

COMPARISON OF POLAR MOTION PREDICTION RESULTS SUPPLIED BY THE IERS SUB-BUREAU FOR RAPID SERVICE AND PREDICTIONS AND RESULTS OF OTHER PREDICTION METHODS

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ABSTRACT. In this paper, four different methods for the prediction of x , y pole coordinates are investigated. We examined the accuracies of autocovariance (AC), least-squares extrapolation (LS), a least-squares extrapolation and autoregressive combination (LS+AR), and a least-squares extrapolation and neural networks combination (LS+NN) in predicting pole position. The most accurate prediction is the combination of the least-squares extrapolation and the autoregressive prediction of the least-squares extrapolation residuals applied to the complex-valued pole coordinates data. The problem of any prediction method of pole coordinates data in the polar coordinate system is a significant prediction error of the integrated angular velocity.

1. INTRODUCTION

The current prediction method of polar motion data carried out in the IERS Rapid Service/Prediction Center, called in this paper the USNO prediction, is the least-squares extrapolation of a Chandler circle, and annual and semiannual ellipses fit to the last 400 days of the combined pole coordinate data (McCarthy and Luzum 1991, IERS 2003a). The differences between this LS extrapolation and the last observed pole position determined in the USNO combination and the rate reported by the IGS in their rapid series are used to adjust the curve. The polar motion prediction errors for a few days in the future are several times greater than their determination error, which is of the order of 0.1 mas. The main reasons for poor accuracy prediction of pole coordinate data are irregular amplitude and phase variations of short period oscillations with periods less than one year (Kosek 2000) and irregular phase and amplitude variations of the annual oscillation (Kosek *et al.* 2001, 2002). The two biggest maxima of the annual oscillation phase and amplitude preceded the two biggest El Niño events in 1982/83, 1997/98 (Kosek *et al.* 2001, 2002). We examined the abilities of the AC, LS, LS+AR, and LS+NN techniques to predict the x , y pole coordinates. In this paper the polar motion predictions were computed directly from the x , y pole coordinate data or from the predictions of the radius and angular velocity in the polar coordinate system (Kosek 2002, 2003).

2. DATA

The analysis used the USNO pole coordinate data resulting from combination of observational data in the years 1973 - 2003.8 with a sampling interval of 1-day (IERS 2003a), the IERS EOPC01 and EOPC04 pole coordinate data in the years 1846 - 2002 and 1962 - 2003.8 with the sampling intervals of 0.05 years and 1-day, respectively (IERS 2003b). To create one pole coordinate data file the EOPC01 data were interpolated with a 1-day sampling interval before 1962 and these interpolated data were extended from 1962 to 1976 by the EOPC04 data and by the USNO pole coordinate data after 1976.

3. AUTOCOVARANCE, AUTOREGRESSIVE AND NEURAL NETWORKS PREDICTIONS

The biased autocovariance estimations of a stationary and equidistant complex-valued time series z_t , $t = 1, 2, \dots, n$ and of the same time series extended by the first AC prediction point z_{n+1} are given by the following formulae:

$$\hat{c}_{zz}^{(n)}(k) = \frac{1}{n} \sum_{t=1}^{n-k} z_t \bar{z}_{t+k}, \quad \text{for } k = 0, 1, \dots, n-1 \quad (1)$$

$$\hat{c}_{zz}^{(n+1)}(k) = \frac{1}{n+1} \sum_{t=1}^{n-k+1} z_t \bar{z}_{t+k} \quad \text{for } k = 0, 1, \dots, n \quad (2)$$

The first predicted value is determined by the principle that the autocovariance of the extended time series coincide as closely as possible with the autocovariance estimated from the given series and it is expressed by the minimum condition (Kosek 1993, 1997, 2002; Kosek *et al.* 1998):

$$R(z_{n+1}) = \sum_{k=1}^{n-k} |\hat{c}_{zz}^{(n)}(k) - \hat{c}_{zz}^{(n+1)}(k)|^2 = \min, \quad (3)$$

The solution of the ensuing equation $\partial R(z_{n+1})/\partial z_{n+1} = 0$ yields the first prediction value:

$$z_{n+1} = \sum_{k=1}^{n-k} \bar{\hat{c}}_{zz}^{(n)}(k) z_{n-k+1} / \hat{c}_{zz}(0). \quad (4)$$

The second prediction point can be computed in the same way after the first one is added at the end of the time series. The following predictions are computed in a similar fashion.

In the AR prediction method the complex-valued autoregressive coefficients were computed using the Brzeziński (1994, 1995) algorithm, which is the modification of the Barrodale and Erickson (1980) algorithm for the maximum entropy coefficients of a real-valued time series. The optimum autoregressive order was estimated by Akaike's goodness-of-fit criterion: $\sigma_M(n+M+1)/(n-M-1)$, in which M is the optimum autoregressive order, n is the number of data and σ_M is the variance of the residuals.

In time series prediction by neural networks (NN) the main problem is to design the structure of the network and effectiveness of the training algorithm (Schuh *et al.* 2002). In this investigation the NN Toolbox of Matlab 5.3, in which the topology of the network consisted of two layers, was used. The input and hidden layers include 4 neurons with radial basis (*radbas*) transfer function and 2 neurons with linear (*purelin*) transfer function, respectively (Kalarus and Kosek 2003). This NN was generated using the *newff* Matlab function, which creates a feed-forward backpropagation network. The fastest and optimal method of training the NN

using Matlab function *trainlm* was used which updates weight and bias values according to the Levenberg-Marquardt optimization (More 1978).

4. POLAR MOTION PREDICTION IN THE POLAR COORDINATE SYSTEM

To predict the x, y pole coordinate data in the polar coordinate system, the observed data were first transformed to the radius and angular velocity (Kosek and Kalarus 1993). The first prediction points of the radius and angular velocity were transformed back to the Cartesian coordinate system using linear intersection formulae (Kosek 2002, 2003). To compute the radius it is necessary to compute the mean pole. The mean pole was computed using an Ormsby (1961) low pass filter and predicted by the LS method (Kosek 2003).

In order to compute predictions of the radius and angular velocity the AC prediction and the combination of the LS prediction with the autoregressive prediction of the LS extrapolation residuals (LS+AR) were applied. In the AC prediction the last 40 years of the radius and angular velocity time series were used. In the LS+AR prediction the LS model which consists of six oscillations with periods of 2220 days (6.1 years), 1200, 650, 310, 200 and 130 days (Kosek and Kalarus 2003) was fit to the last 35 years of the radius and angular velocity data and then the autoregressive coefficients were estimated from the last six years of the radius and angular velocity LS extrapolation residuals. The differences between the AC and LS+AR methods and USNO's combination solution for the x, y pole coordinates and their corresponding radius and angular velocity estimates are shown in Figure 1.

The mean prediction errors of the radius, integrated angular velocity, as well as the x and y pole coordinate data are shown in Figure 2. It can be noticed that the problem of prediction of pole coordinate data in the polar coordinate system is the significant error in the prediction of the integrated angular velocity. The prediction errors of the radius are smaller than those of the integrated angular velocity.

5. POLAR MOTION PREDICTION IN THE CARTESIAN COORDINATE SYSTEM

In the LS+AR prediction the LS extrapolation model of the Chandler circle, annual and semiannual ellipses and a bias was fit to the last ten years of the complex-valued pole coordinate data. The complex-valued autoregressive coefficients were computed from the last 870 days (twice the Chandler period) of the complex-valued LS extrapolation residuals.

To predict the x, y pole coordinate data by the combination of the LS and NN prediction methods (LS+NN) the LS model which consists of the linear trend as well as the Chandler and annual oscillations was computed from the beginning of the IERS EOPC04 data to the starting prediction epoch. The LS polar motion extrapolation residuals were interpolated with a 10 day sampling interval to reduce the computation time of training the NN. The pattern of training the NN was equal to 100 days in order to compute the first prediction point (Kalarus and Kosek 2003).

In the LS+AR and LS+NN prediction methods, the polar motion prediction is the sum of the LS extrapolation model and the AR or NN predictions of the LS extrapolation residuals. The differences between the LS+AR and LS+NN predictions of the x, y pole coordinate data and their future values at different starting prediction epochs are shown in Figure 3. It can be noticed that the prediction errors of the LS+AR prediction method are smaller than for the USNO and LS+NN prediction. The mean prediction errors of the x and y pole coordinate data in 1984-2003.7 for the USNO, LS+AR and LS+NN prediction methods are shown in Figure 4. Usually the mean prediction errors of the LS+AR prediction are less than for the USNO prediction in x and y . The mean prediction errors of the LS+NN prediction are less than for

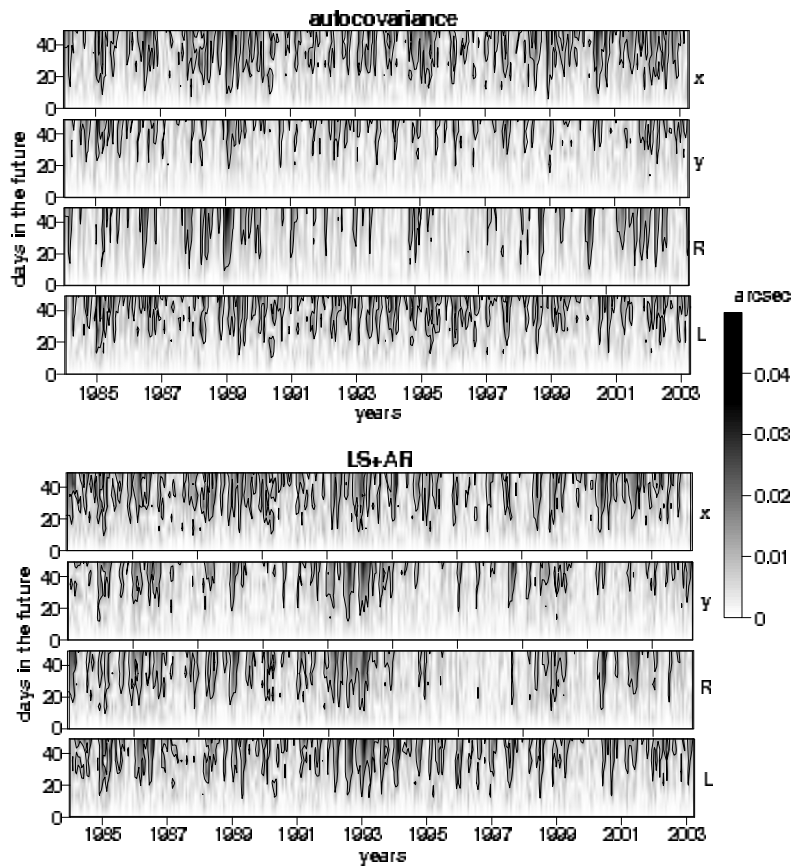


Figure 1: The absolute values of the difference between the pole coordinate data (x, y), radius R , integrated angular velocity L and their AC and LS+AR predictions computed at different starting prediction epochs in the polar coordinate system (contour lines at 0.01 arcsec).

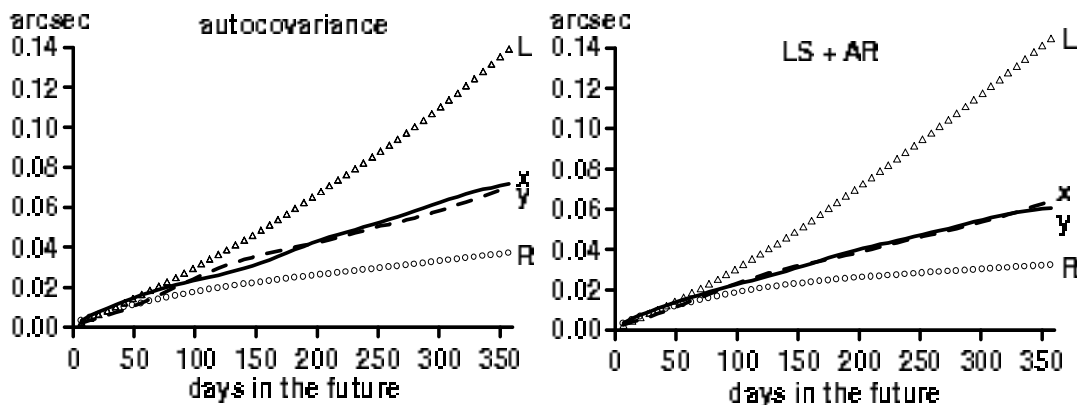


Figure 2: The mean prediction errors in 1984-2003.8 of the radius R (circles), integrated angular velocity L (triangles) and x (solid line), y (dashed line) pole coordinate data for the AC and LS+AR prediction methods applied in the polar coordinate system.

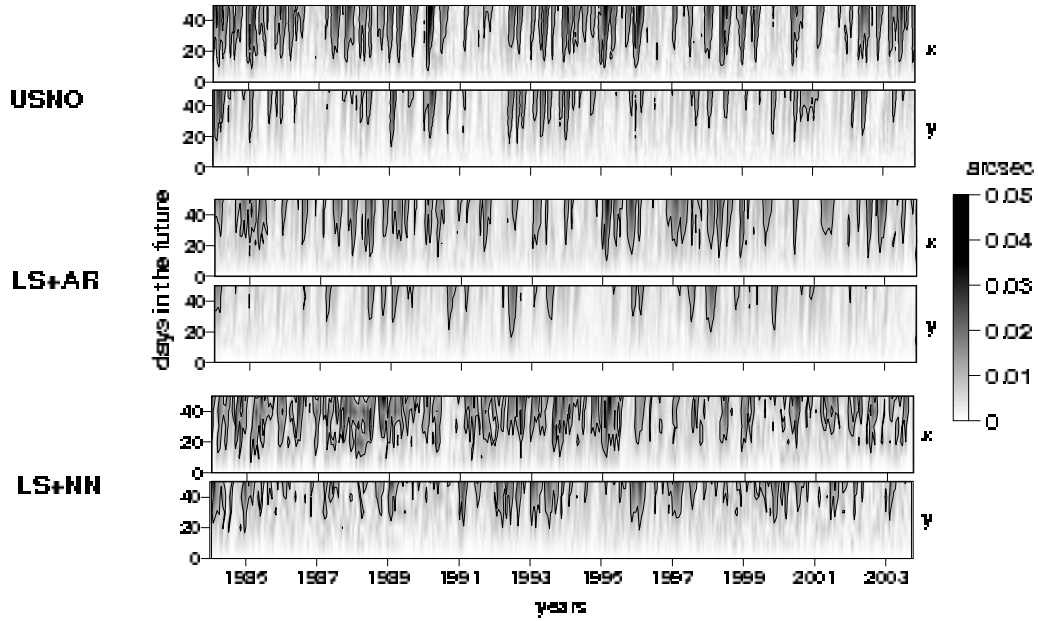


Figure 3: The absolute values of the difference between the x , y pole coordinate data and their USNO, LS+AR and LS+NN predictions computed at different starting prediction epochs (contour lines at 0.01 arcsec).

the UNSO prediction for prediction lengths greater than 30 to 40 days in x and for prediction lengths greater than 100 days in y . The mean prediction errors of the LS+AR and LS+NN predictions are of the same order for x and are less for the LS+AR prediction than for the LS+NN prediction in y for prediction lengths less than 100 days.

6. CONCLUSIONS

The problem of any prediction method of pole coordinate data in the polar coordinate system is the error in the prediction of the integrated angular velocity. The prediction errors of pole coordinate data using the combination of the LS+AR prediction method are smaller than for the USNO prediction. For predictions of less than 40 days into the future only the LS+AR out performs USNO, while for predictions greater than 100 days both LS+AR and LS+NN will

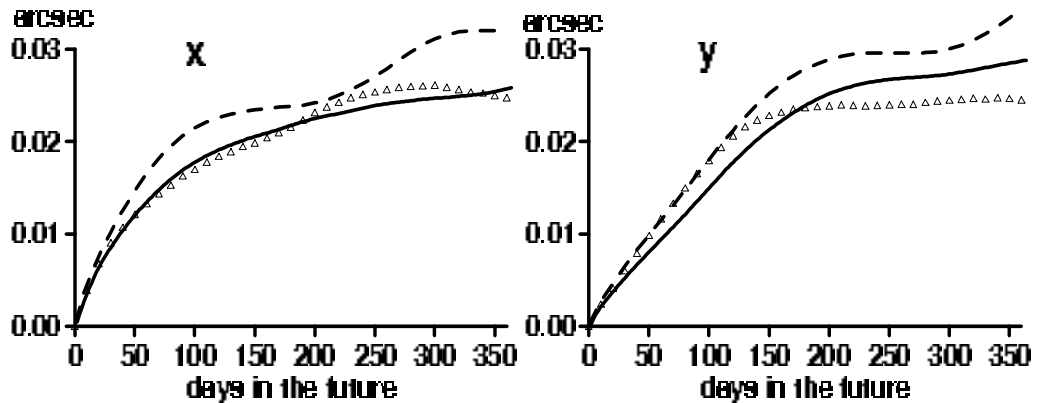


Figure 4: The mean prediction errors of the x and y pole coordinate data in 1984-2003.8 for the USNO (dashed line), LS+AR (solid line) and LS+NN (triangles) prediction methods.

perform better in both the x and y pole coordinate.

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