

## Postprint of Data Analysis Research Based on Time-Frequency Data Platform

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### Abstract

Time-frequency data resources constitute important national information assets. The time-frequency data platform is designed based on time-frequency data generated from the operation of the National Time Service Center, along with time-frequency-related data published by the Bureau International des Poids et Mesures (BIPM) and the International Earth Rotation and Reference Systems Service (IERS). This data platform can provide abundant data resource support for timekeeping technology research. This study first introduces the construction of the time-frequency data platform, and subsequently conducts timekeeping technology research utilizing the local timekeeping system comparison and long-distance link comparison data aggregated by the platform. The research includes atomic clock status evaluation, focusing on analyzing abnormal jumps in atomic clocks and investigating jump data processing methods. For different types of timekeeping clocks, the study analyzes and compares atomic clock performance indicators such as fluctuation and stability. Furthermore, clock difference prediction research is performed based on the ARIMA model. The aforementioned research results can provide important references for the continuous and reliable operation of timekeeping systems.

### Full Text

### Preamble

#### Data Analysis and Research Based on the Time-Frequency Data Platform

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**Abstract:** Time-frequency data resources constitute important national information assets. The time-frequency data platform is designed based on time-frequency data generated from the daily operations of the National Time Service Center, as well as relevant data published by the Bureau International des Poids et Mesures (BIPM) and the International Earth Rotation and Reference Systems Service (IERS). This platform provides abundant data resources for time-keeping technology research. This paper first introduces the construction of the time-frequency data platform, then utilizes local time-keeping system comparison data and long-distance link comparison data collected by the platform to conduct time-keeping technology research. This includes atomic clock state evaluation with a focus on analyzing abnormal atomic clock jumps and developing processing methods for jump data. For different types of time-keeping clocks, we analyze and compare performance indicators such as fluctuation characteristics and stability. Additionally, clock difference prediction research is conducted based on the ARIMA model. These research results provide important references for the continuous and reliable operation of time-keeping systems.

**Keywords:** time-frequency; data platform; time-keeping technology; atomic clock; time-keeping system

## Introduction

With the continuous advancement of science and technology in China, time has become a crucial research topic [1]. High-precision time significantly impacts numerous sectors, including satellite navigation and metrology in scientific research, as well as transportation, power distribution, and social production in daily life [2-3]. Research on time encompasses long-distance comparison techniques, where high-precision time comparison based on the BeiDou system shows broad prospects, and local time-keeping systems, where studies on time-keeping technology, atomic clock physical performance, and time-keeping system steering control are of great significance. All such research fundamentally relies on the collection and integration of time-frequency data resources.

In response to the growing demand for time-frequency data resource services, a dedicated time-frequency data platform has emerged [4-5]. The establishment of this platform plays a vital role in standardized storage, data sharing, network formation, user services, and research-driven applications of time-frequency data. The platform employs a multi-layer application architecture with component-based development, implementing data classification and grading. The system demonstrates strong stability and can meet large-scale application demands, featuring high efficiency, security, and scalability. Currently, the constructed data

service platform integrates data from local time-keeping systems, remote link comparisons, and international service agencies, covering atomic clock weights, clock rates, frequency drift, CGGTTS, RINEX, and bulletin data. At the data structure level, the platform comprehensively classifies and categorizes data, essentially satisfying users' one-stop application needs.

Users can perform deep mining of time-frequency data resources through the platform to conduct fundamental research and realize their full value. This paper focuses on three critical aspects that serve as essential references for stable time-keeping system operation: atomic clock performance analysis, abnormal atomic clock jumps, and clock difference prediction. These studies are vital for ensuring continuous and reliable time-keeping system operation. While current applications are not limited to these areas, future work will integrate more relevant data resources to enable multi-level and multi-faceted research.

## 1. Construction of the Time-Frequency Data Platform

Time-frequency data holds significant application value for astronomy, geodynamics, physics research, information transmission, power distribution, deep space exploration, space travel, navigation and positioning, weapons testing, seismic monitoring, and metrology [6]. Consequently, constructing a dedicated time-frequency data platform is of profound importance.

The platform implements standardized storage based on the structural characteristics of time-frequency data and follows a multi-layer application architecture. The core and bottom layer of the data platform is not directly exposed, which effectively enhances database security. The data module division of the time-frequency data platform is completed according to time-frequency data classification and grading standards. These classification criteria include data usage methods, data release schedules, data characteristics, update frequencies, and data volume. Current platform data resources include atomic clock comparison data, atomic clock status parameter data, data released by BIPM, and bulletin data.

The system platform exhibits strong scalability. With the addition or removal of atomic clocks, updates to time-keeping system modules, and increasing access demands, the system can be upgraded by scheduling and upgrading components at different system levels or extending newly added components to meet new requirements and evolving database construction demands.

The constructed platform features security, integrity, reliability, continuity, and authority, providing crucial foundational technical support for time-frequency scientific research and development, as well as basic guarantees for various time-frequency technology and application studies. [Figure 1: see original paper] shows the homepage of the time-frequency data platform.

## 2. Time-Keeping Technology Research

### 2.1 Abnormal Jumps in Atomic Clocks and Processing Methods

Based on local time-keeping system measurement data and real-time atomic clock performance metrics from the time-frequency data platform, research on abnormal atomic clock jumps and related processing methods can be conducted.

Atomic clock jumps are classified into phase jumps and frequency jumps [7]. Phase jumps are more pronounced and cause relatively strong disturbances to the entire time-keeping system [8-10]; therefore, this paper focuses primarily on phase jumps. The causes of phase jumps are numerous, including atomic clock physical anomalies, environmental temperature and humidity variations, electromagnetic interference, and power interruptions. Abnormal jumps affect the stable operation of time-keeping systems. For instance, atomic clock jumps can cause fluctuations in continuously operating time-keeping systems. Moreover, if the atomic clock's weight is not restricted, it can lead to abnormal steering calculations for the system.

Abnormal jump detection is based on threshold values; values exceeding the threshold are identified as anomalies. Detection thresholds are typically set based on empirical values. After identifying abnormal values, processing methods such as least squares fitting can be applied. This method calculates a fitting polynomial by minimizing the sum of squared deviations. The principle assumes a fitting polynomial:

$$y = a_0 + a_{1x} + a_{2x}^2 + \dots + a_{mx}^m$$

The sum of squared fitting deviations is expressed as:

$$\sum_{i=1}^n e_i^2 = \sum_{i=1}^n (y_i - a_0 - a_{1x}i - a_{2x}i^2 - \dots - a_{mx}i^m)^2$$

The minimum value corresponds to an extremum where partial derivatives equal zero. Taking partial derivatives of the right side and simplifying yields:

$$\begin{cases} \frac{\partial}{\partial a_0} \sum e_i^2 = 0 \\ \frac{\partial}{\partial a_1} \sum e_i^2 = 0 \\ \vdots \\ \frac{\partial}{\partial a_m} \sum e_i^2 = 0 \end{cases}$$

This leads to the normal equations:

$$\begin{pmatrix} n & \sum x_i & \cdots & \sum x_i^m \\ \sum x_i & \sum x_i^2 & \cdots & \sum x_i^{m+1} \\ \vdots & \vdots & \ddots & \vdots \\ \sum x_i^m & \sum x_i^{m+1} & \cdots & \sum x_i^{2m} \end{pmatrix} \begin{pmatrix} a_0 \\ a_1 \\ \vdots \\ a_m \end{pmatrix} = \begin{pmatrix} \sum y_i \\ \sum x_i y_i \\ \vdots \\ \sum x_i^m y_i \end{pmatrix}$$

The fitted values are then:

$$\hat{y} = X(X^T X)^{-1} X^T Y$$

A cesium atomic clock Cs3436 from the National Time Service Center of the Chinese Academy of Sciences was randomly selected from the time-frequency data platform. After removing constants and converting to nanoseconds, a phase jump was assumed to occur at Julian Day 59370.253, as shown in [Figure 2: see original paper]. The least squares fitting method was applied to correct the jump, with results shown in [Figure 3: see original paper]. The results demonstrate that this method effectively corrects abnormal jumps, proving the algorithm's validity.

## 2.2 Performance Analysis of Time-Keeping Atomic Clocks

Using bulletin data, atomic clock phase data, rate data, and long-distance link comparison data from the time-frequency data platform, performance analysis of time-keeping atomic clocks can be conducted [11-13]. Stability is a crucial metric for evaluating atomic clocks, and Allan variance is a commonly used method in the time domain for analyzing time-frequency stability with good confidence. The Allan variance calculation formula is:

$$\sigma_y^2(\tau) = \frac{1}{2(M-1)} \sum_{i=1}^{M-1} (x_{i+1} - x_i)^2$$

where  $x_i$  represents the  $i$ -th phase data interval,  $M$  is the number of continuous measurements, and  $\tau$  is the sampling interval.

Three cesium clocks and three hydrogen masers from the National Time Service Center of the Chinese Academy of Sciences were randomly selected from the time-frequency data platform for January 2022 comparison data. The relevant fluctuation characteristics are shown in [Figure 4: see original paper], and stability calculation results are shown in [Figure 5: see original paper].

The data processing procedure involves selecting one month of atomic clock difference data for rate and frequency drift prediction, followed by frequency correction. As shown in [Figure 4: see original paper], cesium atomic clocks exhibit more pronounced clock difference fluctuations, while hydrogen masers show smaller fluctuations but possess long-term trend components. [Figure 5: see original paper] presents the stability comparison of the six clocks calculated

using Allan variance. The results indicate that hydrogen masers have better short-term stability than cesium clocks, but due to their generally larger frequency drift, their long-term stability deteriorates.

### 2.3 Clock Difference Prediction Based on ARIMA Model

Atomic clock difference prediction forms the basis for calculating reference values in time-keeping system dynamic control [14] and also serves an atomic clock anomaly detection function. When the difference between predicted and actual clock differences exceeds a certain range, the atomic clock is deemed abnormal. Therefore, clock difference prediction is of great significance [15-20].

Since atomic clock difference data are often non-stationary sequences, the ARIMA model transforms non-stationary data into stationary data through differencing. The modeling is simple, and the computation process depends only on the data itself. Thus, this paper adopts the ARIMA model for clock difference prediction. The ARIMA model consists of two components: the AR (AutoRegressive) model and the MA (Moving Average) model.

The AR model can be expressed as:

$$x_t = \phi_1 x_{t-1} + \phi_2 x_{t-2} + \dots + \phi_p x_{t-p} + u_t$$

where  $p$  is the order of the autoregressive model and  $\phi_i$  are the autoregressive coefficients. Typically,  $u_t$  in the AR model is a  $q$ -order moving average.

The MA model is expressed as:

$$u_t = \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \dots + \theta_q \varepsilon_{t-q}$$

where  $\varepsilon_t$  is white noise.

The general ARIMA model expression is:

$$x_t = \phi_1 x_{t-1} + \dots + \phi_p x_{t-p} + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \dots + \theta_q \varepsilon_{t-q}$$

The core of the ARIMA model is predicting current data from historical data. For non-stationary data, differencing is applied to obtain stationary data as model input. The autoregressive order  $p$ , moving average order  $q$ , and differencing order  $d$  must be determined. The differencing order  $d$  is determined by the number of differences required to make the sequence stationary, while  $p$  and  $q$  can be obtained through autocorrelation and partial autocorrelation functions or based on AIC and BIC criteria.

A hydrogen maser VCH067 from the National Time Service Center of the Chinese Academy of Sciences was randomly selected from the time-frequency data

platform for one month of data as the research basis. The ARIMA model was applied for prediction. The clock difference prediction results are shown in [Figure 6: see original paper], the residuals between predicted and actual clock differences are shown in [Figure 7: see original paper], and the RMS of the prediction is shown in [Figure 8: see original paper].

As shown in [Figure 6: see original paper] and [Figure 7: see original paper], the ARIMA model-based clock difference prediction results show good agreement with actual clock difference data, with consistent trends. The residuals between predicted and actual clock differences remain within  $\pm 0.2$  ns. [Figure 8: see original paper] shows the root mean square error of the predicted clock difference calculated using a daily sliding window, which essentially remains within 0.1 ns. These results demonstrate that ARIMA model-based clock difference prediction performs well and can provide references for both time-keeping system clock difference prediction and satellite clock difference prediction.

## Conclusion

This paper first introduced the background and specific deployment of the time-frequency data platform construction. Subsequently, fundamental research was conducted using local atomic time comparison data and international bulletins from the data platform, including analysis and processing methods for atomic clock jumps, investigation of time-keeping atomic clock fluctuation characteristics, stability performance analysis, and clock difference prediction research based on the ARIMA model. These three fundamental studies provide references for stable, reliable, and continuous operation of time-keeping systems. As the time-frequency data platform continues to improve and the variety of datasets expands and optimizes, its application space will undoubtedly become broader.

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*Note: Figure translations are in progress. See original paper for figures.*

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