VLBI ANALYSIS CENTER AT THE MAO OF THE NAS OF UKRAINE

S. Bolotin

Main Astronomical Observatory, NAS of Ukraine
27 Akademika Zabolotnoho St., 03680 Kyiv, Ukraine
e-mail: bolotin@mao.kiev.ua

The current state and activities of the VLBI Data Analysis Center at the Main Astronomical Observatory, Kyiv is described. The new generation of the VLBI data analyzing "SteelBreeze" software is announced.

INTRODUCTION

The VLBI Data Analysis Center at the Main Astronomical Observatory (AC MAO) was established in 1995. The primary goal of the AC MAO is the software developing and the data analysing of the VLBI observations for IERS and IVS submissions. The VLBI data processing has a more than 10 years history at the Main Astronomical Observatory:

- 1990: "KIEV-GEODYNAMICS-R" software was developed by Kur'yanova, Medvedsky and Yatskiv [7]. It was capable to estimate the Earth Orientation Parameters (EOP), coordinates of stations and radio sources by processing series of selected VLBI experiments; the calculations were being conducted on OS 360/370 type computer.
- 1992: Development of the *SteelBreeze ver.*1 software was initiated. This software was fully independent from previous one. Originally, it was created for MS DOS operating system, and then was migrated to Windows 3.1. The software was written on Pascal programming language.
- 1994: Direct estimation of the diurnal and semidiurnal polar motion was made from the CONT'94 VLBI observations (see [2]). The polar coordinates (dX_p and dY_p) and $d(UT1-UTC)$ have been estimated on the 14-days interval with about 5 min resolution.
- 1995: First submission of the "GAOUA R" solution to IERS was made. RSC, SSC and EOP estimations based on 177707 group delays were obtained in this solution.
- 1998: Start of development of the *SteelBreeze ver.*2 software. The new version of the software reflects major changes in technique of developing (*e.g.*, *SteelBreeze ver.*2 written on the $C++$ language, running on Linux, Solaris, FreeBSD and other operating systems, uses Qt widget library for graphics user interface).
- 1999: AC MAO has started to act as the IVS Analysis Center.
- 2000: The source tree of the *SteelBreeze ver.*2 software was realized for public access under the GNU public license.

HARDWARE EQUIPMENT

Data analysis and software developing are executing on an Intel Pentium II 400MHz based computer with 192M RAM. It has a SCSI interface connected to 3 hard disk drives with 9, 4 and 6 Gb capacity (it is allowable up to 15 units). The Main Astronomical Observatory has a 33.6 Kb Internet connection. The computer of the AC MAO is operated by the Linux/GNU system. Despite of so humble hardware equipment, it is possible to make data processing of almost all available VLBI observations. The main limitation in hardware is a narrow bandwidth of an Internet connection, which makes impossible for the MAO to act as an Operation Center of IVS.

STEELBREEZE VER.1 SOFTWARE

SteelBreeze software was developed as a tool for geodetic VLBI data analysis. It uses Least Square estimation of various geodynamical parameters with the Square Root Information Filter (SRIF) algorithm [1]. The SRIF uses the Householder's transformation for matrix triangularization which makes it smart and insensitive for computer roundoff. The SRIF makes also possible to introduce a stochastic model for parameter estimation. *SteelBreeze* was written originally on Pascal programming language with Object Oriented Design.

The software imports the geodetic VLBI observations in different formats (NGS cards, MarkIII databases, VDB binaries). It stores the observations in its own inner binary format as well as catalogues of radio sources, stations of observations, EOP, ephemerides, and some other data sets.

It analyses the VLBI data (time delay) of single and multiple set of sessions. The time delay is modeled according to the IERS Conventions 1996, plus additional models (tectonic plate motions, nutation, wet and hydrostatic zenith delay, mapping function, *etc*). The software makes estimations of the following parameters: Earth orientation parameters, coordinates and velocities of selected set of stations, coordinates of selected set of radio sources, Love numbers, clock function and wet zenith delay.

SRIF algorithm allows to make estimations of unbiased parameters as well as stochastic ones. In the software each estimated parameter can be considered as following:

- global parameter: unbiased estimation of this parameter for all set of selected sessions (typically useful for source and station coordinates estimating, *etc.*);
- local parameter: unbiased estimation of this parameter at each session, the estimates of different sessions are considered to be independent (*e.g.*, EOP);
- local parameter with time propagation: unbiased estimation of this parameter at each session, the estimates of adjacend sessions are dependent according to a given rule;
- stochastic parameter: a behavior of estimated parameter is assumed varying from time to time with a given rule (it is implemented random walk process in the software), this type is useful for estimating of clock parameters and wet zenith delays;
- stochastic parameter with time propagation: the same as above, but adjacend estimations for different sessions are tied with the same rule.

As an example of VLBI data processing using *SteelBreeze* software we present the GAOUA 2000 R 01 solution. The group delay data were acquired on different VLBI networks since January 6, 1998 till December 28, 1999. In total 288583 dual frequency Mark III group delays from 176 sessions were processed.

The initial values of station coordinates were taken from ITRF94. The initial values of station velocities were modeled according to plate tectonic motion NNR-NUVEL1A model. The origin of the obtained realization of terrestrial reference frame was linked to ITRF94 by requiring that the vector sum of the adjusted station coordinates be equal to the corresponding sum for a set of 15 stations. The solution SSC(GAOUA) 00 R 01 consists of the set of coordinates for 26 stations.

The initial values of the radio sources coordinates were taken from RSC(WGRF) 95 R 01 solution. The right ascension origin of the obtained realization of celestial reference frame was defined by setting the sum of right ascensions of adjusted sources equal to the corresponding sum of the sources from RSC(WGRF) 95 R 01 solution for a set of 60 radio sources. The RSC(GAOUA) 00 R 01 solution consists of the set of coordinates of 191 radio sources.

The IAU 1980 Nutation model and initial values of EOP(IERS) 97 C 04 were applied. The polar motion and UT1 were corrected for diurnal and semidiurnal tidal variations according to Herring and Dong [4].

The orientation between terrestrial and celestial reference frames was defined by EOP from EOP(IERS) 97 C 04 solution for the reference date December 28, 1999.

Tropospheric refraction in the local zenith direction caused by hydrostatic and water vapor components of the neutral atmosphere was modeled according to Saastamoinen [6]. The zenith delays have been mapped to line of sight elevations with the MTT mapping function of Herring [3] for both hydrostatic and wet components.

Calibration data collected at each observing site were applied to correct for variations in the electrical lengths of the cables between the radio receivers and the data acquision systems.

The wet zenith delay and clock offset were estimated as stochastic processes and were modeled as random walk with following magnitudes of power spectral density of ruled white noise: for clock offset 20^2 ps^2/hour, and for wet component of tropospheric delay 1.0 cm^2/hour.

The weighted rms post-fit residuals of this solution was 38.4 ps.

The second example of data processing is focused on estimating the polar coordinates and the Earth rotation with a high time resolution. For this purpose we processed the observations of the NASA-R&D network during the period of January 11–26, 1994. These observations were carried out under the terms of the extensive VLBI/GPS campaign, when VLBI stations made nearly continuous series of observations.

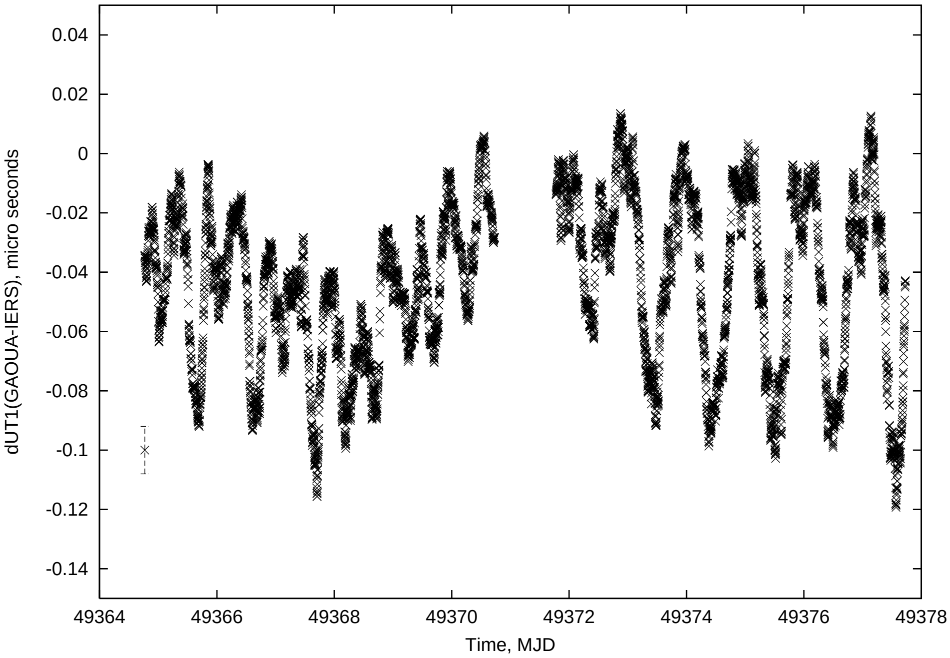

Figure 1: Estimated variations of the Earth rotation, $d(UT1 - UTC)$

The procedure of data analyzing was the same as for the previous example with the exception: coordinates of sources and stations were fixed, the wet zenith delay and the clock offset were estimated as stochastic parameters, polar motion and Earth rotation were estimated as stochastic parameters with time propagation to ensure continuity in their behavior. The magnitudes of power spectral density of ruled white noise of estimated parameters were assumed to: for clock model: 18^2 ps^2/hour; for wet component of tropospheric delay: 1.0 cm^2/hour; for $d(UT1 - UTC)$: 0.012^2 mts^2/hour; for dX and dY: 0.16^2 mas^2/hour.

This solution is based on the 27975 group delays. The 6279 estimations of the polar motion and the Earth rotation were obtained. The weighted rms post-fit residuals of this solution were equal to 10.2 ps. The estimated values of the Earth rotation variations are shown in Figure 1. The comparison of these estimations and Herring and Dong model is presented in Figure 2.

STEELBREEZE VER.2 SOFTWARE

The *SteelBreeze ver.1* software has had a set of limitations: it was written on the non-portable programming language, its design does not allow to extend it for analyzing additional geodynamical techniques, there are inner limitations in capacities of databases, which may cause to fail processing sessions with large set of observations (more then 15535). Due to these reasons in 1998 the developing of the *SteelBreeze ver.1* software was stopped and the new generation of the software was created. The new *SteelBreeze ver.2* software inherits all algorithms from previous version and expands them to overcome the limitations. However, there are some changes.

In new version the routine of data processing is carried out for selected time interval and does not depend on intervals of sessions; it makes possible to process sessions for overlapped time intervals. The algorithms of database manipulation are improved. New type of estimated parameters was added: "arc"; a parameter of this type is determined on selected time interval and does not depend on boundaries of a session. The graphic user interface is improved. A screenshot of the *SteelBreeze ver.2* software is shown in Figure 3.

The difference between version 1 and 2 of *SteelBreeze* software lies mostly in software developing technique. The *SteelBreeze ver.2* software is written on *C++*. It is executing on computers with different operating systems (Linux, FreeBSD, Solaris, *etc.*) and architecture (Intel, SPARCstation). It uses Qt user interface library. It is distributed under the GNU public license and its sources are available on the following URL:

http://sourceforge.net/projects/steelbreeze

for public access.

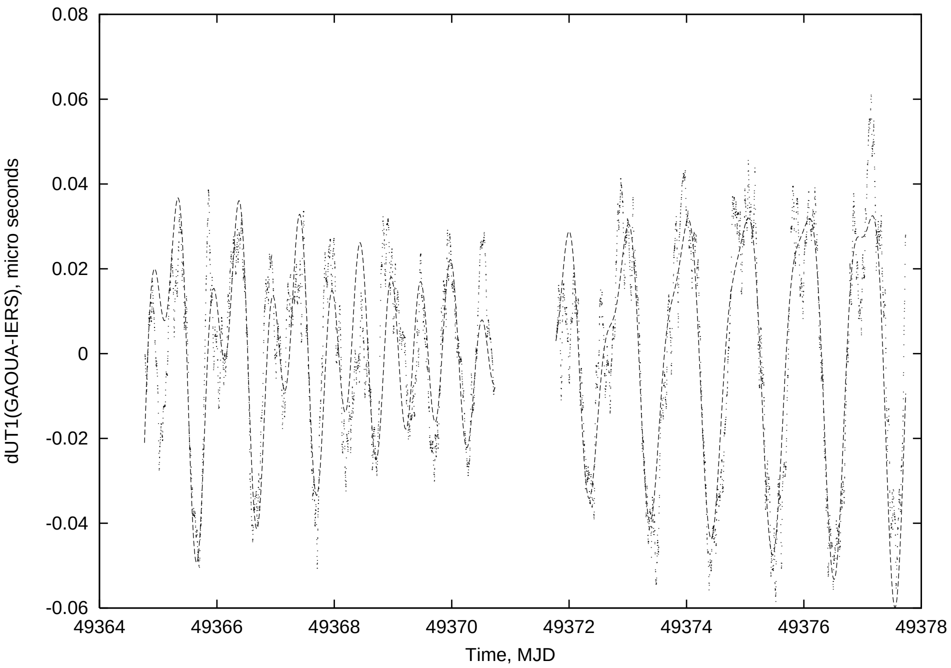

Figure 2: Subdaily variations in $d(UT1 - UTC)$. The dots are the estimated values after elimination of long period variations. The dotted line is the variations in $d(UT1 - UTC)$ according to Herring and Dong, 1993

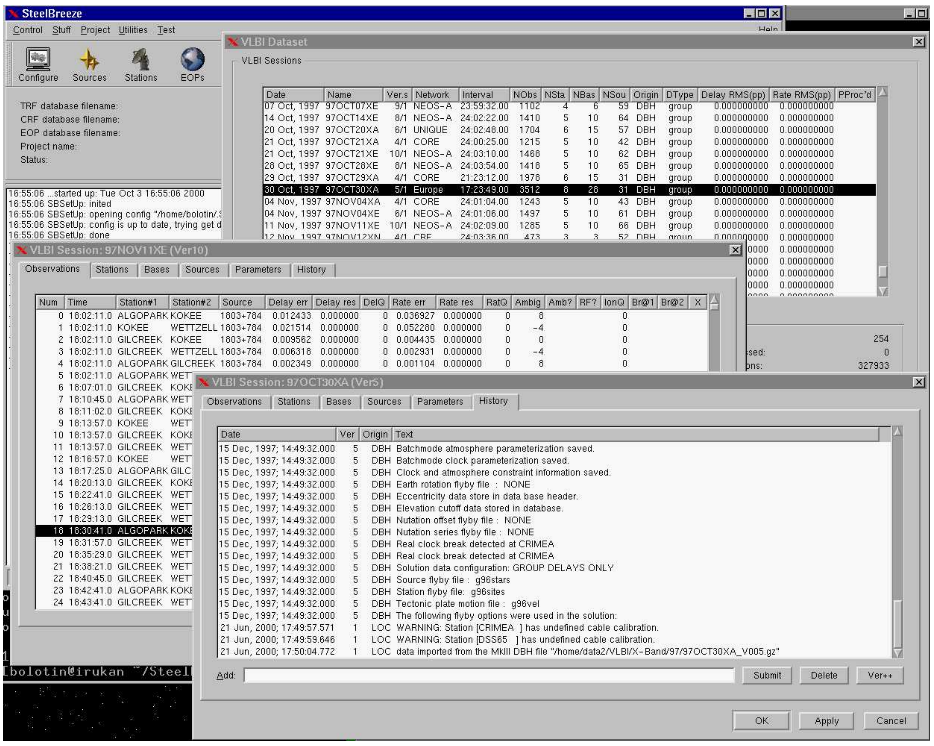

Figure 3: The screenshot of the *SteelBreeze ver.2* software

REFERENCES

[1] *Biermann G. J.* Factorization Methods for Discrete Sequential Estimation // Math. Sci. and Eng. Ser.–1977.–**128**.

[2] *Bolotin S.* Hight frequency variations of EOP from extensive VLBI operations in January 1994 // Proc. 2nd EVN/JIVE Symp.–1995.–P. 13–18.

[3] *Herring T. A.* // Proc. Symposium on Refraction of Transatmospheric Signals in Geodesy / Eds J. C. De Munch, T. A. Th. Spoelstra.–Netherland Geodetic Commision, Delft, Netherlands, Publications on Geodesy, 1992.–N 36.–P. 157–164.

[4] *Herring T. A. and Dong D.* Measurement of diurnal and semi-diurnal rotational variations and tidal parameters of Earth // J. Geophys. Res.–1994.–**99**.–P. 18051–18071.

[5] International Earth Rotation Service, IERS Conventions / Ed. D. D. McCarthy.–Paris, France, 1996.

[6] *Saastamoinen J.* Atmospheric Correction for the Troposphere and Stratosphere in Radio Ranging of Satellites // The Use of Artificial Satellite for Geodesy: Geophys. Monogr. Ser. / Eds S. W. Henriksen, *et al.*–AGU, Washington, D.C., 1972.–**15**.–P. 247–251.

[7] *Yatskiv Ya. S., Kur'yanova A. N., Medvedsky M. M.* Program Complex "Kiev-GR1" for Reduction of the VLBI Observations, Kiev, 1991.–preprint ITF-91-37R.