EVRF2007 as Realization of the European Vertical Reference System

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Abstract

Since 1994 the IAG Sub-commission for Europe (EUREF) has enhanced the Unified European Leveling Network (UELN) and defined a European Vertical Reference System (EVRS). Half of the participating countries provided new national leveling data to the UELN data centre after the release of the last solution EVRF2000. Therefore, a new realization of the EVRS was computed and published under the name EVRF2007. The datum of EVRF2007 is realized by 13 datum points distributed over the stable part of Europe. The measurements have been reduced to the common epoch 2000 using the land uplift model of the Nordic Geodetic Commission (NKG). The results of the adjustment are given in geopotential numbers and normal heights, which are reduced to the zero tidal system. At the EUREF symposium in Brussels (June 2008) Resolution No. 3 was adopted which proposes to the European Commission that EVRF2007 is adopted as the vertical reference for pan-European geo-information.

1. Introduction

In 1994 the work on the Unified European Leveling Network was resumed after a break of 10 years under the name UELN-95. Resolution No. 3 of the EUREF symposium 1994 in Warsaw devised the objective to establish an Unified Vertical Datum for Europe at the one-decimeter level with simultaneous extension of the UELN as far as possible to the Eastern European countries. After four years' of work the EUREF symposium 1998 in Bad Neuenahr/Ahrweiler decided to hand over the results to the participating countries under the name UELN-95/98. This resolution was realized in January 1999.

One year later at the EUREF symposium 2000 in Tromsø a first definition of the European Vertical Reference System (EVRS) was adopted. The realization on the base of the UELN 95/98 solution got the name EVRF2000.

In the meantime the importance of harmonization of the vertical reference of spatial coordinates increased on the one hand and the extension, density and topicality of the available data were improved on the other hand.

The needs for an improved common European vertical reference system was recognized at a workshop on "Vertical Reference Systems for Europe", held on April 5th to 7th, 2004 in Frankfurt am Main. This workshop was jointly organized by the Joint Research Center (JRC) of the European Commission and by EuroGeographics, Expert Group Geodesy with support from the IAG Sub-Commission for Europe EUREF.

Resolution No. 3 of the EUREF symposium 2005 held in Vienna recognized already the need for a new realization of the EVRS. The EUREF symposium 2007 in London considered again that the progress in national leveling data information makes possible an improved realization of EVRS (Resolution No. 3 EUREF symposium London 2007).

2. Data

The last results of an UELN adjustment were handed over to the participating countries in January 1999. Since then a lot of new data have been delivered to the UELN data center (SACHER et al. 2006). The following 14 countries made their current first order leveling networks available (see Figure 1):

- Estonia (1999) - new part of the network
- Latvia (1999) - new part of the network
- Romania (2000) - new part of the network
- Lithuania (2001) - new part of the network
- Switzerland (2002) - update
- Bulgaria (2003) - new part of the network
- the Netherlands (2005) - update
- Finland (2005) - update
- Norway (2005) - update
- Sweden (2005) - update
- Slovakia (2007) - update
- Lithuania (2007) - update
- Poland (2007) - update
- Portugal (2007) - update

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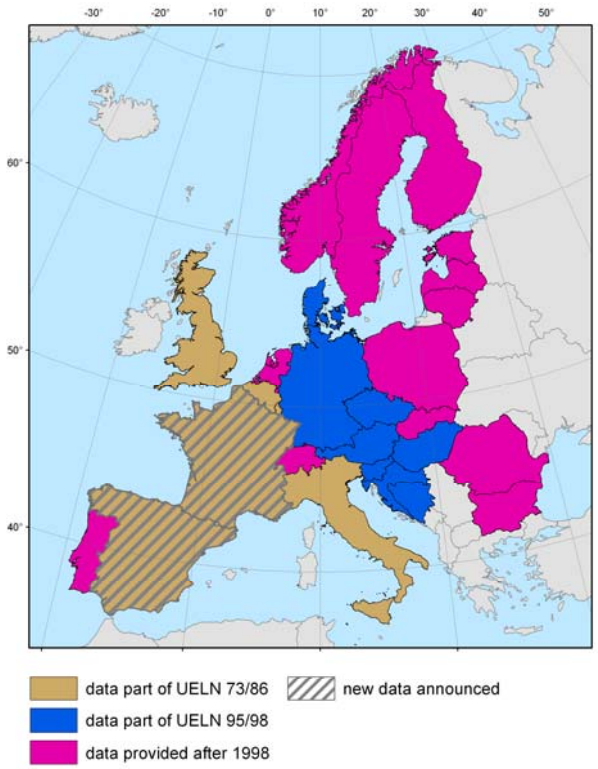

Figure 1: Development of the UELN data base

3. Datum of EVRF2007

In the UELN-95/98 solution as well as in the previous adjustments (UELN-73) the datum was realized by one benchmark in the Netherlands (EHRNSPERGER and KOK 1986).

The last datum realization of EVRS – the EVRF2000 – was defined as follows (IHDE and AUGATH 2002):

The vertical datum of the EVRS is realized by the zero level through the Normaal Amsterdams 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 gravity field potential through NAP, W_{NAP}, is set to be the normal potential of the GRS80

$$W_{NAP}^{REAL} = U_{0GRS80}.$$

The EVRF2000 datum is fixed by the geopotential number and the equivalent normal height of the reference point of the UELN No. 000A2530/13600.

The datum point of EVRF2000 – 000A2530, internal UELN-No. 13600 – was not identical with the datum point of the national leveling network of the Netherlands (000A2350). The point 000A2530 is not contained in the current leveling network of the Netherlands and therefore no longer available as a datum point.

The EVRS2007 datum is realized, no any longer by a single point, but by a number of datum points distributed over Europe. We have strived to keep the level of the EVRF2000 datum in the EVRF2007. Therefore the new UELN adjustment was fitted to the EVRF2000 solution by choosing several datum points and introducing their EVRF2000 heights in the free adjustment of the current network. This was realized by introducing the condition equation

$$\sum_{i=1}^{13}(c_{EVRF\,2000} - c_{EVRF\,2007}) = 0 \qquad (1)$$

into the adjustment. For this purpose it was important to choose stable points located on the stable part of the European plate. In December 2006 the chairman of EUREF sent letters to all countries participating in the UELN project asking them for proposals of datum points for the next adjustment. Figure 2 shows the proposed datum points.

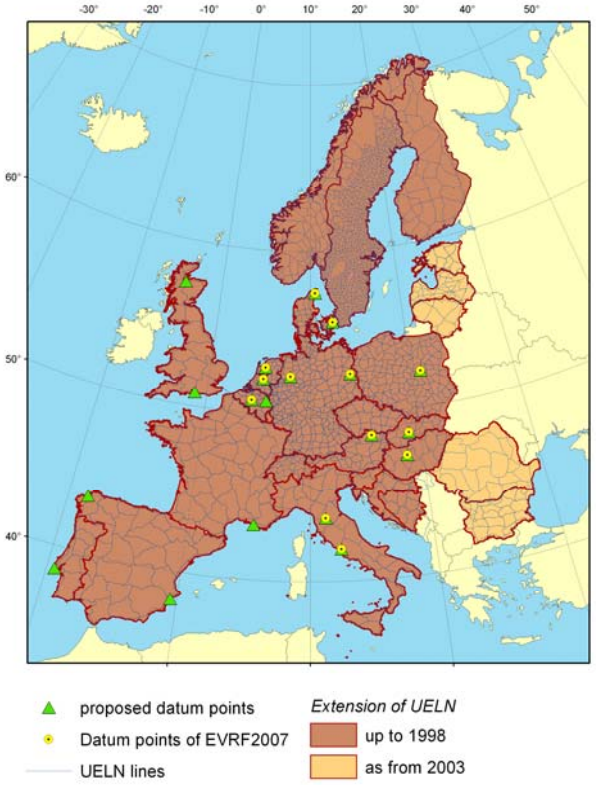

Figure 2 Proposed and finally used datum points

Several adjustment variants were performed with different selections of datum points. The height changes caused by the different datum points were in the range of 1-5 mm. In the final variant only 13 of the 20 proposed datum points are used for the following reasons:

- The Netherlands proposed 3 datum points. One of these points changed its height considerably compared to the EVRF2000 adjustment. Strangely such a difference doesn't appear between the two national adjustments of the 4th and 5th primary leveling of the Netherlands. We suppose this is

caused by different weight determinations in the adjustments of the 4th primary leveling, performed by the Rijkswaterstaat on the one hand and the UELN data center on the other hand. It was decided to use only 2 of the 3 points.

- Great Britain proposed 2 datum points. Currently the island is only connected by one uncertain height difference to the continental network. After a planned inclusion of a measured height difference through the tunnel considerable height variations in these datum points are to be expected. That's why in the final variant these 2 datum points weren't used.
- We see a similar problem with the datum points of France, Spain and Portugal. For about 2009 we expect new leveling data of Spain as well as a partial update of the French data. French colleagues reported about an observed tilt in the North-South-direction of the old national leveling IGN69 network of about 25 cm (REBISCHUNG et al. 2008). After including the new data of France and Spain, variations in the datum points of France, Spain and Portugal are highly probable. Therefore the proposed datum points of France, Spain and Portugal are not used in the final variant.

4. Epoch of the Measurements

The measurements in the UELN data base originate from very different epochs (see Figure 3). This weak point of the project can be remedied only partly by the development of a kinematic network using information on the velocity of the points.

In the EVRF2000 adjustment the data of Finland, Norway and Sweden were reduced to the epoch 1960. The other data had not been corrected to a common epoch.

In the beginning of this century the Scandinavian countries renewed their leveling networks. By the Nordic Geodetic Commission (NKG) a common adjustment of leveling data around the Baltic Sea was performed – called BLR2000 (MÄKINEN et al. 2005). The data of Finland, Norway, Sweden, Denmark, the Netherlands, Poland, Estonia, Latvia, Lithuania and the Northern part of Germany were included in this adjustment. All data were reduced to the epoch 2000 by the land uplift model NKG2005LU (see Figure 4). The same point in the Netherlands as in the adjustment EVRF2000 was used as datum point.

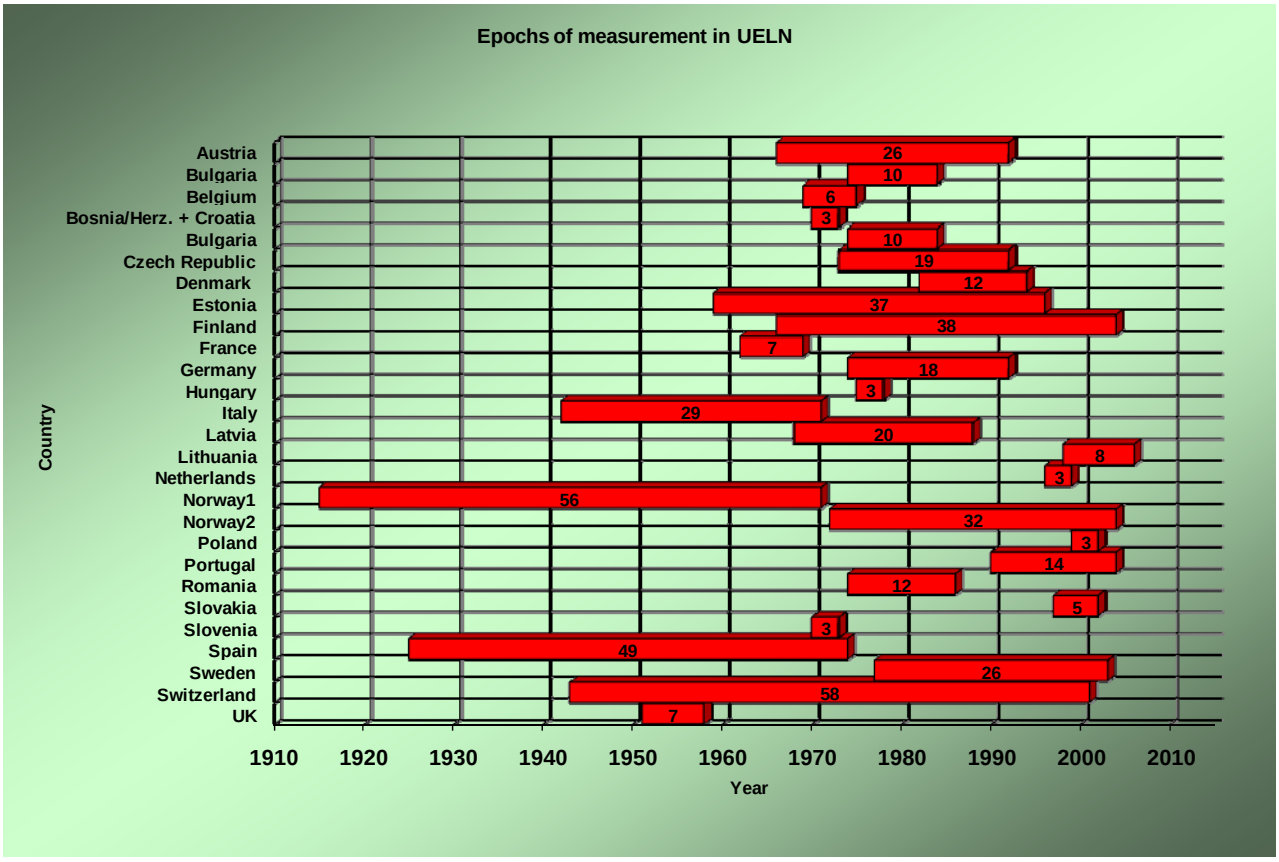

Figure 3 Epochs of the measurements in the UELN data base

In 2005 the new leveling data of Finland, Sweden and Norway were handed over to the UELN data center together with the land uplift model NKG2005LU (ÅGREN and SVENSSON 2007). The uplift differences from this model were used for the reduction of the UELN data to epoch 2000. The reductions were applied in three different modalities:

Variant a) only the data of Finland, Norway and Sweden were reduced as in the UELN 95/98.

Variant b) the data of Finland, Norway, Sweden and additionally Denmark were reduced.

Variant c) in this variant all data which are located in the area of the NKG2005LU were reduced as in the BLR2000 adjustment.

In all variants was assumed that the datum points have the velocity zero.

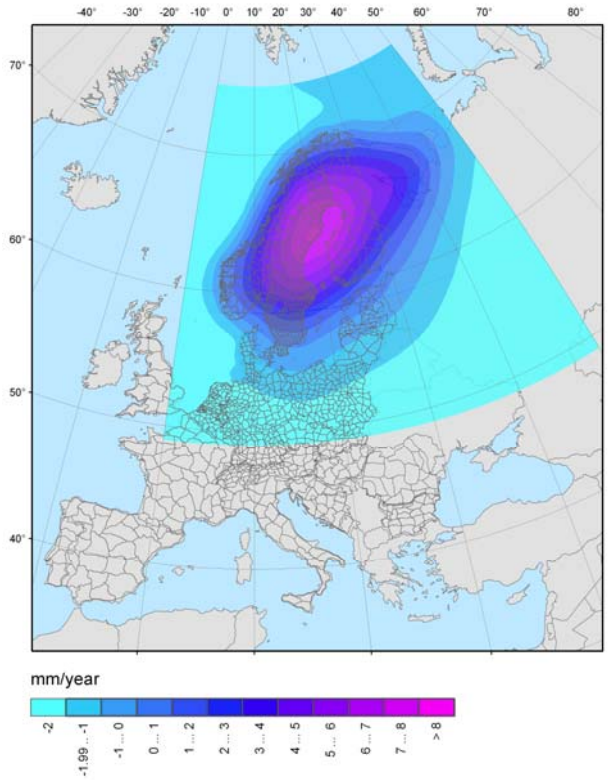

Figure 4: The NKG2005LU and UELN lines

The adjusted geopotential numbers of the respective UELN adjustment variant were compared to the results of BLR2000. To achieve comparability the UELN adjustments were performed in the mean tidal system. The main reasons for the differences in all variants are new leveling data of the Netherlands, Poland and Lithuania, which were provided to the UELN data center after the BLR2000 adjustment, and some minor data changes in Norway, Finland and Denmark. The other reason for the differences is the different use of the land uplift model. In the BLR2000 all data which are located in the area of the model were reduced to epoch 2000. By contrast in variants a) and b) only the data of certain countries were reduced.

As expected, we find the smallest differences in variant c). The standard deviation of the weight unit is for all three variants 1.1 kgal·mm. For most of the network blocks there are only very small differences in the results of the variant component estimation between the three variants. Only the standard deviation of 1 km leveling for the network of Lithuania was reduced from 0.96 kgal·mm to 0.87 kgal·mm. Figure 5 shows the differences between the results of variant c) and the BLR2000. In the final EVRF2007 we applied the NKG2005LU model to the whole network as in variant c).

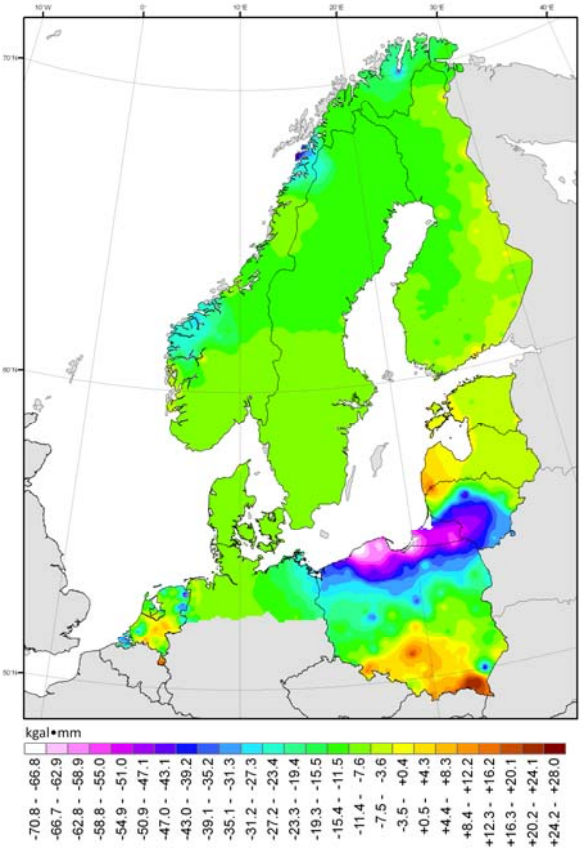

Figure 5: Variant c) compared to BLR2000

5. Tidal corrections

The earth tides, caused by the gravitational forces of Moon and Sun, induce a permanent deformation of the earth crust. Different concepts to handle this deformation are described in EKMAN 1989, MÄKINEN and IHDE 2007, IHDE et al. 2008, MÄKINEN 2008. The IAG resolution no.16 recommends for the treatment of tidal corrections for gravity and station positioning the concept of zero tide. That means to retain the effect of the deformation and eliminate the effect of the tidal attraction.

The EVRS definition contains the clause: "The EVRS is a zero tidal system, in agreement with the IAG Resolutions." (IHDE and AUGATH 2002). In the EVRF2000 this part of the definition was not realized,

no reductions because of the permanent tides have been applied to the data by the UELN computing center.

The countries delivered their data in different tidal systems, and the actual systems were not known to the UELN computing center. As a result, the tidal system of the EVRF2000 is mixed. At present, we know that it is mostly mean-tide (see below).

In the scope of the Geodetic Information and Service System CRS project (SACHER et al. 2005) in 2004 a questionnaire about their national height systems was sent to all European countries. To clarify the situation, the questionnaire contained amongst others the question about the tidal system of the national heights. Most of the countries answered that their heights were in the mean tidal system. Some countries which have other national systems sent explicitly data in the mean tide system to the UELN data center (NL, Scandinavia). We got new data in the non-tidal system from Denmark and Poland. We didn't get information about the tidal system from Italy, Czech Republic, Croatia, Bosnia-Herzegovina and Latvia. The data of Czech Republic and Latvia were part of the common adjustment of the Eastern European countries in the seventies which was in the mean tidal system. The data of Bosnia-Herzegovina, Croatia and Slovenia originate from a common network of the former Yugoslavia. So we can assume that they are all in the mean tidal system as we already know about Slovenia. Italy remains unknown.

In order to realize the EVRS definition regarding the tidal system, an additional column was implemented in the measuring table of the UELN data base which contains the geopotential difference in the zero tidal system.

There was the question how to deal with the reduction of the datum points. In a first step the geopotential numbers of all datum points were corrected by

$$-0.28841 \cdot \sin^2 \varphi - 0.00195 \cdot \sin^4 \varphi + 0.09722 \quad \text{in kgal·m} \quad (2)$$

to bring them from the mean-tide system to the zero-tide system (MÄKINEN, 2008).

The resulting reductions ranged between –0.030 (Italy) and –0.108 (Denmark) kgal·m. In order to minimize the differences to the EVRF2000 solution we added the constant of +0.08432 kgal·m, the value of the tidal correction of point 13600 (000A2530) with opposite sign, to the correction described in formula (2). This is equivalent to the assumption that the NAP datum of EVRF2000 is in the zero tidal system in accordance with the EVRS2000 definition (IHDE et al. 2008). Figure 6 shows the resulting differences of the adjusted geopotential numbers to the adjustment EVRF2000.

6. Summary of the Adjustment Parameters

The datum of EVRF2007 is realized by 13 datum points (see Table 3). The geopotential numbers of these points are introduced into the free adjustment with the results from the EVRF2000 adjustment reduced to the zero tidal system (see EKMAN 1989, MÄKINEN and IHDE 2007, IHDE et al. 2008, MÄKINEN 2008) by:

$$C_{dp2007} = C_{p95/98} - 0.28841 \cdot \sin^2 \varphi - 0.00195 \cdot \sin^4 \varphi + 0.09722 + 0.08432 \quad \text{in kgal·m.} \quad (3)$$

The geopotential differences are reduced from the mean-tidal system to zero-tide by

$$\Delta C_Z = \Delta C_M - 0.28841 \cdot (\sin^2 \varphi_2 - \sin^2 \varphi_1) - 0.00195 (\sin^4 \varphi_2 - \sin^4 \varphi_1) \quad \text{in kgal·m.} \quad (4)$$

Additionally, the geopotential differences are reduced to the epoch 2000 by means of the land uplift model NKG2005LU. That concerns the data of Finland, Norway, Sweden, Denmark, Germany, Poland, Lithuania, Latvia and Estonia (see Figure 4).

Table 1 shows the parameters of the EVRF2007 adjustment compared to the EVRF2000 adjustment.

A variance component estimation was performed in which the observations of each national network were introduced as a separate group (GRAFAREND 1984). Table 2 shows the results of the variance component estimation for EVRF2000 and EVRF2007. Table 3 gives a description of the 13 datum points with their coordinates and geopotential numbers before and after the adjustment.

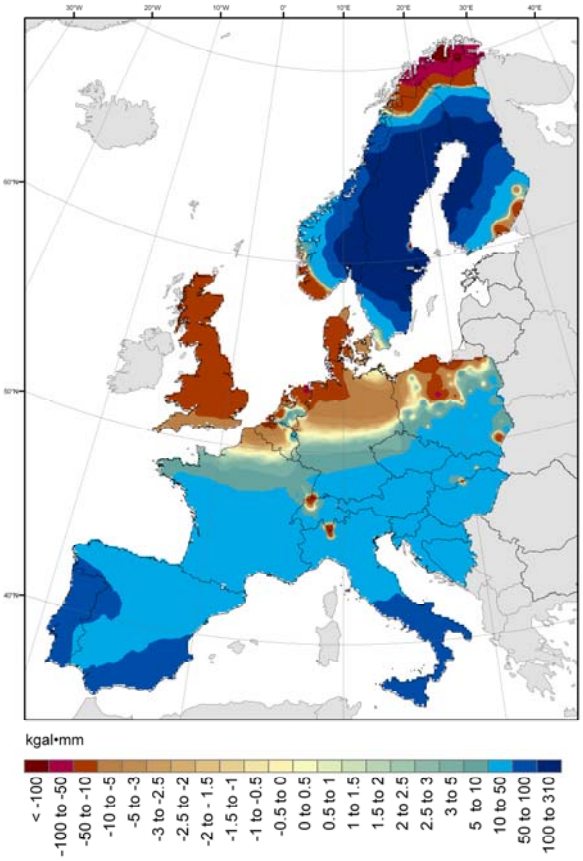

Figure 6: Differences of EVRF2007 zero tidal system to EVRF2000

Table 1: Parameters of the adjustment

Parameter	EVRF2000	EVRF2007
Number of datum points:	1	13
Number of unknowns:	3063	8133
Number of measurements:	4263	10568
Number of condition equations:	0	1
Degrees of freedom:	1200	2436
A-posteriori standard deviation referred to 1 km leveling distance in kgal·mm:	1.10	1.12
Mean value of the standard deviation of the adjusted geopotential numbers (≙ heights), in kgal·mm:	19.6	16.2
Average redundancy:	0.281	0.231

7. Delivery of the Results

In preparation to the EUREF symposium 2008 in Brussels the preliminary adjustment results were handed over to the participating countries together with a report. At that time there was no agreement on the exchange of leveling data between the countries. Therefore in that first step only the national part of the adjustment results were handed over to the respective country.

Each country received two Excel files. The first one contained point- related data: the national and UELN point identifiers, adjusted geopotential numbers and normal heights and their standard deviation. The second one contained measurement related data: the start and end point of the measurements, weight, improvement, standardized improvement, redundancy, adjusted geopotential differences and their standard deviations. The files contained also the border connections, including the end points of these connections in the neighboring country.

At the EUREF symposium June 2008 in Brussels EVRF2007 was adopted as new realization of the EVRS. Resolution No. 3 of the symposium proposes to the European Commission that EVRF2007 is adopted as the vertical reference for pan-European geo-information.

The representatives of most UELN participating countries agreed to exchange the complete results with each other.

After the presentation of the preliminary results some minor data updates of Norway as well as some additional measurements in connection with the EUVN_DA project were included. The results of the final EVRF2007 will be provided to all participating countries in autumn 2008.

8. Outlook

The availability of EVRF2007 necessitates an update of the Geodetic Information and Service System CRS. Transformation parameters between national height systems and EVRF2007 will be calculated and provided at http://crs.bkg.bundde/crs-eu/ in 2009.

After providing the EVRF2007 results the development of the UELN will be continued.

The delivery of the new leveling network of Spain has been announced for about 2009. Besides that, a partial re-measurement of the French leveling network (NIREF) has been performed (REBISCHUNG et al. 2008). The data will be provided to the UELN data centre in 2009 at the earliest. After including NIREF it will also be possible to include the measurement between France and Great Britain through the tunnel. This has not been possible until now, because the end point of the tunnel measurement in France is only connected to this new network. Furthermore, the integration of some bordering loops of Russia is planned for 2009 as a step towards closing the Baltic Ring.

Thanks to all countries which provided their leveling data to the UELN data base!

All other interested countries are invited to participate in the UELN project too.

Table 2: Results of the variance component estimation

Country	Number of observations	Standard deviation in kgal·mm	Number of observations	Standard deviation in kgal·mm
	EVRF2000		EVRF2007	
Austria	145	0.80	167	0.82
Belgium	54	1.22	63	1.24
Switzerland	13	1.06	413	1.09
Germany (ep. 2000)	755	0.85	846	0.85
Denmark (ep. 2000)	1036	0.59	197	0.91
Spain	101	1.85	140	1.75
France	175	2.01	348	2.02
Italy	97	1.76	110	1.75
Netherlands	932	1.08	1424	0.75
Portugal	22	1.77	30	2.09
Great Britain	60	1.72	60	1.72
Norway_old (ep. 2000)	194	1.67	352	1.62
Norway_new (ep. 2000)			397	1.29
Finland (ep. 2000)	89	0.76	262	0.73
Sweden (ep. 2000)	122	1.74	4206	1.00
Czech Republic	82	1.10	117	1.16
Hungary	54	0.52	82	0.47
Croat., Bosn.-Herz.,Slov.	79	0.90	112	0.90
Poland (ep. 2000)	179	0.99	476	0.88
Slovakia	74	1.41	215	1.55
Romania			133	1.75
Estonia (ep. 2000)			78	1.30
Latvia (ep. 2000)			159	1.72
Lithuania (ep.2000)			72	0.87
Bulgaria			109	1.14
total	4263	1.10	10568	1.11

Table 3: Datum points

Point number	Point number		Latitude	Longitude	geop. number EVRF2000 (mean tide)	geop. number EVRF2000 (zero tide)	adjusted geop. number EVRF2007 (zero tide)	difference EVRF2007-EVRF2000
(UELN)	(national)		degree (ETRS89)		kgal·m			kgal·mm
102105	937856	AT	48.664867	15.674783	300.7350	300.7535	300.7504	-3.0
200038	IGNMK	BE	50.799167	4.359400	96.0126	96.0204	96.0073	-13.1
401110	3614/00005	DE	52.349783	8.015300	92.6957	92.6958	92.6871	-8.7
401658	3549/01400	DE	52.480500	13.983567	53.6216	53.6211	53.6139	-7.2
514004	00204009190	DK	55.666017	12.393367	14.0516	14.0357	14.0471	+11.4
514182	05304009619	DK	57.447017	10.511600	16.5915	16.5674	16.5860	+18.5
800432	35 (Firenze)	IT	43.776000	11.259883	48.7903	48.8335	48.8335	+0.0
800441	44 (Roma)	IT	41.909850	12.476050	16.9251	16.9776	16.9776	-0.1
913000	000A1013	NL	52.851417	5.518967	5.6427	5.6404	5.6364	-4.0
913011	000A1112	NL	52.141733	5.360567	41.0248	41.0260	41.0251	-0.9
1103000	Nadap II	HU	47.255750	18.620017	172.9876	173.0131	173.0090	-4.1
1706115	26330081	PL	52.230100	20.948383	110.6861	110.6868	110.7007	+13.9
1905325	EH-V.	SK	48.606500	19.017333	267.5548	267.5735	267.5709	-2.7
							Total:	**+0.0**

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