

IAG Inter-Commission Project 1.2

Vertical Reference Frames

Minutes of the project meeting

August 31, 2004 Porto, Portugal

Members of IAG ICP 1.2:

See annex 1

Meeting place: University Residence, Faculty of Science, Departamento de Matematica Aplicada (DMA), Rue Campo Alegro 696, room 0.31
Begin: August 31, 2004, 5.30 p.m.; End: 7.30 p.m.

Participants: Matt Amos, Wolfgang Bosch, Alessandro Capra, Robert Cunderlik, Will Featherstone, Petr Holota, Johannes Ihde, Adolfientje Kasenda, Bill Kearsley, Jan Krynski, Gunter Liebsch, Urs Marti, Jaakko Mäkinen, Marcel Mojzes, Dan Roman, Zdislav Sima, Jaroslav Simek, Viliam Vatrt, Marc Veronneau, Marie Vostiskova, Herbert Wilmes

Agenda:

1. Roll call of participants
2. Objectives, program activities, expected results [J.Ihde]
3. Discussion about view to ICP1.2 strategy [V. Vatrt et al.]
4. Agreement about principles for conventions, open questions
5. Information of local reference frames needed for transformation in a regional and global vertical system [G. Liebsch]
6. Actions

Minutes:

1. Objectives, program activities, expected results

J. Ihde gave an overview about the terms of references, the objectives and activities of the ICP 1.2 (see annex 2). Information about the project are available on the IAG home page of Commission 1 (<http://iag.dgfi.badw.de/>).

Main goals of the project are a proposal for the definition of a global vertical reference system and the development of strategies for its realization. A further item is related to regional vertical reference systems. Important topics are the unification of vertical reference networks on a continental scale, the collection of information about regional vertical reference frames and the determination of transformation parameter between various vertical reference frames.

2. Discussion about view to ICP1.2 strategy

The discussion was opened by a presentation of Bursa et al. held by V. Vatrt (Title: "Towards a Global Vertical Reference System (GVRS) and a Global Vertical Reference Frame", annex 3).

They suggested a definition of the GVRS adopting 4 fundamental parameters (W_0 obtained by satellite altimeter observations and a geopotential model, GM, ω and J_2) and the tide reference system (zero-frequency tide, meantide or tide-free system). Estimations for W_0 were presented based on observations of the TOPEX/POSEIDON mission and EGM96. The uncertainty of W_0 was given with $0.3 \dots 0.5 \text{ m}^2\text{s}^2$. These parameters are the basis for the determination of the normal gravity potential and the equipotential ellipsoid and therefore for the derivation of the parameters a, α, γ_e .

For practical applications offsets between the global and regional vertical datum can be determined using GPS/levelling points in sufficiently large areas. The methodology was applied to the territory of the USA and Canada.

After the presentation the discussion was opened. Main items of the discussion were the

- importance of W_0 in the definition of a global vertical reference system,
- necessity of the agreement of W_0 with an equipotential surface, which minimizes the global mean sea-surface topography for certain epoch,
- adoption of a new number for W_0 , respectively the acceptance of existing conventions,
- the importance of tide gauge observations and satellite altimetry for the determination of the mean sea surface and the role of the mean sea surface for the definition and realization of the global vertical reference system as well as the unification of regional vertical reference frames.

J. Krynski argued, that the IERS convention defines the standards, models and procedures for the terrestrial reference system. This conventions bases on resolutions of the IUGG, IAU and IAG. They include a number of W_0 . The current definition is part of many applications

beyond the definition and realization of a global vertical reference system, e.g. time transfer. Therefore, there is no additional degree of freedom for another choice of W_0 .

J. Ihde pointed out, that the number of W_0 is not necessary for the unification of vertical reference frames. According to his opinion the definition of the global vertical reference system should base on a and U_0 . Furthermore, he mentioned the different tidal systems, which are in use for gravimetric applications, levellings and in positioning.

J. Simek emphasized, that the different tidal systems can be converted to each other, but the tidal system must be specified for each data set.

W. Bosch mentioned the limitations of satellite altimetry (sampling, global coverage) and discussed current problems in coastal applications (tidal correction etc.).

This short summary of the debate only reflects the main items of the discussion. Further contributions expressed controversial opinions, but also the broad interest of the participants for this topic.

3. Agreement about principles for conventions, open questions

J. Ihde came up with parts of a proposal for a CHS, WHS, WHF concept. He pointed out different possibilities for the determination of local, regional and global vertical reference frames, the datum realization and their relation to the sea level. D. Roman stressed the importance of regional improvements of the global geopotential models for this purposes. Finally, there was no common agreement about the concepts. (annex 4)

4. Information of local reference frames needed for transformation in a regional and global vertical system

G. Liebsch reported about the progress in the establishment of an information system about the vertical reference frames used in Europe (annex 5). Descriptions of the national vertical reference frames as well as transformation parameters into the European Vertical Reference Frame (EVRF2000) were published in the "Information and Service System for European Coordinate Reference Systems" (<http://www.crs.bkg.bund.de/crs-eu>). The system includes information for the most European countries participating at the United European Levelling Network (UELN). The differences between the vertical reference frames were modelled by a 3 parameter transformation (1 vertical Offset, 2 Rotations in east and north direction). The accuracy of this transformation is less than cm for the most European national height systems. This European Information System could serve as an example for other regions.

5. Actions

A result of the controversial discussion about the definition and realization of a global vertical reference system was the composition of two work packages. The first work package will address

- convention and standards for a Conventional Height System, a World Height System and a World Height Frame
 - relationships to the CTRS, CTRF and gravity standards
 - datum realization (handling of information of the satellite altimetry, possible role of the TIGA project, mean earth ellipsoid versus W_0)

This work package will be executed in collaboration of J. Ihde, J. Krynski (chair), J. Mäkinen and V. Vatrt.

The second work package is related to the unification of height systems and the collection and distribution of information about the different national height systems including transformation parameters. Members of the group are M. Amos, A. Kasenda, Bill Kearsly, G. Liebsch, D. Roman (chair) and Marc Veronneau.

Everybody is asked to contribute to the work packages. Both groups shall present first results till end of March 2005.

The next ICP 1.2 meeting is planned for spring 2005 during the EGS Conference in Vienna on 24.-29.04.2005. First results of our project shall be presented on the IAG Scientific Symposium in Cairns, Australia on 22.-26 August 2005.

Annexes:

1. Mailing list of the members of the IAG ICP 1.2 and the participants of the meeting
 2. Objectives and activities and expected results of the ICP 1.2
 3. Presentation of M. Burša, S. Kenyon, J. Kouba, Z. Šíma, V. Vatrt, M. Vojtíškova:
Towards a Global Vertical Reference System and Global Vertical Reference Frame
 4. Presentation of J. Ihde: Agreements about principles for conventions, open questions.
 5. Presentation of G. Liebsch about the extension of the “Information and Service System
for European Coordinate Reference Systems” for the height component.

Keeper of the minutes: G. Liebsch, BKG
November 2004

Annex 1

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Annex 2: Objectives, Program Activities, Expected Results

Based on the classical and modern observations, the ICP1.2 on Vertical Reference Frames shall study the consistent modelling of both, geometric and gravimetric parameters, and provide the fundamentals for the installation of a unified global vertical reference frame.

Objectives

- 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).

Program of Activities

- Harmonization of globally used height data sets;
- Study of combination procedures for height data sets from different techniques;
- Study of information on regional vertical systems and their relations to a global vertical reference system for practical applications;
- Unification of regional (continental) height systems.

Actions, Structure of Work, Work Packages

- Definition (WHS) Conventions for datum, codes, time dependent variations, parameters
- Realization (WHF) Conventions and specification for procedures of computations (data reductions, selections of alternatively procedures), selection of data, station distribution
- Realization of a WHF prototype
- Relationship between existing VRF and WHF
- Combination of WHF and ITRF (consistency)
- WHF Meta data information system
- Promotion ICP1.2
- Cooperation with other IAG sub-commissions and projects

Annex 3: Presentation of

M. Burša, S. Kenyon, J. Kouba, Z. Šíma, V. Vatrt, M. Vojtíškova:
Towards a Global Vertical Reference System and Global Vertical
Reference Frame

TOWARDS A GLOBAL VERTICAL REFERENCE SYSTEM (GVRS) AND GLOBAL VERTICAL REFERENCE FRAME (GVRF)

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**Special Study Group
GLOBAL GEODESY TOPICS: SATELLITE ALTIMETRY
APPLICATIONS (SSG GGSA)**

IAG ICP-1.2, PORTO, PORTUGAL

August 30- September 3, 2004

1st STEP: ADOPTING A REFERENCE VALUE W_0

- THEORETICALLY, CAN BE ARBITRARY
- PRACTICALLY, ADVANTAGEOUS WHEN

$$\int_{S_0} (W - W_0)^2 dS_0 = \text{minimum}$$

(S_0 stands for the World Ocean Surface)

Table 1. Yearly mean values of W_0 and $R_\theta = GM/W_0$; based on and EGM96 and Topex/Poseidon altimetry, no IB corrections applied.

Year	Number of points	W_0 [m ² ·s ⁻²]	rms [m ² ·s ⁻²]	R_θ [m]	rms [m]
1993	203 856	62 636 856.157	0.005	6 363 672.5452	0.000 5
1994	206 973	62 636 856.168	0.005	6 363 672.5440	0.000 5
1995	205 746	62 636 856.163	0.005	6 363 672.5445	0.000 5
1996	203 960	62 636 856.158	0.005	6 363 672.5450	0.000 5
1997	216 757	62 636 856.157	0.005	6 363 672.5451	0.000 5
1998	206 803	62 636 856.162	0.005	6 363 672.5446	0.000 5
1999	203 764	62 636 856.162	0.005	6 363 672.5446	0.000 5
2000	208 814	62 636 856.157	0.005	6 363 672.5452	0.000 5
2001	208 402	62 636 856.151	0.005	6 363 672.5457	0.000 5
2002	197 951	62 636 856.149	0.005	6 363 672.5460	0.000 5
1993 -2002	2 063 026	62 636 856.158	0.002	6 363 672.5450	0.000 2

($R_\theta = GM/W_0$ - the geopotential scale factor)

ADVANTAGEOUS PROPERTIES OF W_0 :

- SUFFICIENTLY STABLE (see Table 1)
- INVARIANT WITH RESPECT TO THE TIDAL REFERENCE SYSTEM

ACTUAL ACCURACY:

$$\pm(0.3-0.5) \text{ m}^2\text{s}^{-2} \quad \pm(3-5) \text{ cm}$$

DUE TO THE LIMITING FACTOR:

CALIBRATION ERROR
OF TOPEX/POSEIDON
ALTIMETER SYSTEM $\sim 3-5$ cm

CONSEQUENTLY, THE ROUNDED VALUE
RECOMMENDED (Burša et al., see SSG GGSA papers, especially 2002)

$$\underline{W_0 = (62\ 686\ 856.0 \pm 0.5) \text{ m}^2\text{s}^{-2}} \quad (1)$$

BESIDES $W_0(1)$, THREE OTHER PRIMARY FUNDAMENTAL GEODETIC PARAMETERS SHOULD BE ADOPTED:

$$GM = (398\ 600\ 441.8 \pm 0.8) \times 10^6 \text{ m}^2 \cdot \text{s}^{-2} \quad (2)$$

$$\omega = 7\ 292\ 115 \times 10^{-11} \text{ rad} \cdot \text{s}^{-2} \quad (3)$$

$$J_2 = (1\ 082\ 635.9 \pm 0.1) \times 10^{-9};$$

...in the zero-frequency tide system, (4.1)

or

$$J_2 = (1\ 082\ 666.7 \pm 0.1) \times 10^{-9};$$

...in the mean tide system, (4.2)

or

$$J_2 = (1\ 082\ 626.7 \pm 0.1) \times 10^{-9}.$$

...in the tide-free system. (4.3)

**SPECIFYING THE TIDE
REFERENCE SYSTEM (the zero,
mean, or tide-free) IS REQUIRED
FOR A DEFINITION OF THE
GVRS**

AFTER ADOPTING THE FOUR FUNDAMENTAL CONSTANTS (1) - (4) THE NORMAL GRAVITY POTENTIAL AND THE EQUIPOTENTIAL ELLIPSOID E_θ IS UNIQUELY DETERMINED:

$$E_\theta = E_\theta(GM, \omega, W_\theta, J_2) \quad (5)$$

ON THE BASIS OF THE PIZZETTI's THEOTRY

CONSEQUENTLY, THE THREE UNIQUELY DETERMINED, DERIVED PARAMETERS ARE :

$$a = a (GM, \omega, W_0, J_2) \quad (6)$$

$$\alpha = \alpha (GM, \omega, W_0, J_2) \quad (7)$$

$$\gamma_e = \gamma_e (GM, \omega, W_0, J_2) \quad (8)$$

Table 2. The derived parameters and W_0

TIDAL SYSTEM	a [m]	$1/\alpha$	W_0 [m 2 s $^{-2}$]	γ_e [mGal]
zero	6378136.58	298.25645	62 636 856.0	978 032.672
mean	6378136.68	298.25234	62 636 856.0	978 032.687
tide-free	6378136.55	298.25769	62 636 856.0	978 032.667

AFTER ADOPTING THE REFERENCE W_0 -
value, THE GEOPOTENTIAL DIFFERENCES

$$\delta W_{0i} = W_0 - W_{0i}$$

for the i th LVD SHOULD BE DETERMINED

-A METHODOLOGY WAS DEVELOPED BY
SSG GGSA AND PRACTICALLY APPLIED

-ACCURACY DEPENDS ON THE
RESOLUTION OF THE GEOPOTENTIAL
MODEL (see EGM96R in Table 3 and Fig. 1)

-THERE MAY ALSO BE ADDITIONAL
DISTORTIONS DUE TO SYSTEMATIC
LEVELLING ERRORS etc.

Table 3. EGM96R, according to (NRC, 1997)

<i>s</i> [km]	EGM96R [mm]
10	400.0
100	260.0
200	150.0
400	90.0
600	55.0
1 000	30.0
2 000	10.0
4 000	2.5
6 000	1.0

EGM96R [mm]

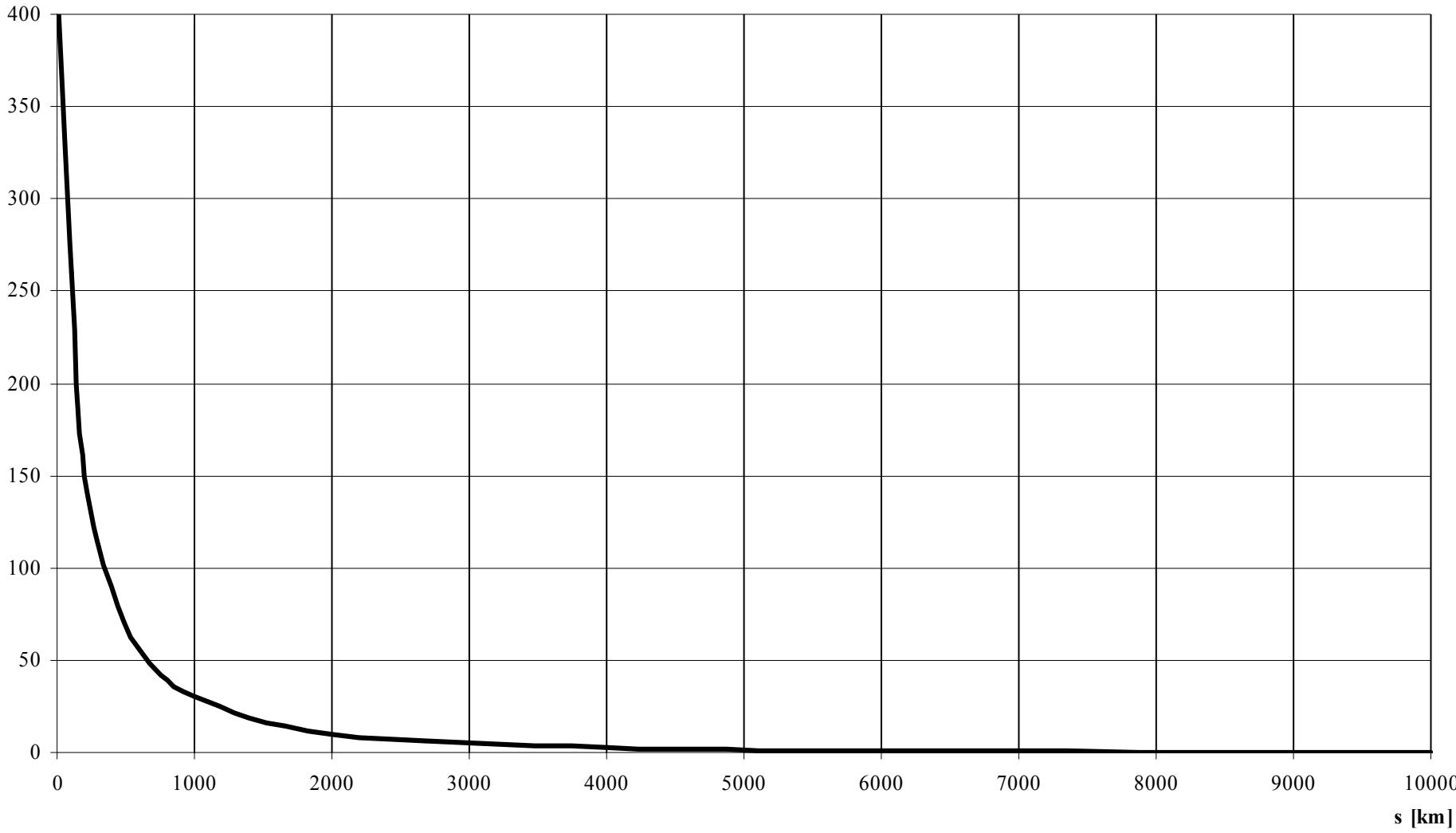


Figure 1. EGM96R, according to (NRC, 1997) ¹²

EXAMPLE OF A SUCCESSFUL APPLICATION OF SSG GGSA METHODOLOGY:

- NAVD 88
- SUFFICIENTLY LARGE AREA, COVERING THE TERRITORY OF U.S.A. AND CANADA
- NORMAL, TIDALLY CORRECTED, HEIGHTS AVAILABLE
- ACCURATE TIDE-FREE GPS COORDINATES AVAILABLE
- TIDE-FREE EGM96

Table 4. Geopotential values $W_{\theta i}$ at the local vertical datums (LVDs); $\delta H_{\theta i}$ is the vertical shift of the LVD origin, related to the reference surface $W=W_0$. EGM96R is the estimated resolution error of EGM96, according to NRC 1997

Territory	LVD i	Number of GPSLS	EGM96R [cm]	$W_{\theta i}$ [$m^2 s^{-2}$]	$W_{\theta i} - W_0$ [$m^2 s^{-2}$]	$\delta H_{\theta i}$ [m]
USA	NAVD88	5168	1.0	$62\ 636\ 861.27 \pm 0.51$	$+5.27 \pm 0.11$	-0.54 ± 0.01
Canada	NAVD88	1311	1.4	$62\ 636\ 861.54 \pm 0.53$	$+5.54 \pm 0.17$	-0.56 ± 0.02

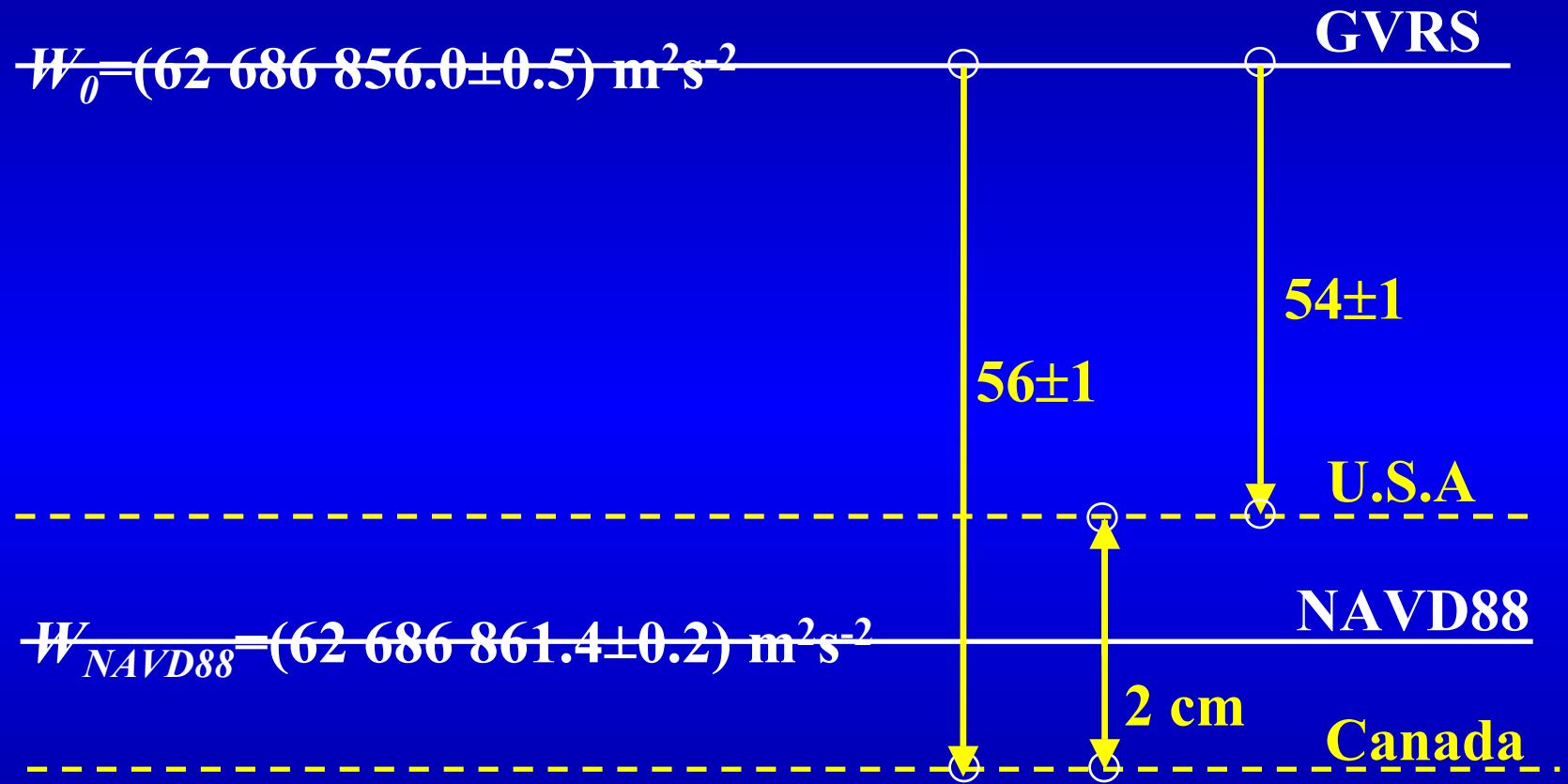


Figure 2. Vertical shifts (in cm) of LVD realizing the NAVD88 vertical system

DISCUSIONS, CONCLUSIONS

- GVRS CAN BE SPECIFIED BY A REFERENCE W_0 -VALUE
- GVRS REQUIRES THAT “PRIME LVDs” BE SELECTED ON SEVERAL CONTINENTS
- TIDAL SYSTEM OF THE GVRS MUST BE SPECIFIED: AN ABSOLUTE NECESSITY
- AREA COVERED BY THE “PRIME LVDs” SHOULD BE SUFICIENTLY LARGE, THE EGM RESOLUTION SHOULD BE SUFICIENTLY HIGH (see Table 3 and Fig.1)¹⁶

- THE “1st ORDER GVRF” BE DENSIFIED USING LEVELLING CONNECTIONS AMONGST LVDs, SITUATED ON THE SAME CONTINENT
- EUROPE: THE MOST SUITABLE IS LVD_{KRONSTADT}, SINCE IT COVERS THE LARGEST AREA OF EUROPE

-ON THE BASIS OF EUVN HEIGHT
SOLUTION (Ihde and Augath: The Vertical
System for Europe, 2001) WE DETERMINED
 $(W_0)_{\text{NAP}} = (62\ 636\ 857.55 \pm 0.61) \text{m}^2\text{s}^{-2}$

-HOWEVER, THE ACTUAL ACCURACY IS
LOWER THAN THE ESTIMATE ABOVE
BECAUSE NOT UNIFORM EUVN DATA
REGARDING THE TIDE SYSTEM

**-ALL THE DATA USED SHOULD BE
UNIFIED IN REGARDS TO THE TIDE
REFERENE SYSTEM**

NOTE THAT CURRENTLY:

**THE GPS COORDINATES:TIDE-FREE
EGM96:
HEIGHTS:
TIDE-FREE
NOT UNIQUE**

SSG GGSA papers on GVRS, GVRF, and W_0

Burša M., Kouba J., Raděj K., True S. A., Vatrt V., Vojtíšková M., 1999a: Determination of the geopotential at the tide gauge defining the North American Vertical Datum 1988 (NAVD88). *Geomatica*, 53, 459-466.

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Burša M., Kouba J., Müller A., Raděj K., True S.A., Vatrt V., Vojtíšková M., 2001: Determination of geopotential differences between local vertical datums and realization of a World Height System. *Studia Geophys. Geod.*, 45, 127-132.

Burša M., Kenyon S., Kouba J., Raděj K., Vatrt V., Vojtíšková M., Šimek J, 2002: World height system specified by Geopotential at tide gauge stations. IAG Symposium, Vertical Reference System. Cartagena, February 20-23, 2001, Colombia, Proceedings, Springer Vlg. 2002, 291- 296.

Burša M., Groten E., Kenyon S., Kouba J., Raděj K., Vatrt V., Vojtíšková M., 2002: Earth's dimension specified by geoidal geopotential. *Studia Geophys. Geod.*, 46, 1-8.

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Burša M., Kenyon S., Kouba J., Raděj K., Šíma Z, Vatrt V., Vojtíšková M, 2004: A Global Vertical Reference Frame based on four regional vertical datums. *Studia Geophys. Geod.*, 48, 493-502.

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Annex 4: Presentation of
J. Ihde.
Agreements about principles for conventions, open questions.

(3) Agreement about Principles for Conventions, Open Questions

CHS, WHS, WHF - Concept, Definition, Realization incl. Unification, Tests

Unification

- Continents – local and regional

- Levelling adjustment

$$W_p = W_0 - c_p \text{ (levelling)}$$

- GGM + GNSS (GPS/lev.)

$$W_p = U_p + T_p \text{ (BVP)}$$

- Global

- GGM + GNSS (GPS/lev.)

GNSS, GGM and levelling in one system



Datum Realization and Relation to Sea Level (SL)

$W = \text{const.}$, MSL

- Local

- MSL at VRS tide gauges**

- Global

- MSL and SST at VRS tide gauges**

- GGM ($W = \text{const.}$) + GNSS + Altimetry (SL)**

GGM, GNSS, Altimetry, SLO in a common system (parameters, data reductions)



Present Situation

- The 3D terrestrial reference system ITRS/ITRF is consistent within 10^{-9} .
- Worldwide there are some hundred physical height systems (on the solid surface of the Earth) realized by
 - different tide gauges (inconsistencies within 2 m range)
 - spirit levelling reduced by different theories (10^{-6})
 - at different epochs
 - and as static systems.
- In the frame of global spatial cm geodesy the physical heights appear as inconsistent elements.



Objectives of a Unified Global Height Reference System

- Integration of global geometric and physical data (ITRF, absolute gravity, satellite altimetry, satellite gravity missions)**
- Data reduction for global solutions**
- Data exchange with other communities**
- Unifications of height datums for navigation engineering, global spatial data infrastructure, ...**



Elements of a physical height system

- i. Reference surface
- ii. Height datum
- iii. Vertical component (height)

- Definitions of the elements
- Conventions for the realization including handling of the time variation of Earth, measurements and parameters

Working concept:

The Earth surface P (solid and fluid) is determined by its geometry X_P and the potential of the Earth gravity field W_P on it at any time.



EVRS Conventions (Definition)

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 :

$$W_0 = U_0.$$

datum

geocentric, including oceans and atmosphere

- 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 - ΔW_P is also designated as geopotential number c_P :

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

W_0 independend from the tidal system (Bursa)

coordinate system

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

$$\begin{aligned} W_p &= U_p + T_p \quad (\text{BVP}) \\ W_p &= W_0 - c_p \quad (\text{levelling}) \end{aligned}$$

Normal heights are equivalent to geopotential numbers.

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

- c) The EVRS is a zero tidal system¹, in agreement with the IAG Resolutions No 16 adopted in Hamburg in 1983

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.

frame



Comparison of EUREF and SIRGAS Concepts

EUREF

EVRS conventions (2000)

- a) Geopotential differences
 - $\Delta W_P = W_0 - W_P = c_P$,
normal h. H_n are equivalent
- b) {EUVN/ETRS89}
- c) $W_0 = U_0$ (mean Earth ellipsoid)
- d) $W_P = U_P + T_P$
- e) zero tidal system
- f) Realization at present by UELN (lev., NAP) {ECGN}

SIRGAS

WG III „Vertical Datum“ (2001)

- a) Geopotential numbers c_p normal heights H_n
- b) ellipsoidal heights h in ITRF
- c) W_0 from a global gravity model (GGM)
- d) T_P from a GGM (quasigeoid)
- e) time dependent (velocities)
- f) Realization by a set of fundamental stations



Height Components and Tidal Systems

	gravity $g/\Delta g$	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 outside 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	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	N_n (EGM96)			X_n ITRFxx, ETRS89	



Open questions, structure of work

- **Definition (WHS) Conventions for datum, codes, time dependent variations, parameters**
- **Realization (WHF) Conventions and specification for procedures of computations (data reductions, selections of alternatively procedures), selection of data, station distribution**
- **Realization of a WHF prototype**
- **Relationship between existing VRF and WHF**
- **Combination of WHF and ITRF (consistency)**
- **WHF Meta data information system of transformation parameters**
- **Publications, papers, posters and leaflet**
- **Public relations, home page**
- **Cooperation with other IAG sub-commissions and projects**



Annex 5: Presentation of
G. Liebsch
Extension of the “Information and Service System for European
Coordinate Reference Systems” for the height component

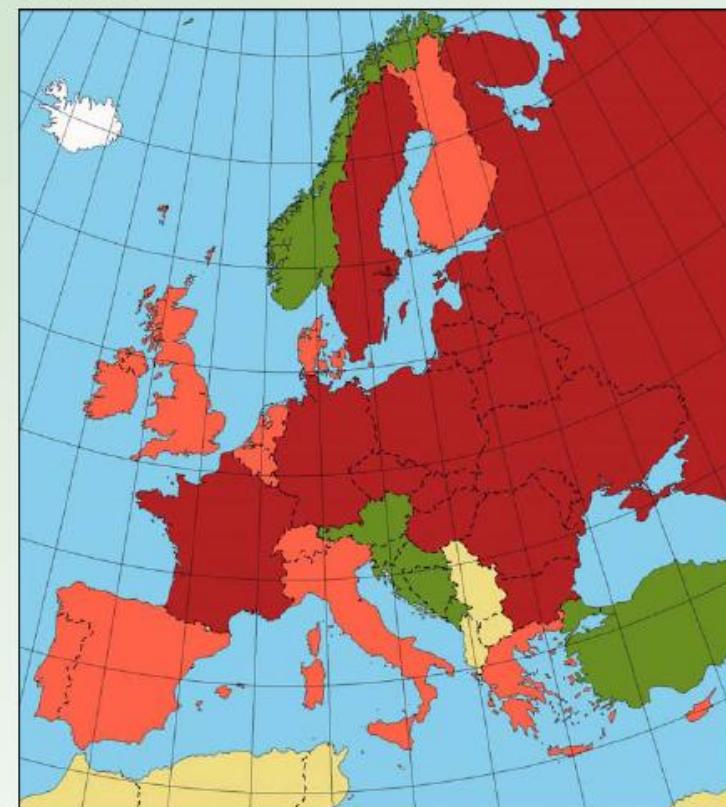


Height Systems in Europe

Reference Tide Gauges of National Height Systems in Europe



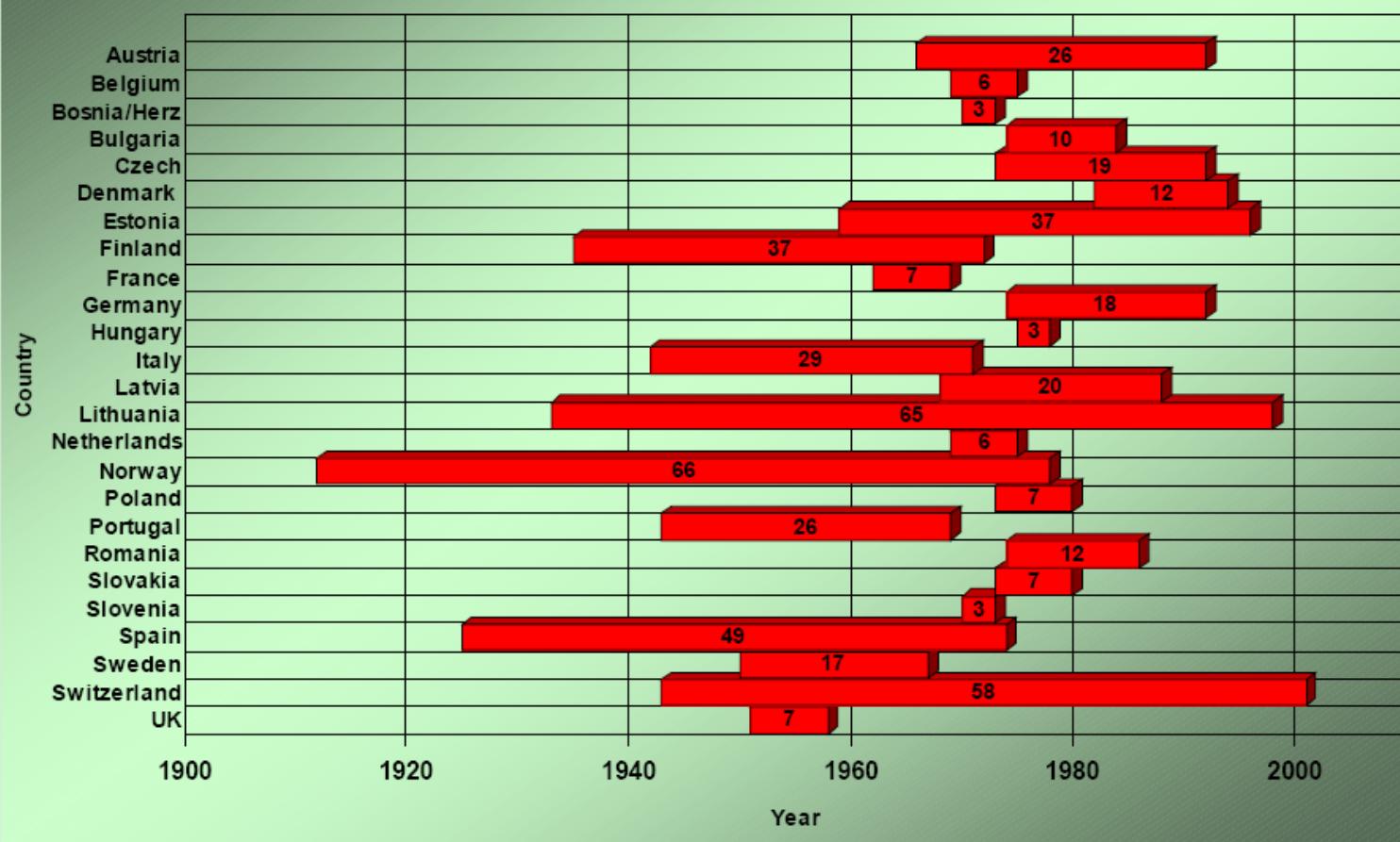
Kind of Heights of National Height Systems in Europe



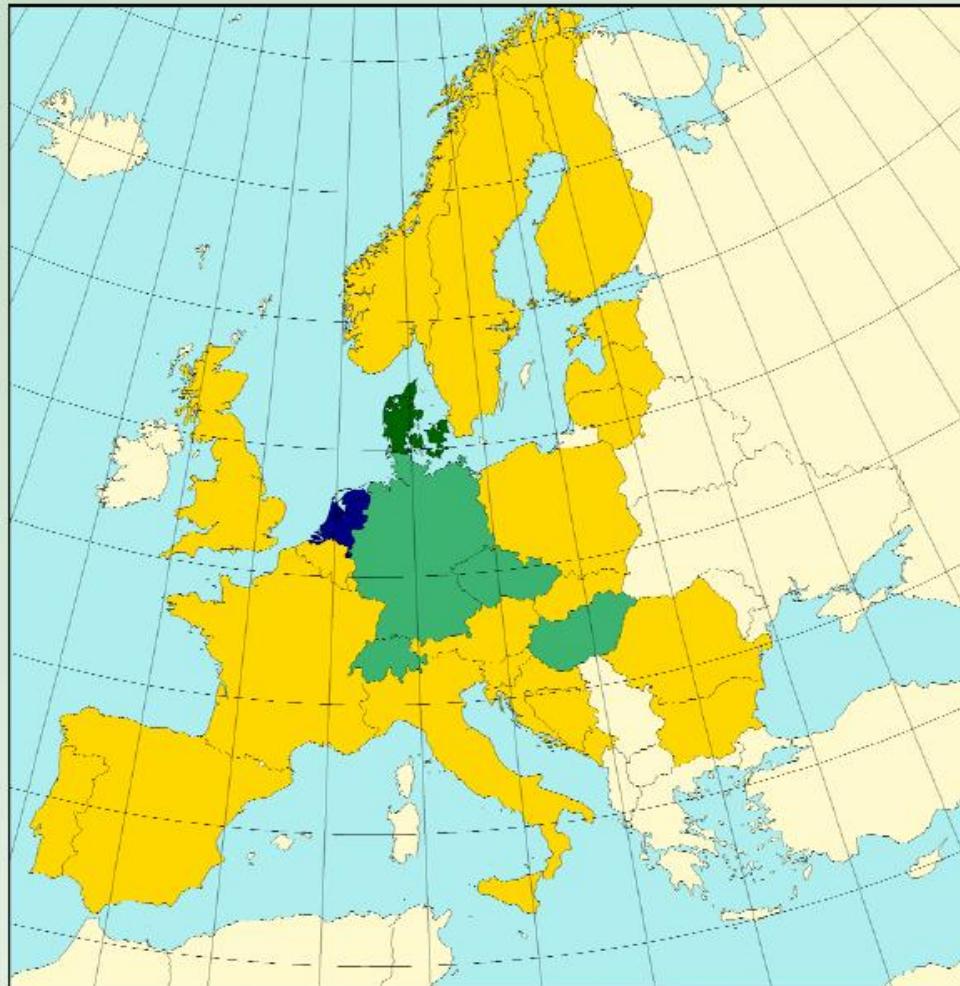
Legend for Kind of Heights:

- normal heights (Dark Red)
- orthometric heights (Red)
- no information (Yellow)
- no levelling heights (White)
- normal orthometric heights (Green)

Measurement epochs of UELN 95



Number of Epochs in the UELN Data Base



October 2003

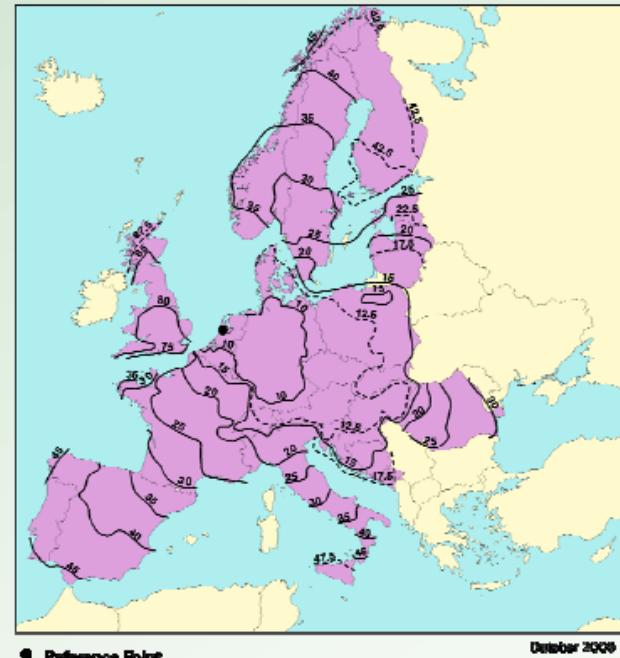
- no measurements
- one epoch
- two epochs
- three epochs
- four epochs

UELN95/98 the EVRS Frame EVRF2000

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



United European Levelling Network 1995
(UELN-95/98)



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

3-Parameter-Height-Transformation

similarity transformation with 1 translation and 2 rotations:

$$H(II) = H(I) + a_1 + a_2 \cdot M_o \cdot (LAT - LAT_o) + a_3 \cdot N_o \cdot (LON - LON_o) \cdot \cos(LAT)$$

$H(I)$: height in the source system [m]

$H(II)$: height in the target system [m]

M_o : radius of curvature in the meridian of GRS80 [m] in P_o

N_o : radius of curvature perpendicular to the meridian of GRS80 [m] in P_o

LAT: latitude in ETRS89 [radian]

LON: longitude in ETRS89 [radian]

$P_o (LAT_o, LON_o)$: Reference point of the transformation

a_1 ...vertical translation [m]

a_2 ...slope in the direction of the meridian, positive when up northwards [radian]

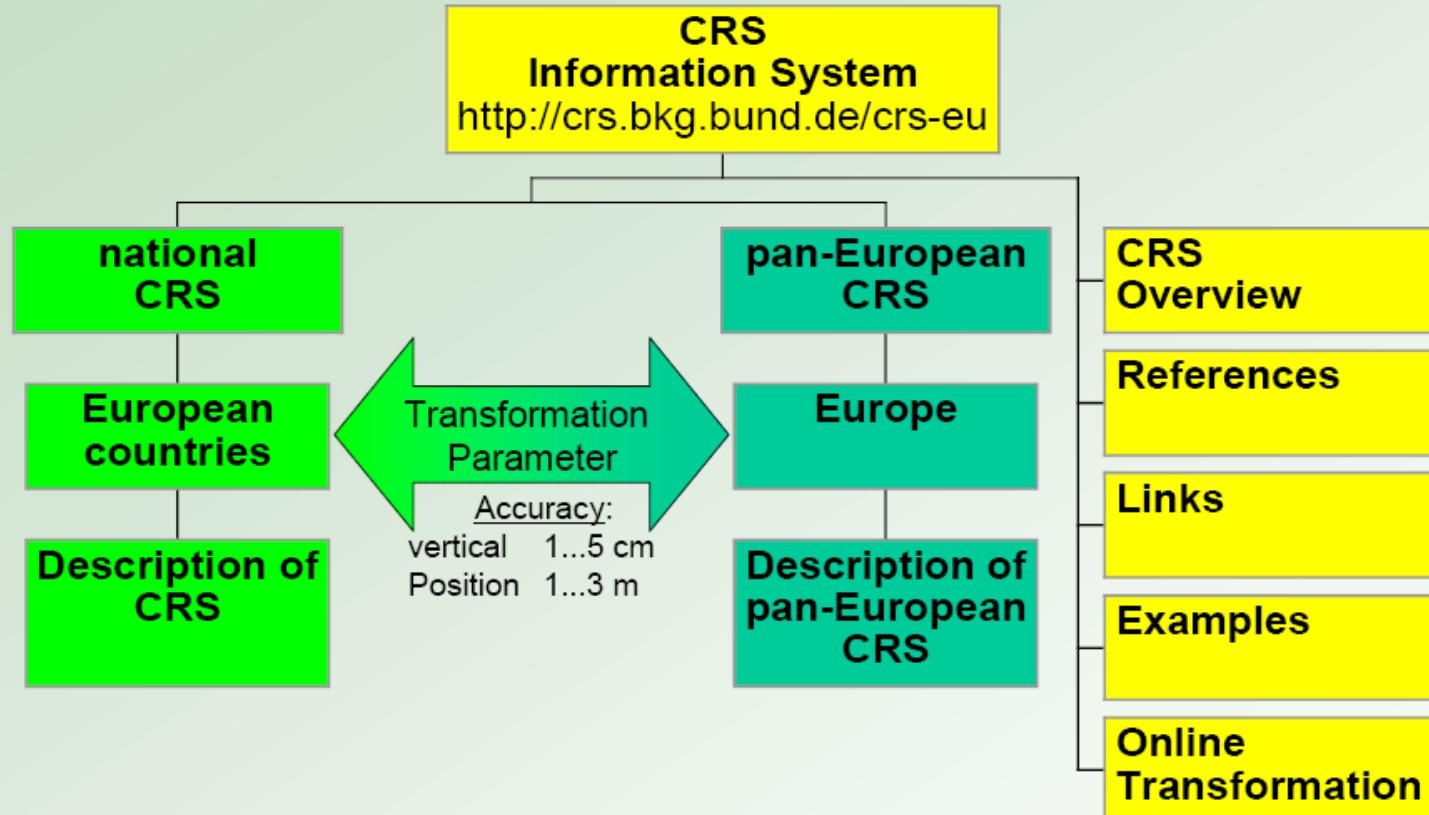
a_3 ...slope in the direction perpendicular to the meridian, positive when up eastwards [radian]

Transformation parameters from national height reference systems to EVRF2000

Country	Verification by the country	identical points number + kind	Parameters			RMS in cm	residual deviations	
			translation in cm	incl. in latitude in cm / 100km	incl. in longitude in cm / 100km		min in cm	max in cm
AT	x	114 UELN	- 35.6	- 2.8	- 2.8	3.1	-6.1	+6.1
BA/HR		40 UELN	- 34.5	- 0.3	- 0.9	0.7	-1.0	+1.4
BE		4 EUVN	- 231.1	- 0.8		0.2	-0.2	+0.2
BG	x	36 UELN	+ 18.2	+ 0.1	- 0.2	0.2	-0.6	+0.4
CH (LN02)	x	225 UELN	- 24.5	- 10.2	- 1.6	3.3	-8.6	+9.4
CZ		53 UELN	+ 11.6	+ 1.7		1.4	-3.5	+2.8
DE (DHHN92)	x	443 UELN	+ 1.4	- 0.1		0.2	-0.7	+0.6
DE (DHHN85)	x	363 UELN	+ 1.7	- 0.1	+ 0.1	0.4	-2.6	+1.3
DE (SNN76)	x	73 UELN	+ 15.7	+ 0.4	+ 0.3	0.4	-1.1	+0.8
DK	x	707 UELN	+ 1.1	+ 0.1	+ 0.5	0.3	-0.9	+0.8
EE	x	36 UELN	+ 13.3	- 0.7	+ 0.2	0.3	-0.5	+0.5
ES	x	70 UELN	- 48.6	- 0.2	+ 0.3	1.0	?	?
FI		7 EUVN	+ 22.0			0.3	-0.3	+0.8
FR	x	8 EUVN	- 48.6			0.5	-0.4	+1.0
GB	x	5 EUVN	+ 8.1	- 2.7	- 1.1	1.9	-1.2	+2.2
HU	x	36 UELN	+ 13.7	+ 0.4	- 0.1	0.3	?	?
IT		9 EUVN	- 35.3	+ 0.2	+ 0.3	0.7	-0.6	+1.1
LT		46 UELN	+ 10.2		+ 0.1	0.2	-0.2	+0.3
LV		123 UELN	+ 10.5		+ 0.2	0.7	-2.0	+2.2
NL	x	757 UELN	- 0.5			0.2	-2.1	+0.4
NO	x	117 UELN	- 0.1	- 0.5	+ 1.7	3.7	-7.6	+7.0
PL		98 UELN	+ 16.0	+ 0.5		0.5	-2.0	+0.9
PT	x	5 EUVN	- 31.5			1.3	-1.4	+2.1
RO		46 UELN	+ 2.8	+ 0.1	+ 0.1	0.2	-0.5	+0.9
SE		21 EUVN+Tide G	+ 1.0	- 0.6		1.1	-2.3	+2.0
SI	x	9 UELN	- 41.1	- 1.6	+ 0.4	0.3	-0.4	+0.4
SK		3 EUVN	+ 12.2	+ 1.0		0.2	-0.1	+0.1



Information System for European CRS



Description of CRS: Example Germany

Description of CRS - DE_AMST / NH	
Country	Germany
Country identifier	DE
CRS identifier	DE_AMST / NH
CRS alias	DHBN92
CRS valid area	Germany
CRS scope	
CRS remarks	mean geoid
Datum identifier	Amsterdam
Datum alias	NHN
Datum type	vertical
Datum anchor point	Wallenhorst 3614/00005
Datum realization epoch	1992; sea level 1684 MHT
Datum valid area	Germany
Datum scope	
Datum remarks	geopotential number of point No.110 from the UELN-73/B6 adjustment was fixed
Coordinate system identifier	normal heights
Coordinate system type	gravity related
Coordinate system dimension	1
Coordinate system remarks	
Coordinate system axis name	height
Coordinate system axis direction	up
Coordinate system axis unit identifier	metre

according to ISO 19111

Transformation Parameter: Example Germany

Description of Transformation - DE_AMST / NH to EVRF2000

Operation identifier	DE_AMST / NH to EVRF2000	Operation parameter name	vertical translation
Country	Germany	Operation parameter value	+0.014 m
Country identifier	DE	Operation parameter remarks	
Operation valid area	Germany	Operation parameter name	slope in the direction of the meridian (positive when up northwards)
Operation scope		Operation parameter value	-0.001°
Source coordinate reference system identifier	DE_AMST / NH	Operation parameter remarks	Equivalent to -0.0005 m height change at a distance of 100 km of Po. To be in agreement with formulas the slope parameter has to be converted to Radians.
Target coordinate reference system identifier	EVRF_AMST / NH	Operation parameter name	slope in the direction perpendicular to the meridian (positive when up eastwards)
Operation version	443 identical points	Operation parameter value	0.
Operation method name	3 parameter height transformation	Operation parameter remarks	
Operation method name alias			
Operation method formula	$H(\text{II}) = H(\text{I}) + a_1 + a_2 \cdot (\text{LAT} - \text{LAT}_{\text{O}}) + a_3 \cdot \text{No} \cdot (\text{LON} - \text{LON}_{\text{O}}) \cdot \cos(\text{LAT})$ <p>H(I): height in the source system [m] H(II): height in the target system [m] Mo: radius of curvature in the meridian of GRS80 [m] in Po No: radius of curvature perpendicular to the meridian of GRS80 [m] in Po LAT: latitude in ETRS89 [radian] LON: longitude in ETRS89 [radian] Po(LAT_O, LON_O): Reference point of the transformation</p> <p>a1...vertical translation [m] a2...slope in the direction of the meridian [radian] a3...slope in the direction perpendicular to the meridian [radian]</p>		
Operation method parameters number	3		
Operation method remarks	coordinates of the reference point Po: Lat = 51° 3' N Lon = 10°13' E		