The European Vertical Reference System (EVRS), Its relation to a World Height System and to the ITRS

J. IHDE[1], W. AUGATH[2]

Introduction

The Technical Working Group of the IAG Subcommission for Europe (EUREF) was asked by the European Commission to define a common height reference system for the exchange of geoinformation in Europe and to describe its realization on the basis of the European height projects United European Levelling Network (UELN) and European Vertical Reference Network (EUVN). EUREF decided to define an European Vertical Reference System (EVRS) as world height system (WHS) (http://evrs.leipzig.ifag.de/). EUREF endorsed UELN95/98 and EUVN as realizations of EVRS using the name EVRF2000, characterized by:

- the datum of 'Normaal Amsterdams Peil' (NAP)
- gravity potential differences with respect to NAP or equivalent normal heights.

The relation of the EVRF2000 to the WHS has to be derived.

The decision for the realization of the European Vertical Reference System (EUVN) in 1995 was a big step toward a modern integrated reference system for Europe which combines GPS coordinates, gravity related heights and sea level heights in one data set. Problems of the relations between gravity-related height reference systems, spatial reference systems, tide gauge and gravity networks will be discussed within of the EVRS.

1. Present status

A height reference system is characterized by the vertical datum and the kind of gravity related heights. The vertical datum is in most cases related to the mean sea level which is estimated at one or more tide gauge stations. The tide gauge stations of the national height systems in Europe are located at various oceans and inland seas: Baltic Sea, North Sea, Mediterranean Sea, Black Sea, Atlantic Ocean. The differences between these sea levels can amount to several decimeters. They are caused by the various separations between the sea surface and the geoid.

In addition the used height datums often are of historical nature as well as not all zero levels are referred to the mean sea level. There are also zero levels referred to the low tide (Ostend) or to the high tide. For example the Amsterdam zero point is defined by mean high tide in 1684.

In Europe three different kinds of heights are being used: normal heights, orthometric heights and normal-orthometric heights. Examples for the use of orthometric heights are Belgium, Denmark, Finland, Italy and Switzerland. Today normal heights are being used in France, Germany, Sweden and in the most countries of Eastern Europe.

2. United European Levelling Network (UELN)

After a break of ten years the work on the UELN was resumed in 1994 under the name UELN-95. The objectives of the UELN-95 project were to establish a unified height system for Europe at the one decimeter level with the simultaneous enlargement of UELN as far as possible to include Central and Eastern European countries and the development of a kinematic height network "UELN 2000" step by step. Starting point for the UELN-95 project was a repetition of the adjustment of the UELN-73/86. In contrast to the weight determination of the 1986 adjustment for UELN-95 the weights were derived from a variance component estimation of the observation material which was delivered by the participating countries and introduced into the adjustment.

The adjustment is performed in geopotential numbers as nodal point adjustment with variance component estimation for the participating countries and as a free adjustment linked to the reference point of UELN-73 (Amsterdam).

The development of the UELN-95 is characterized by two different kinds of enlargements: The substitution of data material of such network blocks (which had been already part of UELN-73) by new measurements with improved network configuration and on the other hand by adding new national network blocks of Central and Eastern Europe which were not part of UELN-73.

In the year 1998 more than 3000 nodal points were adjusted and linked to the Normaal Amsterdams Peil (the reference point of the UELN-73). The normal heights in the system UELN-95/98 are available for more than 20 participating countries.

3. European Vertical Reference System (EVRS)

The Spatial Reference Workshop in Marne-la-Valleé in November 1999 recommended the European Commis-

[1] Johannes Ihde, Bundesamt für Kartographie und Geodäsie, Richard-Strauss-Allee 11, D-60598 Frankfurt am Main, Germany, Fax: +49 69 6333 425; Tel.: +49 69 6333 250; e-mail: ihde@.ifag.de

[2] Wolfgang Augath, Geodätisches Institut, Technische Universität Dresden, Mommsenstrasse 13, D-01062 Dresden, Germany, Fax: +49 351 463 37201; Tel.: +49 351 463 34249 (Sekr.), - 7503 (selbst); e-mail: wolfgang.augath@mailbox.tu-dresden.de

sion European reference systems for referencing of geo data. For the height component the workshop recommended that the European Commission:

- adopts the results of the EUVN/UELN initiatives when available as definitions of vertical datum and gravity-related heights;
- includes the EUVN reference system so defined for the specifications of the products to be delivered to the EC, within projects, contracts, etc;
- future promotes the wider use of the European vertical reference system within all member states by appropriate means (recommendations, official statement, …).

The Technical Working Group of the IAG Subcommission for Europe (EUREF) was asked to define a European Vertical Reference System and to describe its realization. After a discussion at the plenary of the symposium it was decided to specify the definition. Two contributions in this discussion about the treatment of the permanent tidal effect (MÄKINEN, EKMAN) are added to this publication.

The principles of the realization of the EVRS were adopted at the EUREF Symposium 2000 in Tromsø by the resolution no. 5:

The IAG Subcommission for Europe (EUREF) noting the recommendation of the spatial referencing workshop, in Marne-la-Vallée 27-30 November 1999, to the European Commission to adopt the results of the EUVN/UELN projects for Europe wide vertical referencing, decides to define an European Vertical Reference System (EVRS) characterized by:

- *the datum of 'Normaal Amsterdams Peil' (NAP)*
- *gravity potential differences with respect to NAP or equivalent normal heights,*

endorses UELN95/98 and EUVN as realizations of EVRS using the name EVRF2000, asks the EUREF Technical Working Group to finalize the definition and initial realization of the EVRS and to make available a document describing the system.

For referencing of geoinformation in a unique system transformation parameters between the national heights systems and the EVRS frame are also available, see Sacher et al. (1999a).

4.1 Definition

The European Vertical Reference System (EVRS) is a gravity-related world height reference system. It is defined by the following conventions:

a) The vertical datum is the zero level for which the Earth gravity field potential W_0 is equal to the normal potential of the mean Earth ellipsoid U_0:

$$W_0 = U_0.$$

b) The height components are the differences ΔW_P between the potential W_P of the Earth gravity field through the considered points P and the potential of the EVRS zero level W_0. The potential difference $-\Delta W_P$ is also designated as geopotential number c_P:

$$-\Delta W_P = W_0 - W_P = c_P.$$

Normal heights are equivalent to geopotential numbers.

c) The EVRS is a zero tidal system in agreement with the IAG Resolutions.[3]

4.2 Realization - The European Vertical Reference Frame 2000 (EVRF2000)

The EVRS is realized by the geopotential numbers and normal heights of nodal points of the United European Levelling Network 95/98 (UELN 95/98) extended for Estonia, Latvia, Lithuania and Romania in relation to the Normaal Amsterdams Peils (NAP). The geopotential numbers and normal heights of the nodal points are available for the participating countries under the name UELN 95/98 to which is now given the name EVRF2000.

4.2.1 Realization of the datum

a) 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:

$$c_{NAP} = 0.$$

b) 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

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

c) The EVRF2000 datum is fixed by the geopotential number 7.0259 $m^2 s^{-2}$ and the equivalent normal height 0.71599 m of the reference point of the UELN No. 000A2530/13600.

4.2.2 Frame - The Adjustment of UELN-95/98

The adjustment of geopotential numbers was performed as an unconstrained adjustment linked to the reference point of UELN-73 (in NAP). Both the geopotential numbers and the normal heights of UELN 95/98 of the adjustment version UELN-95/13 were handed over to the participating countries as the UELN-95/98 solution in January 1999.

[3] In a) and b) the potential of the Earth includes the potential of the permanent tidal deformation but excludes the permanent tidal potential itself.

Figure 1: United European Levelling Network 1995 (UELN-95/98 – extended for Estonia, Latvia, Lithuania and Romania)

Parameters of the UELN-95/98 adjustment are the following:

- number of fixed points: 1
- number of unknown nodal points: 3063
- number of measurements: 4263
- degrees of freedom: 1200
- a-posteriori standard deviation referred to a levelling distance of 1 km: 1.10 kgal · mm
- mean value of the standard deviation of the adjusted geopotential number differences: 6.62 kgal · mm
- mean value of the standard deviation of the adjusted geopotential numbers ($\hat{=}$ heights): 19.64 kgal · mm
- average redundancy: 0.281

The normal heights H_n were computed by $H_n = c_p/\bar{\gamma}$ where $\bar{\gamma}$ is the average value of the normal gravity along the normal plumb line between the ellipsoid and the telluroid. The average value of the normal gravity along the normal plumb line is determined by

$$\bar{g} \approx g_n = g_0 - \frac{0.3086\ mgal/m \cdot h}{2} + \frac{0.072 \cdot 10^{-6}\ mgal/m^2 \cdot h^2}{2}$$

with the Gravity Formula 1980 and latitude in ETRS89.

4.3 Relations between the EVRS Datum Definition (WHS) and EVRF 2000 Datum (NAP)

The potential of the Earth gravity field in the NAP is processed by

$$W_{NAP} = W_0 + \Delta W_{SST} + \Delta W_{TGO}$$

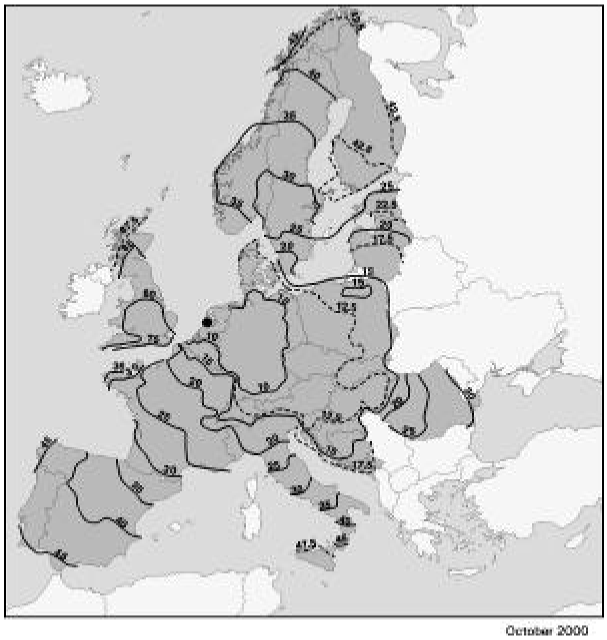

Figure 2: UELN 95/98 – Isolines of Precision [kgal · mm]

where

ΔW_{SST} is the sea surface topography potential difference at the tide gauge Amsterdam in relation to a geoid with $W_0 = U_0$.

ΔW_{TGO} is the potential deviation between the NAP level W_{NAP} and the level of the mean sea surface at the tide gauge Amsterdam.

The relation between the EVRS datum and its realization in EVRF2000 is expressed by

$$\begin{aligned}\Delta W_{EVRS} &= W_{NAP} - W_{NAP}^{REAL} \\ &= W_{NAP} - U_{0\,GRS80} \\ &= U_0 - U_{0\,GRS80} + \Delta W_{SST} + \Delta W_{TGO}\end{aligned}$$

ΔW_{EVRS} is the offset to a world height system. The relation to a world height system with $W_0 = U_0$ needs the knowledge of the sea surface topography and the deviation in the NAP in connection with the normal potential at the mean Earth ellipsoid U_0 (at present $U_0 \sim 62636856\ m^2 \cdot s^{-2}$) at a cm-accuracy level.

5. Relations between national height systems in Europe and the EVRS2000 datum (NAP)

As already mentioned in clause 2 three different kinds of heights (normal heights, orthometric heights and normal-orthometric heights) are used in Europe. Examples for the use of orthometric heights are Belgium, Denmark, Finland, Italy and Switzerland. Today normal heights are used in France, Germany, Sweden and in most countries of Eastern Europe. In Norway, Austria and in the countries of the former Yugoslavia normal-orthometric heights are used.

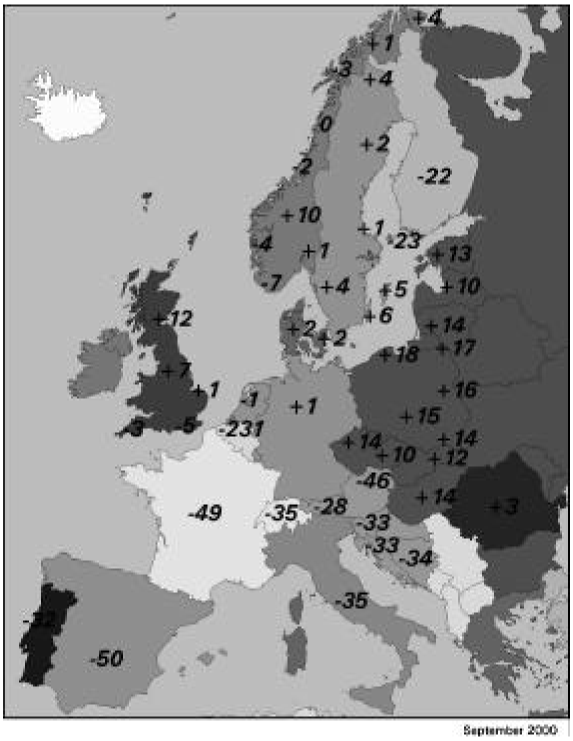

Figure 3: Differences between EVRF2000 zero level and the zero levels of national height systems in Europe (in cm)

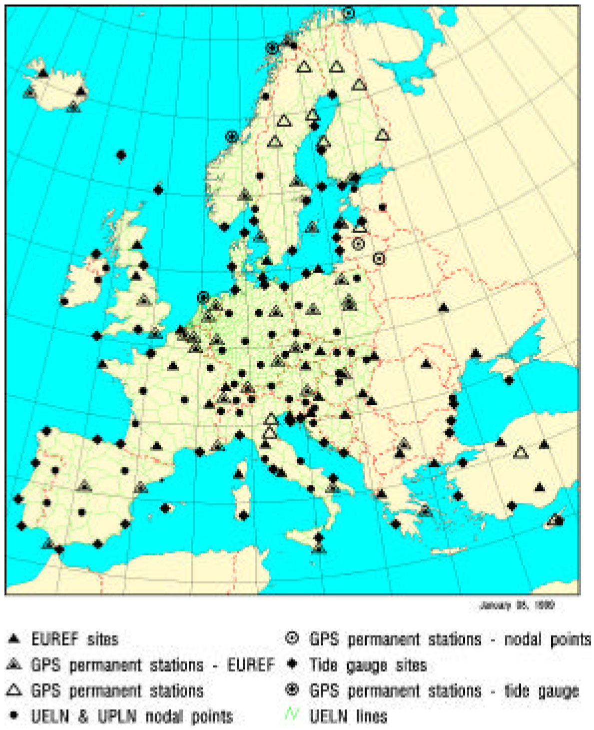

Figure 4: The European Vertical Reference Network

The vertical datum is determined by the mean sea level which is estimated at one or more tide gauge stations.

The reference tide gauge stations to which the zero levels of the national European height systems in Europe are related are located at various oceans and inland seas: Baltic Sea, North Sea, Mediterranean Sea, Black Sea, Atlantic Ocean. The differences between the zero levels can come up to several decimeters. (cf clause 1)

Figure 3 shows the distribution of the mean transformation parameters from the national height systems to the EVRF2000.

6. European Vertical Reference Network (EUVN)

The EUVN is an integrated spatial network: At all EUVN points three-dimensional coordinates and geopotential numbers are derived. In addition to the geopotential numbers the corresponding normal heights are provided. In the tide gauge stations the connection to the sea level is realized. Finally the EUVN is representing a geometrical-physical reference frame. (Figure 4)

The initial practical objective of the EUVN project was to unify different national height datums in Europe within few centimeters also in those countries which were not covered by the UELN. Additionally this project was thought as preparation of a geokinematic height reference system for Europe and a way to connect levelling heights with GPS heights for the European geoid determination.

In total the EUVN consists of about 196 sites: 66 EUREF and 13 national permanent sites, 54 UELN and UPLN (United Precise Levelling Network of Central and Eastern Europe) stations and 63 tide gauges.

The final GPS solution was constrained to ITRF96 coordinates (epoch 1997.4) of 37 stations. For many practical purposes it is useful to have the ETRS89 coordinates available. To reach conformity with other projects, the general relations between ITRS and ETRS were used. The connection levellings and normal heights are given in UELN-95/98.

7. Relations between ITRS and EVRS/WHS

Table 1 shows the comparison of the conventions, the parameters and the realization between the International Terrestrial Reference System (ITRS) and the European Vertical Reference System (EVRS) which is defined as a world height system but realized as a continental vertical system. Only the origin of both is identical defined. For a height system a zero level surface has to be agreed. W_0 as zero level has the advantage that it is in difference to the semi-major axis and the flattening of the mean earth ellipsoid independent from the tidal system. The main difference has to be considered at the realization: The ITRS/ITRFxx coordinates are given in the noon tidal system, the EVRS heights are given in the zero tidal system.

Table1: Relations between ITRS and EVRS/WHS (conventions, parameters, realization)

ITRS IUGG Resolution No. 2, Vienna 1991	WHS/EVRS IAG Subcommission for Europe, Resolution No. 5, Tromsö 2000
origin	
(Explicit) Geocentric, the center of mass being defined or the whole Earth, including oceans and atmosphere.	*(Implicit)*
orientation	
Initial BIH orientation.No global residual rotation with respect to horizontal motions at the Earth´s surface.	No necessary convention
units-scale	
SI unit meter The ITRS scale consistent with the Geocentric Coordinate Time (TCG)	SI units meter and seconds. The scale of the Earth body W_o is approximated by the normal potential of the mean Earth ellipsoid U_o which includes the masses of the oceans and the atmosphere.
coordinates	
quasi-Cartesian system X	potential of the Earth gravity field $W_P = W(X) = U_P + T_P$ (GPM) $= W_O - C_P$ (Levelling)
system parameters	
	mean Earth ellipsoid (U_o, GM, J_2, ω
realization	
ITRF 2000 tide-free	EVRF 2000 (UELN 95/98, ETRS89, GRS 80) $W_p = W_{NAP} + C_p$ (Levelling) , zero tidal system

8. Components for the height parameter combination

Table 2: Components for height parameter combination and their dependence from tidal systems

	gravity **g/Dg**	**geoid** **W/N**	**levelling height** **DH**	**altimetry** **h**	**mean sea level** **msl**	**position** **X/h**
Mean tidal system **Mean/zero crust** (Stokes is not valid if masses outsite the Earth surface)	Δg_m	N_m	ΔH_m	Relation to N_m for oceanographic studies	h_{msl}	
Zero tidal system **Zero/mean crust** (Recommended by IAG Res. No. 16, 1983)	Δg_z —Stokes→	N_z (EGG97)	(EVRF2000) ΔH_z			
Non-tidal system **Non-tidal crust** (far away from the real earth shape – there is no reason for the non tidal concept)	Δg_z —Stokes→	N_n (EGM96)				X_n ITRFxx, ETRS89

The EVRS is a zero tidal system, conforming to the IAG Resolutions No 16 adopted in Hamburg in 1983 and to the handling of the gravity data. In contradiction to this the ITRFxx coordinates are given in the non-tidal system, the same is with the global geopotential model EGM96. The European geoid was reduced to the zero tidal system. The non-tidal system/crust is far away from the real Earth shape - there is no reason for the non tidal concept. The Stokes formulae is not valid for the mean tidal system, but the mean sea level is reduced to the mean/zero geoid for oceanic studies. (Mäkinen, 2001)

9. Conclusions

This contribution has shown that there is a need for a common geometric/physical terrestrial reference system for the combination of geometric and earth gravity field related observations.

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