Preliminary results of processing of EUREF observations using non-fiducial strategy

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Abstract

Abstract. Analysis of the official EUREF weekly solution series reveals some systematic seasonal errors, especially in the height component. We suspect that the standard fiducial processing strategy causes these errors. In the present investigation non-fiducial strategy has been used to process a subnetwork of 33 EUREF station for GPS weeks 938-1042: free weekly solutions obtained as Helmert-based combinations of daily solutions followed by Helmert transformation to ITRF97. Bernese, PyGPS and GROSS program packages were used for computations. Comparison to the EUREF solution shows that obtained coordinate time series most likely are free from seasonal errors. The authors consider it important for such a solution to accompany the official one. A comparison of our and EUREF solution and the VLBI one obtained at the IAA is planned.

1. Introduction

The main goal of this paper is a search for an optimal strategy for processing of GPS observations collected from the EUREF network to obtain as long as possible continuous coordinate time series for European GPS stations for further investigation and comparison with results obtained with VLBI and SLR techniques.

Of course, such a coordinate time series are regularly issued by the EUREF analysis centers. Two series are publicly available:

- Series computed at the BKG (early at the CODE) and distributed as SINEX files by ftp (hereafter referred as official EUREF solution).
- Series computed by the EUREF CB, ROB and distributed as plots in the EUREF CB web page.

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The former solution is computed from combination of 12 (at the moment) AC individual solutions using "standard" strategy with fixing coordinates of a set of selected fiducial stations. Unfortunately, it is affected by a periodical change of terrestrial reference system (ITRF 1994 $\to$ 1996 $\to$ 1997 $\to \dots$) and set of fiducial stations (GPS weeks 860, 947, 982, 1021, 1057). Besides, as one can see below, this coordinate time series affected, evidently, by serious systematical errors. This makes the official EUREF solution taken "as is" unsuitable for practical scientific use.

The latter solution is made by removing constrains from previous solution (Carine Bruyninx, private communication) and provides much more stable coordinate time series but it is not distributed in SINEX file. This also makes it impossible to use this solution in scientific researches.

So, we tried to obtain more stable and free of network distortion independent solution using non-fiducial strategy. We plan, after final adjusting of methodology, recompute independent coordinate time series for EUREF subnetwork of about 35 stations suitable for further comparison with data obtained with VLBI and SLR technique.

2. Processing methodology

2.1. Selection of stations

For this research 33 EUREF/ITRF stations were selected. Stations of our primary interest are:

- Russian stations;
- Stations located in Fennoscandia collocated with BSL and BIFROST networks;
- Stations collocated with VLBI and, when possible, with SLR.

Of course, stations with long observational history was preferred where a choice was possible. Several stations for improvement of network geometry was also added. Unfortunately, choice of stations was also limited by computer facilities.

2.2. Control and automation of data processing

Detailed description of the motivations and the technical issues underlying the adopted way to control the processing of GPS data is given in (Voinov, 1998, 2000). Let us summarize here the issues, which are important for the subsequent discussion.

In the scientific applications of the Bernese GPS processing package one meets situations, where the flexibility of its MENU and BPE subsystems is not sufficient. In particular, many of scientific users of the package have their own libraries suited for various specific purposes, not covered by Bernese software. Direct integration of such libraries with Bernese software seems very cumbersome and not reliable, especially due to possible interference of runtime systems.

In such situations so called "scripting languages" occur very helpful. They usually provide convenient extension mechanism, which allow easily enriching such language with operations, implemented in C or Fortran and linked to the core of interpreter.

In that way a special software package PyGPS (Voinov, 1998, 2000) has been written with the use of scripting language Python. PyGPS provides a power tool to join Bernese (or other specific program package for processing of the GPS observations) and data processing package GROSS, and MAL library (Malkin et al., 1999) to enable both to automate the overall control over the GPS data processing and to apply some custom data analysis methods.

2.3. PyGPS package

PyGPS is a software package aimed at the high level control and automation of GPS processing with the use of Bernese Software v. 4.0. Its core language is Python, some components are written in C and Fortran and organized as Python extension modules.

In brief, the package consists of some general purpose modules, not necessary related to the Bernese software, and a wrapper over the MAIN subsystem of the Bernese software. General purpose modules deal with GPS date and time arithmetic, RINEX files, the data processing package GROSS and library MAL. The Bernese-related part of the package exploits heavily the object-oriented features of the Python language, and programmer is encouraged to build his/her own class hierarchies, based on these fundamental classes, which would comprise his/her own experience with particular sets of processing parameters, occurred suitable in some particular situations.

The processing automation, gained of the use of the scripting language Python, resulted in the implementation of some special strategy of preprocessing which enabled to “save” as much of the original site-specific data as possible, without deeper investigation of possible obscure problems with the corresponding observation data.

The reason, underlying that strategy, is that usually the observation data are not of uniform quality, and when single differences are created, different pieces of one and the same file could be engaged when combined with different second data files. As a result, the quality of preprocessing and ambiguity resolution may be different for different combinations of original zero-difference files, even when the latter are of good quality with little number of outliers.

On the other hand, the set of single-difference files could not be greater than N-1 where N is the number of sites. Once one has created such a set, and once some outliers baselines occurred in this set, there will be “empty places” in the mentioned N-1 positions for linearly independent baselines. These places could be filled by another baselines, which hopefully would expose greater quality at the preprocessing step.

The original contribution to the processing strategy, accomplished with PyGPS, concludes in a special iteration loop, aimed at creation of a set of baselines together with their preprocessing and ambiguity resolution. This step is described in a special issue of the proceedings of the Finnish Geodetic Institute.

2.4. Processing strategy

We have used non-fiducial strategy in this research. The motivation of such a choice of processing strategy is the following.

Fiducial strategy used for computation of the official EUREF solution presupposes that coordinates of fiducial stations precisely follow the linear model of accepted terrestrial reference system, e.g. ITRF. Errors in coordinates of fiducial stations, peculiar station motion, local displacements, equipment change, etc. may result in errors distributed over whole processed network. Especially important is that this errors can cause a network distortion that evidently cannot be fully compensated by the normal procedure of removing constraints.

On the other hand, non-fiducial strategy have some advantages in our opinion:

- Free network solution used on the first step of processing does not cause a distortion of network.
- Resulting free network solution can be easily transformed to any reference system and later re-transformed to another one using much simpler procedure than needed for removing constraints.

This strategy was successfully tested during processing of the BSL 1993 and 1997 campaigns (Springer and Malkin, 1995; Voinov and Malkin, 1999). So, we tried to use the same approach to the processing of the EUREF network.

The main aim of our processing is to produce uniform weekly solutions for coordinates of selected EUREF stations. This processing is done in three steps:

1. *Computation of a daily free network (non-fiducial) solution.*

Orbits and EOP were fixed to IGS values. Optimal baseline configuration was chosen using combination of one of the strategies provided by Bernese with original method of iterating rejection of "bad" baselines using results of preprocessing and ambiguity resolution. Such a method allows to avoid manual station and baseline selection and prevents unnecessary automatic rejecting.

2. *Computation of a weekly free network solution.*

This processing has been done in several convergent iterations repeated independently for every week.

First, a day with maximum number of stations is chosen, and all other days are reduced to it via a Helmert transformation.

Then the average X, Y, Z are computed for each station for all available reduced day solutions. For each day an average is computed without this day. If this day deviates from that average for more than 3 corresponding sigma, then it is discarded. After such a cycle over all days the final average is computed without those outlier days.

After having obtained the average for all the stations, this set of average coordinates is taken as a new reference for the Helmert transformation (instead of the aforementioned day with maximum number of stations) and the entire iteration is repeated.

Seven parameter Helmert transformation is used at this and the next step of processing.

3. *Transformation of weekly free network solution to ITRF97.* Two possibilities were explored at this step: to use nine fiducial stations or to use all stations, which are present both in the ITRF definition and in our list. Our preliminary conclusion is that the second method provides more stable results.

This paper presents results of processing of 22 stations on 105 weeks interval and 11 stations on 42 weeks interval obtained at the moment.

3. Results and comparisons

Resulting coordinate time series are presented in Figures 1–3 in comparison with the series obtained from the official EUREF weekly solution produced by CODE/BKG. It is clear that only stations that are not used as fiducial in the EUREF solution can be compared here.

One can see that some stations showing seasonal terms in EUREF coordinates are free from that in non-fiducial solution. This coordinate time series is very similar to the EUREF

CB one. Unfortunately, detailed comparison is impossible for latter is not available in SINEX files.

We have still problems with some stations, especially with TROM and NYAL. Evidently, they will be replaced by TRO1 and NYA1 at the next stage of this work.

Table 1 shows the Allan variance and the amplitude of annual term in coordinate time series, also in comparison with the EUREF solution. Only stations with at least one year time span series are used for determination of seasonal term. One can see that random errors in weekly coordinates for both solutions are very close, whereas amplitude of annual terms in non-fiducial solution is less than in the EUREF one. It should be mentioned here that EUREF solution is combined one unlike IAA solution which is individual. Hence, for proper comparison of random errors precision of the EUREF coordinates should be multiplied by about 1.5 (since in average three solutions for each station is used in the EUREF combination). As to seasonal terms, one can suspect that the official EUREF solution is affected by systematic errors caused by insufficient stability of fiducial stations. As to non-fiducial coordinate time series, they are most likely free from seasonal errors.

To estimate possible loss of geophysical signal during computation of non-fiducial solution we plot in Figure 4 time series of Helmert transformation parameters obtained at the final stage of transformation of free network weekly solutions to ITRF97. Seasonal variations of transformation parameters are clearly visible and should be investigated in more details to clarify if these reflect real seasonal variations in orientation of subnetwork or it is result of seasonal errors in station coordinates.

It should be mentioned here that independent comparison of non-fiducial and EUREF CB series could give very useful data about long term stability of the EUREF (or another network) stations, which is important for selection of fiducial stations used by EUREF ACs.

4. Conclusion

Results of this paper allow to make the following conclusions:

1. Official EUREF solution distributed in SINEX format files contains, evidently, substantial systematic errors caused, most probably, by errors in modeling of coordinates of fiducial stations. Besides, this series is not continuous due to periodical change of reference coordinate system and set of fiducial stations. So, this solution is suitable for scientific researches only for experienced users possessed needed software. For this reason, not all interested parties can use the official EUREF solution.

2. Though "standard" fiducial strategy in combination with removing constraints procedure allows to obtain coordinate time series close to free-network solution, this procedure is more complicated because requires quite sophisticated software. Besides, such a solution can be affected by residual systematic errors introduced during "standard" processing strategy with selected fiducial stations.

3. Non-fiducial approach can provide stable continuous coordinate time series free from network distortion even for variable list of stations, providing adjusted network has sufficient size to use full seven parameter Helmert transformation. Comparatively simple software is needed for this method.

4. It would be very desirable to compute and distribute in SINEX files non-fiducial solution (or, at least, solution computed by EUREF CB) for whole EUREF network.

Investigations will be continued with longer and more uniform coordinate time series which also will be compared with series obtained with other space geodesy technique.

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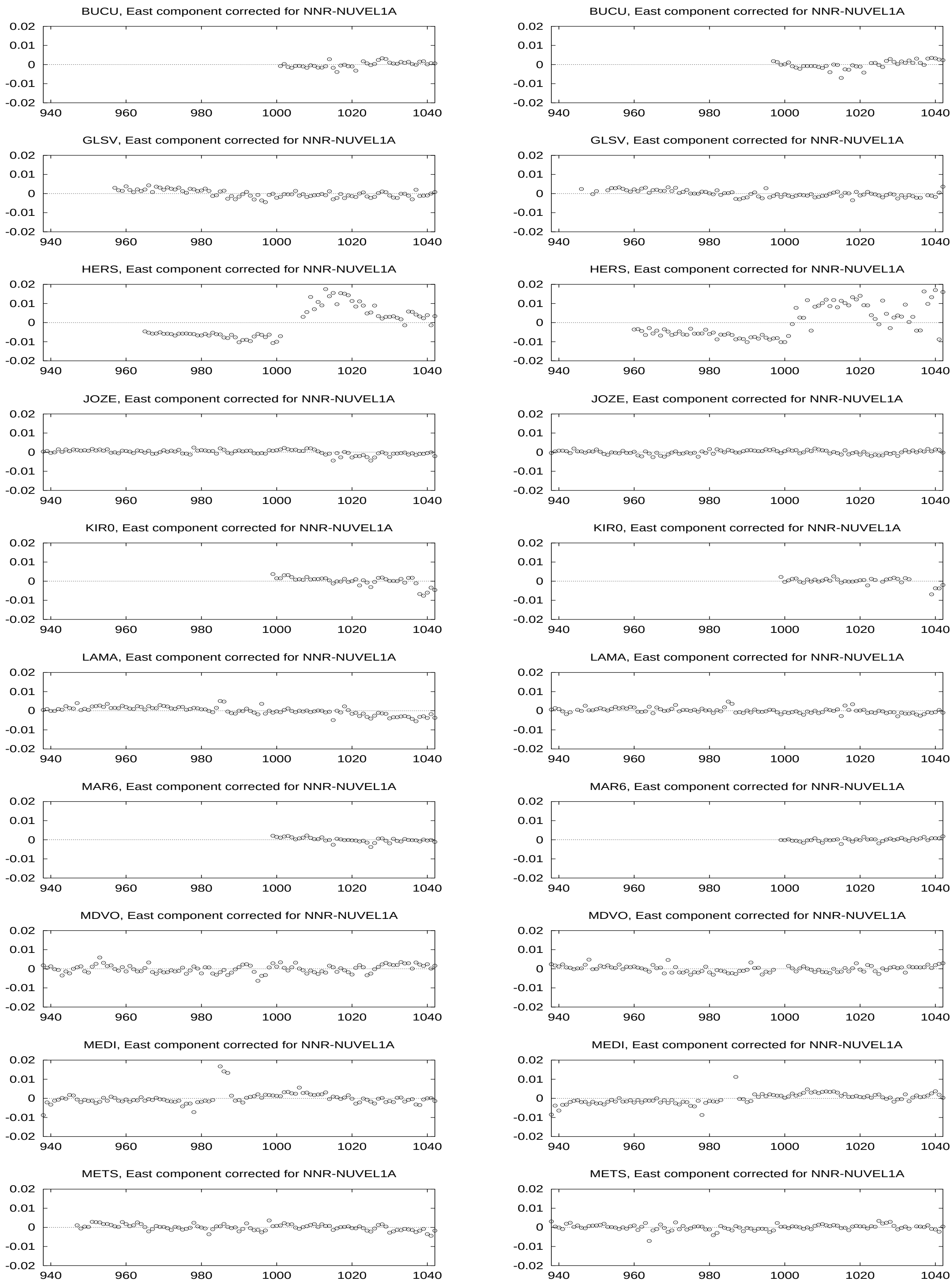

Fig. 1. East component of station displacement (EUREF solution on the left and IAA solution on the right).

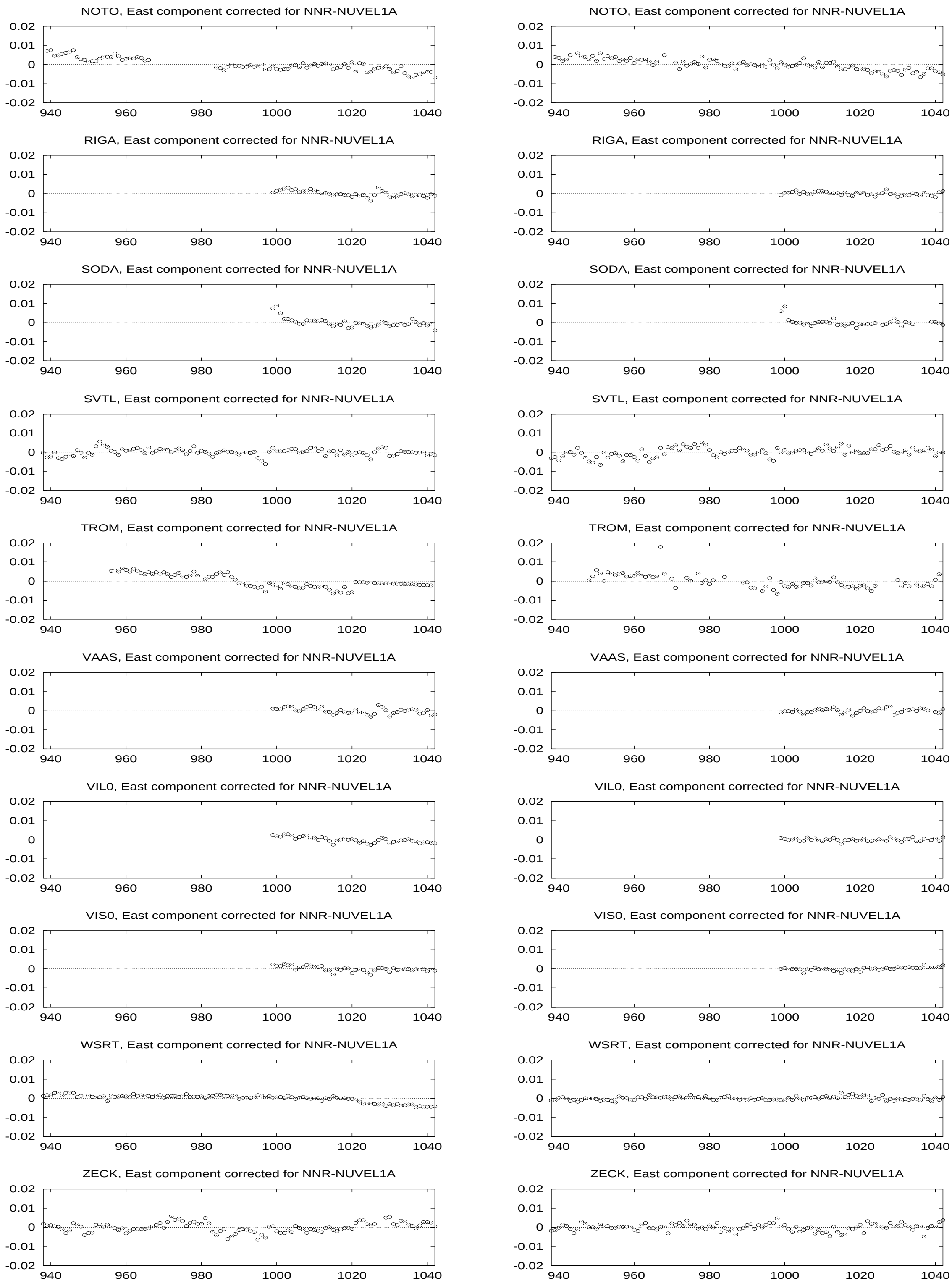

Fig. 1. (cont.) East component of station displacement (EUREF solution on the left and IAA solution on the right).

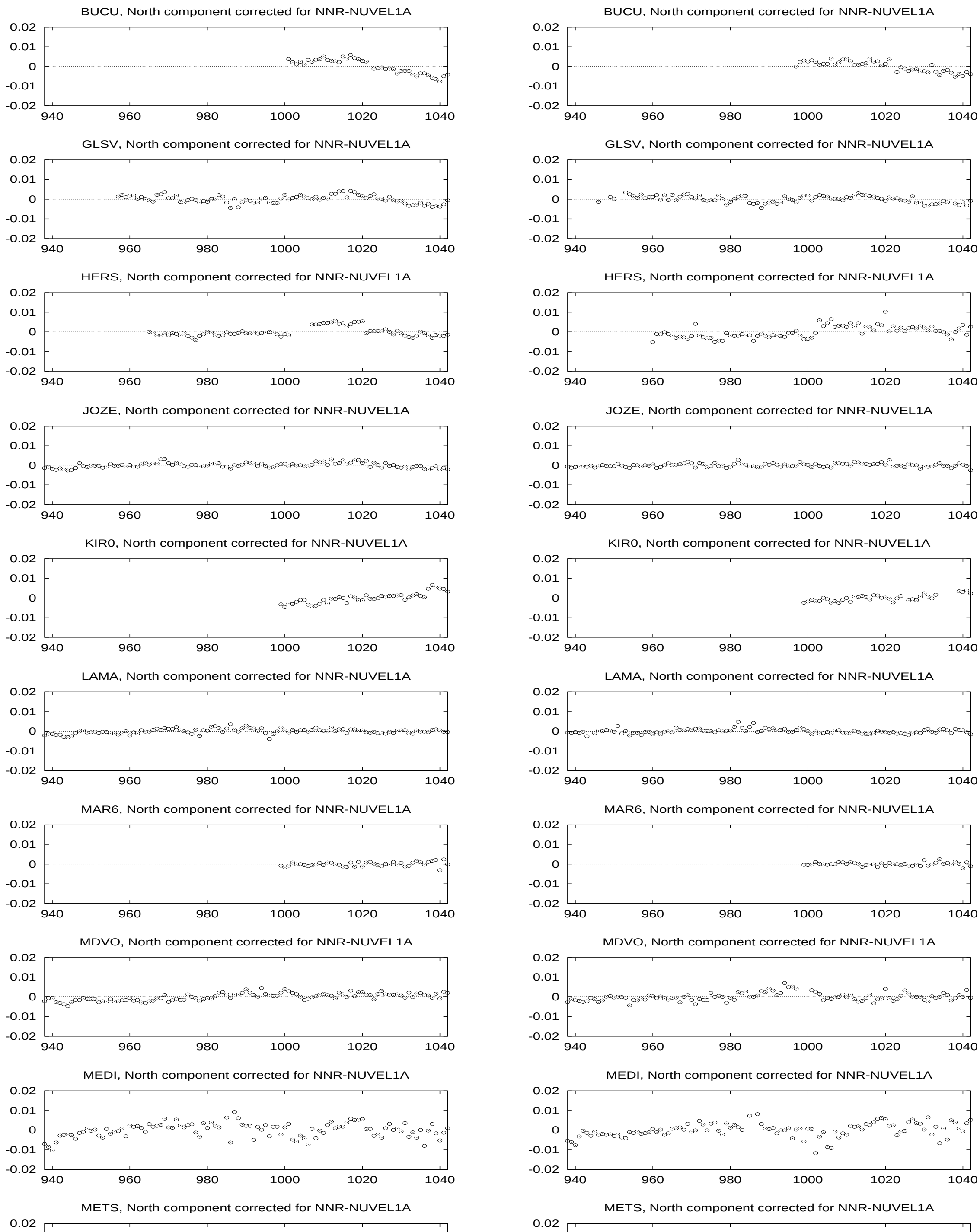

Fig. 2. North component of station displacement (EUREF solution on the left and IAA solution on the right).

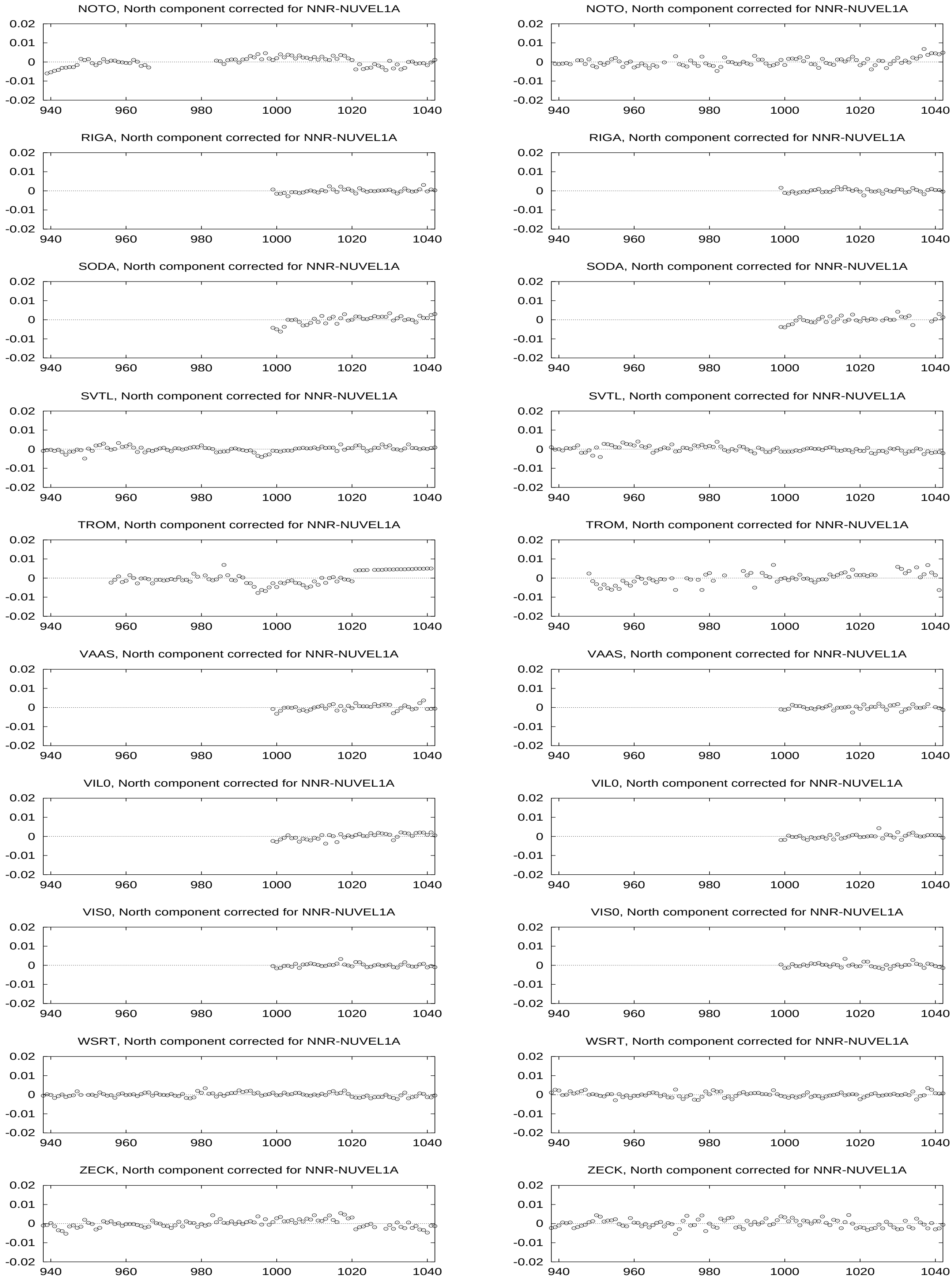

Fig. 2. (cont.) North component of station displacement (EUREF solution on the left and IAA solution on the right).

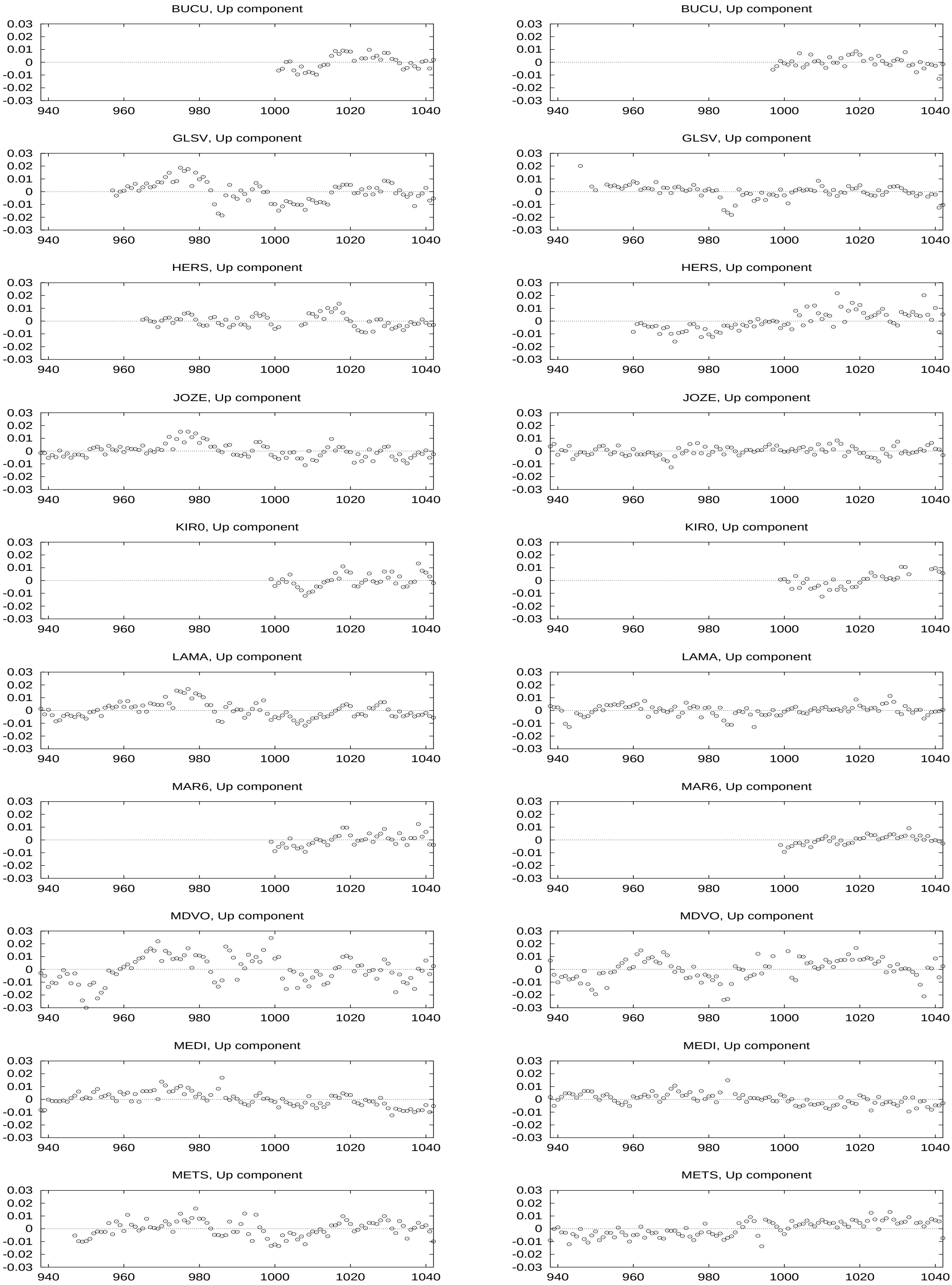

Fig. 3. Up component of station displacement (EUREF solution on the left and IAA solution on the right).

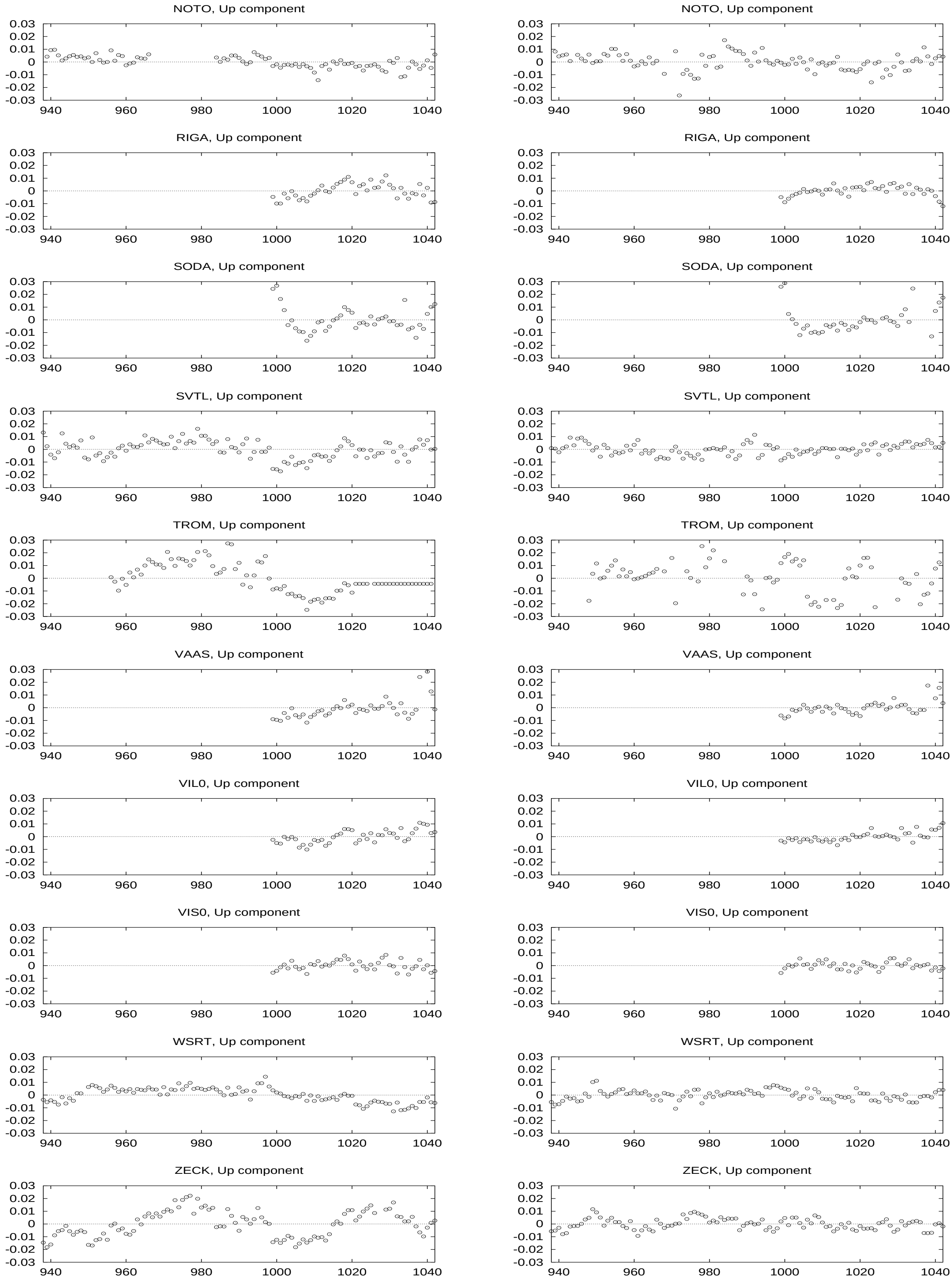

Fig. 3. (cont.) Up component of station displacement (EUREF solution on the left and IAA solution on the right).

Table 1. Allan variance and amplitude of annual term in coordinate time series, E, N, U.

Station	N	Weeks	Allan variance, mm		Annual term, mm	
			EUREF	IAA	EUREF	IAA
BUCU	45	997-1042	1.2 1.0 2.8	1.5 1.3 3.8	— — —	— — —
GLSV	92	946-1042	1.2 1.1 3.7	1.2 1.1 3.0	1.0 1.7 7.0	0.6 1.4 3.5
HERS	83	960-1042	2.2 1.1 2.8	4.4 1.9 5.0	6.8 2.4 2.3	5.5 2.0 3.5
JOZE	105	938-1042	0.9 0.8 3.1	0.9 0.8 2.9	0.7 0.9 3.7	0.9 0.4 1.6
KIR0	38	999-1042	1.2 1.2 3.2	1.3 1.0 3.5	— — —	— — —
LAMA	104	938-1042	1.2 0.9 2.9	1.1 0.9 3.0	0.4 0.3 5.6	0.4 0.7 2.8
MAR6	44	999-1042	0.8 1.2 3.5	0.8 0.9 2.1	— — —	— — —
MDVO	102	938-1042	1.5 1.1 5.6	1.4 1.3 5.1	0.3 0.5 6.6	0.6 1.0 6.4
MEDI	102	938-1042	1.8 2.4 2.7	1.7 2.6 2.8	1.9 1.9 3.3	1.8 2.2 1.7
METS	104	938-1042	1.1 1.8 4.0	1.3 1.9 3.5	2.2 2.6 4.9	0.3 1.6 0.9
NOTO	99	939-1042	1.2 1.3 3.0	1.4 1.5 4.7	1.1 3.0 2.2	0.8 0.9 4.1
RIGA	44	999-1042	0.9 1.0 3.7	0.9 0.9 2.7	— — —	— — —
SODA	39	999-1042	1.1 1.4 5.0	1.3 1.4 7.0	— — —	— — —
SVTL	105	938-1042	1.3 1.0 4.4	1.7 1.2 3.2	1.1 1.0 6.9	1.1 0.6 1.9
VAAS	43	999-1042	1.1 1.2 4.7	1.0 1.1 3.6	— — —	— — —
VIL0	44	999-1042	0.7 1.2 3.0	0.8 1.2 2.7	— — —	— — —
WSRT	105	938-1042	0.6 0.8 2.3	0.9 1.1 2.7	0.4 0.3 1.0	0.6 0.6 2.1
ZECK	105	938-1042	1.4 1.4 3.8	1.5 1.7 2.6	2.1 1.2 11.8	0.6 1.0 0.5
Mean			1.2 1.2 3.6	1.4 1.3 3.6	1.6 1.4 5.0	1.2 1.1 2.6

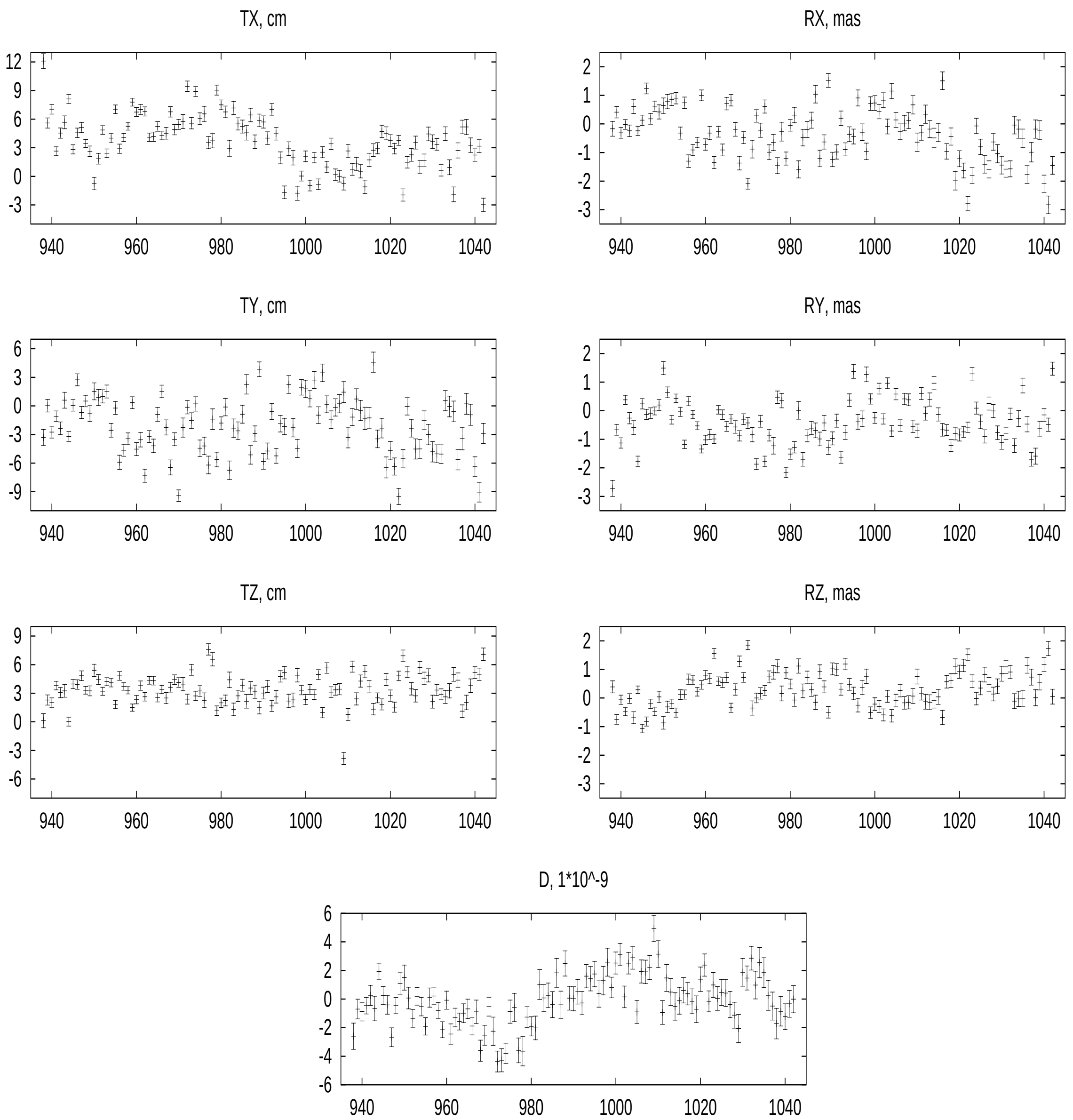

Fig. 4. Time series of transformation parameters between free weekly solutions and ITRF97.