The implementation of IGS08 in the EPN ETRS89 maintenance products

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Ambrus Kenyeres
EPN Reference Frame Coordinator

FÖMI Satellite Geodetic Observatory, Hungary

1. Introduction

The ITRF2008 densification solution based on the EUREF Permanent Network (EPN) has been iteratively discussed within the EUREF TWG and has been presented and accepted at the EUREF2012 symposium in Paris (Kenyeres, 2012). This solution was however never provided to the EUREF user community because from the start it has been considered as an intermediary solution. Indeed, this ITRF2008 densification solution was based on the weekly EPN_REPRO1 results (GPS week 834 – 1408) and the routine EPN weekly solutions (GPS week 1409 - 1631) and it is compatible with the igs05.atx and epn_05.atx[1] antenna models. This termination date of GPS week 1631 had to be set because of the introduction at GPS week 1632 (17 April 2011) of the new IGS08 frame (Rebischung, 2011) and an updated antenna PCV model, igs08.atx (Schmid, 2011). As EPN follows the IGS modeling standards, the igs08.atx antenna model (version epn_08.atx) and the related IGS08 frame have been simultaneously introduced in the routine EPN analysis at GPS week 1632, causing jumps in several time series.

This report will focus on the follow-up of the ITRF2008 densification solution and will take into account the most recent weekly EPN solutions to generate a new EPN cumulative solution that is expressed in the IGS08 frame and compatible with the most recent antenna model (igs08.atx/epn_08.atx). The presented densification solution comprises weekly SINEX files up to GPS week 1680 and designated as IGS08_C1680.

2. Handling of the change of antenna model

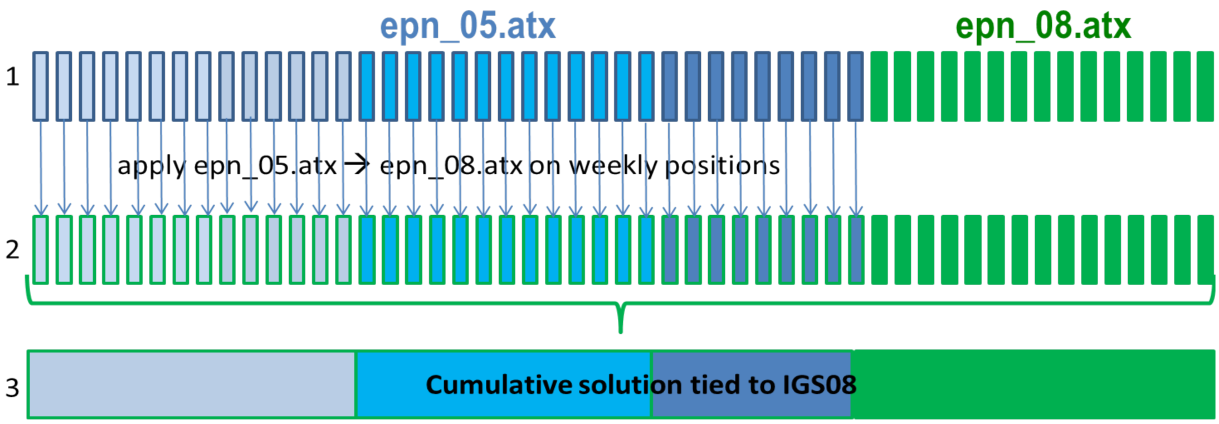

Figure 1: The three steps to be performed in order to generate a cumulative EPN solution compatible with the epn_08.atx antenna model. Each block in a horizontal line stands for a weekly EPN solution. In different shades of blue: the EPN_REPRO1 solution (GPS week 834 -1408) and routine weekly EPN solutions (GPS week 1409 - 1631). Step 1 shows that these weekly solutions have been computed with the epn_05.atx antenna model. In green, the solutions after GPS week 1631 are shown. They already have been computed using the epn_08.atx model. Step 2 shows that the solutions that were computed with the epn_05.atx model need to be corrected to be compatible with the epn_08.atx model. In step 3 the cumulative EPN solution can be generated based on a set of weekly EPN solutions that are all compatible with epn_08.atx and that the resulting solution will be expressed in the IGS08 frame.

[1] The antenna calibration model used within the EPN, epn_0x.atx, is based on the igs_0x.atx but includes additional individual antenna calibrations for a subset of the EPN stations.

Both the igs05.atx and igs08.atx set of antenna models are based on absolute calibration models (where available), but in igs08.atx several type-mean calibrations have been updated or new absolute calibrations have been implemented. As explained in the introduction and shown in Figure 1 the weekly EPN solutions are based on two different antenna models: up to GPS week 1631 the epn_05.atx model, while from GPS week 1632 the epn_08.atx model is used. This means that in order to compute a new cumulative EPN solution compatible with the epn_08.atx antenna model, it will be necessary to correct the weekly EPN solutions prior to GPS week 1632 so that they are compatible with the igs08.atx (epn_08.atx) antenna model. As the epn_08.atx also contains individual antenna calibrations, the model update did not affect EPN sites, where individual PCV models are available and implemented.
The correction consists of applying site- and antenna specific offsets to the positions in the weekly SINEX files prior to GPS week 1632. Within the IGS the position offsets were derived comparing PPP-based positions obtained with the igs05.atx and igs08.atx models for the a subset of IGS stations (Rebischung, 2011). Based on these computations, the IGS released a tool to compute the position corrections based on antenna type and station latitude (Griffiths, 2011).

Within EUREF it was decided to deploy a similar PPP approach as the IGS, but instead of applying it only for a subset of stations the full historical EPN data set before GPS week 1632 has been involved. For that purpose Q. Baire and colleagues (ROB) computed the epn_05.atx – epn_08.atx corrections site-by-site using the PPP approach. This work has been presented at the EUREF2011 symposium (Baire et al., 2011). The results were validated through comparison with the IGS PPP computations and also cross checked with the correction tool provided by IGS. The agreement with the tool offered by IGS was very good, the mean differences are below the mm- level in all three components with an RMS of 0.1, 0.1 and 0.2 mm in the north, east and up-components, respectively. Using these computed position corrections from epn_05.atx to epn_08.atx, Q. Baire modified the weekly EPN SINEX files before GPS week 1632 (see also Figure 1) and made them available for the computation of the epn_08.atx-based cumulative solution. Thanks to the corrections the new cumulative solution, up to GPS week 1680 includes now consistent input SINEX files with respect to the antenna model used (epn_08.atx).

3. Reference Frame Definition

As explained in the introduction, this new densification solution will be tied to the IGS08 frame instead of the ITRF2008. The reason for this choice is that the ITRF2008 is based on GNSS solutions obtained with the old igs05.atx antenna model. After the release of the ITRF2008, the IGS created the IGS08 frame. It consists of a subset of the stations in the ITRF2008 for which the igs05.atx to igs08.atx position offset has been applied (see the previous section). Consequently the IGS08 frame is the frame that needs to be used together with the igs08.atx or epn_08.atx calibration model. As both the ITRF2008 and the IGS08 frames share the same underlying origin, scale, and orientation (Rebischung et al. 2012) the transformation parameters of ITRF2008 are also valid for IGS08. Figure 2 shows the difference between the IGS08 and ITRF2008 ositions at epoch 2005.0 for the EPN sites available in the IGS08 SINEX file (ftp://igs-rf.ign.fr/pub/IGS08/IGS08.snx).
The IGS08 frame comes with a SINEX file (see above) and a set of refined solution numbers (ftp://igs-rf.ign.fr/pub/IGS08/soln_IGS08.snx). These IGS08 solution numbers have been used as a basis to generate the EPN specific solution number file. The EPN solution number definitions and outliers implemented for the ITRF2008 densification solution have been carefully re-revised and a complete agreement was reached. The request and proposals from C.Bruyninx for a more strict outlier rejection (deletion of longer data sections, where the station log file indicated tracking problems) were also considered. Although those corrections caused minor changes in the results (mm-s in the positions at certain solution numbers), the elimination and indication of periods with degraded equipment performance is considered as important. The detailed quality analysis of the input RINEX data done by J. Dousa (Dousa, 2012) called the attention to the more careful treatment of the input coming from the LACs, his results and indicators should be considered in the next EPN reprocessing.

The reference frame sites of the cumulative solution were taken from the published IGS08 SINEX product. While the IGS05.SNX reference SINEX solution (Ferland, 1996) contained only one single set of solution numbers (the latest one) for each station, the new IGS08 SINEX involves complete historical IGS station solution numbers and therefore a set of reference frame sites covering the entire observation history can be selected, which in addition can be extended to the future without loosing consistency (if no antenna change occured at the stations). If the IGS08 SINEX is periodically updated (as being done with the release of IGb08 – (Rebischung (2012)), then the set of our reference frame sites e.g. for the densification can be maintained on longer term without loosing consistency.

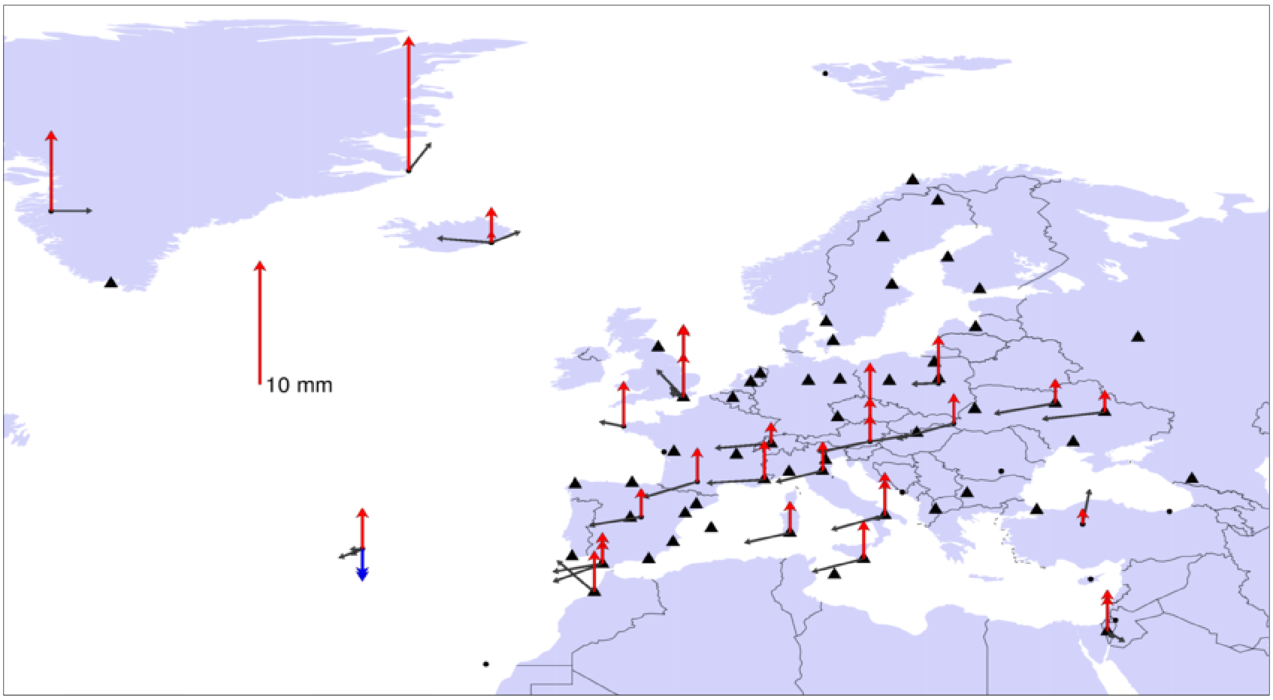

Figure 2. Position differences between the officially published ITRF2008 and IGS08 solutions over all EPN sites at epoch 2005.0. The red/blue vertical arrows correspond to the UP component, while the black thin arrows correspond to the 2D position differences. The observed differences practically show the station-specific corrections due to the discussed antenna calibration updates. The sites used for the reference frame realisation are indicated with black triangles.

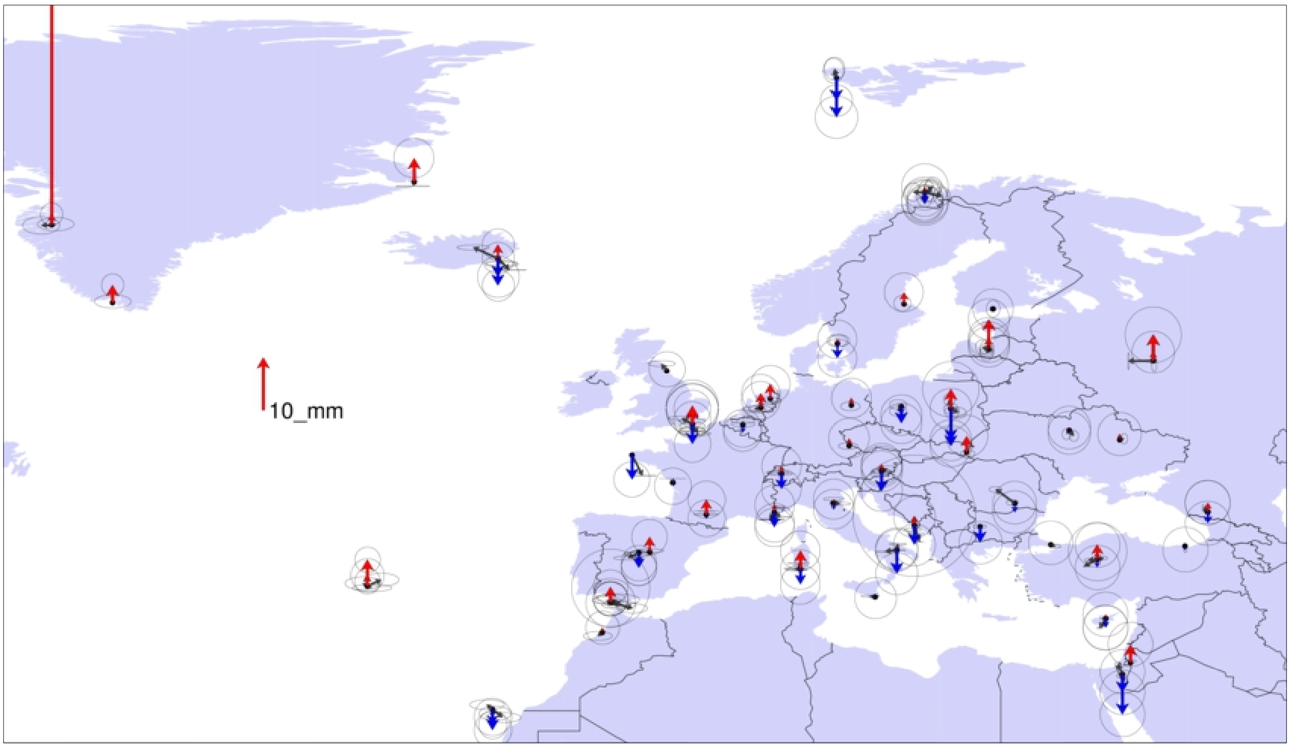

Figure 3. The position differences and their uncertainties between the IGS08 and its EPN densification solution (called IGS08_C1680) at epoch 2005.0. The red/blue vertical arrows correspond to the UP component, while the black thin arrows correspond to the 2D-position differences. Multiple arrows indicate multiple solution numbers. The agreement is certainly very good, on average better than 2 mm in the positions and 0.2 mm/year in the velocities. The only difference worth to be noted is the height component at KELY, which is due to the different handling of the UP eccentricity in the IGS and EPN solutions. In EPN_REPRO1 the Up- eccentricity (0.0762 m) was correctly set before the antenna change at GPSweek 1133, while in the IGS solution it was kept zero.

In order to express the cumulative solution in the IGS08 frame, the same subnetwork (55 sites, 101 solution numbers – see Figure 2.) as for the ITRF2008 densification have been used. The correct realisation of the Minimum Constraints has been validated by computing the 14-parameter transformation parameters between the IGS08 and its densification solution using the selected reference frame sites only. The computed parameters were practically zero, confirming the validity of the referenvce frame realisation. Another check of the the cumulative solution was done by comparing the original and estimated IGS08 coordinates and velocities (see Fig. 3-4).

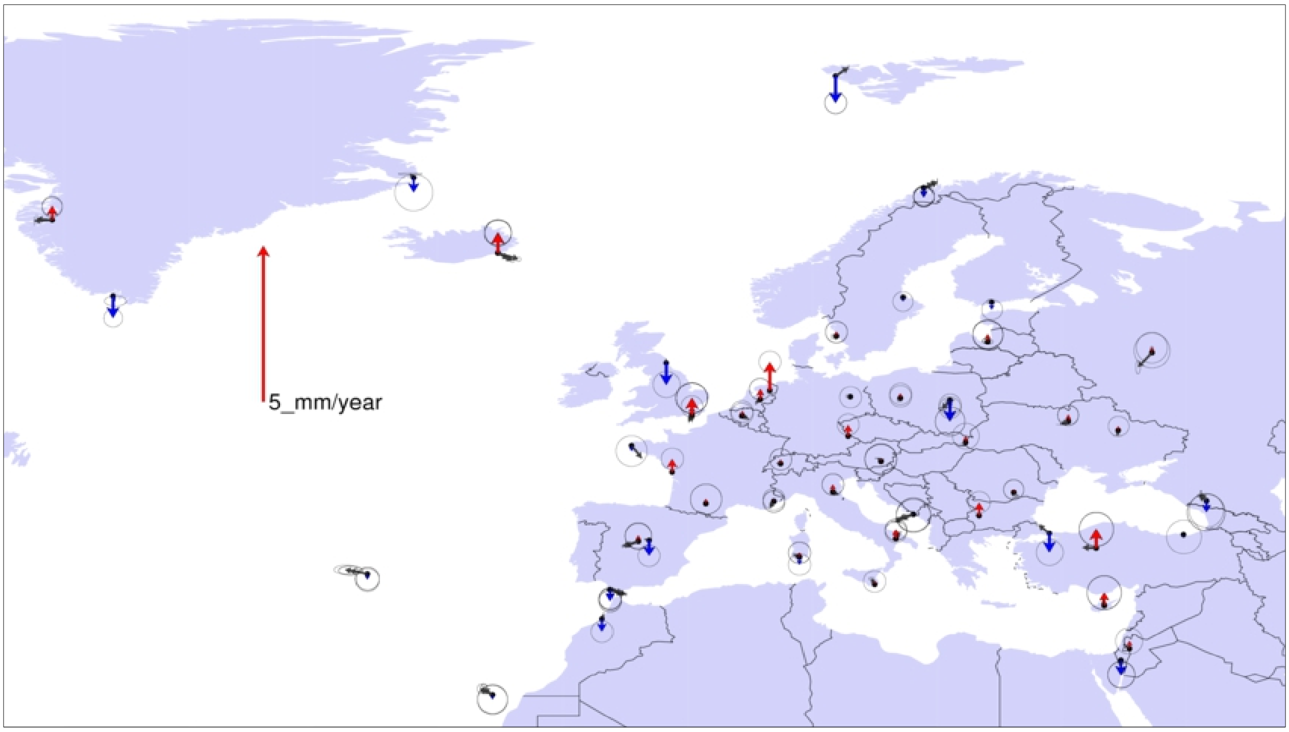

Figure 4. The velocity differences and their uncertainties between the IGS08 and its EPN densification solution (IGS08_C1680). The differences are well below the 0.6 mm/year level for all componenets, except WSRT and NYA1, where the up- value reaches 0.9 mm/year.

4. Results

With the reference stations described above and the input data set described in Section 3, the CATREF software (Altamimi et al, 2004) has been used to compute a new EPN cumulative solution. The agreement of this solution with the original IGS08 has already been outlined in the previous section.

Further consistency indicator is the comparison of the ITRF2008 (C1631/IGS05) and the IGS08 (C1680/IGS08) densification solutions. The position comparison in Fig.5. unseparably shows the differences caused by the frame change and antenna calibration model update. The agreement level is within the ±4 mm range (the standard deviation is 1 mm in 2D and better than 3 mm in UP) with exceptions up to 9 mm in the UP component. The differences mainly reflects the applied PCV corrections (remember that the EPN uses indivual antenna calibration models at several stations, while the IGS does not). The velocity comparison (not in this report) shows practically zero differences, except the few sites where additional weaker data sections were removed from the EPN densification solution of the IGS08.

However when the ITRF2008 densification velocities (see the Introduction) are compared to the IGS08 C1680 solution (Fig. 6.) large differences are observed. The affected sites typically have a very short data history in ITRF2008 and the inclusion of additional one year data altered (improved) significantly their velocitiy estimates. This plot is added to emphasize the importance of the station categorisation.

Due to the introduction of the improved antenna models in IGS08 one may expect the decrease of the offsets at antenna replacements. At this densification solution such investigation was not targeted yet, but planned for the future. Within EPN however moderate effect is expected, as siginificant portion of the antennae have individual calibration, where the type-mean antenna model upgrade has no effect.

The EPN densification solution IGS08_C1680 of the IGS08 will replace the last EPN cumulative solution ITRF2005_C1600 (densification of the ITRF2005). The new solution accumulates the effects of the ***(1)*** reference frame change, ***(2)*** antenna calibration model upgrades, and ***(3)*** additional 80 weeks of data. For the practice it is important to know the size of position changes (see Figure 7) between these two solutions. The average difference is 3 mm in 2D and 6 mm in the UP component. Considering the substantial background changes and the weakness of the ITRF2005 densification solution, this agreement level is considered very good and the observed changes are within the threshold of the geodetic practice, where cm-stability reference coordinates are expected.

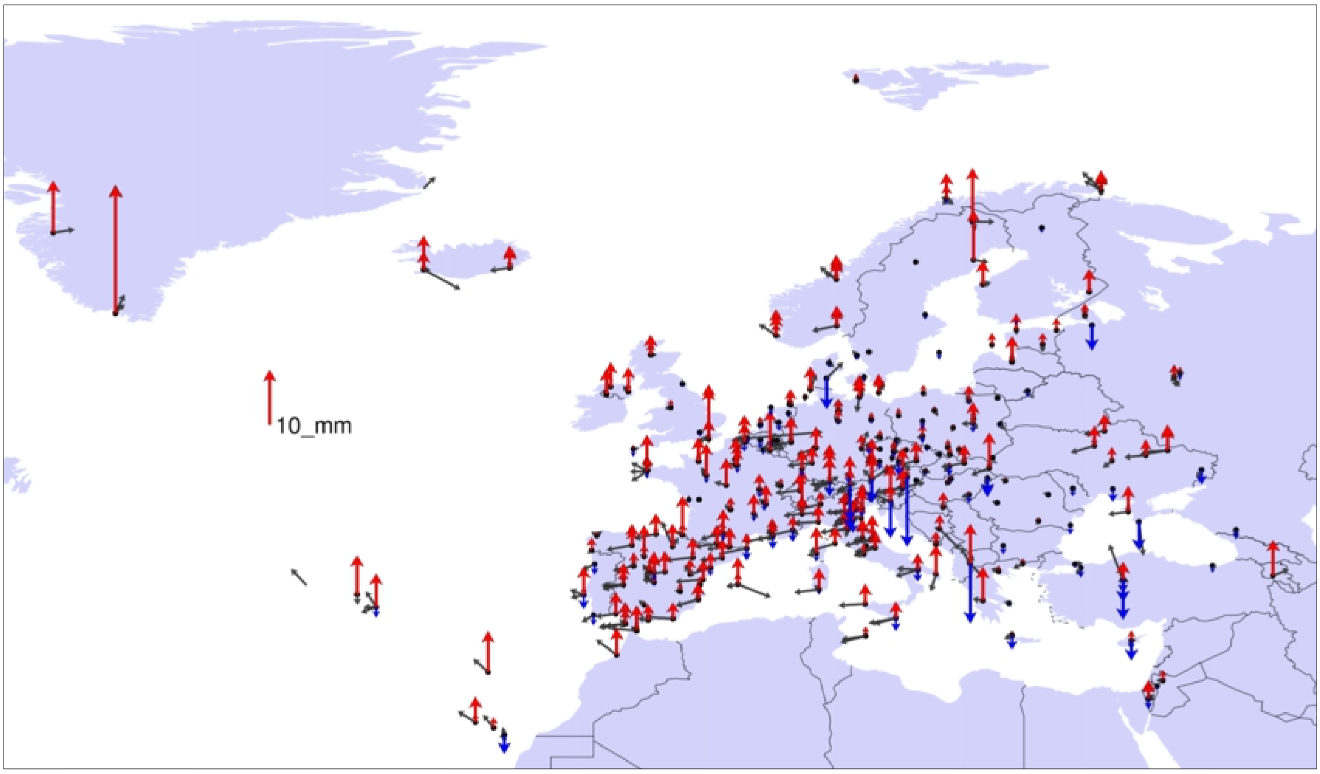

Figure 5. The 2D and UP position differences between ITRF2008 (C1631/IGS05) and new IGS08_C1680 densification solutions at epoch 2005.0. To avoid overcrowded map the uncertainties are not plotted, therefore it is noted here, that the differences are in general below the significance level.

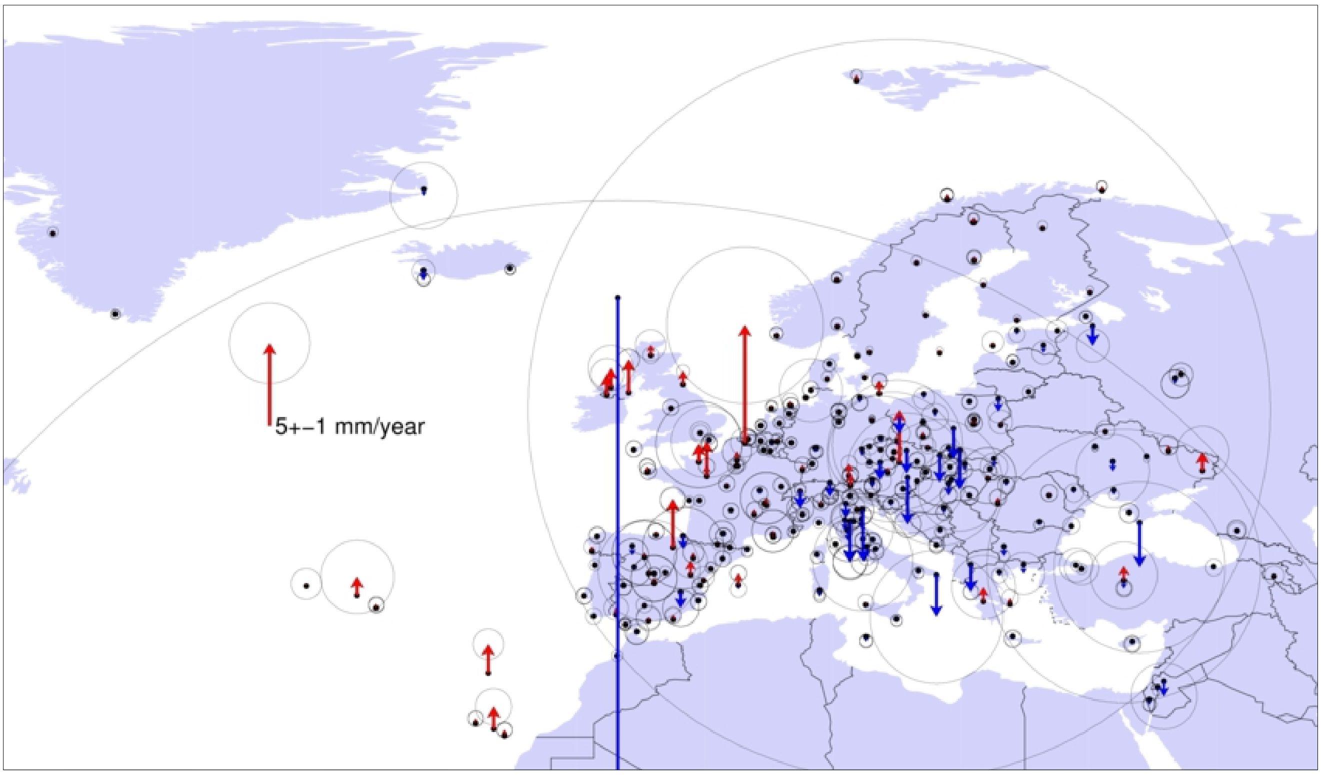

Figure 6. The UP velocity differences and their uncertainties between the ITRF2008 (C1631/IGS05) and the IGS08_C1680 densification solutions.The largest uncertainty ellipses and differences (ARGI, KUNZ, KTVL, LIL2) are related to stations which had very short observation series in C1631.

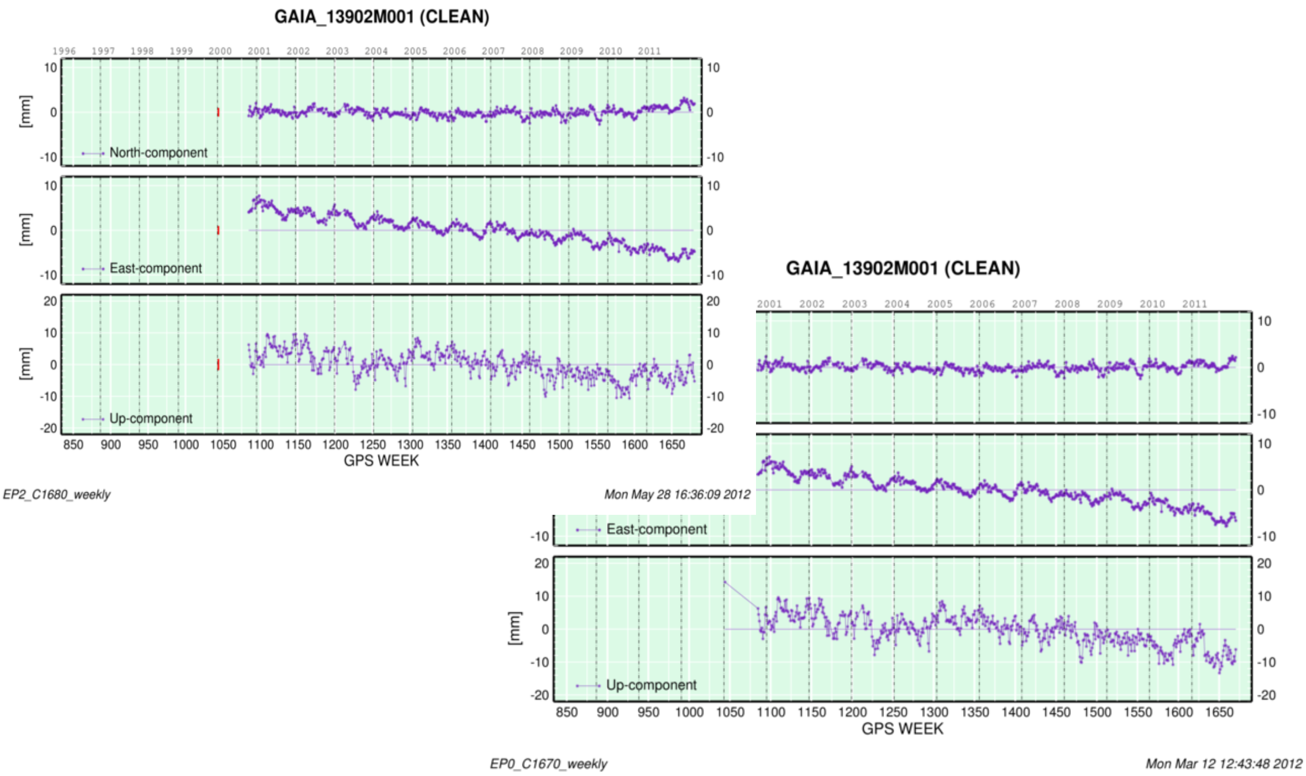

Figure 7. The position time series of GAIA station in the IGS08_C1680 (left) and the ITRF2008_C1680 (the ITRF2008 densification solution extended up to GPSweek 1680) (right) densification solutions. The UP offset at GPSweek 1631 due to the introduction of IGS08 in the routine EPN analysis has clearly disappeared in the IGS08_C1680 densification solution.

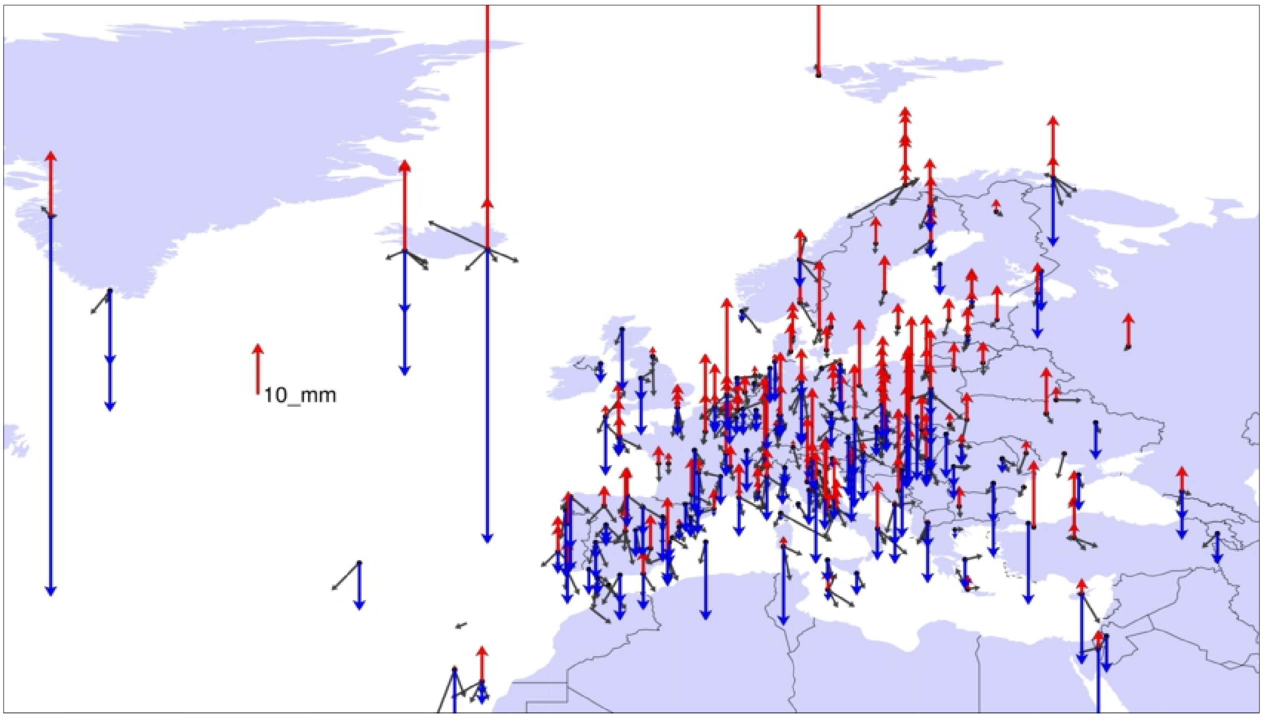

Figure 8. The position differences between the ITRF2005_C1600 and IGS08_C1680 cumulative solutions at epoch 2005.0. The larger up difference at KELY is due to the earlier discussed issue on UP excentricity handling, while at HOFN in the ITRF2005_C1600 solution the velocities were not constrained to be the equal in the subsequent time series sections.

5. Revised EPN site categorisation

Based on the strictly cleaned EPN weekly SINEX solutions, and compatible with igs08.atx, a series of cumulative solutions from week 1440 up to 1680 has been computed with 15-week steps. These 17 solutions were „densified" with 11 more solutions, computed at 5-week steps for the last part of the series to provide statistics for the categorisation. The cumulative solution series is being used to support the decision on the site quality and sort the sites into class A and B, where only class A stations are recommended to be used as reference stations for ETRS89 densifications (Bruyninx et al., 2012).

The same strategy and categorisation criteria were used as at the ITRF2005 densification and maintenance solution. This is a pragmatic approach and considers the consolidation of the successive velocity estimates as main factor to test the expected stability of the ETRS89 coordinates. The main criterion is the stationarity of the station velocity estimates, where all 3 components are treated separately.

A class A site should have better than

- 0.5 mm/year velocity 'repeatability' computed over the last year (corresponding to 10 successive estimation in 5-weekly steps),
- 0.5 mm/year velocity uncertainty extracted from the last 3 successive cumulative solutions (none of the components in any of the 3 solutions can exceed the limit).

For both cases, all components are checked separately and all must fulfill the requirements. Stations having less than 2 years of data are still not considered in this test.

In addition, starting with this new cumultive solution, the site selection criteria have become more restrictive to avoid that sites exhibiting significant noise or harmonic variation, but still have a stable long-term velocity, will be classified as Class A. For that purpose an additional filter was implemented in the current categorisation procedure: stations showing position repeatability in the residual time series larger than 2 mm in 2D and 5 mm in the UP component were exluded from class A. The position repeatability is computed from the weekly residual time series over the complete series from the beginning up to the latest week included into the cumulative solution.Due to this additional constraint e.g. BOLG, HOFN, MAS1, MORP, ZECK (too noisy series) and CNIV, KHAR (high seasonal signal), which where previously Class A stations were moved to class B. Sites showing temporary tracking problems may temporarily excluded from the combination (see Fig.10.). Although with the current setup the EPN has lost some easternmost reference stations in class A, the maintenance of the highest quality made this step necessary.

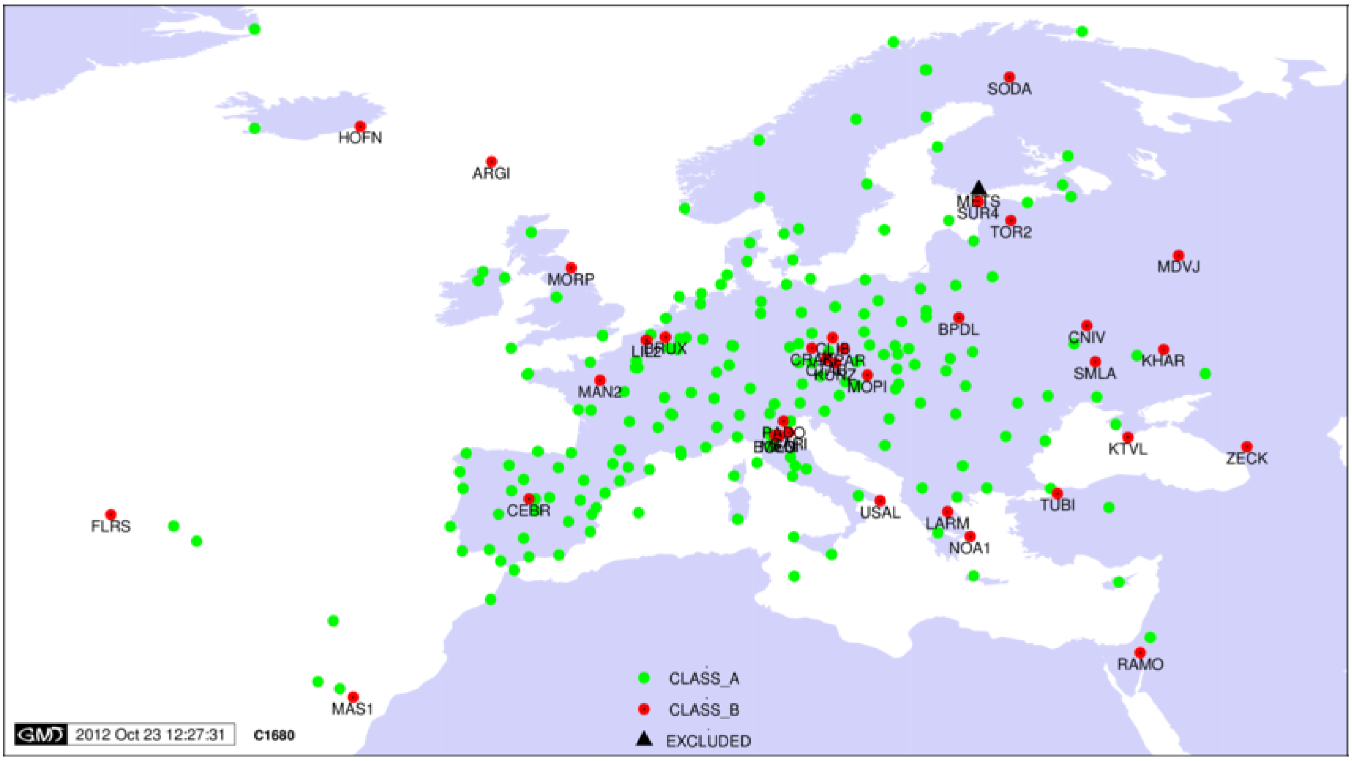

Figure 9. EPN site categorisation, version C1680.

An additional change compared to the ITRF2005/ETRS89 maintenance approach is that when a station is not present in any weeks of the 15-week update section then the station is not listed in the actual products (see Figure 10.).

The EPN ETRS89 maintenance products are:

- class A SINEX and SSC files
- class B SSC file

The products are disseminated in the same format with the same access on the EPN CB web-pages.

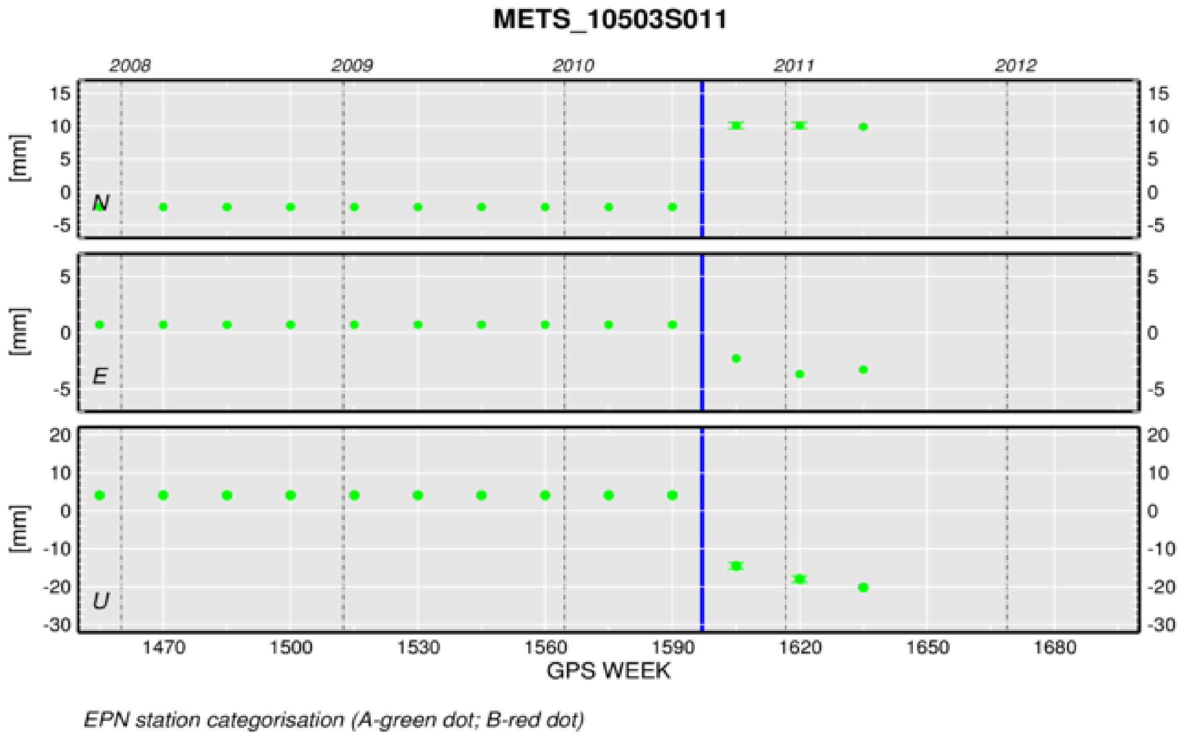

Figure 10. Categories of a temporarily excluded startion (METS) in the 15-weeks update series.

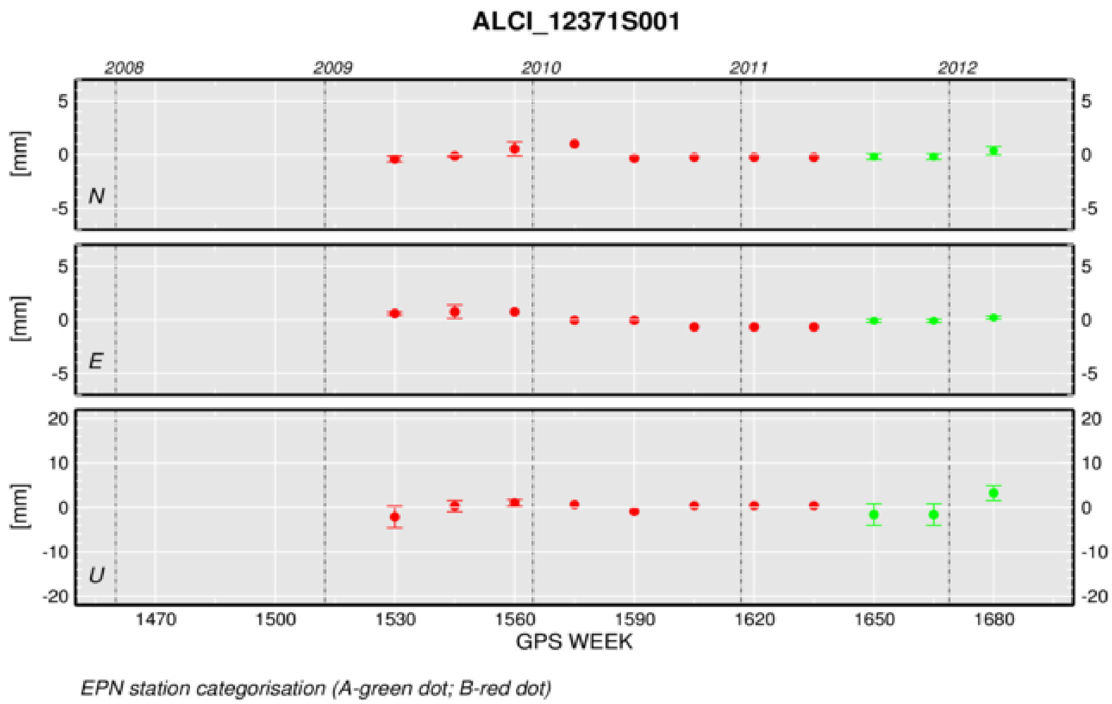

Figure 11. Categories of a new station (ALCI) in the 15-weeks update series.

6. Summary

A new EPN cumulative solution is available for the long-term maintenance of the ETRS89, based on the analysis of the EPN observations. The cumulative solution comprises the weekly combined EPN SINEX solutions from GPSweek 834 up to GPSweek 1680 (24 March 2012). The solution is partly based on the products of the EPN_REPRO1 (up to GPSweek 1408), and the routine weekly EPN SINEX product series. In order to derive a solution fully compatible with the new IGS antenna model (igs08.atx) and the IGS08 reference frame the EPN-REPRO1 products and the routine EPN solutions before GPSweek 1632 were converted as described in Chapter 2.

The IGS08 densification solution (IGS08_C1680) will directly replace the previously released ITRF2005 maintenance solution. As its last update dated back to GPSweek 1600 (EPN_ETRF2000_C1600) the new release should also bridge a gap of almost 2 years. The quality of the IGS08 densification solution and its agreement level with the previous release have been carefully tested and were shown in this report. The densification solution itself is in perfect agreement with the underlying IGS08 frame. The observed level of agreement (below 1 cm on average at epoch 2005.0) in the ETRF2000 coordinates - considering the numerous changes (data content, data and metadata review, reference frames, PCV models) - is very good and tolerable by the geodetic practice. The associated site categorisation strategy has also been upgraded, the introduced severity targeted the exclusion of sites from class_A with higher noise in their time series.

The products of this new EPN solution are expressed in both IGS08 and ETRF2000. The densification solution is also updated each 15 weeks. The related files are accessible on the EPN CB web-site or can be downloaded from the ftp://epncb.oma.be/pub/station/coordinates/EPN/ FTP site.

The naming convention was slightly changed in order to distinguish the ETRF2000 coordinates derived earlier from ITRF2005 and now from IGS08.

EPN_A_ITRF2005_***CWWWW***.SSC and SNX	EPN_A_IGS08_***CWWWW***.SSC
EPN_A_ETRF2000_***CWWWW***.SSC and SNX	EPN_A_ETRF2000(R08)_***CWWWW***.SSC

The CWWWW term indicates the latest release of the maintenance solution, which involves weekly SINEX solutions up to GPSweek WWWW.

Outlook

The new multi-year EPN solution densifies the IGS08 in Europe and is designed for the long-term maintenance of the ETRS89 and its densifications. This solution is tied to the IGS08 reference frame which provides historical information on solution numbers. In addition, the IGS regularly updates this frame to reflect changes in the frame-defining IGS core network since 2009.5. The first update is the release of the IGb08 frame and an associated antenna calibration model (Rebischung, 2012) at GPS week 1709 (7 October 2012). The new antenna calibration model is still known as igs08.atx but some antenna calibration models for currently active stations have been upgraded. The introduction of IGb08 and the update of the antenna calibration model will affect some EPN sites and will therefore be taken into account in the EPN multi-year solutions generated after week 1709.

The IGS08 densification and the follow up ETRS89 maintenance solutions are exclusively based on the multi-year observations and product series of the EPN. This cumulative solution however can be considered as backbone for the recently initiated action on the densification of the EPN using the dense national active networks. In order to get a homegeneous product the correction of the SINEX files from national densifications from igs05.atx to igs08.atx will also be necessary. Due to the huge amount of stations it is recommended to use the IGS tool (Griffiths, 2011) for the conversion.

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