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Future height systems in the Nordic countries, their relation to the EVRS2000 and to INSPIRE GIS standards

by

Working Group for Height Determination of the Nordic Geodetic Commission

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Summary

We discuss the relationship of EVRS2000 and EVRF2000 to future national height systems in Europe and specifically in Finland, Norway, and Sweden. The EVRF2000 in these countries is based on their second precise levellings and the height differences refer to the epoch 1960.0. It will be soon obsolete when the third levellings are completed. We propose a practical procedure to achieve a quick update of the realization of the EVRS2000 (interpreted simply as the NAP datum) in these countries. The projected update has a consistent epoch (e.g. 2000.0) with regard to the vertical motion caused by the postglacial rebound, and is consistently in the zero tidal system. It does not depend on the current levelling campaigns in Estonia, Latvia and Lithuania or the connection around the Gulf of Finland to be completed, but anticipates the UELN-200x (or whatever, when the above conditions are fulfilled) to better than the formal EVRF2000 precision in the area. With support from EUREF, especially from countries around the Baltic, the realization can be achieved in time to be useful for the creation of a new Swedish national height system in early 2004.

1. Background

Figure 1. *The UELN-95/98 network, status August 2000 (Sacher et al., 2002). Note that the "Nordic Block" is only connected to the main network through the Danish straits; there is no tie around the Gulf of Finland. The Finnish, Norwegian, and Swedish data are here from the Second levellings. In Chapter 5 we propose to cross the Gulf of Finland to 2…3 cm accuracy using two independent methods: oceanographic levelling and GPS/geoid.*

Sweden, Finland and Norway are about to complete their third precision levellings and in Iceland a national levelling campaign is in progress. After this the countries will adopt new height systems[1]. In Denmark the third

[1] For shortness, we write "height system" when we mean a system of gravity-related heights: geopotential numbers above a reference potential level, and normal or orthometric heights deduced from them.

levelling was performed 1986–1992 and the new height system DVR90 introduced in 2001. This paper will mainly deal with the systems of Sweden, Finland and Norway; the situation and problems of Iceland are rather different, and Denmark already has a new height system. In addition, levellings and height systems of other countries around the Baltic Sea, especially those of Estonia, Latvia, and Lithuania are relevant to the discussion.

In the Nordic and UELN (United European Levelling Network) parlance, the concept of a Nordic Height Block is well established. In a more narrow sense, it means the networks of Finland, Norway and Sweden. There are two reasons why it has been something of a special case. First, in the UELN-55 (Simonsen, 1960), UELN-73/86 (Ehrnsperger and Kok, 1986), and UELN-95/98 (Sacher et al., 1999) the countries are connected to the rest of net only by a single junction between Sweden and Denmark (Figure 1). As a matter of fact, in the UELN-55 the Nordic Block was adjusted separately at the Finnish Geodetic Institute (FGI) computing centre (Kääriäinen, 1960). In 2000 a second junction between Sweden and Denmark was levelled across the newly built bridge; it strengthens the connection but is so close to the first junction that the large-scale network geometry remains essentially the same.

Second, the Nordic Block is unique in UELN in that from the very beginning it has been necessary to take into account the vertical motion due to the postglacial rebound (PGR), see Figure 2. In the UELN-55 the levelling observations were reduced to the epoch 1944.0 at the FGI. For the UELN-73/86 and UELN-95/98, the observations were reduced to 1960.0 by Finland, Norway, and Sweden before delivery to the computing centre. Within the block, there is also a tradition of regional height systems for scientific use: The Nordic height system 1960 (NH60) is based on rectified results of the second levellings of Denmark, Finland, Norway and Sweden (Ekman and Mäkinen, 1996a; Mäkinen, 2000) and has been applied especially in oceanography (Carlsson, 1998).

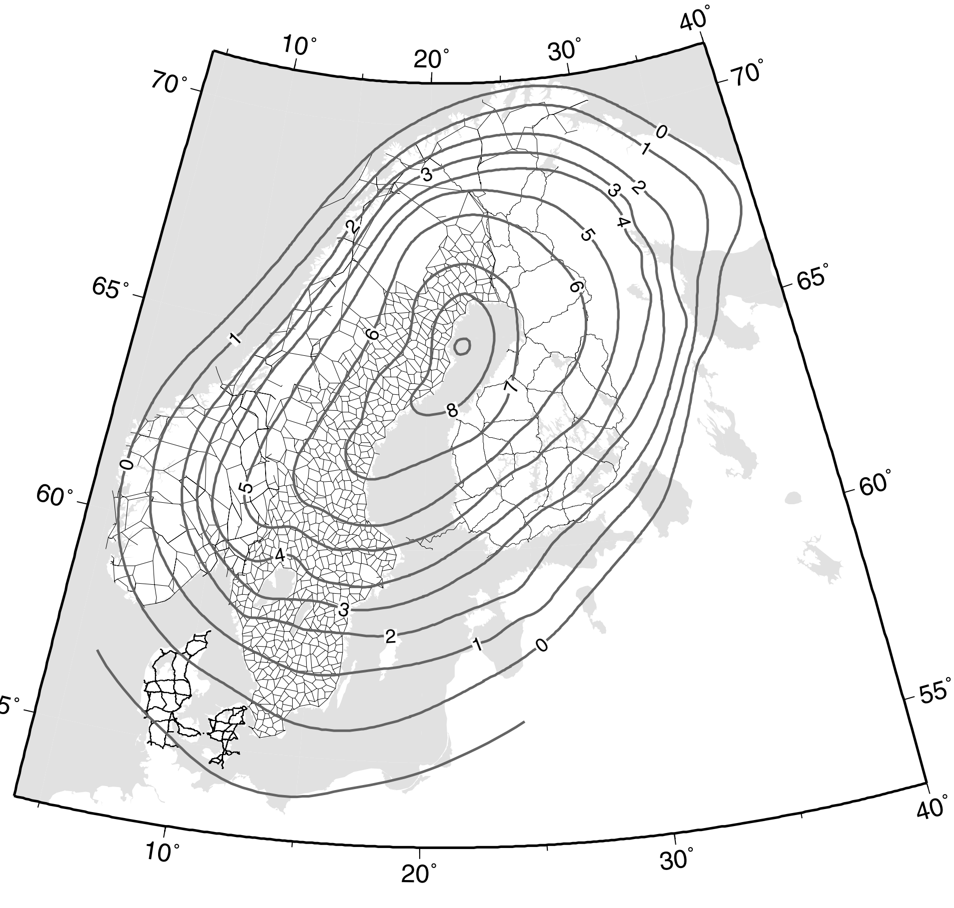

Figure 2. *Contemporary uplift rates (mm/yr) relative to mean sea level, digitized from the map by Ekman (1996), and the precision levelling networks of Denmark, Finland, Norway and Sweden (2002). The uplift map is based on tide gauges, repeated precise levelling (first two campaigns), and lake tilts. In the original, some sections of the isobases are drawn with a dashed line, to indicate uncertainty. The presentation of networks is in part schematic, with straight lines connecting nodal points.*

The questions on height systems that the Nordic countries are facing are both similar and interconnected, and obviously call for cooperation. On the initiative of its chairman at the time (Jean-Marie Becker), the Working

Group for Height Determination (WGH) of the Nordic Geodetic Commission (NKG)[2], in June 2001 established two Sub-Working Groups for the calculation of the Nordic Height Block. The emphasis was on a regional net for scientific use, a successor to the NH60. However, it was obvious from the beginning that the task was closely connected with both the national height systems for practical use, and with their relationship to the European Vertical Reference System EVRS2000 and its present realization European Vertical Reference Frame EVRF2000, as well as to any future realization. The benefits of having practical systems close to each other were recognized, and at the same time voices especially from the GIS community pointed at the importance of EVRF2000 as an impending European GIS standard. Thus at the 14th General Assembly of the NKG in 2002, the following resolution (No. 2) was approved (Poutanen and Suurmäki 2002, p. 298):

The Nordic Geodetic Commission

recognizing the importance of unified Nordic, European and global height systems for practical georeferencing and science,
pointing out that the coming introduction of new height systems in Finland, Norway and Sweden provides a unique opportunity to adopt systems with minimal differences from each other and from the European Vertical Datum,
noting that the work of the Working Group for Height Determination and its Sub-Working Groups on the Nordic Height Block, provides a frame work for studying and clarifying the issues involved,
recommends the representatives of the National Mapping Authorities and Geodetic Institutions in NKG to be active for the adoption of such systems.

The time for the task is limited, since Lantmäteriet (National Land Survey) in Sweden will complete the field work of the Third levelling in 2003 and has made rather a strong commitment to adopt a new height system immediately afterwards in 2004. At that time, a number of important advances in the area will be incomplete. Finland and Norway will still have field work to do. While work on the connection of Finnish and Russian networks is in progress since 2002, the tie around the Gulf of Finland will be available some time later. The new levelling campaigns in Estonia, Latvia and Lithuania will be continuing. These developments, when completed, will very much strengthen the connection of the Nordic block with the rest of the UELN network, and we must anticipate their influence. Otherwise a new EVRS2000 realization in Sweden in 2004 might become obsolete quite quickly. That could for instance cause uncomfortably large discrepancies when neighbours adopt their new systems somewhat later. One way of avoiding this is to anticipate a new UELN200x or perhaps even an EVRF20xx around the Baltic.

The Presidium of the NKG then at its meeting in February 2003 took up the question. Referring to the resolution mentioned, it asked the "Working Group for Height Determination to write a Position paper on the required conditions on a European height system in order to make a connection of an unified Nordic Height system to that system possible for practical use. The paper shall be presented by a representative from the Working Group on the meeting of the EUREF Technical Working Group on June 3, 2003 in Toledo, Spain" (end quote). The TWG has graciously accepted to accommodate such a presentation. The outcome is this paper, presented as a collective work of the NKG Working Group for Height Determination. Views expressed here do not not necessarily represent the position of national mapping agencies.

2. Introduction

Now, it is not the task of the EUREF or its TWG to act as arbiters of national height systems. Conversely, what right would some members of the EUREF have to require that joint European efforts in the UELN and EVRF be tailored to their local needs? Therefore, this paper takes a wider view of the subjects at hand.

First, the question of whether and how to attach national height systems to a European height system (i.e., to make a national realization of the European Vertical Reference System EVRS2000) is by no means unique to the Nordic countries. In fact, it is known that many European countries that are about to complete a new national precise levelling are weighing whether to change from their present height datum to the EVRS2000. A discussion of the issues involved can only be beneficial. Even in the Nordic countries, from a resolution at a geodesists' meeting there is still a long way to national decisions.

[2] The Nordic Geodetic Commission (NKG), founded in 1953, is an association of geodesists from Denmark, Finland, Iceland, Norway, and Sweden. It has a central role in their co-operative geodetic efforts. Its bodies include the quadrennial General Meeting, a Presidium, Working Groups, and Task Forces. See http://www.nkg.fi, and Jonsson et al. (2002).

Second, the Nordic countries have (geographically) large-scale intra-plate motions, due to the postglacial rebound, that are quite large compared to those ordinarily encountered in the EUREF area. A discussion of how we deal with them can be instructive for all concerned.

Third, if the Nordic countries decide to go ahead with a program where they attach their national systems (and/or a unified Nordic height system) to the EVRS2000, using the EVRF2000 (or more generally, the UELN or an EVRF20xx), they need cooperation and support from the EUREF members around the Baltic, as well as from the UELN computing centre. The technical steps are outlined in detail in what follows.

Fourth, we touch the question of a European GIS-height standard. There are efforts within the INSPIRE initiative (http://www.ec-gis.org/inspire/) of the European Commission (EC) to create a European GIS standard, and the standardization of the geodetic reference frame is a necessary part of the work. If such a standard is adopted in the near future, it only can be the EVRF2000. This is also the proposal of the INSPIRE Architecture and Standards Position Paper (http://inspire.jrc.it/reports/position_papers/inspire_ast_pp_v4_3_en.pdf).

However, in Finland, Norway, and Sweden the EVRF2000 will soon be obsolete as it is based on the second levellings and its epoch is 1960.0. New national systems and UELN200x will differ from EVRF2000 up to 0.4 m, due to the PGR during the last 40 years, and the difference will depend on the position in the PGR area. While technically it is not a problem to provide location-dependent (and not only country-dependent) transformation parameters from the national systems to the EVRF, it would be a pity if the standard stagnate for a long time at the "old" version EVRF2000. INSPIRE obviously is totally dependent on the geodetic community, ultimately the EUREF in this matter, and an arrangement that might make it possible to update the standard, if not in name, then at least in the numbers involved, could perhaps be thought out.

In the sequel, we address the items one, two, three in detail. As this position paper is also directed to a wider audience than the TWG, or specialists on height systems, or indeed geodesists, we apologize if the discussion may part appear rather obvious for some readers.

3. The modalities of national realizations of EVRS2000

As previously mentioned, there is no official EUREF or EUREF TWG position on the national height systems of the EUREF member countries. However, the analogy to the ETRS89 in 3D is very persuasive and many surveyors more or less draw a parallel between adopting a national realization of the ETRS89 for the 3D-positioning, and referring heights to the NAP using EVRF2000. And in the 3D-system the EUREF and its TWG do have a gatekeeper role. The advantages of having a national system in the ETRS89 are well known, and this is acquiring a political dimension through EC adoptions. And the road to an internationally acknowledged ETRS89 realization goes through TWG scrutiny and EUREF resolution. We are not proposing that the EUREF abandon its role as a controller of ETRS89 realizations. Neither are we suggesting that it set up a similar procedure for national EVRS2000 realizations[3]. (In the post-GOCE world this might actually be warranted.) We are simply pointing out the current difference.

Despite the apparent parallel in European systems, ETRS89 for 3D and EVRS2000 for heights, there is a fundamental difference in both ease and accuracy of national realizations, and in immediate benefits. This difference is a direct consequence of the technologies presently used: GPS for 3D, and levelling for potential differences (i.e., heights), even over large distances. It is thought that after the GOCE mission the difference will largely disappear, but for some years to come it will persist.

[3] Perhaps some anecdotes are permitted here. We have found out that many surveyors do believe that EUREF exercises some control or steering of new national height systems. For instance, in the debate on whether to adopt normal or orthometric heights for a national system, the argument has been used that EUREF frowns on the latter; the evidence being the EUREF resolution in Tromsö in 2000 that adopts normal heights for EVRF2000. We have also been contacted by town surveyors who have come across the EVRF2000 documentation in the web, and have taken it for a blueprint of future national heights all over Europe.

So, it is instructive to look at the similarities and differences. In the following, the viewpoint is that of a practical surveyor, or developer/user of GIS, mapping or navigation applications, who only wants “to be in the common European system, never mind the technicalities”. Then in the 3D we have immediately both a well-defined geodetic paradigm to interpret this request, and a set of clear-cut steps available, that well-nigh guarantee a scientifically solid national system with a number of practical advantages. By this we obviously mean that

(a) a national realization of ETRS89 will be sought
(b) ETRS89 is defined by the position of the stable part of the Eurasian plate in ITRS in the epoch 1989.0
(c) a state-of-the-art realization can be achieved any time through tracking station coordinates in the ITRS/$ITRF_{xx}$
(d) the task only requires a limited duration of GPS observations and it is in principle independent of work performed by other countries for similar purposes
(e) however, other countries will also have adopted similar choices
(f) thus if the work has been performed carefully, the national systems will
    i) between neighbouring countries be consistent enough to permit even high-precision geodetic work without transformations
    ii) in all Europe be consistent enough for GIS, mapping, and navigation without transformations

All this has been extremely successful. Then the question naturally arises, whether the success can be repeated with heights. Could we have national height systems in Europe that are, if not an outright part of a European height system, at least so close to it that transformation parameters for many purposes (say, GIS) could be ignored altogether? This request is not posed in precise geodetic terms, and it is then the duty of geodesists to formulate the question rigorously and to look for the range of possible answers to it. This is what we try to do in the sequel.

Let us look at a height analogue to the 3-D solution outlined above.

(A) a national (or regional) realization of EVRS2000 will be sought
(B) the vertical datum of the EVRS2000 is the level $W=W_0$ for which the potential W of the Earth’s gravity field equals the normal potential U_0 of the mean Earth ellipsoid (Anonymous, 2000; Ihde and Augath, 2000)
  - in addition, zero tidal system and normal heights (equivalent with geopotential numbers) are specified
(C) a state-of-the art access to the datum would be
  - use the global expansion of the geopotential W=W(x,y,z), possibly amended by regional gravity data, and evaluate it at a number of points (x,y,z), between which the potential differences are known from levelling, too
    i) usually it is thought that for national-size networks this will only be practicable after the GOCE mission has vastly improved the accuracy of the W(x,y,z)
    ii) (but even using EGM96, Burša et al. [2002] are surprisingly successful on some country patches)
    iii) after GOCE, the error in W(x,y,z) will be of the order of the equivalent of 1 cm only, for features larger than 100 km
    iv) every country could then access the EVRS2000 global datum, or some tide gauge datum like the NAP without the intervening chain of levelling networks
    v) in this sense, the height datum problem of countries could become “atomized” and only then would it be reminiscent of the national realization of the ETRS89
    vi) of course, joint levelling networks and joint adjustments would still be needed, to avoid offsets at boundaries and to improve accuracy etc.
  - that was a future prospect; at the moment the access to the EVRS2000 is made through the conventional European realization EVRF2000 which is defined by
    i) the assumption that the GRS80 ellipsoid is the mean Earth ellipsoid
    ii) the assumption that W at NAP equals U_0
    iii) taking UELN-95/98 geopotential numbers over NAP
    iv) the approximation in the assumptions (i,ii) exceeds the present measurement accuracy but that is not essential for the discussion that follows
    v) the issue is really the consistency and accuracy of transferring the reference throughout the European network, the problem would be the same even with a strictly “realistic” interpretation of the NAP (or any other datum)
(D) now, the realization of a new national (or regional) height system in the EVRS2000 through the EVRF2000 (more generally through the UELN) depends completely on the other national levellings in the UELN

(E) in practice the realization can be done for instance

i) fitting the new national network to the existing EVRF2000 heights in the country/region
ii) fitting the new national network to the EVRF2000 heights at the borders of the country/region
iii) performing a regional or a complete readjustment of UELN, incorporating the new regional data plus any other relevant data that may have become available since the EVRF2000
iv) waiting for the next EVRF20xx where all new data will be incorporated and adopting the EVRF20xx as a national system

Compared to the advantageous situation in the 3D case, all these solutions are unsatisfactory from a conceptual or/and from a practical point of view. We repeat that this is not due to any shortcoming of the EVRS2000 definition or its EVRF2000 realization; it is simply a consequence of the technique (levelling) used to transfer the potential differences over long distances. For instance, the nearest analogy to E(i,ii) in the 3D case might be that we would have been obliged to "freeze" the European ETRS89 realizations to the original EUREF89 campaign solution and still would be obtaining our national ETRS89 realizations by fits to it.

Note that unless quite many countries revise their national height systems as described above, the practical benefits for any single one of them may be quite limited, as compared to the use of transformations (from national systems otherwise defined) to the EVRF2000. Even then, in realizations of the type (iii) done over the years in patchwork fashion, it could be difficult to attain over-the-border consistency of a couple of centimetres. A European consistency of national height systems, (of the kind we today have in the 3-D systems with the national realizations of the ETRS89), could in practice only be obtained by all countries getting their height systems from a joint UELN adjustment. This in fact does not seem quite so far-fetched: it is likely that the national levelling campaigns now in progress in Europe will be the last of their kind, after which the "final UELN20xx" could be performed. However, then we will already be in the post-GOCE era, and the game may look completely different.

All told, it would seem that for any country with a well-functioning national height system and no immediate need to revision, the idea of switching to EVRF2000 now should be treated with caution. We have a major technology jump ahead of us in the determination of potential differences (heights), almost comparable to the move from terrestrial techniques to satellite methods in positioning. Changing a national height system is a laborious practical undertaking that one would not like to repeat very often. Now, it is difficult to predict the future but it would seem likely that the Word Height System character of the EVRS2000 definition will be retained, at most with minor modifications. In the post-GOCE era, the EVRF20xx would then be (1) a genuine realization of a global height system (2) with a strong contribution from W(x,y,z) (or, if one prefers, GPS/geoid) even to its internal structure. With (considerable) exaggeration, one might claim that EVRF20xx could have as little resemblance to the EVRF2000 as the ETRF89 had to the ED87.

On the other hand, if the national system must be changed now, there is a lot to be said for a realization of EVRS2000 based on the NAP datum, as opposed to local mean sea level or the continuation of some other old TG datum. Perhaps if sufficiently many countries have adopted the NAP by 20xx, the pressure to keep NAP in the EVRF20xx will be so high that the EVRS2000 global definition is changed!

In the Nordic countries, we cannot wait until 20xx, the new height systems must be adopted before that. When in the sequel we discuss their attachment to the EVRS2000, it will be on terms of a method like E(iii) above.

4. Geodetic reference systems in the Nordic countries: Time-tag everything!

The primary subject of this paper are "gravity-related heights". However, (1) the determination of 3D position (codeword "GPS"), (2) the determination of the geopotential ("geoid"), and (3) the determination of geopotential differences ("gravity-related heights") form a tightly-knit triple, not only in theory but in modern geodetic practice, too. In this discussion, then, PGR effects in all three must be treated, although it turns out the coupling between them is not critical for the present problem. We will presently see that due to the PGR, most geodetic systems and frames in the Nordic countries have either (1) an epoch and velocities, or (2) at least an epoch attached to them. However, for the practical user they are invariably **static**; the kinematic part (velocities) is for the scientific user only.

4.1. Past and present height systems

Precise levelling was the first geodetic technique accurate enough for the PGR to have a detectable influence on the results. As a consequence, the history of height systems in the Nordic countries is intimately connected with the determination of PGR. The uplift must be taken into account in the processing of the levelling results, and in the definition of the height systems; on the other hand repeated precise levelling was for a long time the only method of determining vertical rates inland. Table 1 presents a summary of the precision levellings and height systems of Denmark, Finland, Norway and Sweden from the end of the 19th century up to the present.

Table 1. *Simplified summary of precision levellings and height systems in Denmark, Finland, Norway, and Sweden, adapted from Mäkinen et. al. (2002). For more details see Mäkinen (1987), Ekman (1995), Schmidt (2000, 2002), and the original publications listed there. Explanation of columns:*

1 Country
2 First precision levelling, years when performed
3 First precision levelling, estimated error in $mm/(km)^{1/2}$
4 First precision levelling, resulting height system
5…7 As 2…4, but for second precision levelling
8…10 As 2…4, but for third precision levelling

Systems given in **boldface** *refer to a definite epoch and in them the vertical velocities are explicitly accounted for (see text). Various error estimates can be found in the literature, depending on the material used and the method adopted. In Norway, there is no sharp separation into second and third levelling, the division here is for convenience of presentation only.*

1	2	3	4	5	6	7	8	9	10
Country	First levelling			Second levelling			Third levelling		
	Years	m_0	System	Years	m_0	System	Years	m_0	System
Denmark	1885–1904	1.4	DNN GM	1938–1953	0.8	DNN GI DNN GM **1950.5**	1986–1992	1.0[&]	**DVR90**
Finland	1892–1910	1.3	NN	1935–1975	0.7	**N60** (N43[*], LN[*])	1978–2004	0.8	
Norway	1890–1909		NN	1916–1953	2.1	NN 1954, NNN	1954–2006	1.7[§]	
Sweden	1886–1905	4.4	RH00	1951–1967	1.6	**RH70**	1979–2003	1.1	

[*] *Temporary systems* [&] *Only large loops included* [§] *Pooled estimate for second and third levellings*

Thus already after the second levellings, height systems were adopted where

(i) in the processing, a vertical velocity was determined for the bench marks
(ii) the influence of the PGR during the time span of the work was accounted for
(iii) the heights in the system refer to a specific epoch, which appears in the **boldface** system names in Table 1.

The vertical velocities (i) determined are sometimes called "official land uplift numbers", which may appear strange to the geophysically minded. They are important in the maintenance of the height systems. While the systems are **static** to the practical user, for whom the heights are fixed, they are **kinematic** to the scientific user when needed, for instance in maintenance. E.g., a section of maintenance levelling performed in Finland in 2003 is reduced to 1960.0 for PGR before computing heights in the N60 system. In future systems the "land uplift numbers" used at creation are perhaps not the ones that will be used in maintenance over the decades, as our knowledge of vertical velocities is rapidly improving.

Sweden completes its Third Levelling this year (Table 1, column 8), and there is a previous commitment by the Lantmäteriet (Land Survey) to introduce a new height system already in early 2004 (Eriksson et al., 2002). Finland and Norway will take some more time and are not similarly pressed. However, both have sufficient data that preliminary joint adjustments can be done.

Latest UELN involvement. The Finnish, Norwegian, and Swedish data in the UELN-73/86 and UELN-95/98 are the same, only the weighting was changed from a-priori values to results of variance component estimation. Between the UELN-73/86 and UELN-95/98 the Danish data was exchanged from the Second to the Third levelling.

More details of present height systems in the Nordic and neighbouring countries are given in Table 2.

Table 2. *Properties of height systems currently in use in the Nordic and in the Baltic countries, from Mäkinen et al. (2002). Compiled from Ekman (1995), Mäkinen (1987), Anonymous (2000), Schmidt (2000, 2002).*

System	Denmark DVR90	Finland N60	Norway NN1954	Sweden RH70	UELN-95/98 EVRF2000	Baltic Baltic H.S.
Reference TG	Average	Helsinki	Tregde	Amsterdam	Amsterdam	Kronstadt
Sea level year	1990	1944	1952	1684 MHT	1684 MHT	1833
System epoch	1990	1960	Vague	1970	Vague/1960.0*	Vague
Heights	Orthometric	Orthometric	Orthometric	Normal	Normal	Normal
Tidal system	Non-tidal[&]	Mean	Mean	Non-tidal	Mixed	Mean
Transfer in cm to EVRF2000[§]	+1…+3	+19…23	–10…+14	–2…+7		+8…+15

**For differences in Finland, Norway and Sweden.* [&]*Input to UELN-95/98 is in the mean tidal system.*
[§]*Based on the full set of UELN points*

There are simple interpretations of some figures in the last row. For Denmark, the DVR90 datum is the MSL of the surrounding seas averaged over 10 TGs. Their range is 12 cm and it turns out that the average SST in EVRF2000 is close to the NAP. The datum of RH70 in Sweden is in fact NAP, but based on the UELN-55.

The offsets between the height systems do not depend only on the reference datums, but on the epochs as well. An epoch difference of 10 years could introduce a place-dependent offset of maximally 0.1 m.

4.2. National ETRS89 realizations

Obviously any valid ETRS89 realization is in the epoch 1989.0 as far as the motion of the Eurasian plate is concerned. However, the issue here is the PGR that causes both radial and tangential motion. The GPS observations are processed, say in ITRF96, epoch 1997.0 and then results transformed into ETRS89. However, the last transformation only concerns the motion of the Eurasian plate. Conventionally, no correction for radial motion nor for intra-plate tangential motion is applied. The internal geometry remains at 1997.0. The tangential motion is concentrically (but not symmetrically) away from the uplift center (Milne et al., 2001; Johansson et al., 2002) and it is up to 2 mm/yr. Models are now available for it, either based on the BIFROST observations (Johansson et al., 2002) or from a geophysical model fitted to them (Milne et al., 2001).

Here we are mostly concerned with the radial motion. The ordinary GPS user, processing in, say 2003, his observations with the published coordinates of the national ETRS89 realization (internally in 1997.0) will get them in 1997.0, too, except for the differential motion of the receiver site and the reference sites since 1997.0. With time, this must probably be taken into account.

Table 3. *Internal epochs of the Nordic national ETRS89 realizations. Comments in text.*

Country	Denmark	Finland	Norway	Sweden
System/campaign	EUREF-DK94	EUREF-FIN	EUREF-NOR94, EUREF-NOR95, EUREF-NOR96	SWEREF 99
Internal epoch	1994-09-15	1997.0	appr. 1997	1999.5
Published in	Fankhauser and Gurtner (1995)	Ollikainen et al. (2000)	Kristiansen and Harsson (1999)	Lidberg and Jivall (2000)

Table 3 shows the “internal” epochs of the Nordic national ETRS89 realizations. The epoch differences are large enough to introduce intra-Nordic radial and tangential discrepancies on the 1 cm level.

Obviously, the epochs of the existing height systems (Table 2) do not coincide with the internal epochs in Table 3. It has been argued that the epochs of the new height systems should be chosen to do that. However, at least for the GPS/geoid height determination this does not hold any major benefit. The much larger PGR motion (during 30…40 years) between the epochs in Table 2 and Table 3 has been easily accommodated in the corresponding tailored geoids (section 4.4).

4.3. Gravimetric geoids, gravity data

Ekman and Mäkinen (1996b) estimated a peak geoid change rate of 0.6 mm/yr, due to the PGR. At the present accuracy of regional gravimetric geoids this is a negligible figure, but one could try to think out how epoch effects traverse the geoid computation. It starts with a global harmonic expansion of the geopotential (EGM). The PGR change takes place in harmonics below 60. The mean epoch of the satellite tracking data in the EGM could be thought of as its epoch. Then perhaps terrestrial data is added to the EGM, with discrepancies in the epochs between-countries, and discrepancies in the epochs of gravity and heights within countries. Modern computations of regional geoids rely on the remove-restore technique and thus the epoch effects enter the computation one more time, in the residuals of the regional terrestrial data relative to the EGM. What comes out could perhaps be partly described as "epoch" and partly as systematic error like the effect of any data offsets. Analysing this is outside the scope of this paper.

In the Nordic countries, only the system RG82 of the Fundamental Gravity Network of Sweden has a completely rigorous treatment of the epoch. Both absolute gravity measurements and gravity differences in it are reduced to the epoch 1982.0 (Haller and Ekman, 1988). In Finland gravity refers approximately to 1963, the mean epoch of the relative measurements of the First Order Gravity Network and of the ties to absolute stations (Kääriäinen and Mäkinen, 1997). The Danish precision gravity reference network has the approximate epoch 1986 (Andersen and Forsberg, 1996). The Norwegian first order network was measured in 1969. Gravity change due to the PGR is about –2 µgal per cm of uplift relative to the Earth's center of mass, or maximally –2 µgal/yr. (Model result is -1.6 µgal/cm, e.g., Wahr et al., [1995], observed –2.0 µgal/cm [Ekman and Mäkinen, 1996b]; the discrepancy is not significant.) Thus approximate corrections for the epoch differences are straightforward when required.

In a few years, GOCE will give a high-precision high-degree EGM, with epoch of about 2006. GRACE will give its rate of change in the degree range of the PGR signal.

The regional geoid currently in use is the NKG-96 (Forsberg et al., 1997), and it has served as basis for the national tailored geoids discussed in the next section. In NKG-96, epoch differences (or other differences) between national systems of gravity and height are not accounted for. In the new NKG-2003 (in progress) offsets between height systems are corrected for (R. Forsberg, personal information).

4.4. Tailored geoids

The present Nordic tailored geoids (height reference surfaces) in Table 4 are based on the NKG-96 geoid (see section 4.3). The tailored geoids are valid in the epoch of the ETRS89 realization, and must in the future be updated for PGR. Note that it is only the differential PGR between the user site and stations of ETRS89 realization that counts. Thus the updates do not need to be very frequent.

Table 4. *Nordic tailored geoids (height reference surfaces). The information about the height systems and ETRS89 realizations is from Tables 2 and 3 and is only repeated here for easier comparison. SWEN 01L is the only one where a separate step to model geoid change due to PGR between the two epochs was included. In others it was incorporated in the empirical fit.*

Country	Denmark	Finland	Norway	Sweden
Geoid name	DVR90g2002.01	FIN2000	VREF2000x	SWEN 01L
Height system/ ETRS89 realization	DVR90/EUREF-DK94	N60/EUREF-FIN	NN1954/ EUREF-NOR9y	RH70/SWEREF 99
Epochs	1990.0/1994-09-15	1960.0/1997.0	Vague/1997	1970.0/1999.5
Published in		Ollikainen (2002)	Solheim (2000)	Engberg et al. (2002)

5. Objectives

5.1. Goals and premises

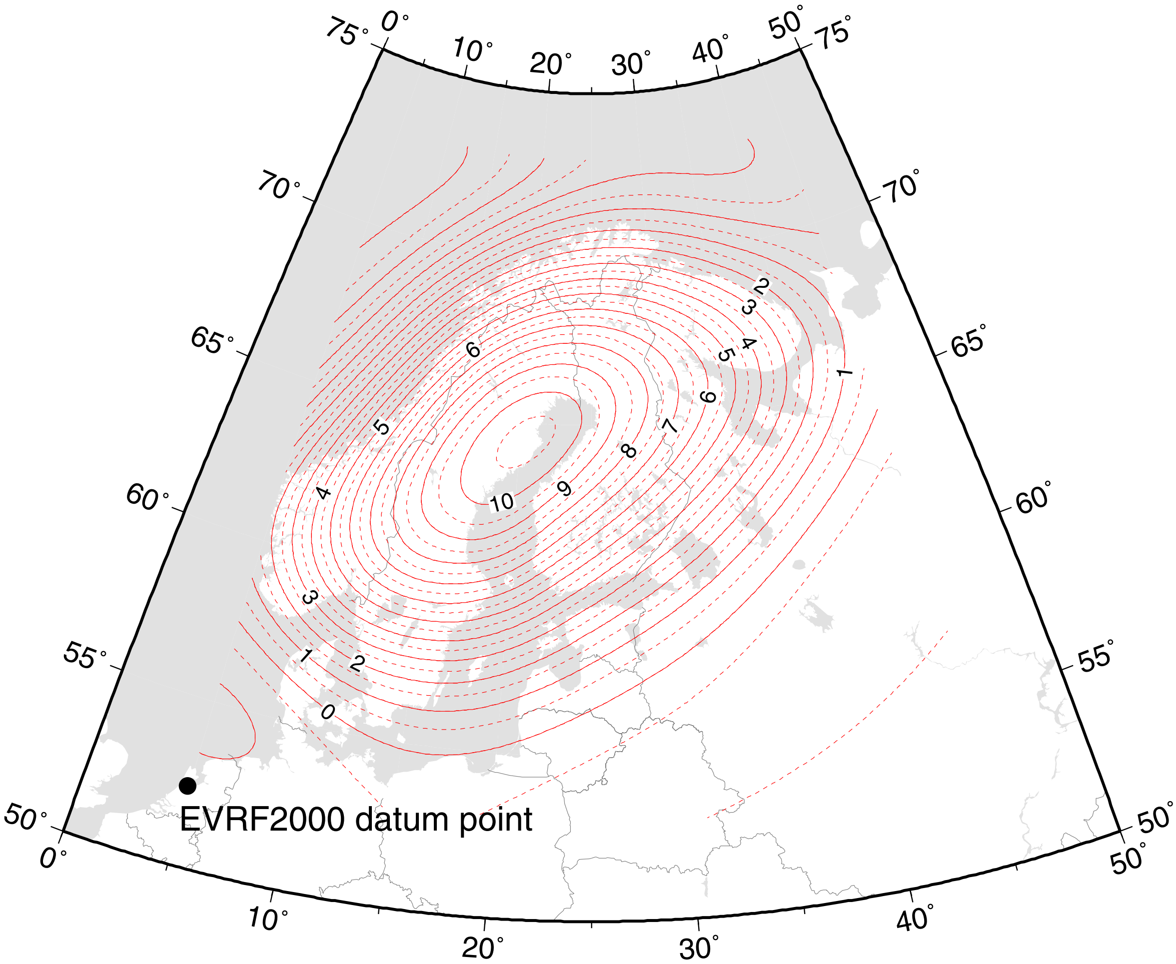

Figure 3. *PGR rates relative to the geoid in mm/yr according to Milne et al. (2001). The rates are predicted from a geophysical model of the PGR. The model was obtained by fitting Earth rheology to the 3D velocities observed in the BIFROST permanent GPS network (Johansson et al., 2002), using the deglaciation history by Lambeck et al. (1998). It is thus completely independent from the map in Figure 2 but agrees with it rather well. The difference between the two maps is in principle the rise in mean sea level 1892–1991, i.e. during the tide gauge record used for Figure 2.*

Our purpose is to set up an EVRS2000 realization in the Nordic countries, with the following properties:

(1) it will be available in time for the adoption of the new Swedish national height system in 2004
(2) it can be set up using only observations already available in 2003
    (i) it does not rely on the completion of the Finnish and Norwegian third levellings, nor on the Estonian, Latvian, or Lithuanian campaigns
(3) its datum is the NAP
(4) it is consistently in the zero tidal system
(5) its epoch is consistent in the postglacial rebound area, at least around the Baltic Sea, (if needed, to the EVRF2000 datum point)
    (i) epoch 2000.0 has found wide acceptance in the Nordic countries
(6) to guard against later discrepancies, it takes into account the closing of the Nordic-Baltic loop east of the Baltic Sea
    (i) the tie can be made over the Gulf of Finland using oceanographic levelling and GPS/geoid and thus does not depend on the schedule of a levelling connection around the Gulf of Finland

(7) it takes into account the shortcutting of the loop around the Gulf of Bothnia using the oceanographic levelling and the GPS/geoid tie over the Aland sea
(8) it is as close as possible to the eventual EVRF20xx, performed when the current works have been completed

Remarks: (1) and (2) are practical necessities, (3) is the same realization as in EVRF2000, and (4) is part of the EVRS2000 definition. Further, (5) is necessary since postglacial rebound effects are not limited to Finland, Norway and Sweden (Figure 3). Tilt affects height differences even where the rates themselves are small.

As to the epoch choice (5i), the review in Chapter 4 was intended to show that no strong arguments for some particular epoch can be deduced from the epochs of other geodetic reference systems in the area. Thus the choice can be made on the basis of the levellings only. The Nordic discussion concerning the epoch choice will not be repeated here (see for instance http://www.nkg.fi/NKG_Working_Group_Height_Minutes_2002.pdf). Epoch 2000.0 appears to be emerging as a reasonable compromise between different requirements and viewpoints.

A number of regional models of vertical velocities are available to reduce the levellings to the chosen epoch; see for instance Figures 2 and 3, Lambeck et al. (1998), Scherneck et al. (2002). Within the WGH, "country-sized" models derived from repeated levelling, tide gauges, and permanent GPS have been computed and are now being merged (Engsager 2002; Mäkinen at al. 2003; Saaranen and Mäkinen 2002; Svensson 2002; Vestøl 2002). The WGH will choose the model to use by October 2003.

The oceanographic and GPS/geoid ties over the Gulf of Finland have been calculated (Ollikainen et al., in preparation). Their accuracy can be estimated as 2…3 cm. This compares favourably with the present open UELN loop; from Figure 2 of Sacher et al. (2002) it has a precision of about 40 mm. The oceanographic tie over the Aland sea was published by Ekman and Mäkinen (1996a). The GPS/geoid tie over the Aland sea was measured in 2002 (Jivall et al. 2002).

5.2. Inventory of data

Table 5 shows levelling data along a schematic loop around the Baltic in clockwise direction, starting from and returning to the EVRF2000 datum point. From levelling years and PGR tilts one can see that even outside the Nordic Block, reductions to the epoch 2000.0 may amount to tens of millimetres.

Table 5. *Country-by-country summary of levelling data, clockwise around the Baltic, starting from and returning to the EVRF2000 datum point. UELN-95/98 years are from Sacher et al. (2002). Tilts are estimated using the PGR model of Figure 3, roughly from international junction to international junction when traversing the country. Norway's PGR tilt is in parentheses since it is parallel to part of Swedish range. Reduction to zero tidal system (Ekman, 1989) is junction to junction, too. Poland and Germany are traversed roughly in east-west direction, and thus the treatment of the permanent tide does not matter here.*

Country	Levelling years	Data was used in UELN-95/98	PGR tilt mm/yr	Tidal system in UELN-95/98	Rough reduction to zero tidal system, mm
Netherlands	1969–1975	x			
Germany	1974-1992	x	+0.5	mean?	
Denmark	1982–1994	x	+1.3	mean	–5
Sweden (3rd)	1979–2003		+9.5		
Norway (3rd)	1916–2003–(2006)		(+2.5)		
Finland (3rd)	1978–2003–(2004)		–7.0		
Gulf of Finland	GPS/geoid SST/TGs		–1.0	mean	+3
Estonia	1959–1996–(2005)	x	–1.5	mean	+7
Latvia	1968–1988–(2005)	x	–1.0	mean	+7
Lithuania	1933–1998–(2005)	x	–0.5	mean	+10
Poland	1973–1980	x	0	nontidal	
Germany	1974–1992	x	–0.3	mean?	
Netherlands	1969–1975	x			

5.3. Work plan

The steps to take:

(1) Compile available levelling results around the Baltic. In fact, the data available right now suffices.
(2) Compile oceanographic and GPS/geoid crossings of Aland Sea and Gulf of Finland
(3) Select model for PGR
(4) Reduce all data to 2000.0
(5) Analyse misclosure of Baltic levelling ring
(6) Adjust in the epoch 2000.0.

Software for the tasks is available at many Nordic institutions, in particular at the Nordic Computing Centre at the Danish National Survey and Cadastre.

5.4. Proposal for cooperation

To realize the plan, the Working Group for Height Determination asks for support and cooperation from the EUREF community, especially the countries around the Baltic, the TWG, and the UELN computing centre.

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