PROJECT: GLOBAL ANALYSIS OF 1979-2004 VLBI DATA

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ABSTRACT. VLBI observations for the last 25 years will be used for new revision of the International Celestial Reference Frame (ICRF), the International Terrestrial Reference Frame (ITRF) and the IERS Earth's Orientation Parameters (EOP) with the help of a new software QUASAR (Quantitative Analysis and Series Adjustment in Radioastrometry). The package QUASAR allows to compute the residuals $(O - C)$ according to IERS Conventions (2003) and to analyze their by single-/multi-series or global adjustment using parametric, stochastic and dynamical models of data.

1. GENERAL STATEMENT

There are approximately 2200 radio sources and 150 stations in about 5 million VLBI observations that were curried out during last 25 years. The goal objective is reanalysis of these data for revision and extension of ICRF-Ext.1 and ITRF(VLBI) reference frames and correction of IERS(EOP)C04 reference series. The main components of this project are following:

a) Data base: all observation at global VLBI-network during 1979-2004.

b) Theoretical foundation: IERS Conventions (2003) (McCarthy, Petit, 2003) and Genaralized Least-Squares Techniques (Gubanov, 1997, 2001).

c) Expected results: new versions of ICRF, ITRF and IERS(EOP) series; proper motion of source position due to changing structure effects; variation of base lines; parametrization of free core nutation as stochastic process; refined luni-solar precession and nutation terms; more precise Love/Shida numbers, tidal phase lag; tropospheric wet-delay, its horizontal gradients and mupping function; antenna offsets, and atmospheric loading coefficients for all sites, etc.

d) Period of realization: 2003-2005.

e) Research group: V.S.Gubanov, I.F.Surkis, Yu.L.Rusinov (IAA) and post-graduate students of SPbSU.

f) Financial support: grant No. 03-02-17591 of the Russian Foundation for Basic Research.

2. PACKAGE QUASAR: CONFIGURATION, TUNING AND CONTROL

Software QUASAR was developed during 1998-2002 by Prof. V.S.Gubanov and Ph.D. I.F.Surkis with collaboration of Dr. I.A.Vereschagina (Kozlova) and Dr. Yu.L.Rusinov. The description of astronomical reductions, data analysis techniques, application results and user guide have been published by these co-authors in IAA Communications, No. 141–145, 2002.

As is obvious from below flow diagram (Fig. 1) the programmed package QUASAR allows to carry out single-series, multi-series and global solutions. As well seven different methods for analysis of diurnal stochastic signals may be used. The iteraton process can be realized with respect to both unknown parameters and covariance of signals.

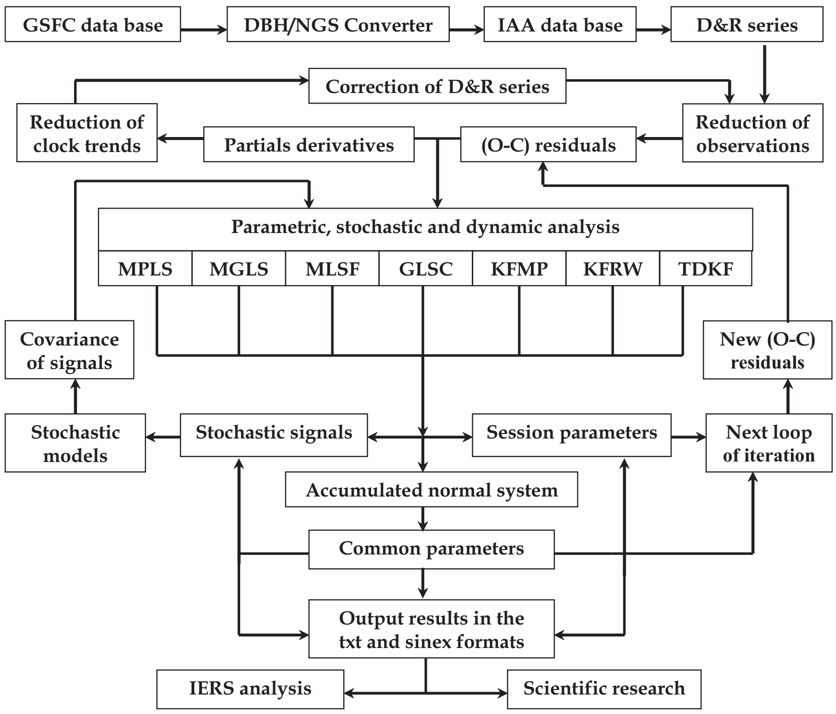


Figure 1: Configuration of the package QUASAR.

The main tuning and control functions are following: a) support and visualization of data base; b) reduction of delay/rate measurements and calculation of partials; c) correction of local clocks diurnal trend to quadratic model; d) parametrization of covariance function for all type stochastic signals; e) choice of stochastic analysis techniques; f) control of single-/multi-series or global solution processes; g) estimation of all signals and session or global parameters; h) regularization of random parameters; i) iteration process; j) preparation of ICRF, ITRF and EOP corrections in the IERS formats.

3. REDUCTION OF CLOCK TREND TO QUADRATIC MODEL

Sometimes the quadratic model for daily clock trend was not acceptable, because of local hydrogen masers have not been stable enough. For this reason the residuals (O − C) for all available VLBI observations were corrected using QUASAR graphic system. As a result, the RMS of clock stochastic component is decreased by 10 times. In all other respect these corrected data are not changed practicaly. For example, this process is demonstrated on Figs. 2-5 for the NEOS-A 011106xe session.

Fig. 2 - The base line names for NEOS-A 011106xe session.

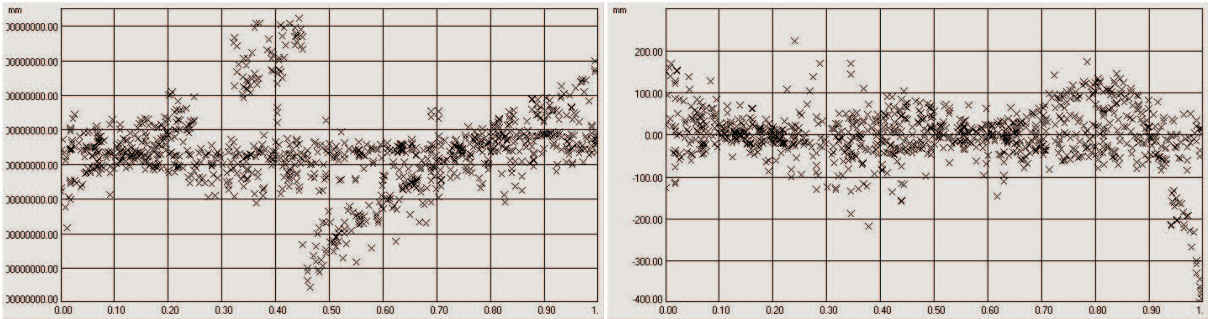


Figure 3: Original residuals (O − C) after elimination of clock quadratic trends for all VLBI stations (left) and then after elimination of the phase breaks (right).

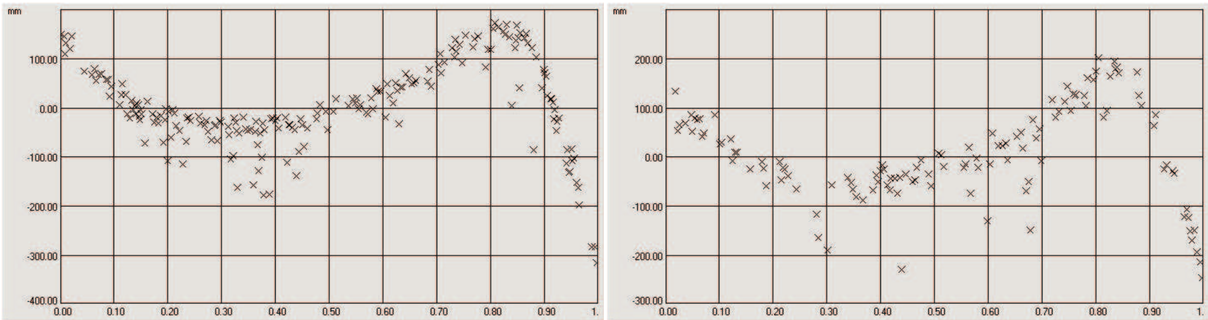


Figure 4: (O − C) residuals for Wettzell - Fortaleza (left) and Wettzell - Kokee baselines (right).

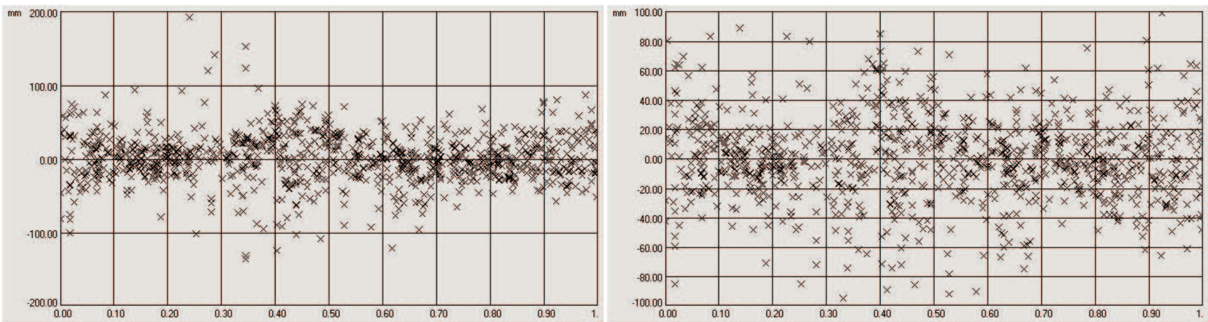


Figure 5: Reduction of Wettzell clock trend to quadratic model (left) and filtration of all residuals (O − C) under "4-sigma" criterion (right).

4. PARAMETRIC AND STOCHASTIC ANALYSIS TECHNIQUES

The diurnal variable parameters (DVP) may be analysed by seven different techniques: a) Multi-Parameter Least-Squares (MPLS), b) Multi-Group Least-Squares (MGLS), c) Moving Least-Squares Filter (MLSF), d) Global Least-Squares Collocation (GLSC), e) Kalman Filter of Markov's Process (KFMP), f) Kalman Filter of Random Walk (KFRW), g) Two-Dimension Kalman Filter (TDKF).

The first two of them (MPLS and MGLS) are well known. They use the Least-Squares (LS) techniques and DVP representation showed in Fig. 6. As opposed to MPLS, the MGLS technique have to do with a few fragmets (groups) of diurnal session duration of each about 1 hours. In general, the change of DVP inside every group may be presented as bound constrained polynomial trend (Gubanov, Kozlova and Surkis, 2002).

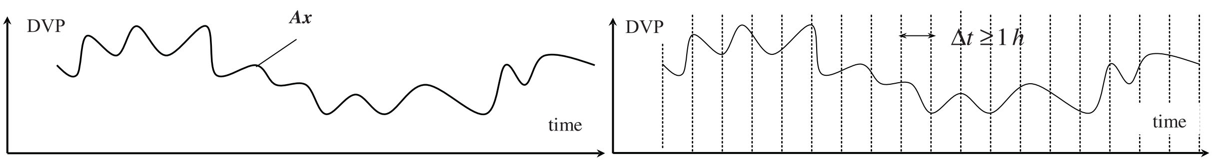


Figure 6: DVP representations being used by MPLS (left) and MGLS (right) techniques.

The MLSF technique is given as following recurrence relations (Gubanov, 2001):

$$\hat{\mathbf{x}}_{k,k+1} = \mathbf{D}_{k,k+1}\mathbf{D}^{-1}_{k-1,k}(\hat{\mathbf{x}}_{k-1,k} - \mathbf{K}_{k-1,k}\mathbf{l}_{k-1}) + \mathbf{K}_{k,k+1}\mathbf{l}_{k+1},$$
$$\mathbf{D}_{k,k+1} = (\mathbf{I} - \mathbf{K}_{k,k+1}\mathbf{A}_{k+1})(\mathbf{I} - \mathbf{K}_{k-1,k}\mathbf{A}_{k-1})^{-1}\mathbf{D}_{k-1,k},$$

where $(\mathbf{l}_k, \mathbf{A}_k, \mathbf{Q}_k)$ are data for group number $k = 0, 1, 2, \ldots$; $\mathbf{l}_k$ is the vector of $(\mathrm{O-C})_k$ residuals, $\mathbf{A}_k, \mathbf{Q}_k$ are the matrices of their partials and covariances, respectively; $\hat{\mathbf{x}}_{k-1,k}$ and $\mathbf{D}_{k-1,k}$ are estimates of parameters vector and its a posteriori covariance matrix derived from combined LS-solution for two preceding groups with numbers $k-1$ and k; $\hat{\mathbf{x}}_{k,k+1}$ and $\mathbf{D}_{k,k+1}$ are similar solution for next two groups k and $k+1$ (see left side of Fig. 7). The amplification matrices are follows:

$$\mathbf{K}_{k-1,k} = \mathbf{D}_{k-1,k}\mathbf{A'}_{k-1}\mathbf{Q}^{-1}_{k-1},$$
$$\mathbf{K}_{k,k+1} = \mathbf{D}_{k-1,k}\mathbf{A'}_{k+1}(\mathbf{Q}_{k+1} + \mathbf{A}_{k+1}\mathbf{D}_{k-1,k}\mathbf{A'}_{k+1})^{-1}.$$

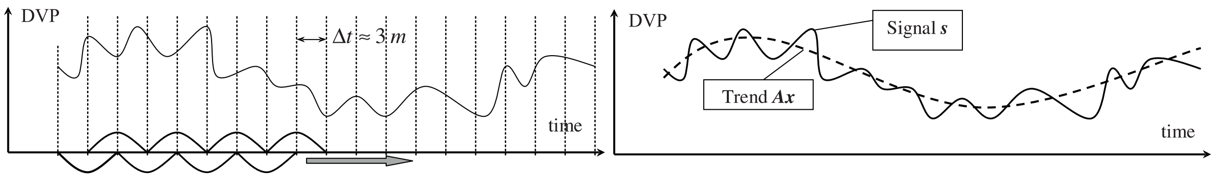


Figure 7: DVP representation being used by MLSF (left) and GLSC (right) techniques

The GLSC technique deals with DVP representation in the form DVP $= \mathbf{Ax} + \mathbf{s}$, where $\mathbf{Ax}$ is diurnal polinomial trend and $\mathbf{s}$ is correlated random component the auto-covariance of which must be a priori known (see right side of Fig. 7). Preliminary analysis of NEOS-A VLBI data (Gubanov, Surkis, Kozlova and Rusinov, 2002) shows that the normalized auto-covariance functions of wet and clock random components are very similar for all stations (see Fig. 8). Their pecularities and variances may be corrected by iteration (see Fig. 1).

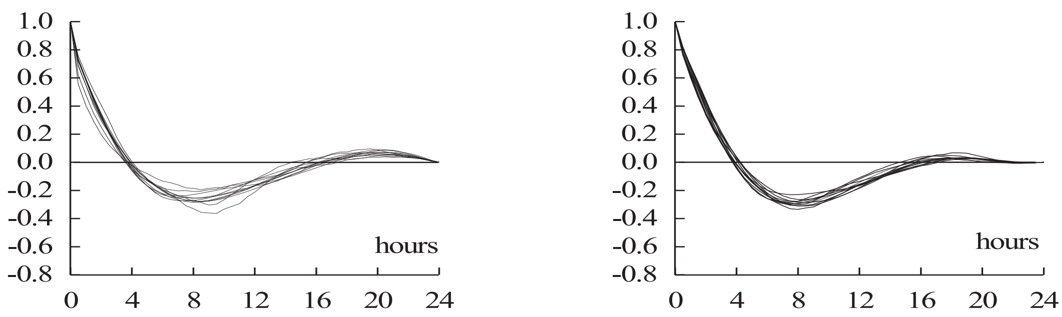


Figure 8: Normalized auto-covariance functions of wet (left) and clock (right) random componets for each NEOS-A stations after averaging by all session of observations

Being averaged for all stations these covariance functions may be modeled by expression

$$q(\tau) = \sigma^2 \sum_{n=0}^{n=2} \frac{b_n}{\cos\phi_n} e^{-\alpha_n|\tau|}\cos(\omega_n\tau + \phi_n), \quad (\omega_0 = 0, \phi_0 = 0), \tag{1}$$

where ω_n is cyclic frequency of n-th component of covariance function, $\alpha_n > 0$ – damping factor, b_n – dimensionless coefficients such as $\sum_{n=0}^{n=2} b_n = 1$, ϕ_n – phase under condition $|\phi_n| \leq |\arctan(\alpha_n/\omega_n)|$ that provide the positive definite function $q(\tau)$.

The GLSC-technique is developed in detail (Moritz, 1983; Gubanov, 1997). As far as a priori information about unknown parameters and random signals is used in this technique GLSC-estimates are the most precise and reliable then some kind of other linear estimates. Serious difficulties arising from inversion very large matrix in analysis of VLBA, Bb023 and other programs may be eliminated by sharing their sessions onto several sub-sessions.

If a priori exponential auto-covariance function or, at last, its leading segment are known then the KFMP technique may be used for analysis of Markov's process. However, GLSC-analysis of VLBI data shows that the mean values b_0 in expression (1) for wet and clock stochastic components are not exceed 0.1 so that one-dimension Markov's process is not representative for these signals. In an opposite way the KFRW tecnique have not to do with a priori covariance and, therefore, is very popular. In this technique the transition matrix is equal of unit-matrix and KFRW-solution provides non-stationary random walk identical of Brownian motion.

The TDKF technique is more acceptable from theoretical and practical points of view (Gubanov, Kozlova and Surkis, 2002). It is known that if some stationary random process $u(t)$ have continuously derivative $v(t) = du/dt$, two-dimension process $z(t) = (u(t), v(t))$ is Markov's one. In this case the discrete dynamic system perturbed by "white" noise $w(i)$ proves to be form

$$z(i+1) = \Phi(i+1,i)z(i) + w(i)$$

with the transition matrix

$$\Phi(i+1,i) = \begin{bmatrix} q_{uu}(\tau_i) & q_{uv}(\tau_i) \\ q_{vu}(\tau_i) & q_{vv}(\tau_i) \end{bmatrix} \begin{bmatrix} q_{uu}(0) & 0 \\ 0 & q_{vv}(0) \end{bmatrix}^{-1},$$

where auto-covariance function $q_{uu}(\tau)$ is defined by (1), $q_{uv}(\tau) = -q_{vu}(\tau) = dq_{uu}(\tau)/d\tau$, $q_{vv}(\tau) = -d^2q_{uu}/d\tau^2$ and $q_{uu}(0) = \sigma^2$, $q_{vv}(0) = \sigma^2 \sum_{n=0}^{n=2} b_n(\alpha_n^2 + \omega_n^2)$.

5. STOCHASTIC REGULARIZATION

Stochastic regularization is taking into account of a priori auto-covariance of unknown random parameters in LS-solutions. Let we have the linear system $\mathbf{l} = \mathbf{Ax} + \mathbf{r}$ where $\mathbf{l}$ is (O – C) residuals, $\mathbf{A}$ – the matrix of partials, $\hat{\mathbf{x}}$ – the vector of corrections to reference systems such as ICRF, ITRF or EOP and $\mathbf{r}$ – the random vector of observation errors with known auto-covariance matrix $\mathbf{Q}_{rr}$. The LS-technique using principle $\mathbf{r}'\mathbf{Q}_{rr}^{-1}\mathbf{r} = min.$ leads to normal system $\mathbf{W}\hat{\mathbf{x}} = \mathbf{h}$ and its solution $\hat{\mathbf{x}} = \mathbf{W}^{-1}\mathbf{h}$. According to Fisher's theory of information (Gubanov, 1997) the matrix of normal system have to contain the total amount of information on vector $\mathbf{x}$ both *a posteriori* and *a priori* ones. In considered case the matrix $\mathbf{W} = \mathbf{D}_{xx}^{-1}$ presents only a posteriori information deribed from LS-solution. However, if the vector $\mathbf{x}$ is the centered random set or sequence and its a priori information $\mathbf{R} = \mathbf{Q}_{xx}^{-1}$ is known the more precise regularizated corrections $\hat{\mathbf{x}}_R$ may be obtained by relation

$$\hat{\mathbf{x}}_R = (\mathbf{W} + \mathbf{R})^{-1}\mathbf{h} \tag{2}$$

that should be also from Generalized Least-Squares (GLS) principle $\mathbf{r}'\mathbf{Q}_{rr}^{-1}\mathbf{r} + \mathbf{x}'\mathbf{Q}_{xx}^{-1}\mathbf{x} = min.$

The relation (2) is equivalent to the follows:

$$\hat{\mathbf{x}}_R = (\mathbf{W} + \mathbf{R})^{-1}\mathbf{W}\hat{\mathbf{x}}, \tag{3}$$

$$\hat{\mathbf{x}}_R = \mathbf{Q}_{xx}(\mathbf{Q}_{xx} + \mathbf{D}_{xx})^{-1}\hat{\mathbf{x}}. \tag{4}$$

It is easy to see that the eqs. (3) - (4) represent the generalized weighting and LSC-filtering of LS-solution $\hat{\mathbf{x}}$, respectively (Gubanov, 1997). In order to the estimates $\hat{\mathbf{x}}_R$ were found as unbiased the errors of revised referense systems $\mathbf{x}$ have to be centered random sets or sequences. To this objective the parameters of their systematic errors must be included to common ones in process of multi-series or global solution (see Fig. 1).

The regularization leads to decrease the corrections $\hat{\mathbf{x}}_R$ and their a posteriori variances. If we have precise reference systems and rough or not enough observations this effect may be very essential. On the contrary, it become negligible. In fact, the precise reference system can not be improved by using of poor observations.

6. PRELIMINARLY RESULTS OF NEOS-A DATA COLLOCATION

The results demonstrated at Figs. 9 - 10 may be considered as the proof of this that the GLSC-estimations of wet-component of tropospheric path-delay are real.

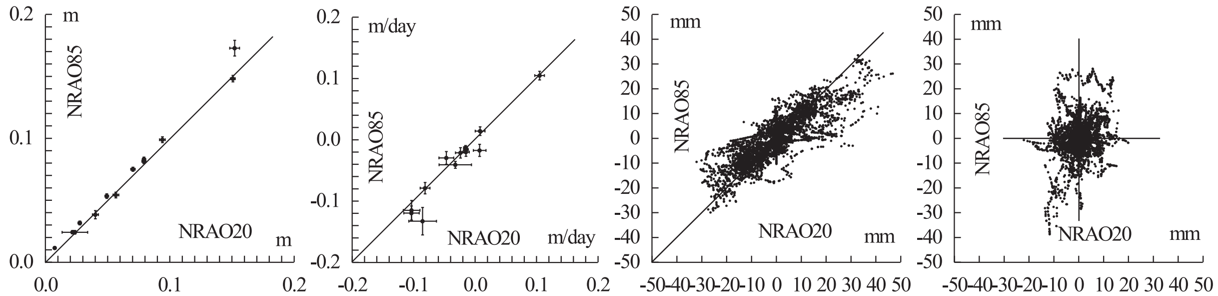


Figure 9: Regression of GLSC-estimates of diurnal wet-delay, wet-rate, wet-signals and clock-signals (from left to right) for NRAO20 and NRAO85 stations located at the same site of NRAO by GLSC-analysis of simultaneous observations

These data shows that the atmosphere over NRAO20 and NRAO85 stations is practicaly common but their clocks are different.

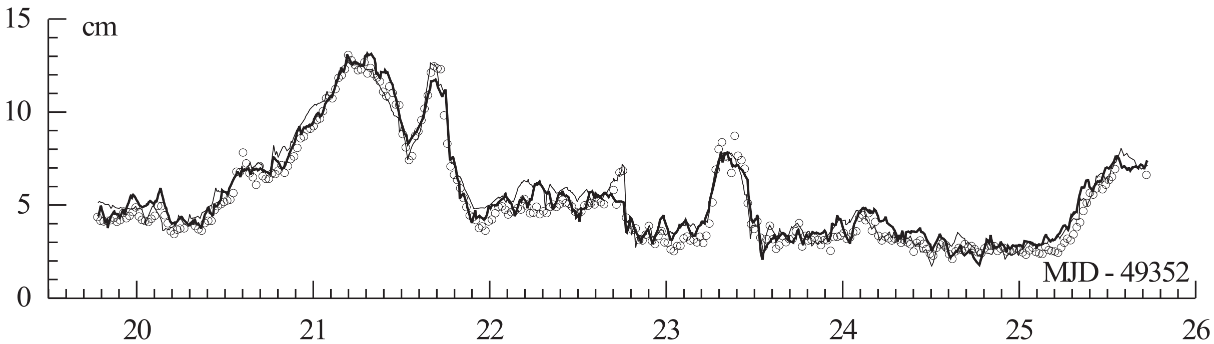
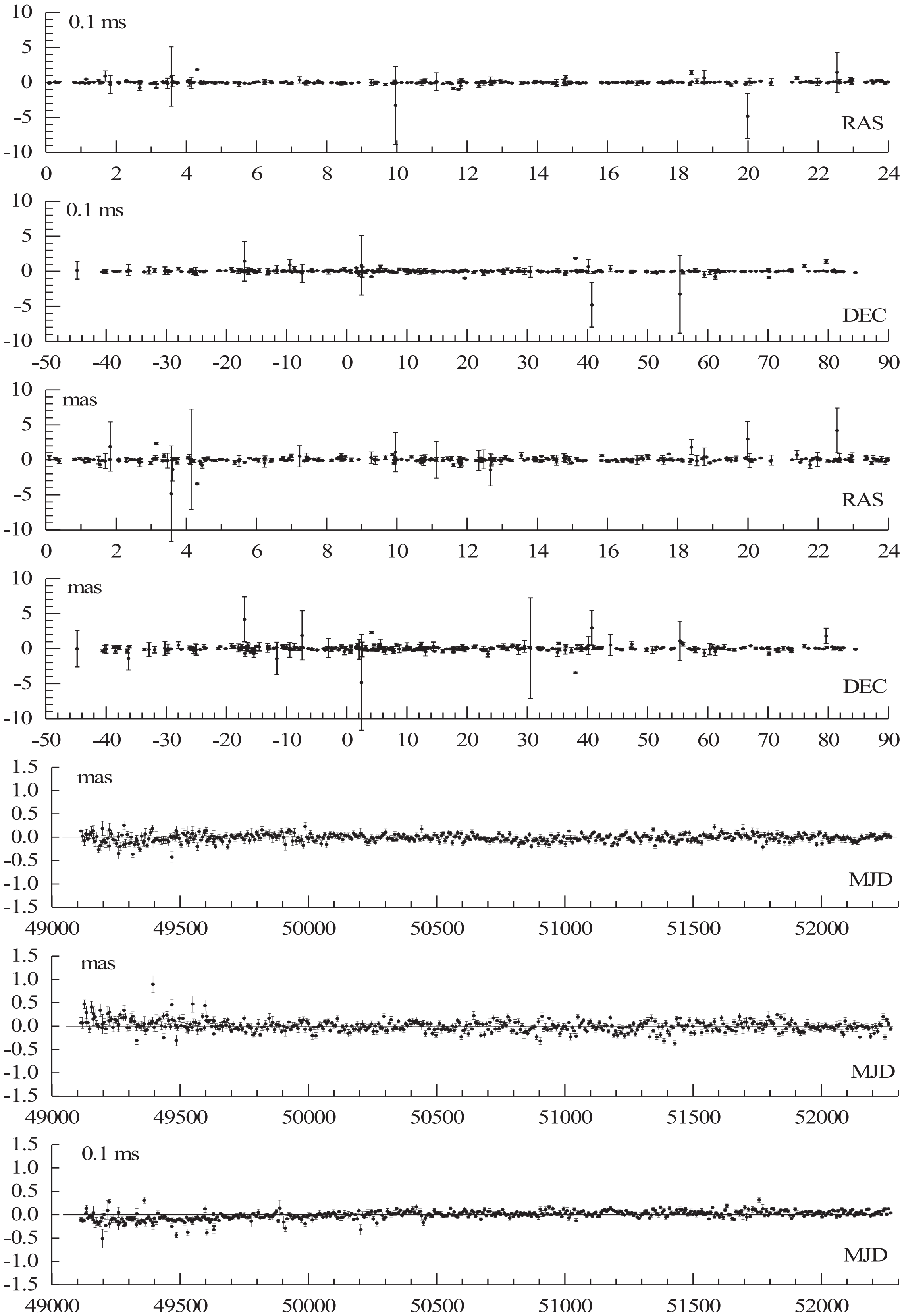
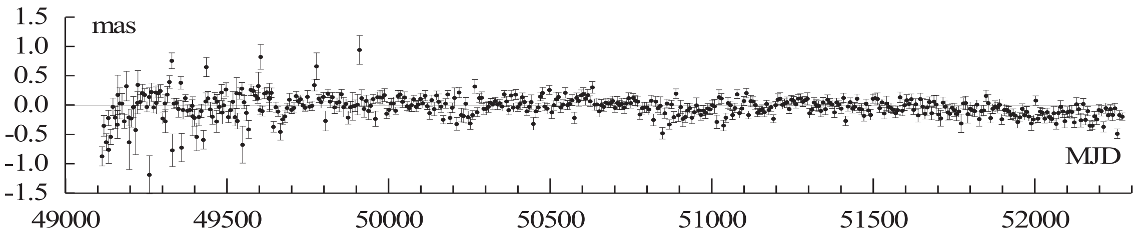


Figure 10: The Onsala total zenith wet-delays including stochastic components derived by GLSC-analysis from six last sessions of CONT94 program shared each onto two sub-sessions (thin and thick lines) in comparison with WVR-measurements (circles).

We can see from Fig. 10 that the GLSC-estimates are not only realiable as they are in agreement with independent WVR-data but also very similar for shared sub-sessions.

Further, the regularizated corrections of both the ICRF-Ext.1 catalogue and IERS(EOP)C04 time-series are demonstrated in Fig. 11. A priori uncertainties of source positions was taken from the preface of ICRF-Ext.1 catalogue (Gambis, 1999). Analogous values for IERS(EOP)C04 are contained in any IERS Annual Report.





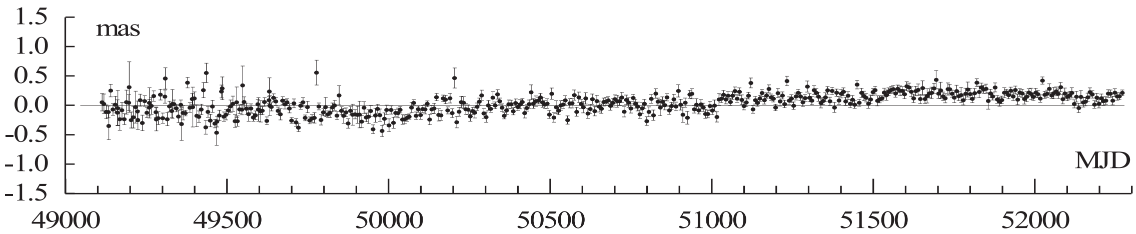


Figure 11: Corrections (up to down) of $\Delta\alpha_\alpha \cos\delta$, $\Delta\alpha_\delta \cos\delta$, $\Delta\delta_\alpha$, $\Delta\delta_\delta$, $\Delta\psi \sin\epsilon$, $\Delta\epsilon$, $\Delta(\mathrm{UT1}-\mathrm{UTC})$, Δx_P and Δy_P.

At present the software QUASAR is ready for global analysis of any amount of VLBI observations by means of GLSC-technique. In what follows the testing and tuning of alternative MLSF and TDKF techniques and introducing of new tranformation from TRS to CRS are needed.

7. REFERENCES

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