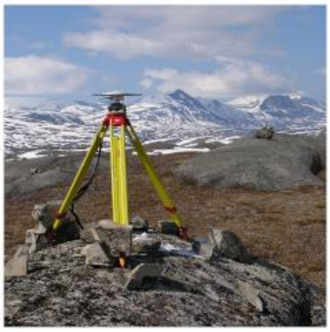
The Norwegian vertical reference frame NN2000

Report no. 19-04811-4



Document information:

Title: The Norwegian vertical reference frame NN2000
Date: 2020-06-25
Report no.: 19-04811-4
ISBN: 978-82-7945-247-8
Authors: Dagny I. Lysaker and Olav Vestøl
Classification: Free
Summary: Documentation of the Norwegian vertical reference frame NN2000.
Keywords: NN2000, height system, GNSS, leveling
Reviewer: Vegard Ophaug

Please cite this report as follows:

Lysaker, D.I. and Vestøl, O., 2020. The Norwegian vertical reference frame NN2000. Technical report of the Norwegian Mapping Authority 19-04811-4, ISBN 978-82-7945-247-8.

Preface

We started writing this report in 2008 when the Norwegian leveling network was first calculated. Originally, the intention was to cover just the realization of NN2000 in the leveling network. When the final calculation of the leveling network was ready in 2012, further writing stopped. When we years later resumed writing, the calculation of NN2000 in the GNSS network and the implementation in the municipalities were almost completed. It was natural to include also a documentation of these tasks in this report.

We hope this report will serve as a documentation on how we realized NN2000 in Norway, both theoretically and in practice. In addition to surveyors, geodesists, geophysicists, and cartographers, we think foreign companies operating in Norway may be potential readers. For this last group we have written the report in English.

Chapter 1 to 5 cover the realization of NN2000 in the leveling network, Chapter 6 the realization in the GNSS network, and Chapter 7 provides key parameters of NN2000.

The authors, Hønefoss June 25, 2020

Acknowledgment

We would like to thank our colleagues Per Christian Bratheim, Matthew Simpson, and Kristian Breili for valuable contributions to this report. We would also like to thank Per Christian Bratheim, in his role as section head, for patiently waiting for this report to be ready.

Contents

Chapter 1

Introduction

Over the last two decades, georeferencing of cartographic data has changed from a national/regional to a continental/global perspective. Due to space techniques, especially Global Navigation Satellite Systems (GNSS), a completely new solution for horizontal control networks has been determined.

The Regional Reference Frame Sub-Commission for Europe (EUREF) defined the European Terrestrial Reference System (ETRS) in 1989 (Boucher & Altamimi, 1992). It is based on the definition of the International Terrestrial Reference System (ITRS), and realized through the European Terrestrial Reference Frame (ETRF) at epoch 1989.0. In Norway, this was implemented by GNSS campaigns in 1994-1996. All counties of Norway had changed to the new reference system by spring 2009.

Vertical reference systems realized by precise leveling alone do not allow global solutions. For gravity related heights, often called physical heights, realization of global reference systems may in the future be possible by a combination of GNSS and global geoid models following the definitions of the International Height Reference System (IHRS). However, EUREF has so far focused on leveling and leveling networks to realize physical heights, and has since 1994 worked on the definition and realization of a vertical reference system/frame for Europe, i.e., the European Vertical Reference System (EVRS) realized by the European Vertical Reference Frame (EVRF). See, e.g., Rülke et al. (2012) for details on the status of height system unifications in Europe.

The former national height system of Norway, NN1954, was strongly deformed, mainly due to postglacial land uplift (Lysaker et al., 2006). The lack of correction to an unique reference epoch, caused systematic errors, but with variation depending on the time of realization. The Nordic countries, especially Sweden and Finland faced the same challenges with height systems deformed by land uplift. In order to obtain new and accurate national height systems, cooperation through the Nordic Geodetic Commission (NKG) for a unified height system was initiated in the 1980s when new leveling programs started in all the Nordic countries. The cooperation has resulted in great improvements in the common Nordic leveling network, used in the calculation of EVRF2000, and later in EVRF2007.

The present national height system of Norway is called NN2000. It is, however, not identical to neither EVRF2000 nor EVRF2007. As shown in Chapter 2.2, a special Nordic realization was carried out, which NN2000 results from. Thus NN2000 is consistent to the Swedish height system RH2000 and the Finnish N2000.

In Norway, the differences to EVRF2007 varied originally from 0 to 2 cm. Due to new measurements at the west coast of Norway after the release of EVRF2007, the difference to EVRF2007 increased. In Sogn og Fjordane the differences after the final adjustment vary from -4 to 6 cm, and for Møre og Romsdal, Hordaland and Rogaland the differences vary from -3 to 3 cm.

This report describes the fundamental parameters defining NN2000, and how the new heights are realized through the leveling network, the passive geometric network (Landsnettet), and in the map databases.

Chapter 2

Background and evolvement leading to NN2000

Early attempts to establish a height system for Norway were rooted in the 1864 general assembly of the Mittel-Europäische Gradmessung in Berlin. This organization is considered as a precursor of the International Association of Geodesy (IAG), and following its recommendations a tide gauge was mounted in the harbor of Oslo in 1876 to provide a long-term mean sea level reference. Leveling campaigns began in 1887, but the progress was slow. After recording sea level observations for 14 years, a reference marker on the property of the Geographical Survey of Norway in Oslo was established and connected to the tide gauge by leveling. The reference marker was called Normal Null (NN) and served as the fundamental benchmark for all leveling in Southern Norway up until the adjustment of NN1954.

2.1 Short description of NN1954 and NNN1957

In 1916, modern leveling instruments were acquired and the leveling program intensified. The measurements were made along the main communication lines south of the Arctic Circle (at latitude of 66°33' N), and in 1953 most of the southern part of the country was covered. In the meantime, tide gauges had been set up at several locations along the coast. The tide gauge records showed different long-term trends essentially due to differences in land uplift along the coast. In Oslo, the uplift rate was found to be about 3 mm/yr. Oslo was thus considered an unsuitable site for a fundamental benchmark, and a new tide gauge was established at Tregde (near the southern extreme of Norway) where the uplift rate was observed to be close to zero.

The leveling network for the southern part of Norway (between 58° and 66.3° latitude) was adjusted in 1956 and tied to mean sea level determined by seven tide gauges along the coast, each with 22 to 68 years of observations. The tie was obtained by the height of the fundamental benchmark at Tregde above mean sea level. The vertical reference frame was called NN1954, and the results were reported by Trovaag & Jelstrup (1956).

A fundamental problem arose in the realization of the height system. While the leveling program had been running for 40 years, post glacial land uplift had systematically deformed the network. No reliable land uplift model existed in 1956, so the adjustment did not take land uplift into account. This also applies to later extensions of the network and lead to a strongly deformed network with no common reference epoch. In some areas, Lysaker et al. (2006) found differences of more than 20 cm between the original NN1954 and NN1954 corrected for land uplift.

An additional problem was the lack of observed gravity values along the leveling lines in the 1956 adjustment, needed for calculating geopotential numbers (see Chapter 3). Instead, spheroidal-orthometric corrections were used in order to achieve what was assumed to be orthometric heights (Trovaag & Jelstrup, 1956). However, Lysaker et al. (2006) demonstrated that the spheroidal-orthometric correction is shown to give values closer to normal heights than orthometric heights. The spheroidal-orthometric correction uses Clairaut's formula for gravity instead of observed gravity. Details on the correction can be found in Trovaag & Jelstrup (1956) and Lysaker et al. (2006).

Due to practical considerations, the leveling network north of the Arctic Circle was originally a separate entity defining a height system called Nord-Norsk Null 1957 (NNN1957) and referred to the tide gauge in Narvik. In 1974, the two networks were connected by a 200 km leveling line from Fauske to Narvik. The difference between the two systems was measured to 28 mm, which was less than the expected accuracy for such a distance. Nevertheless, the name NNN1957 was used until 1 January 1996, when the Norwegian Mapping Authority (NMA) formally decided to use the term NN1954 for both systems and consider them as one common height system for mainland Norway (Statens kartverk, 2009b).

2.2 The Baltic Leveling Ring (BLR2000)

Work on establishing a common European vertical reference frame started in 1945. Following the resolution of the International Union of Geodesy and Geophysics (IUGG) General Assembly in Rome 1954, the network was referred to as the United European Levelling Network (UELN) or Réseau Européen Unifié de Nivellement (REUN). The work resumed in 1994, and four years later EUREF calculated a network consisting of new data together with improved existing datasets and used Normaal Amsterdam Peil (NAP) as fundamental benchmark. The network was denoted United European Levelling Network 95/98 (UELN95/98). At the EUREF symposium in Tromsø in 2000, a new definition of EVRS was adopted followed by a new realization of the UELN called EVRF2000.

Finland and Sweden planned to finish their third national precise leveling by 2001, which was expected to lead to new national height systems. Resolution number 2 of the 14th General Assembly of the Nordic Geodetic Commission (NKG) in October 2002 outlined a common goal for the new national height systems:

> *The Nordic Geodetic Commission (NKG) recommends the representatives of the national mapping authorities and geodetic institutions in NKG to be active for the adoption of a unified Nordic height system with minimum differences from national height systems and from the European Vertical Datum.*

All three countries experienced strong land uplift and faced the same challenges in the treatment of this phenomenon. Additionally, a connection to the fundamental point of the EVRS realization was required to fulfill the resolution. At first glance, a direct adoption of EVRF2000 in the Nordic countries would be the obvious thing to do. However, there were reasons not to do so. First, the connection of the Nordic countries (Norway, Sweden and Finland) to the rest of Europe was weak. Only a single line measured by trigonometric techniques between Denmark and Sweden connected the whole block. Additionally, the UELN95/98 data were not consistent in the treatment of post glacial land uplift. Some countries experiencing land uplift, did not account for this, while others did. Unfortunately, the leveling data were referenced to different epochs, often by using old and uncertain land uplift models. The Nordic countries wanted updated and consistent land uplift corrections for the whole region, and a solid connection between Denmark and Sweden.

The Nordic Geodetic Commission
The Nordic Geodetic Commission (NKG, 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. In order to forward its vision, the Commission arranges general meetings every four years, and summer schools also every four years, in 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. (Adopted from www.nordicgeodeticcommission.com)

When the Øresund Bridge between Denmark and Sweden was opened in 2000, the mapping authorities in Sweden and Denmark leveled the connection between the two countries, considerably improving the connection of the Nordic countries to the rest of Europe. There was still a need for an even better connection.

The NKG Working Group for Height Determination (NKGWGH) initiated the work of closing the loop around the Baltic countries in order to have another connection, the Baltic Leveling Ring (BLR). Unfortunately, it was not possible to close the loop around the Gulf of Finland through Russia with leveling data, but alternative methods were used (Mäkinen et al., 2005). A close cooperation between the NKG, all the Baltic countries, the Netherlands, and the UELN computing center was established following a proposal from the NKGWGH to the Technical Working Group of EUREF (Mäkinen et al., 2003). The Nordic countries compiled and screened their new leveling data, tested and adopted land uplift models, and performed regional adjustments. Estonia, Latvia, Lithuania, Poland, Germany, and the Netherlands made their leveling data, stored in the UELN database and used for the EVRF2000 calculation, available to the NKGWGH. Using these data, together with the latest precise leveling data in Denmark, Sweden, Finland, and all precise leveling in Norway (1916-2003), the working group calculated the BLR. All leveling data in Figure 2.1 were referred to epoch 2000.0 by applying the NKG2005LU uplift model (Ågren & Svensson, 2007) prior to the adjustment. The geopotential number (see Chapter 3) at NAP was kept fixed, and the computations were performed in the mean tide system before the result was transformed into the zero tide system. Finally, the resulting geopotential numbers were transformed into normal heights, resulting in the BLR2000 height system (Mäkinen et al., 2005).

The Swedish national height system RH2000 is a subset of the BLR2000 and the Finnish national height system N2000 is a slightly modified version of BLR2000. The calculation of the Norwegian height system NN2000 follows the same procedure as described for BLR2000. The geopotential numbers of the connection points to the Swedish and Finnish network were kept fixed, so NN2000 can be considered as an extension of RH2000

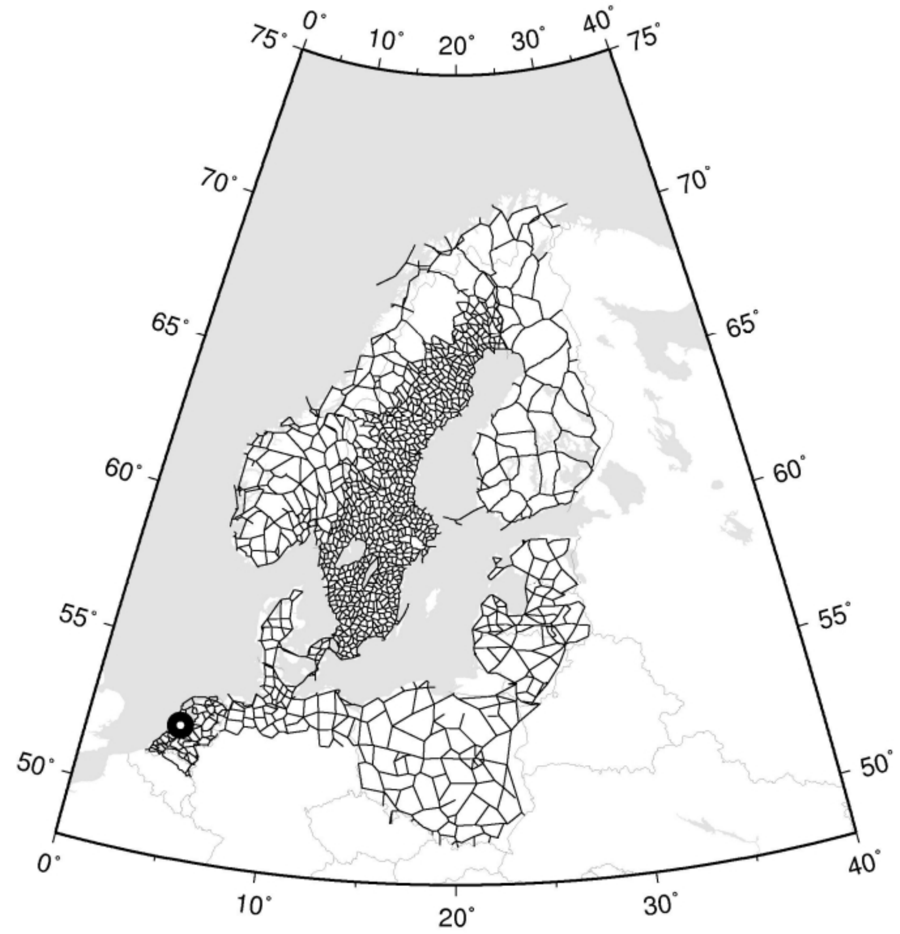


Figure 2.1: The Baltic Leveling Ring (BLR). The dark circle is the fundamental point in Amsterdam, Normaal Amsterdam Peil (NAP).

and N2000. Further details on the calculation of NN2000 are presented in Chapter 5.

2.3 Further developments in Europe

After EVRF2000 was published, more countries have added data to the UELN and several countries have provided new data, e.g., the Netherlands and the Nordic countries. During the work with BLR2000, the problems concerning postglacial land uplift and a common reference epoch were thoroughly addressed and revealed shortcomings in the EVRF2000. Enhanced EVRS conventions and parameters were needed, and a new realization EVRF2007 was released. The main differences between EVRF2000 and EVRF2007 are summarized below. For more details see Sacher et al. (2009).

- The datum point of EVRF2000 (000A2530) was not included in the new national leveling network of the Netherlands and is therefore no longer available as a datum point. In order to keep the level of the EVRF2000 datum, EVRF2007 is realized by 13 datum points in which the difference to EVRF2000 in sum is set to zero.
- In EVRF2000, the data from Finland, Norway and Sweden were reduced to the

epoch 1960, while the other data had not been corrected to a common epoch. For EVRF2007, the common reference epoch is 2000.0. All data within the coverage of the NKG2005LU model (Ågren & Svensson, 2007) have been corrected with this model.

- The EVRS definition of a zero tide system was not realized in EVRF2000, the tide system was mixed and unknown. The tide system of the national leveling data has been clarified and EVRF2007 is uniformly reduced to the zero tide system.

EUREF adopted EVRF2007 as the new realization of the EVRS at the EUREF symposium in Brussels, June 2008, after the adjustment of NN2000 was finished. The definitions and realizations of EVRF2000 thus form the basis of NN2000, as well for the Swedish RH2000 and the Finnish N2000. The establishment of EVRF2007 aimed at keeping the differences to EVRF2000 small. The differences between EVRF2007 and NN2000 were between 0 and 20 mm throughout Norway, the NN2000 heights always higher than EVRF2007 heights. After the recalculation of the western part, however, the differences are higher due to new important measurements in the county of Sogn og Fjordane after the release of EVRF2007 (see Chapter 5).

Chapter 3

Theoretical baseline for NN2000

In order to properly define a vertical reference system, four choices have to be made:

1. Type of heights
2. Reference epoch and land uplift model[1]
3. Zero level
4. Permanent tide system

For NN2000, the choices must agree with the definition of EVRS2000 as determined by the EUREF Technical Working Group (Augath & Ihde, 2002).

Definition of the national vertical reference system NN2000:
NN2000 is a zero tide vertical reference system tied to NAP at epoch 2000.0. The NKG land uplift model (NKG2005LU) is applied. The vertical reference system is realized through normal heights at 19000 first order benchmarks throughout the country.

The four choices are addressed below.

3.1 Height type

Precise height determination over large areas must be based on geopotential numbers, since leveling alone does not yield unambiguous height values. This is owing to the non-parallel equipotential surfaces of the Earth's gravity field (Hofmann-Wellenhof & Moritz, 2005). The geopotential number (C) at point A is defined as the difference between the gravity potential at the geoid (W_0) and at the point A (W_A).

$$C = W_0 - W_A = \int_0^A g\,dn \tag{3.1}$$

Here g is the observed gravity and dn the leveled height difference (Hofmann-Wellenhof & Moritz, 2005, p. 159). An accuracy of 10^{-6} m/s^2 (0.1 mGal) on g is sufficient for surface gravity observations along the leveling lines (Torge, 1989, p. 91).

---

[1] Mainly for regions experiencing land uplift

From the geopotential numbers, heights of different types are derived (Hofmann-Wellenhof & Moritz, 2005, p. 168).

$$\text{height} = \frac{C}{G} \tag{3.2}$$

The type of height obtained depends on the choice of gravity (G). If mean gravity along the plumb line is used, orthometric heights are achieved, while the use of mean normal gravity yields normal heights. NN2000 gives normal heights. The definition and description of orthometric heights are included to better see the difference.

3.1.1 Orthometric heights

The orthometric height is defined as the distance from the geoid along the curved plumb line to the point of interest. From Equation (3.2), orthometric heights are given (Hofmann-Wellenhof & Moritz, 2005, Equation 4-27):

$$\text{orthometric height} = H = \frac{C}{\overline{g}}, \tag{3.3}$$

where $\overline{g}$ is mean gravity along the plumb line. On the geoid, the orthometric height equals zero. In order to calculate orthometric heights from geopotentials, the mean gravity along the plumb line has to be known. Real mean gravity values are impossible to obtain since the density distribution of the Earth is only approximately known, and it is difficult to measure gravity inside the Earth. Thus, orthometric heights are always approximated. Almost exclusively, Helmert heights (Hofmann-Wellenhof & Moritz, 2005, p. 163) are used as an approximation to strictly defined orthometric heights. Helmert (1890) used the Poincaré and Prey gravity gradient to evaluate the mean gravity value halfway down the plumb line from observed gravity at the Earth's surface. Poincaré and Prey reduction assumes normal gravity and a Bouguer plate of constant density. Hence, Helmert heights are based on three assumptions: 1) gravity is behaving linearly between the geoid and the surface; 2) constant density; and 3) fixed free-air gradient. Tenzer et al. (2005) have defined a more rigorous orthometric height, in that the mean gravity along the plumb line is evaluated more accurately.

3.1.2 Normal heights

In order to avoid dealing with the unknown mean gravity along the plumb line, Molodensky formulated the theory of normal heights in 1945. That is, "orthometric heights" in a normal gravity field. This means that actual mean gravity is replaced by normal mean gravity ($\overline{\gamma}$), i.e., the mean of normal gravity between a reference ellipsoid and the telluroid (Hofmann-Wellenhof & Moritz, 2005, Equation 4-61):

$$\text{normal height} = H^N = \frac{C}{\overline{\gamma}} \tag{3.4}$$

The reference surface is then a mathematical ellipsoid instead of the physical geoid. The advantage with normal gravity is that the formula is easily evaluated without approximations. The physical meaning however, is not that obvious. If the Earth's gravity potential at a point P is W_P, then there is a point Q on the plumb line where the normal potential

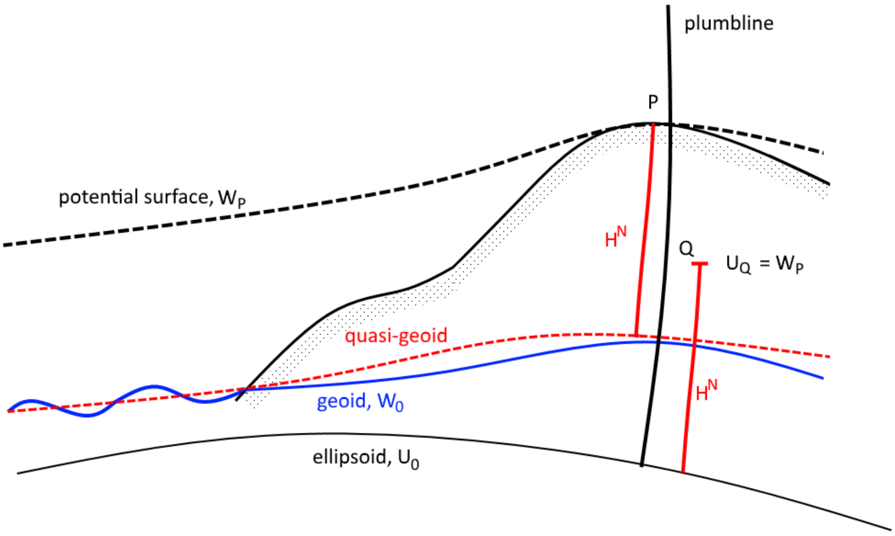


Figure 3.1: Principal sketch of normal heights.

U_Q equals the actual potential $W_P = U_Q$. The normal height is then the distance from the ellipsoid to point Q, see Figure 3.1. All points Q define the telluroid. The telluroid is an approximation to the Earth's surface, the topography of a "normal Earth", but it does not mirror the actual topography. If the normal height is deposed from point P along the plumb line, the normal heights define another surface, the quasi-geoid. The quasi-geoid may also be regarded as a reference surface for normal heights. As a rule of thumb, the difference between the geoid and the quasi-geoid, or equally orthometric and normal heights, is 0.1 times the square of the height in kilometer (Hofmann-Wellenhof & Moritz, 2005).

3.2 Reference epoch and postglacial land uplift

Many countries hardly experience any vertical land motion. Norway and the other Nordic countries however, are located in the Fennoscandia uplift area. During the last ice age, the Earth's crust was deformed due to the weight of the ice masses. When the ice melted, the elastic crust started to rebound to its pre-deformed position. This rebound is slow because of the viscosity of the Earth's mantle. Fennoscandia is an area exposed to post-glacial rebound and several models describing the vertical motion are available. Ekman (1991) gives a review of some of the scientific work on the subject. There are different approaches to calculating the present-day uplift field. Geophysicists use the theory on how the Earth responses to changes in ocean and ice loads to obtain their land uplift models, while geodesists obtain empirical models from observations from tide gauges, leveling, and lately permanent GNSS stations. The NKG land uplift model (NKG2005LU) shown in Figure 3.2 is a combined model. A smoothed version of the empirical model of Vestøl (2006) is merged with the GIA model of Lambeck et al. (1998). Further details on the smoothing and combination may be found in Ågren & Svensson (2007).

Due to land uplift, leveling data have to be corrected to a common epoch to obtain a

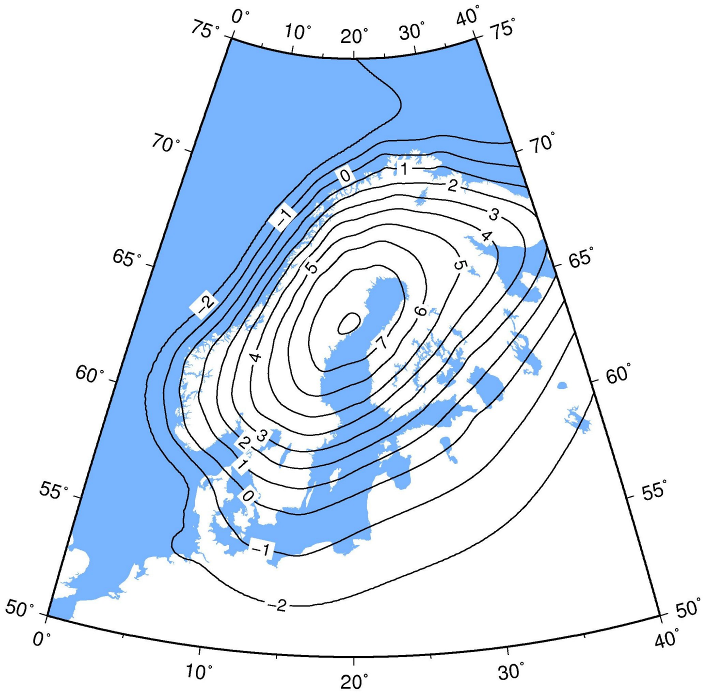


Figure 3.2: The land uplift model NKG2005LU. The isolines indicate the estimated vertical velocity in millimeters per year relative to mean sea level (1892-1991). Outside the -2 mm/yr isobar, the value is set to the constant -2 mm/yr.

consistent vertical reference frame. To minimize the influence of errors in the uplift model, it would be advantageous to choose the mean epoch of the leveled data or an epoch close to it. On the other hand, from practical considerations an epoch as close to current time as possible is desired. As a compromise, the epoch 2000.0 was selected.

3.3 Zero level

Since 1860, most countries in Europe have realized vertical reference systems based on national precise spirit leveling networks. They are in most cases related to mean sea level at one or more tide gauges and realized through some kind of gravity-related heights (Augath & Ihde, 2002). Orthometric heights refer to the geoid. Normal heights refer to the reference ellipsoid. Thus, today the zero level of a vertical reference system is realized through a reference marker with known height or geopotential number. That is, the gravity potential W_0 is set equal to the normal geopotential U_0 for a mean Earth. In order to follow the resolution of the NKG General Assembly from October 2002, the realization of the zero level for NN2000 is equal to the zero level of the EVRS, which is also the zero level of the Swedish vertical reference system, RH2000 (Ågren & Svensson, 2007) and the Finnish vertical reference system N2000. The realization follows the regulations of Augath & Ihde (2002):

The vertical datum of the EVRS is realized by the zero level through the Normaal Amsterdam Peil (NAP). Following this, the geopotential number in the NAP is zero:

$$C_{NAP} = 0$$

- For related parameters and constants the Geodetic Reference System 1980 GRS80 is used. Following this the Earth's gravity potential through NAP (W_{NAP}) is set to be the normal potential of the GRS80.

$$W_{NAP} = U_{GRS80}$$

- The EVRF2000 datum is fixed by the geopotential number and the equivalent normal height of the reference point 000A2530/13600 of the UELN.

The zero level of NN2000 is in other words the zero level of benchmark 13600 in the UELN numbering system. This zero level is 0.71599 m below the top of the benchmark and is the exact NAP reference.

Station name	**UELN number**	**Position in ETRS89** ellipsoidal latitude and longitude	**Height in UELN95/98** geopotential number and normal height	**Gravity in IGSN71**
Reference point of EVRS 000A2530 The Netherlands	13600	$52° 22' 53''$ $4° 54' 34''$	7.0259 m^2/s^2 0.71599 m	9.81277935 m/s^2

3.4 Permanent tide system

The Earth is affected by the gravitational attraction from celestial bodies, mainly the Moon and the Sun. The attraction is dependent on the position of the celestial bodies and thus periodic. The effect on the Earth's crust is called Earth tides. Gravitational attraction may be expressed in terms of a potential, and for the celestial bodies it is called the tide generating potential. It deforms the Earth's crust, and has a perturbing effect directly on the Earth's gravity potential. Tidal effects influence local gravity and are detected in gravity observations. The effect may be split in two terms, one is due to the direct change in the gravity field. Secondly, the observed gravity will change because the height has changed due to the deformation of the crust.

The long time mean of the tidal effects is called the permanent tide. Thus, the tide generating potential may be divided into a permanent and a periodic part (Ekman, 1989). Gravity data are utilized for both height realization and geoid determination. To avoid confusion, it is important to handle the permanent tidal effects consistently. There are three different geoid definitions; mean tide, zero tide, and tide free (Torge, 2001).

1. Mean tide geoid: The gravitational effect of the permanent tidal potential is kept

in the gravity observations. Corresponds to how the geoid and the crust actually behave in the long time mean.

2. Zero tide geoid: The gravitational effect of the permanent tidal potential is split in two terms, one direct that is due to the lunisolar attraction (Moon and Sun) and one indirect due to the deformation of the Earth. The direct effect is eliminated and the indirect effect is kept in the gravity observations. Corresponds to the crust in the long time mean, and the geoid if we assume there is no Moon or Sun, but still with a deformed crust.
3. Tide free geoid: The gravitational effect of the permanent tidal potential is eliminated from the gravity observations. Corresponds to a geoid and a crust assuming there is no Moon or Sun.

According to Augath & Ihde (2002), EVRS has adopted the zero tide geoid, as has the BLR 2000. Thus, the zero tide system was chosen for NN2000 as well.

Chapter 4

Data and measuring methods

Within Europe, precise leveling data still are the preferred data source for realizing national and regional height systems (Rülke et al., 2012), and NN2000 is no exception. Additionally, due to the rough terrain in Norway, fjord crossings are needed to build up a network of closed loops. Since leveling alone does not yield unambiguous height values, reliable gravity data are important to obtain geopotential differences. This chapter describes the data needed and used for realizing NN2000.

4.1 Precise leveling

When NN2000 was first realized in 2008, the leveling network consisted of 26.000 km of precise spirit leveling data form 1916 to 2008. For the final adjustment in 2012, some more kilometers were added, while a few old lines were rejected. This is further described in Chapter 6. Within the NKGWGH, the Nordic countries first agreed upon common guidelines for precise leveling in 1984. The leveling took many years to complete and the original guidelines were slightly modified in all countries. Erikson et al. (2014) describe in detail the original guidelines and the different modifications in all countries.

Precise leveling is performed by double leveling, i.e., all lines are leveled back and forth. The measuring procedure involves one instrument and two invar leveling staffs. The maximum allowed distance between the instrument and the staffs are 50 m and the leveling is performed in sections, where a section has a marked benchmark in both ends. The difference between the distance of the foresights and the backsights for one section should not exceed 5 m. Temperature is measured at the start and at the end of a section, in order to correct for the invar string's thermal expansion. A brief historical overview of the NMA's precise leveling data is summarized in Table 4.1, where some milestones are outlined for each period. Figure 4.1 provides an overview of kilometers of double-run leveling measured per year from 1952 to 2016.

Following international recommendations, the maximum accepted difference between the foresight and backsight measurements was in 1972 reduced from 4 to 2 mm multiplied by the square root of the distance in kilometers. The observations before and after 1972 are referred to as the old and new data, respectively.

Table 4.1: Overview of precise leveling carried out by the Norwegian Mapping Authority. Requirement is the highest accepted difference between the foresight and backsight measurements and s is the distance in kilometers.

Period	**Instruments**	**Req.**	**Remarks**
1916 - 1953	Levels with optical micrometer. 1919 - 1946: Zeiss levels. From 1946: Wild N-3 levels. Staff's scale on invarstrings. Normal meter of invar for calibrating the staffs. Foot leveling.	$4\sqrt{s}$ mm	With one exception, all lines are measured in the southern part of Norway. All existing lines before 1916 were releveled. On average 250 km were leveled, in both directions, each year. The normal meter was calibrated to the international standard meter.
1954 - 1979	Instruments with compensator pendulum in the end of the period. Foot leveling.	$4\sqrt{s}$ mm From 1972: $2\sqrt{s}$ mm	The leveling network was extended to the northern part of Norway. One line, from Fauske to Narvik, connected the northern network with the southern in 1974.
1980 - 1996	Motorized leveling. In average, the production increases from 5 to 10 km single run leveling per day. The staffs were calibrated at the calibration basis at Lantmäteriet in Sweden every year.	$2\sqrt{s}$ mm	Start of cooperation in the 1980s with Lantmäteriet on leveling in the area close to the border. Plans for extending the leveling network to as many municipalities as possible.
1997 →	Digital levels. Foot leveling only. The staffs were calibrated at in-house calibration basis every year.	$2\sqrt{s}$ mm	The main motivation for leveling was to establish a dense and even distribution of GNSS/leveling points.

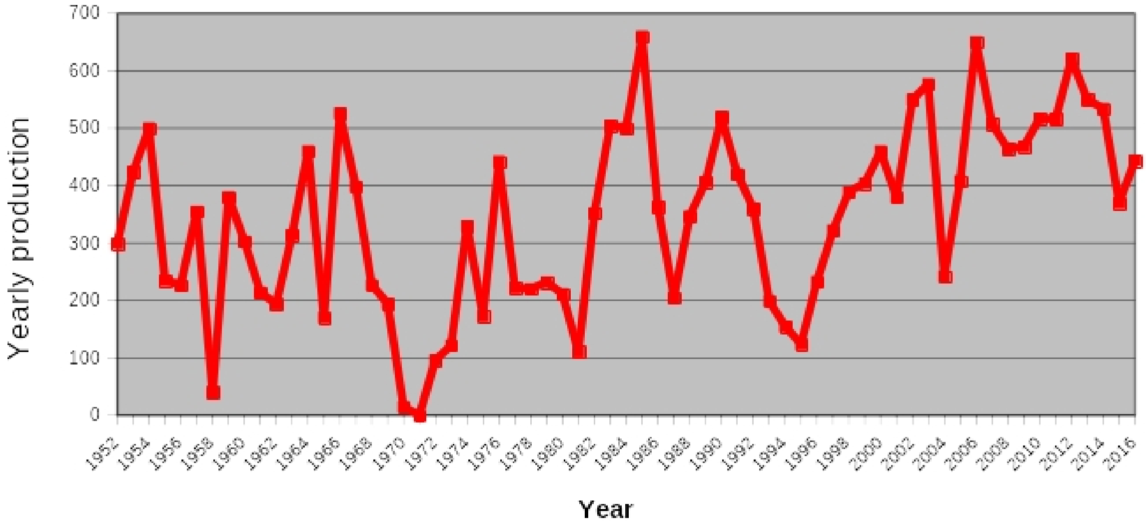


Figure 4.1: Kilometers of double-run leveling measured per year from 1952 to 2016.

4.1.1 The leveling network

The Norwegian precise leveling data consist of single lines from 1916 to present, and almost all data are needed to form a network covering the entire country. As shown in the left part of Figure 4.2, there are single lines that are releveled once and twice, but without forming a network.

The Norwegian data can not be divided into a first, second or third order leveling network like in other Nordic countries. Still, the precise leveling data stored in the database of NMA are divided into first order and second order data. The second order data amount to 1100 km. Today, the classification criteria is unclear, since the instruments, rejection limits, and other requirements appear to be the same as for the first order leveling. Nevertheless, the classification is preserved for historical reasons.

Additionally, leveling data from the Norwegian National Rail Administration (called Norges Statsbaner, NSB, at the time of observation) are stored in NMA's database. This leveling was accomplished during the 1960's, the 1970's and the 1980's, and heights were measured along the railways on benchmarks established every 500 m. The railway lines have been connected to first order benchmarks close to the tracks. The railway leveling data amount to 3680 km and 7180 benchmarks. The second order leveling data and the railway data are shown in the right part of Figure 4.2.

The first leveling lines have benchmarks every third kilometer, newer lines have an approximate spacing between the benchmarks of 1 km. By 2008 the first order leveling network consisted of 19000 benchmarks.

4.2 Fjord crossings

Leveling lines should form closed polygons or loops for control. Due to long fjords and high mountains, this is often difficult in Norway. To obtain control, it has been necessary to cross fjords where there is no tunnel or bridge. This requires the use of other measuring

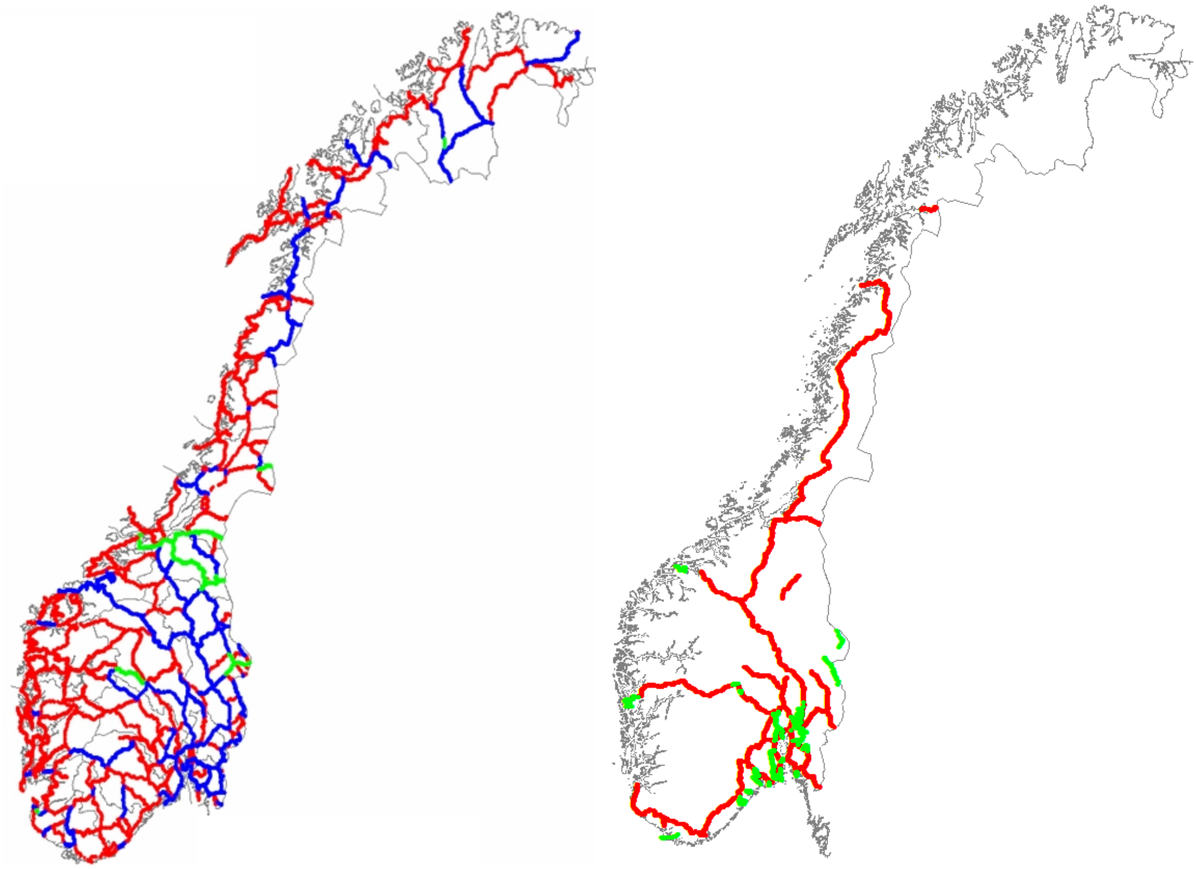


Figure 4.2: Left: Norwegian first order leveling network. Red lines are measured once, blue lines are measured twice, and green lines are measured three times. Right: The railway leveling network (red) and the second order leveling lines (green) throughout Norway.

techniques than ordinary leveling. During the years, different techniques have been in use. Unfortunately all of these techniques suffer from lower accuracies than leveling because of refraction and geoid variations. Up to 1995, we used leveling instruments and special targets on the staffs. Later, accurate total stations have been used.

The problems with refraction were reduced by simultaneous measurements from both sides of the fjord. Additionally, bad weather conditions were avoided. The best weather for fjord crossing measurements is when there is as little sun as possible, preferably clouded with no rain or strong wind.

Geoid variations are complex and may give an unreliable result. It is necessary to assume that the deflection of the vertical is either the same on both sides of the fjord or the same value, but with opposite sign. If not, the result will be systematically wrong. No measurement of the deflection of the vertical has been performed, so we do not know if this assumption is fulfilled. However, if the geoide changes irregularly over the fjord, these requirements alone may not be enough to avoid systematic errors.

In addition to simultaneous measurements, it has been normal procedure to swap the instruments, including the observer, one or several times during the observation campaign. The height difference is then calculated for each setup. It turns out that the result often changes systematically depending on which side the instrument is located. This indicates

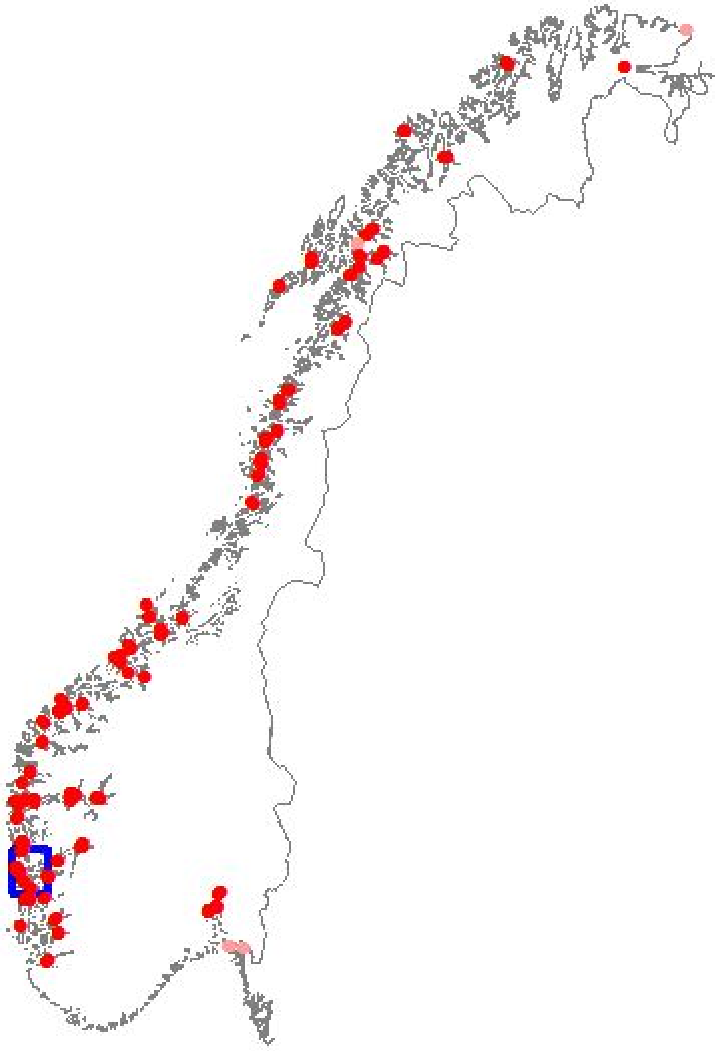


Figure 4.3: All fjord crossings in the first order leveling network. The pink dots show crossings later replaced by leveling through a tunnel or across a bridge. Figure 4.4 shows a more detailed view of the area within the blue rectangle.

that instrument and human errors influence the measurements.

Altogether, there are 116 fjord crossings in the first order leveling network. They are shown in Figure 4.3. Three of them, (marked in pink in Figure 4.3) were replaced with ordinary precise leveling when new bridges or tunnels opened. Usually there is only one fjord crossing in the same loop, but a few loops have two crossings. Unfortunately, there is one case with ten fjord crossings in the same loop as shown in Figure 4.4.

The quality of the leveling network is degraded due to all the fjord crossings. In particular, long crossings are unfortunate. As seen in Table 4.2, the average distance of the ten longest crossings are 4.4 km and in total 24 are longer than 3 km. For future height systems it is important to quality-assess the fjord crossings. Combination of GNSS and a geoid model may contribute to this, as well as local tide gauge measurements.

Table 4.2: Statistics of the fjord crossings.

Total number	116
Average distance (m)	2004
Median distance (m)	1741
Average distance of the 10 longest (m)	4401
Number of crossings longer than 3 km	24

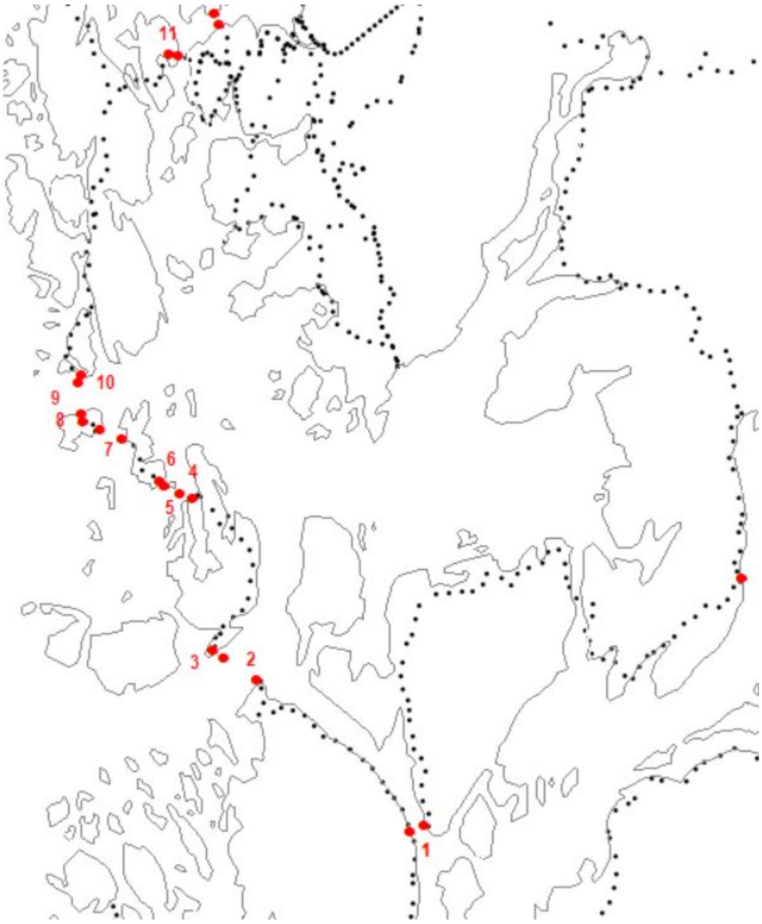


Figure 4.4: Map of leveling loop in Sunnfjord with ten fjord crossings.

4.3 Gravity data

In addition to the leveled height difference, gravity is needed to determine the geopotential difference between two benchmarks. As long as the distance between the benchmarks is within a few kilometers, it is sufficient to know the gravity at the benchmarks and use the mean value for the entire leveled section (Hwang & Hsiao, 2003). From around 1950 to 2000, gravity has been measured directly on most of the benchmarks along the leveling lines and usually the same year as they were leveled. The gravity measurements have been relative measurements observed in closed loops, starting and ending at a gravity benchmark point (basis point). Several LaCoste & Romberg (LCR) instruments have been used.

From the end of the 1960's, a new gravity network for geoid determination was established and the leveling lines, although still measured, had second priority. The gravity network consists of a basis network with approximately 280 points marked with a benchmark and a relative network with measurements every 5 km covering all of Norway, approximately 7000 points. In addition to the NMA measurements, the Geological Survey of Norway (Norges Geologiske Undersøkelse, NGU) has collected a large amount of gravity data (approximately 65000 points). NGU has connected all their gravity data to the basis network. Since 1990, NMA and NGU store all gravity values in a common Norwegian gravity database.

Although gravity has not been measured at the benchmarks of new leveling lines after 2000, the gravity network is still densified by relative measurements with LCR instruments, and more recently by Scintrex CG5 instruments. In addition, absolute gravity has been observed at around 20 sites with instruments of the FG5 type (Breili et al., 2010; Ophaug et al., 2016) and at approximately 250 sites with A10 instruments. The gravity database makes it possible to interpolate gravity with sufficient accuracy in the benchmarks not measured. For the calculation of NN2000 we have used interpolated values for all benchmarks.

Chapter 5

Calculation of NN2000

The calculation and implementation of NN2000 heights consist of two parts, the leveling network and the passive GNSS network. This chapter describes the calculation of the leveling network, and Chapter 6 describes the determination of heights in the passive GNSS network (Landsnettet).

The calculation of the leveling network was carried out in several steps, which are described in the sections below. First, the observations were screened for outliers as part of the land uplift determination (Vestøl, 2006). Second, the leveling network was adjusted using geopotential differences and least squares adjustment (LSA). The LSA was done in three steps. In the first step, the geopotential numbers from the BLR adjustment described in Section 2.2 at common points along the Swedish and Finnish border were held fixed. In the last two steps, the result from the previous step(s) were kept fixed. All three steps were carried out using the commercial adjustment software Gemini Oppmåling (version 5.4).

The adjustments were finished in 2008, but the western part of Norway showed large misfits. The results for the western part were thus considered as preliminary. After collecting more leveling data and controlling several fjord crossings, the final NN2000 adjustment was done in 2012, with only height values in the four westernmost counties changing.

5.1 Preparations for the adjustment

5.1.1 Geopotential numbers

Geopotential differences were used in the adjustment of the leveling network. The geopotential difference (C_{AB}) between two points A and B was obtained from leveled height differences (dn_{AB}) and interpolated gravity values (g_A and g_B) according to

$$C_{AB} = dn_{AB} \frac{g_A + g_B}{2} \tag{5.1}$$

In Equation (5.1), gravity should be in kilogal (10 m/s^2). This means that the height differences generally are multiplied with a number varying around 0.98. The result is a geopotential number with unit g.p.u. (geopotential unit).

5.1.2 Permanent tide and reference epoch

Both leveled height differences and gravity have to be in the same tide system. Since we do not apply any tidal correction to our leveling observations, they are referring to the mean tide system. Periodic tidal corrections were applied to the gravity data, but no permanent tide corrections. This results in mean tide values for gravity as well. Consequently, the LSA of the leveling network was done in the mean tide system, and the adjusted values were converted to the zero tide system afterwards.

Additionally, all leveling observations need to be corrected to a common reference epoch. We used the land uplift model NKG2005LU (Ågren & Svensson, 2007) to correct the observations from the observation epoch to 2000.0. Since some leveling lines go back to 1916, this correction is essential in order to fulfill the requirement of a common reference epoch for the whole network.

5.1.3 Outlier detection

The leveling lines are shown in Figure 5.1. The data set includes the railway leveling lines as well, since they all are connected to NMA's first order leveling network and are used for land uplift determination. Before the adjustment, outliers were detected and removed from the data. We used multiple Student's t-test, which implies that an outlier (∇) is estimated for each observation, one at a time. Then test values can be calculated by dividing the outlier on its standard error (s_∇) (Pelzer, 1985; Revhaug, 1989):

$$t = \frac{\nabla}{s_\nabla}, \tag{5.2}$$

Following Revhaug (1989), a t-value higher than three was set as rejection criterion. Sometimes suspicious lines consist of smaller parts that individually cannot be rejected based on their t-value. However, by removing the entire line and performing a Fisher test based on the reduction of the weighted sum of squared residuals, we may sometimes reject the entire line as an outlier. This is a possibility, even when the smaller parts individually do not exceed the rejection limit (see Revhaug (2007) for further details).

Outliers cannot be detected without considering the land uplift. Since the leveling observations are important input to the land uplift calculation, the outlier test was performed as part of the land uplift determination, as described in Vestøl (2006).

The outlier test identified 13 first order leveling lines, partly or completely, as listed in Table 5.1. Additionally, four lines in the railway network listed in Table 5.3 were rejected. The rejected lines are not used in the first step (Section 5.2), the adjustment of the nodal points. In step two (Section 5.3), and step three (Section 5.4), the rejected first order lines and railway lines, respectively, are again included.

5.1.4 Weighting strategy

The observations were assigned weights proportional to the inverse of the leveled distance using Equation (5.3)

$$w_i = \frac{1}{s_0^2 d_i}, \tag{5.3}$$

where w_i is the weight of observation i, s_0 is the standard error for 1 km leveling, and d_i is the leveled distance in kilometers. s_0 was set to 1.34 mm for observations prior to

Table 5.1: Rejected first order leveling lines. We rejected all lines with a t-value larger than three. Stars (*) in column four indicate that we used the Fisher-test instead of the Student's t-test.

Line number	**Obs. year**	**Outlier (cm)**	**t-value**	**Description**	**Remark**
307	1953	10.2	4.7	Alta - Kautokeino	
327	1982	8.3	4.5	Sortland - Fiskebøl	Suspicious fjord crossing over Hadselfjorden
228	1984	-8.8	4.3	Brønnøysund - Leirfjord	
85	1935	7.5	4.1	Nybergsund - Sørvollseter	
250	1987	8.1	3.8	Rutledal - Leirvik (part of line 250-1987)	Suspicious fjord crossing over Sognefjorden
39	1942	5.8	3.7	Gol - Borlaug	
250	1987	-6.8	3.6	Gjølanger - Vevring (part of line 250-1987)	Crossing Dalsfjorden and Førdefjorden
70	1944	5.1	3.3	Tonstad - Sinnes (part of line 70-1944)	From point C38N0019 to point C38N0043
289	1989	-2.8	3.2	Kjenn - Drøbak (part of line 289-1989)	From point G36N0216 to point G35N0113
223	1976	3.0	3.3	Lærdal - Revsnes - Kaupanger	Suspicious fjord crossing over Sognefjorden
101	1990	3.2	4.7*	Fannrem - Heimsjø	
11	1998	2.6	3.1	Nesodden - Bekkelaget	Student work including a 5 km long fjord crossing
265	1990	5.4	3.8*	Støren - Røros	
203	1957	4.5	3.1	Mo - Umbukta	

1972, and to 1.12 mm after 1972, according to variance component estimation (see Vestøl (2006)).

Additionally, observations were assigned lower weights if they included one or more fjord crossings. Assuming vertical angles over fjords with an accuracy of $\alpha = 0.2$ mgrad, the corresponding accuracy of the height difference (s_f) is

$$s_f = d_f \cdot \sin\alpha, \tag{5.4}$$

where d_f is the distance over the fjord. The total accuracy (s_T) for the line is then

$$s_T = \sqrt{s_0^2 d_i + s_f^2}, \tag{5.5}$$

and the corresponding weight:

$$\frac{1}{\sqrt{s_0^2 d_i + s_f^2}} \tag{5.6}$$

5.2 Step one: Adjustment of nodal points

The leveling data were organized into lines between nodal points, i.e., points where the lines in the leveling network intersect. For each line, the geopotential differences between benchmarks were summed up to a geopotential difference between the nodal points. After removal of outliers, a LSA of the geopotential differences was performed, keeping the geopotential numbers along the border fixed (the red points in Figure 5.1).

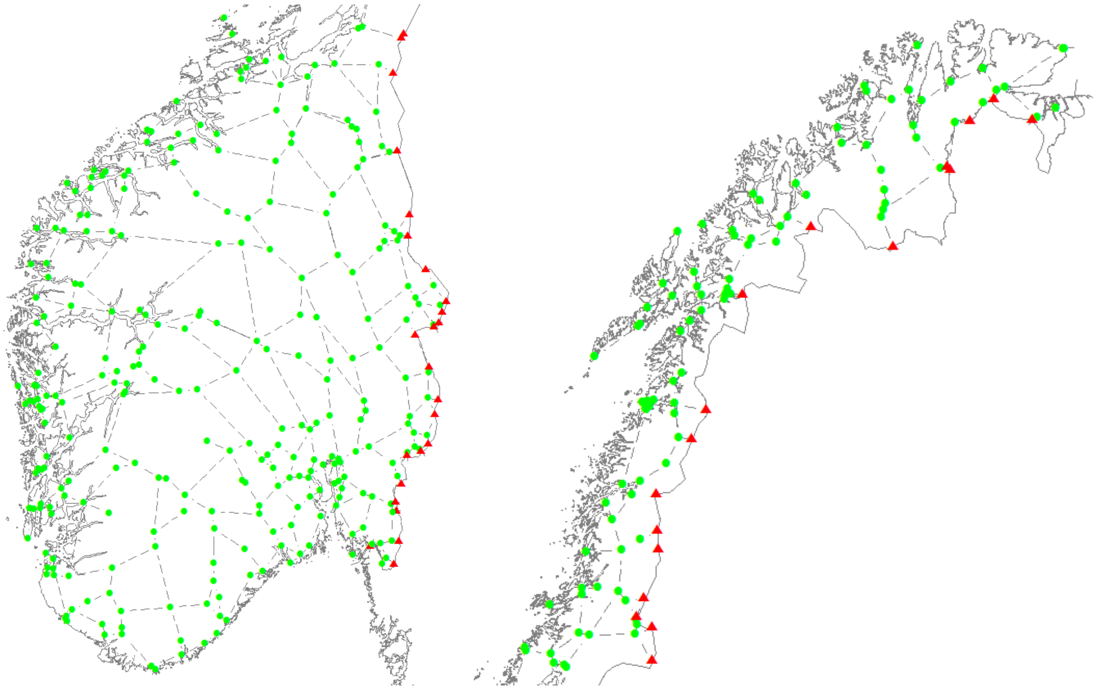


Figure 5.1: The first order leveling network and the railway leveling network organized as lines between nodal points. Green dots: Nodal points with unknown geopotential number. Red dots: Points with known geopotential number from the BLR adjustment.

5.2.1 Discussion on weights

Using the weighting strategy described in Section 5.1.4, the a posteriori standard deviation of the unit weight from the adjustment in Gemini Oppmåling is 1.11. It is arguable that the old observations should have been assigned smaller weights since they are affected by the uncertainty of the uplift model. Another issue regarding weighing is the fact that we have calculated the total accuracy of two or more fjord crossings in the same line, just by simply adding the standard errors. From the law of error propagation, the correct procedure for calculating the accuracy is to calculate the square root of the sum of squared errors. This blunder was done unintentionally and it was not discovered before writing this report. However, the effect is small compared to the accuracy of the result.

5.2.2 Quality of the leveling network

To get an impression of the quality of the leveling network, the residuals from the adjustment listed in Appendix B.2 and the loop misclosures may be examined. The loop misclosure is the sum of all geopotential differences in a closed polygon or leveling loop. If there is no error and we correct for land uplift, this sum ought to be zero. However, the misclosure for many loops is far from zero. Figure 5.2 shows the loops with misclosure exceeding the assumed measuring error with a factor of three, i.e., the loop misclosure is three times higher than 1 mm multiplied by the square root of the leveled distance in kilometers. 9 of 114 loops exceed this limit. Table 5.2 lists the 19 loops with the highest loop misclosure, including those shown in Figure 5.2.

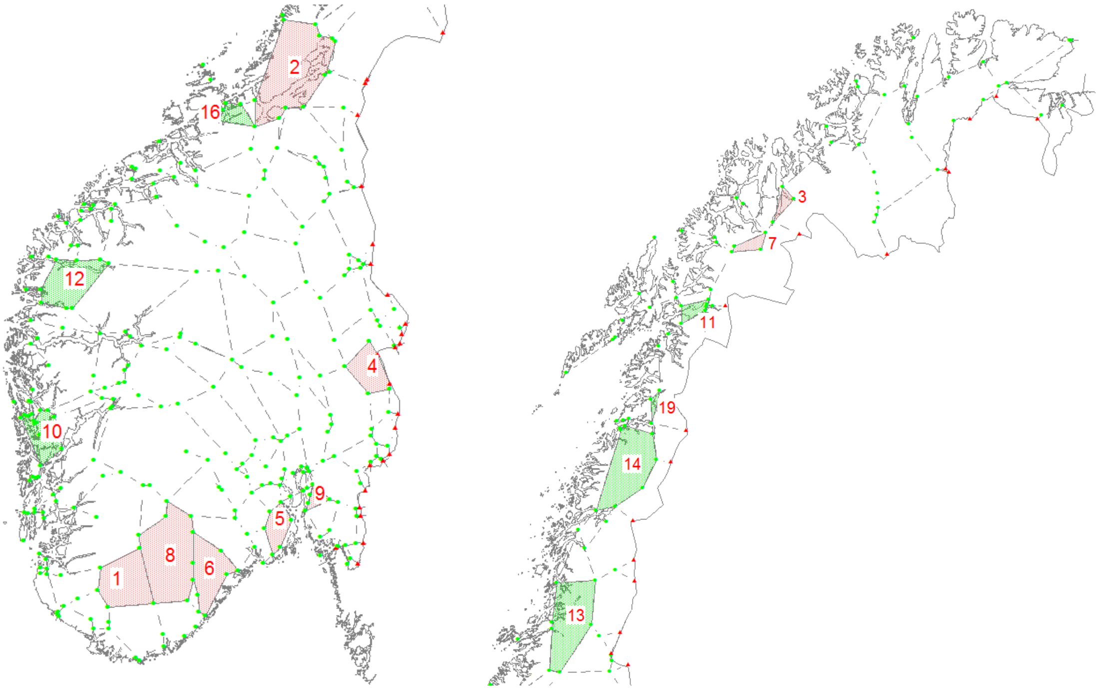


Figure 5.2: Leveling loops that exceed or are close to the limit for maximum accepted misclosure. The limit is set to 3 mm multiplied by the square root of the leveled distance in kilometers (3 mm $\sqrt{d(\text{km})}$). The numbers identify the loops listed in Table 5.2.

Table 5.2: The loop misclosure for the 19 worst loops in the network. The value in the last column is higher than one if the misclosure exceeds the limit of three times the assumed leveling accuracy. d is distance in kilometers.

Loop identifier	**Misclosure (cm)**	**Distance (km)**	**Misclosure divided by $\sqrt{d}$ (km)**	**Fraction of 3 mm per $\sqrt{d}$ (km)**
1	-6.52	230.7	-0.43	1.43
2	-7.50	446.4	-0.35	1.18
3	-4.60	170.0	-0.35	1.18
4	5.00	205.4	0.35	1.16
5	4.25	170.2	0.33	1.09
6	-5.37	276.8	-0.32	1.08
7	4.20	170.6	0.32	1.07
8	6.34	397.5	0.32	1.06
9	-3.15	105.8	-0.31	1.02
10	4.90	287.3	0.29	0.96
11	-3.60	155.5	-0.29	0.96
12	-5.40	356.5	-0.29	0.95
13	5.60	442.7	0.27	0.89
14	-6.10	531.3	-0.26	0.88
15	-6.00	542.3	-0.26	0.86
16	3.13	161.8	0.25	0.82
17	3.75	263.8	0.23	0.77
18	3.64	278.9	0.22	0.73
19	2.40	122.6	0.22	0.72

Sometimes one or more lines in a loop are releveled once or twice. In such cases, the average value is used when calculating the misclosure. It might be difficult to determine the specific line causing a high misclosure. Since the outlier detection previously described also solved for an unknown land uplift, it is challenging to separate land uplift from measurement errors, especially when the redundancy is low. When calculating the misclosure, the land uplift model NKG2005LU (Ågren & Svensson, 2007) has been used to correct the observations to the reference epoch 2000.0.

The standard errors of the adjusted geopotentials listed in Appendix B range from 0.001 to 0.023 g.p.u. In general, the standard error increases with the distance from the known points located along the Swedish and Finnish border. These standard errors do not say anything about the relative accuracy between points. Additionally, they are to some extent misleading since we did not reduce the weight of the oldest measurements, which are influenced by the uncertainty of the land uplift model. However, they give a general indication of the quality of the network, showing that big residuals degrade the accuracy.

5.3 Step two: Adjustment of the first order network

The first order network was determined using LSA, where the geopotential numbers of the nodal points were kept fixed. The rejected lines from the outlier detection in the first step were again included, now as geopotential differences between neighboring benchmarks in the line. As a consequence, the sum of squared residuals will scale up and increase the standard error of the calculated geopotential numbers in this step. However, this will not affect the determined geopotential number in any other point than those in the rejected line.

When a benchmark is situated on anything but bedrock, old observation(s) connected to the point are rejected if instability has been proven. This was done automatically when the observations were exported from the leveling database into Gemini.

The weighting strategy in the second step was the same as in the first. The reduced weights of the fjord crossings have now the effect that these observations get a bigger part of the residuals and reduce the errors on land correspondingly.

The adjustment included 18823 unknown points. In addition, we had 414 nodes with known geopotential number from the first step. The number of observations were 21205, which gave 2382 degrees of freedom. The standard errors from this adjustment is of little interest since they do not reflect the uncertainty of the nodal points from the first step, and as mentioned, they are scaled up because lines rejected in the first step now are included.

5.4 Step three: Adjustment of the second order and the railway networks

The railway network was first organized as lines between nodal points in the first order network and became part of the outlier detection. Table 5.3 lists the rejected lines, and indicate outliers up to 8 cm.

Table 5.3: Rejected railway-leveling lines. We rejected all lines with a t value higher than three.

Line number	Obs. year	Outlier (cm)	t value	Description	Remark
400	1974	8.2	4.9	Finse - Uppsete (part of line 400-1974)	From point D33N0094 to C32N0007
422	1965	-3.6	3.8	Nordstrand - Ski (part of line 422-1965)	From point G35N0041 to G35N0048
427	1969	3.8	3.2	Eina - Gjøvik (part of line 427-1969)	From point G33N0010 to G32N0035
421	1966	-2.2	3.1	Egersund - Helleland (part of line 421-1966)	From point B39N0009 to B39N0005

The rejection of these lines in the first step had no implications on the adjustment in the third step. However, in the outlier analysis we rejected these lines, and this information is important to get a correct picture of the accuracy of the railway leveling. Nevertheless, we used the lines in the third step keeping the first order points fixed.

The second order network is not really a network. As shown in Figure 4.2, it consists of short lines only. Together with the railway network, these lines were calculated in a common LSA, using geopotential numbers and the same weighting strategy as for the first step.

5.5 From geopotential numbers to height values

The adjustments in all three steps were based on geopotential numbers and differences obtained by Equation (5.1). The Norwegian height system NN2000 should, according to its definitions, give normal heights in the zero tide system. Therefore, the resulting geopotential numbers (with unit g.p.u) from all adjustments were converted to normal heights in meters, and transformed from the mean tide system to the zero tide system.

The transformation between the mean and zero tide system followed Equation (5.7) (Ekman, 1989)

$$C_{\mathrm{ZT}} = C_{\mathrm{MT}} - 0.296 \cdot (\sin^2 \varphi_N - \sin^2 \varphi_S), \tag{5.7}$$

where C_{ZT} is the geopotential number in the zero tide system, C_{MT} is the geopotential number in the mean tide system, φ_S is the latitude of Normaal Amsterdam Peil (NAP), and φ_N is the latitude of the point of interest. Note that Equation (5.7) is not strictly correct for geopotentials. The factor 0.296 should have been multiplied by $\bar{\gamma}$. Unfortunately, this blunder was discovered during the preparation of this report and leads to a systematic error of about 0.7 mm in southern and 1.5 mm in northern Norway. We think such a small error will not be significant for the users.

Normal heights were then obtained by Equation (3.4) with $C = C_{\mathrm{ZT}}$:

$$H^N = \frac{C_{\mathrm{ZT}}}{\bar{\gamma}}. \tag{5.8}$$

Following Ihde et al. (2002), the mean normal gravity along the normal plumb line is given

$$\bar{\gamma} = \gamma - \frac{0.3086H + 0.000000072H^2}{2}, \tag{5.9}$$

where γ is the normal gravity at the reference ellipsoid. Since we do not know the height H exactly, we iterate Equation (5.8) and (5.9) three times and substitute H with H^N for each iteration (see Hofmann-Wellenhof & Moritz (2005, Section 4.4)).

The normal gravity at the ellipsoid is conventionally determined by (Moritz, 2000)

$$\gamma = 978032.67715 \left(\frac{1 + 0.001931851353 \sin^2 \varphi}{\sqrt{1 - 0.0066943800229 \sin^2 \varphi}} \right) \tag{5.10}$$

which is based on Somigliana's closed formula.

The results from all steps in the adjustments are stored in the leveling database of NMA, both the final geopotential numbers and the normal heights in both the mean and the zero tide systems. Additionally, geopotential numbers and normal heights in the tide free system are determined and stored for the sake of completeness. Thus, every point has three different normal heights and three different geopotential numbers.

5.6 The 2012 adjustment

The adjustments described so far were finished in 2008, but the western part of the country showed large misfits. The loop crossing Sognefjorden, as shown in Figure 5.3, had a misclosure of 10.5 cm in the 2008 adjustments, which was the largest in the network. We suspected errors in the westernmost fjord crossing, and opened the loop by rejecting that measurement in the adjustment (this is the reason why this loop is not marked in Figure 5.2). We were not satisfied with this solution, since we could not prove that this was the only possible explanation of the large misclosure. Moreover, eliminating the fjord crossings strongly influenced the result for the entire western part of the network. It was decided that the 2008-adjustment should still be retained, but for the four western counties (Rogaland, Hordaland, Sogn og Fjordane, and Møre og Romsdal), the result was regarded as preliminary.

A new adjustment was planned to take place when we had carried out more measurements. From 2009 to 2011, we repeated the western and eastern fjord crossing over Sognefjorden at locations some kilometers away from where the crossings first were done. In addition, we leveled a new line splitting the big loop in two. Finally, we remeasured the line marked in blue in the right panel of Figure 5.3.

In the right panel of Figure 5.3, the loop misclosure of 10.5 cm is now strongly reduced. On the other hand, the situation has become more complicated. The second biggest loop in southwest has a misclosure qualifying for a 17th place in Table 5.2. More serious is the extreme value of 6 cm for the small eastern loop crossing Sognefjorden three times. The enlarged map in Figure 5.4 shows more details. Two of the fjord crossings in the north, Vangsnes-Eitorn and Hella-Dragsvik, are both measured two times. Vangsnes-Eitorn in 1963 and 2011, and Hella-Dragsvik in 1962 and 2004. Based on a separate outlier test, we rejected the 1963-crossing for Vangsnes-Eitorn, and it is not included in the loop misclosure of 6 cm. We were not able to identify any more erroneous line or fjord crossing. Hence, we used them all, hoping that the average is closer to the truth.

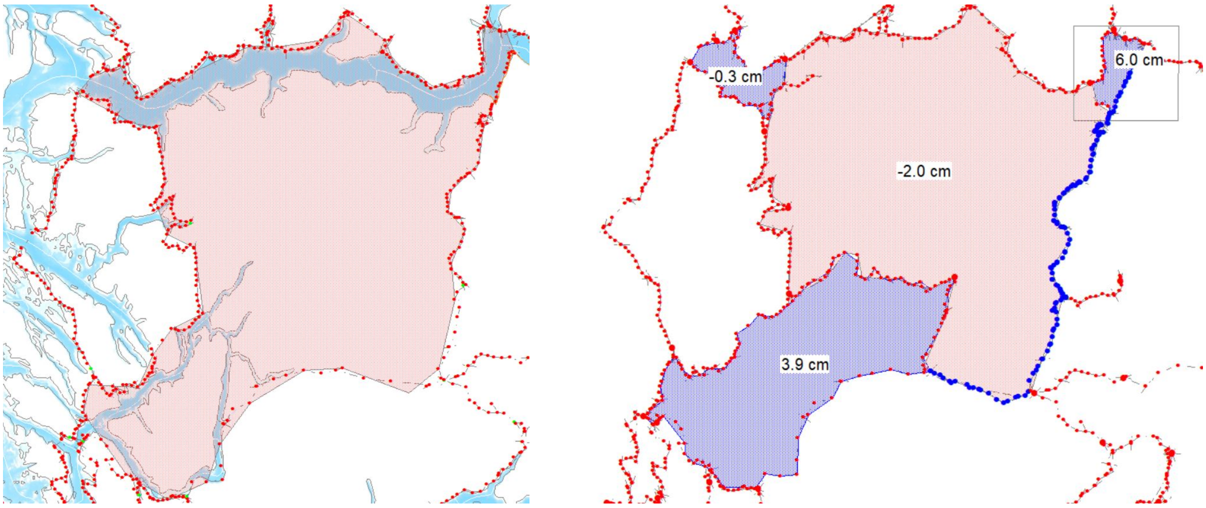


Figure 5.3: Left: The shaded loop has a misclosure of 10.5 cm and is 599 km long. Right: Loop misclosures across Sognefjorden after including new leveling data and new fjord crossing observations. Figure 5.4 shows more details for the loop inside the black rectangle.

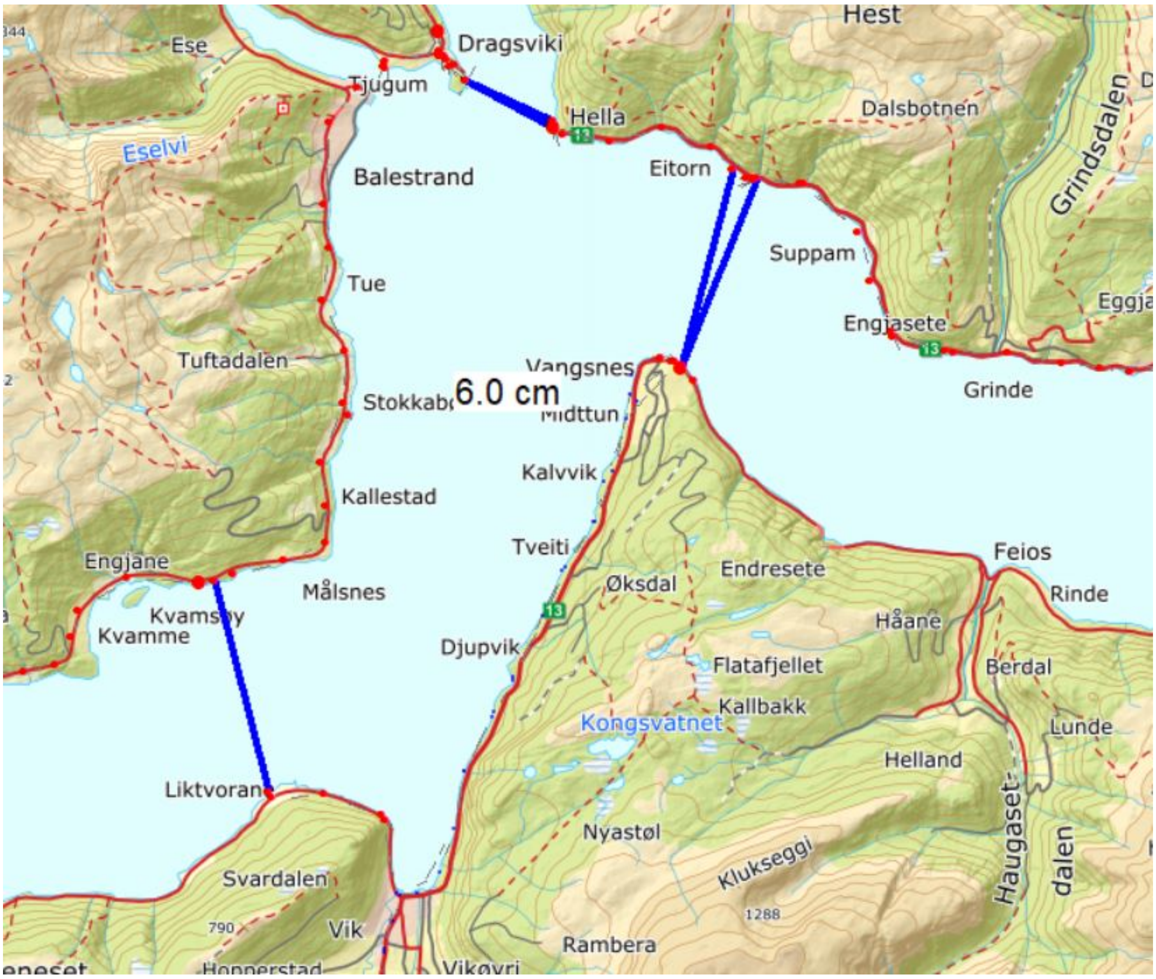


Figure 5.4: Overview of the loop with the largest loop misclosure. The crossings Vangsnes-Eithorn and Hella-Dragsvik are measured two times and the crossing Liktvoran-Kvamsøy is measured one time.

Also an area north of Sognefjorden was investigated in the period 2009 to 2011. In order to identify errors, we controlled several fjord crossings by remeasuring them and measured new leveling lines that split bigger loops.

As shown in Figure 5.5, we have split the big green loop into three separate ones. The result is somewhat difficult to interpret. The error seems to be located in the northern loop where there is a fjord crossing involved. However, also the two other loops have high misclosures. Note that there is no loop misclosure indicated for the loop below the big green one. The reason is that the western line was rejected in the 2008 adjustment, but it is still marked on the map. In the 2012 adjustment, the eastern line was releveled and rejection is not obvious anymore. Instead, we have rejected the old eastern line from 1936. From a statistical point of view, multippel t test does not identify the western line as an outlier, and we kept the line even if the misclosure is large. In our search for errors, we remeasured the two fjord crossings with the result shown in Table 5.4.

The 2012 adjustment followed the procedure outlined for the 2008 adjustment: First, final geopotentials on the nodal points were calculated, and then new heights at all points on lines connected to nodal points. The weighting strategy was the same and the down-weighting of fjord crossings has a significant effect in this area, where we have many of them.

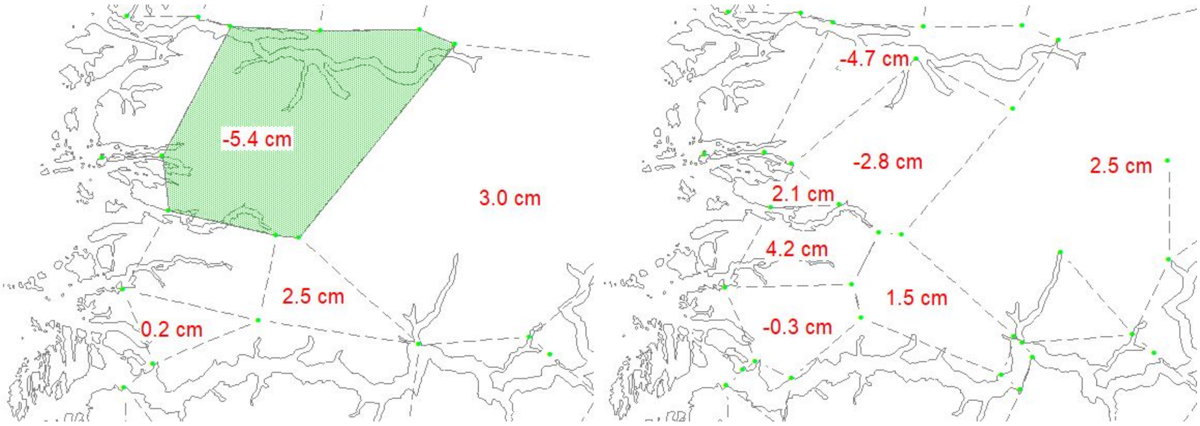


Figure 5.5: Loops north of Sognefjorden before (left) and after (right) the new measurements. High loop miclosures appear in new loops.

Railway lines and second order lines in the four western counties had to be recalculated based on the 2012 adjustment. We followed the same procedure as described in Section 5.4.

5.7 Can we trust the heights around Sognefjorden?

From Figure 5.6 it is clear that the fjord crossings closest to the mouth of Sognefjorden have large effect on the estimated heights. To find support for keeping the western fjord crossing, we conducted an independent test where we made use of GNSS and a gravimetric geoid model. NKG released a new quasigeoid model for the Nordic countries in 2016, the NKG2015qgeoid (Ågren et al., 2016). Trying to fit this model to our GNSS/leveling points by least squares collocation, would have revealed an error of 10 cm in the leveling network as a systematic shift in the signals over the fjord. We cannot see anything of this at the western crossing. The average correction to the GNSS/leveling point is 11 and 13 mm for the northern and southern side, respectively - using eight points located between the fjord crossing on the northern side and five on the southern. At the eastern crossing, we have not as many GNSS/leveling points between the locations of the crossings. Nevertheless, doing the same test here indicates a systematic shift of 33 mm when we use the six closest points on the northern side and the three on the southern (see Figure 5.7).

At the time of calculation, NKG2016qgeoid did not exist and we could not perform the

Table 5.4: Remeasured fjord crossings.

Fjord	**Year**	**Height difference (m)**	**Distance (m)**
Dalsfjorden	1987	-18.781	1412
Dalsfjorden	2008	-18.792	1412
Førdefjorden	1987	-0.243	1217
Førdefjorden	2008	-0.241	1217

test described above. However, other models existed and gave approximately the same result. This indicated that keeping the western fjord crossing was a correct choice. At the eastern crossing, the fit is not so good, which is understandable keeping in mind the loop misclosure of 6 cm, which is large for a small loop and the worst for the entire Norwegian leveling network.

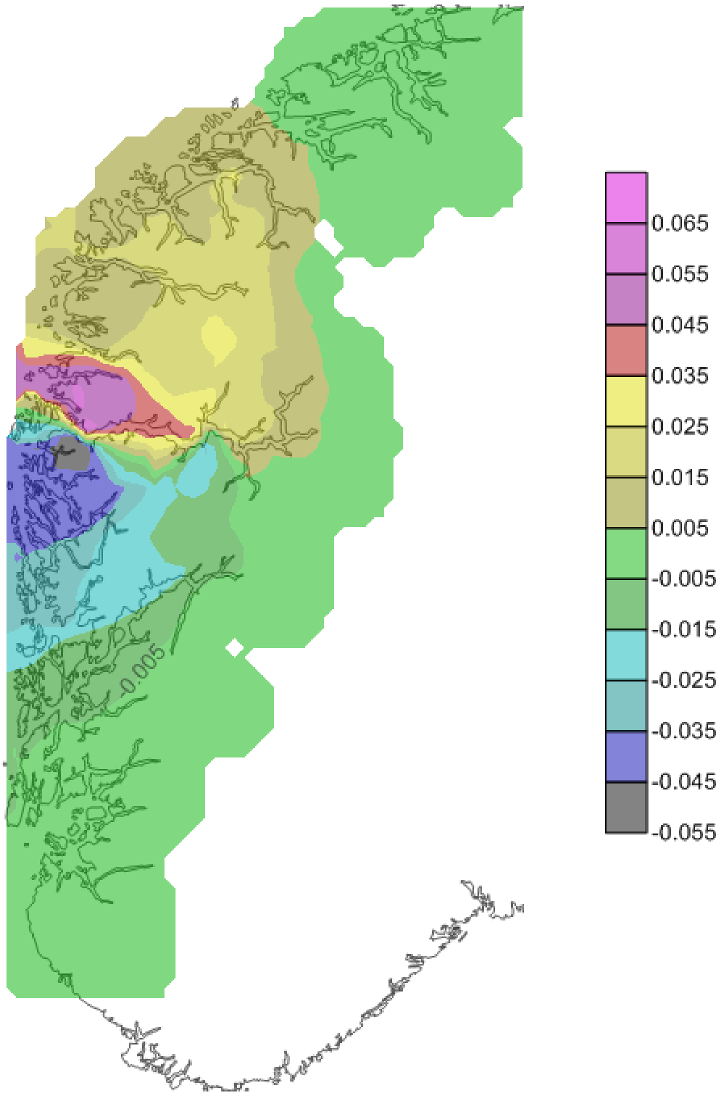


Figure 5.6: The difference between the preliminary 2008 adjustment and the final 2012 adjustment for the western part of Norway.

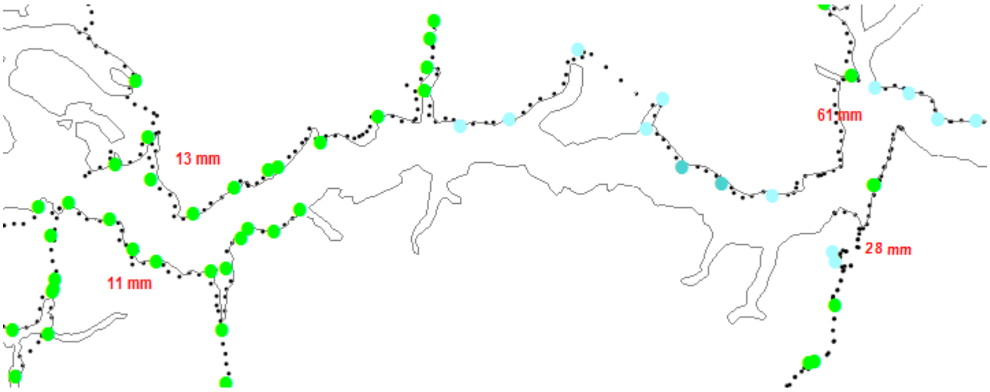


Figure 5.7: GNSS/leveling points on both sides of Sognefjorden. The colors indicate the sum of signal and trend when constraining the gravimetric geoid model NKG2015qgeoid to the points by least squares collocation. Green < 3.3 cm, light blue < 7.3 cm, and dark blue < 10.3 cm.

Chapter 6

The heights in the passive GNSS network (Landsnettet)

The previous chapters describe the implementation of new heights in the leveling network as the first realization of the new height system NN2000. The majority of the points in the GNSS reference network, usually called Landsnettet, are not directly connected to the Norwegian leveling network, so the heights have to be determined by other means. We have used the ellipsoidal heights in combination with a fitted geoid model to obtain the NN2000 normal heights in the Landsnett points. Fitted geoid models are normally called height reference (HREF) models. The same HREF-model is used for surveying with real-time kinematic (RTK) positioning systems. The points in Landsnettet are used as fixed points in surveying and mapping projects and a number of other purposes.

In this chapter, we will describe the steps of the implementation of NN2000 in all Norwegian municipalities. Most of the work described in this chapter was done as a cooperation between the Geodetic Institute and the regional offices of the NMA, as shown in Figure 6.1. The work was financed through the Geovekst cooperation.

Geovekst
Geovekst is a national program for co-operation on establishing digital geographic data in Norway. The basic concept is pooling of money for jointly executed projects for establishing, improving and maintaining large-scale digital geographic data. The general Geovekst program includes the State Road Department, the Board of Electricity Companies, the Norwegian Association of Local Authorities, Norwegian Mapping Authority, the Telecommunication Department, and the Ministry of Agriculture. Other services may participate in the program in specific regions. The Norwegian Mapping Authority undertakes the coordinating role both on national and regional level. The practical execution is organized as individual projects through which digital data are established and administrated in specific, limited geographic areas. The projects are based on an agreed set of standard rules and manuals, which facilitate the exchange and sharing of data across administrative boundaries.

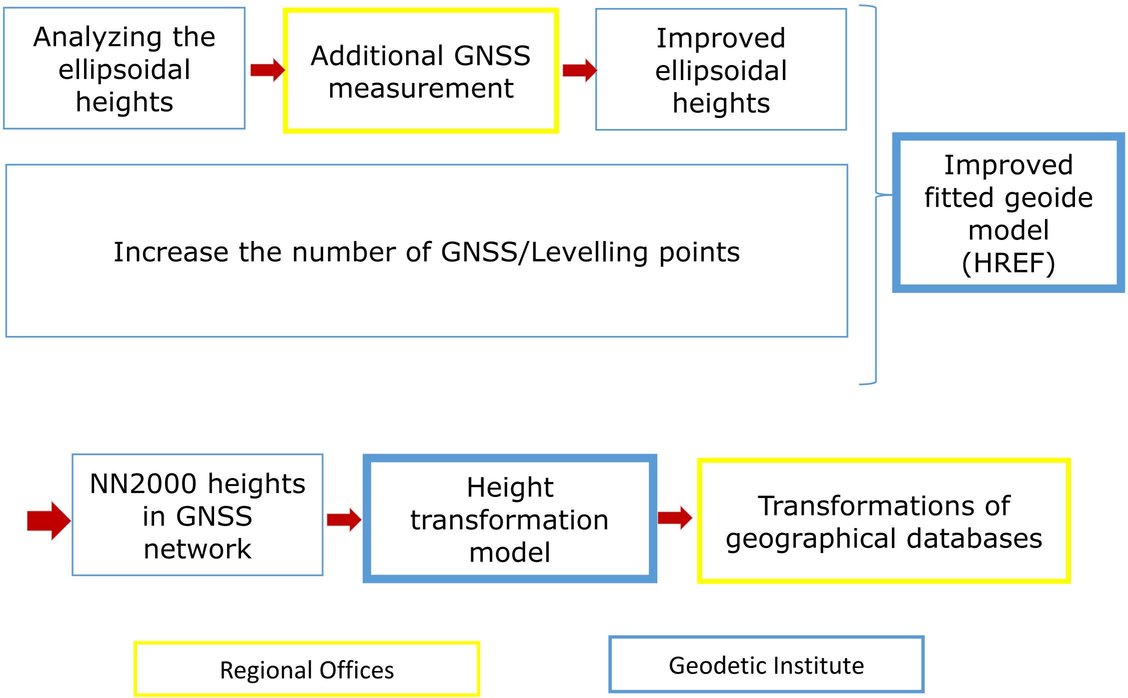


Figure 6.1: Workflow for the implementation of NN2000.

6.1 The ellipsoidal heights

The existing passive GNSS network was established in the 1993-2008 period. The network consists of 12.000 control points with coordinates in EUREF89, the Norwegian realization of ETRS (European Terrestrial Reference System). The core part of the network (100 points) is measured by three-days GPS campaigns and densified by a network of GPS baselines with observation time from 1 to 4 hours. Initially, our focus was on the horizontal components. Later, it became clear that the quality of the ellipsoidal heights in EUREF89 was insufficient for serving as GNSS/leveling points in a fitted geoid model. Finding a suitable strategy for improving the ellipsoidal heights was subject to long internal discussions. The conclusion was to calculate the ellipsoidal heights in the new reference frame, IGS05N, using the campaign measurement as fixed points, i.e., these points were given infinitely large weights. The ellipsoidal heights were then transformed to EUREF89 by equations described in Appendix A. The selected method for improving the ellipsoidal heights is described in the following paragraphs.

6.1.1 GNSS campaign measurements

From 2009, GNSS campaigns were conducted in order to evaluate the quality of EUREF89. The new GNSS coordinates were calculated in the reference frame IGS05N, epoch 2009.58, and based on stations in the Continuously Operating Reference Stations (CORS) network of Norway. The calculations were done in the Bernese GNSS Software. From 2010, the purpose of these campaigns changed. From then on, the GNSS campaigns were carried out on selected points in the control point network as a basis for updating the ellipsoidal heights. The idea was to realize a new reference frame in IGS05N with an associated transformation to EUREF89. This transformation is defined in Appendix A. Another motivation for the GNSS campaigns was to densify the network of GNSS/leveling points. This was achieved by GNSS measurement on leveling benchmarks.

The GNSS campaign points were selected based on these criteria:

- Density about 30-40 km
- Bedrock or other stable foundation
- Good GNSS conditions
- Leveled height in NN2000

6.1.2 GNSS baselines and CPOS measurements

A subset of points were remeasured with GNSS in order to strengthen the original baseline network from 1993-2008. The horizontal position and the ellipsoidal height of the points were determined by observing baselines with static GNSS as well as the CPOS RTK network service (Ouassou et al., 2015). At each point we wanted to strengthen, two baselines were observed over 2-4 hours, depending on conditions. One CPOS measurement was taken when setting up the equipment for observing the GNSS baselines, and a second was taken when taking it down, regardless of the distance from the CORS. One CPOS *measurement* was a combination of at least three *registrations* with separate initialization of the CPOS receiver. Note that a dedicated CPOS service, was set up in the reference frame IGS05N and the observed coordinates were consequently determined in IGS05.

Guidelines for the GNSS campaigns are given by Kartverket (2020). For example, the surveyors were required to test their CPOS equipment at the NMA head office in Hønefoss. The test was done by measuring a well-defined control point and comparing the measured height to the given height.

GNSS baseline measurement is time consuming, especially in fjord and mountain areas. To speed up the work, the CPOS service was tested as an alternative to GNSS baselines in 2012. A distance limit of 15 km from the nearest CORS was set for the CPOS measurements to keep up with accuracy requirements. For measurements further away from CORS, battery-powered temporary reference stations were used. The temporary stations were connected to the CORS network by the mobile phone network. The stations were set up over the campaign points discussed in Section 6.1.1. The surveyor visited each point three times. The time separation was set to at least six hours, and spread over two days. As it turned out, the logistics of this method were rather challenging. Measurements were going on simultaneously at several locations, and there was a shortage of available temporary reference-station kits. Poor mobile network coverage proved to be a problem in many areas. In addition, there was a risk of antenna height errors at the temporary reference stations. As a consequence, this approach was in use only in 2012.

6.1.3 Weighting of the campaign observations

As described in Section 6.1.1 and Section 6.1.2 the observations were of three types:

1. GNSS campaigns over five days, calculated in the Bernese GNSS Software.

2. Baselines with a length of 1 to 10 km observed over 1 to 4 hours, processed with various software.

3. CPOS measurements.

The individual observation weight as well as the relative weight between the different types of observations will influence the result. The weight is given as $1/\sigma^2$, where σ is the standard error of the observation.

For the baselines we found the standard error of the derived height difference by using the formula

$$\sigma_{dh} = \sqrt{k_1^2 + k_2 d^2 + k_3 dh^2}, \tag{6.1}$$

where $k_1 = 0.01$ m, $k_2 = 0.001$, and $k_3 = 0.025$. d is the distance and dh the height difference, both in kilometers. We have found the three k-parameters in this formula by using the variance component estimation method described by Mathisen (1977). The third part in the formula is the most interesting one, penalizing vectors with larger height differences.

For the CPOS measurements, we used the standard error given by the CPOS system to calculate the weight. As mentioned in Section 6.1.2, a measurement consisted of at least three registrations. In the adjustment we used the mean value and the mean standard error of these three registrations to represent one measurement. The CPOS system provides standard errors of each component of the coordinate given in a geocentric Cartesian coordinate system. In addition, the correlations between each component are given. Following the law of error propagation, the standard error of a mean ellipsoidal height observation was calculated from the standard errors of each coordinate component. At each point we obtained two such mean observations, one when setting up the antenna for base line measurement and the second one when taking it down.

For the campaign measurements we could not use the standard error given by the Bernese GNSS Software directly. Those estimates were too optimistic. Two possible weighting strategies were discussed:

1. Use fixed campaign points in the adjustment, i.e., give them infinite weight.

2. Calculate weights based on variance component estimation.

The accuracy of the campaign coordinates was considered superior to the baselines. Thus, for practical reasons, the first strategy was selected.

For the last two observation types, the baselines and the CPOS measurements, we performed a simple variance component estimation procedure to make sure that the relative weight between them was correct. This typically gave standard errors of the unit weight close to one, for both observation types. If not, we scaled the two observation types relative to each other in order to obtain a value closer to one.

6.1.4 The calculation

We used IGS05N as reference frame. Since the ellipsoidal heights of the campaign points are fixed in the adjustment, we have two types of observations only:

- Height differences from GNSS baselines

- Observed ellipsoidal heights in IGS05N from CPOS

To avoid possible systematic errors in CPOS, we typically estimated an unknown bias for each day.

Usually the network covered a county or a part of a county, including some thousand observations and some thousand unknown heights. Before the final LSA, we tested all observations for outliers. The rejection criterion was set to three (see Section 5.1.3) and rejected observations were flagged in the observation database as outliers. Another important test was the calculation of external reliability (the effect of the undetectable outliers on the estimated parameters) and the assignment of height classes. The requirements for the different classes are listed in Table 6.1.

The Norwegian guidelines for GNSS networks (Statens kartverk, 2009a), define requirements for the relative reliability of the height difference between two neighbor points. The relative reliability (Δ) is obtained by combining the numbers in Table 6.1 with Equation (6.2).

$$\Delta = \sqrt{l\left(p^2 + 2\frac{k^2}{l^2}\right.} \tag{6.2}$$

Here l is the slope distance in kilometers between two points, and p and k are parameters given in Table 6.1. According to the Norwegian guidelines, the points in the GNSS reference network should have a relative reliability fulfilling the same requirement as stated for height class A. The guidelines say nothing about the other two criteria, i.e., the standard error and the absolute reliability. Those are internal requirements used by the NMA. This means that all points assigned to height class A, fulfill the Norwegian guidelines. It turns out that also points assigned to other classes than A, fulfill the Norwegian requirements. In total, 81.6% of the points in the GNSS reference network, fulfill the Norwegian guidelines for ellipsoidal heights, as shown in Table 6.2.

Defining quality criteria for a geodetic reference network is not straightforward. Depending on perspective and use, different criteria are preferred. We believe that the existing Norwegian regulations alone are not sufficient. For some purposes, the absolute reliability (the difference from a reference value) is a more useful quality indicator, e.g., when controlling the CPOS equipment. As a rule of thumb, points that belong to class A and B are qualified for most surveying and mapping purposes dealing with ellipsoidal heights, points in class C may be poor, and proints in height class F should be avoided if possible.

Table 6.1: Requirements for standard error and external reliability (relative and absolute) for the different ellipsoidal height classes.

	A	**B**	**C**	**F**
Standard error	< 6 mm	< 8 mm	< 10 mm	> 10 mm
Relative reliability	p=6 ppm, k=6 mm	p=6 ppm, k=10 mm	p=6 ppm, k= 15 mm	
Absolute reliability	< 8 mm	< 12 mm	< 15 mm	> 15 mm

Table 6.2: Statistics of different ellipsoidal height classes.

	A	**B**	**C**	**F**	**Sum**
Number of points	5761	4598	922	324	11605
Number of points in percent of all	49.6	39.6	7.9	2.8	100
Number of points fulfilling Norwegian requirements	5761	3180	416	115	9472
Number of points fulfilling Norwegian requirements in percent of the total	49.6	27.4	3.6	1.0	81.6

Both IGS05N and EUREF89 ellipsoidal heights are stored in the database. This means that we have realized the ellipsoidal heights of our GNSS reference network in two different reference frames that are related by a mathematical transformation. We also stored all three quality measures for all individual points and the assigned height class as an overall quality indicator.

6.2 Final NN2000 heights

The final NN2000 heights for our GNSS reference network were calculated by transforming the height components of the GNSS-observations to normal height differences by using the latest updated HREF model. The CPOS-observed ellipsoidal heights were transformed to normal heights using the same HREF model. An alternative approach could have been to transform ellipsoidal heights directly to normal heights in NN2000 using the HREF model. However, this method would degrade the leveled heights, and was therefore not used.

6.2.1 The gravimetric geoid model, GNSS/leveling points, and HREF

A main challenge of this procedure was that we needed a high-quality geoid model to obtain NN2000 heights on points in the GNSS reference network that are not leveled. To obtain the desired quality, gravimetric geoid models must be constrained to GNSS/leveling points, i.e., points that are leveled and with accurate and reliable ellipsoidal height. Such models are called height reference models or just HREF models. In Norway, the difference between a pure gravimetric model and the geoid heights derived through the GNSS/leveling points is more than 15 cm in the worst cases, even if we solve for a shift or a bias between them. The average difference is 3-4 cm in terms of RMS depending on the models.

The first challenge was to find a gravimetric geoid model on which we could base the

HREF model. The most recent geoid model from NKG at the time, the NKG2004 model, was out of date. Several Norwegian geoid models calculated by the NMA were tested, and the gravimetric geoid model NMA2013v30 was selected. Except for three pilot areas (Kristiansand area, Hamar-Lillehammer region, and Trondheim), we have used this model for the implementation of NN2000 in all Norwegian counties. In the pilot areas we used the NKG2004 model, the presumably best model at the time.

Another challenge was to establish a sufficiently dense network of GNSS/leveling points. The three major issues were:

- The extent and density of the precise leveling network.
- The distribution and the total number of GNSS/leveling points.
- The quality of the ellipsoidal heights in the GNSS/leveling points.

They were addressed as follows:

1. The leveling network was extended and densified such that the distance to the nearest GNSS/leveling point was less than 15 km in populated areas and along public roads.
2. GNSS campaigns were accomplished in existing or new GNSS/leveling points with a distance of approximately 15 km between them. If the horizon around the leveled benchmark was not good, an eccentric set-up was considered.
3. All other GNSS/leveling points were remeasured with CPOS and two baselines to neighboring points in the GNSS reference network as described in Section 6.1.2.

By the end of the project in 2018, these actions had resulted in 3299 GNSS/leveling points. These points were then used to fit the gravimetric geoid model NMA2013v30 to obtain HREF models. We have calculated all HREF models by least squares collocation. When making the models, we predicted values at all points in a grid with spacing 0.02° in the north-south direction and 0.04° in the east-west direction. This corresponds to $\sim$2.2 km for both directions. Two types of HREF models were calculated, one referring to ellipsoidal heights in EUREF89 and another one to IGS05N. The complete names of the models are HREF2018a_NN2000_Euref89 and HREF2018a_NN2000_IGS05N. Note that before we reached the final model, a number of intermediate models were calculated and used when calculating heights in the municipalities. These intermediate models were successively updated regionally before the height calculation and make up the final one for this region. This means that for an updated region the intermediate model does not differ from the final one.

6.2.2 Heights in island communities

The leveling network does not cover the many islands along the coast of Norway, where the distance to the nearest GNSS/leveling point may by far exceed the recommended maximum distance of 15 km. The consequence is that the HREF model turns into a pure gravimetric geoid model. Our experience suggests that there is a risk of systematic errors in the geoid model in this type of landscape. Therefore, we have to determine the NN2000 height by other means.

Table 6.3: Fjord crossings based on local tide gauge observations.

Municipality	**Island**	**Distance**	**Remark**
Kvitsøy	Kvitsøy	12 km +12 km	Relative tide gauge observations only Connected both to Randaberg in south and to Arsvågen in north
Utsira	Kvitsøy	19 km	Relative tide gauge observations only
Solund	Sula	5 km	Relative tide gauge observations + normal fjord crossing
Smøla	Smøla	6 km	Relative tide gauge observations + normal fjord crossing
Hasvik	Sørøya	25 km	Relative tide gauge observations only

One option is normal fjord crossings using vertical angle measurements, but over distances longer than 5 km, the uncertainty will be higher than accepted. Another and more reliable approach, is to use temporary tide gauges to transfer the NN2000 height to the island. We connected both tide gauges to benchmarks by leveling, i.e., to a leveled benchmark on the mainland and to a point in the GNSS reference network on the island. The required length of the tide gauge record depends on distance, weather, oceanographic aspects, and the requested accuracy. For short distances and good conditions, the standard error converges to less than 1 cm after just a few hours. For longer distances, days are required to reach the same result. Furthermore, seasonal differences complicate the picture. The crucial factor, is that the water level on both sides of the fjord on average coincides with the same potential surface. If this condition is not fulfilled, the accuracy will degrade accordingly. The tide gauge method is used for the five crossings listed in Table 6.3.

We intended to use the same type of relative tide gauge measurements to several more island communities and municipalities in Møre og Romsdal, Nordland, and Finnmark, but there was no time to do this. Instead, a special combination of GNSS and HREF was used for the remaining islands. As already mentioned above, the underlying gravimetric model in the HREF-model has an increasing influence when moving away from the GNSS/leveling points, especially towards the outskirts of the model where extrapolation rather than interpolation determines the HREF values. Recently, the NKG2015qgeoid was released, which quality is expected to surpass the NMA2013v30 goeid on which the HREF model was based. For the island communities, the geoid heights from the NKG2015qgeoid were used to determine NN2000 heights on the island and later update the HREF model. The procedure followed five steps:

1. The NKG2015qgeoid-model was fitted to GNSS/leveling points on the mainland.

2. For one or more high quality Landsnett-points on the island, the NN2000 normal height was computed by subtracting the geoid height derived from the fitted NKG2015qgeoid model from the ellipsoidal height.

3. The island-points, were then added to the HREF model as new GNSS/leveling

Table 6.4: The calculation of NN2000 at central benchmarks in island municipalities. The second column lists the high-quality benchmarks on the islands, the third column their ellipsoidal height, the fourth column the raw value of the gravimetric model, the fifth column the predicted signal using least squares collocation and GNSS/leveling points on the main land as observations, and the sixth column the final NN2000 height (column 3 minus the sum of column 4 and 5).

Municipality	**Central benchmark**	**Ellipsoidal height (m)**	**Geoid height NKG2015q**	**Predicted correction**	**Final NN2000 height**	**Remark**
Midsund	C26T0329	49.317	44.62	-0.091	4.788	
	C26T0166	46.135	44.73	-0.085	1.490	
	C26T0327	56.473	44.791	-0.103	11.785	
Haram	C27T0533	67.122	44.868	-0.058	22.312	Only for Haramsøyene
Meløy	J14T0202	36.234	33.646	0.000	2.588	
Vega	H17T0092	58.309	37.115	-0.047	21.241	
Træna	H15T0025	81.423	37.317	-0.038	44.144	
Lurøy	I15T0131	43.39	35.776	-0.068	7.682	Only for Lovund and Solvær
Radøy	I15T0139	65.661	34.777	-0.038	30.922	Only for the islands
Karlsøy	P04T0099	33.322	29.881	-0.011	3.452	For Vannøya
	P04T0100	35.158	30.439	-0.008	4.727	
Skjervøy	R04T0094	62.254	29.324	-0.023	32.953	For Arnøya

points, and an updated HREF model based on the NMA2013v30 geoid was calculated.

4. The normal heights in NN2000 of the remaining Landsnett points on the island were calculated based on the updated HREF model.

5. If there were any leveling lines on the island, one of the selected points in step two should be connected and the NN2000 heights in the line calculated from this.

This procedure was used for the island communities listed in Table 6.4.

6.3 The transformation between NN1954 and NN2000

The transformation of geographical data and map databases from NN1954 to NN2000 was the final task in the long process of implementing the new height system. The transformation model is based on a set of common points with reliable heights in both height systems.

The benchmarks in the leveling network are obvious candidates as common points. Away from the leveling lines, the points in the GNSS network are equally good candidates as they are used as reference points for a number of purposes including airborne light detection and ranging (LiDAR) measurements and aerial mapping.

The differences between the height systems NN2000 and NN1954 show an irregular pattern, see Figure 6.2. This means that a mathematical transformation would be inaccurate. Instead, we have made a grid model describing the differences. This transformation model is similar to the HREF models in terms of format and idea.

The model is based on least squares collocation. In addition to a parametric model of the differences, we also estimated signals describing the irregularities. In sum, the parametric part and the signals describe the difference between the two height systems.

The transformation model was updated regionally. The selection of common points was done in two stages:

1. Nodal points in the leveling network and some points in the lines connecting them. The model was then tested on the heights of points in the GNSS reference network in the area, typically a county.

2. Additional common points were added in areas where the test revealed systematic differences.

This procedure resulted in one or two new models every year, named by the year and a letter (a, b, c and so on). The final model was named NNTrans2018a. The model contains predicted values in a grid with spacing 0.025° in the north-south direction and 0.05° in the east-west direction, corresponding to around 2.8 km for both directions. We converted the grid file into a binary file, using a file format often referred to as the KMS format. Note that the file format is exactly the same as for the HREF models, only the spacing is different.

In least squares collocation, the covariance function plays a central role, as it tells the system about the correlation between the signals and their variance. It thus controls the smoothness of the final model. Especially important is the relationship between the variance of the observations, the common points, and the variance of the signals. We have run the collocation in two steps. In both steps, we used a polynomial surface of third degree as the parametric part and an exponential function to describe the signal's covariance (often this function is referred to as a Gauss-Markov process of first degree). We found the covariance by using the following model (Moritz, 1980):

$$C_{ss} = \sigma^2 e^{-\beta d}. \tag{6.3}$$

In the first step, we set σ to 26 mm and β to ln(2)/35, i.e., the covariance reaches its half value after 35 km. The standard error of the common points, the observations, was set to 14 mm. In the second step, we reduced σ to 10 mm, β to ln(2)/5, and the standard error of the observation to 10 mm, the same as for σ.

The parameters above result from many experiments. They seem to work reasonably well. Establishing such transformations is in many ways not an exact science. On one side, we aim at avoiding points that have erroneous heights in the old system, while on the other side, we might be forced to use them as common points when they have been reference points for the geographical data we will transform to the new height system.

As a practical solution, the Geodetic Institute provided the regional offices of the NMA with suggestions to which common points to use, as well as information on how well the

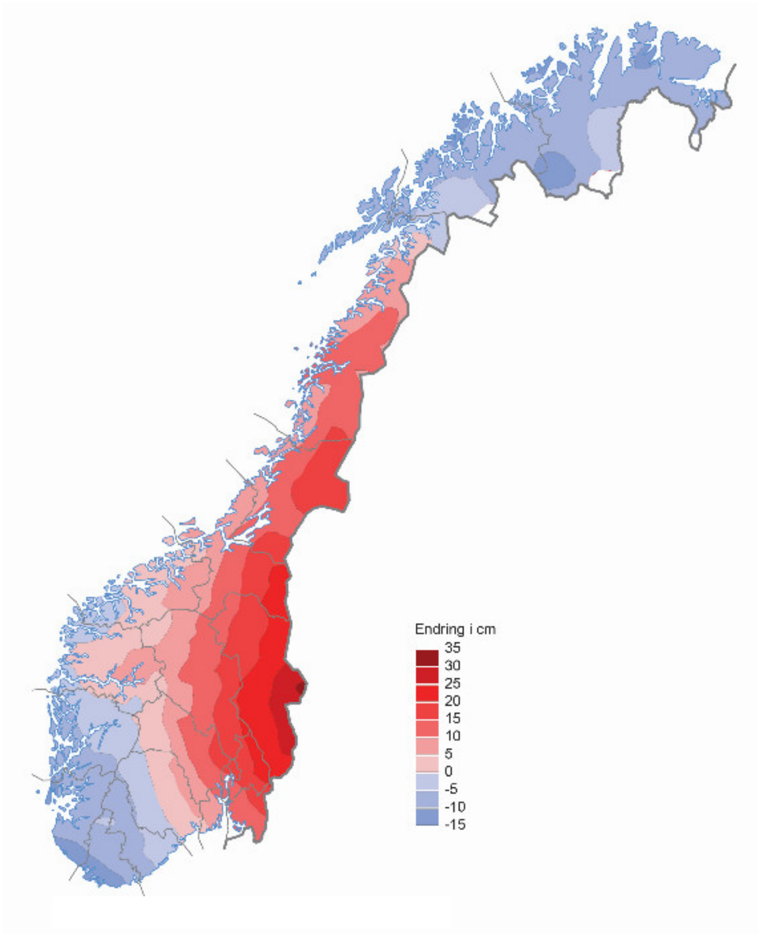


Figure 6.2: The difference between NN1954 and NN2000, the transformation model NNTrans.

remaining points fitted into the transformation. Normally the deviations were less than 3 cm. In Sogn og Fjordane, where the terrain is rough and the old heights inaccurate, the difference reached 5 cm in some points. Points in remote areas with large deviations were discarded, as surveyors most likely would never use them for precise height determination in the future.

When we had agreed upon what common points to use, the Geodetic Institute sent over the final transformation model, and the regional offices performed the transformation of the map databases. The map databases are shared among the partners in the Geovekst program, and thus, the municipalities, the road administration, and all other partners obtained updated map databases in NN2000.

Chapter 7

Key parameters of NN2000 and recommendations for further reading

The vertical reference frame NN2000, realized for Norway and implemented in all municipalities in the period 2013 to 2018, has the following characteristics:

		Remarks
Fundamental benchmark	NAP	Normaal Amsterdam Peil Benchmark named 000A2530 in Netherlands and 13600 in the UELN numbering system
Reference epoch	2000.5	Since the land uplift correction is based on whole years and the leveling is mainly done during summers, the reference epoch is more correctly 2000.5.
Permanent tide system	Zero tide	
Type of heights	Normal heights	
Land uplift model	NKG2005LU	
HREF model	HREF2018b	The HREF model has been continuously updated as NN2000 was implemented in new areas and municipalities. The assumed final model was HREF2018a. Later the same year, an error was found resulting in HREF2018b. This is per November 2019 the latest official model. NN2000 height plus a HREF value give ellipsoidal height in EUREF89, i.e., height above the GRS80 ellipsoid, in the tide free system, and with reference epoch 1995.0.
Geoid model	NMA2013v30	Used as underlying gravimetric model when making HREF models.

For further reading, we recommend Gerlach et al. (2013); Harsson & Pettersen (2014) and Revhaug (2019).

Bibliography

Ågren, J. & Svensson, R., 2007. Postglacial Land Uplift Model and System Definition for the New Swedish Height System RH2000, Reports in Geodesy and Geographical Information Systems 2007:4, Lantmäteriet, ISSN 280-5731.

Augath, W. & Ihde, J., 2002. Definition and Realization of Vertical Reference Systems - The European Solution EVRS/EVRF 2000, in *Proceedings of FIG XXII International Congress, Washington*, pp. 19–26.

Boucher, C. & Altamimi, Z., 1992. The EUREF Terrestrial Reference System and its first realizations, in *EUREF Meeting, Bern, Switzerland March*, http://www.euref.eu/symposia/book2001/1_3.pdf.

Breili, K., Gjevestad, J. G., Lysaker, D. I., Omang, O. C. D., & Pettersen, B. R., 2010. Absolute gravity values of Norway, *Norsk Geografisk Tidsskrift - Norwegian Journal of Geography*, **62**(2), 79–84, http://dx.doi.org/10.1080/00291951.2010.481125.

Danielsen, J. S., 2001. A LAND UPLIFT MAP OF FENNOSCANDIA, *Survey Review*, **36**(282), 282–291, https://doi.org/10.1179/sre.2001.36.282.282.

Ekman, M., 1989. Impacts of geodynamic phenomena on systems for height and gravity, *Bull. Geod.*, **63**, 281–296, doi:10.1007/BF02520477.

Ekman, M., 1991. A concise history of postglacial land uplift research (from its beginning to 1950), *Terra Nova*, **3**(4), 358 – 365.

Erikson, P.-O., Vestøl, O., Jepsen, C., Keller, K., Mäkinen, J., Saaranen, V., Valsson, G., & Hoftuft, O., 2014. Review of current and near-future levelling technology - a study project within the NKG working group of Geoid and Height Systems, Reports in Geodesy and Geographical Information Systems 2014:2, Lantmäteriet, ISSN 280-5731.

Gerlach, C., Šprlák, M., Bentel, K., & Pettersen, B. R., 2013. Observasjon validering, modellering – historiske linjer og nye resultater i norsk forskning om jordens tyngdefelt, *KART OG PLAN*, **73**, 128–150.

Häkli, P., Lidberg, M., Jivall, L., Nørbech, T., Tangen, O., Weber, M., Pihlak, P., Aleksejenko, I., & Paršeliūnas, E., 2016. The NKG2008 GPS campaign - final transformation results and a new common Nordic reference frame, *Journal of Geodetic Science*, **6**(1), https://doi.org/10.1515/jogs-2016-0001.

Harsson, B. G. & Pettersen, B. R., 2014. Noen trekk fra geodesiens utvikling i Norge de siste 200 år, *KART OG PLAN*, **74**, 6–15.

Helmert, F. R., 1890. Die Schwerkraft im Hochgebirge, insbesondere in den Tyroler Alpen in geodätischer und geologischer Beziehung, Veröffentlichung des Königlichen Preussischen Geodätischen Institutes.

Hofmann-Wellenhof, B. & Moritz, H., 2005. *Physical Geodesy*, Springer, ISBN 3-211-23584-1.

Hwang, C. & Hsiao, Y.-S., 2003. Orthometric corrections from leveling, gravity, density and elevation data: a case study in Taiwan, *Journal of Geodesy*, **77**(5), 279–291, https://doi.org/10.1007/s00190-003-0325-6.

Ihde, J., Augath, W., & Sacher, M., 2002. The Vertical Reference System for Europe, in *Vertical Reference Systems, International Association of Geodesy Symposia*, edited by H. Drewes, A. H. Dodson, L. P. S. Fortes, L. Sánchez, & P. Sandoval, vol. 124, pp. 345–350, Springer, Berlin, Heidelberg.

Kartverket, 2020. Innføring av NN2000 - Praktisk brukerhåndbok, Tech. Rep. 19-04811-5, Kartverket, Prepared by Bratheim, P.C. and Vestøl, O.

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), 375–387.

Lysaker, D., Pettersen, B., Mathisen, O., & Solheim, D., 2006. The Norwegian height system NN1954 revisited, *Nordic Journal of Surveying and Real Estate Research*, **3**(1), 7–19.

Mäkinen, J., Lidberg, M., Schmidt, K., Takalo, M., Lilje, M., Engsager, K., Eriksson, P.-O., Jepsen, C., Olsson, P.-A., Saaranen, V., Svensson, R., & Vestøl, O., 2003. Future height systems in the Nordic countries, their relation to the EVRS2000 and to INSPIRE GIS standars, in *Report on the Symposium of the IAG Subcommission for Europe (EUREF) held in Toledo, 4 - 7 June 2003*, edited by J. Torres & H. Hornik, vol. 13, EUREF.

Mäkinen, J., Lilje, M., Ågren, J., Engsager, K., Eriksson, P.-O., Jepsen, C., Olsson, P.-A., Saaranen, V., Schmidt, K., Svensson, R., Takalo, M., & Vestøl, O., 2005. Regional Adjustment of Precise Levellings around the Baltic, in *Report on the Symposium of the IAG Subcommission for Europe (EUREF) held in Vienna, Austria, 1 - 4 June 2005*, pp. 171–183.

Mathisen, O., 1977. Estimation and testing of variances and covariances., Guest lecture at Uppsala University.

Milne, G. A., Davis, J. L., Mitrovica, J. X., Scherneck, H.-G., Johansson, J. M., Vermeer, M., & Koivula, H., 2001. Space-Geodetic Constraints on Glacial Isostatic Adjustment in Fennoscandia, *Science*, **291**, 2381–2385.

Moritz, H., 1980. *Advanced physical geodesy*, Wichmann, Karlsruhe.

Moritz, H., 2000. Geodetic Reference System, *Journal of Geodesy*, **74**(1), 128–133.

Nørbech, T., Engsager, K., Jivall, L., Knudsen, P., Koivula, H., Lidberg, M., Madsen, B., Ollikainen, M., & Weber, M., 2008. Transformation from a Common Nordic Reference Frame to ETRS89 in Denmark, Finland, Norway, and Sweden – status report, in *Proceedings of the 15th General Meeting of the Nordic Geodetic Commission, Copenhagen, Denmark May 29 - June 2, 2006*, edited by P. Knudsen, pp. 68–75, DTU Space, Technical Report No. 1.

Ophaug, V., Breili, K., Gerlach, C., Gjevestad, J. G. O., Lysaker, D. I., Omang, O. C. D., & Pettersen, B. R., 2016. Absolute gravity observations in Norway (1993–2014) for glacial isostatic adjustment studies: The influence of gravitational loading effects on secular gravity trends, *Journal of Geodynamics*, **102**, 83–94, https://doi.org/10.1016/j.jog.2016.09.001.

Ouassou, M., Jensen, A. B. O., Gjevestad, J. G. O., & Kristiansen, O., 2015. Next generation network real-time kinematic interpolation segment to improve the user accuracy, *International Journal of Navigation and Observation*, **2015**, article ID 346498.

Pelzer, H., 1985. *Geodätishe Netze in Landes- und Ingenieurvermessungen II. Vorträge des Kontaktstudiums Februar 1985 in Hannover*, chap. 2.2.4.1, Wittwer.

Revhaug, I., 1989. *Feillære og utjevningslære*, Landbruksbokhandelen, ISBN 82-557-0310-1.

Revhaug, I., 2007. Grovfeilsøk ved multippel testing med Students t-test og Fisher F-test, *KART OG PLAN*, **67**(2), 101–107.

Revhaug, I., 2019. Om høyde og ny vertikal referanseramme NN2000, *KART OG PLAN*, **112**, 54–64, https://doi.org/10.18261/issn.2535-6003-2019-01-05.

Rülke, A., Liebsch, G., Sacher, M., Schäfer, U., Schirmer, U., & Ihde, J., 2012. Unification of European height system realizations, *Journal of Geodetic Science*, **2**(4), 343 – 354, https://doi.org/10.2478/v10156-011-0048-1.

Sacher, M., Liebsch, G., Ihde, J., & Mäkinen, J., 2009. EVRF2007 as Realization of the European Vertical Reference System, *AGU Spring Meeting Abstracts*, **68**.

Statens kartverk, 2009. Grunnlagsnett, Tech. rep., Statens kartverk, Available at https://kartverket.no/globalassets/standard/bransjestandarder-utover-sosi/grunnlag.pdf, last visited March 2020.

Statens kartverk, 2009. Norges offisielle HØYDESYSTEMER og REFERANSENIVÅER, versjon 2.1, Tech. rep., Statens kartverk, Available at https://www.kartverket.no/globalassets/standard/bransjestandarder-utover-sosi/hoydesystemer_referansenivaaer.pdf, last visited March 2020.

Tenzer, R., Vaníĉek, P., Santos, M., Featherstone, W., & Kuhn, M., 2005. The rigorous determination of orthometric heights, *Journal of Geodesy*, **79**, 82–92, doi 10.1007/s00190-005-0445-2.

Torge, W., 1989. *Gravimetry*, Walter de Gruyter GmbH & Co, ISBN 978-3-11-010702-9.

Torge, W., 2001. *Geodesy*, Walter de Gruyter GmbH & Co, 3rd edn., ISBN 3-11-017072-8.

Trovaag, O. & Jelstrup, G., 1956. Precise levelling in South Norway, Geodetic publications 5, Geographical Survey of Norway.

Vestøl, O., 2006. Determination of postglacial land uplift from levelling, tide gauge and GPS time series, *Journal of Geodesy*, **80**(5), 248–258.

Ågren, J., Strykowski, G., Bilker-Koivula, M., Omang, O., Märdla, S., Forsberg, R., Ellmann, A., Oja, T., Liepins, I., Parseliunas, E., Kaminskis, J., Sjöberg, L., & Valsson, G., 2016. The NKG2015 gravimetric geoid model for the Nordic-Baltic region, Paper presented at the 1st Joint Commission 2 and IGFS International Symposium on Gravity, Geoid and Height Systems, 19-23 Sep. 2016, Thessaloniki, Greece.

Appendix A

Transformation from IGS05N to EUREF89

The transformations from IGS05N to EUREF89 are similar to the transformations between ITRF and national realizations of ETRF, as outlined by Nørbech et al. (2008) and Häkli et al. (2016). This procedure includes two steps. First, coordinates in IGS05N at epoch 2009.58 are transformed to IGS05N at epoch 1995.0 by Equation (A.1). Then, Equation (A.3) provides the transformation to EUREF89.

Transformation from reference epoch 2009.58 to 1995.0

Intraplate deformations in Fennoscandia between 1995.0 and 2009.58 are corrected by applying the NKG_REF03vel velocity model. The horizontal part of this model originates from the glacial isostatic adjustment model by Milne et al. (2001) and the vertical part is based on NKG2005LU (Ågren & Svensson, 2007).

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\substack{\text{IGS05N} \\ 1995.0}} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\substack{\text{IGS05N} \\ 2009.58}} + (1995.0 - 2009.58) \cdot R \cdot \begin{bmatrix} \dot{n} \\ \dot{e} \\ \dot{u} \end{bmatrix}_{\text{NKG03}} \tag{A.1}$$

The rotation matrix R transforms the velocities from a topocentric coordinate system ($\dot{n}$, $\dot{e}$, $\dot{u}$) to a geocentric Cartesian coordinate system ($\dot{x}$, $\dot{y}$, $\dot{z}$). The rotation matrix is defined in, e.g., Torge (2001, Equation 2.28):

$$R = \begin{bmatrix} -\sin\varphi\cos\lambda & -\sin\lambda & \cos\varphi\cos\lambda \\ -\sin\varphi\sin\lambda & \cos\lambda & \cos\varphi\sin\lambda \\ \cos\varphi & 0 & \sin\varphi \end{bmatrix} \tag{A.2}$$

Transformation from IGS05N to EUREF89 at epoch 1995.0

The 7-parameter Helmert transformation includes the effects of rigid plate motion and differences in reference frame realizations.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{EUREF89}} = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + (1 + D) \cdot \begin{bmatrix} 1 & R_z & -R_y \\ -R_z & 1 & R_x \\ R_y & -R_x & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\substack{\text{IGS05N} \\ 1995.0}} \tag{A.3}$$

The transformation parameters below were calculated by the Norwegian Mapping Authority using 46 points with coordinates in both IGS05N and EUREF89 given at the reference epoch 1995.0 (see Table A.1).

$$\begin{aligned}
T_x &= -9.50 \cdot 10^{-2} \text{ m} \\
T_y &= 1.39 \cdot 10^{-2} \text{ m} \\
T_z &= -7.48 \cdot 10^{-2} \text{ m} \\
D &= 14.24 \cdot 10^{-9} \\
R_x &= -5.061461 \cdot 10^{-9} \text{ rad} \\
R_y &= -6.8772088 \cdot 10^{-8} \text{ rad} \\
R_z &= 7.5243374 \cdot 10^{-8} \text{ rad}
\end{aligned}$$

Table A.1: Coordinates of the 46 points used to calculate the transformation in Equation (A.3) between IGS05N and EUREF89 at the reference epoch 1995.0. The EUREF89 coordinates differ slightly from the official values at that time since they are corrected for land uplift to the reference epoch 1995.0 using the model by Danielsen (2001). The official coordinates at that time referred to either 1994, 1995 or 1996.

	IGS05N			**EUREF89**		
Point	*X*	*Y*	*Z*	*X*	*Y*	*Z*
AA03	3278077.8441	521844.1398	5428195.4668	3278078.2045	521843.8823	5428195.2420
AA04	3243165.3614	429952.9689	5457302.8749	3243165.7233	429952.7187	5457302.6656
AA05	3281097.3959	488819.1034	5429535.3086	3281097.7592	488818.8502	5429535.0969
AK05	3099618.3074	617374.9992	5521715.5940	3099618.6841	617374.7678	5521715.3852
BU01	3187312.2539	544755.3068	5479521.5761	3187312.6175	544755.0618	5479521.3555
BU03	3173492.7273	552661.1213	5486564.2360	3173493.0901	552660.8757	5486564.0195
BU04	3166703.4731	524374.7549	5493381.5346	3166703.8447	524374.5121	5493381.3274
BU05	3148909.1743	574088.8678	5498631.3924	3148909.5506	574088.6298	5498631.1872
BU07	3146682.2836	536793.5440	5503536.0791	3146682.6540	536793.3063	5503535.8683
BU09	3126628.8848	549195.3273	5513697.7571	3126629.2555	549195.0881	5513697.5482
BU11	3128277.3688	424193.4348	5524926.4100	3128277.7274	424193.1894	5524926.2007
FI01	2010883.3560	871741.0253	5969789.2207	2010883.7627	871740.8691	5969789.0925
FI02	1977931.8254	922156.9368	5973108.8674	1977932.2431	922156.7899	5973108.7590
HE01	2988028.9400	655957.2604	5578669.2278	2988029.3209	655957.0307	5578669.0256
HE02	3108470.6451	661270.7202	5511756.3640	3108471.0299	661270.4800	5511756.1535
HE03	3069510.5511	652308.8352	5534424.7630	3069510.9293	652308.6041	5534424.5540
HE04	3062695.0338	599495.7977	5544011.4761	3062695.4124	599495.5552	5544011.2612
HE05	3048371.6604	624628.5707	5549217.3292	3048372.0420	624628.3411	5549217.1302
HE06	2988391.3932	583379.2328	5586113.2903	2988391.7720	583378.9981	5586113.0907
HO01	3205325.4959	343742.4332	5485280.7047	3205325.8426	343742.1820	5485280.4958
HO04	3129230.4736	375091.3994	5526674.8220	3129230.8300	375091.1566	5526674.6203
HO06	3116481.9949	350935.5059	5535349.3723	3116482.3516	350935.2610	5535349.1617
MR01	2919455.1049	392482.4747	5638243.2184	2919455.4745	392482.2476	5638243.0322
MR08	2882133.8982	413951.1790	5655885.5640	2882134.2598	413950.9559	5655885.3691
NO02	2382528.2053	657261.9907	5860248.8590	2382528.5936	657261.8027	5860248.7081
NO03	2277560.9620	655910.5926	5901596.7103	2277561.3496	655910.4154	5901596.5638
NO13	2444605.8765	598587.6939	5840988.1610	2444606.2668	598587.5011	5840988.0028
NO16	2327352.2146	664908.6588	5881668.6825	2327352.6074	664908.4755	5881668.5323
NO17	2336650.8528	626667.9973	5881804.4095	2336651.2441	626667.8157	5881804.2613
NT04	2807246.1386	541526.3414	5682404.2590	2807246.5154	541526.1202	5682404.0807
NT06	2701426.6558	551988.5594	5732131.0853	2701427.0309	551988.3494	5732130.9109
OP01	3122014.4117	589817.8019	5512228.5918	3122014.7866	589817.5633	5512228.3823
OP02	3030855.1196	557051.0868	5565813.4042	3030855.4976	557050.8561	5565813.2109
OP03	3016020.9547	423676.1925	5586866.1129	3016021.3108	423675.9519	5586865.9057
OP04	2974674.6012	401250.6875	5609877.4675	2974674.9594	401250.4535	5609877.2590
OP05	2954720.6252	479776.1959	5614303.6532	2954720.9988	479775.9674	5614303.4664
OP06	2944196.9228	420762.2545	5623991.2180	2944197.2933	420762.0206	5623991.0262
OP08	3059018.5516	500520.6950	5556588.3775	3059018.9178	500520.4591	5556588.1667
OP09	3037059.6446	471822.2467	5571395.0041	3037060.0043	471822.0062	5571394.7948
OP11	2983891.0598	501190.7183	5596423.3999	2983891.4328	501190.4840	5596423.2095
OP12	2983498.8276	449804.5737	5601016.1306	2983499.1879	449804.3394	5601015.9272
ST06	2817277.3753	454318.6003	5685095.5226	2817277.7515	454318.3813	5685095.3501
ST08	2727005.9733	505994.0458	5724330.6461	2727006.3536	505993.8335	5724330.4655
TE02	3230138.2882	484265.1408	5460332.3212	3230138.6543	484264.8933	5460332.1085
TE04	3189685.4170	403407.9670	5491275.1352	3189685.7666	403407.7159	5491274.9161
TR02	2102021.9747	719850.9158	5958615.1455	2102022.3738	719850.7450	5958615.0063

Table A.2: Residuals (in meters) of the transformation from IGS05N to EUREF89 at epoch 1995.0. The residuals are given both in a Cartesian coordinate system (dX, dY, dZ) and transformed to a topocentric coordinate system (dN, dE, dU). The residuals are graphically illustrated in Figure A.1 and A.2.

Point	dX	dY	dZ	dN	dE	dU
AA03	0.004	0.005	0.004	-0.002	0.004	0.006
AA04	-0.003	-0.001	-0.009	-0.002	-0.001	-0.009
AA05	-0.001	-0.000	-0.009	-0.003	-0.000	-0.008
AK05	-0.001	-0.007	0.003	0.004	-0.007	0.001
BU01	0.005	-0.001	0.007	-0.000	-0.002	0.009
BU03	0.006	0.001	0.004	-0.003	-0.000	0.007
BU04	-0.004	-0.002	-0.005	0.002	-0.001	-0.006
BU05	-0.005	-0.005	-0.005	0.003	-0.004	-0.007
BU07	-0.002	-0.005	0.001	0.003	-0.005	-0.001
BU09	-0.001	-0.002	0.000	0.001	-0.002	-0.000
BU11	0.003	0.002	0.000	-0.003	0.002	0.002
FI01	0.003	0.001	0.004	-0.002	-0.000	0.005
FI02	-0.004	-0.005	-0.013	0.001	-0.003	-0.014
HE01	-0.000	-0.000	0.005	0.002	-0.000	0.004
HE02	-0.007	0.002	0.004	0.007	0.003	0.000
HE03	0.000	-0.005	0.005	0.003	-0.005	0.004
HE04	-0.004	0.006	0.011	0.008	0.007	0.009
HE05	-0.005	-0.005	-0.003	0.003	-0.004	-0.006
HE06	-0.003	0.004	0.002	0.003	0.004	0.000
HO01	0.007	0.001	-0.007	-0.009	0.000	-0.002
HO04	0.002	-0.001	-0.008	-0.005	-0.002	-0.006
HO06	-0.000	0.001	0.002	0.001	0.001	0.002
MR01	-0.006	-0.002	-0.007	0.002	-0.001	-0.009
MR08	0.005	-0.003	0.004	-0.002	-0.003	0.006
NO02	0.003	0.002	-0.001	-0.004	0.001	0.000
NO03	0.005	-0.001	0.002	-0.003	-0.002	0.004
NO13	-0.004	0.002	0.001	0.004	0.003	0.000
NO16	-0.000	0.002	0.002	0.001	0.002	0.002
NO17	-0.001	-0.001	-0.000	0.001	-0.001	-0.001
NT04	-0.000	0.003	-0.006	-0.003	0.003	-0.005
NT06	0.004	-0.001	-0.002	-0.004	-0.001	0.000
OP01	-0.002	-0.002	0.001	0.003	-0.002	0.000
OP02	-0.005	-0.004	-0.008	0.001	-0.003	-0.010
OP03	0.008	0.005	0.007	-0.004	0.004	0.010
OP04	0.005	0.001	0.011	0.000	0.001	0.012
OP05	-0.004	-0.002	-0.009	-0.000	-0.001	-0.010
OP06	-0.005	0.004	-0.003	0.002	0.004	-0.005
OP08	0.002	-0.001	0.007	0.002	-0.002	0.007
OP09	0.007	0.004	0.007	-0.003	0.003	0.010
OP11	-0.003	0.002	-0.007	-0.001	0.003	-0.008
OP12	0.006	0.002	0.005	-0.003	0.001	0.008
ST06	-0.006	-0.001	-0.013	-0.000	-0.000	-0.014
ST08	-0.005	-0.001	0.002	0.005	0.000	0.000
TE02	-0.003	-0.002	-0.004	0.001	-0.002	-0.005
TE04	0.009	0.003	0.005	-0.005	0.002	0.009
TR02	-0.000	0.007	0.008	0.001	0.006	0.008

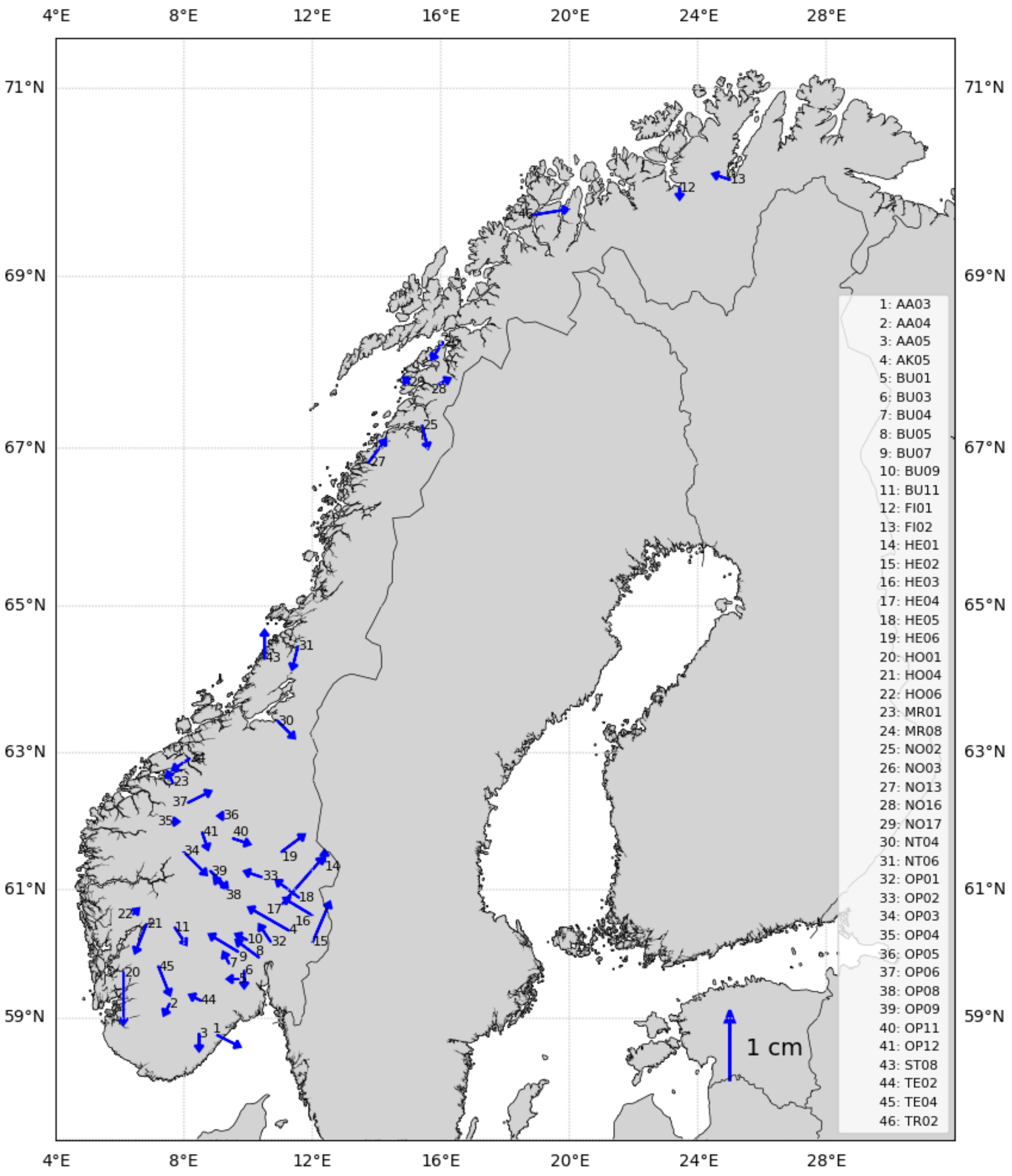


Figure A.1: Residual vectors ($\sqrt{dN^2 + dE^2}$) of the transformation from IGS05N to EUREF89 at epoch 1995.0.

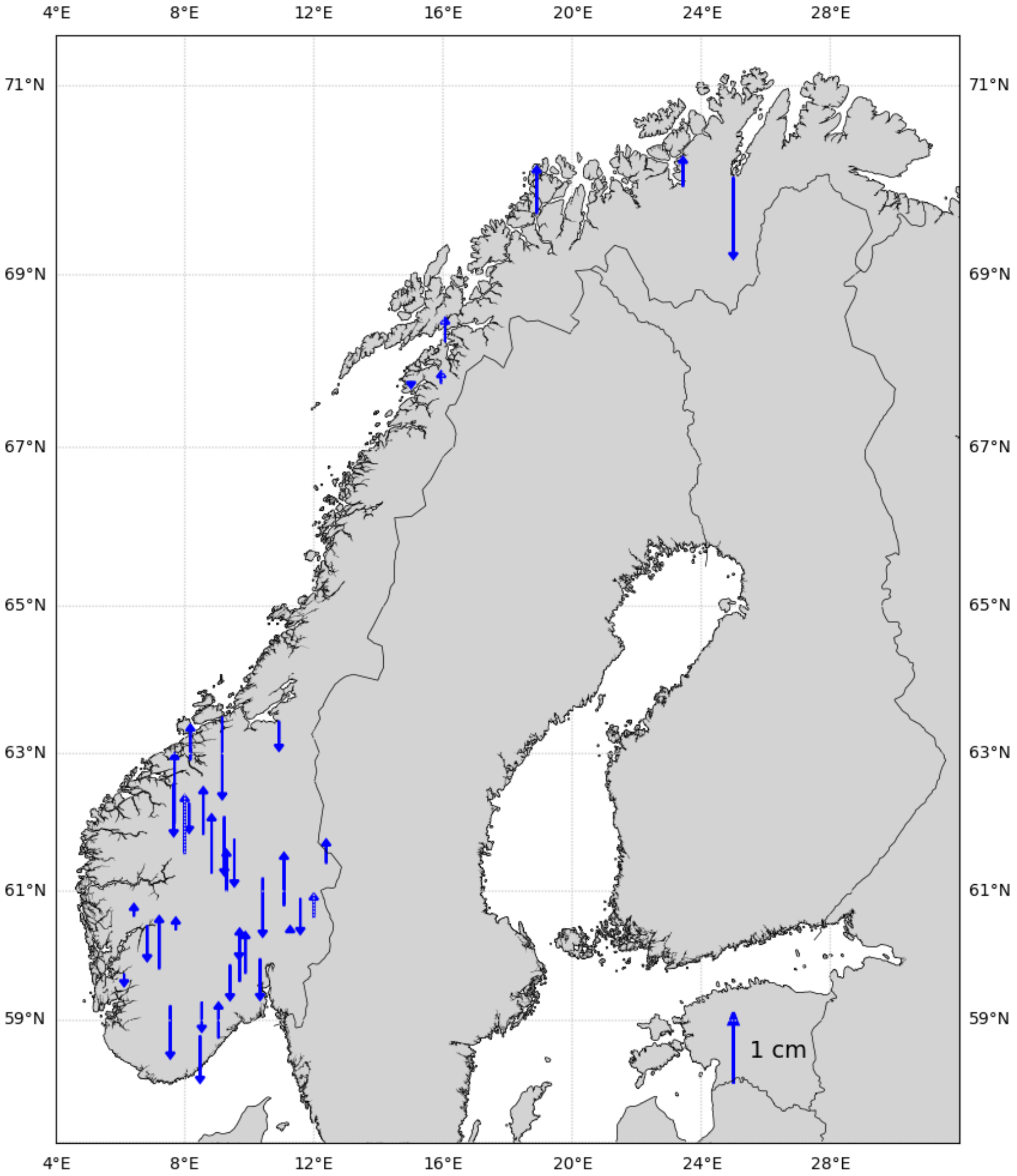


Figure A.2: Height residuals (dU) of the transformation from IGS05N to EUREF89 at epoch 1995.0. See Figure A.1 for site-identifiers.

Appendix B

Results from the 2008 adjustment

B.1 Geopotential numbers from the Baltic Leveling Ring adjustment

Table B.1: Nodal points with geopotential numbers from the Baltic Leveling Ring adjustment.

Point ID	**North [m]**	**East [m]**	**Geopotential [g.p.u.]**
61237	7857857.230	1182283.550	66.519
2241402	7162736.160	746847.193	305.200
H24N0020	7026812.460	653151.320	546.538
H27N0064	6949443.500	657286.524	818.968
H29N0035	6863891.570	667347.350	654.173
H35N0054	6644214.950	666963.340	130.710
H36N0031	6597562.300	655638.500	235.952
H36N0041	6588925.000	655809.600	150.140
H36N0058	6616243.800	661302.090	132.191
H37N0033	6558769.100	658858.200	143.847
H37N0080	6553334.370	630015.520	63.933
H38N0006	6535888.670	653642.050	142.720
I23N0006	7066548.440	663713.577	513.140
I24N0001	7062044.450	661220.622	426.958
I28N0003	6885336.010	669050.900	784.098
I30N0036	6830803.580	685466.034	568.950
I31N0024	6798606.940	705711.878	408.250
I31N0037	6773366.450	694120.235	303.070
I31N0073	6776970.910	698879.067	387.233
I31N0075	6787839.150	701750.209	404.652
I32N0007	6733052.350	688503.349	234.921
I32N0053	6764930.050	674549.412	435.797
I33N0033	6699806.880	697599.491	280.748

Table continues on next page

Point ID	**North [m]**	**East [m]**	**Geopotential [g.p.u.]**
I34N0013	6685077.110	694383.419	245.936
I34N0052	6656307.210	688143.081	145.784
I35N0006	6648518.260	680925.186	131.777
J20N0044	7203540.190	735791.953	514.052
J21N0101	7177153.900	724919.321	310.486
J22N0002	7116964.700	746105.529	347.728
K16N0022	7346226.810	752145.436	517.349
K17N0015	7295663.690	754086.281	588.971
K18N0017	7269491.490	754639.471	419.061
L14N0046	7420537.170	800350.405	594.731
M13N0002	7460468.170	820188.499	847.341
N09N0143	7619589.180	870550.571	506.600
R07N0054	7711513.640	965158.504	518.303
U08N0016	7685169.830	1076920.140	385.377
W06N0039	7794256.410	1151358.660	142.186
W06N0054	7789847.020	1155119.330	160.836
Y04N0042	7886712.180	1215640.490	32.392
Z05N0003	7858150.510	1268608.990	82.557

B.2 Geopotential numbers of nodes in the Norwegian leveling network

Table B.2: Geopotential numbers of nodes in the Norwegian leveling network.

Point ID	**Geopotential number [g.p.u]**	**Standard error [g.p.u]**
A29N0010	2.282	0.016
A30N0019	4.314	0.016
A31N0007	22.964	0.016
A31N0011	15.948	0.020
A33N0021	42.947	0.017
A33N0035	50.319	0.017
A33N0037	3.433	0.018
B27N0003	3.829	0.013
B27N0032	2.252	0.017
B27N0033	27.547	0.014
B28N0039	28.526	0.015
B28N0063	11.945	0.016
B28N0071	7.250	0.014
B28N0162	2.351	0.016
B29N0002	7.696	0.014
B29N0012	39.919	0.014
B29N0025	14.091	0.014
B30N0007	66.115	0.014
B30N0011	14.333	0.014
B30N0087	34.354	0.015
B30N0119	34.552	0.015
B31N0006	112.094	0.014
B31N0023	11.160	0.016
B32N0043	4.650	0.020
B33N0017	16.204	0.015
B33N0021	19.823	0.015
B33N0059	20.214	0.015
B33N0090	2.639	0.016
B33N0105	59.523	0.016
B33N0146	31.783	0.016
B33N0163	34.383	0.017
B33N0181	35.964	0.017
B34N0010	3.544	0.018
B34N0011	17.762	0.016

Table continues on next page

Point ID	**Geopotential number [g.p.u]**	**Standard error [g.p.u]**
B34N0015	118.067	0.016
B34N0089	10.213	0.016
B34N0106	196.296	0.017
B35N0076	3.401	0.015
B35N0109	26.965	0.016
B35N0122	35.752	0.016
B35N0124	44.145	0.016
B35N0136	14.097	0.017
B35N0170	1.003	0.017
B36N0015	25.491	0.015
B36N0020	55.815	0.015
B36N0029	34.986	0.015
B36N0032	4.394	0.015
B36N0061	22.631	0.014
B36N0123	9.690	0.014
B36N0146	3.760	0.015
B36N0154	52.613	0.015
B36N0168	6.026	0.014
B37N0029	1.763	0.018
B37N0091	62.560	0.018
B38N0010	2.555	0.017
B38N0020	43.070	0.017
B38N0029	125.705	0.016
B38N0037	8.517	0.017
B38N0041	6.694	0.017
B38N0045	45.919	0.017
B39N0005	85.633	0.016
B39N0009	8.396	0.016
B39N0065	35.595	0.016
B39N0076	1.818	0.016
C26N0004	18.536	0.012
C26N0008	36.698	0.012
C27N0068	49.705	0.013
C27N0079	21.023	0.012
C27N0089	70.820	0.014
C27N0130	25.764	0.013
C28N0013	271.767	0.014
C29N0007	91.361	0.013
C29N0013	6.847	0.013
C31N0029	6.545	0.012
C31N0069	2.078	0.011
C32N0007	840.952	0.012

Table continues on next page

Point ID	**Geopotential number [g.p.u]**	**Standard error [g.p.u]**
C32N0013	457.018	0.013
C32N0022	217.329	0.014
C32N0031	808.043	0.012
C32N0075	5.701	0.012
C32N0083	9.024	0.012
C33N0004	105.599	0.013
C33N0017	32.528	0.014
C33N0026	30.473	0.014
C33N0030	110.521	0.013
C33N0098	10.915	0.015
C35N0005	966.024	0.012
C35N0026	105.762	0.014
C35N0090	507.388	0.014
C36N0082	739.154	0.016
C38N0019	711.173	0.015
C38N0043	79.833	0.015
C39N0019	205.265	0.015
C39N0045	53.083	0.016
C39N0072	133.504	0.015
C39N0102	182.489	0.016
C40N0016	16.784	0.015
C40N0027	13.966	0.016
D25N0040	9.312	0.011
D26N0004	45.348	0.011
D26N0021	131.471	0.011
D26N0031	1.828	0.010
D26N0053	25.252	0.010
D26N0127	44.448	0.012
D27N0016	3.674	0.010
D28N0010	502.173	0.010
D31N0011	498.155	0.011
D31N0053	3.829	0.011
D31N0168	139.940	0.011
D33N0015	969.738	0.012
D33N0023	781.919	0.011
D33N0094	1276.188	0.012
D35N0010	563.067	0.012
D35N0013	544.814	0.012
D36N0036	552.294	0.011
D36N0113	405.226	0.012
D37N0006	252.136	0.013
D37N0014	340.359	0.013

Table continues on next page

Point ID	**Geopotential number [g.p.u]**	**Standard error [g.p.u]**
D39N0007	180.367	0.014
D40N0005	3.296	0.016
D40N0021	19.202	0.015
D40N0029	63.106	0.015
D40N0053	1.588	0.017
E23N0013	11.382	0.019
E23N0016	2.629	0.023
E24N0001	2.943	0.010
E24N0017	5.546	0.010
E24N0073	37.136	0.010
E25N0011	127.732	0.009
E26N0011	87.303	0.010
E26N0013	3.205	0.010
E28N0011	603.053	0.009
E28N0024	652.029	0.008
E29N0008	367.104	0.011
E29N0016	360.098	0.010
E31N0001	940.585	0.010
E31N0014	460.571	0.011
E31N0038	1071.378	0.011
E32N0031	266.282	0.010
E34N0014	1085.588	0.014
E34N0017	235.743	0.010
E35N0002	192.478	0.011
E35N0050	166.043	0.012
E35N0053	188.756	0.012
E36N0019	384.238	0.012
E37N0004	243.928	0.012
E37N0040	89.473	0.013
E38N0001	221.252	0.013
E38N0009	154.885	0.013
E38N0020	140.421	0.014
E38N0022	193.763	0.013
E39N0007	154.808	0.014
E39N0017	44.579	0.013
E39N0023	24.158	0.013
E39N0046	13.526	0.014
E40N0007	21.012	0.014
F24N0034	5.495	0.008
F24N0081	11.331	0.008
F25N0008	25.382	0.007
F25N0031	138.284	0.007

Table continues on next page

Point ID	**Geopotential number [g.p.u]**	**Standard error [g.p.u]**
F26N0027	401.755	0.007
F26N0053	421.481	0.006
F27N0015	527.954	0.008
F28N0006	903.795	0.009
F29N0019	286.141	0.008
F30N0015	194.042	0.007
F31N0038	465.059	0.010
F32N0001	365.535	0.009
F32N0008	505.141	0.009
F32N0025	148.485	0.010
F34N0026	102.740	0.008
F34N0038	222.537	0.009
F34N0074	101.478	0.009
F35N0001	152.716	0.008
F35N0010	180.344	0.009
F35N0015	187.548	0.009
F35N0024	56.569	0.009
F35N0032	23.916	0.008
F35N0039	6.548	0.008
F35N0043	14.022	0.007
F35N0071	400.814	0.009
F36N0011	151.151	0.010
F36N0034	113.196	0.010
F36N0063	92.362	0.009
F37N0010	27.560	0.010
F37N0019	44.550	0.010
F37N0044	3.301	0.010
F37N0054	33.025	0.010
F37N0083	43.445	0.009
F38N0003	2.816	0.010
F38N0014	39.719	0.012
G21N0003	3.860	0.011
G22N0004	22.954	0.008
G22N0047	3.769	0.010
G24N0008	29.094	0.006
G24N0019	4.952	0.005
G24N0056	92.882	0.006
G25N0003	67.148	0.006
G26N0001	380.309	0.007
G26N0108	264.354	0.007
G28N0018	496.640	0.006
G28N0038	499.610	0.006

Table continues on next page

Point ID	**Geopotential number [g.p.u]**	**Standard error [g.p.u]**
G29N0021	328.019	0.006
G30N0021	427.462	0.006
G31N0009	183.005	0.008
G32N0035	205.253	0.008
G32N0052	132.955	0.007
G33N0010	395.087	0.008
G34N0009	152.655	0.008
G34N0019	304.501	0.008
G34N0057	199.466	0.009
G34N0102	86.108	0.008
G35N0013	106.757	0.006
G35N0027	79.844	0.007
G35N0041	37.100	0.006
G35N0048	127.576	0.005
G35N0068	54.839	0.009
G35N0101	37.727	0.006
G35N0113	82.683	0.006
G35N0262	36.941	0.008
G35N0281	131.708	0.008
G35N0340	10.766	0.006
G35N0364	30.409	0.007
G36N0006	12.532	0.008
G36N0018	41.896	0.009
G36N0023	69.725	0.006
G36N0031	7.106	0.006
G36N0049	137.068	0.005
G36N0129	3.627	0.008
G36N0216	53.247	0.006
G37N0036	46.487	0.004
G37N0083	14.440	0.005
G37N0113	6.744	0.008
H19N0005	10.629	0.012
H20N0009	49.029	0.012
H20N0054	3.614	0.015
H21N0070	21.434	0.008
H22N0005	30.460	0.007
H22N0007	41.093	0.008
H22N0040	43.359	0.008
H23N0014	54.658	0.007
H23N0024	14.428	0.006
H24N0011	214.259	0.003
H25N0016	528.497	0.006

Table continues on next page

Point ID	**Geopotential number [g.p.u]**	**Standard error [g.p.u]**
H26N0021	703.671	0.004
H26N0052	651.956	0.008
H26N0153	447.480	0.007
H27N0011	640.491	0.004
H27N0059	748.490	0.002
H27N0112	603.361	0.005
H29N0011	582.572	0.005
H29N0030	745.370	0.003
H29N0032	659.984	0.003
H29N0048	657.738	0.003
H29N0060	659.264	0.004
H29N0104	630.135	0.004
H30N0012	394.198	0.005
H31N0021	216.675	0.006
H31N0045	507.364	0.004
H32N0012	193.190	0.005
H33N0013	127.209	0.008
H33N0022	153.760	0.005
H34N0002	126.622	0.009
H34N0004	115.985	0.006
H34N0028	145.817	0.005
H34N0031	151.130	0.005
H34N0042	144.024	0.004
H35N0017	166.715	0.003
H35N0025	158.308	0.003
H35N0042	137.637	0.002
H35N0046	130.064	0.002
H35N0051	146.563	0.002
H36N0003	105.505	0.004
H36N0027	131.133	0.002
H36N0034	132.329	0.002
H37N0005	11.444	0.003
H37N0009	76.592	0.002
H37N0020	112.390	0.002
H37N0043	19.531	0.002
H38N0001	151.574	0.002
H38N0017	124.959	0.003
I11N0021	8.023	0.023
I16N0011	16.045	0.010
I17N0002	3.752	0.009
I18N0011	5.531	0.012
I19N0030	112.288	0.014

Table continues on next page

Point ID	**Geopotential number [g.p.u]**	**Standard error [g.p.u]**
I21N0014	22.719	0.008
I30N0018	447.455	0.004
I31N0005	353.414	0.003
I31N0009	351.203	0.004
I31N0020	480.889	0.002
I31N0036	305.705	0.001
I33N0003	410.163	0.003
I33N0021	244.337	0.003
I34N0006	170.920	0.003
J16N0020	1.781	0.009
J16N0037	4.181	0.006
J16N0087	11.365	0.008
J18N0007	130.001	0.007
J18N0052	219.853	0.005
J20N0001	219.641	0.007
J20N0014	420.181	0.005
J21N0056	405.897	0.003
J21N0095	524.079	0.003
J21N0114	428.524	0.002
K09N0003	16.440	0.017
K10N0009	4.426	0.018
K10N0054	5.427	0.018
K13N0017	37.923	0.008
K13N0022	35.189	0.009
K13N0047	22.756	0.009
K13N0110	31.478	0.008
K13N0122	15.577	0.009
K13N0127	10.842	0.009
K15N0023	262.044	0.007
L07N0033	1.820	0.020
L08N0004	4.905	0.016
L09N0037	6.723	0.014
L10N0009	114.858	0.010
L10N0037	3.298	0.010
L12N0047	41.303	0.009
L12N0098	23.644	0.009
L13N0017	90.211	0.006
L13N0110	5.803	0.007
L14N0025	156.387	0.004
M06N0023	10.413	0.015
M08N0012	7.484	0.010
M09N0014	35.017	0.009

Table continues on next page

Point ID	**Geopotential number [g.p.u]**	**Standard error [g.p.u]**
M09N0027	3.414	0.009
M10N0033	101.491	0.009
N07N0016	3.690	0.010
N07N0018	24.334	0.011
N09N0005	7.211	0.005
N09N0008	7.410	0.006
N09N0027	6.496	0.006
N09N0035	9.333	0.005
N09N0041	93.268	0.005
N09N0173	187.303	0.006
O06N0003	22.184	0.010
O06N0015	1.862	0.011
O07N0003	79.929	0.008
O07N0008	16.457	0.009
P07N0016	77.772	0.007
P07N0031	3.448	0.007
P07N0068	94.330	0.009
R05N0001	6.971	0.012
R06N0066	34.447	0.011
T04N0006	17.497	0.014
T04N0072	45.290	0.016
T07N0002	331.893	0.006
U03N0015	13.394	0.015
U03N0025	6.518	0.016
U05N0004	51.451	0.010
U06N0003	492.202	0.009
U06N0015	386.064	0.007
U07N0016	475.682	0.006
U07N0020	341.090	0.006
V03N0008	74.097	0.011
V04N0021	9.690	0.008
V05N0006	69.568	0.007
W02N0001	4.957	0.016
W03N0010	15.679	0.010
W04N0017	12.455	0.011
W06N0011	127.802	0.003
X03N0009	40.715	0.012
X05N0020	111.560	0.006
Y03N0021	40.842	0.010
Y04N0022	47.785	0.007
Z04N0001	96.913	0.004
Z04N0007	15.037	0.005

Table continues on next page

Point ID	**Geopotential number [g.p.u]**	**Standard error [g.p.u]**
Æ05N0079	18.942	0.009
Æ05N0080	72.056	0.003
Ø03N0004	6.985	0.012
Ø03N0007	14.050	0.012

B.3 Geopotential differences for Norwegian leveling lines

Table B.3: Geopotential differences for lines in the Norwegian leveling network.

Line number	From	To	Geopotential difference [g.p.u.]	Residual [g.p.u.]	Relative std. error [g.p.u.]	Distance [m]
1-1927	G35N0041	G35N0048	90.48881	-0.01235	0.00564	17710
1-1927	G35N0340	G35N0041	26.33428	0.00019	0.00418	9729
10-1952	G35N0113	G36N0129	-79.04974	-0.00576	0.01102	48190
10-1952	G36N0129	F35N0043	10.39761	-0.00318	0.00623	21600
10-1952	G35N0101	G35N0113	44.95797	-0.00277	0.00358	7130
10-1988	G35N0113	G36N0129	-79.04827	-0.00723	0.00921	44393
10-1988	G35N0101	G35N0113	44.95442	0.00078	0.00306	7448
10-1988	G35N0048	G35N0101	-89.84603	-0.00299	0.00343	9389
100-1928	F25N0008	F25N0031	112.90485	-0.00310	0.00752	31520
100-1928	G24N0056	F25N0008	-67.50041	-0.00021	0.00828	38160
100-1964	F25N0008	G24N0056	67.50857	-0.00795	0.00823	37740
100-1979	F25N0008	F25N0031	112.89972	0.00203	0.00618	30475
100-1990	F25N0008	G24N0056	67.50274	-0.00212	0.00691	38063
101-1928	F25N0008	E25N0011	102.35786	-0.00739	0.01020	57960
101-1928	E25N0011	E24N0001	-124.78424	-0.00461	0.00557	17250
101-1964	E24N0001	E24N0073	34.19297	-0.00061	0.00406	9170
101-1964	E25N0011	F25N0008	-102.34786	-0.00261	0.01042	60460
101-1964	E24N0073	E25N0011	90.59906	-0.00256	0.00502	14030
102-1926	G24N0008	G24N0019	-24.14665	0.00399	0.00691	26600
102-1930	G24N0019	H24N0011	209.32047	-0.01331	0.00950	50290
102-1930	H24N0011	H24N0020	332.28486	-0.00573	0.00620	21380
102-1964	H24N0011	H24N0020	332.28600	-0.00687	0.00620	21380
102-1964	G24N0008	G24N0019	-24.13924	-0.00342	0.00696	26950
102-1964	G24N0019	H24N0011	209.31160	-0.00444	0.00952	50510
103-1935	H25N0016	H26N0021	175.16369	0.01035	0.00917	46780
103-1974	H27N0059	H26N0021	-44.81875	-0.00071	0.00409	13310
103-1992	G24N0019	H25N0016	523.52272	0.02236	0.01059	89325
103-1992	H25N0016	H26N0021	175.17050	0.00354	0.00780	48527
103-1992	H26N0021	H27N0059	44.81646	0.00300	0.00465	17205
104-1926	H22N0005	H22N0007	10.63438	-0.00118	0.00320	5710
104-1926	H22N0007	I21N0014	-18.37899	0.00459	0.01139	72190
104-1926	H23N0014	H22N0005	-24.18300	-0.01459	0.00935	48680
104-1926	G24N0019	H23N0014	49.72548	-0.01960	0.01015	57320
104-1930	I21N0014	J20N0001	196.92501	-0.00244	0.01228	84000
104-1930	J18N0007	I17N0002	-126.25028	0.00135	0.00994	55080
104-1930	J20N0001	J18N0007	-89.62768	-0.01260	0.01088	65920
104-1990	H22N0005	H22N0007	10.63317	0.00003	0.00265	5610

Table continues on next page

Line number	From	To	Geopotential difference [g.p.u.]	Residual [g.p.u.]	Relative std. error [g.p.u.]	Distance [m]
106-1929	E31N0001	E31N0038	130.79694	-0.00419	0.00326	5930
106-2004	D31N0168	C31N0069	-137.85936	-0.00297	0.00344	9444
106-2004	D31N0053	D31N0168	136.11305	-0.00204	0.00521	21611
106-2004	E31N0038	D31N0053	-1067.54948	0.00133	0.00999	79604
106-2004	E31N0001	E31N0038	130.78964	0.00311	0.00276	6068
11-1933	G35N0101	G35N0068	17.11130	0.00024	0.00641	22910
11-1933	G35N0048	G35N0101	-89.85156	0.00254	0.00447	11150
11-1954	G35N0068	G35N0041	-17.74492	0.00594	0.03176	12280
12-1922	G35N0027	F35N0043	-65.82167	-0.00084	0.00671	25100
12-1922	G35N0340	G35N0027	69.08078	-0.00222	0.00742	30699
12-1976	G35N0364	G35N0027	49.43478	0.00018	0.00518	21351
12-1990	G35N0027	F35N0043	-65.82198	-0.00053	0.00602	28897
12-1995	G35N0340	G35N0364	19.64350	0.00010	0.00381	11563
13-1938	H34N0002	H33N0013	0.58391	0.00313	0.00524	15290
13-1938	G35N0013	G34N0057	92.69936	0.00908	0.00892	44350
13-1938	G34N0057	H34N0002	-72.84761	0.00351	0.00555	17140
13-1938	G35N0340	G35N0013	95.97899	0.01269	0.00787	34509
13-1966	G35N0340	G35N0013	95.99155	0.00013	0.00743	30719
15-1929	G35N0013	H34N0004	9.22644	0.00146	0.00614	20990
15-1929	H34N0004	H34N0028	29.83466	-0.00302	0.01071	63870
15-1966	G35N0013	H34N0004	9.22506	0.00284	0.00724	29220
15-1966	H34N0004	H34N0028	29.83563	-0.00399	0.01061	62700
16-1931	H35N0025	H36N0027	-27.17513	0.00041	0.00825	37930
16-1931	H35N0017	H35N0025	-8.40484	-0.00198	0.00603	20220
16-1931	H34N0004	H35N0017	50.71803	0.01171	0.00870	42170
16-1985	H35N0025	H35N0017	8.40928	-0.00246	0.00501	19980
16-1985	H36N0027	H35N0025	27.17849	-0.00377	0.00695	38540
17-1932	H35N0025	H36N0058	-26.12212	0.00508	0.00433	10445
17-1985	H35N0025	H36N0058	-26.11257	-0.00447	0.00379	11449
18-1932	H34N0042	H35N0046	-13.96239	0.00171	0.00520	15060
18-1932	H35N0046	H35N0042	7.57813	-0.00491	0.00452	11390
18-1932	H34N0028	H34N0042	-1.79184	-0.00049	0.00459	11710
18-1932	H35N0042	H35N0017	29.08457	-0.00668	0.00685	26140
18-1985	H35N0017	H35N0042	-29.07697	-0.00092	0.00540	23205
18-1985	H35N0042	H35N0046	-7.57081	-0.00241	0.00387	11950
19-1927	G35N0340	G34N0019	293.74638	-0.01078	0.01166	75719
19-1927	G34N0019	G34N0009	-151.84834	0.00263	0.00616	21130
19-1927	G34N0009	G34N0102	-66.54852	0.00127	0.00428	10220
19-1939	G35N0340	G34N0019	293.72446	0.01114	0.01121	70019
2-1931	G35N0048	G36N0023	-57.84422	-0.00738	0.00501	13960
2-1931	G36N0023	G36N0216	-16.47268	-0.00556	0.00435	10543
2-1931	G36N0216	G36N0031	-46.14195	0.00179	0.00423	9963
2-1931	G36N0031	G37N0083	7.32011	0.01368	0.00864	41602
2-1931	G37N0083	G37N0036	32.04162	0.00536	0.00683	25982
20-1936	G34N0019	G33N0010	90.58493	0.00076	0.00853	40560

Table continues on next page

Line number	From	To	Geopotential difference [g.p.u.]	Residual [g.p.u.]	Relative std. error [g.p.u.]	Distance [m]
20-1936	G33N0010	G32N0035	-189.82760	-0.00667	0.00606	20480
20-1939	G33N0010	G32N0035	-189.83972	0.00545	0.00608	20580
20-1939	G34N0019	G33N0010	90.59053	-0.00484	0.00829	38273
201-1957	L14N0025	L13N0017	-66.15134	-0.02536	0.01065	63184
201-1957	K15N0023	L14N0025	-105.64270	-0.01354	0.01034	59534
201-1957	L13N0017	K13N0017	-52.28225	-0.00589	0.00961	51450
201-1957	J16N0037	K15N0023	257.87190	-0.00907	0.01004	56150
201-1957	J16N0020	J16N0037	2.39673	0.00304	0.00764	32470
201-1957	K13N0017	K13N0022	-2.73266	-0.00134	0.00433	10450
201-1957	I17N0002	J16N0020	-1.97684	0.00581	0.01056	62150
201-1982	K13N0022	K13N0047	-12.43128	-0.00092	0.00359	10288
201-1998	K13N0047	K13N0017	15.16798	-0.00179	0.00501	20016
201-1998	K13N0017	L13N0017	52.28733	0.00081	0.00805	51641
201-1998	L13N0017	L13N0110	-84.40801	-0.00007	0.00557	24708
201-1998	L14N0025	K15N0023	105.65321	0.00303	0.00864	59563
201-1998	K15N0023	J16N0037	-257.86832	0.00549	0.00843	56588
201-1998	L13N0110	L14N0025	150.58346	0.00132	0.00707	39878
202-1961	L13N0017	M13N0002	757.13035	-0.00014	0.01041	60320
203-1998	J16N0037	K16N0022	513.16395	0.00414	0.00738	43416
204-1966	H21N0070	I21N0014	1.29005	-0.00538	0.00639	22730
204-1966	G22N0004	H21N0070	-1.49881	-0.02092	0.01210	81540
204-2002	H21N0070	G22N0004	1.52740	-0.00767	0.00910	65947
205-1963	G22N0004	G22N0047	-19.18325	-0.00181	0.00921	47190
205-1963	G22N0047	G21N0003	0.09162	0.00000	0.00388	8380
205-1981	F24N0081	G22N0047	-7.58601	0.02396	0.01580	136419
205-1981	F25N0008	F24N0081	-14.05382	0.00287	0.00676	36413
205-2002	G22N0004	G22N0047	-19.18055	-0.00451	0.00777	48078
206-1963	H22N0007	H22N0040	2.26786	-0.00235	0.00617	21230
206-1963	H22N0040	G22N0004	-20.40072	-0.00413	0.00534	15860
206-1990	H22N0007	H22N0040	2.26767	-0.00216	0.00506	20397
206-2002	G22N0004	H22N0040	20.40483	0.00002	0.00450	16128
207-1959	D27N0016	C27N0079	17.34809	0.00050	0.01282	91570
207-1959	C27N0079	C27N0068	28.67976	0.00237	0.00716	28570
207-1959	C27N0068	B27N0003	-45.88028	0.00437	0.00487	13220
207-2005	C27N0068	B27N0003	-45.87214	-0.00377	0.00452	16282
207-2005	C27N0079	C27N0068	28.68435	-0.00222	0.00613	29941
207-2005	D27N0016	C27N0079	17.33978	0.00881	0.01058	89231
208-1960	C27N0079	C27N0089	49.78938	0.00803	0.00922	10160
208-1960	C28N0013	C29N0007	-180.41975	0.01396	0.01216	82350
208-1960	C27N0089	C28N0013	200.94575	0.00114	0.00546	16630
209-1960	C27N0089	C28N0013	200.94397	0.00292	0.00722	29050
21-1935	H33N0013	G32N0035	78.02054	0.02342	0.01141	72470
21-1977	H33N0013	G32N0035	78.05259	-0.00863	0.00944	70977
210-1962	B30N0007	C31N0029	-59.56587	-0.00478	0.01349	86800
211-1962	C31N0029	C31N0069	-4.47476	0.00805	0.00829	38290

Table continues on next page

Line number	**From**	**To**	**Geopotential difference [g.p.u.]**	**Residual [g.p.u.]**	**Relative std. error [g.p.u.]**	**Distance [m]**
211-1962	C31N0069	E29N0008	365.02361	0.00256	0.01598	142200
211-2005	C31N0029	C31N0069	-4.46515	-0.00156	0.00698	38884
212-1964	E29N0016	F32N0001	5.42566	0.01176	0.01537	131520
213-1963	C31N0029	C32N0022	210.78701	-0.00269	0.02415	67550
214-1964	B33N0059	B34N0089	-9.99281	-0.00760	0.01021	58070
214-1964	B34N0089	B35N0076	-6.81090	-0.00113	0.02803	96290
215-1965	B35N0076	C35N0026	102.35923	0.00185	0.01083	65350
216-1964	B35N0076	B36N0061	19.23009	-0.00039	0.00476	12620
216-1964	B36N0020	B36N0015	-30.32229	-0.00129	0.00315	5510
216-1964	B36N0029	B36N0020	20.83179	-0.00291	0.00413	9510
216-1964	B36N0032	B36N0029	30.59410	-0.00197	0.00283	4470
216-1964	B36N0061	B36N0032	-18.23578	-0.00146	0.00751	31370
216-1990	B36N0020	B36N0029	-20.82740	-0.00148	0.00308	7563
217-1963	B36N0015	B37N0029	-23.72837	0.00000	0.00865	41140
218-1966	B36N0168	B36N0123	3.66217	0.00171	0.00787	34490
218-1966	B36N0061	B36N0168	-16.60551	0.00018	0.00462	11910
218-1966	B36N0123	B38N0029	116.03206	-0.01667	0.02864	160661
218-2003	B36N0168	B36N0123	3.66514	-0.00126	0.00651	33812
219-1967	H29N0048	H29N0032	2.24413	0.00173	0.00370	7610
219-1967	H29N0060	H29N0048	-1.53031	0.00410	0.00573	18280
219-1967	H27N0112	H29N0060	55.88319	0.01979	0.01221	82990
219-1989	H29N0048	H29N0032	2.24419	0.00167	0.00310	7680
219-1989	H29N0060	H29N0048	-1.52783	0.00162	0.00479	18270
219-1989	H27N0112	H29N0060	55.89897	0.00401	0.01016	82364
22-1935	G32N0035	G31N0009	-22.26383	0.01616	0.01031	59170
22-1977	G32N0035	G31N0009	-22.24035	-0.00732	0.00843	56634
220-1968	B29N0002	B29N0025	6.39713	-0.00123	0.00448	11190
220-1968	B29N0025	A29N0010	-11.80954	0.00000	0.00636	22550
220-1985	B29N0002	B29N0025	6.39459	0.00131	0.00373	11110
221-1968	D26N0004	D25N0040	-36.03578	0.00059	0.01235	54340
222-1968	J21N0056	2241402	-100.68928	-0.00722	0.00770	33002
222-1968	I21N0014	J21N0056	383.18964	-0.01195	0.01221	82960
222-1992	J21N0056	2241402	-100.68555	-0.01095	0.00627	31319
222-2002	J21N0056	2241402	-100.70683	0.01033	0.00641	32783
223-1976	D31N0011	D31N0053	-494.32637	0.00035	0.00750	44884
223-1976	D31N0168	C31N0069	-137.86474	0.00241	0.00370	10927
224-1976	L14N0025	L14N0046	438.34573	-0.00222	0.00548	23979
224-1998	L14N0025	L14N0046	438.33876	0.00475	0.00551	24163
225-1969	M10N0033	L10N0037	-98.19833	0.00551	0.00760	32170
225-1969	N09N0027	M10N0033	94.97596	0.01838	0.01000	54070
225-1974	L10N0037	L10N0009	111.54793	0.01231	0.01178	29640
225-1974	L10N0009	L12N0047	-73.57561	0.02066	0.01011	81490
225-1974	L12N0047	L13N0017	48.90554	0.00217	0.00959	65680
225-1999	L12N0047	L10N0009	73.54900	0.00595	0.01010	81280
225-1999	L10N0009	L10N0037	-111.55260	-0.00764	0.01179	30264

Table continues on next page

Line number	**From**	**To**	**Geopotential difference [g.p.u.]**	**Residual [g.p.u.]**	**Relative std. error [g.p.u.]**	**Distance [m]**
225-1999	L10N0037	M10N0033	98.19475	-0.00193	0.00633	31987
226-1981	F25N0008	F24N0034	-19.89569	0.00864	0.00773	47663
226-1981	F24N0034	E24N0017	0.04819	0.00343	0.00555	24596
226-1981	E24N0017	E23N0013	5.83598	0.00000	0.01465	51321
227-1983	H21N0070	H20N0009	27.58650	0.00797	0.00989	77993
227-1983	H20N0009	H20N0054	-45.41479	0.00000	0.00830	54958
228-1984	I16N0011	I17N0002	-12.29475	0.00219	0.00755	45459
228-1984	H19N0005	I18N0011	-5.11458	0.01618	0.01409	77606
228-1984	H20N0009	H19N0005	-38.40015	0.00098	0.00346	9567
229-1983	G36N0031	G36N0049	129.97215	-0.01049	0.00833	55278
23-1936	H33N0013	G32N0052	5.74376	0.00288	0.00962	51560
230-1983	F34N0074	F35N0071	299.33649	-0.00046	0.00498	19789
230-1983	F35N0071	F35N0010	-220.47124	0.00183	0.00455	16486
230-1983	F35N0024	F34N0074	44.90669	0.00171	0.00591	27806
231-1984	H38N0001	H37N0009	-74.98039	-0.00142	0.00529	22349
232-1984	H38N0001	H38N0017	-26.61814	0.00306	0.00327	8550
232-2000	H38N0001	H38N0017	-26.61365	-0.00143	0.00329	8642
233-1984	F37N0010	F37N0083	15.88132	0.00385	0.00637	32389
233-1984	F37N0083	F36N0063	48.92119	-0.00413	0.00518	21387
233-1984	F36N0063	F35N0001	60.34975	0.00385	0.00681	36950
234-1985	H35N0042	H35N0054	-6.92711	0.00014	0.00210	3515
235-1984	C27N0068	C27N0130	-23.94118	-0.00012	0.00308	7571
235-1984	C27N0130	B28N0039	2.76404	-0.00192	0.01232	20140
235-1984	B28N0039	B28N0071	-21.27732	0.00184	0.00941	70629
235-1984	B28N0071	B29N0012	32.66810	0.00060	0.00540	23216
236-1985	I34N0006	I34N0013	75.01800	-0.00244	0.00616	30230
237-1989	G37N0036	G37N0083	-32.05268	0.00570	0.00470	17599
237-1989	G37N0083	G36N0031	-7.35208	0.01829	0.00749	44675
238-1985	F37N0083	F37N0044	-40.15612	0.01150	0.00680	36828
239-1986	G37N0036	H37N0043	-26.94734	-0.00868	0.00535	22858
239-1986	H36N0003	G37N0036	-59.01313	-0.00450	0.00726	42055
24-1933	G32N0052	G31N0009	50.04682	0.00283	0.01081	65020
240-1985	B29N0025	B28N0063	-2.15129	0.00451	0.01162	71249
240-1985	B28N0063	B28N0039	16.57741	0.00380	0.01067	29051
241-1988	G35N0048	G36N0049	9.48320	0.00846	0.00708	39983
241-1988	G36N0049	H36N0003	-31.56419	0.00093	0.00403	12973
242-1984	H19N0005	I19N0030	101.65834	0.00000	0.00681	36965
243-1984	B36N0032	B36N0029	30.59046	0.00167	0.00276	6059
243-1984	B36N0029	B36N0146	-31.22561	-0.00017	0.00390	12149
243-1984	B36N0146	B36N0154	48.85252	0.00000	0.00326	8480
244-1985	B36N0123	C35N0090	497.69664	0.00158	0.00933	69364
245-1984	H38N0001	H38N0006	-8.86064	0.00698	0.00392	12243
245-2000	H38N0001	H38N0006	-8.84863	-0.00503	0.00393	12288
246-1985	B36N0123	C36N0082	729.46482	0.00000	0.00683	37137
247-1985	B30N0119	B29N0002	-26.86558	0.00924	0.01209	80908

Table continues on next page

Line number	From	To	Geopotential difference [g.p.u.]	Residual [g.p.u.]	Relative std. error [g.p.u.]	Distance [m]
247-1985	B30N0011	B30N0087	20.01837	0.00306	0.00696	38652
247-1985	B30N0087	B30N0119	0.19393	0.00345	0.00739	43559
248-1985	B28N0071	B28N0162	-4.89957	0.00000	0.00532	22569
249-1985	B30N0119	A30N0019	-30.23806	0.00000	0.00458	16690
25-1929	G32N0052	H32N0012	60.23312	0.00132	0.00798	35455
25-1976	G32N0052	H32N0012	60.23505	-0.00061	0.00664	35096
250-1987	B31N0023	A31N0007	11.80397	-0.00038	0.00608	29454
250-1987	B33N0181	B33N0163	-1.58025	0.00000	0.00437	15234
250-1987	B33N0163	A31N0011	-18.44871	0.01358	0.01414	69003
251-1985	C27N0130	B27N0033	1.78328	0.00000	0.00402	12895
252-1987	B28N0063	B27N0032	-9.69237	0.00000	0.00503	20184
253-1986	I31N0036	I31N0073	81.53022	-0.00269	0.00290	6723
254-1986	I31N0075	I31N0020	76.23840	-0.00112	0.00339	9146
255-1986	I32N0007	I32N0053	200.87692	-0.00092	0.00754	45365
256-1986	B33N0146	B33N0181	4.18474	-0.00425	0.01008	26358
256-1986	B33N0181	B33N0105	23.56027	-0.00079	0.00435	3383
256-1986	B33N0090	B33N0146	29.14396	0.00056	0.00355	10067
257-1986	B33N0146	A33N0021	11.16262	0.00098	0.00337	6322
257-1994	A33N0021	A33N0035	7.37164	0.00090	0.00322	8260
257-1994	B35N0122	B36N0015	-10.26248	0.00223	0.01218	53840
257-1994	B35N0109	B35N0122	8.78583	0.00024	0.00400	12730
257-1994	A33N0035	B35N0109	-23.38350	0.02977	0.01855	81390
258-1988	F36N0063	G36N0006	-79.82179	-0.00844	0.00597	28366
259-1988	G36N0006	G36N0129	-8.90682	0.00180	0.00595	28204
26-1929	H33N0022	H32N0012	39.43900	-0.00956	0.00898	44900
26-1929	H34N0031	H33N0022	2.63613	-0.00562	0.00873	42410
26-1929	H34N0028	H34N0031	5.31055	0.00242	0.00371	7680
26-1966	H33N0022	H32N0012	39.44401	-0.01457	0.00898	44880
26-1966	H34N0031	H33N0022	2.62529	0.00522	0.00876	42690
26-1966	H34N0028	H34N0031	5.31592	-0.00295	0.00371	7680
260-1989	I30N0018	I30N0036	121.48974	0.00565	0.00493	19410
260-1989	I31N0024	I30N0018	39.19827	0.00634	0.00579	26709
261-1989	H29N0048	I28N0003	126.36495	-0.00476	0.00672	36026
262-1989	G35N0048	G35N0041	-90.47026	-0.00620	0.00542	23404
262-1989	G35N0041	G35N0340	-26.33692	0.00245	0.00355	10026
263-1984	H37N0080	H37N0043	-44.40219	0.00022	0.00178	2530
263-1984	H37N0043	H37N0009	57.06374	-0.00311	0.00364	10550
264-1989	H27N0112	H27N0011	37.12916	0.00038	0.00419	14020
265-1992	H26N0153	H26N0052	204.47676	0.00000	0.00444	15739
265-1992	G26N0108	H26N0153	183.12995	-0.00428	0.00507	20520
266-1990	F35N0032	F35N0039	-17.36709	-0.00179	0.00438	15280
266-1990	F35N0039	F35N0043	7.47724	-0.00317	0.00443	15616
266-1990	F35N0001	F35N0032	-128.78400	-0.01559	0.00493	19370
267-1990	H25N0016	H24N0011	-314.23926	0.00134	0.00858	58696
267-1990	H24N0011	H24N0020	332.27162	0.00751	0.00527	22116

Table continues on next page

Line number	From	To	Geopotential difference [g.p.u.]	Residual [g.p.u.]	Relative std. error [g.p.u.]	Distance [m]
268-1990	B39N0009	B39N0005	77.23322	0.00328	0.00358	10210
268-1990	B39N0005	C39N0102	96.85499	0.00115	0.00506	20400
268-1995	C39N0102	C38N0043	-102.65738	0.00152	0.00583	27109
269-1991	G35N0262	F35N0043	-22.92326	0.00420	0.00409	13367
269-1991	G35N0281	G35N0262	-94.77146	0.00442	0.00551	24176
27-1929	H34N0031	I33N0021	93.20934	-0.00189	0.00760	32190
27-1934	I33N0021	I33N0003	165.82885	-0.00323	0.00838	39110
27-1934	I33N0003	H33N0022	-256.38104	-0.02151	0.00856	40840
27-1986	I32N0007	I33N0003	175.24266	-0.00086	0.00256	5240
27-1986	I33N0003	I33N0021	-165.83082	0.00520	0.00670	35780
272-1991	I24N0001	I23N0006	86.18068	0.00132	0.00302	7266
274-1991	H23N0024	I24N0001	412.53429	-0.00460	0.00761	46113
274-1991	H23N0014	H23N0024	-40.22913	-0.00015	0.00257	5250
276-1991	E24N0017	E24N0001	-2.61518	0.01222	0.01047	11830
277-1991	E23N0013	E23N0016	-8.75384	0.00000	0.01088	25884
278-1991	I32N0053	H31N0045	71.56078	0.00606	0.00569	25846
279-1991	I31N0009	I30N0018	96.25040	0.00169	0.00623	30970
28-1929	I33N0021	I33N0033	36.40854	0.00228	0.00477	12678
28-1986	I33N0021	I33N0033	36.41097	-0.00015	0.00394	12382
280-1991	I34N0013	I33N0021	-1.59747	-0.00135	0.00595	28231
281-1991	G35N0262	G35N0281	94.76881	-0.00177	0.00410	13408
281-1996	G35N0281	G34N0102	-45.58637	-0.01313	0.00723	41719
282-1985	B39N0009	B39N0076	-6.57657	-0.00162	0.00198	3140
282-1990	B39N0009	B39N0076	-6.57984	0.00165	0.00200	3180
283-1991	G28N0038	H27N0112	103.74813	0.00285	0.00769	47136
285-1992	G24N0008	G24N0019	-24.14010	-0.00256	0.00568	25703
286-1992	G24N0019	H24N0011	209.29894	0.00822	0.00824	54189
287-1992	J22N0002	J21N0056	58.16458	0.00392	0.00810	52255
289-1989	G36N0031	G36N0216	46.13485	0.00531	0.00367	10752
29-1932	H35N0046	H35N0051	16.49604	0.00272	0.00379	8020
29-1932	I34N0006	H34N0042	-26.89876	0.00275	0.00564	17740
29-1932	I34N0052	I34N0006	25.13612	0.00032	0.00438	10690
29-1932	H35N0051	I34N0052	-0.77815	-0.00036	0.00517	14890
29-1985	I34N0052	I34N0006	25.13636	0.00008	0.00392	12261
29-1985	H35N0051	I34N0052	-0.77836	-0.00015	0.00418	13930
29-1985	H35N0046	H35N0051	16.49923	-0.00047	0.00322	8290
290-1992	B38N0037	B37N0091	54.04294	0.00000	0.00408	13247
291-1993	C32N0075	C32N0083	3.32187	0.00088	0.00305	7395
291-1995	D31N0053	C32N0075	1.86613	0.00555	0.00765	46645
292-1993	D26N0021	C26N0004	-112.93233	-0.00284	0.00645	33143
293-1993	C26N0004	D26N0127	25.91310	-0.00146	0.00463	17059
293-1993	D26N0127	D25N0040	-35.12864	-0.00686	0.01002	67600
294-1993	D26N0127	C26N0008	-7.74975	0.00000	0.00246	4841
295-1993	J21N0095	J21N0114	-95.55695	0.00172	0.00335	8944
295-1993	J21N0114	J21N0101	-118.03746	-0.00044	0.00214	3635

Table continues on next page

Line number	From	To	Geopotential difference [g.p.u.]	Residual [g.p.u.]	Relative std. error [g.p.u.]	Distance [m]
295-1993	J21N0056	J21N0095	118.18144	0.00119	0.00485	18764
295-2002	J21N0114	J21N0101	-118.03894	0.00104	0.00216	3733
295-2002	J21N0095	J21N0114	-95.55498	-0.00025	0.00323	8324
295-2002	J21N0056	J21N0095	118.18077	0.00186	0.00488	18986
296-1987	B39N0009	B39N0065	27.19883	0.00000	0.00337	9077
298-1993	B34N0015	B34N0106	78.22874	0.00000	0.00228	4160
299-1989	B36N0015	B36N0020	30.32458	-0.00100	0.00295	6116
3-1927	H36N0003	G37N0036	-59.01438	-0.00325	0.00841	39360
3-1927	G36N0049	H36N0003	-31.56387	0.00061	0.00419	9760
3-1927	G35N0048	G36N0049	9.48742	0.00424	0.00752	31470
30-1932	H35N0051	I35N0006	-14.78439	-0.00112	0.00279	4340
30-1985	H35N0051	I35N0006	-14.78762	0.00211	0.00261	5410
301-1956	N09N0027	N09N0035	2.83700	-0.00056	0.00505	5630
301-1956	N09N0035	N09N0005	-2.12198	0.00072	0.00286	4570
301-2000	N09N0035	N09N0005	-2.12059	-0.00067	0.00246	4809
303-1956	N09N0005	N09N0041	86.05806	-0.00107	0.00411	9390
303-1956	N09N0041	N09N0143	413.34316	-0.01160	0.00719	28781
303-1999	N09N0041	N09N0143	413.32868	0.00288	0.00570	25924
303-2000	N09N0005	N09N0041	86.05586	0.00113	0.00355	10055
304-1956	M09N0014	M09N0027	-31.60213	-0.00122	0.00599	19980
304-1956	N09N0008	M09N0014	27.61815	-0.01148	0.00931	48270
304-1956	M09N0027	M08N0012	4.08250	-0.01223	0.00815	29090
304-1999	M09N0014	M09N0027	-31.60203	-0.00132	0.00475	18024
304-2000	M09N0027	M08N0012	4.06344	0.00683	0.00609	29543
305-1935	O06N0003	O06N0015	-20.33061	0.00860	0.00601	20110
305-1952	P07N0016	O06N0003	-55.58890	0.00108	0.01026	58680
305-2000	P07N0016	O06N0003	-55.58704	-0.00078	0.00870	60280
305-2000	O06N0003	O06N0015	-20.31517	-0.00684	0.00536	22908
306-1956	P07N0031	R07N0054	514.86951	-0.01463	0.01021	58010
306-2000	P07N0031	R07N0054	514.83912	0.01576	0.00936	69809
307-1969	T07N0002	U08N0016	53.46639	0.01810	0.00971	52560
307-1975	U07N0016	U07N0020	-134.59153	0.00007	0.00364	10560
307-1975	U07N0020	T07N0002	-9.19747	-0.00006	0.00377	11340
307-1975	U06N0003	U06N0015	-106.13483	-0.00271	0.00601	28790
307-1975	U05N0004	U06N0003	440.75530	-0.00449	0.00774	47730
307-1975	U06N0015	U07N0016	89.61866	-0.00149	0.00482	18540
307-1992	U06N0015	U07N0016	89.61744	-0.00027	0.00498	19785
307-2001	U07N0020	U07N0016	134.59039	0.00107	0.00365	10642
307-2001	T07N0002	U07N0020	9.19761	-0.00008	0.00368	10788
307-2001	U08N0016	T07N0002	-53.49704	0.01255	0.00812	52616
308-1953	V03N0008	U03N0015	-60.70350	0.00000	0.00920	47110
308-1969	U03N0015	U03N0025	-6.87630	0.00000	0.00460	11802
309-1955	W06N0011	W06N0054	33.03719	-0.00281	0.00528	15510
309-1955	V05N0006	W06N0011	58.21665	0.01658	0.01025	58510
309-1955	V04N0021	V05N0006	59.86900	0.00896	0.00608	20560

Table continues on next page

Line number	From	To	Geopotential difference [g.p.u.]	Residual [g.p.u.]	Relative std. error [g.p.u.]	Distance [m]
309-2002	W06N0011	W06N0054	33.03311	0.00127	0.00465	17263
309-2006	V04N0021	V05N0006	59.88482	-0.00686	0.00521	21630
309-2006	V05N0006	W06N0011	58.24565	-0.01242	0.00859	58783
31-1917	F35N0032	F35N0001	128.82404	-0.02445	0.00644	23120
31-1927	F35N0039	F35N0043	7.47270	0.00137	0.00448	11160
310-1962	Y04N0022	61237	18.73301	0.00147	0.00812	36707
310-1962	Z04N0001	Y04N0022	-49.13010	0.00174	0.00882	43340
310-1983	W06N0039	W06N0011	-14.38525	0.00087	0.00436	15174
310-1983	61237	X05N0020	45.03959	0.00158	0.00590	27752
310-1983	X05N0020	W06N0039	30.62173	0.00410	0.00950	71950
311-1932	N09N0005	N09N0008	0.19984	-0.00110	0.00354	6990
311-2000	N09N0005	N09N0008	0.19840	0.00034	0.00295	6949
312-1932	O07N0003	O07N0008	-63.46828	-0.00374	0.00441	10840
312-1932	N09N0008	N09N0173	179.89149	0.00164	0.00556	17242
312-1932	O07N0008	P07N0016	61.33608	-0.02120	0.01141	72500
312-1932	N09N0173	O07N0003	-107.37697	0.00251	0.01248	86732
312-2000	N09N0173	O07N0003	-107.37233	-0.00213	0.00938	70131
312-2000	N09N0008	N09N0173	179.89235	0.00078	0.00501	19970
313-1952	P07N0016	P07N0031	-74.32481	0.00121	0.00614	20990
313-2000	P07N0016	P07N0031	-74.32250	-0.00110	0.00523	21794
314-1952	P07N0031	R05N0001	3.48642	0.03683	0.03772	70310
315-1952	T04N0006	U05N0004	33.96045	-0.00640	0.01160	74960
315-1952	R05N0001	T04N0006	10.53779	-0.01215	0.01599	142420
316-1953	U05N0004	V03N0008	22.64176	0.00456	0.01289	92500
317-1953	W03N0010	V04N0021	-5.98178	-0.00673	0.01038	60010
317-1953	V03N0008	W03N0010	-58.41992	0.00148	0.00733	29960
317-2006	W03N0010	V04N0021	-5.99601	0.00750	0.00913	66499
318-1953	X03N0009	Y03N0021	0.12296	0.00452	0.01089	66050
318-1953	V04N0021	W04N0017	2.76173	0.00277	0.00853	40560
318-1953	W04N0017	X03N0009	28.25551	0.00442	0.01077	64630
318-1953	Y03N0021	Z04N0001	56.06732	0.00322	0.00919	47070
319-1954	Ø03N0004	Ø03N0007	7.06176	0.00364	0.00541	3270
319-1954	Z04N0007	Ø03N0004	-8.05151	-0.00106	0.01506	126260
319-1954	Z04N0001	Z04N0007	-81.87520	-0.00019	0.00470	12280
319-1983	Ø03N0004	Ø03N0007	7.06673	-0.00133	0.00327	8524
319-2001	Z04N0007	Ø03N0004	-8.05332	0.00075	0.01271	128691
319-2001	Z04N0001	Z04N0007	-81.87562	0.00023	0.00399	12705
32-1922	F35N0043	G36N0006	-1.49597	0.00655	0.00705	27710
32-1922	G36N0006	G36N0018	29.36925	-0.00529	0.00667	24790
32-1922	G36N0018	F37N0054	-8.86867	-0.00206	0.00883	43410
32-1922	F37N0054	F37N0044	-29.72076	-0.00392	0.00543	16420
32-1922	F37N0044	F37N0019	41.24862	0.00039	0.00825	37950
32-1941	F37N0044	F37N0019	41.24913	-0.00012	0.00777	33650
32-1941	F37N0054	F37N0044	-29.72137	-0.00331	0.00543	16400
32-1941	G36N0018	F37N0054	-8.85407	-0.01666	0.00873	42490

Table continues on next page

Line number	From	To	Geopotential difference [g.p.u.]	Residual [g.p.u.]	Relative std. error [g.p.u.]	Distance [m]
32-1941	F35N0043	G36N0006	-1.48596	-0.00346	0.00622	21550
32-1941	G36N0006	G36N0018	29.36955	-0.00559	0.00666	24680
320-1969	O07N0008	N07N0016	-12.76462	-0.00235	0.00895	44630
320-1969	N07N0016	N07N0018	20.64431	0.00000	0.00447	11110
320-1980	N07N0018	M06N0023	-13.92150	0.00000	0.00943	70918
321-1974	R06N0066	R05N0001	-27.47383	-0.00226	0.00555	24589
321-1974	P07N0031	R06N0066	31.00626	-0.00692	0.00971	75141
322-1976	L08N0004	L07N0033	-3.08456	0.00000	0.01134	102489
322-1976	L09N0037	L08N0004	-1.81834	0.00000	0.00640	32673
322-1976	M09N0027	L09N0037	3.30976	0.00000	0.00957	73081
323-1978	U07N0020	W06N0011	-213.26861	-0.01982	0.01212	117010
323-2002	U07N0020	W06N0011	-213.29720	0.00877	0.01226	119846
324-1979	Æ05N0080	Æ05N0079	-53.11477	0.00000	0.00787	49385
324-1979	Z04N0007	Æ05N0080	57.01838	0.00057	0.01031	84671
325-1979	Æ05N0080	Z05N0003	10.50032	0.00005	0.00312	7764
326-1979	T04N0006	T04N0072	27.79335	0.00000	0.00795	50409
327-1982	K10N0009	I11N0021	3.59733	0.00000	0.01317	131412
327-1982	K09N0003	K10N0009	-12.01377	0.00000	0.00628	31489
328-1982	N09N0041	N09N0027	-86.77631	0.00413	0.00505	20310
329-1968	K10N0054	K10N0009	-1.00124	0.00000	0.00371	7650
33-1927	F37N0044	F38N0003	-0.48505	-0.00014	0.00547	16650
33-1988	F37N0044	F38N0003	-0.48529	0.00010	0.00457	16649
330-1995	B35N0122	B35N0124	8.39341	0.00000	0.00185	2724
330-1995	B35N0124	B35N0136	-30.04742	0.00000	0.00228	4146
331-1995	B35N0124	B35N0170	-43.14231	0.00000	0.00330	8697
332-1995	A33N0035	A33N0037	-46.88662	0.00000	0.00542	23391
333-1996	J18N0007	J18N0052	89.85417	-0.00191	0.00703	39391
333-1996	J18N0052	K17N0015	369.11929	-0.00166	0.00662	34955
334-1996	J18N0052	K18N0017	199.20766	-0.00003	0.00693	38233
337-1996	J20N0014	J21N0101	-109.69616	0.00122	0.00670	35747
337-1996	J20N0001	J20N0014	200.53603	0.00353	0.00625	31125
338-1996	J20N0014	J20N0044	93.86860	0.00246	0.00625	31143
339-1997	F34N0074	F34N0038	121.05763	0.00199	0.00544	23627
34-1917	F35N0024	G34N0102	29.53933	-0.00048	0.00802	35790
34-1917	F35N0032	F35N0024	32.65107	0.00185	0.00668	24840
340-1997	G37N0083	G37N0113	-7.69609	0.00000	0.00568	25716
341-1997	H29N0104	H29N0060	29.12805	0.00053	0.00473	17800
342-1997	E34N0017	E35N0002	-43.27028	0.00475	0.00708	39970
343-1997	D37N0006	C38N0019	459.04500	-0.00761	0.00917	67066
344-1998	K13N0017	K13N0110	-6.44334	-0.00162	0.00460	16847
344-1998	K13N0122	K13N0127	-4.73566	0.00000	0.00203	3300
344-1998	K13N0110	K13N0122	-15.89892	-0.00155	0.00384	11771
344-2007	J16N0087	K13N0122	4.17919	0.03306	0.01775	251243
345-1998	F24N0081	F24N0034	-5.83537	-0.00072	0.00467	17404
346-1999	F35N0071	F35N0015	-213.26442	-0.00176	0.00406	13150

Table continues on next page

Line number	**From**	**To**	**Geopotential difference [g.p.u.]**	**Residual [g.p.u.]**	**Relative std. error [g.p.u.]**	**Distance [m]**
347-1999	M10N0033	M09N0014	-66.47960	0.00585	0.01208	35692
348-1999	E40N0007	D40N0021	-1.81613	0.00590	0.00809	52180
349-1999	L12N0098	L12N0047	17.67871	-0.01987	0.01286	18266
349-1999	L13N0017	L12N0098	-66.56073	-0.00582	0.00696	38606
35-1927	G34N0102	F32N0008	419.03662	-0.00412	0.01418	112020
350-2003	D36N0113	D36N0036	147.06962	-0.00139	0.00597	28396
350-2003	D37N0014	D36N0113	64.86948	-0.00250	0.00800	51057
351-2000	O07N0003	N07N0016	-76.24024	0.00125	0.00654	34069
352-2000	M09N0027	N09N0173	183.89798	-0.00816	0.00940	70378
353-2000	O07N0003	P07N0068	14.39079	0.01031	0.00816	53099
353-2000	P07N0068	P07N0016	-16.56486	0.00662	0.00654	34129
354-2001	Z04N0001	Y04N0042	-64.52107	0.00019	0.00430	14717
355-2006	W03N0010	W02N0001	-10.72197	0.00000	0.01176	110314
356-2002	I16N0011	J16N0087	-4.67729	-0.00247	0.00802	51264
356-2002	J16N0087	J16N0037	-7.17722	-0.00684	0.00691	38077
357-2002	H22N0005	H23N0024	-16.02823	-0.00347	0.00786	49221
358-2002	J18N0007	I18N0011	-124.45936	-0.01072	0.01147	104926
359-2003	F30N0015	F31N0038	271.01721	0.00017	0.00852	57896
359-2003	F31N0038	F32N0001	-99.52410	0.00027	0.01077	92492
36-1941	G33N0010	F32N0025	-246.59984	-0.00235	0.00953	50540
36-1941	F32N0025	F32N0008	356.65802	-0.00197	0.00872	42320
36-1941	F32N0008	F32N0001	-139.60405	-0.00117	0.00502	14050
360-2003	B36N0146	B36N0168	2.26596	-0.00040	0.00609	29532
361-2003	C32N0031	C32N0083	-799.01607	-0.00300	0.00563	25302
362-1954	H38N0001	H38N0017	-26.61258	-0.00250	0.00402	9022
362-1954	H38N0006	H38N0001	8.85548	-0.00182	0.00469	12260
363-2004	C31N0029	B31N0006	105.55968	-0.01069	0.01000	79693
363-2004	B31N0006	B31N0023	-100.93277	-0.00069	0.00821	53708
365-2005	K13N0110	L13N0110	-25.67763	0.00265	0.00964	74132
366-2006	D25N0040	E24N0073	27.83096	-0.00752	0.01080	92910
367-2006	B31N0006	A31N0007	-89.13073	0.00086	0.00915	66729
368-2007	L09N0037	K09N0003	9.71642	0.00000	0.00816	53075
369-2007	B32N0043	A31N0011	11.30283	-0.00445	0.00809	52185
369-2007	B33N0163	B32N0043	-29.72748	-0.00603	0.00942	70676
37-1937	F34N0038	E32N0031	43.76414	-0.01905	0.01370	104530
37-1937	G34N0102	F34N0026	16.63590	-0.00371	0.00450	11290
37-1937	F34N0026	F34N0038	119.80487	-0.00790	0.00684	26070
37-1986	G34N0102	F34N0026	16.63200	0.00019	0.00369	10877
370-2007	B35N0109	B34N0089	-16.75778	0.00574	0.00896	64039
38-1932	E32N0031	F32N0001	99.25455	-0.00152	0.00928	47910
38-1947	E32N0031	F32N0001	99.25032	0.00271	0.00928	47910
4-1927	H38N0001	H38N0006	-8.84629	-0.00737	0.00477	12650
4-1927	H37N0009	H38N0001	74.98699	-0.00518	0.00563	17670
4-1927	H37N0005	H37N0009	65.14717	0.00097	0.00409	9300
4-1927	G37N0036	H37N0005	-35.04466	0.00113	0.00625	21750

Table continues on next page

Line number	From	To	Geopotential difference [g.p.u.]	Residual [g.p.u.]	Relative std. error [g.p.u.]	Distance [m]
40-1916	E31N0014	F32N0001	-95.03374	-0.00219	0.01070	63710
40-1916	E31N0001	E31N0014	-480.01258	-0.00086	0.00669	24940
40-1916	D31N0011	E31N0001	442.42710	0.00229	0.00792	34950
40-1941	E31N0001	F32N0001	-575.03196	-0.01741	0.01228	83990
40-1941	D31N0011	E31N0001	442.43144	-0.00205	0.00693	26740
40-2003	F32N0001	E31N0001	575.06180	-0.01243	0.01040	86192
41-1949	E32N0031	D33N0023	515.64752	-0.01113	0.00982	53750
42-1927	F35N0010	F35N0015	7.19868	0.00456	0.00541	16320
42-1927	E34N0017	D33N0023	546.18355	-0.00811	0.01334	99180
42-1927	F35N0015	E34N0017	48.19844	-0.00264	0.00692	26690
42-1927	F35N0001	F35N0010	27.62596	0.00239	0.00595	19730
42-1999	F35N0015	E34N0017	48.19232	0.00348	0.00577	26533
43-1942	D33N0015	C33N0030	-859.20610	-0.01113	0.01215	82160
43-1951	D33N0023	D33N0015	187.82642	-0.00678	0.00649	23460
44-1927	C32N0007	C32N0013	-383.93418	0.00037	0.00629	22020
44-1950	D33N0015	D33N0094	306.45525	-0.00531	0.00788	34560
44-1950	D33N0094	C32N0031	-468.14096	-0.00451	0.00726	29370
44-1950	C32N0031	C32N0007	32.90866	0.00012	0.00356	7050
44-1951	C32N0013	C33N0004	-351.41971	0.00038	0.00640	22810
45-1925	C33N0017	C33N0004	73.06953	0.00060	0.00604	20320
45-1925	C33N0026	C33N0017	2.05489	0.00034	0.00619	21370
45-1925	C33N0030	C33N0026	-80.06417	0.01614	0.03030	15190
45-1989	C33N0030	C33N0098	-99.60449	-0.00134	0.01249	4687
45-1995	C33N0026	C33N0098	-19.55791	0.00011	0.00356	10110
46-1950	C33N0017	B33N0059	-12.31338	-0.00124	0.01280	91200
46-1950	B33N0059	B33N0017	-4.01190	0.00215	0.00574	18338
46-1950	B33N0017	B33N0021	3.61695	0.00204	0.00542	16358
46-1986	B33N0021	B33N0017	-3.61870	-0.00029	0.00434	15009
47-1915	B33N0017	B33N0021	3.61895	0.00004	0.00502	14020
47-1915	C33N0004	B33N0017	-89.39717	0.00267	0.01122	70150
48-1927	C33N0004	C32N0022	111.73039	0.00017	0.00614	20970
49-1950	B34N0011	B33N0090	-15.12368	0.00014	0.00388	8370
49-1950	B33N0021	B34N0011	-2.06131	0.00031	0.00575	18420
5-1932	H36N0003	H36N0027	25.62321	0.00523	0.00688	26330
5-1932	H36N0027	H36N0034	1.19182	0.00379	0.00397	8760
5-1932	H37N0020	H37N0009	-35.79897	0.00130	0.00487	13210
5-1932	H36N0034	H37N0020	-19.93844	-0.00097	0.00784	34260
5-1984	H36N0027	H36N0034	1.19448	0.00113	0.00327	8550
5-1984	H37N0020	H37N0009	-35.79782	0.00015	0.00400	12740
5-1984	H36N0034	H37N0020	-19.94741	0.00800	0.00755	45400
5-1988	H36N0003	H36N0027	25.62466	0.00378	0.00578	26591
50-1951	B33N0021	B33N0105	39.69651	0.00344	0.00667	24800
50-1951	B33N0105	B33N0090	-56.88594	0.00145	0.00640	22840
51-1951	B34N0011	B34N0015	100.30487	0.00000	0.00271	4090
51-1951	B34N0015	B34N0010	-114.52335	0.00000	0.00561	17546

Table continues on next page

Line number	From	To	Geopotential difference [g.p.u.]	Residual [g.p.u.]	Relative std. error [g.p.u.]	Distance [m]
52-1925	D35N0010	C35N0005	402.95279	0.00414	0.00794	35080
52-1925	C35N0005	C35N0026	-860.26841	0.00674	0.00991	54670
52-1925	C35N0026	C33N0030	4.74804	0.01074	0.01128	70900
52-1991	D35N0010	C35N0005	402.95758	-0.00065	0.00651	33810
52-1997	C35N0005	C35N0090	-458.63563	-0.00066	0.00601	28763
53-1923	D35N0013	D35N0010	18.24983	0.00328	0.00390	8460
53-1923	E37N0004	E36N0019	140.31004	-0.00001	0.00669	24915
53-1923	E36N0019	D36N0036	168.05381	0.00242	0.00845	39740
53-1923	D36N0036	D35N0013	-7.48516	0.00474	0.00817	37160
53-1991	D35N0013	D35N0010	18.25430	-0.00119	0.00327	8530
53-1998	D35N0013	D36N0036	7.48193	-0.00151	0.00668	35527
54-1945	D36N0036	E35N0002	-359.82263	0.00598	0.01289	92510
54-2001	D36N0036	E35N0002	-359.79927	-0.01738	0.01090	94761
55-1918	E35N0050	E35N0053	22.71289	0.00000	0.00341	6460
55-1918	F36N0011	E35N0050	14.89167	0.00091	0.00765	32560
55-1924	E35N0002	E34N0014	893.11041	0.00000	0.00827	38090
55-1924	E35N0050	E35N0002	26.43285	0.00152	0.00991	54660
56-1918	F37N0010	F37N0019	16.99210	-0.00253	0.00573	18300
56-1918	F35N0001	F36N0011	-1.56975	0.00465	0.00831	38470
56-1918	F36N0034	F37N0010	-85.63657	0.00095	0.00730	29640
56-1918	F36N0011	F36N0034	-37.95603	0.00092	0.00421	9880
57-1922	F36N0034	E36N0019	271.03876	0.00373	0.01047	61060
58-1919	F38N0014	E38N0022	154.04110	0.00279	0.00541	16270
58-1919	E38N0022	E39N0023	-169.61542	0.01054	0.01052	61680
58-1919	F37N0019	F38N0014	-4.82478	-0.00552	0.00867	41850
59-1936	E37N0040	E37N0004	154.46917	-0.01419	0.00917	46840
59-1936	F38N0014	E37N0040	49.76631	-0.01248	0.00860	41185
6-1932	H37N0005	H37N0080	52.48990	-0.00041	0.00378	7862
60-1920	E38N0020	E38N0009	14.46337	0.00120	0.00678	25610
60-1920	E38N0009	E38N0001	66.37157	-0.00438	0.00600	20050
60-1920	E38N0001	E37N0004	22.67599	-0.00013	0.00851	40350
60-1920	E39N0017	E38N0020	95.84058	0.00108	0.00644	23110
60-1920	E39N0023	E39N0017	20.41894	0.00160	0.00481	12890
60-1949	E38N0001	E38N0009	-66.35586	-0.01133	0.00625	21720
60-1949	E37N0004	E38N0001	-22.66300	-0.01286	0.00869	42050
61-1939	E39N0023	E39N0046	-10.63384	0.00098	0.00612	20860
61-1939	E39N0046	E40N0007	7.48528	0.00130	0.00622	21560
61-1939	E40N0007	D40N0021	-1.80423	-0.00600	0.00970	52380
61-1999	E39N0046	E40N0007	7.48678	-0.00020	0.00530	22378
62-1919	E39N0007	D39N0007	25.56786	-0.00924	0.00963	51650
62-1919	E39N0017	E39N0007	110.22733	0.00191	0.00667	24740
63-1949	E39N0007	E38N0009	0.06851	0.00847	0.00771	33140
64-1921	D40N0029	D39N0007	117.25761	0.00299	0.00922	47350
64-1921	D40N0021	D40N0029	43.90317	0.00114	0.00570	18110
65-1939	D39N0007	D37N0006	71.79660	-0.02776	0.01228	83980

Table continues on next page

Line number	**From**	**To**	**Geopotential difference [g.p.u.]**	**Residual [g.p.u.]**	**Relative std. error [g.p.u.]**	**Distance [m]**
65-1939	D37N0006	D37N0014	88.22697	-0.00334	0.00613	20900
65-1939	D37N0014	D35N0010	222.71561	-0.00771	0.01189	78760
65-2003	D37N0006	D37N0014	88.22376	-0.00013	0.00525	22009
66-1922	D40N0021	D40N0005	-15.90486	-0.00067	0.00866	41784
66-1922	D40N0005	C40N0016	13.48831	-0.00099	0.01055	61980
67-1953	D40N0005	D40N0053	-1.70810	0.00000	0.00488	13270
68-1944	C39N0019	C40N0016	-188.46665	-0.01418	0.00701	27390
68-1978	C40N0016	C39N0072	116.72619	-0.00565	0.00427	14531
68-1978	C39N0072	C39N0019	71.76757	-0.00729	0.00485	18739
69-1948	D39N0007	C39N0019	24.88003	0.01767	0.01215	82270
7-1932	H37N0020	H37N0033	31.45061	0.00686	0.00450	11300
7-1985	H37N0020	H37N0033	31.46134	-0.00387	0.00373	11094
70-1944	B38N0010	B38N0020	40.51722	-0.00213	0.00370	7630
70-1944	B38N0020	B38N0029	82.64273	-0.00752	0.00624	21670
70-1944	B38N0029	C38N0019	585.47320	-0.00515	0.00987	54200
70-1972	B38N0020	B38N0029	82.63089	0.00432	0.00519	21460
70-1972	B38N0010	B38N0020	40.51508	0.00001	0.00309	7600
70-1989	B38N0010	B38N0020	40.51389	0.00120	0.00312	7760
70-2003	C38N0019	C38N0043	-631.33314	-0.00696	0.00697	38745
70-2003	C38N0043	C39N0019	125.43674	-0.00516	0.00724	41744
71-1921	B39N0009	B38N0010	-5.83775	-0.00371	0.01067	63370
71-1921	B39N0005	B39N0009	-77.24062	0.00412	0.00429	10250
71-1921	C40N0027	C39N0045	39.11652	0.00027	0.00467	12170
71-1921	C39N0045	B39N0005	32.54906	0.00108	0.00935	48710
71-1921	C40N0016	C40N0027	-2.80881	-0.00915	0.00681	25830
71-1921	B38N0010	B38N0037	5.96866	-0.00616	0.00480	12850
71-1949	B38N0010	B38N0037	5.95655	0.00595	0.00472	12410
71-1978	C40N0027	C40N0016	2.82550	-0.00754	0.00600	28660
72-1949	B38N0010	B38N0041	4.14554	-0.00652	0.00446	11070
72-1989	B38N0010	B38N0041	4.13427	0.00475	0.00381	11562
73-1949	B38N0010	B38N0045	43.36412	0.00000	0.00438	10690
74-1933	G31N0009	F30N0015	11.03005	0.00698	0.00977	53110
74-1933	F30N0015	F29N0019	92.09370	0.00520	0.01017	57560
74-2005	F30N0015	F29N0019	92.09006	0.00884	0.00913	66454
75-1929	F29N0019	E29N0016	73.95427	0.00295	0.00874	42570
75-1929	E29N0016	E29N0008	7.00674	-0.00051	0.00673	25230
75-1929	E29N0008	C29N0013	-360.25659	-0.00026	0.01505	126210
76-1937	B30N0011	B31N0006	97.75365	0.00708	0.00814	36920
76-1937	B30N0007	B30N0011	-51.78503	0.00264	0.00394	8650
76-1937	C29N0013	B30N0007	59.23850	0.02954	0.01433	114290
77-1930	C29N0007	B29N0012	-51.43973	-0.00260	0.00717	28640
77-1930	C29N0013	C29N0007	84.51830	-0.00431	0.00545	16530
77-1930	B29N0012	B29N0002	-32.23458	0.01103	0.00674	25300
77-1985	B29N0012	B29N0002	-32.21503	-0.00852	0.00559	24930
78-1933	F29N0019	E28N0024	365.87994	0.00781	0.00910	46130

Table continues on next page

Line number	From	To	Geopotential difference [g.p.u.]	Residual [g.p.u.]	Relative std. error [g.p.u.]	Distance [m]
78-1933	E28N0024	F28N0006	251.76342	0.00297	0.00682	25915
78-2005	F29N0019	E28N0024	365.88609	0.00166	0.00843	56636
79-1925	E28N0011	D28N0010	-100.88380	0.00398	0.00835	38860
79-1925	D28N0010	D27N0016	-498.50460	0.00544	0.00912	46370
79-1925	E28N0024	E28N0011	-48.97306	-0.00223	0.00691	26580
79-2005	D28N0010	D27N0016	-498.49847	-0.00069	0.00777	48145
79-2005	E28N0024	E28N0011	-48.97835	0.00306	0.00552	24265
79-2005	E28N0011	D28N0010	-100.87965	-0.00017	0.00716	40883
8-1932	H36N0034	H36N0041	17.80935	0.00172	0.00310	5360
8-1985	H36N0034	H36N0041	17.81078	0.00029	0.00257	5274
80-1924	F27N0015	F26N0027	-126.19821	-0.00042	0.00691	26560
80-1924	F28N0006	F27N0015	-375.83953	-0.00131	0.00934	48560
80-1924	F26N0053	G25N0003	-354.33737	0.00481	0.00795	35230
80-1924	F26N0027	F26N0053	19.72052	0.00492	0.00611	20760
80-1980	F26N0053	F26N0027	-19.72646	0.00102	0.00394	12350
80-1991	G25N0003	F26N0053	354.33338	-0.00082	0.00661	34856
81-1935	H31N0021	G30N0021	210.79612	-0.00846	0.01035	59640
81-1935	H32N0012	H31N0021	23.48494	0.00008	0.00801	35730
81-1935	G30N0021	G29N0021	-99.44385	0.00012	0.00756	31820
81-1976	G30N0021	G29N0021	-99.44779	0.00406	0.00640	32658
81-1976	H31N0021	G30N0021	210.79233	-0.00467	0.00861	59117
81-1976	H32N0012	H31N0021	23.48667	-0.00165	0.00668	35619
81-2003	G30N0021	G29N0021	-99.43802	-0.00571	0.00639	32573
82-1934	H31N0045	I31N0005	-153.94828	-0.00155	0.00638	22680
82-1934	H32N0012	H31N0045	314.18269	-0.00853	0.00882	43320
82-1966	H31N0045	I31N0005	-153.94926	-0.00057	0.00637	22630
82-1966	H32N0012	H31N0045	314.18559	-0.01143	0.00881	43180
82-1991	H31N0045	I31N0005	-153.94934	-0.00049	0.00530	22430
83-1934	I31N0036	I31N0037	-2.63725	0.00178	0.00209	2430
83-1934	I31N0005	I31N0036	-47.70304	-0.00550	0.00712	28220
83-1986	I31N0037	I31N0036	2.63486	0.00061	0.00175	2428
84-1934	I31N0005	I31N0020	127.46770	0.00758	0.00697	27030
84-1934	I31N0020	I31N0024	-72.64096	0.00168	0.00395	8710
84-1978	I31N0005	I31N0020	127.47258	0.00270	0.00573	26160
84-1978	I31N0020	I31N0024	-72.63974	0.00046	0.00330	8678
84-1986	I31N0020	I31N0024	-72.63904	-0.00024	0.00328	8590
84-1991	I31N0005	I31N0020	127.47575	-0.00047	0.00567	25595
85-1967	I31N0005	I31N0009	-2.21043	-0.00106	0.00386	8290
85-1967	H30N0012	H29N0030	351.18318	-0.01152	0.00972	52640
85-1967	I31N0009	H30N0012	42.99601	-0.00045	0.00542	16390
85-1991	I31N0005	I31N0009	-2.21030	-0.00119	0.00324	8390
85-1997	I31N0009	H30N0012	42.99988	-0.00432	0.00450	16137
86-1935	H29N0032	H29N0035	-5.80728	-0.00339	0.00409	9330
86-1935	H29N0030	H29N0032	-85.38601	-0.00006	0.00351	6860
86-1967	H29N0030	H29N0032	-85.38306	-0.00301	0.00351	6860

Table continues on next page

Line number	From	To	Geopotential difference [g.p.u.]	Residual [g.p.u.]	Relative std. error [g.p.u.]	Distance [m]
86-1989	H29N0032	H29N0035	-5.81360	0.00293	0.00339	9180
87-1934	H31N0021	H30N0012	177.51036	0.01302	0.01106	68070
88-1935	H29N0011	H29N0030	162.79700	0.00050	0.00700	27310
88-1935	G30N0021	H29N0011	155.10525	0.00464	0.00924	47530
88-1997	H29N0104	H29N0030	115.23715	-0.00284	0.00455	16533
88-1997	H29N0011	H29N0104	47.56471	-0.00152	0.00366	10671
88-2003	G30N0021	H29N0011	155.11943	-0.00954	0.00778	48195
89-1933	F30N0015	G29N0021	133.98161	-0.00490	0.01193	79230
89-2003	F30N0015	G29N0021	133.98217	-0.00546	0.01035	85341
9-1932	H36N0027	H36N0031	104.81906	-0.00038	0.00312	5410
90-1918	G28N0018	G28N0038	2.96650	0.00325	0.00651	23632
90-1918	G28N0038	H27N0112	103.76453	-0.01355	0.00897	44772
90-1918	H27N0112	H27N0011	37.13298	-0.00344	0.00464	12000
90-1937	G28N0018	G29N0021	-168.62641	0.00473	0.00988	54360
90-1967	H27N0112	H27N0011	37.13657	-0.00703	0.00677	25519
90-1977	G29N0021	G28N0018	168.62688	-0.00520	0.00829	54781
90-1977	G28N0018	G28N0038	2.97412	-0.00437	0.00598	28554
91-1937	F28N0006	G28N0018	-407.16486	0.01020	0.01137	72030
92-1933	G28N0038	F26N0027	-97.84740	-0.00717	0.01194	79450
92-1980	G28N0038	F26N0027	-97.86681	0.01224	0.00989	77968
93-1930	G26N0001	G25N0003	-313.17296	0.01226	0.01077	64630
93-1930	H26N0153	G26N0001	-67.16838	-0.00211	0.00357	7110
93-1930	H27N0011	H26N0153	-193.01531	0.00430	0.00853	40540
93-1967	G26N0108	G25N0003	-197.19506	-0.01046	0.00983	53843
93-1967	G26N0001	G26N0108	-115.94977	-0.00541	0.00444	10974
93-1967	H26N0153	G26N0001	-67.16883	-0.00166	0.00336	6277
93-1967	H27N0011	H26N0153	-193.00639	-0.00462	0.00867	41909
93-1992	H26N0153	G26N0001	-67.17164	0.00115	0.00282	6318
94-1920	H27N0011	H27N0064	178.47816	-0.00074	0.00917	46780
94-1972	H27N0064	H27N0059	-70.48129	0.00358	0.00344	9450
94-1977	H27N0011	H27N0059	108.01176	-0.01205	0.00684	37307
94-1989	H27N0059	H27N0064	70.47541	0.00230	0.00337	9070
94-1989	H27N0011	H27N0059	108.00079	-0.00108	0.00688	37740
95-1924	G25N0003	G24N0008	-38.06281	0.00881	0.01003	56000
95-1964	G24N0056	G24N0008	-63.78504	-0.00301	0.00565	17750
95-1967	G25N0003	G24N0056	25.72480	0.00925	0.00840	39290
95-1990	G24N0056	G25N0003	-25.74017	0.00612	0.00696	38660
95-1990	G24N0008	G24N0056	63.78661	0.00144	0.00491	19193
96-1943	F27N0015	E26N0013	-524.74842	-0.00082	0.01153	74070
97-1949	D26N0031	D26N0053	23.42601	-0.00150	0.00993	54930
97-1949	E26N0013	D26N0031	-1.38311	0.00587	0.00881	43230
97-1949	D26N0053	D27N0016	-21.58061	0.00277	0.00863	41510
97-2005	D26N0053	D26N0031	-23.42150	-0.00301	0.00835	55530
97-2005	D27N0016	D26N0053	21.57735	0.00049	0.00724	41748
98-1928	F26N0053	F25N0031	-283.19644	-0.00094	0.00805	36107

Table continues on next page

Line number	**From**	**To**	**Geopotential difference [g.p.u.]**	**Residual [g.p.u.]**	**Relative std. error [g.p.u.]**	**Distance [m]**
98-1943	E26N0013	E26N0011	84.10106	-0.00278	0.00583	18930
98-1943	E26N0011	F25N0031	50.97491	0.00548	0.01344	97114
98-1979	F26N0053	F25N0031	-283.19671	-0.00067	0.00684	37338
99-1948	D26N0021	D26N0031	-129.64550	0.00177	0.00633	22350
99-1948	D26N0004	D26N0021	86.13631	-0.01247	0.01037	27710
99-1948	E26N0011	D26N0004	-41.95003	-0.00560	0.00707	27850
99-2005	D26N0031	D26N0021	129.63932	0.00441	0.00693	38286

Kartverket
www.kartverket.no

Postal and billing address:
P.O. Box 600 Sentrum, 3507 Hønefoss, Norway
Telephone: (+47) 32 11 80 00
Email: post@kartverket.no
VAT number: 971 040 238