EUREF's Efforts to Meet the Challenge of the Changing Geodetic Landscape

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Key words: EUREF, Regional Reference System, GNSS, ETRS89, EVRS

SUMMARY

The IAG Sub-commission 1.3a EUREF (http://www.euref.eu) is a joint effort of European research agencies and National Mapping and Cartographic Agencies with the goal to define, realize, maintain and provide access to the European Reference Frame. The EUREF key infrastructures are the EPN (EUREF Permanent Network, http://epncb.oma.be/) and the UELN (United European Leveling Network). The EPN consists of 250 GNSS stations in a well-organized environment and serves as the backbone for the realization of and access to the European Terrestrial Reference System (ETRS89). Applying a 15-week update cycle, EUREF generates cumulative site positions and velocities suitable for national ETRS89 densification projects and geo-information applications. The latest cumulative EPN coordinates include the results of the first complete reprocessing of the historical EPN data.
The EPN tracking network is a multi-GNSS network with 66% of the stations observing both GPS as GLONASS signals and 46 Galileo-ready stations. However, there are still many concerns with respect to the proper tracking of the new satellite signals by the different receiver types, handling and availability of receiver antenna calibrations, and formats issues. File (RINEX) as well as real-time (RTCM) formats have to be enhanced significantly to keep pace with the new signals. For that purpose, the EPN is closely working together with the International GNSS Service (IGS) and RTCM. As part of a test project, the first EPN station operators started in 2010 to submit GNSS observation data in RINEX version 3 format to the EPN data centers. In addition, more than 50% of the EPN stations stream their data in real time. As a Pilot Project, EUREF is broadcasting (http://www.euref-ip.net) satellite orbit corrections in the ETRS89 allowing users to derive in real time ETRS89 coordinates at the few dm-level. Analogous corrections referred to other regional reference frames are available from the global broadcaster http://products.igs-ip.net, e.g. for SIRGAS95 or SIRGAS2000.
UELN, as the backbone of the realization of the new European Vertical Reference System EVRS2007, is a commonly adjusted leveling network of 25 European countries related to 13 well-distributed datum points. The EVRS2007 geopotential numbers and the equivalent normal heights are expressed in the zero tidal system. EVRS2007 is promoted for acceptance by the European Commission as official vertical datum. The EVRS2007 will be related to a global vertical height system.

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1. INTRODUCTION

The long-term objective of EUREF, as defined in its Terms of Reference is "the definition, realization and maintenance of the European Reference Systems, in close cooperation with the pertinent IAG components (Services, Commissions, and Inter-Commission projects) as well as EuroGeographics". For more information see http://www.euref.eu.

The results and recommendations issued by the EUREF sub-commission support the use of the European Reference Systems in all scientific and practical activities related to precise geo-referencing and navigation, Earth sciences research and multi-disciplinary applications. EUREF applies the most accurate and reliable terrestrial and space-borne geodetic techniques available, and develops the necessary scientific principles and methodology. Its activities are focused on a continuous innovation and on evolving user needs, as well as on the maintenance of an active network of people and organizations, and may be summarized as follows:

- Maintenance of the ETRS89 (European Terrestrial Reference System) and the EVRS (European Vertical Reference System) and upgrade of the respective realizations;
- Refining the EUREF Permanent Network (EPN) in close cooperation with the International GNSS Service (IGS);
- Improvement of the European Vertical Reference System (EVRS);
- Contribution to the IAG Project GGOS (Global Geodetic Observing System) using the installed infrastructures managed by the EUREF members.

These activities are reported and discussed at the meetings of the EUREF Technical Working Group (TWG) and annual EUREF Symposia, an event that occurs every year since 1990, with an attendance of about 100-150 participants coming from more than 30 European countries and other continents, representing Universities, Research Centers and NMCA (National Mapping and Cadastre Agencies). The organization of the EUREF Symposia is supported by EuroGeographics, the consortium of the European National Mapping and Cadastral Agencies, reflecting the importance of EUREF for practical purposes.

In addition to the already existing partnerships with EUMETNET and EuroGeographics, EUREF and CERGOP (Central European GPS Geodynamic Network Consortium) signed a Memorandum of Understanding (MoU) at EUREF symposium at Chisinau, Moldova in 2011. The general goal of the MoU is to create the conditions to facilitate data exchange and promote the co-operation between EUREF and CERGOP in order to improve the

densification of the European GNSS network for reference frame definition and geodynamical applications, and support the ECGN (European Combined Geodetic Network) project.
EUREF is an associated member of the International Committee on Global Navigation Satellite Systems (ICG) since 2009. The main ICG objective is to promote greater compatibility and interoperability among current and future providers of the Global Navigation Satellite Systems (GNSS). The annual ICG meetings review and discuss progress towards the realization of its main objective, as well as developments in GNSS where contributions from ICG members, associate members and GNSS user community are considered.

2. CONVENTIONAL FRAME ETRF2000

By definition, the ETRS89 is linked to the International Terrestrial Reference System (ITRS), and the relationship between the two systems can be fully described by a 14-parameter similarity transformation (Altamimi and Boucher, 2001). Up to the release of the ITRF2005, each new realization of the ITRS (i.e. ITRFyy) was followed by a new realization of the ETRS89 (i.e. ETRFyy). Changes in origin and scale components between ITRFyy frames are therefore transmitted to ETRFyy frames, causing coordinate changes which are undesirable for geo-referencing applications of the ETRS89. In order to remedy this, from ITRF2005 on, the TWG decided to continue using the ETRF2000 as the ETRS89 realization and adopted the ETRF2000 as the conventional realization of the ETRS89. The ETRF2000 will thus also be the ETRS89 frame adopted in conjunction with the latest release of the ITRS, ITRF2008 (Altamimi et al., 2011).
The mathematical transformation from ITRFyy to ETRF2000 is achieved by a two-step approach using two successive Helmert transformations (ITRFyy → ITRF2000 followed by ITRF2000 → ETRF2000), or can be done by one single 14-parameter transformation (directly from ITRFyy → ETRF2000), (Altamimi, 2011). The parameters of all these transformations are available from the Memo by Boucher and Altamimi (2011). To help users to perform the necessary transformations, an on-line transformation tool, which allows conversions/transformations between any ITRS/ITRS, ITRS/ETRS89 and ETRS89/ETRS89 realization has been put on-line at http://epncb.oma.be/_productsservices/coord_trans/.
A second reason for the change of ETRS89 coordinates in time is local geodynamics. A preliminary study of the influence of these geodynamics on the lifetime of ETRS89 coordinates has been performed by the TWG. First results are given by Caporali et al. (2011); it makes recommendation for the update rate of the national ETRS89 densifications taking into account the local geodynamics in each European country.

3. EUREF PERMANENT GNSS NETWORK (EPN)

The EPN is the permanent GNSS network created by EUREF. Its primary objective is to maintain and provide access to the ETRS89. The EUREF TWG is responsible for the general management of the EPN. The EPN Coordination Group and the EPN Central Bureau implement the operational policies of the EUREF TWG.
The EPN is based on a well-determined structure including GNSS tracking stations, operational centers, local and regional data centers, local analysis centers, a combination

centre and a Central Bureau (Bruyninx et al, 2011). These different EPN components (all based on voluntary contributions) follow specific guidelines set up by the EUREF TWG.
The EPN is the European densification of the International GPS Service (IGS) network. Therefore, the EPN uses the same standards and exchange formats as the IGS.
Almost 250 EPN stations are operated today by NMCA and other scientific and technical Institutions. The number of sites that record GLONASS data simultaneously with GPS data or stream real time data is steadily increasing (66 % and 49 % respectively).
To prepare for the Galileo system, already some EPN station operators make available GNSS observation data in RINEX version 3 format in addition to their routine data submissions in the RINEX 2.11 format. The goal is to support developers preparing for the future Galileo system and to foster the development of the EPN towards a multi-system GNSS network.
Instructions for becoming an EPN station are available at http://www.epncb.oma.be/_organisation/guidelines/procedure_becoming_station.pdf.

Fig. 1 EUREF Permanent GNSS Network (EPN), status Oct. 2012

4. EPN RE-PROCESSING ACTIVITIES

Since the start of the EPN operations, its data are routinely analyzed by the EPN Local Analysis Centers in order to derive precise station coordinates and tropospheric zenith path delays. Throughout the years, the EPN has become more precise and reliable thanks to historical improvements of modeling parameters affecting the satellites (orbits, reference frame, and antenna calibration model), the propagation media (troposphere and ionosphere), the receiver units (e.g. elevation cut-off, antenna calibration model), geophysical phenomena (e.g. tidal forces, loading related to ocean, ground water and atmospheric pressure variations) and the reference frames. The EUREF TWG has therefore decided to reprocess all historical EPN data using present-day state-of-the-art models and to obtain improved and consistent coordinates, position time series and tropospheric parameters for each EPN site. This first reprocessing (known as EPN-REPRO1) was done in 2011 for EPN observations gathered between Jan. 1996 and Jan. 2007. Different software packages, namely BERNESE, GIPSY/OASIS and GAMIT were used for the analysis (Habrich, 2011 and Völksen, 2011).

The reprocessing was done using the epn_05.atx antenna calibration model which is derived from the igs05.atx model. The reprocessed EPN results were used for weekly combined positions (in SINEX format) and tropospheric delays generated by the EPN Analysis Coordinator and EPN Troposphere Coordinator, respectively. At its fall meeting in Oct. 2011, the EUREF TWG endorsed the EPN-REPRO1 results and gave the green light to the EPN Reference Frame Coordinator for the generation of a new cumulative EPN position/velocity solution including the EPN-REPRO1 results.
It is quite clear that the new realization of the ITRS, the ITRF2008, and the present update of the antenna calibration model (igs08.atx or epnc_08.atx) will require another re-analysis of the entire EPN applying the most recent models, strategies and standards. This will be done as soon as the IGS will make available new reprocessed orbit and clock products.

5. EUREF DENSIFACTION OF THE ITRF

5.1 Using the EPN

Because the number of permanent GNSS tracking sites in Europe has grown considerably, only a selection of these sites (mostly those belonging to the IGS) are included in recent realizations of the ITRS. The latest realization of the ITRS, the ITRF2008, is based on observations from space geodetic techniques (GNSS, DORIS, VLBI, and SLR) up to December 2009.5 and does not take into account any of the IGS/EPN data gathered after that date. Consequently it cannot reflect the most recent status of the EPN (due to e.g. antenna changes). The limited number of stations and the lack of frequent updates limit therefore the use of the ITRF for national densifications of the ETRS89.
The EUREF TWG decided at its meeting of Nov. 3-4, 2008 in Munich, to release regularly recomputed cumulative official updates of the ITRS/ETRS89 coordinates/velocities of the EPN stations. Using the 15-weekly updates of the EPN site coordinates, the EPN sites are classified in two classes:

- Class A stations with positions at 1 cm accuracy during the time span of the used observations (thanks to providing accurate station velocity estimates);
- Class B stations with positions at 1 cm accuracy at the epoch of minimal variance of each station.

Following the EUREF “Guidelines for EUREF Densifications” (Bruyninx et al., 2010), only Class A EPN stations can be used for densifications of the ETRS89.
Table 1 gives an overview of the weekly EPN SINEX files available for the computation of a new EPN cumulative position/velocity solution:

Solution	GPS week Start	GPS week End	Antenna Calibration Model
EPN-REPRO1	835	1399	epn_05.atx
Routine	1400	1631	epn_05.atx
Routine	1632	Now	epn_08.atx

Table 1: Overview of the weekly EPN SINEX files including the antenna calibration model used in the analysis.

In order to have a consistent set of weekly SINEX solutions, the EUREF TWG asked the ROB (Royal Observatory of Belgium, see Baire et al. 2011) to correct the solutions before week 1632 to make them consistent with the epn_08.atx antenna calibration model. Using these corrected SINEX files, complemented with the present-day EPN weekly SINEX files; a new cumulative EPN position/velocity solution has been created and tied to the IGS08 reference frame (see Kenyeres, 2011; Kenyeres, 2012). The computations were done using the CATREF software (Altamimi et al., 2007) and it will be followed by 15-weekly updates. The resulting station coordinates are available from http://www.epncb.oma.be/_productsservices/coordinates/. Figure 2 shows the map of Class A and Class B stations outcome of the latest cumulative EPN solution.

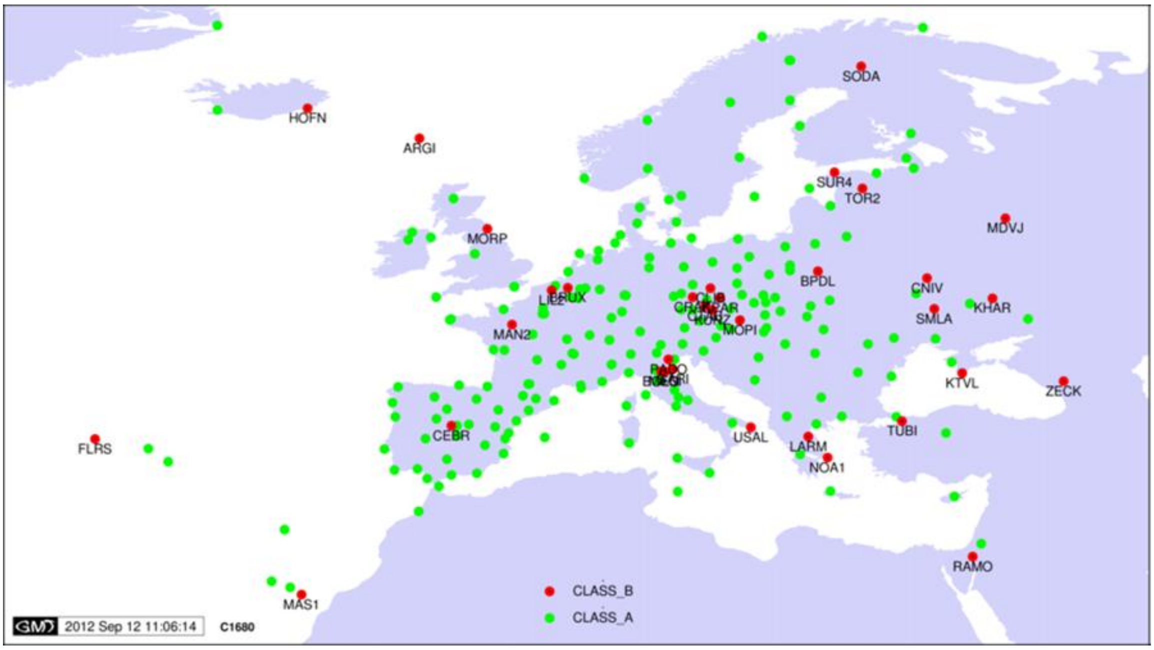

Fig. 2 EPN site categorization, status Oct. 2012. In green: Class A stations; in red: class B stations.

5.2 Using the National GNSS Densification Networks

Many European countries operate national dense GNSS networks, whose stations are not all included in the EPN. In order to take advantage of these data for creating a dense European velocity field, EUREF invited these countries to routinely analyze these data following EUREF guidelines and to submit the weekly positions to EUREF. Several countries (Poland, Estonia, Latvia, Slovakia, Hungary, Austria, Bulgaria, Czech Republic, and Italy) responded positively and provide now weekly SINEX solutions to the EPN Reference Frame Coordinator who combines these solutions with the weekly EPN solution and then stacks them to get consistent cumulative position/velocity solutions for the resulting densified EPN network (containing today already about a 1000 sites). Thanks to EUREF's Memorandum of Understanding with CERGN, also a CERGN solution (bi-annual campaigns) was submitted. This work is still in progress (see Kenyeres et al, 2012) and it will be an important input for the new EUREF Working Group on "Deformation Modeling".

6. EPN REAL-TIME ANALYSIS PROJECT

The EPN Project on "Real-time Analysis" (http://epncb.oma.be/_organisation/projects /RT_analysis) focuses on the processing of the EPN real-time data to derive and disseminate real-time GNSS products.

The EPN regional broadcaster at BKG (Federal Agency for Cartography and Geodesy, http://www.euref-ip.net) is broadcasting satellite orbits in the ETRS89 (realization ETRF2000). Based on these orbit and clock corrections, users can directly derive real-time coordinates referred to ETRS89 at few dm-level (Fig. 3; more details are given in Söhne, 2011). Additional solutions for other regional datums, e.g. for SIRGAS95 or SIRGAS 2000, are implemented and could be found at http://products.igs-ip.net.

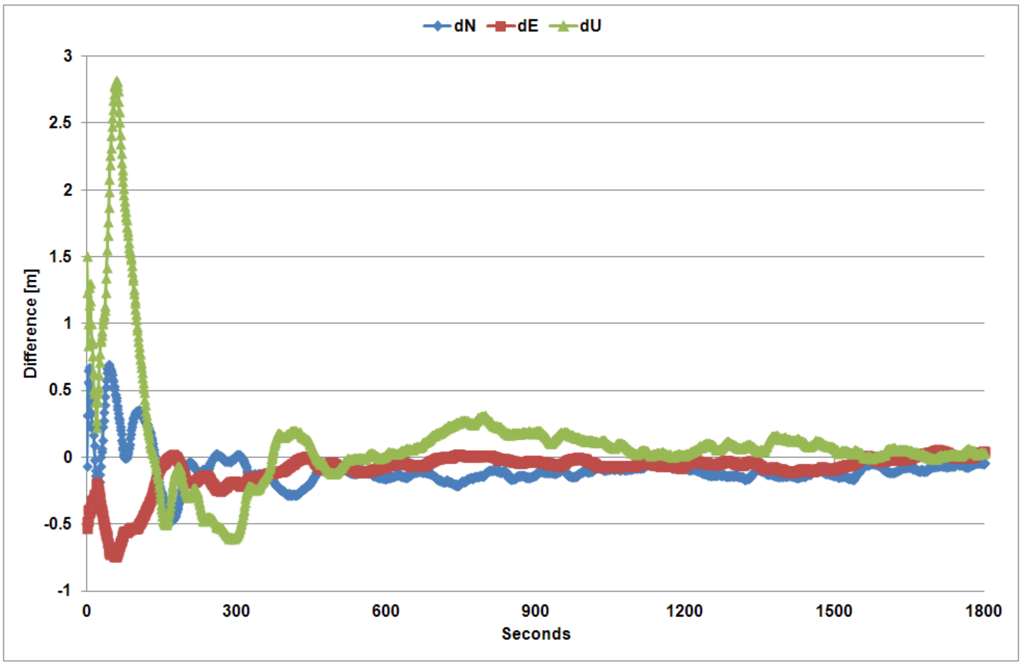

Fig. 3 Differences of real-time coordinates using the BKG Ntrip Client (BNC) with ETRS89-related satellite and orbit corrections for station ZIM2 w.r.t. the ETRS89 coordinates

One aim of the project is to increase the reliability of the EPN real-time data flow and to minimize the possibility of data and products outage. For this purpose, two additional regional broadcasters have been put in operation, one at ASI (Italian Space Agency, http://euref-ip.asi.it/) and one at ROB (http://www.euref-ip.be/). Based on the existence of three regional broadcasters, several stations and national broadcasters started uploading their data in parallel to all of the broadcasters.

To ensure the product generation without interruption and without jumps, it is necessary to have a backup processing running in an identical environment. This scheme could be implemented on a second computer at the same facility or, to overcome problems at the facility itself, at another place. In case of an outage in the production scheme at the master facility the broadcaster will switch to the backup solution using the same source table entry.

Therefore the user will notice neither any interruption nor any change in the origin of the streamed data.
While for the first step of the estimation of parameter corrections, i.e. satellite orbits and clocks, a globally distributed network (50-60 stations) is sufficient, any further steps, e.g. improved ambiguity fixing, ionosphere and troposphere corrections which go for an improved accuracy of the real-time Precise Point Positioning (PPP), require a denser network of real-time stations like the EPN or SIRGAS could provide.

7. EUROPEAN VERTICAL REFERENCE SYSTEM (EVRS)

In 1994 the IAG Sub-commission for Europe (EUREF) started the work on the Unified European Leveling Network (UELN) and resumed and enhanced previous projects, which existed in the Western and Eastern part of Europe separately. A European Vertical Reference System (EVRS) was defined in 2000 and the associated realization was named EVRF2000. During the following years about 50 % of the participating countries provided new national leveling data to the UELN data center. Therefore a new realization of the EVRS was computed and published under the name EVRF2007. The datum of EVRF2007 is realized by 13 datum points distributed evenly over the stable part of Europe. The measurements have been reduced to the common epoch 2000 by applying corrections for the glacial isostatic adjustment (land uplift) in Fenno-Scandinavia, which are provided by the Nordic Geodetic Commission (NKG). The results of the adjustment are given in geopotential numbers and normal heights, which are reduced to the zero tidal system. At the EUREF symposium June 2008 in Brussels, Resolution No. 3 was approved proposing to the European Commission the adoption of the EVRF2007 (Figure 4) as the mandatory vertical reference for pan-European geo-information.

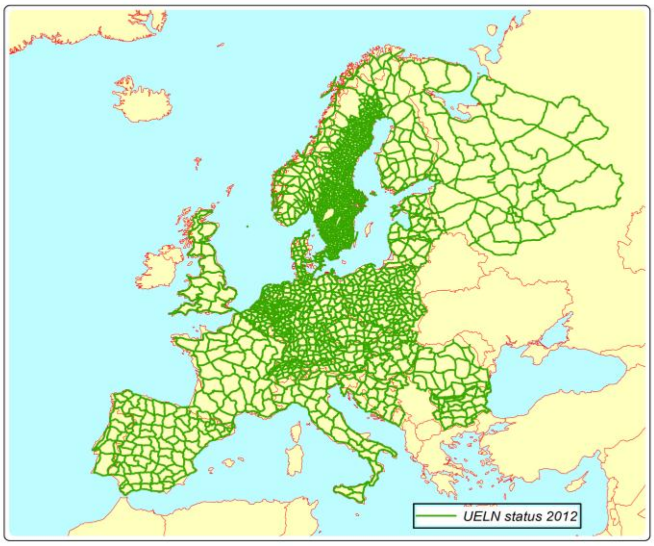

Fig. 5 EVRF2007 including extensions

The availability of EVRF2007 forced an update of the Geodetic Information and Service System. Transformation parameters between national height systems and EVRF2007 were

estimated and are provided at http://www.crs-geo.eu/ since April 2010. Furthermore the transformation parameters to EVRF2000 are available. Additionally the online-transformation for heights of single points was implemented.
In the meantime, the UELN is continuously enhanced using additional or updated leveling data submitted by different countries. EUREF received in 2009 the European part of first order leveling network of Russia. Together with connection measurements between the national networks of Finland and Russia is was possible to close the loop around the Baltic see and strengthen the adjustment process. In addition, the new first order leveling data of Latvia (2011), and Spain (2012) were received by EUREF. For the next years Belarus and Ukraine announced to provide their leveling data and join the UELN. A new UELN adjustment will be computed after receiving the new data.

8. PROMOTION AND ADOPTION OF THE ETRS89 AND EVRS

Since 1989, many European countries have defined their national reference frames in ETRS89 by calculating national ETRS89 coordinates following the EUREF guidelines. The difference of the ETRS89 coordinates adopted in each country for a set of EPN stations with respect to the ETRS89 coordinates recently estimated by the EPN is now monitored on a regular basis by EUREF (Brockmann, 2010). These national ETRS89 coordinates can differ from the latest cumulative EPN coordinates due to e.g. differences in datum definition (different ETRFyy frames) and differences in used observation periods.

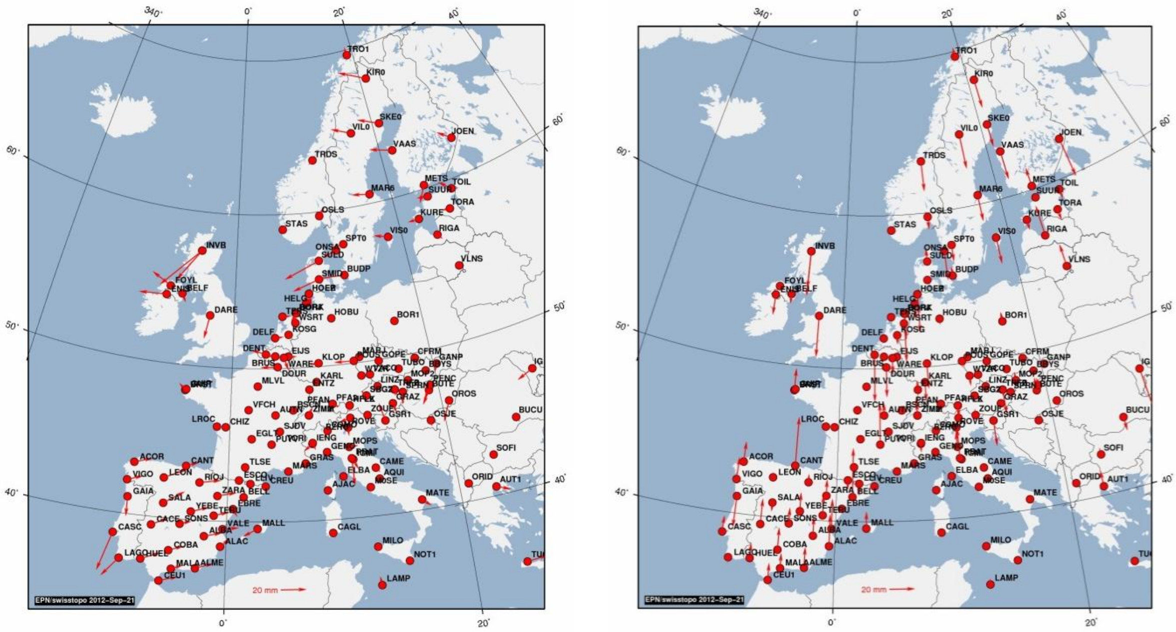

Fig. 5 Difference between official ETRS89 coordinates adopted in the different countries and the latest EPN cumulative coordinate solution

The results of the comparison show an agreement of a few cm (see Figure 5). In addition, EUREF recently provided a new questionnaire to the NMCA on the utilization of the ETRS89 and EUREF products in their country and the first results have been presented by Ihde et al.

(2011). Up to now, 60% of the contacted countries replied to the questionnaire. About 85% stated that they adopted the ETRS89 in their country while other 10% were still working on this issue.

INSPIRE (Infrastructure for Spatial Information) was adopted in March 2007 by the Directive 2007/2/EC of the European Parliament and the Council. The goal of INSPIRE is to deliver an interoperable and integrated European spatial information service to users from different communities. The INSPIRE Directive addresses 34 spatial data themes needed for environmental applications, with key components specified through technical implementing rules. "Coordinate Reference Systems" (CRS) is one of the important themes. It establishes the geographical reference for many other themes. This makes INSPIRE a unique example of a legislative "regional" approach. To ensure that the spatial data infrastructures of the member states are compatible and usable in a trans-boundary context, the Directive requires that common Implementing Rules (IR) are defined and applied in a number of specific areas (metadata, data specifications, network services, data and service sharing and monitoring and reporting). These IRs are adopted as Commission decisions or regulations and are binding in their entirety. The Commission is assisted in this process by a regulatory committee composed of representatives of the member states and chaired by a representative of the Commission (known as the comitology procedure). Thanks to the efforts of the EUREF TWG, the ETRS89 and the EVRS, defined by EUREF, play now a fundamental role in the CRS IR.

The descriptions of national and pan-European geodetic reference systems are available by a Service System for European Coordinate Reference Systems (CRS). Transformation parameters between national geodetic reference systems and the European ETRS89 and EVRF2007 were calculated and provided. Additionally, an online-transformation capability for coordinates and heights of single points is implemented.

9. CONCLUSION

Since more than 15 years EUREF maintains the geodetic infrastructure that is the providing access to the European reference system (ETRS89) as well as the European height reference system (EVRS). The EPN, the GNSS network providing access to the ETRS89, is presently modernizing to take into account new satellite signals and to respond to the evolving needs of real-time users requesting access to the ETRS89 at the dm-level. In addition, a complete reprocessing of all historical EPN data has allowed computing improved station positions and velocities that can be used for national densifications of the ETRS89.
Concerning the height, a European Vertical Reference System was defined in 2000 and the associated realization was named EVRF2000. It is based on the Unified European Leveling Network, which is continuously enhanced -using additional or- updated leveling data submitted by the different countries.
Thanks to the efforts of the EUREF TWG, the ETRS89 and the EVRS play a fundamental role in the implementation of the EC INSPIRE Directive.

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BIOGRAPHICAL NOTES

Dr. C. Bruyninx manages the GNSS research group at the Royal Observatory of Belgium. As chair of the EUREF Technical Working group, she is strongly involved in EUREF activities and more specifically the EUREF Permanent Network (EPN) for which she manages the EPN Central Bureau since 1996. At the IAG level, she chairs the Working Group on 'Integration of Dense Velocity Fields in the ITRF' within sub-commission 1.3. She is also heavily involved in the IGS. This is reflected by her membership in the IGS Governing Board, several of the IGS Working Groups as well as the IGS Infrastructure Committee. C. Bruyninx is also a member of the advisory editorial board of "GPS Solutions". Her research activities concentrate on the use of permanent GNSS tracking stations for different types of applications including reference frame maintenance, measurement of long-term ground deformations, and monitoring of the Earth atmosphere.

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