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Analysis of the Midnight Mean Correction in the Study of Secular Variation of the Geomagnetic Field

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Article

Keywords: secular variation, main magnetic field, midnight mean value, external fields

Posted Date: September 15th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10834291/v1

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Analysis of the Midnight Mean Correction in the Study of Secular Variation of the Geomagnetic Field

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Abstract: The external geomagnetic field changes rapidly over time, which can directly affect the calculation accuracy of the secular variation (SV) of the geomagnetic field. The external geomagnetic field changes calmly at night. Therefore, we usually use diurnal correction to uniformly calculate the observed data to the midnight hours of the specified date to eliminate the external field elements. However, in practice, the geomagnetic field still contains significant external field factors (denoted by Δ) during the midnight hours. This paper analyzes the influence of Δ on SV calculation, proposes a technical idea of eliminating Δ factors through midnight mean correction, and develops a midnight mean correction method based on the weighted least squares method. Subsequently, the midnight mean correction test is conducted using the data from 33 reference geomagnetic observatories and 967 field repeat stations in the Geomagnetic Network of the Chinese mainland, and the results are statistically analyzed. The main conclusions include: ① The Δ factors fluctuate at high frequency and are significantly correlated with the magnetic disturbance intensity, which can cause complex interference to the SV results. ② By using the weighted least squares method to fit the nighttime mean values in the magnetic quiet days, the internal and external field elements can be reasonably decomposed, thereby effectively eliminating the influence of the Δ factors on the SV results. ③ The Δ factors appear large spatial scale, and their values and spatial distribution patterns change rapidly over time, and are significantly affected by the intensity of magnetic disturbance. During the magnetic disturbance days, the absolute value mean(AVM) of the Δ factors of horizontal component (H), declination (D) and vertical component (Z) are 3.4 times, 2.5 times and 2.7 times respectively that during the quiet days. The Standard deviations are respectively 1.3 times, 2.1 times and 1.2 times that during the quiet days. ④ In the case of field survey data processing, the midnight mean corrections have produced definite effects. The values and spatial distribution patterns of the SV results of the D, I (inclination) and F (total intensity) have changed significantly. The AVMs of the SV correction values are 0.11 ', 0.27 ' and 5.55 nT respectively, and the relative change rates of the SV results are 2.3%, 7.4%, and 14.6% respectively.

Keywords: secular variation; main magnetic field; midnight mean value; external fields

1. Preface

The geomagnetic field is a multi-source field, and the temporal variation characteristics of the elements of each field source are different. The slow variation in the intensity and direction of the

Earth's main magnetic field over time is called secular variation (SV). SV is an important part of geomagnetics research. Relevant scholars have conducted a large number of studies, including the establishment of SV models, global and regional characteristics of SV, SV prediction, etc[1-5]. SV originates from the main magnetic field. To study SV, it is first necessary to eliminate the influence of other magnetic field elements. Overall, the geomagnetic field is composed of external field and internal field. In addition to the main magnetic field, the internal field also includes the crustal magnetic field. However, the temporal variation of the crustal magnetic field is very slow and is usually ignored in SV studies. In contrast, although the proportion of external field in the geomagnetic field is very low (on average globally, external field only accounts for 1% of the Earth's total magnetic field), their temporal variations are rapid and complex, which can cause complex disturbances to SV calculation. Therefore, how to eliminate the influence of external field is a technical problem that must be faced in SV research.

Geomagnetic observations provide fundamental data for SV research. Meanwhile, various global and regional main magnetic field models established based on measurement data have further become the core tools for SV research[6-13]. In data processing, external field is often eliminated through two ways. The first one is to preprocess the observed data using diurnal variation correction before establishing the main magnetic field model. This method takes advantage of the fact that the external field variation is most calm during the midnight hours. It uniformly refers the observation time of the data to 0:00 on a certain day to eliminate the external field elements. The second approach is to further establish a specialized external field model to independently describe the external field. For instance, as a primary method for studying global magnetic fields, spherical harmonic analysis has achieved remarkable success in the separation of internal and external fields. By separately solving the spherical harmonic coefficients of the internal and external fields, independent models of the internal and external fields can be established simultaneously, thereby clearly decomposing the internal and external fields at the model representation level.

The establishment of the external field model is of great significance for improving the accuracy of the main magnetic field model. Traditional spherical harmonic models such as international geomagnetic reference field(IGRF) usually ignores the external field elements during modeling, which affects the accuracy of the main magnetic field model in a way [14-15]. With the in-depth application and research of satellite magnetic data, in recent years, models such as comprehensive model of the geomagnetic field (CM) and CHAMP/Orsted/SAC-C model (CHAOS) have further improved the description accuracy of the main magnetic field and SV by establishing specialized external field models, playing an important role in related research work [16-19]. However, as global models, due to the diverse components of the external field and the complex temporal and spatial variations, as well as the limitations of basic data resources, models such as CM still have significant computational errors[20-22]. The regional geomagnetic field analysis methods such as spherical cap harmonic and rectangular harmonic can also achieve the separation and treatment of internal and external fields in principle, but essentially they are similar to spherical harmonic analysis and will also face similar difficulties. Therefore, there are considerable difficulties in further improving the accuracy of the external field model.

As mentioned above, in addition to establishing an external field model, methods to eliminate the influence of external fields also include performing diurnal variation correction processing on the observed data. Diurnal variation correction eliminates the external field elements by reducing

the observed data to the midnight hours when the external field variation is relatively calm. Is there still room for technological improvement in diurnal variation correction? The midnight mean value is the average of the geomagnetic field values from 0 to 3 local time, and is usually used as the reference value for diurnal variation correction. However, by observing the time-series curve of the mean value of the observatory at midnight, it can be found that its values fluctuate frequently with the changing trend, indicating that it still contains obvious external field elements (represented by the symbol Δ in this paper). Some scholars have pointed out this problem[23-24]. When conducting SV studies, researchers often perform some preliminary preprocessing for the midnight mean, such as calculating the annual mean, moving average, and selecting data in quiet days, to reduce calculation errors. However, since no effective stripping treatment was carried out on the Δ factors, its influence cannot be fully eliminated. Field geomagnetic measurement is another important ground-based magnetic measurement method. Through regular repeated measurements, SV information with high spatial resolution can be obtained. Before the field measurement data is used, it needs to be processed by diurnal variation correction to uniformly calculate the measurement data of each observation point to the midnight mean value of the specified date. Since we are unable to average or smooth single midnight mean, the influence of the Δ factor is more severe, which may lead to significant systematic deviations for SV results. Obviously, if we can further correct the Δ factors, it will provide higher-quality basic data for SV research, and obtain more reliable SV results. Compared with improving the external field model, this is a more direct and convenient method.

In conclusion, common diurnal correction cannot completely eliminate the influence of external fields, and the Δ factors in the midnight mean value can have complex influence on the calculation results of SV. To address this issue, this paper intends to separate the Δ factors based on the time variation characteristics of the Δ factors and perform correction processing using the weighted least squares method to enhance the accuracy of SV results (Since the processing object is the external field in the midnight mean, this processing procedure is named midnight mean correction). Furthermore, tests are conducted using observatory and field data to systematically analyze the temporal and spatial variation characteristics of the Δ factors, in order to explore the significance and role of midnight mean correction in SV calculation.

2. Data and Methods

1. Adopted data

The China Earthquake Administration has established a large-scale seismic and geomagnetic observation system in the Chinese mainland, which includes two major subsystems:network of observatories and network of field repeat stations, and is rich in data. This paper selects the data of 2020 and 2021 from 33 reference geomagnetic observatories and 967 field stations in the central and eastern regions of China (figure 1) for the midnight mean correction test. The average distance between observatories is approximately 500 km. The recording components are H, D and Z. Data quality control was carried out through a series of strict procedure[25-26]. The average space between repeat stations is some 70km, and the measurement components are D, I and F. The positions of the stations are strictly fixed by burying marble markers.

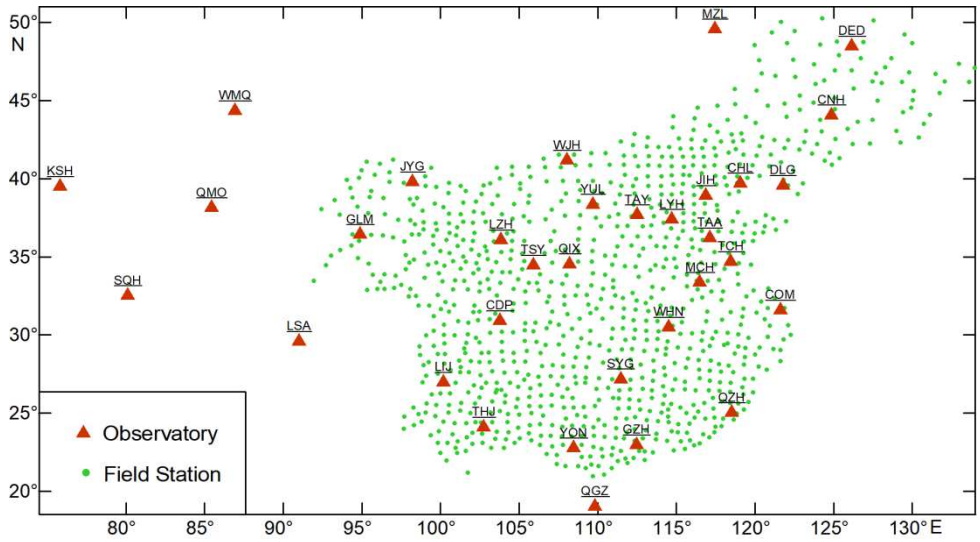


Figure 1 The spatial distribution of the geomagnetic observatories and field repeat stations used

2. The methods

2.1 Basis for Selecting Methods

The separation of internal and external fields is the basis of the midnight mean correction. In this paper, the separation method is selected based on the morphological characteristics of the temporal variation of the midnight mean. Taking the annual midnight mean values of the three components H, D and Z of LYH Observatory in 2023 as an example, the time-series variation curves are plotted (figure 2). The main magnetic field originates from the outer core of the Earth. Due to the shielding effect of the high-conductivity mantle, only long-period (more than several years) variation can be observed on the ground[27]. The high-frequency fluctuations of the midnight mean value in the figure indicate that in addition to the main magnetic field, there are also visible external field elements (the temporal variation of the crustal magnetic field is close to static and can be ignored).

The external field is composed of quiet variation and disturbance variation. The quiet variation appears a solar day cycle, and the variation amplitude at midnight is very small. Therefore, the Δ factors are mainly composed of disturbance variation. To further check the influence of magnetic disturbance intensity on the Δ factors, blue dots and red asterisks are respectively marked for quiet days and disturbance days in the figure. It can be seen that:

1. The midnight mean value varies day by day, but the overall trend remains stable. It reflects the characteristic that the SV varies slowly while the Δ factor does rapidly.

2. The average fluctuation range of the midnight mean value on disturbance days is significantly greater compared with quiet days, while the fluctuation range on other common days lies between the two.

3. The fluctuation ranges of some data are significantly large, and form outliers. Most of these outliers occur on disturbance days and are generally biased towards a specific direction (H tends to be negative, while D and Z tend to be positive). Outliers may also occur during quiet period, but their quantity and amplitude are significantly lower.

From the above analysis, it can be seen that the midnight mean value contains obvious Δ factors and will interfere with the SV results. The Δ factors appears to be obvious bias, so the common method and moving average calculations are difficult to completely eliminate their influence. It is necessary to remove them through targeted midnight mean correction. Based on the

morphological characteristics of the midnight mean value, this paper intends to select the midnight mean value in quiet days and apply the weighted least squares method to fit them, divide the internal source field and the Δ factor and obtain more reliable SV results.

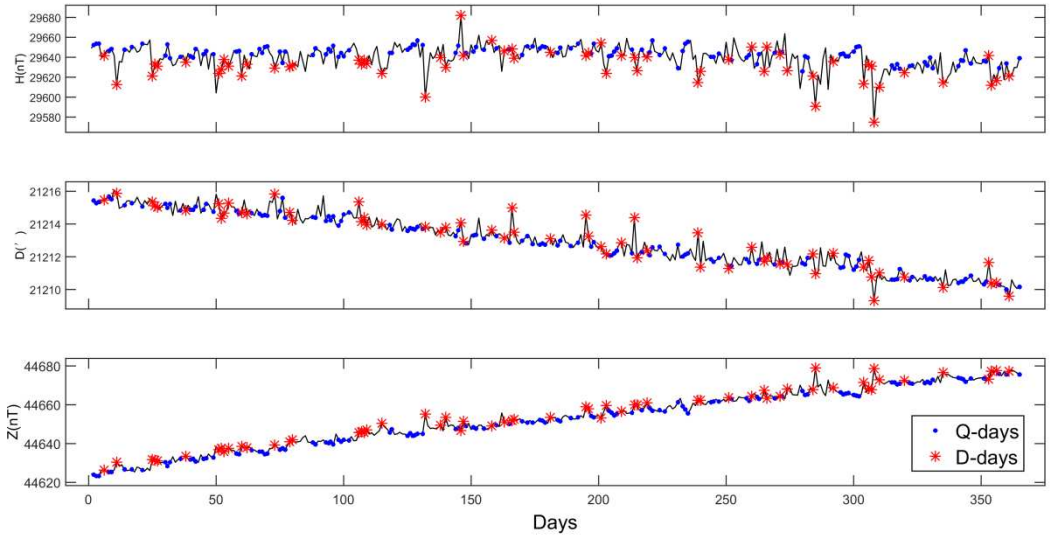


Figure 2 The time-series variation of midnight mean value of LYH observatory in 2021

2.2 Weighted Least Squares Algorithm

The conventional least square method assigns the same weight to each data point, and minimizes the sum of squares of the fitting residuals of each data point. The fitting residual of outliers is very large, which will cause deviations in the fitting results. As mentioned above, even during the quiet days, the midnight mean value shows a high-frequency fluctuation pattern with a certain number of outliers, which requires targeted treatment. The weighted least squares method also known as the robust least squares method, is based on the principle of large residual and small weight. It sets very small fitting weight for outliers, obtains stable fitting results through iterative algorithms, and achieves the optimization of the conventional least squares algorithm[11,28-30]. Let the measured value be Z, the fitted value be $\hat{Z}$, and the weight value be W. Then the fitting result of the weighted least squares method should satisfy:

$$S = \sum_{i=1}^{n} W_i (Z_i - \hat{Z}_i)^2 = min, (i = 1,2,\cdots,n) \qquad (1)$$

The SV pattern is gentle and approaches a linear change within 1 to several years. Considering the possible geomagnetic sharp change phenomenon, the fitting number adopted in this paper is 2. Supposedly there are m midnight mean values on a certain observatory, where the i-th value is Z_i(i= 1,2,...) m), corresponding to the number of days X_i, establish the dependent variable vector Z, the independent variable combination matrix X, the fitting coefficient vectorθ , and the fitting residual vector ε as follows:

$$Z = \begin{bmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_i \\ \vdots \\ Z_m \end{bmatrix}, \quad X = \begin{bmatrix} X_1^2 & X_1 & 1 \\ X_2^2 & X_2 & 1 \\ \vdots & \vdots & \vdots \\ X_i^2 & X_i & 1 \\ \vdots & \vdots & \vdots \\ X_m^2 & X_m & 1 \end{bmatrix}, \quad \theta = \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix}, \quad \varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_i \\ \vdots \\ \varepsilon_m \end{bmatrix} \qquad (2)$$

The matrix of the linear equation set to be solved is obtained as:

$$Z = X\theta + \varepsilon \qquad (3)$$

Through the weight function, the weight value assigned to the i-th midnight mean is W_i (i= 1,2,... (m), establish the diagonal matrix W of the weight values:

$$W = \mathrm{diag}\{W_1, W_2, \cdots, W_i, \cdots, W_m\} \qquad (4)$$

Then the coefficient vector θ can be solved by the following formula:

$$\theta = [X^T W X]^{-1} X^T W Z \qquad (5)$$

2.3 Weight Function

The weight function determines the distribution strategy of the fitting weights for each data point and directly affects the fitting effect. Before performing weighted least squares fitting, an appropriate weight function should be selected based on the characteristics of the data sample. The dimensions and variation ranges of geomagnetic components vary from place to place. To facilitate unified analysis, it is necessary to standardize the fitting residuals first. Let there be m midnight means, and the residual set of the previous fit is $\{\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_i, \cdots, \varepsilon_m\}$. Let the mean of the fitting residuals be $\bar{\varepsilon}$ and the standard deviation be σ_ε, then the standardized residual valueε_i' of the i-th midnight mean is:

$$\varepsilon_i' = \frac{\varepsilon_i - \bar{\varepsilon}}{\sigma_\varepsilon} \qquad (6)$$

Based on the morphological characteristics of the Δ factors, this paper selects $1/(\varepsilon'^2 + 1)$ as the basic weight function. Meanwhile, to completely suppress the influence of outliers, the weight of the data points that $|\varepsilon'|$ is greater than 2 times the standard deviation is directly set to 0 (Figure 3). The weight function $f_w(\varepsilon')$ used can be expressed by the following formula:

$$f_{w(\varepsilon')} = \begin{cases} 0, & \varepsilon' < -2 \\ 1/(\varepsilon'^2 + 1), & -2 \le \varepsilon' \le 2 \\ 0, & \varepsilon' > 2 \end{cases} \qquad (7)$$

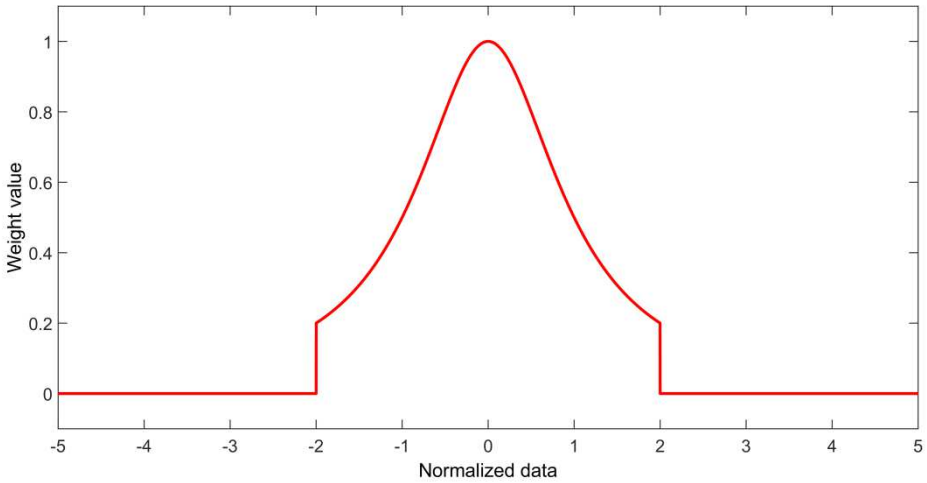


Figure 3 Weight function diagram

3. Result Analysis

3.1 Observatory data test

Taking the midnight mean values of the LYH observatory in 2021 as an example, by selecting the data on quiet days and applying the weighted least squares method for fitting, the separation of internal and external fields can be achieved. The fitting residuals are regarded as Δ factors, and the fitting curves are the SV results corrected by the midnight mean. This paper will focus on

analyzing the spatiotemporal variation characteristics of the Δ factors to explore the specific influence of midnight mean correction for SV results.

3.1.1 SV results

During the research period, the SV patterns of the three components H, D, and Z are stable, but the trends are different (figure 4). The H remains basically at the same level of change throughout the year, the D shows a stable downward trend, while the Z demonstrates an upward trend. The quadratic term coefficients of the three components are respectively 0.39%, 0.01%, and 0.04% of the linear term coefficients [Table 1], with the linear term coefficients holding absolute advantage, indicating that the SV of the three components at LYH observatory mainly changed linearly in 2021.

Table 1 SV Fitting Coefficients

components	quadratic coefficients	Linear coefficients	**Constant**
H	-0.000270	0.068639	29643.60
D	-0.000001	-0.014281	21215.54
Z	-0.000060	0.160781	44625.06

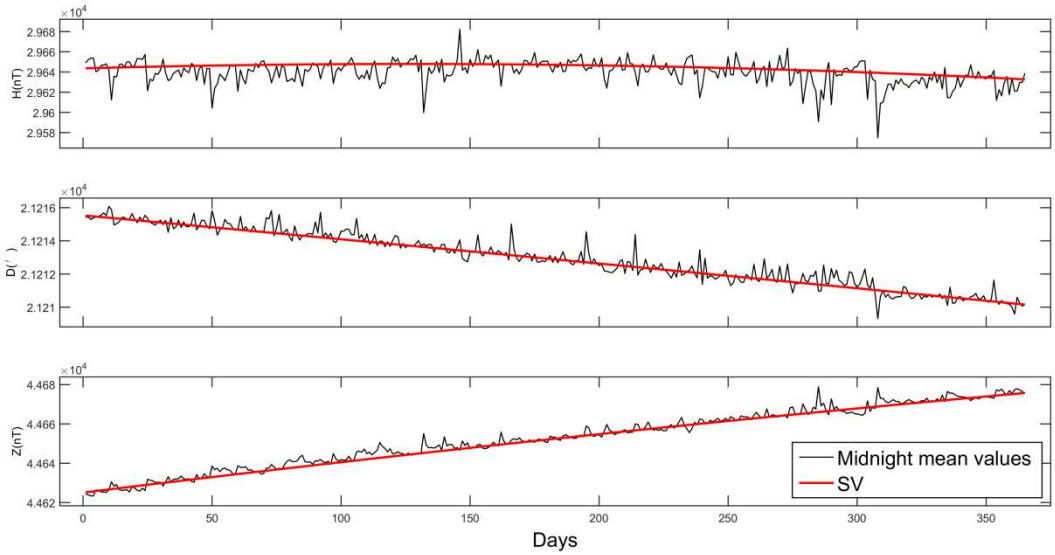


Figure 4 The result of midnight mean value correction

3.1.2 Composition of Δ

(1) Time-series variation characteristics

Unlike the pattern of SV, the Δ factors in the midnight mean fluctuate frequently around the 0 (Figure 5). The average value, standard deviation (σ), and absolute value mean (AVM) of Δ factors of disturbance days, quiet days and other common days throughout the year are classified and statistically analyzed. The results are shown in Table 2. During the quiet days, the average value, σ, and AVM of the Δ factors are all relatively small, indicating its intensity and fluctuation range are both small, and generally fluctuate around 0. During the disturbance days, the σ and AVM of the Δ factors both significantly increase, indicating that the intensity and fluctuation amplitude of the Δ factors also increase as the disturbance intensity increase, . Meanwhile, the average values of ΔH, ΔD, and ΔZ are -13.22nT, 0.22 ', and 3.07nT respectively, indicating that all three elements have shown significant bias.

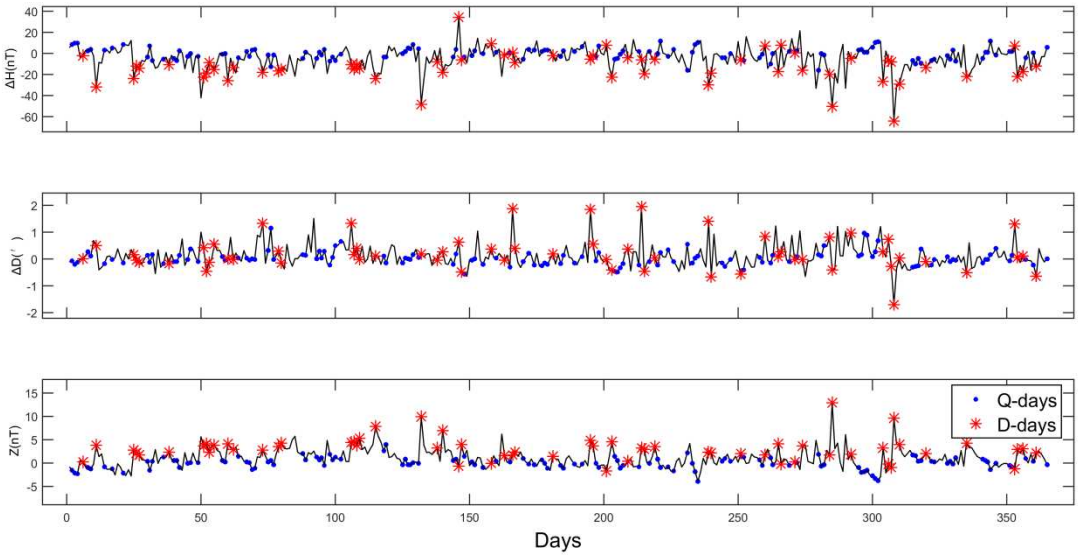


Figure 5 The time-series variation of Δ factors

Table 2 Basic Statistical Results of Δ factors

Date Type	days	Average			σ			AVM		
		H(nT)	D(′)	Z(nT)	H(nT)	D(′)	Z(nT)	H(nT)	D(′)	Z(nT)
Quiet	120	-0.08	0.02	-0.06	5.43	0.27	1.23	4.26	0.19	0.91
Disturbance	60	-13.22	0.22	3.07	14.95	0.66	2.59	15.69	0.47	3.23
Common	185	-4.43	0.11	1.11	9.67	0.38	1.81	7.86	0.28	1.64

Further process the values of the above Δ factors according to Formula 6, statistically analyze their distribution and draw a histogram (Figure 6). It can be shown that the distributions of the three elements all rapidly decay from the central high value to both sides, presenting quasi-normal distribution characteristic. If ±2 times is regarded as the standard deviation of outlier criterion, then the number of outliers of ΔH, ΔD and ΔZ are 15, 19 and 14 respectively, and their proportions in the annual data are 4.1%, 5.2% and 3.8% respectively. Meanwhile, the distribution of outliers is very uneven. The ratios of positive and negative outliers of ΔH, ΔD and ΔZ are 13:2, 1:18, 3:11 respectively.

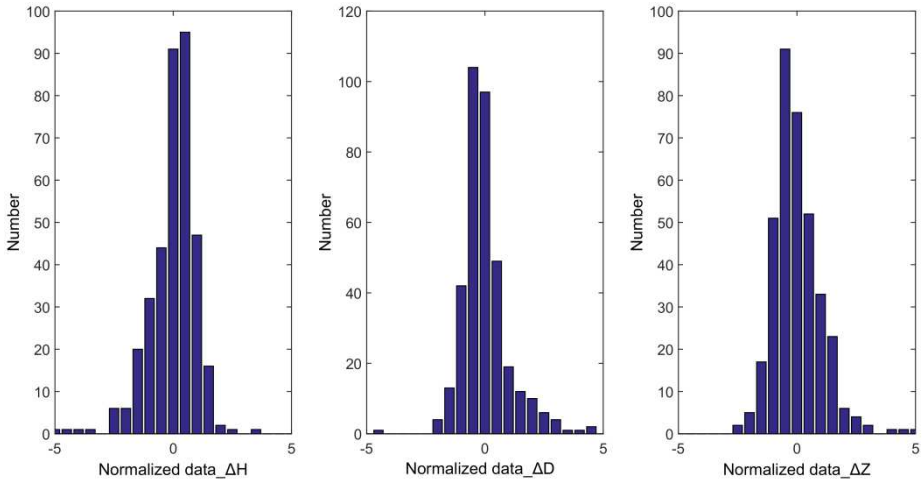


Figure 6 Statistical histogram of Δ factor values

(2) Spatial distribution characteristics

To check the spatial distribution characteristics of Δ factors, the above-mentioned midnight

mean correction method is utilized to further decompose internal and external field of the midnight mean for the 33 reference geomagnetic observatories of the China Geomagnetic Network throughout 2021. Taking the Δ factors of each observatory for three consecutive days from May 10th to 12th, 2021 (Figure 7) as an example to analyze, which magnetic disturbance intensity during this period is highly representative. It shows that May 10th is an common day, May 11th is a quiet day, and May 12th is a disturbance day. It can be seen:

1. The spatial continuity of the Δ factors is generally good with large spatial scale, but it also appears a certain degree of regional and local characteristics. This indicates that the Δ factors, while being controlled by the long-distance high-altitude current system, are also affected by the underground electrical structure.

2. The intensity and spatial distribution pattern of the Δ factors change rapidly over time. During the disturbance days, the intensity of the Δ factors and the degree of spatial difference (contour density) are both greater than those during the quiet days.

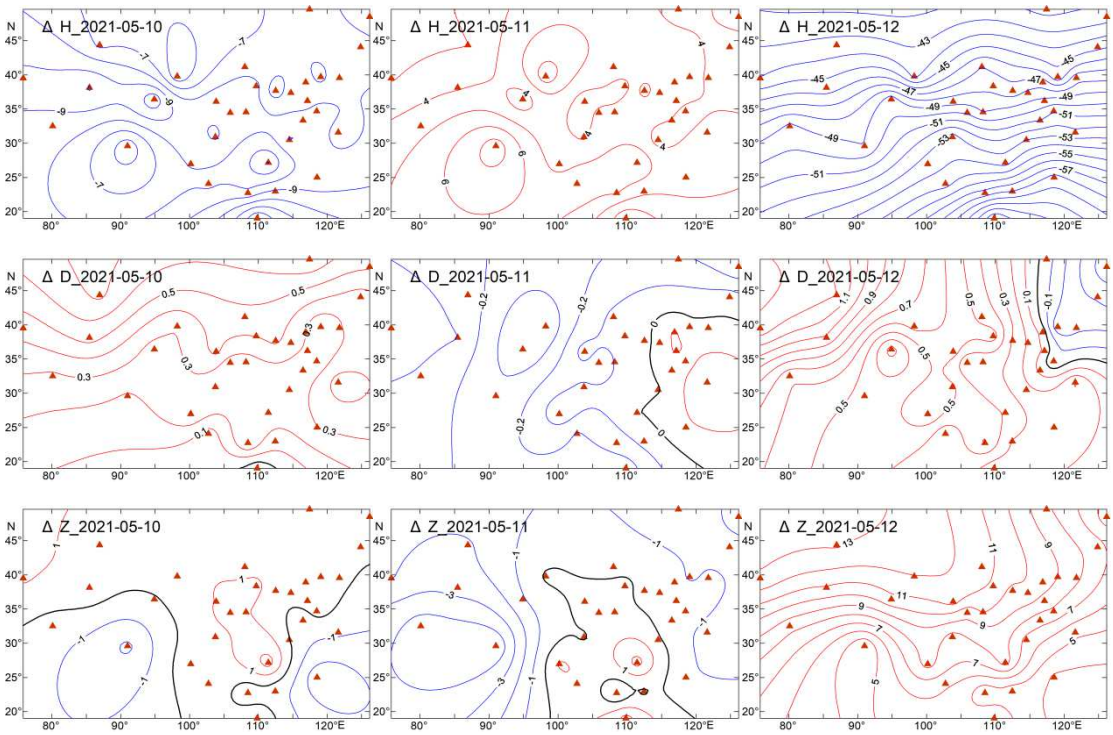


Figure 7 Spatial distribution of Δ factors in Chinese mainland from May 10 to May 12, 2021

The analysis results of average value, σ, and AVM of Δ factors for each observatory are shown in [Table 3]. Due to the high-frequency fluctuation of Δ factors and small-size samples, the above statistical results appear high randomness. Based on the classification of quiet days, disturbance days, and other common days, this paper further classifies and analyzes the Δ factors of 33 reference geomagnetic observatories throughout 2021. The results are shown in [Table 4]. It can be seen that AVMs of ΔH, ΔD and ΔZ of the network during disturbance days are 3.4, 2.5 and 2.7 times that during quiet days respectively, and the σs are 1.3, 2.1 and 1.2 times respectively. This indicates that the intensity of Δ factors significantly increases, and the spatial difference also becomes obvious as the disturbance intensity increases.

Table 3 Statistics of Δ factors of China Geomagnetic Network from May 10 to May 12, 2021

Dates	**Average**			σ			**AVM**			**Note**
	H(nT)	D(′)	Z(nT)	H(nT)	D(′)	Z(nT)	H(nT)	D(′)	Z(nT)	

2021-05-10	-8.14	0.32	0.29	1.52	0.16	1.02	8.14	0.33	0.81	Common
2021-05-11	4.34	-0.08	-0.61	1.11	0.14	1.54	4.34	0.12	1.15	Quiet
2021-05-12	-49.69	0.32	8.40	4.95	0.39	2.55	49.69	0.41	8.40	Disturbance

Table 4 Statistics of Δ factors of China Geomagnetic Network in 2021

Date Type	Days	Average			σ			AVM		
		H(nT)	D(′)	Z(nT)	H(nT)	D(′)	Z(nT)	H(nT)	D(′)	Z(nT)
Quiet	120	-0.36	0.02	-0.09	3.60	0.19	1.40	4.98	0.21	1.17
Disturbance	60	-14.77	0.30	2.83	4.72	0.40	1.63	17.14	0.52	3.16
Common	185	-5.13	0.14	1.03	3.90	0.26	1.35	8.83	0.30	1.76

3.2 Field survey data test

The field data from all repeat stations needs to be corrected for diurnal variation, converted to the average value of midnight on a certain quiet day, and then used for SV calculation in the measurement area. As mentioned earlier, the diurnal variation correction datasets still contain Δ factors, and the intensity and spatial feature of the Δ factors change rapidly over time, thus lead to complex interference to the SV results between the two measurement periods. This paper will conduct the midnight mean correction test using the field data from the central and eastern regions of China in 2020 and 2021. The diurnal variation correction reference dates for these two measurement periods are April 30, 2020 and April 9, 2021 respectively.

(1) Single measurement period midnight mean correction

The correction of the midnight mean value for field data is accomplished based on the data from geomagnetic observatories. This paper conducts the midnight mean value correction trial with the midnight mean values of 33 reference geomagnetic observatories in the China Geomagnetic Network for two consecutive years 2020 and 2021. The midnight mean correction is carried out in batches according to the measurement period. Taking the data of 2020 as an example, the processing procedure is as follows:

1. By using the aforementioned weighted least squares method, the internal and external fields of the midnight mean values of each observatory are decomposed to obtain their continuous Δ values.

2. Select the Δ values of each observatory on April 30, 2020, annual diurnal variation correction base date as the reference Δ values.

3. Taking each repeat station as the unit, the reference Δ values of the 12 geomagnetic observatories closest to a certain repeat station are selected to establish a second-order Taylor polynomial model as the spatial reference field for the midnight mean correction of this repeat station (Su et al., 2022), and the midnight mean correction is performed for the diurnal variation correction results of the repeat station.

4. By performing the midnight mean correction one by one, the midnight mean correction dataset of the survey area can be obtained.

After completing midnight mean correction of all field data for 2020 and 2021, the spatial distribution of ΔD, ΔI and ΔF in the survey area are made (Figure 9), and the average value, σ, AVM of Δ values are statistically analyzed [Table 4]. The results show that ΔD, ΔI and ΔF all have clear spatial distribution inhomogeneity. The characteristics and spatial distribution patterns of Δ values of different elements are different, and the differences between Δ values of the same element for two periods are significant.

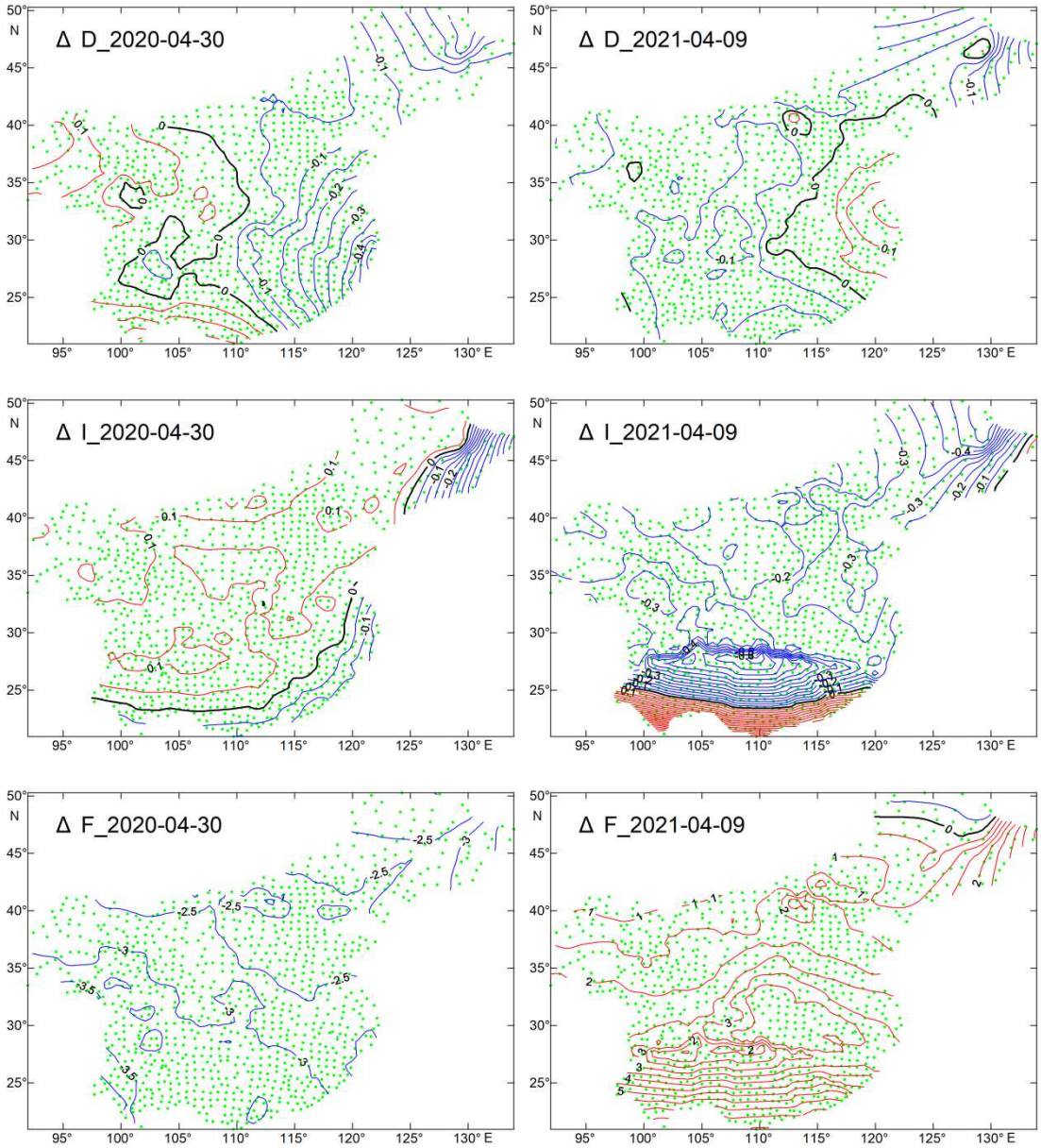


Figure 8 The spatial distribution of Δ values of survey area on April 30, 2020 and April 9, 2021

Table 4 Statistics of Δ values of survey areas of central and eastern China on April 30, 2020 and April 9, 2021

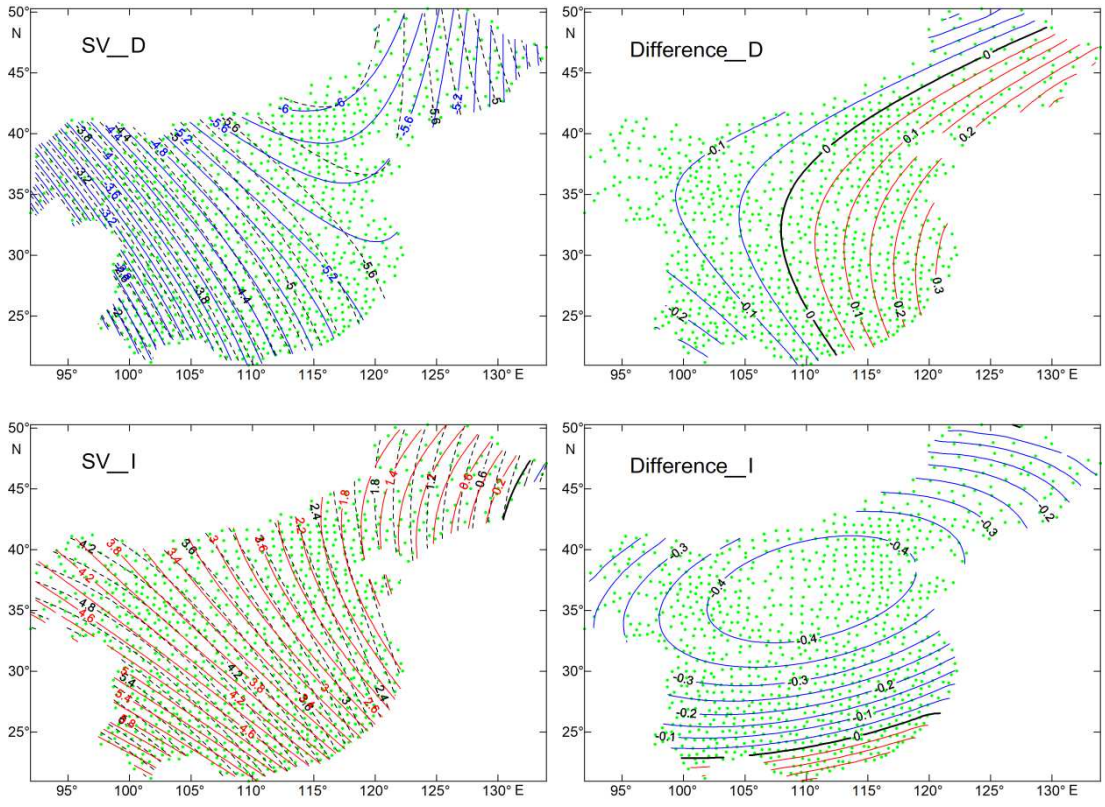
Date	Average			σ			AVM		
	D(′)	I(′)	F(nT)	D(′)	I(′)	F(nT)	D(′)	I(′)	F(nT)
2020-04-30	-0.05	0.05	-2.90	0.12	0.08	0.44	0.09	0.08	2.90
2021-04-09	-0.04	-0.21	2.65	0.06	0.21	1.54	0.06	0.27	2.67

(2) Influence on SV calculation

The calculation of SV in the survey area involves the correction of the midnight mean values of two measurement periods, further complicates the influence of the midnight mean value correction. When using field data for SV calculation, it can be carried out in two ways. Mode 1 is to establish the main magnetic field models of the measurement area for two measurement periods respectively, and then obtains the SV results of the measurement areas by calculating the difference between the two main magnetic field models. Method 2 is to directly establish the SV

model of the measurement area by using the variation of all repeat stations between two measurement periods. In contrast, Method 2 is more straightforward. This paper adopts Method 2 for analysis and discussion.

By adopting Method 2, the second-order Taylor polynomial models of the SV results in the measurement areas before and after the midnight mean correction are established respectively, and their spatial distribution graphs are plotted (Figure 9). For ease of comparison, the two graphs are superimposed in the figure. The graphs before and after the midnight mean correction are respectively drawn with solid colored lines and dashed black lines. It can be seen that after the midnight mean correction, the overall shape of the SV spatial distribution of the D, I and F 3 elements is basically similar, but the positions and curvatures of the contour lines have changed significantly, and the two versions of the contour lines generally intersect. To further clarify the influence of the midnight mean correction, the difference between the two versions of the SV model (denoted as "Difference") is calculated and plotted, which is listed on the right side of the SV graph. "Difference" expresses the influence of the midnight mean correction, which is equivalent to the difference between the Δ values of two measurement periods. SV and Difference respectively describe the results of the main magnetic field and the Δ factor varying over time. The spatial distribution patterns of the two graphs are significantly different, indicating that their physical resources are distinct.



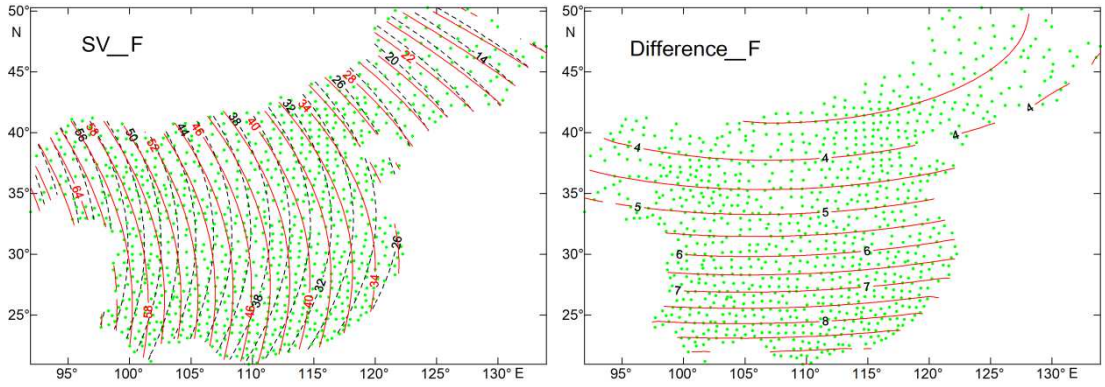


Figure 9 Comparison of SV results in the measurement area before and after midnight mean correction

The maximum value, minimum value, average value, σ, and AVM of the "Difference" values at all repeat stations are statistically analyzed, and the results are shown in Table 5. The AVM values of Difference_D, Difference_I and Difference_F in the table are 0.11 ', 0.27 ', and 5.55 nT respectively, and before the midnight mean correction, the AVM values of SV_D, SV_I and SV_F are 4.67 ', 3.65 'and 41.67nT respectively, and the ratios of the two are 2.3%, 7.4% and 14.6% respectively. The ratios are equivalent to the relative rate of change resulting from the correction of the midnight mean value of SV in the measurement area, indicating that the midnight mean correction has produced obvious effect.

Table 5 Statistical results of "Difference" values in the survey area

Components	Minimum	Maximum	**Average**	σ	**AVM**
Difference_D(′)	-0.27	0.35	0.01	0.13	0.11
Difference_I (′)	-0.44	0.21	-0.26	0.16	0.27
Difference_F (nT)	3.12	9.51	5.55	1.71	5.55

4. Discussion

The midnight mean value still contains significant Δ factors, so the traditional diurnal variation correction does not fully eliminate the external field in the observed data. The Δ factors contain relatively complex temporal and spatial variation characteristics, which can cause complex interference to the SV results. The precise separation of the internal and external fields is the key to the midnight mean correction. In this paper, based on the different temporal variation characteristics of the internal and external fields, the weighted least square method is used to decompose the different components of the magnetic fields. However, the spectrum of the temporal variation of the external field is broad, with the variation period ranging from a few tens of a second to 11 years. Among them, the long-period elements are difficult to be effectively removed through fitting calculations. When using spectral analysis methods to decompose internal and external field elements, similar problems also exist due to the overlap of SV and external field variation in the low-frequency band. Principal component analysis is another important method for analyzing the temporal variations of the geomagnetic field. Its essence is to decompose the different elements based on the degree of common variation among observatories data. However, both the external field variation and SV have extensive spatial scale, that is, they have highly similar common variation characteristics. Therefore, they will still be mixed together in the results of principal component analysis and cannot be effectively separated. Due to the limitations of the

author's research level, this paper only makes a preliminary technical attempt at the midnight mean correction. With the development of more scientific theories on the separation of internal and external fields, the methods adopted in this paper will also be improved and optimized accordingly.

Acknowledgments

This research was jointly supported by Spark Program of Earthquake Sciences(Grant Number XH26003A), Science & Technology Fundamental Resources Investigation Program (Grant Number 2024FY101100) and The Earthquake Science and Technology Program of Hebei Province（Grant Number DZ2024112200008).Appreciate the Mobile Geomagnetic Technology Team of China Earthquake Administration and Geomagnetic Network Center for providing the data.

DATA AVAILABILITY STATEMENT

All computational codes are available upon request from the authors. Relevant data is provided for shared services in accordance with the requirements of the China Earthquake Administration.

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