Status of the European Reference Frame (EUREF)

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Abstract EUREF (www.euref.eu) is the IAG (International Association of Geodesy) Reference Frame Sub-commission for Europe integrated in Sub-Commission 1.3 – Regional Reference Frames, of Commission 1 – Reference Frames, of the IAG.

The activities carried out by EUREF are related to the definition, realization and maintenance of the European Reference Frame. EUREF focuses on both the geo-spatial and the vertical components and has the participation of almost all the European countries.

This paper presents an overview of the status and recent developments of EUREF core projects, which are aimed at upgrading European-wide geodetic reference systems to support both scientific and continental geo-referencing activities.

Keywords EUREF · Regional Reference Frames · ETRS89 · GNSS permanent network · EPN · EUVN · EVRS2007 · UELN

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1 Introduction

EUREF (http://www.euref.eu) is the Reference Frame Sub-commission for Europe integrated in Sub-Commission 1.3 – Regional Reference Frames,

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of Commission 1 - Reference Frames, of the IAG (International Association of Geodesy).

The long-term objective of EUREF is the definition, realization and maintenance of the European Reference Frame, focusing on both the geo-spatial and the vertical components.

EUREF's mission is to provide the best possible unique and homogeneous reference system and respective realization, to be used Europe-wide in all scientific and practical activities related to precise georeferencing and navigation, Earth Sciences research and multidisciplinary applications.

For that, EUREF makes use of the most accurate and reliable terrestrial and space-borne techniques available, and develops the necessary scientific background and methodology for the combination of heterogeneous measurements.

The activities in support of these objectives must result in a set of high quality products and services. For this, EUREF focuses on a continuous innovation and on the developing user needs, as well as on the maintenance of an active network of people and organizations (Adam et al., 2001).

Almost all the European countries participate in the activities. Furthermore, EUREF works in close cooperation with the pertinent IAG components as well as EuroGeographics, the consortium of the NMCA (National Mapping and Cadastre Agencies) in Europe.

The present status of activities and the main accomplishments, in the period between the IUGG (International Union of Geodesy and Geophysics) General Assemblies held in Sapporo 2003 and Perugia 2007, are, namely:

- Overview and organisation of EUREF;
- Realization of the European Terrestrial Reference System 1989 (ETRS89) and the relationships with the International Terrestrial Reference System (ITRS) realizations;
- The EUREF Permanent Network (EPN), its contribution to the maintenance of the European Terrestrial Reference Frame (ETRF) and the International Terrestrial Reference Frame (ITRF) and the related special projects;
- Real-Time Activities and the development of the standards and the operational means to disseminate GNSS data via the Internet, in the context of the efforts within the IAG towards real-time data dissemination;
- The European Vertical Reference System (EVRS), including the status of the Unified European Levelling Network (UELN) and of the European Unified Vertical Network Densification Action (EUVN_DA);
- The status of the adoption of the ETRS89 by the European countries and organisation as official systems since its definition in 1990 (EUREF, 1992);
- Outreach, external liaisons and symposia;
- Summary of results.

2 Overview and Organisation

At the annual Symposium held in Bratislava (June 2004), the Terms of Reference (ToR) of EUREF were adopted. The ToR contain the description of EUREF, its objectives, activities, organization and the rules for membership according to the general rules expressed in the Statutes and By-laws of IUGG and, consequently, of IAG. The complete text can be found at http://www.euref_iag.net/html/Overview_of_EUREF_Terms_of_reference.html.

The Chair represents EUREF and is assisted by a Secretary. The main tasks are the overall coordination and management, as well as facilitating the achievement of EUREF objectives.

A fundamental element in the structure is the EUREF Technical Working Group (TWG), which acts as a scientific board, and has the task to govern the following activities:

- to coordinate and develop the EPN;
- to evaluate and classify results of GNSS campaigns as EUREF densification or extension;
- to coordinate the actions for the realization of a European Height System;
- to identify the actions for the continuation and development of EUREF;
- to set up the working groups to run the projects defined by the plenary;
- to prepare the recommendations for the EUREF plenary.

At present the TWG is composed by 17 members. It met 11 times in the period 2003–2007. Information about TWG membership, meeting agendas, and various contributions are available at http://www.euref-iag.net/html/twg.html.

3 The ETRS89

3.1 Definition; Relation with the ITRS

At the EUREF symposium held in Firenze, 1990, the following resolution was adopted (EUREF, 1992, Boucher and Altamimi, 1992):

"The IAG Sub-commission for the European Reference Frame (EUREF) recommends that the system to be adopted by EUREF will be coincident with ITRS at the epoch 1989.0 and fixed to the stable part of the Eurasian Plate, and will be known as European Terrestrial Reference System 1989 (ETRS89)" (http://www.euref.eu/html/resolutions.html#Florence).

As a consequence of this definition, and given its link with the ITRS, the ETRS89 realizations are characterized by a clear transformation formula between both systems. The different realizations of the ETRS89 are named ETRFyy which are linked to their corresponding ITRFyy realizations.

The general relationship between the two systems is described in Boucher and Altamimi (2007) since the tectonic movement of the Eurasian plate can be described in relation to the ITRS.

Both systems are related by a shift between ITRFyy and ETRFyy at epoch 1989.0 and a rotation which accounts for the motion of the stable part of the Eurasian plate since 1989. The general model is a 14 parameter transformation (Eqs. (1), (2) and (3) below), where most of the parameters are 0.

For the positions:

$$\boldsymbol{XE}(t_c) = \boldsymbol{XI_{YY}}(t_c) + \boldsymbol{T_{YY}} + \boldsymbol{dR_{YY}}.\boldsymbol{XI_{YY}}(t_c).(t_c - 1989.0) \quad (1)$$

$\boldsymbol{XE}(t_c)$ – position vector in ETRS89 at epoch tc
$\boldsymbol{XI_{YY}}(t_c)$ – position vector in ITRFyy at epoch tc
$\boldsymbol{T_{YY}}$ – translation vector from ITRFyy to ETRF89
tc – central epoch of observations
$\boldsymbol{dR_{YY}}$ – matrix containing the 3 rotation rates in ITRFyy, in the form

$$\boldsymbol{dR_{YY}} = \begin{pmatrix} 0 & -dR3_{YY} & dR2_{YY} \\ dR3_{YY} & 0 & -dR1_{YY} \\ -dR2_{YY} & dR1_{YY} & 0 \end{pmatrix} \quad (2)$$

For the velocities:

$$\boldsymbol{dXE_{YY}} = \boldsymbol{dXI_{YY}} + \boldsymbol{dR_{YY}}.\boldsymbol{XI_{YY}} \quad (3)$$

$\boldsymbol{dXE_{YY}}$ – velocity vector in ETRS89
$\boldsymbol{dXI_{YY}}$ – velocity vector in ITRS

The values for the rotation rates of the Eurasian plate since 1989 are presented in Table 1.

Table 1 Rotation rates for the $ITRF_{YY}$ realizations

YY	dR1 (mas)	dR2 (mas)	dR3 (mas)
89/90	0.11	0.57	−0.71
91/92	0.21	0.52	−0.68
93	0.32	0.78	−0.67
94/96/97	0.20	0.50	−0.65
00	0.081	0.490	−0.792
	±0.021	±0.008	±0.026
05	0.054	0.518	−0.781
	±0.009	±0.006	±0.011

The most recent values are derived from the ITRF2005 velocity field (Altamimi et al., 2007). It can be seen that for the 2000 and 2005 realizations, the accuracies of the parameters are presented as well, since they are derived from the computation of the ITRF itself. The transformation procedure is currently under discussion.

A complete description of ETRS89, ETRFyy and procedures for computations in ETRS89 can be found at http://lareg.ensg.ign.fr/EUREF.

3.2 Realizations

The ETRS89 was first realised by the European Terrestrial Reference Frame 1989 (ETRF89), the European sub-set of ITRF89 (SLR and VLBI sites).

For the subsequent realizations, GPS campaigns were organised in order to constitute a network of high-precision geodetic reference sites. The first one was EUREF89, covering 92 sites all over Europe. For quality assessment purposes, the sites are classified as follows:

- CLASS A (1 cm accuracy independent of epoch) *permanent GPS observations*
- CLASS B (1 cm accuracy at a specific epoch) *GPS campaigns since 1993*
- CLASS C (5 cm accuracy at a specific epoch)

The computation of the campaigns is performed according to specifications that can be summarized as follows (Boucher and Altamimi, 2007):

– compute the coordinates in ITRS at the central epoch of the observations using the most recent ITRFyy solution;
– transform the coordinates in ETRS89 at the central epoch of the observations (see Sect. 3.1).

Between 2003 and 2007 the following campaigns have been validated by the TWG and accepted as class B standard, increasing to 39 the number of campaigns validated since 1993:

– EUREF-Slovakia-2001 campaign in Slovakia;
– EUREF-Pol-2001 campaign in Poland;
– EUREF-Austria-2002 campaign in Austria;
– EUREF-Hungary-2002 campaign in Hungary;
– EUREF-Armenia-2002 campaign in Armenia;
– EUREF-GB-2001 (re-computation of the campaign in Great Britain);
– EUREF-NKG-2003 campaign in the Baltic countries. Points from Latvia and Lithuania included in the data base;
– EUREF-BG-2004 campaign in Bulgaria, combined with the EUREF-BG92/93, previously accepted in 1996.

4 EUREF Permanent Network (EPN)

4.1 Description

A key instrument in maintaining and providing access to the ETRS89 is the EUREF Permanent Network (EPN), created in 1995.

Presently the EPN covers the European continent with continuous observing dual frequency GPS and GPS/GLONASS receivers operating under well-defined standards and guidelines that guarantee the efficiency of the EPN and the long-term quality of its products (Bruyninx and Roosbeek, 2007).

The EPN constitutes the European contribution to, and densification of, the International GNSS Service (IGS), and as such it strives for complete consistency with the IGS standards and models: IGS orbits and ERPs (Earth Rotation Parameters) are used for all EPN processing and the same models are used for the antenna phase centers of both satellites and receivers.

The total number of EPN stations comprises now more than 200, and 37 of these stations provide both GPS and GLONASS data.

The number of stations providing hourly data has increased to 84%. In addition, 42% of the EPN stations also submit data to the International GNSS Service; 10 of them contribute to the TIGA (Tide Gauge Benchmark Monitoring) Pilot Project of the IGS.

The "Procedure for becoming an EPN station" has been completely revised and has been in effect since December 2006. The most important changes concern the new requirements to submit a commitment letter guaranteeing that the station will be operated following EPN guidelines for a minimal duration of 5 years and the fact that all new EPN stations must have an antenna/radome with true absolute calibrations available from the EPN CB.

In addition, the 'Guidelines for EPN Stations and Operational Centres' have also been reviewed. The new guidelines were issued in order to improve the data flow within the EPN and to guarantee the availability of the EPN data at the regional (European) level in two regional data centres: BKG (Federal Office of Cartography and Geodesy, Germany) and OLG (Space Research Institute, Department of Satellite Geodesy Austrian Academy of Sciences, Austria).

Detailed information about the EPN can be found at the web site of the EPN Central Bureau (http://epncb.oma.be/).

4.2 Analysis and Reference Frame Realization

Sixteen Analysis Centers each process a sub-network of the EPN following the rules and guidelines set up by the EUREF Technical Working Group. The Analysis Centres submit weekly free-network coordinate solutions to the EPN Combination Centre which combines the individual sub-network solutions into one official EUREF coordinate solution including all tracking stations. This solution is tied to the same ITRFyy as the IGS orbits. Since GPS week 1303 (December 2004), the minimal constraint approach is used to tie the weekly solution to the ITRFyy.

Starting in GPS week 1400, the IGS orbits are aligned to the IGS05 which is the IGS realization of the ITRF2005 (Altamimi, 2006); at the same time the IGS replaced its relative antenna phase center models with absolute models.

EUREF followed these procedures and switched to absolute antenna phase center models simultaneously

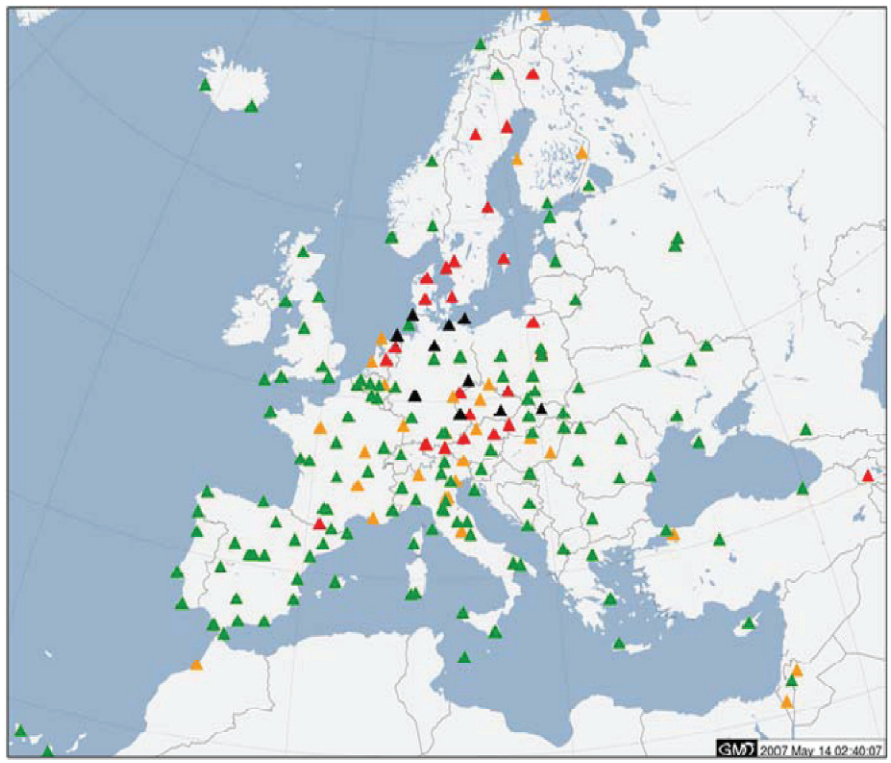

Fig. 1 Calibration types of the EPN stations: A1 – *black*; A2 – *green*; B – *yellow*; No calibration available – *red*

with the IGS. Individual antenna calibrations are used where available. The EUREF solutions, starting GPS week 1400, are tied to the IGS05. For a further discussion on the consequences see Bruyninx et al. (2006).

The EPN stations are classified as follows (see Fig. 1) with respect to the antenna phase center models (Bruyninx and Roosbeek, 2007):

- Type A: absolute phase center models based on robot calibrations
  - A1: Individual calibrations
  - A2: Type calibrations
- Type B: Absolute phase centre model based on relative model

4.3 EPN Projects

To stimulate the multi-disciplinary use of the EPN, EUREF has created different projects based on the EPN infra-structure:

- *Time Series monitoring Project*

The general task of the Time Series Analysis Special Project (TSA_SP) set up in 2000 is to promote the use of the EPN products for geophysical studies. Based on the periodically computed cumulative solution of the EPN combined weekly SINEX product, the TSA_SP maintains a database of the station coordinate offsets and outliers, estimates the most up-to-date coordinate and velocity solutions and performs noise and harmonic analysis of the time series (Kenyeres and Bruyninx, 2004).

The TSA_SP contributed to the ITRF2005 by providing the offset and outlier database of the EPN stations. After the release of ITRF2005 including its regional densification, the regularly updated EPN coordinate and velocity solution computed by the TSA_SP is considered as official for EPN stations. All results are displayed at the EPNCB web-pages.

- *Troposphere Project*

The project goal is to derive tropospheric (zenith total delay) parameters as part of the estimation.

The basic task within this activity is to produce a combined troposphere solution with input from the individual troposphere solutions of all Analysis Centers, which contribute to the coordinate solution. A 'rapid' combination derived to a given time contributes to the global IGS combined troposphere product (Söhne and Weber, 2004).

– *EUREF-IP Project*

Another project based on the EPN structure is EUREF-IP (IP for *Internet Protocol*), with the goal to collect and disseminate GNSS data in real-time via the Internet. Under this project the transport protocol Ntrip (Networked Transport of RTCM via Internet Protocol) was developed. In September 2004 (Weber et al., 2005) Ntrip has been included in the standards of RTCM (Radio Technical Committee for Maritime Services). EUREF-IP established an IP address for its Ntrip Broadcaster service at http://www.euref-ip.net/home.

The total number of world-wide Ntrip Broadcaster installations known is about 85. The total number of reference stations available via Ntrip technology amounts to approximately 1700; 52 of them are EPN stations, which is about one quarter of the EPN stations (see Fig. 2).

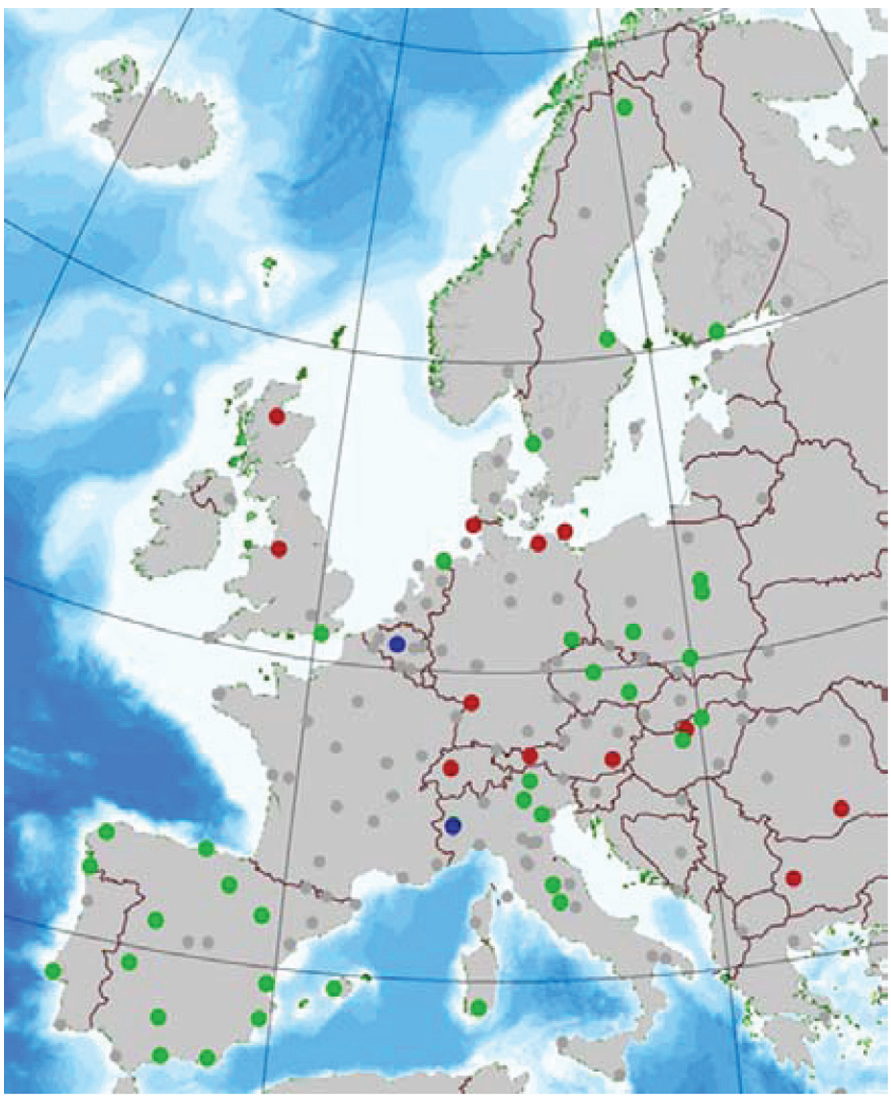

Fig. 2 EPN stations delivering real-time data: RTCM – *green*; raw data – *red*; RTIGS – *blue*

EPN stations use Ntrip to stream their real-time GNSS data providing full carrier phase data in raw or RTCM format; EUREF also provides the necessary tools to convert the streams to RINEX. As can be seen in Fig. 2, the RTIGS format developed by the IGS is used as well.

The current EUREF-IP efforts focus on developing a Monitoring/Notification system to reach and maintain a professional level of service availability, develop Ntrip towards full HTTP compatibility, introduce UPD as an additional data transport option, and encourage more EPN station operators to participate in EUREF-IP with real-time raw or RTK data.

Recognizing that the project EUREF-IP reached a high level of performance and acceptance, including stations outside Europe, and the importance of real-time activities within the IAG, it was decided at the EUREF 2007 Symposium to turn this project into a routine service (EUREF, 2007).

This new routine service is supported by a White Paper developed by the EUREF TWG available at http://www.epncb.oma.be/_organisation/guidelines/EPNRT_WhitePaper.pdf. In addition, guidelines have been developed for

- Reference stations
- NTRIP Broadcasters
- High-rate RINEX Data Centers

5 European Vertical Reference System

The definition of the European Vertical Reference System 2000 (EVRS2000), including a European Vertical Datum and the realization procedure, is being revised, considering that the progress in global gravity models will soon make possible the realization of EVRS in relation to a World Height System.

The vertical datum of the EVRS2000 was realized by one levelling pillar in the Netherlands which was related to the zero level of the Amsterdam Pile (NAP).

The EVRS2007 definition considers that the datum shall be realized by various datum points distributed over Europe. These points must be distributed in such a way that the level of EVRS2000 is kept (Ihde et al., 2007).

The heights are fit to the EVRS2000 solution by introducing the results of UELN 95/98 (Unified European Levelling Network) of the datum points in the free adjustment (Sacher et al., 2007).

The UELN 95/98 developed in recent years by integration of the levelling networks of Estonia (1999), Latvia (1999), Romania (2000), Lithuania (2001) and Bulgaria (2002) and by replacement of old data by complete national first order levelling networks of Switzerland (2002), The Netherlands (2005), Finland (2005), Norway (2005) and Sweden (2005).

The recent situation concerning the delivery of new data is shown in Fig. 3. Contacts are being established

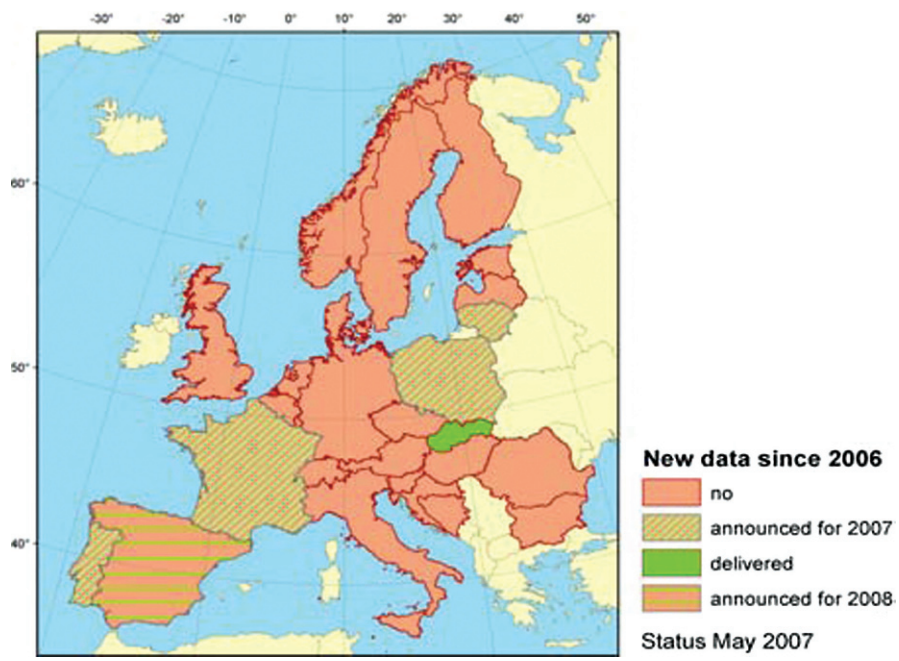

Fig. 3 New data for UELN – situation in May 2007

with Russia for the inclusion of new levelling data in the Baltic area. Further information about the European Vertical Reference System and UELN can be found at http://crs.bkg.bund.de/evrs/.

6 European Unified Vertical Network – Densification Action

In 1997 a GPS campaign consisting of 196 sites collocated at nodal points of the UELN and near tide gauges was established. This set of points constitutes the European Vertical GPS Reference Network (EUVN97) and provides the link between the vertical and geo-spatial components of the frame.

This project allowed for the computation of parameters to transform the heights of the different national height systems in Europe, related with the different tide gauges, into a common European height reference system, with decimeter accuracy.

The comparison between the EUVN GPS-levelling derived heights and the adopted European geoid model (EGG97), showed however some non-systematic effects.

To investigate these effects, the EUVN Densification Action (EUVN_DA) was initiated in 2003. The purpose is to collect accurate and dense information on levelling and ETRS89 coordinates selected from the national networks and constituting a homegenous GPS/levelling network and database.

This information will allow for the realization of an accurate height reference surface (fitted geoid) as well (Kenyeres et al., 2007). Until May 2007 a total of 1434 GPS/levelling points were collected all over Europe (see Fig. 4).

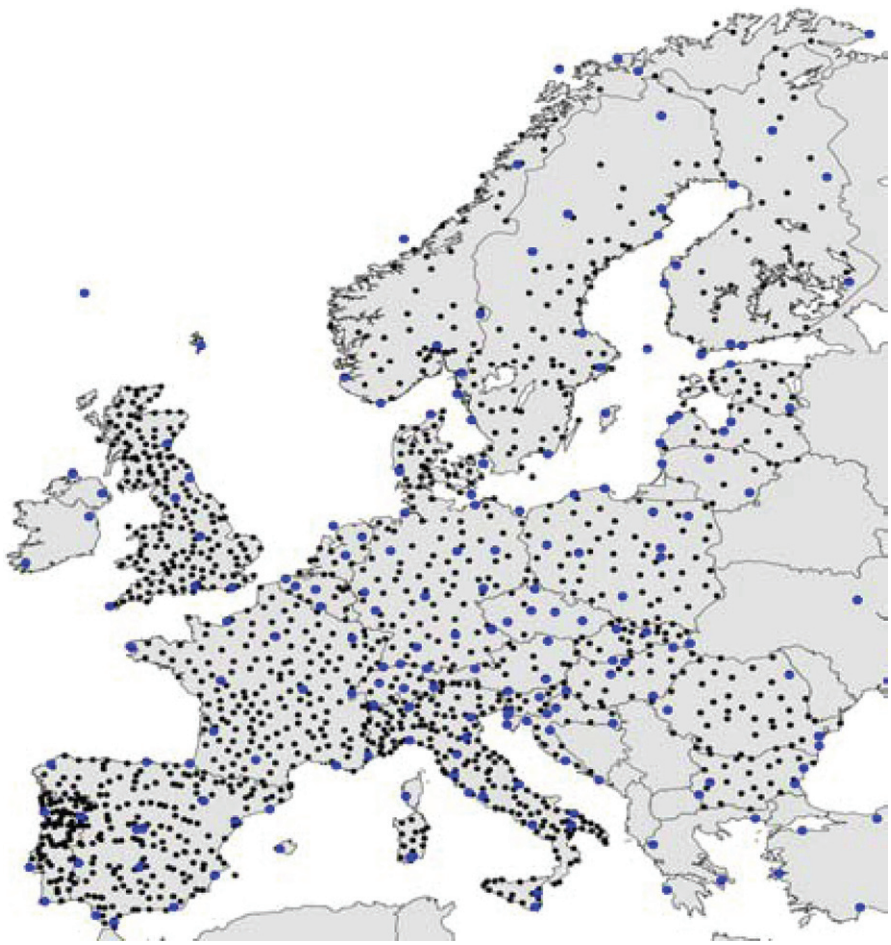

Fig. 4 EUVN_DA – situation in May 2007

7 Adoption and Promotion of the ETRS89

An important consequence of the definition and realization of the European reference system ETRS89 is its adoption by Eurocontrol and the on going process of adoption by several NMCA. Furthermore, there is a recommendation by the European Commission to adopt ETRS89 as the geodetic datum for geo-referenced information and promote the use of ETRS89 within member states.

In a joint cooperation between EUREF and EuroGeographics, the description of national coordinate reference systems (CRS) in Europe and the transformation parameters between CRS and ETRS89 for practical purposes, are available at http://crs.bkg.bund.de. The published information follows the ISO 19111 Spatial Referencing by Coordinates standard (Ihde et al., 2001).

In 2005 it was decided to continue to promote the use and adoption of the ETRS89 and to collect the most accurate and complete information on this subject.

Consequently, a survey was conducted jointly by EUREF and EuroGeographics among 41 NMCA.

From the 41 countries contacted, 28 answered the questionnaire representing about 68% of the total. The 3 different situations are as follows:

- 2 will not adopt (7% of the answers);
- 5 will adopt in the near future (18% of the answers);
- 21 have already adopted (75% of the answers).

The countries that stated that they will not adopt the ETRS89 are Luxembourg and Turkey. On the other hand, since the realization of the questionnaire, one of the countries that announced the adoption of the ETRS89 in the near future has already adopted, increasing to 22 the number of countries that announced the adoption of this system.

8 Outreach and External Liaisons; Symposia

Besides the web portal http://www.euref-iag.net, a new address was created in the "eu" domain, http://www.euref.eu. Both addresses coexist and give access to a portal that links to all the EUREF structures and projects; its main contents are information about the EUREF structure and documentation related with the symposia and TWG meetings.

The existing liaison with EuroGeographics continued through its Expert Group on Geodesy (ExGG) and was recently upgraded by the establishment of a Memorandum of Understanding (MoU) between both organizations.

Another MoU was signed with EUMETNET, a network of 21 European national meteorological services, with the purpose of creating the conditions to facilitate the data exchange and to promote the increase of cooperation, for the benefit of both the meteorological and geodetic communities.

There is a natural relationship between the work developed by EUREF and European initiatives related to geo-spatial information.

One of the most important ongoing actions is INSPIRE, aiming at the establishment of an infrastructure for spatial information in Europe that will help to make spatial or geographical information interoperable. EUREF already registered as one of the Spatial Data Interest Communities (SDIC) and proposed experts for the drafting teams in its area of expertise.

EUREF is also represented as an Associate Member at the IGC (International Committee on GNSS) of the United Nations.

In the last four year period symposia took place at Bratislava (Slovakia) in June 2004, at Vienna (Austria) in June 2005, at Riga (Latvia) in June 2006 and at London (UK) in June 2007.

These meetings are usually attended by about 120 participants from more than 30 countries in Europe.

The EUREF web portal contains the contributions presented at the symposia, as well as the full set of resolutions of all symposia since 1990 (http://www.euref-iag.net/html/symposia.html).

9 Summary

EUREF is continuously developing activities related to the establishment, maintenance and promotion of the ETRS89 (European Terrestrial Reference System) and EVRS (European Vertical Reference System).

The ETRS89 has been recommended for adoption by several European organizations and is used by the majority of the European countries.

The realization of the EVRS2007 with new data sets and the possibility to align EVRS to a World Height System is in a very advanced stage. The UELN covers presently almost all the European countries.

The EUREF Permanent Network maintains and provides access to ETRS89 using post-processing as well as real-time access. These activities reached the routine status and enable the contribution of EUREF to many projects in different fields of the geo-sciences requiring real-time GNSS data.

EUREF is now-a-days a key organization for the support of a geodetic infra-structure in Europe and will certainly be an important partner in the implementation of the Global Geodetic Observing System (GGOS) thanks to the broad network of people and institutions that contribute to its work.

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