



## Guidelines for EUREF Densifications

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Version 3: 24-05-2012: Encourage the use of GLONASS observations

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*This document outlines the procedure for computing station coordinates (and velocities) in the ETRS89 (European Terrestrial Reference System), in particular in the framework of national densifications of the ETRS89. The document also describes how to proceed to request a EUREF validation of the densification.*

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## 1. Introduction

This document outlines the procedure for computing station coordinates (and velocities) in a realization of the European Terrestrial Reference System (ETRS89), in particular in the framework of national densifications of the ETRS89. The document also describes the procedure to request a EUREF validation of this ETRS89 densification.

In the following, we will use the word “campaign” in a broad sense: it can refer to

- A GNSS observation campaign of a couple of days or weeks, where only coordinates are estimated;
- Observations gathered over a long duration of time. This can be the case of permanent GNSS stations (preferred) or repeated GNSS campaigns (discouraged) on sites that are not permanently occupied. In both cases, velocities need to be estimated in addition to coordinates and the total observation period should cover at least three years.

Similar to the procedures used in the early years of EUREF (See Annex), the basic principle of computing station coordinates (and velocities) in a European Terrestrial Reference Frame (ETRF) consists of two steps:

- 1) compute station coordinates (and velocities) in a realization of the International Terrestrial Reference System (ITRS)
- 2) transform them from this ITRS realization to a realization of the ETRS89 using EUREF TN-1 (Altamimi, 2017).

Before computing station coordinates (and velocities) in the ITRF<sup>2</sup>, a set of reference stations, with well-known ITRF coordinates and velocities must be chosen. Once this set is defined, their GNSS data are processed together with the data from the densification stations. In the early years, the ITRF position/velocities of the reference stations were obtained from the International Earth Rotations and Reference Systems Service (IERS) and were updated at each successive realisation of the ITRS. In recent years, to account for changing GNSS antenna calibration models, the ITRF coordinates/velocities of selected stations of the International GNSS Service (IGS) were corrected by the IGS to be fully consistent with the actual GNSS data analysis models. These lists of station coordinates/velocities are known as IGS<sub>yy</sub>, with yy referring the underlying ITRF.

The last realization of the ITRS is the ITRF2014 (Altamimi et al., 2016). It is consistent with the igs08.atx GNSS antenna calibration model. In January 2017, the IGS started to use the IGS14 (Rebischung et al., 2016) for the generation of its products. At the global level, the IGS14 is equivalent to the ITRF2014 in the sense that they share the same underlying origin, scale and orientation. But, the IGS14 coordinates are consistent with the igs14.atx antenna calibration model used in present-day GNSS data analysis (since GPS week 1934).

For the densifications campaign, the frame of the estimated GNSS coordinates in step 1 should ideally be the frame of the IGS orbits computed together with the consistent antenna calibration model. Hence, from Jan. 2017, the GNSS coordinates of the densification campaign should be computed in IGS14<sup>3</sup>. In this text, we will use ‘IGS orbits and Earth Rotation Parameters (ERP)’ in the broad sense as they refer to the combined IGS orbits and ERP or to the orbits and ERP generated by one of the global GNSS analysis centres contributing to the combined IGS products.

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<sup>2</sup> International Terrestrial Reference Frame, realization of the ITRS

<sup>3</sup> For GNSS observations before Jan. 2017, the use of an older frame and associated antenna calibration model might be more appropriate (see [http://epncb.oma.be/\\_productservices/analysiscentres/combsolframe.php](http://epncb.oma.be/_productservices/analysiscentres/combsolframe.php)) to ensure consistency with the used IGS orbits.

Although IGS14 reference stations could be used directly as reference stations for densifications of the ETRF<sup>4</sup>, the EUREF Permanent Network (EPN), which was established in 1996 (Bruyninx, 2004) has the maturity and reliability to be used directly to densify in Europe realisations of the ETRS89 or ITRS. The “Guidelines for EUREF Densifications” outline how this densification can be done.

Densifying the ETRF requires first that EUREF defines those EPN stations that can be used as reference stations and releases a set of well-known ITRF coordinates and velocities for them (section 2). This activity falls under the responsibility of the EUREF Reference Frame Coordinator (RFC).

## 2. EUREF Densification of the ITRF

EUREF releases (through the EUREF RFC) its own regional densification of the ITRF including multi-year ITRS/ETRS89 coordinates/velocities of the EPN stations. These coordinates/velocities are regularly updated and can then be used as reference coordinates/velocities for densifying the ITRS/ETRS89 realizations over Europe.

As not all EPN stations are suitable as reference stations, EUREF categorized the EPN stations taking the station quality and the length of available observation span into account (Kenyeres, 2009):

- **Class A** stations with coordinates at the 1 cm precision<sup>5</sup> and velocities at the 1mm/yr precision at all epochs
- **Class B** stations with coordinates at the 1 cm precision at the epoch of minimal position variance<sup>6</sup> of each station

Considering Resolution no 1 of the EUREF symposium in Wroclaw, 2017:

*The IAG Reference Frame Sub-commission for Europe (EUREF) expresses its sincere thanks to the EUREF community for the valuable information contained in the responses to the ETRS89 questionnaire and considering that the questionnaire results show the diverse requirements regarding national implementations of ETRS89 respects the different countries’ decisions on adopting their preferred ETRS89 realisations including the recommended ETRF2000 however noting the improved accuracy and stability of the origin and scale parameters of the ITRF2014 and the significance of an improved ETRS89 realisation based on the ITRF2014 urges the TWG to make available all the defining parameters of the ETRF2014 with an origin coinciding with that of ITRF2014 and to provide the full series of transformation parameters between ITRF and ETRF versions in an updated technical memo.*

and the EUREF Governing Board (GB) decision to release the multi-year ETRS89 coordinates/velocities of the EPN stations in both the ETRF2000 and ETRF2014 frames, the latest multi-year EUREF densification of the ITRF/ETRF contains the following files:

### A) For **class A** stations

A.1) in the ITRS, densifying the IGS14 frame:

- EPN\_A\_IGS14\_CWWWW.SSC: site coordinates and velocities
- EPN\_A\_IGS14\_CWWWW.SNX.Z: SINEX file

<sup>4</sup> European Terrestrial Reference Frame, realization of the ETRS89

<sup>5</sup> A station is moved to class A when the station has more than 1 year of observations, the formal uncertainty of the last velocity estimate is below 0.5 mm/yr and the agreement (in terms of repeatability) between the velocity estimates from the last 10 consecutive cumulative solutions (available internally every 5 weeks) is below 0.5 mm/yr in all three velocity components. In addition, the last solution for that station should be not older than 2 years.

<sup>6</sup> While estimating for each site a position and velocity, the epoch of minimal position variance (EMPV) is the epoch which minimizes the variance of the position (coordinates with the best precision). The epoch of minimal variance often corresponds to the mean epoch of observations. For a detailed description of the EMPV, we refer to Altamimi et al., 2002.

- A.2) in the ETRS89, ETRF2000 frame:
  - EPN\_A\_ETRF2000\_CWWWW.SSC: site coordinates and velocities
  - EPN\_A\_ETRF2000\_CWWWW.SNX.Z: SINEX file
- A.3) in the ETRS89, ETRF2014 frame:
  - EPN\_A\_ETRF2014\_CWWWW.SSC: site coordinates and velocities
  - EPN\_A\_ETRF2014\_CWWWW.SNX.Z: SINEX file
- B) For **class B** stations
  - B.1) in the ITRS, densifying the IGS14 frame:
    - EPN\_B\_IGS14\_CWWWW.SSC: site coordinates at epoch of minimal variance, no velocities!
  - B.2) in the ETRS89, ETRF2000 frame:
    - EPN\_B\_ETRF2000\_CWWWW.SSC: site coordinates at epoch of minimal variance, no velocities!
  - B.3) in the ETRS89, ETRF2014 frame:
    - EPN\_B\_ETRF2014\_CWWWW.SSC: station coordinates at epoch of minimal variance, no velocities!

#### Terminology:

EPN\_[A/B]\_[IGS14/ETRF2000/ETRF2014]\_C[WWWW]:

- A/B: class A or class B stations
- IGS14/ETRF2000/ETRF2014: frame of the realization
- C: indicates that it is a cumulative solution
- WWWW: all EPN observations until GPS week WWWW are used for this solution

Only class A stations can be used as reference stations for the densification of the ETRS89 realizations. The associated files can be downloaded from the EPN Central Bureau; the most recent realization is available through the links:

- In the ITRS:
  - o [ftp://epncb.oma.be/epncb/station/coord/EPN/EPN\\_A\\_IGS14.SSC](ftp://epncb.oma.be/epncb/station/coord/EPN/EPN_A_IGS14.SSC)
  - o [ftp://epncb.oma.be/epncb/station/coord/EPN/EPN\\_A\\_IGS14.SNX.Z](ftp://epncb.oma.be/epncb/station/coord/EPN/EPN_A_IGS14.SNX.Z)
- In the ETRS89:
  - o [ftp://epncb.oma.be/epncb/station/coord/EPN/EPN\\_A\\_ETRF2000.SSC](ftp://epncb.oma.be/epncb/station/coord/EPN/EPN_A_ETRF2000.SSC)
  - o [ftp://epncb.oma.be/epncb/station/coord/EPN/EPN\\_A\\_ETRF2000.SNX.Z](ftp://epncb.oma.be/epncb/station/coord/EPN/EPN_A_ETRF2000.SNX.Z)
  - o [ftp://epncb.oma.be/epncb/station/coord/EPN/EPN\\_A\\_ETRF2014.SSC](ftp://epncb.oma.be/epncb/station/coord/EPN/EPN_A_ETRF2014.SSC)
  - o [ftp://epncb.oma.be/epncb/station/coord/EPN/EPN\\_A\\_ETRF2014.SNX.Z](ftp://epncb.oma.be/epncb/station/coord/EPN/EPN_A_ETRF2014.SNX.Z)

Note that previous releases (also the ones in previous reference frames), are regularly moved to the archive directory <ftp://epncb.oma.be/pub/station/coord/EPN/archive/>.

## 3. GNSS Data Analysis

This section provides guidelines for the analysis of GNSS campaigns with the goal to densify the ETRS89. These guidelines are necessary to guarantee the consistency of the campaign analysis with the official ETRS89/ITRS coordinates and velocities released by EUREF. The present guidelines, consider that the GNSS data analysis is done using the so-called “network approach”.

### 3.1 GNSS Data from the Densification Area

The sites to be included in the densification should be observed with GNSS receivers that comply with the present requirements for permanent EPN tracking stations, available from [http://epncb.oma.be/documentation/guidelines/guidelines\\_station\\_operationalcentre.pdf](http://epncb.oma.be/documentation/guidelines/guidelines_station_operationalcentre.pdf).

It is recommended to use GNSS antennae which have absolute calibrations values, preferably azimuth and elevation dependent values. Ideally, the observation period must cover at least three non-overlapping days of 24-hour data at a 30-second sampling rate. If, GLONASS observations are available, then a combined GPS+GLONASS data analysis is recommended. Adding Galileo measurements should be done with care as long as no reliable calibrations for the ground receiver antennas are available.

### 3.2 Reference Stations

The reliability of the reference frame realization will increase with growing number of reference stations (the realization will become less sensitive to a problem caused by an individual reference station) and with the geographical extent of the reference stations (Legrand and Bruyninx, 2009). The reference stations shall fulfil the following criteria:

- Class A EPN stations part of the latest EUREF realization of the ITRS/ETRS89, see [ftp://epncb.oma.be/epncb/station/coord/EPN/EPN\\_A\\_IGS14.SSC](ftp://epncb.oma.be/epncb/station/coord/EPN/EPN_A_IGS14.SSC)
- Have observation data covering the time frame of the densification project
- Without a GNSS equipment change since the last EUREF realization (indicated by the GPS week WWWW in the filename)
- Their estimated coordinates tied to the EPN\_A\_IGS14 should agree better than 10 mm with the EPN\_A\_IGS14 coordinates during the full period that the reference station was used in the densification project.

Because the reference epochs of the densification campaign and of the EPN\_A\_IGS14 coordinate file are in general different, the agreement in the coordinates is verified at the mid epoch of the densification campaign. For this purpose, the reference coordinates of the EPN\_A\_IGS14 stations are mapped to the campaign epoch using the reference velocities and taking into account the discontinuity file available at the EPN ([ftp://epncb.oma.be/pub/station/coord/EPN/EPN\\_discontinuities.snx](ftp://epncb.oma.be/pub/station/coord/EPN/EPN_discontinuities.snx)).

At least 5 reference stations surrounding the densification area and all potential reference stations within the densification zone should be included by using their original tracking data available from the EPN Data Centres. In addition, the EPN station position time series (<http://www.epncb.oma.be/productsservices/timeseries/>) should be verified to avoid reference stations with noisy time series or with large (exceeding 1 cm in amplitude) periodic signals. Take also into account that the coordinates of a reference station might change over time (due to e.g. equipment changes) and make sure you use the coordinates valid during the densification period by taking into account the EPN discontinuity file.

### 3.3 Orbits and Earth Rotation Parameters

Use final IGS orbits and Earth Rotation Parameters (ERPs) and ensure yourself that they are based on similar antenna models as used in the GNSS data analysis of the densification. If GPS-GLONASS data are processed, combined GPS-GLONASS orbits are recommended as input.

### 3.4 GNSS Processing Method

Generate daily network solutions by estimating site coordinates for all stations in the network. The GNSS data analysis should be conform to the guidelines for EPN Local Analysis Centres ([http://epncb.oma.be/documentation/guidelines/guidelines\\_analysis\\_centres.pdf](http://epncb.oma.be/documentation/guidelines/guidelines_analysis_centres.pdf)) to guarantee consistency between the densification solution and the EPN solution.

By fixing IGS orbits and ERPs, the daily solution is implicitly aligned to the ITRF that was used to generate IGS products. However, in order to enhance the alignment of the estimated coordinates to

the ITRF, the minimum constraints approach on the selected reference stations can eventually be used, as outlined in Altamimi (2003).

Use the same antenna calibration values as used by the EPN analysis centres (see [http://epncb.oma.be/documentation/equipment\\_calibration/](http://epncb.oma.be/documentation/equipment_calibration/)), currently the epn\_14.atx, available from [ftp://epncb.oma.be/pub/station/general/epn\\_14.atx](ftp://epncb.oma.be/pub/station/general/epn_14.atx).

## 4 Stacking and Reference Frame Definition

In the next step, the daily network solutions should be combined to estimate coordinates (and velocities, see 4.1) for each site in the densification project. Take into account, that if a station is affected by coordinate jumps, then multiple sets of coordinates (each with a validity period) have to be estimated for that station.

### 4.1 Velocity Estimation

Velocity estimation is mandatory for all stations with an observation time of 3 years or more in the densification project.

In case observations prior to GPS week 1934 (January 2017, date of the introduction of the igs14.atx/epn\_14.atx antenna model) are included in the densification project, it is expected that these observations are also processed using the latest epn\_14.atx calibration model. If such a processing is really not possible, then position jumps might occur during the stacking at the epoch of the change of the antenna calibration model and they might degrade the solution. Methods for reducing the coordinate jumps might be applied, e.g. using a latitude-dependent model ([ftp://igs.org/pub/station/coord/new\\_calib/lat\\_models.txt](ftp://igs.org/pub/station/coord/new_calib/lat_models.txt)). In any case, always carefully inspect the jumps and introduce position discontinuities where necessary.

### 4.2 Optional Combination with EPN SINEX Solutions

Depending on the available processing capacities, the daily network solutions of the densification project can be combined at the SINEX level with the final daily combined SINEX solutions from the EPN (covering at least the period of the densification). This combination can be useful to verify your results but also to obtain an extended European-wide network including the densification network. The number of reference stations can then be increased. Daily EPN solutions are available as SINEX files from the EUREF Regional Data Centre at BKG. Only densification solutions generated using the same processing options as the daily EPN solutions should be used.

### 4.3 Stacking and Computation of ITRS Coordinates

The daily network solutions (or the extended daily densification network solutions (from 4.2) are stacked to compute ITRS coordinates at the central epoch of observations, by tying the network to EPN\_A\_IGS14 using minimum constraints (MC) approach on the set of EPN Class A stations (see 3.2), and this on the coordinates as well as the velocities, if applicable. During this process, the coordinates for all stations in the network are estimated. If necessary (see 4.1) site velocities can be derived.

### 4.4 Transformation to ETRS89

Convert the obtained ITRS coordinates at the epoch of observation (and velocities, if applicable) to the ETRS89 by using the published transformation parameters (in EUREF TN-1, Altamimi (2017)). The “ETRS89/ITRS TRANSFORMATION” utility on the EPN web site can be used to carry out the transformation (see [http://epncb.oma.be/productservices/coord\\_trans/](http://epncb.oma.be/productservices/coord_trans/)). The actual ITRS frame to be used is the ITRF2014. The ETRS89 frame to be used depends on the national situation, e.g. a country

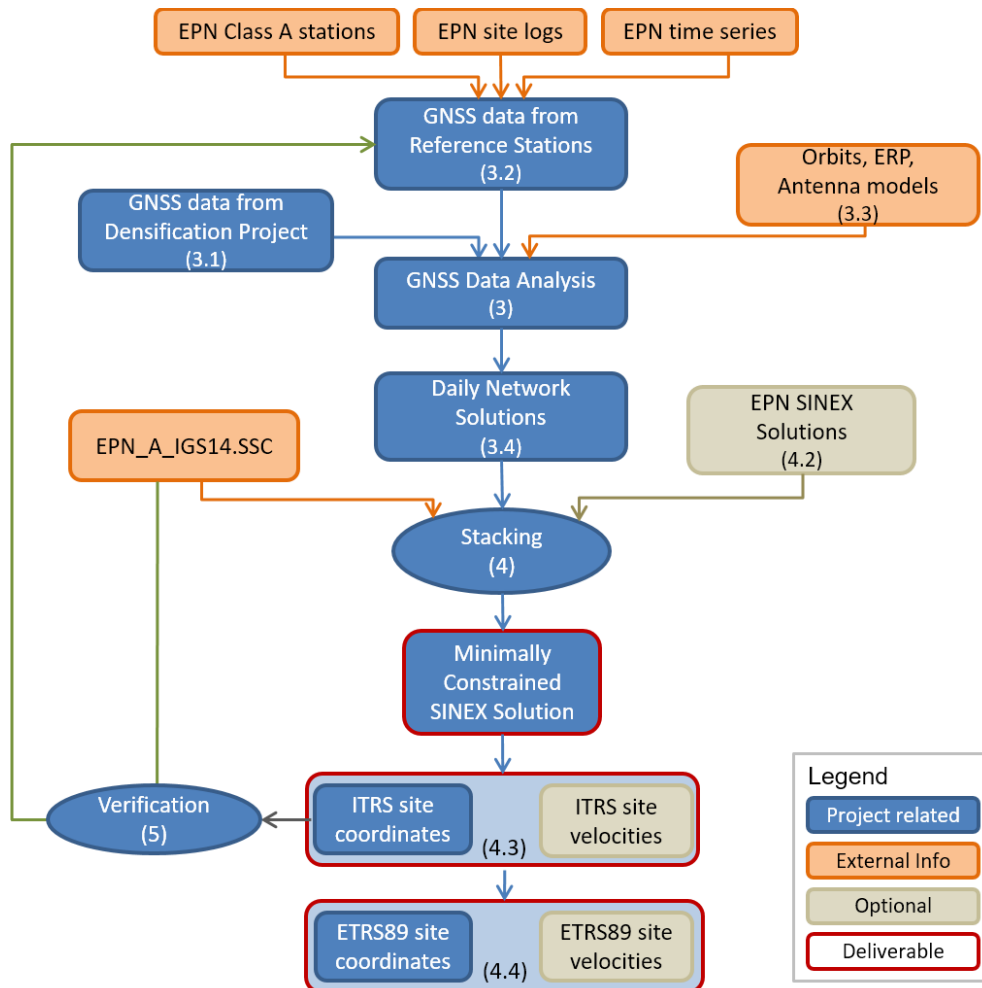
whose previous EUREF densification is in the ETRF97 might wish to express again its coordinates in this frame in order minimize coordinate changes with respect to previous national realizations.

## 5 Verification

Validate your results by performing the following tests:

- Verify the ambiguity resolution
- Verify the daily repeatabilities (in North, East, Up) of the residual position time series of the densification solution.
- Verify the difference of the estimated coordinates (and velocities) of the reference stations with EPN\_A\_IGS14 (at the same epoch); all reference stations should agree better than 10 mm for coordinates with the EPN\_A\_IGS14 values over the full duration of the densification project. If not, eliminate the reference station, notify the EPN Central Bureau and iterate.
- Compare the obtained ETRS89 coordinates with the coordinates obtained from previous EUREF densification campaigns. Take, if the reference epochs are different, the ETRS89 velocities into account.

## 6 Summary of the Procedure





## 7 Validation and Deliverables

### 7.1 Report to EUREF Governing Board

If validation by the EUREF GB is requested, then a full report of the densification campaign must be submitted to the EUREF GB at least 2 weeks before the next GB meeting and the results should be presented by the analysis centre at this EUREF GB meeting.

The report should contain:

1. Description of the densification project
  - a. List of densification stations (full names, 9-char ID, domes numbers, map)
  - b. Observation period (permanent, campaign type)
  - c. GNSS equipment (IGS standard names for receiver and antenna/radome)
  - d. Monument description
2. Other data used in the processing
  - a. List of reference stations and list of verifications performed to check their performance during the time frame of the densification project
  - b. If used, list of EPN SINEX solutions
  - c. Orbits, ERP
  - d. Antenna calibration models
3. Processing strategy
  - a. Software (and version)
  - b. Schematic processing method
  - c. Elevation cut off
  - d. Positioning mode (using the so-called “network approach”)
  - e. Modelling of loading effects
  - f. Ambiguity resolution strategy
  - g. Modelling of troposphere (e.g. a priori model, mapping function, constraints, gradients, ...)
  - h. Modelling of ionosphere (e.g. higher order corrections)
  - i. As far as they exist, alternative strategies for test purposes
4. Results from the processing
  - a. Daily mean ambiguity resolution percentages, separated per system in case of a multi-GNSS solution
5. Method of stacking the daily solutions
  - a. Method for stacking the daily network solutions in one densification solution
  - b. Parameters used to tie the densification solution to the EPN Class A reference stations: name of the EPN Class A SSC file (see section 3.2), parameters of the minimum constraints procedure, including identification of reference stations, the used reference coordinates/velocities and validity periods
  - c. In case velocities have been estimated: list of introduced discontinuities
6. Results from stacking the daily solutions
  - a. Residual position time series: comparison of the daily coordinate estimates of each station (repeatabilities in North, East and Up) with respect to the stacked solution. Outliers should be identified, explained and eliminated.
  - b. Comparison between estimated ITRF coordinates (and velocities, if applicable) and reference coordinates (and velocities, if applicable) (used in 5.b), expressed in North, East and Up.
7. Transformation to ETRS89
  - a. Transformation to the ETRS89 (including parameters used and selected realization)



- b. Comparison between new ETRS89 coordinates and ETRS89 coordinates from previous ETRS89 densifications (expressed in North, East and Up)

Remark: the SINEX files must be compliant with the official specifications and contain all the mandatory blocks.

## 7.2 Deliverables

Once the densification has been validated by the GB, it will be included in the EUREF densification data base. For that purpose, the following deliverables need to be submitted to the EUREF GB:

1. Site description forms (complete the appropriate fields in the Site Information Form available from <ftp://epncb.oma.be/pub/station/general/blank.log>)
2. Minimally constrained solution that is aligned to the ITRS realization in SINEX format
3. List of coordinates for all stations in the network in the ITRS at epoch of observation  
or  
List of coordinates & velocities for all stations in the network in the ITRS (for densification projects requiring velocity estimation)
4. List of coordinates for all stations in the network in the ETRS89 (indicate the frame used) at epoch of observation  
or  
List of coordinates & velocities for all stations in the network in the ETRS89 (indicate the frame used)
5. List of reference stations
6. Coordinates and velocities used for the reference stations (including their validity period and name of the EPN Class A SSC file, see 3.2.)

## 8 References

Altamimi, Z., Sillard P., and Boucher C. (2002), ITRF2000: A new release of the International Terrestrial Reference Frame for earth science applications, *J. Geophys. Res.*, 107(B10), 2214, doi:10.1029/2001JB000561

Altamimi Z. (2003), Discussion on How to Express a Regional GPS Solution in the ITRF, EUREF Publication No. 12, Verlag des Bundesamtes für Kartographie und Geodäsie, Frankfurt am Main, pp. 162-167

Altamimi, Z., P. Rebischung, L. Métivier, and X. Collilieux (2016), ITRF2014: A new release of the International Terrestrial Reference Frame modeling nonlinear station motions, *J. Geophys. Res. Solid Earth*, 121, 6109–6131, doi:10.1002/2016JB013098.

Altamimi Z. (2017), EUREF Technical Note 1: Relationship and Transformation between the International and the European Terrestrial Reference Systems, <http://etrs89.ensg.ign.fr/pub/EUREF-TN-1.pdf>

Bruyninx C. (2004), The EUREF Permanent Network: a multi-disciplinary network serving surveyors as well as scientists, *Geoinformatics*, Vol. 7, pp. 32-35

Legrand J., Bruyninx C. (2009), EPN Reference Frame Alignment: Consistency of the Station Positions, *Bulletin of Geodesy and Geomatics*, Vol. LXVIII, no. 1, pp. 19-34

Kenyeres A. (2009), Maintenance of the EPN ETRS89 coordinates, presented at the EUREF TWG 2009 Spring Meeting, Feb. 26-27, 2009, Budapest, available from [http://www.euref.eu/TWG/EUREF%20TWG%20minutes/49-Budapest2009/03-e-ETRSmaint\\_TWGrepBP.pdf](http://www.euref.eu/TWG/EUREF%20TWG%20minutes/49-Budapest2009/03-e-ETRSmaint_TWGrepBP.pdf)



Rebischung P., Schmid R., Herring T. (2016), Upcoming switch to IGS14/igs14.atx, IGSMAIL-7399, <https://lists.igs.org/pipermail/igsmail/2016/001233.html>

## Annex: Historical Background

A first set of guidelines describing how to compute EUREF densifications using products from the International GPS Service was presented at the 1994 EUREF symposium in Warsaw (Gurtner, 1994). The basic principle consisted in first computing coordinates in the ITRF at the central epoch of observation by performing all GPS computations in the same ITRF (International Terrestrial Reference Frame) version as the one of the IGS orbits that were used. During that process, the coordinates of GPS sites included in the ITRF realization were held fixed. In a second step, the computed ITRF coordinates were converted to the ETRS89 (European Terrestrial Reference System) using the Memo by Boucher and Altamimi (2011).

In 1995, the EUREF Technical Working Group (TWG) complemented this set of guidelines with a list of deliverables for EUREF campaigns (Van der Marel, 1995). The goal was to provide the National Mapping Agencies with clear instructions on how to submit their national EUREF densifications to the EUREF TWG for validation; the paper also included a list of items that had to be provided to EUREF in order to include the campaign in the EUREF Campaign Database.

In 1997, the original densification guidelines were updated (Gurtner et al, 1997) in order to make full use of the IGS network and its European densification, both established in the meantime. In this paper, the basic concept was extended to use SINEX solutions from the EUREF Permanent Network. The idea was to combine the loosely constrained regional SINEX solution of the densification network (which included at least 3 surrounding EPN stations) with the SINEX solution from the EPN and to constrain or fix the ITRF coordinates of the best sites in the combined network.

In 2003, Altamimi (2003) introduced the concept of minimal constraints for aligning a regional solution to the ITRF. This concept, which differed from the original method where the coordinates of a set of reference sites were fixed or heavily constrained to their ITRF coordinates, proposes to align a regional solution to the ITRF using a transformation formula. The advantage of the minimal constraint approach is that it yields an optimal datum definition together with preserving the original characteristics of the regional solution.

The concept of the minimal constraints is just one example of the many evolutions within the geodetic and GNSS community since 1993. In praxis, most countries defined the geodetic datum of their national ETRF realization using campaigns by the method of "heavily constraining" ITRF coordinates and applying the transformation formulas according to Boucher and Altamimi (2011) to derive ETRF coordinates.

In the meantime, the EPN, which was established in 1996 (Bruyninx, 2004) has reached maturity and reliability to be used directly to densify in Europe realisations of the ETRS89 or ITRS. The "Guidelines for EUREF Densifications" outline how this densification can be done.

### References

- Altamimi Z. (2003), Discussion on How to Express a Regional GPS Solution in the ITRF, EUREF Publication No. 12, Verlag des Bundesamtes für Kartographie und Geodäsie, Frankfurt am Main, pp. 162-167
- Altamimi Z., Collilieux X., Métivier L. (2011), ITRF2008: an improved solution of the international terrestrial reference frame, *Journal of Geodesy*, Volume 85, Issue 8, pp.457-473
- Boucher C., Altamimi Z. (2011), Memo: Specifications for reference frame fixing in the analysis of a EUREF GPS campaign, <http://etrs89.ensg.ign.fr/memo-V8.pdf>
- Bruyninx C. (2004), The EUREF Permanent Network: a multi-disciplinary network serving surveyors as well as scientists, *Geoinformatics*, Vol. 7, pp. 32-35

Gurtner W. (1994), The use of IGS Products for the Densification of Regional/Local Networks, EUREF Publication No. 3, Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung, Bayerischen Akademie der Wissenschaften, Munich, pp. 184-199

Gurtner W., Boucher C., Bruyninx C., Van der Marel H. (1997), The use of the IGS/EUREF Permanent Network for EUREF Densification Campaigns, EUREF Publication No. 6, Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung, Bayerischen Akademie der Wissenschaften, Munich, pp. 50-51

Van der Marel H. (1995), Deliverables for EUREF Campaigns, EUREF Publication No. 4, Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung, Bayerischen Akademie der Wissenschaften, Munich, pp. 275