DETERMINATION OF EOP FROM COMBINATION OF SLR AND VLBI DATA AT THE OBSERVATIONAL LEVEL

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ABSTRACT. Time series of Earth orientation parameters (EOP) are commonly obtained independently from the processing of high accuracy modern observations such as VLBI, SLR, LLR, and GPS. This paper is devoted to an attempt of determination of EOP series from the joint analysis of SLR and VLBI measurements at the observation level. We used laser ranges to geodetic satellites LAGEOS, LAGEOS 2, and Etalon 1&2. All range measurements are taken from the Crustal Dynamics Data Informational System (CDDIS) and European Data Center (EDC). VLBI observations of distant quasars are obtained from the NEOS-A campaign. Processing of these measurements is performed in two steps. On the first stage the short arc technique with the arc length of 7 days is applied to all SLR measurements to adjust orbital parameters along with coefficients to the radiation pressure reflectance model and along track acceleration terms. All these parameters are considered to be non-stochastic. For VLBI measurements zenith component of troposphere delay and its gradients in horizontal and vertical directions are adjusted as stochastic signals on each day of observation. Both coordinates of quasars and site coordinates are considered to be accurately known and are not improved. It is very important that both SLR and VLBI observations are processed by the same program package, using the same astronomical constants and models for different kinds of measurements.

On the second stage SLR and VLBI observations are mixed to determine corrections to variables mentioned above along with all five Earth rotation parameters. Kalman filtering procedure is used to solve the system of conditional equations. Combining SLR and VLBI measurements on the short one day arc makes it possible to get standard deviations of parameters 1.5 times smaller to compare with that obtained by means of each technique separately. Applying Kalman filtering method to the longer observational time span of 7 days allows us to derive EOP variations with subduinal periods.

1. INTRODUCTION

Satellite laser ranging as well as very long baseline interferometry is the most useful techniques used to derive geodynamic information. Now a number of program packages are developed to process observation of different kinds. It is obvious that all these packages consist basically of similar procedures and routines, and only a small fraction of them is specific for each package. It is clear that it is possible to construct a universal program package for any type of ephemeris applications. It is the programming system ERA (Ephemeris Research in Astronomy) that is intended to process different types of high precision observations (Krasinsky, 1997). The use of the ERA system permits us to obtain Earth orientation parameters from the combination of SLR and VLBI data at the observational level. In particular, mixing SLR measurements of LAGEOS 1 & 2 and Etalon 1 & 2 satellites with the VLBI observations of quasars we can improve all parameters of Earth rotation.

2. DATA ANALYSIS

The data analysis was performed using the software, which is basically follows the IERS Conventions 1996 (McCarthy, 1996). The dynamical model for LAGEOS-type satellites includes the following perturbations:

- Gravitational perturbations due to the Sun, the Moon and planets (JPL DE403 planetary ephemeredes);
- Newtonians terms caused by the non-geodetic motion of the Earth (coupling of the external mass action and the Earth quadrupole moment effect) - indirect acceleration due to the oblateness of the Earth;
- Newtonian perturbing acceleraion due to the Earth's non-sphericity. The Earth gravity field is calculated according to the EGM model truncated to the 20-th degree and order with the following values for the coefficients $\overline{C}_{20}, \overline{C}_{21}, \overline{S}_{21}$ and their rates:

$$\begin{array}{rrrr} & & \dot{\overline{C}}_{20} = & 1.162 \times 10^{-11}/\text{year}, \\ \overline{C}_{21} = & -0.187 \times 10^{-9}, & \dot{\overline{C}}_{21} = & -1.300 \times 10^{-11}/\text{year}, \\ \overline{S}_{21} = & 1.195 \times 10^{-9}, & \dot{\overline{S}}_{21} = & 1.100 \times 10^{-11}/\text{year}. \end{array} \tag{1}$$

- The changes in the geopotential coefficients $\overline{C}_{21}, \overline{S}_{21}$ due to the dynamic polar motion according to the formulas:

$$\begin{aligned} \Delta\overline{C}_{21} &= K_f \overline{C}_{20}\sqrt{3}(x_p(t) - \overline{x}_p(t)), \\ \Delta\overline{S}_{21} &= -K_f \overline{C}_{20}\sqrt{3}(y_p(t) - \overline{y}_p(t)), \end{aligned} \tag{2}$$

  where

  $K_f = 0.331$;

  $\overline{x}_p, \overline{y}_p$ – mean values of $x-$ and $y-$ pole coordinates at the epoch $t_0 = 2000.0$ which are calculated according to formulas:

$$\begin{aligned} \overline{x}_p(t) &= \overline{x}_p(t_0) + \dot{\overline{x}}_p(t_0)(t - t_0), \\ \overline{y}_p(t) &= \overline{y}_p(t_0) + \dot{\overline{y}}_p(t_0)(t - t_0), \end{aligned} \tag{3}$$

  with the following numerical values of the mean coordinates and their rates:

$$\begin{array}{ll} \overline{x}_p(t_0) = 0.054\text{mas}, & \dot{\overline{x}}_p(t_0) = 0.00083\text{mas/year}, \\ \overline{y}_p(t_0) = 0.357\text{mas}, & \dot{\overline{y}}_p(t_0) = 0.00395\text{mas/year}. \end{array} \tag{4}$$

- Perturbations due to the direct solar radiation pressure;
- Along-track empirical acceleration (the coefficient is considered to be a solve-for parameter for each orbital arc);
- Relativistic terms (Schwarzschild terms, Lense-Thirring terms due to the Earth rotation, quadrupole terms).

3. OBSERVATIONS AND RESULTS

Laser ranges to geodetic satellites LAGEOS, LAGEOS 2, and Etalon 1&2, and VLBI observations of extragalactic objects obtained within the NEOS–A program were used to derive Earth orientation parameters. Determination of EOP from the joint processing of these measurements was performed by means of two different statistical methods — standard least squares procedure and Kalman filtering method. In both cases short arc technique with the arc length of 7 days was applied to all SLR measurements to adjust orbital parameters along with coefficients to the radiation pressure reflectance model and along track acceleration terms. All these parameters are considered to be non-stochastic. For VLBI measurements zenith component of troposphere delay and its gradients in horizontal and vertical directions are adjusted as stochastic signals on a day of observation. Covariation functions for these parameters were calculated on the basis of the model of troposphere (Stotskii, 1992) and "random walk" procedure for clock modeling described in (Vasilyev, 1999). Neither coordinates of quasars nor site coordinates are not improved in these cases.

Table 1: Corrections to the EOP and their formal uncertainties obtained from different sets of observations.

EOP	VLBI	VLBI+ L1+L2	VLBI+ L1+L2+E1+E2	SLR
x_p (mas)	-0.326 86	-0.001 44	0.023 43	0.099 86
y_p (mas)	0.034 84	0.204 31	0.208 30	0.202 82
UT1-UTC (ms)	0.026 5	0.017 4	0.015 4	
$d\psi$ (mas)	-0.260 143	-0.190 133	-0.182 130	
$d\epsilon$ (mas)	0.240 72	0.187 67	0.227 65	

In the first case the SLR and VLBI observations are mixed to determine corrections to variables mentioned above along with all five Earth rotation parameters in the frame of the weighted least squares method. Table 1 illustrates corrections to the Earth orientation parameters to compare with the EOP(IERS) C 04 and their formal uncertainties obtained from different sets of observations (pure VLBI observations or VLBI measurements combined with SLR observations of different satellites — LAGEOS (L1), LAGEOS 2 (L2), Etalon 1 (E1), and Etalon 2 (E2)) on a day period of time. It is clear that combining SLR and VLBI measurements on the short one day arc allows us to get standard deviations of pole coordinates smaller to compare with those obtained by means of each technique separately.

At the second stage Kalman filtering procedure is used to solve the system of conditional equations. Applying the Kalman method to the combination of VLBI and SLR data on the period of one month permits us to derive continuous set of Earth orientation parameters on the whole period with high resolution. Table 2 shows root mean square and formal uncertainties of this one-month EOP set as compared with that of EOP(IERS) C 04.

One can see that both *rms* and formal uncertainties of celestial pole coordinates obtained

Table 2: Formal uncertainties and root mean square residuals of determination of the EOP on 28 days period.

EOP	VLBI+SLR		VLBI		SLR	
	rms	formal	rms	formal	rms	formal
x_p (mas)	0.16	0.06	0.07	0.13	0.23	0.07
y_p (mas)	0.20	0.05	0.16	0.13	0.27	0.06
UT1-UTC (ms)	0.013	0.007	0.011	0.007		
$d\psi$ (mas)	0.27	0.20	0.18	0.22		
$d\epsilon$ (mas)	0.23	0.10	0.24	0.11		

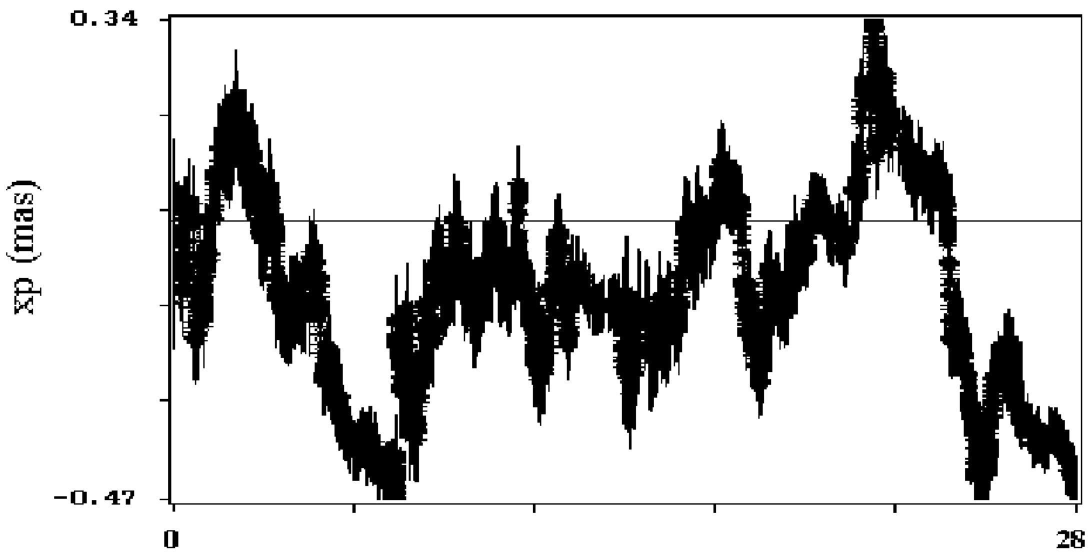

Figure 1: Differences of x_p and EOP(IERS) C 04 derived by means of Kalman filtering.

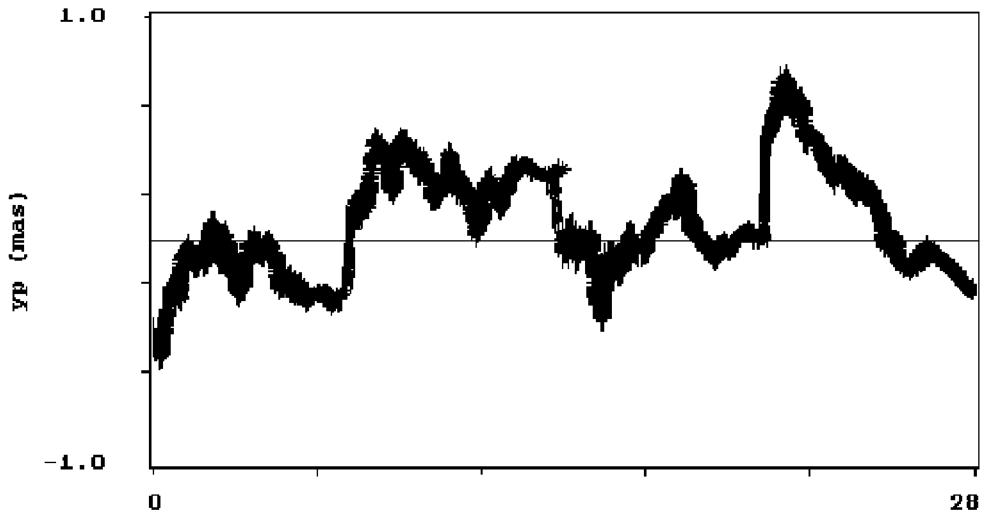

Figure 2: Differences of y_p and EOP(IERS) C 04 derived by means of Kalman filtering.

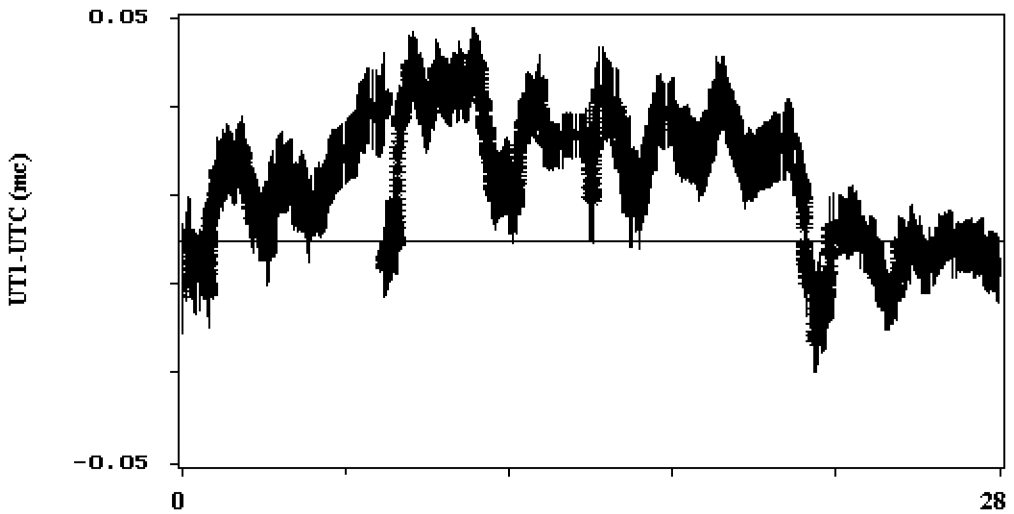

Figure 3: Differences of UT1–UTC and EOP(IERS) C 04 derived by means of Kalman filtering.

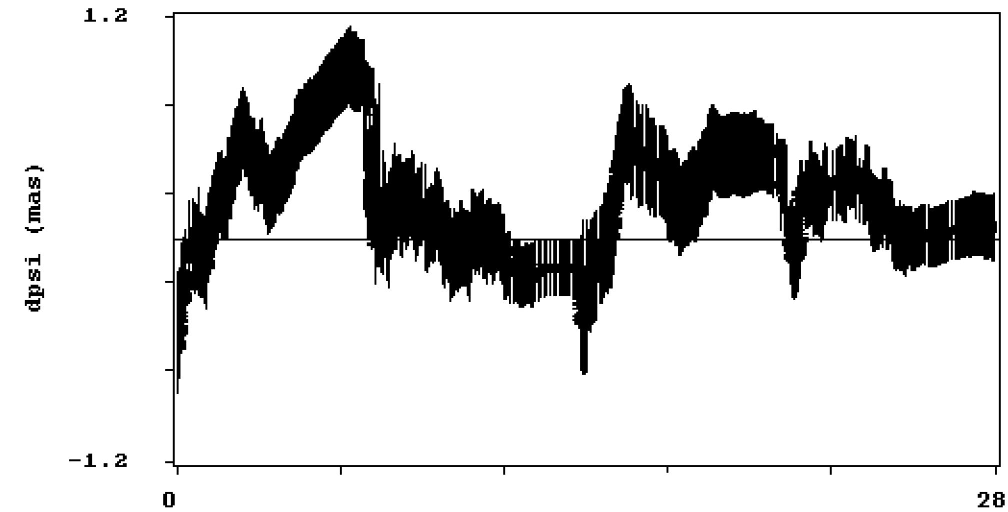

Figure 4: Differences of $d\psi$ and EOP(IERS) C 04 derived by means of Kalman filtering.

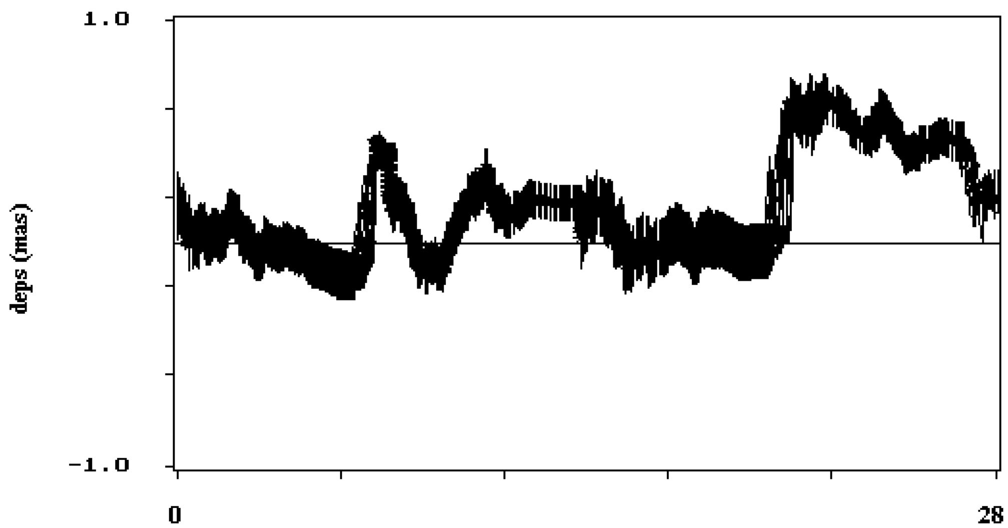

Figure 5: Differences of $d\epsilon$ and EOP(IERS) C 04 derived by means of Kalman filtering.

from combination of SLR and VLBI data are not better then that of derived from each technique separately. But an attaching SLR observations to the VLBI measurements gives us the possibility to determine celestial pole ofsets on the whole period of time (Figures 1–5 illustrate differences between x_p, y_p, UT1–UTC and EOP(IERS) C 04 values derived by means of Kalman filtering procedure).

4. CONCLUSIONS

- It is very important that both SLR and VLBI observations are processed by the same program package, using the same astronomical constants and models for different kinds of measurements;
- Processing both VLBI and SLR observations permits us to obtain all five Earth orientation parameters on the whole time span;
- Application of stochastic estimation to combine observational data allows us to determine continuous set of EOP with high time resolution.

5. REFERENCES

McCarthy, D. D., (ed.)., 1996, IERS Conventions 1996, *Technical Note 21.*

Andersen, P. H., 2003, Combination of the VLBI, GPS and SLR observations at the observation level, *Proc. EGS-AGU-EUG Joint Assembly 2003*, Nice, France, 386.

Shuygina, N. V., 2000, Determination of the Earth rotation parameters from the Lageos SLR and VLBI data, *Proc. Journees 1999 and IX Lohrmann-Kolloquium: Motion of celestial bodies, astrometry and reference frames*, M. Soffel, N. Capitaine (eds.), 214–216.

Yaya, P., 2002, Combination of geodetic techniques to determine the Earth orientation parameters, *Proc. Journees 2001 Influence of geophysics, time and space reference frames on Earth rotation studies*, N. Capitaine (ed.), 46–50.

Stotskii, A. A., 1992, Path length fluctuation through the Earth troposphere: turbulent model and data of observations, *Proc. of the specialist meeting on microwave radiometry and remote sensing applications*, Westmaster R. (ed.), 256–261.

Krasinsky, G. A., Vasilyev, M. V., 1997, ERA: knowledge base for ephemeris and dynamical astronomy, *Proc. IAU Coll. No. 165*, Poznan, Poland, I. M. Wytrzyszczak, J. H. Lieske, R. A. Feldman (eds.), 239–244.

Vasilyev, M., 1999, Real time autonomous orbit determination of GEO satelliteusing GPS, **ION–GPS–99**, Nashville, USA, 451–457.