Charter

EUREF working group on "EPN Densification"

History and background

The last two decades numerous trials targeted the realisation of a continental-scale velocity field and velocity model in Europe based on the collection of individual, and more or less independent, ***cumulative*** GNSS solutions stemming from various sources. Those included active and campaign-style GNSS networks, and mostly focused only on cumulative velocity solutions, which were transformed into a common frame using overlapping stations. A comprehensive summary can be found in the work done by Holger Steffen and presented at the EGU2013 General Assembly (http://meetingorganizer.copernicus.org/EGU2013/EGU2013-8181.pdf as of 2015-03-30).

The first trial to do the ***regional level*** combination using SINEX files in a common adjustment has been done in the frame of the 4-year work (2007-2011) of the International Association of Geodesy (IAG) Working Group (WG) on "Regional Dense Velocity Fields", where cumulative SINEX files with position and velocity estimates from the different regional reference frame sub-commission of the IAG were used to create a global multi-year integrated SINEX product. However, this WG was directly faced with inconsistencies between the input solutions related to:

- Station naming and DOMES numbers
- Introduction of discontinuity epochs
- Modelling
- Handling of constraints due to occasional differences in the processing methodology

making it impossible to generate a consistent combined solution (see in http://meetingorganizer.copernicus.org/EGU2013/EGU2013-7612.pdf).

The main conclusion was that a reliable densification based on the combination of solutions must exclusively rely on SINEX inputs and the combination should be done in the following steps:

- metadata harmonization;testing and filtering on the individual network level;
- cross-checking between the individual networks;
- combination of all inputs on the weekly level;
- creation of the cumulative product using the combined weekly SINEX solutions.

Any of the steps above involves iterations and increasingly extensive consistency checks.

In the frame of the European Positioning System (EUPOS) initiative, Ambrus Kenyeres proposed in 2009 the EUPOS Combination Centre (ECC). Based on weekly SINEX solutions submitted by 6 EUPOS countries (Latvia, Estonia, Poland, Czech Republic, Slovakia, Hungary), the concept above was tested and proved to be very successful.

Following the success of the ECC, the combination work slowly extended to more and more European countries. Based on the promising results of ECC and the recommendations of the IAG

WG “Regional Dense Velocity Fields”, the EUREF Technical Working Group (TWG) decided to launch the EPN densification project and nominated the EPN Reference Frame Coordinator (RFC) to take the lead. At the EUREF 2010 symposium, all EUREF countries were asked in a resolution to the support of the EPN Densification with delivery of their weekly GNSS-based scientific analysis results for the GNSS networks they operate.

As of December 2014, the weekly SINEX solutions stemming from 15 partners including 19 networks are available. Bulgaria and Spain are providing daily SINEX solutions, which are converted into weekly ones. The database includes more than 2300 stations covering almost the whole continent and additionally two networks (BIGF, UK and SGN, France) having global coverage. In addition to the solutions stemming from permanent GNSS networks, the combination with long term operational campaign-style networks - e.g. Central European GPS Geodynamic Network (CEGRN) - is also being considered to be included in the near future.

The success of this densification created a hardly manageable workload for the RFC. As the densification results are planned to become an official EUREF product, a more formal and collaborative environment is necessary for the preparation of SINEX input solutions and metadata as well as the validation of the combination products.

Target and the way to reach

The primary target of the EPN Densification is to realize a dense, continental-scale (European), homogeneous, high quality position and velocity product. This product must be in full agreement with the EPN cumulative solution, which serves as its backbone and is used to tie it to the ITRS/ETRS89. As decided by the EUREF TWG, the velocity product outcome of the EPN densification will be the primary input for the EUREF “WG on Deformation models“ where it will be prepared for the extension of ETRS89 to areas outside of the tectonically stable part of Europe. The position product shall also be offered to NMCAs for extended testing of their own ETRS89 realisations**.**

The densification product is exclusively based on individual GNSS data analysis products provided in the form of daily or weekly COV SINEX files. The input is stemming from national entities (NMCAs, academic institutions or universities), which are routinely processing a dense GNSS network (including EPN and non-EPN stations), usually focused on their own national networks. The scientific processing is generally performed with the Bernese GNSS analysis software. There is no GIPSY contribution yet, the only non-Bernese submission is from Bulgaria, which provides daily GAMIT SINEX solutions. A significant part (8 out of 15) of the Analysis Centers (ACs) contributing to the routine EPN products are also contributing to the EPN Densification. Thanks to the availability of the EPN Analysis Guidelines, the contributions to the EPN densification are in a good agreement, however still not completely homogeneous.

Network acronym	Territory covered	Number of sites processed	Number of EPN stations	Non-EPN sites with valid DOMES number	Sites with virtual DOMES number
AGR	The Netherlands	26	17	6	3
AMO	Austria	136	32	29	75
ASG	Poland	149	39	103	7
BGF	UK+global	426	42	354	30
BUL	Bulgaria	106	23	1	82
CAT	Catalonia, Spain	154	23	110	21
CEG	CEGRN permanent	100	72	11	17
CGC	CEGRN epoch	172	59	16	97
CZE	Czech Rep.	62	37	24	1
EST	Estonia	99	22	77	0
GGI	Latvia	71	29	42	0
GKU	Slovakia	63	18	42	3
GRE	Greece by OLG	123	25	1	97
GRF	Germany	135	102	28	5
IBE	Iberia	425	80	198	147
MON	Middle-East	109	27	42	40
SGN	France+global	601	138	463	0
SGO	Hungary	87	29	42	16
UPA	Italy	481	35	78	368

Table on the participating networks/ACs as of March, 2015. One of the most important contribution is from Italy, prepared by UPA, where the necessary metadata harmonization is in progress.

Planned tasks, activities

- Preparation/revision of guidelines (all WG members): the EPN densification is highly relying on the analysis work being done by national entities, who are already contributing to the EPN or following the EPN guidelines. The WG will collect information on the analysis strategy and models implemented by the ACs contributing to the densification and should check them and propose changes or revisions if necessary to reach maximum consistency between all EPN-related products. The need for revision of the existing EPN guidelines to accommodate the densification needs will be evaluated, and when necessary new or extended guidelines will be proposed. The WG will improve the consistency of the GNSS analysis, and stimulate all contributing partners to issue regular re-processing of their dense networks in agreement with EPN reprocessing activities.
- Monitoring of SINEX availability (RFC): in the frame of the EPN densification no RINEX data is collected nor handled. The current focus lays on the collection of weekly SINEX solutions. Later the feasibility of the combination on daily level shall be investigated. The input SINEX solutions are collected, handled and stored by the RFC. The re-distribution of the submitted SINEX data is not considered, this remains the responsibility of the

contributing partners. The expected update rate of the multi-year combined dense velocity field is twice per year, but the input SINEX solutions should be available on a routine basis, with a delay comparable to the routine EPN analysis (allowing 5 more weeks delay as maximum). The availability of the submitted SINEX solutions will be monitored and in case of a significant delay, a notification will be sent out to the affected contributor. At this preparatory phase no monitoring is planned.

- Metadata (preferably sitelogs and/or station identifiers and equipment information) collection and screening (dedicated WG members): in the context of the EPN Densification, the national permanent GNSS stations will be called EPN densification stations. In some of the networks, the stations have been installed and named without taking into account international conventions and information from existing metadata databases of identifiers. To reliably combine all these networks, metadata homogenization is mandatory. This is a huge work, especially in the establishment phase and in the case of large networks (see the table above). The Working Group shall cooperate with other international groups and bodies - as IGS, IERS, EPOS, E-GVAP – to harmonize station metadata.
    - The main issue is the allocation of official ***DOMES numbers and unique 4-character station names***. All SINEX providers will contribute to this work, as the identifiers will have to be requested by them from the International Earth Rotation and Reference Systems Service (IERS). This database is maintained by IERS in co-operation with the EPN RFC. Only sites with valid DOMES numbers will be included in the official EPN densification solution. The WG shall also be prepared for the introduction of the planned 9-char station names.
    - The main source of metadata are the station log files (in the IGS/EPN format). In support of the EPN densification, the existing EPN station log validation and submission system, elaborated and maintained at the EPN Central Bureau (CB) is presently extended to allow submission (storage and distribution) of station logs of the EPN densification stations. ***Stations without metadata may not be considered as active EPN densification site and will during the operational phase also not be included in the official EPN densification solution.***
- Preliminary time series analysis, proposal for discontinuity epochs (dedicated WG members): the individual AC solutions should first be pre-analysed - preferably by the provider or by the WG members responsible for the GNSS processing. The target of this pre-analysis is to detect metadata inconsistencies (between the log files and the reality and between the different input solutions), find and eliminate outliers and propose discontinuities (due to equipment changes or whatever physical effects, which are also appearing in the time series). The final decision is taken by the RFC at the final combination considering all information available from the different contributing solutions. The information on the discontinuities and unusable data periods, collected by the WG members shall be exchanged and stored in a dedicated, internationally recognized SINEX file (soln.snx).
- combination (RFC) : the combination of the available and checked SINEX solutions is being done with the CATREF software, developed by Z. Altamimi. The procedure involves three levels of combination:

- separate multi-year combination of the individual contributions from each analysis center for checking purposes;
- weekly combination of all individual solutions and the EPN weekly solution;
- multi-year combination of the integrated weekly SINEX files. They may be considered as densification weekly SINEX files. This combination is being done using exactly the same approach and same reference network as the EPN cumulative solution, allowing the full compatibility with the EPN cumulative solution.

– Product test and validation (all WG members): each combination phase incorporates quality tests. Most of the tests are related to the homogenization and filtering of the available material allowing the success of the multi-year combination at the end. As the EPN densification will be an official product of EUREF a careful and thorough validation by dedicated WG members will be performed. The WG will formulate the necessary validation procedure.

– Maintenance of the related website (EPN CB and RFC): the densification results shall be ***freely distributed to partners contributing*** to the combined product. External partners and interested groups may have access to the velocity product. The future product access policy may discussed within the WG. All public information related to the EPN Densification WG will be published at the EPN CB website. The densification web pages shall be presented as an extension following the structure of the existing EPN CB pages. They will include metadata (e.g. station log files, Operational Center forms, Analysis Center forms, Bernese combined STA file, EPN densification discontinuity file) and analysis results (position and velocity estimates, various plots about site distribution, site age, velocities).

Co-operations

The EPN densification by definition requires broad international co-operations. Two levels of co-operations are distinguished:

1. The natural partners are the SINEX providers (mainly NMCAs); the success of the EPN densification very much depends on their work, willing- and readiness for the collaboration. However this is not a one-way co-operation and data flow. In return, the EPN densification WG will provide them tested and cleaned SINEX files and the combined position/velocity product, which they can use e.g. for validation of their national realization of ETRS89. In order to be able to create a densification solution covering the full continent a good working co-operation and positive feedbacks are needed to convince all potential partners.
2. EPN densification is a space geodetic initiative and project willing to serve the geodetic community on different ways, but the targeted velocity field and velocity model is certainly within the interest of geophysicists and vice versa. The WG therefore welcomes input from their side too, on one hand, to extend its database and knowledge and, on the other hand, contribute to constrain and better understand the tectonic processes of our continent and the adjacent areas. Those two communities must communicate, co-operate and well understand each other. The co-operation is now possible within the frame of European Plate Observing System (EPOS), where, EUREF has been recognized as the main pan-European partner

contributing to EPOS in the field of GNSS. Additionally, the EPN densification was included into the EPOS-IP (Implementation Phase) project, where through the common actions a long-term fruitful partnership will be established.

There are other initiatives and projects running in Europe which are dealing with dense networks. As already mentioned, EUPOS is supporting the EPN Densification WG with the results of ECC. The results of the CEGRN campaigns and CEGRN permanent GNSS stations are also involved, according to the MoU (Memorandum of Understanding) between Central European GPS Geodynamic Project (CERGOP) and EUREF. The E-GVAP network (http://egvap.dmi.dk/) is another example of dense GNSS network in Europe, set up to provide its EUMETNET members with European GNSS delay and water vapour estimates for operational meteorology in near real-time and linked to EPN through a MoU between EUMETNET and EUREF. Although the mandate of the IAG WG on the "Integration of dense velocity fields into the ITRF" is terminating soon, this group is a key partner on the global scale, which was supported by EUREF and EPN as the European part of the global network.

WG Membership

Three kinds of membership are distinguished for the moment:

- Analysts of EPN ACs, who are providing large or multiple network solutions and who are able to support the densification with well prepared, pre-filtered data;
- Experts, who are supposed to contribute to the preparation of the guidelines and able to test and validate the densification product;
- Operators of EPN densification stations (EPN Operational Centers), who make available station metadata and whose RINEX data are processed by an EPN Analysis Center;

The following TWG members are proposed to be member of the WG to optimally represent the above described qualifications:

Ambrus Kenyeres	WG chair, combination
Carine Bruyninx	guidelines, website, validation
Alessandro Caporali	analyst, validation
Martin Lidberg	validation, product test (chair Deformation WG)
Günter Stangl	analyst, chair EUREF Campaign Database
Zuheir Altamimi	validation