The Nordic Geodetic and Geodynamic Observing System (NGGOS):
An NKG plan for the contribution from an absolute gravimetry network (NGGOS/AG)

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1 Foreword

For some time now, there have been activities in the various Nordic countries in the field of absolute, or ballistic, gravimetry. Uses for such measurements include primarily geodynamic studies, but may be useful in support of gravimetric survey as well, being one way to calibrate survey data to an absolute level.

With these things in mind, the Presidium of NKG has turned to the NKG Working Group for Geodynamics and requested a draft for an *NKG Geodynamics plan for Absolute Gravimetry.*

2 Introduction

This proposal contemplates the continuation of research work in gravimetry and concentration on absolute gravimetry as the prevailing method. Inter-Nordic coordination through the Nordic Geodetic Commission and its working group for geodynamics has led to a concerted multi-decade effort to observe gravity change in conjunction with crustal dynamics and post-glacial land uplift. This effort using relative (spring-) gravimeters along the lad-uplift gravity lines has attracted international attention (Ekman and Mäkinen, 1996; Ekman 1991; Mäkinen et al. 1986).

In the last decade, absolute gravimetry measurements have been added at key points in the area, especially at locations where space geodetic observations and/or sea level observations are carried out. The NKG Working Group for Geodynamics has not been coordinating these efforts. However, the group would provide a suitable forum for coordination in the future, and most of its members have been involved in various ways in these measurements.

Continuation, concentration and future coordination of efforts in absolute gravimetry is to be seen with respect to the scientific merit that monitoring and studying the long-term temporal change of gravity as a geodetic and geophysical parameter can bear out. The scope of this work comprises applications in planetary geodesy as a method to contribute to and corroborate global geodetic reference systems. It reaches out into related disciplines as it can provide parameters for geophysical research on the rheology of mantle and crust, constraints for hazard analysis, and, perhaps most importantly, can help constrain parameters that relate to global climatic change. Being aware of the potential of the monitoring work, this group wants to point out the necessity to obtain an observing system with sufficient stability and observing plans with sufficient feasibility to last through a couple of decades.

Absolute gravity determinations take advantage from close relations to fundamental units in physics. Gravity is seen as a physical earth parameter with local, regional and global implications. Combined with precise, space-geodetic determinations of position measurements can sense the effect of mass changes in the surrounding of the surveyed locations and discriminate the effects due to the vertical movement of the surface. Records of Absolute gravity determinations provide a valuable source of information which can be used and referred to by future scientists. However, this group sees the major strength of the proposal in its potential synergy, contributing to ongoing activities in geodesy and physical earth sciences. Within geodesy, absolute gravity integrates as a fundamental technique into the monitoring of changes of position, reference surfaces and reference frames.

Notion of the relations of absolute gravimetry with the other geodetic techniques provided the motivation to set the headline as to emphasise its integration into a Nordic Geodynamics Observing System. A number of activities represented in the working groups of NKG are already fitting into this framework, and documents produced by these groups in the future will strengthen the ties between the activities, the groups and their members.

The efforts detailed below should be seen as primarily a joint effort in geodesy shared by the geodetic institutes and research facilities in the Nordic countries. Absolute gravimetry is considered as one technique of a handfull others by which geodetic reference is maintained and changes are monitored. Related techniques are mostly found in space geodesy, but also terrestrial, as used in sea-level monitoring, and for height-system maintenance. Relations with space geodesy are manifold. Gravity change and site motion determined by e.g. GPS and VLBI have bearing on large-scale mantle and crust parameters. Gravity change will in the future also be studied by means of effects on satellite orbits. Satellite altimetry of the sea level provides parameters that can be tested with gravimetry. In some cases gravimetry takes the role of an independent test method, an augmentation of observations, a provider of constraints for parameter inversion etc.

In this draft, we will first take inventory of existing activities in the Nordic countries; then, we will formulate a possible common philosophy for the choice of absolute gravimetric measurement stations, the requirements they should meet, and their locations.

3 Current status

The Fennoscandian land uplift gravity lines and their stations are shown in Figure 1. A few of these stations coincide with points where absolute gravity has been determined, see Figures 2 and 3.

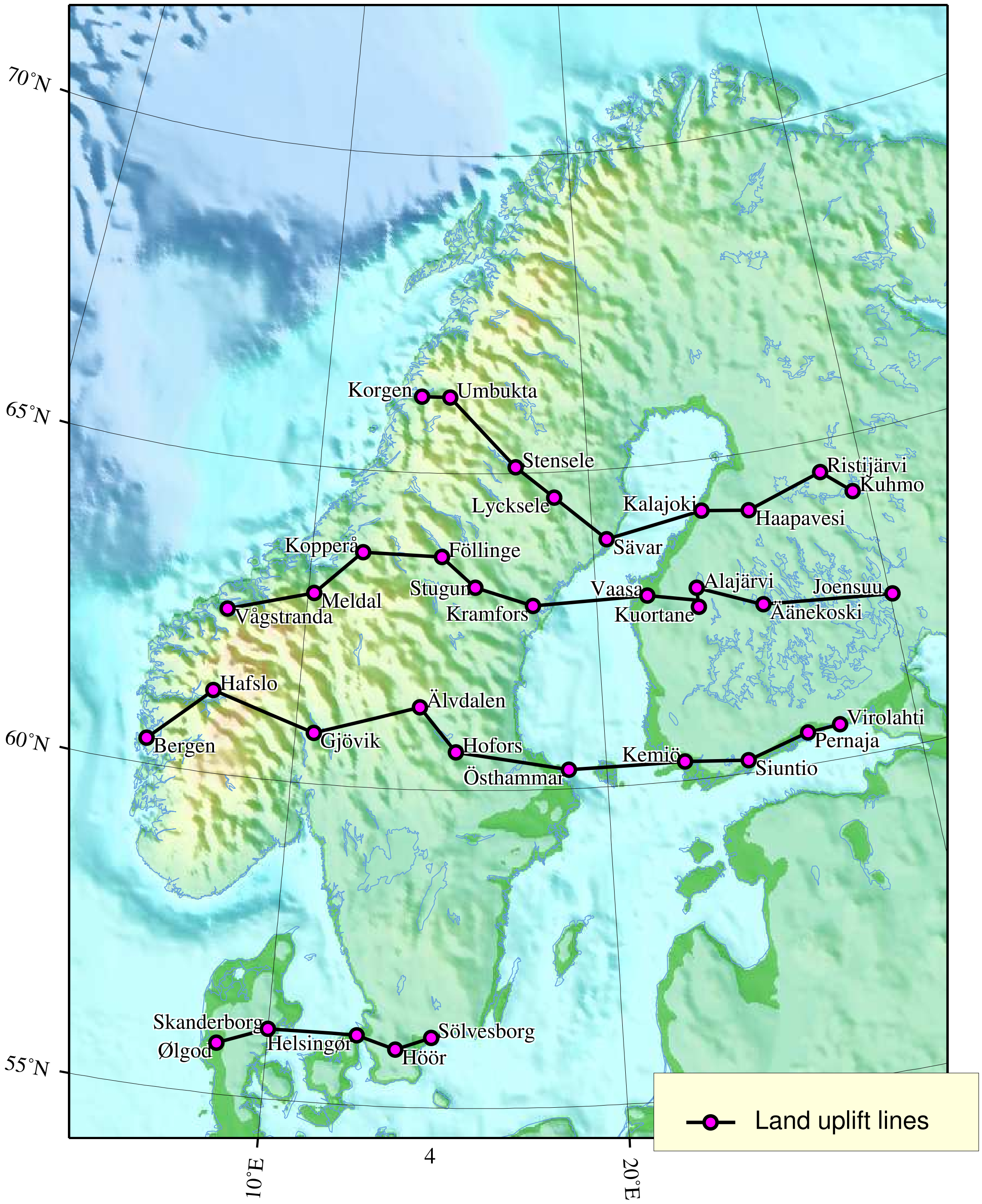

Figure 1: The Fennoscandian land uplift gravity lines.

3.1 Denmark / Færø Islands / Greenland

Current situation: The following absolute gravity points exist:

Tebstrup, København, Elsinore
Torshavn
Thule, Nuuk, Ilulissat

Thule is co-located with permanent GPS.

Existing measurements in Denmark were done in 1987 with Hannover JILA-3, on Færø Islands in 1987, and in Greenland 1988.

Future plans:

- Repeat measurements at 10 years interval
- Co-location with permanent GPS – resources permitting.

3.2 Finland

Current situation: The following absolute gravity stations exist:

- Metsähovi* (1979-)
- 63° land uplift gravity line:
  Vaasa* AA (1979-), Vaasa AB (1995), Joensuu* (1999),
- Others:
  Sodankylä* (1976-), Virolahti* (1999), Masala, Ilomantsi, Vihti

Explanation: (*) means co-location with GPS; (19xx-) means: operating from: [name] means: selected or "either-or" alternatives, no measurements yet. Metsähovi is also co-located with GPS, GLONASS, SLR, DORIS, and superconducting gravimeter.

It is intended that all stations will be used both for geodynamics (land uplift, solid Earth tides) and for gravity reference.

3.3 Iceland

Current situation: The following absolute gravity points exist:

Höfn*, Egilstaðir, Akureyri, Holmavík, Reykjavík*, Haumyrar, Herdubreiðarlindir, Gardur+, Húsavík+, Krafla+, Laugar+, and Skútustaðir+.

Stations with a * are co-located with permanent GPS. Höfn is near a tide gauge. Reykjavík* is also co-located with a DORIS beacon. Stations with a + are located along a levelling line from Akueiri to Vofnafjördur. Observation teams involved in the measurements so far were from BKG (Germany), FGI (Finland) and University of Hannover (Germany).

3.4 Norway

Current situation: The following absolute gravity points exist:

Hønefoss, Stavanger, Trysil, Trondheim, Tromsø, Ny-Ålesund, Kolsnes, and Troll.

Most of these sites have several (up to three) measurement points. At Andøya, a pier for absolute measurements is available. Ny-Ålesund and Tromsø are directly co-located with permanent GPS, VLBI, DORIS and other space geodetic techniques, while tide gauges are nearby. At Stavanger and Trondheim, permanent GPS and tide gauges are within a 10 km radius. At Andøya, a permanent GPS receiver is running next to the absolute gravity pier while a tide gauge is within 10 km as well.

Most sites (except Andøya) have been involved in repeated absolute measurements, although not always on the same measurement point. The two largest campaigns were in 1992-93 and 1995 (see Roland, 1998). These Nordic campaigns involved instruments from Finland (FGI), United States (NOAA) and Germany (IfAG).

In 1998, four points in Norway and two points in Sweden were revisited with the German instrument (BKG, formerly IfAG). Ny-Ålesund was measured for the second time in 2000 with the instrument of the University of Strasbourg.

3.5 Sweden

Current situation: The following absolute gravity points exist:

Onsala, Göteborg, Mårtsbo, Skellefteå (a.k.a. Furuögrund), Kiruna (a.k.a. Esrange).

Onsala is co-located with GPS and VLBI has been measured with JILA and FG5 instruments from NOAA and BKG.

Gothenburg has been measured in 1976 by the Italian group's IMGC (Marson) instrument and with a JILA instrument.

Mårtsbo, co-located with permanent GPS, has been measured with IMGC, JILA and two FG5.

Furuögrund = Skellefteå, is co-located with permanent GPS and has been measured with JILA and FG5.

Esrange = Kiruna, is co-located with permanent GPS and has been measured with FG5.

4 A proposal

It is generally felt that

1. Absolute gravimetry in geodynamically interesting locations through out the whole area contains high scientific merit.
2. Absolute gravimetric measurements should be repeated at regular intervals of a few years.
3. *Co-location* of absolute gravimetry with permanent GPS and/or tide gauges, is highly desirable and in fact essential for most geodynamic studies. Combination of different measurement techniques, detecting both surface displacements and gravity changes, are necessary for a complete understanding of the dynamics of the underlying processes. Co-location with superconducting gravimeters (SG) again allows accurate monitoring of very long term trends, albeit at a high cost.
The principle of co-location reflects the nature of the absolute gravimetry network as a subnetwork in the larger scheme of the Nordic Geodynamics Observing System, which again belongs to similar systems on a global scale geared to gaining an understanding of global change and its consequences. We refer to documents detailing the concepts and aims of co-location, Bevis (2000) and Plag et al. (2000).
4. The concept of a *Nordic absolute gravimetry network* makes sense scientifically and practically only if it is designed as a *multipurpose* network, i.e. a gravity base network in conjunction with geodynamics *and* global change research.
5. The number of stations chosen to be part of such a network should be *limited*, which will make it more likely that

(a) effective co-location with often expensive equipment (e.g., superconducting gravimeter, SG) can be considered, and
(b) limited resources will be directed effectively and the necessary instrumentation and sufficiently frequent re-occupation (5 years max) will actually take place.

Therefore, it is proposed to establish a Nordic absolute gravimetry network (NGGOS/AG) of stations meeting most or all of the following requirements:

1. The stations have to be of geodynamic interest:

   (a) a major geodynamic interest consists of the $63°$ gravity uplift line, which has the longest history of measurement, and where by co-location, the relative gravimetry time series could be extended using absolute instruments.

   It would be of the utmost scientific interest to have absolute stations spanning the full range of the $63°$ line, i.e. on both sides of the Gulf of Bothnia. We call upon all to co-operate to make this a reality.

   (b) Solid Earth tides could be another area of interest, especially ocean loading. This would favour choice of location close to coasts.

2. The stations should provide a sufficient (but very thin) coverage of all the Nordic national territories, and offer sufficient spatial sampling for studying phenomena of interest. Given limited economic resources, it is clear that this requires a very careful selection of the sites.

3. The stations should be technically suitable for absolute (ballistic) gravimetry; this means preferably on flat bedrock, or on a concrete platform solidly anchored either to the bedrock or deeply rooted (neutral-buoyancy) into sedimentary soil. Lightweight weather protection to allow the sensitive instrument to occupy the site.

4. The station locations should be safe from future development and construction projects (roads, city expansion, ...).

5. The stations should be occupied at regular (but sufficiently dense) temporal intervals. One would think of a time interval similar to that with which the $63°$ line has been occupied with relative instruments, i.e. several years.

6. This is *not* to say that there should be two levels: the “super-stations” to be included in the network, and the “other” category of stations which are only nationally maintained; on the contrary, all stations of sufficient geodynamic interest for which regular re-occupation is

planned should belong to the NGGOS/AG network. However, being able to make the necessary commitment ought in itself to limit the number of stations proposed.

4.1 Proposal for the future

It is proposed that countries participating in the work of the Nordic Geodetic Commission propose stations to be included in the NGGOS/AG network. It is further proposed that the host countries of these stations put them in good shape, maintain them and document them, so scientists from all Nordic countries, and others, can include them in their measurement programs.

The proposed network is shown in Figures 2 and 3 along with the points at which earlier observations have been made. Stations that still need to be established are shown with a special symbol.

4.1.1 Publication policy

It is important that countries participating in the project will make sufficient resources available also for the processing and publication of the measurements obtained within a reasonable time frame.

A framework should be agreed upon which allows the data collectors adequate time to analyse their data and publish scientific results themselves. After that, the data should be made available to project participants in order to jointly publish project results. Following this, the data should be available for use by the scientific community at large. Existing frameworks for publishing gravimetric data, such as the *Bureau Gravimétrique International* (BGI), should be used.

4.1.2 Denmark

Repeated measurements on the sites **Tebstrup, Copenhagen, Elsinore** are planned. Aiming for a 10 year repeat interval, these should be undertaken in the near future.

The same applies to **Thule, Nuuk,** and **Ilulissat** in Greenland and **Torshavn** on the Færø islands.

KMS plans—when the economy permits—to reobserve the exisiting stations ideally at a 10 yr interval and add new absolute gravity sites in

Qaqortoq and **Scoresbysund** at the new locations of the permanent GPS sites.

KMS will also liase with the NOAA/John Wahr group who repeat on a yearly basis observations at two absolute gravity sites at **Kangerlussuaq** and **Kulusuk**, using an FG-5 instrument. It is not known at present how long time in the future the NOAA measurements will be continued.

4.1.3 Iceland

Höfn and **Reykjavík** are obvious choices. Selection is due to co-location with GPS and tide gauge at Höfn.

4.1.4 Finland

Finland proposes that the following four stations are chosen, **Metsähovi, Vaasa, Joensuu** and **Sodankylä**.

Of these stations, one (Metsähovi) is massively co-located, two (Joensuu and Vaasa) are co-located with $63°$ gravity profile points, and all four are co-located with GPS.

Metsähovi is proposed to serve as a fundamental station for the Nordic network. The purpose of the fundamental station is that instruments can be intercompared, and temporal behaviour can be studied by coimparison with the superconducting gravimeter.

4.1.5 Norway

Norway is at this point in time not ready to propose a final site list. Current limitations in funds have led to a stop of activities related to absolute gravity measurements. It is not clear whether these activities will be taken up again in the future. However, a priority of sites may be deduced from the inclusion of four sites in the 1998 campaign. Thus, **Ny-Ålesund, Trysil,** and **Tromsø** are likely to have high priority, if there are any future absolute gravity measurements.

In Stavanger, the tide gauge has been moved and no decision has been made concerning a new gravity point. In **Trondheim**, a new building was constructed since April 1998 right next to one of the two gravimetric points. **Kolsnes** was measured for Statoil and may be considered as a potential candidate.

It has been suggested to establish an absolute point at Vågstranda due to its location on the 63° line. However, this would require the possibility for co-location with a permanent GPS station.

4.1.6 Sweden

By agreement and compatibility with Finland also in Sweden continuing the occupation of the 63° gravity line is important. Therefore future efforts to observe with profile will comprise absolute gravimetry. The set of absolute gravity stations will therefore consist of **Kramfors** and Norderåsen. The latter site, near Östersund, is colocated with GPS and is to replace Stugun. The other stations where absolute gravimetry is to continue comprise **Skellefteå** (in the land uplift centre, co-located with GPS and within 10 km distance from the Furuögrund tide gauge), **Mårtsbo** (permanent GPS, tide gauge within 10 km distance), **Onsala** (massively co-located, two tide gauges within 30 km distance), and **Kiruna-Esrange** (colocated with permanent GPS).

5 Requirements to reach the goal

Observing the change of gravity in the Nordic region involves a long timescale. The scope of this proposal is therefore *until further reconsideration*. The number of locations that participate in this plan has been limited to a reasonably small size, trading off the necessary spatial resolution needed to sample the postglacial rebound signal, obtain the necessary redundancy to study systematic influences e.g. from oceanic and hydrological loading effects, and utilising co-location with existing permanent GPS stations and tide gauges.

The coordinated operation of absolute gravity measurements needs to reach a steady state of activities. This is only possible with a stable availability of instruments and personnel. The present level of support is insufficient to provide neither of them. The aim of this document is to show the level of activities necessary for a minimum level of scientific merit. The relatively small number of stations allows that each one can be reobserved at least once every second year. With increased levels of funding an expanded plan would primarily propose the same amount of stations to be reobserved more densely in time before additional stations would be considered. On a two-year reobservation scheme the current plan considers twelve stations to be measured per year.

Because of changing of scope of BKG, future activities headed by this institute will most probably not be possible. The role of BKG would rather be to

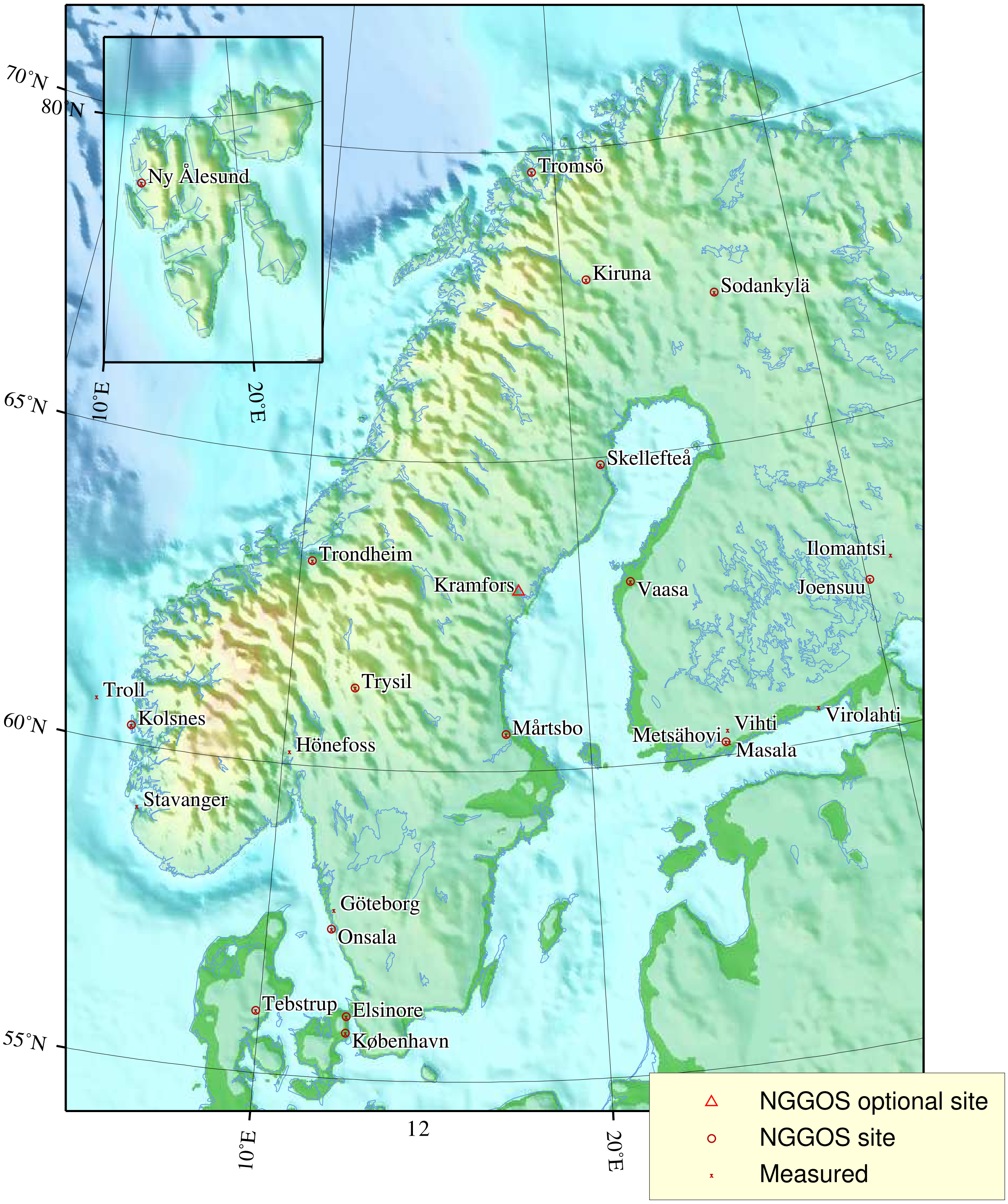

Figure 2: Existing measurement points of absolute gravity and proposed network stations. Stations shown as open triangles need to be established.

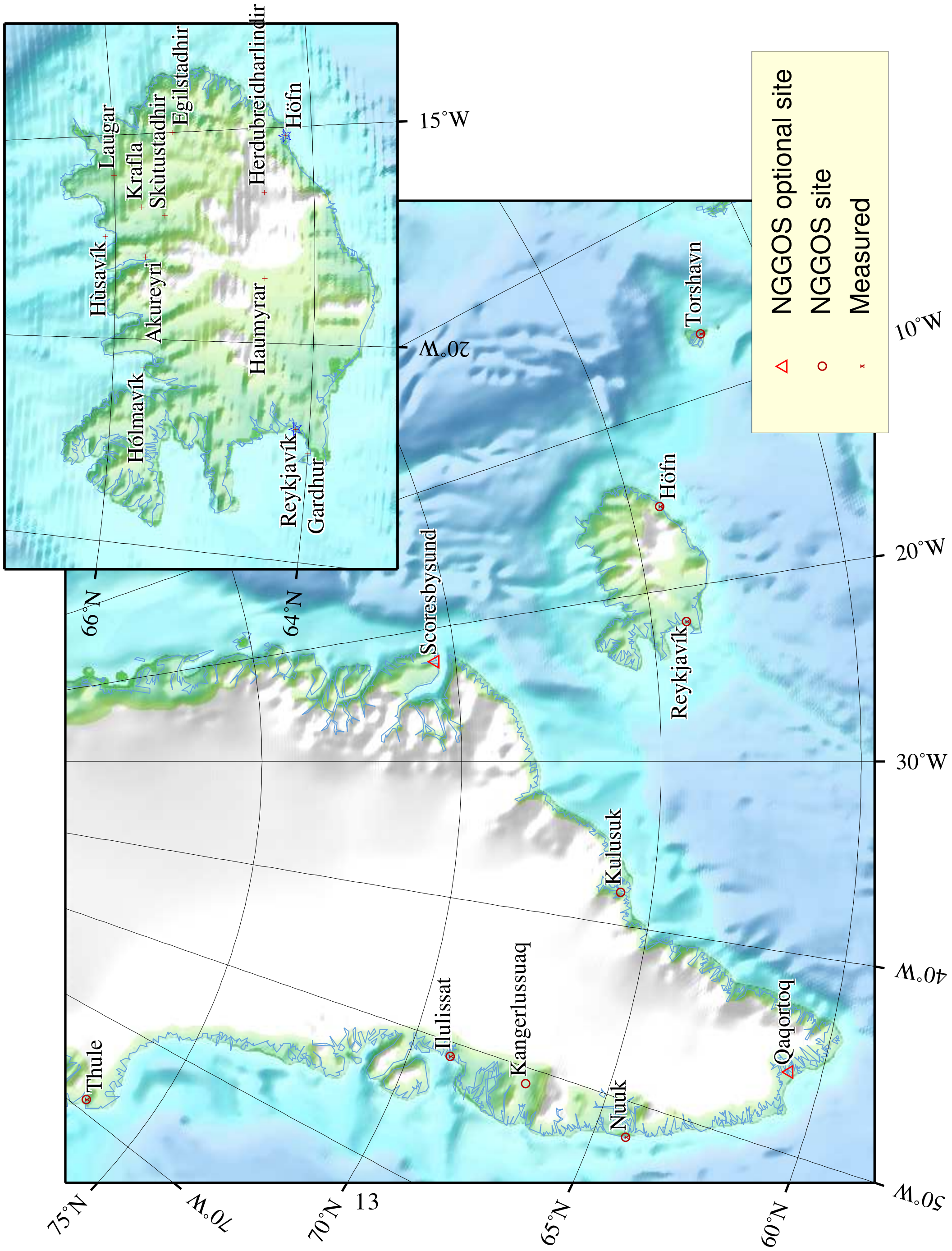

Figure 3: Existing measurement points of absolute gravity and proposed network stations. Stations shown as open triangles need to be established.

train observers and, to a limited extent, provided instruments on loan. The extent needs to be negotiated.

In all, at least one absolute gravimeter in addition to the currently existing instruments at the Finnish Geodetic Institute should be available for the work outlined above. Acknowledging the high level of activity and allocation of resources that the Finnish Geodetic Institute has been spending, it appears necessary that agencies or institutes of the other countries consider to contribute to the resources.

The authors of this report look foreward to the approval of the absolute gravimetry plan by the presidium of the NKG. We also look beyond the approval and anticipate the studies of all NKG working groups in the framework of a Nordic Geodynamic Observing System. Plans and frameworks thus clear-cut will certainly facilitate decisions of research financing bodies.

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Martin Vermeer has served as the coordinator of this work until early 2000.

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