NORDISKA KOMMISSIONEN FÖR GEODESI
HEIGHT DETERMINATION WORKING GROUP
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Working group for Height Determination

Minutes of the meeting at the Technical University of Helsinki, Espoo, Finland, March 18–19, 2002.

Participants:

Estonia
Harli Jürgenson — *Eesti Põllumajandusülikool*
Andres Rüdja — *Planserk A/S*
Ants Torim — *Maa-amet*

Finland
Jaakko Mäkinen — *Geodeettinen laitos*
Markku Poutanen — *Geodeettinen laitos*
Paavo Rouhiainen — *Geodeettinen laitos*
Veikko Saaranen — *Geodeettinen laitos*
Mikko Takalo — *Geodeettinen laitos*
Mauri Väisänen — *Geodeettinen laitos*
Martin Vermeer — *Helsingin teknillinen korkeakoulu*

Iceland
Markus Rennen — *Landmælingar Íslands*

Latvia
Jānis Kaminskis — *Valsts Zemes Dienests*

Norway
Olav Vestøl — *Statens Kartverk*

Sweden
Jean-Marie Becker — *Lantmäteriverket*
Per-Ola Eriksson — *Lantmäteriverket*
Mikael Lilje — *Lantmäteriverket*
Per-Anders Olsson — *Lantmäteriverket*
Runar Svensson — *Lantmäteriverket*

Chairman: *Jean-Marie Becker*
Secretaries: *Jaakko Mäkinen and Mikael Lilje*

Session on common questions

Opening of the meeting
The chairman opened the meeting at 9.20 a.m. and welcomed all participants. The absence of Danish participation was regretted and get-well wishes to Klaus Schmidt expressed. Martin Vermeer introduced the Technical University and in particular its Institute of Geodesy.

Approval of the agenda
The proposed agenda was accepted.

Minutes of the previous meeting
The minutes of the previous meeting in Akranes, June 19, 2001 were approved.

Minutes of the present meeting
The secretary was instructed to send the minutes of the present meeting to the NKG website.

National reports:

***Finland* (Veikko Saaranen)**
Altogether 411 km of double run levelling was performed in 2001. The following lines of the Third levelling were levelled: 71 (Sirkka–Inari, 190 km), 72 (Ivalo–Inari, 45 km), and no. 73 (Sodankylä–Inari, 165 km). This closed the loop XXI. The closing error was 19 mm for a circumference of 500 km.

Control levellings were performed for all mareographs.

Development of comparator for system calibration of digital levels has continued and the first results were promising.

Levelling data base is under construction.

***Norway* (Olav Vestøl)**
Norway performed altogether 386 km double run levelling in 2001, of which 87 km were done by a Swedish team from Metria. In 2002 the plan calls for 325 km plus 205 km by Metria. After this the work has almost caught up with its long-term schedule (only 50 km behind). A novelty is that the 2002 work will be open to bids by commercial contractors, according to government regulations. Finland is asked to level from Utsjoki to Nuorgam to close the loop across the border.

The digital level DiNi12 has been used. Some strange phenomena in the deltas of bench mark intervals have been observed.

A levelling database is under construction.

***Sweden* (Per-Ola Eriksson)**
The levelling of new lines was completed in 2001 but control levelling of entire loops continues. The total production in 2001 was 3224 km, of this 304 km were relevellings

due to rejected intervals, thus the net production was 2920 km. Two teams were out and the daily production per team was 12.7 km, an all-time record.

The tasks now are (1) cleaning of the database, (2) choice of and experiments with adjustment program(s), (3) investigation of systematic effects in the levelling, (4) relevelling, and updating of data, and (5) preliminary final adjustment. Control levellings will continue in 2002–2003. The aim is to obtain the new height system immediately after the completion of field work in 2003.

***Latvia* (Jānis Kaminskis)**
Levelling work started in 2000. In 2001 the first loop in the border area against Belarus was completed. Altogether 397 km of double-run levelling with DiNi12 instruments were performed. In 2002 a second loop and 300 km in western Latvia are planned. The plan for future includes totally 3000 km of levelling, after which new heights will replace the 1977 catalogue currently in use (Baltic system).

The permanent GPS stations Riga and Irbene are active, more are planned in the future.

***Estonia* (Ants Torim, Andres Rüdja)**
The foundation of the Estonian Vertical Network (EVN) are the 6 loops (1800 km) of high-precision levelling in mainland established by the Cadastre Department in 1933–1943. Later high precision levelling was performed by the Main Board of Geodesy and Cartography on the line Narva–Tallinn–Pärnu–Ikla (505 km in 1948 and 1970) and extensively by the Academy of Sciences: 2067 km in1951–1969 and 2208 km in 1970–1991. The last mentioned work includes two loops on the islands (Saaremaa and Hiiumaa).

The renovation of the EVN is connected with the reconstruction of the national high-precision geodetic (GPS) network, which started in 1996. The GPS net was designed considering the location of the levelling lines and of the gravimetric net, in view of an integrated network concept.

The re-levelling plan includes 8 loops and about 2380 km. It is planned to take place in 2002–2006.

In 2001 a test section of 30 km was levelled with the DiNi11 digital level. The estimated error was as low as 0.14 $\mathrm{mm}/\sqrt{\mathrm{km}}$, possibly due to the very favourable season (late autumn).

***Iceland* (Markus Rennen)**
In 2001 levelling efforts continued through the cooperation between the Public Road Administration (Vegagerðin), the National Power Company (Landsvirkjun) and the National Land Survey of Iceland (Landmælingar Íslands). About 222 km was levelled using digital instruments from Zeiss and Wild. This included 57 km of lines levelled in 1997–1998, which had to be relevelled due to the major earthquakes in 2000. For 2002 the plan is to send three teams to level 330 km in Northern Iceland, which would close the big loop around the island.

The third permanent GPS station, Akureyri, started in August 2001. The two earlier ones are Reykjavík and Höfn.

Tests of the Digital Level Zeiss DiNi12 (Mikko Takalo)
Both normal field work and test field measurements show that some instruments have a tendency to accumulate deltas (sum of forward and backward runs) with the same sign. This value can be as large as 1 mm/km in absolute value. However, the levelling result (half of the difference of the two runs) is all right. An explanation could be non-reversibility of the instrument compensator after turning the instrument from back rod to fore rod.

Partial obstruction of the rod sighting may result in an error of several millimetres without warning.

Control levellings in Sweden (Per-Anders Olsson)
Loops with closing errors larger than two-sigma are levelled in their entirety. The proportion is obviously a function of the assumed sigma. With $\sigma=1.15\ \mathrm{mm}/\sqrt{\mathrm{km}}$, relevelling is required for 4.4 percent of the loops. In 2000 and 2001 control was performed for 10 and 15 loops, respectively. The comparison between old and new levelling shows some examples of long-wavelength error accumulation, but it is difficult to judge whether this is statistically significant. Control levellings will be continued in 2002 and completed in 2003.

Refraction corrections in Finnish precise levelling (Mikko Takalo)
Mikko described the theory and practice of the Kukkamäki method, both using observations of the vertical gradient of temperature, and using only meteorological observations. He pointed out that a third variant is available: to predict vertical gradients from meteorological observations and use them as if they were observed. This was pioneered by Taavitsainen (Reports of the FGI 81:4). He obtained the prediction equations statistically, by regressing observed gradients on observed meteorological and other environmental data in the Third levelling. However, at that time the material was still limited and nowadays one could get much better equations by analysing the entire Third levelling. FGI uses the prediction to patch up missing gradient observations, e.g. due to a broken thermometer.

Corrections for refraction in the Third precision levelling of Sweden (Per-Anders Olsson)
Per-Anders had used Kukkamäki's method and meteorological observations (i.e., neither observed nor predicted gradient data). The resulting refraction correction looks very much like a scale correction, which is expected. It is about +15 mm for an elevation difference of 500 m.

Technical session of the Sub-working group on land uplift for the Nordic Block

Heights and velocities: Rigorous joint adjustment vs. corrections to the last levelling (Jaakko Mäkinen)
This report is distributed separately.

Determination of land uplift by comparing Second and Third Swedish precision levelling (Runar Svensson)

The mean epoch of the Second precision levelling is 1960 and precision 1.6 $\mathrm{mm}/\sqrt{\mathrm{km}}$. The corresponding figures for the Third precision levelling are 1991 and 1.15 $\mathrm{mm}/\sqrt{\mathrm{km}}$. The average time difference is thus 31 years but the Second levelling ended in the south where the Third levelling started, and the time interval there is much shorter, in places only 15 years. Because the network structure is different, it is difficult to obtain uplift rates in a single joint adjustment of the levelling data.

Instead, an iterative approach has been adopted: First, both levellings are reduced to their mean epochs using an existing land uplift map (Martin Ekman's). Then they are adjusted in their mean epochs, and a comparison of the results yields new land uplift values. They are then used to reduce the levellings to their mean epochs again and the procedure repeated until convergence.

The result is a very plausible-looking land uplift surface. Only in the area with the short time interval some erratic features appear. Another concern is that the land uplift surface thus determined appears to be slightly tilted (down North) relative to land uplift results from tide gauges. The tilt is 2.4×10^{-9}/yr, or 2.4 mm/yr over a distance of 1000 km. The tilt appears to be statistically significant, and will be further investigated.

Land uplift by use of least squares collocation (Olav Vestøl)

Due to the difficult conditions, only a fraction of Norwegian lines have been relevelled. Thus it is not possible to determine land uplift from levellings alone. In Olav's approach land uplift in Norway is determined by collocation in a simultaneous adjustment of all levellings (1916–2001) and land uplift rates at 21 tide gauges. Altogether 674 levelling observations (including some Swedish and Finnish lines) are used. The land uplift trend surface is bicubic polynomial. The covariance function for the uplift goes to zero at 72 km distance.

The method appears very successful. For instance, it does not seem to be a problem that in some parts of Norway there is very little "depth" in the data support perpendicular to the coast where the tide gauges are. A second adjustment showed Norway and Finland together and Sweden can be added, too. Experimental adjustments are planned to clarify the contribution of the different datasets (levelling and tide gauges).

Comparison between vertical velocities from Bifrost model, repeated precise levelling, tide gauges, and GPS rates from Finnref and Bifrost (Jaakko Mäkinen).

Distributed separately

Closing the first day; Poster Session (Martin Vermeer); Opening the second day

The chairman closed the day's proceedings at 6 p.m.. A highly successful poster session was presided over by Martin Vermeer from 7 p.m. onwards. The session of March 19 was opened by the chairman at 9.30 a.m.

Technical session of the Sub-working group on Transfer and Calculation (Mikael Lilje chairing)

Status report of actions agreed at last meeting (Hønefoss, October 10, 2001)

1. Test data from Norway and Finland shall be sent to Denmark
   Norway has sent in all data and Finland one loop.
2. On-site education for running the database if necessary from respective country
   Not done.
3. Respective country together with Denmark will set up Telnet connections to KMS and the database
   Not done.
4. Sweden and Denmark will adjust the Swedish Third Precise Levelling using three different types of land uplift models (Ekman, Bifrost and Lambeck).
   Sweden has tested adjusting using Ekman and Bifrost. The model by Lambeck has still not become available in digital form.
5. Denmark will make it possibility to use the Danish adjustment program with a land uplift model.
   Done.
6. Finland will investigate the different models compared to repeated levellings.
   Done and reported on during the meeting.

Adopting the EVRS/EVRF2000 definitions for the NH20xx as far as possible—pros and cons (Jaakko Mäkinen)

The EVRS2000 (European Vertical Reference System) definition is very general. The vertical datum is the level surface $W=W_0$ at which the potential W_0 of the Earth's gravity field equals the normal potential U_0 of the mean earth ellipsoid (at the ellipsoid's surface). The only other items are that geopotential numbers and the zero tidal system are used. These latter two will probably be adopted in the Nordic countries in any case.

The Normaal Amsterdams Peil (NAP) is introduced only in the realization, i.e., in the EVRF2000 (European Vertical Reference Frame). It is stated that the datum is realized by the level through NAP, and that GRS80 quantities are used. (This means that the GRS80 ellipsoid is assumed to be the mean earth ellipsoid, and that at NAP level W is assumed to coincide with the U_0 of the GRS80). The EVRF2000 is then realized by the UELN95/98 results relative to the NAP.

The datum definition has interesting consequences. It makes EVRS2000 a global system. Anybody who, say in New Zealand, determines W values for bench marks can then use them to refer their heights to the European vertical reference system. The scientist could compute a mean earth ellipsoid of his own and use its U_0 instead of GRS80, and still be in EVRS2000.

Remark: The EVRS2000 datum definition using W_0 and U_0 has in fact raised controversy particularly in Germany. Its proponents consider the globalness and generality an advantage: There is no need to change the EVRS2000 definition if we want to adopt in Europe a world height datum based on W_0 and U_0, even if it would be radically different from NAP in realization. The opponents more or less consider the same feature a disadvantage: The definition in fact could force us to change the realization even if we do not want to. It only works for the moment because the relationship of NAP to U_0 is not well known. When we find out how much W at NAP differs from U_0 we have either to abandon NAP, abandon the EVRS2000 definition, or stop pretending that the realization is in harmony with the definition. In the same way, new values of U_0 should in principle change the datum realization.

To return to the Nordic question: If we go by the letter of EVRS2000/EVRF2000, we see that as long as W for terrestrial points is relatively poorly determined, almost any datum we choose can be claimed to refer to EVRS2000. But if we want strict allegiance to the present *realization* EVRF2000, we should not only adopt NAP, but to fix all bench marks at their UELN95/98 values.

This fixing we obviously are not going to do. So it all boils down to the question whether to take NAP as the datum or not. Even if the answer is positive, there is plenty of things to consider how this in practice should be done. For instance, the connection using UELN95/98 has a mixed tidal system and no definite epoch. Could/should we correct for that? New UELN versions are likely to come around all the time, when should we stop? And apparently we will get a closing error of several centimetres around the Baltic, etc.

The importance of NAP in practical work stems from a need for a European system for georeferencing for GIS and related purposes at 0.1 m accuracy in height, first expressed by CERCO. In 1999 the Spatial Reference Workshop in Marne-la-Vallée recommended to the European Commission that the EUVN/UELN (which as we know happens to refer to NAP) should be adopted for the purpose.

The advantages and drawbacks were discussed later in the session.

Discussion concerning strategic decisions on the network and height system

Purpose of the discussion. The discussion was intended to concern the “Scientific Height System”. Jaakko Mäkinen pointed out that for such decisions there was no hurry, since the preparations would not be any different. The decision is only needed before the mouse is clicked or the <enter> pressed for the “final adjustment”. Moreover, several variants could be produced for different purposes. Because of schedule problems there will be no joint Nordic “practical” or “legal” heights. However, we could make it our aim to produce national practical heights that differ so little across the border that for most purposes the discrepancy could be ignored. An analogy are ETRS89 realizations like SWEREF and EUREF-FIN. The scientific height system (or one version of it) could be used as a vehicle in this harmonization: if the national systems differ little from it, they will differ little from each other. Now, if we want to harmonize practical heights then we are in a hurry to start the discussion. While the persons present have no juridical authority to make decisions on the national height systems, as the foremost experts in their countries their factual influence will be very high.

Sweden wanted to focus on the scientific height system (Nordic Height Block) since there is no guarantee that decisions at the meeting concerning national systems would be followed in the countries. While there is an advantage if different countries are able to adopt the same principles in the national systems, there is already a discrepancy between Denmark and Sweden, since Denmark will surely not recalculate its height network.

In the ensuing debate both national systems and the Nordic scientific height system were discussed, but decisions concerned the scientific system only.

Orthometric or normal heights. Sweden pointed out that Resolution 5 at the EUREF2001 in Tromsö adopts normal heights. Finland countered that the resolution is strictly about EVRS2000, not about regional or national height systems in Europe. However, the general opinion appeared to be that normal heights would be acceptable for the Nordic Block.

Concerning national height systems, Sweden (which has normal heights at present) expressed cautious support for orthometric heights but did not meet with much enthusiasm. Finland and Norway would be perfectly happy with normal heights, even if both countries have orthometric heights now. Baltic countries are used to normal heights and see no problem in continuing with them. It was pointed out that if Sweden and Norway make different choices, then on their boundary metric heights for the same BMs calculated from the same geopotential numbers could differ by more than 50 mm. The discussion then moved to the usefulness of computing “true” orthometric heights (troublesome) as opposed to Helmert heights with standard density (easy), or to normal heights (simple). Martin Vermeer remarked that if orthometric heights are calculated using densities from geological sources (as in the Second Levelling in Finland) then those density estimates become a part of the height system. The point was raised that perhaps we should not try to make things easy for ourselves when choosing between the pair normal heights/quasigeoid or orthometric heights/classical geoid. Instead, we should make it easy for the end user who wants to produce heights using GPS. Martin thought that the choice would not make much difference, but because of the strong dependence of quasigeoid heights (or rather height anomalies) on elevation, they (and the fitted height reference “surface”) should/could be expressed as a function (or grid) of 3-D position, rather than as a function (grid) of horizontal position only. I.e., *zeta=zeta(phi, lambda,h)* instead of *zeta=zeta(phi, lambda)*.

Tidal system. All were prepared to heed the IAG resolution of 1983 recommending the zero system. It was pointed out that in addition, a version in the mean system would be produced for oceanographers.

Zero reference point. The NAP did not meet heavy opposition. The fact that then points with zero height could be up to 0.15 m underwater with respect to the Baltic MSL did not seem worry anybody, considering that typical rms variation in monthly MSL in the Baltic is 0.2 m. On the other hand, the advantage of being (with NAP) close to the “European GIS standard” was not considered that important either, in view that transformation parameters would be available. As far as national systems are concerned, even if they de facto derive from NAP they would need a concrete reference within the country, e.g.. a fundamental BM or an ensemble of BMs.

The reference year. Sweden thought that the reference year should be the mean epoch of Swedish and Finnish third-levelling observations, i.e., about 1990. Then the influence of errors from inaccurate land uplift corrections would be minimum. In the future, when better land uplift information is available, it could be used to update the heights. If heights are now referred to, say, 2005, we cannot later get rid of the error made 1990–2005.

Others pointed out the Public Relations problem of going out in 21st century with heights labelled 1990. The reference year should at least begin with a 2. Moreover, if heights refer to 1990, for a number of purposes we must anyway shuttle between 1990 and the present, using the land uplift information available now.

Other interesting epochs were brought forward: 1997.0 and 1999.5, i.e., the epochs of the positions (with respect to land uplift) in EUREF-FIN and SWEREF 99, respectively. However, it was remarked that for GPS-levelling, any epoch differences between the levelling network and the GPS reference can be incorporated in the "height reference surface".

It was pointed out that for minimizing differences between national height systems their epochs should be equal. Ten years of difference already causes a step and tilt of several centimetres. Finland and Norway seemed prepared to "return from the future" a little bit to meet Sweden somewhere in the present.

Session on the future of the WG for height determination

The future of the WG for height determination

The chairman of the WG started the discussion remarking that the WG had been established in 1986 with the mission of working with the ongoing precision levellings in the Nordic countries. These levellings are now completed or approaching completion. Would not this be the right time to close down the WG altogether, he rhetorically asked.

This suggestion met with general protest. It was pointed out that even if the field work will be completed soon, a major task remains in the computation, implementation, and dissemination of the new height systems. The networks need to maintained, and new techniques developed for this and other height determinations. The present technique of GPS + geoid model is not accurate enough to replace even second-levelling on shorter distances (cf. the enclosed plot by Markku Poutanen).

The meeting unanimously supported the continuation of the WG. The following joint Nordic problems should be treated during the term 2002–2006:

- the completion of the field work
- the computation and analysis of the levelling networks
- the treatment of the land uplift
- the principles and adjustment of new national height systems and of the joint Nordic system
- implementation and dissemination of the national systems, information activities, user support, problems of transition
- methods and techniques of maintenance of the networks
- new height determination techniques

Cooperation with other Working Groups and with the Presidium

It was agreed that the cooperation with other WGs had been good and boundaries to them should continue to be flexible, as often same problems are treated, albeit from different angles and with a different depth and target. Joint meetings could be arranged when pertinent, but with care. Some members who had participated in recent three-WG meetings had the feeling that the focus tends to get lost when there is a large general audience.

Problems had been encountered in the cooperation with the Presidium though. Two points were raised in the discussion: First, it was complained that the Presidium informs the WGs and the NKG membership very sparsely of its activities. Second, the impression of some WG members was that the Presidium tends to assume a domineering posture in its dealings with the WGs, while such function is not foreseen by the NKG statutes.

In the opinion of the meeting, one way of improving the cooperation between the Presidium and the WGs would be to change the structure of the Presidium such that it would consist of the chairmen of the WGs plus one representative from each country. Although a change in the NKG statutes at the next General Assembly cannot be initiated this late, the WG decided to request that a discussion on the future structure of the Presidium be included in its program. The secretary was instructed to transmit this request to the Organizing Committee.

Thanks to the departing chairman

The WG expressed its thanks and congratulations to Jean-Marie Becker for his energetic and highly successful work during four terms as the chairman of the WG.

Closing the meeting

The chairman thanked the participants and the local organizers for the successful meeting and closed it at 3 pm.