorla. New cameras and computers were installed in the comparison system in 2013 and reconstruction of the computation software is ongoing.

5.4. EMRP SIB60

The European Metrology Research Programme (EMRP) SI Broader Scope project SIB60, "Metrology for long distance surveying", is a three-year (2013–2016) joint research project of nine European national metrology institutes and three universities with the key objective to improve the traceability and to reduce the uncertainty of long-distance metrology. Most deliverables of the project expected from the FGI-GG are related to three work packages: (WP2) GNSS-based distance measurement, (WP4) Improving surveying practice and (WP5) Local tie metrology at fundamental geodetic stations.

In the work package for GNSS-based distance measurement (WP2) the aim is to demonstrate the potential and to analyze the limitations of GNSS-based distance measurement. Many of the tasks are related to the existing and developed test facilities at the Metsähovi Fundamental Station of the FGI. The work was started by making a report on GNSS processing parameters and models to be studied within the project. GNSS data has been collected for verification of antenna calibration tables in the new "Revolver" test field, for Metsähovi static pillar network, and for comparison of GPS distances with traceable high precision EDM distances. Before the upgrade of the Metsähovi network, simulations of different GNSS test field configurations were made. After that measurements and processing of data sets were made to verify the selected simulation configurations. Finally, the design of the test field upgrade was composed and put into practice and recommendable calibration measurement procedures were developed.

Fig. 12. GNSS antenna test field, "revolver", at Metsähovi. Photo M. Poutanen

The work package for improving surveying practice (WP4) includes, among many other tasks, a set of geodetic baselines, which a few of the participants measure using different methods and instruments, old and new, utilizing different expressions of traceability chain. Processing of observations and computations for results will be equal for the participants. One of the scales of the comparison originates at the Nummela Standard Baseline, at which other measuring participants visit or from which the scale is transferred to other baselines.

The scale of the Nummela Standard Baseline has been transferred to other geodetic baselines and test fields using the Kern ME5000 EDM instrument no. 357094 and the Kern prism reflector no. 374414 as the transfer standard. For section lengths ranging from tens of metres to more than a kilometre expanded uncertainties ranging from 0.2 mm to 0.9 mm have been obtained.

In June 2011, soon after the completion of a previous EMRP project "Absolute long distance measurement in air" in 2008–2011, the FGI-GG calibrated the 8-pillar 600-m baseline of the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany. The results can be compared with the results obtained using newly developed methods and instruments. Another comparison was possible between two methods to obtain weather data for velocity corrections for EDM observations, namely between the classical psychrometers and barometers of the FGI-GG and the modern automated weather station system of the PTB (including 60 temperature sensors along the baseline). Results and experiences were reported in two peer review articles (Pollinger et al., 2012, Jokela et al., 2012). The FGI-GG repeated the calibration in July 2014 within the SIB60 WP4, with somewhat different results. Comparisons and analyses are continuing in year 2015.

As another part of the SIB60 WP4, the FGI-GG calibrated the 8-pillar 1 100-m baseline of the Universität der Bundeswehr München in October 2014 (Fig. 13). The maximum differences from the previous results from measurements in 2009–2011 were 0.2 mm.

In the work package for local ties (WP5) most of the tasks are still ahead.

5.5. More scale transfer measurements

In addition to the baseline measurements related to the SIB60 project, the FGI-GG has recently performed a few other scale transfer measurements to baselines abroad. In May–June 2012 the FGI-GG calibrated the 6-pillar 330-m geodetic baseline, extended by a seventh pillar to a test field, of the Universitat Politècnica de València (UPV) in Spain.

In July 2014 the FGI-GG calibrated the 6-pillar 1 320-m geodetic baseline, extended by a seventh pillar to a test field, of the Vilnius Gediminas Technical University (VGTU) in Lithuania. This baseline at Kyviškės has been calibrated five times since 1997 using the same equipment, which provides a remarkable time series in largely varying (> 30 K) temperature conditions. In addition, the VGTU 15-m indoor baseline with 16 mounting plates was calibrated using a Leica TC2003 tacheometer, now for the third time since 1997.

A few traceable baseline measurements, precise levellings and azimuth determinations were performed for domestic customers. Repeated measurements at the Olkiluoto baseline, begun in 2002, were ended in 2012.

Fig. 13. The UniBW geodetic baseline near Munich is suitable for comparisons between GNSS and terrestrial measurements. The scale of also this baseline is now traceable to Nummela. Photo J. Jokela

Fig. 14. Scale transfer from Nummela to the UPV geodetic baseline and test field in Valencia. Photo L. Garcia-Asenjo Villamayor

5.6. Levelling calibrations

Period 2011-2014 has been quite busy in the FGI's comparator laboratory. We have built a new modern levelling comparator which is so far in test use only. In addition, the FGI's old comparator has been working well with minor needs of renewal. Originally our comparator was planned to fulfil FGI's own calibration needs. Now most of our customers come from Estonia, Latvia, Lithuania, Denmark, and Sweden and of course from Finland. The clients represent both private and public sector. The amount of certificated rod and system calibrations have varied yearly: 2011/33, 2012/15, 2013/10 and 2014/22.

Heli Suurmäki's thesis "Scale anomaly detection by rod comparator" for the degree of Bachelor of Engineering was approved in the Metropolia University of Applied Sciences in autumn 2011.

5.7. Acceleration of free fall

The FG5-221(called FG5X-221 after an upgrade of the instrument in 2013) is the Finnish national standard for the acceleration of free-fall and as such it participated in the European Comparison of Absolute Gravimeters ECAG-2011 (EURAMET.M.G-K1) and the 9th International Comparison of Absolute Gravimeters ICAG-2013 (CCM.G.-K2). Yearly comparisons were made between the FG5-221 and the FG5-233 of Lantmäteriet. In 2014, the end stations of the Masala-Vihti calibration line for relative gravimeters were measured with the FG5X-221.

6. References

2014:

Bilker-Koivula, M., 2015. Assessment of high resolution global gravity field models for geoid modelling in Finland. In: U. Martti (Ed.): Proc. of the International Symposium on Gravity, Geoid and Height Systems (GGHS2012), IAG Symp 141, 2014. In press

Bolin, B., Jedicke, R., Granvik, M., Brown, P., Howell, E., Nolan, M. C., Jenniskens, P. M., Chyba, M., Patterson, G. and R. Wainscoat, 2014. Detecting Earth's Temporarily-Captured Natural Satellites – Minimoons. Icarus 241, pp. 280–297. Astro-ph: 1406.3534.

Bouquet A., Baratoux D., Vaubaillon J., Gritsevich M.I., Mimoun D., Mousis O., Bouley S. (2014): Simulation of the capabilities of an orbiter for monitoring the entry of interplanetary matter into the terrestrial atmosphere // Planetary and Space Science, 103, 238-249, http://dx.doi.org/10.1016/j.pss.2014.09.001

Bowell, E., Oszkiewicz, D. A., Wasserman, L. H., Muinonen, K., Penttilä, A. and D.E. Trilling, 2014. Asteroid spin-axis longitudes from the Lowell Observatory database. Meteoritics and Planetary Science. 49(1), pp. 95-102.

Buga, A., Putrimas, R., Slikas, D. and J. Jokela, 2014. Kyviskes Calibration Baseline: measurements and improvements analysis. The 9th International Conference "Environmental Engineering", May 22–23, 2014, Vilnius, Lithuania, Selected papers, Vilnius Gediminas Technical University Press Technika, 5 p. http://enviro.vgtu.lt

Christou, A., Oberst J., Lupovka V., Dmitriev V. and M. Gritsevich, 2014. The meteoroid environment and impacts on Phobos. Planetary and Space Science, in print (SI on Phobos). Doi: http://dx.doi.org/10.1016/ j.pss.2013.07.012 (21.8.2013)

Chyba, M., Granvik, M., Jedicke, R., Patterson, G., Picot, G. and J. Vaubaillon, 2014. Designing Rendezvous Missions with Mini-Moons using Geometric Optimal Control. Journal of Industrial and Management Optimization 10(2), pp. 477–501.

Collilieux, X., Altamimi, Z., Argus, D.F., Boucher, C., Dermanis, A., Haines, B.J., Herring, T.A., Kreemer, C.W., Lemoine, F.G., Ma, C., MacMillan, D.S., Mäkinen, J., Métivier, L., Ries, J., Teferle, F.N. and X. Wu, 2014. External evaluation of the Terrestrial Reference Frame: report of the task force of the IAG sub-commission 1.2. In C. Rizos and P. Willis (eds), Earth on the Edge: Science for a Sustainable Planet. Proceedings of the IAG General Assembly, June 28–July 2, 2011, Melbourne, Australia, IAG Symposia, 139, pp. 197–202.

Cook, N., Ragozzine, D., Granvik, M. and D. C. Stephens, 2014. Realistic Detectability of Close Interstellar Comets. In revision for Astrophysical Journal.

Denneau, L., Jedicke, R., Fitzsimmons, A., Hsieh, H., Kleyna, J., Granvik, M., Micheli, M., Spahr, T., Veres, P., Wainscoat, R., Burgett, W. S., Chambers, K. C., Draper, P. W., Flewelling, H., Huber, M. E., Kaiser, N., Morgan, J. S. and J.L. Tonry, 2014. Observational constraints on the catastrophic disruption rate of small main belt asteroids. Icarus 245, pp. 1–15.

Granvik, M., 2014. Luonnontieteiden lumoissa. In ``Bon Sauvage - Luovuuden synty'' (H. Aho, S. Ketola, T. Piilola, Eds.). Kustannus Taide Oy, Helsinki, Finland.

Gritsevich, M., Lyytinen E., Moilanen J., Kohout T., Dmitriev V., Lupovka V., Midtskogen V., Kruglikov N., Ischenko A., Yakovlev G., Grokhovsky V., Haloda J., Halodova P., Peltoniemi J., Aikkila A., Taavitsainen A., Lauanne J., Pekkola M., Kokko P., Lahtinen P., Larionov M. (2014): First meteorite recovery based on observations by the Finnish Fireball Network. In Proceedings of the International Meteor Conference, Giron, France, 18-21 September 2014 Eds.: Rault, J.-L., Roggemans, P. International Meteor Organization, ISBN 978-2-87355-028-8, pp. 162-169.

Gritsevich, M., Lyytinen, E., Kohout, T., Moilanen, J., Midtskogen, S., Kruglikov, N., Ischenko, A., Yakovlev, G., Grokhovsky, V., Haloda, J., Halodova, P., Lupovka, V., Dmitriev, V., Peltoniemi, J., Aikkila,. A., Taavitsainen, A., Lauanne, J., Pekkola, M., Kokko, P., and P. Lahtinen, 2014. Analysis of the bright fireball over Kola peninsula on April 19, 2014 followed by successful meteorite recovery campaign // Meteoritics and Planetary Science, 49, MetSoc 2014 special issue, A143.

Gritsevich, M., Vinnikov, V., Kohout, T., Tóth, J., Peltoniemi, J., Turchak, L. and J. Virtanen, 2014. A comprehensive study of distribution laws for the fragments of Košice meteorite. Meteoritics and Planetary Science, 49(3), pp. 328–345. http://dx.doi.org/10.1111/maps.12252.

Gritsevich, M., Vinnikov, V., Kuznetsova, D., Kohout, T., Pupyrev, Yu., Peltoniemi, J., Lupovka, V., Dmitriev, V., Tóth, J., Britt, D., Turchak, L. and J. Virtanen, 2014. Preatmospheric parameters and fragment distribution: A case study for Košice meteoroid // Meteoritics and Planetary Science, 49, MetSoc 2014 special issue, A144.

Gritsevich, M.I., Lukashenko, V.T. and L.I. Turchak, 2015. Elementary functions approximation for the solution of meteor physics equations // Mathematical Modelling 27, 25-33 (in Russian)

Grokhovsky, V.I., Kohou,t T., Gritsevich, M. and E.V. Koneva, 2014. Physical properties, structure and fracturing of the Chelyabinsk LL5 meteorite body // Meteoritics and Planetary Science, 49, MetSoc 2014 special issue, A145.

Hakala, T., Riihelä, A., Lahtinen, P. and J.I. Peltoniemi, 2014. Hemispherical-directional reflectance factor measurements of snow on the Greenland Ice Sheet during the Radiation, Snow Characteristics and Albedo at Summit (RASCALS) campaign. Journal of Quantitative Spectroscopy and Radiative Transfer, 146, pp. 280–289.

Hines, D.C., Videen, G., Zubko, E., Muinonen, K., Shkuratov, Y., Kaydash, V.G., Knight, M.M., Sitko, M.L., Lisse, C.M., Mutchler, M., Hammer, D. and P.A. Yanamandra-Fisher, 2014. Hubble Space Telescope pre-perihelion ACS/WFC imaging polarimetry of Comet ISON (C/2012 S1) at 3.81 AU. Astrophysical Journal Letters 780, L32, 1-6.

Honkavaara, E., Markelin, L., Hakala, T. and J. Peltoniemi, 2014. The metrology of directional, spectral reflectance factor measurements based on area format imaging by UAVs. Photogrammetrie, Fernerkundung, Geoinformation, (3), pp. 175–188.

Häkli, P., Jivall, L., Lidberg, M., Nørbech, T., Tangen, O., Engsager, K., Weber, M., Pihlak, P., Aleksejenko, I. and E. Paršeliunas. The NKG2008 GPS Campaign - final transformation results and a new common Nordic reference frame. Journal of Geodetic Science. In review

Ihde, J., Habrich, H., Sacher, M., Söhne, W., Altamimi, Z., Brockmann, E., Bruyninx, C., Caporali, A., Dousa, J., Fernandes, R., Hornik, H., Kenyeres, A., Lidberg, M., Mäkinen, J., Poutanen, M., Stangl, G., Torres, J. and C. Völksen, 2014. EUREF's contribution to national, European and global geodetic infrastructures. In C. Rizos and P. Willis (eds), Earth on the Edge: Science for a Sustainable Planet. Proceedings of the IAG General Assembly, June 28–July 2, 2011 Melbourne, Australia, IAG Symposia, 139, pp. 189–196. Doi: 10.1007/978-3-642-37222-3_24.

Jedicke, R., Bolin, B., Granvik, M. and E. Beshore, 2014. An improved technique for quantifying observational selection effects in asteroid surveys. In revision for Icarus.

Jedicke, R., Granvik, M., Micheli, M., Ryan, E., Spahr, T. and D. K. Yeomans, 2014. Surveys, Follow-up & Population Statistics. Chapter submitted for Asteroids 4.

Jiang, Z., Pálinkáš, V., Francis, O., Merlet, S., Baumann, H., Becker, M., Jousset, P., Mäkinen, J., Schulz, H.R., Kessler-Schulz, K.U., Svitlov, S., Coulomb, A., Tisserand, L., Hu, H. and Ch. Rothleitner, 2014. Accurate gravimetry at the BIPM Watt Balance site. In C. Rizos and P. Willis (eds), Earth on the Edge: Science for a Sustainable Planet. Proceedings of the IAG General Assembly, June 28–July 2, 2011, Melbourne, Australia, IAG Symposia 139, pp. 371–376.

Jokela, J., 2014. Length in Geodesy – On Metrological Traceability of a Geospatial Measurand. Publ. Finn. Geod. Inst. 154, 240 p. http://urn.fi/URN:ISBN:978-951-711-310-6.

Jokela, J., 2014. Munich baseline measured with EDM traceable to Väisälä interferometer, Dataset. EMRP SIB60 "Metrology for long distance surveying" Deliverable 4.2.2. 6 p.

Jokela, J., 2014. PTB 600 m baseline measured with EDM traceable to Väisälä interferometer, Dataset. EMRP SIB60 "Metrology for long distance surveying" Deliverable 4.2.1. 6 p.

Kallio U., 2014. At least 5 different test field configuration simulated. EMRP SIB60 project deliverable 2.6.1. http://www.ptb.de/emrp/sib60-home.html

Kallio U., Koivula, H., Nikkonen, V. and P. Häkli, 2014. GNSS datasets compiled, including datasets measured with PCO and PCV calibrated antenna systems. EMRP SIB60 project deliverable 2.3.4. http://www.ptb.de/emrp/sib60-home.html

Kallio, U. and S. Nyberg, 2014. Field tests of at least 3 different test field configurations performed. EMRP SIB60 project deliverable 2.6.2. http://www.ptb.de/emrp/sib60-home.html

Kallio, U., 2014. Calibration measurement procedure for the upgraded Metsähovi GNSS test field. EMRP SIB60 project deliverable 2.6.4. http://www.ptb.de/emrp/sib60-home.html

Kallio, U., Koivula, H., Marila, S. and J. Kuokkanen, 2014. Design for the upgraded Metsähovi GNSS test field. EMRP SIB60 project deliverable 2.6.3. http://www.ptb.de/emrp/sib60-home.html

Kohout, T., Gritsevich, M., Grokhovsky, V., Yakovlev, G., Haloda, J., Halodova, P., Michallik, R., Penttilä, A. and K. Muinonen, 2014. Mineralogy, reflectance spectra, and physical properties of the Chelyabinsk LL5 chondrite - Insight into shock-induced changes in asteroid regoliths. Icarus, 228, pp. 78-85. http://dx.doi.org/10.1016/j.icarus.2013.09.027.

Kohout, T., Havrila, K., Tóth, J., Husárik, M., Gritsevich, M., Britt, D., Borovička, J., Spurný, P., Igaz, A., Svoreň, J., Kornoš, L., Vereš, P., Koza, J., Zigo, P., Gajdoš, Š., Világi, J., Čapek, D., Krišandová, Z., Tomko, D., Šilha, J., Schunová, E., Bodnárová, M., Búzová, D. and T. Krejčová, 2014. Density, porosity and magnetic susceptibility of the Košice meteorite shower and homogeneity of its parent meteoroid. Planetary and Space Science, 93–94, pp. 96–100. http://dx.doi.org/10.1016/j.pss.2014.02.003.

Koivula H. ja J. Kaivosoja, 2014. Maksuttoman paikannuspalvelun tarkkuus. Käytännön maamies 10/2014, pp. 28-30.

Krýnski, J., Dykowski, P., Sękowski, M. and J. Mäkinen, 2014. On the estimate of accuracy and reliability of the A10 absolute gravimeter. In C. Rizos and P. Willis (eds), Earth on the Edge: Science for a Sustainable Planet. Proceedings of the IAG General Assembly, June 28–July 2, 2011, Melbourne, Australia, IAG Symposia 139, pp. 279–302.

Kuznetsova Daria; Gritsevich Maria; Vinnikov Vladimir (2014): The Kosice meteoroid investigation: from trajectory data to analytic model. In Proceedings of the International Meteor Conference, Giron, France, 18-21 September 2014 Eds.: Rault, J.-L., Roggemans, P. International Meteor Organization, ISBN 978-2-87355-028-8, pp. 178-181.

Jivall, L., Kempe, T., Lilje, C., Nyberg, S., Häkli, P., Kollo, K., Pihlak, P., Weber, M., Kosenko, K., Sigurðsson, Þ., Valsson, G., Prizginiene, D., Paršeliūnas, E. and O. Tangen, Report from the project NKG GNSS AC, NKG General Assembly Proceedings. Submitted

Moreno-Ibáñez M., Gritsevich M. and J.M. Trigo-Rodríguez, 2015. New methodology to determine the terminal height of a fireball // Icarus, 250, 544–552, http://dx.doi.org/10.1016/j.icarus.2014.12.027

Muinonen, K., Penttilä, A. and G. Videen, 2014. Multiple scattering of light in particulate planetary media. In Polarimetry of stars and planetary systems. Kolokolova, L., Levasseur-Regourd, A.-C. and J. Hough, Eds. Cambridge University Press, Cambridge, U.K., 17 p.

Muinonen, K., Penttilä, A., Granvik, M., Virkki, A., Fedorets, G., Wilkman, O. and T. Kohout, 2014. Asteroids, Comets, Meteors 2014, Book of Abstracts. University of Helsinki, Finland, pp. 1-637.

Mäkinen, J., Virtanen, H., Bilker-Koivula, M., Ruotsalainen, H., Näränen, J. and A. Raja-Halli, The effect of helium emissions by a superconducting gravimeter on the rubidium frequency standards of absolute gravimeters. The 3rd International Gravity Field Service (IGFS) General Assembly, (IGFS 2014), June 30 -July 6, 2014, Shanghai, China. http://202.127.29.4/meetings/igfs2014. In review

Nordman, M., Poutanen, M., Kairus, A. and J. Virtanen, 2014. Using the Nordic Geodetic Observing System for land uplift studies. Solid Earth, 5, 1–9, http://www.solid-earth.net/5/673/2014/se-5-673-2014.html. Doi: 10.5194/se-5-673-2014.

Nordman, M., Virtanen, H., Nyberg, S. and J. Mäkinen, submitted. Non-tidal loading by the Baltic Sea: comparisons of modelled deformation with GNSS time series (GeoResJ).

Nyberg, S., Kallio, U. and H. Koivula, 2014. GPS Deformation Measurements at Olkiluoto in 2013. Posiva Working Report 2014-39, 30 p. http://posiva.fi/files/3780/WR_2014-39.pdf.

Pascal, C., Klemann, V., Poutanen, M. and B. Vermeersen, 2014. Lithosphere-cryosphere interactions. Special Issue, Solid Earth.

Peltoniemi J.I., Gritsevich M. and E. Puttonen, 2015. Reflectance and polarization characteristics of various vegetation types // Springer Praxis Books, Light Scattering and Radiative Transfer, Light Scattering Reviews 9, pp. 257-294, http://dx.doi.org/10.1007/978-3-642-37985-7_7

Peltoniemi, J.I., Hakala, T., Suomalainen, J., Honkavaara, E., Markelin, L., Gritsevich, M., Eskelinen, J., Jaanson, P. and E. Ikonen, 2014. Technical notes: A detailed study for the provision of measurement uncertainty and traceability for goniospectrometers. Journal of Quantitative Spectroscopy and Radiative Transfer, 146, pp. 376–390. http://dx.doi.org/10.1016/j.jqsrt.2014.04.011.

Pentikäinen, H., Penttilä, A., Muinonen, K. and J. Peltoniemi, 2014. Spectroscopic investigations of meteorites. Journal of Quantitative Spectroscopy and Radiative Transfer, 146, pp. 391–401.

Pollinger, F., M. Astrua, A. Bauch, S. Bergstrand, B. Görres, J. Jokela, U. Kallio, H. Koivula, H. Kuhlmann, V. Kupko, K. Meiners-Hagen, M. Merimaa, W. Niemeyer, P. Neyezhmakov, M. Poutanen, F. Saraiva, S. Schön, S.A. van den Berg, J.-P. Wallerand and M. Zucco. Metrology for long distance surveying – a joint attempt to improve traceability of long distance measurements. IAG Scientific Assembly, Potsdam, Germany, September 1–6, 2013. Accepted.

Poutanen, M. and H. Steffen, 2014. Land Uplift at Kvarken Archipelago / High Coast UNESCO World Heritage area. Geophysica, 50(2), 25-40.

Poutanen, M., Bilker-Koivula, M., Ruotsalainen, H., Saari, T. and J. Virtanen, 2014. GOCE, Geoid and Heights. In: Proceedings of 2014 Dragon 3 mid-term results symposium, May 26-29, 2014, Chengdu, China.

Poutanen, M., Ihde, J., Bruyninx, C., Francis, O., Kallio, U., Kenyeres, A., Liebsch, G., Mäkinen, J., Shipman, S., Simek, J., Williams, S. and H. Wilmes, 2014. Future and development of the European Combined Geodetic Network ECGN. In C. Rizos and P. Willis (eds), Earth on the Edge: Science for a Sustainable Planet. Proceedings of the IAG General Assembly, June 28–July 2, 2011, Melbourne, Australia, IAG Symposia 139, pp. 121–127.

Poutanen, M., J. Ihde, C. Bruyninx, O. Francis, U. Kallio, A. Kenyeres, G. Liebsch, J. Mäkinen, S. Shipman, J. Simek, S. Williams and H. Wilmes, 2014. Future and development of the European Combined Geodetic Network ECGN. In Earth on the Edge: Science for a Sustainable Planet (Ed. C. Rizos and P. Willis), International Association of Geodesy Symposia Volume 139. Springer Berlin Heidelberg, pp. 121-127. Doi: 10.1007/978-3-642-37222-3_15.

Raja-Halli, A., Näränen, J. and M. Poutanen. New telescope and observatory building to Metsähovi, Finland. 18th International Workshop on Laser Ranging, 13-Po29, November 2013.

Riikonen J., Kettunen, N., Gritsevich, M., Hakala, T., Särkkä, L. and R. Tahvonen, submitted. Growth and development of Norway spruce and Scots pine seedlings under different light spectra // Environmental and Experimental Botany.

Räbinä, J., Mönkölä, S., Rossi, T., Penttilä, A. and K. Muinonen, 2014. Comparison of discrete exterior calculus and discrete-dipole approximation for electromagnetic scattering. Journal of Quantitative Spectroscopy and Radiative Transfer, 146, pp. 417-423. DOI: 10.1016/j.jqsrt.2014.02.011

Saaranen V, 2014. Pyhäjoki precise levelling measurements in 2014. Fennovoima.

Saaranen, V. and P. Rouhiainen, 2014. Precise Levelling Campaigns at Olkiluoto in 2012-2013. Posiva Working Report 2014-40, 314 p. http://www.posiva.fi/files/3781/WR_2014-40.pdf; http://www.posiva.fi/files/3782/APPENDIX_I-VIII.pdf

Saaranen, V., Rouhiainen, P. and H. Suurmäki, 2014. The Analysis of the Bedrock Deformation in Olkiluoto Using Precise Levelling Measurements. Posiva Working Report 2013-69, 68 p. http://www.posiva.fi/files/3526/WR_2013-69.1.pdf

Saari T. and M. Bilker-Koivula, 2014. Evaluation of GOCE-based Global Geoid Models in Finnish Territory. Submitted to Newton Bulletin.

Saari T. and M. Bilker-Koivula. Evaluation of GOCE-based Global Geoid Models Over Finland', In: proceedings of the 17th NKG General Assembly 2014, 1-4 September 2014, Göteborg, Sweden. Submitted

Saari, T., Poutanen, M., Saaranen, V., Kaartinen, H., Kukko, A. and S. Nyberg. Height Determination Techniques for the Next National Height System of Finland - A Case Study. Survey Review. Submitted

Schunová, E., Jedicke, R., Walsh, K. J., Granvik, M., Wainscoat, R. and N. Haghighipour, 2014. Properties and evolution of NEO families created by tidal disruption at Earth. Icarus 238, 156–169.

Shkadov, V., Osiptsov, A., Baranov, V., Ostapenko, N., Arafaylov, S., Gritsevich, M., Turchak, L. and V. Kotelkin, 2014. To the Memory of Vladimir Petrovich Stulov. Moscow University Bulletin. Series 1. Mathematics and Mechanics, 5, pp. 71-72 (in Russian).

Svensson, J., Virkkula, A., Meinander, O., Kivekäs, N., Hannula, H.-R., Peltoniemi, J. I., Gritsevich, M., Järvinen, O., Heikkilä, A., Kontu, A., Hyvärinen, A.-P., Neitola, K., Brus, D., Dagsson-Waldhauserova, P., Anttila, K., Hakala, T., Kaartinen, H., Vehkamäki, M., De Leeuw, G. and H. Lihavainen, submitted. Soot on Snow Experiments: Light-absorbing impurities effect on the natural snowpack // The Cryosphere.

Trigo-Rodríguez, J.M., Lyytinen, E., Gritsevich, M., Moreno-Ibáñez, M., Bottke, W.F., Williams, I., Lupovka, V., Dmitriev, V., Kohout, T. and V. Grokhovsky, submitted. Orbit and dynamic origin of the recently recovered Annama’s H5 chondrite // MNRAS (Monthly Notices of the Royal Astronomical Society) Letters.

Turchak, L.I and M.I. Gritsevich, 2014. Meteoroids Interaction with the Earth Atmosphere // Journal of Theoretical and Applied Mechanics, 44(4), 15-28, http://dx.doi.org/10.2478/jtam-2014-0020

Uunila, M., Zubko, N., Poutanen, M., Kallunki, J. and U. Kallio, 2014. Metsähovi Radio Observatory Network Station 2013 Annual Report. International VLBI Service for Geodesy and Astrometry 2013 Annual Report, edited by K.D. Baver, D. Behrend and K.L. Armstrong, NASA/TP-2014-217522, p. 135-138.

Vasily, D., Valery, L. and M. Gritsevich, 2014. A new approach to meteor orbit determination. In Proceedings of the International Meteor Conference, 18-21 September 2014, Giron, France. Eds.: Rault, J.-L., Roggemans, P. International Meteor Organization, ISBN 978-2-87355-028-8, pp. 157-159.

Vaubaillon, J., Koten, P., Margonis, A., Toth, J., Rudawska, R., Gritsevich, M., Zender, J., McAuliffe, J., Pautet, P.D., Jenniskens, P., Koschny, D., Colas, F., Bouley, S., Maquet, L., Leroy, A., Lecacheux, J., Borovicka, J., Watanabe, J. and J. Oberst, 2015. The 2011 Draconids: the first European airborne meteor observation campaign // Earth, Moon, and Planets, http://dx.doi.org/10.1007/s11038-014-9455-5

Vestøl, O., Eriksson, P.-O., Jepsen, C., Keller, K., Mäkinen, J., Saaranen, V., Valsson, G. and O. Hoftuft, 2014. Review of current and near-future levelling technology – a study project within the NKG working group of Geoid and Height Systems. Lantmäterirapport 2014:2, Reports in Geodesy and Geographical Information System, Lantmäteriet, Gävle, 51 p. http://www.lantmateriet.se/Global/Kartor%20och%20geografisk%20information/GPS%20och%20m%C3%A4tning/Geodesi/Rapporter_publikationer/Rapporter/Lantmaterirapport_2014_2.pdf

Videen, G. and K. Muinonen, 2014. Light-scattering evolution from particles to regolith. Journal of Quantitative Spectroscopy and Radiative Transfer. Doi: 10.1016/j.jqsrt.2014.05.019.

Wilkman, O. and K. Muinonen, 2014. Asteroid lightcurve phase shift due to rough-surface shadowing. Meteoritics and Planetary Science. 49, pp. 1-7.

Wilkman, O., Muinonen, K., Videen, G., Josset, J.-L., Souchon, A. and the SMART-1/AMIE team, 2014. Lunar photometric modeling with SMART-1/AMIE imaging data. Journal of Quantitative Spectroscopy and Radiative Transfer. 146, pp. 529-539.

Virkki, A., Muinonen, K. and A. Penttilä, 2014. Radar albedos and circular-polarization ratios for realistic inhomogeneous media using the discrete-dipole approximation. Journal of Quantitative Spectroscopy and Radiative Transfer. 146, 480-491.

Virkki, A., Muinonen, K. and A. Penttilä, 2014. Infering asteroid surface properties from radar circular-polarization ratios. Meteoritics and Planetary Science. 49, pp. 86-94.

Virtanen, H., Bilker-Koivula, M., Mäkinen, J., Näränen, J., Raja-Halli, A. and H. Ruotsalainen, 2014. Comparison between measurements with the superconducting gravimeter T020 and the absolute gravimeter FG5-221 at Metsähovi, Finland in 2003-2012. Bull. Inf. Marées Terrestres 2014, 148,11923-11928.

Virtanen, J., Torppa, J., Näränen, J., Muinonen, K., Granvik, M., Poikonen, J., Lehti, J., Säntti, T. and T. Komulainen, 2014. Streak Detection and Astrometric Reduction. ESA Final Report, ESOC Contract No. 4000108373/13/D/SR.

Virtanen, J., Torppa, J., Näränen, J., Muinonen, K., Granvik, M., Poikonen, J., Lehti, J., Säntti, T. and T. Komulainen, 2014. Streak detection and astrometric reduction: prototype implementation and performance assessment. ESA Technical note, Contract No 4000108373/13/D/SR.

Virtanen, J., J. Torppa, J. Näränen, K. Muinonen, M. Granvik, J. Poikonen, J. Lehti, T. Säntti, T. Komulainen 2015. Streak Detection and Analysis Pipeline for Space-debris Optical Images. Advances in Space Research. In revision.

Virtanen, J., Torppa, J., Näränen, J., Muinonen, K., Granvik, M., Poikonen, J., Lehti, J., Säntti, T. and T. Komulainen, 2014. Streak detection and astrometric reduction: candidate algorithms. ESA Technical note, Contract No 4000108373/13/D/SR.

Zubko, E., Muinonen, K., Videen, G. and N.N. Kiselev, 2014. Dust in Comet C/1975 V1 (West). Monthly Notices of the Royal Astronomical Society. 440(4), pp. 2928-2943

2013:

Francis O., H. Baumann,T. Volarik, C. Rothleitner, G. Klein, M. Seil, N. Dando, R. Tracey, C. Ullrich, S. Castelein, Hu H., Wu K., Shen C., Xuan S., Tan H., Li Z., V. Palinkas, J. Kostelecky, J. Mäkinen, J. Näränen, S. Merlet, T. Farah, C. Guerlin, F. Pereira Dos Santos, N. Le Moigne, C. Champollion, S. Deville, L. Timmen, R. Falk, H. Wilmes, D Lacovone, F. Baccaro, A. Germak, E. Biolcati, J. Krynski, M. Sekowski, T. Olszak, A. Pachuta,

J. Agren, A. Engfeldt, R. Reudink, P. Inacio, D. McLaughlin, G. Shannon, M. Eckl, T. Wilkins, D. van Westrum and R. Billson (2013). The European Comparison of Absolute Gravimeters 2011 (ECAG-2011) in Walferdange, Luxembourg: results and recommendations, Metrologia, 50, 257-268.

Häkli, P., U. Kallio and J. Puupponen (2013): From Passive to Active Control Point Networks – Evaluation of Accuracy in Static GPS Surveying. Environment for Sustainability, FIG Working Week 2013, Abuja, Nigeria, 6–10 May 2013.

Jiang Z, V Pálinkáš, O Francis, H Baumann, J Mäkinen,L Vitushkin, S Merlet, L Tisserand, P Jousset, C Rothleitner, M Becker, L Robertsson and E F Arias (2013). On the gravimetric contribution to watt balance experiments. Metrologia 50, 452–471 doi:10.1088/0026-1394/50/5/452.

Jivall, L., P. Häkli, P. Pihlak and O. Tangen (2013): Processing of the NKG 2008 campaign. In Henriksen, S. and A. Jørgensen (Editors): Proceedings of the 16th General Assembly of the Nordic Geodetic Commission. Sundvolden, Norway, September 27-30, 2010. p. 143–149.

Kallio U., N. Zubko: The effect of the systematic error in the axis offset value on the coordinates estimated in VLBI data analysis, in Proceedings of the 21st meeting of the European VLBI group for Geodesy and Astronomy, March 5-8, 2013, ed. By N. Zubko and M. Poutanen

Kallio, U. and M. Poutanen: Local Ties at Fundamental Stations, in Z. Altamimi and X. Collilieux (eds.), Reference Frames for Applications in Geosciences, International Association of Geodesy Symposia 138, DOI 10.1007/978-3-642-32998-2_23 © Springer-Verlag Berlin Heidelberg 2013

Karila, K., M. Karjalainen, J. Hyyppä, J. Koskinen, V. Saaranen, P. Rouhiainen (2013). A Comparison of Precise Leveling and Persistent Scatterer SAR Interferometry for Building Subsidence Rate Measurement. ISPRS Int. J. Geo-Inf. 2013, 2, 797-816.

Lidberg, M., P. Häkli, K. Engsager, T. Nørbech and P. Pihlak (2013): The NKG 2008 GPS campaign – transformation results. In Henriksen, S. and A. Jørgensen (Editors): Proceedings of the 16th General Assembly of the Nordic Geodetic Commission. Sundvolden, Norway, September 27-30, 2010. p. 150–156.

Markkanen, J., Lindqvist, H., Nousiainen, T. P., Muinonen, K. & Järvenpää, S. (2013) p. 39-40 2 p.Volumetric current integral equation formulation for modeling scattering by atmospheric aerosol particles

Mäkinen J., T. Hokkanen, H. Virtanen, A. Rajahalli, R. Mäkinen (2013), Local hydrological effects on gravity at Metsähovi, Finland: implications for comparing observations by the superconducting gravimeter with the global hydrological models and with GRACE, IAG symposium series 140, Springer. Gravity, Geoid and Height Systems (GGHS2012) Venice, Italy, October 9-12, 2012, Editor: Urs Marti

Nordman M., H. Virtanen, S. Nyberg, J. Mäkinen, J. Virtanen and H. Ruotsalainen (2013) Itämeren aiheuttamaa maan kuormitusta geodeettisissa aikasarjoissa. XXVI Geofysiikan päivät, 21-22.5.2013, Helsinki www.geofysiikanseura.fi/pdf/GFP2013_kirja.pdf, s.81-84.

Nyberg S., U. Kallio and H. Koivula (2013): GPS Deformation Measurements at Olkiluto in 2012. Posiva Working Report 2013-16. POSIVA Oy, Olkiluoto. 28 pages.

Nyberg S., U. Kallio, H. Koivula (2013). GPS monitoring of bedrock stability at Olkiluoto nuclear waste disposal site in Finland from 1996 to 2012. Journal of Geodetic Science, 3(2), 121–126, ISSN (Print) 2081-9943, DOI: 10.2478/jogs-2013-0017.

Nyberg, S., U. Kallio, P. Häkli, J. Jokela, H. Koivula, V. Saaranen and P. Rouhiainen (2013): Monitoring the Bedrock Stability in Olkiluoto – Summary of Campaign Based GPS Measurements in 1996–2011. Posiva Working Report 2013-63. POSIVA Oy, Olkiluoto. 82 pages.

Poutanen M., Kallio, U., Koivula, H., Näränen, J., Raja-Halli, A., Zubko, N. Renewal of Metsähovi observatory, Proceedings of the 21th Meeting of the European VLBI Group for Geodesy and Astronomy, edited by N. Zubko and M. Poutanen, p 67-71, 2013.

Raiskila S., J. Plado, H. Ruotsalainen and L. J. Pesonen (2013). Geophysical Signatures of the Keurusselkä Meteorite Impact Structure - Implications for Crater Dimensions, Geophysica 49(1-2), 3–23.

Rastorgueva, E., Ramakrishnan, V., Zubko, N. A potential use of AGN single-dish monitoring for optimization of Geo-VLBI scheduling, Proceedings of the 21th Meeting of the European VLBI Group for Geodesy and Astronomy, edited by N. Zubko and M. Poutanen, p. 193-197, 2013.

Rastorgueva, E., Zubko N. Alert system for the VLBI database of ICRF2 sources. Preparatory case study. Proceedings of Science, 11th EVN symposium, 2013.

Ruotsalainen H. (2013), Maan rakenteen ja geodynamiikan kallistushavaintoja kolmannen sukupolven interferometrisella pitkällä vesivaa'alla Lohjan Tytyrissä, XXVI Geofysiikan päivät, 21-22.5.2013, Helsinki www.geofysiikanseura.fi/pdf/GFP2013_kirja.pdf, s.113-117.

Saari, T. (2013) GOCE User Toolboxin käyttö Itämeren meritopografian visualisoinnissa. Teoksessa: Andrei, O. & Vermeer, M. (toim.). GEONAVPOS: Seminar publications on Geodesy, Navigation and Positioning. S. 113–138. Aalto University publication series SCIENCE + TECHNOLOGY, 12/2013. ISBN 978-952-60-5214-4. ISSN 1799-4896. ISSN 1799-490X. http://urn.fi/URN:ISBN:978-952-60-5214-4.

Saari, T. (2013) Height Determination Techniques for National Height Systems. Master's thesis. Aalto University, School of Engineering. Espoo. 94+22 p. (In Finnish)

Uunila, M. and Zubko, N. Metsähovi Radio Observatory - IVS Network Station. International VLBI Service for Geodesy and Astrometry 2012 Annual Report, edited by K. D. Baver, D. Behrend, and K. Armstrong, NASA/TP-2013-217511, p. 112-115, 2013.

Virtanen J., Johanna Torppa, Jyri Näränen, Karri Muinonen, Mikael Granvik. Jonne Poikonen, Jussi Lehti, Tero Säntti, Tuomo Komulainen. "Streak detection and astrometric reduction: review." ESA Technical note. (STREAKDET_FGI_TN_001), Contract No 4000108373/13/D/SR.

Virtanen J., M. Granvik, K. Muinonen, and D. Oszkiewicz. "Bayesian Orbit Computation Tools for Objects on Geocentric Orbits". In Proceedings of Sixth European Conference on Space Debris (22-25 April 2013 ESOC, Darmstadt, Germany)

Virtanen, H., M. Bilker-Koivula, J. Mäkinen, J. Näränen, A. Raja-Halli, H. Ruotsalainen (2013): 'Suprajohtava gravimetrin T020 ja absoluuttigravimetrin FG5-221 mittausten vertailua Metsähovissa vuosina 2003-2012.' In: Veikkolainen, T., K. Suhonen, J. Näränen, T. Korja, K. Kauristie, S. Kaaslainen (Eds.): XXVI Geofysiikan Päivät, Helsingissä 21.-22.05.2013. Geofysiikan Seura, Helsinki, 2013. www.geofysiikanseura.fi/pdf/GFP2013_kirja.pdf, s.155-158.

Zubko N. and M. Poutanen (Ed), 2013. Proceedings of the 21st Meeting of the European VLBI Group for Geodesy and Astronomy. Reports of the Finnish Geodetic Institute, pp. 268 (2013)

Zubko, N., Poutanen, M., Böhm, J., Nilsson, T. Analysis of VLBI data with different stochastic models, International VLBI Service for Geodesy and Astrometry 2012 General Meeting Proceedings, edited by D. Behrend and K. D. Baver, NASA/CP-2012-217504, p. 236-240, 2013.

Zubko, N., Rastorgueva, E. A case study of source structure influence on geodetic parameter estimation, Proceedings of the 21th Meeting of the European VLBI Group for Geodesy and Astronomy, edited by N. Zubko and M. Poutanen, p. 189-191, 2013.

2012:

Francis O., G. Klein, H. Baumann, N. Dando, R. Tracey, C. Ullrich, S. Castelein, H. Hua, W. Kang, S. Chongyang, X. Songbo, T. Hongbo, L. Zhengyuan, V. Pálinkás, J. Kostelecký, J. Mäkinen, J. Näränen, S. Merlet, T. Farah, C. Guerlin, F. Pereira Dos Santos, N. Le Moigne, C. Champollion, S. Deville, L. Timmen, R. Falk, H. Wilmes, D. Iacovone, F. Baccaro, A. Germak, E. Biolcati, J. Krynski, M. Sekowski, T. Olszak, A. Pachuta, J. Ågren, A. Engfeldt, R. Reudink, P. Inacio, D. Mclaughlin, G. Shannon, M. Eckl, T. Wilkins, D. Van Westrum and R. Billson, 2012. Final report of the regional key comparison EURAMET.M.G-K1: European Comparison of Absolute Gravimeters ECAG-2011, Metrologia Technical Supplement, 49, 07014, doi:10.1088/0026-1394/49/1A/07014.

Granvik, M., Vaubaillon, J., and Jedicke, R. (2012a) The population of natural Earth satellites, Icarus 218(1), 262–277.

Granvik, Virtanen, Jedicke, Vaubaillon, Chyba, 2012. Bayesian orbit-computation methods applied to temporarily-captured natural Earth satellites. In: Proc. of the Int. Symposium on Orbit Propagation and Determination (2011, Lille, France), accepted.

Gritsevich M.I., Stulov V.P., Turchak L.I. (2012): Consequences for Collisions of Natural Cosmic Bodies with the Earth Atmosphere and Surface // Cosmic Research, 50(1), 56–64, http://dx.doi.org/10.1134/S0010952512010017

Häkli P. and H. Koivula (2012): Transforming ITRF Coordinates to National ETRS89 Realization in the Presence of Postglacial Rebound - Evaluation of Nordic Geodynamical Model in Finland. Proceedings of the 2009 IAG Symposium, Buenos Aires, Argentina, 31 August 31 - 4 September 2009. Eds. Kenyon, S; M. Pacino; U. Marti. International Association of Geodesy Symposia, Vol. 136. Springer Verlag. p. 77-86, doi: 10.1007/978-3-642-20338-1_5.

Jiang, Z., V. Pálinkáš, F. E. Arias, J. Liard, S. Merlet, H. Wilmes, L. Vitushkin, L. Robertsson, L. Tisserand, F. Pereira Dos Santos, Q. Bodart, R. Falk, H. Baumann, S. Mizushima, J. Mäkinen, M. Bilker-Koivula, C. Lee, I. M. Choi, B. Karaboce, W. Ji, Q. Wu, D. Ruess, C. Ullrich, J. Kostelecký, D. Schmerge, M. Eckl, L. Timmen, N. Le Moigne, R. Bayer, T. Olszak, J. Ågren, C. Del Negro, F. Greco, M. Diament, S. Deroussi, S. Bonvalot, J. Krynski, M. Sekowski, H. Hu, L. J. Wang, S. Svitlov, A. Germak, O. Francis, M. Becker, D. Inglis, and I. Robinson, 2012. The 8th International Comparison of Absolute Gravimeters 2009: the first Key Comparison (CCM.G-K1) in the field of absolute gravimetry. Metrologia 49 (2012), pp 666–684, doi:10.1088/0026-1394/49/6/666.

Jiang, Z., V. Pálinkáš, O. Francis, P. Jousset, J. Mäkinen, S. Merlet, M. Becker, A. Coulomb, K. U. Kessler-Schulz, H. R. Schulz, Ch. Rothleitner, L. Tisserand, and D. Lequin, 2012. Relative Gravity Measurement Campaign during the 8th International Comparison of Absolute Gravimeters (2009). Metrologia 49, 95–107.

Jokela J., P. Häkli, M. Poutanen, U. Kallio and J. Ahola, 2012. Improving length and scale traceability in local geodynamical measurements. In: Geodesy for Planet Earth. Proceedings of the 2009 IAG Symposium, Buenos Aires, Argentina, 31 August 31 - 4 September 2009. Eds. Kenyon, S; M. Pacino; U. Marti. International Association of Geodesy Symposia, Vol. 136. Springer Verlag. p.59-66, doi: 10.1007/978-3-642-20338-1_8.

Jokela, J., F. Pollinger, N. R. Doloca and K. Meiners-Hagen, 2012. A comparison of two weather data acquisition methods for the calibration of the PTB geodetic baseline. Paper no. TC14-O-18 in Proceedings of the XX IMEKO World Congress "Metrology for Green Growth", September 9–14, 2012, Busan, Republic of Korea. 6 p. ISBN 978-89-950000-5-2-95400.

Kairus A., 2012. Using the Nordic Geodetic Observing System for Land Uplift Studies. Master's thesis. Aalto University, School of Engineering. Espoo. 52 p. (In Finnish)

Kallio U. and M. Poutanen, 2012. Can we really promise a mm-accuracy for the local ties on a geo-VLBI antenna. In: Geodesy for Planet Earth. Proceedings of the 2009 IAG Symposium, Buenos Aires, Argentina, 31 August 31 - 4 September 2009. Eds. Kenyon, S; M. Pacino; U. Marti. International Association of Geodesy Symposia, Vol. 136. Springer Verlag. p. 35-42, doi: 10.1007/978-3-642-20338-1_5.

Kallio, U., H. Koivula, S. Nyberg, P. Häkli, P. Rouhiainen, V. Saaranen, Z. Cirule, D. Dobelis and V. Golovka (2012): GNSS antenna offset field test in Metsähovi. Proceedings, FIG Working Week 2012, Knowing to manage the territory, protect the environment, evaluate the cultural heritage. Rome, Italy, 6-10 May 2012.

Kallio, U., S. Nyberg, H. Koivula, J. Jokela and M. Poutanen, 2012. GPS Operations at Olkiluoto, Kivetty and Romuvaara in 2010. Posiva Working Report 2011-75. POSIVA Oy, Olkiluoto. 58 pages.

Koivula H., P. Häkli, J. Jokela, A. Buga, R. Putrimas (2012): GPS Metrology – Bringing Traceable Scale to Local Crustal Deformation GPS Network. Proceedings of the 2009 IAG Symposium, Buenos Aires, Argentina, 31 August 31 - 4 September 2009. Eds. Kenyon, S; M. Pacino; U. Marti. International Association of Geodesy Symposia, Vol. 136. Springer Verlag. p. 105-112, doi: 10.1007/978-3-642-20338-1_5.

Koivula, H., J. Kuokkanen, S. Marila, T. Tenhunen, P. Häkli, U. Kallio, S. Nyberg, and M. Poutanen, 2012. Finnish Permanent GNSS Network. Proceedings of the 2nd International Conference and Exhibition on Ubiquitous Positioning, Indoor Navigation and Location-Based Service (UPINLBS 2012), 3–4 October 2012, Helsinki, Finland. IEEE Catalog Number: CFP1252K-ART. ISBN: 978-1-4673-1909-6.

Koivula, H., U. Kallio, S. Nyberg, J. Jokela and M. Poutanen, 2012. GPS Operations at Olkiluoto in 2011. Posiva Working Report 2012-36. POSIVA Oy, Olkiluoto. 58 pages.

Kuokkanen J., 2012. Auxiliary measurements of the First Order Gravity Net of Finland. Aalto University, School of Engineering. Espoo. 57 p. (In Finnish)

Mäkinen J., 2012. Gravity gradients above piers in absolute gravimetry: use remove-restore for the pier attraction. In: Peshekhonov V.G. (ed), Proceedings of the IAG Symposium on Terrestrial Gravimetry (TG-SMM2010), Saint Petersburg, Russia, 22–25 June 2010, pp 90–97.

Pollinger, F., T. Meyer, J. Beyer, N. R. Doloca, W. Schellin, W. Niemeier, J. Jokela, P. Häkli, A. Abou-Zeid and K. Meiners-Hagen (2012) The upgraded PTB 600 m baseline: a high-accuracy reference for the calibration and the development of long distance measurement devices. Meas. Sci. Tech. 23 (2012) 094018, 11 p. doi:10.1088/0957-0233/23/9/094018. Online at http://stacks.iop.org/MST/23/094018

Poutanen M. (2012): Space Geodesy: Observing Global Changes. In From the Earth’s Core to Outer Space (Ed. Ilmari Haapala). Lecure notes in Earth Systems Sciences 137. Chapter 20, pp. 279-293. Springer Verlag Heidelberg. DOI 10.1007/978-3-642-25550-2_20.

Poutanen, M., M. Holopainen, P. Häkli, K. Junttila, U. Kallio, H. Koivula, S. Nyberg, M. Ollikainen, J. Puupponen, R. Ruotsalainen ja P. Tätilä, 2012. Julkisen hallinnon suositus 184 Kiintopistemittaus EUREF-FIN-koordinaattijärjestelmässä.

Sacher M., I. Aleksejenko, A. Barbadillo, G. Demianov and V. Saaranen (2012): Advancements of the Unified Leveling Network since the adoption of EVRF2007. EUREF Symposium June 6-8, 2012 Paris.

Saaranen V., P. Rouhiainen and H. Suurmäki, 2012. Precise Levelling Campaigns at Olkiluoto in 2010 and 2011. Working Report 2012-64. Posiva Oy, Olkiluoto.

Sękowski M., Krýnski J., Dykowski P., and J. Mäkinen, 2012. Effect of laser and clock stability and meteorological conditions on gravity surveyed with the A10 free-fall gravimeter – first results. Reports on Geodesy 92:1: 47–59.

Valsson G., Þ. Sigurðsson, J. S. Erlingsson, T. Theodórsson, J. Mäkinen and V. Saaranen, 2012. Landshæðarkerfi Íslands ISH2004 Tækniskýrsla. LMÍ-2012/01. http://www.lmi.is/wp-content/uploads/2012/07/Landshaedarkerfi_taeknuskyrsla.pdf

2011:

Azouigui, S., T. Badr, J.-P. Wallerand, P. Juncar, S. van den Berg and J. Jokela (2011) Submicrometer resolution distance meter based on synthetic wavelength interferometry. 3rd Workshop of the EMRP JRP “Absolute long distance measurement in air”, Prague, Czech Republic, May 27, 2011. 17 p. presentation at http://www.longdistanceproject.eu

Buga, A., J. Jokela, R. Putrimas and A. Zigmantiene (2011) Analysis of EDM instruments calibration at the Kyviškes calibration baseline. In Cygas, D. and K. F. Froehner (eds.) 8th International Conference “Environmental Engineering”, Vilnius, Lithuania, May 19–20, 2011, Selected Papers, p. 1301–1305.

Gritsevich M., Koschny D. (2011): Constraining the luminous efficiency of meteors // Icarus, 212(2), 877-884, http://dx.doi.org/10.1016/j.icarus.2011.01.033

Häkli, P., H. Koivula, K. Arsov, U. Kallio, J. Mäkinen, J. Näränen, M. Poutanen, A. Raja-Halli, V. Saaranen and N. Zubko (2011): I Reference Frames. In Poutanen et al. (Eds): Geodetic Operations in Finland 2008–2011. Finnish Geodetic Institute, Kirkkonummi 2011. p. 5–11. ISBN 978-951-711-284-0.

Häkli, P., H. Koivula, T. Tenhunen, H. Kuusniemi and R. Chen (2011): IV Positioning and other applications. In Poutanen et al. (Eds): Geodetic Operations in Finland 2008–2011. Finnish Geodetic Institute, Kirkkonummi 2011. p. 22–24. ISBN 978-951-711-284-0.

Jiang, Z., O. Francis, L. Vitushkin, V. Palinkas, A. Germak, M. Becker, G. D’Agostino, M. Amalvict, R. Bayer, M. Bilker-Koivula, S. Desogus, J. Faller, R. Falk, J. Hinderer, C. Gagnon, T. Jakob, E. Kalish, J. Kostelecky, Chiungwu Lee, J. Liard, Y. Lokshyn, B. Luck, J. Mäkinen, S. Mizushima, N. Le Moigne, C. Origlia, E.R. Pujol, P. Richard, L. Robertsson, D. Ruess, D. Schmerge, Y. Stus, S. Svitlov, S. Thies, C. Ullrich, M. Van Camp, A. Vitushkin, W. Ji and H. Wilmes (2011): 'Final report on the Seventh International Comparison of Absolute Gravimeters (ICAG 2005)', Metrologia 48 (2011), pp. 246-260.

Jokela, J., J. Mäkinen, P. Häkli, H. Koivula and P. Rouhiainen (2011): V Metrology and standardization. In Poutanen et al. (Eds): Geodetic Operations in Finland 2008–2011. Finnish Geodetic Institute, Kirkkonummi 2011. p. 25–28. ISBN 978-951-711-284-0.

Kallio Ulla, Sonja Nyberg, Hannu Koivula, Jorma Jokela, Markku Poutanen (2011): GPS operations at Olkiluoto, Kivetty and Romuvaara in 2010. Posiva Working Report, 2011 (2011-XX), Posiva Oy, Olkiluoto.

Mäkinen Jaakko, Markku Poutanen, Pasi Häkli, Ulla Kallio, Hannu Koivula, Maaria Nordman, Sonja Nyberg, Hannu Ruotsalainen(2011): III Geodynamics. In Poutanen et al. (Eds): Geodetic Operations in Finland 2008–2011. Finnish Geodetic Institute, Kirkkonummi 2011. p. 5–11. ISBN 978-951-711-284-0.

Mäkinen Jaakko, Mirjam Bilker-Koivula, Jyri Näränen, Arttu Raja-Halli, Hannu Ruotsalainen, Heikki Virtanen, Jenni Virtanen 2011: Gravity Field, Geodetic Operations in Finland 2008 - 2011.

Marila, S. ja Honkavaara E., Peltolohkorekisterin tarkkuustutkimus, EU-laadunvalvonta ja peltolohkorekisterin tarkkuuteen vaikuttavista tekijöistä. Geodeettisen laitoksen tiedonantoja 2011:1. 35 sivua (in Finnish).

Marila, S., 2011, diplomityö, Peltolohkorekisterin tarkkuus ja laatu, Aalto-yliopiston insinööritieteiden korkeakoulu

Muinonen, K., Videen, G., Nousiainen, T., Zubko, E., and Penttilä, A., Eds., (2011). Electromagnetic and Light Scattering by Nonspherical Particles XII, Journal of Quantitative Spectroscopy and Radiative Transfer 112, Special Issue, Elsevier.

Nyberg Sonja, Ulla Kallio, Pekka Lehmuskoski (2011). Analysing the local deformations at Olkiluoto using GPS and levelling time series, in Posiva Working Report 2011-07, Proceedings of a Seminar on Sea Level Displacement and Bedrock Uplift, 10-11 June 2010, Pori, Finland

Oszkiewicz, D., Muinonen, K., Bowell, E., Trilling, D., Wasserman, L. H., Penttilä, A., and Pieniluoma, T. (2011). Asteroid phase curves from Lowell Observatory photometric database. In Electromagnetic & Light Scattering XIII Conference (Proceedings), F. Borghese, P. Denti, P. G. Gucciardi, M. A. Iat `i, O. M. Marag_o, and R. Saija, Eds. (Taormina, Italy, September 26-30, 2011), AAPP 89, C1V89S1P072, 5 pp.

Poutanen, M. (2011): Present bedrock movements and land uplift. In Proceedings of a Seminar on Sea Level Displacement and Bedrock Uplift,10-11 June 2010, Pori, Finland (Ed. A. Ikonen, T. Lipping). Posiva Working Report 2011-07. P. 25-35. Olkiluoto.

Poutanen, M., P. Häkli, J. Jokela, H. Koivula, J. Mäkinen and H. Suurmäki (Eds.) (2011): Geodetic Operations in Finland 2008–2011. Finnish Geodetic Institute, Kirkkonummi 2011. 39pp. ISBN 978-951-711-284-0.

Poutanen, M., P. Häkli, U. Kallio, S. Nyberg, P. Rouhiainen ja V. Saaranen (2011): Geodeettisten havaintoaineistojen kokoaminen, käsittely ja analyysi Simon-Pyhäjoen alueelta mahdollisen ydinvoimalan sijoitusalueen liikuntojen selvittämiseksi.

Ruotsalainen, H. E. Geodynamics with an interferometrical fluid level tiltmeter in Lohja, Finland. Physics Days 2011, Helsinki, Finland, March 29-31, 2011, Proceedings of the XLV Annual Conference of the Finnish Physical Society and the Second Nordic Physics Meeting, 347 (2011). https://www.physics.helsinki.fi/fp2011/uploads/Proceedings.pdf

Suurmäki, H. (2011) Scale anomaly detection by rod comparator. Bachelor's thesis. Metropolia University of Applied Sciences, Land Surveying Degree Programme. 27 p. (In Finnish) https://www.theseus.fi/bitstream/handle/10024/36854/Mittakaa.pdf?sequence=1

Thomas, I. D., M. A. King, M. J. Bentley, P. L. Whitehouse, N. T. Penna, S. D. P. Williams, R. E. M. Riva, D. A. Lavallee, P. J. Clarke, E. C. King, R. C. A. Hindmarsh, and H. Koivula (2011). Widespread low rates of Antarctic glacial isostatic adjustment revealed by GPS observations. Geophys. Res. Lett., doi:10.1029/2011GL049277.

Zubko, E., Muinonen, K., Shkuratov, Y., and Videen, G. (2011). Negative polarization of agglomerate particles with various densities. In Electromagnetic & Light Scattering XIII Conference (Proceedings), F. Borghese, P. Denti, P. G. Gucciardi, M. A. Iat `i, O.M. Marag_o, and R. Saija, Eds. (Taormina, Italy, September 26-30, 2011), AAPP 89, C1V89S1P098, 5 pp.

Zubko, N., Poutanen, M. (2011). Crustal movements in Europe with EUROPE and IVS-T2 VLBI networks, Proceedings of the 20th Meeting of the European VLBI Group for Geodesy and Astronomy, p.150-153, 2011

Norwegian Mapping Authority
Geodetic Institute 2010-2014
Country report NKG General Assembly 01.-04.September 2014

Brandalslaguna, the location for the new geodetic observatory in Ny-Ålesund, Svalbard

Edited by: Reidun Kittelsrud, Oddgeir Kristiansen, Per Christian Bratheim and Per Erik Opseth

Norwegian Mapping Authority
Geodetic Institute
Kartverksveien 21
3511 HØNEFOSS
NORWAY

www.kartverket.no

1. Introduction

The Norwegian Mapping Authority (NMA) builds and operates geodetic infrastructure in Norway and Svalbard and has a strong focus on geodetic analysis and interpretation.
In addition to the overall responsibility to provide a national geodetic reference frame suitable for use of modern global satellite positioning systems, activities this period have been based on our three goals:

- The performance of positioning should be at the level of 1 centimeter in a national geodetic reference frame. The system should also provide integrity.
- To observe and analyze geophysical processes and contribute to a more precise observation of the Earth so that we with greater certainty can measure climate changes such as changes in sea level.
- Make sure that GNSS will be optimized for Norway and the northern areas

2. Infrastructure

By 2012, the permanent GNSS network was nationwide with stations located 70 km apart. From 2013, parts of the network are densified to 35 km between stations. The aim is to achieve an improved accuracy of the CPOS service in densely populated areas. This work will continue until 2015. By August 2014, the network consists of approximately 180 permanent GNSS stations, including stations located in Svalbard and Jan Mayen. Most stations are tracking both GPS and GLONASS, and from 2013 all new stations also tracks Galileo, Beidou and QZSS.

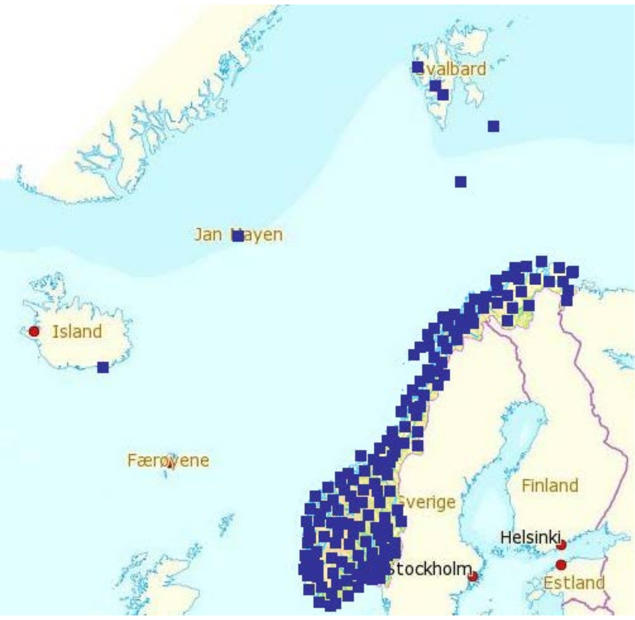

Figure 2-1 *GNSS receiver network (1hz)*

Realtime GNSS data are collected using our own developed linux software, Realtime Data Acquisition. This software was installed in 2012, and has since given us a reliable collection of GNSS data.
In 2013, a standard for real-time GNSS services was published. The purpose of the standard is to ensure that the quality of permanent GNSS networks and RTK services are sufficiently well documented. In 2014 we will start offering raw data from the PGS network for providers who will offer their own RTK services.

Due to the research projects on ionospheric disturbances a GNSS scintillation receiver network has been established and operational with 12 stations since 2014.

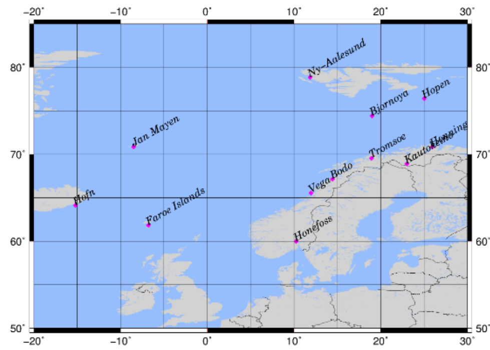

Figure 2-2 *GNSS scintillation receivers (100hz)*

The NMA is upgrading the geodetic observatory in Ny-Ålesund in the Arctic to a core network station within the Global Geodetic Observing System (GGOS). The Norwegian government has in 2013 allocated 30 million Euros to the building of the new observatory which will combine all geodetic measurement techniques at one site. NMA will adapt to the VGOS standard and extend the activity to integrate Satellite Laser Ranging (SLR). The NMA's Ny-Ålesund Observatory at 79º N will serve as a keystone for the network of geodetic stations in the northern hemisphere.
The current status is that the two antennas supporting the VGOS standard are being built by Mechatronics, the road to the new station area is done and the area itself will be prepared with the fundaments this autumn.
A redundant fibre optic cable between Longyearbyen and Ny-Ålesund has been delivered by Uninett and will be operational early 2015.

Fig. 2-3 *Brandalslaguna, the location for the new geodetic observatory in Ny-Ålesund, Svalbard*

The NMA provided hosting services and maintenance of 5 EGNOS Ranging and Integrity Monitoring Stations (RIMS) from 2007 until the end of 2013. From 2014, this responsibility was handed over to Kongsberg Satellite Services Provider (KSAT). The change is partly due to a shift of operations towards improved reference frames and GNSS monitoring

3. The NN2000 project

NN2000 is the name of the new height system replacing the old NN1954. The implementation of this new system nationally as well as locally in the municipality, is a major task that has been going on intensively for the last four years. It includes precise leveling and re-computing ellipsoidal heights in our geodetic network. New geoid and height reference models are also important issues to be solved. In the end the outcome is a transformation model bringing geographical databases in question over to the new height system.

The leveling network was calculated in NN2000 back in 2008 in connection with the Baltic Leveling Ring project. As a part of the implementation in the municipalities this network is now extended with lines into new areas, typically mountain valleys or fjord villages.

Since Euref89 was implemented in 1996, there have been doubts about the accuracy of the ellipsoidal heights. Therefore, we decided in 2009 to establish a new reference frame, called IGS05N. Around 700 stations in our network have been observed for five days or more and calculated in the Bernese Software. The coordinates are well constrained to the IGS05N-coordinates at our permanent GNSS stations. Before NN2000 is implemented, the ellipsoidal heights in the geodetic network for the area are calculated in IGS05N using available GPS-baselines and, if necessary, new vectors are measured to strengthen the ellipsoidal heights. RTK-measurements are also used. After the adjustment, the ellipsoidal heights are transformed back to Euref89 using a transformation model developed for this purpose. The horizontal components of the Euref89-coordinates remain unchanged.

An important part of the NN2000-project is making a geoid model well fitted to the reference frames, either NN2000 and EUREF89 or NN2000 and IGS05N. For this purposes we need GPS/leveling points – points with both reliable NN2000-height and ellipsoidal heights. We use leveled points either in our geodetic network or leveling benchmarks determined in IGS05N from five days of GPS-measurement. The project is a cooperation between several state organizations dealing with maps and geographical data. The NMA's regional offices have the leadership, whereas the geodetic institute is responsible for the leveling and the five days measuring campaigns in addition to reference frames issues, geoid models and transformation models. Normally private companies do the additional GNSS-measurements. So far the activity has been in southern Norway, however projects are now started in two municipalities in northern Norway.

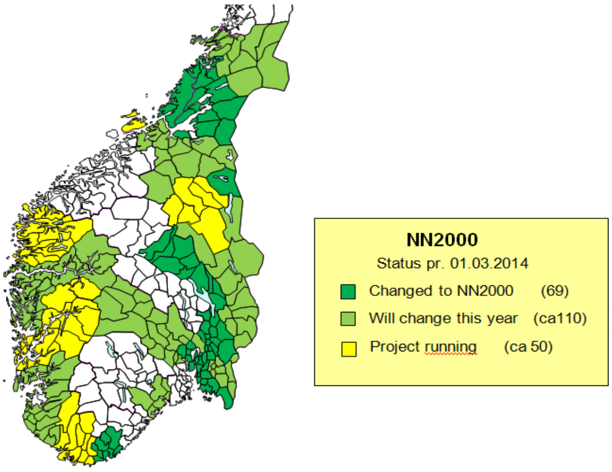

Fig. 3-1 *Status of NN2000 rollout in Norwegian municipalities*

4. Geoid improvement

The underlying gravity measurements for the geoid have been recalculated, with position and height information updated to WGS84 and NN2000, respectively. The data has also been cleaned for outliers.
New gravity measurements have been collected at sea and large lakes with the interest of filling large data gaps. We have measured several fjords (Sognefjord, Oslofjord, Trondheimsfjord, Boknafjord, and fjords around Molde and Ålesund) and lakes (Mjøsa, Nisser, Vråvatn and Telemarkskanalen), in addition to small areas of the Barents Sea.

We have also made more than 900 new land gravity measurements to check the quality of the old measurements. Absolute gravity values have been measured with both FG5 and A10.
The A10 measurements is in cooperation with the Institute of Geodesy and Cartography in Warsaw.

The plan is to measure all the remaining base point of the Norwegian gravity network and then recalculate all gravity observation based on new gravity absolute values.

5. Positioning service

The positioning service CPOS now has nearly 2800 paying users, 1700 more than at end of 2010. Most users are still from the traditional municipal surveying, but the segment with most growth is within the construction work and machine guidance.
The CPOS service is based on a network of 180 permanent geodetic stations all over the Norwegian mainland, including some stations at the border: 12 in Sweden (from SWEPOS) and 6 in Finland (from Geotrim Oy).
Our newly started availability monitor shows an availability of the CPOS service of 99,8 % during a typical month. The network is also the basis for the DPOS service, which by that is considerably densified.

In 2011 we installed the first monitor stations to log the accuracy at different locations in Norway. In 2014 we have 8 such stations located in 4 pairs: one close to a reference station and one further away. The results are so far only used for internal surveillance.

The stability and reliability of the CPOS service is improved by a completely renewal of software and IT infrastructure. The new
software from Trimble, Pivot Platform, is now installed in a fully redundant system based on virtual servers. The IT infrastructure and services are monitored at the control centre in the daytime, and during night by a IT infrastructure operator. In spring 2014 we moved into a new redecorated and more functional control centre.

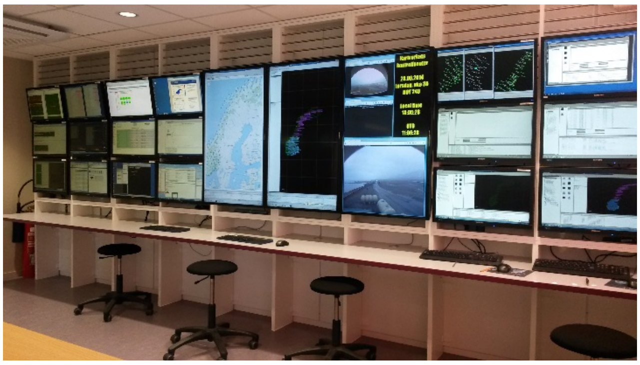

Fig. 5-1 *The control centre at Hønefoss*

NMA strives to improve the availability and also include integrity in the CPOS service. In order to do this we seek to make the software processing more robust during ionospheric activity. Furthermore, investigations are done in order to find algorithms to compute integrity values, both of the data sent from the network, and to discover local disturbances. These projects are done in cooperation with the software supplier, Trimble.
As part of the research collaboration with Trimble to improve troposphere modelling, we have installed Vaisala PTU 300 weather sensors on selected GNSS reference stations. Six stations were installed during spring 2014, and seven more are installed this autumn. The completed weather station network will reach from near sea level in the inner Oslo fjord, across the southern Norwegian mountain range, and down to Stavanger on the west coast. The highest station is 1050 meters a.s.l. The weather sensors deliver pressure, temperature and relative humidity measurements in real-time to the control centre.

Fig. 5-2 *Installation of weather sensor – Haukeli station*

6. Research in geodesy and Earth science at the NMA

Geophysical processes

The new geodetic observatory in Ny-Ålesund will fulfill the requirements for a GGOS core station and be an important station for global geodetic reference frames. To fully exploit the station for global geodesy it is mandatory to have control over local and regional geophysical processes that affect the observatory. Processes like plate-tectonics, neo-tectonic, sea-level rise, glacial isostatic adjustment and the elastic response on the ongoing de-glaciation in the area contribute to local deformations in the area. The processes have different temporal and spatial scale, and the Norwegian Mapping Authority will continue the research activities to understand these processes (e.g. Omang & Kierulf 2011, Kierulf etal 2009).

NMA has since the last NKG general assembly made a large effort to improve the Norwegian and Fennoscandian GNSS velocity field. Both for GIA studies, reference frame issues and to study local neo-tectonic processes. These activities have resulted in several research publications (Kierulf etal 2012 & Kierulf etal 2014). Results from NMA, GNSS analysis have been used to study local neo-tectonic deformation in Ranafjord area (Olesen etal 2013) and the new velocity field is an important part of the NEONOR2 projects, which aims to study neo-tectonic activities in northern Norway. (These projects have participants from all larger groups studying geophysical processes in Norway, NGU, NGI, UiO, NORUT and UiB).
To improve the infrastructure for earth observations in

Norway and Europe, NMA participate in the NNEC (Norwegian National EPOS Consortium which is the Norwegian node of EPOS)

Sea level changes
The NMA has developed software and skills for processing geophysical data records from several altimetry satellites. The data can be combined in order to estimate global and regional sea level changes over the last 20 years.

NMA is taking a leading role in updating 21st century sea level projections for Norway using data from the 5th report of the IPCC (Intergovernmental Panel for Climate Change). This sea level report will form part of a larger report “Klima i Norge 2100” - which will examine other aspects of future climate in Norway. The report will also be adopted as official sea level advice for Norway i.e. for use in coastal land management and engineering.

Troposphere
NMA investigates if the use of dense regional weather models or pressure measurements at ground level, may improve accuracy for network-RTK users. Differences in tropospheric activity between base stations and network-RTK users, such as local weather conditions or larger height variations, may decrease the accuracy at end user level. This may be especially noticeable in Norway with its constantly changing weather conditions which are sweeping across the country, and various topography, where end users may be located at completely different altitudes than the reference stations. The analysis is performed together with NMAs network-RTK provider, Trimble.

Space weather
NMA researchers are active in the topic of space physics related to GNSS, as the dynamic ionosphere activities in the auroral and polar regions pose a challenge for GNSS-based systems. The objectives are to understand the impact of space weather on GNSS services, to monitor the active ionosphere, and ultimately to provide some sort of forecast regarding the impact of space weather on GNSS services.
In 2012, NMA established a national ionosphere monitoring service (http://sesolstorm.kartverket.no/), which displays the state of the ionosphere as seen by NMAs receiver network.
In 2013, in an ESA project, NMA developed an expanded version of the ionosphere monitoring service in English, which is to be a part of ESAs space weather portal.

In 2013/14, NMA reached data-sharing agreements with owners of GNSS receiver networks in Denmark and Sweden, allowing additional data input into the ionosphere monitoring.

NMA has also deployed a network of 12 scintillation receivers in Norway, Iceland and the Faroe Islands.
NMA is involved in research projects with both international (e.g. ESA, CNES, DLR) and national (e.g. UiO, UiT) organizations/institutions.

In particular, NMA has an important role in the ESA project "Arctic Testbed", whose objective is to provide recommendations to improve EGNOS performance at high latitudes.
NMA will continue to build competence, monitoring infrastructure and systems, participate in research and development projects and perform studies on space weather and its impacts.

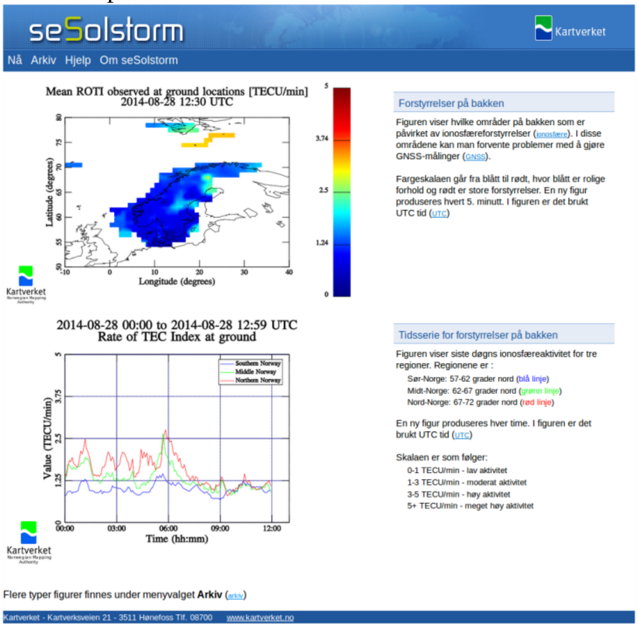

Fig. 6-1 *NMA’s monitoring service for ionospheric disturbances of GNSS* http://sesolstorm.kartverket.no

GEOSAT
Version 1.0 of our GEOSAT software soon enters it’s final year of development. With the GEOSAT software the individual observations from VLBI, GNSS, SLR and DORIS will be combined epoch-by-epoch in a factorized Kalman filter. During the combination, technique-dependent calibration parameters will be estimated along with parameters of primary interest (orbital parameters, station coordinates, Earth orientation parameters etc). This relative calibration of the techniques is anticipated to increase the consistency between the techniques in scale and orientation of the terrestrial and celestial reference frames and their relative orientations.

Ocean circulation
The NMA has studied how geodetic data, such as gravity and geoid, in combination with mean sea level data from altimetry may be used to obtain the ocean circulation in the Norwegian and Greenland sea. It also shows that using geodetic data give a better fit to observation (i.e. mooring) data than oceanographic models.

References

Kierulf, H. P., Steffen H, Simpson MJR, Lidberg J, WU P, Wang H (2014) A GPS velocity field for Fennoscandia and a consistent comparison to glacialisostatic adjustment models. J. Geophys. Res. Solid Earth, 119, doi:10.1002/2013JB010889

Kierulf HP, Ouassou M, Simpson MJR, Vestøl O (2012) A continuous velocity field for Norway. J of Geodesy 87:337–349, doi:10.1007/s00190-012-0603-2

Kierulf HP, Plag HP, Kohler J (2009) Measuring Surface deformation induced by present-day ice melting in Svalbard. Geophys J Int 179(1):1–13, doi:10.1111/j.1365-246X.2009.04322.x

Olesen O, Kierulf HP, Bro¨nner M, Dalsegg E, Fredin O, Solbakk T (2013) Deep weathering, neotectonics and strandflat formation in Nordland, northern Norway. Norwegian J of Geology 93(3-4):189–213

Omang, O.C.D. and Kierulf, H.P. (2011). Past and present-day ice mass variation on Svalbard revealed by superconducting gravimeter and GPS measurements. Geophysical Research Letters 38: doi: 10.1029/2011GL049266. issn: 0094-8276.

7. Physical geodesy at Norwegian University of Life Sciences (NMBU)

A project to validate the gravimetric satellite GOCE with ground based data in Norway has been successfully completed. Based on GOCE results, new projects (funding PhD students) have been initiated to re-examine the Norwegian height system in a global context and to investigate methods to combine satellite altimetry and in-situ tide gauge data in the Norwegian coastal zone.

The NMBU absolute gravimeter made extensive observing series at Ny-Ålesund,
Svalbard in close collaboration with the Norwegian Mapping Authority, who operates a superconducting gravimeter at the same site. The NMBU absolute gravimeter has also made first epoch observations inside the NVE (Norwegian Water Resources and Energy Directorate) glacial laboratory underneath the Svartisen glacier. The intention is to estimate ice mass changes with time to validate results from other approaches.

References

Gerlach, G., Sprlak, M., Bentel, K., Pettersen, B. R., 2013, Observation, validation, modeling – historical lines and recent results in Norwegian gravity field research. Kart og Plan vol. 73, p. 128-150. ISSN 0047-3278.

Harsson, B. G., Pettersen, B. R., 2014, Two centuries of geodesy in Norway (in Norwegian). Kart og Plan vol. 74, p. 6-15. ISSN 0047-3278.

Pettersen, B. R., Harsson, B. G., 2014, Two centuries of gravimetry in Norway (in Norwegian). Kart og Plan vol. 74, p. 46-59. ISSN 0047-3278.

Sprlak, M., Gerlach, C., Pettersen, B. R., 2012, Validation of GOCE global gravity field models using terrestrial gravity data I Norway. Journal of Geodetic Science vol. 2, p. 134-143.

Sprlak, M., Pettersen, B. R., Omang, O. C. D., Lysaker, D. I., Sekowski, M., Dykowski, P., 2014, Comparison of GOCE global gravity field models to test fields in Southern Norway. IAG Symposium, in press. (Springer).

8. Research at Norwegian University of Science and Technology (NTNU) - Geomatics

Geomatics group at NTNU is placed at the Department of Civil and Transport Engineering. The majority of courses support the popular 5 year integrated master’s degree program in Civil and Environmental Engineering, Geomatics is also part of this program. Geomatics research focuses on nearly all aspects of spatial information, from the collection of data to the presentation of the data itself or its derivatives. The division teaches in all university levels with Geodesy as a special field within Geomatics. Last year, the Department decided, in its strategy program, to prioritize use of satellite technologies in Civil and transport engineering focusing on geodetic and remote sensing satellites. The Geomatics group has also defined and registered PhD courses in satellite geodesy. Geomatics group is strongly involved in national and international co-operations within geodesy and Earth sciences.

Recent Research activities

Our recent research activities have been focusing on “Earth Mass Change Tracking using GRACE Satellite Gravity data”. The Gravity Recovery and Climate Experiment (GRACE) satellite gravity mission has been providing valuable information regarding Earth’s gravity field. GRACE not only maps the Earth’s static gravity field but it also measures temporal variation in the Earth’s gravity field to a scale of several hundred kilometers and with a period of around one month. GRACE detects changes in the gravity field caused by redistribution of mass within the Earth and on or above the Earth’s surface. Due to its global coverage, GRACE provides an excellent tool for mapping the gravity field over large areas.

Our research activities have been dealing with the estimation of present-day Earth's mass transport and its redistribution by using observations from GRACE satellite mission. GRACE measures the gravity fluctuations which are primarily related to redistribution of water around the globe. GRACE data has yield profound new insights into melting rates of ice sheets and mountain glaciers, land hydrology, ocean circulation, and sea level rise. Focus areas of our research have been Greenland (to estimate Ice sheet mass balance), Oceans (to estimate Ocean mass variations), and land (to estimate continental water storage changes).

Greenland: In this part, first, the ice melting rate in the Greenlandic ice sheet is studied. This is done by analyzing the time series of monthly GRACE Level 2 release 05 gravity field solutions from three different data sets, CSR (Center for Space Research), GFZ (Geoforschungszentrum), and JPL (Jet Propulsion Laboratory) with respect to their long-term temporal changes. A method for reducing the leakage effects is developed. As an example, the ice mass balance is estimated to -183 ± 11 Gt/yr based on the CSR release 05 and smoothing by a parameter of during February 2003 to November 2012, corresponding to an equivalent global sea level rise of 0.51 ± 0.05 mm/year. The results also show that the spatial distribution of the ice mass loss is changing with time and the ice mass loss is accelerating. For example, its acceleration is a rate of –32±6 Gt/yr2 during 2002 to 2011. In addition we have estimated Greenland ice-melt spread. Our model shows rapid mass loss of the Greenland icecap is now spreading from southern portions to northwest Greenland coast in 2007-2012. The ice loss rate has doubled over the 9 year period. The summers of 2003, 2005, 2007 and 2008 are observed to be among the warmest years since 1961. Our model reveals large mass losses in these years, indicating strong correlation between summer temperature and the ice loss observed by GRACE.

Ocean: In the second focus area, the investigations have been dedicated to the determination of water mass changes in the Nordic Seas. It is determined by analyzing the time series of monthly GRACE level 2 release 04 data from GFZ during October 2002 to October 2010. The striping errors are reduced by using a non-isotropic filter and the data are smoothed by a parameter of according to Gaussian smoothing radius of 530 km. The time series of water mass changes are used to study the steric sea height variations over the Nordic Seas during the same period of study. This is done by analyzing the time series of monthly sea level anomaly from ENVISAT (Environmental Satellite) altimetry data, cycles 10 to 93, among the time series of water mass changes. The results show that the interdisciplinary nature of the GRACE measurements have opened up the unique opportunity to enhance our knowledge on the interaction between Earth system components and their response to climate variability.

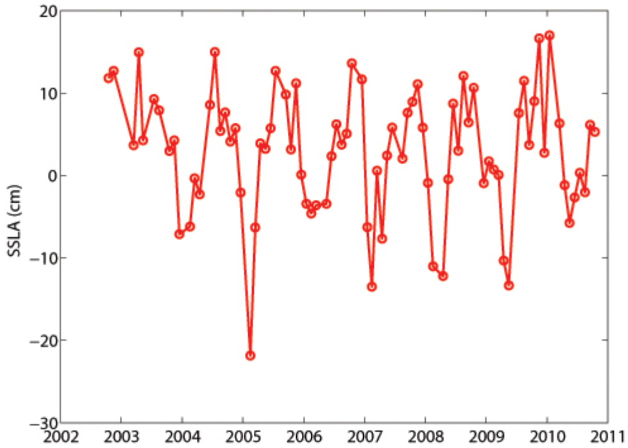

Figure 8-1: *Steric sea level anomaly changes (Sea level changes due to variations in Temperature and salinity) over the Nordic Seas during October 2002 to October 2010. Joodaki et al. (2012)*

Land: In the third focus area on land, we have been investigating variations of the continental total water storage, total groundwater storage, and anthropogenic contributions across the Middle East. By using a mascon analysis method and GRACE level 2 release 05 data from CSR during February 2003 to December 2012, the time series of total water storage, total ground water storage and anthropogenic contributions are estimated over this region.
The region is subdivided to seven mascons including Iran, Iraq, Syria, eastern Turkey (east of 35o longitude), northern and southern Saudi Arabia (north and south of 25o latitude), and the region immediately west of Caspian Sea. To separate the groundwater variations into naturally occurring and anthropogenic components, we subtract the CLM4.5 (version 4.5 of the Community Land Model) 2003–2012 groundwater trend (which does not include anthropogenic contributions) shown in Figure 4 (left), from the GRACE -minus- SSCR total groundwater trend (Soil moisture + Snow + Canopy + River storage, computed from CLM4.5). The result represents anthropogenic groundwater variations. The results show that Iran with a rate of 25±6 Gt/yr has the most groundwater loss rate during February 2003 to December 2012 in this region. The Iran's rate of groundwater loss from the GRACE data is supported by an analysis of in situ well data from across Iran. The results also show that the GRACE mission is able to monitor monthly water storage changes within river basins and aquifers that are 200,000 km2 or larger in area, and, can contribute to water management at regional and national scales, and to international policy discussions as well. For more information see Joodaki et al. (2014).

References:

G. Joodaki and H. Nahavandchi (2010) Greenland mass balance estimation from satellite gravity measurements, ESA Living Planet Conference, ESA Special Publication SP-686.

G. Joodaki and H. Nahavandchi (2012a) Mass loss of the Greenland ice sheet from GRACE time-variable gravity measurements, Studia geophysica et geodaetica 56, 197-214, DOI: 10.1007/s11200-010-0091-x.

G. Joodaki and H. Nahavandchi (2012b) Mass balance and mass loss acceleration of the Greenland ice sheet (2002–2011) from GRACE gravity data, Journal of Geodetic Science, 2(2), 156-161 DOI: 0.2478/v10156-011-0032-9.

H. Nahavandchi and G. Joodaki (2012) Greenland ice-melt spread into Northwest revealed by GRACE, Kart og Plan, Volume 72, Annual 105, 234-240.

G. Joodaki, H. Nahavandchi, and K. Ghazavi (2012) Steric sea level changes from ENVISAT and GRACE in the Nordic Seas, 20 years of Progress in Radar Altimetry symposium, ESA publication.

G. Joodaki, J. Wahr, and S. Swenson (2014) estimating the Human Contribution to Groundwater Depletion in the Middle East, from GRACE Data, Land Surface Models, and Well Observations, Water Resources Research, Volume 50, Issue 3, pages 2679–2692.

National Report of Sweden to the NKG General Assembly 2014 – geodetic activities in Sweden 2010–2014

Dan Norin[a], Jan M. Johansson[b] Stig-Göran Mårtensson[c], Mehdi Eshagh[d]
[a]Lantmäteriet, SE-801 82 Gävle, Sweden, dan.norin@lm.se
[b]Onsala Space Observatory, SE-439 92 Onsala, Sweden, jan.johansson@chalmers.se
[c]HiG, the University of Gävle, SE-801 76 Gävle, Sweden, sgm@hig.se
[d]University West, SE-461 86 Trollhättan, Sweden, mehdi.eshagh@hv.se

1. Geodetic activities at Lantmäteriet

1.1 Introduction

At Lantmäteriet (the Swedish mapping, cadastral and land registration authority) the geodetic activities during 2010–2014 have been focused on:

- The operation, expansion and services of SWEPOS™, the Swedish national network of permanent reference stations for GNSS[1].
- The implementation of the Swedish national reference frame SWEREF 99 and the national height system RH 2000 (ETRS[2]89 and EVRS[3] realisations, respectively).
- The improvement of Swedish geoid models.

Some of the activities are performed within the framework of NKG[4]. Resources have also been allocated for the renovation of the gravity network.

The geodetic work within Lantmäteriet is based on a 10-year strategic plan for the years 2011–2020 called Geodesy 2010, which was released in 2011 (Lantmäteriet, 2011).

1.2 Satellite positioning (GNSS)

Lantmäteriet operates the NKG EPN[5] LAC[6] in co-operation with Onsala Space Observatory at Chalmers University of Technology. The NKG LAC contributes with weekly and daily solutions based on final CODE[7] products, using the Bernese GNSS Software. Version 5.2 is used since GPS[8] week 1765 (November 2013). The EPN sub-network processed by the NKG LAC consisted by the time for the 17th NKG General Assembly in September 2014 of 61 stations concentrated to northern Europe, where more stations are expected to be added further on, see Figure 1.1. This means that twelve stations have been added to and one station has been redrawn from the NKG LAC sub-network between the 2010 assembly and the 2014 assembly. The NKG LAC has also contributed to the EPN reprocessing activities. NKG has through Lantmäteriet been represented at the seventh and eighth EUREF[9] LAC's Workshops, which were held in 2010 and 2013.

Fig. 1.1. *The NKG EPN LAC sub-network of permanent reference stations for GNSS is concentrated to northern Europe (in May 2016 it consisted of 74 stations). Source: www.epncb.oma.be.*

A GNSS analysis centre project has been started within NKG during the last four-year period and it is chaired by Lantmäteriet (Jivall et al., 2014). The project is aiming at a

[1] GNSS = Global Navigation Satellite Systems
[2] ETRS = European Terrestrial Reference System
[3] EVRS = European Vertical Reference System
[4] NKG = Nordiska Kommissionen för Geodesi (Nordic Geodetic Commission)
[5] EPN = EUREF Permanent Network
[6] LAC = Local Analysis Centre
[7] CODE = Centre for Orbit Determination in Europe, Switzerland
[8] GPS = Global Positioning System
[9] EUREF = the IAG Reference Frame Subcommission for Europe

dense and consistent velocity field in the Nordic and Baltic area. Consistent and combined solutions will be produced based on national processing using the Bernese GNSS Software version 5.2 following the new EPN Analysis guidelines. The operational phase began during the summer 2014.

The EGNOS[10] RIMS[11] that was inaugurated at Lantmäteriet in Gävle already during 2003 has been successfully supported by Lantmäteriet since then.

During the years 2010–2012, Lantmäteriet chaired the Swedish Board of Radio Navigation (RNN).

1.3 Network of permanent reference stations for GNSS (SWEPOS)

SWEPOS™ is the Swedish national network of permanent GNSS stations (Lilje et al., 2014); see the new SWEPOS website available on swepos.se or through www.lantmateriet.se/swepos. SWEPOS is operated from the headquarters of Lantmäteriet in Gävle and a relocation of this control centre to new premises within the building took place during 2012, see Figure 1.2.

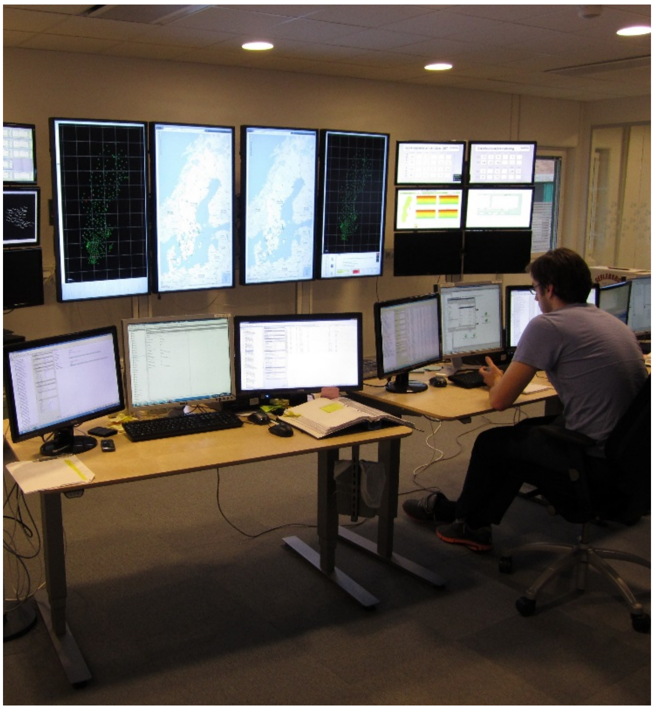

Fig. 1.2. *The SWEPOS control centre.*

Since the first SWEPOS stations were established in 1993, the 20th anniversary of SWEPOS took place in 2013.

The purposes of SWEPOS are:

- Providing single- and dual-frequency data for relative GNSS measurements.
- Providing DGNSS[12] corrections and RTK[13] data for distribution to real-time users.
- Acting as the continuously monitored foundation of SWEREF 99.
- Providing data for geophysical research and for meteorological applications.
- Monitoring the integrity of the GNSS systems.

SWEPOS uses a classification system of permanent reference stations for GNSS developed within the NKG (Engfeldt et al., 2006). The system includes four different classes; A, B, C and D, where class A is the class with the highest demands.

By the time for the 17th NKG General Assembly in September 2014 SWEPOS consisted of totally 305 stations, 38 class A stations and 267 class B ones, see Figures 1.3 and 1.4.

Fig. 1.3. *Hässleholm is one of the SWEPOS stations belonging to class A. It has both a new monument (established in 2011) and an old monument (from 1993).*

[10] EGNOS = European Geostationary Navigation Overlay System

[11] RIMS = Ranging and Integrity Monitoring Station

[12] DGNSS = Differential GNSS

[13] RTK = Real Time Kinematic

Fig. 1.4. *Söderboda is a SWEPOS station with a roof-mounted GNSS antenna mainly established for network RTK purposes belonging to class B.*

This means that the total number of SWEPOS stations has increased with 110 stations since the previous NKG General Assembly, see Figure 1.5.

The class A stations are built on bedrock and have redundant equipment for GNSS observations, communications, power supply, etc. They have also been connected by precise levelling to the national precise levelling network. Class B stations are mainly established on top of buildings for network RTK purposes. They have the same kind of instrumentation as class A stations (dual-frequency multi-GNSS receivers with antennas of Dorne Margolin choke ring design), but with somewhat less redundancy.

The 21 original class A stations have two kinds of monuments; the original concrete pillars as well as newer steel grid masts established during 2011, see Figure 1.3. Steel grid masts were chosen after an evaluation of several different designs and they are equipped with individually calibrated antennas and radomes of the type LEIAR25.R3 LEIT.

The total number of SWEPOS stations included in EPN has increased from 7 to 17 during the time between the NKG General Assemblies in 2010 and 2014. The seven stations included prior to 2010 are all part of the 21 original SWEPOS stations. These stations are Onsala, Mårtsbo, Visby, Borås, Skellefteå, Vilhelmina and Kiruna (ONSA, MAR6, VIS0, SPT0, SKE0, VIL0 and KIR0). Daily, hourly and real-time (EUREF-IP) data (1 Hz) are delivered for all stations except Vilhelmina, where only daily and hourly files are sub-

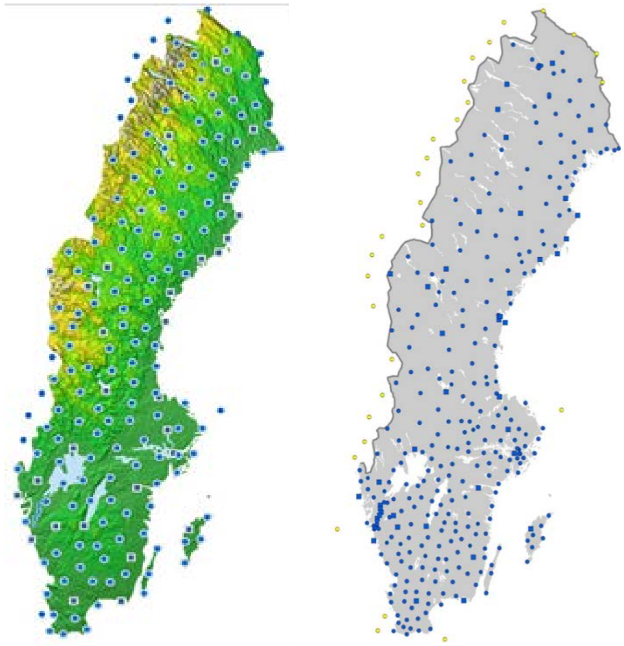

Fig. 1.5. *The SWEPOS network by the time for the previous NKG General Assembly in 2010 to the left and by the time for the 17th NKG General Assembly in September 2014 to the right. Squares indicate class A stations and dots indicate class B ones. Stations in neighbouring countries used in the SWEPOS Network RTK Service are also marked, but stations from other service providers are not marked.*

mitted. The 10 new Swedish EPN stations (all included during the summer 2014) also originate from the 21 original SWEPOS stations, but from the newer monuments (i.e. the steel grid masts). The new monuments at the eleven remaining original SWEPOS stations are also expected to become EPN stations during 2014–2016 (in May 2016 only one station remained).

Five of the original SWEPOS stations (Onsala, Mårtsbo, Visby, Borås and Kiruna) are included in the IGS[14] network and the new monumentation on three of them (ONS1, MAR7 and KIR8) also contribute as stations in the IGS-MGEX[15] campaign. This campaign has been set-up to track, collate and analyse all available GNSS signals.

1.4 SWEPOS services

SWEPOS provides real-time services on both metre level (DGNSS) and centimetre level (network RTK), as well as data for post-processing in RINEX[16] format. An automated post-processing service is also available. This service utilises the Bernese GNSS Software, where version 5.0 has been used

[14] IGS = International GNSS Service

[15] IGS-MGEX = IGS Multi-GNSS Experiment

[16] RINEX = Receiver Independent EXchange format

since 2008 (a transition to version 5.2 took place during 2015).

The SWEPOS Network RTK Service reached national coverage during 2010. Since data from permanent GNSS stations are exchanged between the Nordic countries, good coverage of the service in border areas and along the coasts has been obtained by the inclusion of twenty Norwegian SATREF stations, four Norwegian Leica SmartNet stations, five Finnish Geotrim stations, one Finnish Leica SmartNet station, three Danish Leica SmartNet stations and two Danish Geodatastyrelsen (Danish Geodata Agency) stations.

The service has supplied RTK data for both GPS and GLONASS since April 2006. By the time for the 17th NKG General Assembly in September 2014, it had approximately 2400 subscriptions, which means some 920 new users since the previous NKG General Assembly four years ago, see Figure 1.6.

Fig. 1.6. *Personnel from Lantmäteriet introducing network RTK for Mr Stefan Attefall, by that time Swedish Minister for Public Administration and Housing. Photo: Anna Eklund.*

During the past four years, Lantmäteriet has also signed cooperation agreements with three international GNSS service providers. This is done in order to increase the use of GNSS data from the SWEPOS stations and the providers are using the data in their own services.

With the main purpose to improve the performance of the network RTK service, a general densification of the SWEPOS network is going on since 2010 by establishing approximately 40 new stations each year. More comprehensive densifications have also been performed in some areas to meet the demands for machine guidance in large-scale infrastructure projects.

After the original Close-RTK project (Emardson et al., 2009), a second part of this project has investigated how network RTK measurements are affected by the ionosphere (Emardson et al., 2011). The investigation was done by analysing archived SWEPOS data from the previous solar maximum around 1999–2004. The project also included the development of an ionospheric monitoring service. The service can be accessed via the SWEPOS website and can also be downloaded as applications for smartphones.

Existing guidelines concerning the use of the network RTK service have been improved, where also time correlation effects for points measured close to each other in time have been studied more in detail (Odolinski, 2012). Lantmäteriet is also working on a series of handbooks for mapping and surveying, see Section 1.10.7.

A SWEPOS user group exists with the main purpose to support the development of SWEPOS and its services. The user group consists of representatives from governmental and non-governmental organisations as well as from the private sector.

SWEPOS also offers a single frequency network DGNSS Service as a supplement to the network RTK service. Both services are since June 2012 utilising Trimble Pivot Platform GNSS Infrastructure Software. Together with the new software, absolute antenna models (igs08.atx) were implemented (implying that the SWEREF 99 coordinates of the SWEPOS stations were adjusted to comply with the new antenna models). The software is operating in virtual reference station mode, but so-called network RTK correction messages have been tested (Norin et al., 2012). An implementation of this as an additional service option is planned, as well as options for new GNSS and the new GPS signals.

The early Swedish DGPS[17] service called EPOS, which used correction data from SWEPOS, ended its operation during 2012.

1.5 Implementation of SWEREF 99

SWEREF 99 was adopted by EUREF as the realisation of ETRS89 in Sweden at the EUREF 2000 symposium in Tromsö (Jivall & Lidberg, 2000). It is used as the national geodetic reference frame since 2007 and has been used for Swedish GNSS services since 2001.

By defining SWEREF 99 as an active reference frame we are exposed to rely on the positioning services of SWEPOS, like the network RTK service. All alterations of equipment and software as well as movements at the reference stations will in the end affect the coordinates. In order to be able to check all these alterations, so-called consolidation points

[17] DGPS = Differential GPS

have been introduced by Lantmäteriet (Engberg et al., 2010). The approximately 300 so-called SWEREF points from the RIX 95 project are used for this purpose, see Figure 1.7, and they are remeasured in a yearly programme with 50 points each year. The large project RIX 95 lasted 1995–2008 and involved GPS measurements on totally 9029 control points (Norin et al., 2013).

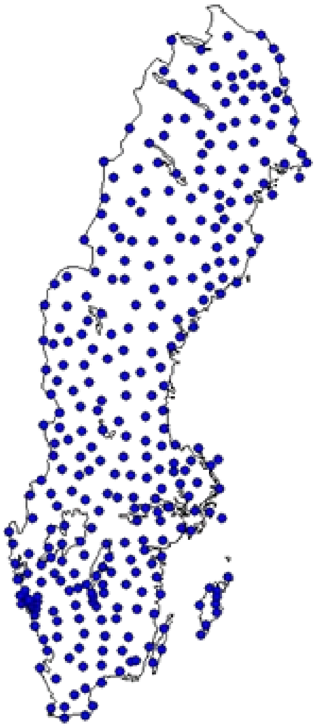

Fig. 1.7. *The approximately 300 SWEREF points from the RIX 95 project, which totally included 9029 points.*

The work regarding the implementation of SWEREF 99 among different authorities in Sweden, such as local ones, is in progress (Kempe et al., 2013). 97 % of the 290 Swedish municipalities had by the time for the 17th NKG General Assembly in September 2014 started the process to replace their old reference frames with SWEREF 99. The number of municipalities that have finalised the replacement increased from 192 to 264 during the four years-period.

To rectify distorted geometries of local reference frames, the municipalities utilise correction models created with the help of Lantmäteriet in combination with transformation parameters obtained from RIX 95. The rectification is made by a so-called rubber sheeting algorithm and the result will be that all geographical data are positioned in a homogenous reference frame, the national SWEREF 99.

1.6 Implementation of RH 2000

The third precise levelling of the mainland of Sweden lasted 1978–2003, resulting in the new national height system RH 2000 in 2005. The network consists of about 50,000 bench marks, representing roughly 50,000 km double run precise levelling measured by motorised levelling technique. Since the beginning of the 1990's, a systematic inventory/updating of the network is continuously performed. When an update is required, the new levelling is done through procurement procedures. Such procedures are also used for the remeasurements of the 300 SWEREF points described in Section 1.5.

The work with implementing RH 2000 among different authorities in Sweden is in progress (Kempe et al., 2014). 70 % of the 290 Swedish municipalities had, in co-operation with Lantmäteriet, by the time for the 17th NKG General Assembly in September 2014 started the process of analysing their local networks, with the aim to replace the local height systems with RH 2000. 159 municipalities had by that time finalised the replacement for all activities, which is 126 more than by the time for the previous NKG General Assembly four years ago.

1.7 Geoid models

The national Swedish geoid model SWEN08_RH2000 was released in the beginning of 2009. It has been computed by adapting the Swedish gravimetric model KTH08 to SWEREF 99 and RH 2000. KTH08 was computed in cooperation between Lantmäteriet and Professor Lars E. Sjöberg and his group at KTH[18] in Stockholm. The GNSS/levelling adaption was made by utilising a large number of geometrically determined geoid heights, computed as the difference between heights above the ellipsoid determined by GNSS and levelled normal heights above sea level. The standard uncertainty of SWEN08_RH2000 has been estimated to 10–15 mm everywhere on the Swedish mainland with the exception of a small area in the north-west. The standard uncertainty is larger in the latter area and at sea, probably around 5–10 centimetres.

According to Geodesy 2010, the ultimate goal is to compute a 5 mm (68 %) geoid model by 2020. To reach this goal – to the extent that is realistic – work is going on to establish a new fundamental gravity network/system as well as to improve the Swedish detail gravity data by new gravity measurements. One region where such measurements have been performed is on Lake Vänern (Ågren et al., 2014), see Figure 1.8.

[18] KTH = Kungliga Tekniska Högskolan (Royal Institute of Technology)

Fig. 1.8. *Relative gravity measurements in March 2011 on Lake Vänern, the largest lake in Sweden. Photo: Mikael Lindblom.*

In cooperation with KTH, it is also investigated what is required of geoid determination data, method and theory to reach this uncertainty over Sweden (Ågren & Sjöberg, 2014). Two projects are currently running in the NKG Working Group of Geoid and Height Systems. The first aims at computing a new common geoid model over the Nordic countries (Ågren et al., 2015), while the second investigates what is required to reach 5 mm uncertainty over the Nordic area.

In order to improve the Baltic Sea geoid model, Lantmäteriet is also engaged in the FAMOS[19] project (which has the main purpose to increase the safety of navigation in the Baltic Sea). The first part of the project (FAMOS Freja) started in 2014.

1.8 Gravimetry

Absolute gravity observations have been carried out at 14 Swedish sites since the beginning of the 1990's, see Figure 1.9. This means that no sites have been added since the previous NKG General Assembly.

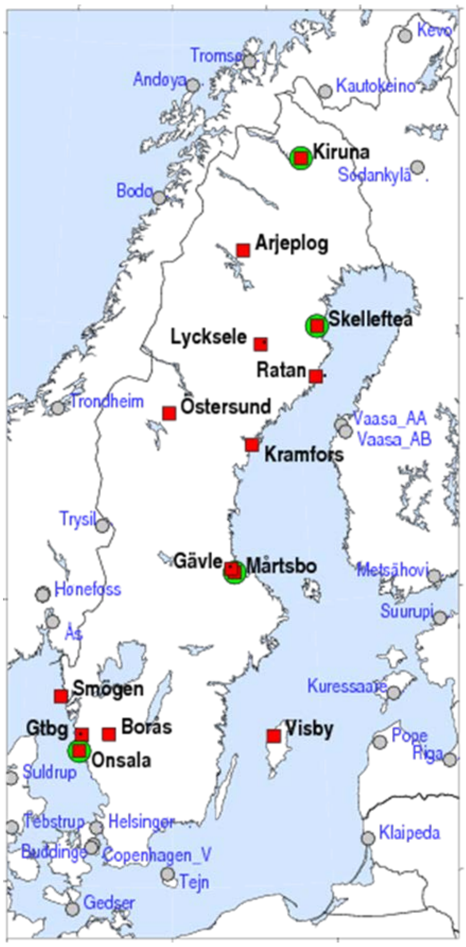

Fig. 1.9. *The 14 absolute gravity sites in Sweden (red squares) and sites in neighbouring countries (grey circles). The four sites with time series more than 15 years long have a green circle as background to the red square.*

All sites, except for Göteborg (Gtbg) which no longer is in use, have been observed by Lantmäteriet since 2007. The observations have been carried out with an absolute gravimeter (Micro-g LaCoste FG5 - 233), which Lantmäteriet purchased in autumn 2006. The objective behind the investment was to ensure and strengthen the observing capability for long-term monitoring of the changes in the gravity field due to the Fennoscandian GIA[20].

All Swedish absolute gravity sites (except for Göteborg) are co-located with reference stations in the SWEPOS network. Onsala is also co-located with VLBI[21]. Skellefteå, Smögen, and Visby are co-located with tide gauges.

Absolute gravity observations have also been performed abroad, namely on two Danish sites, one Finnish site, two Norwegian sites, three Serbian sites, three sites in Republic of Macedonia and four sites in Bosnia and Herzegovina.

[19] FAMOS = Finalising Surveys for the Baltic Motorways of the Sea

[20] GIA = Glacial Isostatic Adjustment

[21] VLBI= Very Long Baseline Interferometry

Furthermore, six inter-comparisons have been carried out; three times in Luxembourg with 19–25 other gravimeters, one time with 22 other gravimeters in Paris and twice with four other gravimeters in Wettzell.

The absolute gravity observations are co-ordinated within NKG, and observations have also been performed by several groups (BKG[22], IfE[23], NMBU[24] and FGI[25]) together with Lantmäteriet.

The establishment of a new Swedish fundamental gravity network is planned to be finalised around 2016. The work started in 2011 in co-operation with IGiK[26], using their absolute gravimeter A-10 – 020 for the observations. 83 sites have until 2014 been measured in co-operation with IGiK.

At Onsala Space Observatory, a super-conducting gravimeter was installed during 2009. The investment should be seen as an additional important instrument at the Onsala geodetic station, but also in view of the efforts regarding absolute gravity for studying temporal variations in observed gravity. This gravimeter has until 2014 been calibrated three times by Lantmäteriet's absolute gravimeter (FG5).

1.9 Geodynamics

The main purpose of the repeated absolute gravity observations of Lantmäteriet is to support the understanding of the physical mechanisms behind the Fennoscandian GIA process. GIA-induced gravity change was studied in a PhD project by Per-Anders Olsson, who successfully defended it in October 2013 (Olsson, 2013). One key parameter is the relation between gravity change and geometric deformation (Olsson et al., 2015).

Research regarding the 3D geometric deformation in Fennoscandia and adjacent areas is foremost done within the BIFROST[27] effort (Johansson et al., 2015 and Lidberg et al., 2015). Reprocessing of all observations from permanent GPS stations is a continuous activity. In addition, another velocity field including the majority of the Norwegian GNSS stations is published in a study introducing the GIA-reference frame approach (Kierulf et al., 2014). GIA models can by using this method be constrained with minimal influence of errors in the global reference frame or biasing signals from plate tectonics.

NKG2005LU, the Nordic land uplift model that includes the vertical component only, will be substituted with the new model called NKG2016LU. The new land uplift model will be developed as a combination and modification of the mathematical model of Olav Vestøl and a new geophysical model currently developed within an NKG activity (Steffen et al, 2014c). This improved geophysical model (NKG201xGIA) will deliver both vertical and horizontal motions, as well as gravity-rates-of-change and geoid change. Additionally, uncertainty estimates will be provided for all fields. Within this NKG modelling activity, a database of relative sea levels will be made publicly available. Parts of this database have already been beneficial in recent investigations (Steffen et al., 2014a,b).

Lantmäteriet is involved in the EUREF working group on "Deformation models", which aims at obtaining a high resolution velocity model for Europe and adjacent areas and significantly improving the prediction of the time evolution of coordinates. This will help overcome the limitations in the use of ETRS89 and also lead to a general understanding of the physics behind such a velocity field. An inventory of published velocity fields is established. The velocity model including deformations will be developed once the densified EPN velocity field becomes available.

1.10 Further activities

1.10.1 Diploma works

During the period 2010–2014 totally nine diploma works have been performed at Lantmäteriet by students from KTH, Lund University, University of Gävle and University West in Trollhättan (all not published). Eight of the diploma works have mainly been focused on GNSS and to large extent the SWEPOS services. One of them has been focused on geodetic reference systems (the vertical component).

1.10.2 Doctoral dissertation

One person from Lantmäteriet has performed doctoral studies at Chalmers University of Technology during the last four year-period (Olsson, 2013), see Section 1.9.

1.10.3 Arranged workshops and seminars

The yearly EUREF symposium was arranged in Gävle June 2nd–5th 2010 in co-operation with KTH and Chalmers University of Technology. It gathered 129 participants from 29 countries, see Figure 1.10.

[22] BKG = Bundesamt für Kartographie und Geodäsie, Germany

[23] IfE = Institut für Erdmessung at Leibnitz University, Hannover, Germany

[24] NMBU = Norges Miljø- og Biovitenskapelige Universitetet, Norway

[25] FGI = Finnish Geospatial Research Institute, Finland

[26] IGiK = Institute of Geodesy and Cartography, Poland

[27] BIFROST = Baseline Inferences for Fennoscandian Rebound Observations Sea level and Tectonics

Fig. 1.10. *The EUREF 2010 symposium was held in Gävle. Photo: Örjan Zakrisson.*

In co-operation with Chalmers University of Technology, the 17th NKG General Assembly was arranged in Göteborg September 1st–4th 2014.

A training school on GIA modelling was held in Gävle in June 2011 within the ESSEM[28] COST[29] Action ES0701 "Improved constraints on models of glacial isostatic adjustment".

For Swedish GNSS users, seminars were arranged in Gävle in October 2011 and October 2013. The aim of these seminars held every second year is to highlight development of GNSS techniques, applications of GNSS and experiences from the use of GNSS. Many locally organised seminars have also had key speakers from Lantmäteriet, who have informed about e.g. SWEPOS, SWEPOS services and the implementation of SWEREF 99 and RH 2000. Lantmäteriet is also giving courses in e.g. geodetic reference frames and GNSS positioning.

Among meetings which have taken place in Gävle, a meeting of the RTCM SC-104[30] in February 2010 and a meeting of the EUREF Technical Working Group in March 2014 can be mentioned.

1.10.4 Participation in projects overseas

Lantmäteriet are involved (partly through the state-owned company Swedesurvey) in several projects abroad. Many projects have a geodetic part and typical components are the update of geodetic reference frames and the implementation of modern surveying techniques based on GNSS.

Countries where geodetic personnel have made visits for assignments 2010–2014 are Albania, Belarus, Bosnia and Herzegovina, Botswana, Georgia, Ghana, Indonesia, Jamaica, Kenya, Mongolia, Namibia, Republic of Macedonia, Russia, Rwanda (see Figure 1.11) and Serbia.

Fig. 1.11. *Personnel from Lantmäteriet introducing RTK surveying for RNRA[31] in Rwanda. Photo: Dan Norin.*

Besides the projects overseas, Lantmäteriet has also been represented and involved in different international seminars and working groups. Commission 5 (Positioning and Measurement) within FIG[32] has been chaired by Lantmäteriet during the period 2011–2014 and an article submitted to FIG was declared "Article of the Month January 2014" (Schwieger & Lilje, 2013).

1.10.5 Website

The Lantmäteriet website (www.lantmateriet.se/geodesi) has extensive geodetic information. Here also transformation parameters and geoid models are easily and freely accessible.

1.10.6 Digital geodetic archive

Lantmäteriet has a digital geodetic archive with descriptions of national control points and their coordinates and heights etc., which has been accessible through a website since October 2007. The number of registered external users who pay a small yearly fee has since the previous NKG General Assembly four years ago increased from 109 to 191.

[28] ESSEM = Earth System Science and Environmental Management

[29] COST = European Cooperation in Science and Technology

[30] RTCM SC-104 = Radio Technical Commission for Maritime Services Special Committee No 104

[31] RNRA = Rwanda Natural Resources Authority

[32] FIG = Fédération Internationale des Géomètres (International Federation of Surveyors)

1.10.7 Handbooks for mapping and surveying

Lantmäteriet is working on a series of handbooks for mapping and surveying called HMK (“Handbok i mät- och kartfrågor”), with the aim to contribute to an efficient and standardised handling of surveying and mapping issues in Sweden (Alfredsson et al., 2014). The handbooks are divided into two main parts, geodesy and geodata capture, together with an introduction document.

1.10.8 National elevation model

Lantmäteriet is responsible for the production of a new Swedish national elevation model. The mainly used method for the data capture is airborne laser scanning and the production started in July 2009. 82 % of the Swedish territory has until 2014 been scanned, where the remaining part is mostly in the mountainous part of Sweden. The main part of the scanning is expected to be finalised during 2016.

2. Geodetic activities at Chalmers University of Technology and Onsala Space Observatory

2.1 Introduction

Onsala Space Observatory is the Swedish national facility for radio astronomy. It is hosted by the Department of Earth and Space Sciences at Chalmers University of Technology, where the Space Geodesy and Geodynamics research group are focused on three techniques for geodetic, geophysical and other earth oriented applications:

- Geodetic VLBI.
- Gravimetry.
- GNSS.

The main interests in the work are geodynamic phenomena and atmospheric processes. The deformation of the Earth’s crust due to mass redistribution, inter- and intraplate tectonics, loading effects, and variations in the Earth’s orientation and rotation are among others studied. The study of spatial and temporal variations of water vapour in the atmosphere can also be mentioned. The studied research topics are addressed using a variety of observational techniques together with theoretical work.

2.2 Geodetic VLBI

The Space Geodesy and Geodynamics research group has actively participated in the observing programme of IVS[33], where the 20 metre radio telescope and VLBI equipment at Onsala Space Observatory have been used. The work is part of IVS’ earth rotation programme, terrestrial reference programme, celestial reference system programme, and the European geodetic VLBI series. Approximately 40–50 sessions per year are observed. Additionally, Onsala in 2011 and in 2014 participated in two 15-day long continuous VLBI campaigns named CONT11 and CONT14 organised by IVS. The CONT11 and CONT14 campaigns involved thirteen VLBI stations on five continents. Two of the stations (Onsala and the Japanese station Tsukuba) also sent the observational data from COST11 in real-time to the correlator station at the Geospatial Information Authority of Japan, where the data were analysed in near real-time. This unique setup resulted in near real-time observations of variations of the Earth rotation angle almost uninterruptedly during the whole campaign.

In 2012, the collaboration with the Japanese colleagues continued in order to improve the latency of Earth rotation parameters. Several so-called ultra-rapid dUT1-experiments were conducted, where the earth rotation angle (expressed as difference between astronomical time and UTC[34]) was determined in near real-time using the baseline Onsala-Tsukuba. The concept was extended to an ultra-rapid determination of all three Earth orientation parameters, i.e. two polar motion components and the earth rotation angle, with a network of four stations in Sweden, South Africa, Japan and Australia.

Observations of GLONASS satellites have been conducted through a number of experimental VLBI observations. The goal for these studies is to investigate whether it is possible to establish so-called space-ties between the different space geodetic techniques. While earlier experiments involved radio telescopes equipped with dedicated L-band systems, like the Onsala 25 metre and the Medicina 32 metre telescope, the experiments in 2013 and 2014 were conducted involving also the 20 metre geodetic radio telescope in Wettzell. A new L-band system have been developed and installed at Wettzell, which extracts the L-band signals from the S-band signal chain. It was verified that the Wettzell L-band system works fine and fringes were found successfully on the Onsala-Wettzell baseline. Total delay values agreed with rms 0.8–0.9 ns for group delays and 0.2–0.4 ns for phase delays (via integrated delay rates).

A new rack for VLBI was installed at Onsala in 2011, see Figure 2.1.

[33] IVS= International VLBI Service for Geodesy and Astrometry

[34] UTC = Coordinated Universal Time

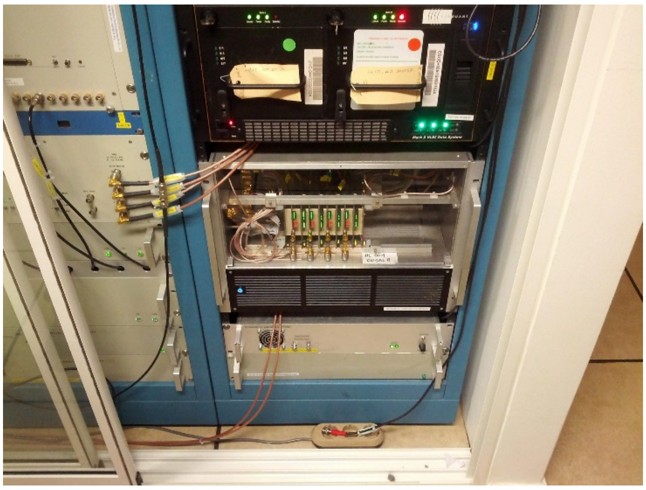

Fig. 2.1. *The new rack for VLBI at Onsala Space Observatory is a modern digital backend system.*

An analogue Mark4 rack has operationally been used for more than 40 years for both astronomical and geodetic VLBI. The new rack is a modern digital backend/Mark5B+ system and it has been used in parallel with the old Mark4/Mark5A system since 2011.Tests with parallel recordings have been performed during numerous geodetic VLBI sessions and no significant differences have been found between the analogue and digital backends. The old analogue backend has now been phased-out and will be placed in the museum. A second digital backend was installed during autumn 2014 to work with Mark5C.

A proposal for a new Twin-Telescope for VLBI at Onsala Space Observatory was accepted for funding by Knut and Alice Wallenberg Foundation in April 2012. The project started in 2013 and includes the construction of two new radio telescopes. The telescopes will be part of the VGOS[35] network and are expected to contribute with a significant improvement in accuracy within the project.

2.3 Gravimetry

On June 10th 2009, a super-conducting gravimeter (SCG, series number GWR-054) was taken into operation at Onsala Space Observatory. Five years of gravity measurement with the instrument at one sample per second, of which only 0.4 percent have been lost, have provided a rich data base. Of interest from the processing are tidal effects, annual perturbations, Kattegat basin oscillations, dynamic air pressure response and the background noise power spectrum. The instrument communicates one-second data to the world since January 2013. A link makes numeric data available for download with a latency of about one minute and other links allow to identify seismic events and the cause of microseismic noises.

The super-conducting gravimeter has been calibrated by absolute gravity measurements. Altogether six calibration campaigns have been carried out up to this date. Two different absolute gravimeters, one from Lantmäteriet and one from IfE in Hannover have been used (both Micro-g LaCoste FG5), see Figure 2.2.

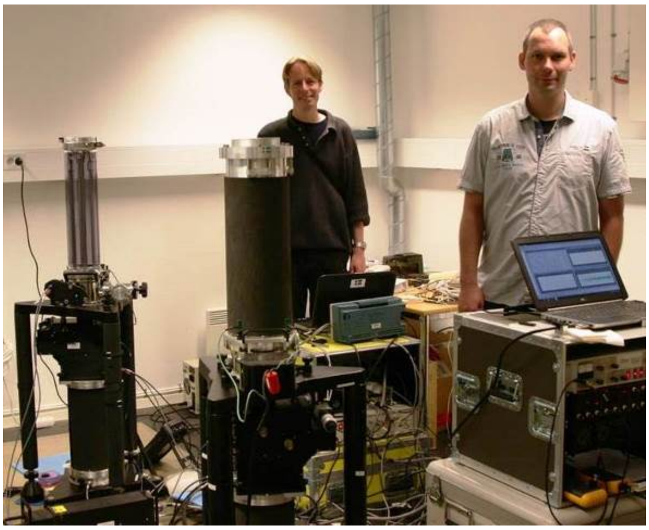

Fig. 2.2. *Calibration of the super-conducting gravimeter with two absolute gravimeters (both Micro-g LaCoste FG5) in May 2014.*

2.4 GNSS

During 2008 a project started in order to measure local sea level and its variation using GNSS signals. The measurements are done using a GNSS-based tide gauge, which consists of two antennas mounted on a beam extending in southward direction over the coastline at Onsala Space Observatory (Löfgren & Haas, 2014), see Figure 2.3. The antennas are aligned along the local vertical with one antenna facing toward zenith direction and the other facing toward nadir. The zenith-looking antenna is Right-Hand-Circular-Polarized (RHCP) while the nadir-looking antenna is Left- Hand-Circular-Polarized (LHCP). The zenith-looking antenna receives predominantly the direct RHCP satellite signals, while the nadir looking antenna receives predominantly signals that are reflected off the sea surface and thus have changed polarization to LHCP in the reflection process. The GNSS receivers are connected to one antenna each and individually record multi-frequency signals of several GNSS. The analysis of phase measurements performed with the corresponding GNSS receivers allows to estimate the local sea surface height and its variation.

[35] VGOS = VLBI2010 Global Observing System

Fig. 2.3. *The GNSS tide gauge installation, with one zenith-looking and one nadir-looking antenna (covered by hemispherical radomes), at Onsala Space Observatory. The radome of the 20 metre radio telescope in the background.*

The BIFROST project was started in 1993 (Johansson et al., 2015). The first primary goal was to establish a new and useful three-dimensional measurement of the movements in the earth crust based on GNSS observations, able to constrain models of the GIA process in Fennoscandia. Data from about 40 permanent reference stations for GNSS has been used. In 2013, a new BIFROST GNSS solution was produced including GNSS data from 1993 to 2013. This solution is the most accurate BIFROST solution ever produced, and uses e.g. a consistent geodetic reference frame, models for absolute calibration of antenna phase centre variations and higher order ionospheric effects.

The long term stability in the atmospheric water vapour content has been studied using GPS together with VLBI, microwave radiometry and radiosondes using simultaneous measurements over a more than ten years long period. Water vapour is an effective green-house gas and accurate measurements over long time are of crucial importance when assessing possible global warming scenarios.

2.5 Further activities

2.5.1 Official tide gauge station at Onsala Space Observatory

The Swedish national network of tide gauge stations is operated by SMHI[36]. An agreement for a joint responsibility in constructing and operating a new station at Onsala Space Observatory was signed in 2013. The station is motivated by the fact that Onsala is located at the coast and loading effects on the Earth's crust are important. The modelling of the sea level in Kattegatt is complicated and the available tide gauge data today are at least 20 kilometres away. The new tide gauge will complement the existing GNSS-based tide gauge and also three pressure sensors submerged into the sea at the same location in the summer of 2011.

2.5.2 Doctoral dissertation

Three PhD theses have successfully been defended during 2010–2014 (Ning, 2012, Olsson, 2013 and Löfgren, 2014).

2.5.3 Arranged seminars

The yearly EUREF symposium was arranged in Gävle June 2nd–5th 2010 in co-operation with Lantmäteriet and KTH. It gathered 129 participants from 29 countries.

The European Frequency and Time Forum 2012 was arranged in Göteborg April 23rd–27th 2012 in co-operation with SP Technical Research Institute of Sweden. The meeting had 320 participants and 20 exhibitors.

In co-operation with Lantmäteriet, the 17th NKG General Assembly was arranged in Göteborg September 1st–4th 2014.

3. Geodetic activities at HiG, the University of Gävle

UNIVERSITY
OF GÄVLE

3.1 Introduction

The Department of Industrial Development, IT and Land Management at the University of Gävle (www.hig.se) offers graduate and postgraduate education as well as performs research in geodesy, engineering surveying and GIS[37].

3.2 The graduate programme in Land Management and Land Surveying

In 2009 the then existing graduate programme in Geomatics was comprehensively revised and at the same time renamed to the more appropriate Land Management/Land Surveying (LM/LS) programme. Thus two for the Swedish labour market demanded specialisations were offered. The two specialisations, LM and LS, share several courses which are of importance for both – like surveying courses.

The success of the new programme is shown in Table 3.1 in form of number of applicants (students' first choice) since its establishment.

---

36 SMHI = Swedish Meteorological and Hydrological Institute

37 GIS = Geographic Information Systems

Table 3.1. *The number of applicants at the LM/LS programme at HiG from 2009.*

Academic year	*LM*	*LS*	*Total*
2009/10	17	34	51
2010/11	34	29	63
2011/12	25	42	67
2012/13	56	62	118
2013/14	65	80	145
2014/15	55	81	136

3.3 Staff, research and quality in geodesy and engineering surveying

The increasing number of applicants to the LM/LS programme has involved an increasing number of enrolled students. Consequently, the number of staff has increased. By the time for the 17th NKG General Assembly in September 2014 there were four highly qualified (PhDs) lecturers/researchers in geodesy/surveying employed. Their main task is lecturing, with research up to approximately 20–30 %. An increase in research is expected, particularly since an application for the entitlement of awarding postgraduate and PhD qualifications has been approved with effect from January 1st 2015. The research area has been defined as "Geospatial Information Science" and comprise besides LM and LS also Spatial Planning and Computer Science.

Research has primarily been focused on applied geodesy and presently monitoring movements on the surface of the Earth by different platforms, such as UAS[38], is of increasing interest. A main project has been running during 2014 aiming at evaluating the ultimate uncertainty of UAS-produced terrain models. The latter has been evaluated with respect to newly, by SIS[39], issued specifications for producing and control of digital ground models.

The geodetic research activities at HiG also include:

- Gravity inversion.
- Crustal thickness determination using gravimetric-isostatic methods.
- Study on upper-mantle parameters for GIA modelling using land uplift data and Moho.
- Deformation monitoring using geodetic sensors.

The LM/LS graduate programme was during 2013 reviewed by UKÄ[40]. It received, as the only Swedish programme within the area, the highest rank "Very high quality".

[38] UAS = Unmanned Aircraft Systems

[39] SIS = Swedish Standards Institute

[40] UKÄ = Universitetskanslersämbetet (Swedish Higher Education Authority)

4. Geodetic activities at University West (UW)

HÖGSKOLAN VÄST

4.1 Introduction

The surveying engineering programme at University West (UW) is under the Department of Engineering Science. This programme offers graduate education and performs research in geodesy and geodetic surveying.

4.2 Surveying engineering programme

The surveying engineering programme of UW is the most popular engineering programme of the university and offers only the graduate training in this subject. This programme has not different directions like other Swedish universities and the degree that the students will receive is not specified whether it is in the Land Management (LM) or the Land Surveying (LS). During the first 2.5 years of studies, all courses are compulsory for the students. In the second half of the third year, when they have to select the subject for their thesis, they are free to work either on LM or LS. The programme offers 6 geodetic courses, which amongst them, three are obligatory and the rest of them are optional for those who are interested to learn more about geodesy.

During the last four years, the programme has been successful and served more than 50 students per year. The result of the review by UKÄ was "High quality" for this programme at UW.

4.3 Staff and research in Geodesy

Being the only university in the western part of Sweden which has this programme and having capacity of training more than 50 students per year, has increased the capability of UW to hire more experts. So far, UW has been successful to employ two professors (one in geodesy and one in LM), one associate professor in GIS, and three instructors in construction, LM and geodetic measurements.

Most of the geodetic activities of UW are related to the researches of its professor in geodesy. One geodetic PhD students from KTH has been at UW for six months and worked under the professor in geodesy (his supervisor) for optimisation of the Lilla Edet GNSS deformation monitoring network. In June 2014, the university hosted a guest researcher from the Czech Republic for a study about satellite gravimetric missions with the professor in geodesy. In September 2014, a Spanish professor of geodesy visited the university for initiating possible collaborations in geodesy and geophysics.

The geodetic research activities of UW, which started after employing the professor in geodesy in 2013, include:

- Optimisation and design of geodetic monitoring networks.
- Gravity field recovery from satellite missions.
- Geophysical studies using satellite data, like Moho and sub-crustal stress determination.
- Geoid and applications of gravity data.

5. References

Alfredsson A., Sunna J., Persson C.-G., Jämtnäs L. (2014): HMK – Swedish handbook in surveying and mapping. FIG XXV International Congress, June 16–21 2014, 8 pages, Kuala Lumpur, Malaysia. Also in NKG 17th General Assembly, September 1–4 2014, Göteborg, Sweden (slightly updated).

Emardson R., Jarlemark P., Bergstrand S., Nilsson T., Johansson J. (2009): Measurement accuracy in network-RTK. **SP report 2009:23**, SP Technical Research Institute of Sweden, Borås, Sweden.

Emardson R., Jarlemark P., Johansson J., Bergstrand S. (2011): Ionospheric effects on network-RTK. **SP report 2011:80**, SP Technical Research Institute of Sweden, Borås, Sweden.

Engberg L. E., Lilje M., Ågren J. (2010): Is there a need of marked points in modern geodetic infrastructure? FIG XXIV International Congress, April 11–16 2010, 7 pages, Sydney, Australia.

Engfeldt A., Jepsen C., Hedling G., Thorsen S. O. (2006): Classification of permanent reference stations for GNSS. PM, NKG.

Jivall L. & Lidberg M. (2000): SWEREF 99 – an updated EUREF realisation for Sweden. In Torres & Hornik (eds): *EUREF Publication No 9*, EUREF 2000 Symposium, June 22–24 2000, pp. 167–175, Tromsö, Norway.

Jivall L., Kempe T., Lilje C., Nyberg S., Häkli P., Kollo K., Pihlak P., Weber M., Kosenko K., Sigurðsson Þ., Valsson G., Prizginiene D., Paršeliūnas E., Tangen O. (2014): Report from the project NKG GNSS AC. NKG 17th General Assembly, September 1–4 2014, 5 pages, Göteborg, Sweden.

Johansson J., Kierulf H. P., Kristiansen O., Lidberg M., Steffen H. (2015): The BIFROST project: 21 years of search for the true crustal deformation in Fennoscandia. In *Geophysical Research Abstracts*, EGU 2015 General Assembly, April 12–17 2015, 17, **EGU2015-9228**, Vienna, Austria.

Kempe C., Alfredsson A., Andersson B., Engberg L. E., Dahlström F., Lohasz G. (2013): The process of changing from local systems into SWEREF 99 – a challenge for Lantmäteriet and a great step for the municipalities. In Henriksen & Jørgensen (eds): *Proceedings of the 16th General Assembly of the Nordic Geodetic Commission*. NKG 16th General Assembly, September 27–30 2010, pp. 136–142, Sundvollen, Norway.

Kempe C., Alm L., Dahlström F., Engberg L. E., Jansson J. (2014): On the transition to the new Swedish height system RH 2000. FIG XXV International Congress, June 16–21 2014, 9 pages, Kuala Lumpur, Malaysia. Also in NKG 17th General Assembly, September 1–4 2014, Göteborg, Sweden (slightly updated and with the title “Swedish municipalities implementing the new national height system RH 2000”).

Kierulf H. P., Steffen H., Simpson M. J. R. S., Lidberg M., Wu P., Wang H. (2014): A GPS velocity field for Fennoscandia and a consistent comparison to glacial isostatic adjustment models. *Journal of Geophysical Research*, **119 (8)**, pp. 6613–6629.

Lantmäteriet (2011): Geodesy 2010 – a strategic plan for Lantmäteriet’s geodetic activities 2011–2020. 16 pages, Gävle, Sweden.

Lidberg M., Steffen H., Johansson J., Kierulf H. P., Kristiansen O. (2015): The BIFROST project: 21 years of search for the true crustal deformation in Fennoscandia. EUREF 2015 Symposium, June 3–5 2015, Leipzig, Germany.

Lilje M., Wiklund P., Hedling G. (2014): The use of GNSS in Sweden and the national CORS network SWEPOS. FIG XXV International Congress, June 16–21 2014, 11 pages, Kuala Lumpur, Malaysia.

Löfgren J. (2014): Local Sea Level Observations Using Reflected GNSS Signals. *Doktorsavhandlingar vid Chalmers tekniska högskola*, **Ny serie Nr 3637**, Chalmers University of Technology, Göteborg, Sweden.

Löfgren J. S. & Haas R. (2014): Sea level observations using multi-system GNSS reflectometry. NKG 17th General Assembly, September 1–4 2014, 5 pages, Göteborg, Sweden.

Ning T. (2012): GPS meteorology: With focus on climate application. *Doktorsavhandlingar vid Chalmers tekniska högskola*, **Ny serie Nr 3356**, Chalmers University of Technology, Göteborg, Sweden.

Norin D., Sunna J., Lundell R., Hedling G., Olsson U. (2012): Test of RTCM version 3.1 network RTK correction messages (MAC) in the field and on board a ship for uninterrupted navigation. ION[41] GNSS 2012, September 17–21 2012, pp. 1147–1157, Nashville, USA.

Norin D., Sjöberg L. E., Johansson J. M. (2013): National report of Sweden to the NKG General Assembly 2010 – geodetic activities in Sweden 2006–2010. In Henriksen & Jørgensen (eds): *Proceedings of the 16th General Assembly of the Nordic Geodetic Commission*. NKG 16th General Assembly, September 27–30 2010, pp. 62–101, Sundvollen, Norway.

Odolinski R. (2012): Temporal correlation for network RTK positioning. *GPS Solutions*, **16 (2)**, pp. 147–155.

Olsson P.-A. (2013): On modelling of postglacial gravity change. *Doktorsavhandlingar vid Chalmers tekniska högskola*, **Ny serie Nr 3583**, Chalmers University of Technology, Göteborg, Sweden.

Olsson P.-A., Milne G., Scherneck H.-G., Ågren J. (2015): The relation between gravity rate of change and vertical displacement in previously glaciated areas. *Journal of Geodynamics*, **83**, pp. 76–84.

Schwieger V. & Lilje M. (2013): Innovative and cost effective spatial positioning. FIG Working Week 2013, May 6–10 2013, 16 pages, Abuja, Nigeria.

Steffen H., Kaufmann G., Lampe R. (2014a): Lithosphere and upper-mantle structure of the southern Baltic Sea estimated from modelling relative sea-level data with glacial isostatic adjustment. *Solid Earth*, **5 (1)**, pp. 447–459.

Steffen H., Wu P., Wang H. (2014b): Optimal locations of sea-level indicators in glacial isostatic adjustment investigations. *Solid Earth*, **5 (1)**, pp. 511–521.

Steffen H., Barletta V. R., Kollo K., Milne G. A., Nordman M., Olsson P.-A., Simpson M. J. R., Tarasov L., Ågren J. (2014c): NKG201xGIA – a model of glacial isostatic adjustment for Fennoscandia. NKG 17th General Assembly, September 1–4 2014, 2 pages, Göteborg, Sweden.

Ågren J. & Sjöberg L. E. (2014): Investigation of gravity data requirements for a 5 mm-quasigeoid model over Sweden: In Marti (ed.): *Gravity, geoid and height systems. IAG[42] Symposia*, GGHS[43] 2012, October 9–12 2012, **141**, pp. 143–150, Venice, Italy.

Ågren J., Engberg L. E., Alm L., Dahlström F., Engfeldt A., Lidberg M. (2014): Improving the Swedish quasigeoid by gravity observations on the ice of Lake Vänern. In Marti (ed.): *Gravity, geoid and height systems. IAG Symposia*, GGHS 2012, October 9–12 2012, **141**, pp. 171–178, Venice, Italy.

Ågren J., Strykowsi G., Bilker-Koivula M., Omang O., Märdla S., Oja T., Liepiņš I., Paršeliūnas E., Forsberg R., Kaminskis J., Ellmann A., Sjöberg L. E., Valsson G. (2015): On the development of the new Nordic gravimetric geoid model NKG2015. IUGG[44] 26th General Assembly, June 22–July 2, 2015, Prague, Czech Republic (oral presentation).

41 ION = Institute of Navigation, USA

42 IAG = International Association of Geodesy

43 GGHS = Gravity, Geoid and Height Systems

44 IUGG = International Union of Geodesy and Geophysics

List of published geodetic papers 2010–2014
– Lantmäteriet (the Swedish mapping, cadastral and land registration authority)

Lantmäteriet: Reports in Geodesy and Geographical Information Systems (Rapportserie: Geodesi och Geografiska informationssystem)

2006:2: **Norin D**., **Engfeldt A**., **Öberg S**., **Jämtnäs L**.: Kortmanual för mätning med SWEPOS Nätverks-RTK-tjänst (3rd edition published in December 2010).

2010:1: **Reit B.-G.**: Om geodetiska transformationer (also available in English with the title On geodetic transformations).

2010:2: **Odolinski R.**: Studie av noggrannhet och tidskorrelationer vid mätning med nätverks-RTK.

2010:3: **Odolinski R.**: Checklista för nätverks-RTK.

2010:4: **Eriksson P.-O.** (ed.): Höjdmätning med GNSS – vägledning för olika mätsituationer.

2010:5: **Eriksson P.-O.** (ed.): Anslutning av lokala höjdnät till RH 2000 med GNSS-stommätning.

2010:6: **Engfeldt A.** & **Odolinski R.**: Punktbestämning i RH 2000 – statisk GNSS-mätning mot SWEPOS.

2010:7: **Lord J.**: Test av GNSS-mottagare från DataGrid (diploma work).

2010:11: **Ågren J.** & **Engberg L. E.**: Om behovet av nationell geodetisk infrastruktur och dess förvaltning i framtiden.

2011:2: **Jansson J.**: Undersökning av mätosäkerheten i det förtätade SWEPOS-nätet i Stockholmsområdet – vid mätning med nätverks-RTK (diploma work).

2011:3: **Liu K.**: A study of the possibilities to connect local levelling networks to the Swedish height system RH 2000 using GNSS (diploma work).

2012:3: **Lundell R.**: Undersökning av nätverks-RTK-meddelande tillsammans med olika GNSS-mottagare – vid nätverks-RTK-mätning i SWEPOS nät av fasta referensstationer (diploma work).

2014:2: Vestøl O., **Eriksson P.-O.**, Jepsen C., Keller K., Mäkinen J., Saaranen V., Valsson G., Hoftuft O.: Review of current and near-future levelling technology – a study project within the NKG working group of Geoid and Height Systems.

2014:5: **Ohlsson K.**: Studie av mätosäkerhet och tidskorrelationer vid mätning med nätverks-RTK i SWEPOS 35 km-nät (diploma work).

Lantmäteriet: International journals

Brandes C., **Steffen H.**, Bönnemann C., Plenefisch T., Gestermann N., Winsemann J. (2014): Aktive Tektonik in Norddeutschland: glazial-isostatische Ausgleichs-bewegungen und/oder Folgen der Erdöl/Erdgas-Förderung? (Active tectonics in Northern Germany: Glacial Isostatic Adjustment and/or a consequence of hydrocarbon production?). Erdöl Erdgas Kohle, 130 (4), pp. 138–143.

Hill E. M., Davis J. L., Tamisiea M. E., **Lidberg M.** (2010): Combination of geodetic observations and models for glacial isostatic adjustment fields in Fennoscandia. Journal of Geophysical Research, 115 (B7), 12 pages.

Jensen J., Dangendorf S., Wahl T., **Steffen H.** (2014): Meeresspiegeländerungen in der Nordsee: Vergangene Entwicklungen und zukünftige Herausforderungen mit einem Fokus auf die Deutsche Bucht (Sea level changes in the North Sea region: recent developments and future challenges with focus on the German Bight). Hydrologie und Wasserbewirtschaftung, 58 (6), pp. 304–323 (in German).

Jansson P. & **Persson C.-G.** (2013): The effect of correlation on uncertainty estimates – with GPS examples. Journal of Geodetic Science, 3 (2), pp. 111–120.

Kierulf H. P., **Steffen H.**, Simpson M. J. R. S., **Lidberg M.**, Wu P., Wang H. (2014): A GPS velocity field for Fennoscandia and a consistent comparison to glacial isostatic adjustment models. Journal of Geophysical Research, 119 (8), pp. 6613–6629.

Lidberg M., Johansson J. M., Scherneck H.-G., Milne G. A. (2010): Recent results based on continuous GPS observations of the GIA process in Fennoscandia from BIFROST. Journal of Geodynamics, 50 (1), pp. 8–18.

Mårtensson S.-G., Reshetyuk Y., **Jivall L.** (2012): Measurement uncertainty in network RTK GNSS-based positioning of a terrestrial laser scanner. Journal of Applied Geodesy, 6 (1), pp. 25–32.

Odolinski R. (2012): Temporal correlation for network RTK positioning. GPS Solutions, 16 (2), pp. 147–155.

Olsson P.-A., **Ågren J.**, Scherneck H.-G. (2012): Modelling of the GIA-induced surface gravity change over Fennoscandia. Journal of Geodynamics, 61, pp. 12–22.

Pettersen B. R., Bilker-Koivula M., Breili K., **Engfeldt A.**, Falk R., Gitlein O., Gjevestad J. G. O., Hoppe W., Lysaker D. I., Mäkinen J., Dahl Omang O. C., Reinhold A., Timmen L. (2010): An accuracy assessment of absolute gravimetric observations in Fennoscandia. Nordic Journal of Surveying and Real Estate Research, 7 (1).

Poutanen M. & **Steffen H.** (2014): Land Uplift at Kvarken Archipelago /High Coast UNESCO[45] World Heritage area. Geophysica, 50 (2), pp. 25–40.

Scherneck H.-G., **Lidberg M.**, Haas R., Johansson J. M., Milne G. A. (2010): Fennoscandian strain rates from BIFROST GPS: A gravitating, thick-plate approach. Journal of Geodynamics, 50 (1), pp. 19–26.

Steffen H., Brunk W., Leven M., Wedeken U. (2014): From San Francisco to Tōhoku – 111 yr of continuous earthquake recording in Göttingen. History of Geo- and Space Sciences, 5 (1), pp. 1–10.

Steffen H., Kaufmann G., Lampe R. (2014): Lithosphere and upper-mantle structure of the southern Baltic Sea estimated from modelling relative sea-level data with glacial isostatic adjustment. Solid Earth, 5 (1), pp. 447–459.

Steffen H., Wu P., Wang H. (2014): Optimal locations of sea-level indicators in glacial isostatic adjustment investigations. Solid Earth, 5 (1), pp. 511–521.

Steffen H. & Wu P. (2014): The sensitivity of GNSS measurements in Fennoscandia to distinct three-dimensional upper-mantle structures. Solid Earth, 5 (1), pp. 557–567.

Steffen R., Wu P., **Steffen H.**, Eaton D. (2013): Effects of changes in frictional strength on the fault behaviour in northeastern Canada. Elements, 31 (1), pp. 20–23.

Steffen R., Wu P., **Steffen H.**, Eaton D. W. (2014): The effect of earth rheology and ice-sheet size on fault slip and magnitude of postglacial earthquakes. Earth and Planetary Science Letters, 388, pp. 71–80.

Steffen R., Wu P., **Steffen H.**, Eaton D. W. (2014): On the implementation of faults in finite-element glacial isostatic adjustment models. Computers & Geosciences, 62, pp. 150–159.

Steffen R., **Steffen H.**, Wu P., Eaton D. W. (2014): Stress and fault parameters affecting fault slip magnitude and activation time during a glacial cycle. Tectonics, 33, pp. 1461–1476.

Vey S., **Steffen H.**, Müller J., Boike J. (2013): Inter-annual water mass variations from GRACE in central Siberia. Journal of Geodesy, 87 (3), pp. 287–299.

Wang H., Jia L., **Steffen H.**, Wu P., Jiang L., Hsu H., Xiang L., Wang Z., Hu B. (2013): Increased water storage in North America and Scandinavia from GRACE gravity data. Nature Geoscience, January 2013, 6 (1), pp. 38–42.

Wang H., Xiang L., Wu P., **Steffen H.**, Jia L., Jiang L., Shen Q. (2013): Effects of the Tibetan Plateau crustal structure on the inversion of water trend rates using simulated GRACE/GPS data. Atmospheric and Ocean Sciences, 24 (4-I), pp. 505–512.

Wu P., Wang H., **Steffen H.** (2013): The role of thermal effect on mantle seismic anomalies under Laurentia and Fennoscandia from observations of Glacial Isostatic Adjustment. Geophysical Journal International, 192 (1), pp. 7–17.

Yildiz H., Forsberg R., **Ågren J.**, Tscherning C. C., Sjöberg L. E. (2012): Comparison of remove-compute-restore and least squares modification of Stokes' formula techniques to quasi-geoid determination over the Auvergne test area. Journal of Geodetic Science, 2 (1), pp. 53–64.

Zhao S., Lambeck K., **Lidberg M.** (2012): Lithosphere thickness and mantle viscosity inverted from GPS-derived deformation rates in Fennoscandia. Geophysical Journal International, 190 (1), pp. 278–292.

Ågren J. & **Svensson R.** (2011): The height system RH 2000 and the land uplift model NKG2005LU. Mapping and Image Science, 2011:3, pp. 4–12, KS[46].

[45] UNESCO = United Nations Educational Scientific and Cultural Organisation

[46] KS = Kartografiska Sällskapet (Swedish Cartographic Society)

Lantmäteriet: Swedish journals

Edberg E. (2012): Big Brother SWEPOS? Sinus, nr 4 2012, pp. 20–21, SKMF[47].

Engberg L. E. & **Persson C.-G.** (2010): God mätsed eller ”Hur man utnyttjar tidigare generationers samlade erfarenheter”. Sinus, nr 1 2010, pp. 8–9 and 23, SKMF.

Engberg L. E. (2012): Tyngdkraftsmätning på Vänerns is. Sinus, nr 1 2012, pp. 6–7, SKMF.

Engberg L. E. (2013): Galileo: Naturvetenskapens fader. Samhällsbyggaren, nr 1-2013, pp. 17–20.

Engberg L. E. (2013): Längdmätning under 60 år – en tillbakablick på utvecklingen. Sinus, nr 2 2013, pp. 9–11, SKMF.

Engfeldt A. (2011): Den långa resan till Makedonien Del 1 (2). Sinus, nr 1 2011, pp. 12–13, SKMF.

Engfeldt A. (2011): Den långa resan till Makedonien Del 2 (2). Sinus, nr 2 2011, pp. 12–13, SKMF.

Engfeldt A. (2012): NKG:s höstskola i Lammi. Sinus, nr 4 2012, pp. 12–14, SKMF.

Engfeldt A. (2013): Virtuell Rinex – ett alternativt sätt att erhålla en bra position. Sinus, nr 2 2013, pp. 27–29, SKMF.

Hedling G. (2010): GLONASS i RTK-mätning. RNN[48] bulletin, nr 1-2010, pp. 2–6.

Hedling G. (2010): Rapport från RTCM-SC104-mötet i Gävle 3–4 februari 2010. RNN bulletin, nr 1-2010, pp. 7–8.

Hedling G. (2010): Reserapport från IGS Workshop i Newcastle 2010-06-27–2010-07-03. RNN bulletin, nr 2-2010, pp. 2–3.

Hedling G. (2010): Reserapport från RTCM SC-104-mötet i Portland OR, USA 20–21 september 2010. RNN bulletin, nr 2-2010, pp. 4–5.

Hedling G. (2011): Reserapport från RTCM SC-104-kommitténs möte i Portland Oregon, 19–20 september 2011. RNN bulletinen, nr 1 2011, pp. 9–10.

Hedling G. (2012): Reserapport från 2012 European Frequency and Time Forum i Göteborg 24–26 april 2012. RNN-bulletinen, nr 1 2012, pp. 6–7.

Hedling G. (2012): Reserapport från RTCM SC-104-mötet i Nashville 2012-09-17 till 2012-09-18. RNN-bulletinen, nr 1 2012, pp. 8–9.

Hunnes A. & **Engfeldt A.** (2010): Intergeo 2010 i Köln. Sinus, nr 4 2010, pp. 12–13, SKMF.

Holm H. & **Persson C.-G.** (2010): Färdighet ersätter behörighet när Mätningskungörelsen upphört. AMA-nytt – Anläggning, 2/2010, pp. 24–25.

Håkansson M. (2012): RTCM SC-104-möte i Bern 16–17 januari 2012. RNN-bulletinen, nr 1 2012, pp. 2–5.

Jansson J. (2014): Tyngdkraftsmätning i fjällen. Sinus, nr 4 2014, pp. 24–25, SKMF.

Joelsson J. (2010): Var finns Sveriges lägsta punkt? Konkurrens om åtråvärd attraktion.Gränssnittet, 2/2010, p. 34, Lantmäteriet.

Jonsson B. (2010): SWEPOS®. Sinus, nr 4 2010, p. 16, SKMF.

Jonsson B. (2010): SWEPOS® möjliggör positionsbestämning i SWEREF 99 och RH 2000 med centimeternoggrannhet. Kart & Bildteknik, 2010:4, pp. 6–10, KS.

Jonsson B. (2010): SWEPOS® Nätverks-RTK-tjänst – nuläge och framtid. RNN bulletin, nr 2-2010, p. 6.

Jonsson B. & **Wiklund P.** (2013): SWEPOS® 20 år – från idé till nationell positionstjänst. Kart & Bildteknik, 2013:4, pp. 14–16, KS.

Jonsson B. & **Wiklund P.** (2014): SWEPOS® – 20 års utveckling av GNSS-tekniken. Sinus, nr 1 2014, pp. 18–22, SKMF.

Lagerquist C. (2013): Bo-Göran gjorde unik internationell gränsmätning. Gränssnittet, 2013 #4, pp. 18–21, Lantmäteriet.

Lilje M. (2011): Geodesi 2010 – Lantmäteriets strategiska plan för geodesiverksamhet. Sinus, nr 3 2011, pp. 16–17, SKMF.

Lilje M. (2012): SWEPOS – samordning och enhetlighet är nyckelorden. Gränssnittet, #3, p. 35, Lantmäteriet.

Lilje M. & Bäärnhielm G. (2012): Gerard Mercator, 1512–1594. Aspect, nr 2 - 2012, pp. 14–17. Also in Sinus, nr 1 2012, pp. 16–18, SKMF, in Kart & Bildteknik, 2012:3, pp. 14–16, KS and in i Målebladet, NR4/2012, pp. 10–13, Kort- og Landmålningsteknikernes Forening.

Löndahl-Åkerman E. & **Engberg L. E.** (2013): Byta höjdsystem till RH 2000? Kart & Bildteknik, 2013:2, pp. 12–15, KS. Also in Sinus, nr 2 2013, pp. 16–18, SKMF.

Malm B.-L. (2010): Ett referenssystembyte med många fördelar. Kart & Bildteknik, 2010:4, p. 11, KS.

[47] SKMF = Sveriges Kart- och Mätningstekniska Förening (Swedish Mapping and Surveying Association)

[48] RNN = Radionavigeringsnämnden (Swedish Board of Radio Navigation)

Malm B.-L. (2012): Mätprecision A och O när E4 dras om i Sundsvall. Gränssnittet, 2012 #3, pp. 8–11, Lantmäteriet.

Malm B.-L. (2012): Efter GPS och Glonass kommer Galileo. Gränssnittet, 2012 #3, p. 12, Lantmäteriet.

Norin D. (2011): Noteringar från 2011 års CGSIC-möte. RNN bulletinen, nr 1 2011, pp. 11–13.

Norin D. (2012): Noteringar från 2012 års CGSIC-möte. RNN-bulletinen, nr 1 2012, pp. 10–12.

Norin D. (2014): Wilhelm Struve mer aktuell än någonsin. Samhällsbyggaren, nr 2-2014, pp. 34–35.

Persson C.-G. (2010): GUM, en guide för att uttrycka mätosäkerhet. Sinus, nr 1 2010, pp. 26–27, SKMF. Also in Kart & Bildteknik, 2010:1, pp. 22–23, KS.

Tähtikivi A. (2014): Svensk geoprocess – enhetliga referenssystem. Kart & Bildteknik, 2014:2, pp. 26–27, KS.

Wiklund P. (2011): Nuläge och framtid för SWEPOS®. RNN bulletinen, nr 1 2011, pp. 14–17.

Öberg S. (2010): SWEPOS Nätverks-RTK-tjänst – nuläge och framtid. RNN bulletin, nr 1-2010, p. 9.

Öberg S. (2010): Reseberättelse CGSIC konferens, Portland, Oregon, USA. Sinus, nr 4 2010, pp. 22–23, SKMF.

Öberg S. & **Norin D.** (2010): Noteringar från 2010 års CGSIC-möte. RNN bulletin, nr 2-2010, pp. 7–8.

Lantmäteriet: Conference proceedings and compilation works

Alfredsson A., **Engberg L. E.**, **Engfeldt A.**, **Jivall L.**, **Kempe C.**, **Lidberg M.**, **Lilje C.**, **Lilje M.**, **Norin D.**, **Steffen H.**, **Wiklund P.**, **Ågren J.** (2014): National Report of Sweden to the EUREF 2014 Symposium – geodetic activities at Lantmäteriet. EUREF 2014 Symposium, June 4–6 2014, 8 pages, Vilnius, Lithuania.

Alfredsson A., **Sunna J.**, **Persson C.-G.**, **Jämtnäs L.** (2014): HMK – Swedish handbook in surveying and mapping. FIG XXV International Congress, June 16–21 2014, 8 pages, Kuala Lumpur, Malaysia. Also in NKG 17th General Assembly, September 1–4 2014, Göteborg, Sweden (slightly updated).

Brandes C., Winsemann J., **Steffen H.**, Plenefisch T., Bönnemann C. (2013): Glacial isostatic adjustment as a key for understanding the neotectonics of northern Germany. DGMK[49]/ÖGEW[50] Frühjahrstagung, Fachbereich Aufsuchung und Gewinnung, April 18–19 2013, Celle, Germany.

Bruyninx C., Ihde J., Altamimi Z., Brockmann E., Caporali A., Dach R., Dousa J., Fernandes R., Habrich H., Hornik H., Kenyeres A., **Lidberg M.**, Mäkinen J., Pacione R., Poutanen M., Sacher M., Söhne W., Stangl G, Torres J., Völksen C., Weber G. (2012): EUREF's efforts to meet the challenge of the changing geodetic landscape. FIG 8th Regional Conference, November 26–29 2012, 12 pages, Montevideo, Uruguay.

Caporali A., **Lidberg M.**, Stangl G. (2011): Lifetime of ETRS89 coordinates. EUREF 2011 Symposium, May 25–28 2011, 4 pages, Chisinau, Moldova.

Emardson R., Jarlemark P., Johansson J., Bergstrand S., **Hedling G.** (2011): Error sources in network RTK. ION GNSS 2011, September 20–23 2011, pp. 2175–2178, Portland, USA.

Engberg L. E., **Lilje M.**, **Ågren J.** (2010): Is there a need of marked points in modern geodetic infrastructure? FIG XXIV International Congress, April 11–16 2010, 7 pages, Sydney, Australia.

Engberg L. E., **Jivall L.**, **Lidberg M.**, **Engfeldt A.**, **Eriksson P.-O.**, **Jonsson B.**, **Lilje M.**, **Norin D.**, **Ågren J.** (2010): National report of Sweden to the EUREF 2010 Symposium – geodetic activities at Lantmäteriet. EUREF 2010 Symposium, June 2–5 2010, 9 pages, Gävle, Sweden.

[49] DGMK = Deutsche Wissenschaftliche Gesellschaft für Erdöl, Erdgas und Kohle e.V.

[50] ÖGEW = Österreichische Gesellschaft für Erdölwissenschaften

Engberg L. E., **Jivall L.**, **Lidberg M.**, **Engfeldt A.**, **Eriksson P.-O.**, **Jonsson B.**, **Lilje M.**, **Norin D.**, **Ågren J.** (2011): National Report of Sweden to the EUREF 2011 Symposium – geodetic activities at Lantmäteriet. EUREF 2011 Symposium, May 25–28 2011, 9 pages, Chisinau, Moldova.

Engberg L. E., **Alm L.**, **Dahlström F.**, **Ågren J.**, **Engfeldt A.**, **Lidberg M.** (2011): Relative gravity measurements on the ice of lake Vänern. EUREF 2011 Symposium, May 25–28 2011, 6 pages, Chisinau, Moldova.

Engberg L. E., **Engfeldt A.**, **Jivall L.**, **Kempe C.**, **Lidberg M.**, **Lilje C.**, **Lilje M.**, **Norin D.**, **Steffen H.**, **Wiklund P.**, **Ågren J.** (2013): National Report of Sweden to the EUREF 2013 Symposium – geodetic activities at Lantmäteriet. EUREF 2013 Symposium, May 29–31 2013, 8 pages, Budapest, Hungary.

Engfeldt A. (2010): Statisk höjdmätning mot SWEPOS. In Elfström (ed.): Program Dokumentation, SKMF MätKart 10, May 19–21 2010, pp. 47–50, Kalmar, Sweden (in Swedish).

Eriksson P.-O. (2010): Anslutning av lokala höjdnät till RH 2000 med GNSS-stommätning. In Elfström (ed.): Program Dokumentation, SKMF MätKart 10, May 19–21 2010, pp. 44–46, Kalmar, Sweden (in Swedish).

Eriksson P.-O. (2013): Height determination using GNSS – guidelines for different survey applications. In Henriksen & Jørgensen (eds): Proceedings of the 16th General Assembly of the Nordic Geodetic Commission. NKG 16th General Assembly, September 27–30 2010, pp. 165–168, Sundvollen, Norway.

Francis O., van Dam T., Germak A., Amalvict M., Bayer R., Bilker-Koivula M., Calvo M., D'Agostino G.-C., Dell'Acqua T., **Engfeldt A.**, Faccia R., Falk R., Gitlein O., Fernandez, Gjevestad J., Hinderer J., Jones D., Kostelecky J., Le Moigne N., Luck B., Mäkinen J., Mclaughlin D., Olszak T., **Olsson P.-A.**, Pachuta A., Palinkas V., Pettersen B. R., Pujol R., Prutkin I., Quagliotti D., Reudink R., Rothleitner C., Ruess D., Shen C., Smith V., Svitlov S., Timmen L., Ulrich C., van Camp M., Walo J., Wang L., Wilmes H., Xing L. (2010): Results of the European comparison of absolute gravimeters in Walferdange (Luxembourg) of November 2007. In Mertikas (ed.): Gravity, geoid and earth observation. IAG Symposia, June 23–27 2008, Vol. 135, pp. 31–36, Chania, Greece.

Gabrielsson B., Eliardsson P., Alexandersson M., Wiklundh K., Stenumgaard P, **Hedling G.**, **Frisk A.**, **Wiklund P.** (2014): Autonomous detection of electromagnetic interference in the GPS band. NKG 17th General

Assembly, September 1–4 2014, 1 page, Göteborg, Sweden.

Häkli P., **Lidberg M., Jivall L.**, Nørbech T., Tangen O., Weber M., Pihlak P., Aleksejenko I., Paršeliūnas E. (2014): The NKG2008 GPS campaign – final transformation results and a new common Nordic reference frame. NKG 17th General Assembly, September 1–4 2014, Göteborg, Sweden (published in Journal of Geodetic Science, 6 (2016) (1), pp. 1–33).

Ihde J., Habrich H., Sacher M., Söhne W., Altamimi Z., Brockmann E., Bruyninx C., Caporali A., Dousa J., Fernandes R., Hornik H., Kenyeres A., **Lidberg M.**, Mäkinen J., Poutanen M., Stangl G., Torres J. A., Völksen C. (2014): EUREF´s contribution to national, European and global geodetic infrastructures. In Rizos & Willis (eds): Earth on the edge: Science for a sustainable planet. IAG Symposia, IAG General Assembly, June 28–July 7 2011, Vol. 139, pp. 189–196, Melbourne, Australia.

Ihde J., Altamimi Z., Brockmann E., Bruyninx C., Caporali A., Dach R., Dousa J., Fernandes R., Habrich H., Kenyeres A., **Lidberg M.**, Pacione R., Geos E., Poutanen M., Söhne W., Stangl G., Torres J. (2016): EUREF's GNSS infrastructure real time and Galileo ready. In Rizos & Willis (eds): IAG 150 Years. IAG Symposia, IAG Scientific Assembly, September 1–6 2013, Vol. 143, Potsdam, Germany (in press).

Jarlemark P., **Lidberg M.**, **Kempe C.**, **Jivall L.**, Johansson J. M., Ning T. (2013): Station calibration of the SWEPOS network. EUREF 2012 Symposium, June 6–9 2012, 6 pages, Paris, France.

Jivall L., **Engberg L. E.**, **Lidberg M.**, **Engfeldt A.**, **Wiklund P.**, **Norin D.**, **Ågren J.**, **Lilje M.** (2012): National Report of Sweden to the EUREF 2012 Symposium – geodetic activities at Lantmäteriet. EUREF 2012 Symposium, June 6–9 2012, 9 pages, Paris, France.

Jivall L., Häkli P., Pihlak P., Tangen O. (2013): Processing of the NKG 2008 GPS campaign. In Henriksen & Jørgensen (eds): Proceedings of the 16th General Assembly of the Nordic Geodetic Commission. NKG 16th General Assembly, September 27–30 2010, pp. 143–149, Sundvollen, Norway.

Jivall L. (2014): Comparison of Vienna Mapping Function (VMF1) and Global Mapping Function (GMF) for NKG GNSS AC. NKG 17th General Assembly, September 1–4 2014, 5 pages, Göteborg, Sweden.

Jivall L., **Kempe T.**, **Lilje C.**, Nyberg S., Häkli P., Kollo K., Pihlak P., Weber M., Kosenko K., Sigurðsson Þ., Valsson G., Prizginiene D., Paršeliūnas E., Tangen O. (2014): Report from the project NKG GNSS AC. NKG 17th General Assembly, September 1–4 2014, 5 pages, Göteborg, Sweden.

Jämtnäs L., **Sunna J.**, Emardson R., Jonsson B. (2010): Quality assessment of network-RTK in the SWEPOS™ network of permanent GNSS stations. FIG XXIV International Congress, April 11–16 2010, 15 pages, Sydney, Australia. Also in Scheider & Schwieger (eds) (2010): GNSS 2010 – Vermessung und Navigation im 21. Jahrhundert, DVW[51]-Seminar GNSS 2010, October 4–5 2010, Köln, Germany (slightly updated).

Kempe C., **Alfredsson A.**, **Andersson B.**, **Engberg L. E.**, **Dahlström F.**, **Lohasz G.** (2010): The process of changing from local systems into SWEREF 99 – a challenge for Lantmäteriet and a great step for the municipalities. EUREF 2010 Symposium, June 2–5 2010, 8 pages, Gävle, Sweden. Also in Henriksen & Jørgensen (eds) (2013): Proceedings of the 16th General Assembly of the Nordic Geodetic Commission. NKG 16th General Assembly, September 27–30 2010, pp. 136–142, Sundvollen, Norway (slightly updated).

Kempe T., **Jivall L.**, **Lidberg M.** (2013): Station calibration of the SWEPOS™ network. In Henriksen & Jørgensen (eds): Proceedings of the 16th General Assembly of the Nordic Geodetic Commission. NKG 16th General Assembly, September 27–30 2010, pp. 183–186, Sundvollen, Norway.

Kempe C., **Alm L.**, **Dahlström F.**, **Engberg L. E.**, **Jansson J.** (2014): On the transition to the new Swedish height system RH 2000. FIG XXV International Congress, June 16–21 2014, 9 pages, Kuala Lumpur, Malaysia. Also in NKG 17th General Assembly, September 1–4 2014, Göteborg, Sweden (slightly updated and with the title "Swedish municipalities implementing the new national height system RH 2000").

Kierulf H. P., **Steffen H.**, Simpson M., **Lidberg M.** (2014): GNSS velocity field for Fennoscandia and a consistent comparison to glacial isostatic adjustment models. NKG 17th General Assembly, September 1–4 2014, 1 page, Göteborg, Sweden.

[51] DVW = Deutscher Verein für Vermessungswesen

Lazić S. & **Wiklund P.** (2011): Status, activities, services of the control center of a national network of GNSS stations of Republic of Serbia AGROS – active geodetic reference base Serbia. In Joksic (ed.): Proceedings of papers. First Serbian Geodetic Congress, December 1–3 2011, pp. 182–189, Belgrade, Serbia.

Lidberg M., Häkli P., Engsager K., Nørbech T., Pihlak P. (2013): The NKG 2008 GPS campaign – transformation results. In Henriksen & Jørgensen (eds): Proceedings of the 16th General Assembly of the Nordic Geodetic Commission. NKG 16th General Assembly, September 27–30 2010, pp. 150–156, Sundvollen, Norway.

Lilje M. & **Engberg L. E.** (2011): Strategic plan for geodesy in Sweden. FIG Working Week 2011, May 18–22 2011, 12 pages, Marrakech, Morocco. Also in FIG 8th Regional Conference, November 26–29 2012, Montevideo, Uruguay (slightly updated and with the title "A strategic plan for the development of geodesy in Sweden").

Lilje M., **Wiklund P.**, **Hedling G.** (2014): The use of GNSS in Sweden and the national CORS network SWEPOS. FIG XXV International Congress, June 16–21 2014, 11 pages, Kuala Lumpur, Malaysia.

Mäkinen J., **Engfeldt A.**, Gitlein O., Kaminskis J., Klopping F., Oja T., Omang O. C. D., Paršeliunas E., Pettersen B. R., Strykowski G., Wilmes H. (2016): Absolute gravity measurements in the Fennoscandian postglacial rebound area: history, network, results. In Rizos & Willis (eds): IAG 150 Years. IAG Symposia, IAG Scientific Assembly, September 1–6 2013, Vol. 143, Potsdam, Germany (in press).

Norin D., **Sunna J.**, **Lundell R.**, **Hedling G.**, Olsson U. (2012): Test of RTCM version 3.1 network RTK correction messages (MAC) in the field and on board a ship for uninterrupted navigation. ION GNSS 2012, September 17–21 2012, pp. 1147–1157, Nashville, USA.

Norin D., Sjöberg L. E., Johansson J. M. (2013): National report of Sweden to the NKG General Assembly 2010 – geodetic activities in Sweden 2006–2010. In Henriksen & Jørgensen (eds): Proceedings of the 16th General Assembly of the Nordic Geodetic Commission. NKG 16th General Assembly, September 27–30 2010, pp. 62–101, Sundvollen, Norway.

Norin D. (2014): Struve Geodetic Arc activities in Sweden. In Kollo et al. (eds): Friedrich Georg Wilhelm von Struve. Association of Estonian Surveyors Special journal, pp. 3–6, Tallinn, Estonia.

Norin D., Johansson J. M., Mårtensson S.-G., Eshagh M. (2014): National report of Sweden to the NKG General Assembly 2014 – geodetic activities in Sweden 2010–2014. NKG 17th General Assembly, September 1–4 2014, 26 pages, Göteborg, Sweden.

Odolinski R. (2010): Checklista för nätverks-RTK. In Elfström (ed.): Program Dokumentation, SKMF MätKart 10, May 19–21 2010, pp. 51–53, Kalmar, Sweden (in Swedish).

Odolinski R. (2013): Swedish user guidelines for network RTK. FIG XXIV International Congress, April 11–16 2010, 14 pages, Sydney, Australia. Also in Henriksen & Jørgensen (eds) (2012): Proceedings of the 16th General Assembly of the Nordic Geodetic Commission. NKG 16th General Assembly, September 27–30 2010, pp. 129–135, Sundvollen, Norway (slightly updated).

Olsson P.-A., Milne G., Scherneck H.-G., **Ågren J.** (2014): Investigations of the relation between gravity and vertical displacement change rates in formerly glaciated areas. NKG 17th General Assembly, September 1–4 2014, 2 pages, Göteborg, Sweden.

Persson C.-G. (2010): Nya HMK. In Elfström (ed.): Program Dokumentation, SKMF MätKart 10, May 19–21 2010, pp. 61–63, Kalmar, Sweden (in Swedish).

Persson C.-G. (2011): GUM – Guide to the Expression of Uncertainty in Measurement – and its possible use in geodata quality assessment. EuroGeographics Q-KEN Working Group Meeting, October 25 2011, Riga, Latvia.

Poutanen M. & **Steffen H.** (2013): Geodetic observations and land uplift at Kvarken archipelago and High Coast UNESCO World Heritage area. In Kvarken Council Report – cooperation between scientists and managers, 7 pages.

Sarib R. & **Lilje M.** (2014): GNSS CORS networks and linking to ITRF. In Blick (ed.): Reference frames in practice manual. FIG Publication No 64, pp. 47–49, Copenhagen, Denmark.

Scherneck H.-G., **Engfeldt A.**, **Olsson P.-A.**, Timmen L. (2014): Five years of gravity measurement at Onsala Space Observatory: The absolute scale. NKG 17th General Assembly, September 1–4 2014, Göteborg, Sweden.

Schwieger V. & **Lilje M.** (2013): Innovative and cost effective spatial positioning. FIG Working Week 2013, May 6–10 2013, 16 pages, Abuja, Nigeria.

Simpson M. J. R**,** Nilsen E. Ø., Breili K., Kierulf H. P., **Steffen H.**, Ravndal O. R. (2014): NKG201xGIA – a model of glacial isostatic adjustment for Fennoscandia. NKG 17th General Assembly, September 1–4 2014, 2 pages, Göteborg, Sweden.

Steffen H., Barletta V. R., Kollo K., Milne G. A., Nordman M., **Olsson P.-A.**, Simpson M. J. R., Tarasov L., **Ågren J.** (2014): NKG201xGIA – a model of glacial isostatic adjustment for Fennoscandia. NKG 17th General Assembly, September 1–4 2014, 2 pages, Göteborg, Sweden.

Sunna J., **Jämtnäs L.**, **Jonsson B.** (2013): Improving RTK positioning with SWEPOS™ – lessons from theory and practice. In Henriksen & Jørgensen (eds): Proceedings of the 16th General Assembly of the Nordic Geodetic Commission. NKG 16th General Assembly, September 27–30 2010, pp. 124–128, Sundvollen, Norway.

Teo C., **Lilje M.**, Mills J. (2013): Critical issues relating to the integration of land and marine geospatial information. UN-GGIM[52] Third session, July 24–26 2013, Cambridge, Great Britain.

Timmen L., **Engfeldt A.**, Scherneck H.-G. (2014): Observed secular gravity trend at Onsala station with the FG5 gravimeter from Hannover. NKG 17th General Assembly, September 1–4 2014, Göteborg, Sweden (published in Journal of Geodetic Science, 5 (2015) (1), pp. 18–25).

Torres J., Bitenc V., Caporali A., Cruddace P., **Engberg L. E.**, Garayt P., Habrich H. (2010): The contribution of EUREF to Inspire. EUREF 2010 Symposium, June 2–5 2010, Gävle, Sweden.

Veljković Z., Lazić S., **Jivall L.** (2011): Results of the EUREF Serbia 2010 campaign. EUREF 2011 Symposium, May 25–28 2011, 6 pages, Chisinau, Moldova.

Veljković Z., **Jivall L.**, Milenović V., Lazić S. (2011): EUREF Serbia 2010 – a new ETRS 89 realization in Serbia. In Joksic (ed.): Proceedings of papers. First Serbian Geodetic Congress, December 1–3 2011, pp. 190–196, Belgrade, Serbia.

Vestøl O., **Ågren J.**, Oja T., Kall T., Aleksejenko I., Paršeliūnas E., Rüdja A. (2014): NKG2014LU_test – a new empirical land uplift model over Fennoscandia. NKG 17th General Assembly, September 1–4 2014, 2 pages, Göteborg, Sweden.

Ågren J. & Sjöberg L. E. (2014): Investigation of gravity data requirements for a 5 mm-quasigeoid model over Sweden: In Marti (ed.): Gravity, geoid and height systems. IAG Symposia, GGHS 2012, October 9–12 2012, Vol. 141, pp. 143–150, Venice, Italy.

Ågren J., **Engberg L. E.**, **Alm L.**, **Dahlström F.**, **Engfeldt A.**, **Lidberg M.** (2014): Improving the Swedish quasigeoid by gravity observations on the ice of Lake Vänern. In Marti (ed.): Gravity, geoid and height systems. IAG Symposia, GGHS 2012, October 9–12 2012, Vol. 141, pp. 171–178, Venice, Italy.

Ågren J. & Hauska H. (2013): Referenssystem och kartprojektioner. In Harrie (ed.): Geografisk informationsbehandling – teori, metoder och tillämpningar, 6:e omarbetade upplagan, pp. 79–102, Stockholm, Sweden (in Swedish).

Ågren J., Eklundh L., Olsson H., Harrie L., Klang D. (2013): Insamling av geografiska data. In Harrie (ed.): Geografisk informationsbehandling – teori, metoder och tillämpningar, 6:e omarbetade upplagan, pp. 103–138, Stockholm, Sweden (in Swedish).

Ågren J. (2014): NKG Working Group Geoid and height systems – report 2010–2014. NKG 17th General Assembly, September 1–4 2014, Göteborg, Sweden.

[52] UN-GGIM = United Nations Committee of Experts on Global Geospatial Information Management

Lantmäteriet: Other geodetic publications

Ekman M. & **Ågren J.** (2010): Reanalysing astronomical coordinates of old fundamental observatories using satellite positioning and deflections of the vertical. Small Publications in Historical Geophysics, No 21, Summer Institute for Historical Geophysics, Åland Islands. Also in Henriksen & Jørgensen (eds) (2013): Proceedings of the 16th General Assembly of the Nordic Geodetic Commission. NKG 16th General Assembly, September 27–30 2010, pp. 173–179, Sundvollen, Norway.

Ekman M. & **Ågren J.** (2012): A study of Celsius' astronomical latitude determination of the Uppsala observatory using satellite positioning and deflection of the vertical. Small Publications in Historical Geophysics, No 23, Summer Institute for Historical Geophysics, Åland Islands.

Ekman M. & **Ågren J.** (2013): A partial reanalysis of the French arc measurement at the Arctic Circle to prove Newton's theories. Small Publications in Historical Geophysics, No 26, Summer Institute for Historical Geophysics, Åland Islands.

Jansson P. & **Persson C.-G.** (2013): Om osäkerheten i arealbestämningar. Teknisk rapport, TRITA SoM 2013-15, KTH, Stockholm, Sweden (in Swedish).

Jansson P. & **Persson C.-G.** (2014): Uncertainty in area determination. Report, TRITA SoM 2014-14, KTH, Stockholm, Sweden.

Lantmäteriet (2011): Geodesy 2010 – a strategic plan for Lantmäteriet's geodetic activities 2011–2020. 16 pages, Gävle, Sweden.

Lantmäteriet et al. (2013): Geodetisk och fotogrammetrisk mätnings- och beräkningsteknik. 304 pages, Sweden (version 2013-10-28, in Swedish).

Olsson P.-A. (2011): Contribution to the modelling of postglacial gravity change in Fennoscandia. Chalmers Technical report No 44L, Chalmers University of Technology, Göteborg, Sweden.

Olsson P.-A. (2013): On modelling of postglacial gravity change. Doktorsavhandlingar vid Chalmers tekniska högskola, Ny serie Nr 3583, Chalmers University of Technology, Göteborg, Sweden.

Persson C.-G., **Sunna J.**, **Lithén T.** (2014): HMK – Referenssystem och geodetisk mätning. 82 pages, Östersund, Sweden (Version 2013 and Version 2014, in Swedish).

Persson C.-G., **Lithén T., Lönnberg G., Svärd T.** (2014): HMK – Introduktion. 25 pages, Östersund, Sweden (Version 2013 and Version 2014, in Swedish).

Persson C.-G., Lithén T., Lönnberg G., Svärd T. (2014): HMK – Geodatakvalitet. 69 pages, Östersund, Sweden (Version 2014, in Swedish).

Persson C.-G. (ed.) (2014): HMK – Ordlista och förkortningar. 26 pages, Östersund, Sweden (Version 2013, Version juli 2014 and Version december 2014, in Swedish).

List of published geodetic papers 2010–2014 – HiG, the University of Gävle

HiG, the University of Gävle: International journals (selection of articles)

Bagherbandi M. (2012): Global earth isostatic model using smoothed Airy-Heiskanen and Vening Meinesz hypotheses. Earth Science Informatics, 5 (2), pp. 93–104.

Bagherbandi M. & Sjöberg L. E. (2012): A synthetic Earth gravity model based on a topographic-isostatic model. Studia Geophysica et Geodaetica, 56 (4), pp. 935–955.

Bagherbandi M. & Sjöberg L. E. (2012): Modelling the density contrast and depth of the Moho discontinuity by seismic and gravimetric-isostatic methods with an application to Africa. Journal of African Earth Sciences, 68, pp. 111–120.

Bagherbandi M., Tenzer R., Sjöberg L. E., Novak P. (2013): Improved global crustal thickness modelling based on the VMM isostatic model and non-isostatic gravity correction. Journal of Geodynamics, 66, pp. 25–37.

Bagherbandi M., Tenzer R., Sjöberg L. E. (2014): Moho depth uncertainties in the Vening-Meinesz Moritz inverse problem of isostasy. Studia Geophysica et Geodaetica, 58 (2), pp. 227–248.

Liu Z., Koyi H. A., Swantesson J. O. H., Nilfouroushan F., **Reshetyuk Y.** (2013): Kinematics and 3-D internal deformation of granular slopes: analogue models and natural landslides. Journal of Structural Geology, 53, pp. 27–42.

Mårtensson S.-G., **Reshetyuk Y.**, Jivall L. (2012): Measurement uncertainty in network RTK GNSS-based positioning of a terrestrial laser scanner. Journal of Applied Geodesy, 6 (1), pp. 25–32.

Mårtensson S.-G. & **Reshetyuk Y.** (2014): Noggrann och kostnadseffektiv uppdatering av DTM med UAS för BIM. Technical Report, 2015:030, 52 pages, Trafikverket, Borlänge, Sweden (in Swedish).

Reshetyuk Y. (2010): Direct georeferencing with GPS in terrestrial laser scanning. ZfV – Zeitschrift für Geodäsie, Geoinformation und Landmanagement, 135 (3), pp. 151–159.

Reshetyuk Y. (2010): A unified approach to self-calibration of terrestrial laser scanners. ISPRS[53] Journal of Photogrammetry and Remote Sensing, 65 (5), pp. 445–456.

Reshetyuk Y. & **Mårtensson S.-G.** (2014): Terrestrial laser scanning for detection of land fill gas: a pilot study. Journal of Applied Geodesy, 8 (1), pp. 87–96.

Sjöberg L. E. & **Bagherbandi M.** (2013): A study on the Fennoscandian postglacial rebound as observed by present-day uplift rates and gravity field model GOCO02S. Acta Geodaetica et Geophysica, 48 (3), pp. 317–331.

[53] ISPRS = International Society for Photogrammetry and Remote Sensing

List of published geodetic papers 2013–2014 – University West (UW)

University West (UW): International journals (peer-reviewed publications)

Eshagh M. (2013): On the reliability and error calibration of some recent Earth's gravity models of GOCE with respect to EGM08. Acta Geodaetica et Geophysica Hungarica, 48 (2), pp. 199–208.

Eshagh M. (2013): An integral approach to regional gravity field refinement using Earth gravity models. Journal of Geodynamics, 68, pp. 18–28.

Eshagh M. & Ghorbannia M. (2013): The use of Gaussian equations of motions of a satellite for local gravity anomaly recovery. Advances in Space Research, 52 (1), pp. 30–38.

Eshagh M. & Ebadi S. (2013): Geoid modelling based on EGM08 and the recent Earth gravity models of GOCE. Earth Science Informatics, 6, pp. 113–125.

Eshagh M. (2013): Numerical aspects of EGM08-based geoid computations in Fennoscandia regarding the applied reference surface and error propagation. Journal of Applied Geophysics, 96, pp. 28–32.

Eshagh M. (2014): A theoretical study on terrestrial gravimetric data refinement by Earth gravity models. Geophysical Prospecting, 62, pp. 158–171.

Eshagh M. (2014): Determination of Moho discontinuity from satellite gradiometry data: linear approach. Geodynamics Reserach International Bulletin, 1 (2), pp. 1–13.

Eshagh M. (2014): From tensor to vector of gravitation. Artificial Satellites, 49 (2), pp. 63–80.

Eshagh M. (2014): From satellite gradiometry data to the sub-crustal stress due to the mantle convection. Pure and Applied Geophysics, 171, pp. 2391–2406.

Eshagh M. (2014): Integral development of Vening Meinesz-Moritz formula for local determination of Moho discontinuity with applications in Iran. Geodynamics Research International Bulletin, 2 (3), pp. I–IX.

Eshagh M. & Ebadi S. (2014): A strategy to calibrate errors of Earth gravity models. Journal of Applied Geophysics, 103, pp. 215–220.

Eshagh M. & Bagherbandi M. (2014): Combined Moho estimators. Geodynamics Reserach International Bulletin, 1 (3), pp. 1–11.

Eshagh M. & Ghorbannia M. (2014): The effect of the spatial truncation error on the variance of gravity anomalies derived from inversion of satellite orbital and gradiometric data. Advances in Space Research, 54 (2), pp. 261–271.

Nozari M. & Eshagh M. (2014): An alternative approach to Eulerian Pole determination and unification of velocity fields of tectonic motions. Tectonophysics, 617, pp. 79–87.

University West (UW): Conference proceedings and compilation works

Alizadeh K. M. A. & Eshagh M. (2014): Optimization of Lilla Edet Land Slide GPS Monitoring Network. NKG 17th General Assembly, September 1–4 2014, Göteborg, Sweden (poster presentation).

Ebadi S. & Eshagh M. (2014): A method for calibrating errors of the Earth gravity models. Geomatics 93 conference, May 24–25 2014, Tehran, Iran (in Persian).

Ebadi S. & Eshagh M. (2014): Investigations into the recent Earth's gravity models of GOCE in comparison with EGM08. Geomatics 93 conference, May 24–25 2014, Tehran, Iran (in Persian).

Ebadi S. & Eshagh M. (2014): Precise geoid determination based on the recent developments in the gravimetric data. Geomatics 93 conference, May 24–25 2014, Tehran, Iran (in Persian).

Eshagh M. (2013): A discussion on the use of EGM08 and GOCE for geoid modelling in Fennoscandia. IAG Scientific Assembly, September 1–6 2013, Potsdam, Germany (poster presentation).

Eshagh M. (2014): On the relation between Moho and sub-crustal stress induced by mantle convection. NKG 17th General Assembly, September 1–4 2014, Göteborg, Sweden (poster presentation).

Eshagh M. & Tenzer R. (2014): Sub-crustal stress induced by mantle convection from gravity data. In Jin & Barzaghi (eds.): IGFS[54] 2014, IAG Symposia, 3rd IGFS General Assembly July 1–6 2014, Vol. 144, Shanghai, China (in press).

Eshagh M. & Alizadeh K. M. A. (2014): Two-epoch optimal design of displacement monitoring networks. NKG 17th General Assembly, September 1–4 2014, Göteborg, Sweden (poster presentation).

Eshagh M. & Romeshkani M. (2014): Determination of sub-crustal stress due to mantle convection using GOCE gradiometric data. UNESCO 5th GOCE users workshop, November 25–28, Paris, France (poster presentation).

Fernandez J., Tiampo K. F., Rundle J. B., Eshagh M. (2014): Geodynamical studies using integrated gravity studies. AGU[55] Fall Meeting, December 15–19 2014, San Francisco, USA (abstract).

Ghorbannia M. & Eshagh M. (2014): Evaluation of Gaussian equations of motion of a satellite for local Earth's gravity field recovery over Iran. Geomatics 93 conference, May 24–25 2014, Tehran, Iran (in Persian).

Gu X., Tenzer R., Eshagh M., Hwang C. (2014): Crustal stress in Taiwan. In Jin & Barzaghi (eds.): IGFS 2014, IAG Symposia, 3rd IGFS General Assembly, July 1–6 2014, Vol. 144, Shanghai, China (in press).

Tenzer R., Eshagh M., Shen W. (2014): Distribution of the sub-crustal stress in central Eurasia. In Jin & Barzaghi (eds.): IGFS 2014, IAG Symposia, 3rd IGFS General Assembly July 1–6 2014, Vol. 144, Shanghai, China (in press).

Tenzer R. & Eshagh M. (2014): Stress field along continent-to-continent collision zones. 5th International workshop on multi-observations and interpretations of Tibet, Xinjiang and Siberia (TibXS), August 10–15, 2014, Guiyang, China (oral presentation).

[54] IGFS = International Gravity Field Service

[55] AGU = American Geophysical Union

NKG2014LU_test –
A new empirical land uplift model over Fennoscandia

Olav Vestøl, **Jonas Ågren, Tõnis Oja, Tarmo Kall, Ivars Aleksejenko, Eimuntas Paršeliūnas, Andres Rüdja**
Norwegian Mapping Authority
3507 Hønefoss, Norway
e-mail: olav.vestol@statkart.no

Introduction

The land uplift model NKG2005LU is almost 10 years old, and has served as an official model in the Nordic countries in this time period. We now have more data available to improve and test this model: GNSS-derived velocities from longer time series and from more stations, repeated leveling from Denmark and the Baltic countries, and an increased number of sea-level rates from tide gauges in Norway. We have also new and better GIA-models available.

The new model was computed in a project of the Working Group of Geoid and Height Systems with Olav Vestøl as project leader. We have called the model NKG2014LU_test to indicate it is a first attempt towards the new official land uplift model that will eventually replace NKG2005LU. The NKG2014LU_test model will now be critically tested by the other groups of the NKG.

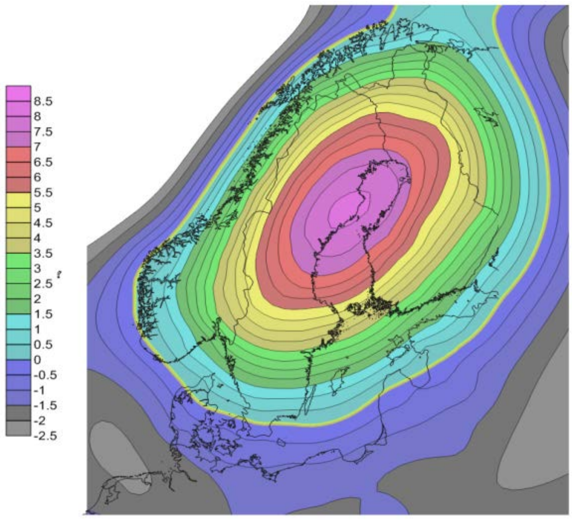

Figure 1. *NKG2014LU_test. The apparent land uplift (mm/year). The contour interval is 0.5 mm/year.*

The calculation

The model is calculated in more or less the same way as NKG2005LU by first using least square collocation where the land uplift is estimated as trend and signals. (Vestøl 2006; Ågren & Svensson 2007)

This strictly empirical model is then compared with the GIA-model, and a difference model (residual surface) is calculated by using least square collocation a second time. NKG2014LU_test is finally obtained by correcting the GIA-model with the difference model.

In contrast to NKG2005LU no extra smoothing of the strictly empirical model was applied, and the latter is almost identical to NKG2014LU_test in the area covered with observations. Far away from the observations, the GIA-model is totally dominating, as before.

The GIA-model used for NKG2005LU was computed by Kurt Lambeck in 1998. Now a new GIA model called i82_g5102 was used, computed by Holger Steffen as a collaboration within the NKG Working Group of Geodynamics. It is based on a new ice model of Lev Tarasov. For further information see Steffen et al. (2014).

The result

As for NKG2005LU, two versions of the model are calculated; an apparent (APP) and an absolute (ABS). The first one gives the rise relative to mean sea level for the reference time period 1892-1991, while the latter gives the rise relative to the geometric reference frame ITRF2008. Furthermore, the following approximate linear relationship is estimated to relate these different types of land uplift:

$$ABS = (APP + 1.27) \times 1.079$$

To use a linear model is obviously an approximation, which we will need to reconsider for future models. However, at the present time, we judge that this approximation is not significant, considering the errors of the now available observations, and by comparing with results from GIA model computations.

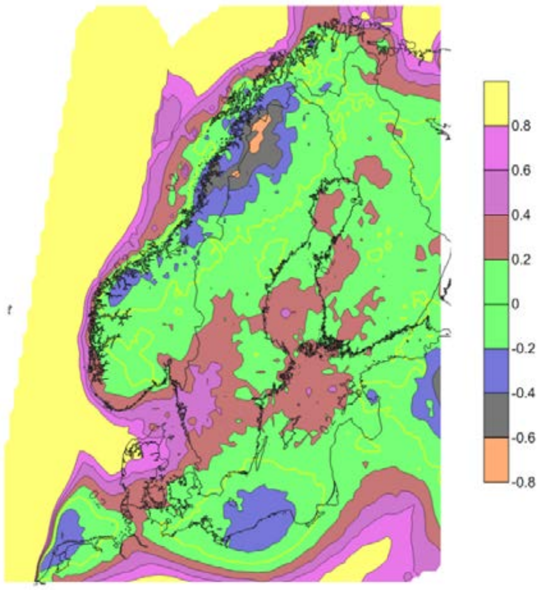

Figure 2. *The difference between the models (mm/year). NKG2014LU_test ÷ NKG2005LU. The contour interval is 0.2 mm/year. The biggest differences are in Denmark and north in Sweden near the Norwegian border.*

References

Ågren, J. & Svensson, R., 2007. *Postglacial Land Uplift Model and System Definition for the New Swedish Height System RH 2000*, Lantmäteriet. Available at: http://www.lantmateriet.se/templates/LMV_Page.aspx?id=2688 [Accessed September 4, 2012].

Lambeck, K., Smither, C. & Ekman, M., 1998. Tests of glacial rebound models for Fennoscandinavia based on instrumented sea- and lake-level records. *Geophysical Journal International*, 135(2), pp.375–387.

Vestøl, O., 2006. Determination of postglacial land uplift in Fennoscandia from leveling, tide-gauges and continuous GPS stations using least squares collocation. *Journal of Geodesy*, 80(5), pp.248–258.

Steffen H., Barletta V. R., Kollo K., Milne G.A., Nordman M., Olsson P.A., Simpson M.J.R, Tarasov L., Ågren J. (2014) NKG201xGIA – a model of glacial isostatic adjustment for Fennoscandia. Proceedings of the 17th General Assembly of the Nordic Geodetic Commission, Göteborg, Sweden, September 1–4, 2014

The effects of a helium contaminated rubidium cell and reduced drop distances on absolute gravity estimates – first results

Kristian Breili* (1, 2) and Ove Christian Dahl Omang (1)
(1) Geodetic Institute, Norwegian Mapping Authority, Kartverksveien 21, 3511 Hønefoss, Norway.
(2) Department of Mathematical Sciences and Technology, Norwegian University of Life Sciences, P.O. Box 5003, 1432 Ås, Norway.
*Corresponding author; e-mail: kristian.breili@kartverket.no

Introduction

Absolute gravimeters (AG) of the FG5-type (Niebauer et al. 1995) and superconducting gravimeters (SG) (Goodkind 1999) are complex instruments where systematic errors are easily introduced. We address two instrumental problems met when conducting repeated AG-campaigns during the winter and summer 2013 in Ny-Ålesund, Svalbard. The two problems are: (1) helium contaminating the rubidium cell providing the frequency of the AG-clock; and (2) reduced drop distances. The problems are discussed with a view to the record from a collocated SG.

Data and analysis

The AG-campaigns were processed with standard methods using the g-software provided by Micro-g LaCoste. Each drop was applied corrections for Earth tides, ocean tide loading, atmospheric loading (ATL), and polar motion. For the ATL-corrections, we used an admittance factor of -0.42 µgal/hPa (1 µgal=10^{-8} m/s²) adopted from Sato et al. (2006). The SG-data were applied the same types of corrections as used for the AG-campaigns. In addition, a correction of -2.37±0.32 µgal/yr was applied in order to compensate for the linear drift of the SG (Omang and Kierulf, 2011).

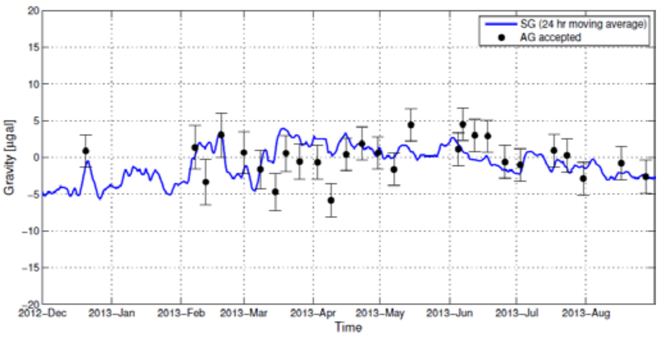

Fig. 1. *Averages of the AG-campaigns (black markers) with bars representing the total uncertainty and the SG-record (blue line).*

Figure 1 shows the AG-campaigns together with the SG-record. The AG-SG-residuals range from -5.9 to 3.7 µgal with a standard deviation of 2.8 µgal. Several AG-SG residuals are larger than one standard deviation, especially during February, March, and April. For these months, the SG-record shows increased variation and the AG-campaigns do not track the same signals. This indicates that instrumental effects disturb either the AG- or the SG-observations.

The effect of helium contamination

The AG was located in the same room as the SG which leaks about 0.6 liters of liquid helium per week. The helium molecules have the ability to penetrate into the rubidium cell that provides the frequency of the AG-clock. The effect is a frequency change. If not compensated, a frequency error of 0.01 Hz implies a gravity error of 2 µgal, as a rule of thumb. Hence, the frequency of the rubidium cell should be regularly calibrated.

Calibrations towards a hydrogen maser in Ny-Ålesund revealed that the frequency of the rubidium cell changed by 0.02 Hz within approximately 4 months. Note that later calibrations indicate that the frequency started to return back to its old value after the instrument was taken back to an atmosphere with normal helium concentration (see Fig. 2).

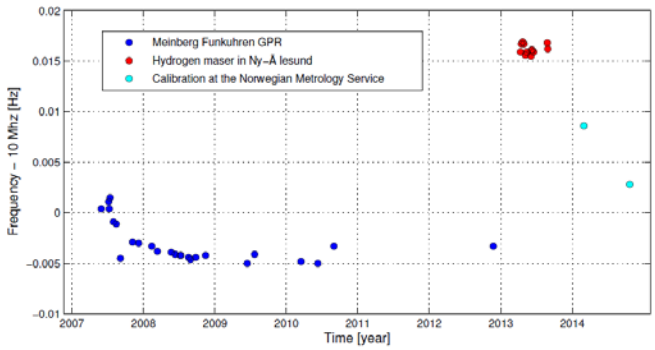

Fig. 2. *Calibrated frequencies of the FG5-226 clock.*

Unfortunately, we were not able to calibrate the frequency in between 23 November 2012 and 11 April 2013. Therefore, we use frequencies interpolated between these two calibrations for the first eleven campaigns. Figure 3 illustrates the range of gravity estimates obtainable for each campaign by varying the frequency between the old (lower end) and the new (upper end) calibrated values. It is clear that the large AG-SG residuals are not an effect due to lack of calibrations. Actually, changing the frequency will increase the AG-SG residuals for several of these campaigns.

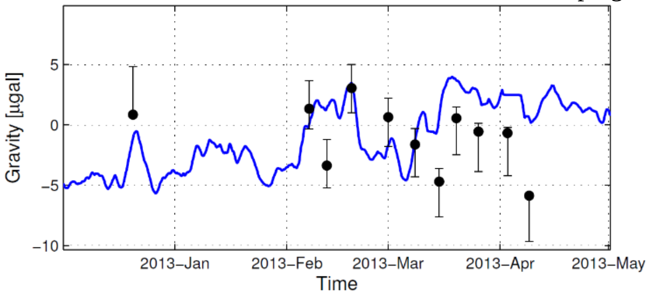

Fig. 3. *The bars indicate the gravity range obtainable by varying the clock-frequency between the old and new value.*

The effect of reducing the distance of each drop

The second problem is related to the chart lifting the proof-mass to its initial position before each drop. When a drop is triggered, the chart accelerates faster than gravity and the proof-mass will be in free-fall until the chart brakes and catches the proof-mass gently. However, for many of the campaigns in Ny-Ålesund, the chart did not pull away from the proof-mass sufficiently fast. As a consequence, the separation between the chart and the proof-mass was reduced, leading to shorter drops than normal. The origin of this problem is presently not fully understood.

Fortunately, the drops can still be processed by adjusting the number of fringes used to estimate gravity. We opt to use the fringes 25 to 372 for all campaigns, i.e. time/distance pairs between 40 and 160 ms. This configuration ensured at minimum 20 drops per set and 10 sets per campaign.

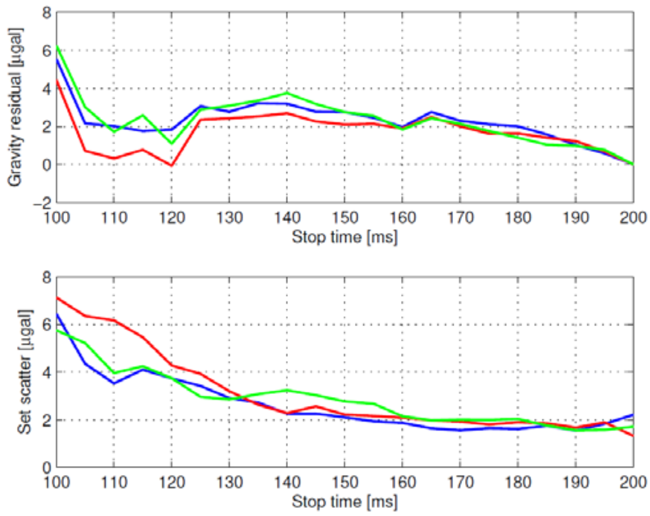

Fig. 4. *Gravity (upper) and set scatter (lower) for three campaigns estimated for a range of stop times.*

Using different windows of fringes, it is possible that biases in the gravity estimates are introduced. This is crucial especially for drops with structured fringe-residuals (Charles and Hipkin 1995). In addition, there is a chance that the set of drops in each campaign may change. Typically, the set scatter of the campaigns will increase, because less time/distance pairs are included in the estimations. However, increased noise level can be compensated by increasing the number of drops/sets.

Effects of using different fringe-windows are illustrated in Fig. 4 for three campaigns in Ny-Ålesund. As long as the stop time is beyond 150 to 160 ms, the change in the campaign average is within 2-3 µgal and the set scatter stays around 2 µgal. This indicates that these campaigns do not have structured fringe residuals, but we do not rule out possible structured fringe residuals in other campaigns from Ny-Ålesund. Analyses of stations at the mainland of Norway (not shown here) indicate that the effect can be much more pronounced than for the three examples shown in Fig. 4

Concluding remarks

The assessment of the uncertainty introduced by interpolating the frequency of the AG-clock and the modest gravity change due to reduced drop distances imply that the origin of the large AG-SG residuals is not revealed at present. Future work will address instrumental effects in the SG-record. Among others, it is known that changes in the external temperature may influence on the electronics of the SG (Goodkind 1999).

Acknowledgement

The authors thank the crew of the Norwegian Mapping Authority in Ny-Ålesund for conducting most of the AG-campaigns and in kind contributions. Jon Glenn Gjevestad and Bjørn Ragnvald Pettersen at the Norwegian University of Life Sciences are acknowledged for providing the FG5-226 during the winter and summer 2013.

References

Charles. K. & Hipkin R. (1995). Vertical gradient and datum height corrections to absolute gravimeter data and the effect of structured fringe residuals. *Metrologia*, **32**, 193-200.

Goodkind, J.M. (1999). The superconducting gravimeter. *Review of Scientific Instruments*, **70**(11), 4131-4152.

Omang, O.C.D. & Kierulf, H.P. (2011). Past and present-day ice mass variation on Svalbard revealed by superconducting gravimeter and GPS measurements. *Geophysical Research Letters*, **38**, L22304.

Niebauer, T.M., Sasagawa, G.S., Faller, J.E., Hilt, R., and Klopping, F. (1995). A new generation of absolute gravimeters, *Metrologia*, **32**, 159-180.

Sato, T., Boy, J.P., Tamura, Y., Matsumoto, K., Asari, K., Plag, H.P., & Francis, O. (2006). Gravity tide and seasonal gravity variation at Ny-Ålesund, Svalbard in Arctic, *Journal of Geodynamics*, **41**, 234-241.

Five years of gravity measurement at Onsala Space Observatory: The absolute scale

Hans-Georg Scherneck[1], Andreas Engfeldt[2], Per-Anders Olsson[2], Ludger Timmen[3]

1. Chalmers University of Technology, Earth and Space Sciences, Gothenburg, and Onsala Space Observatory, Sweden. Tel. +46-31-772 5556, email hgs@chalmers.se

2. Lantmäteriet, Gävle, Sweden

3. Leibniz University Hannover, Institut für Erdmessung, Hannover, Germany

Introduction

Not many Absolute Gravity (AG) stations are equipped with a stationary, continuously operating gravimeter. Since June 2009, a Superconducting Gravimeter (SG), GWR #054, has been recording gravity change at Onsala Space Observatory. In this article we describe how we make use of this facility in application to AG campaigns (Timmen et al.,2015). Since June 2009, seven campaigns have taken place with instrument FG-5 #220 (Hannover) and FG-5 #233 (Lantmäteriet). Campaigns at Onsala are usually extended in time in order to calibrate the SG using the tidal variations during several consecutive days, perferably at periods of spring tides. In reverse, analysis of the SG recordings, now stretching more than 40,000 hours, provides AG data processing with robust and accurate parameters for the reduction of tides, atmospheric attraction and loading, and polar motion.

The SG sensor shows a drift behaviour. However, we can show that, when environmental effects and tides have been fitted to the gravity series, the residual consists of a stochastic noise component of on the order of 5 nm/s^2, superimposed on a largely uniform linear drift curve. Exponential decay features exist, one at the start of the operation and one after a repair of a sensor card. The rate of linear drift changed significantly at this event. An offset may occur at times of cold-head exchange, like in autumn 2013, but in each branch of the slope no additional features appear to require further attention. In Fig, 1 we show the drift signal together with the residual and the limits for plus-minus one standard-deviation of the drift parameters.

Reducing the AG observations has the goal to arrive at consistent mean values for sets of AG measurements freed from predictable time dependent influences. A long-term set of such means is the basis for determining the rate of change of gravity at observing stations.

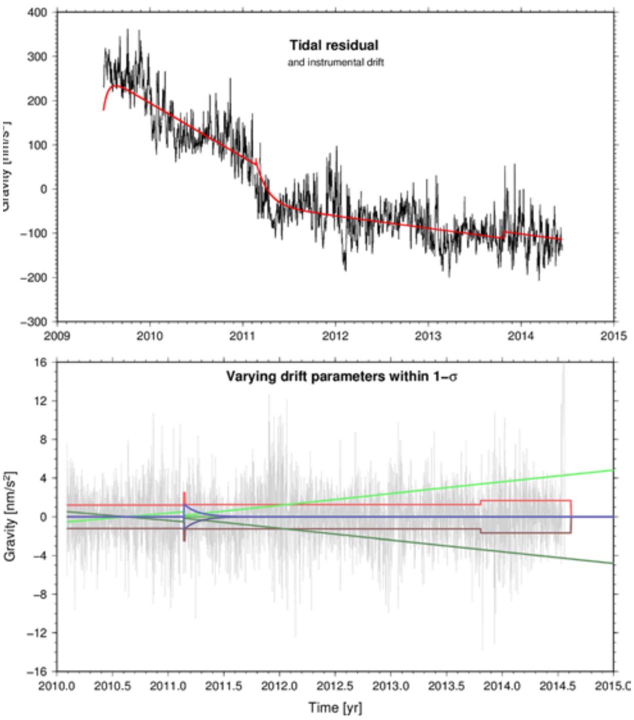

Fig 1. *Top: "Tidal residual" has only tides removed; atmospheric effects are fully visible. The red line shows the adjusted drift curve. Bottom: grey curve shows total residual (extended model). Ranges bounded by coloured lines explore the standard-deviations of the drift parameters.*

Direct reduction of AG-data

The SG's residual's rarely exceeding a range of ±5 nm/s^2 encourages us to directly use the SG recordings for reducing the AG observations after removing the SG's drift curve. Some technical terms used in AG data acquistion will be referred to below.

A campaign consists of a number of *projects* between which an instrument's orientation or the platforms are swapped. In each project order of 1000 free-fall *drops* are performed. The drop measurements are grouped in *sets*. Between sets pauses are scheduled that allow servicing.

Findings

In particular, the annual cycle appears to host a major perturbation. Despite a persistent problem of covariance with the polar motion that still requires additional years of observation for constraining the effect at the 10 nm/s^2 level, it seems likely that the annual wave at Onsala appears at a factor of 2 of the solar gravity tide. In one particular solution of the SG-analysis (*Scherneck*, this volume) the polar motion coefficient was determined near the expected value of 1.164±0.007 while the Sa coefficient was 2.38±0.02. The second harmonic, Sqa, also contains an large additional co-tidal signal. In lieu of ground water records at the station and assessment of the potential fluid elevation during the growing season in the forest nearby we currently cannot offer an explanation.

What we do find with certainty are drift terms in the AG-sets, changing from project to project, see the red symbols in Fig. 2. Since we did not re-verticalize the AG metres during a project (in order to keep the records free from offsets and thus avoid covariance with the SCG-calibration factors to be determined), these drift terms are greater in our series than in routineous AG-campaigns when re-verticalisation is more closely attended to.

The extended set of empirical tide parameters from the SG analysis (loading tides intrinsically included) is trivial to include in the AG reduction. Instead, the major gain we expected from the direct SG-reduction method is a bypassing of atmospheric attraction and loading effects, entangled with the Kattegat sea level, that make the whole situation difficult to capture in a parsimonious set of model parameters. These perturbations have time scales of days or longer. And by the same token, any unidentified perturbation will also be removed. However, as the SG data analysis shows, there is very little long-term signal left in particular with the extended SG observation model. The remainder amounts to an RMS of on the order of 8 nm/s^2 (taken from 42,000 hourly samples using the simpler of the two models, see *Scherneck*, this volume). Figure 2 shows a comparison of reduced AG results derived with the standard and the direct-SG method.

Figure 3 hints at the performance of three methods of reducing atmospheric effects in gravity plottet against each other (hourly values for the time span from Feb. 2010 to Oct. 2014). The method labeled “Atmacs by-the-book” uses the published values (correcting an inadvertant sign flip in the global loading channel); the “SG-mix” designates the linear combination from the standard analysis of the SC data. The coarse method, multiplying station pressure with 3.0 nm/s^2/hPa, falls on the unity slope with the SG-mix, while the unmodified Atmacs data appears to overpredict the effect. Kattegat nontidal loading appears to play a much less powerful role.

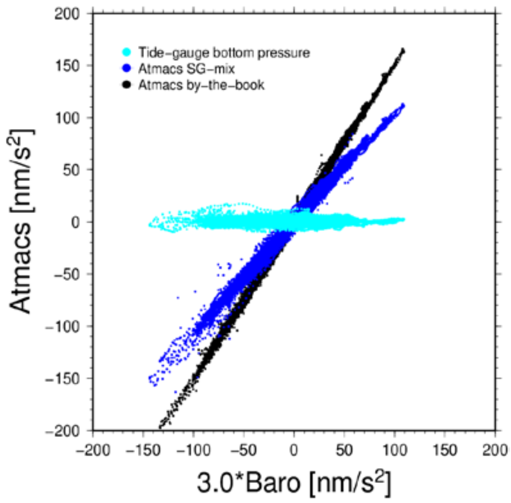

Fig. 3 – *Barometric corrections plotted against each other. “SG-mix” - Atmacs model components remixed by fit to the SG records (standard analysis);includes the tide gauge bottom pressure proxy. The bottom pressure plotted alone shows that its impact is one order of magnitude less than the atmospheric terms. Limitation of performance of the local barometer method at the ±15 nm/s^2 level can be concluded from the dark-blue set.*

Conclusions

Owing to the success of the data analysis of the Superconducting gravimeter (SG) at Onsala, we are confident that, with the exception of instrumental drift, the gravity variations at this site are accurately captured with empirical models of perturbations in the environment. The outcome is a sensible test of the Atmacs model for atmospheric effects (http://atmacs.bkg.bund.de/) and a high-resolution tide prediction model. Direct reduction of Absolute gravity measuments (AG) with SG data offers an – in principle – more rigorous method. However, considerable spread remains in the AG results, exceeding the typical repeatability limits of AG (± 20 nm/s^2).

Reference: L. Timmen, A. Engfeldt, H-G. Scherneck, 2015. Observed secular gravity trend at Onsala station with the FG5 gravimeter from Hannover; *J.Geod.Sc.*, submitted.

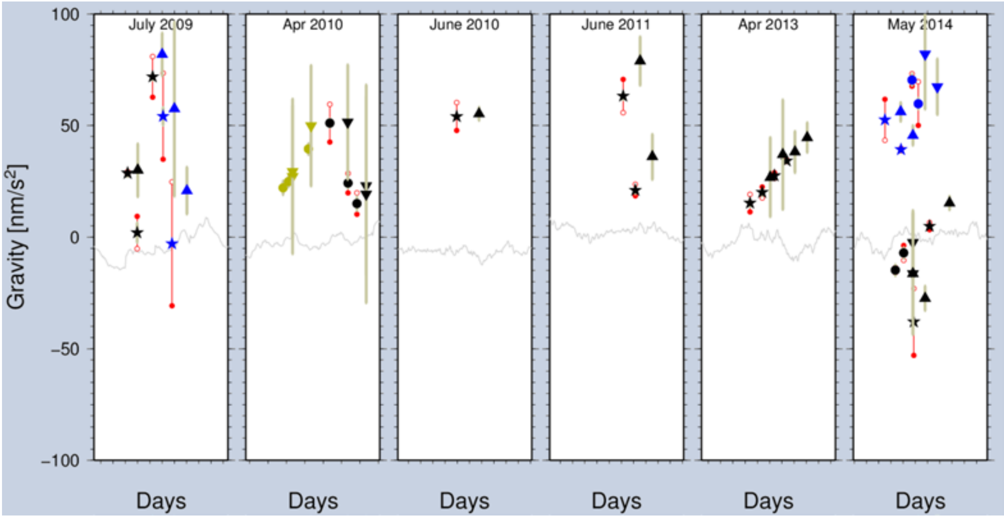

Fig. 2 – *Comparison standard AG data reduction (S) versus direct subtraction of drift-freed SG (D). Symbols:*
*FG5 #233: * S, ▲ D.*
FG5 #220: ● S, ▼ D.
Colours code monuments, black for AA, blue for AC and yellow for AS (the old platform). Platform tie offset AS-AA has been removed. The D-symbols are offset to the right.
Red: ○ Slope begin, ● end.
Grey bars: 1 std. deviation.
Grey line: SG residual of standard analysis.

NKG201xGIA – a model of glacial isostatic adjustment for Fennoscandia

Holger Steffen[1], Valentina R. Barletta[2,3], Karin Kollo[4], Glenn A. Milne[5], Maaria Nordman[6], Per-Anders Olsson[1], Matthew J.R. Simpson[7], Lev Tarasov[8], Jonas Ågren[1]

[1]Lantmäteriet, Gävle, Sweden.
[2]DTU Space, Lyngby, Danmark
[3]currently at: Ohio State University, Columbus, USA
[4]Estonian Land Board, Tallinn, Estonia & Aalto University, Espoo, Finland
[5]University of Ottawa, Ottawa, Canada
[6]Finnish Geodetic Institute, Masala, Finland
[7]Kartverket, Hønefoss, Norway
[8]Memorial University of Newfoundland, St John's, Canada
e-mail: holger.steffen@lm.se, vr.barletta@gmail.com, karin.kollo@maaamet.ee, gamilne@uottawa.ca, maaria.nordman@fgi.fi, Per-Anders.Olsson@lm.se, Matthew.Simpson@kartverket.no, lev@mun.ca, Jonas.Agren@lm.se

Introduction

Glacial isostatic adjustment (GIA) is a dominant process in northern Europe, which is observed with several geodetic and geophysical methods. This process is the dominant source for observed land uplift of about 1 cm/year, which is especially visible at the coastal areas of the Gulf of Bothnia in Finland and Sweden. There, about 700 hectares of new land is rising from the sea every year. People in the area have had to adjust to the changing environment for thousands of years.

GIA affects the establishment and maintenance of reliable geodetic and gravimetric reference networks in the Nordic countries. To support a high level of accuracy in the determination of position, adequate corrections have to be applied with dedicated models.

Currently, there are efforts within a NKG activity towards a model of glacial isostatic adjustment for Fennoscandia. The new model, NKG201xGIA, to be developed in the near future will complement the forthcoming empirical NKG land uplift model, which will substitute the currently used empirical land uplift model NKG2005LU (Ågren & Svensson, 2007). Together, the models will be a reference for vertical and horizontal motion, gravity and geoid change and more. NKG201xGIA will also provide uncertainty estimates for each field.

Current status

Following former investigations, we will base the GIA model on a combination of an ice and an earth model. The selected reference ice model, GLAC, for Fennoscandia, the Barents/Kara seas and the British Isles is provided by Lev Tarasov and co-workers. It is generated with a three-dimensional thermo-mechanically climate-forced model driven by 30 input parameters and calibrated against ice margin information, present-day uplift and relative sea-level records (Tarasov et al., 2012). The Bayesian calibration accounts for uncertainties in the constraints to infer a posterior probability distribution for past ice sheet evolution (Tarasov et al., 2012). This ice model is thus different to commonly used geophysical models such as ICE-5G (Peltier, 2004), which lack glaciological self-consistency and uncertainty estimates.

We combine GLAC with the ice history of North America, Greenland, Patagonia and Antarctica taken from ICE-5G to get a global model that fulfills the sea-level equivalent of about 125 m at about 25 ka BP. As GLAC contains a little bit less ice in northern Europe than ICE-5G, we increase the ice thickness of the remaining ICE-5G ice sheets by 2%.

The first test version of our GIA model presented at the 17th NKG General assembly uses a simple three-layer earth model consisting of a 90 km thick lithosphere and two mantle layers representing the upper and lower mantle subdivided at 670 km depth. Upper and lower mantle viscosity are set to 7×10^{20} and 2×10^{21} Pa s, respectively, which are reasonable averages of earth model VM2, the corresponding earth model of ICE-5G (Peltier, 2004). Other model parameters such as ice and water density, Earth radius, moment of inertia, etc. are taken from the benchmark study by Spada et al. (2011). This earth model, called i82, thus represents a good global approximation.

A first test compares the calculated uplift velocities of this model to recent GPS observations presented in Kierulf et al. (2014). The initial GIA model fits the majority of observations such as from GPS well (Fig. 1). Smaller differences are found for stations in central Norway at the coast, which is suggested to be influenced by other tectonic processes (Kierulf et al., 2014). Overall, our first test model provides a better fit than other combinations of this particular earth model i82 and selected ice models (Fig. 1).

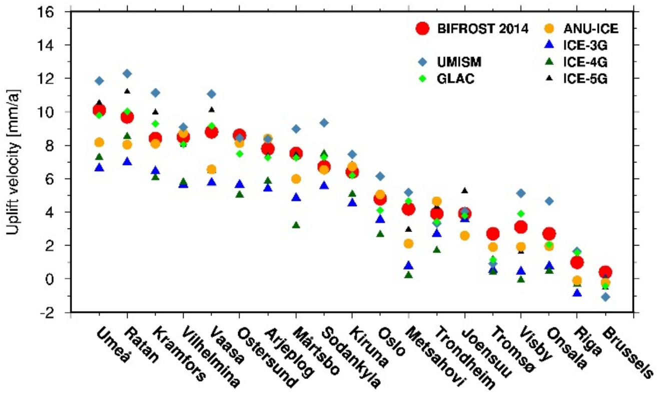

Fig. 1: *Comparison of observed uplift velocities (red dots) at selected GPS stations (Kierulf et al., 2014) to calculated uplift velocities of six combinations of earth model i82 with different ice models. Results of the first test version of our GIA model using GLAC are marked with a green diamond.*

Outlook

In the following years we will continue our mutually beneficial co-operation towards NKG201xGIA with further improved versions of GLAC. Tests of different ice and earth models will be performed based on the expertise of each involved modeler. This includes studies on high resolution ice sheets, different rheologies, lateral variations in lithosphere and mantle viscosity and more. This will also be done in co-operation with scientists outside NKG which help in the development and testing of the model. The immediate next step is to tune a slightly improved GIA model with a levelling/ tide gauge/GPS combination provided by Olav Vestøl and Jonas Ågren, which is likely to result in a new ice-earth model combination. In addition, a relative sea-level database for northern Europe will be compiled and made publicly available in future.

References

Ågren, J., Svensson, R. (2007): Postglacial Land Uplift Model and System Definition for the New Swedish Height System RH 2000. *Reports in Geodesy and Geographical Information Systems Rapportserie, LMV-Rapport* **4**, Lantmäteriet, Gävle.

Kierulf H.P., Steffen H., Simpson M.J.R., Lidberg M., Wu P., Wang H. (2014): A GPS velocity field for Fennoscandia and a consistent comparison to glacial isostatic adjustment models. *J. Geophys. Res.* **119**(8), 6613-6629.

Peltier W.R. (2004): Global glacial isostasy and the surface of the ice-age earth: the ICE-5G (VM2) model and GRACE. *Ann. Rev. Earth Planet. Sci.* **32**, 111–149.

Spada, G., Barletta, V.R., Klemann, V., Riva, R.E.M., Martinec, Z., Gasperini, P., Lund, B., Wolf, D., Vermeersen, L.L.A., King, M.A. (2011): A benchmark study for glacial isostatic adjustment codes. *Geophys. J. Int.* **185**, 106–132.

Tarasov, L., Dyke, A.S., Neal, R.M., Peltier, W.R. (2012): A data-calibrated distribution of deglacial chronologies for the North American ice complex from glaciological modeling. *Earth Planet. Sci. Lett.* **315–316**, 30–40.

Investigations of the relation between gravity and vertical displacement change rates in formerly glaciated areas

Per-Anders Olsson[1], Glenn Milne[2], Hans-Georg Scherneck[3], Jonas Ågren[1]

1. Lantmäteriet, SE-801 82 Gävle, Sweden
2. University of Ottawa, Ottawa, ON Canada
3. Chalmers University of Technology, SE-439 92 Onsala, Sweden

Introduction

The relation between the GIA-induced rate of change of gravity, $\dot{g}$, and vertical displacement of the crust, $\dot{u}$, is important from different aspects. It contains information on the underlying geophysics, and a trustworthy relation also allows to combine observations of $\dot{g}$ and $\dot{u}$ with the prospect to strengthen the overall observational accuracy of the GIA phenomenon.

Several papers have investigated the ratio between $\dot{g}$ and $\dot{u}$, e.g. Wahr et al. (1995), James and Ivins (1998), Fang and Hager (2001), Purcell et al. (2011) and Memin et al. (2012). Common for these are that they present rough estimates of the ratio for areas with present day ice mass variations, like Greenland and Antarctica.

We have studied the relation between $\dot{g}$ and $\dot{u}$ in Fennoscandia and North America, previously glaciated areas, in order to investigate if it can be determined accurate enough for geodetic purposes, if it can be considered linear and if not, how it varies and why. In this extended abstract we present the most important aspects and results of this work. A detailed description and more results can be found in Olsson et al. (2015).

Method

We have used a GIA-model to predict $\dot{g}$ and $\dot{u}$ in Fennoscandia and North America and studied their relation with respect to different earth model parameters, different ice sheet geometry, evolution in time, and local effects (from local GIA-induced sea level variations).

The GIA-model pursues the normal mode approach for a 1-dimensional earth rheology (Peltier 1974, 1976). We solve the sea level equation (originally introduced by Farrell and Clark, 1976) however augmented with time dependent coast line geometry (Mitrovica and Milne, 2003; Kendall et al., 2005) employing the ICE-5G ice history (Peltier, 2004). Load Love numbers are computed from the PREM earth model (Dziewonski and Anderson, 1981) using compressible and incompressible earth rheology and a set of different lithospheric thicknesses and viscosity profiles.

Results

The relation between $\dot{g}$ and $\dot{u}$ was first examined by fitting a linear regression line to predicted rates in Fennoscandia and North America respectively (Fig. 1), such that

$$\dot{g} = C\dot{u} + g_0.$$

The results differ slightly between Fennoscandia and North America due to fact that their ratio depends on the dominant spherical harmonic degree of the load, which is lower in North America than in Fennoscandia owing to the larger extent of the ice load in North America. Different earth model parameters did not affect the results significantly.

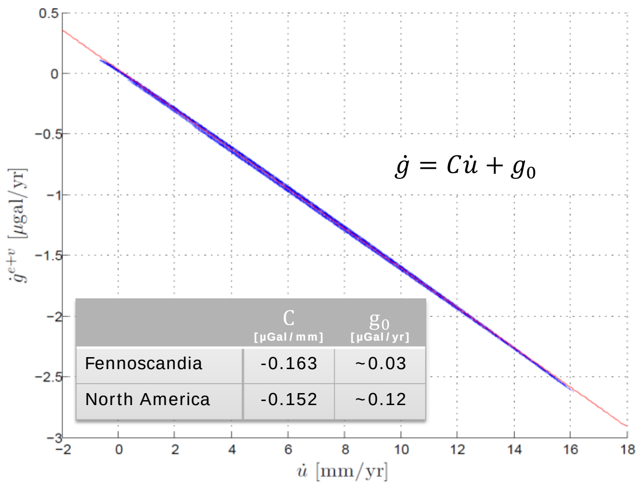

Fig 1. *Linear regression fit between predicted values of $\dot{g}$ and $\dot{u}$.*

The spatial deviation between the linear relation and fully modelled predictions,

$$\epsilon = \dot{g} - (C\dot{u} + g_0),$$

is shown in Fig. 2.

Local effects, such as direct attraction and high degree elastic deformation from nearby GIA-induced sea level variations, were investigated. They were found to be inefficient for changing the results above significantly other than in extreme cases, like when the gravity station was located closer to the sea than 10 times the height of the station.

We also studied how the ratio between $\dot{g}$ and $\dot{u}$ has evolved in time since the last glacial maximum. It turned out that the ratio changes significantly with time. This is partly due to the initial elastic contribution from the melting ice but also the pure viscous ratio change with time which indicate that ratios estimated for areas with present day ice melting (see the introduction above) may not be valid for areas like Fennoscandia and North America where the ice is since long gone.

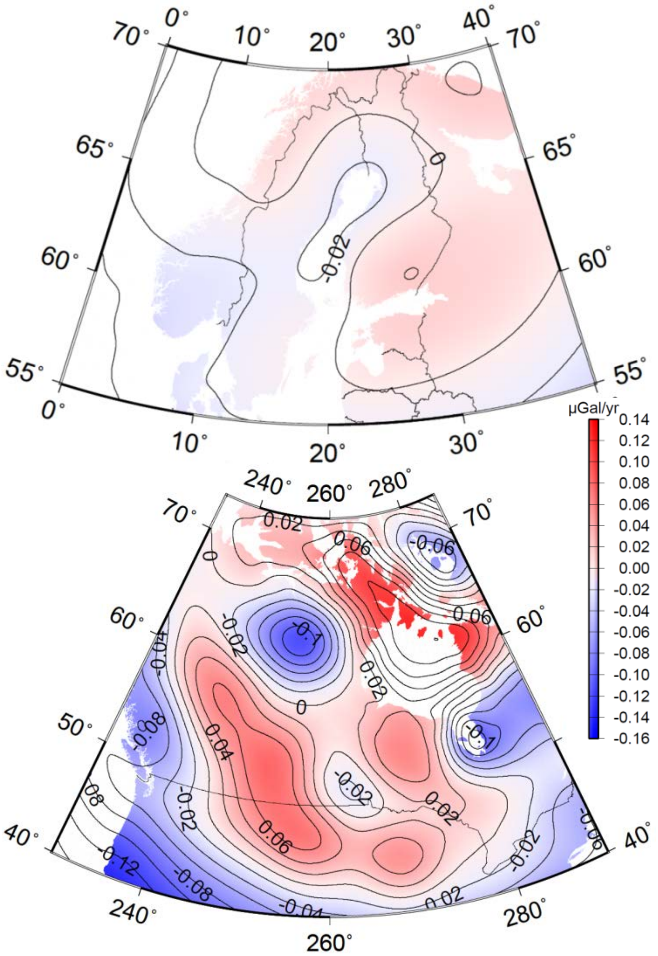

Fig 2. *Residuals between $\dot{g}$ estimated with a linear relation to $\dot{u}$ (see Fig. 1) and explicitly modelled $\dot{g}$.*

Summary and conclusions

We have shown that using the normal mode approach with a 1-dimensional earth rheology the predicted relation between $\dot{g}$ and $\dot{u}$ is close to linear within Fennoscandia (-0.163 µGal/mm) and North America (-0.152 µGal/mm) but differs slightly between the two regions. The dependence on chosen earth model parameters is weak.

Using the linear relation to predict $\dot{g}$ from $\dot{u}$ differs less than 0.04 µGal/yr in Fennoscandia and less than 0.17 µGal/yr in North America compared to explicitly modelling $\dot{g}$. This can be compared to an expected observational accuracy of 0.1 µGal/yr after 15-25 years of annual or semi-annual absolute gravity observations (Van Camp et al., 2005).

For stations located very close to the sea (less than 10 times the height of the station) the direct attraction from nearby sea level variations has to be treated with care.

References

Fang M., Hager B.H. (2001). Vertical deformation and absolute gravity. *Geophys. J.Int.* 146 (2), 539–548.

Farrell W.E., Clark J.A. (1976). On postglacial sea level. *Geophys. J. R. Astr. Soc.* 46, 467–667.

James T., Ivins E. (1998). Predictions of Antarctic crustal motions driven by present-day ice sheet evolution and by isostatic memory of the Last Glacial Maximum. *J. Geophys. Res.* 103 (B3), 4993–5017.

Kendall R.A., Mitrovica J.X., Milne G.A. (2005). On post-glacial sea level-II. Numerical formulation and comparative results on spherically symmetric models. *Geophys. J. Int.* 161, 679–706.

Mitrovica J.X., Milne G.A. (2003). On post-glacial sea level: I. General theory. *Geophys. J. Int.* 154, 253–267.

Memin A., Hinderer J., Rogister Y. (2012). Separation of the geodetic consequencesof past and present ice-mass change: influence of topography with applicationto Svalbard (Norway). *Pure Appl. Geophys.* 169, 1357–1372.

Olsson P.-A., Milne G., Scherneck H.-G., Ågren J. (2015): The relation between gravity rate of change and vertical displacement in previously glaciated areas. *J. Geodyn.* 83, 76–84. http://dx.doi.org/10.1016/j.jog.2014.09.011

Peltier W.R. (1974). The impulse response of a Maxwell Earth. *Rev. Geophys. SpacePhys.* 12 (4), 649–669.

Peltier W.R., Andrews J.T. (1976). Glacial-isostatic adjustment – I. The forward problem. *Geophys. J. R. Astr. Soc.* 46 (3), 605–646.

Peltier W.R. (2004). Global glacial isostasy and the surface of the ice-age Earth: the ICE-5G (VM2) model and GRACE. *Annu. Rev. Earth Planet. Sci.* 32, 111–149.

Purcell A., Dehecq A., Tregoning P., Potter E.K., McClusky S.C., Lambeck K., (2011). Relationship between glacial isostatic adjustment and gravity perturbations observed by GRACE. *Geophys. Res. Lett.* 38, L18305.

Van Camp M., Williams S.D.P., Francis O. (2005). Uncertainty of absolute gravity measurements. *J. Geophys. Res.* 110 (B05406).

Wahr J., DaZhong H., Trupin A. (1995). Predictions of vertical uplift caused by changing polar ice volumes on a viscoelastic earth. *Geophys. Res. Lett.* 22 (8), 977–980.

A GNSS velocity field for Fennoscandia and a consistent comparison to glacial isostatic adjustment models

Halfdan P. Kierulf [1,2], Holger Steffen[3], Matthew Simpson[1], Martin Lidberg[3]
[1]Norwegian Mapping Authority, Geodetic Institute 3511 Hønefoss, Norway
[2]Department of Geosciences, University of Oslo, Oslo, Norway
[3]Lantmäteriet. 801 82 Gävle, Sweden
e-mail: halfdan.kierulf@kartverket.no

Abstract

In Fennoscandia, the process of Glacial Isostatic Adjustment (GIA) drives ongoing crustal deformation. The vertical and horizontal movements of the Earth can be measured to a high degree of precision using Global Navigation Satellite System (GNSS) data. Crustal velocities obtained from GNSS observations have proved to be an useful tool in constraining GIA models. However, reference-frame uncertainties, plate tectonics, intra-plate deformations as well as other geophysical processes contaminate the results. Former studies have shown that different International Terrestrial Reference Frames (ITRF) had large discrepancies, especially in the vertical component, which hampered geophysical interpretation.

We present new velocity estimates for the Fennoscandian and North-European GNSS network using the processing package GAMIT/GLOBK. Our GNSS velocity field is directly realized in a GIA reference frame (Fig. 1.). Using this method (named the GIA-frame approach) we are able to constrain GIA models with minimal influence of errors in the global reference frame or biasing signals from plate tectonics. We are also able to provide consistent GIA-free plate velocities for the Eurasian plate. We compare our results to different one- and three-dimensional GIA models employing different global ice-load histories.

The GIA models generally provide good fit to the data but there are still significant discrepancies in some areas. We suggest that these differences are mainly related to inaccuracies in the ice models and/or lateral inhomogeneities in the earth structure under Fennoscandia. Thus, GIA models still need to be improved, but our new velocity field and the GIA-frame approach provides a base for further improvements.

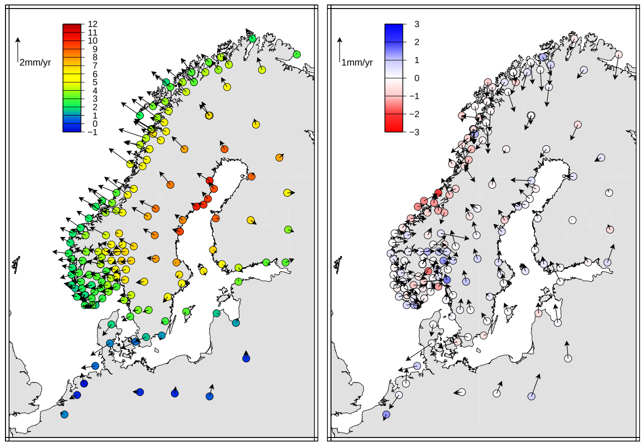

Fig.1. *The GNSS velocityfield realized in the reference frame of the best fit GIA-model and the residuals between the observations and this GIA-model (see Kierulf et al., 2014, for details). The best fitting GIA-model was using the ice model from Lambeck et al. (1998), with a lithospheric thickness of* 140 *km, an upper-mantle viscosity of* 7×10^{20} *Pa s and a lower-mantle viscosity of* 4×10^{21} *Pa s. The horizontal agreement was 0.52 mm/yr (weighted RMS) and the vertical agreement was 0.42 mm/yr.*

References

Kierulf, H. P., H. Steffen, M. J. R. Simpson, M. Lidberg, P. Wu, and H. Wang (2014), A GPS velocity field for Fennoscandia and a consistent comparison to glacial isostatic adjustment models, J. Geophys. Res. Solid Earth, 119, doi:10.1002/2013JB010889.

Lambeck, K., C. Smither, and P. Johnston (1998), Sea-level change, glacial rebound and mantle viscosity for Northern Europe, Geophys. J. Int., 134, 102144, doi:10.1046/j.1365-246x.1998.00541.x.

Summary of the Galileo Commercial Service Status and Plans

Invited Paper

Ignacio Fernández Hernández, Laurens Bogaardt
European Commission - DG Enterprise and Industry
Breydel, Avenue d'Auderghem 45, 1040 Brussels, Belgium
e-mail: Ignacio.Fernandez-Hernandez@ec.europa.eu
e-mail: Laurens.Bogaardt@ec.europa.eu

Abstract
This short paper discusses the current status of the Commercial Service of Galileo, the European global navigation satellite system. Once fully operational, Galileo will comprise 24 operational plus some spare satellites and a large ground infrastructure across the globe, providing position, velocity and timing information to civil users. The Commercial Service aims to supplement this with high accuracy data and authentication by transmitting additional data in the E6 band. The current AALECS Project has already shown Galileo's capability to correctly transmit encrypted CS data and will, in the near future, support the connection of external service providers to test the transmission of their own data in the real CS signal. This paper summarises the Galileo CS status and plans as presented at the "Reference Frames, Positioning and Navigation" Seminar of the 2014 NKG General Assembly (September 2014).

Introduction to Galileo
The Galileo nominal constellation consists of 24 satellites in Medium Earth Orbit (MEO). These satellites circle above the earth's surface at an altitude of 23228 km. At this height, which is over 3000 km higher than the GPS system, it takes the satellites 14 hours and 22 minutes to complete a full orbit. This means each device makes 17 revolutions around the earth in 10 days. The satellites are divided into 3 orbital planes, inclined at 56° to the equator. Each plane consists of 8 functioning satellites and 2 spares. There is a 15° phasing between the planes. This conforms to the Walker 24/3/1 configuration.

Supporting the Galileo satellite system, the ground infrastructure comprises the Ground Mission Segment (GMS) and the Ground Control Segment (GCS). This can be seen in Fig. 1. The GMS enables the generation and distribution of mission data, such as satellite orbit determination and time synchronisation data. This subsystem includes Ground Sensor Stations (GSS) and Mission Up-Link Stations (ULS) scattered across the globe. The GCS monitors the Galileo constellation and provides control functions. It currently includes five Telemetry, Tracking and Commanding Facilities (TTCF). Two Mission Ground Control Centres (GCC) centralise several GMS key

Fig. 1: *Galileo Ground Segments including GCC, TTCF, ULS and GSS.*

functions critical for the provision of the Galileo services. These are located in Fucino, Italy, and in Oberpfaffenhofen, Germany (Nurmi, Lohan, Sand, & Hurskainen, 2014).

Once Full Operational Capability (FOC) is reached, Galileo will offer several services. The Open Service (OS) is freely accessible for the use of positioning, navigation, and timing. The Public Regulated Service (PRS) works with encrypted signals and allows authorized governmental bodies access to more robustness and higher availability. The Search and Rescue Service (SAR) of Galileo will assist in locating people in distress. Unique to this service is that it also provides a confirmation to the person in distress that help is on the way. Such a Return Link Service Provider (RLSP) facilitates the rescue operations and helps to identify and reject false alerts. The Integrity Monitoring Service (IMS) provides vital integrity information for life-critical applications. Finally, the Commercial Service (CS) aims to provide services which go above-and-beyond that of the OS. In particular, the CS aims to deliver authentication of signals and a higher accuracy in navigation than the OS. The key feature of the CS, with respect to other GNSS, is the capability to broadcast external data in real time across the globe.

The Commercial Service

Via the commercialisation of additional services, the Commercial Service forms a source of revenue for the EU to support the Galileo activities which can be "*exploited through a revenue-sharing mechanism with the private sector*". In the current EU GNSS Regulation, one of the objectives of the CS is defined as "*the development of applications for professional or commercial use by means of improved performance and data with greater added value than those obtained through the open service*" (European Union, 2013).

The CS will provide two independent services: authentication, understood as the ability of the system to guarantee the users that they are utilizing signals coming from the Galileo satellites and not from any other source, and high accuracy, the ability of the system to provide a positioning accuracy in the order of a few centimetres. Users may take advantage of either one or both of these. Two encrypted signals in the E6 band, combined with the OS signals, provide this data with "*greater added value*" to the end-user. Such users may include sectors and applications like geodesy, construction, maritime or agriculture. An additional objective of the CS is to promote innovation, offering new functionalities, such as techniques that combine Galileo signal authentication with receiver-based technologies for end-to-end civil location security services and applications.

The proper reception of the signals in the E6 band is crucial for the CS. Numerous actions are currently taking place with this goal in mind, including signal reception testing activities by EC's Joint Research Centre (JRC) and industry. Furthermore, discussions are ongoing with telecommunication regulators and other communities using the E6 band, such as the International Amateur Radio Union (IARU). Bi-lateral cooperation activities with the U.S., Japan and Chinese authorities are also carried out.

The E6 signal operates on a carrier frequency of 1278.75 MHz. It is split into two components: E6-B, which carries data, and E6-C, which is the pilot tone. The data is sent using a symbol rate of 1000 sps. The first 16 symbols are used to make sure the receiver can synchronise with the page transmission. The remaining 984 symbols convolutionally encode 492 bits of data. Of these 492 bits, the first 14 inform the page type, while the last 24 consist of the CRC with 6-bit tail. This leaves 448 bps which can effectively be used to transfer data. This breakup of the available bandwidth is shown in Fig. 2.

Sync	Symbols	Total [symbols]
16	984	1000

Word			Tail	Total [bits]
Page type	Commercial Data / key Management	CRC		
14	448	24	6	492

Fig. 2. *Breakup of the bits within a one-second CS data page.*

The available data bandwidth of, at most, 448 bps per satellite is adequate to broadcast high accuracy data, such as precise information concerning clocks and orbits. This allows for Precise Point Positioning (PPP). When the service is operational, data will come from an external source through the GNSS Service Centre (GSC) and will, then, be transmitted to satellites before finally reaching the end-user. Therefore, only satellites connected to ground (connected to ULS) can transmit CS data. The current scheme allows data transmission from several sources, meaning that it will be technically possible to allow several services in parallel from different Commercial Service Providers (CSP). An example of a potential allocation of bandwidth can be seen in Fig. 3.

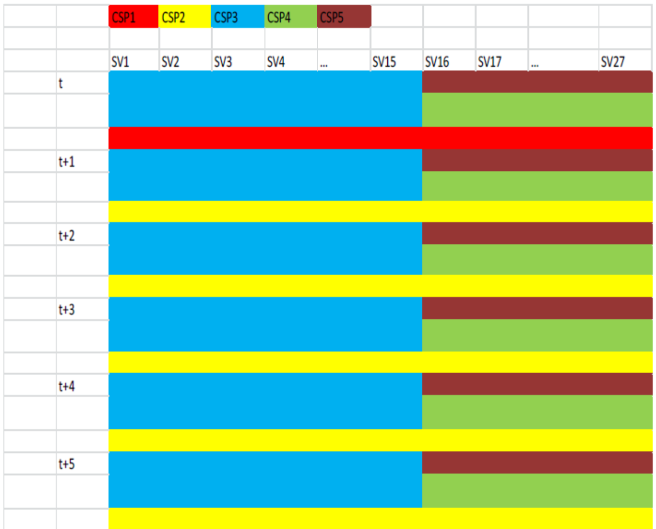

Fig. 3. *Potential breakup of the service provision within a multi-second signal.*

In this somewhat arbitrary example, 5 CSPs share the total capacity, in a way that could segment the high accuracy market with different service levels while leaving some capacity to provide authentication support data.

Galileo satellites will have a better coverage in high latitudes than geostationary satellites, which are used at the moment for satellite-based high accuracy services (Fernández Hernández, Simón, Blasi, Payne, Miquel, & Boyero, 2014). The use of the Galileo satellites for the transmission of this added-value data, therefore, provides a significant advantage. As discussed in the following section, the data latency which is achievable will only be of a few seconds, though the exact number is to be confirmed. This data should allow for centimetre-level accuracy.

Besides offering a higher level of accuracy with respect to Galileo's OS, the CS aims to address a need of the GNSS community: authentication. Several studies have shown that GPS signals are vulnerable to spoofing (Humphreys, 2012; Pozzobon, et al., 2013; Kerns, Shepard, Bhatti, & Humphreys, 2014). Galileo will offer authentication with the purpose of ensuring that the processed signals are the ones transmitted from the satellites. The exact service performance and provision scheme are currently under analysis. Several key elements can, however, already be identified. The CS signal includes encrypted spreading codes which can be used to protect the signal time-of-arrival against replay attacks. Over-the-air key management of these codes may take up a few dozen bps, leaving the lion's share of the available 448 bps for the purpose of providing high accuracy signals. In addition, some of the 20 bps spare bandwidth from E1-B I/NAV may be used to provide an OS authentication service for the public benefit of worldwide GNSS users. The authentication service will require additional ground infrastructure for key management, service exploitation, etc.

Authentication and high accuracy are foreseen to be provided and exploited separately. This allows users to opt for data authentication of the OS signal, data plus code authentication of the CS signal or simply an unauthenticated CS high accuracy signal. For the OS, a lighter Navigation Message Authentication (NMA) service could be provided on the E1 signals with a lower receiver and key management complexity, adequate for less critical applications. The CS authentication would rely on higher receiver and key management complexity and robustness, adequate for high security commercial applications such as tracking and tracing of dangerous goods. This service offering will allow users to adopt the service most suitable for their target security level and setup.

Service Concept Studies

The European Commission (EC) launched two parallel studies in December 2012 for the duration of 1 year. The first study, called CESAR ("Galileo CommErcial Service, A Reality"), was managed by GNSS consultancy firm France Development Conseil (FDC) and included the participation of major GNSS high accuracy service providers and infrastructure developers as Trimble and Fugro. The second study, called GALCS (GALileo Commercial Service definition), was managed by GMV and included the participation of CGI and Helios Consulting. The budget for each study was approximately 0.4 million euro.

Both these groups analysed service concepts and performance of High Accuracy and Authentication under certain Galileo system assumptions, such as the satellite number, system latency, allocated bandwidth, etc. The studies included simulated and real SIS results. It was concluded that there is interest from external service providers to provide high accuracy services from the Galileo constellation but that security accreditation involved still needs to be examined. High accuracy data requires a substantial amount of data bandwidth and is sensitive to transmission latency. The studies concluded that a reliable low-latency channel is required. The remaining E6-B bandwidth could accommodate the authentication process.

The AALECS Project

In January 2014, the EC launched the Authentic and Accurate Location Experimentation with the Commercial Service (AALECS) project, also known as the CS Demonstrator. A consortium led by GMV, including CGI, QASCOM, IFEN, Veripos and KU Leuven, was awarded the contract. The project has a total budget of 4 million euro and is expected to last around two and a half years. It has the objective to develop and test the CS with real signals in space (SIS) and support future service providers. The main focus of the project is authentication, as high accuracy PPP technologies are more mature and their markets more consolidated (Rodríguez, et al., 2014).

An Early Proof-Of-Concept (EPOC) was the first step in this project and aimed to test the capability of the Galileo System to correctly transmit encrypted CS data in the E6 band and to demonstrate user applications at terminal level. Fig. 4 depicts schematically the communications links established between the EPOC and third parties, which starts with the generation of authenticated orbit and clock predictions 1-2 days in advance. These were then uploaded during weekly test slots in which three satellites were in view over the EU. The Galileo satellites transmitted the data in the E6-B signal and data-authenticated PPP were computed using the received results. These tests included static- and kinematic-, as well as open sky-, rural- and urban test environments. The EPOC's signal-in-space tests started in June 2014. By August 2014, accuracy down to the level of a few decimetres and authentication were already demonstrated using only Galileo and GPS signals.

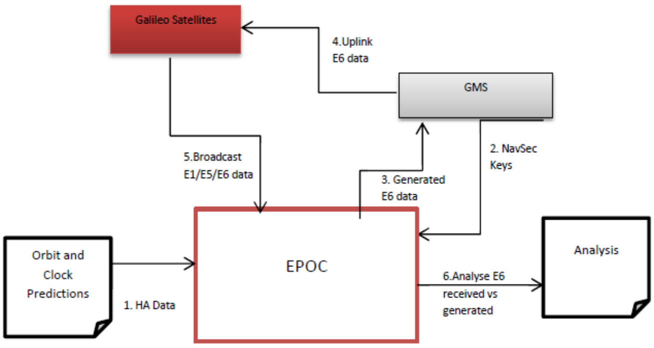

Fig. 4. *Schematic description of the EPOC.*

The second phase of the AALECS project is the Demonstrator Platform, which should be completed by mid-2015. This platform will be a powerful and complex system composed of four main elements: CS Receiver (RXP), CS Provider Test-bed (PTB), CS Emulator (EMU) and Signal Generator (SG). The CS Demonstrator platform will, then, connect to the Galileo system through the GSC, which will enable the transmission of real time E6 SIS data with a latency of some seconds. Once this step is properly validated, the CS Demonstrator will start the third phase, in which it will support the connection of external service providers to test the transmission of their own data in the real Galileo CS signal.

The GSC, which will transmit the CS data to the Galileo satellites, is located in Torrejón de Ardoz, Madrid, Spain. To allow external data providers to connect to the satellites via the GSC and the CS Demonstrator, in phase 3 of the

AALECS project, the test setup needs to be secure. The Galileo security teams are coordinating with the GSC to develop and accredit an architectural solution according to Galileo security requirements.

Next Steps

Service Concept Studies have indicated that the benefit of the CS is significantly higher if available in the first generation of Galileo satellites. The current CS roadmap foresees an early service in the 2017 timeframe, provided that the current Galileo planning holds. This will allow the already established high accuracy market to integrate the CS in their solutions and the coverage and performance of existing PPP services.

To ensure that the CS will be able to achieve the goals outlined in the introduction, several steps remain to be taken. The AALECS project will continue to test key features of the CS in a close-to-operational environment. Eventually, the platform may be opened to potential commercial service providers to allow them to test the adequacy of their solutions through the CS transmission channel. The GSC needs to be developed and accredited in order to allow the E6-B external data transmission. Agreement is needed on the exploitation model for the two main features of the CS: high accuracy and authentication. This is currently the topic of discussions between the EC, the European GNSS Agency (GSA) and Member States. What seems already certain is that the commercialisation of high accuracy and authentication will be done in collaboration with the private sector.

Conclusions

The Commercial Service of Galileo is underway and on track. Two independent studies have shown what the possibilities for the commercial exploitation of GNSS signals are and a CS Demonstrator is currently testing the high accuracy service and authentication. If the CS becomes available in the first generation of Galileo satellites, it will offer the first truly global high accuracy service to date. It will offer increased civil security and robust authentication service for EU Institutional Users.

Acknowledgements

The authors would like to thank the AALECS project members, including I. Rodríguez, G. Tobías, the EPOC team (D. Calle, E. Carbonell, E. Göhler) and other GMV/IFEN/CGI/QASCOM teams; EC/GSA CS team and EC management (J. Simón, R. Blasi, O. Valdés, T. Miquel, L. Dimitrijeva, E. Châtre), ESA services (C. Payne), ESA operations (A. Pena and team), Spaceopal (P. Fedele and team), CESAR (C. Taillandier and team), the GALCS team, JRC, Prof. V. Rijmen, Prof. G. Seco and Prof. A. Jensen.

References

European Union. (2013). Regulation (EU) No 1285/2013 of the European Parliament and of the Council. Brussels: Official Journal of the European Union.

Fernández Hernández, I., Simón, J., Blasi, R., Payne, C., Miquel, T., & Boyero, J. P. (2014). The Galileo Commercial Service: Current Status and Prospects. *Coordinates*, 18-25.

Humphreys, T. (2012). UAVs Vulnerable to Civil GPS Spoofing. *Inside GNSS*.

Kerns, A., Shepard, D., Bhatti, J., & Humphreys, T. (2014). Unmanned Aircraft Capture and Control Via GPS Spoofing. *Journal of Field Robotics*, 617-636.

Nurmi, J., Lohan, E. S., Sand, S., & Hurskainen, H. (2014). *Galileo Positioning Technology*. Dordrecht: Springer.

Pozzobon, O., Sarto, C., Dalla Chiara, A., Pozzobon, A., Gamba, G., Crisci, M., et al. (2013). Developing a GNSS Position and Timing Authentication Testbed. *Inside GNSS*, 45-53.

Rodríguez, I., Tobías, G., Calle, D., Martín, J., Pozzobon, O., Canale, M., et al. (2014). Preparing for the Galileo Commercial Service – Proof of Concept and Demonstrator Development. *Proceedings of the ION GNSS+*. Institute of Navigation.

CAT II/III GBAS Challenges

Nadezda Sokolova, Aiden Morrison
SINTEF ICT, Communication Systems Dept.
Strindveien 4, 7034, Trondheim, Norway
e-mail: nadia.sokolova@sintef.no

Introduction

Instrument Landing System (ILS) provides a very adequate precision approach and landing service that supports CAT I/II/III aircraft operations. However it has systemic limitations that have led to several attempts to replace it. Among these limitations are multipath issues that can be attributed to nearby building construction or aircraft, leading to navigation sensitive regions in airport movement areas, and resulting in traffic density limitations or the need to have one system per runway versus one per airport for GBAS (Ground Based Augmentation System). Microwave Landing System (MLS) was designed to overcome these minor disadvantages but has not found global acceptance and implementation because of aircraft installation issues limiting its adoptability.

In comparison, Ground Based Augmentation System (GBAS) is being designed to take advantage of the rapid acceptance and implementation of GPS as an en-route navigation system. While achieving the integrity needed for precision approach and landing operations has proved a lengthy and on-going process, sufficient integrity has been established and standardized for supporting operations in CAT I conditions, however most transport aircraft need the full capability to operate in CAT II/III conditions.

SINTEF ICT is involved in GBAS CAT II/III development through participation in the Single European Sky ATM Research (SESAR) program, and a number of national projects considering implementation of CAT II/III GBAS in challenging environments of Northern Europe, such as “Arctic GBAS” funded by the Norwegian Space Centre over the last 5 years, and the NORGAL project funded by the Research Council of Norway. In both projects, SINTEF ICT works closely with Indra Navia, manufacturer of precision landing equipment, focusing on performance analysis and enhancement of GBAS design to ensure system certification for a wider range of geographical locations, including the high latitude regions of Norway and Northern Europe. All the tests and data analysis in the project are performed using Indra Navia's GBAS prototype.

Research topics investigated by SINTEF ICT include two of the main challenges to GBAS operation, namely anomalous ionosphere behavior, in particular scintillation and gradient effects, and interference caused by use of personal privacy jamming devices (PPDs) designed to defeat GPS/GNSS based vehicle-tracking systems.

Interference

As radio frequency interference (RFI) becomes more recognized as a threat, the challenge of its detection and mitigation in both individual GNSS receivers and GNSS augmentation systems is becoming ever more important and receiving commensurate attention. Intentional interference to GNSS signals (jamming) so far has typically targeted non-aviation users, but it has also affected the ground infrastructure of aviation users. One significant example is the proliferation of the so-called personal privacy jamming devices (PPD) designed to defeat GPS based vehicle-tracking systems, which in some cases have disrupted aviation applications (e.g., Newark airport). Several studies on characterization of PPDs available on the market have been performed and results describing the operation, signal types, and power levels are publicly available (Grabowski, 2013; Kraus et al 2011).

A GBAS ground reference receiver has to meet a number of stringent requirements to its performance in regard to interference (ED-144; ED-114A; GalMOPS). In order to meet these requirements some special interference mitigation techniques e.g. pulse blanking are implemented in the receiver's firmware or front end, however, the receiver still remains vulnerable to the interference types that are supported by PPDs (CW, chirp signal with saw-tooth function or chirp with frequency bursts). Therefore, most of the tests and simulations performed within GBAS related projects at SINTEF ICT are focused on the degradation of GNSS receiver performance in the presence of different types of jamming signals.

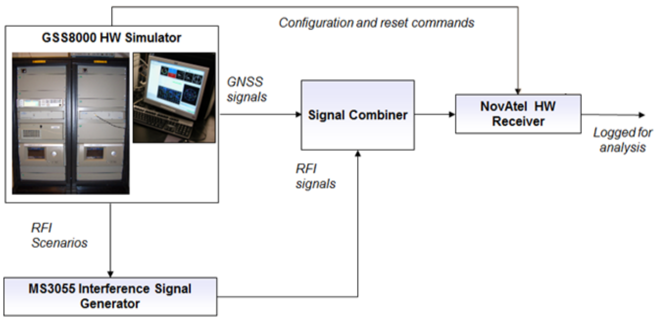

Fig.1. *An example of HW simulator setup used for conducting jamming simulations.*

Performance degradation is typically measured in terms of parameters such as carrier to noise density ratio, pseudo-range and carrier phase noise characteristics. For this purpose, a Spirent GSS8000 HW GNSS simulator is used in combination with an interference signal generator. Figure 1 illustrates an example of the HW setup used for jamming simulation.

Anomalous Ionosphere

Under normal conditions the ionosphere poses little threat to the integrity or availability of navigation signals, appearing as only a slowly changing nuisance parameter. The connection between satellite navigation and space weather through the ionosphere is caused by the fact that the ionosphere is a dispersive medium at the radio frequencies used by satellite navigation signals. As such, a change in the Total Electron Content (TEC) of the ionosphere encountered along the ray path between a satellite and a user results in an apparent change in the range between the satellite and the user as well as an alteration of the signal phase. Under normal conditions the ionosphere is highly correlated spatially and does not pose a threat to either navigation or signal tracking, as the signal dynamics are very low frequency and the spatial distribution can be well modeled by the Klobuchar or NeQuick model parameters broadcast by the GPS and Galileo satellites respectively. Similarly, the GBAS users can almost completely remove the ionosphere error using differential corrections.

However, the ionosphere medium sometimes is subjected to unpredictable perturbations. Ionospheric anomalies, which may exhibit large spatial or temporal decorrelation over a short baseline, can pose potential integrity threats to GBAS users as the existing GBAS architectures cannot fully mitigate these effects by monitoring. Furthermore, when the irregularities in the ionosphere are sufficiently intense, they can scatter radio waves and generate rapid fluctuations (scintillation) in the amplitude and phase of radio signals. These effects occur frequently in equatorial and high-latitude regions and have the potential to impact multiple satellites at solar maximum. Due to high continuity requirements, frequent scintillations might pose a potential threat for GBAS operation in the equatorial and high-latitude regions. Thus, understanding the scintillation phenomena in terms of rate of occurrence, magnitude, spectral content and number of satellites affected at the user side is necessary in order to certify GBAS for operation in such regions.

Characterization of the phase scintillation phenomena and parameterization of the gradient threat typical for the high latitude regions of Norway are some of the activities carried out by SINTEF ICT in cooperation with the Norwegian Mapping Authority (NMA) that owns and operates the SATREF network monitoring the ionosphere over Norway composed of a set of more than 170 permanently installed GNSS receivers and a number of ionosphere scintillation monitors. Figure 2 illustrates an example of phase scintillation statistics in terms of maximum standard deviation of smoothed phase observables (σ_φ) observed from the NMA's scintillation monitor located in Tromsø, Norway, (70°N,19°E). An event in this case is defined as σ_φ above 0.2 rad for two consecutive epochs.

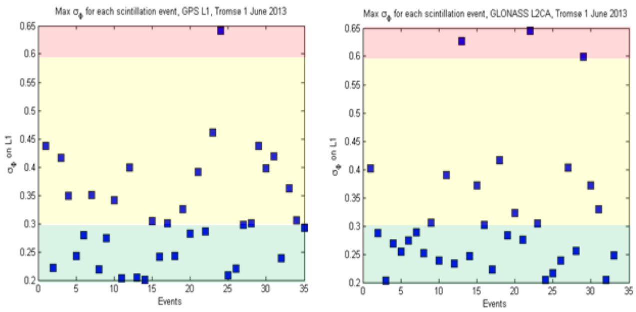

Fig.2. *Maximum σ_φ values observed on GPS L1 (right) and GLONASS L2C (left), Tromsø, 01.06.2013. (Andalsvik et al 2014).*

References

NORGAL: Nordic concept for CAT III/Autoland based on GBAS, RCN BIA project: https://www.forskningsradet.no/prosjektbanken_beta/#/project/228943

Grabowski, J. C. (2012) “Personal Privacy Jammers,” in *GPS World*, April, pp. 28-37.

Kraus, T., R. Bauernfeind, B. Eissfeller, "Survey of In-Car Jammers - Analysis and Modeling of the RF Signals and IF Samples (Suitable for Active Signal Cancelation)," Proceedings of ION GNSS 2011, Portland, OR., Sept. 20-23, 2011, pp. 430-435.

Andalsvik Y. L., Jacobsen K. S., Sokolova N., Morrison, A. and M. Stakkeland, (2014) SESAR 15.3.7: Anomalous Ionosphere Characterization. 15th International GBAS Working Group meeting, 3-6 June 2014, Eurocontrol Experimental Centre, Bretigny-sur-Orge, France.

ED-144, High-level performance requirements for a global navigation satellite system/ground based augmentation system to support precision approach operations, EUROCAE, October 2007.

ED-114A, Minimum operational performance specification for Global Navigation Satellite Ground Based Augmentation System ground equipment to support Category I operations, EUROCAE, March 2013.

GalMOPS: Minimum operational performance specification for airborne open service Galileo satellite receiving equipment, version 3.2, EUROCAE, June 2013.

Balanced Least Absolute Value Estimator and its applications in navigation problems

Milan Horemuz
KTH
Drottning Kristinas väg 30
100 44 Stockholm, Sweden
e-mail: horemuz@kth.se

Extended abstract

This presentation is based on the following paper:
Horemuž M. and Zhao Y. (2014). Motion of moving camera from point matches: comparison of two robust estimation methods. IET Computer Vision, E-first. DOI: 10.1049/iet-cvi.2013.0271.

Identification of outliers is an important step in all parameter estimation problems. Undetected errors in the observations with unexpected amplitudes will cause a bias in the estimated parameters. To obtain an unbiased estimation of the parameters, a robust estimator should be applied.

This presentation discusses the most known methods for robust parameter estimation (M-estimators and RANSAC) and introduces a less known estimator BLAVE (Balanced Least Absolute Value Estimator).

M-estimators reduce the effect of gross errors by minimizing a suitable objective function, which is a function of residuals. The choice of the function depends on the problem at hand. There are two main drawbacks with these kinds of estimators: no closed solution exists for most of the objective functions (iterative solutions are required) and the "robustness" of M-estimators depends both on the chosen function and on the geometry of the observations; the unbiased solution is not always guaranteed.

The basic idea of BLAVE is to reweight the observations so that they have an equal influence on the results, hence the name balancing. Then, when the L1 estimator is applied, the advantage of the median for direct observations can be utilized: the balanced observations whose residuals deviate significantly from the median of all residuals are considered as outliers. The main advantage of this method is that it is a general method, since it takes into account the geometry of observations and it produces unbiased results as long as there is a sufficient number of inliers (more than 50%) and there are no dependencies between the observations.

The performance of the BLAVE is compared with RANSAC empirically by application to the image based navigation problem (determination of motion of camera from point matches). A linearized model for this estimation problem is derived. The tests were performed on a simulated scene with added random noise and gross errors as well as on actual images taken by a mobile mapping system. The greatest advantage of BLAVE is that it processes all observations at once as well as its median-like property: the estimated parameters are not influenced by the size of the outliers. It can tolerate up to 50% outliers in data and still produce unbiased results.

RANSAC is an iterative method to estimate the parameters of a mathematical model from a set of observations in presence of outliers. It is a non-deterministic algorithm leading to a reasonable result only with a certain probability, and this probability increases as more iterations are carried out. The greatest disadvantage of RANSAC is that the results are not repeatable due to the random sampling of data. Moreover, the results are less accurate, because RANSAC generally does not produce "best-fit" parameter estimation. The number of trials, which must be tested by RANSAC to find a reasonable solution, depends on the portion of outliers in data.

Our tests confirmed the theoretical prediction: the number of iterations and hence computational time of the RANSAC algorithm increases geometrically with the proportion of outliers. The number of iterations does not depend on the number of observations if the goal is to find a reasonable solution (i.e. solution not affected by outliers), but it must be increased significantly if the best solution is to be found. In addition, the choice of the error threshold is a basic problem for RANSAC since there is no general method for choosing it. Many times in our tests some inliers were incorrectly marked as outliers due to the inappropriate error threshold.

BLAVE method could successfully estimate the parameters in presence of outliers in the data sets. The computation time was shorter for smaller amount of observations and it is independent on the number of outliers, which is a great advantage, compared with RANSAC. The computational time of the BLAVE estimator is not influenced by the number of outliers, but it increases with the number of all observations.

Autonomous Detection of Electromagnetic Interference in the GPS band

Björn Gabrielsson[1], Patrik Eliardsson[1], Mikael Alexandersson[1], Kia Wiklundh[1], Peter Stenumgaard[1], Gunnar Hedlin[2], Anders Frisk[2], Peter Wiklund[2]
[1]Swedish Defence Research Agency, Linköping, Sweden
[2]Lantmäteriet, Sweden

Summary

Problems with radio interference caused by unintended interference signals from electronic systems have been known since radio's infancy and came into focus when radio broadcasting started almost 100 years ago. Radio interference can have different origins. The concept of "man-made noise" is usually used for general environmental noise generated in urban areas and close to industries. Locally generated interference signals come from the various electronic systems in the vicinity of a wireless receiver. Equipment that generates high levels of radio interference includes, for example, personal computers, charging equipment for battery-powered products, microwave ovens and low-energy lamps. The third group of interference signals is from intentional jamming by transmitters in order to hinder or completely block wireless communication. The ability to efficiently use this kind of interference has previously only been with military actors but is spreading to civilian actors in that dedicated jamming equipment now is sold openly and inexpensively via the Internet, see Figure 1. Already today jammers are used to knock out vital communications, positioning and alarm systems, both in connection to riots and criminal activities. GPS jammers are also used by commercial drivers (e.g. truck drivers) to avoid that the driving routes are tracked by the employers. These jammers can accidentally interfere with GPS-receivers vital for lots of critical societal functions.

Fig. 1. *GPS jammer connected to the cigarette lighter socket in cars. Photo: Peter Johansson, FOI.*

The need of continuously monitoring the GPS-band for interference signals has been highlighted in recent years and in UK and US, national monitoring systems have been designed for this purpose (The Guardian/Sentinel and Patriot Watch respectively). Continuous measurements over longer times are necessary to get a thorough picture of how the interference varies over longer time. In order to control the radio noise environment in a cost effective manner is therefore necessary to have access to portable equipment that can be monitored remotely. Such system must enable both detection and a classification of an interference event. A quick automatic classification of the relevant waveform characteristics is needed so that relevant registered events can be selected for deeper analysis. Also the cost of the equipment must be reasonable in several applications. To meet the above requirements, research has been carried out in order to design a portable device for remote monitoring of the GNSS spectrum.

The monitoring system developed by FOI have been active in approximately one year and deployed at various sites in the region of Stockholm. Several interference events have been detected by systems. Some of the detected incidents are so severe the GPS receiver lost its tracking of the satellites, see Figure 2. The possible source of the interference is so far unknown it could be both unintentional electromagnetic interference (EMI) or intentional jamming.

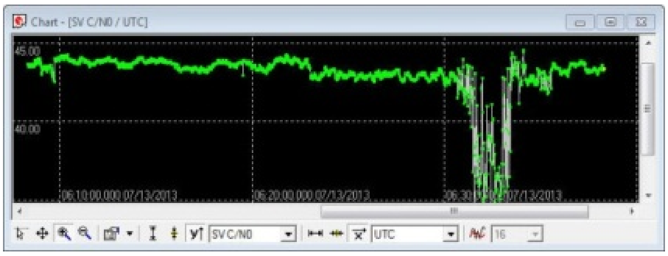

Fig. 2. *The variation of the signal-to-noise [dBHz] averaged over all tracked satellite signals for one of the detected incidents. The first two thirds of the time series shows normal variation. The interference signal is active during the last third of the plot.*

By increasing the coverage of the monitoring system, a better picture of how widespread the GNSS jamming threat is in Sweden can be given. A possible opportunity to increase the coverage is to implement interference detection and monitoring system in the already existing infrastructure SWEPOS. Lantmäteriets Network of permanent stations SWEPOS constitute a grid of stations covering almost the entire area of Sweden. Initial results from monitoring the GNSS spectrum at one SWEPOS station will be presented and discussed together with already obtained results from Stockholm.

Report from the project NKG GNSS AC

Lotti Jivall[1], Tina Kempe[1], Christina Lilje[1], Sonja Nyberg[2], Pasi Häkli[2], Karin Kollo[3], Priit Pihlak[3], Mette Weber[4], Ksenija Kosenko[5], Þórarinn Sigurðsson[6], Guðmundur Valsson[6], Dalia Prizginiene[6], Eimuntas Paršeliūnas[7], Oddvar Tangen[8]

[1] Lantmäteriet
Lantmäterigatan 2C, SE 80182 Gävle
e-mail: Lotti.Jivall@lm.se

Introduction

GNSS processing has been carried out under the framework of NKG for a long time. The NKG Local Analysis Center (LAC) of EUREF Permanent Network (EPN) has been contributing to the final EPN-products since the start of EPN 1996. Onsala Space Observatory started the operation of NKG EPN LAC and Lantmäteriet is responsible for this task since 2002.

NKG has also contributed to E-GVAP (the EUMETNET EIG GNSS water vapour programme) with near realtime troposphere solutions processed by Onsala Space observatory in co-operation with SMHI (Swedish Meteorological and Hydrological Institute) and earlier also with Kartverket in Norway.

Two large GPS-campaigns, NKG 2003 and NKG 2008, have been organized within NKG to get common reference frames as a basis for inter Nordic projects and for development of transformations between current ITRF solutions and the Nordic and Baltic national ETRS 89 realizations. These campaigns included both permanent stations and passive geodetic points defining the national ETRS 89. The processing was carried out as a co-operation between several national analysis centers.

With the background of GNSS-analysis within NKG and the fact that almost all Nordic and Baltic countries either performed or planned to start daily/weekly processing of their own national permanent GNSS networks as well as the need for consistent and densified GNSS solutions in the area, a resolution was formed at the General Assembly 2010 recommending the establishment of a distributed NKG GNSS Analysis Centre.

The project

The project "NKG GNSS Analysis Centre" was formed within the working group "Reference Frames, Positioning and Navigation" with the aim to provide a common and combined GNSS solution for the Nordic and Baltic countries based on analysis of permanent GNSS-stations. The future products from NKG GNSS AC could be considered as densifications of the products from NKG EPN LAC.

The most obvious objective is to compute consistent solutions with velocities to be used for constraining of GIA-models, being an important component for the maintenance of the national reference frames in the Nordic and Baltic area.

In the future also other products as troposphere parameters and near real-time solutions could be considered.

Seven national organizations participate in the project and there is one observing organization which also contributes, i.e. all Nordic and Baltic countries are represented. The project, which started in 2012, is divided into three phases before finally reaching the operational phase; pre-study phase including a benchmark test, definition phase and start-up phase.

Pre-study – part 1

The pre-study started with a questionnaire to gather information on processing facilities and strategies (parameters, models, etc.) in each participating country or institute. All organizations have the Bernese GNSS Software (Dach et.al. 2007) and the main part declared that they would procure the latest version 5.2, when it is available. The use of the same software and settings is a prerequisite for a homogeneous combined solution consisting of several sub-networks. Some institutions also have other software available. The Bernese Software runs under Windows at all institutions except two, where it runs under UNIX or LINUX. Some institutions performed continuous (daily or weekly) processing already before the project start.

The proposals from the participants in the project cover all countries in the Nordic/Baltic area. Except for some hesitation in Lithuania and Norway, this is done by local processing in each country, which is optimal as the national organizations have better understanding and control over what is happening at the national stations.

For the important tasks of combining the solutions from the participating local processing centres and performing time-series analysis, we got positive answers from some participants who were interested to contribute with these tasks.

Pre-study –part 2

The second part of the pre-study deals with the processing strategy. We should of course follow the guidelines for EPN analysis centres (EPN Coordination group, 2013), but as we all use the same software we could be more strict and reach a higher level of consistency. It was decided at an early stage that the Bernese version 5.2 should be used, but the release was delayed, so we decided to start up with Bernese version 5.0.

Benchmark test

A benchmark test was defined, which should be run by each participating organization to prove that the solutions were consistent. The benchmark test consists of one week of data (GPS-week 1682). All GPS/GLONASS-stations of the NKG EPN sub-network (35 EPN-stations) were chosen for the test – see Fig. 1.

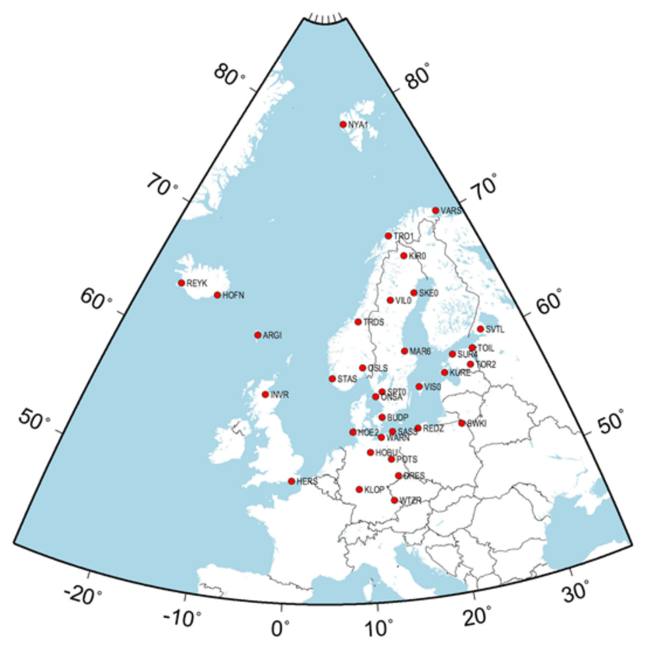

Fig. 1: *Stations for the NKG GNSS AC Benchmark test.*

For the processing with version 5.0, the same processing setup as for the NKG 2008 campaign was used with some modifications concerning coordinates and antenna models. Five local analysis centres (LAC) participated in the Benchmark test with version 5.0. The coordinate agreement was on the 0.1 mm level (a few stations differed 0.1 mm) and the combination of the LAC solutions were fine. An additional test was made with free solutions (non-constrained solutions) and then one of the solutions differed up to 23 mm. This LAC solution was saved in covariance SINEX instead of normal equation SINEX, so we concluded that we should avoid mixing different types of SINEX-files. We did also note a systematic scale and rotation between the free and the constrained solutions.

Furthermore, a test was made with different baseline definitions yielding in differences up to 0.5 mm horizontally and 1.9 mm vertically. The differences are considered to be so small that it does not matter if different analysis centres use different approaches for baseline definition, especially considering that we will have different baselines between the EPN-stations, which is the backbone holding the LAC-solutions together.

The Bernese GNSS software version 5.2 was released by the end of 2012. The new version comprises a number of new options and models. After initial testing at some LACs we concluded that some issues need more extensive testing before final decision on processing setup:

- Strategy for ambiguity resolution
- Troposphere mapping function
- Clustering

Strategy for ambiguity resolution

The new version included an example setup with an advanced ambiguity resolution scheme, which included different strategies for different baseline lengths with overlap. The processing time increased considerably (especially with the original setup) and the question was how much the gain in resolved ambiguities and daily repeatability would be. Another disadvantage with the advanced ambiguity resolution scheme was that there was not a single number for the rate of resolved ambiguities presented to the user, just rates for each strategy. We developed routines for the calculation of a single number for the rate of resolved ambiguities to overcome this. Tests performed on the network of the benchmark test revealed that the rate of resolved ambiguities improved ca. 10%-units for GPS and 1-2%-units for GLONASS. However the daily repeatability was just improved by ca. 1 %. Our conclusion from this was that the improvements (and differences) were very small and considering that we will have different networks and baselines it is up to each LAC to decide which ambiguity resolution strategy to use.

Troposphere mapping function

The guidelines for EPN analysis centres were updated with respect to the new options in the new version of the Bernese GNSS Software, but regarding troposphere mapping function it was open to use either Global Mapping Function (GMF) or Vienna Mapping Function (VMF1). We made a study to see the differences in coordinate estimation and to decide which model to use for the NKG EPN LAC and for the GNSS AC project (Jivall, 2014 a). The study was based on one year of data from the benchmark test network and resulted in the following conclusions:

- A small improvement of the repeatability of the height component is noted for VMF1 compared to GMF, in average ca. 0.4 mm in the RMS, corresponding to 8- 10% lower values for VMF1 than for GMF. This is valid both for the full year and for the summer period.
- The coordinate differences on a single day could be up to 14 mm in height and in general up to 6 mm. This is too much to neglect when combining solutions from different sub-networks, which means that it is important that we use the same mapping function for all national analysis centres contributing to NKG AC.
- For one third to half of the stations (depending on the selected time period) there were systematic

differences in estimated heights between VMF1 and GMF significant on 2 sigma level. The largest difference was 3.6 mm, but there were just two stations with a significant systematic difference larger than 2 mm.

Based on this study we decided to use VMF1 for NKG EPN LAC and hence also for the NKG GNSS AC. The NKG EPN LAC started to use Bernese version 5.2 and VMF1 from GPS-week 1765 (Nov. 2013).

Later on, when the proposed Bernese setup using VMF1 was used on large networks divided into clusters, it turned out that sometimes bad results were achieved and that GMF actually performed better in these cases. The problem with VMF1 seems to be connected to the interpolation in the a priori model between clusters.

Clustering

For large networks based on double difference processing it is necessary to divide also the final solution into clusters (the network size limit depends on the computer). There are several possible ways of defining clusters in the Bernese. Based on earlier experiences we have seen that clustering sometimes gives problem with the combined solution, especially when not all baselines in a cluster are connected to each other.

Some tests were performed on the NKG EPN sub-network, consisting of 52 stations (Jivall, 2014 b). Three different ways for cluster definition were tested using the Bernese setup for NKG EPN LAC (e.g. VMF1). The first two ways could be considered as standard ways in the Bernese Software and the last one was developed to assure that the clusters always are built up by baselines which are connected to each other.

- Clusters made in SNGDIF using a CLU-file
- Clusters formed by the routine MKCLUS based on the baselines from SNGDIF
- Clusters defined in several steps. First defining clusters on station level and then define the baselines within each cluster. Finally the clusters are connected to each other by defining baselines between the clusters.

The tests performed are of course affected by the problems with VMF1 and clustering. They showed shifts up to several cm between different parts of the network when using the clusters defined in SNGDIF.

Using MKCLUS on single differences seemed to work much better. Also with this strategy it is quite common that not all baselines are connected within a cluster, but in general this is no problem. Differences up to 8 mm caused by single baselines, not connected to the rest of the cluster, have been seen in the tests presented here.

The alternative strategy, which ensures that the baselines are connected within each cluster, shows promising results for the test data, but in tests with a larger network, it is also suffering from the problems with VMF1 and clustering.

Bernese Processing setup for NKG GNSS AC

Three different BPE (Bernese Processing Engine) setups were prepared:

- NKG_R2S.PCF for QIF-only (Quasi Ionosphere-free) ambiguity resolution
- NKG_R2Sall.PCF for the advanced ambiguity resolution scheme
- NKGcR2S.PCF for QIF-only and the alternative clustering

The first two setups were usable both for full network processing and clustering with MKCLUS on single differences.

VMF1 was originally used in the setups, but when the problems with VMF1 and clustering was discovered and understood, we decided to use GMF instead as we did not see any fast solution for the VMF1 and clustering problem.

The benchmark test was re-run with version 5.2, first with VMF1 and later on with GMF. The NKG EPN-solution had been running for more than half a year with VMF1 and as we got signals from EPN to continue using VMF1, we decided to add an additional solution with GMF to be used for the NKG GNSS AC combinations. (The NKG EPN solution is not divided into clusters so there is no problem with VMF1.)

The agreement between the LAC solutions of the benchmark test was almost 100% after some trouble-shooting and iteration.

The processing setup could be summarized in the following way:

- Follow guidelines for EPN analysis centres
- 3º, 10º and 25º -solutions (the latter for elevation cut-off test)
- GMF troposphere mapping function
- GPS + GLONASS
- Final CODE-products
- Exclude stations with equipment changes affecting daily and weekly solutions
- Regularly updated antenna models as used in EPN (individual)
- Ambiguity resolution and baseline definition according to preference of each LAC

Test to combine national sub-networks

A test was made to run the selected processing setup on the (preliminary) national sub-networks. Data from GPS-week 1785 was used and combined with the NKG EPN solution. Some issues were found, mainly connected to antenna models (type/individual). The experiences were used as input for the next step.

NKG AC Definition

The NKG AC Definition phase means defining NKG AC for continuous routine processing and comprises the following parts:

- Responsibilities
- Prepare a structure for the ftp-server
- Definition of national sub-networks
- Definition of data policy
- Schedules for submissions
- Decision on solutions to submit

Each LAC processes their own national sub-network and the NKG EPN network acts as a backbone connecting the different national sub-networks. The stations in the national sub-networks should be selected with the following criteria:

- Stable well-performing stations, reasonable national coverage
- At least 5 IGS/EPN stations for the connection to IGSxx (IGb08)
- At least 6 EPN stations common with the NKG EPN network

Each LAC proposed stations for their sub-network and after co-ordination with the project leader and neighboring LACs the networks were settled. The combined network of NKG GNSS AC (summer 2014) is shown in Fig. 2. Iceland and Lithuania are not yet included.

Fig. 2: *The combined network of NKG GNSS AC, Nov. 2014. Red dots are stations included in the NKG EPN-solution and the black dots are national stations.*

Two combination centres are responsible for combining the national solution and the NKG EPN-solution, Lantmäteriet uses the Bernese Addneq2 for the combination and Finnish Geodetic Institute uses CATREF (Altamimi et.al. 2003). The combined solutions are named NKL and NKF, respectively.

Both the national LAC-solutions and the combined solutions are submitted to an ftp-server hosted by the Danish Geodata Agency. The server has been used for work like the NKG GNSS campaigns in the NKG working group for Reference Frames, Positioning and Navigation for the last ten years. When setting it up as an operational archive for NKG GNSS AC solutions and products, some measures are taken to increase the security, e.g. separate logins for each LAC with differentiated reading/writing permissions and backup routines. The structure of the ftp-archive has been developed and is similar to the structure used by EPN and IGS, but using separate directories for each LAC to facilitate the differentiated reading/writing permissions.

Draft guidelines have been prepared describing the responsibilities, processing setup, schedules for submitting solutions, station naming etc.

NKG AC Start up

We decided to start the operational processing from GPS-week 1795 (June 2014), although not following the strict deadlines for submitting solutions while still developing and refining the processing routines. Before starting with GPS-week 1795, the week 1785 was re-run for the final sub-networks and the final processing strategy to see that everything was OK.

There have been some iteration (and re-processing of some LAC-solutions) in the beginning to get good consistent solutions. Today (Nov 2014) there are five national LACs contributing with daily and weekly solutions on a regular basis (EST, FGI, LAT, LM_ and SK_ covering Estonia, Finland, Latvia, Sweden and Norway).

The routines for combination are still under development, but preliminary combined solutions are available for NKL at the GST-ftp-server. The combinations will be re-run when more LAC-solutions are added. The combination routines used for EPN has been used as an example, but of course been adapted for the NKG GNSS AC. Routines and software for checking the SINEX-files before combination has been developed in order to detect inconsistencies at an early stage. Outlier detection and rejection limits have been discussed between the two combination centres.

Next steps

When the operational processing is running smoothly focus will be on the next step, which is re-processing of the networks back to 1997. For the re-processing we decided to process just GPS-data, but the ambition is to process the NKG EPN network both with GPS only and GPS+GLONASS as a test. We suspect that the changed GLONASS geometry might affect the time series and estimated velocities at high latitudes.

When the re-processing is completed and combined, which is planned to be accomplished by the autumn 2015, the daily combined solutions will be stacked to time series and station velocities will be estimated.

Conclusions

The NKG GNSS AC is a good example of an operative collaboration between the Nordic and Baltic countries under the framework of NKG.

When starting the NKG GNSS AC project there were three of the participating organizations that performed routine based processing every week of their permanent stations. Today there are five organizations doing this and another two organizations have started the work, all using the same processing setup!

The project has been delayed due to several reasons, one is the release of the version 5.2 of the Bernese GNSS Software. However, the project group has been a good forum for the examination of the new features in the new version of the Bernese Software.

References

Altamimi, Z., P. Sillard, and C. Boucher (2003): CATREF Software: Combination and Analysis of Terrestrial Reference Frames, Publication of Laboratoire de Rechereche en Géodésie, Institut Géographique National, 2003.

Dach, R., U. Hugentobler, P. Fridez, M. Meindl (Eds); (2007): Bernese GPS Software Version 5.0. User manual, Astronomical Institute, University of Bern.

EPN Coordination group (2013): Guidelines for the EPN Analysis Centres. http://www.epncb.oma.be/_documentation/guidelines/guidelines_analysis_centres.pdf

Jivall L. (2014a): Comparison of Vienna mapping Function(VMF1) and Global Mapping Function (GMF) for NKG GNSS AC. NKG General assembly 2014, Gothenburg.

Jivall L. (2014b): Test of clustering for regional networks using the Bernese version 5.2. Internal PM, Lantmäteriet 2014.

From Passive to Active Control Point Networks – Evaluation of Accuracy in Static GPS Surveying

Pasi Häkli*, Ulla Kallio and Jyrki Puupponen
*Finnish Geospatial Research Institute (FGI), National Land Survey of Finland
Geodeetinrinne 2, FI-02430 Masala, Finland
e-mail: pasi.hakli@nls.fi

Summary

Over the past decade, active GNSS stations have become increasingly essential for surveying. Positioning services, such as network-RTK, have revolutionized surveying practices and challenged traditional control point networks and the ways of measuring them. A change from a passive to active definition of control point networks would require a comprehensive change in measuring principles. Until now, surveyors making geodetic measurements have been obliged to do the measurements hierarchically relative to the nearest higher order control points.

In Finland, the definition of the national ETRS89 realization, EUREF-FIN, is based on traditional passive networks instead of active GNSS stations. Since the average spacing of active stations in network-RTK services is approximately 70 km, and for passive networks much less, the use of active stations would require measurements neglecting the hierarchy of the (defining) passive networks. In this paper, we evaluate the accuracy of static GPS surveying through active stations with regard to the official passive control point networks in EUREF-FIN.

The results of this study allow us to conclude that the consistency of static GPS surveying from active GNSS stations with respect to the official hierarchical passive control point network is in the order of 1–3 cm (rms). However, some systematic features can be seen. One issue that needs more careful consideration is the determination of ETRS89 coordinates for active GNSS networks. In Finland, the reference frames (i.e. positions of control points) are influenced by postglacial rebound that challenges the determination and maintenance of accurate static coordinates, especially in wide areas and over a long time span. This study suggests that the obtained accuracy can be improved by correcting for the postglacial rebound effect.

The study was originally presented at the FIG Working Week 2013 in Abuja, Nigeria. Full paper can be found online in the proceedings of the FIG Working Week 2013 (http://www.fig.net/pub/fig2013/techprog.htm)

HMK – Swedish handbook in surveying and mapping

Anders Alfredsson, Johan Sunna and Lars Jämtnäs
Lantmäteriet
SE-801 82 Gävle, Sweden
Email: anders.alfredsson@lm.se

Introduction

Lantmäteriet, the Swedish mapping, cadastral and land registration authority, has a long tradition of supporting the Swedish surveying and mapping community. In the mid-90s a set of nine handbooks was published covering different subjects such as geodesy, photogrammetry, cartography and digitizing. These books where widely spread within the mapping community in Sweden and some parts are still used today. When the old set of handbooks was published, the aim was to raise the awareness and the knowledge about surveying methods, and to reach out to the community in a standardized way. This was accomplished with very good results. Today, new techniques and new working methods have indeed increased the demands for updated handbooks.

To keep the recommendations updated with new techniques, several reports and publications have been published meanwhile over the years. Now it is time to gather all recommendations and to get an overall picture of the situation. In the writing of the new handbook several different information sources are used. Together with the older books, the recommendations will be based on our own investigations, reports and knowledge, but also reports and guidelines from other organizations and authorities around the world.

The new Swedish handbook in surveying and mapping is divided into two main parts, geodesy and geodata capture together with an introduction document. The introduction document will give an overview of the different documents in HMK and will serve as an introduction to the different parts, in addition there will also be a separate document describing the geodata quality. The two main parts are then divided into several different sections as well. The part of geodata capture includes the following sections; aerial photography, photogrammetric surveying, laser scanning, orthophoto and digital elevation models. This paper will focus on the geodetic part of the handbook. As the geodetic part will provide the basic recommendations in geodetic surveying, the geodata capture part will use the geodetic part as reference for the related recommendations.

Lantmäteriet has the overall responsibility to produce the handbook, but KTH (Royal institute of technology) and HiG (University of Gävle) together with some other organizations are involved in the work to write the handbook.

The aim of the handbook

The handbook shall:

- Contribute to an efficient and standardized handling of survey and mapping issues in Sweden.
- Cover the needs for both a description of the Swedish geodetic infrastructure and actual surveying recommendations.
- Meet the demands from the surveying community in Sweden with recommendations on how geodetic surveying shall be performed and what parameters that shall be reflected on.
- Be used for both educational purposes and in procurement processes.

To set the recommendations, various investigations in different fields will be needed. The investigations will result in a number of technical reports that will be the basis for the recommendations in the handbook.

GUM

The terminology to express uncertainties will follow GUM (Guide to the Expression of Uncertainty in Measurement). The GUM terminology is introduced in the field of geodata capture and geodesy within the aim of HMK to give standardized recommendations and to raise the awareness of the community.

Digital publishing of the handbook

All parts of HMK will be published in digital format at a special website as pdf-files; no printed book will be made. By this the procedure to publish new versions of the documents will be simplified. All documents will be published on the website; www.lantmateriet.se/hmk. The first official documents in the geodata capture section where published in 2013, and in 2015 the plan is to publish the first parts of the geodetic section.

To keep the documents updated, revisions will be made once a year.

Together with the actual handbook, the technical reports will be published at the website as well.

Time plan

The first version of all documents in the geodetic part will be published in March 2015 in conjunction with the Swedish conference Position 2015.

New chapters will be added to the handbook during 2015 to include methods that are not handled in the first version.

Structure of the geodetic part of the handbook

The geodetic part of the handbook is divided into three sections as seen in figure 1: a knowledge base, surveying guidelines and a section aimed at supporting users to choose a suitable surveying method. The idea is that the handbook should be possible to read in two directions. If the reader wants to have information for educational purposes, the handbook should be read from top to bottom, but if used in a procurement procedure than it can be read from bottom and up. In the latter case the reader will be directed directly to the recommended parts in the guideline structure and not forced to read the whole document to get the needed information.

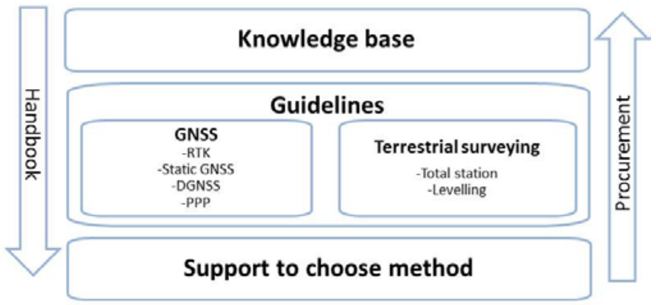

Fig. 1. Structure of the geodetic part of the handbook

Knowledge base

The knowledge base section will include information concerning the geodetic infrastructure in Sweden such as reference systems and frames, map projections and geodetic surveying in general. All recommendations will be based on the actual situation that are valid for the Swedish conditions, such as geoid model and map projections. Together with the recommendations, the handbook can be used in an educational purpose and provide a basic understanding for the national geodetic infrastructure. The reader can use the handbook to understand how to use the geodetic infrastructure in a proper manner. For example understanding how new points are established with respect to the reference benchmarks.

Nowadays when the GNSS techniques are common, a survey can be performed with respect to either active GNSS stations (e.g. network RTK) or passive benchmarks. To get these different realizations of the reference system to be handled together, it is important to calculate the uncertainty derived from different reference stations/benchmarks of the established points. The handbook will describe this procedure and include tables with expected uncertainties for benchmarks and services.

By reading the knowledge base for an educational purpose, the reader will get a common sense in geodetic surveying in general. By recommendations in basic geodetic handling, the handbook will help the user to make their own decisions.

Guidelines

The guideline section will be divided into at least two documents, GNSS and terrestrial techniques. The GNSS section is the first one to be published. It will consist of recommendations for GNSS based surveying techniques and methods. In the first version, to be published during 2014, the guidelines will focus on the standalone surveying methods. Later it will be supplemented with combined methods such as GNSS integrated with totalstation.

One of the key issues in the handbook is the need of describing control methods for geodetic surveying. The control procedures will be described in a separate chapter and connected with links from each survey method. Methods to control network RTK measurements have been investigated previously (Odolinski 2010b), but will be described in more detail in the new handbook, to cover a wider range of surveying scenarios.

GNSS

The guidelines for the GNSS methods is the first section to be published. Initially, the GNSS section will include guidelines for static GNSS, RTK and network-RTK. Later on guidelines for Virtual RINEX, DGNSS and Precise Point Positioning (PPP) will be included as well.

All techniques can be used in different ways, with different observation times for instance. Depending on how the techniques are used, different measurement uncertainties can be expected. The guidelines will take this fact into account and describe up to five different surveying strategies for each technique. The different strategies will be designed so that significant differences for expected uncertainty will be distinguished. The GNSS guidelines will also contain recommendations on the degree of measurement details (e.g. PDOP) to be included in the survey report.

To be able to give specific recommendations in the guidelines and set the parameters for the different levels of expected uncertainty, some additional investigations are needed. In the RTK chapter for example we will study how the temporal correlation between observation sessions affects the measurement uncertainty.

Since the last edition of HMK, the processing of static GNSS has developed, we need to investigate the validity of our recommendations and in some cases also decide what our recommendations shall be. For instance no official recommendations on how to use the ionosphere-free combination (L3) exist.

Terrestrial surveying

Most of the recommendations from the previous edition of HMK are still valid in the area of terrestrial surveying. The work with this section is mainly to take all relevant recommendations from the previous handbooks and to update and adjust them to the current situation.

Support to choose method

If the reader wants to use the handbook in a procurement procedure this is the first document that the reader will enter. The idea is that the reader will get support to choose an appropriate surveying method based on the tolerance requirements and the actual conditions at the survey site. The expected uncertainty together with basic parameters affecting the survey will support the user to choose both an appropriate surveying technique and to set the level of that technique. The document will be designed with tables and diagrams to help the user as clear as possible. If more information is needed to make the decision, then other parts of the handbook can be read as complement.

Challenges

To produce a handbook that spans virtually the entire area of geodata capture is a large and time-consuming work. The biggest challenge in the geodetic part is to write the handbook in a way that it meets the demand from the users and to get the users to actually use the handbook.

The content of the handbook shall reflect the demands in the survey community and give support in the surveyor's daily work. To give this support it is mandatory to describe all surveying methods and techniques that are needed and useful. The handbook shall also be designed in a way that makes it easy to understand and to use both in the everyday fieldwork and in procurement procedures.

When the recommendations are any kind of numeric values, it is of most importance that the values are verified and tested properly. The challenge is to develop field tests and analysis methods that result in the actual recommendation values, and also to verify the correctness of the values.

The plan is now to publish the geodetic part of the handbook during March 2015. It will be a challenge to produce all sections and to have all investigations done in time, the time plan has been extended already.

Concluding remarks

The geodata capture and surveying community in Sweden will benefit from having a collection of recommendations and standards that are adapted to Swedish conditions.

HMK, the Swedish handbook in surveying and mapping will provide support in the whole field of geodata capture and geodesy to the surveying community in Sweden. To offer support in such a wide area requires a major effort on coordination between different organizations. The HMK project is mainly coordinated from Lantmäteriet, but other authorities and organizations are involved as well.

References

ISO/IEC Guide 98-3:2008 Uncertainty of measurement -- Part 3: Guide to the expression of uncertainty in measurement (GUM:1995) Url:www.iso.org/sites/JCGM/GUM-introduction.htm

NORIN D, ENGFELDT A, JOHANSSON D, LILJE C, 2006: Short manual for surveying with SWEPOS Network RTK service. Rapportserie: Geodesi och Geografiska informationssystem, 2006:2, Lantmäteriet, Gävle. (In Swedish). Url:http://www.lantmateriet.se/Global/Kartor%20och%20geografisk%20information/GPS%20och%20m%c3%a4tning/Geodesi/Rapporter_publikationer/Rapporter/LMV-Rapport_2006_2_utgava3.pdf, visited 2014-03-17

ODOLINSKI R, 2010: Swedish User Guidelines for Network RTK. XXIV FIG Congress, Sydney 2010

ODOLINSKI, 2010b: User Guidelines for Network RTK. Rapportserie: Geodesi och Geografiska informationssystem, 2010:3, Lantmäteriet, Gävle. (In Swedish). Url:http://www.lantmateriet.se/Global/Kartor%20och%20geografisk%20information/GPS%20och%20m%c3%a4tning/Geodesi/Rapporter_publikationer/Rapporter/LMV-Rapport_2010_3.pdf, visited 2014-03-17

Sea level observations using multi-system GNSS reflectometry

Johan S. Löfgren & Rüdiger Haas
Chalmers University of Technology, Department of Earth and Space Sciences,
Onsala Space Observatory, SE-439 92 Onsala (Sweden)
e-mail: johan.lofgren@chalmers.se, rudiger.haas@chalmers.se

Introduction

Information on sea level and its changes are important in connection to global climate change processes. For centuries, sea level has been observed with coastal tide gauges and since some decades with satellite altimetry. Furthermore, during recent years the application of Global Navigation Satellite System (GNSS) reflectometry, also known as GNSS-R, for sea level observations has been developed, see e.g., Martin-Neira M. (1993), Lowe *et al.* (2002), Gleason *et al.* (2005), Löfgren *et al.* (2011a,b; 2014), Larson *et al.* (2013a,b), and Löfgren & Haas (2014). Various methods exist, using ground-based, airborne and space-borne systems, and using different analysis methods. We present results from a dedicated GNSS tide gauge installed at the Onsala Space Observatory at the Swedish west coast. This installation consists of commercially-off-the-shelf GNSS equipment, including geodetic-type choke-ring antennas and geodetic-type receivers and allows for analysis using both phase and Signal-to-Noise Ratio (SNR) data.

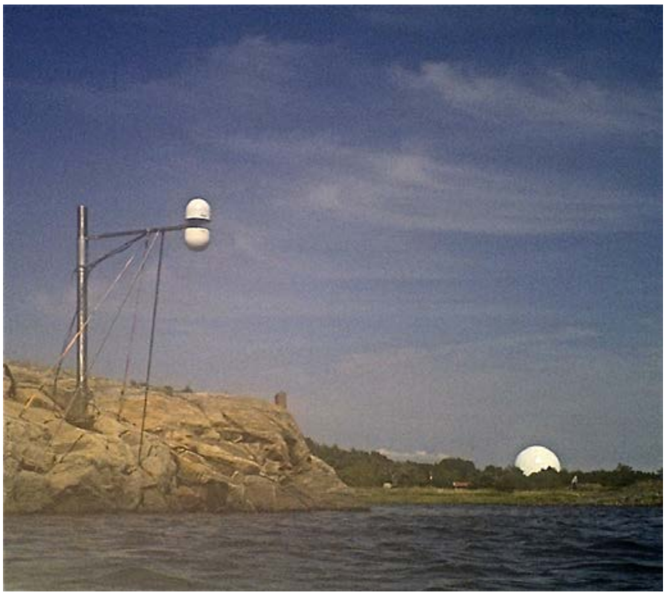

Fig. 1. *The GNSS tide gauge installation, with one zenith-looking and one nadir-looking antenna (covered by hemispherical radomes), at the Onsala Space Observatory in Sweden. The radome of the 20 metre radio telescope is visible in the background.*

The GNSS tide gauge installation

The GNSS tide gauge consists of two antennas mounted on a beam extending in southward direction over the coastline. The antennas are aligned along the local vertical, with one antenna facing toward zenith direction and the other facing toward nadir, see Fig. 1. The zenith-looking antenna is Right-Hand-Circular-Polarised (RHCP) while the nadir-looking antenna is Left-Hand-Circular-Polarised (LHCP). The zenith-looking antenna receives predominantly the direct RHCP satellite signals, while the nadir-looking antenna receives predominantly signals that are reflected off the sea surface and thus have changed polarization to LHCP in the reflection process.

Each antenna (Leica AR25 multi-GNSS choke-ring) is connected to a GNSS receiver of model Leica GRX1200 GG PRO. Each receiver individually record multi-frequency signals of several GNSS with 1 Hz sampling rate. The signals used for this study are Global Positioning System (GPS) and GLObalnaya NAvigatsionnaya Sputnikovaya Sistema (GLONASS) carrier-phase and Signal-to-Noise Ratio (SNR) data (recorded with resolution 0.25 dBHz) in both L-band frequency bands. More information about the installation is given in Löfgren & Haas (2014) and Löfgren *et al.* (2014).

Analysis methods

The recorded GNSS data can be analysed in two different ways to derive information on the sea level and its variation. In the first analysis strategy, carrier-phase data are used from both the zenith-looking RHCP antenna and the nadir-looking LHCP antenna. As previously described, the zenith-looking antenna receives the direct RHCP satellite signals, working in the same way as a geodetic GNSS station and the nadir-looking antenna receives the satellite signals that have reflected off the sea surface. Depending on the elevation angle of the transmitting satellite, the signal will change polarization after reflection. After reflection off the sea surface, most of the signal will turn into a LHCP signal (LHCP is dominant for reflections from elevation angles of about 10 to 90 degrees) and is thus received by the receiver connected to the nadir-looking LHCP antenna.

With this in mind, data from both receivers can be analysed together applying geodetic-type phase-delay analysis with, e.g., a single-difference or double-difference strategy, see Löfgren *et al.* (2011a,b), Löfgren (2014), and Löfgren & Haas (2014). These analysis methods determine the baseline between the two antennas (or actually the baseline between the zenith-looking antenna and the nadir-looking antenna mirrored in the sea surface), which is proportional to the height of the installation above the sea surface. This distance will change with a changing sea surface.

In the second analysis strategy, SNR data are used from only the zenith-looking RHCP antenna. The single zenith-looking installation is the standard setup for any geodetic GNSS station and the SNR-strategy can therefore be used for any GNSS installation close to the ocean, see Larson *et al.* (2013a,b), Löfgren (2014) and Löfgren *et al.* (2014).

Even though the RHCP antenna is designed to receive GNSS signals from the upper hemisphere and suppress signals from the lower hemisphere, i.e., signals reflected in the surroundings, a portion of the satellite signals that have reflected off the sea surface will reach the antenna. These reflected signals (also called multipath signals) interfere with the direct satellite signals and the composite signals are recorded by the GNSS receiver. This effect is most dominant for signals from lower satellite elevations (about 0 to 30 degrees) and depends on the antenna gain pattern in combination with the reflected signal polarisation, which is dominantly RCHP for low satellite elevations (about 0 to 10 degrees) and then decreasing for increasing satellite elevation.

This interference effect is especially visible in the recorded SNR of the zenith-looking antenna and the multipath oscillations in the SNR can be used to derive the distance between the sea surface and the antenna. Again, this distance will change with a changing sea surface.

The two different analysis strategies have advantages and disadvantages. Furthermore, the sea level results from both strategies can be combined with standard positioning of the zenith-looking antenna to give absolute sea level information, i.e. sea level with respect to the International Terrestrial Reference Frame.

Sea level results

The GNSS-derived sea level was compared to independent sea level observations from a co-located traditional tide gauge (pressure sensors). As an example, sea level time series from both analysis strategies, phase-analysis and SNR-analysis, both systems, GPS and GLONASS, and both frequency bands, L_1 and L_2, are presented in Fig. 2 for 20 days in 2012 (October 9 to 29). In addition, a combined

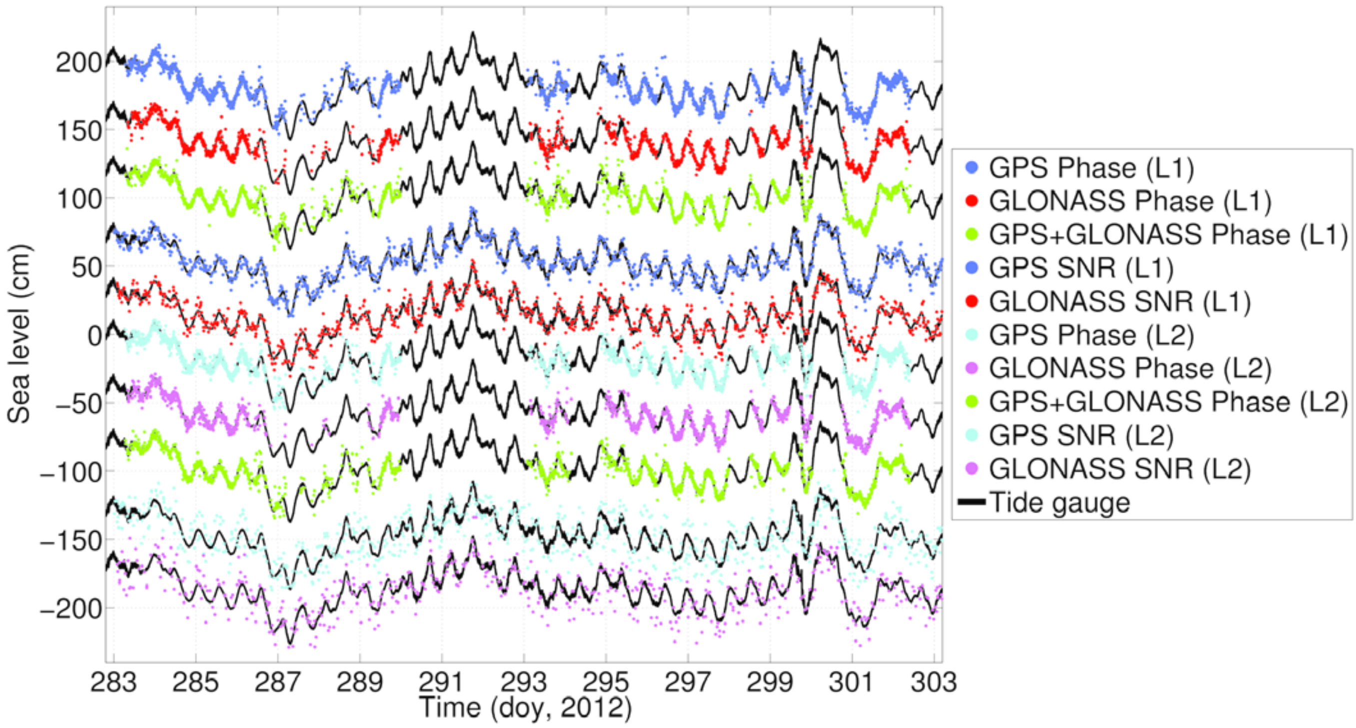

Fig. 2. *Sea level derived from the GNSS tide gauge at the Onsala Space Observatory during 20 days in 2012 (October 9 to 29). From top to bottom the sea level times series are derived from: GPS phase (L_1), GLONASS phase (L_1), GPS and GLONASS phase (L_1), GPS SNR (L_1), GLONASS SNR (L_1), GPS phase (L_2), GLONASS phase (L_2), GPS and GLONASS phase (L_2), GPS SNR (L_2) and GLONASS SNR (L_2). Each time series is paired with the independent sea level observations from the co-located tide gauge (black line). A mean is removed from each time series and the pairs are displayed with an offset of 40 cm to improve visibility.*

Tab. 1. *Comparison of GNSS-derived sea level, for both the SNR-analysis strategy and the phase-analysis strategy, and the sea level from the co-located traditional tide gauge. Shown are results from GPS-only, GLONASS-only, and from multiple-GNSS analysis (GPS+GLONASS).*

		GPS		**GLONASS**		**GPS+GLONASS**	
		L1	**L2**	**L1**	**L2**	**L1**	**L2**
SNR	**Solutions (nr)**	1516	1229	1254	882		
	Correlation coefficient	0.97	0.86	0.96	0.87		
	Standard deviation (cm)	4.0	8.9	4.7	8.9		
Phase	**Solutions (nr)**	1534	1495	1408	1286	1581	1484
	Correlation coefficient	0.95	0.95	0.96	0.96	0.95	0.96
	Standard deviation (cm)	3.5	3.5	3.3	3.2	3.7	3.4

phase-analysis solution of GPS and GLONASS data is shown for both L_1 and L_2 in Fig. 2. The times series are compared in a relative sense, i.e., a mean is removed for each time series. In Fig. 2, each GNSS time series is displayed together with the time series from the co-located traditional tide gauge and each time series pair is offset from each other by 40 cm to increase visibility.

From Fig. 2, it is possible to conclude that all GNSS-derived time series show the same sea level variations as seen by the co-located traditional tide gauge. The time series resulting from the SNR-analysis are noisier than those resulting from the phase-analysis and the sea level from SNR-analysis of the data from frequency band L_2 (not GPS L_{2C}) appears to be the noisiest. Furthermore, there are gaps in the phase analysis time series, which are not present in the SNR analysis time series. This is consistent with previous studies, see Löfgren *et al.* (2011b) and Löfgren & Haas (2014), showing that the geodetic GNSS receiver has problems tracking the reflected signal in rough sea surface conditions. However, the SNR solutions (with data from the zenith-looking antenna) appear to be unaffected by the sea surface roughness in this study.

In order to quantify the comparison between the GNSS-derived sea level and the sea level observations from the co-located traditional tide gauge, the correlation coefficient and the standard deviation are calculated for each time series pair seen in Fig. 2. The results of the comparison are presented in Tab. 1.

First of all, the high correlation coefficients of 0.86 to 0.97, shown in Tab. 1, demonstrate the strong agreement between the traditional tide gauge sea level observations and the GNSS-derived sea level. The correlation coefficients for the phase-analysis strategy, for separate and combined GPS and GLONASS analysis, show similar results for both frequency bands (0.95 to 0.96). However, for the SNR-analysis strategy, the results from frequency band L_1 shows a better agreement to the tide gauge sea level than the results from frequency band L_2, with correlation coefficients of 0.96 to 0.97 and 0.86 to 0.87, respectively.

The values of the standard deviation for the phase-analysis are on the same order (3.2 to 3.7 cm) for both systems (separate and combined) and for both frequency bands, see Tab. 1. This is better than for the SNR-analysis, where the standard deviation is lower for frequency band L_1 than for frequency band L_2 with values of 4.0 to 4.7 and 8.9, respectively.

There are no combined solutions for the SNR-analysis, see Tab. 1. The reason is that each observed satellite arc is analysed separately (compare with the phase-analysis where all observations are combined in a least-squares solution each epoch). However, one option for "combination" of the SNR-analysis results would be to merge the GPS and GLONASS time series into a single GNSS SNR time series.

A comment should also be made regarding the number of solutions for the respective analysis strategies in Tab. 1, which appear to be more or less the same for the 20 days This is because of the previously explained problems for the geodetic receiver connected to the nadir-looking antenna with tracking the reflected signals in rough sea surface conditions. The actual rate of solutions or temporal resolution for the SNR-analysis is about 30 to 50 solutions per day and for the phase-analysis the same number is 144 continuous solutions per day for this study. Furthermore, the temporal resolution of the phase-analysis solutions can be as high as the sampling rate of the GNSS receiver.

Conclusion

The aim of this study was to show sea level results obtained from GNSS reflectometry data from the GNSS tide gauge at the Onsala Space Observatory and compare them to sea level observations from a co-located traditional tide gauge. Two analysis strategies have been presented: SNR-analysis, using SNR data from one zenith-looking RHCP antenna (can be used with data from any GNSS station close to the ocean), and phase-analysis, using phase data from both a zenith-looking RHCP antenna and a nadir-looking LHCP antenna together. The two strategies have been applied to multi-system data (GPS and GLONASS data) in both the L_1 and L_2

frequency band. In addition to separate analysis for the data of the two systems, GPS and GLONASS data have been combined for the phase-analysis.

In comparison between the GNSS-derived sea level and sea level from the co-located traditional tide gauge, the correlation coefficients were 0.86 to 0.97, showing that the variations in the sea level are well represented by the GNSS observations.

Our results show that the phase-analysis strategy with GPS and GLONASS, using signals in the L_1 and L_2 frequency bands, gives a standard deviation on the order of 3-4 cm when compared to the independently observed sea level observations from the co-located traditional tide gauge. The corresponding results derived from the SNR-analysis strategy are worse by a factor of about 1.5 and 3 for the L_1 and L_2 (not L_{2C}) frequency bands, respectively. However, the SNR-analysis method appears to have advantages in conditions of high sea surface roughness. Furthermore, no major differences can be seen in the results from GPS and GLONASS data, i.e. both systems appear to provide equally good sea level observations.

As previously mentioned, the standard deviation values of the combined solution are on the same level as that of the separate solutions (perhaps even slightly higher than expected). The phase-analysis combination was done without consideration of inter-system biases (GNSS and receiver dependent) and antenna phase centre corrections. A future multi-system solution could therefore benefit from the inclusion of parameters for these biases and corrections.

Future plans for the the two analysis strategies are to, in addition to GPS and GLONASS observations, include multi-frequency observations from Galileo and BeiDou and to evaluate the sea level results against sea level from other GNSS reflectometry techniques and new traditional tide gauges at the Onsala Space Observatory.

As suggested, merging the SNR-analysis sea level results from the different systems can be beneficial by, e.g., increasing the temporal resolution of the sea level time series. Another future improvement could be to use both analysis strategies in a filter approach in order to benefit from the individual advantages.

References

Gleason S., Hodgart S., Sun Y., Gommenginger C., Mackin S., Adjrad M.,Unwin M. (2005): Detection and Processing of bistatically reflected GPS signals from low Earth orbit for the purpose of ocean remote sensing. *Trans. Geosci. Remote Sensing* 43(6), 1229-1241.

Larson K.M., Löfgren J.S., Haas R. (2013a): Coastal sea level measurements using a single geodetic GPS receiver. *Adv. Space Res* 51(8), 1301-1310.

Larson K.M., Ray R.D., Nievinski F.G., Freymueller J.T. (2013b): The accidental tide gauge: a case study of GPS reflections from Kachemak Bay, Alaska. *IEEE GRSL* 10(5), 1200-1205.

Lowe S.T., Zuffada C., Chao Y., Kroger P., Young L.E., LaBrecque J.L. (2002): 5-cm-Precision aircraft ocean altimetry using GPS reflections. *Geophys. Res. Lett.* 29(10), 4 p.

Löfgren J.S., Haas R., Johansson J.M. (2011a): Monitoring coastal sea level using reflected GNSS signals. *J. Adv. Space Res.* 47(2), 213-220.

Löfgren J.S., Haas R., Scherneck H.-G., Bos M.S. (2011b): Three months of local sea level derived from reflected GNSS signals. *Radio Sci.* 46, 12 p.

Löfgren J.S. (2014): Local sea level observations using reflected GNSS signals. *PhD dissertation*, Department of Earth and Space Sciences, Chalmers University of Technology, 62 p.

Löfgren J.S., Haas R. (2014): Sea level measurements using multi-frequency GPS and GLONASS observations. *EURASIP J. Adv. Sig. Pr.* 2014:50, 13 p.

Löfgren J.S., Haas R., Scherneck H.-G. (2014): Sea level time series and ocean tide analysis from multipath signals at five GPS sites in different parts of the world. *J. Geodyn.* 80, 66-80.

Martin-Neira M. (1993): A PAssive Reflectometry and Interferometry System (PARIS): Application to ocean altimetry. *ESA J.* 17, 331–355.

Evaluation of GOCE-based Global Geoid Models Over Finland

Timo Saari and Mirjam Bilker-Koivula
National Land Survey of Finland, Finnish Geospatial Research Institute, Department of Geodesy and Geodynamics
Geodeetinrinne 2, FI-02430 Masala, Finland
e-mail: timo.saari@nls.fi, mirjam.bilker-koivula@nls.fi

Introduction

The European Space Agency's (ESA) Gravity field and steady-state Ocean Circulation Explorer (GOCE) made its final electrostatic gravity gradiometer observations in the fall of 2013, before it re-entered into the Earth's atmosphere. By then it had exceeded its expected lifespan of one year with more than three additional years. Thus, the satellite mission collected more data from the Earth's gravitational field than expected, and more comprehensive global geoid models have been derived ever since.

In this study the global geoid models produced by the GOCE satellite mission are analyzed. Altogether 15 GOCE models are evaluated over Finnish territory.

Description of data

In the following we shortly describe the GOCE gravity field models that were evaluated over Finland. In addition, the ground truth data (GPS-levelling and gravity) is described.

GOCE gravity field models

We analyzed all of the GOCE global gravity field models that were calculated by the GOCE High-level Processing Facility (HPF) (Rummel et al, 2004) by ESA. The HPF uses three different gravity field modelling methods resulting in three different models: direct (DIR), time-wise (TIM) and space-wise (SPW). A description of the three methods is given in (Pail et al, 2011). The DIR models are calculated starting with an a priori model (EIGEN-5C) and complementary (Gravity Recovery And Climate Experiment (GRACE) and Laser Geodynamics Satellites (LAGEOS)) data as an improvement for the lower degrees and orders. The TIM and SPW models are based on GOCE data only. DIR and TIM models have been released for 5 data levels and SPW models for 2 data levels.

In addition to the models by HPF, we analyzed three alternative global gravity field models from GOCE: the JYY models by Yi et al (2013) and the ITG model by Schall et al (2014). The JYY models use complementary data from the GRACE gravity field model ITG-Grace2010s, which is used also in the DIR solutions. The ITG model is based on GOCE data only. The GOCE models analyzed in this study are described in Tab. 1, where also the data acquisition periods and the maximum degrees and orders of the models are presented.

Tab. 1. *GOCE global gravity field models.*

GOCE Model	Data acquisition period	Max d/o	Reference
DIR1	1/11/2009–1/2010	240	Bruinsma et al, 2010
DIR2	1/11/2009–7/2010	240	Bruinsma et al, 2010
DIR3	1/11/2009–4/2011	240	Bruinsma et al, 2010
DIR4	1/11/2009–8/2012	260	Bruinsma et al, 2013
DIR5	1/11/2009–20/10/2013	300	Bruinsma et al, 2013
TIM1	1/11/2009–1/2010	224	Pail et al, 2010
TIM2	1/11/2009–7/2010	250	Pail et al, 2011
TIM3	1/11/2009–4/2011	250	Pail et al, 2011
TIM4	1/11/2009–6/2012	250	Pail et al, 2011
TIM5	1/11/2009–20/10/2013	280	Pail et al, 2011
SPW1	1/11/2009–1/2010	210	Migliaccio et al, 2010
SPW2	1/11/2009–7/2010	240	Migliaccio et al, 2011
JYY_02S	1/11/2009–31/8/2012	230	Yi et al, 2013
JYY_04S	1/11/2009–19/10/2013	230	Yi et al, 2013
ITG-02	1/11/2009–30/6/2010	240	Schall et al, 2014

GPS-levelling data

For the comparison of the height anomalies, two GPS-levelling datasets were used: The European Vertical Reference Network - Densification Action (EUVN-DA) dataset and the dataset of the National Land Survey (NLS) of Finland.

The EUVN-DA dataset consists of the 50 Finnish EUVN-DA GPS-levelling points (Ollikainen, 2006). The points have EUREF-FIN GPS coordinates as well as N2000 heights (Bilker-Koivula, 2010). The dataset of the NLS of Finland consists of 526 GPS-levelling points taken from the register of the NLS. The accuracy (classes 1 to 3) and distribution of the points is not homogenous and the dataset partly overlaps with the EUVN-DA dataset. The coverage of the datasets is presented in Fig. 1.

Both GPS-levelling datasets were corrected for the land uplift taking place between the epoch of the N2000 levelling data (2000.0) and the epoch of the EUREF-FIN GPS data (1997.0). The GPS data was transformed to epoch 2000.0 using vertical velocities taken from the NKG2005LU land uplift model (Vestøl, 2005; Ågren and Svensson, 2007). For a more detailed description of the GPS-levelling datasets see Bilker-Koivula (2015).

Gravity data

For the comparison of the free-air gravity anomalies the gravity database of the Finnish Geodetic Institute (FGI) was used. The database contains gravity observations from early 20th century to present. Observations include terrestrial gravity measurements as well as measurements at sea, mainly on ice. All of the data in the gravity database were transformed from epoch 1963.0 to 2000.0, which is the epoch of the current height system of Finland N2000. Also the tide system was changed from mean tide to the zero tide. Gravity data from before 1938, mainly pendulum data, was removed. The coverage of the gravity dataset is presented with the GPS-levelling datasets in Fig. 1.

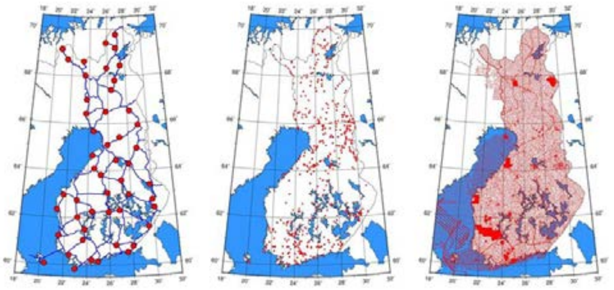

Fig. 1. *The coverage of the GPS-levelling and gravity datasets in Finnish territory: EUVN-DA with 1st order precise levelling network (left), NLS (middle) and gravity database of the FGI (right).*

Evaluation of the height and gravity anomalies

The GOCE gravity field models were compared with the ground data in Finnish territory. For the comparison, height anomalies and free-air gravity anomalies were calculated from the GOCE models using the pyGravsoft-software (Forsberg and Tscherning, 2008).

At first, all of the GOCE models (that have a maximum degree and order of at least 240) by HPF were calculated up to degree and order 240, and were compared against GPS-levelling data. The results of the comparisons can be seen in Fig. 2. Generally, the DIR models agree better with the GPS-levelling data, most probably due to the use of complementary data from the observations of GRACE and LAGEOS. All modelling methods show an improvement of the later models over the earlier models. This was expected, as the later models include more GOCE data.

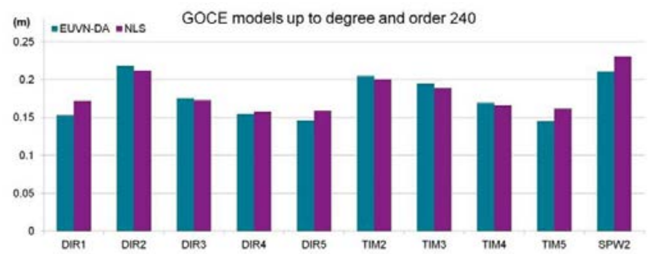

Fig. 2. *Comparison of the height anomalies from the GOCE models up to degree and order 240 and GPS-levelling data: standard deviations of the differences (m).*

Next, we calculated the height and gravity anomalies from all of the GOCE models, described in Tab. 1, using all available coefficients and compared them with the GPS-levelling and gravity data. Fig. 3 shows the standard deviations of the height anomalies compared to the EUVN-DA and the NLS data. In addition, Fig. 3 includes the gravity anomalies (dotted curve) compared to terrestrial gravity data.

The best results are achieved with the latest DIR and TIM models, where the standard deviations of the height anomalies are for the DIR5 model 0.163 m (EUVN-DA) and 0.165 m (NLS), and for the TIM5 model 0.163 m (EUVN-DA) and 0.179 m (NLS). Standard deviations of the gravity anomalies behave in a similar fashion: 9.91 mgal (DIR5) and 10.14 mgal (TIM5).

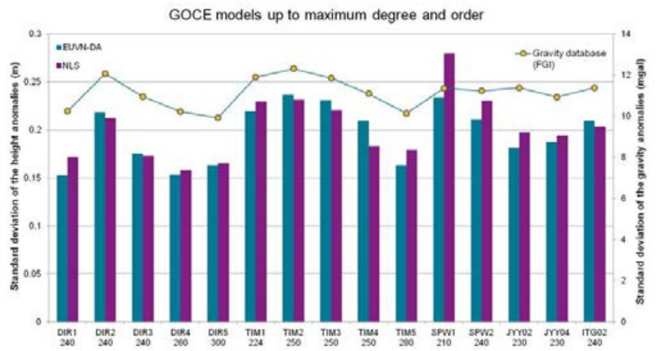

Fig. 3. *Comparison of the height and gravity anomalies from the GOCE models using all available coefficients against GPS-levelling and gravity data: standard deviations of the differences (m) and (mgal).*

Conclusion

In this study the global geoid models produced by the GOCE satellite mission were analyzed. Altogether 15 GOCE gravity field models were evaluated with GPS-levelling data and gravity observations over Finland.

As expected, in most cases the later geoid models gave better results than earlier models. All of the latest GOCE models gave standard deviations of the height anomaly differences of around 15 cm and of gravity anomaly differences of around 10 mgal over Finland. In addition, Fig. 3 expresses that the best solutions are not always achieved with the highest maximum degree and order of the satellite gravity field models, since the highest coefficients (above 240) may be less accurately determined.

Acknowledgements

This research has been funded by a grant of Vilho, Yrjö and Kalle Väisälä Foundation, and the ESA-MOST Dragon 3 contract No. 4000110315/14/I-BG.

References

Ågren J. & Svensson R. (2007): Postglacial Land Uplift Model and System Definition for the New Swedish Height System RH 2000. *LMV-Rapport 2007:4*. Reports in Geodesy and Geographical Information Systems. Gävle, Sweden. 124 p. ISSN 280-5731.

Bilker-Koivula M. (2010): Development of the Finnish height conversion surface FIN2005N00. *Nordic Journal of Surveying and Real Estate Research*, **7:1**, 76-88.

Bilker-Koivula M. (2015): Assessment of high resolution global gravity field models for geoid modelling in Finland. In: U. Marti (ed.): *Proceedings of the International Symposium on Gravity, Geoid and Height Systems (GGHS2012), IAG Symp.* **141**. in print.

Bruinsma S. L., Marty J. C., Balmino G., Biancale R., Foerste C., Abrikosov O. & Neumayer H. (2010): GOCE Gravity Field Recovery by Means of the Direct Numerical Method. *ESA Living Planet Symposium 2010*. Bergen, Norway. 27.6–2.7.2010.

Bruinsma S. L., Foerste C., Abrikosov O., Marty J. C., Rio M. H., Mulet S. & Bonvalot S. (2013): The new ESA satellite-only gravity field model via the direct approach. *Geophysical Research Letters*, **40:14**, 3607–3612. DOI: 10.1002/grl.50716.

Forsberg R. & Tscherning C. C. (2008): An overview manual for the GRAVSOFT Geodetic Gravity Field Modelling Programs. 2. edition, August 2008. Available online: http://www.researchgate.net/publication/258889946_An_overview_manual_for_the_GRAVSOFT_Geodetic_Gravity_Field_Modelling_Programs. Accessed 25.11.2014.

Migliaccio F., Reguzzoni M., Sanso F., Tscherning C. C. & Veicherts M. (2010): GOCE data analysis: the space-wise approach and the first space-wise gravity field model. *ESA Living Planet Symposium 2010*. Bergen, Norway. 27.6–2.7.2010.

Migliaccio F., Reguzzoni M., Gatti A., Sanso F. & Herceg M. (2011): A GOCE-only global gravity field model by the space-wise approach. *Proceedings of the 4th International GOCE User Workshop*. Munich, Germany. 31.3–1.4.2011.

Ollikainen M. (2006): The EUVN_DA campaign in Finland. *Publications of the Finnish Geodetic Institute*, **135**, 39 p.

Pail R., Goiginger H., Mayrhofer R., Schuh W., Brockmann J. M., Krasbutter I., Hoeck E. & Fecher T. (2010): GOCE gravity field model derived from orbit and gradiometry data applying the time-wise method. *ESA Living Planet Symposium 2010*. Bergen, Norway. 27.6–2.7.2010.

Pail R., Bruinsma S., Migliaccio F., Christoph F., Goiginger H., Schuh W. D., Höck E., Reguzzoni M., Brockmann J. M., Abrikosov O., Veicherts M., Fecher T., Mayrhofer R., Krasbutter I., Sansò F. & Tscherning C. C. (2011): First GOCE gravity field models derived by three different approaches. *Journal of Geodesy*, **85:11**, 819-843. DOI: 10.1007/s00190-011-0467-x.

Rummel R., Gruber T. & Koop R. (2004): High level processing facility for GOCE: products and processing strategy. In: Lacoste H (ed): *Proceedings of the 2nd international GOCE user workshop GOCE, The Geoid and Oceanography*. ESA SP-569, ESA. ISBN:92-9092-880-8; ISSN:1609-042X.

Schall J., Eicker A. & Kusche J. (2014): The ITG-Goce02 gravity field model from GOCE orbit and gradiometer data based on the short arc approach. *Journal of Geodesy*, **88:4**, 403-409. DOI 10.1007/s00190-014-0691-2.

Vestøl O. (2005): Determination of Postglacial Land Uplift in Fennoscandia from Leveling, Tide-gauges and Continuous GPS Stations using Least Squares Collocation. *Journal of Geodesy*, **80:5**, 248–258. DOI:10.1007/s00190-006-0063-7.

Yi W., Rummel R. & Gruber T. (2013): Gravity field contribution analysis of GOCE gravitational gradient components. *Studia Geophysica et Geodaetica*, **57:2**, 174-202. DOI 10.1007/s11200-011-1178-8.

Utilization and Quality Control of State-of-the-art Digital Elevation Data

Thomas Knudsen, Simon Kokkendorff, Andrew Flatman, Thorbjørn Nielsen, Gitte Rosenkranz, Kristian Keller

Danish Geodata Agency, Copenhagen, Denmark

Introduction

The next version of the Danish Digital Elevation Model (DK-DEM) will be based on newly collected data which on all parameters surpasses what was the case for the original DK-DEM: Data density is expected to be 8 times larger, while both plane and elevation accuracy will be significantly improved.

Also, newer combined LiDAR and camera systems will be utilized. Hence color observations (RGB) will be assigned to each observation. The systems also record continuous series of laser reflections, so the point reflections are complemented with sets of full reflection profiles (“Full Waveform Data”, FW).

So far, FW and RGB primarily contributes to the data provider’s post processing of the collected data (classification, etc.): Coming years will show the operational advantage of the new data types.

The greater data density, the increased accuracy, and the new data types has made it necessary to develop new quality control procedures at Geodatastyrelsen:

— Partly because the data provider’s expected accuracy exceeds the accuracy of some of the control data available,

— Partly because new data types (FW and RGB) requires radically different control methods and

— Partly because the large amounts of data (about 100 terabytes uncompressed) places increased demands for efficiency and flexibility in both algorithms, data flow and reporting

The main focus of this paper is to describe these quality control procedures, and their specific implementation. But given their origin within the scope of the tender and production progression towards a new DK-DEM, we will start with a brief outline of the events that resulted in the procurement of a new elevation data set.

Setting

The original DK-DEM, referrred to as DK-DEM(2007) below, was finalized in 2009. It was based on LiDAR data recorded in the time frame 2005–2007.

DK-DEM(2007) resulted in a massive increase of the use of elevation data in Denmark. Hence, already a few years later it was evident that an update, and probably also a data densification, was much needed.

After consultations with stakeholders, the Danish Geodata Agency issued a tender for “new data for DK-DEM”. The tender was issued in 2013, and the data is to be collected during three flight seasons (two spring seasons and one fall season) during 2014–2015.

The tender was formulated as a *beauty contest*, i.e. the bidders were asked to specify how high data quality they could provide given a fixed maximum price. The only fixed requirement was that the quality of the new data had to be at least as high as the DK-DEM(2007) data. Here, the most extensive meaning of the term *data quality* was applied, including the aspects of data density, spatial accuracy, spatial precision and point classification correctness. From the description above

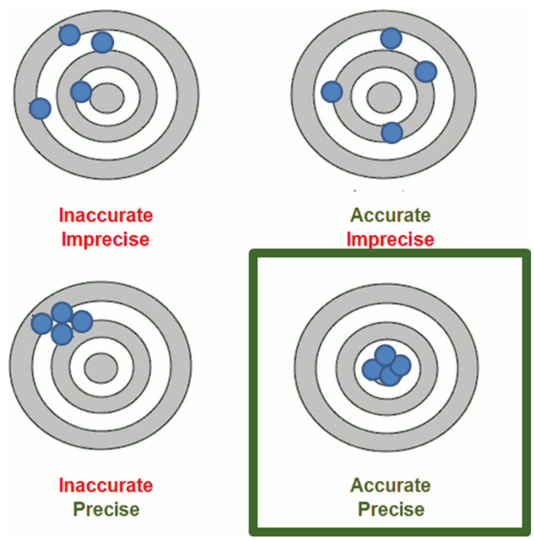

Figure 1: Precision (repeatability, consistency) vs. Accuracy (accordance, conformity)

it should be evident that the term “state-of-the-art digital elevation data” used in the title of this paper, should not be taken to mean data that on *every parameter* exceeds everything else available. The art in question is the art of providing the best overall quality (in the extended meaning of the word) given a fixed price.

Since the winning bid was defined by quality parameter values stated by the bidders, the main task of the Danish Geodata

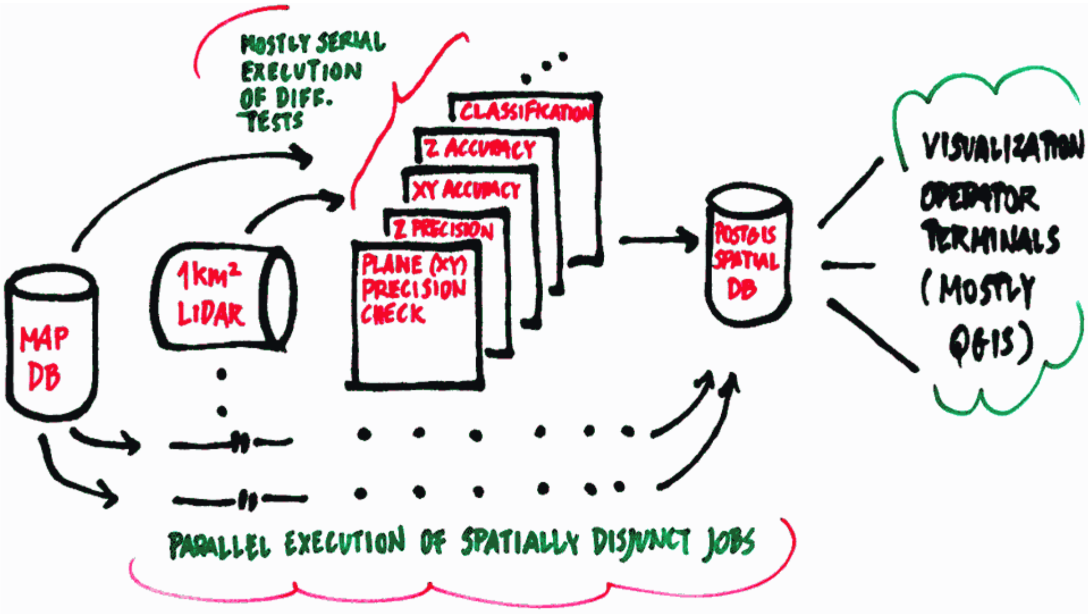

Figure 2: Whiteboard schematic of the QC system: Since data are provided in 1 km × 1 km tiles, each tile can be assigned to a separate processor, so tests are run in parallel on as many processor kernels as available. All results are written to a spatial database, which serves as integration platform, so results can be followed on the operator terminals as the work progresses.

Agency (GST) was to check that the data provided was actually in accordance with the quality offered. But since the quality offered was higher than expected—specifically by exceeding the accuracy of available test data—implementing these checks showed to be more involved than expected.

Data quality target parameters

The main data quality parameters used were

- Point density and coverage
- Vertical accuracy
- Vertical precision
- Horizontal accuracy
- Horizontal precision
- Point target classification correctness

Given data for accepted voids (mostly lakes and rivers) the first of these items is trivial to check and will not be discussed here. The last of these items is primarily checked by human operators. The process is designed to give clues for potential classification blunders by augmentation of the original point cloud with data for point classification statistics and spatial characteristics. The procedure will not be discussed here, where the focus will be on the precision and accuracy parameters.

As indicated by figure 1, *you are accurate when you hit the bullseye, and you are precise when you do it again (and again, and again. . .).*

The target values for the new DK-DEM data are:

- 5 cm vertical accuracy
- 2 cm vertical precision within a single flight strip, 5 cm between overlapping strips
- 15 cm horizontal accuracy
- $<$ 15 cm horizontal precision

As we will see below, especially the horizontal items are tricky to check.

Quality control

Philosophy

The philosophy behind the quality control system is to prefer spatial coverage for elegance: We prefer a somewhat involved procedure that leads to extensive spatial coverage, rather than a more elegant procedure that can (in principle or practice) be carried out as spot checks only. The reason for this is that since we are dealing with a geospatial dataset, there is reason to assume that the imprecisions and inaccuracies are also of spatial nature. By preferring spatially extensive checks, our quality control data reports become spatial as well. This

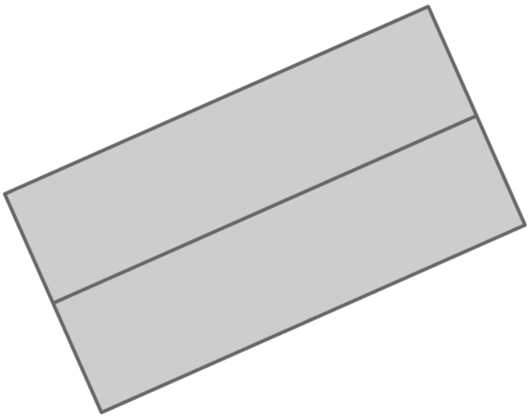

Figure 3: The FOT map database stores building outlines only. In cases where the outline is exactly rectangular we hypothesize that the roof is symmetric, and construct a roof ridge as the center line between the two long sides of the rectangle.

makes it easier to hypothesize about the source of the errors, but also to communicate about this with users and data providers.

Hence, we have in general aimed to design checks building on comparison with data from the existing geospatial data stack, dealing with their quality level, rather than collecting specially designed control data sets, which can realistically be done for a very limited number of test spots only.

Vertical accuracy.

In a topographic (although not in a geodetic) sense, the vertical accuracy of the LiDAR data is extraordinarily high. So for this parameter we need to supplement the spatially extensive tests with a number of spot checks.

The remaining checks are based solely on internal statistics of the LiDAR point cloud, or on comparison with existing map data.

Vertical precision.

The vertical precision of a LiDAR data set is basically the variance of a number of neighbouring points belonging to the same horizontal surface. So knowing the position and extent of a horizontal surface, the vertical precision can be derived trivially.

In our case we identify test areas for vertical precision using the road centerline theme from the national map database, FOT. Since Denmark is so densely populated, doing this along *all* major roads results in a large and spatially extensive quality control data set.

Obviously, the test for precision when including overlapping strips can be carried in the overlap zone only. But it can be done all the way along all overlap zones, and hence give a very good indication of the spatial characteristics of this parameter also.

Horizontal accuracy.

For DK-DEM(2007), the horizontal accuracy requirement was on the order of 1 m. Since the expected accuracy of the FOT building theme is at least twice as good, DK-DEM(2007) could be spot checked by plotting FOT building outlines on top of the normalized surface model (i.e. the difference between the surface model and the terrain model, where terrain points has zero height and buildings and vegetation appear as blobs of non-zero height). See Hawa (2011) for details.

This is not viable for data having an accuracy of 15 cm, since the expected accuracy of the building outline corner points is only known to be “better than 50 cm”.

For the specific, but common, sub-class of buildings with rectangular outline and symmetric roof, we can, however, obtain a slightly more well defined target for comparison than the outline itself: In these cases the roof ridge is placed exactly in the center of the building rectangle and can be estimated from the four corner points of the outline (see figure 3).

Also, the building outlines are photogrammetrically registered by skilled stereo operators from accurately georeferenced stereo pairs. So we may very well suppose that the “better than 50 cm” in these simple and easy-to-register cases really is much better than that.

In these cases, we can derive a homologous roof ridge model by computing the 3D Hough transform of the LiDAR point cloud patch delineated by the corresponding photogrammetrically derived building outline: The roof ridge is taken to be the intersection of the two primary Hough components.

The orthogonal distance between the two roof ridge models is taken as a local estimate of the accuracy. Strictly speaking, this is an estimate of the 1D projection of the position error vector only. The overall 2D picture is reconstructed by combining information from local groups of buildings with different roof ridge directions.

If both the mean and the variance of local clusters of these estimates are small, we can conclude that *both* the photogrammetrical *and* the LiDAR roof ridges are highly accurate. While this is intuitively evident, it can be formally derived as a consequence of variance propagation. See Knudsen et al. (2011) for details.

As already mentioned, this algorithm works for rectangular, symmetric roofs only. While it is easy to make sure we work on rectangular buildings only, symmetry must be taken as an assumption.

Fortunately asymmetric roofs tend to result in substantially different accuracy estimates, which can be discarded by a simple threshold based outlier rejection. What remains are the symmetric rectangular buildings. And since there tends to be large numbers of these, they can give a very good impression of the data set quality, as demonstrated in figure 4.

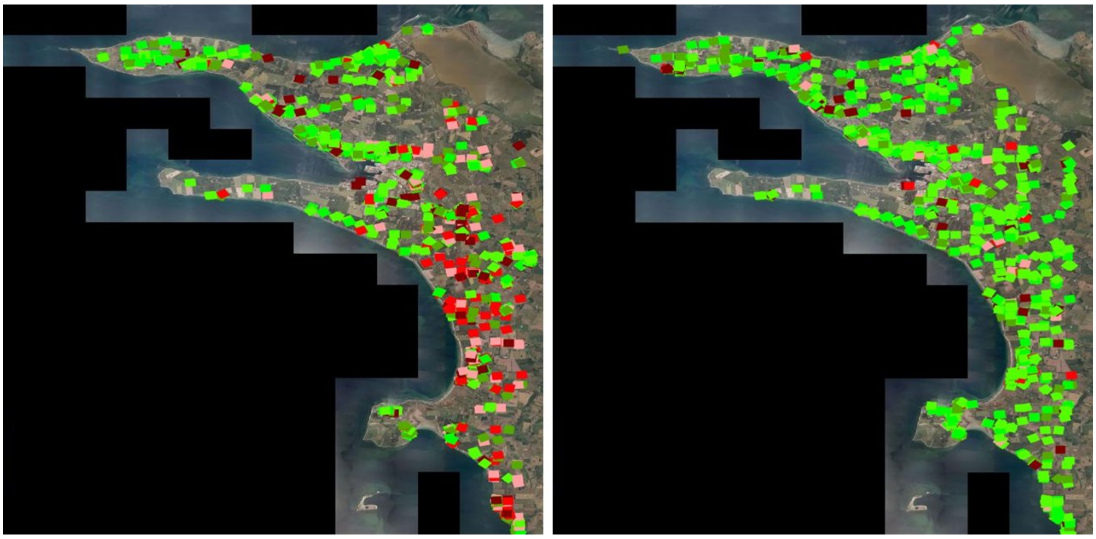

Figure 4: In this part of the country, initial checks showed that the horizontal accuracy was less than expected (indicated by the large number of red spots in the left panel). Given this evidence, the data provider was able to debug the processing chain and reprocess, leading to the much improved test result shown in the right panel.

Horizontal precision.

Once the horizontal accuracy framework is established, estimating the horizontal precision is almost trivial. It is simply a matter of running the accuracy algorithm on both LiDAR strips of the overlap zones.

Then, rather than comparing a LiDAR roof ridge model with a photogrammetrically derived one, we compare sets of two homologous LiDAR roof ridge models.

Implementation

Implementation wise, the GST LiDAR quality control system is based on open source components, primarily from the OSGeo (GDAL, PostGIS, QGIS) and Scientific Python (NumPy, SciPy) stacks. The system specific code is also being open sourced.

This open source distribution philosophy supports the parallel execution paradigm used, since all available hardware can be utilized without any licensing problems.

Experience and Conclusion

As yet, the system has only been used for QC of the first part of a new Danish elevation model. The experience has, however, been both pleasant and very positive. Especially notable is the usefullness of doing full spatial coverage tests (rather than scattered sample checks). This means that error detection and error reports are exactly as spatial as the point cloud data they concern. This makes it very easy for both data receiver and data provider, to discuss and reason about the nature and causes of irregularities.

References

M. Nour Hawa. A method for determination of horizontal accuracy of a digital elevation model. In Hawa et al. (2011), pages 10–14. URL ftp://ftp.kms.dk/download/Technical_Reports/KMS_Technical_Report_10.pdf. 3

M. Nour Hawa, Thomas Knudsen, Simon L. Kokkendorff, Brian P. Olsen, and Brigitte C. Rosenkranz. Horizontal accuracy of digital elevation models. Technical Report 10, National Survey and Cadastre (KMS), Copenhagen, Denmark, 2011. URL ftp://ftp.kms.dk/download/Technical_Reports/KMS_Technical_Report_10.pdf. 4

Thomas Knudsen, Simon L. Kokkendorff, Brigitte C. Rosenkranz, and Brian P. Olsen. On the horizontal accuracy of digital elevation models. In Hawa et al. (2011), pages 6–9. URL ftp://ftp.kms.dk/download/Technical_Reports/KMS_Technical_Report_10.pdf. 3

Swedish municipalities implementing the new national height system RH 2000

Christina Kempe, Linda Alm, Fredrik Dahlström, Lars E Engberg, Jakob Jansson
Lantmäteriet
Geographic and Land Information – Geodesy, SE-801 82 Gävle, Sweden
e-mail: christina.kempe@lm.se

Summary

Sweden consists of some 300 municipalities, all of them more or less having used their own unique height system. A new national height system, RH 2000, was implemented in 2005 by Lantmäteriet, the Swedish mapping, cadastral and land registry authority. Most of the municipalities are now changing to use the national height system also locally, to make more efficient use of GNSS in their own organisation and to harmonise their data with the existing regional and national data. In this process, Lantmäteriet provides readjustment of the old local levelling networks in the new national RH 2000 frame, possibly with some supplementary measurements accomplished by the municipality. This paper describes this transition process, seen in the light of the municipalities being self-governing to a large extent and Lantmäteriet, the national geodetic authority, only having an advisory role.

The preferred method results in RH 2000 heights for the benchmarks in the local height networks and a translation parameter for transformation of other height data. Except from this, the analysis of the local height network gives a good knowledge of the existing deficiencies. When the transition to RH 2000 is completed, more advantages are attained, such as using the same height reference frame in all parts of the municipality, a decreased risk of mixing different height systems and that data in a well-known high quality reference frame will be more attractive to external users.

The municipality will also have the opportunity to use GNSS technology for a wider range of applications where height determination is required.

Introduction

In Sweden there are some 300 municipalities, all of them using their own, more or less unique, height system. In order to harmonise local, regional and national data the local authorities are urgently requested to change from their old local to the new national height system.

Background

Local height networks versus national height networks

The first height control networks for municipalities were established in the beginning of the last century. Most of them were in a very weak way connected to the national network prevailing at that time in Sweden; see the *Densification of earlier precise levelling networks* section. Since then height control networks have been established in almost every urban area. Nowadays, we have 290 local authorities and almost every municipality has their own height control network and in some areas, there is more than one network because a fusion of two or more municipalities into one has taken place.

In Sweden, the responsibility for geodetic control networks is divided between the local authorities and Lantmäteriet, the Swedish mapping, cadastral and land registry authority. The main cause for this is different aims of the networks. The responsibility for Lantmäteriet has been to establish ground control for official mapping in small scales. The local authorities establish control networks for urban development.

Lantmäteriet is the national geodetic authority but has no power against municipalities and other authorities. Lantmäteriet cannot do anything else than give proposals and advice to the local authorities concerning their reference systems. Lantmäteriet is responsible for all national geodetic networks and the local authorities are responsible for their own networks.

The new national height system RH 2000 was introduced in 2005, to replace the preceding RH 70. The new system is more homogeneous than RH 70 and well adapted to Sweden's neighbouring countries and the European height system (Svensson et al., 2006).

Densification of earlier precise levelling networks

The first precise levelling in Sweden was performed in 1886-1905, resulting in the height system RH 00. The second precise levelling was carried out in 1951-1967, resulting in the height system RH 70; see Figure 1.

These networks were not sufficiently dense and the coverage of the country was poor. When height control was needed for national small-scale mapping, these networks were densified by primary and secondary levelling lines of much lower accuracy.

The accuracy of the densification lines was sufficient for its purposes, but far lower than required for precise levelling or connection of local height networks. But since the benchmarks of these densification lines were the only points with heights available, they were nevertheless used for connection of local height networks. Depending on e.g. these poor connecting points, many local height networks are distorted.

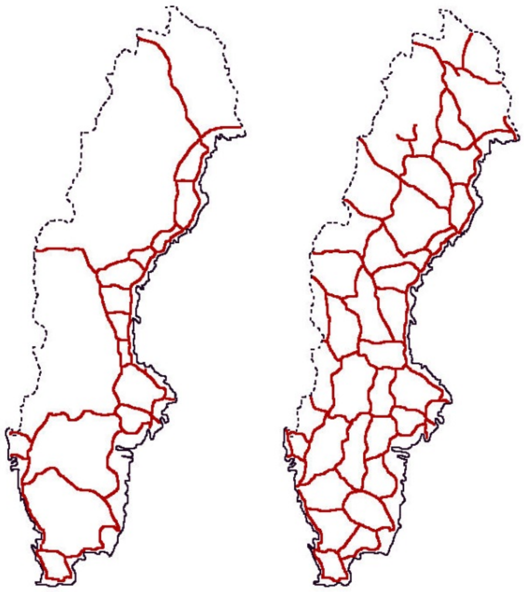

Fig. 1. Levelling lines of the first (on the left hand side) and second (on the right hand side) precise levelling of Sweden.

The third precise levelling of Sweden

The fieldwork of the third precise levelling of Sweden – the base of the new national height system RH 2000 – lasted from 1979 until 2001.

The earlier precise levelling networks were not sufficiently dense and the second levelling was mainly located along railroads, which made the benchmarks hard to reach. Many benchmarks had also been destroyed over the years. The demands from the users for better coverage and accessibility had increased, and the aim of the third precise levelling was therefore to create a network covering the whole country, dense enough to allow local users to connect their measurements to easily accessible benchmarks; see Figure 2. (Svensson et al., 2006)

Fig. 2. Levelling lines of the third precise levelling of Sweden.

Work on national and local level

The reference system used nationally must meet several criteria. It must be modern in such a way that positioning using modern technologies should be possible without destroying the high accuracy that modern instruments can achieve. The reference frame should make it possible to easily and efficiently exchange data with neighbouring countries as well as users within the country, which means that the connections to other reference frames must be well known or we should work in the same reference frame.

Locally, we nowadays have several hundreds of different geodetic networks. Lantmäteriet recommends the local authorities to tie their local networks to the national reference frame or – preferably – to use the national reference frame.

To help municipalities and other users, Lantmäteriet has developed routines to do the transition from old, distorted height systems to the new national height system RH 2000. When the transition is completed and the distortions of the local networks have been analysed, the municipality will have the opportunity to use GNSS technology and the national geoid model SWEN08_RH2000 (Ågren, 2009) for a wider range of applications where height determination is required.

The corresponding process of exchanging local plane coordinate systems for the new national reference frame SWEREF 99 is described in Kempe et al. (2006).

Measures to take in order to change height system in a municipality

There are a few different methods that can be suitable for the transition to RH 2000 in a municipality; cf. the following sections. Lantmäteriet recommends readjustment of the old local levelling networks in the new national RH 2000 frame, possibly with some supplementary measurements accomplished by the municipality.

Irrespective of the method chosen, it is important to carefully inform all users – within the organisation as well as external users – of the imminent transition to the new height system. Another essential action is to make a practice of labelling all height information with the reference frame used. It is not possible to see from a single height value, which height system it stems from. That is one of the reasons why the information activities are crucial.

Readjustment of the local height networks

The municipalities compile and deliver their old levelling data to Lantmäteriet, which can provide adjustment assistance as well as analysis of the networks.

The levelling data of the local height networks are normally of high accuracy, also in older networks. However, the heights of the benchmarks in the densified national networks were often of poor quality, thereby causing distortions of the local networks when used for connection to the national height network. In some cases, the poor connections forced the municipalities to use only one benchmark of the national network, to avoid distortion of the local network. This also leads to the fact that the level of different local height networks can typically differ by a few centimetres up to more than a decimetre, even though they are said to be established in the same reference frame; see Figure 3.

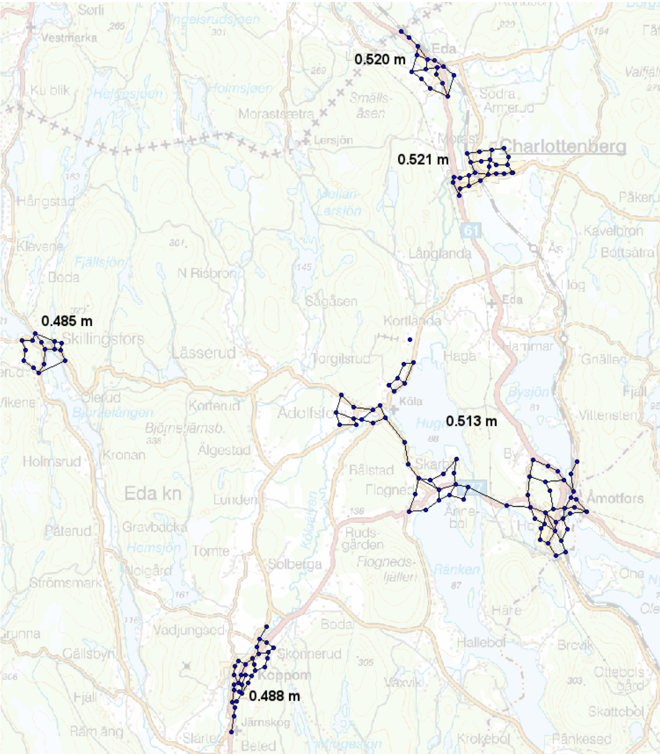

Fig. 3. The system difference to RH 2000 for the villages in Eda municipality. The local height reference frame in all of the villages is said to be the same.

To readjust the local height networks, the old levelling data are connected to benchmarks with RH 2000 heights from the third precise levelling. This means that the municipality must be able to list their levelling data digitally, and deliver them to Lantmäteriet in a given format. Except from the levelling data, local heights and coordinates of the local benchmarks are required.

The data are stored in a database, and the network is drawn on a map to facilitate the search for gross errors; see Figure 4.

The next step is to find out which benchmarks of the local network are common with third precise levelling benchmarks. There are often already a number of common benchmarks, since local benchmarks to a large extent were used in the third precise levelling network. If supplementary connection points are needed, the municipality is recommended to perform these, in general short, levellings to obtain further connection points.

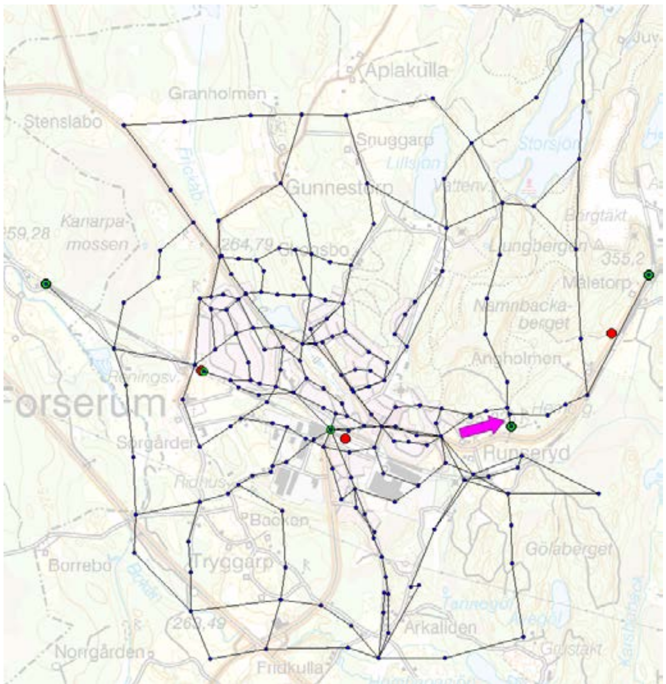

Fig. 4. A local height network, with benchmarks (blue). The third precise levelling benchmarks are red and the benchmarks of the local network that are common with third precise levelling benchmarks are green. One supplementary connecting levelling was done (see arrow).

When the number and distribution of connection points is satisfactory, and the errors of the network have been evaluated and eliminated to an adequate level, the network is readjusted, using the RH 2000 heights from the third precise levelling as fixed.

The new RH 2000 heights of the local network are compared to the old local heights. Hereby a clear view of the distortions of the local height system is obtained. An average system difference – a translation – between RH 2000 and the local system can also be computed, for transformation of other height data than the high quality benchmarks.

Depending on the magnitude of the distortions, one system difference can be used for the whole network or municipality. If the distortions are large, it may be suitable to split the area into separate parts, for each of which a translation is computed; see Figure 5.

Using one or more translations is the most robust method for transformation of data. Other methods for transformation of data are utilised only in exceptional cases. To use e.g. an inclined plane transformation or a rubber-sheeting algorithm, plane coordinates are required for the objects to be transformed.

Finally, Lantmäteriet delivers the database, maps, adjustment – input data as well as results – and the height comparison with the resulting translation parameters, together with a written report.

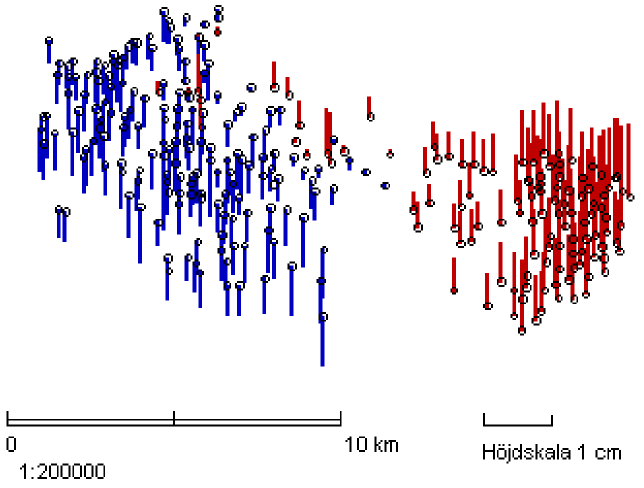

Fig. 5. *Initially, one translation was computed for this local network as shown in the figure. The vectors show the deviation of each point from the average system difference. When the distortions of the local height system became clear, two different translations were computed – one for the western part and one for the eastern part.*

The replacement of old local heights of the benchmarks, by the RH 2000 height from the adjustment, and transformation of other height data to RH 2000 is then done by the municipality or their consultant, e.g. the GIS system provider.

Alternative methods

Of course there are cases where the levelling data cannot be recovered, or where the third precise levelling lines are too distant. Then there are a few alternative methods to be used, even though the method described in the *Readjustment of the local height networks* section is the most favourable in the long-term view.

When the local levelling data cannot be recovered but there is a third precise levelling line available, a number of loops with local benchmarks can be levelled from third precise levelling benchmarks. Doing so will provide RH 2000 for these local benchmarks, but other bench-marks in local height network will not get RH 2000 heights. The translation – for transformation of other height data – that can be obtained by this operation will be uncertain due to the weak basis.

If the distance from the local height network to a third precise levelling line is too distant to justify connection by levelling, a number of the local benchmarks can be surveyed by GNSS technology, using the national geoid model to obtain RH 2000 heights for the benchmarks. The absolute RH 2000 position will be determined by the GNSS surveys, by applying the average system difference between the local height system and RH 2000 to one of the benchmarks. The original levelling data of the network can then be adjusted with minimal constraints. The RH 2000 heights from the GNSS surveys are not used as fixed, because this is likely to distort the levelling network. By using this method, the local height network can be seen as an RH 2000 network. The translation – for transformation of other height data – that can be obtained by this operation will be as uncertain as the height determination by GNSS technology.

If neither the levelling data can be recovered, nor is the third precise levelling available, GNSS technology can be used to obtain RH 2000 heights for a number of the local benchmarks. This will form the base for computation of an average system difference – a translation – between the local height system and RH 2000. This translation should be used only for transformation of other height data than the benchmarks in the local height network. The RH 2000 heights of the surveyed benchmarks should not be used for further levelling.

Concluding remarks

By analysing the local height system, good knowledge of the existing deficiencies is obtained. When the transition to RH 2000 is completed, more advantages are attained:

- The same height reference frame is used in all parts of the municipality
- The risk of mixing different height systems is decreased
- Data in a well-known high quality reference frame will be more attractive to external users
- Data exchange between different producers/users is facilitated

When the transition is completed and the distortions of the local networks have been analysed, the municipality will have the opportunity to use GNSS technology in combination with the national geoid model SWEN08_RH2000 (Ågren, 2009) for a wider range of height determination applications.

References

Kempe C, Alfredsson A, Engberg L E, Lilje M, 2006, *Correction Model to Rectify Distorted Co-ordinate Systems*. FIG XXIII International Congress, October 8-13 2006, Munich, Germany.

Kempe C, Eriksson P-O, 2007, *Lantmäteriets arbete med kommunala plan- och höjdsystem*. MätKart 2007, Uppsala, Sweden (in Swedish).

Olsson P-A, Eriksson P-O, 2005, *Nationella höjdsystem – historik*. Lantmäteriet, PM, Gävle (in Swedish).

Svensson R et al., 2006, *The New Swedish Height System RH 2000 and Geoid Model SWEN 05LR*. FIG XXIII International Congress, October 8-13 2006, Munich, Germany.

Ågren J, 2009, *Beskrivning av de nationella geoid-modellerna SWEN08_RH2000 och SWEN08_RH70*. Lantmäteriet, Rapportserie: Geodesi och Geografiska informationssystem, 2009:1, Gävle (in Swedish).

Latvian digital zenith camera in test applications

Janis Kaminskis (1), Inese Janpaule (2), Ansis Zarins (2), Markus Rothacher (1)
(1) ETH Zurich Geodesy and Geodynamics Lab, Institute of Geodesy and Photogrammetry
Robert-Gnehm-Weg 15, CH-8093 Zurich, Switzerland
e-mail: janisk@ethz.ch, markus.rothacher@ethz.ch
(2) University of Latvia, Institute of Geodesy and Geoinformation
Raina blv. 19, LV-1586 Riga, Latvia
e-mail: inesej@inbox.lv, ansiszx@inbox.lv

Introduction

Development of a digital zenith telescope prototype, improvement of zenith camera construction and analysis of experimental vertical deflection measurements for applications in Latvian geodetic network has been performed at the Institute of Geodesy and Geoinformation (GGI) University of Latvia.

At first, the prototype camera has been constructed and tested (Fig. 1). Original optical system, zenith camera construction design and control and data processing software was developed and hardware components were integrated.

A number of observation sessions were performed in Riga and outside Riga and a huge amount of observation data have been processed in order to evaluate prototype zenith camera properties, such as influence of fundament vibrations, convection, background lights, to find optimal structure of observation sessions.

Design of improved zenith camera construction, based on acquired experience, has been completed. Expected accuracy of vertical deflection measurements is about 0.1". The task now is to acquire a representative set of real observations as a proof of digital zenith camera's qualities and capacity and to promote its scientific use for national economy.

Digital zenith camera in Riga

Continuing digital zenith camera project, a prototype camera has been built and an extensive test research carried out, looking for solutions and design elements which might present problems and should be improved (Abele et. all, 2012). In general, camera properties were found close to expected. The most problematic aspect of prototype camera was mechanical stability of camera assembly. Effects of thermal deformations during observation sessions were found to be a serious disturbing factor. Also necessity to improve extent of automation was obvious. As a result, an improved camera design was made (Fig. 4). It uses different approach to observation process – motorized levelling will be performed in each camera position before measurements, ensuring, that tiltmeter readings are always small and minimizing problems arising from tiltmeter scale and orientation uncertainty.

Fig. 1. *First prototype camera design*

Experimental determination of plumb line

Difference between directions to reference ellipsoid normal and tiltmeter axis in rotating coordinate system. In ideal circumstances it should make circle with radius of plumb line deflection value (shown by thin black line).

However, in reality, thermal deformations change tiltmeter axis direction relative to optical system, resulting in spiraling trajectory (Fig. 2). Observations are made outside Riga in Ikskile to reduce influence of ground vibrations caused by intensive city transport. As we can see from plot, we have made 119 expositions in total there, shown by pink crosses, and latter all shots mathematically approximated with green spiral shaped trajectory. From there we can construct circle, shown in black, which shows actual value of deflection of vertical (DoV), for example, in Ikskile site number 1003 we have obtained DoV value 9,71”. For the precise timing we use GPS and that is indicated in all recorded files. During observations we have recorded drift in X axis 10”/h and in Y axis 5”/h.

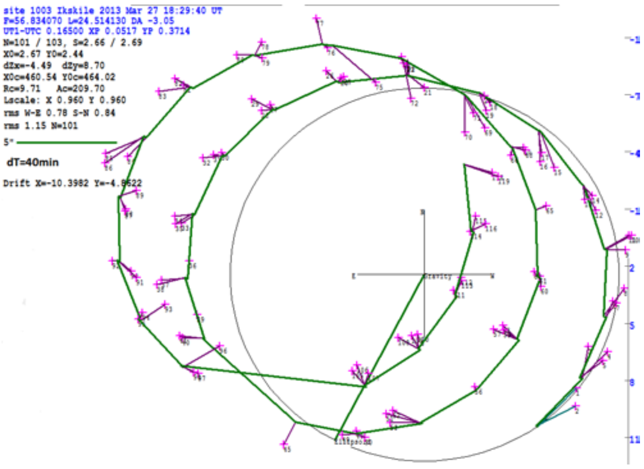

Fig. 2. *Difference between ellipsoid normal and tiltmeter axis with spiraling trajectory*

Drift in orientation of mechanical components due to changes in temperature (Fig. 3) illustrates necessity to make measurement session as short as possible. Some bending of instrument assembly has occurred besides tilting of support surface, resulting in decidedly non-linear drift of tiltmeter and imager relative orientation. Observation sessions must be short (a few minutes) to avoid most of effects of this bending or include them in linear drift model. During our experimental observation session for 53 minutes, we recorded changes within zenith camera system relative positions for up to 16”. To avoid such influence we recommend make observation sessions as short as it can be successfully realized.

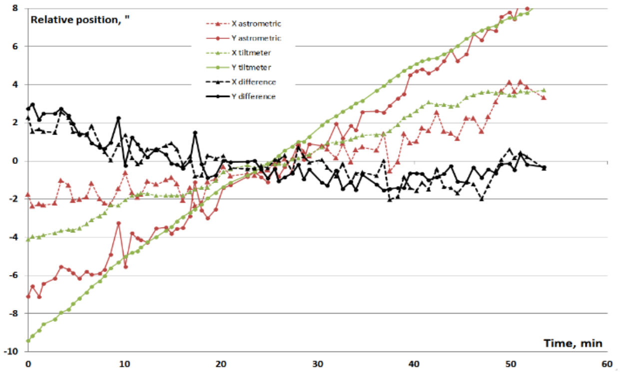

Fig. 3. *Drift in orientation of astrometric and tiltmeter subsystems and their difference*

Technical features of zenith camera

For construction of digital zenith camera we must use certain astrometric and gravimetric devices or sensors. Our first prototype camera has such following astrometric and gravimetric subsystems:

- 20 cm catadioptric telescope, F=1373 mm
- CCD field of view 0.35 x 0.27 dg, 1360 x 1024 pixels (CCD resolution ~1” per pixel)
- Reference star catalogue: subset of NOMAD (Naval Observatory Merged Astrometric Dataset) up to 15m
- Reference stars per frame: 4 ... 23, average 12
- Star magnitude: 6m ...13m with 0.1-0.3 sec exposure
- Source of apparent places: NOVAS (Naval Observatory Vector Astrometry Software)
- RMS of star image position: 0.3” ... 1.5”, average 0.5”
- Zenith position accuracy for frame: 0.1” ... 0.2”
- Precision tiltmeter HRTM with 50 prad (~1e-5") resolution in +-2' range
- Frame timing accuracy 1-5 msec

After the series of tests with first prototype camera, we recognize necessary improvements. Few of such improvements are made for astrometric subsystem in a following way for the new camera:

- 8 inch catadioptric telescope, F=2000 mm
- CCD field of view 0.5 x 0.39 dg, 3300 x 2500 pixels
- Star magnitude: up to 14m
- Computer controlled levelling
- Wireless data transmission

We can rotate our digital zenith camera continuously approximately with an angular speed 360 degrees in about 10 sec. In addition, we can switch direction of rotation from clockwise to opposite for our new zenith camera prototype. That is the advantage of implemented wireless data transmission system. There might be improvements needed to increase the rate of data transfer from CCD to data storage. That improvement can come together with progress in image processing technologies for data transfer.

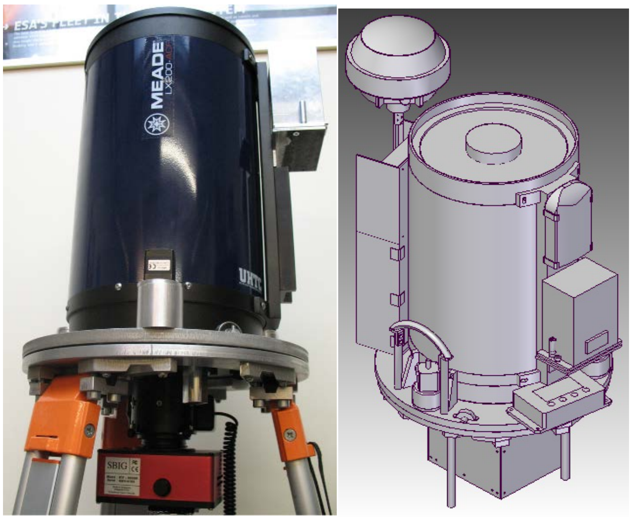

Fig. 4. *Second prototype or newest camera design*

Assumptions for control of geoid models

Precise information on a gravity field and/or DoV measurements are necessary for the contemporary provision of a height reference system in the country, in particular when geodetic measurements are performed with GPS/GNSS receivers. The above-mentioned receivers measure three Cartesian space coordinates and provide a height above the mathematical ellipsoid surface, but do not measure height above sea level. For the determination of height above sea level, it is necessary to know a geoid model value in each of the corresponding points of measurement. The more precise the geoid model, the more precisely we can determine the height over sea level if we are using GPS/GNSS receivers for work. The more precise the results of measurements, the wider are their application, and the benefit arising from them is not only economic, but also very practical and facilitates geodetic work in general. For example, if a geoid model is very precise, we can replace the precise geometrical levelling, which is expensive and time-consuming, with the DGPS/DGNSS method for the transfer of heights.

In addition, we plan to use our zenith camera for independent control of geoid models to see how accurate particular geoid model fits to vertical deflections obtained from digital zenith camera observations. As a national official geoid model for more than 18 years has been used LV98 (Kaminskis, 2010).

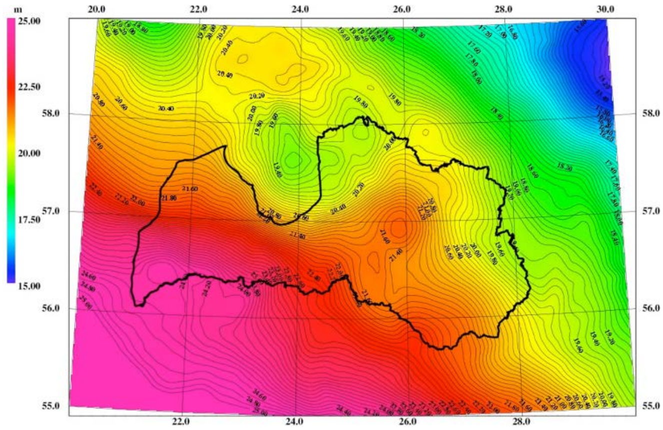

Fig. 5. *LV98 – Latvian official geoid model up to 2014.*

To locate areas for deeper explorations, we do different geoid model comparisons. As a starting point on quality control for chosen particular model could be its verification with global gravity field models, such as EGG97, EGM2008 and Eigen different versions. We have done such work and received good results shown on next plots (see Figures 6 and 7).

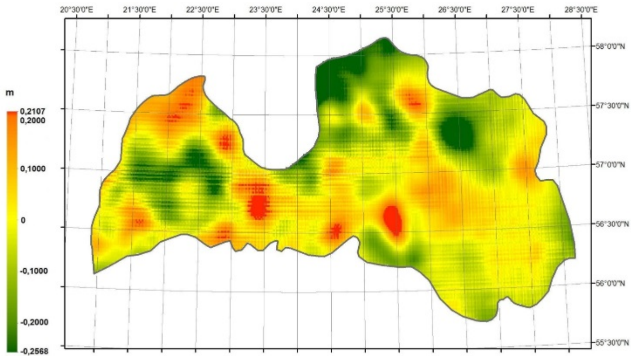

Fig. 6. *Comparison of LV98 to global EGG97 gravity model*

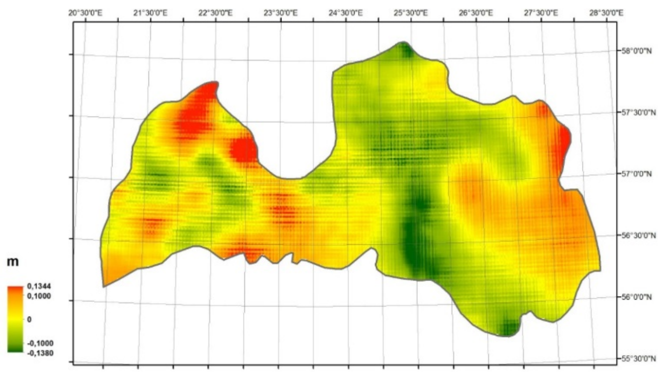

Fig. 7. *Comparison of LV98 to global EGM2008 gravity model*

In addition, statistical data indicate good correspondence between local or regional model to the available global models. We can also make statement that the accuracy of the fitted LV98 geoid in general is very close to 4cm on the mainland. Statistical data of comparison to different global gravity field models are presented in Table 1.

Table 1. *Statistics of LV98 and global model comparison*

	Min (m)	Max (m)	RMS (m)
LV'98-EGG97	-0,257	0,211	**0,058**
LV'98-EGM2008	-0,138	0,134	**0,044**
LV'98-Eigen6c	-0,203	0,201	0,063
LV'98-Eigen5c	-0,211	0,480	0,123
LV'98-GO_CONS_GFC_2_DIR_R3	-0,461	1,077	0,272

To analyze rightness of proposed new model, like in Latvian case LV14 since December 2014, it is possible to make simple comparison with official geoid models from neighbor countries where they overlap. For Latvia, we analyze cases with Lithuanian, Estonian and Swedish geoid models. In all cases, we recognize similar strange pikes, where we are not able to find physical explanation (Vallis et. all, 2014). As a more known case for geodesists, we describe Swedish geoid model SWEN08_RH2000 (Agren et. all, 2009).

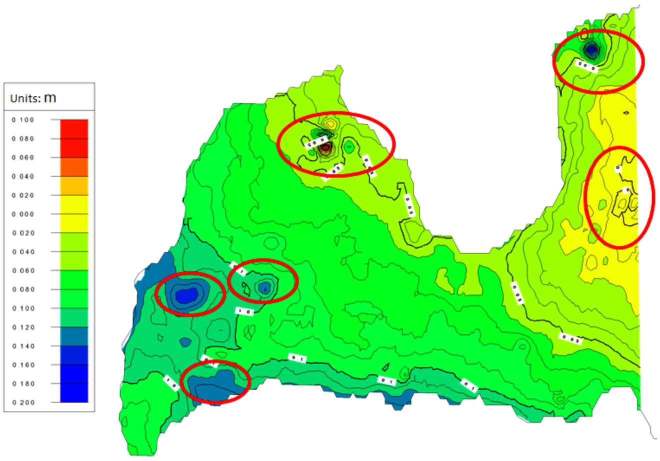

Fig. 8. *SWEN08_RH2000 in comparison to LV14 geoid*

On a Figure 8 we recognize pikes with positive and negative values. There we have peculiar differences from -20 cm till +10 cm just over the Western part of Latvia. This indistinctness falls into responsibility of LV14 authors to clarify problems in gravimetric data or into computation technique applied.

Conclusions

Due to implementation of new national wide geoid models and in case of serious contradictions to other geoid models, like in Latvian case with model LV14 the DoV measurements are essential. As we would be able to obtain DoV values in a modern way nowadays with 0.1" accuracy, for example, over distances of several 100 km with astronomical levelling can achieve centimetre level and then it is very useful for centimetre level geoid models (Hirt et. all, 2010). It also would be of our interest to support current ongoing NKG2014 geoid modelling computation around the Baltic Sea. In this case, independent observations of vertical deflections should be used for quality control or even to perform fine adjustment of existing quasi-geoid model (Featherstone et. all, 2009). With set of DoV measurements, we not only control local or global geoid models, but also can create totally new and independent geoid model for some area based on vertical deflection observations by digital zenith camera.

Acknowledgements

This research is supported by Sciex-NMSch Project 13.325 REG - "Research on Earth Gravity by zenith cameras" and FOTONIKA-LV FP7-REGPOT-CT-2011-285912.

References

Abele M.; Balodis J.; Janpaule I.; Lasmane I.; Rubans A.; Zarins A. (2012) Digital Zenith camera for vertical deflection determination. Geodesy and Cartography 38(4): 123–129.

Kaminskis J. (2010): Latvian geoid model and its development. Doctoral dissertation, Riga: Riga Technical University, 151 p. ISBN 978-9934-507-27-4 (in Latvian).

Vallis A., Kaminskis J., Teremko I. (2014) Research on quasi-geoid model LV14. Latvia University of Agriculture Faculty of Rural engineering scientific conference, Dec 2014, DOI: 10.13140/2.1.3763.3609.

Agren J., Sjoberg L.E., Kiamehr R. (2009) The new gravimetric quasigeoid model KTH08 over Sweden. Journal of Applied Geodesy 3 (2009), 143–153. DOI 10.1515/JAG.2009.015.

Hirt C., Burki B., Somieski A., Seeber G. (2010) Modern Determination of vertical deflections using digital zenith cameras. Journal Surveying Engineering 136(1), Feb 2010, 1-12. DOI: 10.1061/_ASCE_SU.1943-5428.0000009.

Featherstone W.E., Lichti D.D. (2009) Fitting gravimetric geoid models to vertical deflections. J.Geod 83:583-589. DOI: 10.1007/s00190-008-0263-4.

Five years of gravity measurement at Onsala Space Observatory: The superconducting gravimeter

Hans-Georg Scherneck
Chalmers University of Technology, Earth and Space Sciences, Gothenburg, and Onsala Space Observatory, Sweden. Tel. +46-31-772 5556, email hgs@chalmers.se

Introduction

Five years of gravity measurement with the superconducting gravimeter at one sample per second, of which only 0.4 percent have been lost, have provided a rich data base. Results of processing and analysis will be shown. The presentation will provide an overview of tidal effects, annual perturbations, Kattegat basin oscillations, dynamic air pressure response, instrumental function and occasional malfunction, drift determination and the background noise power spectrum.

The instrument provides 1-s data to the world with one minute latency. A short overview over the on-line products available from an http-server will be given. The use of the station for long-term absolute gravity determination and its collocation with VLBI and GNSS monuments of among the longest existing site histories is emphasized. The inevitable noise with its source in the nearby Kattegat is accompanied by geometrical and gravimetrical variations of the Earth surface. Notwithstanding, the Onsala team believes that they have contributed a reliable and long-time stable observation resource for geodesy and geodynamics in the Nordic region.

Installation and ancillary sensors

The permanent installation of the Superconducting gravimeter (SG, GWR #54) at Onsala Space Observatory (OSO) is housed in a separate building established in 2009 and located at a distance far enough from the 20m radio telescope so that gravity perturbations due to moving of the 90 ton dish and counterweight mass dipole during pointing remain below 0.005 nm/s^2. The building has thermal and irradiation shielding on the outside including a 3 meter polystyrene apron. It rests on crystalline bedrock with a relatively low crack frequency. Controlled ground water pumping at the deepest position of the location is to keep the fractures at constant water filling levels. The interior has air conditioning and controlled air circulation; the SG-cabin passively coupled SG cabin. Two antimagnetic concrete platforms for Absolute gravimetry in the main room and the SG platform in the cabin rest on the crystalline while the floors rest only on the surrounding basement wall.

The list of ancillary sensors, routinely recorded and kept in openly accessible data bases, include: Barometer, gravimeter subsystems (temperatures, pressures, Helium levels, and tilt meters); room sensors record platform temperatures. Platform surface height is measured with a 4 m long, deep anchored Invar bar. A groundwater level monitoring well exists; its instrumentation is in progress. Uppsala University has installed a broadband seismometer station of the Swedish National Seismic Network. OSO operates a bubbler-type tide gauge, a GNSS tide gauge, and a weather station (air and sea temperatures, wind, rain), and also these recordings are kept in a data base open to the public.

The live Internet pages

Since January 2012 a set of Internet pages is available under http://holt.oso.chalmers.se/hgs/SCG/monitor-plot.html. Updated every minute with one minute latency, they show observations from the SG and ancillary sensors. An overview of data from the recent 30-day period is given, and links provide monthly spectrograms of microseismic noise, temperatures, tilt regulators, weekly tide analysis, and much more. As a self-service for looking back, visitors can enter the date and time of their interest. Numeric 1-s data can be picked up too. One-minute data as supplied to the Global Geodynamics Project is available at http://holt.oso.chalmers.se/hgs/4GGP/. Another entry point is found at
http://holt.oso.chalmers.se/hgs/SCG/scgnews.html.

Data analysis – two observation models

For the purpose of an automatized analysis running at the end of each week, a standard set of time series is included in the least-squares fit under the premise that all processes in the environment affect what is read from the SG statically, thus a set of conceptually stationary coefficients are estimated. Besides a spectral breakdown of luni-solar tides into wavegroups of at least 1 cyc/yr width, the following effects are accounted: Polar motion (POLI – in phase, POLX – quad-phase); atmospheric attraction and loading using *Atmacs* (2014) (BAGL – global load, BAGN – global Newtonian, BARL – regional and local); Kattegat bottom pressure at one of two tide gauges nearby (RIOS); a set of drift signals (exponential decay after repair of a sensing device in the SG; SLP1, SLP2 – two events, both introducing biases and slopes; and an offset after a coldhead replacement).

A few more details: the sea bottom pressure is mimicked using the sum of barometric pressure and water column pressure (tide gauge reading times water density times normal gravity). The tide gauge stations used are Ringhals (up to August 2013) and the bubbler-type device at Onsala (thereafter). The time series supplied for the SG analysis have been stripped of luni-solar tides, the purpose being that the tide coefficients that describe the gravity variations as measured by the SG are conceived to contain all tidal effects, astronomical, solid-earth, and ocean loading. The notion that oceanic tides, especially in basins like Kattegat, contain nonlinear-modulation products leads me to expect that wavegroup responses would be rather different from what a gravity measurement is showing (being dominated by the tidal forces from moon and sun), so removing the Kattegat tides from the tide-gauge series bequeaths the gravity tide coefficients the Kattegat gravity contribution, enabling the prediction of gravity change with a parsimonious set of parameters. The quad-phase signal of Polar motion is obtained by Hilbert transformation; delayed effects, like a lagging polar ocean loading tide or a delayed response of the solid earth due to internal friction could be captured with the two orthogonal series. The reason for the split of Atmacs into three parallel series reflects my finding that each coefficient has always come out significantly different from unity in the pilot tests of alternative strategies. On the time scale of days air pressure drives the water level with excitation of basin dynamics. On the annual and sub-annual time scale the solar cycle and its harmonics leave an imprint in the air pressure and consequently in the sea level. Parameter correlation (and non-robust solutions) are but bound to arise.

An extended model has been devised that is a little clumsy to run automatically. Noting that the time series of BARL and RIOS show significant cross-correlation with both, the residual of the standard analysis, and between each other, a set of Wiener filters (±64 h duration) have been devised for this three-some of signals so that time-delayed (and time-advanced) effects can be accounted for. Four series are introduced in addition to the sea bottom pressure proxy; “input” and “output” are referred to in terms of linear system theory. RIBA: RIOS is input, Atmacs is output; BARI – the reverse of RIBA; BAWF: Atmacs in, gravity out; RIWF: bottom pressure in, gravity out. My most recent analysis with this model has not distinguished global load and global Newtonian in the Atmacs series. Results are given in Tab. 1.

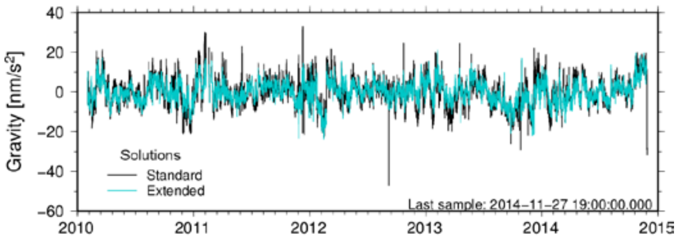

Fig. 1 – *Residuals from SG least-squares analysis, using the standard model (black curve) and the extended model (blue).*

Conclusions

With an extended reduction model that includes time-delayed and time-advanced series of air pressure, a sea bottom pressure proxy and their mutual interactions using Wiener filters, it is possible to arrive at a 5 nm/s2 RMS residual from gravity recordings at Onsala spanning Feb. 2010 through Sep. 2014. The Atmacs air pressure attraction and loading model has been split into three channels (regional plus local attraction, loading, global attraction), and the admittance coefficients of these channels turned out significantly different from unity. There is obvious parameter covariance between the atmospheric, sea level-related, long-period solar tide and polar motion terms; most noticably the anomalous solar annual tide settles at a more normal amplitude in the extended model. A large cross-phase component of polar motion is observed in either of the solutions. Measurements of ground water in the fractures of the station’s bedrock or of surface hydrological processes might render solutions more robust in the future.

Reference:

Atmacs (2014), http://atmacs.bkg.bund.de

Table 1 – *A shortlist of coefficients, solved with least-squares to fit the series of hourly SG-records from Feb. 2, 2010 to Sep. 30, 2014. Of the tide coefficients (32 pairs) only those associated with the solar long-period species are shown (the short-period tides make up 90% of the total signal RMS). The standard and the extended models are compared. Note that the global atmospheric attraction* (BAGN) *amd loading* (BAGL) *response in the standard model are traded against the Wiener-filtered Kattegat terms in the extended model, primarily the bottom pressure series* RIWF, *and also against the ter-annual tide* S_{ta}.

Signal	Coefficient Standard model	Coefficient Extended model	Unit	Contribution Std. m., %	Contribution Ext. m., %
Sa	2.10 ±0.08, -9.5°	1.149 ±0.036, -34°	δ, κ	2.6	1.40
Ssa	1.163 ±0.07, -3.0°	1.178 ±0.003, -2.8°	δ, κ	8.6	8.73
Sta	1.13 ±0.11, 5°	1.324 ±0.050, 6.8°	δ, κ	0.5	0.57
Sqa	12.5 ±2.7, -174°	8.5 ±1.2, 175°	δ, κ	0.21	0.15
BAGN	-1.485 ±0.055	-0.729 ±0.030	-	0.57	0.28
BAGL	0.905 ±0.025	-0.147 ±0.017	-	1.34	0.22
BARL	-0.678 ±0.004	-0.845 ±0.003	-	5.99	7.55
RIOS	0.147 ±0.002	0.0205 ±0.0026	nm/s²/hPa	0.47	0.06
POLI	1.216 ±0.020	1.277 ±0.009	-	3.11	3.25
POLX	-0.385 ±0.017	-0.415 ±0.008	-	0.95	1.01
SLP2	-27.47 ±0.20	-29.48 ±0.10	nm/s²/yr	n.a.	n.a.
RIBA	-	0.058 ±0.011	nm/s²/hPa	-	0.04
BARI	-	-0.004 ±0.009	hPa s²/nm	-	0.00
RIWF	-	0.342 ±0.004	nm/s²/hPa	-	1.05
BAWF	-	-0.0083 ±0.0004	-	-	0.11
RMS	7.39	5.27	nm/s²	469	469

Regional 21st Century Sea Level Projections for Norway Based on IPCC AR5 Science

Matthew J.R. Simpson[1,*], Even Ø. Nilsen[2], Kristian Breilli[1,3], Halfdan P. Kierulf[1], Holger Steffen[4] and Oda Roaldsdotter Ravndal[5]

[1]Geodetic Institute, Norwegian Mapping Authority, 3507 Hønefoss, Norway, [2]Nansen Environmental and Remote Sensing Center, and Bjerknes Centre for Climate Research, Bergen, Norway, [3]Department of Mathematical Sciences and Technology, Norwegian University of Life Sciences, P.O. Box 5003, 1432 Ås, Norway, [4]Lantmäteriet, Lantmäterigatan 2c, 80102 Gävle, Sweden, [5]Norwegian Hydrographic Service, Norwegian Mapping Authority, Tinngata 8, 4014 Stavanger.

*Corresponding author; e-mail: Matthew.Simpson@kartverket.no

Introduction

Official sea level advice for Norway is being updated using data from the 5th report of the International Panel for Climate Change (IPCC AR5) (Church et al., 2013a). This is a collaborative effort between Kartverket and the Bjerknes Centre for Climate Research.

IPCC AR5 and Sea Level

There are two main advances in sea level science presented in AR5: (1) sea level projections are given a likelihood (owing to our improved understanding of past sea level changes and advances in ice modelling) and (2) regional sea level projections are presented for the first time.

Different Representative Concentration Pathways (RCPs) describe a range of possible climate futures. We examine RCP2.6, 4.5 and 8.5. The numbers correspond to the changes in radiative forcing in the year 2100 relative to the pre-industrial (e.g. RCP4.5 = +4.5W/m^2).

For the period 2081-2100 relative to 1986-2005 projected global sea level rise is:

- RCP2.6 mean 0.4 m, *likely* range 0.26 to 0.55 m
- RCP4.5 mean 0.47 m, *likely* range 0.32 to 0.63 m
- RCP8.5 mean 0.63 m, *likely* range 0.45 to 0.82 m

Note that following the calibrated language of the IPCC, the *likely* range corresponds to a probability of 66-100%. This means there is up to a 33% chance that future sea level will lie outside of the range of the projections.

The IPCC AR5 states that only the collapse of the marine-based sectors of the Antarctic ice sheets can lead to a global sea level rise significantly above the *likely* range. Some evidence (Joughin et al., 2014) suggests that collapse is potentially underway for the Thwaites Glacier basin but the time scale is very uncertain (200 to 900 years).

Regional Relative Sea Level Projections

Regional sea level can be substantially different from global mean changes owing to spatial variations in (1) ocean density, ocean mass redistribution and circulation (2) ocean mass changes and associated gravitational effects on sea level and (3) vertical land motion and associated gravitational effects on sea level.

We present regional relative sea level projections for Norway using findings largely from AR5. The main difference between our results and those shown in AR5 are that we adopt a new Glacial Isostatic Adjustment (GIA) field with corresponding gravity changes (Kierulf et al., 2014) and an estimate of sea level changes owing to the gravitational effects of ocean mass redistribution (Richter et al., 2013).

Methodology

Here we briefly outline the method used to calculate the regional relative sea level projections. Coupled Atmosphere–Ocean General Circulation Models (AOGCMs) simulate sea surface height changes relative to the geoid resulting from natural and anthropogenic forcings. Ocean density, mass redistribution, circulation and sea level are simulated together in the models. These sea surface height data from the AOGCMs are available from the CMIP5 model database (http://cmip-pcmdi.llnl.gov/cmip5/). Note that there are 21 models to contribute to the model ensemble. Results from the individual models are interpolated to a 1 x 1 degree grid.

Projections of the glacier and ice sheet mass contributions, on the other hand, are currently dealt with offline (i.e. not in the AOGCMs). Surface mass balance changes are computed using regional climate modelling. Whereas, ice dynamical changes are based upon observations and preliminary modelling efforts. Changes in ocean mass due to human activity, the impoundment of water in dams and pumping of groundwater, are also taken into account. For each of these mass contributions the corresponding gravitational effects on sea level were computed (Farrell and Clark, 1976).

As mentioned above, we use results from Kierulf et al. (2014) when considering GIA and associated gravitational effects on sea level. We opt to use a solution which combines observations of vertical land motion from permanent GPS stations with modelled gravitational changes.

The procedure used to combine the separate contributions and their respective uncertainties is detailed in Church et al. (2013b).

Results

Here we show some preliminary results from our analysis. Figure 1 shows projected relative sea level changes and associated uncertainties for the city of Bergen. Over the period 1986-2005 to 2081-2100 we project a relative sea level change for RCP2.6 of 0.23 m (*likely* 0.05 to 0.4 m), for RCP4.5 of 0.31 m (*likely* 0.12 to 0.49 m) and for RCP8.5 of 0.48 (*likely* 0.25 to 0.71 m). Thus, projected sea level changes for Bergen, and the rest of Norway, are somewhat below the projected global sea level rise.

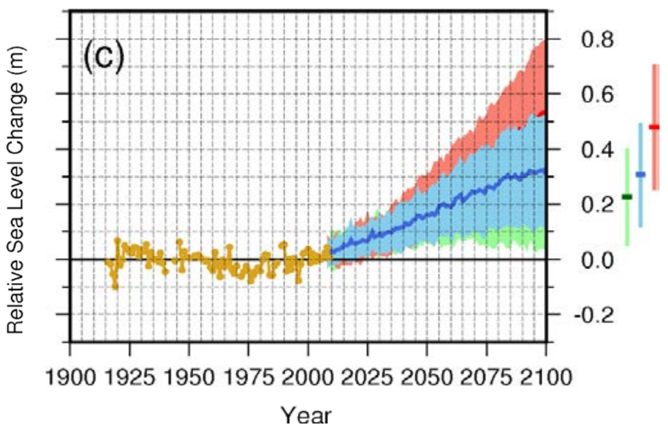

Fig 1. *Relative sea level projections for RCP4.5 (blue) and RCP8.5 (red) for Bergen. The vertical bars on the right side of the panels represent the ensemble mean and ensemble spread (the likely range) for RSL change calculated over the period 1986-2005 to 2081-2100. Annual mean tide gauge observations are shown in yellow.*

Concluding Remarks

Changes in mean sea level cause a change in the height of extreme sea level events. It is also true that the frequency of sea level exceeding any particular fixed height in the landscape will also change. For example, what is now defined as the 200 year storm surge return level (i.e. we expect this height to be exceeded only once every 200 years) will be reached more often as mean sea level increases. This has clear implications for coastal planning and management.

Planning law in Norway states that, depending on the size of the consequences, buildings should be built above the 20, 200 or 1000 year storm surge return levels (TEK10). These levels are calculated from the statistical analysis of historical records. We aim to combine our sea level projections with the storm surge return levels using the statistical method of Hunter (2012). In doing so, we hope to provide information on future changes in extreme sea levels that will be of use for coastal engineers and decision makers.

References

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan (2013a): Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change Supplementary Material. In: Climate Change (2013b): The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Available from www.climatechange2013.org and www.ipcc.ch.

Farrell, W. E., and J. A. Clark (1976): On postglacial sea level. Geophys. J. R. Astron. Soc., 46, 647–667.

Hunter, J., (2012): A simple technique for estimating an allowance for uncertain sea-level rise. Clim. Change, 113, 239–252.

Joughin, I et al. (2014): Marine Ice Sheet Collapse Potentially Under Way for the Thwaites Glacier Basin, West Antarctica. Science 344 (6185): 735-738

Kierulf, H. P., H. Steffen, M. J. R. Simpson, M. Lidberg, P. Wu, and H. Wang (2014): A GPS velocity field for Fennoscandia and a consistent comparison to glacial isostatic adjustment models, J. Geophys. Res. Solid Earth, 119, doi:10.1002/2013JB010889.

Richter, K., R. E. M. Riva, H. Drange (2013): Impact of self-attraction and loading effects induced by shelf mass loading on projected regional sea level rise. Geophys. Res. Lett., 40 (1–5), doi: 10.1002/grl.50265

(TEK10) http://lovdata.no/dokument/SF/forskrift/2010-03-26-489#KAPITTEL_3

Recommendation for the Public Administration 184 (JHS184): Measuring control points in EUREF-FIN reference frame

Pasi Häkli*, Markku Poutanen, Hannu Koivula, Ulla Kallio, Sonja Nyberg, Marko Ollikainen, Pekka Tätilä, Reino Ruotsalainen, Jyrki Puupponen, Kimmo Junttila and Matti Holopainen

*Finnish Geospatial Research Institute (FGI), National Land Survey of Finland
Geodeetinrinne 2, FI-02430 Masala, Finland
e-mail: pasi.hakli@nls.fi

Summary

In the past, guidelines for geodetic measurements in Finland have been given in various and separate documents with varying formal status. Most of them were also partly outdated or missed some essential information. In order to improve this situation, most guidelines in Finland are now gathered under the umbrella of the recommendations for public administration (JHS). These e.g. promote the use of national realizations of the ETRS89 (EUREF-FIN) and the EVRS (N2000). In 2012, a new recommendation for measuring of control points (JHS184) was prepared. The recommendation describes the classification of EUREF-FIN points, allowed measurement methods, defining the coordinates and the accuracy requirements.

The recommendation can be found online in the webpage of JHS (http://www.jhs-suositukset.fi/suomi/jhs184)

Comparison of the Vienna Mapping Function (VMF1) and Global Mapping Function (GMF) for NKG GNSS AC

Lotti Jivall
Lantmäteriet
Lantmäterigatan 2C, SE 80182 Gävle
e-mail: Lotti.Jivall@lm.se

Abstract

For the NKG GNSS Analysis Centre (Jivall et al. 2014), which is based on distributed processing, a common processing strategy is needed. One of the parameters to investigate is the choice of mapping function for the tropospheric modelling. The newest and most advanced models in the Bernese GNSS Software (version 5.2) are Global Mapping Function (GMF) and Vienna Mapping Function (VMF1). Following the recommendations in Guidelines for EPN Analysis centres (EPN Coordination group, 2013), either one of these mapping functions should be used, but no preferences are given.

This paper presents the results of a comparison between coordinate estimation using the two mapping functions on one year of data from northern Europe. The calculations have been performed with the Bernese GNSS Software version 5.2 (Dach et al. 2007).

Questions we would like to answer:

- Does VMF1 perform better than GMF?
- How large differences are there in general between coordinates estimated with VMF1 and GMF, respectively?
- Is there any systematic difference between GMF and VMF1 in terms of estimated coordinates?

Troposphere modelling and mapping functions

Troposphere mapping functions are used in the analyses of GNSS and VLBI to map zenith hydrostatic and wet delays to any elevation angle and vice versa.

Vienna Mapping Function (VMF/VMF1) and Global Mapping Function (GMF) as well as Niell Mapping Function (NMF) use continued fraction form according to the formula below.

$$m_n(E) = \left(1 + \frac{a}{1 + \frac{b}{1 + c}}\right) \Big/ \left(\sin E + \frac{a}{\sin E + \frac{b}{\sin E + c}}\right)$$

E is the elevation and a, b and c are coefficients dependent on at least latitude and day of year.

In case of VMF/VMF1 the b- and c-coefficients are based on the empirical equations and the a-coefficient origins from rigorously ray traced mapping functions at 3° elevation from numerical weather models for the actual time of observations. VMF1 is an update of VMF where the b- and c-coefficients have been re-determined (Boehm et al. 2006a). The a-coefficients are available in a global grid in 6-hour files and could be obtained from http://ggosatm.hg.tuwien.ac.at/DELAY/GRID/VMFG/.

GMF is using the same b-and c-coefficients as VMF1 (Boehm et al. 2006b). The a-coefficients of GMF are obtained from an expansion of VMF1-parameters on a global grid of monthly means from September 1999 to August 2002.

According to (Boehm et al. 2006b) VMF1 is currently the mapping function providing the most accurate and reliable geodetic results globally. The GMF is proposed to be used as a back-up for VMF, if the a-coefficients for VMF are not available or VMF could not be used for some other reason.

The VMF shows a mean improvement of 5-10% versus results obtained by NMF for VLBI analyses (Boehm, Schuh 2004).

When selecting the troposphere modelling GMF in the Bernese software, the Global Pressure Temperature model, GPT, (Boehm et al. 2007) will be used together with the GMF mapping function. In case of VMF, the data from the European Centre for Medium-Range Weather Forecasts, ECMWF, will be used together with the VMF1 mapping function. Furthermore, the dry (hydrostatic) component of the tropospheric delay will be modelled a priori and the wet component will be estimated from the GNSS observations.

Errors in the a priori model will imply that a part of the delay will be mapped with the wet instead of the hydrostatic mapping function (or vice versa), thus biasing the estimated troposphere delays as well as station heights. It has been shown that modeling hydrostatic zenith delays with mean (or slowly varying empirical) pressure values (like GPT) instead of the true pressure values (like ECMWF) results in a partial compensation of atmospheric loading (Steigenberger et al. 2009).

In the study of Steigenberger four global GPS solutions were computed, where the mapping functions VMF1 and GMF were combined with both of the a priori models GPT and ECMWF. GPT resulted in better coordinate repeatability than ECMWF when using the same mapping function (either VMF1 or GMF). One could also see that the mapping function VMF1 performed slightly better than GMF when using the same a priori model for the hydrostatic delay.

A direct comparison of the mean station height repeatability between GMF/GPT and VMF1/ECMWF reveals slightly better repeatability for GMF/GPT (9.30 compared to 9.38 mm) in the global reference frame solution but slightly higher value for GMF/GPT (5.35 compared to 5.28) for the average of daily repeatability on weekly basis for the year 2004.

The absolute height difference in the global solutions with GPT/GMF and ECMWF/VMF1, respectively, range from -5.9 mm to +6.4 mm, but 81% of the stations are below 1 mm.

Test data set

The same sub-net of EPN (European Permanent Network) used for the benchmark test of NKG AC, i.e. 35 stations that observe both GPS and GLONASS in the EPN NKG LAC sub-network, were chosen for the test – see Fig.. The antennas at the stations are all choke ring antennas of different brands (Allen Osborne, Ashtech, Javad, Leica, Trimble and Topcon) except for six Trimble Zephyr antennas.

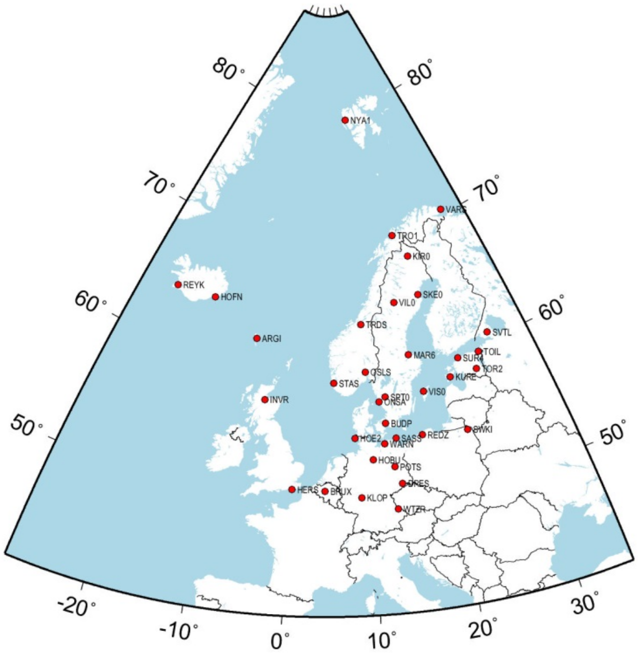

Fig.1: *Stations in the benchmark test for the NKG GNSS AC project used for the test of tropospheric mapping functions.*

We decided to analyse a full year to get experiences from all seasons and the period 2012 doy 154 – 2013 doy 153 was arbitrarily chosen.

The analysis was made both on the full year but also on just the summer months June-August 2012 to avoid periods with possible snow on antennas and radomes.

Processing

The data was processed with Bernese version 5.2 using the standard processing setup RNX2SNX, which is based on double difference processing. GMF was used as tropospheric mapping function for the float solution and the ambiguity resolution. Two final solutions where produced, one using GMF and one using VMF1. The elevation cut-off in the final solutions was set to 3°. In order to speed up the processing just GPS-data were processed and the ambiguity resolution was performed using QIF (Quasi Ionosphere-Free algorithm) only.

Before starting the processing, a comparison was made for a single day between the setup above using GMF in the pre-processing and just VMF1 in final solution on one hand, and a setup using VMF1 in all steps on the other. The comparison revealed negligible differences.

Analysis method

The daily coordinate repeatability was analysed as a measure of the quality of the estimated coordinates. The ITRF coordinates were first transformed to UTM zone 33 to get the repeatability in north, east and up (height). As the ITRF-coordinates have a time dependent trend, this was extracted by linear regression before computing RMS-values of the residuals.

The hypothesis is that VMF1 gives slightly better results than GMF and we expect the daily coordinate repeatability to be lower for VMF1.

The daily differences for each station were also analysed to see if we could see any systematic differences between the two mapping functions and also to see how large the differences could be on a single day. The daily differences were calculated as residuals in a 4-parameter Helmert transformation, solving for translations and a scale factor. Daily maximum and minimum values were analysed as well as station wise time series of the differences.

The analyses mentioned above were done both for the full year and for the summer period, to see if we come to different conclusions depending on season and if periods with snow accumulated on antennas/radomes are included.

Coordinate repeatability

The daily RMS after extraction of a linear trend is on a general level c. 1-2 mm per horizontal component and 3-5 mm in height.

The relative difference between the solutions with VMF1 and with GMF is found in Tab. 1. The RMS with VMF1 is divided by the RMS with GMF, i.e. a negative value (marked in the table) means that VMF1 is better in terms of daily repeatability.

As expected, VMF1 shows on average slightly smaller RMS in height (in the order of 8-10%, GMF has 10-13% higher RMS than VMF1). It is significant on 2 sigma level with respect to the standard deviation of the average. There is no significant improvement on the horizontal components.

The improvement for VMF1 is on the same level as earlier noted between VMF and NMF (Boehm, Schuh 2004) and considerably larger than reported by Steigenberger et al. 2009. The reason for our larger improvement is probably that our solutions are regional and not global.

Tab. 1: *Relative difference between daily RMS when using VMF1 and GMF, respectively*.

Full year				Summer			
RMS VMF1/GMF				RMS VMF1/GMF			
Stn	N	E	U	Stn	N	E	U
ARGI	-3%	5%		ARGI	-4%	3%	-19%
BRUX	-2%	-5%	-11%	BRUX	-16%	-8%	-8%
BUDP	-11%	-1%	-20%	BUDP	-1%	-1%	-28%
DRES	12%	-2%	5%	DRES	21%	0%	0%
HERS	6%	-2%	9%	HERS	-6%	2%	5%
HOBU	-4%	2%	-3%	HOBU	-8%	0%	-4%
HOE2	-16%	3%	-7%	HOE2	-10%	4%	-24%
HOFN	-1%	-2%	-4%	HOFN	2%	11%	1%
INVR	-11%	14%	-23%	INVR	-6%	4%	-24%
KIR0	1%	0%	6%	KIR0	-2%	-3%	-3%
KLOP	5%	-4%	0%	KLOP	5%	-2%	-1%
KURE	1%	0%	-20%	KURE	3%	3%	-23%
MAR6	2%	4%	-1%	MAR6	2%	4%	-2%
NYA1	3%	-3%	-3%	NYA1	3%	-1%	-11%
ONSA	16%	1%	-3%	ONSA	8%	1%	-16%
OSLS	2%	1%	0%	OSLS	-4%	2%	2%
POTS	0%	0%	-10%	POTS	1%	0%	-9%
REDZ	0%	1%	-18%	REDZ	-1%	4%	-23%
REYK	-10%	13%	-4%	REYK	-5%	6%	6%
SASS	13%	-1%	-14%	SASS	9%	0%	-9%
SKE0	-3%	2%	4%	SKE0	-3%	-1%	4%
SPT0	9%	-3%	-1%	SPT0	1%	-1%	-3%
STAS	9%	10%	-10%	STAS	0%	5%	-13%
SUR4	-6%	-5%	-19%	SUR4	2%	-3%	-27%
SVTL	1%	-2%	1%	SVTL	-3%	-1%	-1%
SWKI	2%	-2%	-15%	SWKI	2%	-2%	-21%
TOIL	-8%	-2%	-16%	TOIL	1%	-5%	-20%
TOR2	-2%	6%	-9%	TOR2	4%	10%	-24%
TRDS	-10%	1%	-2%	TRDS	-7%	1%	-3%
TRO1	-6%	-5%	-23%	TRO1	1%	-6%	-9%
VARS	-5%	-4%	-16%	VARS	4%	-3%	-14%
VIL0	9%	2%	4%	VIL0	-2%	1%	-2%
VIS0	6%	4%	-1%	VIS0	6%	5%	0%
WARN	-1%	-1%	-19%	WARN	12%	0%	-18%
WTZR	-7%	0%	-4%	WTZR	-1%	-1%	-8%
Average	0%	1%	-7%	Average	0%	1%	-10%
Stdv	7%	5%	9%	Stdv	7%	4%	10%
Stdv_average	1.4%	0.8%	1.6%	Stdv_average	1.1%	0.7%	1.7%
Sigma_level	0.2	0.8	4.5	Sigma_level	0.2	1.1	5.7

However for single stations, VMF has higher RMS than GMF. This occurs e.g. for the Swedish sites KIR0 and VIL0 in the full year solution where there are problems with accumulated snow in the winter.

In the analysis of the summer months both KIR0 and VIL0 have smaller RMS with VMF1 than with GMF, but there are still some stations which have slightly larger RMS with VMF1: DRES, HERS, HOFN, OSLS, REYK, SKE0, VIS0.

Helmert fits to IGb08

The Helmert fits to the official IGb08 coordinates were also analysed. RMS values of the 3-parameter transformations are plotted for the GMF and VMF solutions – see Fig. 2. For the main part of the days, 8 stations have been used for the fit (HERS, HOFN, MAR6, NYA1, ONSA, POTS, TRO1 and WTZR). (There were 6 stations one day and 7 stations 21 days out of the 366 days.) The two graphs look very similar, but the mean of the RMS for VMF1 is slightly smaller than for GMF; 4.7 mm compared to 4.9 mm and the standard deviation is 1.16 mm for VMF1 and 1.25 mm for GMF.

A decreasing trend of the RMS values is also seen in Fig. 22, but the reason for this is not understood.

IGb08 was introduced first in October 2012 in the EPN-processing, but for this study we have used the IGb08 coordinates and corresponding antenna models for the whole period. There is also just one station that has changed equipment during the period (HOFN in May 2013).

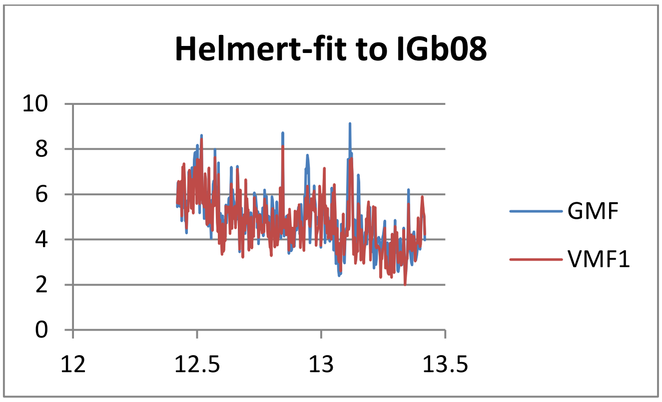

Fig. 2: *Helmert-fit to IGb08.*

Coordinate differences

The daily differences between the solutions with GMF and VMF1 after a 4-parameter Helmert transformation (translation and scale) range up to 14 mm in height and 2 mm in the horizontal components during the full year. The maximum differences for a single day are in average c. 0.5 mm in the horizontal components and 6 mm in height for the same period. Corresponding values for the summer are maximal values up to 12 mm in height and 1 mm in the horizontal components, and average maximal values of 5 mm in height and c. 0.5 mm in the horizontal components. The values are quite similar for the full year and summer only.

The residuals of the 4-parameter Helmert transformation were also accumulated for each station into station time series – see example in Fig. 3. It can clearly be seen that the differences are correlated in time.

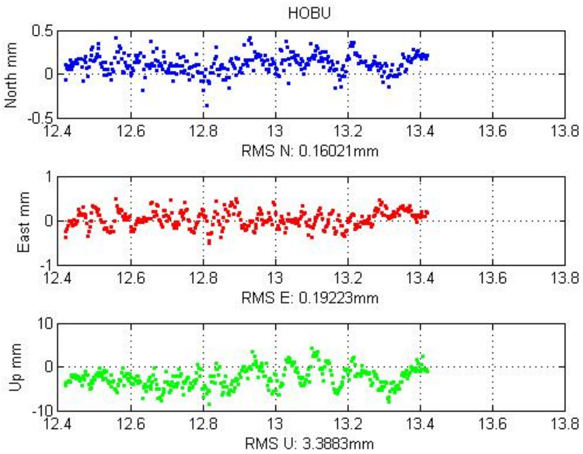

Fig. 3: *Coordinate difference after a 4-parameter Helmert transformation between processing with GMT and VMF1, example for the station HOBU, which is the station that shows the largest systematic difference between the two mapping functions.*

The average of the differences for each station (i.e. the systematic effect) was computed and compared to the standard deviation of the average. Stations with significant height differences on 2-sigma level are listed in Tab. 2.

Tab. 2: *Average differences based on data for the full year and the summer period, respectively. The last column reflects the sigma-level for significant differences, computed by dividing the average value with the standard deviation for the average value.*

Full year					Summer period				
	Average			Factor		Average			Factor
Station	N	E	U	U	Station	N	E	U	U
HOBU	0.1	0.0	-2.5	6.6	HOBU	0.1	0.0	-3.3	12.7
DRES	0.2	0.0	-3.6	6.5	POTS	0.1	0.0	-2.8	8.4
OSLS	-0.1	-0.1	0.8	4.7	OSLS	-0.2	-0.1	0.7	4.8
ONSA	0.0	0.0	0.8	3.8	DRES	0.2	-0.1	-1.6	3.9
SPT0	0.1	0.0	0.5	3.1	KLOP	0.0	0.0	-1.0	3.8
NYA1	0.1	0.1	-1.7	3.1	ONSA	0.0	0.0	0.8	3.7
INVR	-0.2	0.0	2.0	2.8	REYK	0.1	0.0	-1.6	3.6
REYK	0.2	0.0	-1.7	2.6	MAR6	-0.1	-0.1	0.5	3.6
BUDP	-0.1	0.0	1.1	2.6	VIL0	-0.1	-0.1	0.6	3.2
HOE2	-0.1	0.0	1.0	2.5	TRDS	-0.1	-0.1	0.5	2.9
STAS	0.0	0.0	0.7	2.2	SPT0	0.0	0.0	0.4	2.7
WTZR	-0.2	-0.1	0.9	2.1	INVR	-0.2	-0.1	1.8	2.6
					KIR0	0.1	0.0	0.8	2.5
					STAS	-0.1	-0.1	0.7	2.4
					KURE	-0.1	0.0	1.1	2.2
					SUR4	0.0	0.0	0.9	2.2
					SKE0	-0.1	-0.1	0.5	2.1
					BUDP	-0.1	0.0	0.7	2.0
					NYA1	0.2	0.0	-0.8	2.0

There are some stations with a systematic difference of a few mm (up to 3.6 mm) between coordinates determined using the two different mapping functions. 80% of the stations have a systematic difference less than 1 mm during the summer period, which agrees well with the results of Steigenberger et al. 2009. Our maximum systematic difference is smaller which probably is because of the solution being regional, a smaller number of stations and maybe also due to the rather good antenna types used in our test data.

Conclusions

A small improvement of the repeatability of the height component is noted for VMF1 compared to GMF, in average c. 0.4 mm in the RMS, corresponding to 8-10% lower values for VMF1 than for GMF. This is valid both for the full year and for the summer period.

There are individual variations, especially during winter time when snow is accumulated on the antennas/radomes at some stations.

The fit to fiducial stations in IGb08 is also somewhat better for VMF1 than GMF (average 4.7 mm and standard deviation 1.16 mm compared to 4.9 mm and 1.25 mm for GMF).

The coordinate differences on a single day could be up to 14 mm in height and on average up to 6 mm. This is too much to neglect when combining solutions from different sub-networks, which means that it is important that we use the same mapping function for all national analysis centres contributing to NKG AC.

For one third to one half of the stations (depending on the selected time period) there were systematic differences in estimated heights between VMF1 and GMF significant on 2 sigma level. The largest difference was 3.6 mm, but there were just two stations with a significant systematic difference larger than 2 mm. 80% of the stations had less than 1 mm systematic difference in height.

The systematics in coordinate estimation between the mapping functions seen in this study are on the same level as reported earlier by e.g. Steigenberger et al. 2009.

The existing systematic differences mean that we might get a change of trend for some stations if we would combine e.g. re-processed solutions using VMF1 with operational solutions where GMF is used. Therefore it is best to use the same setup for both operational processing and future re-processing. In case of using VMF1 it is suggested to use GMF as back-up if the grid-files are not available, this mixing of VMF1 and GMF is not considered to be a problem as long as it is just concerns single days or maybe a week.

References

Boehm J, Schuh H (2004): Vienna mapping functions in VLBI analyses. GEOPHYSICAL RESEARCH LETTERS, VOL. 31, L01603, doi: 10.1029/2003GL018984, 2004.

Boehm J, Werl B, Schuh H (2006a): Troposphere mapping functions for GPS and very long baseline interferometry from European Centre for Medium-Range Weather Forecasts operational analysis data. JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, B02406, doi: 10.1029/2005JB003629, 2006

Boehm J, Niell A, Tregoning P, Schuh H (2006b): Global Mapping Function (GMF): A new empirical mapping function based on numerical weather model data. GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L07304, doi:10.1029/2005GL025546, 2006.

Boehm, J., R. Heinkelmann and H. Schuh (2007), Short Note: A global model of pressure and temperature for geodetic applications, *Journal of Geodesy*, doi: 10.1007/s00190-007-0135-3.

Dach, R., U. Hugentobler, P. Fridez, M. Meindl (Eds); (2007): Bernese GPS Software Version 5.0. User manual, Astronomical Institute, Universtiy of Bern.

EPN Coordination group (2013): Guidelines for the EPN Analysis Centres. http://www.epncb.oma.be/_documentation/guidelines/guidelines_analysis_centres.pdf

Jivall L et al. (2014): Report from the project NKG GNSS AC. NKG General assembly 2014, Gothenburg.

Steigenberger P, Boehm J, Tesmer V (2009): Comparison of GMF/GPT with VMF1/ECMWF and implications for atmospheric loading. J Geod (2009) 83:943–951.doi 10.1007/s00190-009-0311-8.

Elections

The meeting agreed upon the following working groups, with related keywords.

Working group of Geodynamics

Keywords

- Absolute gravimetry/Superconducting gravimetry/Satellite gravimetry
- Temporal variation in gravity
- Crustal deformation
- Post glacial rebound/GIA

Working group of Reference Frames

Keywords

- Reference frames
- EPN
- ETRS 89, ITRF
- Transformations to National realisations of ETRS89
- Densified velocity field
- GNSS Time series

Working group of Positioning and Navigation

Keywords

- Real-time positioning (dGPS, RTK, PPP)
- Positioning/navigation services
- New GNSSs and modernisation
- Quality checking / monitoring
- Making reference frames and vertical reference systems available to users

Working group of Geoid and Height Systems

Keywords

- Geoid determination methods
- NKG Geoid and databases
- Levelling networks and height systems
- Future height systems
- Height determination methods
- Empirical land uplift modelling
- Mean sea level
- Tide gauges

The following chairpersons for the working groups were elected.

Working group chairs

Geodynamics: Matthew Simpson (Norway)

Reference Frames: Pasi Häkli (Finland)

Positioning and Navigation: Per Knudsen (Denmark)

Geoid and height systems: Jonas Ågren (Sweden)

Appointment of members to the NKG Presidium

As national representatives in the new Presidium,the following persons were announced:

Denmark	Niels Andersen Kristian Keller
Finland	Jarkko Koskinen Markku Poutanen
Iceland	Thorarinn Sigurdsson Gudmundur Valsson
Norway	Per-Erik Opseth Torbjørn Nørbech
Sweden	Mikael Lilje Jan Johansson

The Presidium elected Niels Andersen as chairperson and Mikael Lilje as secretaty for the 2014-2018 period.

* Note that the working group chairpersons are also members of the Presidium.

Resolutions

The accepted resolutions follow below.

Resolution No 1: Outreach

The Nordic Geodetic Commission
recognizing that geodesy is an important part of modern society as well as sciences about studies of the planet earth and climate change

noting that geodesy is unknown for the wider community

noting a general decrease in the number of students in natural sciences

noting the need for qualified geodetic expertise in the future

recommends the geodetic community to improve its ability in outreach activities towards society in general and young people in particular.

Resolution No 2: The importance of the gravity field and improved geoid model

The Nordic Geodetic Commission
recognizing the importance of the availability of an accurate geoid model for society, science and for oceanographic studies, and the user needs of a geoid model at the 5 mm uncertainty level in the NKG activity area

noting the transition to EVRS as reference for hydrographic surveys and navigation in the Baltic Sea

noting the needs for improvements in the data set of gravity observations at land and at sea

noting the benefit of further developments in theory of geoid determination, as well as in its implementation

asks the working group on Geoid and height systems to complete the work towards the NKG2014 geoid model,

and continue its work towards further improved geoid models.

Resolution No 3: Positioning and Navigation

The Nordic Geodetic Commission
recognizing the increasing use of high accuracy GNSS applications on land, sea and in the air for a large variety of professional uses

noting the real time positioning services and its increasing importance for a wide range of sectors in modern society

noting the intense development in the GNSS satellite segment, as well as methods for real time positioning services

noting the importance of the ground based infrastructure for these services and in particular the GNSS reference stations

recommends the exchange of knowledge and experience on modernisation of GNSS, on methods for real time GNSS service, and on the operation of GNSS stations, in order to increase our ability to meet present and future challenges.

Resolution No 4: Reference Frames

The Nordic Geodetic Commission
recognizing the need for precise and consistent reference frames in all GNSS based positioning and navigation, as well as for scientific studies

noting the upcoming ITRF2013

noting the importance of the work done by the NKG GNSS Analysis Centre

noting the improved models of crustal deformations under development within the NKG working groups

noting the need for an improved GNSS station velocity field for Fennoscandia

also noting the special geophysical conditions for management of geodetic reference frames on Iceland

asks the working group on Reference frames to develop and implement new findings in products (e.g. transformations and deformation models) and making these available for the benefit of the wider user groups.

Resolution No 5: Tide gauge and mean sea levels

The Nordic Geodetic Commission
recognizing the increasing need for monitoring changes in mean sea level

noting that mean sea level is changing due to climate change

noting that the geodetic control of the tide gauge stations lacks standardization and that access to tide gauge data is challenging

noting that reliable and standardized sea level information is needed in geodetic research on development of vertical reference systems

noting the importance of tide gauge installations colocated with GNSS instrumentation

recommends the members of NKG to be active in work on standardization of tide gauge operation, access to data, and data processing.

Resolution No 6: Geodetic contribution to the study of global change

The Nordic Geodetic Commission
recognizing the visible effects of climate change such as loss of sea ice, land ice, and resulting land uplift in the polar regions

noting the importance of geodetic observations for the study of global change, in the polar regions in particular

noting the foreseen implementation phase of the European Plate Observing System (EPOS)

noting the importance of the concept of Glacial Isostatic Adjustment (GIA) for the understanding of global change

recommends the members of NKG to continue the development of methods for modelling of GIA in the context of international scientific cooperation.

Resolution No 7

The Nordic Geodetic Commission and its members
present at the 17th general meeting of the Commission in Göteborg express their sincere thanks to Lantmäteriet and Chalmers University of Technology, to the scientific committee and to the local organizing committee for the fantastic arrangement and fruitful atmosphere during the meeting and at the social events.

Reports in Geodesy and Geographical Information Systems from Lantmäteriet (the Swedish mapping, cadastral and land registration authority)

2010:3 Odolinski Robert: Checklista för nätverks-RTK.

2010:4 Eriksson Per-Ola (ed.): Höjdmätning med GNSS – vägledning för olika mätsituationer.

2010:5 Eriksson Per-Ola (ed.): Anslutning av lokala höjdnät till RH 2000 med GNSS-stommätning.

2010:6 Engfeldt Andreas & Odolinski Robert: Punktbestämning i RH 2000 – statisk GNSS-mätning mot SWEPOS.

2010:7 Lord Jonas: Test av GNSS-mottagare från DataGrid.

2010:11 Ågren Jonas & Engberg Lars E: Om behovet av nationell geodetisk infrastruktur och dess förvaltning i framtiden.

2011:2 Jansson Jakob: Undersökning av mätosäkerheten i det förtätade SWEPOS-nätet i Stockholmsområdet – vid mätning med nätverks-RTK.

2011:3 Liu Ke: A study of the possibilities to connect local levelling networks to the Swedish height system RH 2000 using GNSS.

2012:3 Lundell Rebecka: Undersökning av nätverks-RTK-meddelande tillsammans med olika GNSS-mottagare – vid nätverks-RTK-mätning i SWEPOS nät av fasta referensstationer.

2014:2 Vestøl Olav, Eriksson Per-Ola, Jepsen Casper, Keller Kristian, Mäkinen Jaakko, Saaranen Veikko, Valsson Guðmundur, Hoftuft Olav: Review of current and near-future levelling technology – a study project within the NKG working group of Geoid and Height Systems.

2014:5 Ohlsson Kent: Studie av mätosäkerhet och tidskorrelationer vid mätning med nätverks-RTK i SWEPOS 35 km-nät.

2015:1 Fredriksson Annika & Olsson Madeleine: Jämförelse av höjdmätning med olika GNSS-mottagare i SWEPOS Nätverks-RTK-tjänst.

2015:2 Norin Dan, Johansson Jan M, Mårtensson Stig-Göran, Eshagh Mehdi: Geodetic activities in Sweden 2010–2014.

2015:4 Andersson Bengt, Alfredsson Anders, Nordqvist Anders, Kilström Ronald: RIX 95-projektet – slutrapport.

2016:1 Engfeldt Andreas: RG 2000 – status March 2016

2016:2 Engfeldt Andreas: Preparations and plans for the new national gravity system, RG 2000

LANTMÄTERIET

Vaktmästeriet 801 82 GÄVLE Tfn 026 - 65 29 15 Fax 026 - 68 75 94
Internet: www.lantmateriet.se