Advancing the Geodetic Infrastructure in Europe through EUREF

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Key words: Engineering survey; GIM; GNSS/GPS; GSDI; Positioning; Reference frames, Reference systems; Standards

SUMMARY

The International Association of Geodesy (IAG) Reference Frame Sub-Commission for Europe, EUREF, merges efforts of National Mapping and Cadastral Agencies (NMCA), Universities and research institute to define, realize and maintain the European Terrestrial Reference System 1989 (ETRS89) and the European Vertical Reference System (EVRS) for scientific and practical purposes in Europe. These systems are the basis for geo-referencing in Europe and have been endorsed by the European Union INSPIRE directive (Infrastructure for Spatial Information in the European Community), Eurocontrol and EuroGeographics.

The realization, maintenance and development of the ETRS89 is primarily done through the EUREF Permanent GNSS Network (EPN). EPN consists of continuously operating GNSS stations (~350 stations), supported by Data and Analysis Centres and a Central Bureau that is responsible for the monitoring and management of the EPN. All contributions to the EPN are provided on a voluntary "best effort" basis, with more than 100 European agencies/universities involved. The EPN operates under well-defined standards and guidelines which guarantee the long-term quality of the EPN products.

In response to an increasing demand both from the National Mapping Agencies and research groups, the backbone EPN has been complemented with additional national CORS networks with rigorously computed station coordinates and velocities. At present, the dense European network incorporates ten times more stations as the core EPN sites and benefits from the contribution of some 25 different Institutions.

The physical (gravity related) height system EVRS is realized through common adjustment of the Unified European Levelling Network (UELN) where the vast majority of the European countries contribute.

In the presentation we will discuss current and future challenges regarding continental scale geodetic infrastructure and the contribution from EUREF. In particular we will discuss the development of European geoid model, models for crustal deformations, realization of the emerging International Height Reference System (IHRS) in Europe and establishment of the precise relation between recent releases of IHRF and EVRF.

At the end we will touch on the future role of EUREF in the emerging organizational landscape. E.g. the European Plate Observing System (EPOS) has entered its pilot operational phase in 2020, and progress are reported from the UN-GGIM sub-committee on Geodesy. This calls for mutual collaborations in order to achieve common goals to the benefit for the wider user society.

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1. Introduction

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2. The EUREF Permanent GNSS Network - EPN

The EUREF Permanent Network (EPN) is a science-driven network of permanent GNSS tracking stations established in 1996 (http://epncb.oma.be/). Through its daily and weekly computed network solutions it is used by EUREF to realize and provide access to the ETRS89. The EPN includes:

- a network of about 350 continuously operating GNSS (Global Navigation Satellite Systems, such as GPS, GLONASS, Galileo, Beidou, ...) reference stations,
- data centres providing access to the station data,
- analysis centres that routinely analyze the GNSS data,
- product centres and coordinators that generate the EPN products,
- and a Central Bureau that is responsible for the daily monitoring and management of the EPN.

Figure 1. The EUREF Permanent Network, EPN.

The EPN provides access to the ETRS89 by making publicly available the GNSS tracking data as well as precise positions, velocities and tropospheric parameters of all EPN stations. Based on these products, the EPN contributes also to monitoring of crustal deformations in Europe, and supports long-term climate monitoring, numerical weather prediction and the monitoring of sea-level variations.

The EPN tracking stations are also integrated in the successive realizations of the International Terrestrial Reference System, which is the basis for the European Terrestrial Reference System 1989 (ETRS89). Since the EPN is the European densification of the network of the International GNSS service, IGS (http://igscb.jpl.nasa.gov/), a complete harmonization of standards between the global and European network is put forward.

All contributions to the EPN are provided on a voluntary "best effort" basis, with more than 100 European agencies/universities involved. The EPN apply a distributed approach with some 20 organizations involved and operates under well-defined standards and guidelines (http://epncb.oma.be/_documentation/guidelines/) which guarantee the long-term quality of the EPN products.

Operation and recent developments of the EPN

The EPN is managed by the Central Bureau (CB), which also acts as the Network Coordinator. The CB, managed by the Royal Observatory of Belgium, is operationally monitoring the EPN station performance in terms of data availability, correctness of metadata, and data quality. The maintenance of the station site logs has been automated by using the "Metadata Management and Dissemination System for Multiple GNSS Networks" (M^3G, available from https://gnss-metadata.eu) (Bruyninx et al. 2019). The EPN has been continusouly growing with 15, 20 and 17 new stations in the years 2018 to 2020 respectively. Emphasis is given to the fact that as many as possible stations should observe and transmit the observational data of the European GNSS Galileo, and optimally also the Chinese GNSS BeiDou.

Products

The EPN Analysis Centers (ACs) operationally process GNSS observations collected at the EPN stations. EUREF is following a distributed approach, i.e. 16 ACs are providing final weekly and daily coordinate and other solutions of their designated subnetworks. The coordinate and troposphere parameters are combined to get the final EUREF solutions. To get homogeneous results following the state-of-the-art in modelling and processing, EUREF is reprocessing the whole network, following the global reprocessing within the International GNSS Service (IGS).

To maintain the European Terrestrial Reference System (ETRS89), EUREF releases, each 15 weeks, an update of multi-year coordinates and velocities of the EPN stations in the latest ITRS/ETRS89 realizations. The consistency of the EPN multi-year solutions is validated by comparison to, for example, the IGS multi-year solution and shows good agreement.

In May 2020, the IGS published a revision of the IGS14, namely the IGb14. The first EPN multi-year solution in IGb14 (C2115) has been published in November 2020. Thanks to the five more years of input data in IGb14 compared to IGS14, the agreement between the EPN and IGS multi-year solutions has been improved when using IGb14.

3. EPN Densification

EUREF introduced a project on EPN Densification (Kenyeres et al 2019), which as of today is a collaborative effort of 27 European GNSS ACs providing series of daily or weekly station position estimates of dense national and regional GNSS networks and delivered in SINEX format. The individual solutions are combined into one homogenized set of station positions and velocities. Such a set is extremely valuable for cross-border and large-scale geodetic and geophysical applications. The most recent results cover the period from November 2006 to April 2020 (GPS weeks 1400 to 2100) using inputs expressed in IGS14. The combined multi-year solution includes 31 networks with positions and velocities of some 3300 stations, well covering Europe. The description of the EPN Densification, station metadata, and results are available from the EPN Densification webpages (https://epnd.sgo-penc.hu/).

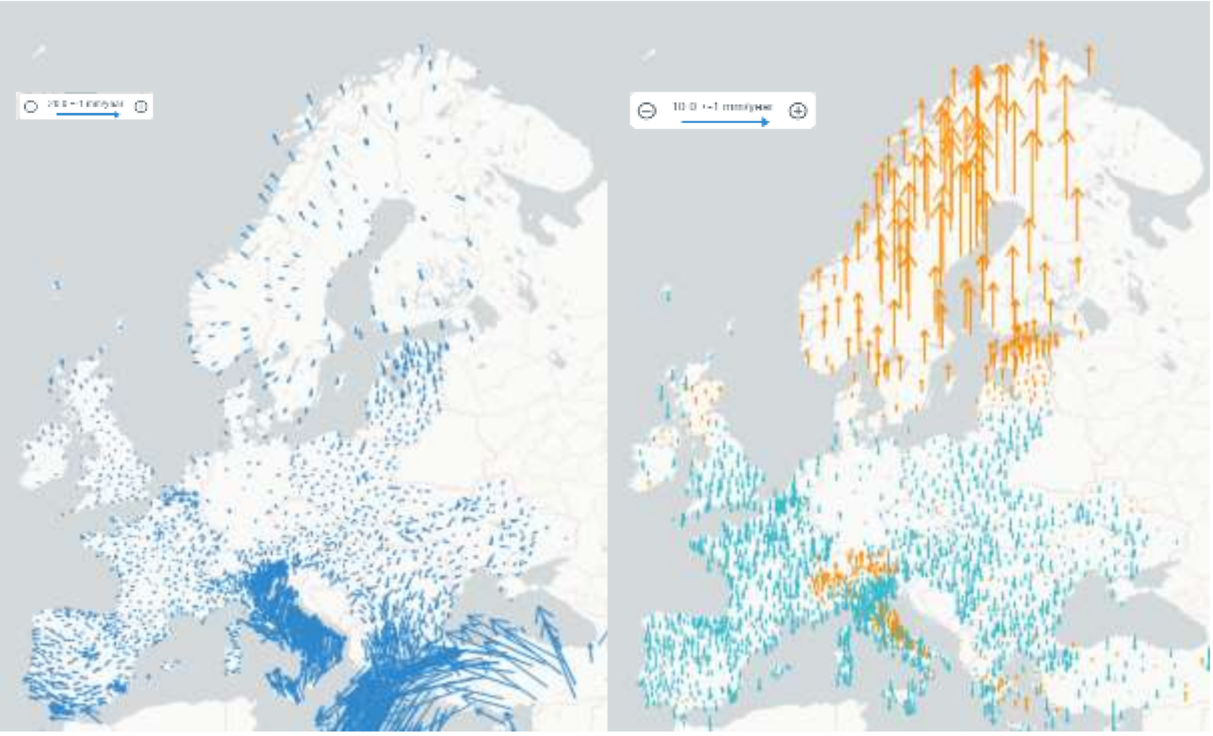

Figure 2. Horizontal and vertical velocities from the EPN Densification (in ETRS89).

4. European Dense Velocities

Complementary to the EPN Densification, EUREF introduced a project on dense velocities. The velocity estimates in ETRF2000, derived by currently 30 contributors, are the direct input to the generation process of a dense velocity field for Europe. In addition to results from GNSS permanent networks, densified solutions stemming from GNSS campaigns, InSAR or levelling are also included. In some countries, as e.g. in the Nordic countries, velocity models are already in use. They can be integrated to indicate possible differences between modeled and observed velocities. Also the results of the EPN Densification project are included. The alignment of the geodetic datum of each input is controlled by overlapping stations. More than 6000 individual station velocities are available for Europe. The description and detailed results are available on http://pnac.swisstopo.admin.ch/divers/dens_vel/index.html.

5. European Vertical Reference System and Frame, EVRS and EVRF

The EVRS is the European Vertical Reference System that are realized through a common adjustment of available national precise levelling networks. The height reference is the level of the Normaal Amsterdam Peil, NAP.

The recent realization EVRF2019 (Sacher and Liebsch 2019) includes about 14 000 observations and 11 000 unknowns (nodal points). The average standard uncertainty of the observations is close to 1mm/√km. In areas with clear secular vertical velocities where vertical velocity models are available (Fennoscandia and Switzerland), the epoch has been reduced to year 2000.0.

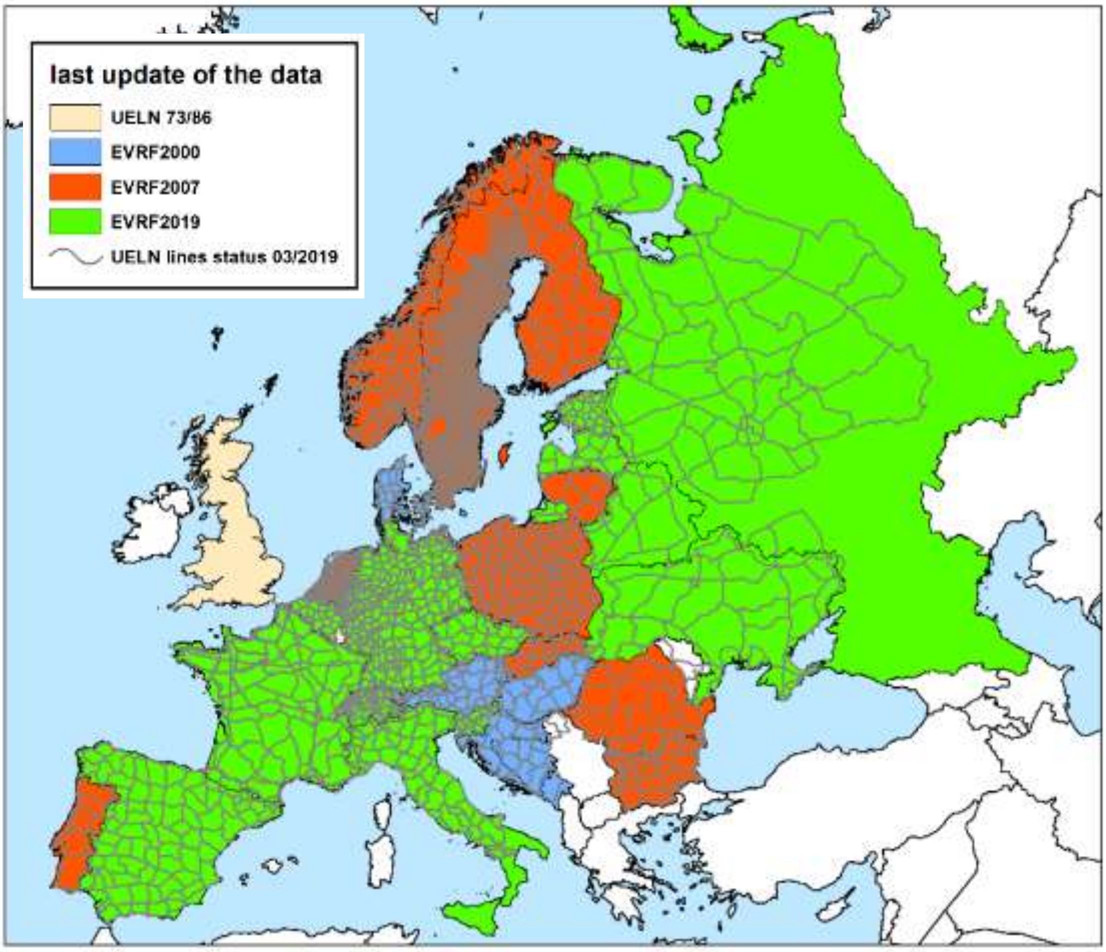

Figure 3. The United European Levelling Network, UELN, which is the basis for the recent new realization of the EVRS, EVRF2019.

6. Advancing the geodetic infrastructure

The EUREF Governing Board (GB) is currently in the process to renew the EUREF strategy. The task is still work in progress, but some challenges and foreseen developments have been identified.

The realization of ETRS89

The ETRS89 is defined as coincident to ITRS at the epoch 1989.0 and co-moving with the European tectonic plate. It is realized in ETRFs by precise relations from ITRFs (Altamimi 2017). The proper realization is therefore dependent on the long term stability within and between ITRFs. The achievement of the global goal of 1 mm and 0.1 mm/yr for ITRF is therefore important also for EUREF and the precise and consistent realization of the ETRS89.

Height reference surface (HRS)

The refinement of the UELN with new levelling data and extension to countries not yet included will continue and updates of the realization of the EVRS are foreseen. However, a product that connects the EVRFs and ETRFs at the continental scale are not yet available. The European gravimetric quasigeoid models are available (Denker 2015) but are not adapted to the EVRF and ETRF and have therefore have low performance as transformation product.

To overcome these limitations, it is proposed to compute a European quasigeoid model ("EVRF geoid") as an official EVRS height reference surface, consistent with the latest EVRS and ETRS89 realizations (Schwabe et al 2020).

An important background work to achieve this will be to improve the dataset with GNSS-determined UELN points (or levelled EPN/EPN-D stations), originally established in the effort on "European unified vertical network densification act" EUVN-DA.

International Height Reference System and Frame

At the global level, the International Height Reference System, IHRS, is under construction and we see progress towards its first realisation in the International Height Reference Frame, IHRF (Sánchez et al 2021). Since EVRS and IHRS will be used in parallel for a long time, it means that we from EUREF should realize the IHRF within Europe and establish precise and welldefined relations between IHRF and recent releases of the EVRF;

Deformation/velocity model

In Europe, there are network RTK services available in most (all?) countries. These are usually operated so the user will get the position in the national reference frame, which in most cases is a realization of the ETRS89. It is, however, also foreseen an emerging mass market for precise positioning based on centimetre level positioning services worldwide without any regional or national reference frames. There will be also precise point positioning (PPP) service from Galileo and other provides. These worldwide services will most likely provide the positions in a kinematic reference frame (in practice recent ITRF in current epoch). The need for the precise relations between realizations of ETRS89 and ITRF becomes therefore more important. The precise knowledge of the crustal deformations within the EUREF area of interest is therefore vital. A first version of such a European velocity model has been developed based on results from EPN Densification and European Dense Velocities (Steffen et al 2019) and the efforts towards a EUREF product continues.

GNSS and climate

A side product from scientific GNSS analysis are the estimates of the amount of water vapor in the atmosphere (Pacione et al 2017). The GNSS technology and its infrastructure is approaching 3 decades, which is the time period where change in atmospheric conditions can be considered as "climate change". The time series of tropospheric zenith delay (TZD) at the EPN sites represent a wealth of data that EUREF regularly generates, and its value in global climate monitoring is an important aspect of the EUREF activities. This is of particular importance to consider while performing re-processing of the EPN, where the EPN-Repro3 is foreseen within the coming year(s).

Organizational perspective

From the organizational point of view, we see an emerging organizational landscape. For example, the European Plate Observing System (EPOS) (https://www.epos-ip.org/) has entered its (pre) operational phase in 2020, and progress is reported from the UN-GGIM Subcommittee on Geodesy (SCoG), not to forget the operational processing of dense GNSS networks within the EUMETNET GNSS Water Vapour Programme (E-GVAP). EUREF have good relations and cooperation with these groups and organizations. EUREF has ambition to continue as a key organization on geodetic infrastructure and cooperation in Europe booth from the scientific perspective as well as the practical implementation. Nevertheless, this calls for mutual collaborations in order to achieve common goals to the benefit for the wider user society.

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BIOGRAPHICAL NOTES

Dr. Martin Lidberg is head of the Geodetic Infrastructure Department at Lantmäteriet, the Swedish mapping, cadastral and land registration authority. He has a MSc in Surveying and mapping from the Royal Institute of Technology (Stockholm, Sweden) in 1988, and got his PhD from Chalmers University of Technology (Gothenburg, Sweden) in 2007. He has been working at Lantmäteriet since 1988. Martin is also since 2019 chairman of EUREF.

Dr. Wolfgang Söhne is a senior scientist working in the geodetic department of the Federal Agency for Cartography and Geodesy (BKG) in Frankfurt on Main, Germany. He got his PhD from the Technical University of Darmstadt in 1996. He has been working at BKG since 2001. Since then, he was involved in the EUREF Technical Working Group (now Governing Board) where he became official member in 2008. Since summer 2019, he is the chair of the EUREF Governing Board. He is also member of the IGS Governing Board and the IGS Infrastructure Committee.

Dr. Karin Kollo received her PhD degree in Geodesy from Aalto University, Helsinki. She is a head of Department of Geodesy at Estonian Land Board. Her research focuses on the maintenance of the national reference frames, GNSS analysis, height connection to the tide gauges, as well as geodynamics and studies on the glacial isostatic adjustment. Since summer 2019 she is the secretary of EUREF.

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