EOP Prediction with special focus on SLR

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Abstract

The Earth orientation parameters (EOP) became a significant interest in various fields of Earth sciences, astronomy, and climate change studies, as their variations are related to mass redistribution, gravitational, and geodynamic processes in the Earth system. Moreover, real-time EOP information is needed for many space geodetic techniques applications, including satellite navigation on ground and for low-Earth-Orbiters, as well as real-time tracking and navigation of interplanetary spacecraft, and climate forecasting. Currently, the EOP can be estimated at the best possible accuracies with modern high-precision space geodetic techniques like Very Long Baseline Interferometry (VLBI), Global Navigation Satellite Systems (GNSS), and Satellite Laser Ranging (SLR). However, the complexity and time-consuming data processing always lead to time delays. Consequently, predicting EOP is of great scientific and practical importance. Accordingly, several methods have been developed and applied for EOP prediction. However, the accuracy of EOP prediction is still not satisfactory even for prediction of just a few days in the future. Therefore, new methods or a combination of the existing approaches are investigated to improve the accuracy of the predicted EOP. Such in-depth investigations are currently conducted within the "EOP Prediction Comparison Campaign (EOP-PCC)" organized by IAG and IERS. We will briefly present the EOP-PCC and show our contribution. In this study, we investigate a new prediction package (input data and method) to improve the possibility of bridging the existing gap between the observation and the final estimated product. We run our prediction algorithm with official IERS EOP series as well as with our BKG's single-technique analysis products for VLBI and SLR using the combination of a deterministic and a stochastic method. This method consists of a deterministic part estimated by SSA, whereas Copula is used for modeling the stochastic component. We will show the potential of using the SLR technique to obtain real-time EOP estimates.

Keywords: EOP, Prediction, SLR, Copula-based analysis

1. Introduction

The Earth's axis of rotation and its orientation in space varies depending on the reference frame (terrestrial and celestial) due to various processes that contribute to rotational excitation. Therefore, studying the Earth's rotation can provide valuable information about the Earth's system (Seitz & Schuh, 2010). Real-time EOP are required for several fields and applications, such as fundamental astronomical and geodetic reference systems, precise satellite orbit determination, and space navigation (Kalarus, et al., 2010). The EOP can be monitored using modern, high-precision Spaceborne geodetic sensors such as very long baseline interferometry (VLBI), satellite laser ranging (SLR), lunar laser ranging (LLR), doppler orbitography and radiopositioning integrated by satellite (DORIS), and global navigation satellite system (GNSS). The International Earth Rotation and Reference System Service (IERS) Rapid Service Prediction Center at U.S. Naval Observatory (USNO), Washington DC, is responsible for providing the EOP data from the mentioned space geodetic techniques (Petit & Luzum, 2010). However, the EOP data are made available with a delay of hours. Besides, these estimations could benefit other applications related to astronomy, geodesy, timekeeping, and geophysics. Therefore, it is essential to predict the EOP parameters precisely. Many techniques have been designed and applied for EOP prediction. These techniques are classified into two main groups based on the input data (Modiri, 2021). The first group is the methods that use the information within the EOP time series, such as auto-covariance (AC), least squares (LS) collocation, wavelet decomposition, or neural networks. Also, the hybrid methods, such as the combination of least squares (LS) and auto-regressive (AR), auto-regressive moving average (ARMA), or auto-covariance and neural network. The second group is the methods that consider the geophysical parameters, such as the axial component of effective angular momentum (EAM) (Gross , et al., 1998). All these techniques are implemented and tuned to use the combined EOP data. However, a few studies have been done to predict EOP data using EOP obtained from a single space geodetic technique.

In this study, we investigate the potential of using EOP data obtained from SLR only, VLBI, and a combination of GNSS and VLBI, provided by the federal agency for cartography and geodesy (BKG) to show the potential of delivering operational EOP prediction data in an appropriate accuracy. The combination of singular spectrum analysis (SSA) and Copula-based analysis approach is used to model and predict EOP data for the next 10 days (Modiri, et al., 2018, 2020). The results show that the proposed method can precisely forecast EOP from a single space geodetic technique.

2. Methodology: Combination of Singular spectrum analysis and Copula-based analysis

The copula-based analysis is a stochastic method that is used to analyse and model the dependence structure between random variables that does not depend on their marginal distributions. The copula-based analysis is based on Sklar's theorem, a Copula function C connecting a multivariate distribution function with its univariate counterpart (Joe, 1997). The Copula-based analysis technique is used for different studies, e.g., economics (Patton , 2009), medicine (Namazi, 2022), hydro-meteorology (Laux , et al., 2011), hydro-geodesy and geodesy (Modiri, 2021). The SSA + Copula analysis approach is designed for two algorithms: case 1 only uses the information within a time series, and case 2 considers the information within a time series and other variables.

In case 1, the first part deals with the deterministic component, which SSA can model. Then, the residual of subtracted data by the reconstructed time series can be modelled by Copula-based analysis. Then, the periodic terms are extrapolated, and the anomaly part is predicted using Copula-based analysis separately. Finally, both predicted periodic and anomaly terms are combined (see Fig. 1).

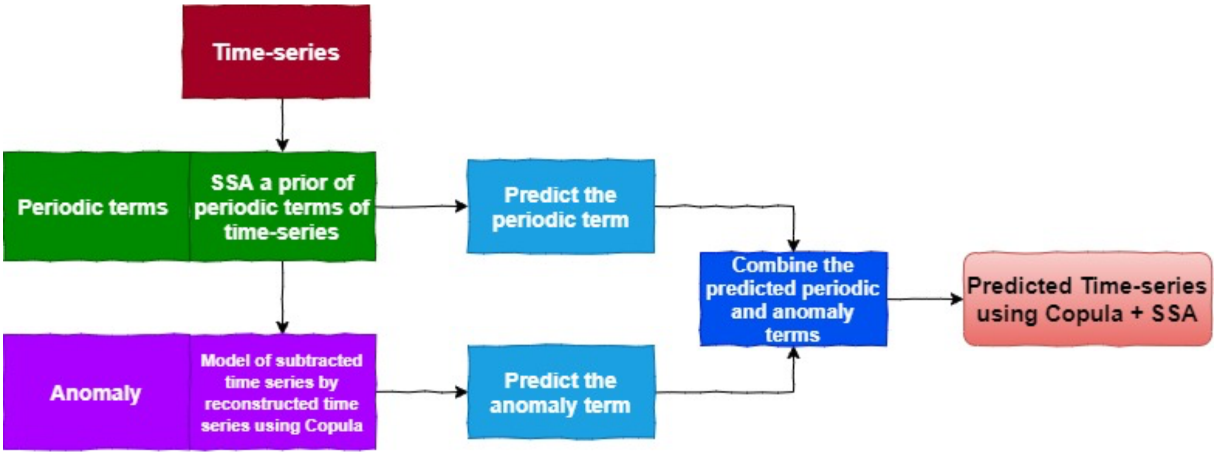

Figure 1: Copula + SSA algorithm for modeling and predicting the time series by using the information within the time series (case 1).

In case 2, the algorithm is aimed at utilizing some variables to forecast the EOP due to their existing relationship. Therefore, the dependence structure between time series one and two arising from geophysical parameters is derived using Copula-based analysis. The Copula-based analysis model the underlying relationship between the time series. The first time series is predicted based on the fitted theoretical Copula by conditioning the predicted second time series. Then, the remaining part is modelled using SSA and extrapolated. Finally, the Copula-based predicted data is added to the SSA forecasted residual (see Fig. 2).

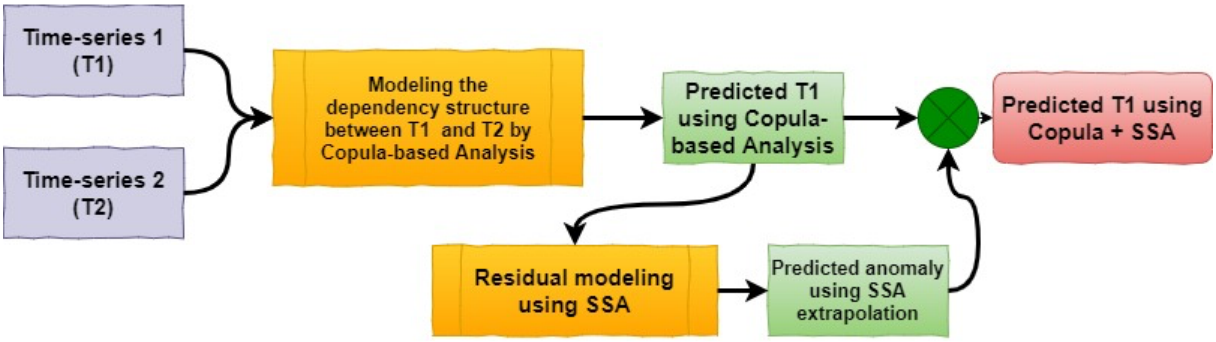

Figure 2: Copula + SSA algorithm for modeling and predicting the time series by using the information within the time series and other variables (case 2).

3. Data description

In this study, the PMx, PMy, and LOD time series (see Fig. 3) are taken from SLR observation provided by the ILRS analysis centre at the federal agency for cartography and geodesy (BKG). Also, the dUT1 data are obtained from the combination of VLBI and GNSS data and provided by the department of Geodesy at BKG (Lengert, et al., 2022). In order to compare and validate the results, the data obtained from the International Earth Rotation and Reference Systems Service (IERS) combined earth orientation parameter (EOP) solutions C04 (available at http://hpiers.obspm.fr/eop-pc/analysis/excitactive.html) are used. The EOP C04 series is derived from different geodetic techniques, and it is consistent with ITRF 2014, and the sampling interval is one day. As a result of mass redistribution in the atmosphere, terrestrial hydrosphere, and oceans, the effective angular momentum (EAM) explains the non-tidal geophysical excitation of the Earth's rotation. There are three main components to EAM data: X, Y, and Z. Polar motion is excited by the X and Y components, while LOD variation is excited by the Z component. A EAM function is dimensionless with a sampling period of 1 day, and it is provided by the Earth System Modeling group at the Deutsches GeoForschungsZentrum Potsdam (ESMGFZ) (Dobslaw & Dill, 2018).

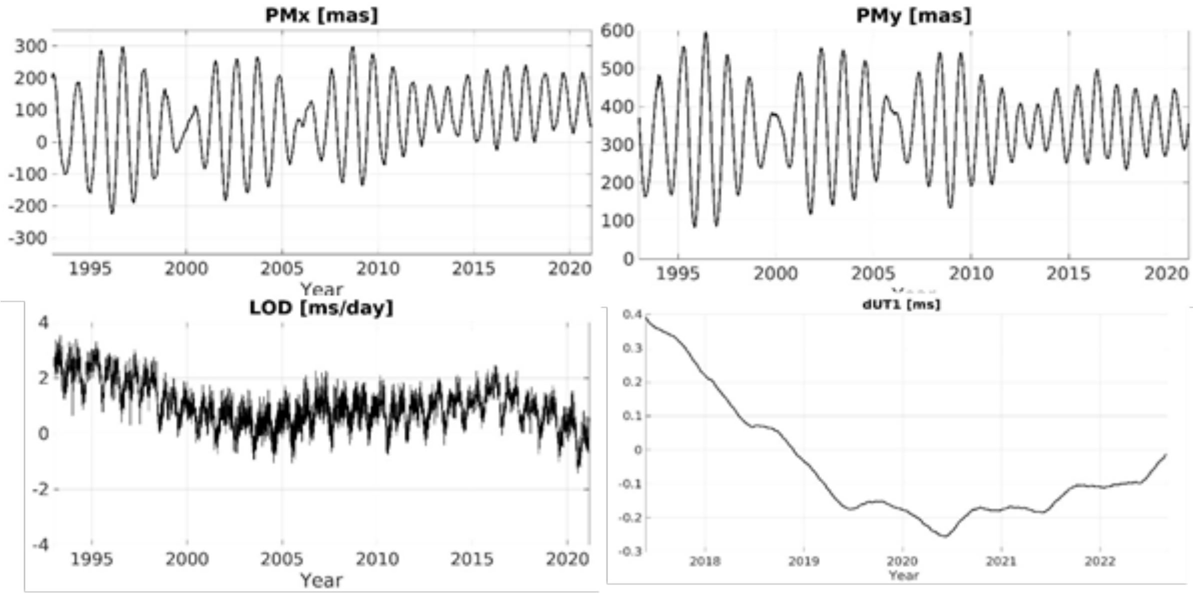

Figure 3: Polar motion and LOD time series obtained from SLR observations. The data are taken from ILRS Analysis center at BKG. dUT1 time series is obtained from the combination of GNSS Rapid sessions and VLBI Intensive sessions.

4. Data processing and analysis

As it was described in the methodology, we designed two algorithm, case 1 for PM and dUT1 prediction and case 2 for LOD prediction.

Case 1:

The observed PM and dUT1 time series can be divided into two components. The first part deals with periodic effects such as annual variation and influences of solid Earth tides on PM and dUT1. First, the SSA is employed to model the periodic terms. Then, the difference between the observed time series and SSA estimated data is modelled using the Copula-based analysis method. After that, the periodic terms of observed time series are extrapolated using the SSA a priori model. Correspondingly, the anomaly part is predicted using the Copula-based model. Finally, the anomaly solution is added to the SSA-forecasted time series.

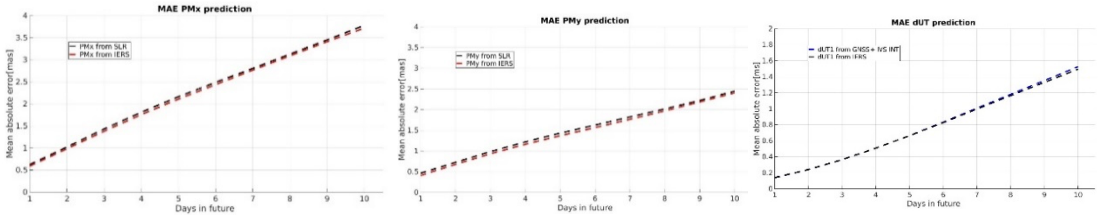

Figure 4: Mean absolute error of predicted EOP data from IERS EOP data.

As can be seen in Fig. 4, the mean absolute error (MAE) is estimated for the different input data for PM and dUT1 obtained form SLR, combined GNSS + IVS Intensive, and IERS. As shown in the results, using only SLR observation and combined GNSS and IVS data as input to the prediction model could maintain the same prediction error level compared to using IERS.

Case 2:

We defined an algorithm for LOD prediction as shown in Fig. 2. It is important to note that LOD can be decomposed into several components (e.g., variations related to the zonal components of solid Earth tides and ocean tides, atmospheric circulation, internal effects, and transfer of angular momentum to the Moon's orbital motion). Considering that the accuracy of the different models may not be homogeneous, we decided to include in the modelling of this study the total variation in LOD. As a result, testing the method's performance that relies partially on previous models for certain components may be more challenging. However, we preferred not to remove too many difficulties when testing the method as a means to get more insight into its capabilities. Therefore, the methodology is structured as follows. First, we analyze the EAMZ, the sum of mass and motion terms of AAM, HAM, and OAM. Then, the dependence structure between observed LOD and EAMZ is captured and modelled by using Copula-based analysis.

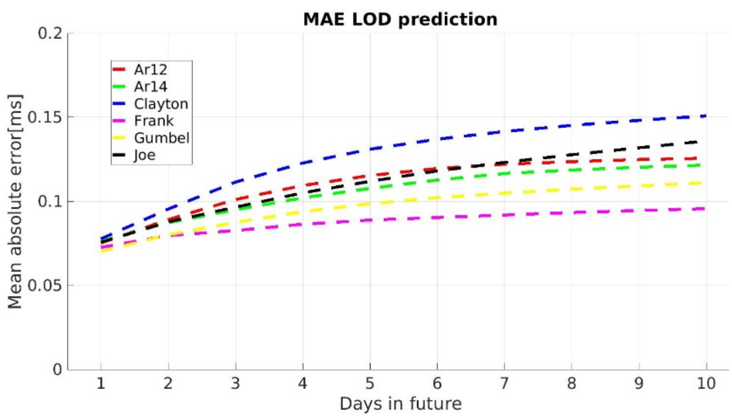

Figure 5: Mean absolute error of predicted LOD data using different Copula-based analysis approach.

5. Conclusion

In this paper, we discussed the importance of EOP prediction as the accuracy of the current EOP prediction still needs to be improved, even for forecasts of a few days into the future. Thus, new approaches/combinations of existing methods are required in order to be investigated to improve the accuracy of the predicted EOP. Therefore, the 2nd Earth Orientation Parameters Prediction Comparison Campaign (EOP PCC) has been performed under the auspices of the IERS since 2021 to discuss the main challenges of EOP prediction.

EOP prediction always faces two major challenges to provide the best prediction data, which input data to use and which prediction methods are superior to others. In order to target these challenges, we run our prediction algorithm with our BKG's single-technique analysis products for VLBI and SLR using the combination of a deterministic and a stochastic method and compare it with the official IERS EOP series as input data. The results show the potential of using only the SLR technique and combined GNSS and VLBI to obtain real-time estimation. Furthermore, the predictions obtained in this study demonstrate a comparable error with the existing methods and official IERS EOP series used for the 2nd EOP PCC.

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