FORECASTING OF THE EARTH ORIENTATION PARAMETERS - COMPARISON OF DIFFERENT ALGORITHMS

W. KOSEK[1], M. KALARUS[1], T. NIEDZIELSKI[1,2]
[1]Space Research Centre, Polish Academy of Sciences
Bartycka 18A, 00-716 Warsaw, Poland
e-mail: kosek@cbk.waw.pl, kalma@cbk.waw.pl, niedzielski@cbk.waw.pl
[2]Institute of Geography and Regional Development, University of Wrocław
pl. Uniwersytecki 1, 50-137 Wrocław, Poland
e-mail: niedzielski@geom.uni.wroc.pl

ABSTRACT. The Earth orientation parameters (EOP) are determined by space geodetic techniques with very high accuracy. However, the accuracy of their prediction, even for a few days in the future, is several times lower and still unsatisfactory for practical use. The main problem of each prediction technique is to predict simultaneously long and short period oscillations of the EOP. It has been shown that the combination of the prediction methods which are different for deterministic and stochastic components of the EOP can provide the best accuracy of prediction. Several prediction techniques, e.g. combination of the least-squares with autoregressive and autocovariance methods as well as combination of wavelet transform decomposition and autocovariance prediction, were used to predict x, y pole coordinates in polar coordinate system and $UT1-UTC$ or length of day (Δ) data. Different prediction algorithms were compared considering the difference between the EOP data and their predictions at different starting prediction epochs as well as by comparing the mean EOP prediction errors.

1. INTRODUCTION

Predictions of Earth orientation parameters (EOP): x, y pole coordinates, universal time ($UT1-UTC$) and nutation-precession corrections dX, dY provide real-time transformation between celestial and terrestrial reference frames. They are required in the process of tracking and navigation of interplanetary spacecrafts by the Deep Space Network. The other precision applications, for instance astronomy, geodesy, communication and time-keeping also need EOP predictions (e.g., Schuh et al. 2002). The EOP predictions are published by the International Earth Rotation and Reference Systems Service (IERS) Rapid Service/Prediction Centre (RS/PC) (e.g. Wooden et al. 2004). Many efforts were made within the IERS RS/PC to improve pole coordinates data (e.g. Kosek et al. 2004) and $UT1-UTC$ data (e.g. Johnson et al. 2005) prediction accuracy.

2. DATA

The following data sets were used in the analysis: (1) x, y pole coordinates data from EOPC01 solution in 1846 to 2000, (2) x, y pole coordinates, $UT1-UTC$ data from the EOPC04_05 solution (IERS 2007), (3) χ_3 component of the atmospheric angular momentum from ncep.reanalysis which is the sum of mass and motion terms.

3. ANALYSIS

In this work the following prediction techniques were used: (1) least-squares (LS) extrapolation, (2) autocovariance (AC) prediction, (3) autoregressive (AR) prediction, (4) multivariate autoregressive (MAR) prediction. Some of these techniques - when combined - enable forecasting the EOP data with a better accuracy than a single prediction technique. The following combinations of at least two prediction techniques called prediction algorithms were used: (1) combination of the LS extrapolation and AR prediction denoted as LS+AR, (2) combination of the LS and MAR denoted as LS+MAR, (3) combination of the discrete wavelet transform (DWT) (Popiński and Kosek 1995) and AC prediction (Kosek et al. 1998) denoted as DWT+AC.

In the LS+AR prediction algorithm first the LS model is fit to x, y pole coordinates data. The differences between the x, y pole coordinates data and their LS models are equal to LS residuals. Prediction of x, y pole coordinates data is the sum of the corresponding LS extrapolation models and the AR predictions of the LS residuals. The LS model consists of the trend, Chandler circle as well as annual and semi-annual ellipses. The length of the LS residuals fit to the autoregressive model is equal to 850 days which is approximately equal to twice of the period of the Chandler oscillations. The autoregressive order was estimated by Akaike's Information Criterion (AIC) and empirically by looking at the minimum prediction errors (Kalarus 2007).

Absolute values of the difference between x, y pole coordinate and their predictions computed by the LS method and by the LS+AR combination, as a function of starting prediction epoch from 1980 till 2007.6 and from one day to one year in the future, are shown in Figure 1. The LS model is fit to different data span of pole coordinates data equal to 5, 10 and 15 years. The prediction errors computed by the LS method are greater than by the LS+AR combination. The increase of the pole coordinates data length fit to the LS model cause increase of the prediction errors in the LS method but their decrease in the LS+AR combination (Fig. 1).

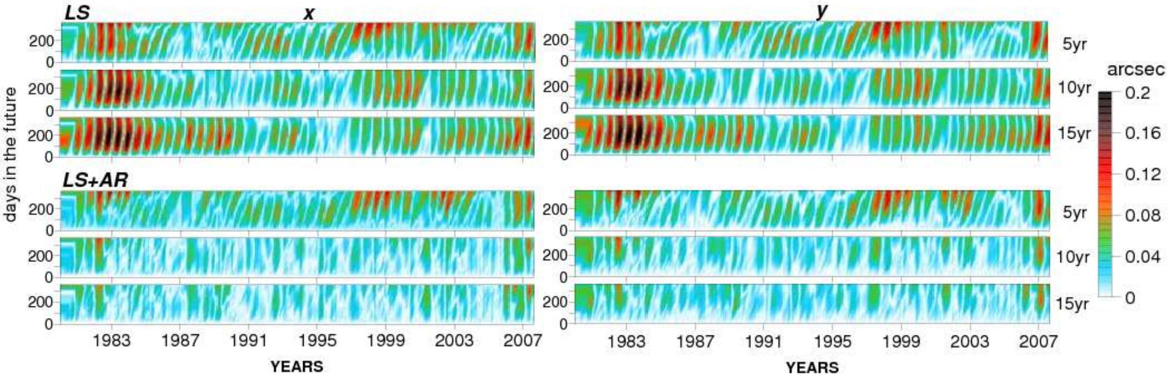

Fig. 1. Absolute differences between x, y pole coordinates data and their predictions computed by the LS and LS+AR combination methods.

The influence of the length of the autoregressive order on prediction errors of EOP data in the AR prediction method was investigated by Kalarus (2007). Empirically computed autoregressive order values for which the prediction errors from 1 to 500 days in the future were minimum are shown in Figure 2. The length of the autoregressive order usually increases with the length of prediction but it should not exceed about 6 years for the EOP data. The mean LS and LS+AR prediction errors of x, y pole coordinates data computed over time span 1980 to 2007 are shown in Table 1. The LS model was fit to 10 years of x, y pole coordinates data and in the LS+AR algorithm the autoregressive order was estimated by the AIC or its empirical value was adopted for longer term predictions. The mean prediction errors of x, y pole coordinates data are smaller for the LS+AR prediction than for the LS one. Longer term prediction accuracy can be improved when the autoregressive order was empirically obtained, however at the same time this autoregressive order is not good for shorter term predictions (Tab. 1).

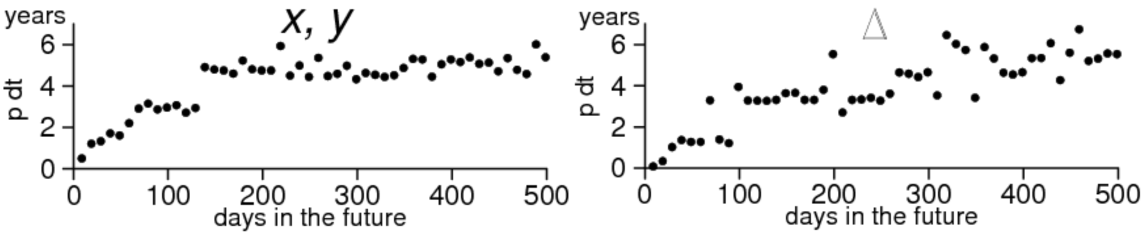

Fig. 2. Empirically computed autoregressive order for which the AR prediction errors of the EOP data have minimum values (Kalarus 2007).

The prediction of x, y pole coordinates data can be also computed in polar coordinate system (Kosek 2002) in which the radius and angular velocity are predicted by the DWT+AC prediction (Kosek 2003, Kosek and Popiński 2006). The radius can be computed from x, y pole coordinates and mean pole computed by the Orsmby low pass filter and prolonged into the future using extrapolation of the LS model. In the DWT+AC method the radius and angular velocity is decomposed by the DWT into frequency components and each frequency component is predicted by the AC prediction (Kosek 2002). The prediction of the radius and angular velocity is the sum of AC predictions of all the frequency components. Afterwards, the predictions of x, y pole coordinates data are computed from the prediction of the radius, angular velocity and the mean pole using linear intersection formulae (Kosek 2002). The DWT+AC mean prediction errors of x, y pole coordinates data computed from October 2006 to August 2007 have reasonable accuracy in comparison with the results of other prediction algorithms (Tab. 1).

	days in the future	5	10	20	30	60	120	180	360
x pole coordinate	time span								
LS	Jan.1980-Jan.2007	3.7	7.0	13.1	18.8	33.7	54.0	60.4	45.8
LS+AR (AIC)	Jan.1980-Jan.2007	1.4	3.1	6.0	8.5	14.3	20.9	23.5	33.1
LS+AR (emp)	Jan.1980-Jan.2007	3.8	8.4	12.0	11.8	15.4	20.6	23.8	29.5
DWT+AC	Oct.2006-Aug.2007	3.2	5.0	8.2	12.7	-	-	-	-
y pole coordinate	time span								
LS	Jan.1980-Jan.2007	3.2	6.3	12.1	17.7	32.8	54.0	61.4	46.8
LS+AR (AIC)	Jan.1980-Jan.2007	0.9	1.9	3.5	5.1	9.7	19.0	26.9	34.0
LS+AR (emp)	Jan.1980-Jan.2007	2.9	6.4	9.5	9.8	13.7	20.6	25.3	30.6
DWT+AC	Oct.2006-Aug.2007	2.5	4.3	7.7	10.2	-	-	-	-

Table 1: Mean prediction errors of x, y pole coordinates data [in mas] computed by the LS, LS+AR and DWT+AC methods.

Prediction of $UT1-UTC$ data are usually computed from prediction of length of day (Δ) data from which tidal model $\delta\Delta$ described in the IERS Conventions (McCarthy and Petit 2004) is subtracted. The $\Delta-\delta\Delta$ data were obtained after subtracting leap seconds from $UT1-UTC$ to derive $UT1-TAI$, next computing time derivative of $UT1-TAI$ to get length of day Δ data and finally subtracting tidal model from Δ data. In this paper, in order to compute $\Delta-\delta\Delta$ prediction the LS, LS+AR, LS+MAR and DWT+AC algorithms were used. After adding tide model to $\Delta-\delta\Delta$ prediction, then integrating prediction of Δ data and adding leap seconds the predictions of $UT1-UTC$ were computed.

In the LS, LS+AR and LS+MAR prediction algorithms the LS model consists of the trend and 18.6, 9.3, 1.0 and 0.5 year oscillations and it is fit to $\Delta-\delta\Delta$ data from January 1962 to starting prediction epoch moving from January 1990 to January 2007. The LS prediction of $\Delta-\delta\Delta$ data is simply extrapolation of the LS model. The LS+AR and LS+MAR prediction of $\Delta-\delta\Delta$ data is the sum of LS extrapolation model and AR and MAR predictions of $\epsilon(\Delta-\delta\Delta)$ residuals obtained as a difference between $\Delta-\delta\Delta$ data and their LS models, respectively (Niedzielski and Kosek 2007). The autoregressive orders in the AR and MAR predictions of $\epsilon(\Delta-\delta\Delta)$ residuals were estimated by AIC and Schwarz Bayesian criterion (SBC), respectively. In the LS+MAR prediction algorithm χ_3 component of atmospheric angular momentum was used as an explanatory variable, i.e. the residuals computed as the difference between the atmospheric angular momentum χ_3 data and LS models consisted of 1.0 and 0.5 year oscillations are considered concurrently with the $\Delta-\delta\Delta$ residuals. The autoregression matrices are estimated by means of a stepwise LS estimation for MAR models (Neumaier and Schneider 2001). Combination LS+MAR provides $UT1-UTC$ predictions with better accuracy than the combination LS+AR which provides smaller mean prediction errors than the LS extrapolation (Tab. 2).

In the DWT+AC algorithm first, $\Delta-\delta\Delta$ data were decomposed into frequency components by the DWT band pass filter and each frequency component was predicted using AC prediction. The prediction of $\Delta-\delta\Delta$ was computed as the sum of DWT+AC predictions of all the frequency components. The mean prediction errors of $UT1-UTC$ data computed from October 2006 to August 2007 are of the same order as those computed by other prediction algorithms (Tab. 2).

4. CONCLUSIONS

The LS+AR combination of x, y pole coordinates data provides their prediction with the highest accuracy. The minimum prediction errors for particular number of days in the future depends on the autoregressive order. Prediction of x, y pole coordinates data with reasonable accuracy can be computed also in the polar coordinate system by forecasting the mean pole, radius and angular velocity using DWT+AC algorithm. Decomposition of time series by the DWT band pass filter solves the problem of forecasting them in different frequency bands. Prediction of $UT1-UTC$ data can be improved by using LS+MAR combination, which takes into account axial component of the atmospheric angular momentum.

	days in the future	5	10	20	30	60	120	180	360
	time span								
LS	Jan.1990-Jan.2007	0.29	0.99	2.90	4.95	10.5	21.0	31.3	66.9
LS+AR (AIC)	Jan.1990-Jan.2007	0.29	0.97	2.66	4.34	8.8	18.0	27.6	62.4
LS+MAR (SBC)	Jan.1990-Jan.2007	0.29	0.99	2.68	4.32	8.4	16.3	24.4	53.8
DWT+AC	Oct.2006-Aug.2007	0.49	1.25	2.84	4.44	-	-	-	-

Table 2: Mean prediction errors of $UT1-UTC$ data [in ms] computed by the LS, LS+AR, LS+MAR and DWT+AC prediction algorithms.

Acknowledgements. Attendance of co-authors M. Kalarus and T. Niedzielski at the Journees 2007 were supported by a conference grant within 'Descartes-nutation project'. T. Niedzielski is supported by the Foundation for Polish Science within the Start Programme (stipends for young researchers). The paper was supported by the Polish Ministry of Education and Science under the project No 4 T12E 039 29.

5. REFERENCES

IERS, 2007, ftp://hpiers.obspm.fr/iers/eop/eopc04_05/eopc04_IAU2000.62-now.

Johnson T., Luzum B.J., Ray J.R., 2005, Improved near-term Earth rotation predictions using atmospheric angular momentum analysis and forecasts. J Geodyn 39: 209221.

Kalarus M., 2007, Analiza metod prognozowania parametrów orientacji przestrzennej Ziemi, PhD thesis (*in Polish*), Warsaw Technical University.

Kosek, W., McCarthy, D.D., Luzum, B.J., 1998, Possible improvement of Earth orientation forecast using autocovariance prediction procedures, Journal of Geodesy 72, 189–199.

Kosek W., 2002, Autocovariance prediction of complex-valued polar motion time series, Advances of Space Research, Vol. 30, No. 2, 375–380.

Kosek W., 2003, Polar motion prediction by different methods in polar coordinate system. Proc. Journees 2002, Systemes de Reference Spatio-Temporels, Bucarest, 125–131.

Kosek W., McCarthy D.D., Johnson T.J., Kalarus M., 2004, Comparison of polar motion prediction results supplied by the IERS Sub-bureau for Rapid Service and Predictions and results of other prediction methods. Proc. Journees 2003, Systemes de Reference Spatio-Temporels, St. Petersburg, 164–169.

Kosek W., Kalarus M., Johnson T.J., Wooden W.H., McCarthy D.D. and Popiński W., 2005, A comparison of LOD and UT1-UTC forecasts by different combination prediction techniques" Artificial Satellites Vol. 40, No. 2, 2005, 119–125.

Kosek W. and Popinski W., 2006, Forecasting of pole coordinates data by combination of the wavelet decomposition and autocovariance prediction. Proc. Journees 2005 Systemes de Reference Spatio-Temporels, 139–140.

McCarthy, D.D., Petit, G. (eds.), 2004. IERS Conventions, IERS Technical Note 32.

Neumaier, A., Schneider, T., 2001, Estimation of parameters and eigenmodes of multivariate autoregressive models, ACM Transactions on Mathematical Software 27, pp. 27–57.

Niedzielski, T., Kosek, W., 2007, Prediction of UT1-UTC, LOD and AAM χ_3 by combination of the least-squares and multivariate stochastic methods, Journal of Geodesy, doi: 10.1007/s00190-007-0158-9.

Popiński W., Kosek W., 1995. Discrete Fourier and Wavelet Transforms in Analysis of Earth Rotation Parameters. Proc. Journees 1995 "Systemes de Reference Spatio-Temporels", Warsaw, 121–124.

Schuh, H., Ulrich, M., Egger, D., Mueller, J., Schwegmann, W., 2002, Prediction of Earth orientation parameters by artificial neural networks, Journal of Geodesy 76, pp. 247–258.

Wooden W.H., Johnson T.J., Carter M.S., Myers A.E., 2004, Near Realtime IERS Products. Proc. Journees 2003, Systemes de Reference Spatio-Temporels, 160-163.