EVRF2007 AS REALIZATION OF THE EUROPEAN VERTICAL REFERENCE SYSTEM (EVRS) IN ROMANIA

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Abstract: *The EVRS realization 2007, which is named EVRF2007, is a continuation of the United European Levelling Network solution UELN 95/98 under consideration of the development of the European Combined Geodetic Network (ECGN) and the realization of a vertical reference system on a global level.*

The datum of EVRF2007 is realized by 13 datum points distributed over the stable part of Europe. The measurements have been reduced to the common epoch 2000 using the land uplift model of the Nordic Geodetic Commission (NKG). The results of the adjustment are given in geopotential numbers and normal heights, which are reduced to the zero tidal system. At the EUREF symposium in Brussels (June 2008) Resolution No. 3 was adopted which proposes to the European Commission that EVRF2007 is adopted as the vertical reference for pan-European geoinformation.

The objectives of EVRF2007 are:

- *to fulfil the EU requirements for seamless, harmonised vertical data;*
- *to prepare recommendations to the European Commission for a future adoption of a common European Vertical Reference System to be proposed in the INSPIRE (Infrastructure for Spatial Information in Europe) Directive;*
- *to provide European users and producers of height information with a vertical reference system, which is based on up-to-date datasets and on advanced conventions for EVRS definition and realization.*

With the EVRF2007 a Europe-wide vertical reference with sub-decimetre accuracy will be possible. The European Gravimetric Geoid EGG 2007 shall be related to the ETRS89 and EVRF2007. Romania joined UELN, EUVN projects and realization of the EVRF providing national data (levelling, gravity, GNSS).

Keywords: *RO_CONST / NH, EVRF2007, normal height transformation*

1. Introduction

In 1994 the work on the Unified European Levelling Network was resumed after a break of 10 years under the name UELN-95. Resolution No. 3 of the EUREF symposium 1994 in Warsaw devised the objective to establish an Unified Vertical Datum for Europe at the one-decimeter level with simultaneous extension of the UELN as far as possible to the Eastern European countries. After four years' of work the EUREF symposium 1998 in Bad Neuenahr/Ahrweiler decided to hand over the results to the participating countries under the name UELN-95/98. This resolution was realized in January 1999.

One year later at the EUREF symposium 2000 in Tromsø a first definition of the European Vertical Reference System (EVRS) was adopted. The realization on the base of the UELN 95/98 solution got the name EVRF2000. The following 14 countries made their current first order levelling networks available (see Figure 1):

- Estonia (1999) - new part of the network
- Latvia (1999) - new part of the network
- Romania (2000) - new part of the network
- Lithuania (2001) - new part of the network
- Switzerland (2002) - update
- Bulgaria (2003) - new part of the network
- the Netherlands (2005) - update
- Finland (2005) - update
- Norway (2005) - update
- Sweden (2005) - update
- Slovakia (2007) - update
- Lithuania (2007) - update
- Poland (2007) - update
- Portugal (2007) – update

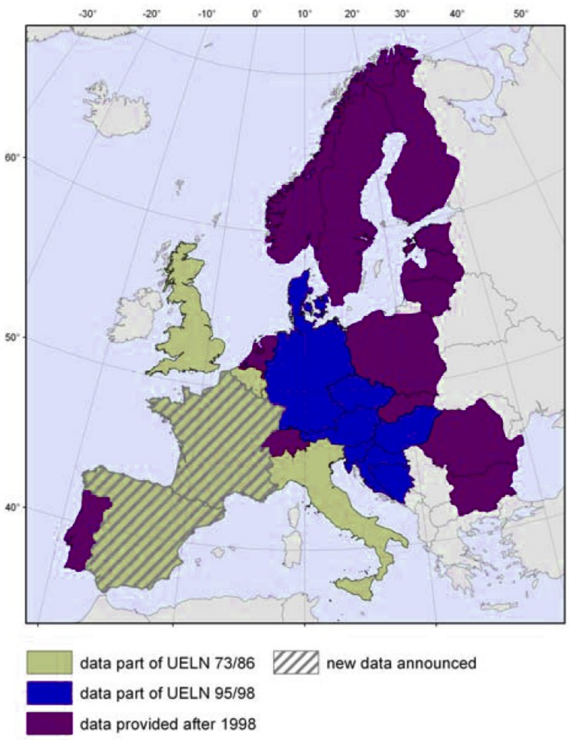

Fig. 1. Development of the UELN data base

The enhancing of the EVRS needs a revision of EVRF2000 conventions and parameters, and a new realization EVRF2007. From practical point of view, the tendency is not to change height values if not necessary. The EUREF community prefers to tie the height values to the height level of EVRF2000 and to keep normal heights. The transformation parameters between the EVRS realization and national height reference systems have to be specified to higher accuracy and topicality.

Levelling, height system definition, 3-D reference, geoid models (European, global), tidal correction, kind of height/geoid model are all related to each other. For many practical applications the choices made and parameters selected in their construction are not critical; however, it is essential that they be consistently implemented throughout.

In future the maintenance process of the EVRF2007 shall be based on a combined monitoring with several observation techniques using the approach of the European Combined Geodetic Network (ECGN), embedded in the Global Geodetic Observing System (GGOS). In addition the EUREF Permanent Network EPN can be used. Although most values behave kinematically we can make them "pseudo static" by referring them to a certain epoch.

The determination of the relationship of the European system EVRS and its realization EVRF to a Global Vertical Reference System (GVRS) and its realization Global Vertical Reference Frame (GWRF), and to the spatial reference frame ITRF is necessary for global georeferencing.

2. EVRS Definition and Datum of EVRF2007

The European Vertical Reference System (EVRS) is a kinematical height reference system. The EVRS definitions fulfil the following four conventions:

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

$$W_0 = W_{0E} = const.$$

and which is in the level of the Normaal Amsterdams Peil (NAP).

(2) The unit of length of the EVRS 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 W_{0E} of the EVRS conventional zero level. The potential difference $-\Delta W_P$ is also designated as the geopotential number c_P

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

Normal heights are equivalent with geopotential numbers, provided that the reference gravity field is specified.

(4) The EVRS is a zero tidal system, in agreement with the IAG Resolutions No. 9 and 16 adopted in Hamburg in 1983.

The last datum realization of EVRS – the EVRF2000 – was defined as follows (IHDE and AUGATH 2002):

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:

$$C_{NAP} = 0\,.$$

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

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

The EVRF2000 datum is fixed by the geopotential number and the equivalent normal height of the reference point of the UELN No. 000A2530/13600.

The EVRS2007 datum is realized, no any longer by a single point, but by a number of datum points distributed over Europe. It was strived to keep the level of the EVRF2000 datum in the EVRF2007. Therefore the new UELN adjustment was fitted to the EVRF2000 solution by choosing several datum points and introducing their EVRF2000 heights in the free adjustment of the current network. This was realized by introducing the condition equation

$$\sum_{i=1}^{13} (c_{EVRF2000} - c_{EVRF2007}) = 0$$

into the adjustment. For this purpose it was important to choose stable points located on the stable part of the European plate. In December 2006 the chairman of EUREF sent letters to all countries participating in the UELN project asking them for proposals of datum points for the next adjustment. Figure 2 shows the proposed datum points.

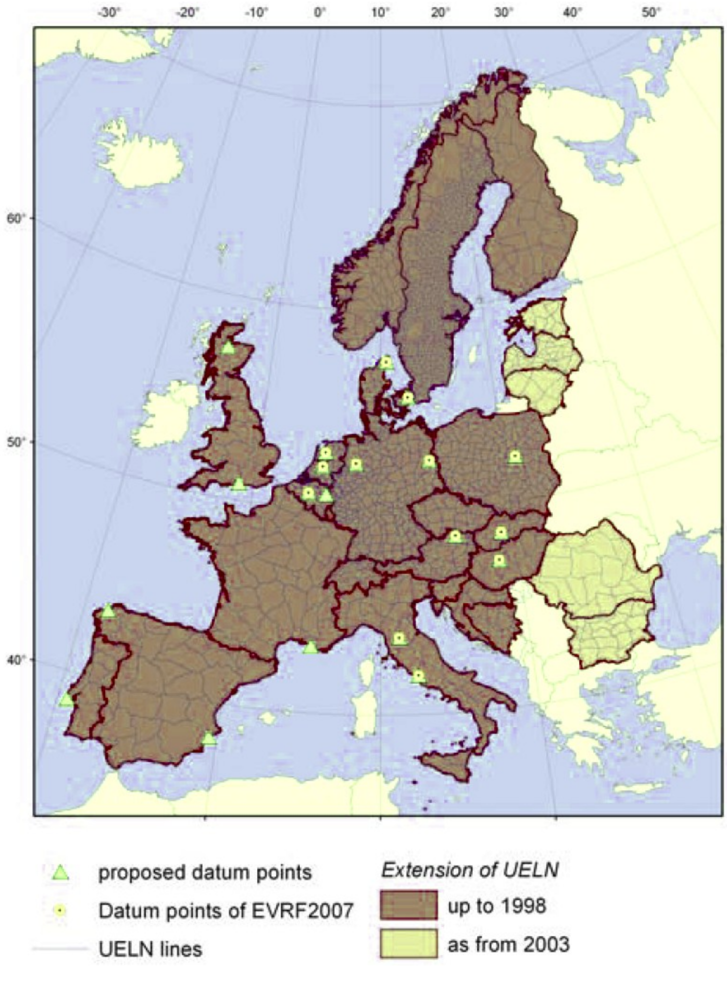

Fig. 2. Proposed and finally used datum points

Several adjustment variants were performed with different selections of datum points. The height changes caused by the different datum points were in the range of 1-5 mm.

3. The tidal system of EVRS

The earth tides, caused by the gravitational forces of Moon and Sun, induce a permanent deformation of the earth crust. Different concepts to handle this deformation are described in EKMAN 1989, MÄKINEN and IHDE 2007, IHDE et al. 2008, MÄKINEN 2008.

- In the *non-tidal* or *tide-free* system, the permanent deformation is eliminated from the shape of the Earth. From the potential field quantities (gravity, geoid, etc.) both the tide-generating potential, and the deformation potential of the Earth (the indirect effect) are eliminated. This corresponds to physically removing the Sun and the Moon to infinity. Typically the permanent deformation is treated using the same Love number h and Shida number *l* for the shape, and the same Love number k for the deformation potential as for the time-dependent tidal effects, instead of estimates for secular (fluid) Love and Shida numbers. We then have the conventional tide-free system.
- In the *mean* system, the permanent effect is not removed from the shape of the Earth. The shape therefore corresponds to the long-time average under tidal forcing. The potential field retains the potential of this average Earth, and also the time-average of the tide-generating potential (though it is not due to the masses of the Earth).
- For the potential field quantities, a "middle alternative", the *zero* system is available. It eliminates the tide generating potential but retains its indirect effect, i.e., the potential of the permanent deformation of the Earth. Thus its logical partner is the mean system for 3-D shape. In order not to need specify separately „zero for geopotential, mean for 3-D", the terminology is adopted that for the 3-D shape we have zero≡mean. In the zero system, the gravity field is generated only by the masses of the Earth (plus the centrifugal force).

The EVRS2007 is a zero-tide system, in harmony with the IAG resolutions of 1983. Therefore geopotential numbers in EVRF2007 shall express the zero-tide geopotential at the mean-tide position of the bench marks.

In the EVRF2000 the EVRS was not a zero tidal system because the countries delivered their data in different tidal systems, and the actual systems were not known to the UELN computing center. As a result, the tidal system of the EVRF2000 is mixed. Then the geopotential numbers of all datum points were corrected by

$$-0.28841\cdot\sin^2\varphi - 0.00195\cdot\sin^4\varphi + 0.09722 \text{ in kgal}\cdot\text{m}$$

to bring them from the mean-tide system to the zero-tide system (MÄKINEN, 2008).

The resulting reductions ranged between –0.030 (Italy) and –0.108 (Denmark) kgal·m. In order to minimize the differences to the EVRF2000 solution we added the constant of +0.08432 kgal·m, the value of the tidal correction of point 13600 (000A2530) with opposite sign, to the correction described in previous formula. This is equivalent to the assumption that the NAP datum of EVRF2000 is in the zero tidal system in accordance with the EVRS2000 definition (IHDE et al. 2008). Figure 3 shows the resulting differences of the adjusted geopotential numbers to the adjustment EVRF2000.

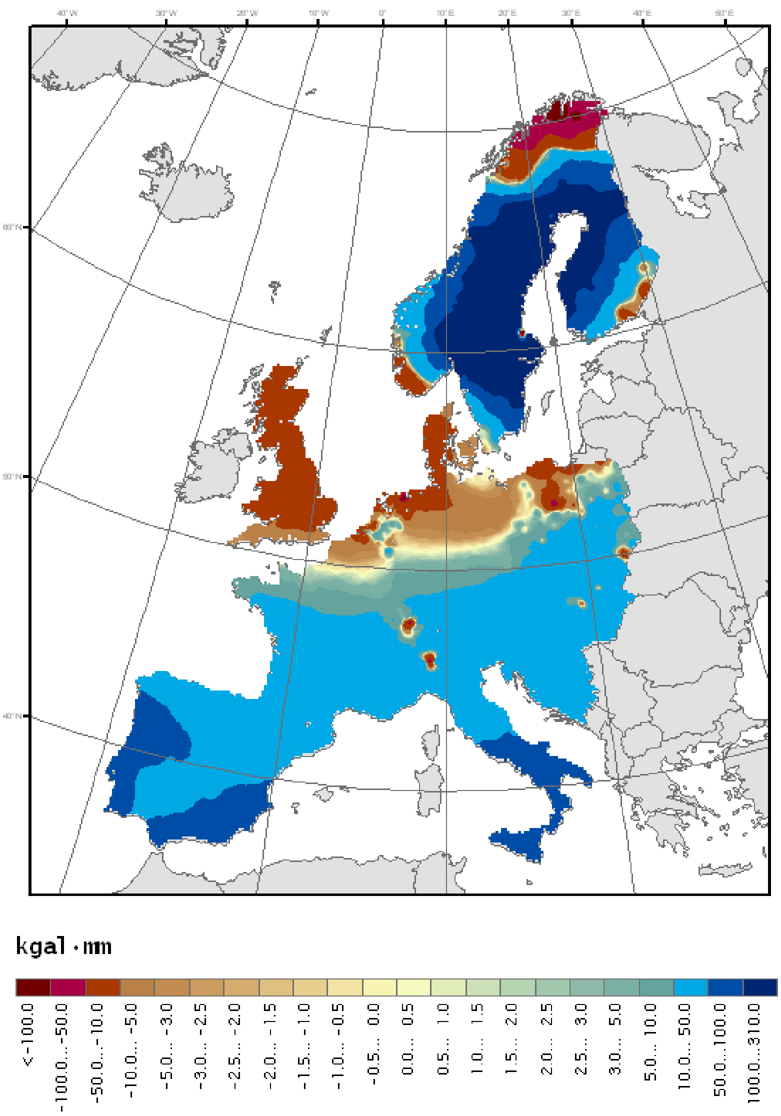

Fig. 3. Differences of EVRF2007 zero tidal system to EVRF2000

4. Summary of the Adjustment Parameters

The datum of EVRF2007 is realized by 13 datum points (see Table 1). The geopotential numbers of these points are introduced into the free adjustment with the results from the EVRF2000 adjustment reduced to the zero tidal system (see EKMAN 1989, MÄKINEN and IHDE 2007, IHDE et al. 2008, MÄKINEN 2008) by:

$$C_{dp2007}=C_{p95/98}-0.28841\cdot\sin^2\varphi-0.00195\cdot\sin^4\varphi+0.09722+0.08432 \text{ in kgal}\cdot\text{m}$$

The geopotential differences are reduced from the mean-tidal system to zero-tide by

$$\Delta C_Z=\Delta C_M-0.28841\cdot(\sin^2\varphi_2-\sin^2\varphi_1)-0.00195\cdot(\sin^4\varphi_2-\sin^4\varphi_1) \text{ in kgal}\cdot\text{m}$$

Additionally, the geopotential differences are reduced to the epoch 2000 by means of the land uplift model NKG2005LU.

Table 1. Datum points

Point number	Point number		Latitude	Longitude	geop. number EVRF2000 (mean tide)	geop. number EVRF2000 (zero tide)	adjusted geop. number EVRF2007 (zero tide)	difference EVRF2007-EVRF2000
(UELN)	(national)		degree (ETRS89)		kgal·m			kgal·mm
102105	937856	AT	48.664867	15.674783	300.7350	300.7535	300.7504	-3.0
200038	IGNMK	BE	50.799167	4.359400	96.0126	96.0204	96.0073	-13.1
401110	3614/00005	DE	52.349783	8.015300	92.6957	92.6958	92.6871	-8.7
401658	3549/01400	DE	52.480500	13.983567	53.6216	53.6211	53.6139	-7.2
514004	00204009190	DK	55.666017	12.393367	14.0516	14.0357	14.0471	+11.4
514182	05304009619	DK	57.447017	10.511600	16.5915	16.5674	16.5860	+18.5
800432	35 (Firenze)	IT	43.776000	11.259883	48.7903	48.8335	48.8335	+0.0
800441	44 (Roma)	IT	41.909850	12.476050	16.9251	16.9776	16.9776	-0.1
913000	000A1013	NL	52.851417	5.518967	5.6427	5.6404	5.6364	-4.0
913011	000A1112	NL	52.141733	5.360567	41.0248	41.0260	41.0251	-0.9
1103000	Nadap II	HU	47.255750	18.620017	172.9876	173.0131	173.0090	-4.1
1706115	26330081	PL	52.230100	20.948383	110.6861	110.6868	110.7007	+13.9
1905325	EH-V.	SK	48.606500	19.017333	267.5548	267.5735	267.5709	-2.7
							Total:	+0.0

A variance component estimation was performed in which the observations of each national network were introduced as a separate group (GRAFAREND 1984). Table 2 shows the results of the variance component estimation for EVRF2000 and EVRF2007.

Table 2. Results of the variance component estimation

Country	Number of observations	Standard deviation in kgal·mm	Number of observations	Standard deviation in kgal·mm
	EVRF2000		EVRF2007	
Austria	145	0.80	167	0.82
Belgium	54	1.22	63	1.24
Switzerland	13	1.06	413	1.09
Germany (ep. 2000)	755	0.85	846	0.85
Denmark (ep. 2000)	1036	0.59	197	0.91
Spain	101	1.85	140	1.75
France	175	2.01	348	2.02
Italy	97	1.76	110	1.75
Netherlands	932	1.08	1424	0.75
Portugal	22	1.77	30	2.09
Great Britain	60	1.72	60	1.72
Norway_old (ep. 2000)	194	1.67	352	1.62
Norway_new (ep. 2000)			397	1.29
Finland (ep. 2000)	89	0.76	262	0.73
Sweden (ep. 2000)	122	1.74	4206	1.00
Czech Republic	82	1.10	117	1.16
Hungary	54	0.52	82	0.47
Croat., Bosn.-Herz.,Slov.	79	0.90	112	0.90
Poland (ep. 2000)	179	0.99	476	0.88
Slovakia	74	1.41	215	1.55
Romania			133	1.75
Estonia (ep. 2000)			78	1.30
Latvia (ep. 2000)			159	1.72
Lithuania (ep.2000)			72	0.87
Bulgaria			109	1.14
total	4263	1.10	10568	1.11

The national reference system for the heights in Romania is Black Sea 1975 datum. Normal heights are available for the National Leveling Network.

The National Leveling Network it is divided in 5 orders (function of precision). The National Precise Leveling Network of I[st] order consists in a number of 19 polygons with a length of 6600 km and includes 6400 points with a density of 1 point/km^2. 24 leveling lines establish the connections with neighbour countries: 2 with Ukraine, 1 with Republic of Moldova, 6 with Bulgaria, 10 with Serbia/Montenegro and 5 with Hungary.

This network was densified till 32 polygons with levelling networks of II[nd] -V[th] order (see Figure 4).

The Romanian contribution to UELN (2000) contains the nodal points of the polygons of first order (65 points) and 89 levelling observations.

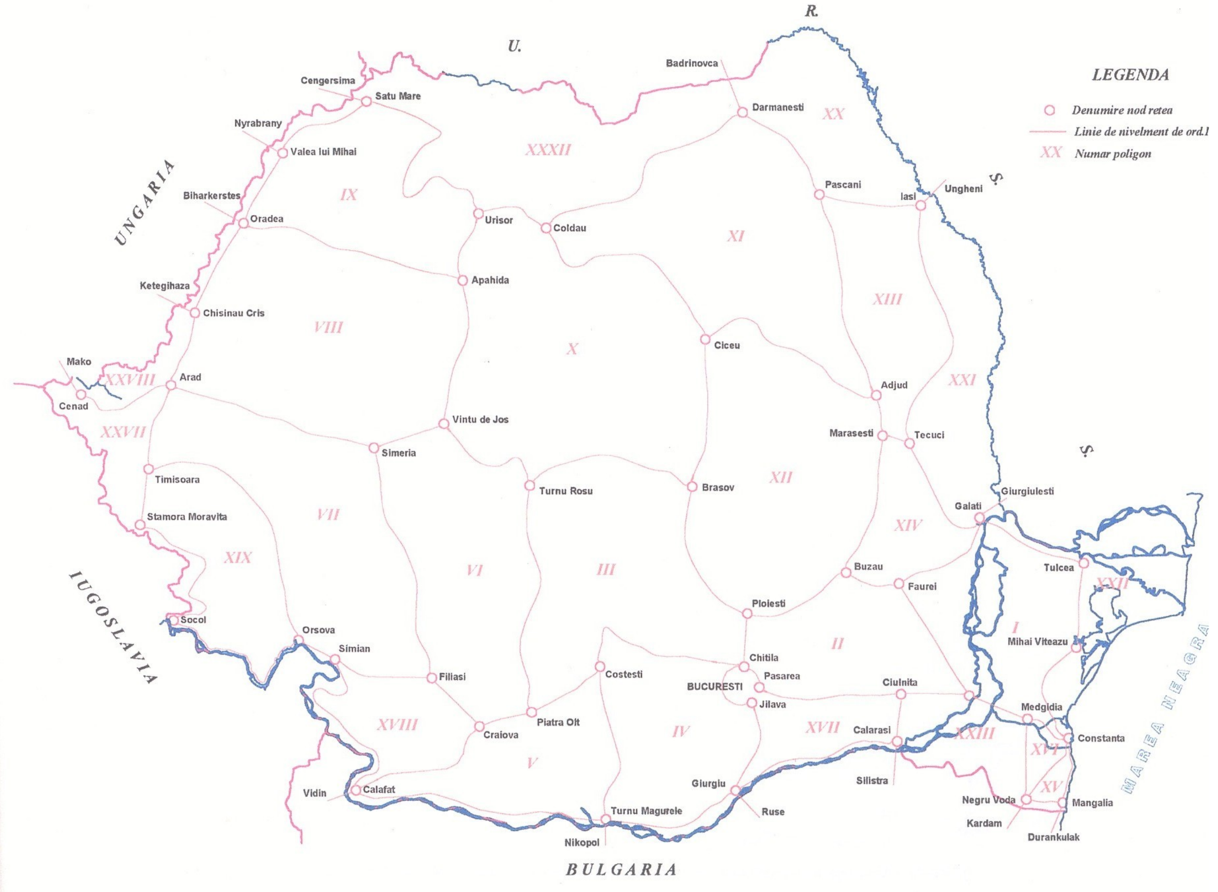

Fig. 4. Romanian Levelling Network

The EUVN97 (European Unified Vertical Network 1997) included 4 points from the Romanian Levelling Network: RO01 (Sirca-Iasi), RO02 (Constanta), RO03 (Timisoara) and RO04 (Tariverde – Height 0) points measured with GPS technology and absolute gravity. For these points the known ETRS89 coordinates and normal heights (precise levelling) in Black Sea 1975 datum were determined together with absolute gravity. For the ECGN project in September 2004, Austrian Federal Office of Metrology and Surveying (BEV– Bundesamt fuer Eich-und Vermessungswessen) in cooperation with Romanian National Agency for Cadastre and Land Registration (NACLR) and Military Topographic Directorate, performed an absolute gravity observation campaign in Romania. A number of 4 absolute gravity stations were observed by JILAg-6 absolute gravimeter. Romania participated with such information to the EVRS realization - EVRF2000. After 2000 year Romania further contributed by providing new data including 43 stations with ETRS89 ellipsoidal heights and normal heights in national height reference system (Figure 5). This was the contribution to the EUVN_DA (Densification Action) project with final result the EVRF2007 realization. 25 European countries participated and submitted the data of more than 1500 high quality GPS/leveling benchmarks. The submitted data was validated and converted into uniform reference frames. The final report was discussed at Technical Working Group meeting and presented at the EUREF2009 symposium, held in Florence (Italy). The results were circulated to all contributing National Mapping Agencies including Romanian National Agency for Cadastre and Land Registration.

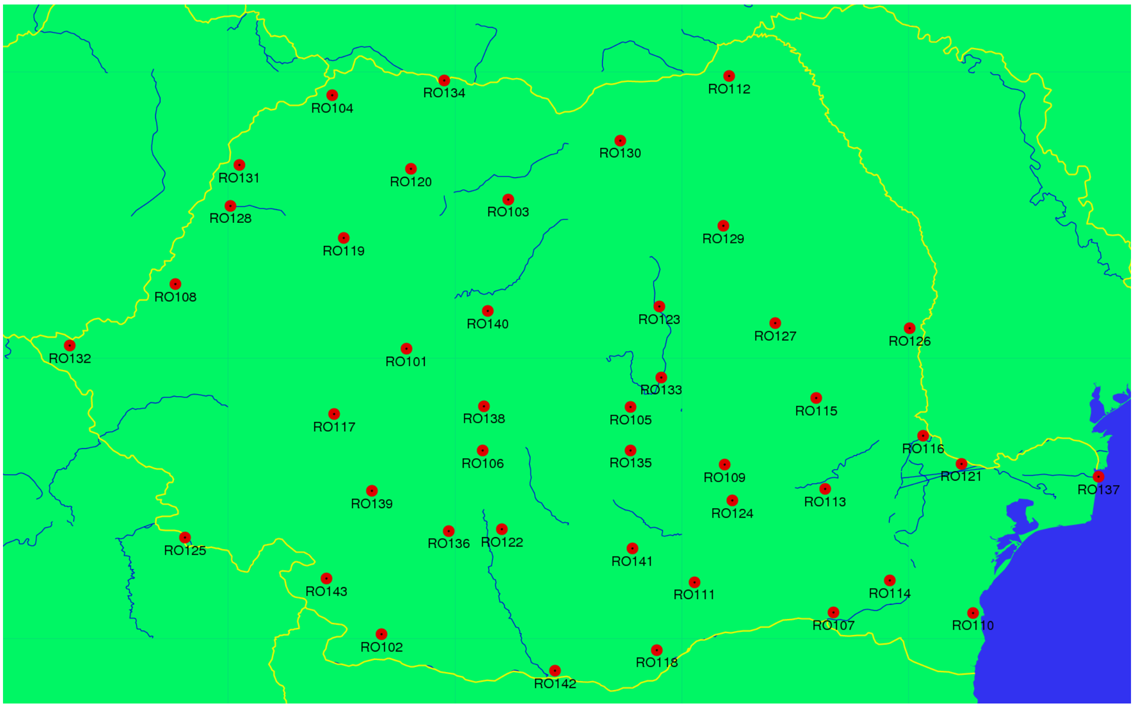

Fig. 5. Romanian contribution to EUVN_DA project (2009)

This action it is continued in Romania by NACLR. For each county it is planned to be realized a number of minimum 5 such stations. At the present there are fully covered a number of 10 counties. New data will be provided periodically to the EUREF for inclusion in new EVRF realizations.

As a final EVRF2007 realization in Romania, a standard transformation parameters were computed by EVRF computing centre from Federal Agency for Cartography and Geodesy (BKG, Germany). These set of parameters realize the transformation of normal heights from Black Sea 1975 System to EVRF2007 (RO_CONST / NH to EVRF2007) (see Annex 1 – Transformation of normal height from RO_CONST / NH to EVRF2007).

Transformation parameters were derived from 48 identical points (UELN nodal points) with a transformation RMS of 0.004 m, and residual deviation between -0.012 m and +0.013 m.

A general view of the EVRF2007 realization in comparison with national height reference systems can be seen on the next picture.

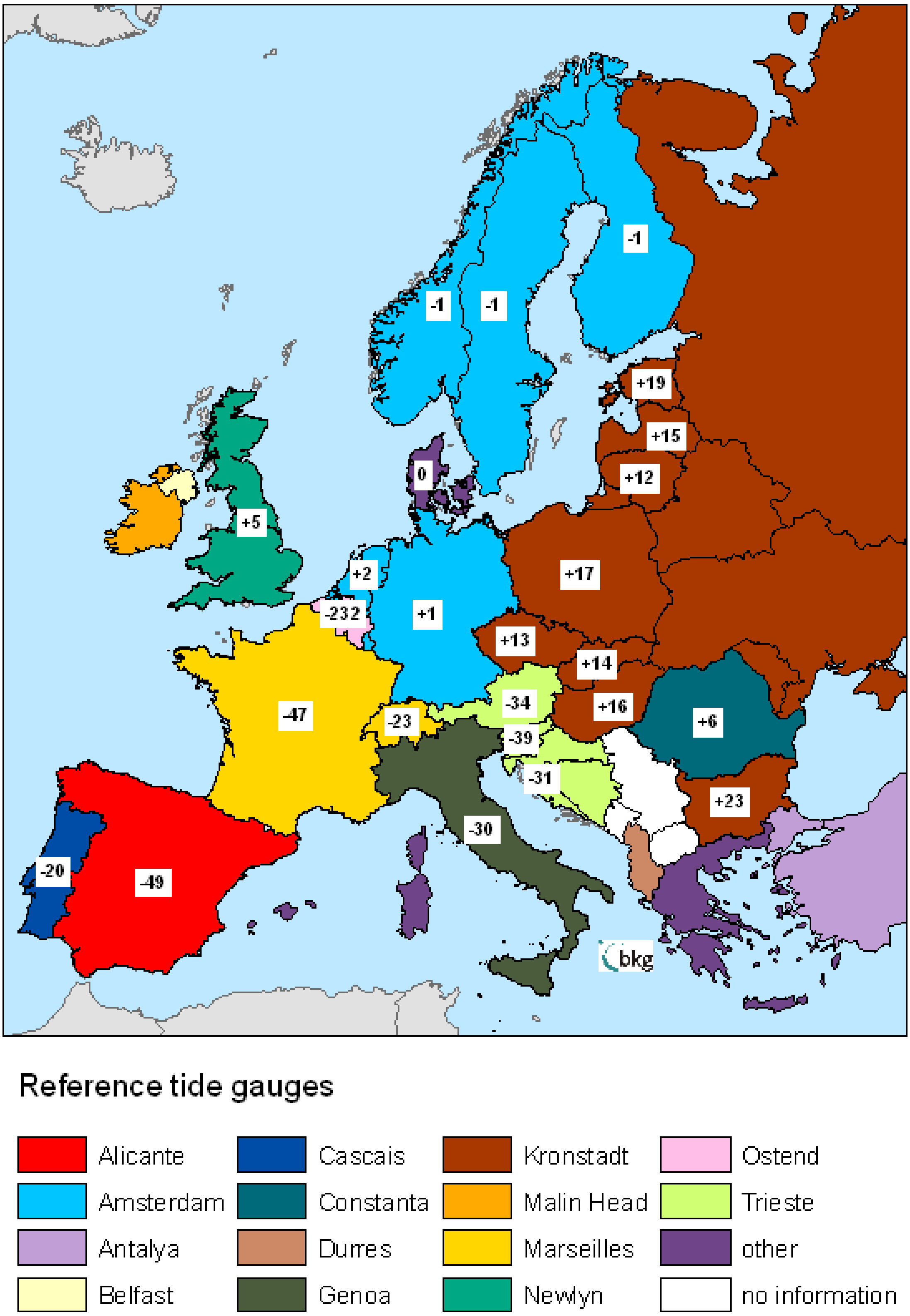

Fig. 6. Mean differences between EVRF2007 and national height reference systems

6. Conclusions

In 2009, NACLR finalized the coordinates transformation including a distorsion model from ETRS89 system to S42 (Krasovski ellipsoid) – Stereographic 1970 projection system and provided TransDatRo software and algorithm for the users.

Transformation of normal heights from Black Sea 1975 System to EVRF2007, finalized at the present moment, complete the most recent link between the national coordinate reference systems and pan-European systems. NACLR intends to include this option in the software package for coordinate transformation TransDatRO which is already published on internet and will be implemented on national Geo-portal for a future simplification in spatial data harmonisation and interoperability.

After NACLR validation the parameters will be published on the on-line information system (http://www.crs-geo.eu/), which contains the descriptions of the different national Coordinate Reference Systems (CRS) for position in Europe as well as the transformation parameters from the national systems to the ETRS89 according to the ISO standard 19111 Geographic information - Spatial referencing by coordinates.

The information system was a common initiative of EuroGeographics, EUREF and the BKG. The national mapping agencies were asked for their support in establishing the system by verifying and completing the information. Since 2004 the information system contains also the description of the European gravity related height systems and the transformation parameters from the national height systems to the EVRF2000 and EVRF2007.

7. References

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ANNEX 1

Transformation of normal height from RO_CONST / NH to EVRF2007

Operation method formula:

H_EVRF2007_tr = H_BlackSee + a1 + a2 · Mo · (LAT - LATo) + a3 · No · (LON - LONo) · cos(LAT)

where:

- H_BlackSee: height in the source system [m] (Black See 1975)
- H_EVRF2007_tr: height in the target system [m] (EVRF2007)
- Mo: radius of curvature in the meridian of GRS80 [m] in the reference point 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(LATo,LONo): reference point of the transformation
- a1: vertical translation [m]
- a2: slope in the direction of the meridian [radian]
- a3: slope in the direction perpendicular to the meridian [radian]

Coordinates of the reference point Po:

LATo [°]	46.016666667
LONo [°]	24.816666667
Operation Parameters :	
a1 [m]	0.062
a2 ["]	-0.005
a3 ["]	0.008
Parameters of ellipsoid GRS80:	
a	6378137
inv_f	298.257222101
Mo and No calculus:	
f	0.003352811
b	6356752.314
e	0.081819191
w	0.998265520
Mo [m]	6368520.0929
No [m]	6389218.9718

Table of common points in Romania

Point	LAT_ETRS89	LON_ETRS89	H_BlackSea	H_EVRF2007_tr	H_EVRF2007	dH
RO101	46.06491803	23.57488450	239.85366	239.9118	239.911	0.0008
RO102	44.03273248	23.35245846	61.22177	61.2846	61.281	0.0039
RO103	47.11521559	24.46975267	345.40503	345.4630	345.463	0.0000
...	...	...	...	...	...	...
RO143	44.43256133	22.86474635	94.04411	94.1043	94.104	0.0001
					Average:	0.0000
					Max:	0.0099
					Min:	-0.0090
					Std. Dev.	0.0036