Dossier du BHI No. S3/1105

LETTRE CIRCULAIRE 41/2001
21 septembre 2001

CADRE GLOBAL DE REFERENCE VERTICALE

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Références :
1. LC 60/ 1994
2. LC 26/ 1995
3. LC 42/ 1995
4. Publication M-4 de l'OHI, Spécification 405
5. LC 30/ 1996
6. LC 1/ 1997
7. LC 25/1997

Monsieur,

1. Les Etats membres de l'OHI discutent depuis 1994 de la question du cadre global de référence verticale. Les résultats principaux de ces discussions sont les suivants :

a) L'adoption de la plus basse mer astronomique (PBMA) comme niveau de référence pour les cartes marines et de la plus haute mer astronomique (PHMA) comme niveau de référence pour les tirants d'air et la modification correspondante du paragraphe 3 de la Résolution A 2.5 de l'OHI (Voir LC 25/ 1997).

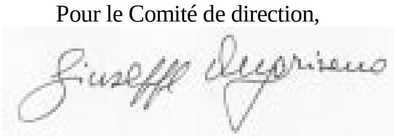
b) Le report de la décision relative à la surface globale de référence verticale à laquelle toutes les profondeurs et toutes les hauteurs pourraient être associées car l'on considère qu'aucune référence, pour une telle surface (ellipsoïde ou géoïde) n'a été définie avec suffisamment de précision. En outre, les résultats des discussions et les recommandations d'autres organismes internationaux compétents par ex. l'Union géodésique et géophysique internationale (UGGI) et l'Association internationale de géodésie (AIG) devraient être connus avant qu'une décision ne soit prise au sein de l'OHI.

2. Récemment, la détermination de systèmes unifiés globaux de références géodésiques verticales a progressé en bénéficiant des nouveaux satellites altimétriques. D'autres progrès peuvent être attendus des résultats des projets de satellite gravimétrique prévus pour 2001-2004. Des propositions quant aux systèmes de référence verticale continentaux et leurs réalisations ont récemment été élaborées pour l'Europe et l'Amérique du Sud. On trouvera davantage de détails dans les documents joints en annexe.

3. Des représentants de l'AIG ayant indiqué que l'AIG pourrait soumettre une proposition de système global de référence verticale en vue de son adoption lors de la prochaine assemblé de l'UGGI en 2003 et compte tenu de l'obligation croissante d'intégrer des données en provenance de sources diverses et affectant également la communauté hydrographique, il pourrait être souhaitable de reprendre les discussions au sein de l'OHI et de définir, pour l'Organisation, une position commune.

4. Il est demandé aux Etats membres de bien vouloir faire parvenir leurs commentaires au BHI avant le 31 décembre 2001.

Pour le Comité de direction,



Contre amiral Giuseppe ANGRISANO
Président

Pièces jointes : Annexes A à C (anglais seulement)

Annexe A – New Results of Geodetic Datum Evaluation within SC-3 of IAG (E. Groten)
Annexe B – The vertical Reference System for Europe (J. IHDE, W. Augath)
Annexe C – European Vertical Reference System (EVRS)

NEW RESULTS OF GEODETIC DATUM EVALUATION WITHIN SC-3 OF IAG

by Erwin Groten, Darmstadt, IPGD
e-mail: groten@ipgs.ipg.verm.tu-darmstadt.de

Biography

Prof. Erwin Groten is Director of the Institute of Physical Geodesy and has been a full professor at Darmstadt Technical University (Germany) at the Institute of Technology since 1970. Prof. Groten is the author of over 200 scientific publications and several text books.

He is currently serving as president of the Special Commission on "Fundamental Constants" of the International Association of Geodesy (IAG). He is a former president of Section V „Geodynamics" of IAG and serves currently as Vice-president of the National Committee of Geodesy and Geophysics of Germany. Moreover he is a member of a large number of scientific and professional international organizations.

His special fields of interest are geodesy, geodynamics, navigation and satellite positioning. He is affiliated with several other universities worldwide.

Abstract

The recent progress in determining global unified vertical geodetic datums within Special Commission 3 of the International Association of Geodesy is described. With increasing significance of sea level variations also the global interrelation of vertical datums being related to mean sea level globally becomes of increasing interest. New attempts to use satellite altimetry and the results obtained from combined applications of repeat GPS together with tide gauge data and gravity field information led to new and more dependable determinations of a unified global vertical geodetic datum to which all major vertical datums have been related. The attempts took profit out of existing oceanographic projects such as GLOSS, COST, WOCE and also of new altimetric satellites. With projects ahead in 2001 up to 2004, such as ENVISAT, JASON, GRACE, GOCE, etc. the reliability of such determination may increase so that the pioneer studies by SC-3 may then lead to a global vertical unified datum as badly needed by geodesy. Geodetic projects which may typically take profit out of those studies are the Western Pacific Geodynamic Project and similar approaches.

1. Introduction

In shallow off-shore areas the definition and implementation of maritime boundaries depends more and more on the definition and determination of mean sea level and its secular variations. Consequently, the use of one and the same up-to-date ellipsoidal systems is relevant to piecewise use of geodesics as realization of maritime delineations. Moreover, it would be appropriate to refer all boundary determinations to one and the same vertical geodetic datum. In other words we would need to refer all such maritime implementation and definitions to one global vertical reference frame.

Grafarend and associates have shown that the dimensions of the presently used ellipsoids in GRS 80 or WGS 84 deviate from the actually best approximation of the earth's best fitting ellipsoid by about half a meter. We know, that local and regional vertical geodetic datums deviate from mean sea level by up to 1.5 m and major geodetic vertical datums may deviate by about 1 m or so. We are now able to determine such deviations globally with accuracy of a few centimeters which is sufficient for any maritime purpose.

Bursa et al. (2001) have, in a series of global investigations, determined recently the deviations of all major geodetic vertical datums from mean sea surface where the latter was defined by its level surface W^0 with W being the geopotential and W^0 the constant W at geoid level which is best approximated by the aforementioned ellipsoid (Grafarend and Ardalan, 2000).

One central problem of modern global geodesy is now to incorporate the ocean surface as part of the earth's surface (being almost two thirds of it). The answer to this question has great impact on the determination of global parameters, the unification of vertical datums up to maritime boundaries. All present solutions to bridge the oceans via discrete networks involving islands and to be satisfied with a more or less undefined mean sea level (MSL) do not fulfill the requirements of $\pm 10^{-9}$-geodesy. For instance, secular changes of the MSL are not considered at all in most definitions and/or implementations of MSL (Le Meur and Huybrechts, 2001; Chao et al., 2000; Gross, 2001 a,b,c; Gross and Chao, 2001).

2. General Aspects

Currently, different types of global reference systems, such as IGS, ITRF, WGS 84, GRS 80, are being used in geodesy. Most of them are, more or less, interrelated. In theory, a Somigliana-Pizzetti system, such as GRS 80, should consist of four independent parameters. The ideal case would be for these parameters to be directly observable, in the sense that they can be directly observed. This is not the case in modern geodesy. Another deficiency is the fact that, even though attempts have been made or, at least considered, those global systems are not yet related to a global vertical (unified) datum. Moreover, the temporal changes of those fundamental parameters have not yet been sufficiently taken into account. Models of horizontal variations prevail. Discrete point fields related to standard tectonic plate models, assuming more or less continuous (with time) motion, are dominating. As far as the global shape of the earth is concerned, polyhedron type models are being used which do not sufficiently cover oceanic areas. Meanwhile the number of altimetric satellites is so large that, together with repeat GPS-controlled global tide gauge systems and substantially improved models for tidal and similar reductions, sufficient accuracy is achieved in deriving fundamental global parameters and their temporal variations. Whether or not ITRF should thus be related to a global vertical datum or an absolute geoid, GRS 80 should be replaced by an improved Somigliana-Pizzetti model etc. is a matter of practical relevance. However, first attempts in that direction by Rapp, Bursa, Grafarend and others indicate the possibility to derive substantially new global models as soon as results from new gravimetric satellite missions (CHAMP, GRACE, GOCE) are available. The details, which should be applied to make optimal models available, have to be discussed.

Global change and related variations are primarily and best evaluated from large and heterogeneous global data sets which need to be referred to precise reference frames and systems. Recent progress in that respect is such that a new generation of parameters can be derived, where global fundamental parameters are superior to discrete sets of regional or local data in view of their integrated global information.

With a triple of new LEO (=low earth orbiting)-satellites for a dedicated gravity field determination

CHAMP
GRACE
GOCE

now, more or less, at hand, we are going to meet the requirements of precise height determination as well as monitoring various mass transport processes at the earth's surface. With an enhanced family of altimeter satellites, enlarged by

ENVISAT
JASON etc.

improved global monitoring of sea and ice surfaces as part of the earth's surface will be available. We will thus achieve in the near future accuracies which correspond to those expected from navigation projects, such as GALILEO, GNSS I and II etc.; moreover the improved gravity field determination will lead to further improve geodetic quantities and parameters now being determined from global GPS or GLONASS observations.

Bursa (2000, 2001) and associates have demonstrated, after the pioneering work of Rapp, Kakkuri and others (see Mäkinen et al. 2000) that the combination of present data sets available in geodesy allow for accuracies of one (or two) decimeters in unifications of regional and global height systems with which global tide gauges etc. are connected. They used combinations of tide gauge, altimetric, gravimetric, levelling and other geodetic satellite information together with classical geodetic data.

In this way it became clear that the combined use of oceanographic together with geodetic and geophysical data and information is worthwhile, and promising in obtaining, in the future, substantial new global information which is not yet available at this time but will enhance the importance of cooperation of oceanographers, geodesists, meteorologists etc. in achieving novel high precision results of great interdisciplinary impact.

The quality of results expected from CHAMP-observations as well as simulation studies from GRACE and GOCE indicate a new quality of resolution of the gravity field as well as of its temporal changes. This leads to improved local and regional resolution as well as to substantially improved contribution to the determinations of global parameters which act as scale factors in determination of global parts of the earth. With two thirds of the earth being covered by oceans the role of atmosphere-ocean solid-earth interaction will become more important in the near future. In this way the interdisciplinary cooperation in dealing with a deformable earth in changing climate becomes crucial. Special Commission 3 (on: Fundamental Constants) of IAG (=Intern. Assoc. of Geodesy) sees a need for better, improved and more detailed cooperation between meteorologists, oceanographers and geodesists.

In putting large and complex masses of data of quite different nature together, the role of exact reference systems and high-precision scaling is of utmost importance to avoid systematic errors in the results. Moreover, many of the mathematical formulations in such data combinations represent inverse problems where non-linear „ill-posed“ problems in the Hadamard-sense play a substantial role. This means that small errors in the „input“ imply large errors in the „output“ so that regularization, i.e. loss of information, is unavoidable. Consequently, external control, i.e. independent data control with redundant data is very important.

For the aforementioned interaction between solid and fluid earth, tectonic and post-glacial processes are relevant wherever long-term trends, as in case of climatic or green house (mean sea level uplift etc.) effects, are considered. The orientation of global reference systems which is now basically provided by satellite or other astronomical techniques (such as VLBI) is also a problem where stability and long-term aspects are crucial. Here again the field of interest of Special Commission 3 of IAG is under investigation and under consideration. Let us go somewhat more in detail:

3. Detailed Considerations

Beside exceptional areas, such as areas of postglacial isostatic readjustment, vertical changes (subsidence and uplift) are mainly of episodic behavior. Geodetic techniques to observe and monitor those height variations and associated deformations are of a relative type, which means that we get only differences, not absolute values of coordinates. Consequently, vertical and horizontal datums are necessary to which such relative measurements are referred. With two thirds of the earth's of the earth's surface being covered by ocean „dynamic heights“ or geopotential numbers and related potential values are relevant so that reference surfaces become available to which ocean dynamics and related variations of the earth surface are globally related. Again: potential cannot be directly observed but only deduced from sets of global parameters; in contrast potential differences

$$dW = g\ dh$$

can be observed or derived from gravity g and height differences dh. Absolute gravimetry is one of the few techniques where absolute values of g can be directly measured. Level surfaces W = const. thus play an eminent role in global description of mean sea level (MSL) etc. where again global parameters, such as the mass of the earth, or the volume of the geoid (being the level surface at MSL) are of utmost importance. The volume of the earth, v, differs from the volume of the geoid; the mass of the earth (being found by applying Kepler's third law to satellite orbits) has to be specified in view of the mass of the atmosphere; it is usually given in terms of GM (="geocentric gravitational constant") where M is the mass of the solid + fluid earth without atmosphere and G = Newtonian Gravitational Constant. Here mass exchanges between ocean and atmosphere interact. Since GM and the volume of the geoid act as scale constants in various cases their exact determination is relevant. Quite often potential differences are sufficient (instead of geopotential itself) so that relative geoid sections can take the role of the geoid itself. Usually, the offset between both is denoted by N_o.

Wherever regional or national heights systems (together with their associated „vertical datums") are unified to a global vertical datum, being related to the („absolute") geoid W^o as the „zero reference" surface from which geodetic heights are counted, we then need exact determinations of the aforementioned global parameters. Temporal changes of mass and volume of the earth thus affect such determinations. In order to go over from the earth's volume to the geoidal volume we consequently need the (orthometric) heights of the points in a discrete station network representing the earth. This discretization is still insufficient at present.

By applying global satellite altimetry, GPS-equipped tide gauge stations and precise long-range positioning (SLR, VLBI, GPS ...) together with repeat gravimetry we can use the average sea surface represented by MSL to get mean volume parameters serving unification of height and elevation networks. Present attempts of that kind deliver accuracies of one or two decimeters at sea, so improved ocean tide models can still lead to improved results.

Geodesy, therefore, strongly depends on the interdisciplinary cooperation with oceanography, meteorology etc. in order to determine such global parameters related to mass and volume of the earth and their temporal variations.

The <u>interaction of ocean and atmosphere</u> in terms of mass and energy exchange, on the one hand, and between solid earth (<u>ocean bottom</u>) and <u>ocean surface</u>, on the other hand, are typical cases where such global parameters are affected. This applies to temporal as well as regional variations. Tidal ocean bottom deformations affecting <u>ocean tides</u> and ocean bottom topography affecting sea surface topography are good examples. In both cases higher accuracy is desired. <u>Sea mounts</u> and the effect of ocean bottom topography on <u>ocean circulation</u> are of similar importance.

In order to interrelate the different tide gauge stations in a unified reference system we need not only their locations in terms of Cartesian or ellipsoidal coordinates but also the geopotential at the tide gauge stations or, at least, the potential difference and related temporal changes. Here again tidal models interfere. In the first case of potential itself the absolute geoid (position and potential value W^o) is required, in the second case of relative positioning the relative geoid is needed.

However, the superiority of the absolute geoid is easily illustrated by the fact that we need, in various cases, gravity anomalies. They are reduced to the geoid using orthometric heights. Whenever, in different regions, they are related to different geoid sections (in the relative way, as is now often the case) instead of the actual geoid W^o, we unavoidably get offsets in the gravity anomalies Δg which differ from region to region and lead globally to serious, systematic errors (Groten, 2000).

Due to the problems described above most global reference systems, such as ITRF (=Intern. Terrestrial Reference Frame), IGS (=International GPS Service), WGS 84 (=World Geodetic System), GRS (=Geodetic Reference System of the Intern. Assoc. of Geodesy (IAG)) are not directly associated with a Vertical Datum and consequently not related to any MSL – or geoid value. The ellipsoid associated with spheroidal systems, such as WGS 84, GRS 80, is basically an artefact without substantial physical background. In the Somigliana or Somigliana-Pizzetti form (Grafarend and Ardalan, 1999) it is a level ellipsoid defined by four "independent" parameters, which, however, nowadays are no longer independent, as they are all basically deduced from the same satellite system. There are proposals and attempts to relate ITRF to a global vertical datum (Kouba, 2000). This would certainly be a good solution. This would basically imply to relate a geopotential at "zero-height" to ITRF in terms of W^o. However, to relate such a parameter to a Somigliana field would imply a fifth parameter which could also replace the semi-major, a, axis of the ellipsoid, as both, W^o and a, act as scale factors. In so far we may use the new satellite triple (CHAMP, GRACE, GOCE) for an improved determination of W^o in order to end up with a consistent parameter set.

4. Vertical datum and permanent tide

With increasing accuracy of modern global reference systems and related observations, such as VLBI (= very long base line measurements), SLR (=satellite laser ranging), GPS (=Global Positioning System), the interest in vertical coordinates has substantially gained. This is true in spite of the fact that, particularly for GPS, the vertical coordinate is weak. As a consequence of this gain of interest also the consistency of those fundamental systems was more carefully considered and minor inconsistencies are being removed. Recently, M. Kumar (priv. comm. 2001) of DoD (US Dept. of Defense) called the attention to apparent inconsistencies in ITRF which are basically related to the permanent tide effect. In view of resolution 16 of IAG which describes the application of permanent tide corrections (only the indirect effect of permanent tide, due to the tidal deformation should be preserved and all direct effects should be removed) he proposed to modify existing reference networks. This problem was, however already discussed earlier, at the GGG-Symposium of IAG at Calgary (Alberta) in August 2000. A modified relation of ITRF to a global vertical datum could easily resolve that and related problems. However, as mean sea level (MSL) is not in agreement with the tidal regimes mentioned above we basically need three different models of tide-reduced earth surfaces (mean, zero tide and tide-free) in order to fulfil different requirements of modeling. All three again differ from reality.

5. Conclusions

In spite of the numerous world-wide efforts of GLOSS, PSMSL, FAPSO, IAG, APSG, EOSS (IOC Group, 2001; Plag et al., 2000) etc. it would certainly be worthwhile to intensify, to some extent, interdisciplinary activities. It will certainly be possible to take profit from a substantially changed situation in geodesy, in a few years, as described above, to solve a variety of complex problems with relatively high precision which affect oceanography, geodesy, solid earth, geophysics, meteorology etc. Thus the progress of geodesy depends on cooperation with oceanography etc.

6. References

Bursa, M., J. Kouba, K. Radej, V. Vatrt and M. Vojtiskova: Geopotential at tide gauge stations used for specifying a World Height System, Czech Armed Forces, Geogr. Service, Prague, 2000

Bursa, M, S. Kenyon, J. Kouba, K. Radej, J. Simek, V. Vatrt, M. Vojtiskova: World Height System Specified by Geopotential at Tide Gauge Stations, paper presented at the IAG-Symposium on Vertical Reference Systems, Feb 20-23, Cartagena, Columbia. 2001

Chao, B.F., V. Dehant, R.S. Gross, R. D. Ray, D.A. Salstein, M. Watkins, and C.R. Wilson: Space geodesy monitors mass transports in global geophysical fluids. *EOS Trans. AGU*, **81**, 247-250, 2000

Grafarend, E. and A. Ardalan: World Geodetic Datum 2000, J. of Geodesy 73, 611:623, 1999

Gross, R.S.: Combinations of Earth orientation measurements: SPACE2000, COMB2000, and POLE2000, Jet Propulsion Laboratory Publ. 01-2, 25 pp., Pasadena, Calif., 2001 a

Gross, R.S.: Gravity, oceanic angular momentum, and the Earth's rotation, in *Proceedings of Gravity, Geoid, and Geodynamics 2000*, in press, Springer-Verlag, New York, 2001 b

Gross, R.S., and B.F. Chao: The gravitational signature of earthquakes, in *Proceedings of Gravity, Geoid, and Geodynamics 2000*, in press, Springer-Verlag, New Yor, 2001

Gross, R.S.: A combined length-of-day series spanning 1832-1997: LUNAR97, *Phys. Earth Planet. Inter.*, **123**, 65-76, 2001 c

Gross, R.S.: The excitation of the Chandler wobble, *Geophys. Res. Lett.*, **27**, 2329-2332, 2000

Groten, E.: A discussion of fundamental constants in view of Geodetic reference systems, pres. at GGG, IAG-Symposium, Banff, Alberta, July 31-Aug. 05, 2000

IOC Group: Reports of Meetings of Experts and Equivalent Bodies, *GOOS Report* No **95** UNESCO, 2001

Kouba, Jan: Intern GPS Service (IGS) and World Height System, paper presented at BATO World Height System Workshop, Prague, Nov. 8-10, 2000

Le Meur, E. and Ph. Huybrechts: A model computation of the temporal changes of surface gravity and geoidal signal induced by the evolving Greenland ice sheet, *Geophys. J. Int.* (2001) **145**, 835-849

Mäkinen, J., H. Koivula, M. Poutanen and V. Saaranen: Contemporary postglacial rebound in Finland: Comparison of GPS results with repeated precise levelling, pres. at GGG, IAG-Symposium, Banff, Alberta, July 31-Aug. 05, 2000

Plag, H.P., P. Axe, P. Knudsen, B. Richter and J. Verstraetan: European Sea Level Observing Systems (EOSS), Status and future developments, COST Action 40, Brussels, EUR 19682, 2000

The Vertical Reference System for Europe

~~{Authors~~J. Ihde[1], W. Augath[2]~~}~~

Introduction

Responding to an urgent request of the Comité ~~Europeen~~ Européen des Responsables de la Cartographie Officielle (CERCO) for an European Height System ~~in~~ a 0.1 m accuracy level the Technical Working Group of the IAG Subcommission on Continental networks for Europe (EUREF) proposed in 1994 a new adjustment and an enlargement ~~to Eastern Europe~~ of the United European Levelling Network to Eastern Europe (Resolution 3 of the EUREF Symposium in Warsaw, 1994). The decision for the realization of the European Vertical Reference System (EUVN) in 1995 was a big step toward a modern ~~compound~~ integrated reference system for Europe which combines GPS coordinates, gravity related heights and sea level heights in one data set. ~~once.~~ It was decided for Europe to derive the gravity related heights as normal heights from geopotential numbers (Resolution 2 of the EUREF Symposium in Ankara, 1996). In 1999 the European Spatial Reference Workshop recommended~~s that~~ the European Commission (EC) to adopt~~s~~ a vertical reference system on the basis of the results of the UELN and EUVN projects for the specifications of the products to be delivered to the EC. Furthermore— it ~~and future~~ promoted ~~s~~ the wider use within all member states in future. ~~:.~~

Present status

A height reference system is characteriz~~s~~ed by the vertical datum and the kind of gravity related heights. The vertical datum is in ~~the~~ 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, ~~Northern~~North Sea, Mediterranean Sea, Black Sea, Atlantic Ocean. The differences between these sea levels can amount— ~~come up~~ to several decimeters. They are caused by the various separations between the sea ~~ocean~~ surface and the geoid.

In addition 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 the most countries of Eastern Europe.

United European Levelling Network (UELN)

After a break of ten years, the work on the UELN was resumed in 1994 under the name UELN-95. The objectives of the UELN-95 project were ~~are~~ to establish a~~n~~ 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 and ~~step by step~~ the development of a kinematic height network "UELN 2000" step by step. Starting point for the UELN-95 project has been a repetition of the adjustment of the UELN-73/86. In contrast

[1] Johannes Ihde, Bundesamt für Kartographie und Geodäsie, Aussenstelle Leipzig, Karl-Rothe-Strasse 10-14, D-04015 Leipzig, Germany, Fax: +49 341 5634 415; Tel.: +49 341 5634 424; e-mail: ihde@leipzig.ifag.de

[2] Wolfgang Augath, Geodätisches Institut, Technische Universität Dresden, Mommsenstrasse 13, D-01062 Dresden, Germany, Fax: +49 351 463 7201; Tel.: +49 351 463 4249 (Sekr.), - 7503 (selbst); e-mail: wolfgang.augath@mailbox.tu-dresden.de

~~contrary~~ to the weight determination of the 1986 adjustment for UELN-95 the weights ~~are~~ were derived from a variance component estimation of ~~from~~ the observation material which was ~~wad~~ delivered by the participating countries and ~~which was~~ introduced into the adjustment.

The adjustment ~~in geopotential numbers~~ is performed in geopotentiail numbers as nodal point adjustment with variance component estimation for the participating countries~~.~~ and ~~The adjustment is performed~~ as a free adjustment linked to the reference point of UELN-73 (Amsterdam).

The development of the UELN-95 is characterized by two different kinds of enlargements: The substitution of data material of such network blocks (which had been already part of UELN-73) by new measurements with improved network configuration, and on the other ~~hand, by~~hand by adding new national network blocks of Central and Eastern Europe which were not part of UELN-73.

In the year 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 in the system UELN-95/98 are available for more than 20 participating countries.

European Vertical Reference Network (EUVN)

The initial practical objective of the EUVN project ~~is~~ was to unify different national height datums in Europe within few centimeters also in ~~such~~ those countries which ~~are~~ were not covered by the UELN. ~~In a~~Additionally ~~this~~Additionally this project ~~is to~~ was thought as prepar~~e~~ation of a geokinematic height reference system for Europe and ~~to~~ 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 will be derived. Finally the EUVN is representing a geometrical-physical reference frame. In addition to the geopotential numbers the ~~corresponding normal~~corresponding normal heights will be provided. In the tide gauge stations the connection to the sea level will be realized.

In total the EUVN consists of about 196 sites: 66 EUREF and 13 national permanent sites, 54 UELN and UPLN (United Precise Levelling Network of Central and Eastern Europe) 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 ~~get~~ reach conformity with other projects, the general relations between ITRS and ETRS were used.

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

European Vertical Reference System (EVRS)

The Spatial Reference Workshop in Marne-la-Valleé in November 1999 recommended the European Commission European reference systems for referencing of geo data. For the height component the workshop recommend~~s~~ed that the European Commission:

- Adopts the results of the EUVN/UELN initiatives when available, as definitions of vertical datum and gravity-related heights;
- Includes the EUVN reference system so defined for the specifications of the products to be delivered to the EC, within projects, contracts, etc;
- Future promotes the wider use of the European vertical reference system within all member states, by appropriate means (recommendations, official statement, ...).

The Technical Working Group of the IAG Subcommission for Europe (EUREF) was asked to define a European Vertical Reference System and to describe ~~their~~ its realization. After a discussion at the ~~planary~~plenary of the symposium it was decided to specify the definition. Two contributions in this ~~discussionon~~discussion ~~about the~~about the ~~tratement~~treatment of the permanent tidal effect (MÄKINEN, EKMAN) are ~~published~~ added ~~in~~ to this publication.

The principles of the realization of the EVRS were adopted at the EUREF Symposium 2000 in Tromsø by the resolution no. 5:

The IAG Subcommission for Europe (EUREF)

noting the recommendation of the spatial referencing workshop, in Marne-la-Vallée 27-

30 November 1999, to the European Commission to adopt the results of the EUVN/UELN projects for Europe wide vertical referencing,
decides to define an European Vertical Reference System (EVRS) characteri~~s~~zed by:

- *the datum of 'Normaal Amsterdams Peil' (NAP)*
- *gravity potential differences with respect to NAP or equivalent normal heights,*

endorses UELN95/98 and EUVN as reali~~s~~zations of EVRS using the name EVRF2000,

asks the EUREF Technical Working Group to finali~~s~~ze the definition and initial reali~~s~~zation of the EVRS and to make available a document describing the system.

For referencing of geo information in a unique system transformation parameters between the national heights systems and the EVRS frame are ~~always available, see Sacher et al.~~ also available, see Sacher et al. (1999a).

References

AUGATH, W. ~~AUGATH, W.~~ (1994): *Proposals for a European Task force on Vertical Datums within the EUREF-Subcommission.* Presented at the EUREF-Symposium in Warsaw, June 8-11, 1994. In: Veröffentlichungen der Bayrischen Kommission für die Internationale Erdmessung. München, Heft Nr. 54, S. 171-175.

AUGATH, W. (1996*): UELN-2000 - Possibilities, Strategy, Concepts - or: How should we realize a European Vertical System?* Presented at the EUREF Symposium in Ankara, May 22-25, 1996. In: Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung. München, 1996, Heft Nr. 57, S. 170 - 174.

EKMAN, M.: *On the permanent tide in the European Vertical Reference System.* In: Veröffentlichung der Bayerischen Kommission für die Internationale Erdmessung. München, 2001, Heft Nr. 61, S.

IHDE, J., ADAM, J., GURTNER, W., HARSSON, B.G., SCHLÜTER, W., WÖPPELMANN, G. (1999a): *The Concept of the European Vertical GPS Reference Network (EUVN).* Presented at the EUREF Symposium in Bad Neuenahr-Ahrweiler, June 10-13, 1998. In: Mitteilungen des Bundesamtes für Kartographie und Geodäsie, EUREF Publication No. 7/II, Frankfurt am Main, 1999, Bd. 7, S. 11 - 22.

IHDE, J., BOUCHER, C., DUNKLEY, P., FARRELL, B., GUBLER, E., LUTHARDT, J., TORRES, J.: *European Spatial Reference Systems – Frames for Geoinformation System*-. Presented at the EUREF Symposium in Tromsö, June 22-24, 2000. In: Veröffentlichung der Bayerischen Kommission für die Internationale Erdmessung. München, 2001,Heft Nr. 61, S.

MÄKINEN, J.*: A note on the treatment of the permanent tidal effect in the European Vertical Reference System (EVRS).* In: Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung. München, 2001, Heft Nr. 61, S.

RUMMEL, R., HECK, B.: *Some Critical Remarks on the Definition and Realization of the EVRS.* In: Veröffentlichung der Bayerischen Kommission für die Internationale Erdmessung. München, 2001, Heft Nr. 61, S.

SACHER, M., IHDE, J., SEEGER, H. (1999a). Preliminary transformation relations between national European height systems and the United European Levelling Network (UELN). *Prepared for the CERCO Plenary, Oslo, September 1998.* Presented at the EUREF Symposium, Prague, June 2-4, 1999. In: Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung. München, 1999, Heft Nr. 60, S. 80 - 86.

SACHER, M., IHDE, J., CELMS, A., ELLMANN, A. (1999b): *The first UELN stage is achieved, further steps are planned.* Presented at the

EUREF Symposium, Prague, June –2–-4, 1999. In: Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung. München, 1999, Heft Nr. 60, S.– 87 –87 - -94.

European Vertical Reference System– (EVRS), International Association of Geodesy, Section I – Positioning, Commission X – Global and Regional Networks, Subcommission for Europe (EUREF). Presented at the EUREF Symposium, Tromsø, June, 22-24, 2000. In: Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung. München, 2001, Heft Nr. 61, S.

Annex C to CL 41/2001

European Vertical Reference System (EVRS)

International Association of Geodesy

Section I – Positioning

Commission X – Global and Regional Networks

Subcommission for Europe (EUREF)

Preamble

This document

- defines the European Vertical Reference System (EVRS) including a European Vertical Datum and the European Vertical Reference Frame as its realization and for practical use as a static system under the name EVRF2000;
- is for adoption by the European Commission to promote widespread use as a defacto standard for future pan–European data products and services.

1. 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 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.[3]

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

2. The European Vertical Reference Frame 2000 (EVRF2000)

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 is now given the name EVRF2000.

2.1 Realization of the datum

a) 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:

$$c_{NAP} = 0.$$

b) For related parameters and constants of 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

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

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

Station name Country	UELN number	POSITION IN ETRS89 ellipsoidal latitude ellipsoidal longitude in ° □□	Height in UELN95/98 geopotential number in m² □s⁻²	normal height in m	Gravity in IGSN71 in m □s⁻²
Reference point of EVRS 000A2530 The Netherlands	**13600**	52° 22□53□ 4° 54□34□	**7.0259**	**0.71599**	9.81277935

2.2 The Adjustment of UELN-95/98

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

Parameters of the UELN-95/98 adjustment are the following:

- number of fixed points: 1
- number of unknown nodal points: 3063
- number of measurements: 4263
- degrees of freedom: 1200
- a-posteriori standard deviation referred to a levelling distance of 1 km: 1.10 kgal · mm
- mean value of the standard deviation of the adjusted geopotential number differences: 6.62 kgal · mm
- mean value of the standard deviation of the adjusted geopotential numbers ($\hat{=}$ heights): 19.64 kgal · mm
- average redundancy: 0.281

The normal heights H_n were computed by $H_n = c_P / \bar{\gamma}$, where $\bar{\gamma}$ is the average value of the normal gravity along the normal plumb line between the ellipsoid and the telluroid. The average value of the normal gravity along the normal plumb line is determined by

$$\bar{\gamma} \approx \gamma_m = \gamma_0 - \frac{0.3086\, mgal/m \cdot h}{2} + \frac{0.072 \cdot 10^{-6}\, mgal/m^2 \cdot h^2}{2}$$

with the Gravity Formula 1980 and latitude in ETRS89.

Figure 1:
United European Levelling Network 1995 [kgal · mm]
(UELN-95/98 – extended for Estonia, Latvia, Lithuania and Romania)

Figure 2:
UELN 95/98 – Isolines of Precision

Addendum

A 1 Datum relations

A 1.1 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 EVRF2000 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.

A 1.2 Relations between the EVRS2000 datum and datums of National Height Systems in Europe

In Europe three different kinds of heights (normal heights, orthometric heights and normal-orthometric heights) are 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 used.

The vertical datum is determined by the mean sea level, which is estimated at one or more tide gauge stations. The reference tide gauge stations to which the zero levels of the national European height systems in Europe are related are located at various oceans and inland seas: Baltic Sea, North Sea, Mediterranean Sea, Black Sea, Atlantic Ocean. The differences between the zero levels can come up to several decimeters. They are caused by the various separations between the ocean surface and the geoid as well as by the definition of the level.

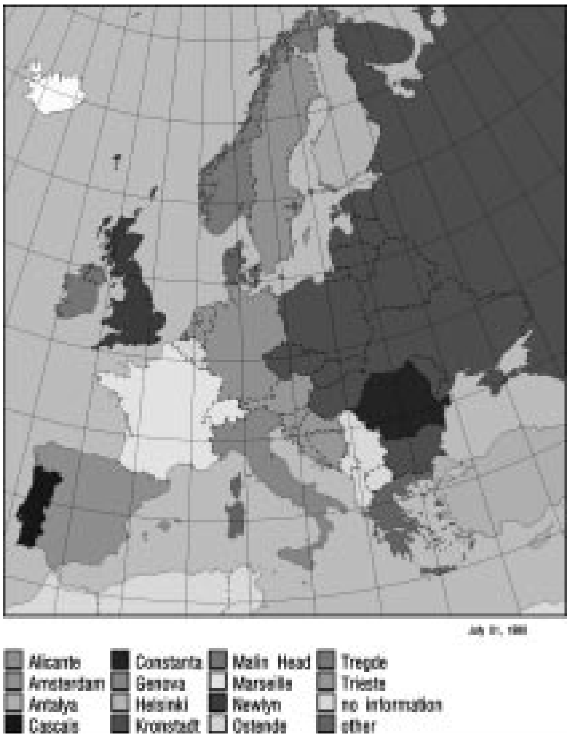


Figure 3: Reference Tide Gauges of National Height Systems in Europe

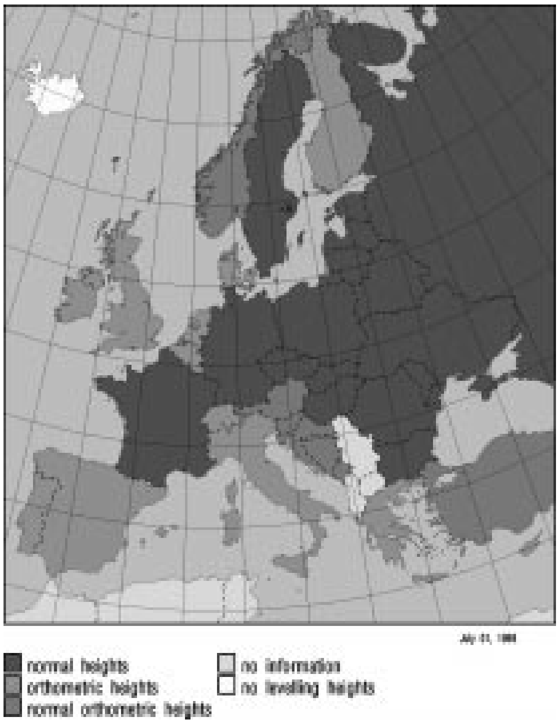


Figure 4: Kind of Heights of National Height Systems in Europe

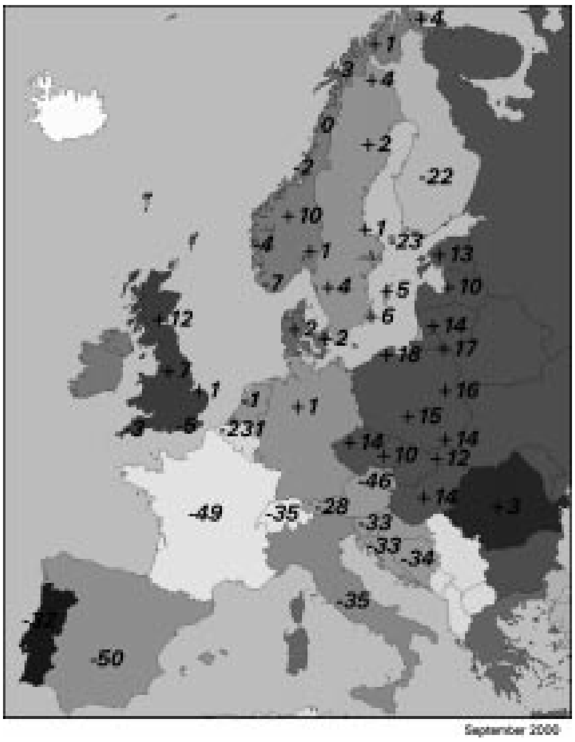


Figure 5: Differences between EVRF2000 zero level and the zero levels of national height systems in Europe (in cm)

The current situation of national height systems in Europe is characterised by Figure 3 and Figure 4.

Figure 5 shows the distribution of the mean transformation parameters from the national height systems to the EVRF2000.

The following table summarizes the information about the relations between the EVRF2000 zero level and the zero levels of national height systems in Europe.

Preliminary Transformation Parameters from National European Height Systems to the EVRF2000

Country (country code)	Reference Tide Gauge	Kind of Heights	UELN-Nat. Height in cm	min/max in cm	No. of Identical Points
Albania	Durres				
Austria	Trieste	NOH	- 35	- 25/- 48	100 (UELN)
Belgium	Ostend	OH	- 231	- 230/- 232	4 (EUVN)
Belorussia	Kronstadt	NO	+ 15		
Bosnia/Herzegovina	Trieste	NOH	- 34	- 33/- 34	5 (UELN)
Bulgaria	Kronstadt	NH	+ 15		
Croatia	Trieste	NOH	- 33	- 32/- 35	4 (UELN)
Czech Republic	Kronstadt	NH	+ 11	+ 8/+ 16	53 (UELN)
Denmark	10 Danish tide gauges	OH	+ 2	+ 1/+ 3	733 (UELN)
Estonia	Kronstadt	NH	+ 13	+ 12/+ 15	36 (UELN)
Finland	Helsinki	OH	+ 22	+ 22/+ 23	8 (EUVN)
France	Marseille	NH	- 49	- 48/- 49	7 (EUVN)
Germany	Amsterdam	NH	+ 1	+ 1/+ 2	431 (UELN)
Greece					
Hungary	Kronstadt	NH	+ 14	+ 13/+ 14	4 (EUVN)
Iceland	no levelling heights				
Ireland	Malin Head	OH			
Italy	Genoa	OH	- 35	- 33/- 36	11 (EUVN)
Latvia	Kronstadt	NH	+ 10	+ 8/+ 12	124 (UELN)
Lithuania	Kronstadt	NH	+ 14	+ 13/+ 14	46 (UELN)
FYR of Macedonia	Trieste	OH			
Moldavia	Kronstadt	NH	+ 15		
Netherlands	Amsterdam	OH	- 1	0/- 3	758 (UELN)
Norway	Tregde	NOH	0	- 7/+ 10	10 (EUVN)
Poland	Kronstadt	NH	+ 16	+ 14/+ 18	117 (UELN)
Portugal	Cascais	OH	- 32	- 29/- 33	5 (EUVN)
Romania	Constanta	NH	+ 3	+ 2/+ 4	64 (UELN)
Russia	Kronstadt	NH	+ 15		
Slovakia	Kronstadt	NH	+ 12	+ 11/+ 13	3 (EUVN)
Slovenia	Trieste	NOH	- 33	- 33/- 34	9 (UELN)
Spain	Alicante	OH	- 50	- 47/- 52	7 (UELN)
Sweden	Amsterdam	NH	+ 3	0/+ 6	11 (EUVN)
Switzerland	Marseille	OH (NH)	- 35 - 17	- 16/- 56 - 15/- 22	7 (EUVN)
Turkey	Antalya	OH			
Ukraine	Kronstadt	NH	+ 15		
United Kingdom	Newlyn	OH	+ 2	+ 12/- 5	5 (EUVN)

Country (country code)	**Reference Tide Gauge**	**Kind of Heights**	**UELN-Nat. Height in cm**	**min/max in cm**	**No. of Identical Points**
Yugoslavia	Trieste	NOH			

(NH ... normal heights, NOH ... normal-orthometric heights, OH ... orthometric heights)

A 2 European Spatial Reference System

A 2.1 European Vertical Reference Network (EUVN)

The initial practical objective of the EUVN project is to unify different European height datums within few centimeters. The EUVN project contributes to the realization of a European vertical datum and to the connection of different sea levels of European oceans with respect to the work of PSMSL (Permanent Service of Mean Sea Level) and of anticipated accelerated sea level rise due to global warming. The project provides a contribution to the determination of an absolute world height system.

At all EUVN points *P* three-dimensional coordinates in the ETRS89 $(X_p, Y_p, Z_p)_{ETRS}$ and geopotential numbers $c_p = W_{o\ UELN} - W_p$ will be derived. Finally the EUVN is representing a geometrical-physical reference frame. In addition to the geopotential numbers c_p normal heights $H_n = c_p / \bar{\gamma}$ will be provided.

In total the EUVN consists of 196 sites: 66 EUREF and 13 national permanent sites, 54 UELN and UPLN (United Precise Levelling Network of Central and Eastern Europe) stations and 63 tide gauges (Figure 4).
The final GPS solution was constrained to ITRF96 coordinates (epoch 1997.4) of 37 stations with an a-priori standard deviation of 0.01 mm for each coordinate component. As a consequence of these tight constraints the resulting coordinates of the reference points are virtually identical with the ITRF96 values. To get conformity with other projects, the general relations were used to transform the ITRS coordinates to ETRS. The coordinate transform formula from ITRF96 to ETRF96 and the final coordinates are given in Ineichen et al 1999.

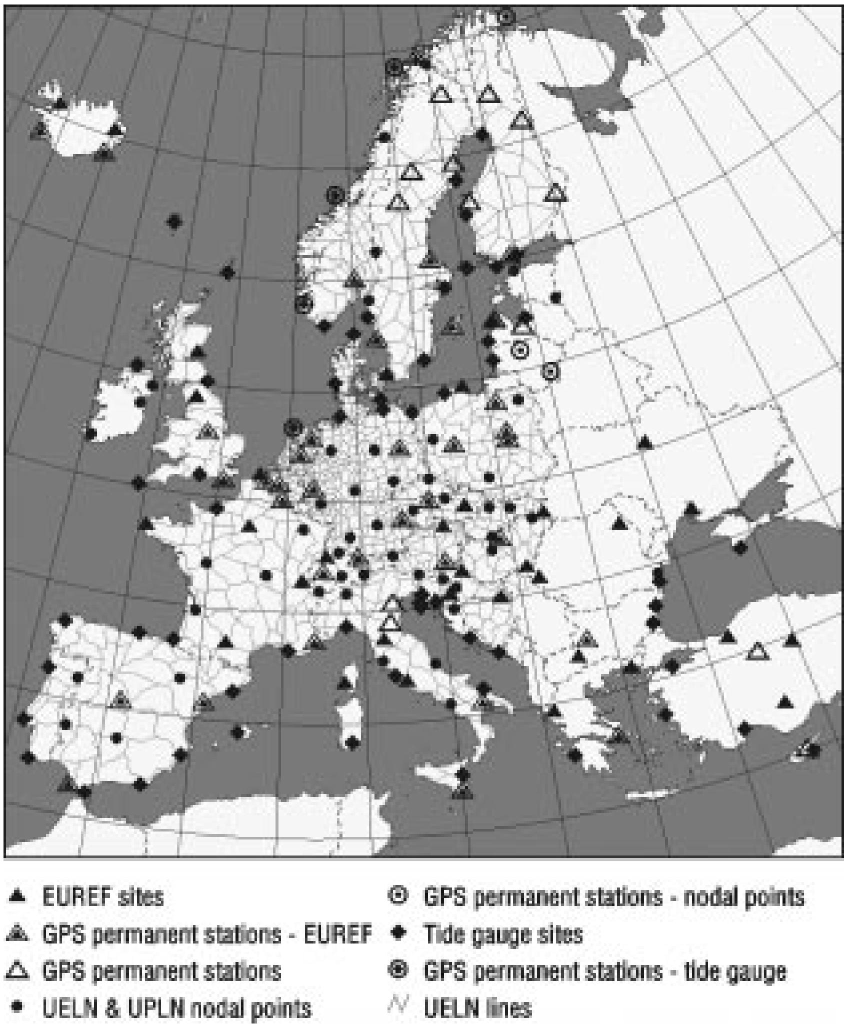


Figure 6: Distribution of EUVN stations

In order to reach the goal it is necessary to connect the EUVN stations by levellings to nodal points of the UELN 95/98 network. The geopotential numbers are related to the EVRS2000 zero level. As the EUVN is a static height network it is necessary to know the value of the mean sea level in relation to the tide gauge bench mark at the epoch of EUVN GPS campaign 1997.5.

The Permanent Service for Mean Sea Level (PSMSL) as member of the Federation of the Astronomical and Geophysical Data Analysis Service (FAGS) is in principle in charge of the data collection. The information which is sent to the PSMSL databank is available for the EUVN project.

A 2.2 A Kinematic European Vertical System (EVS)

The European Vertical System is planned as geokinematic height network as combination of the European GPS permanent station network, the UELN with repeated levellings, the European gravimetric geoid and tide gauge measurements along European coast lines as well as repeated gravity measurements. In May 1999 a special working group was formed to determine the direction of future work. At the first working group meeting three first tasks were established:

- analysis of available repeated levelling measurements and storage in the data base of the UELN
- development of software as base for test computation
- testing of the principles in a test area (Netherlands, Denmark, northern part of Germany).

The GPS observations of about 80 European permanent stations are available. The analysis of 10 European GPS permanent stations shows daily repeatabilities between 7 to 9 mm in the height component. This is in good agreement with the special GPS height campaigns in Germany for deriving GPS levelling geoidal heights ($m_h = \pm 7$ mm).
Furthermore the linear height regression analysis gives for a three year period an accuracy of a GPS height difference of about

$$m_{V_h} = m_h \sqrt{2} / \sqrt{365} \text{ / year} = \pm 0.5 \text{ mm/year},$$

that means from a statistical point of view that a vertical movement of $V_h = 1.0$ mm/year can be significantly determined after a three years GPS observation period ($m_{V_h} = \pm 0.3$ mm/year).
Repeated precise levellings (1 mm $\cdot$ km$^{-1/2}$) with an epoch difference of 20 years give velocities for height differences with an accuracy of about $\pm$ 0.07 mm $\cdot$ km$^{-1/2}$ / year.
From this follows, that GPS permanent stations in a distance of about 300 km can significantly support repeated levellings with above mentioned suppositions. This combination of GPS and levelling is promising for a stable kinematic height reference system (Ihde, 1999).
The observation equation for levelling observations $\Delta h_{ij,k}$ between points i and j at the epoch k is:

$$\Delta h_{ij,k} = H_j - H_i + V_j(t_k - t_0) - V_i(t_k - t_0). \tag{1}$$

Two unknowns per point are to be determined: the levelling height H (gravity related height) at the reference epoch t_0 and the velocity V.
For datum fixing of the network a height for one point at a determined epoch and a velocity for this or another point shall be given.
The relation between levelling heights H and GPS heights h is given by the geoid height N

$$h = H + N. \tag{2}$$

Since the accuracy of the geoid heights resp. geoid height differences is not in the same order like the levelling observations, GPS heights cannot be used as observations. But under the condition of no significant geoid height changes, velocities v derived from GPS permanent station observations can be used as additional observation type in levelling points I

$$v_i = V_i. \tag{3}$$

The unknown velocities V are to be determined in combination with the repeated levellings. It is necessary, that the variance-covariance matrix of the observed GPS velocities is given.

The EVS project has been started in 1999. It would be useful to integrate

- precise absolute gravity measurements
- sea level monitoring in tide gauge stations.

A 3 Geodetic Reference System 1980 (GRS80)

Excerpt from H. MORITZ: *Geodetic Reference System 1980*
Bulletin Géodésique, The Geodesists Handbook, 1988,
International Union of Geodesy and Geophysics

A 3.1 Definition

The GRS80

a) based on the theory of the geocentric equipotential ellipsoid, defined by the following conventional constants:

- equatorial radius of the Earth:
  $a = 6378\ 137$ m,
- geocentric gravitational constant of the Earth (including the atmosphere):
  $GM = 3986\ 005 \times 10^8\ m^3\ s^{-2}$,
- dynamical form factor of the Earth, excluding the permanent tidal deformation:
  $J_2 = 108\ 263 \times 10^{-8}$,
- angular velocity of the Earth:
  $\omega = 7292\ 115 \times 10^{-11}$ rad s^{-1},

b) used the same computational formulas, adopted at the XV General Assembly of IUGG in Moscow 1971 and published by IAG, for the Geodetic Reference System 1967,

c) is orientated in such kind, that the minor axis of the reference ellipsoid, defined above, be parallel to the direction defined by the Conventional International Origin, and that the primary meridian be parallel to the zero meridian of the BIH adopted longitudes.

A 3.2 Numerical Values

Derived Geometrical Constants

$b = 6\ 356\ 752.3141$ m	semiminor axis
$e^2 = 0.006\ 694\ 380\ 022\ 90$	e = first excentricity
$f = 0.003\ 352\ 810\ 681\ 18$	flattening

Derived Physical Constants

$U_0 = 6\ 263\ 686.0850 \times 10\ m^2\ s^{-2}$	normal potential at ellipsoid
$m = 0.003\ 449\ 786\ 003\ 08$	$m = \omega^2 a^2 b\ /\ GM$
$\gamma_e = 9.780\ 326\ 7715\ ms^{-2}$	normal gravity at equator
$\gamma_P = 9.832\ 186\ 3685\ m\ s^{-2}$	normal gravity at pole
$f^* = 0.005\ 302\ 440\ 112$	$f^* = (\gamma_p - \gamma_e)\ /\ \gamma_e$
$k = 0.001\ 931\ 851\ 353$	$k = (b\,\gamma_e - a\,\gamma_e)\ /\ a\,\gamma_e$

A 3.3 Gravity Formula 1980

Somigliana's closed formula for normal gravity is

$$\gamma_O = \frac{a\gamma_e \cos^2\phi + b\gamma_p \sin^2\phi}{\sqrt{a^2\cos^2\phi + b^2\sin^2\phi}} \,.$$

For numerical computations, the form

$$\gamma_O = \gamma_e \frac{1 + k\sin^2\phi}{\sqrt{1 - e^2\sin^2\phi}} \,,$$

with the values of γ_e , k, and e^2 shown above, is more convenient. ϕ denotes the geographical latitude.

The series expansion

$$\gamma_O = \gamma_e \left(1 + \sum_{n=1}^{\infty} a_{2n} \sin^{2n}\phi\right)$$

with

$$a_2 = \frac{1}{2}e^2 + k \,, \qquad a_6 = \frac{5}{16}e^6 + \frac{3}{8}e^4 k \,,$$

$$a_4 = \frac{3}{8}e^4 + \frac{1}{2}e^2 k \,, \qquad a_8 = \frac{35}{128}e^8 + \frac{5}{16}e^6 k$$

becomes

$$\begin{aligned}\gamma_O = \gamma_e(1 &+ 0.0052790414 \sin^2\phi \\ &+ 0.0000232718 \sin^4\phi \\ &+ 0.0000001262 \sin^6\phi \\ &+ 0.0000000007 \sin^8\phi) \,;\end{aligned}$$

it has a relative error of 10^{-10}, corresponding to 10^{-3} μms^{-2} = 10^{-4} mgal.

The conventional series

$$\gamma_O = \gamma_e \left(1 + f^* \sin^2\phi - \frac{1}{4} f_4 \sin^2 2\phi\right)$$

with

$$f_4 = -\frac{1}{2} f^2 + \frac{5}{2} f\, m$$

becomes

$$\gamma_O = 9.780327\left(1 + 0.0053024\sin^2\phi - 0.0000058\sin^2 2\phi\right) ms^{-2} \,.$$

A 3.4 Origin and Orientation of the Reference System

IUGG Resolution No. 7, quoted at the beginning of this paper, specifies that the Geodetic Reference System 1980 be geocentric, that is, that its origin be the center of mass of the earth. Thus, the center of the ellipsoid coincides with the geocenter.

The orientation of the system is specified in the following way. The rotation axis of the reference ellipsoid is to have the direction of the Conventional International Origin for Polar Motion (CIO), and the zero meridian as defined by the Bureau International de l'Heure (BIH) is used.

To this definition there corresponds a rectangular coordinate system XYZ whose origin is the geocenter, whose Z-axis is the rotation axis of the reference ellipsoid, defined by the direction of CIO, and whose X-axis passes through the zero meridian according to the BIH.

A 4 Related Resolutions

(1) Resolution No. 3
of the EUREF Symposium in Warsaw, 8 –11 June 1994

The IAG Subcommission for the European Reference Frame

recognizing the close relationship of vertical datum problems to EUREF activities and

considering the proposal of the EUREF Technical Working Group to respond to an urgent request of CERCO for a European Vertical Datum at the 0.1 m level

recommends

- that the Technical Working Group undertakes action and reports at the next meeting
- an enlargement of UELN to Eastern Europe for this purpose

requests the Eastern European agencies to make their national data available for UELN-CRCM Data Centre at Hanover within 1994.

(2) Resolution No. 2
of the EUREF Symposium in Helsinki, 3 – 6 May 1995

The IAG Subcommission for the European Reference Frame

noting the resolution No. 3 of the EUREF Warsaw Symposium in 1994 and

taking into account the principals of EPTN and EUVERN proposals presented during this meeting

recommends that a European Vertical Reference Network (EUVN) should be defined as part of the EUREF network with stations co-located with the European levelling or tide gauge networks

asks the EUREF Technical Working Group to organize the determination of the EUVN:

- by co-ordinating as many EUREF permanent GPS stations as possible
- by implementing a suitable GPS campaign to obtain a first epoch determination of all the EUVN stations as soon as possible.

(3) Resolution No. 2
of the EUREF Symposium in Ankara, 22 – 25 May 1996

The IAG Subcommission for Europe (EUREF) *recognized* that this Subcommission includes the responsibilities of the former UELN Subcommission

and noting the increasing need for a unified European height system at the decimetre level

decides to realise such a system through the conversion of the future UELN95 results from geopotential numbers to normal heights.

(4) Resolution No. 3
of the EUREF Symposium in Ankara, 22 – 25 May 1996

The IAG Subcommission for Europe (EUREF)

noting the efforts of the European Vertical GPS Reference Network (EUVN) Working Group

endorses their proposal to have a GPS campaign between the 21 and 29 of May, 1997

and urges all EUREF member countries to make their best endeavours in ensuring the success of this campaign.

(5) Resolution No. 4
of the EUREF Symposium in Ankara, 22 – 25 May 1996

The IAG Subcommission for Europe (EUREF)

recognizing the progress of UELN95, the forthcoming EUVN GPS Campaign, and the requirements for a continental vertical reference system at the centimetre level

decides to develop a new European geokinematic height reference network with all available kinematic observations (e.g. GPS, levelling, tide gauges, gravity)

urges all EUREF member countries to deliver relevant data to the data centre, Institut für Angewandte Geodäsie (IfAG)

and asks the Technical Working Group to form a special Working Group to oversee the development of the computation method and methodologies.

(6) Resolution No. 3
of the EUREF Symposium in Bad Neuenahr – Ahrweiler, 10 – 13 June 1998

The IAG Subcommission for Europe (EUREF)

recognizing the outstanding success of the European Vertical Reference Network 97 (EUVN97) GPS Campaign

thanks the EUVN working group and all the contributors to the campaign

accepts the adjustment presented at the symposium and asks the Technical Working Group to derive the final EUVN 97 GPS co-ordinates from this adjustment and

urges all EUREF member countries to submit the requested levelling/gravity and tide gauge data, to the data centre in order to achieve the EUVN objectives.

(7) Resolution No. 4
of the EUREF Symposium in Bad Neuenahr – Ahrweiler, 10 – 13 June 1998

The IAG Subcommission for Europe (EUREF)

recognizing the progress of the UELN95 project work

asks the data centre and Technical Working Group, to make the solution presented at the symposium, available as the UELN98 solution and *urgently requests* the participating countries to make the missing levelling data available, particularly to extend and improve the vertical network to the Black Sea, around the Baltic Sea and including the channel tunnel connection between France and UK.

(8) Resolution No. 1
of the EUREF Symposium in Prague, 2 – 5 June 1999

The IAG Subcommission for Europe (EUREF)

noting resolution 3 of the EUREF Symposium 1998 in Bad Neuenahr – Ahrweiler

accepts the GPS frame of the European Vertical Reference Network 1997 (EUVN97) as class B standard (about 1 cm at the epoch of observation), and

endorses these results as improvements and extensions to EUREF89.

(9) Resolution No. 5
of the EUREF Symposium in Prague, 2 – 5 June 1999

The IAG Subcommission for Europe (EUREF)

recognizing the progress in the UELN95 and EUVN as static height networks,

accepts the concept of an integrated kinematic height network for Europe proposed by the Technical Working Group (e.g. GPS permanent stations, repeated levellings, tide gauge observations, repeated gravity measurements)

asks the Technical Working Group to send a circular letter to the EUREF community detailing the proposal and requirements, and seeking participation in all topics (measurements, computing centre, test area).

(10) Resolution No. 3
of the EUREF Symposium in Tromsø, 22 – 24 June 1999

The IAG Subcommission for Europe (EUREF)

noting resolution 3 of the EUREF Symposium 1998 in Bad Neuenahr-Ahrweiler,

recognizing the completion of the EUVN height solution, which includes GPS/levelling geoid heights,

thanks the National Mapping Agencies for their support in supplying data,

recommends that the GPS/levelling geoid heights of the EUVN solution should be used as fiducial control for future European geoid determinations,

asks the relevant authorities to provide the necessary information for tide gauge connections, to densify the network of EUVN GPS/levelling geoid heights and to complete and extend the EUVN project.

(11) Resolution No. 5
of the EUREF Symposium in Tromsø, 22 – 24 June 1999

The IAG Subcommission for Europe (EUREF)

noting the recommendation of the spatial referencing workshop, in Marne-la-Vallée 27-30 November 1999, to the European Commission to adopt the results of the EUVN/UELN projects for Europe wide vertical referencing, *decides* to define an European Vertical Reference System (EVRS) characterised by the datum of 'Normaal Amsterdams Peil' (NAP) and gravity potential differences with respect to NAP or equivalent normal heights,

endorses UELN95/98 and EUVN as realisations of EVRS using the name EVRF2000,

asks the EUREF Technical Working Group to finalise the definition and initial realisation of the EVRS and to make available a document describing the system.

References

ADAM, J., AUGATH, W., BROUWER, F., ENGELHARDT, G., GURTNER, W., HARSSON, B. G., IHDE, J., INEICHEN, D., LANG, H., LUTHARDT, J., SACHER, M., SCHLÜTER, W., SPRINGER, T., WÖPPELMANN, G.: *Status and Development of the European Height Systems.* In: Proceedings of the IAG General Assembly, Birmingham, July 18-30, 1999, In: IAG Symposia, Vol. 121, Geodesy Begon 2000, Springer, Berlin Heidelberg 2000, p. 55-60.

AUGATH, W. (1994): *Proposals for a European Task Force on Vertical Datums within the EUREF-Subcommission.* Presented at the EUREF Symposium, June 8-10, 1994, Warsaw, Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung, Astronomisch-Geodätische Arbeiten, München, 1994, H. 54, p. 171-175.

AUGATH, W. (1996): *UELN-2000 – Possibilities, Strategy, Concepts – or: How should we realize a European Vertical System?* Presented at the EUREF Symposium in Ankara, May 22-25, 1996. Veröffentlichung der Bayerischen Kommission für die Internationale Erdmessung, München, 1996, H. 57, p. 170-174.

EKMANN, M.: *On the Permanent Tide in the European Vertical Reference System.* Submitted to the EUREF Technical Working Group, August 2000.

EHRNSPERGER, W., KOK, J. J. (1986): *Status and Results of the 1986 Adjustment of the United European Levelling Network - UELN-73.* Paper contributed to the Symposium on Height Determination and Recent Crustal Movements in Western Europe, Federal Republic of Germany, Sept. 15-19, 1986.

GRAFAREND, E. W., ARDALAN, A. A. (1999): World Geodetic Datum 2000. In: Journal of Geodesy (1999) 73, p. 611-623, Springer-Verlag 1999.

IHDE, J., SCHLÜTER, W.: *Proposal for a European Vertical GPS Reference Network (EUVERN).* Presented at the EUREF-Symposium in Helsinki, May 3-6, 1995, Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung, Astronomisch-Geodätische Arbeiten, München, 1995, H. 56, p. 100-105.

IHDE, J., ADAM, J., GURTNER, W., HARSSON, B. G., SCHLÜTER, W., WÖPPELMANN, G.: *The Concept of the European Vertical GPS Reference Network (EUVN).* Presented at the EUREF Symposium in Bad Neuenahr-Ahrweiler, June 10-12, 1998, Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Band 7, Frankfurt a. M. 1999, p. 11-22.

IHDE, J., ADAM, J., GURTNER, W., HARSSON, B. G., SACHER, M., SCHLÜTER, W., WÖPPELMANN, G.: *The Height Solution of the European Vertical Reference Network (EUVN).* Presented at the EUREF Symposium in Tromsò, June 22-24, 2000, in preparation.

INEICHEN, D., GURTNER, W., SPRINGER, T.; ENGELHARDT, G., LUTHARDT, J., IHDE, J.: *EUVN97-Combined GPS Solution.* Presented at the EUREF-Symposium in Bad Neuenahr-Ahrweiler, June 3-5, 1998, Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Band 7, Frankfurt a. M. 1999, p. 23-46.

MÄKINEN, J.: *A Note on the treatment of the permanent tidal effect in the European Vertical Reference System (EVRS).* Submitted to the EUREF Technical Working Group, August 2000.

MORITZ, H. (1988): *Geodetic Reference System 1980.* Bulletin Géodésique, The Geodesists Handbook, 1988, International Union of Geodesy and Geophysics.

SACHER, M., IHDE, J., SEEGER, H. (1998): *Preliminary Transformation Relations between National European Height Systems and the United European Levelling Network (UELN).* Presented at the EUREF Symposium in Prag, June 2-4, 1999, Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung, Astronomisch-Geodätische Arbeiten, München, 1999, H. 60, p. 80-86.

SACHER, M., IHDE, J., CELMS, A., ELLMANN, A.: *The first stage is achieved – further steps are planned*. Presented at the EUREF Symposium in Prag, June 2-4, 1999, Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung, Astronomisch-Geodätische Arbeiten, München, 1999, H. 60, p. 87-94.