Definition and Realization of Vertical Reference Systems –The European Solution EVRS/ EVRF 2000 –

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Key words: Precise Levelling, Vertical Datum, European Vertical Reference System UELN, EUVN

Abstract:

The European Subcommision on Continental Network EUREF was urged by the European Council to deliver European wide solutions for the georeference of common cartographic data. In the field of horizontal reference systems a new solution is available coming from ITRS/ ITRFxx. EUREF has defined the epoch 1.1.1989 as European Terrestrial System (ETRS) in 1989 and realized it as frame (EUREF) by densification and maintenance of the ITRF.

Vertical reference systems realized by precise levellings do not allow new continental or global solutions in a short span of time. Therefore existing data with precise levellings was used and combined as United European Levelling Net (UELN) 95/98 (static solution). In addition a geokinematic solution using repeated levellings and also other height relevant observations is in preparation under the name "European Vertical System (EVS) 2000". In 1997 the European Vertical Reference Network (EUVN) 97 was realized which combines the geoid, the ellipsoid and the sea level in European wide distributed stations.

All these parts are put together in the European Vertical Reference System (EVRS) which is defined as world height system and realized as continental frame. The following paper describes the present status.

Zusammenfassung:

Neue technische Möglichkeiten und politische Änderungen haben oftmals auch Auswirkungen auf einzelne Verfahrenslösungen. Im Bereich der geodätischen Grundlagen hat dies zum Aufbau eines neuen Lage-, bzw. 3D-Bezugssystems geführt, das basierend auf der globalen Lösung des Internationales Terrestrischen Referenzsysteme ITRS/ ITRF 89, Epoche 1.1.1989 als europäisches Bezugssystem ETRS 89 mit der Realisierung ETRF 89 vorliegt. Im Bereich der Höhe wurde von den europäischen Landesvermessungsbehörden eine vergleichbare Lösung erwartet, die auch hier eine europaweit einheitliche Georeferenzierung kartographischer Daten ermöglicht. Da sich physikalische Höhenmessungen nicht so schnell durchführen lassen, wurde auf bestehende Datensätze zurückgegriffen. In Westeuropa lagen sie als United European Levelling Net (UELN, letzter Aufbereitungsstand UELN 73/87) als Zusammenfassung nationaler Datensätze bereits vor. In Osteuropa bestand zwar das United Precise Levelling Network of Central and Eastern Europe (UPLN) mit den beiden geschlossenen Neumessungen in den Fünfziger und Siebziger Jahren. Sie mussten jedoch als nationale Blöcke dem westeuropäischen Datensatz angegliedert werden, da der zentral benutzte Datensatz nicht zur Verfügung stand. Die neue europäische Subkommission für kontinentale Netze EUREF hat dies nach 1994 unter dem Namen UELN

95/98 getan und statische Ausgleichungen der europäischen Nivellementdaten veranlasst, die durch einen kinematischen Ansatz verfeinert werden sollen [European Vertical System (EVS 2000)]. Parallel dazu wurden die beiden Bezugsflächen Geoid und Ellipsoid über das europaweite European Vertical Reference Network (EUVN) 97 in etwa 200 Punkten verknüpft, zu denen neben Stationen des EUREF-Permanent-GPS-Netzes [European Vertical Permanent GPS (EPN)] auch Pegelstationen und Knotenpunkte des UELN gehören.

Das europäische Höhenreferenzsystem EVRS ist in Analogie zum ETRS89 als globales System definiert. Als derzeitige Realisierung EVRF2000 dient das kontinentale UELN95/98, dem derzeit über 20 nationale Höhennetze angehören. Die Ergebnisse der weltraumgestützten Schwerefeldmissionen CHAMP, GRACE und GOCE werden neue Möglichkeiten der Vereinheitlichung von regionalen und kontinentalen Höhensystemen schaffen.

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1. Introduction

Scientific progress and political changes produce changes in technical procedures. Due to space techniques and GPS for the geodetic mass market a total new solution for horizontal control networks was possible and has meanwhile been realized. In the field of vertical networks identical possibilities are not yet available, but a lot of things have changed or will change in the next decade. Therefore it seems to be useful to think over the concept of vertical datums and networks. The European Subcommission on Continental Networks EUREF where national survey agencies and scientific institutes work together closely was urged by the European Council to deliver European wide solutions for the georeference of common cartographic data (Ihde etal. 2000). This caused height-related activities within Europe since 1994 and led to the present status of a European Vertical Reference System (EVRS) which is described in detail in this paper.

2. Classical solutions in Europe

Vertical reference systems realized with the concept of national precise levelling networks have been in use in Europe since 1860.

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.

Additionally 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 most countries of Eastern Europe.

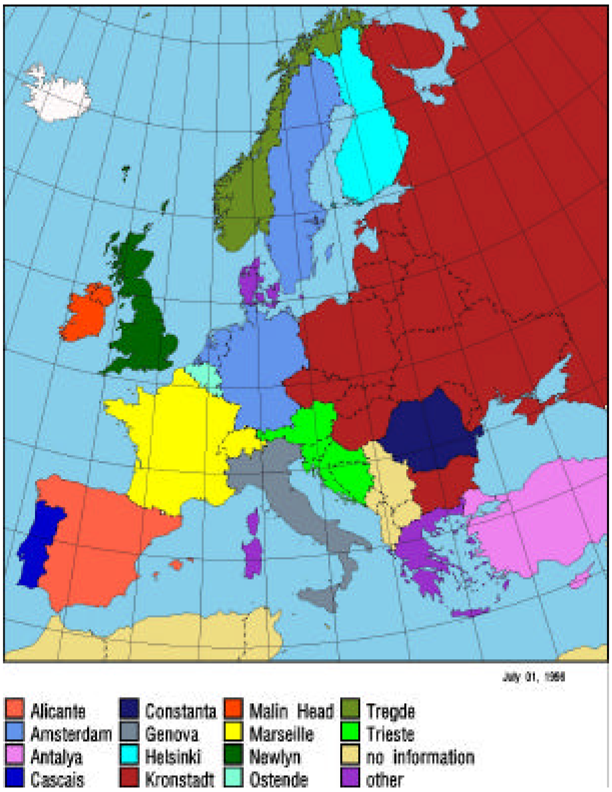

Figure 1: Reference Tide Gauges of National Height Systems in Europe

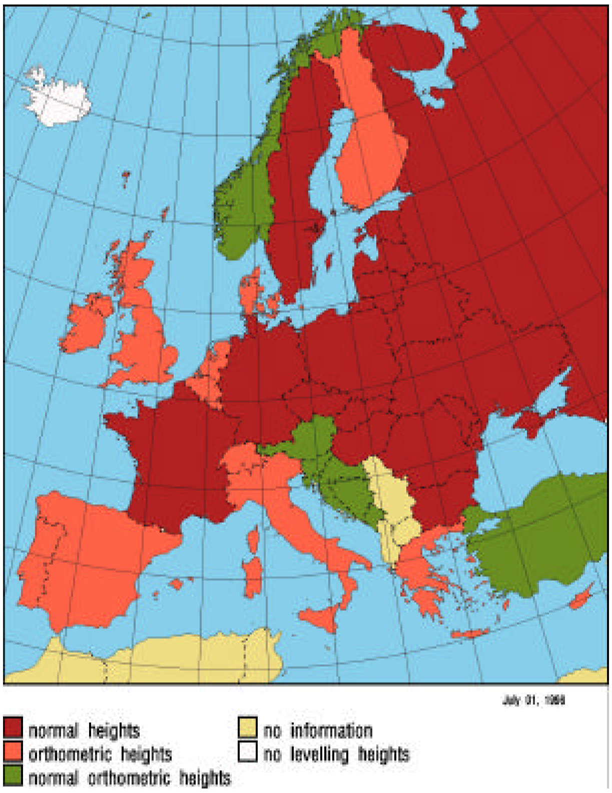

Figure 2: Kind of Heights of National Height Systems in Europe

After 1945 the national systems were unified to continental systems without change of the methodology: gravity related heights coming from precise levelling relative to a tide gauge. Due to political reasons the realization was divided into separate solutions for Western and Eastern Europe (see table 1).

	Western Europe	**Eastern Europe**
zero point	Amsterdam (NAP) (North Sea)	Kronstadt (Baltic Sea)
Height system	no common decision, adjustment with geopotential differences	Normal heights
Use	Scientific use only	National Height System
Data	existing levellings	New measurements
Recent Status	Adjustment 73/86 see Ehrnsperger, Kok (1987)	Total remeasurement 1973-75 (not published)

Table 1: Status 1994 of continental solutions for Vertical Reference Systems in Europe

3. Height-related Activities since 1994

Political changes in Eastern Europe and the ongoing process toward a common Europe led to an urgent request for a common European georeference for cartographic databases. The horizontal solution was realized in 1989 with the European Terrestrial Reference System (ETRS) 1989 which stands for a global solution for Europe coming from ITRS/ ITRF at the epoch 1.1.1989 (Seeger 1992). Meanwhile yearly realizations are available until 2000 as well as extensions to Eastern Europe and permanent supervisions with the EUREF-Permanent GPS Network (EPN) with more than 100 common managed permanent GPS-stations (Bruyninx 2000).

In the field of vertical reference systems the work was resumed in 1994 under the name UELN 95 as a static solution (Augath 1994) and the decision for the development of a kinematic height network [(European Vertical System (EVS) 2000] step by step (Augath 1996).

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. 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 the weights for UELN-95 were derived from a variance component estimation of the observation material which was delivered by the participating countries.

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).

Figure 3: United European Levelling Network 1995 (UELN-95/98 – extended for Estonia, Latvia, Lithuania and Romania)

The development of UELN-95 is characterized by two different kinds of enlargements: The substitution of data material of such network blocks which had already been part of UELN-73 by new measurements with an improved network configuration, and on the other hand by adding new national network blocks of Central and Eastern Europe which had not been part of UELN-73. In the year of 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 of UELN-95/98 are meanwhile available for more than 20 participating countries.

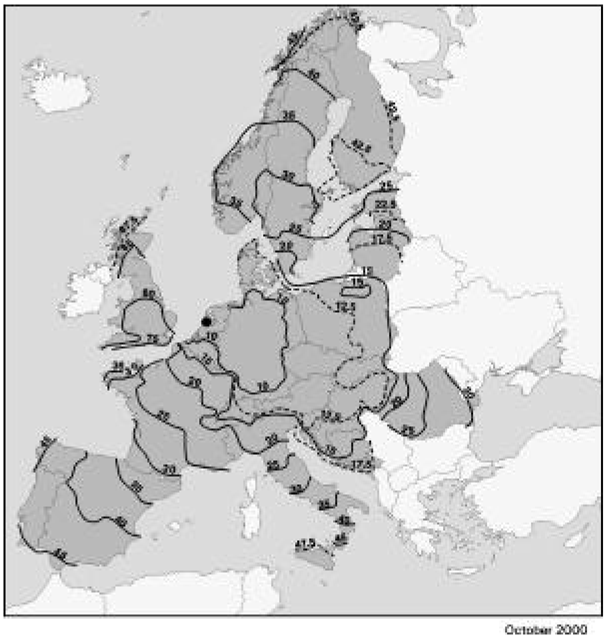

Figure 4: UELN 95)98 – Isoline of Precision [kgal . mm]

In 1997 the European Vertical Reference Network 1997 (EUVN) was realized. 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 a preparation for a geokinematic height reference system for Europe and a way to connect levelling heights with GPS heights for the European geoid determination.

At all EUVN points three-dimensional coordinates in the ETRS89 and geopotential numbers are derived. Finally the EUVN is representing a geometrical-physical reference frame. 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.

In total the EUVN consists of 196 sites: 66 EUREF and 13 national permanent sites, 54 UELN and UPLN 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 official transformation procedures between ITRS and ETRS were used (Boucher, Altamini 1997).

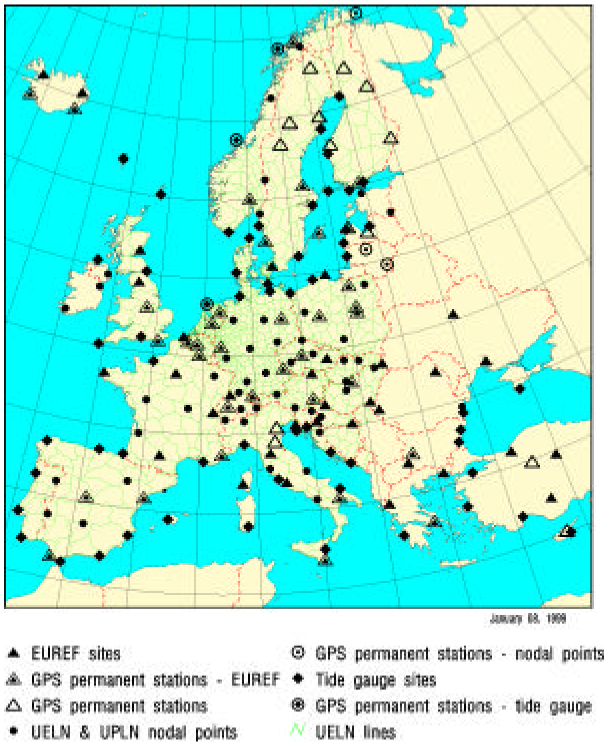

Figure 5: The European Vertical Reference Network

In the year 2000 the connection levellings and computations of normal heights in UELN-95/98 were finished.

4. European Vertical Reference System (EVRS)

4.1 Definition

The main idea of the European Vertical Reference System (EVRS) is correlated with the procedure for 3D-systems:

– clear separation between the definition (EVRS) and the realization (EVRF xx)
– use of global solutions with rigorous transformations for European non-scientific users.

The European Vertical Reference System (EVRS) is a gravity-related 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. Ekmann (2001), Mäkinen (2001).

4.2 The European Vertical Reference Frame 2000 (EVRF 2000)

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 the name EVRF 2000 is now given.

4.3 Relations between the defined and the realized EVRS datum

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

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

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 EVRF 2000 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.

4.4 Relations between the EVRS 2000 datum and datums of National Height Systems in Europe

As already mentioned in Europe three different kinds of heights (normal heights, orthometric heights and normal-orthometric heights) are being used: 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 being used. In figure 6 the differences between national systems and EVRF 200 are put together.

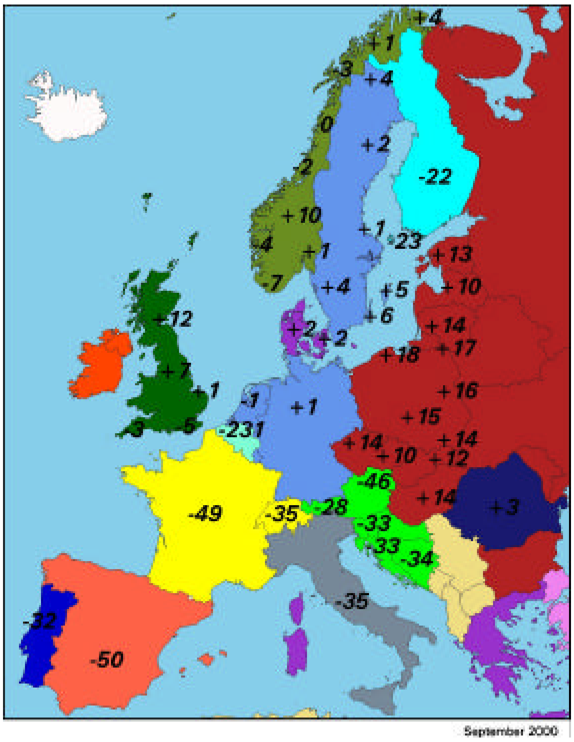

Figure 6: Differences between EVRF2000 zero level and the zero levels of national height systems in Europe (in cm)

4.5 Relations between ITRS and EVRS/ WHS

Table 2 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 identically defined. For a height system (WHS) a zero level surface has to be agreed on. W_0 as zero level has the advantage of being 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 non tidal system, the EVRS heights are given in the zero tidal system.

ITRS	WHS/EVRS
IUGG Resolution No. 2, Vienna 1991	**IAG Subcommission for Europe, Resolution No. 5, Tromsoe 2000**
origin	
(Explicit) Geocentric, the centre 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

Table2: Relations between ITRS and EVRS/WHS (conventions, parameters, realization)

5. Conclusions

The European Vertical Reference System (EVRS) is on its way. Remaining problems with the EVRF 2000 data set have to be seen in the field of identical reduction of all observations into the same system as well as in the missing kinematic component. In this field the project EVS 2000 is processing. With the results of the space based geoid missions as CHAMP, GRACE and GOCE the realization of EVRS has to be thought over.

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