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Storage and Processing of Big Data for Geomagnetic Support of Directional Drilling

Dmitry V. Kudin [1], Alexei D. Gvishiani [1,2], Izabella M. Nikitina [1], Ivan O. Belov [1], Boris A. Dzeboev [1,2,*], Andrew A. Grudnev [1,2], Boris V. Dzeranov [1] and Roman I. Krasnoperov [1]

[1] Geophysical Center of the Russian Academy of Sciences (GC RAS), 119296 Moscow, Russia; a.gvishiani@gcras.ru (A.D.G.); r.krasnoperov@gcras.ru (R.I.K.)
[2] Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences (IPE RAS), 123242 Moscow, Russia
* Correspondence: b.dzeboev@gcras.ru

Abstract: Modern satellite positioning and navigation technologies are not applicable in specific areas such as the exploration of oil and gas deposits by means of directional drilling techniques. Here, we can rely solely on natural geophysical fields, such as the Earth's magnetic field. The precise underground navigation of borehole drilling instruments requires a seamless, near-real-time access to operational geomagnetic data. This paper describes the MAGNUS BD hardware-software system, deployed at the Geophysical Center of the Russian Academy of Sciences, that provides the efficient accumulation, storage, and processing of geomagnetic data. This system, based on the Big Data (BD) technology, is a modern successor of the MAGNUS processing software complex developed in 2016. MAGNUS BD represents one of the first cases of the BD technology's application to geomagnetic data. Its implementation provided a significant increase in the speed of information processing and allowed for the use of high-frequency geomagnetic satellite data and expanding the overall functionality of the system. During the MAGNUS BD system's deployment on a physically separate dedicated cluster, the existing classical database (DB) was migrated to the Arenadata database with full preservation of its functionality. This paper gives a brief analysis of the current problems of directional drilling geomagnetic support and outlines the possible solutions using the MAGNUS BD system.

Keywords: geomagnetic data applications; geomagnetic navigation; magnetic observatories; geomagnetic low-earth orbit satellites; database; Arenadata database; MAGNUS BD system

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Citation: Kudin, D.V.; Gvishiani, A.D.; Nikitina, I.M.; Belov, I.O.; Dzeboev, B.A.; Grudnev, A.A.; Dzeranov, B.V.; Krasnoperov, R.I. Storage and Processing of Big Data for Geomagnetic Support of Directional Drilling. *Appl. Sci.* **2024**, *14*, 9730. https://doi.org/10.3390/app14219730

Academic Editor: Roberto Scarpa

Received: 19 September 2024
Revised: 18 October 2024
Accepted: 22 October 2024
Published: 24 October 2024

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1. Introduction

With respect to the widespread implementation of modern satellite positioning technologies (such as global navigation satellite systems or GNSSs), the Earth's magnetic field (EMF) remains one of the main reliable natural geophysical fields used for the navigation and orientation of artificial objects. An important feature of the geomagnetic method is the capability of the instant determination of an object's orientation. GNSSs allow us to determine the position or direction of a moving object. To determine the orientation of an object requires additional technical solutions, so magnetic navigation is still a necessary backup, and sometimes the only possible method, e.g., the magnetic compass remains an essential element of equipment and instrumentation used for the navigation of vehicles [1–4].

Among the applications of geomagnetic referencing and navigation is support of the mining industry. The extraction of hard-to-recover oil and gas deposits, as well as of the hydrocarbon deposits located at high latitudes, necessitates the implementation of more complex well-drilling technologies. The impossibility of using GNSSs for underground positioning stipulates the application of inertial systems for drill navigation and positioning using geophysical fields, including EMFs [5,6].

The oil depletion in conventional reservoirs has expanded the scope of drilling to include unconventional reservoirs [7]. To develop such reservoirs, it is necessary to use complex extraction technologies. One of these advanced extraction technologies is the method of directional drilling (DD) [8], which is widely used in modern oil and gas exploration practice. This approach entails the drilling of long wells, almost horizontally entering the oil deposit. One of the main methods of underground orientation is geomagnetic referencing using vector magnetometers installed directly on the drilling instrument. The length of the well in this case can vary from 4–5 km to more than 10 km. This process is considered high-tech largely because of the complex spatial profile of the borehole in the multilateral direction [9].

The problem of supporting navigation accuracy improvement in directional drilling has been attracting the attention of researchers for several decades [10,11]. In 1999, an international professional community—the Industry Steering Committee on Wellbore Survey Accuracy (ISCWSA, https://www.iscwsa.net/ (accessed on 3 September 2024)), was founded to create and develop standards for precise navigation while drilling. It united the amassed world's experience in underground navigation and became an independent center for the standardization of technologies and algorithms. Over these years, the industry has evolved from low-resolution main field models to using data from a nearby magnetic observatory, referred to as interpolated in-field referencing (IIFR). IIFR is a complement to high-resolution (decomposition degree greater than 720) models of the full EMF and is included in the international ISCWSA standard. The development of navigation technologies for drilling has opened up a number of knowledge-intensive tasks in the field of new approaches to detecting local magnetic anomalies using ground and UAV surveys [10,12], the field of high-precision modeling of the EMF using spherical harmonics, and that of monitoring the magnetosphere dynamics in real time [13,14].

The problem of geomagnetic data application in the practice of DD has been discussed [11,15–17], and it was shown that it requires high-precision up-to-date data on EMF spatiotemporal variations and relevant analytical methods and instruments. The emerged challenges have received a wide response in the scientific community in the form of high-precision EMF models [18,19]. The results of numerical experiments on the modeling of well-trajectory parameters distinctively illustrate the influence of natural geomagnetic disturbances (e.g., geomagnetic storms) on the DD procedures. The solution to this problem requires new statistical algorithms for predicting the magnetosphere dynamics [20] and the construction of magnetic observatories in the proximity of oil- and gas-extraction sites [6]. A qualitative increase in interest in the correction method using observatory data occurred with the transition to high-latitude and offshore production. There was a transition from academic research [21,22], which modeled the potential for meeting direction accuracy requirements using real-time processing, to implementation in commercial production [6,13]. Compensation for geomagnetic rapid variations in the real-time mode using high-precision magnetometric equipment is currently an indispensable element of the DD routine, especially in the Arctic region. Along with operational geomagnetic data, the control of DD parameters requires the implementation of modern data management technologies and mathematical methods of real-time data analysis [17]. To date, there are many examples of the successful application of IIFR by oilfield service companies [15,23,24].

In this paper, we present the results of the practical application of modern data management techniques based on the Big Data approach with respect to the needs of DD operation and support of the IIFR.

2. Geomagnetic Data and Data Management

From the middle of the 19th century up to the present moment, geomagnetic observatories are the main source of long-term observations of EMF parameters. A magnetic observatory is a sophisticated scientific measuring complex where high-precision magnetometers are installed in special pavilions constructed of non-magnetic materials. The purpose of a magnetic observatory is to measure the magnetic field vector with high accuracy in real time.

Currently, there are more than 120 high-quality magnetic observatories operating around the world, united in the international INTERMAGNET network (www.intermagnet.org (accessed on 3 September 2024)). Magnetic observatories are equipped with a set of standard instrumentation, which necessarily includes vector and scalar magnetometers, as well as a non-magnetic theodolite with a built-in single-component magnetometer. This set of instruments allows for the measurement of all the components of the full geomagnetic vector [25].

In 2009, the Deadhorse Observatory (DED) was deployed for the first time in Alaska for joint use by the US Geological Survey (USGS) for scientific purposes and the oilfield service company Schlumberger for supporting DD [13]. The case of this observatory demonstrates that, when using geomagnetic navigation for DD, several tasks are distinguished:

- Modeling the main EMF with high resolution [26];
- Identifying and modeling the lithospheric field on a regional scale [14];
- Monitoring and accounting for EMF variations associated with space weather [11,13].

Data from magnetic observatories are used to varying degrees in solving each of the three problems listed above. While modern EMF modeling largely uses data from low-orbit satellites [27], the problem of recording EMF variations near drilling sites is solved by constructing a magnetic observatory [13]. In this regard, the interest of oilfield service companies in observatory magnetic observations is growing. At the same time, in some fields, it is possible to use data from existing observatories if they are located close enough to drilling sites. Regular disturbances of the magnetic field are observed at high latitudes that are close to the auroral zone [16,28]. Thus, the efficiency of mineral extraction in the Arctic zone of the Russian Federation can be increased by using the technology of the geomagnetic support of directional drilling [17,29], similar to how it was used in Alaska [13].

Turning to the technology, it is important to note that the data obtained at the observatory must be processed with minimal delay [30] and transmitted to the control center of the drilling station. The center compensates for direction errors or suspends drilling in the event of extreme disturbances. Here, processing means a whole complex of algorithms that eliminate anthropogenic and instrumental interference, calculate the temperature coefficients of magnetometers, etc. [30].

This leads to the need to create systems for processing geomagnetic data in real time. Today, in the Russian Federation, there is the only full-fledged system for collecting, storing, and promptly processing geomagnetic data, MAGNUS (Monitoring and Analysis of Geomagnetic aNomalies in Unified System) [http://mag.gcras.ru/] (accessed on 3 September 2024), created and operating at the Geophysical Center of the Russian Academy of Sciences (GC RAS). The basic functional diagram of MAGNUS is shown in Figure 1.

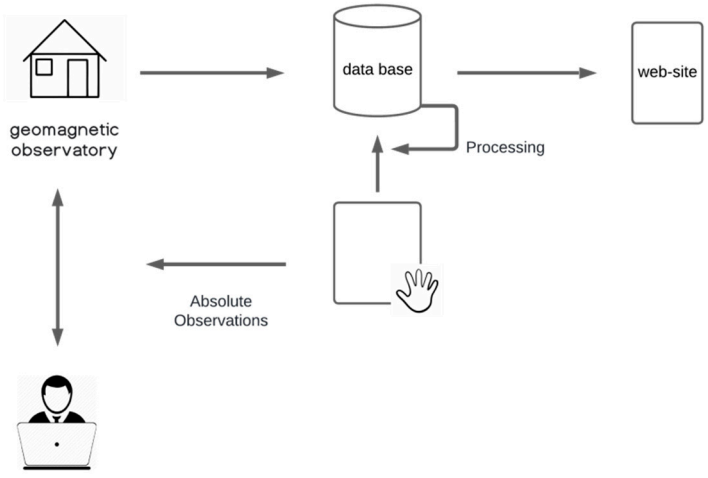


Figure 1. Structural diagram of the MAGNUS system.

MAGNUS receives data from 22 observatories located in Russia and neighboring countries, a significant part of which corresponds to the international INTERMAGNET standard. A map of existing and prospective observatories is shown in Figure 2. It is planned to expand the number of observatories supplying the MAGNUS system with data.

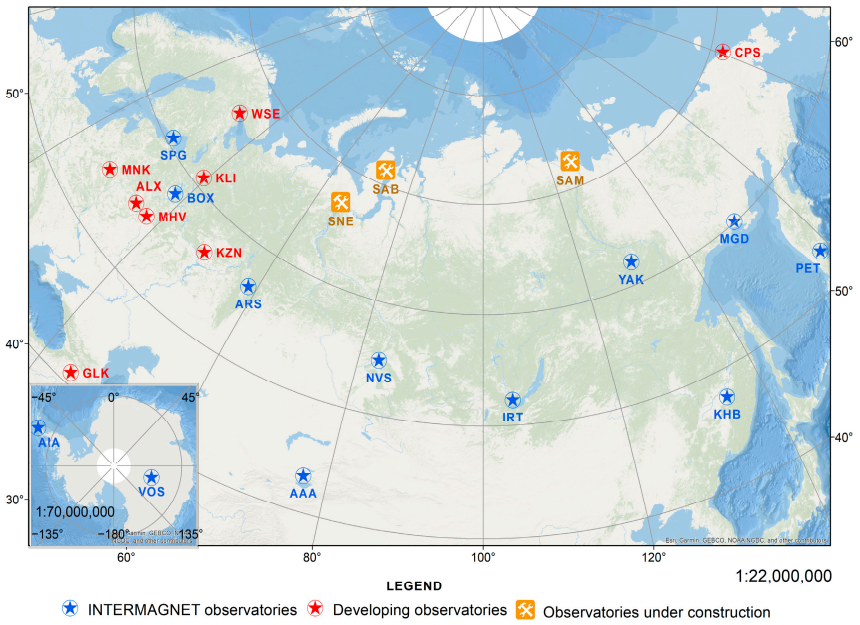


Figure 2. Map of geomagnetic observatories in Russia and neighboring countries.

The MAGNUS 1.0 analytical software package was created in 2016 based on the MySQL database. The initial architecture of the system is described in detail in [31]. Thanks to the open data policy of GC RAS, the system has become a convenient tool for researchers from various organizations. In the period from 2016 to 2024, the system was constantly being developed, and new functionality was consistently being added to it. In addition to the data from magnetic observatories, geomagnetic measurements from Swarm satellites from 2013 to the present were loaded into the database (DB) [32]. With the increase in requirements for the measurement frequencies of observatory magnetometers, an active transition to a 1 s measurement standard began, and data from new observatories were added. All this led to a significant increase in the load on the system. For its further operation, a decision was made to transfer MAGNUS to Big Data (BD) technology [33].

Information systems built on Big Data technologies meet the requirements of simplicity of horizontal scaling and query processing speed [34,35]. The ultimate goal is to create a single scalable system of satellite and ground-based geomagnetic data, MAGNUS BD. In the future, such a system can be used both to solve fundamental geophysical problems and to provide high-quality data to oilfield service companies in real time for the purpose of supporting DD in Russia. This article is devoted to the process of such a transition and the first results obtained.

3. Materials and Methods

When switching to the new BD technology, it was necessary to migrate all data and duplicate the functionality of the original MAGNUS system. Today, the latter includes:

- Original geomagnetic data from 22 ground-based observatories;
- Processed data and calculated indices;
- Geomagnetic data from low-orbit satellites;
- Derived parameters obtained after processing satellite and ground-based data;

- The web system for visualizing and uploading accumulated data, available on the official website of the MAGNUS hardware-software system, http://mag.gcras.ru (accessed on 3 September 2024);
- The set of application programming interfaces (API) in different programming languages.

At the start of the migration, the DB contained more than 400 GB of original and processed data. Due to limitations in the performance of the MAGNUS DB, some of the available information was not loaded, so about 10 TB of satellite and related geophysical data were accumulated in the file storage. Working with these data within the original architecture of the MAGNUS system was impossible.

Prior to the migration, an analysis of the market for technological solutions for the BD DBMS was conducted. An important parameter was the use of open-source software. In this case, we could be sure that the system would function and develop regardless of external sanction changes.

The main feature of systems built on Big Data technology is the implementation of parallel computing [36]. This allows the query to be distributed between several servers (segments) using the query optimizer (master) [37]. The concept of the system is shown in Figure 3.

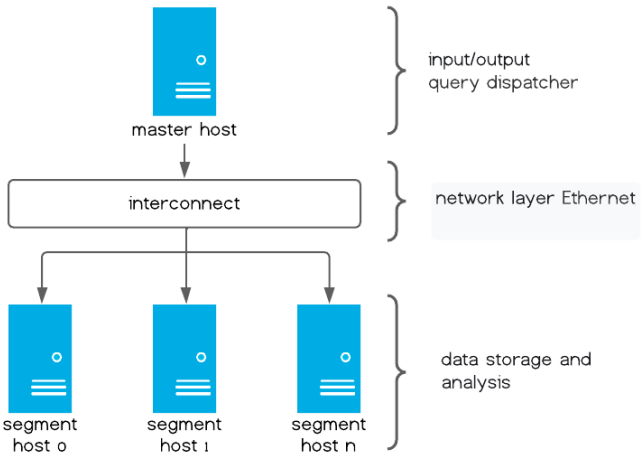


Figure 3. Arenadata database operating principle.

The most widely used open-source data management system in the IT industry at the moment is the Greenplum DBMS. An analysis of its functionality confirmed this system as the optimal choice for deploying a geomagnetic database. In addition, the decision to choose Greenplum was based on the availability of a pool of specialists working with the system, as well as a version of its Russian assembly, the Arenadata database, which has become widespread in the commercial sector, especially after the introduction of sanctions and the departure of many technology giants from the market. Among the major users of this system are VTB, the Federal Tax Service of Russia, Moscow Exchange, and many others.

The Arenadata database is a distributed DBMS that uses the concept of massively parallel processing (MPP) and is based on the open source DBMS–Greenplum. Analytical massively parallel DBMSs are designed to store and process large volumes of data—from single units to hundreds of terabytes of data. The pilot version of the MAGNUS BD system was deployed on the basis of three physical servers, the technical characteristics of which are given in Table 1.

Table 1. Hardware of the MAGNUS BD pilot system.

Host Name	Central Processing Unit (CPU)	Random Access Memory (RAM)	Read-Only Memory (ROM)
master	8× core Intel(R) Xeon(R) CPU E5450 3.00GHz	16 GB	240 GB SSD
seg0	8× core Intel(R) Xeon(R) CPU E5345 2.33GHz	16 GB	1 TB SSD
seg1	8× core Intel(R) Xeon(R) CPU E5345 2.33GHz	16 GB	1 TB SSD
ftp	Intel Core i7-2600 3.40GHz	16 GB	14 TB HDD

Arenadata DB software version 6.26.2.55 was installed using the Arenadata Cluster Manager (ADCM) interface. The ADCM provides the ability to create, configure, and update clusters via a graphical interface or using an API. All operating system services are configured automatically, under the supervision of a specialist who promptly resolves any technical difficulties that arise. The following actions were performed in stages:

- Preparing the environment on the master and segment nodes, including installing the CentOS 7 operating system (open source software), creating users, and configuring access rights for them;
- Downloading and installing ADCM on the manager node, which allows managing the cluster via a graphical interface or API;
- Creating a new Arenadata DB cluster in ADCM via a graphical interface and specifying the necessary parameters, such as the number of nodes, their configuration, and network settings;
- Automatic configuration of all necessary operating system services and Arenadata DB components was performed;
- Starting the cluster and checking its operability. Test queries were executed, the node status was checked, and a test database was created.

For the MAGNUS BD system built on Big Data technology, the structure shown in Figure 4 was proposed, including data sources, a data collection and storage unit, and a data analytics and visualization unit.

The following data were loaded into the MAGNUS BD system:

- Raw minute and second data from 22 ground-based geomagnetic observatories, over 300 GB in volume;
- Processed minute and second data from 22 ground-based observatories, over 35 GB in volume;
- Second and 50 Hz data from the Swarm satellite constellation, over 7 TB in volume.

As a result, in 2024, a fully operational pilot version of the MAGNUS BD system was created at the GC RAS.

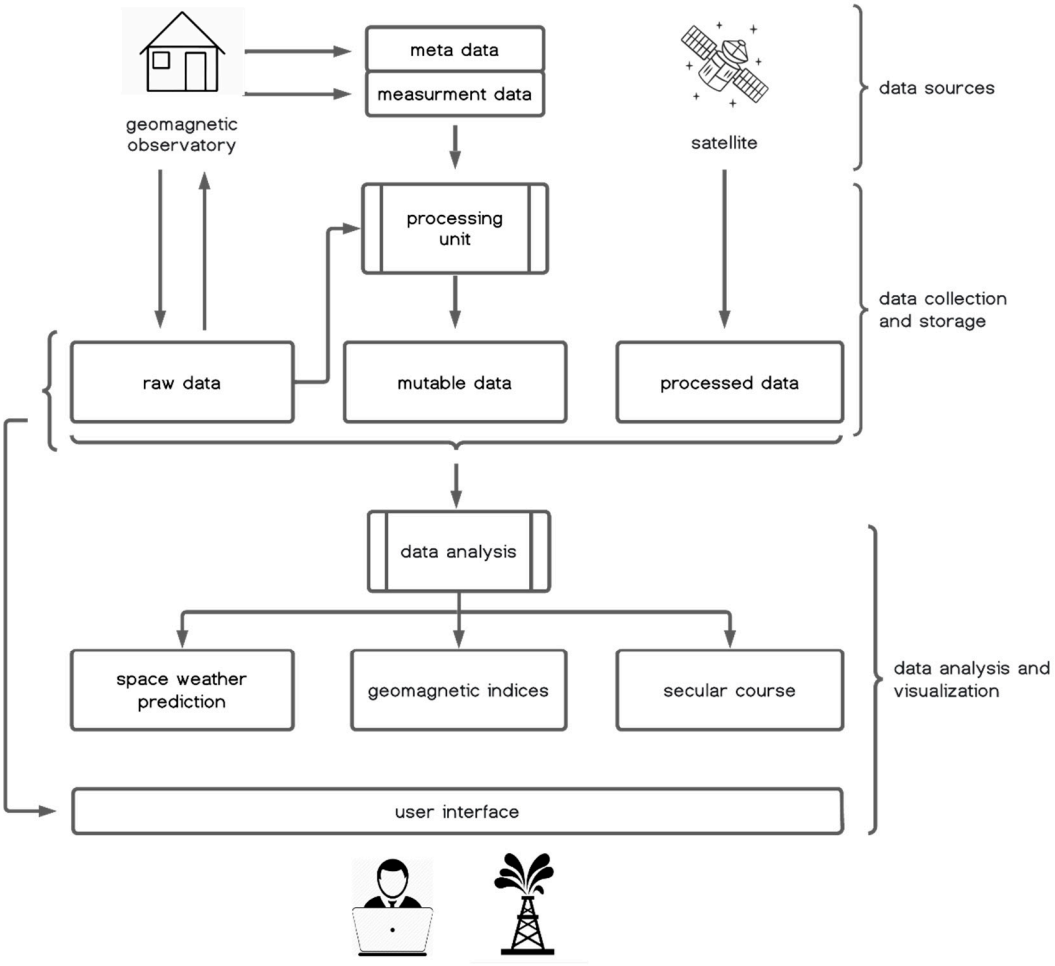


Figure 4. Structural diagram of the MAGNUS BD system.

4. Results

The current MAGNUS system, created in 2016 and based on a classic DB, stores data in a form aggregated by hours. This approach reduces the query time but complicates data retrieval by value. In this regard, the assessment of data availability intervals could only be performed by a complete enumeration of the values for each component.

If, in the case of minute measurements, such an approach was justified, then, when switching to second and especially to satellite data, the assessment of availability became a cumbersome and computationally expensive process. The new MAGNUS BD system, already in its pilot version, achieves high performance by partitioning data by criterion (time) and dividing between physical segments. As a result, the assessment of data gaps is implemented separately, at each observatory. Thus, in the new version of the system, data on the time interval for which there is information, as well as the volume of available data, for any observatory, can be obtained by executing a simple query in SQL. Table 2, as an example, presents the result of executing such a query for 11 observatories by MAGNUS BD.

At the same time, we also have the opportunity to quickly obtain information on the availability of data for one observatory for the desired period of time. Figures 5 and 6 show histograms with information on the volume of data for the Mikhnevo (MHV) and Klimovskaya (KLI) observatories per day for the time period from 1 May 2023, to 30 June 2023. The gap in the data on June 2 and 6 is due to technical problems with the scalar magnetometer after power failures. The synchronous absence of data from the scalar (F) and vector (X, Y, Z) magnetometers is due to power failures that affected all devices at once.

Table 2. Intervals and volumes of available data.

IAGA-Code	Observatory Name	Geographical Coordinates	Compliance With INTERMAGNET Quality Standard	Data Availability Interval		Volume of Available Data, %	
				Start	End	X, Y, Z	F
AAA	Alma-Ata	43.25° N, 76.92° E	yes	1 January 2006	1 June 2024	8.6	-
ARS	Arti	56.43° N, 58.56° E	yes	15 July 2011	29 April 2021	48.8	-
BOX	Borok	58.07° N, 38.23° E	yes	1 January 2017	20 April 2022	84.0	84.1
CPS	Mys Shmidta	68.88° N, 179.37° W	no	2 January 2013	22 May 2024	67.2	65.9
GLK	Gyulagarak	40.93° N, 44.47° E	no	5 February 2020	31 May 2024	68.4	67.3
KLI	Klimovskaya	60.85° N, 39.52° E	no	18 June 2014	31 May 2024	85.7	85.6
MGD	Magadan	60.05° N, 150.72° E	yes	28 February 2008	19 December 2023	80.4	76.6
MHV	Mikhnevo	54.95° N, 37.76° E	no	1 January 2023	31 May 2024	89.2	89.2
NOK	Norilsk	69.40° N, 88.40° E	no	13 March 2009	15 August 2023	55.49	-
SPG	Saint Petersburg	60.54° N, 29.71° E	yes	4 February 2024	31 May 2024	84.9	84.7
WSE	White Sea	66.55° N, 33.10° E	no	1 January 2014	31 May 2024	72.5	72.5

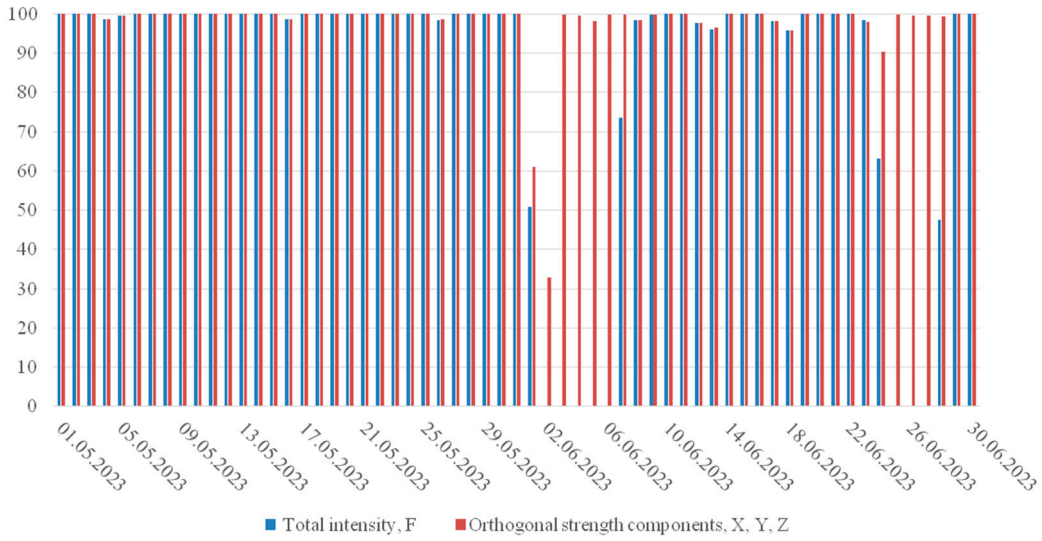


Figure 5. Volume of available data (in percent) from the Mikhnevo observatory in the period from 1 May 2023, to 30 June 2023.

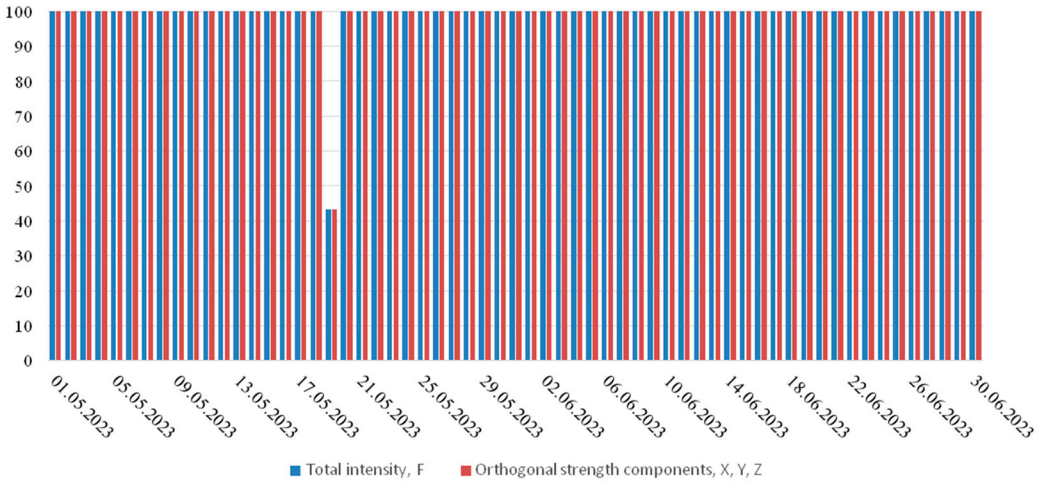


Figure 6. Volume of available data (in percent) from the Klimovskaya observatory in the period from 1 May 2023, to 30 June 2023.

The MAGNUS BD system showed strong results in comparison with the original MAGNUS system. As a result, when executing data requests for the Klimovskaya observatory for different periods of time, the new system showed an increase in speed up to six times (Table 3).

Table 3. Speed of query execution for the Klimovskaya observatory.

Data Request Period	Processing Speed, s	
	MAGNUS BD	MAGNUS
Day	1.3	0.1
Month	1.6	1.6
Year	5.1	22.6
All available data interval	41.1	246.1

At the same time, as it should be in the case of a BD system, the larger the request, the higher the increase in the speed indicators of its execution. This was demonstrated when executing a data request for the entire observation period for all 22 observatories, shown in Figure 7.

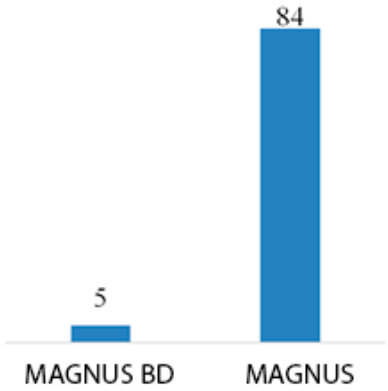


Figure 7. Speed of data query execution for the entire observation period for 22 observatories, sec.

The basis of effective geomagnetic navigation in directional drilling is the processing of geomagnetic data in real time to obtain the direction to magnetic north with an accuracy of 0.1° for declination D and 0.05° for inclination I, as well as, additionally, the modulus of

the full vector F with an accuracy of up to 50 nT according to the ISCWSA error model [22]. Space weather events such as magnetic storms and substorms near the production site lead to strong variations in the angular components of the vector *B* (Figure 8a). Taking into account such rapid variations, an error occurs depending on the processing speed of the incoming data. Figure 8a shows the declination and inclination record during the magnetic storm of 1–3 December, 2023, obtained at the Klimovskaya magnetic observatory (IAGA code KLI). In this case, the azimuth angle correction error of the drill direction in the MAGNUS system based on the averaged *D* values for 15 min exceeds the 1σ threshold in 7.4% of cases, and the 3σ threshold in 1.3% of cases (Figure 8b). The observed deviations are associated with a data processing delay, which can exceed 10 min. The use of real-time processing in the proposed MAGNUS BD system significantly reduces the correction error (Figure 8c). In this case, only 0.4% of *D* errors go beyond the ±1σ range. It should be noted that the requirements for correction accuracy only grow over time, as production rates and drilling speeds are continuously increasing [38,39].

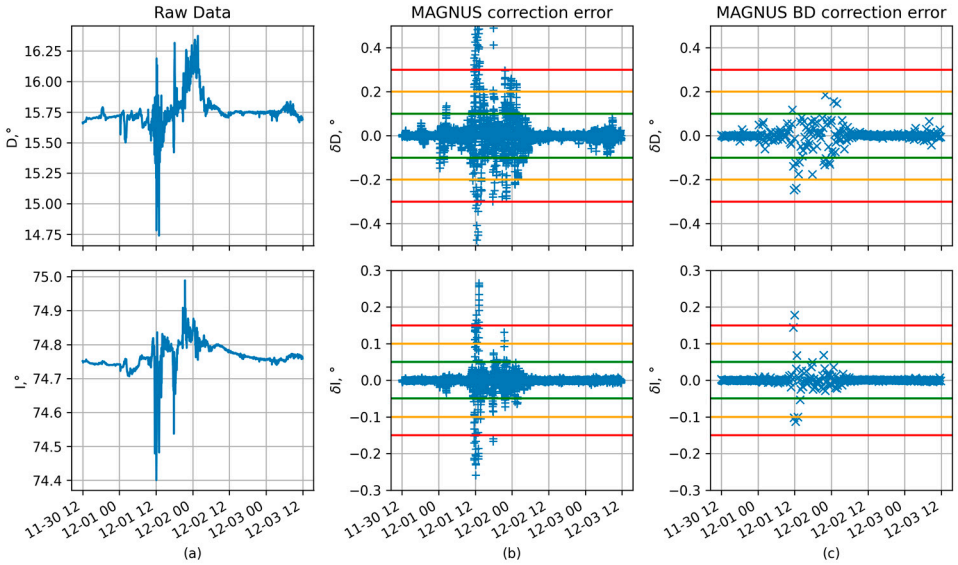


Figure 8. Declination and inclination of the *B* vector during the magnetic storm of 1–3 December according to the Klimovskaya magnetic observatory (KLI) (**a**), correction error via MAGNUS (**b**), correction error via MAGNUS BD (**c**). The lines on the graphs (**b**,**c**) show the thresholds of the ISCWSA error requirements: 1σ (green), 2σ (orange), 3σ (red).

5. Discussion

The capabilities of systems built on the basis of BD have properties in common with the classical data storage and processing systems. The main advantages of BD systems lie in several aspects. Firstly, as shown above, there is a manyfold increase in the speed of query processing in BD-oriented systems compared to classical approaches. Such data processing speeds cannot be achieved by simply increasing the power of the computer, i.e., vertical scaling. The latter method is effective only up to a certain limit. At the same time, the costs of information processing grow exponentially, as a direct consequence of the strengthening of the used computing systems and technologies. At a certain point, the maximum cost value can be reached.

The employment of a BD-oriented approach in such a situation allows one to strengthen the system by using standard server solutions. In the system's application to geomagnetic data, this allows one to quickly and repeatedly scale the MAGNUS BD system, accepting information from new observatories and satellites as well as expanding the range of data by adding new types of information.

In their theoretical basis, BD technologies are based on the involvement of large arrays of information in their processing. They allow identifying information about the

study object at a qualitatively different level, including recognizing previously unknown and even unexpected dependencies [34]. In practice, this is realized by the joint use of "hot" and "cold" data in the work carried out using this type of system. Within the framework of the MAGNUS BD project, "hot" data include information about the state of the Earth's magnetic field, recorded in the modern, generally accepted IAGA format (depth of 5–15 years, depending on the observatory). "Cold" is an array of available observatory records in binary format, including satellite and historical data.

The use of the unified MAGNUS BD system will provide more efficient solutions to a scope of applied problems which require non-trivial mathematical algorithms for processing geomagnetic data, the multi-criteria assessment of geophysical parameters, and the involvement of GIS technologies. An example of such an applied problem is the choice of a site for the construction of a new magnetic observatory to support directional drilling.

When solving this problem, it is necessary to take into account a large number of different groups of geophysical and infrastructure parameters. The first group of parameters includes the values of lithospheric magnetic anomalies, the geological and tectonic structure of the territory, and the locations of existing observatories. The infrastructure group of criteria includes the locations of current and promising sites for the extraction of hard-to-recover reserves, the availability of electricity, and transport accessibility. The choice is made under conditions of strict constraints on the minimum distance to sources of electromagnetic noise such as populated areas, industrial facilities, high-voltage power lines, railways and highways, and runways.

Another urgent task is the construction and updating of high-resolution models of the geomagnetic field for the purposes of directional drilling. Its modeling is based on continuous work with current ground and satellite information, which is Big Data by definition. On the other hand, the construction of new models of the geomagnetic field is traditionally based on a comparative analysis with existing models and verification using ground-based observatory data [40]. This can be effectively brought into action on the basis of MAGNUS BD by implementing existing and creating new algorithms for the system analysis of Big Data.

6. Conclusions

This paper presents the first step in transferring the geomagnetic measurement database of the GC RAS to the Big Data technological base. The Arenadata database based on the Greenplum open source DBMS was selected as the storage technology and deployed on a physical cluster. This is a massively parallel DBMS that is widely used in commercial data processing systems and that has not been used in magnetometric information research before.

An important quality of the Arenadata DB, in contrast to classic DBs, is its support for fast horizontal scaling by adding new segments to the computer cluster. The results of the tests the new MAGNUS BD system show that it significantly outperforms the MAGNUS system, which has existed since 2016, in terms of the speed of executing standard queries, and provides additional tools for working with data.

The capabilities of the new system make it possible to simplify and speed up the process of geomagnetic field modeling using satellite and ground-based data by parallelizing computations.

The use of the Big Data approach will allow the accumulation and prompt transmission of processed and consolidated information from various observatories for the prompt management of the directional drilling process. This will allow a multi-faceted improvement in the accuracy of positioning when developing hard-to-recover oil and gas reserves, including those located in the Arctic region.

Author Contributions: Conceptualization, A.D.G.; Data curation, I.O.B.; Funding acquisition, B.A.D.; Methodology, D.V.K. and A.D.G.; Project administration, A.D.G., I.M.N. and B.A.D.; Resources, A.A.G. and B.A.D.; Software, D.V.K., I.O.B. and A.A.G.; Supervision, A.D.G.; Visualization, I.M.N., I.O.B. and R.I.K.; Writing—original draft, D.V.K., A.D.G., I.M.N., I.O.B., B.A.D., A.A.G., B.V.D. and R.I.K.; Writing—review & editing, D.V.K., A.D.G., I.M.N., I.O.B., B.A.D., A.A.G., B.V.D. and R.I.K. All authors have read and agreed to the published version of the manuscript.

Funding: This work was carried out in the framework of budgetary funding of the Geophysical Center of RAS (No. 075-00443-24-01) and the Schmidt Institute of Physics of the Earth of RAS (No. 075-00273-24-00), adopted by the Ministry of Science and Higher Education of the Russian Federation.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Acknowledgments: This work employed data and services provided by the Shared Research Facility "Analytical Geomagnetic Data Center" of the Geophysical Center of RAS (http://ckp.gcras.ru/ (accessed on 3 September 2024)).

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ADCM	Arenadata Cluster Manager
API	Application Programming Interface
BD	Big Data
DB	Database
DBMS	Database Management System
DD	Directional Drilling
DED	Deadhorse Observatory
EMF	Earth's Magnetic Field
GB	Gigabyte
GNSS	Global Navigation Satellite Systems
ISCWSA	The Industry Steering Committee on Wellbore Survey Accuracy
MPP	Massively Parallel Processing
TB	Terabyte
UAV	Unmanned Aerial Vehicles
USGS	US Geological Survey

References

1. Shockley, J.A.; Raquet, J.F. Navigation of ground vehicles using magnetic field variations. *Navigation* **2014**, *61*, 237–252. [CrossRef]
2. Ogórek, I.; Grzegorzewski, M.; Maciejowski, M. The use of magnetic field and magnetometers in supporting the air navigation. *Annu. Navig.* **2015**, *22*, 21–29. [CrossRef]
3. Pasku, V.; De Angelis, A.; De Angelis, G.; Arumugam, D.D.; Dionigi, M.; Carbone, P.; Moschitta, A.; Ricketts, D.S. Magnetic Field Based Positioning Systems. *IEEE Commun. Surv. Tutor.* **2017**, *19*, 2003–2017. [CrossRef]
4. Chen, J.; Song, S.; Gong, Y.; Zhang, S. An indoor fusion navigation algorithm using HV-derivative dynamic time warping and the chicken particle filter. *Satell. Navig.* **2022**, *3*, 13. [CrossRef]
5. Williamson, H.S. Accuracy Prediction for Directional Measurement While Drilling. *SPE Drill. Complet.* **2000**, *15*, 221–233. [CrossRef]
6. Buchanan, A.; Finn, C.A.; Love, J.J.; Worthington, W.E.; Lawson, F.; Maus, S.; Okewunmi, S.; Poedjono, B. Geomagnetic Referencing—The Real-Time Compass for Directional Drillers. *Oilfield Rev.* **2013**, *25*, 32–47.
7. Li, Q.; Li, Q.; Wang, F.; Wu, J.; Wang, Y. The Carrying Behavior of Water-Based Fracturing Fluid in Shale Reservoir Fractures and Molecular Dynamics of Sand-Carrying Mechanism. *Processes* **2024**, *12*, 2051. [CrossRef]
8. Gooneratne, C.P.; Li, B.; Deffenbaugh, M.; Moellendick, T. *Instruments, Measurement Principles and Communication Technologies for Downhole Drilling Environments*; Springer International Publishing: Cham, Switzerland, 2019; Volume XI, p. 132. [CrossRef]
9. Short, J.A. *Introduction to Directional and Horizontal Drilling*; PennWell Publishing: Tulsa, OK, USA, 1993; 239p.

10. Williamson, H.S.; Gurden, P.A.; Kerridge, D.J.; Shiells, G. Application of Interpolation In-Field Referencing to Remote Offshore Locations. In Proceedings of the SPE Annual Technical Conference and Exhibition, New Orleans, LA, USA, 27–30 September 1998. [CrossRef]
11. Poedjono, B.; Beck, N.; Buchanan, A.; Brink, J.; Longo, J.; Finn, C.A.; Worthington, E.W. Geomagnetic Referencing in the Arctic Environment. In *SPE Arctic and Extreme Environments Technical Conference and Exhibition*; SPE: Richardson, TX, USA, 2011; pp. 1–13.
12. Aleshin, I.M.; Soloviev, A.A.; Aleshin, M.I.; Sidorov, R.V.; Solovieva, E.N.; Kholodkov, K.I. Prospects of Using Unmanned Aerial Vehicles in Geomagnetic Surveys. *Seism. Instrum.* **2020**, *56*, 522–530. [CrossRef]
13. Poedjono, B.; Maus, S.; Manoj, C. Effective Monitoring of Auroral Electrojet Disturbances to Enable Accurate Wellbore Placement in the Arctic. In Proceedings of the OTC Arctic Technology Conference, Houston, TX, USA, 7–9 February 2014. [CrossRef]
14. Love, J.J.; Finn, C.A. The USGS Geomagnetism Program and Its Role in Space Weather Monitoring. *Space Weather* **2011**, *9*, S07001. [CrossRef]
15. Onovughe, E.; Otobong, T. Geomagnetic Referencing Techniques as Vital Directional Reference in Hydrocarbon Drilling. *J. Multidiscip. Eng. Sci. Stud.* **2016**, *2*, 836–841.
16. Gvishiani, A.D.; Lukianova, R.Y. Estimating the influence of geomagnetic disturbances on the trajectory of the directional drilling of deep wells in the Arctic region. *Izv. Phys. Solid Earth* **2018**, *54*, 554–564. [CrossRef]
17. Soloviev, A.A.; Sidorov, R.V.; Oshchenko, A.A.; Zaitsev, A.N. On the need for accurate monitoring of the geomagnetic field during directional drilling in the Russian Arctic. *Izv. Phys. Solid Earth* **2022**, *58*, 420–434. [CrossRef]
18. Nair, M.; Chulliat, A.; Woods, A.; Alken, P.; Meyer, B.; Poedjono, B.; Zachman, N.; John, H. Next Generation High-Definition Geomagnetic Model for Wellbore Positioning, Incorporating New Crustal Magnetic Data. In Proceedings of the Offshore Technology Conference, Virtual and Houston, TX, USA, 16–19 August 2021. [CrossRef]
19. Maus, S.; Nair, M.C.; Poedjono, B.; Okewunmi, S.; Fairhead, D.; Barckhausen, U.; Milligan, P.R.; Matzka, J. High Definition Geomagnetic Models: A New Perspective for Improved Wellbore Positioning. In Proceedings of the IADC/SPE Drilling Conference and Exhibition, San Diego, CA, USA, 6–8 March 2012. [CrossRef]
20. Nair, M.; Woods, A.; Chulliat, P.A.; Boneh, N. A real-time magnetic disturbance model to improve drilling accuracy in low and mid latitudes of the Earth. In Proceedings of the Industry Steering Committee on Wellbore Survey Accuracy (ISCWSA), 42nd meeting. Houston, TX, USA, 1 October 2015. Available online: https://www.iscwsa.net/media/files/files/73a6da7c/06-isc42-real-time-magnetic-disturbance.pdf (accessed on 15 September 2024).
21. Turbitt, C.W.; Clark, T.D.G. *The Use of Lerwick Variometer Measurements to Estimate Magnetic Disturbances over the North Sea*; British Geological Survey: Nottingham, UK, 1994; Technical Report WM/94/21C.
22. Russell, J.P.; Shiells, G.; Kerridge, D.J. Reduction of wellbore positional uncertainty through application of a new geomagnetic in-field referencing technique. In *SPE Annual Technical Conference and Exhibition*; Technical Paper SPE-30452-MS; SPE: Richardson, TX, USA, 1995. [CrossRef]
23. Momot, F.; Humbled, F.; Garbers, M.; Shabanov, S.; Gonsette, A.; Sikal, A.; Cousso, O.; Reynaud, D. First Onsite Automatic Geomagnetic Observatory Improves Well-Bore Positioning. In Proceedings of the International Petroleum Technology Conference, Beijing, China, 26–28 March 2019. [CrossRef]
24. Mitkus, A.; Maus, S.; Willerth, M.; Reetz, A.; Oskarsen, R.T.; Emilsen, M.H.; Gergerechi, A. Challenges and Solutions for Accurate Wellbore Placement in the Barents Sea. In Proceedings of the SPE/IADC International Drilling Conference and Exhibition, Hague, The Netherlands, 5–7 March 2019. [CrossRef]
25. Macmillan, S. Observatories, overview. In *Encyclopedia of Geomagnetism and Paleomagnetism*; Gubbins, D., Herrero-Bervera, E., Eds.; Springer: New York, NY, USA, 2007; pp. 708–711. [CrossRef]
26. International Geomagnetic Reference Field (IGRF). 2024. Available online: https://geomag.bgs.ac.uk/research/modelling/IGRF.html. (accessed on 15 September 2024).
27. Alken, P.; Thébault, E.; Beggan, C.D.; Amit, H.; Aubert, J.; Baerenzung, J.; Bondar, T.N.; Brown, W.J.; Califf, S.; Chambodut, A.; et al. International Geomagnetic Reference Field: The thirteenth generation. *Earth Planets Space* **2021**, *73*, 49. [CrossRef]
28. Reay, S.J.; Allen, W.; Baillie, O.; Bowe, J.; Clarke, E.; Lesur, V.; Macmillan, S. Space weather effects on drilling accuracy in the North Sea. *Ann. Geophys.* **2005**, *23*, 3081–3088. [CrossRef]
29. Kruglyakov, M.; Kuvshinov, A.; Nair, M. A Proper use of the adjacent land-based observatory magnetic field data to account for the geomagnetic disturbances during offshore directional drilling. *Space Weather* **2022**, *20*, e2022SW003238. [CrossRef]
30. Kudin, D.V.; Soloviev, A.A.; Sidorov, R.V.; Starostenko, V.I.; Sumaruk, Y.P.; Legostaeva, O.V. Advanced production of quasi-definitive magnetic observatory data of the INTERMAGNET standard. *Geomagn. Aeron.* **2021**, *61*, 54–67. [CrossRef]
31. Gvishiani, A.; Soloviev, A.; Krasnoperov, R.; Lukianova, R. Automated Hardware and Software System for Monitoring the Earth's Magnetic Environment. *Data Sci. J.* **2016**, *15*, 18. [CrossRef]
32. Macmillan, S.; Olsen, N. Observatory data and the Swarm mission. *Earth Planets Space* **2013**, *65*, 1355–1362. [CrossRef]
33. Vance, T.C.; Huang, T.; Butler, K.A. Big data in Earth science: Emerging practice and promise. *Science* **2024**, *383*, eadh9607. [CrossRef]
34. Gvishiani, A.D.; Panchenko, V.Y.; Nikitina, I.M. Systems Analysis of Big Data for Earth Sciences. *Bull. Russ. Acad. Sci.* **2023**, *93*, 518–525. [CrossRef]
35. Rylnikova, M.V.; Klebanov, D.A.; Makeev, M.A.; Kadochnikov, M.V. Application of artificial intelligence and the future of big data analytics in the mining industry. *Russ. Min. Ind.* **2022**, *3*, 89–92. [CrossRef]

36. Golov, N.; Rönnbäck, L. Big Data normalization for massively parallel processing databases. *Comput. Stand. Interfaces* **2017**, *54*, 86–93. [CrossRef]
37. Bani, F.C.D.; Suharjito, D.; Girsang, A.S. Implementation of Database Massively Parallel Processing System to Build Scalability on Process Data Warehouse. *Procedia Comput. Sci.* **2018**, *135*, 68–79. [CrossRef]
38. Osmundsen, P.; Roll, K.H.; Tveteras, R. Drilling speed–the relevance of experience. *Energy Econ.* **2012**, *34*, 786–794. [CrossRef]
39. Zhang, X.; He, A.; Yan, J.; Shi, L.; He, Z.; Kong, L. Increasing drilling speed in long horizontal intervals in Aktobe Kazakstan. *IOP Conf. Series Earth Environ. Sci.* **2019**, *300*, 022029. [CrossRef]
40. Kozyreva, O.V.; Pilipenko, V.A.; Dobrovolsky, M.N.; Zaitsev, A.N.; Marshalko, E.E. Database of geomagnetic observations in Russian Arctic and its application for estimates of the space weather impact on technological systems. *Sol. Terr. Phys.* **2022**, *8*, 39–50. [CrossRef]

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