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

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EUREF Symposium 2006
Riga, June 2006

I. Objectives of EVRS 2007

(1) Request of EC, Consideration of user requirements in Europe

(2) Realization of an up-to-date European Height Reference Frame

(3) Continuation of the previous development of European Vertical Reference System

(4) Guarantee of a 1 cm accuracy level for datum and network realization

(5) Alignment to IVRS/WHS

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

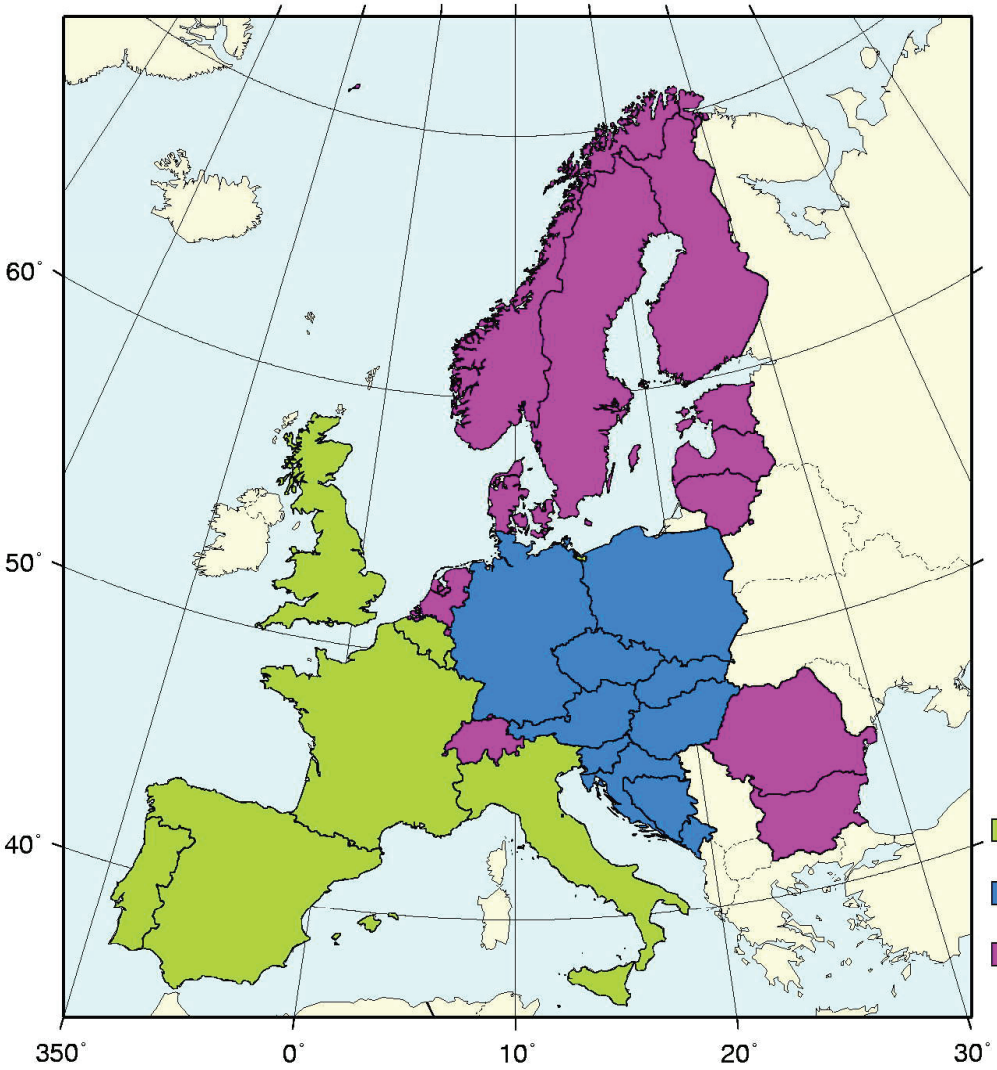
(2) Keeping the vertical datum European NAP level of UELN95/98 at Epoch 2000

by

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

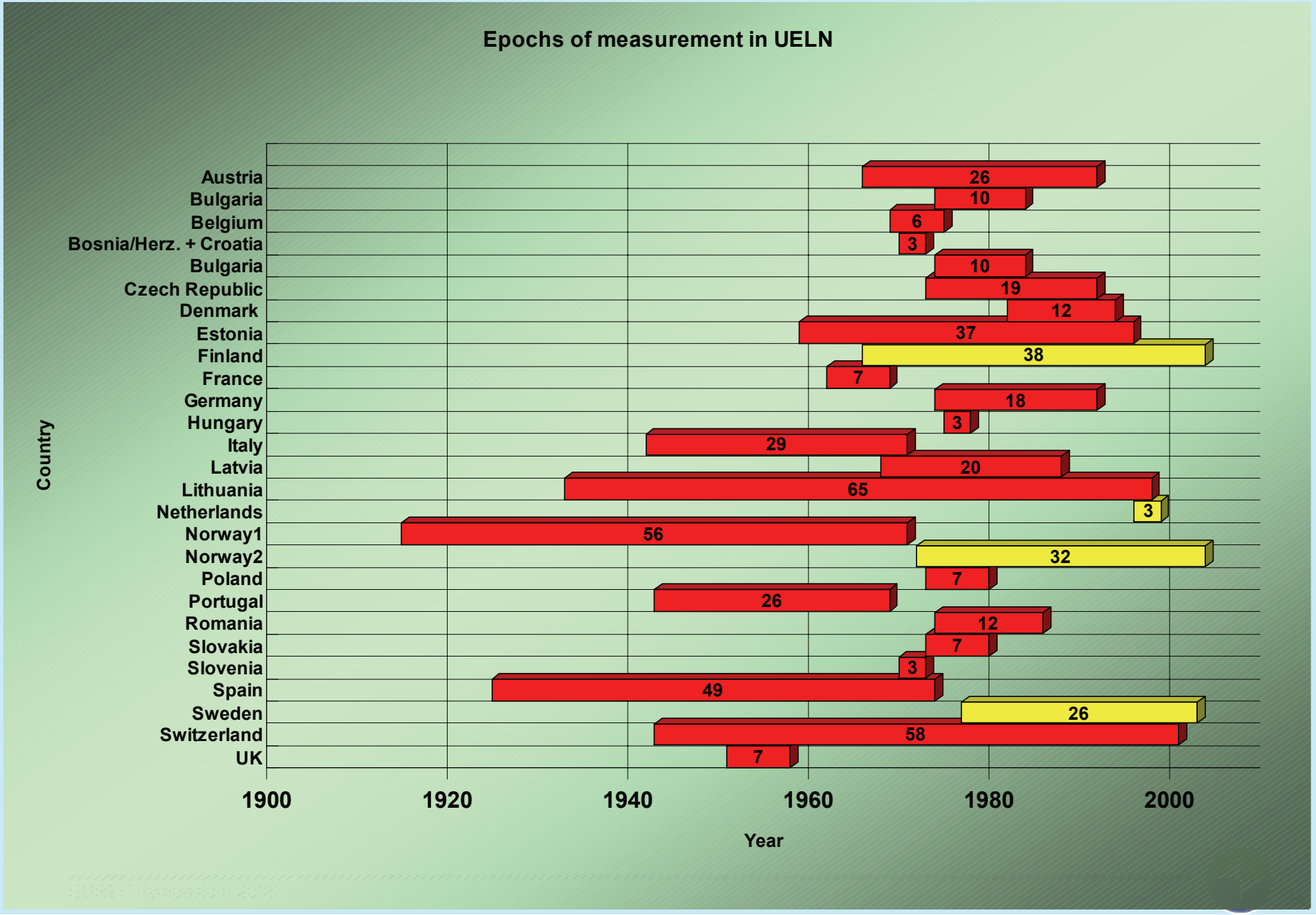
Selection of a couple (3 – 15) of identical points for which it can assumed, that they are stable marked and located in the stable part of the European part plate and connected by precise measurements

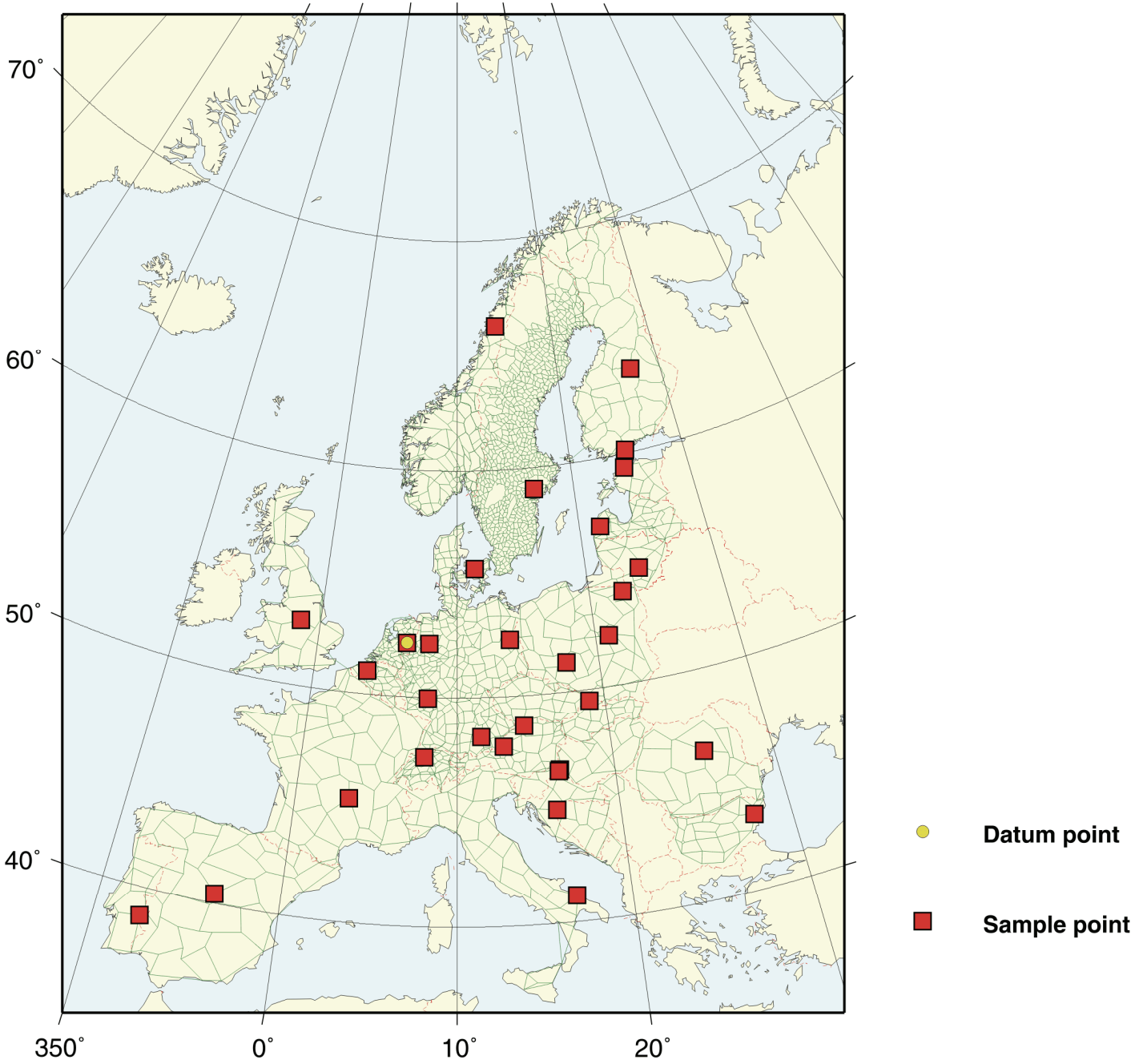
$$\sum_{i=1}^{n} (c_{P2007} - c_{P95/98}) = 0$$

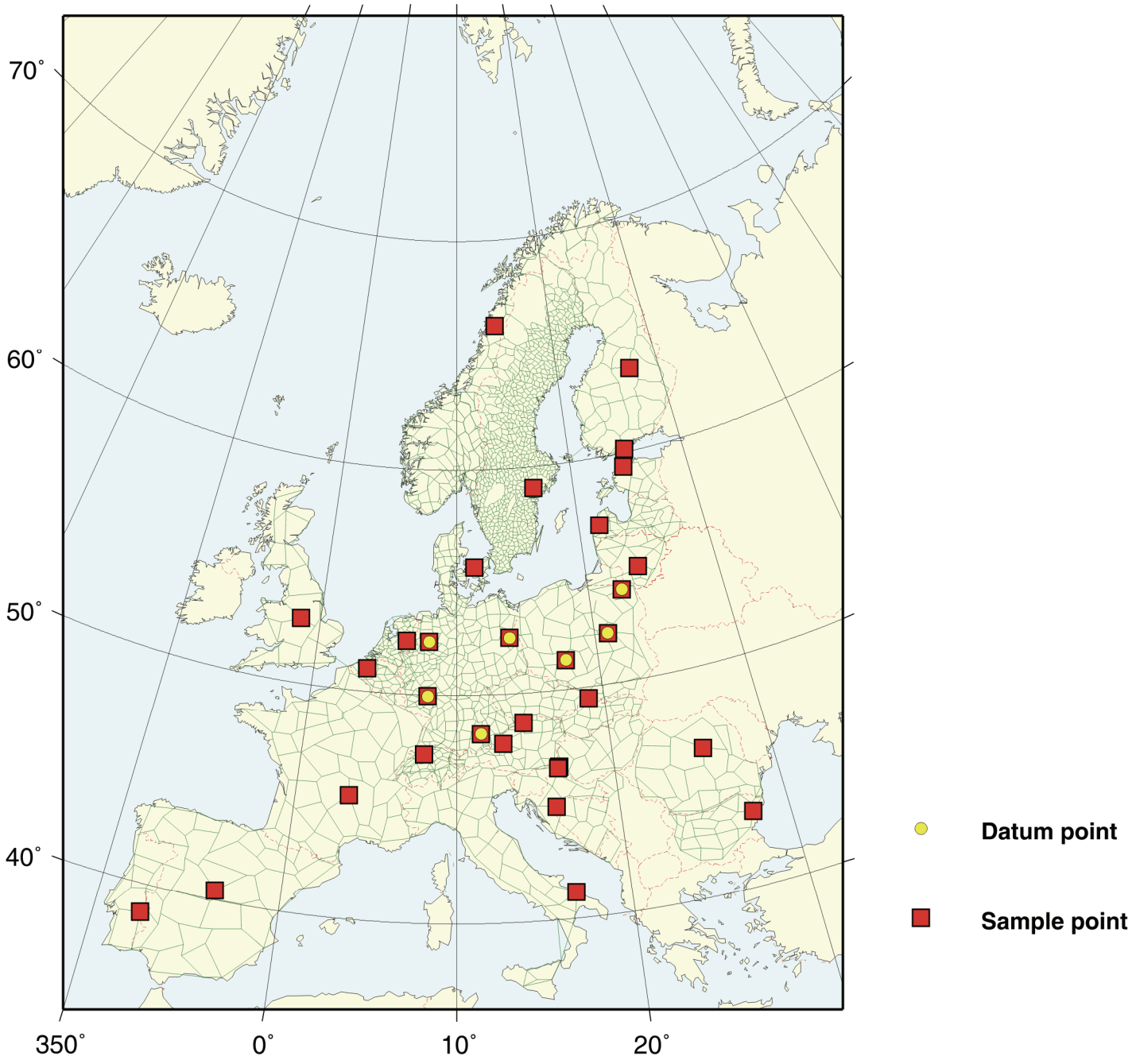


UELN Status April 2006

- Old network blocks – already part of UELN 73/86
- Last changes before handing over of UELN 95/98
- Last changes after 1998


Epochs of measurement in UELN
Country
Austria
Bulgaria
Belgium
Bosnia/Herz. + Croatia
Bulgaria
Czech Republic
Denmark
Estonia
Finland
France
Germany
Hungary
Italy
Latvia
Lithuania
Netherlands
Norway1
Norway2
Poland
Portugal
Romania
Slovakia
Slovenia
Spain
Sweden
Switzerland
UK
26
10
6
3
10
19
12
37
38
7
18
3
29
20
65
3
56
32
7
26
12
7
3
49
26
58
7
1900
1920
1940
1960
1980
2000
Year


70˚
60˚
50˚
40˚
350˚
0˚
10˚
20˚
Datum point
Sample point


70˚
60˚
50˚
40˚
350˚
0˚
10˚
20˚
Datum point
Sample point

UELN Conclusions and Outlook

- New data of first order levelling networks of several European countries have been integrated in UELN since 1998 – especially more than 7000 points of Scandinavia
- additional data are expected
- publishing of a new UELN solution is indicated
- new datum realization is necessary because of considerable height changes in the Netherlands
- the level of the new UELN datum can be defined by the geopotential values of the UELN-95/98 solution of several points in Europe
- the choice of several points in countries with the same measurements as 1998 leads to minimal height variations in the network

EVRS Realization- Time Evolution (i)

(4) Observation of vertical movements of UELN points against a conventional value W0E

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:

$$H_P(t) = H_P^0 + h_P^0(t - t^0)$$

Developments of the ECGN since March 2005

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

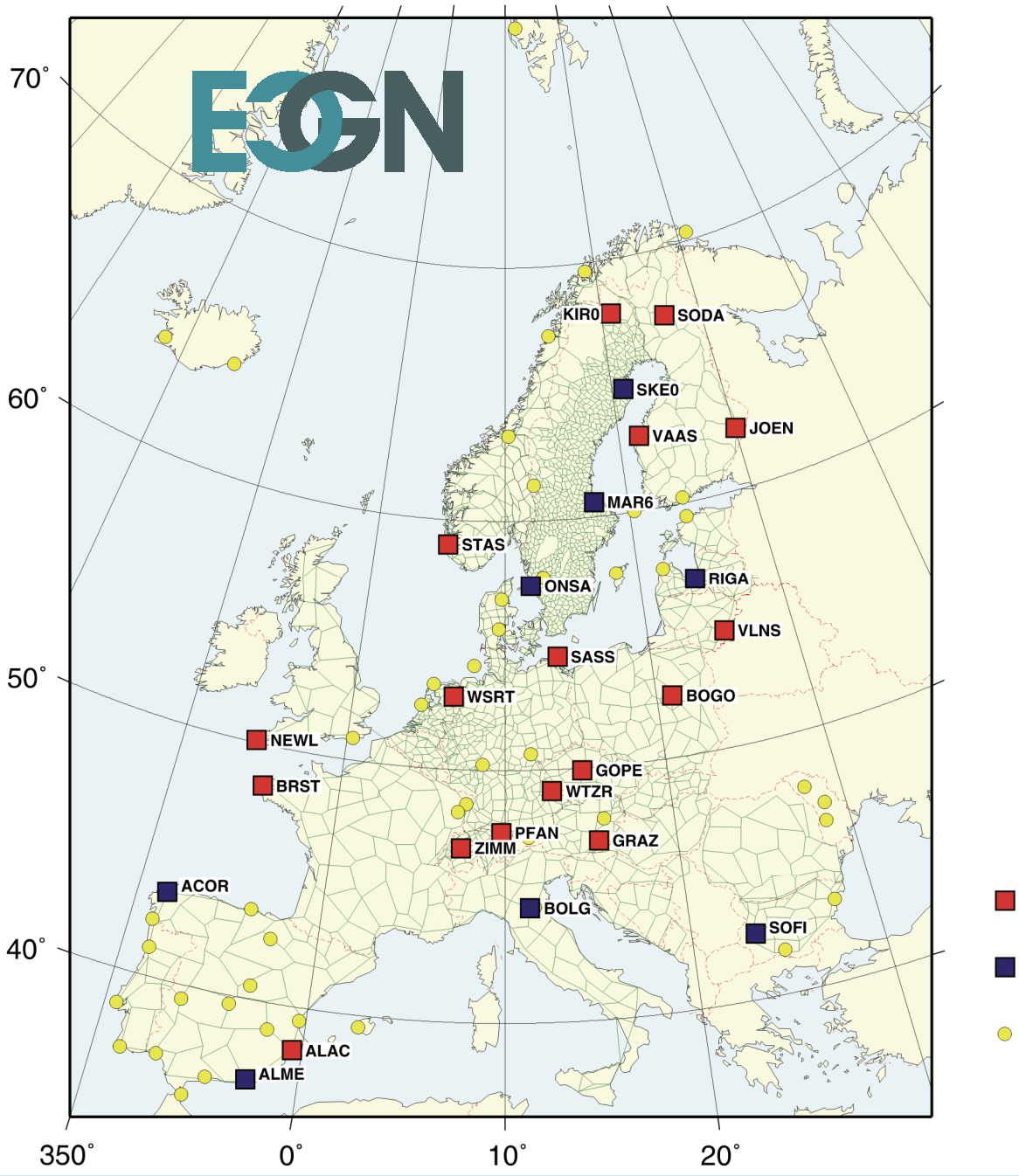
Web: www.bkg.bund.de/ecgn/

(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

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

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

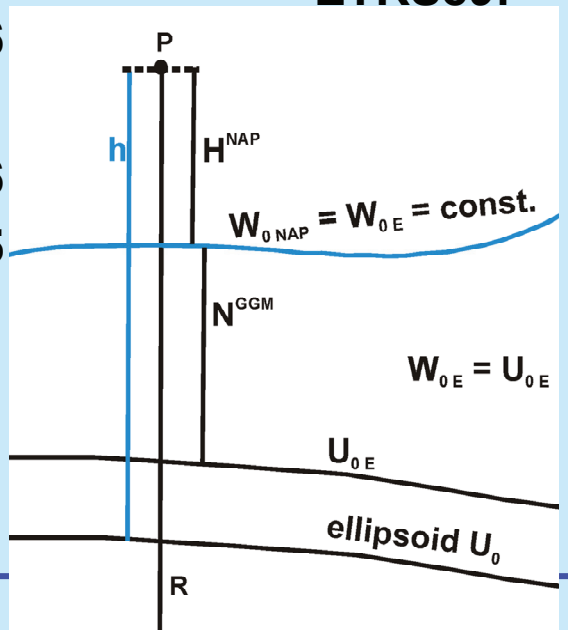
Parameters

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})



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	CG03CEGG (GRS 80)	0.12	0.40	- 0.13
Germany	680	GRS 80	EGM 96	0.29	- 0.62	- 0.22
Germany	680	GRS 80	EGG 97	0.10	+ 0.07	
Germany	680	GRS 80	GCG05	0.02	+ 0.01	

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

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

V. Outlook - The Next Steps

(1) Selection of identical levelling points

Sept. 2006

(2) Selection of ECGN/EVRS datum points

by participating countries and determination of all measure elements

Dec. 2006

(3) New adjustment of the UELN

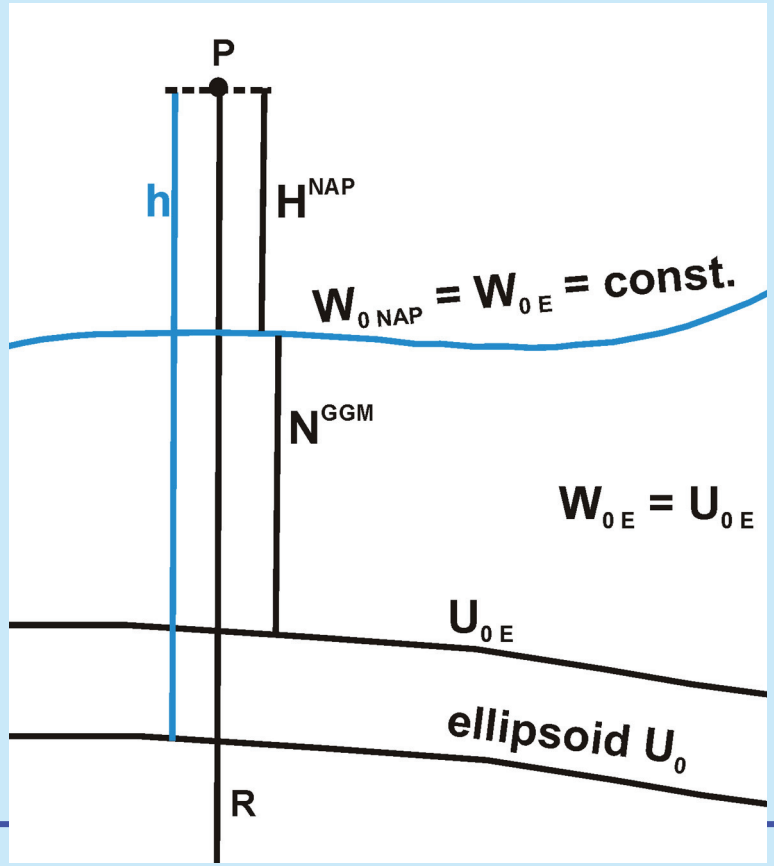
Feb. 2007

(4) Time series analysis of ECGN stations

Beginning Jan. 2007

(5) Full parameter determination with EGG07 and IVRS realization

Sep. 2007


P
h
H^NAP
W0 NAP = W0 E = const.
N^GGM
W0 E = U0 E
U0 E
ellipsoid U0
R

GPS/levelling heights compered with GGM´s

Area	No of points	Refer. ellipsoid	Height datum	GGM	Bias	RMS
Venezuela	150	GRS 80	La Guairo	EGM 96	+ 0.23 m	+/- 0.36 m
Colombia	40	GRS 80	Buenaventura	TEG4	- 2.16 m	+/- 0.06 m
Germany	680	GRS 80	NAP	EGM 96	- 0.62 m	+/- 0.29 m
Germany	680	GRS 80	NAP	EGG 97	+ 0.07 m	+/- 0.10 m
Germany	680	a = 6378136.6 m	W_0 = 62636856 m^2s^2	EGM 96	- 0.09 m	+/- 0.29 m
Europe	160	GRS 80	NAP	EGG 97	+ 0.04 m	+/- 0.20 m
Europe	160	a = 6378136.6 m	NAP	EGM 96	- 0.25 m	

Shape and size of the Earth

Solution	Semi-major axis a in km	flattening f^{-1}	Geocentric gravitational constant GM in $10^8 m^3 s^{-2}$	Remarks
Eratosthenes 230 v.Chr.	6320 (5950)	∞		
Picard 1670	6275	∞		First modern determination
Peru/Lappland Expedition 1735 - 1743	6376,568	310,3		Meter-Definition
Bessel 1830	6377,397155	299,153		
Int. Ell. 1930 (Hayford)	6 378,388	297	3 986 329	
Krassowski 1942	6 378,245	298,3		
Buchar 1958		297,90		Sputnik 2
GRS 67	6 378,160	298,247	3 986 030	IUGG
GRS 80	6 378,137	298,257222101	3 986 005	IUGG
WGS 84	6 378,137	298,25722356		GPS
IUGG 91	6 378,1363 ± 0,0005		3 986 004,41 ± 0,01	

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

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)

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

- 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

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

- Altimetry

- Global gravity model (GGM)

(1.2) Integrated Geodetic Network - 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)

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

- 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

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

- Altimetry

- Global gravity model (GGM)

International Association of Geodesy
Commission 1 *Reference Frames,*
Commission 2 *Gravity Field*

Workshop of
Inter-commission Project 1.2
Vertical Reference Frames

Astronomical Institute
Academy of Science of the Czech Republic

10-11 April, 2006,

Prague, Czech Republic

Gauß-Listing geoid

$$\iint_{\sigma} N^2 d\sigma = \min, \quad \iint_{\sigma} N d\sigma = 0 \,,$$

based on Helmert, (H+M, p. 214, 5-74)

The classical definition of the Gauß-Listing geoid and is the approach for the approximation of the mean Earth ellipsoid

Conditions for W_0 determination. There are several options to align the zero Earth gravity field potential W_0 to the Earth surface/body by minimizing the disturbance potential over

- the geoid *G,* this is the classical definition of the Gauß-Listing geoid and is the approach for the approximation of the mean Earth ellipsoid

  $$\iint_{\sigma} T_G^2 d\sigma = \min, \quad \iint_{\sigma} T_G d\sigma = 0, \qquad (W_0 = U_0)$$

  and equivalent

  $$\iint_{\sigma} N^2 d\sigma = \min, \quad \iint_{\sigma} N d\sigma = 0, \qquad \text{(H+M, p. 214, 5-74)}$$

- the sea surface *S* as

  $$\iint_{S} T_S^2 dS = \min, \quad \iint_{S} T_S dS = 0,$$

- the whole solid and fluid Earth surface σ

  $$\iint_{\sigma} T_p^2 d\sigma = \min, \quad \iint_{\sigma} T_p d\sigma = 0, \text{ equivalent } \iint_{\sigma} (W - W_0)^2 d\sigma = \min, \quad \iint_{\sigma} (W - W_0) d\sigma = 0.$$

EVRS 2006 datum realization

With several selected stable height fundamental points (in minimum 2 per participating countries)

Two ways:

$W_p = W_0 - c_p$ (levelling) *from a former UELN adjustment*

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

$W_p = U_p + T_p$ (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

$$H_n = h_P - \zeta$$

GPS/levelling heights compered with GGM´s

Area	No of points	Refer. ellipsoid	Height datum	GGM	Bias	RMS
Germany	680	GRS 80	NAP	EGM 96	- 0.62 m	+/- 0.29 m
Germany	680	GRS 80	NAP	EGG 97	+ 0.07 m	+/- 0.10 m
Germany	680	a = 6378136.6 m	W_0 = 62636856 m^2s^2	EGM 96	- 0.09 m	+/- 0.29 m
Europe	160	GRS 80	NAP	EGG 97	+ 0.04 m	+/- 0.20 m
Europe	160	a = 6378136.6 m	NAP	EGM 96	- 0.25 m	