Preliminary results of the complete EPN reprocessing computed by the MUT EPN local analysis centre

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Summary. – This paper concerns the reprocessing of the whole EPN network. The reprocessing ended in spring 2008 at Military University of Technology (MUT). The reprocessing was done in cooperation with FOMI Satellite Geodetic Observatory of Hungary (FOMI SGO). The paper includes the description of the whole process, data base sources, software and hardware characteristics and chosen reference frames and finally the comparison between time series of stations coordinates before and after the reprocessing. There are examples of the sites where reprocessing significantly improved the quality of the solutions and sites where no significant improvements were observed.

The authors attempted preliminary frequency analysis of daily solutions using multispectral characteristic and wavelet analysis. Graphic visualization of this method is presented in the final part of this paper.

INTRODUCTION

The reprocessing of GPS observations started from the global and regional permanent networks like IGS and EPN as well as local networks which are in the forefront of current GNSS analysis. In the past various reference frames were used and modeling capabilities provided inhomogeneous coordinate series. The introduction of the superior quality absolute models of GNSS satellite and antenna receiver made the full re-analysis a must.

In response to this need CAG MUT (Centre of Applied Geomatics, Military University of Technology) EPN Local Analysis Centre decided that FENIX supercomputer was capable of computing the complete re-analysis of the available EPN observations.

The analysis started in January 2008, lasted 2 months and produced the first, the most complete and homogeneous set of daily and weekly EPN solutions. Bernese 5.0 software was employed to compute the reprocessing. MUT and FOMI applied processing strategy approved and also used by all EPN LAC (Local Analysis Centre). We used reprocessed IGS orbit and EOP (Earth Orientation Parameters) products created by Potsdam Dresden Reprocessing group (Steigenberger et al., 2006).

ASSUMPTIONS

The coordinate time series analysis and interpretation of weekly and daily results were done in cooperation between MUT and FOMI SGO. Both MUT and FOMI SGO used CATREF software (Altamimi, et al 1994) to create the multi-year solution taking the offset and outlier information into account. Time and frequency analysis were performed using wavelets in order to detect exemplary station specific spectral characteristics.

The above mentioned FENIX cluster consists of 16 servers - HP Server rx1620, each equipped with two Intel Itanium 2 processors with 1.6GHz frequency (FSB 533

MHz). Every server has 4 GB operating store and also 36 GB SCSI disc. The maximum power of cluster processing is about 210 GFLOP. It works under control of 64-bites GNU/Linux operating system with 2.6. nucleus. The Debian GNU/Linux 3.1 Sarge was used as a distribution of GNU/Linux system. The 9TB hard disc storage is cooperating with the cluster.

Apart from operating system and compiler, new programmes were installed: Bernese GPS software 5.0 version, COAMPS 3.1, GAMIT/GLOBK 10.33, Femlab 3.0.which are fully exploiting capabilities of the 64-bites architecture. In order to have Bernese and cluster worked simultaneously, special scripts had to be written. The scripts allowed better and faster calculations, especially in case of many stations.

The evaluation of 24h observations from 54 stations, on the two-processor working unit (2xIA32) lasts 53 minutes, but the same process on FENIX cluster is only 9 minutes. In case of the whole EPN (more than 200 stations) it is about 37 minutes. The same task on the two-processor computer is about 5 hours. The flow chart shown in fig. 2 represents IGS regional and global data centers as well as EPN centers (fig. 2). They were the source of data for CAG to reprocess the whole network (217 stations) (fig. 1). Some stations with EPN statues called 'inactive' were eliminated (34 stations). Fig. 3 illustrates the number of stations which were involved (based on RINEX files) during the reprocessing period from 1995 to 2007. Starting from 1995 receiver and antenna terminology was standarized according to IGS/EPN conventions.

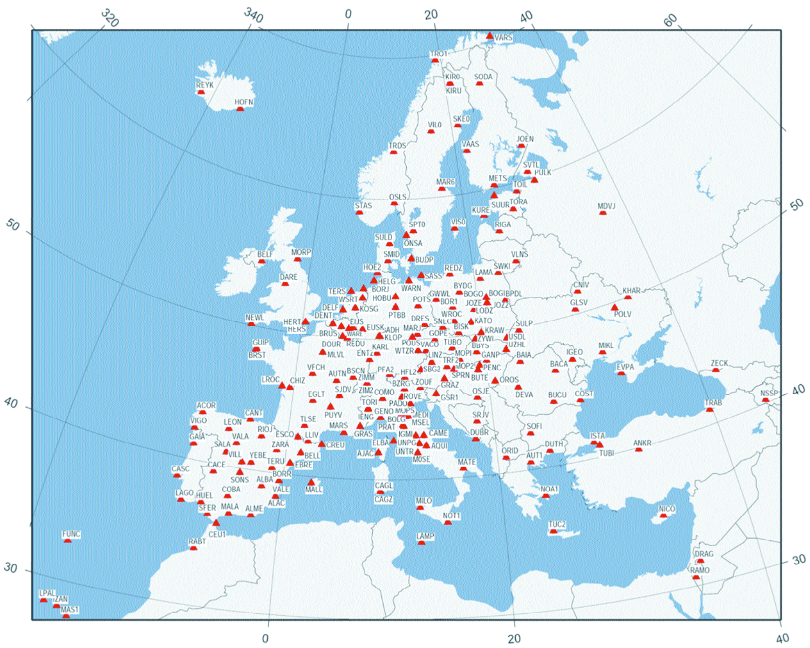
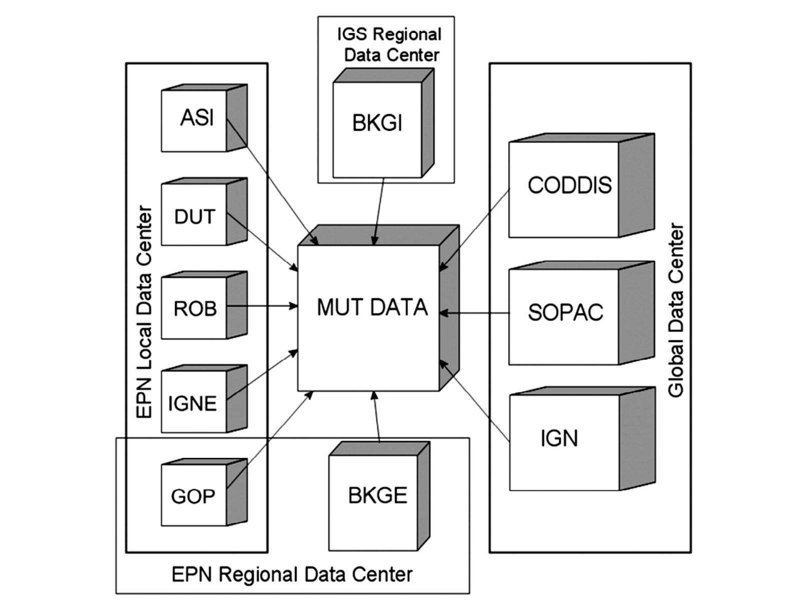


Fig. 1 – List of EPN stations reprocessed in CAG MUT.

EPN Local Data Centers:
Agenzia Spaziale Italiana (ASI)
Delft University of Technology (DUT)
Royal Observatory of Belgium (ROB)
Institut Géographique National (IGNE)
The Geodetic Observatory Pency (GOP)
EPN Regional Data Centre:
Bundesamt für Kartographie und Geodäsie (BKGE)
Austrian Academy of Sciences – Space Research Institute (OLG)
IGS Regional Data Centres:
Bundesamt für Kartographie und Geodäsie (BKGI)
IGS Global Data Centres:
Institut Géographique National (IGN)
Crustal Dynamics Data Information System (CDDIS)
Scripps Orbit and Permanent Array Center (SOPAC)



Data flow EPN Reprocessing

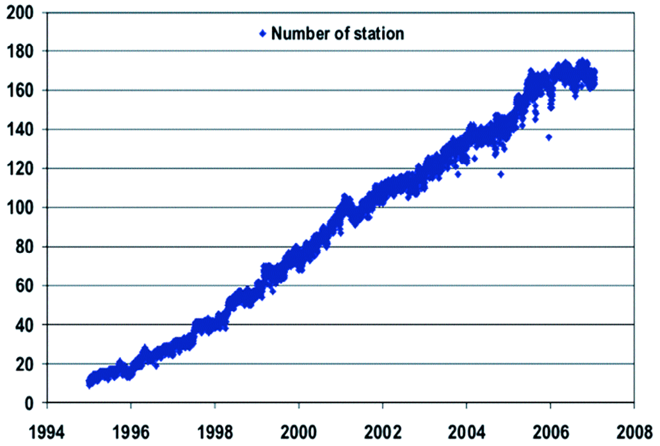


Fig. 3 – EPN reprocessing. Number of stations.

MEASUREMENT MODELS

Calculation of archive phase and code observations were done using Bernese 5.0 software. Slight changes in Bernese software were made to adjust to 64-bite environment of Fenix cluster [Hugentobler et al., 2005]. New satellite ephemeris which are the outcome of the first reprocessing of IGS network were used. Fixed MDA (Munich/Dresden reprocessing orbits version A) orbits and EOP were applied [Steigenberger, et al., 2006].

Phase only observations were analyzed whereas code observations were used to estimate clock corrections. All measures were done according to EPN resolutions (3 degree mask and weighting observations using $\cos^2 z$ functions where z is the zenith angle).

In preprocessing the full sampling rate of 30 s was used. Final sampling rate was 3 minutes (180s).

Dry part of tropospheric delay was modeled according to Saastamoinen model (a priori values were indicated from standard atmosphere and mapped with Dry Niell mapping function) [Niell, 1996]. For the wet part continuous piecewise-linear troposphere parameters were estimated in 1-hour intervals without any a priori model using Wet Niell mapping function. Loose relative and absolute constrains of 5.0 m were applied. In addition continuous piecewise-linear east-west and north-south troposphere gradients with parameter interval of 24 hours were estimated with no a priori constrains [Hugentobler et al., 2005].

First degree ionospheric refraction is reduced by L3 linear combination (iono-free) for double differences phase observations. Second and higher degree components were not modeled. The CODE global ionosphere model (GIM) was used to solve phase ambiguities [Schaer, 1999]. This model helped to increase the number of resolved ambiguities in the QIF (Quasi-Ionosphere-Free) [Mervart, 1995], L5/L3 and L1/L2 ambiguity resolution strategies. For the final adjustment, ionosphere was cancelled out due to ionosphere-free linear combination.

In ionosphere CODE model all free electrons are gathered in infinitesimal single layer on 450 km height. Distribution of free electrons is parametrized by series of harmonic functions of 15th degree and order by every 2 hours. Implementation of ionospheric models reduced the influence of ionospheric storms which appeared with significant intensity during maximum solar activity in year 2000.

In fig. 5 red color indicates huge ionospheric storms. As a result calculated ambiguity diminish (about 20%). Magnetic storm period was the reason for removing daily observations from reprocessing. It concerns stations in the northern area of Europe.

PREPROCESSING

In most cases, cycle slips are fixed looking simultaneously at different linear combinations of L1 and L2. If a cycle slip cannot be fixed reliably, then bad data points are removed or new ambiguities are set up. Data files covering less than 12 hours of data are automatically rejected. Posteriori normalized residuals of the observations are checked for outliers, too. These observations are marked for the final parameter adjustment. Absolute antenna phase centre corrections based on IGS05 model considering antenna radome codes were used during calculations. If antenna/radome pair has no available calibrations, the corresponding values for the radome code «NONE» were used. Satellite antenna absolute phase centre corrections were used based on IGS05 model.

QIF strategy was used to resolve ambiguities in a baseline processing mode using CODE global ionosphere model (for baselines up to 2000 km length). For baseline lengths shorter than 100 km, L5/L3 approach was followed. For baselines shorter than 10 km, L1/L2 approach was used. Fig. 4 shows resolved ambiguities acquired according to presented method. Daily RINEX observation files containing less than 50 percent of possible observation epochs were ignored. The two-step preprocessing method eliminated outliers (rejection criterion of L3 outliers: 0.0020 m; normalized L1 zero-difference zenith value).

In addition the following models were customized:

– planetary ephemeris DE405;
– ocean tides OT_CSRC;
– earth geopotential JGM3;
– nutation IAU2000;
– subdaily pole IERS2000;
– tidal displacements (solid tides according to the IERS 1996/2000 standards);
– ocean loading FES2004.

The datum of the daily and weekly solutions were defined by the Minimum Constraint (MC) approach applied for three Helmert translation parameters. The list of stations defining the datum included the following 14 IGS core stations: BOR1, BRUS, GRAS, HOFN, JOZE, METS, NYA1,ONSA, POLV, POTS, REYK, WSRT, WTZR, ZIMM [www.epncb.oma.be].

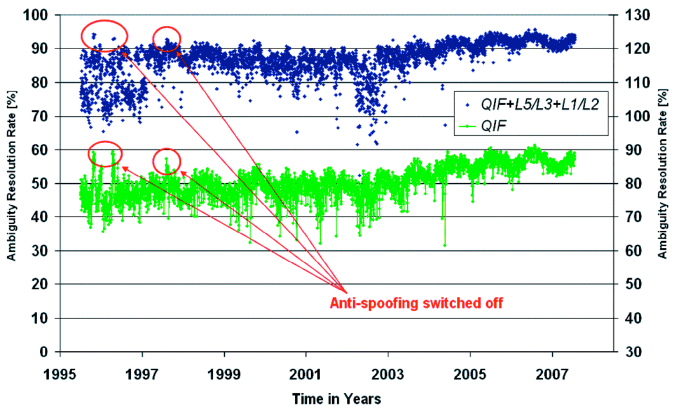


Fig. 4 – Ambiguity resolution rate of 1-day solutions. Blue - cumulative ambiguity resolution QIF+L5/L3+L1/L2.

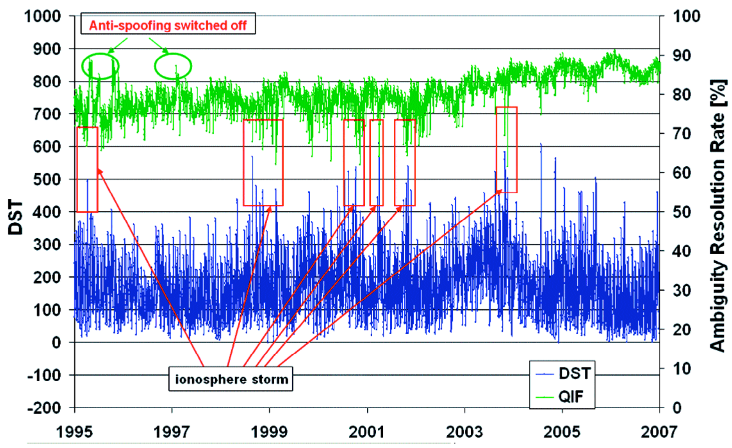


Fig. 5 – Amount of calculated ambiguity processed by QIF method on the background of DST variation index (the DST index is an index of magnetic activity derived from a network of near-equatorial geomagnetic observatories). Circled green colour indicates period (1900s) when Selective Availability and Anty-Spoofing system was inactive.

PROCESSING SCHEME

The reprocessing was developed according to the newest standards used by EPN analysis centres. All calculations were based on RINEX format standarized according to information received from IGS and EPN. Fig. 6 is a general scheme adopted in MUT to compute the calculations. EOP and MDA ephemeris in SP3 format from the first reprocessing of IGS elaborated by Steigenberger [Steigenberger, et al., 2006] were used.

Due to large number of reprocessed stations, EPN network was fractioned into subnetworks. Subnetworks were calculated on cluster computer as a parallel process. Division into subnetworks was done by MKCLUS (Make Clusters) programme. The division was automatic and included 50 to 60 stations. Minimum number of observations per satellite at each epoch value equal 3 was introduced into the MKCLUS programme. In the final process the subnetworks were joined in a group of reference stations. For each subnetwork normal equation in Bernese format was generated. They were joined using ADDNEQ2 programme. Daily solutions were generated in SINEX format. At the same time station coordinates and tropospheric parameters (Troposphere Total Zenith Delay) were determined.

Daily and weekly time series of analyzed stations were obtained. Solutions were archived on CAG servers. Fig. 7 shows an example of daily solutions of detrended (without constant and linear trend) ITRF 2005 cartesian coordinates before and after the reprocessing. The data concerns the same testing period.

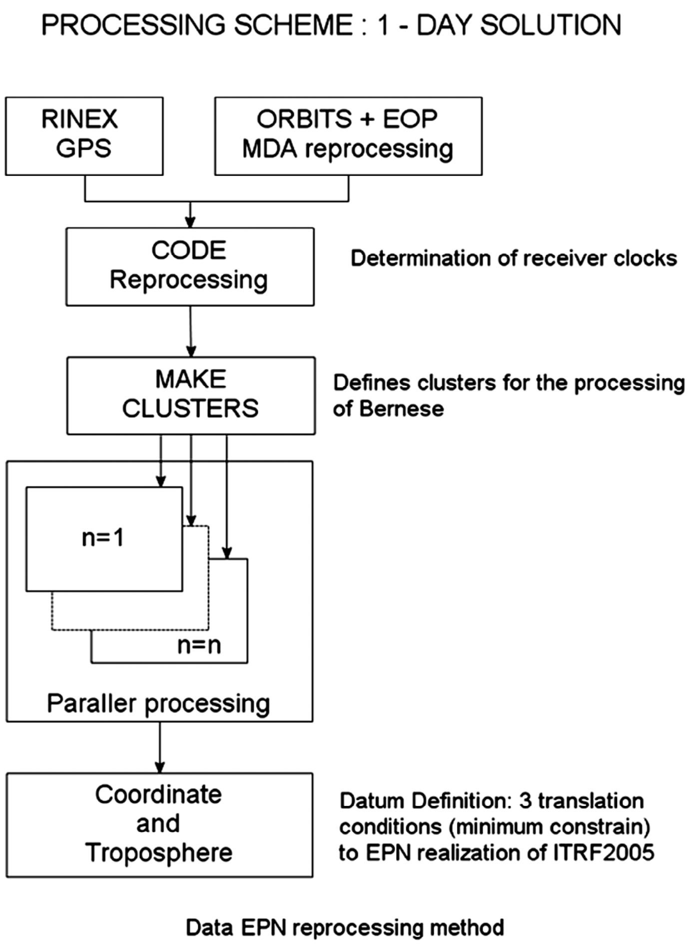


Fig. 6 – Information flow chart.

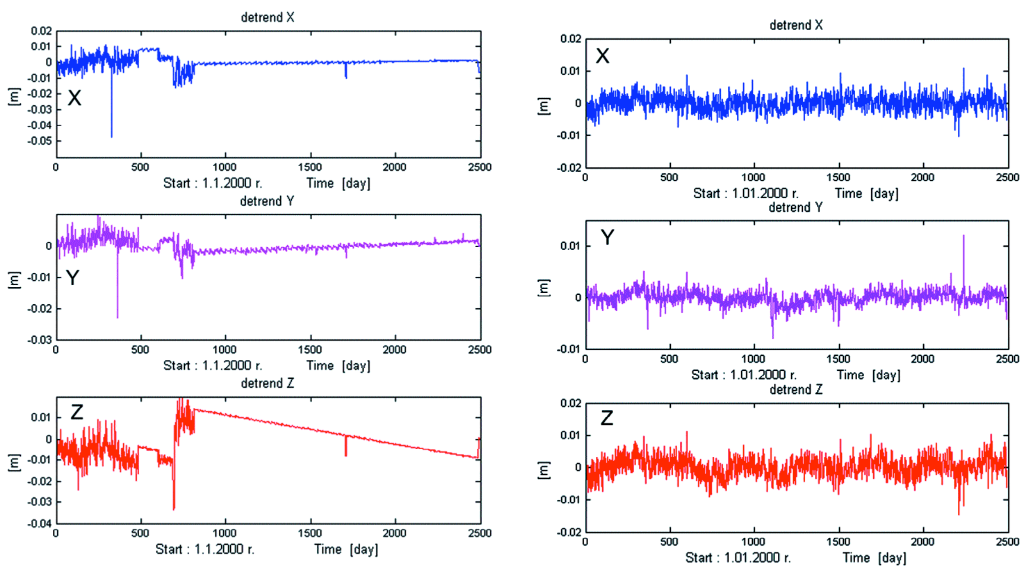


Fig. 7 – The coordinate daily time series of BOR1 (ITRF2005).

Reprocessing evidently improved the quality of the results on most of the EPN stations. Since trend and constant value were eliminated the dispersion and mean error decreased.

However there are exceptions where reprocessing did not bring any improvements in calculations. Despite reprocessing process very few stations have jumps and quite huge oscillation. HOFN (Hoefn, Iceland) station (fig. 8) is in the minority however.

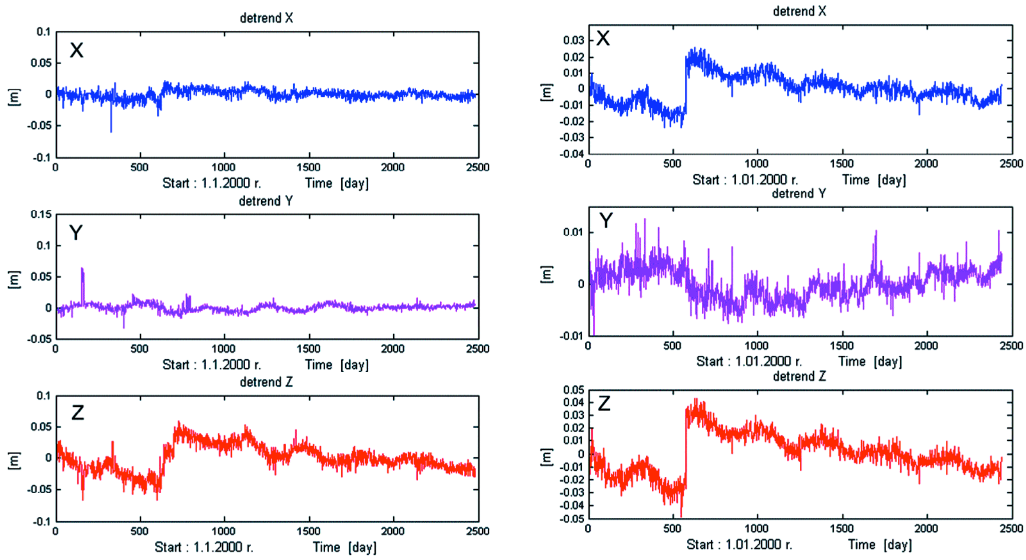


Fig. 8 – The coordinate daily time series of HOFN (ITRF2005).

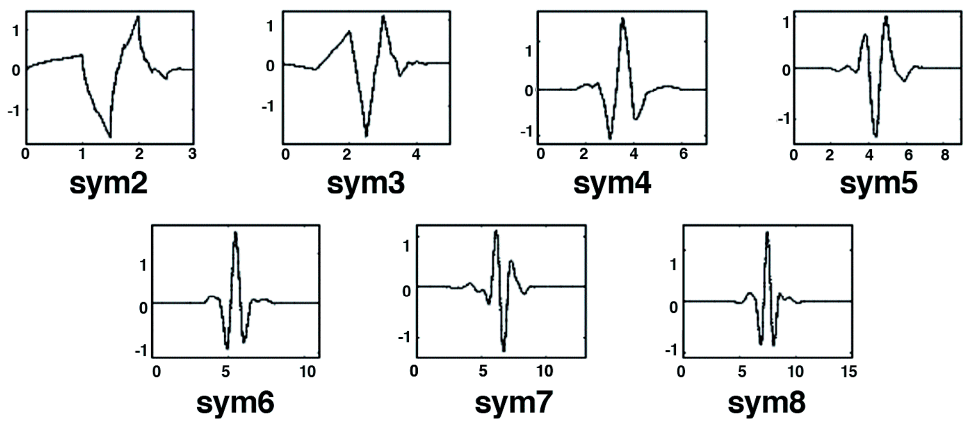


Fig. 9 – Wavelet symlet family.

Based on daily reprocessing data we tried to detect station specific spectral characteristics in time series. Known tools to analyze frequency usually concern Fourier transforms. To target the frequency of time series we chose the wavelet analysis tool. Wavelet based techniques gave the possibility of interpreting time and frequency at the same time. More on wavelet overview can be found on the following web pages: http://www.amara.com/current/wavelet.htmlhttp://cas.ensmp.fr/~chaplais/wavetour_presentation/Wavetour_presentation_US.html.

The Wavelet Toolbox is a collection of functions built on the MATLAB® Technical Computing Environment. It provides tools for the analysis and synthesis of signals and images, and tools for statistical applications as well.

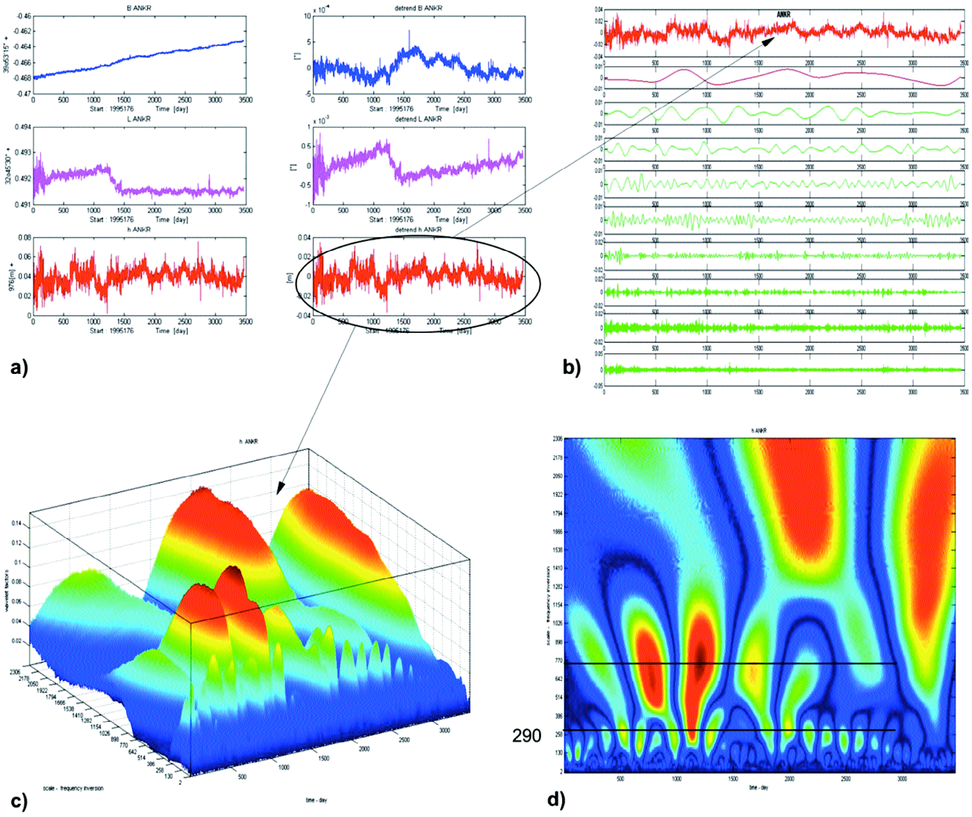


Fig. 10 – The diagrams show exemplary ANKR station and its BLH series together with the results of H wavelet analysis and signal decomposition.

After several attempts to match wave type we decided to use symlet8. The symlets are nearly symmetrical wavelets proposed by Daubechies as modifications to the db (Matlab's shortcut) family. The best effects were obtained through 9th and

10th degree of decomposition. Visualization presented here shows wavelet analyses of one of the stations. This example proves that the frequencies actually exist in time series. As an example the time series of ANKR (Ankara, Turkey) (fig. 10a), especially up component, was analyzed using multispectral wavelets (fig. 10b) and continuous wavelet analysis (fig. 10c). Three-dimensional visualization (fig. 10c) was presented using two-dimensional object (fig. 10d) to characterize a wavelet method which can find characteristic frequencies. In order to conduct frequency analysis correctly, we drew a horizontal line through local extremes of continuous wavelet transform (fig.10 c, d). The way of obtaining the frequency is to read the value from the vertical scale (fig. 11) and to move this value to the scaling curve. The shape and all the parameters of scaling curve depend on a type of used wavelet. In the figure 10d we can see horizontal line which indicates frequency corresponding to the most energetic oscillation discovered in time series.

Further precise analyses of frequency source detection and possible filtration have already started.

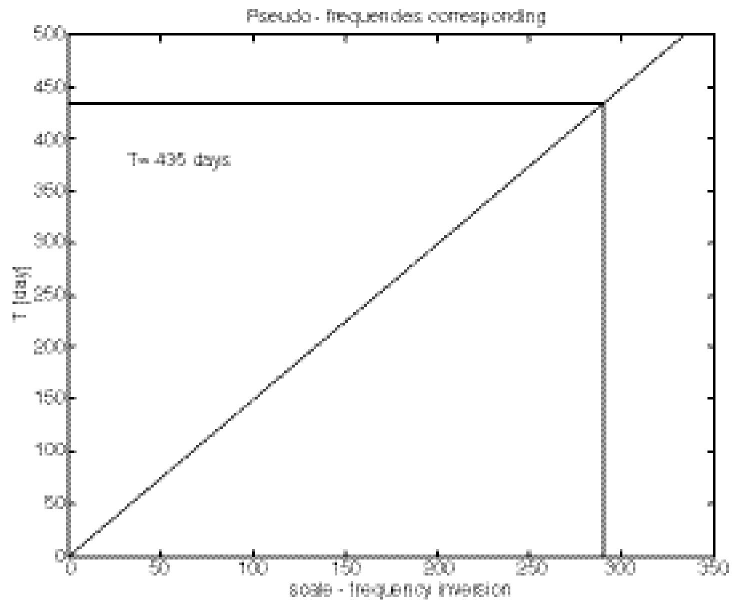


Fig. 11 – Scaling curve.

RESULTS

The tests revealed the superiority of the reprocessing over the original EPN series. All quality measures improved significantly. The computations proved that the wavelet analysis may play an important role in the future analyses and interpretation of EPN coordinate time series. We learned from the computations the following facts: available EPN database is not fully conforming with the current official EPN products. The database must be harmonized and checked. Final reprocessing should be executed based on standard observations in RINEX format, corresponding with the official names of EPN products (EPN SINEX file). RINEX format was modified and changed a few times since 1995. The changes were made in coding system of receivers and antennas in IGS as well. Until the start of the official re-processing all EPN antennas (current and historical) should have real absolute PCV model available. The final reprocessing should be done following the IGS strategy in terms of the troposphere and ionosphere parameter estimation.

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