CODATA COMMITTEE ON DATA INTERNATIONAL SCIENCE COUNCIL

Strategies in the Quality Assurance of Geomagnetic Observation Data in China

PRACTICE PAPER

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ABSTRACT

Geomagnetic observation is an important approach to explore the variations of the Earth's magnetic field. However, factors such as observation environment, observation facilities and observation equipment may affect the quality of observation data. This paper deeply analyzes the factors that may affect the quality of data in China's current geomagnetic observations, and discusses in detail the strategies we have implemented in this field. These strategies include the selection of observation sites, the protection and monitoring of the observation environment, the maintenance and improvement of observation facilities, the maintenance and monitoring of observation equipment, the analysis and processing of interference information, and effective measures in quality control.

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1 INTRODUCTION

The geomagnetic field is a global geophysical field. In order to grasp the spatial distribution and temporal variation of the geomagnetic field and understand the causal relationship between these changes and solar activity, magnetosphere and ionosphere states, and the Earth's internal structure, a certain scale of regional geomagnetic network and global geomagnetic network are necessary. Through years of network construction, China has formed a benchmark geomagnetic observation network composed of 45 observatories (As shown in Figure 1). Each of these stations are equipped with at least two tri-axial fluxgate magnetometers, one fluxgate theodolite and one proton precession magnetometer, mainly used to monitor the spatiotemporal changes of the geomagnetic field in China. These observatories are important places for accurate, continuous, long-term measurement of the Earth's magnetic field and regular publication of definitive data (Dobrovolsky, M et al. 2020; Rasson, Toh & Yang 2010).

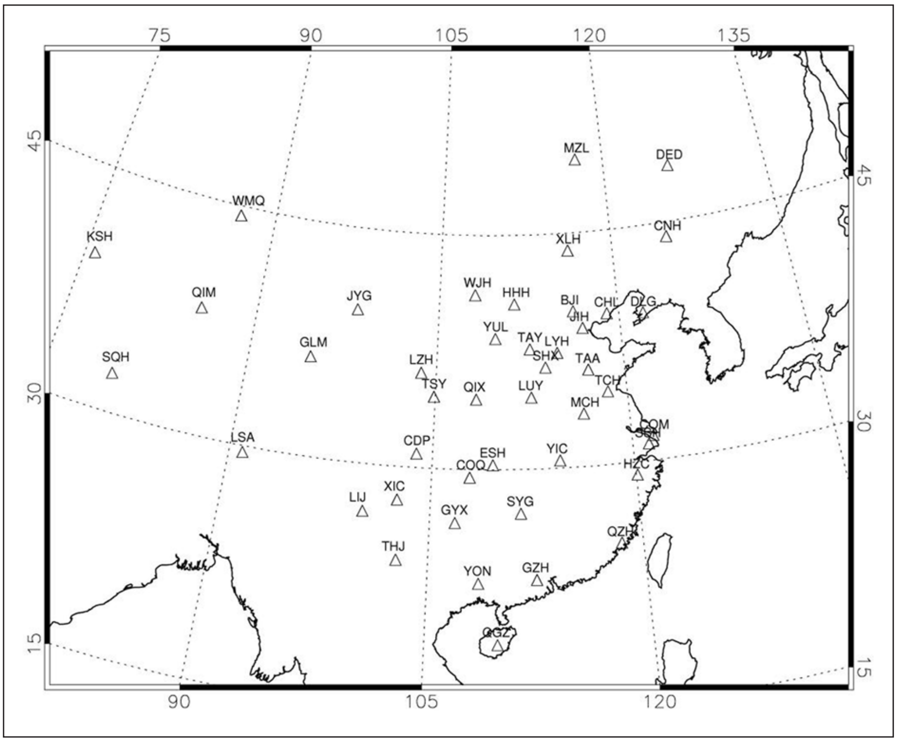


Figure 1 Distribution map of geomagnetic observatories in mainland China.

The construction of the geomagnetic observation network has accumulated a large amount of data resources. These data not only help us to explore the changing rules of the geomagnetic field in depth (Kang et al. 2019; Soloviev et al. 2019; Zhao et al. 2019), but also provide important references for space weather prediction, seismic magnetic relationship research, pipeline anti-corrosion research (Liu et al. 2016), high-voltage power grid protection research (Bolduc et al. 1998, 2000; Boteler et al. 1998; Guo et al. 2015; Kappenman et al. 1996; Liu, Liu & Pirjola 2009; Mohd Anuar et al. 2019), etc. Ensuring data quality is paramount for credible research outcomes and effective applications, thus many efforts are underway to improve the existing observatories in the world (Dawson et al. 2009; Kudin et al. 2021, ; Kudin et al. 2023; Lesur et al. 2017; Linthe et al. 2013; Peltier et al. 2010; Reay et al. 2013; Reda et al. 2011; Soloviev et al. 2018; Zhang et al. 2022). Only when the data source is reliable, the collection and processing methods are scientific and rigorous, and the management is standardized, can we ensure the integrity and reliability of the data, and provide more accurate support for scientific research and applications. For this, we have conducted in-depth research and implemented multiple strategies (Zhu, Yang & Zhang 2010; Yao 2015; Guo et al. 2023). This paper outlines factors impacting data quality in China's geomagnetic network, strategies employed to mitigate these issues, achievements, and future plans for enhancing data quality.

2 FACTORS AFFECTING THE QUALITY OF OBSERVATION DATA AND CORRESPONDING STRATEGIES

The quality of geomagnetic observation data is affected by various factors, such as observation environment, observation facilities, and observation equipment.

2.1 IMPACT OF THE OBSERVATION ENVIRONMENT AND CORRESPONDING STRATEGIES

A clean magnetic environment is an important guarantee for a reliable data source. If the station is located in a magnetic anomaly area or the geomagnetic field gradient of the observation site is uneven, it will affect the observation results.

In addition, any changes in the magnetic environment may affect geomagnetic observation. The rapid economic development and acceleration of urbanization have caused stations that once had excellent observation environments to begin to be affected by various artificial electromagnetic sources. For example, factory buildings containing ferromagnetic materials, high-voltage DC transmission, urban rail DC transportation systems, cars and other moving ferromagnetic materials, etc., all of which will have a serious impact on the quality of observation data.

In response to the impact of the observation environment, we have adopted the following strategies:

1. Strictly follow the Geomagnetic Station Construction Standards (CEA 2004) and the Guide for Magnetic Measurements and Observatory Practice (Jankowski & Sucksdorff 1996) for site selection and construction.
   (1) In the station site selection phase, we will collect and analyze local aeromagnetic maps and geological documents, and select areas with slow and uniform changes in magnetic field contour lines, thick soil cover and weakly magnetic rocks such as limestone and dolomite as the preliminary selection area for the station. Within this area, a site is chosen as the observation field. Centered on this observation field, a cross-shaped measurement line is formed to measure the spatial distribution of the total magnetic field strength F.
   (2) In order to further survey the magnetic field distribution within the observation site and determine whether there are local hidden interference bodies, in the above-mentioned observation site, where the measurement is qualified, a range of 200 m × 200 m is selected, and F is measured at a point distance of 10 m along the east-west or northwest. Within the site range where the horizontal gradient of the total magnetic field strength F is less than 1nT/m, a 100 m × 100 m area is selected as the geomagnetic station observation site.
   (3) By visiting and measuring in person, we investigate the situation of artificial interference sources to ensure that the geomagnetic station and artificial interference sources maintain a sufficient distance.
   (4) During the construction process of geomagnetic observation facilities and observation rooms, we monitor the magnetism of the foundation, walls, ground, piers, etc. of the building in a tracking control manner, and timely discover and eliminate magnetic substances mixed into the building.
2. Strengthen the monitoring and protection of the observation environment.
   (1) Check the changes in the observation environment at regular intervals every day. If any behavior that may affect the normal operation of the observation equipment is found, it should be dealt with promptly and reported to the superior department.
   (2) Regularly re-measure the gradient of the station observation environment. If there are significant changes in the observation environment, an environmental gradient re-measurement should be conducted immediately.
3. Actively respond to stations that have been interfered with by artificial electromagnetic sources.

(1) Faced with increasingly serious environmental interference, we have conducted field research and experiments. In order to reduce the interference of vehicles and other small-sized ferromagnetic objects, we tried to carry out deep well observation (Ren et al. 2012), but this method did not work well for large-scale infrastructure such as high-voltage transmission and subway (Chen et al. 2017). Some stations choose to move to avoid interference, but this becomes more and more difficult with urban development. (2) We focus on the identification and suppression of interference data (Chen et al. 2014; Shen et al. 2005, Tang et al. 2011). For example, we developed an 'Automatic Interference Processing System for High-Voltage Direct Current Transmission on Geomagnetism' ((AIPSHVDC)) (Jiang et al. 2019). Although its automation level needs to be further improved, it has, to some extent, achieved automatic identification and interference line distinction for high-voltage DC transmission interference. Figure 2 shows the processing results of data affected by high voltage direct current interference using this system. The red, solid line in the figure represents the raw data affected by direct current interference, while the blue, dashed line represents the data after discrimination and preprocessing by this system. It can be clearly seen from the figure that the processing effect is outstanding. For the interference of subways and light rails, we have identified and suppressed them by various methods, such as signal filtering, time-domain and frequency-domain analysis, and achieved good results (Chen et al. 2017; Neska et al. 2013; Soloviev et al. 2012; Xie et al. 2011; Zhao et al. 2022). But for the occasional random interference—such as vehicle driving and infrastructure construction, because its occurrence time is not fixed, the shape is irregular, and it is often superimposed with normal magnetic disturbances—research on this type of interference mainly focuses on the analysis of interference phenomena and characteristics, and has not yet formed a unified and effective identification index and suppression method (Fan et al. 2021; Kang et al. 2022). At present, it mainly relies on the spatial correlation of geomagnetic observation data time series changes, and performs preprocessing operations through human-machine interaction (Zhang et al. 2016).

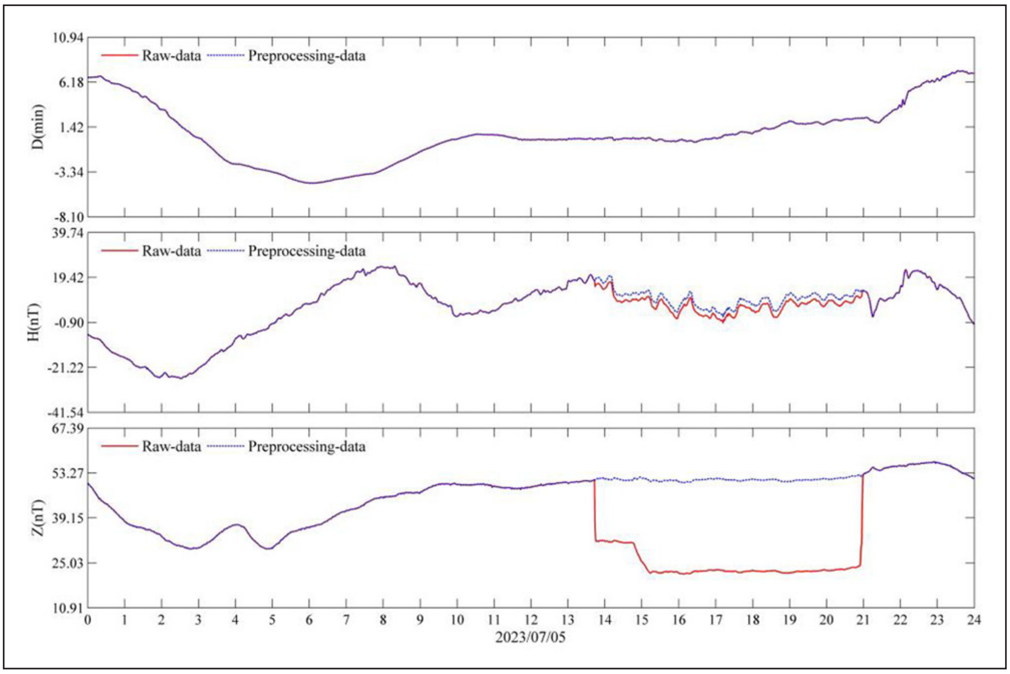


Figure 2 Comparison of daily variable curve before and after data processing.

2.2 IMPACT OF THE OBSERVATION FACILITIES AND CORRESPONDING STRATEGIES

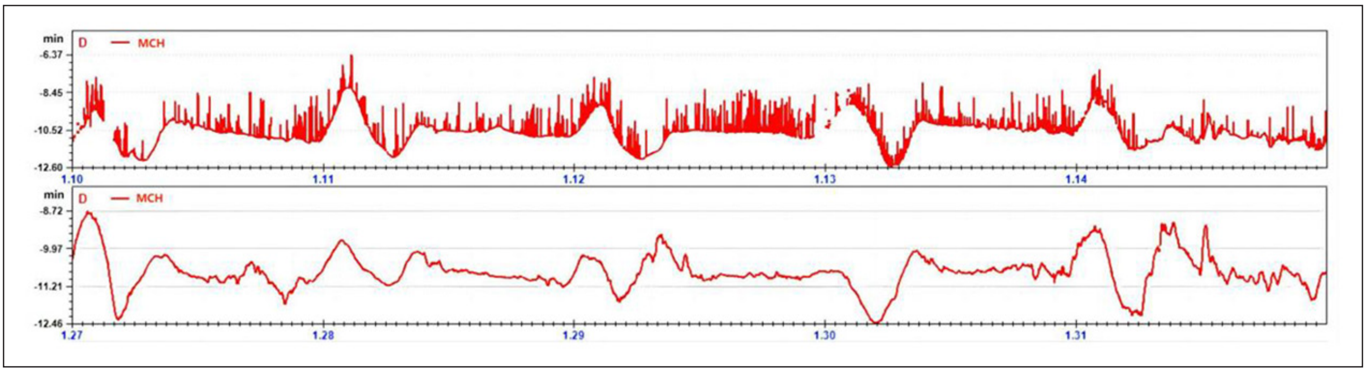
The stability and reliability of observation facilities directly affect the quality of geomagnetic observation data. The recording room, as the storage place for geomagnetic relative recording instruments, must have good insulation and moisture-proofing conditions. The instrument pillar, as the support and fixed base of the geomagnetic instrument, needs to have good stability. The performance of the ferromagnetic materials, electronic components, and coils inside the magnetic flux gate sensor will be affected by temperature. If the temperature change range of the instrument environment is large, it will cause the measured value to deviate from the true value. In addition, if the observation pillar where the probe is installed is unstable, it will cause the observation data to deviate from the normal value of the magnetic field. If the humidity in the recording room is too high, it may cause corrosion and damage to the circuit components of the instrument (Hu et al. 2014), which will cause abnormal observation data. In severe cases, it will damage the instrument and cause data recording interruption.

An azimuth mark is a crucial reference ground target in geomagnetic declination measurements. Due to factors such as terrain, groundwater level, construction method, etc., the azimuth angle of the azimuth mark may change. If the azimuth angle of the mark is not regularly re-measured, the azimuth mark may experience minor errors or tilting due to changes in the environment over time, which will affect the accuracy of the magnetic declination D observation (Wu et al. 2010).

In response to the impact of observation facilities, we have taken the following measures:

1. To ensure the stable operation of the recording instrument, it is very important to strictly control the temperature and humidity of the recording room and closely monitor the stability of the observation pillars (Jankowski & Sucksdorff 1996). The recording instrument is placed in the basement or semi-basement, with a series of isolation doors and insulation materials between the room and the ground entrance, aiming to keep the daily and annual temperature difference within 0.3 °C and 10 °C, respectively. We also use dehumidifiers and calcium chloride agents, and for rooms with excessive humidity, we install an organic glass cover on the probe with silica gel inside. Vaseline is applied on the cover-to-pillar contact for sealing. The upper panel of Figure 3 illustrates the abnormal variation in data caused by the humidity affecting the probe. In the lower panel, after implementing dehumidifying measures, the data returned to its normal daily variation. To ensure the stability of the observation pier, the observation pillar is composed of three parts: the pillar body, the pillar base, and the pillar foundation. The pillar body is located on the pillar base, with an embedded depth of not less than 0.2 meters. Where the bedrock can be excavated, the pillar base is established on the bedrock. Otherwise, the pillar base will be established on the pillar foundation and form a whole with the pillar foundation, and a buffer tank is set around the pillar base. The buffer tank is used to isolate and reduce vibration, impact, and interference from the external environment, protecting the pillar from damage. The pillar foundation is located below the freezing depth of the harder natural soil layer. If the harder natural soil layer cannot be excavated, the pillar foundation should be reinforced. The overall technical requirements of the observation pillar are good stability, no settlement, no tilting, and no vibration (as shown in Figure 4).

Figure 3 The daily variation curves before and after taking dehumidifying measures.



2. Despite the good observational advantages of basements, they come with high construction costs and complex land acquisition issues. We experimented with buried array construction in the Earthquake Background Field Detection Project, dramatically decreasing costs and construction complications. Recently, we refined the previous construction plan, using cylindrical high-density polyethylene tubes with bottoms and no caps as the main body of the instrument warehouse, laying a gravel cushion layer at

the bottom to improve the foundation stability of the buried device, and choosing high thermal resistance insulation materials and increasing insulation thickness to control the daily temperature difference in the warehouse. This improved plan has achieved new breakthroughs in stability, insulation, waterproofing, and moisture-proofing (Zhang et al. 2022). Figure 5 shows data curves recorded by the fluxgate magnetometer at two different measurement points in the Xilinhot geomagnetic station, where GM4 (A) is installed in the basement and GM4 (B) is installed in the buried device. It can be seen from the figure that the daily change curves recorded by the two sets of instruments are consistent, the daily temperature difference is controlled within 0.3 °C, and the thermal insulation effect of the buried device is better than that of the basement, with a smaller temperature change range. In addition, this kind of buried construction is simple, and can be carried out differentially according to different observation environments.

3. To monitor the stability of the azimuth mark, we regularly organize professional observers to re-measure the azimuth angle of the azimuth mark at the stations. Figure 6 shows this process. Figure 6(a) shows the observer installing the fluxgate theodolite. Figure 6(b) shows the observer positioning the target, and Figure 6(c) shows the observer measuring the angle.

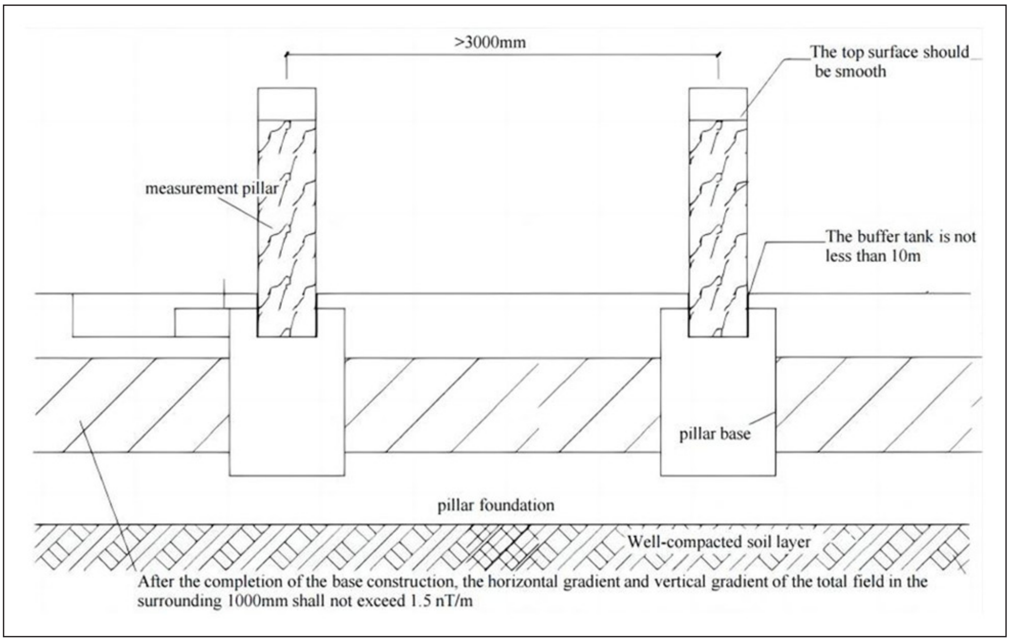


Figure 4 Schematic diagram of the observation pier construction plane.

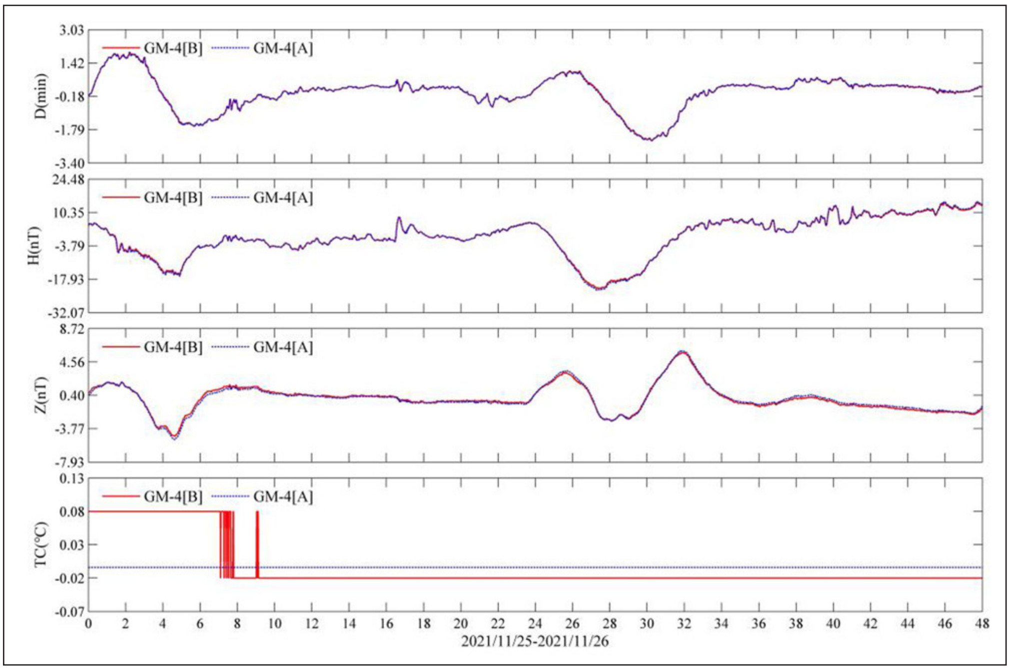


Figure 5 Comparison of the daily variation curves of two sets of instruments installed at different measuring points.

Figure 6 Re-measurement of azimuth.

2.3 IMPACT OF THE OBSERVATION EQUIPMENT AND CORRESPONDING STRATEGIES

The influences from the observation equipment mainly include the instrument's manufacturing process, the temperature characteristics, improper installation and debugging, and operation faults, all of which may cause bias in the observation results. The fluxgate magnetometer, with its strong reliability, simple usage, and wide range of weak magnetic field measurement, has been widely used in stations for continuous measurement of the geomagnetic field relative values. However, due to the limitations of manufacturing and installation technology, the three axes in the fluxgate sensor are not strictly orthogonal (Auster et al. 2002; Pylvanainen 2008; Wang 2018), and there are also issues such as zero field drift (Hu et al. 2016), temperature drift, and residual magnetism in the sensor (Pang 2011), which may lead to the inability of the observation data to accurately reflect the real diurnal variation (Zhang & Yang 2011). In addition, faults in the sensor, analog box, and host during the operation of the instrument; equipment aging; and/or loose or broken transmission lines may all affect the completeness and accuracy of the observation data.

To mitigate these issues, several strategies are employed:

1. Parallel observation, with at least two sets of the same type of instruments at each station. This not only ensures data continuity, but also allows for real-time problem detection and resolution through data comparison analysis.
2. Checking the operating status of the observation system at a fixed time every day. Any detected failure should be promptly addressed, and if necessary, the equipment should be returned to the manufacturer for repair.
3. Periodic instrument calibration and maintenance; participation in the international instrument comparison organized by IAGA every two years to transfer the international standards of the instrument; completion of a comparison and grid value calibration of the absolute observation instrument in China's geomagnetic network once a year, unifying the national instrument standard (He 2019); completion of an accuracy calibration of the diurnal variation of the fluxgate magnetometer once a year (Zhang & Yang 2011). Through regular instrument calibration work, the accuracy of the equipment is ensured.
4. Theoretical analysis and experimental testing to study the relationship between the instrument's directionality and orthogonality and the observation data, thereby carrying out installation correction or algorithm correction (Hu et al. 2016; Jankowski & Sucksdorff 1996; Wang 2018).

3. A COMPLETE QUALITY CONTROL SYSTEM

The China Geomagnetic Network has established a very strict quality control system (Zhang et al. 2016). This system not only real-time monitors the timeliness and continuity of observation data, but also has a dedicated review process to rigorously check the quality of data preprocessing on a regular basis. In addition, the system evaluates indicators such as the consistency, validity, observation accuracy, accuracy, and stability of observation data to ensure the accuracy and completeness of the data. The establishment of this quality control system has greatly guaranteed the data quality of the China Geomagnetic Network, providing reliable data support for related scientific research work.

4 CONCLUSION AND PROSPECT

Considering that geomagnetic observation data may be affected by factors such as the observation environment, observation facilities, and observation equipment, we have adopted a series of strategies to improve the quality of observation data. These strategies include rigorous site selection, environmental safeguarding, ground-buried construction trials, regular instrument calibration, data analysis enhancement, and a comprehensive quality control system. The implementation of these strategies has ensured the integrity and credibility of the geomagnetic station network observation data. Future endeavors will focus on continuously improving data quality and fortifying the management of the geomagnetic observation network.

1. We will continue to carry out ground-buried observation experiments in different regions, design differentiated construction and erection plans for different observation environments, and promote the application in the construction of future national basic stations and dense arrays. At the same time, we will promote the development of low-energy-consumption, portable micro-sensors for application in ground-buried stations.
2. With the rapid development of machine learning technology, machine learning algorithm models have been applied to different business scenarios (Cai et al. 2019; Che et al. 2022; Liu et al. 2019; Liu et al. 2022; Shan et al. 2023). We will delve into the impact mechanism of human-made interference sources, relying on the interference events and a large number of manually annotated signals accumulated in the database of the Geomagnetic Network of China. Our aim is to try to develop a geomagnetic interference event recognition algorithm based on deep learning. This will enable automated, high-precision, and efficient identification and processing of interference events in geomagnetic observation data.

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COMPETING INTERESTS

The authors have no competing interests to declare.

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