Creation of harmonic models of planetary pole dynamics based on satellite observations and spectral correlation approach

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Received May 2, 2024
Revised August 18, 2024
Accepted October 30, 2024

The issues of constructing a dynamic model of the pole allowing for predicting its motion are considered. The method developed for these purposes is based on the spectral correlation approach and regression modeling. As a result of this work, as a practical example, predictive values of the Earth's pole motion were presented.

Keywords: planetary dynamics, pole motion, regression modeling.

DOI: 10.61011/TP.2024.12.60413.384-24

Simulation of planetary body positions with respect to their axes of rotation at various accuracy levels is currently becoming increasingly important [1]. Such investigations are necessary to examine astrophysical processes associated with refinement of the nature of polar vortices that occur in atmospheres of Earth, Mars and Titan, Saturn's moon [2]. Polar vortex scales are probably much more significant for terrestrial exoplanets that have heavy inclinations to the ecliptic plane. These studies are necessary to explore tides from massive bodies that are similar in their principle of action for celestial systems of different sizes — from planetary to galactic [3]. It is particularly important to emphasize the dependences of planet pole motion dynamics on the processes flowing in the liquid core and at the core-mantle interface, and on variations [4]. Importance of this direction is confirmed by anomalous effects of solar wind penetration in Earth's mid latitudes through magnetic field lines that causes lights similar to northern and southern lights. Rotation parameters of planetary objects are also required for precision space navigation and positioning [5]. As the prediction of polar motion is a difficult problem because of the influence of many planetary physical processes, a sufficiently large range of approaches is expected to solve this problem [6]. It should be noted that, unlike deterministic models, regression models are not constant in structure and values of variables throughout the utilization cycle. After predicting one or several future discrete intervals, the model is „updated" in accordance with the current variables. This property is important for predicting celestial body dynamics, including geophysical systems. This study investigates a correlation spectral approach (CSA) to build a harmonic polar and non-polar vibration model. This approach is one of the most reliable for detection of periodic harmonics. This study compares the observed dynamic terrestrial pole model (built directly on the OPEP data) and the theoretical predictive model that is built as an adaptive harmonic regressive model (HRM) describing the polar dynamics during 30 years and represented as a harmonic series. HRM coefficients were determined from the spectral analysis of observations using the stepwise regression method. These approaches are described in detail in [7–11]. The study used Earth's pole positions obtained from ground-based telescopic observations and GPS satellite data that are available at International Earth Rotation and Reference System Service website https://www.iers.org/IERS/EN/Home/home_node.html (OPEP — observed positions of the Earth's pole).

The CSA algorithm contains the following stages: an autocorrelation function (AF) characterizing the spectral power density of a random process is plotted, then the AF is smoothed using a lag window, and then periods and parameters of the variations of latitude from 1 year to hundreds of years are determined using the spectrum. The next stage investigates the structural characteristics of the variations, then implicit variation periods of spectral density depending on frequency parameters are identified. Harmonic expansion coefficients of non-polar variations have a complex structure that includes more than 20 frequency bursts and expressed spectral density differentiation. For CSA verification and validation, polar and non-polar variations of the terrestrial pole were determined using the ground-based and space observation data. Calculation algorithm consisted of the following stages:

1) program spectral window was formed for reduction of unequal observations;

2) general fundamental harmonics in observations were determined using the cross spectral method;

3) the Kalman filter was used for noise component leveling;

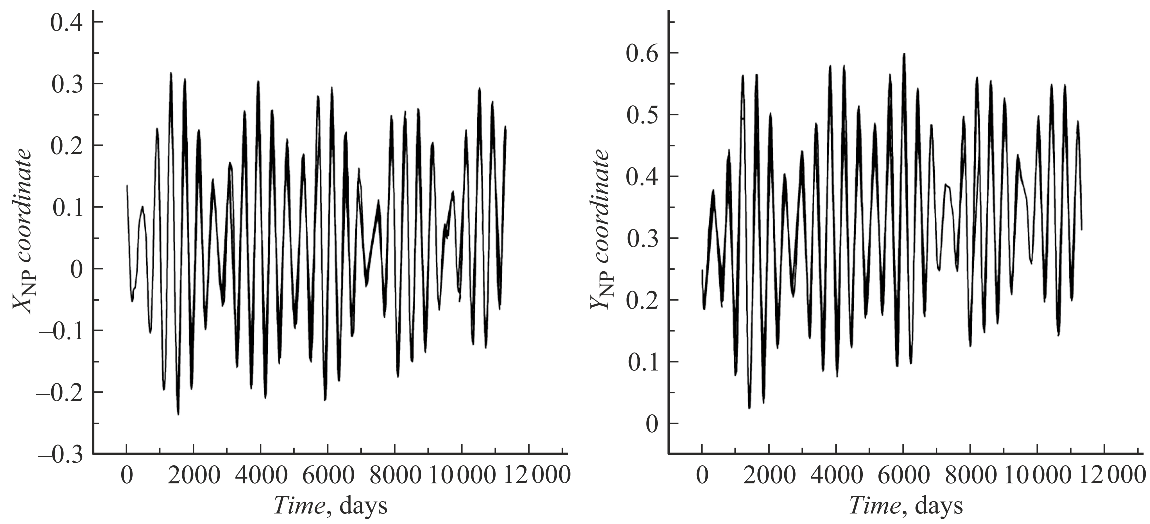

Figure 1. Earth's pole dynamics variations in the X and Y coordinates.

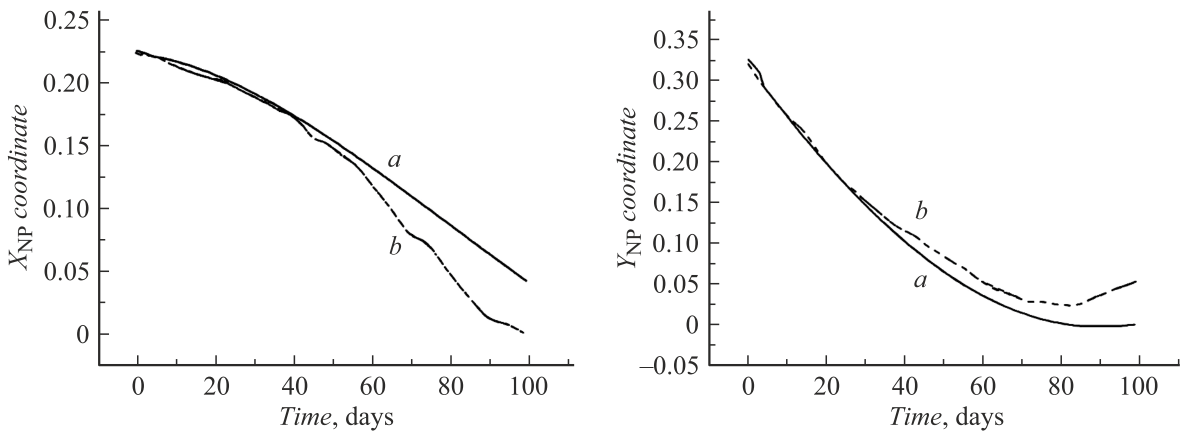

Figure 2. Comparative diagram o theoretical polar motion data (a) and observation data (b) in the X and Y coordinates.

4) the model was processed for computer-assisted formation of the most reliable deviation of the obtained observational model from the predictive theoretical model.

Figure 1 shows the Earth's pole dynamics variations in the X and Y coordinates. Pole coordinate variation analysis determined four fundamental harmonics with periods of 492, 444, 377, 363 days and with the approximation accuracy $(\sigma) = 0.1334$ and prediction accuracy$(\sigma\Delta) = 0.19$. Figure 2 shows the comparative diagram of terrestrial pole motion lines in the X and Y coordinates obtained from observations, and pole motion lines according to the predictive regressive theoretical model created in the work.

Figure 2 suggests that the theoretical model provides good approximation and prediction accuracy in the range of 60 days. Comparison with the North Pole dynamics diagrams plotted by other researchers showed that HRM provided more accurate prediction in the range of 70 days. For this, comparative analysis of our predictive curves with the Naval Observatory USA data was performed. This data is shown on the curves in Figure 3. As shown in diagrams, theoretical predictive values agree well enough both with the observation data and findings achieved by other researchers.

Finally, it should be noted that regressive modeling may be applicable to describe dynamic parameters of planet poles. The approach used in this work to review the observation time series has the following advantages:

1) wider representation of the regressive dynamic model structure;

2) time stability of harmonic expansion terms of the polynomial model;

3) significant increase in the prediction accuracy which is important for solution of practical tasks [12].

The following conclusion can be made: the CSA approach provided a terrestrial pole dynamics prediction for the time range from 50 to 80 days depending on the used observation data. The findings confirm that adaptive dynamic regressions might be useful for modeling celestial body pole motion. They have the following advantages:

1) extension of the mathematical dynamic model structure concept;

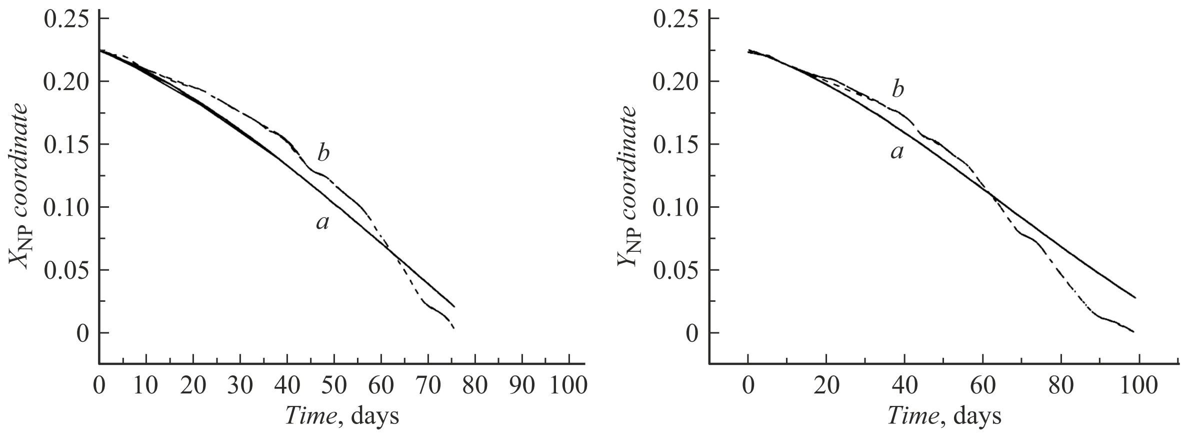

Figure 3. Comparative analysis diagrams of predictive curves (a) with the Naval Observatory USA data (b) in the X and Y coordinates.

2) identification of time-stable harmonics of the observation series expansion, which may be of great practical importance.

It should be noted that pole dynamics prediction activities are necessary not only to explore the nature of polar vortices on the terrestrial planets, but also theoretically they might be applicable to exoplanets. However, a significant number (to be more specific — the most part) of experimentally detected exoplanets are classified as gas planets (hot and warm Jupiters as well as gas giants). Gas giants in the Solar System have a significantly higher atmospheric activity compared with the terrestrial planets and gas exoplanets most likely also have this property. Consequently, pole motion variations of such planets may result in quite significant effects. Therefore, our study may be continued as the investigation of gas planet pole motion.

Funding

This work was supported by Russian Science Foundation, grants no. 24-22-00260.

Conflict of interest

The authors declare no conflict of interest.

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Translated by E.Ilinskaya