European Vertical Reference System (EVRS) 2007 – a Combination of UELN and ECGN

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EUREF Symposium 2006
Riga, June 2006

Contents/Outline

I. Objectives

II. IVRS Conventions – Status

III. EVRS Realization – Principles and Strategy

IV. Role of ECGN

V. Outlook - The Next Steps

IAG Inter-commission Project (ICP) 1.2 Vertical Reference Frames (2003 – 2007)

Objective:

Provide the fundamentals for the installation of a unified global vertical reference frame.

Tasks:

To elaborate a proposal for the definition and realization of a global vertical reference system (World Height System – WHS)

To derive transformation parameters between regional vertical reference frames

To establish an information system describing the various regional vertical reference frames and their relation to a world height frame (WHF).

I. Objectives of EVRS 2007

- **Request of EC, Consideration of user requirements in Europe**
- **Realization of an up-to-date European Height Reference Frame**
- **Continuation of the previous development of European Vertical Reference System**
- **Guarantee of a 1 cm accuracy level for datum and network realization**
- **Alignment to IVRS/WHS**

II. International Vertical Reference System (IVRS) Conventions

Concepts and Terminoloy

Relationship between gravity field, geopotential field and the spatial reference. Between the geopotential scalar field $W(X)$ and the outer Earth gravity vector field $\vec{g}(x)$ the following relationship is valid:

$$\vec{g} = grad\, W = -g \begin{pmatrix} \cos\Phi & \cos\Lambda \\ \cos\Phi & \sin\Lambda \\ & \sin\Phi \end{pmatrix}, \quad g_P = g(X) = |\, grad\, W_P\, |,$$

with natural coordinates

astronomical latitude Φ

astronomical longitude Λ

potential of Earth gravity field W.

In a very general notation we can express the relationship by

- $P(X, W, g) = P(X, W, -\partial W/\partial H)$ **or**
- $W(X) = W_P$ **collocated with** $g(X) = g_P = -\partial W_P/\partial H$.

The two fields are functions of time in a Euclidian affine space. Therefore we have to consider the time dependence *t:*

$$W_p(t) = W_p^0 + \dot{W}_p^0 (t - t^0)$$

$$g_P(t) = g_P^0 + \dot{g}_P^0 (t - t^0) \quad \text{and}$$

$$X_P(t) = X_P^0 + \dot{X}_P^0 (t - t^0)$$

EVRS 2000 definition (Tromsø)

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 of 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[1], conforming to the IAG Resolutions No 16 adopted in Hamburg in 1983**

datum

geocentric, including oceans and atmosphere

W_0 independent from the tidal system (Bursa)

coordinate system

SI units
$m^2 \cdot s^{-2}$

$W_p = U_p + T_p$ *(BVP)*

$W_p = W_0 - c_p$ *(levelling)*

$$H_n = \frac{c_p}{\bar{\gamma}}$$

frame

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

IVRS Conventions

The International Vertical Reference System (IVRS) definition fulfils the following cnventions:

1. **The vertical datum is defined as the equipotential surface for which the Earth gravity field potential is constant:**

   W_0 = const.

   Earth gravity field potential W_0 shall be conventional.

   Comments: Epoch, procedure of processing

2. **The unit of length is the meter (SI). The unit of time is second (SI). This scale is consistent with the TCG time coordinate for a geocentric local frame, in agreement with IAU and IUGG (1991) resolutions. This is obtained by appropriate relativistic modelling;**

3. **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 CVRS conventional zero level W_0. The potential difference ΔW_P is also designated as geopotential number c_P:**

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

4. **The CVRS is a zero tidal system, in agreement with the IAG Resolution No 16 adopted in Hamburg in 1983.**

Realization of IVRS (IVRF)

Two possible procedures:

$W_p = W_0 - c_p$ ***(levelling)*** *from an adjustment of a levelling network*

$$H_n = \frac{c_P}{\bar{\gamma}}$$

$W_p = U_p + T_p$ ***(BVP)***

from a new GGM (IAG2005, or a combined CHAMP/GRACE model (CG01C) or the new EGM

$$\zeta = \frac{T_p}{\gamma_Q} = \frac{W_P - U_P}{\gamma_Q}$$

and GPS heights h_p

$$H_n = h_P - \zeta$$

III. EVRS Realization – Principles and Strategy

(1) New adjustment of the UELN

(2) Keeping the European vertical datum - NAP level - of UELN95/98 at Epoch 2000

(3) Determination of a W_{0E} at Epoch 2000, fixing it and observe the relationship to a W_0 of a IVRS

(4) Observation of vertical movements of UELN points against the conventional value W_{0E}

(5) Reduction of data - Tidal system

EVRS Realization - Network

(1) New adjustment of the UELN

by

using all current available levelling and gravity observations reducing to the epoch 2000

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

EVRS Realization - Datum

(2) Keeping the vertical datum European NAP level of UELN95/98 at Epoch 2000

by

Fitting the UELN07 (free) adjustment to the UELN95/98 solution by identical points.

Selection of a couple (3 – 15) of identical points for which it can assumed, that they are stable marked and located in the stable part of the European part plate and connected by precise measurements

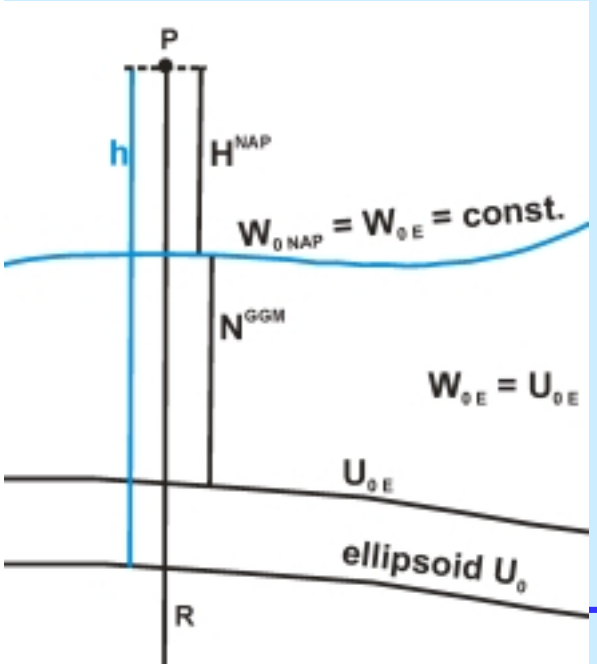
$$\sum_{i=1}^{n} (c_{P2007} - c_{P95/98}) = 0$$

EVRS Realization – IVRS Alignment

(3) Determination of a W_{0E} at Epoch 2000, fixing it and observe the relationship to a W_0 of a IVRS

by

GPS/levelling points of EUVN and ECGN and a European geoid bases on IVRS conventional GGM



$$W_P = W_{0E} - c_P$$

$$W_P = U_P + T_{P\,GGM}$$

$$\text{with} \quad U_P = U_0 + \partial U_0/\partial h \cdot h$$

$$W_P = U_0 + \partial U_0/\partial h \cdot h + T_{P\,GGM}$$

$$W_{0E} = U_0 + \partial U_0/\partial h \cdot h + T_{P\,GGM} + c_P$$

$$W_{0E} = \text{mean } W_{0Ei}$$

EVRS Realization- Time Evolution (i)

(4) Observation of vertical movements of UELN against a conventional value W_{0E}

by

Time series observations of the ECGN as carrier network of the European Vertical Reference Frame and its datum

$$X_P(t) = X_P^0 + \dot{X}_P^0(t - t^0)$$

$$g_P(t) = g_P^0 + \dot{g}_P^0(t - t^0)$$

$$W_p(t) = W_p^0 + \dot{W}_p^0(t - t^0)$$

EVRS Realization - Time Evolution (ii)

Under the condition,

$$v_{hi} = v_{Hi}$$

the velocities of the physical heights H can be derived from time series of the the ITRFxx heights h:

$$H_P(t) = H_P^0 + \dot{h}_P^0 (t - t^0)$$

EVRS Realization – Data Harmonisation

(5) Reduction of data – Tidal System

	gravity g/Δg	geoid W/N	levelling height ΔH	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 **Mean/zero crust** (Recommended by IAG Res. No. 16, 1983)	Δg_z	Stokes → N_z **(EGG97)**	ΔH_z c_p			
Tide-free system **Tide-free crust** (unobservable, far away from the real earth shape – there is no reason for the non tidal/tide free concept)	Δg_n	Stokes → N_n **(EGM96)**				X_n **ITRFxx, ETRS89**

IV. Role of ECGN

Integrated Geodetic Network = 4D Networks

Needs combination of various geodetic methods

- **levelling / repeated (UELN)**

$$\Delta h_{ij}(t_k) + \varepsilon_{\Delta Hijt} = H_{j,ref} + \Delta t_k \cdot v_j - (H_{i,ref} + \Delta t_k \cdot v_{Hi})$$

- **GPS / permanent (EPN)**

$v_{hi} + \varepsilon_{vhi} = v_{hi}$ with the convention $v_{hi} = v_{Hi}$

- **gravity / permanent and repeated**

$$g_i(t_k) + \varepsilon_{git} = g_{i,ref} + \Delta t_k \cdot v_{gi} = g_{i,ref} + \Delta t_k \cdot k \cdot v_{Hi}$$

- **tide gauge / permanent**

$v_{TGi} + \varepsilon_{vTGi} = v_{TGi}$ with the convention $v_{TGi} = v_{hi} = v_{Hi}$

Developments of the ECGN since March 2005

- **April-2005**
  Bologona BOLG (Italy), Trafelberg TRFB (Austria) and Bad Homburg BADH (Germany) get EPN status
- **September 2005**

  The website is new structured and divided in two separate topics and correspondent websites to have a better understanding and access to the information.

  Meta Data Form is additionally as Word-Document (ECGN_meta_data.doc) available.
- **Gravity measurements at several sites: Bologna, Graz, Pfänder, Wettzell, Zimmerwald, Bad Homburg, GOPE, Saßnitz, …**

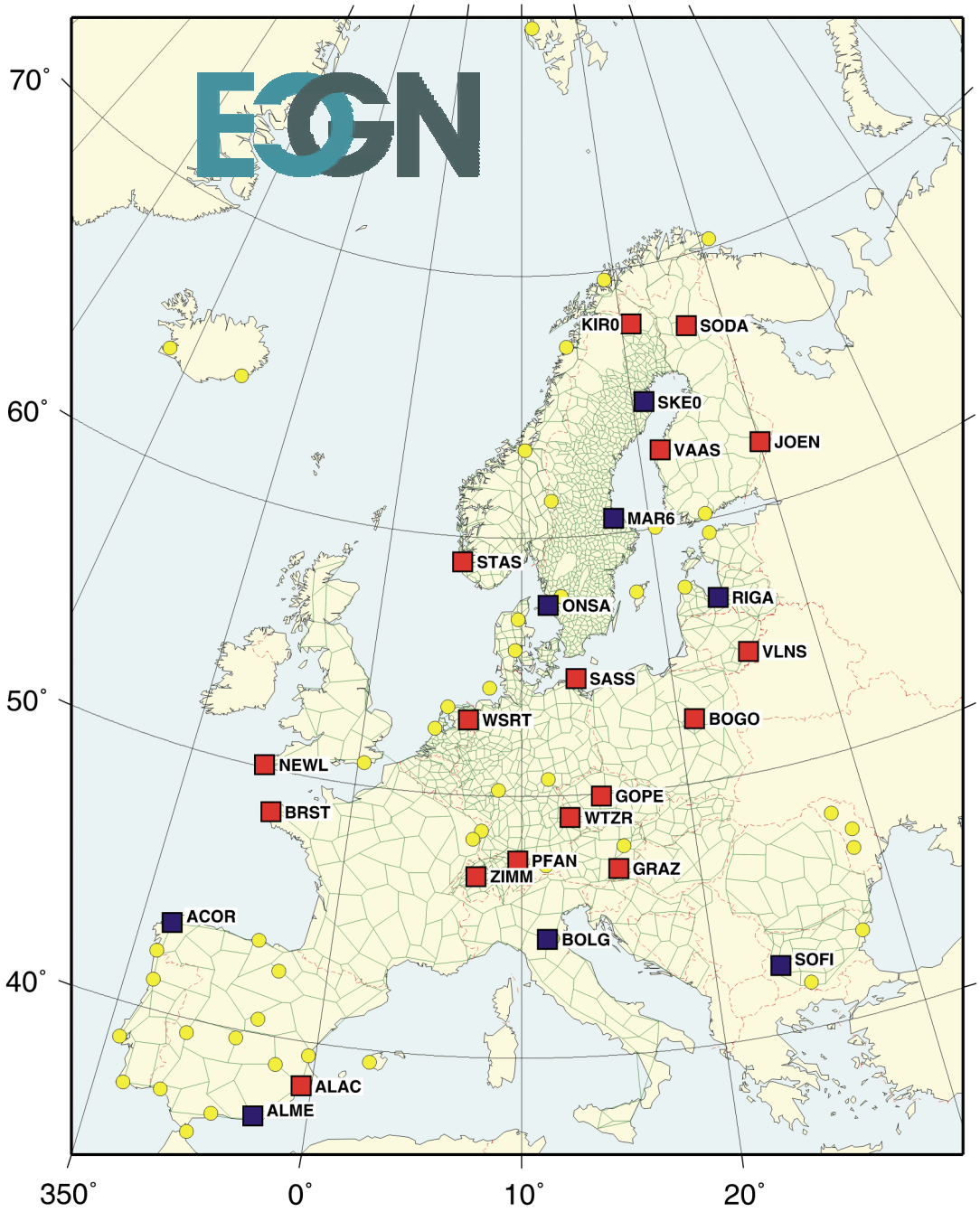
Web: www.bkg.bund.de/ecgn/

(or direct: gibs.bkg.bund.de/ecgn/)

In preparation: Proposal for absolute gravity standardisation and a combined network in an improved reference system (IGFS2006 in Istanbul)

- The present gravity standard is still defined by IGSN71 reference
- Although IAG special study group 3.87 proposed an International Absolute Gravity Basestation Network
- Precise absolute gravity observations are carried out by several international institutions but the cooperation usually remains limited to regional applications
- A proposal for the unification of the global absolute gravity network sites on the basis of already existing projects.
- The standardisation is seen in connection with the requirements of the precise height reference system
- An absolute gravity data base is in construction and will be available end of this year: MySQL, FG5 project data files, selection of meta data informations. A prototype is available and will be introduced at IGFS2006

Selected ECGN stations for EVRS2007 time evolution control



Stations with GNSS, levelling, AG

Desirable additional stations

ECGN stations with missing elements

Parameters of level ellipsoids

ellipsoid	Semi-major axis a in m	flattening f^{-1}	Geocentric gravitational constant GM in $10^8 m^3 s^{-2}$	U_0/W_0 in $m^2 \cdot s^{-2}$	
Int. Ell. 1930 (Hayford)	6 378 388	297	3 986 329		
GRS 67	6 378 160	298.247	3 986 030		
GRS 80	6 378 137	298.257222101	3 986 005	6 263 6860.850	
WGS 84	6 378 137	298.25722356			
IUGG 91	6 378 136.3 0.5		3 986 004.41 0.01		
IERS 2003 Conventions (zero tide)	**6 378 136.6 0.1**	**298.25642 0.00001**	**3 986 004.418 0.008**	**6 263 6856.0 0.5**	
EGM96	6 378 136.3		3 986 004.415		
EIGEN CG01C (tide free)	6 378 136.46		3 986 004.415		

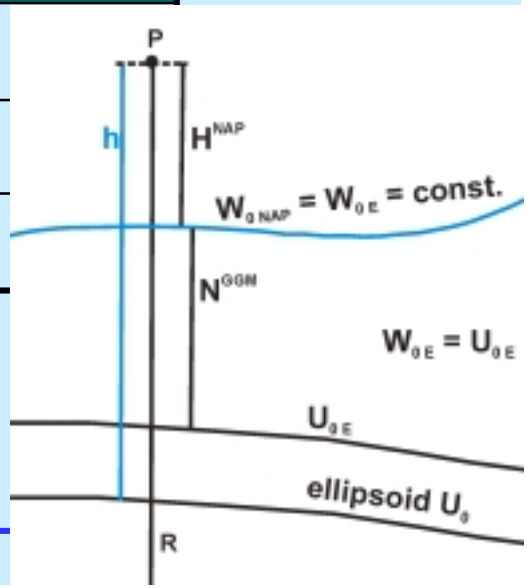
Angular velocity of the Earth rotation ω	7 292 115	10^{-11} rad s^{-1}

GPS/levelling heights compered with GGM´s

Area	No of points	Reference ellipsoid	GGM	RMS	bias*	bias* IERS 2003
EUVN	96	GRS 80	EGM96	0.43	- 0.51	- 0.11
EUVN	96	a = 6378136.3 m	EGM 96	0.43	+ 0.19	
EUVN	96	GRS 80	EGG97	0.19	+ 0.02	
EUVN	96	GRS 80	CG01C	0.28	- 0.61	- 0.21
EUVN (H. Denker)	96	GRS 80	CG03CEG (GRS 80)	0.12	0.40	- 0.13
Germany	680	GRS 80	EGM 96	0.29	- 0.62	
Germany	680	GRS 80	EGG 97	0.10	+ 0.07	
Germany	680	GRS 80	GCG05	0.02	+ 0.01	

*bias = $h^{ETRS} - H^{NAP} - N^{GGM}$

$W_{0E} = 6\ 263\ 6857.28\ m^2\ s^{-2}$



V. Summary and Outlook, Next Steps

- New UELN adjustment 2007, all participating countries are asked to contribute up-to-date data
- Fixing the EVRS2000 datum (NAP)
- Using the ECGN for EVRS time evolution
- Using IAG EGG 2007 solution (on basis of a IAG GGM)
- Alignment to IVRS

V. Summary and Outlook, Next Steps

(1) Selection of identical levelling points

(UELN-DC together with participating countries) *Sept. 2006*

(2) Selection of ECGN/EVRS datum points and determination of all measure elements

(Responsible agencies) *Dec. 2006*

(3) New adjustment of the UELN

(UELN-DC) *Feb. 2007*

(4) Time series analysis of ECGN stations

Beginning Jan. 2007

(5) Full parameter determination with EGG07 and IVRS realization

Sep. 2007

ECGN – CG01C

$$bias = h^{ETRS} - H^{NAP} - N^{CG01C} = U_0 - U_{0E}$$

GRAZ	-0.913
PFAN	-1.072
GOPE	-0.805
FR04	-0.987
WTZR	-0.389
LT02	-0.623
WSRT	-0.585
ES05	-0.649
ZIMM	-1.096
SODA	-0.801
JOEN	-0.736
GB08	-0.855

Statistic		(96 ECGN)
number points:	12	
bias:	- 0.79	(- 0.61)
rms:	0.20	(0.28)
min:	- 1.10	
max:	- 0.39	

Parameters

ETRS89: a = 6378 137 m

a = 6378 136.46 m

GM = 3 986 004.415 10^8 m^3 s^{-2}

(W0 = 6 263 6856.0 m^2 s^{-2})